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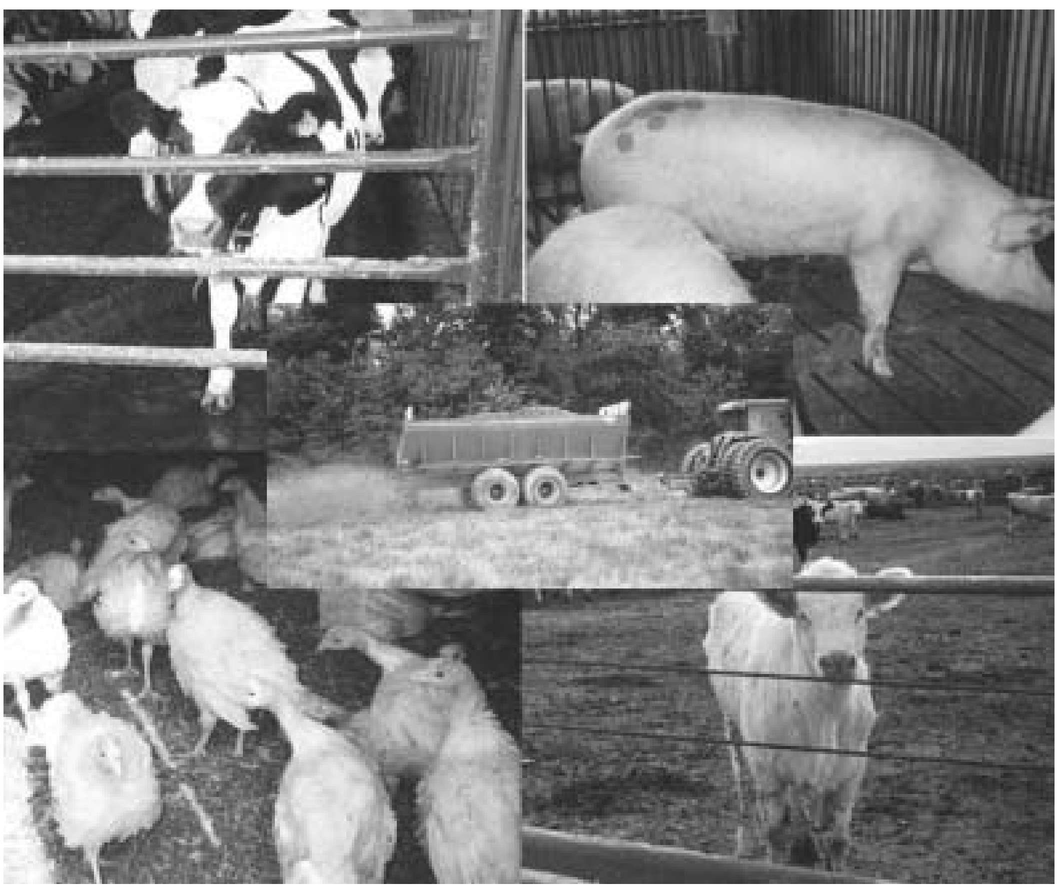

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Development Document for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations

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CHAPTER 1

INTRODUCTION AND LEGAL AUTHORITY

1.0 INTRODUCTION AND LEGAL AUTHORITY

This chapter presents an introduction to the regulations that have been revised for the concentrated animal feeding operations (CAFOs) industry and describes the legal authority that the U.S. Environmental Protection Agency (EPA) has to revise these regulations. Section 1.1 describes the Clean Water Act (CWA), Section 1.2 reviews the Pollution Prevention Act (PPA), and Section 1.3 describes the Regulatory Flexibility Act (RPA).

1.1 Clean Water Act (CWA)

The Federal Water Pollution Control Act Amendments of 1972 established a comprehensive program to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (Section 101(a)). The CWA gives EPA the authority to regulate point source discharges (including CAFOs) into waters of the United States through the National Pollutant Discharge Elimination System (NPDES) permitting program. Under the CWA, EPA issues effluent limitations guidelines, pretreatment standards, and new source performance standards for point sources other than publicly owned treatment works (POTWs). Direct dischargers must comply with effluent limitations in NPDES permits, while indirect dischargers must comply with pretreatment standards.

These effluent limitations guidelines and standards "effluent guidelines" or "ELGs" are national regulations that establish limitations on the discharge of pollutants by industrial category and subcategory. For each category and subcategory guidelines address three classes of pollutants (1) conventional pollutants (i.e., total suspended solids (TSS), oil and grease, biochemical oxygen demand (BOD), fecal coliform bacteria, and pH); (2) priority pollutants (e.g., toxic metals such as lead and zinc, and toxic organic pollutants such as benzene) and (3) nonconventional pollutants (e.g., phosphorus). These technology-based requirements are subsequently incorporated into NPDES permits. The CWA provides that effluent guidelines may include numeric or nonnumeric limitations. Nonnumeric limitations are usually in the form of best management practices (BMPs). The effluent guidelines are based on the degree of control that can be achieved using various levels of pollution control technology, as outlined in Section 1.1.2.

On October 30, 1989, Natural Resources Defense Council, Inc., and Public Citizen, Inc., filed an action against EPA in which they alleged, among other things, that EPA had failed to comply with CWA Section 304(m). (See *Natural Resources Defense Council, Inc., et al.* v. *Reilly*, Civ. No. 89-2980 (RCL) (D.D.C.).) Plaintiffs and EPA agreed to a settlement of that action in a consent decree entered on January 31, 1992. The consent decree, which has been modified several times, established a schedule by which EPA is to propose and take final action for 11 point source categories identified by name in the decree, and for eight other point source categories identified only as new or revised rules, numbered 5 through 12. After completing a preliminary study of the feedlots industry under the decree, EPA selected the swine and poultry portion of the feedlots industry as the subject for New or Revised Rule #8, and the beef and dairy portion of that industry as the subject for New or Revised Rule #9.

Under the decree, as modified, the Administrator was required to sign a proposed rule for both portions of the feedlots industry on or before December 15, 2000, and take final action on that proposal no later than December 15, 2002. As part of EPA's negotiations with the plaintiffs regarding the deadlines for this rulemaking, EPA entered into a settlement agreement dated December 6, 1999, under which EPA agreed to propose to revise the existing NPDES permitting regulations under 40 CFR Part 122 for CAFO by December 15, 2000. EPA also agreed to perform certain evaluations, analyses, or assessments and to develop certain preliminary options in connection with the proposed CAFO rules. (The Settlement Agreement expressly provides that nothing in the agreement requires EPA to select any of these options as the basis for its final rule.)

The remainder of this section describes the NPDES rules and the Effluent Limitations Guidelines and Standards as they apply to the CAFOs industry.

1.1.1 National Pollutant Discharge Elimination System

The NPDES permit program regulates the discharge of pollutants from point sources to waters of the United States. The term "point source" is defined in the CWA (Section 502(14)) as a discernible, confined, and discrete conveyance from which pollutants are or may be discharged. CAFOs are explicitly defined as point sources in Section 502(14). EPA promulgated the current NPDES regulations for CAFOs in the mid-1970s (see 41 FR 11458, March 18, 1976).

1.1.2 Effluent Limitations Guidelines and Standards

EPA promulgated effluent limitations guidelines and standards for the Feedlots Point Source Category in 1974 (40 CFR Part 412) (see 39 FR 5704, February 14, 1974). EPA is revising these regulations, as discussed above and in Chapter 2.

Effluent limitations guidelines and standards for CAFOs are being revised under the authority of Sections 301, 304, 306, 307, 308, 402, and 501 of the CWA, 33 U.S.C. 1311, 1314, 1316, 1317, 1318, 1342, and 1361. Effluent limitations guidelines and standards are summarized briefly below for direct and indirect dischargers.

Direct Dischargers

- Best Practicable Control Technology Currently Available (BPT) (304(b)(1) of the CWA) - In the guidelines for an industrial category, EPA defines BPT effluent limits for conventional, toxic, and nonconventional pollutants. In specifying BPT, EPA looks at a number of factors. EPA first considers the cost of achieving effluent reductions in relation to the effluent reduction benefits. EPA also considers the age of the equipment and facilities, the processes employed and any required process changes, engineering aspects of the control technologies, nonwater-quality environmental impacts (including energy requirements), and such other factors as EPA deems appropriate (CWA 304(b)(1)(B)). Traditionally, EPA establishes BPT effluent limitations based on the average of the best performances of facilities within the industry of various ages, sizes, processes, or other common characteristics. Where existing performance is uniformly inadequate, EPA may require higher levels of control than are currently in place in an industrial category if EPA determines that the technology can be practically applied.

- Best Available Technology Economically Achievable (BAT) (304(b)(2) of the CWA) - In general, BAT effluent limitations represent the best existing economically achievable performance of direct discharging plants in the industrial subcategory or category. The factors considered in assessing BAT include the cost of achieving BAT effluent reductions, the age of equipment and facilities involved, the processes employed, engineering aspects of the control technology, potential process changes, nonwater-quality environmental impacts (including energy requirements), and such factors as the Administrator deems appropriate. EPA retains considerable discretion in assigning the weight to be accorded to these factors. An additional statutory factor considered in setting BAT is economic achievability. Generally, the achievability is determined on the basis of the total cost to the industrial subcategory and the overall effect of the rule on the industry's financial health. BAT limitations may be based on effluent reductions attainable through changes in a facility's processes and operations. As with BPT, where existing performance is uniformly inadequate, BAT may be based on technology transferred from a different subcategory within an industry or from another industrial category. BAT may be based on process changes or internal controls, even when these technologies are not common industry practice.

- Best Conventional Pollutant Control Technology (BCT) (304(b)(4) of the CWA) - The 1977 amendments to the CWA required EPA to identify effluent reduction levels for conventional pollutants associated with BCT technology for discharges from existing industrial point sources. BCT is not an additional limitation, but replaces BAT for control of conventional pollutants. In addition to other factors specified in Section 304(b)(4)(B), the CWA requires that EPA establish BCT limitations after consideration of a two-part "cost-reasonableness" test. EPA explained its methodology for the development of BCT limitations in July 1986 (51 FR 24974). Section 304(a)(4) designates the following as conventional pollutants: biochemical oxygen demand (BOD_5), total suspended solids (TSS), fecal coliform, pH, and any additional pollutants designated by the Administrator as conventional. The Administrator designated oil and grease as an additional conventional pollutant on July 30, 1979 (44 FR 44501).

- New Source Performance Standards (NSPS) (306 of the CWA) - NSPS reflect effluent reductions that are achievable based on the best available demonstrated control technology. New facilities have the opportunity to install the best and most efficient production processes and wastewater treatment technologies. As a result, NSPS should represent the greatest degree of effluent reduction attainable through the application of the best available demonstrated control technology for all pollutants (i.e., conventional, nonconventional, and priority pollutants). In establishing NSPS, EPA is directed to take into consideration the cost of achieving the effluent reduction and any nonwater-quality environmental impacts and energy requirements.

For the purposes of applying the new source performance standards, a source is a new source if it completes construction after the effective date of the final rule. See 40 CFR 122.2. Each source that meets this definition is required to achieve the newly promulgated NSPS upon commencing discharge.

However, the NSPS promulgated in 1974 continue to have force and effect for a limited universe of new sources; for this reason, in the final rule, EPA is including provisions at 40 CFR 412.35(d) and 412.46(e) addressing this limited universe. Specifically, the NSPS established in 1974 will continue to apply for a limited period of time to new sources that completed construction with the time period beginning ten years before the effective date of this rule and ending on the effective date of this rule. Thus, any direct discharging new source that completed construction during this ten year period is subject to the 1974 NSPS for ten years from the date it completed construction or during the period of depreciation or amortization of such facility, whichever comes first. See CWA section 306(d). After that ten-year period expires, the BPT, BCT, and BAT limitations established in this rule apply because they are more stringent than the 1974 NSPS.

Indirect Dischargers

- Pretreatment Standards for Existing Sources (PSES) (307(b) of the CWA) - PSES are designed to prevent the discharge of pollutants that pass through, interfere with, or are otherwise incompatible with the operation of POTWs. The CWA authorizes EPA to establish pretreatment standards for pollutants that pass through POTWs or interfere with treatment processes or sludge disposal methods at POTWs. Pretreatment standards are technology-based and analogous to BAT effluent limitations guidelines for removal of priority pollutants. EPA retains discretion not to issue such standards where the total amount of pollutants passing through a POTW is not significant.
- The General Pretreatment Regulations, which set forth the framework for the implementation of categorical pretreatment standards, are found at 40 CFR Part 403. Those regulations contain a definition of pass-through that addresses localized rather

than national instances of pass-through and establish pretreatment standards that apply to all domestic dischargers (see 52 FR 1586, January 14, 1987).

- Pretreatment Standards for New Sources (PSNS) (307(b) of the CWA) - Like PSES, PSNS are designed to prevent the discharges of pollutants that pass through, interfere with, or are otherwise incompatible with the operation of POTWs. PSNS are to be issued at the same time as NSPS. New indirect dischargers have the opportunity to incorporate into their facilities the best available demonstrated technologies. The Agency considers the same factors in promulgating PSNS as it considers in promulgating NSPS. EPA retains discretion not to issue such standards where the total amount of pollutants passing through a POTW is not significant.

1.2 Pollution Prevention Act

In the PPA of 1990 (42 U.S.C. 13101 et seq., Pub. Law 101-508, November 5, 1990), Congress declared pollution prevention a national policy of the United States. The PPA declares that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible; pollution that cannot be prevented or recycled should be treated; and disposal or other release into the environment should be chosen only as a last resort and should be conducted in an environmentally safe manner. This final regulation for CAFOs was reviewed for its incorporation of pollution prevention as part of EPA effort. Chapters 4 and 8 describe pollution prevention practices applicable to animal feeding operations (AFOs).

1.3 Regulatory Flexibility Act as Amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA)

In accordance with Section 603 of the RFA (5 U.S.C. 601 et seq.), EPA prepared an initial regulatory flexibility analysis (IRFA) that examined the impact of the proposed rule on small entities along with regulatory alternatives that could reduce that impact. The IRFA (available in Chapter 9 of *Economic Analysis of the Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations*) concluded that the economic effect of regulatory options being considered might significantly impact a substantial number of small livestock and poultry operations.

As required by Section 609(b) of the RFA, and as amended by SBREFA, EPA also conducted outreach to small entities and convened a Small Business Advocacy Review Panel to obtain the advice and recommendations of representatives of the small entities that potentially would be subject to the rule's requirements. Consistent with the RFA/SBREFA requirements, the panel evaluated the assembled materials and small entity comments on issues related to the elements of the IRFA. Participants included representatives of EPA, the Small Business Administration (SBA), and the Office of Management and Budget (OMB). Participants from the farming community included small livestock and poultry producers as well as representatives of the major commodity and agricultural trade associations. A summary of the panel's activities and recommendations is provided in the *Final Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule on National Pollutant Discharge Elimination System (NPDES) and Effluent Limitations Guideline (ELG) Regulations for Concentrated Animal Feeding Operations* (April 7, 2000). This document is included in the public record.

For these regulated industries, SBA sets size standards for defining small businesses by amount of annual revenue generated, representing total facility revenue at the farm level (e.g., revenue from all sources including livestock, crop and other farm-related income at a livestock or poultry operation) and expressed as an average over a 3-year period. These size standards vary by North American Industry Classification System (NAICS) code; CAFOs are listed under NAICS 11 (Agriculture, Forestry, and Fishing). On June 7, 2001, SBA increased the size standards used to define small businesses for most agriculture sectors listed under NAICS 11 from $0.5 million to $0.75 million in average annual receipts (see 66 FR 30646). EPA estimates that the final revised regulations for the CAFOs industry affect approximately 6,300 small businesses; see the *Economic Analysis of the Final Revisions to the NPDES and the Effluent Guidelines for Concentrated Animal Feeding Operations* (hereafter referred to as the EA) for additional information.

CHAPTER 2

SUMMARY AND SCOPE OF FINAL REGULATION

2.0 SUMMARY AND SCOPE OF FINAL REGULATION

The final regulations described in this document include revisions of two regulations that ensure manure, litter, and other process wastewaters for CAFOs do not impair water quality. These two regulations are the NPDES described in Section 2.1 and the ELG for feedlots (beef, dairy, swine, poultry, and veal) described in Section 2.2, which establish the technology-based standards that are applied to CAFOs. Both regulations were originally promulgated in the 1970s. EPA revised these regulations to address changes that have occurred in the animal industry sectors over the last 25 years, to clarify and improve implementation of CAFO permit requirements, and to improve the environmental protection achieved under these rules by ensuring effective management of manure by primarily the largest CAFOs. EPA is not revising the ELG for the horse, sheep and lamb, or duck subcategories.

2.1 National Pollutant Discharge Elimination System

As noted in Chapter 1, CAFOs are "point sources" under the CWA. The regulation at 40 CFR 122.23 specifies which AFOs are CAFOs and, therefore, are subject to the NPDES program.

2.1.1 Applicability of the Final Regulation

The final rule retains the definition of an animal feeding operation (AFO) as it was defined in the 1976 regulation at 40 CFR 122.23(b)(1). An AFO means a lot or facility (other than an aquatic animal production facility) where the following conditions are met: (1) animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and (2) crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

The 1976 NPDES regulation uses the term "animal unit," or AU, to identify facilities that are CAFOs. The term AUs is a metric unit established in the 1976 regulation that attempted to equate the characteristics of the wastes produced by different animal types. EPA has decided to eliminate the term animal unit in this final rule. The final regulation described in today's document retains the basic three-tier structure for determining what size AFOs are CAFOs, as well as retaining the existing conditions for defining which medium-sized AFOs are CAFOs. In the final rule, EPA discontinues the use of the term AU for defining these three size-based groups, and instead uses the actual number of animals to define certain AFOs as Large, Medium, and Small CAFOs.

Table 2-1 presents the thresholds for defining AFOs as Large, Medium, and Small CAFOs in each sector. All AFOs with more than the specified number of head or birds in the second column are defined as "Large CAFOs." AFOs with the specified number of animals in the third column are defined as "Medium CAFOs" only if they meet one of the two specified criteria governing the method of discharge (1) pollutants are discharged into waters of the United States through a man-made ditch, flushing system, or other similar man-made device; or (2) pollutants are discharged directly into waters of the United States which originate outside of and pass over, across, or through the facility or otherwise come into direct contact with the confined animals in the operation. Some AFOs in this middle size group may also be designated as CAFOs by EPA or the state NPDES permitting authority. AFOs with fewer than the number of animals in the last column would be defined as "Small CAFOs" only if they are designated by EPA or the state NPDES permitting authority.

Table 2-1. Summary of CAFO Size Thresholds for all Sectors.

Sector	Number of Head or Birds Confined at the AFO		
	Large CAFO	Medium CAFO[a]	Small CAFO[b]
Mature dairy cattle, whether milked or dry	>700	200 – 700	<200
Veal calves	>1,000	300 – 1,000	<300
Cattle other than mature dairy cows or veal calves. Cattle includes but is not limited to heifers, steers, bulls and cow/calf pairs.	>1,000	300 – 1,000	<300
Swine each weighing 55 pounds or more	>2,500	750 – 2,500	<750
Swine each weighing less than 55 pounds	>10,000	3,000 – 10,000	<3,000
Horses	>500	150 – 500	<150
Sheep or lambs	>10,000	3,000 – 10,000	<3,000
Turkeys	>55,000	16,500 – 55,000	<16,500
Laying hens or broilers (uses a liquid manure handling system)	>30,000	9,000 – 30,000	<9,000
Chickens other than laying hens (uses other than a liquid manure handling system)	>125,000	37,500 – 125,000	<37,500
Laying hens (uses other than a liquid manure handling system)	>82,000	25,000 – 82,000	<25,000
Ducks (uses other than a liquid manure handling system)	>30,000	10,000 – 30,000	<10,000
Ducks (uses a liquid manure handling system)	>5,000	1,500 – 5,000	<1,500

[a] Must also meet one of two criteria to be defined as a CAFO, or can be designated by the permitting authority.

[b] Must be designated by the permitting authority.

EPA considered a number of mechanisms for addressing animal types not explicitly covered in the 1976 regulation, specifically immature swine, heifers, and chickens utilizing dry manure handling systems. EPA selected the approach of counting the numbers of mature swine and numbers of immature swine separately, where either one of which could define the facility as a CAFO. Once a facility is defined as a CAFO for either age group of animals, all animals in confinement would be considered as part of the CAFO. Similarly, EPA selected phosphorus in the manure of 1,000 beef cattle for establishing 1,000 heifers as the threshold for a Large CAFO. See Section 2 of this Chapter for more information on EPA's analysis, and Chapter 6 for additional information on the manure and wastewater characteristics.

The final rule includes chicken operations that use "dry" or "wet" manure handling systems. As a result, the scope of the rule is expanded to include chicken operations with "dry" litter management systems. Similarly, EPA is establishing different thresholds for ducks raised in lots as opposed to ducks raised in confinement buildings. EPA's final evaluation concluded that 125,000 broilers and 82,000 layers produce an equivalent amount of manure phosphorus to 1,000 beef cows. The use of annual phosphorus production as the metric for establishing thresholds is consistent with the metric described above for swine and heifers. These analyses are discussed further in Section 2.2.

2.1.2 Summary of Revisions to NPDES Regulations

Overall, this final rule maintains many of the basic features and overall structure of the 1976 NPDES regulations with some important exceptions. First, EPA eliminated the 25-year, 24-hour storm permitting exemption for defining a CAFO. All Large CAFOs have a mandatory duty to apply for an NPDES permit. This removes the ambiguity of whether a Large facility needs to apply for an NPDES permit, even if it discharges only in the event of a large storm event. In the rare occasion that a Large CAFO has No Potential To Discharge (NPTD), the rule provides a process for the CAFO to make such a demonstration to the Director in lieu of obtaining a permit.

The second significant change is that AFOs with chickens are subject to the NPDES rule, regardless of the type of waste disposal system used or whether the litter or manure is managed in a wet or dry form. EPA maintained the existing size criteria for chicken operations with wet manure handling systems, and established different size criteria for chickens with dry manure handling systems based on broad type of chicken (i.e., chickens for meat (broilers) and chickens for eggs (layers)).

Third, under this final rule, all CAFOs covered by an NPDES permit are required to develop and implement a nutrient management plan. The plan would identify prohibitions and practices necessary to demonstrate compliance with any limitations or standards in the permit and, for Large CAFOs, applicable ELGs. This includes requirements to land-apply the manure and wastewater consistent with appropriate agricultural utilization. The plan must address the following nine minimum elements:

- Ensure adequate storage of manure and process wastewater, including procedures to ensure proper operation and maintenance of the storage facilities.
- Ensure proper management of mortalities (i.e., dead animals) to ensure that they are not disposed of in a liquid manure, storm water, or process waste water storage or treatment system that is not specifically designed to treat animal mortalities..
- Ensure that clean water is diverted, as appropriate, from the production area.
- Prevent direct contact of confined animals with waters of the United States.
- Ensure that chemicals and other contaminants handled on-site, are not disposed of in any manure, litter, process wastewater, or storm water storage or treatment system unless specifically designed to treat such chemicals and other contaminants.
- Implement appropriate site specific conservation practices, including as appropriate buffers or equivalent practices, to control runoff of pollutants to waters of the United States.
- Conduct appropriate testing of manure, litter, process wastewater, and soil.
- Land apply manure, litter or process wastewater in accordance with site specific nutrient management practices that ensure appropriate agricultural utilization of the nutrients in the manure, litter or process wastewater.
- Identify specific records that will be maintained to document the implementation and management of the minimum elements described above.

The discharge of manure, litter, or process wastewater to waters of the United States from a CAFO as a result of the application of that manure, litter, or process wastewater by the CAFO to land areas under its control is a discharge from that CAFO subject to NPDES permit requirements, except where it is an agricultural storm water discharge. If the manure, litter, or process wastewater has been applied in accordance with site specific nutrient management practices that ensure appropriate agricultural utilization of the nutrients in the manure, litter, or process wastewater a discharge of manure, litter, or process wastewater from land areas under the control of a CAFO is an agricultural stormwater discharge. "Appropriate agricultural utilization" includes, but is not limited to, land application of manure, litter, or process wastewater in accordance with site specific nutrient management practices.

In addition to new thresholds for chickens, the final rule establishes new, or clarifies existing, thresholds for veal calves, immature swine, cow/calf pairs, ducks that use other than a liquid manure handling system, and heifer operations, as described in Section 2.1.1. This final rule eliminates the formula for calculating whether an AFO is a CAFO due to the accumulation of several different animal types in confinement at one facility[1].

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[1]Previously, an AFO was defined as a CAFO if the number of slaughter steers and heifers multiplied by 1.0, plus the number of mature dairy cattle multiplied by 1.4, plus the number of swine over 55 pounds multiplied by 0.4, plus the number of sheep multiplied by 0.1, plus the number of horses multiplied by 2.0 was greater than 1,000.

In the final rule EPA requires that the CAFO owner or operator to maintain permit coverage for the CAFO until it is properly closed.

EPA requires certain records to be retained on site at the CAFO for 5 years. The specific record keeping, monitoring and reporting requirements of the final rule are as follows:

- A copy of the CAFO's site-specific nutrient management plan.
- All applicable records that will used document the implementation and management identified in the nutrient management plan.
- For Large CAFOs, any additional records specified in the ELGs (see Section 2.2).
- For Large CAFOs, a record of the date, recipient name and address, and approximate amount of manure, litter, or process wastewater transferred to another person.

In addition, the CAFO must submit to the permitting authority an annual report that includes the following:

- The number and type of animals in, whether in open confinement or housed under roof (beef cattle, broilers, layers, swine weighing 55 pounds or more, swine weighing less than 55 pounds, mature dairy cows, dairy heifers, veal calves, sheep and lambs, horses, ducks, turkeys, other).
- Estimated amount of total manure, liter and process wastewater generated by the CAFO in the previous 12 months (tons/gallons).
- Estimated amount of total manure, litter and process wastewater transferred to other person by the CAFO in the previous 12 months (tons/gallons).
- Total number of acres for land application covered by the nutrient management plan.
- Total number of acres under control of the CAFO that were used for land application of manure, litter and process wastewater in the previous 12 months.
- Summary of all manure, litter and process wastewater discharges from the production area that have occurred in the previous 12 months, including date, time, and approximate volume.
- A statement indicating whether the current version of the CAFO's nutrient management plan was developed or approved by a certified nutrient management planner.

2.2 Effluent Limitations Guidelines and Standards

Effluent limitations guidelines and standards are national regulations that establish limitations on the discharge of pollutants by industrial category and subcategory. The final effluent limitations guidelines and standards establish the Best Practicable Control Technology Currently Available (BPT), Best Conventional Pollutant Control Technology (BCT), and the Best Availability

Technology Economically Achievable (BAT) limitations as well as New Source Performance Standards (NSPS) on discharges from the "production area" and the "land application areas" at CAFOs. The term "production area" means that part of an AFO that includes the animal confinement area, the manure storage area, the raw materials storage area, and the waste containment areas. The animal confinement area includes but is not limited to open lots, housed lots, feedlots, confinement houses, stall barns, free stall barns, milkrooms, milking centers, cowyards, barnyards, medication pens, walkers, animal walkways, and stables. The manure storage area includes but is not limited to lagoons, runoff ponds, storage sheds, stockpiles, under house or pit storages, liquid impoundments, static piles, and composting piles. The raw materials storage area includes but is not limited to feed silos, silage bunkers, and bedding materials. The waste containment area includes but is not limited to settling basins, and areas within berms and diversions which separate uncontaminated storm water. Also included in the definition of production area is any egg washing or egg processing facility, and any area used in the storage, handling, treatment, or disposal of mortalities. The term "land application areas" means land under the control of an AFO owner or operator, whether it is owned, rented, or leased, to which manure or process wastewater from the production area is or may be applied.

2.2.1 Applicability of the Final Regulation

EPA has subcategorized the CAFOs Point Source Category based primarily on animal production processes and waste handling and management practices. Large beef feedlots, dairies, and heifer operations typically have outdoor confinement lots where animals are housed for all or at least a portion of their time. The open outdoor lots expose large areas to precipitation, generating large volumes of storm water runoff contaminated with manure, bedding, feed, silage, antibiotics, and other process contaminants. In contrast, nearly all Large swine, poultry, and veal operations utilize total confinement housing. See Chapter 4 for more information on production practices, and Chapter 5 for a discussion of the basis considered for subcategorization. The final rule establishes new effluent limitations and guidelines for Subpart C, covering beef cattle, dairy cattle, and heifers; and Subpart D, covering veal calves, swine, and poultry (chickens and turkeys).

As described in Section 2.1, an AFO is a CAFO if the specific threshold for any one animal sector is met. Consistent with the final NPDES rule, the ELG eliminates the formula for calculating whether Subpart A applies due to the accumulation of several different animal types in confinement at one facility. The final ELG applicability of Subpart A thus only applies to horses and sheep. The final subcategories are listed and described in Table 2-2.

The ELG requirements for Subpart C (dairy and beef cattle other than veal) and Subpart D (swine, poultry, and veal) apply to those operations which are defined as Large CAFOs under the NPDES regulations described in Section 2.1. In the case of Medium or Small CAFOs, or CAFOs not otherwise subject to Part 412, effluent limitations will be established on a case-by-case basis by the permitting authority using best professional judgment (BPJ).

Table 2-2. Summary of Final ELG Subcategorization for CAFOs.

Subpart	Subcategory	Description
A	Horses and Sheep	CAFOs under 40 CFR 122.23 which confine more than 500 horses or 10,000 sheep.
B	Ducks	CAFOs under 40 CFR 122.23 which confine more than 5000 ducks.
C	Dairy and Beef Cattle Other than Veal	CAFOs under 40 CFR 122.23 which confine more than 700 mature dairy cows (either milking or dry) or 1000 cattle other than mature dairy cows or veal calves.
D	Swine, Poultry, and Veal	CAFOs under 40 CFR 122.23 which confine more than 2,500 swine each weighing 55 pounds or more, 10,000 swine each weighing less than 55 pounds, 30,000 laying hens or broilers when the facility uses a liquid manure handling system, 82,000 laying hens when the facility uses other than a liquid manure handling system, 125,000 chickens other than laying hens when the facility uses other than a liquid manure handling system, 55,000 turkeys, or 1,000 veal calves.

In 1974 when the original ELG was promulgated, stand-alone heifer operations were not considered a major livestock operation. However, due to the increased specialization of dairies over the past 25 years, these heifer operations have become more common and more abundant. While most heifers were maintained in pasture, many large dairies place the heifers in confinement at a feedlot. Therefore, EPA has specifically addressed heifer operations to address potential discharges to surface waters. Based on the similarity of the production (animal type and housing) and waste management processes for beef feedlots, dairies, and heifer operations, EPA developed a new subcategory, Subpart C, to address these types of operations under this rule.

Subpart D includes swine, poultry and veal calves, which are predominantly produced in confinement housing with little to no exposure to precipitation. Based on the information in the record, EPA is including operations with immature swine as CAFOs under Subpart D based on their production and waste handling practices. Immature swine operations were not specifically addressed in the 1974 ELG because immature swine were typically raised at a farrow-to-finish operation and not at a separate nursery operation like today. Although many large swine operations continue to have the full range of production phases at one location, these operations are no longer the norm. More frequently, in new operations, several specialized farms are integrated into a chain of production and marketing. Pigs begin in sowherds on one site, move to a nursery on another, and then move again to a finishing facility. Due to the increased construction and reliance on immature swine operations, EPA determined that these operations should be specifically addressed in the ELG.

The simplest approach for including immature swine is to count all swine, regardless of size and age. EPA determined counting all swine equally would increase the effective size of operations that have breeding functions by a factor of seven or more (based on the number of pigs per litter). While this approach would include nursery facilities, this approach also changes the existing basis without improving the regulation. Alternatively, all swine would be counted but a weighting factor could be used to distinguish animal sizes. This approach is inconsistent with EPA's attempt to simplify the regulations by removing mixed animal multipliers and animal unit calculations.

EPA selected the approach of counting the numbers of mature swine and numbers of immature swine separately, where either one of which could define the facility as a CAFO. EPA selected phosphorus in the manure as the metric for Large CAFO thresholds. EPA's analysis equates 2,500 mature swine (weighing over 55 pounds) to approximately 10,000 immature swine (weighing less than 55 pounds) on a phosphorus excreted basis. Once a swine facility is defined as a CAFO for either age group of animals, all animals in confinement would be considered as part of the CAFO. Because the immature operations use virtually the same animal production and waste management processes and are expected to use similar effluent reduction practices and technologies as mature swine operations, EPA has included these immature swine operations under Subpart D.

As discussed in Section 2.1, the final rule expands the scope of the rule to also address chicken operations with "dry" litter management systems. While liquid manure systems continue to be used by approximately 15 percent of the total laying industry (see Chapter 4), continuous flow watering systems have been largely discontinued in favor of more efficient water conserving methods (e.g., on-demand watering). Site visits and consultations with industry further suggest liquid manure handling systems are no longer constructed at laying hen operations.

EPA noted chickens raised for meat production are a different breed of chicken, have a different weight, eat a different diet, and are raised differently than those used for egg production. Therefore EPA considered a number of approaches to determine the final applicability thresholds. EPA evaluated the manure generated from chickens used for meat (broilers) and egg production (layers) and compared manure production to a 1,000 pound beef cow. EPA evaluated daily manure phosphorus production and annual phosphorus production, and determined annual production was more appropriate because annual production reflects the time birds are actually present and generating manure. The annual approach assumes 5 to 6 flocks of broilers are produced each year, for a total of 322 days of manure production in one year. In contrast, each layer flock is raised for either 80 weeks (non-molt flocks) or 105 weeks (molt flocks). Molt flocks go through two cycles of egg production, separated by a non-productive molting period (shedding of feathers and renewal of ovarian activity) induced by withholding food. Manure production greatly diminishes during the two-week molt period. Following the molt, egg production resumes to the end of the flock life. Furthermore, prior to egg-laying age, the bird will typically be raised for 19 weeks as a pullet. On average, layers are in production for 94 weeks. EPA's final evaluation concluded that 125,000 broilers and 82,000 layers produce an equivalent amount of manure phosphorus to 1,000 beef cows.

This rule addresses veal operations under Subpart D along with swine and poultry operations due to the similarity in animal production and waste management processes. See Chapter 5 for additional discussion of the industry subcategorization for this rule.

2.2.2 Summary of Revisions to Effluent Limitations Guidelines and Standards

Large CAFOs covered under Subpart C and Subpart D are required under this final rule to comply with the new effluent limitations guidelines and standards (see Table 2-3). The final guidelines establish BPT, BCT, BAT, and NSPS by requiring effluent limitations and standards and specific BMP that ensure that manure storage and handling systems are inspected and maintained adequately as described in the following subsections. Medium and Small CAFOs are not subject to the ELGs.

2.2.2.1 Land Application Best Practicable Control Technology

EPA set BPTs for land application applicable to any CAFO subject to Subparts C or D. These BMPs include the requirement to develop and implement a nutrient management plan that incorporates the following requirements based on a field-specific assessment:

- *Determination of application rates.* Application rates for manure, litter, and other process wastewater applied to land under the ownership or operational control of the CAFO must minimize phosphorus and nitrogen transport from the field to surface waters in compliance with the technical standards for nutrient management established by the Director. Such technical standards for nutrient management shall:
    - Include a field-specific assessment of the potential for nitrogen and phosphorus transport from the field to surface waters, and address the form, source, amount, timing, and method of application of nutrients on each field to achieve realistic production goals, while minimizing nitrogen and phosphorus movement to surface waters; and
    - Include appropriate flexibilities for any CAFO to implement nutrient management practices to comply with the technical standards, including consideration of multi-year phosphorus application on fields that do not have a high potential for phosphorus runoff to surface water, phased implementation of phosphorus-based nutrient management, and other components, as determined appropriate by the Director.
- *Manure and Soil Sampling.* Manure must be analyzed a minimum of once annually for nitrogen and phosphorus content, and soil analyzed a minimum of once every five years for phosphorus content. The results of these analyses are to be used in determining application rates for manure, litter, and other process wastewater.

- *Inspect land application equipment for leaks*. The operator must periodically inspect equipment used for land application of manure, litter, or process wastewater.
- *Setback requirements.* Manure, litter, and process wastewater may not be applied closer than 100 feet to any down-gradient surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters unless one of the following compliance alternatives are used:
  - *Vegetated buffer compliance alternative*. As a compliance alternative, the CAFO may substitute the 100-foot setback with a 35-foot wide vegetated buffer where applications of manure, litter, or process wastewater are prohibited.
  - *Alternative practices compliance alternative*. As a compliance alternative, the CAFO may demonstrate that a setback or buffer is not necessary because implementation of alternative conservation practices or field-specific conditions will provide pollutant reductions equivalent or better than the reductions that would be achieved by the 100-foot setback.
- *Record keeping requirements for the land application areas.* Each CAFO must maintain on-site a copy of its site-specific nutrient management plan and the following information for a period of five years from the date they are created:
  - Expected crop yields.
  - The date(s) manure, litter, or process waste water is applied to each field.
  - Weather conditions at time of application and for 24 hours prior to and following application.
  - Test methods used to sample and analyze manure, litter, process waste water, and soil.
  - Results from manure, litter, process waste water, and soil sampling.
  - Explanation of the basis for determining manure application rates, as provided in the technical standards established by the Director.
  - Calculations showing the total nitrogen and phosphorus to be applied to each field, including sources other than manure, litter, or process wastewater.
  - Total amount of nitrogen and phosphorus actually applied to each field, including documentation of calculations for the total amount applied.
  - The method used to apply the manure, litter, or process wastewater.

- Date(s) of manure application equipment inspection.

2.2.2.2 Production Area Best Practicable Control Technology

EPA set BPTs for the production area that are applicable to any CAFO subject to Subparts C or D. Under BPT, EPA prohibits the discharge of manure, litter, or process wastewater pollutants into waters of the United States from the production area except overflow from containment facilities if caused by rainfall events and the facility is designed, constructed, operated, and maintained to contain all manure, litter, and process wastewater including the runoff and the direct precipitation from a 25-year, 24-hour rainfall event. The production area must also be operated in accordance with the additional measures and record keeping requirements described below. These requirements do not apply to discharges to ground water with a direct hydrologic connection to surface water, although the permit writer could establish such technology-based limitations on a case-by-case basis. BPT establishes the following additional measures and record keeping requirements for the production area (records are to be kept for five years from the time they are created):

- Weekly inspections of all storm water diversion devices, runoff diversion structures, and devices channelling contaminated storm water to the wastewater and manure storage and containment structure.
- Daily inspection of water lines, including drinking water or cooling water lines.
- Weekly inspections of the manure, litter, and process wastewater impoundments; the inspection will note the level in liquid impoundments as indicated by the depth marker.
- All open surface liquid impoundments must have a depth marker which clearly indicates the minimum capacity necessary to contain the runoff and direct precipitation of the 25-year 24-hour rainfall event.
- Any deficiencies found as a result of these inspections must be corrected as soon as possible.
- Mortalities must not be disposed of in any liquid manure or process wastewater system, and must be handled in such a way as to prevent the discharge of pollutants to surface water, unless alternative technologies are designed and approved to handle mortalities.
- Records documenting the inspections described above.
- Weekly records of the depth of the manure and process wastewater in the liquid impoundment as indicated by the depth marker.
- Records documenting any actions taken to correct deficiencies described above. Deficiencies not corrected within 30 days must be accompanied by an explanation of the factors preventing immediate correction.
- Records of mortalities management and practices used by the CAFO to meet the requirements described above.

- Records documenting the current design of any manure or litter storage structures, including volume for solids accumulation, design treatment volume, total design volume, and approximate number of days of storage capacity.
- Records of the date, time, and estimated volume of any overflow.

EPA set an alternative BPT, described in section 2.2.2.6 below, to encourage innovative technologies.

2.2.2.3 Best Control Technology

EPA set BCT requirements for Subparts C (dairy and beef cattle other than veal subcategories) and D (swine, poultry, and veal subcategories) the same as BPT. Table 2-3 shows the technology basis of BCT for these subcategories.

2.2.2.4 Best Available Technology

EPA set BAT requirements for Subparts C (dairy and beef cattle other than veal subcategories) and D (swine, poultry, and veal subcategories) the same as BPT. Table 2-3 shows the technology basis of BAT for these subcategories.

2.2.2.5 New Source Performance Standards

EPA set NSPS requirements equivalent to BPT requirements for Subpart C (dairy and beef cattle other than veal subcategories) and for the land application area of Subpart D (swine, poultry, and veal subcategories).

EPA set different NSPS requirements for the production area of Subpart D (swine, poultry, and veal subcategories). NSPS requirements for Subpart D prohibit the discharge of manure, litter, or process wastewater pollutants into waters of the United States from the production area. A facility designed, constructed, operated, and maintained to contain all manure, litter, and process wastewater including the runoff and the direct precipitation from a 100-year, 24-hour rainfall event will fulfill the requirement for no discharge. The production area must also be operated in accordance with the additional measures and record keeping requirements described earlier with the exception that all open surface liquid impoundments must have a depth marker which clearly indicates the minimum capacity necessary to contain the runoff and direct precipitation of the 100-year 24-hour rainfall event.

EPA set an alternative NSPS, described in Section 2.2.2.7 below, to encourage innovative technologies and whole-farm multi-media reductions.

For the purposes of applying the new source performance standards, a source is a new source if it commenced construction after the effective date of the final rule. See 40 CFR 122.2. Each source that meets this definition is required to achieve the newly promulgated NSPS upon commencing discharge.

Table 2-3. Summary of Technology Basis for Large CAFOs Covered by Part 412.

Technology Basis	BPT, BCT, and BAT		NSPS	
	Dairy and Beef Cattle other Than Veal Subcategory	Swine, Poultry, and Veal Subcategory	Dairy and Beef Cattle other Than Veal Subcategory	Swine, Poultry, and Veal Subcategory
Zero discharge with overflow provided if caused by rainfall events and the facility is designed, constructed, operated, and maintained to contain all manure, litter, and process wastewater including the runoff and the direct precipitation from a 25-year, 24-hour rainfall event.	✓	✓	✓	
Zero discharge with overflow provided if caused by rainfall events and the facility is designed, constructed, operated, and maintained to contain all manure, litter, and process wastewater including the runoff and the direct precipitation from a 100-year, 24-hour rainfall event.				✓
Development and implementation of a nutrient management plan; and maintain records.	✓	✓	✓	✓
Land application consistent with appropriate agricultural utilization.	✓	✓	✓	✓
Voluntary alternative performance standards for discharges from the production area that achieve equal or better pollutant reduction.	✓	✓	✓	
Voluntary superior environmental performance standards for technologies that achieve overall environmental performance across all media equal or superior to baseline NS.PS				✓
Daily and weekly inspections.	✓	✓	✓	✓
Depth marker for open surface liquid impoundments.	✓	✓	✓	✓
Corrective action.	✓	✓	✓	✓
Mortality handling requirements.	✓	✓	✓	✓
100-foot land application setback or equivalent compliance alternative.	✓	✓	✓	✓
Manure samples at least once per year.	✓	✓	✓	✓
Soil test every 5 years.	✓	✓	✓	✓
Record keeping.	✓	✓	✓	✓

However, the NSPS promulgated in 1974 continue to have force and effect for a limited universe of new sources; for this reason, in the final rule, EPA is including provisions at 40 CFR 412.35(d) and 412.46(e) addressing this limited universe. Specifically, the NSPS established in 1974 will continue to apply for a limited period of time to new sources that completed construction with the time period beginning ten years before the effective date of this rule and ending on the effective date of this rule. Thus, any direct discharging new source that completed construction during this ten year period is subject to the 1974 NSPS for ten years from the date it completed construction or during the period of depreciation or amortization of such facility, whichever comes first. See CWA section 306(d). After that ten-year period expires, the BPT, BCT, and BAT limitations established in this rule apply because they are more stringent than the 1974 NSPS.

EPA has determined that the ten-year period should apply to discharges from the both the CAFO production areas and land application areas even though the 1974 NSPS specifically addressed only discharges from the production area. This determination is based on the manner in which manure, litter, and other process wastewaters at CAFOs are generated and the waste management practices employed for these wastes. EPA recognizes that the land application BMPs established by this rule have the potential to alter the land application practices at the CAFO, which could affect waste management practices at the production area. Animal feeding strategies and waste management practices at the production area determine the form of the wastes (i.e., solid, liquid, or slurry) and the amount of nutrients and other pollutants present in the wastes. The timing of any application and the amount of nutrients (i.e., manure, litter, and other process wastewater) applied is determined by crop needs, irrigation requirements, and other factors such as the availability of manure spreading equipment and climate considerations. The land application BMPs established by this rule include a requirement to develop and implement a nutrient management plan, as well as a requirement to land-apply manure at rates based on technical standards for nutrient management established by the Director. Based on the information in the record, the land application BMPs established by this rule will lead to some changes in the ways CAFOs manage their land application areas. A number of CAFOs affected by this rule will need to reduce the amount of manure and other process wastewaters applied to cropland. As they develop their nutrient management plans some CAFOs may determine they should adjust the timing of manure applications. Since the CAFO must be able to store any wastes generated at the production area until able to land-apply the manure, significant changes in the amount of manure applied or the timing of manure application may affect waste management systems at the production area. Therefore, EPA determined that the ten-year period described above should apply to discharges from both the production areas and the land application areas at CAFOs.

If the production area and land application area wastestreams at CAFOs were more physically distinct, particularly if they were generated and remained distinct and severable throughout all steps of the waste generation and management (or could be managed in such a manner), and the NSPS requirements for the land application area did not significantly affect the waste management infrastructure at the production area, EPA likely would have determined that the ten-year “grandfathering” period would apply only to production area discharges and would not apply to discharges from the land application areas.

Rather than reproduce the 1974 NSPS in the newly revised rule, EPA is referring permitting authorities to the NSPS codified in the 2002 edition of the Code of Federal Regulations for use during the applicable ten-year period. (The 2002 edition of the Code of Federal Regulations presents the 1974 NSPS requirements.) This approach allows EPA to avoid reproducing in the new regulations the requirements of the 1974 NSPS that will soon become outdated.

2.2.2.6 Voluntary Alternative Performance Standards to Encourage Innovative Technologies

In addition to the production area effluent guidelines (baseline effluent guidelines), the final rule establishes provisions for the development of alternative performance standards for discharges from the production area for existing Large CAFOs and new Large beef and dairy CAFOs. The BMPs described under BPT are applicable to all Large CAFOs (both existing and new sources), regardless of whether their NPDES permit limitations are based on the baseline effluent guidelines or the alternative performance standards.

The voluntary alternative performance standards will enable Large CAFOs to develop and implement new technologies and management practices that perform as well as or better than the baseline effluent guidelines at reducing pollutant discharges to surface waters from the production area. CAFOs will have the option to either accept NPDES permit limitations based on the baseline effluent guidelines, or may voluntarily request the permitting authority to establish an alternative BPT/BCT/BAT/NSPS performance standard as the basis for their technology-based NPDES permit limits. The specific requirements imposed by the alternative performance standard would be established by the NPDES permitting authority on the basis of BPJ.

Under this program, CAFOs will be allowed to discharge process wastewater that has been treated by technologies that the CAFO demonstrates will result in equivalent or better pollutant removal than would otherwise be achieved by the baseline effluent guidelines. These regulatory provisions are targeted toward the CAFO’s wastewater discharges, but EPA encourages operations electing to participate in the alternative performance standards program to consider environmental releases holistically and also consider opportunities for achieving improvement in multiple environmental media. To demonstrate that an alternative control technology would achieve equivalent or better pollutant reductions than baseline effluent guidelines, the CAFO must submit a technical analysis, which includes calculating the quantity of pollutant reductions, on a mass-basis where appropriate, based on the site-specific modeled performance of a system designed to comply with the baseline effluent guidelines. The CAFO must also prepare a proposed alternative program plan including the results of the analysis; the proposed method for implementing new technologies and practices, including an approach for monitoring performance; and the results demonstrating that these technologies and practices perform equivalent to or better than the baseline effluent guidelines. This plan must be included with the CAFO’s NPDES permit application or renewal, and will be incorporated into the permit upon approval by the permitting authority.

2.2.2.7 Voluntary Superior EnvironmentalPerformance Standards for New Large Swine/Poultry/Veal CAFOs

The NSPS requirements that apply to production area discharges at new Large swine, poultry, and veal CAFOs are more stringent than the NSPS established for other new sources and the BAT requirements for existing sources. EPA is endeavoring to ensure that this rule does not inadvertently discourage approaches that are superior from a multi-media environmental perspective. Therefore, for new sources subject to Subpart D (Large swine, poultry, and veal CAFOs), EPA is establishing alternative performance standards that provide additional compliance flexibilities specifically designed to encourage CAFOs to adopt innovative technologies for managing and/or treating manure, litter, and process wastewater. Specifically, alternative NPDES permit limitations based upon a demonstration that site-specific innovative or superior to the reductions achieved by baseline standards. The quantity of pollutants discharged from the production area must be accompanied by an equivalent or greater reduction in the quantity of pollutants released to other media from the production are (e.g., air emissions form housing and storage), the land application areas for all manure, litter, and process wastewater at on-site and off-site locations, or both. In making the demonstration that the innovative technologies will achieve an equivalent or greater reduction, the comparison of quantity of pollutants is to be made on a mass basis where appropriate.

In general, EPA expects CAFOs will conduct a whole-farm audit to evaluate releases that occur at the point to generation to minimize or eliminate waste production and air emissions, followed by an evaluation of the waste handling and management systems, and ending with an evaluation of land application and offsite transfer operations. The specific technologies that CAFOs will select and adopt to achieve the pollutant reductions are expected to be most effective for the particular operation. As part of the demonstration the CAFO will need to present information that describes how the innovative technologies will generate improvement across multiple environmental media. The Director has the discretion to request additional supporting information to supplement such a request where necessary. Such information could include criteria and data that demonstrate effective performance of the technologies and that could be used to establish the alternative NPDES permit limitations.

CHAPTER 3

DATA COLLECTION ACTIVITIES

3.0 DATA COLLECTION ACTIVITIES

EPA collected and evaluated data from a variety of sources during the course of developing the revised effluent limitations guidelines and standards for the CAFO industry. These data sources include EPA site visits, industry trade associations, the U.S. Department of Agriculture (USDA), published literature, previous EPA Office of Water studies of the Feedlots Point Source Category, and other EPA studies of AFOs. Each of these data sources is discussed below, and analyses of the data collected by EPA are presented throughout the remainder of this document.

The majority of the data EPA used to support development of the proposed effluent limitations guidelines and standards for the CAFO industry are from existing sources, including data from the USDA, industry, State agricultural extension agencies, and several land grant universities. As defined in the Office of Water 2002 Quality Management Plan, existing (or secondary) data are data that were not directly generated by EPA to support the decision at hand.

In keeping with the graded approach to quality management embodied in the Office of Water's quality management plan, EPA must assess the quality of existing data relative to their intended use. The procedures EPA used to assess existing data for use in developing effluent guideline limitations for CAFOs varied with the specific type of data. In general, EPA's assessment included:

- Reviewing a description of the existing data that explains who collected or produced the data and how the data were collected or produced (e.g., who collected the data, what data were collected; why were the data originally collected; when were the data collected; how were they collected; are the data part of a long-term collection effort, or was this a one-time effort; who else uses the data; what level of review by others have the data undergone).
- Specifying the intended use of the existing data relative to the CAFO final rule.
- Developing a rationale for accepting data from this source, either as a set of acceptance criteria, or as a narrative discussion.
- Describing any known limitations with the data and their impact on EPA's use of the data.

Brief descriptions of the data and their limitations are presented later in this document, as each data source is introduced.

In searching for existing data sources and determining their acceptability, EPA generally used a hierarchical approach designed to identify and utilize data with the broadest representation of the industry sector of interest. EPA began by searching for national-level data from surveys and studies by USDA and other federal agencies. When such survey or study data did not exist, EPA considered other data from federal agencies. An example of non-survey data considered are the USDA costs and capability data, which are based on a consensus of USDA experts.

Where national data did not exist, as the second tier, EPA searched for data from land grant universities. Such data are often local or regional in nature. EPA assessed the representativeness of the data relative to a national scale before deciding to use the data. When such data came from published sources, EPA gave greater consideration to publications in peer-reviewed professional journals compared to trade publications that do not have a formal review process.

The third tier was data supplied by industry. Prior to proposal, EPA requested data from a variety of industry sources, including trade associations and large producers. The level of review applied to data supplied by industry depended on the level of supporting detail that was provided. For example, if the industry supplied background information regarding how the data were collected, such as the number of respondents and the total number of potential respondents, EPA reviewed the results, compared them to data from other potential sources to determine their suitably for use in this rulemaking. If the data provided by industry originated from an identifiable non-industry source (e.g., a state government agency), EPA reviewed the original source information before determining the acceptability of the data. In a limited number of instances, EPA conducted site visits to substantiate information supplied by industry. In contrast, data supplied by industry without any background information were given much less weight and generally were not used by EPA. Further, some data that were supplied by industry prior to the proposal were included in the proposal for comment. In the absence of any negative comments, such data were relied on to a greater extent than data submitted by industry during the comment period itself.

3.1 Summary of EPA's Site Visit Program

EPA conducted approximately 116 site visits to collect information about AFOs and waste management practices. Specifically, EPA visited beef feedlots, dairies, and swine, poultry, and veal operations throughout the United States. A wide range of operations were visited including those demonstrating centralized treatment or new and innovative technologies. EPA chose the majority of facilities with the assistance of the following industry trade associations:

- National Pork Producers Council
- United Egg Producers and United Egg Association
- National Turkey Federation
- National Cattlemen's Beef Association

- National Milk Producers Federation
- Western United Dairymen

EPA also received assistance from environmental groups, such as the Natural Resources Defense Council and the Clean Water Network. The Agency contacted university experts, state cooperatives and extension services, and state and EPA regional representatives when identifying facilities for site visits. EPA also attended USDA-sponsored farm tours, as well as industry, academic, and government conferences.

Table 3-1 summarizes the number of site visits EPA conducted by animal industry sector, site locations, and size of animal operations.

Table 3-1. Number of Site Visits Conducted by EPA for the Various Animal Industry Sectors.

Animal Sector	Number of Site Visits	Location(s)	Size of Operations
Swine	30	NC, PA, OH, IA, MN, TX, OK, UT	900–1 million head
Poultry	6 (broiler)	GA, AR, NC, VA, WV, MD, DE, PA, OH, IN, WI	20,000–1 million birds
	12 (layer)		
	6 (turkey)		
Dairy	29	PA, FL, CA, WI, CO, VA	40–4,000 cows
Beef	30	TX, OK, KS, CO, CA, IN, NE, IA	500–120,000 head
Veal	3	IN	500–540 calves

EPA considered the following factors when identifying representative facilities for site visits:

- Type of animal feeding operation
- Location
- Feedlot size
- Current waste management practices

Facility-specific selection criteria are contained in site visit reports (SVRs) prepared for each facility visited by EPA. The SVRs are located in the administrative record for this rulemaking.

During the site visits, EPA typically collected the following types of information:

- General facility information including size and age of facility, number of employees, crops grown, precipitation information, and proximity to nearby waterways.

- Animal operation data including flock or herd size, culling rate, and method for disposing of dead animals.
- Description of animal holding areas such as barns or pens, and any central areas, such as milking centers.
- Manure collection and management information including the amount generated, removal methods and storage location, disposal information, and nutrient content.
- Wastewater collection and management information including the amount generated, runoff information, and nutrient content.
- Nutrient management plans and BMPs.
- Available wastewater discharge permit information.

This information, along with other site-specific information, is documented in the SVRs for each facility visited.

3.2 Industry Trade Associations

EPA contacted the following industry trade associations and representatives during the development of the proposed and promulgated rules.

US Poultry and Egg Association (USPOULTRY). USPOULTRY is described in their literature as dedicated to the growth, progress, and welfare of the poultry industry and all of its individual and corporate interests. All segments of the industry are represented, from producers of eggs, turkeys, and broilers to the processors of these products and allied companies which serve the industry. USPOULTRY sponsors the world's largest poultry industry show; scientific research; and a comprehensive, year-round educational program for members of the industry.

Capitol Link. Capitol Link represents the interests of many livestock organizations and acts as a liaison with federal agencies such as EPA. They frequently provide comments and data on proposed federal regulatory actions.

National Pork Producers Council (NPPC). NPPC is a marketing organization and trade association made up of 44 affiliated state pork producer associations. NPPC’s stated purpose is to increase the quality, production, distribution, and sales of pork and pork products.

United Egg Producers and United Egg Association (UEP/UEA). UEP/UEA promotes the egg industry in the following areas: price discovery, production and marketing information, unified industry leadership, USDA relationships, and promotional efforts.

National Turkey Federation (NTF). NTF describes itself as the national advocate for all segments of the turkey industry, providing services and conducting activities that increase demand for its members’ products.

National Chicken Council (NCC) and National Broiler Council (NBC). NCC is a trade association representing the vertically integrated companies that produce and process about 95 percent of the chickens sold in the United States. The association provides consumer education, public relations, and public affairs support, and is working to seek a positive regulatory, legislative, and economic environment for the broiler industry. The NCC's activities generally replace those activities conducted prior to proposal by the National Broiler Council.

National Cattlemen's Beef Association (NCBA). NCBA is a marketing organization and trade association for cattle farmers and ranchers, representing the beef industry.

National Milk Producers Federation (NMPF). NMPF is involved with milk quality and standards, animal health and food safety issues, dairy product labeling and standards, and legislation affecting the dairy industry.

American Veal Association (AVA). AVA represents the veal industry, advances the industry's concerns in the legislative arena, coordinates production-related issues affecting the industry, and handles other issues relating to the industry.

Western United Dairymen (WUD). WUD, a dairy organization in California, promotes legislative and administrative policies and programs for the industry and consumers.

Professional Dairy Heifer Growers Association (PDHGA). PDHGA is an association of heifer growers dedicated to growing high-quality dairy cow replacements. The association offers educational programs and professional development opportunities, provides a communication network, and establishes business and ethical standards for the dairy heifer grower industry.

All of the above organizations, along with several of their state affiliates, assisted EPA's efforts to understand the industry by helping with site visit selection, submitting supplemental data, and reviewing descriptions of the industry and waste management practices. These organizations also participated in and hosted meetings with EPA for the purpose of exchanging information. EPA also obtained copies of membership directories and conference proceedings, which were used to identify contacts and obtain additional information on the industry. Publications from trade associations were used to support cost methodologies.

3.3 U.S. Department of Agriculture

EPA obtained data from several agencies within the USDA, including the National Agricultural Statistics Service (NASS), the Animal and Plant Health Inspection Service (APHIS), Natural Resources Conservation Service (NRCS), and the Economic Research Service (ERS) in order to better characterize the CAFO industry. The collected data include statistical survey information and published reports. Data collected from each agency are described below.

3.3.1 National Agricultural Statistics Service

NASS is responsible for objectively providing accurate statistical information and data support services of structure and activities of agricultural production in the United States. Each year NASS conducts hundreds of surveys and prepares reports covering virtually every facet of U.S. agricultural publications. The primary source of data is the animal production facility. NASS collects voluntary information using mail surveys, telephone and in-person interviews, and field observations. NASS is also responsible for conducting a Census of Agriculture every 5 years. EPA gathered information from the following published NASS reports:

- *1997 Census of Agriculture*
- *Hogs and Pigs: Final Estimates 1993 - 1997*
- *Chickens and Eggs: Final Estimates 1994 - 1997*
- *Poultry Production and Value: Final Estimates 1994 - 1997*
- *Cattle: Final Estimates 1994 - 1998*
- *Milking Cows and Production: Final Estimates 1993 - 1997*

The information EPA collected from these sources is summarized below.

1997 Census of Agriculture

The Census of Agriculture is a complete accounting of U.S. agricultural production and is the only source of uniform, comprehensive agricultural data for every county in the nation. The census is conducted every 5 years. The Bureau of the Census conducted this activity until 1997, when the responsibility passed to NASS. The census includes all farm operations from which $1,000 or more of agricultural products are produced and sold. The most recent census occurred in late 1997 and is based on calendar year 1997 data.

The census collects information relating to land use and ownership, crops, livestock, and poultry. USDA maintains this database; EPA compiled data used for this analysis with the assistance of NASS staff. (USDA periodically publishes aggregated data from these databases and also compiles customized analyses of the data for members of the public and other government agencies. In providing such analyses, USDA maintains a sufficient level of aggregation to ensure the confidentiality of any individual operation's activities or holdings.)

EPA developed several size groups to allow tabulation of farm counts by farm size using different criteria than those used in the published *1997 Census of Agriculture*. EPA developed algorithms to define farm size in terms of capacity, or number of animals likely to be found on the farm at any given time. To convert sales of hogs and pigs and feeder pigs into an inventory, EPA divided total sales by the number of groups of pigs likely to be produced and sold in a given year. EPA estimates that the larger grower-finisher farms produce 2.8 groups of pigs per year.

Farrow-to-finish operations produce 2.0 groups of pigs per year. Nursery operations produce up to 10 groups per year. EPA developed data used to determine the groups of pigs produced per year from a survey conducted by APHIS (USDA,1999). For beef feedlots, EPA worked with staff from NASS and NCBA to estimate the number of groups of cattle produced per year at a CAFO, and the capacity of the operation based on the number of cattle sold. EPA estimates that beef feedlots produce between 1 and 2.5 groups of cattle per year, depending on the size of the operation (ERG, 2002).

Hogs and Pigs: Final Estimates 1993 - 1997

EPA used data from this report to augment the swine industry profile. The report presents information on inventory, market hogs, breeding herds, and pig crops, and specifically, the number of farrowings, sows, and pigs per litter. This report presents the number of operations with hogs; however, EPA did not use this information to estimate farm counts because the report provided limited data. Instead, as discussed earlier in this section, EPA used data provided by USDA based on the *1997 Census of Agriculture*.

Chickens and Eggs: Final Estimates 1994 - 1997

EPA used data from this report to augment the poultry industry profile. The report presents national and state-level data for the top-producing states on chickens and eggs including the number laid, and production for 1994 through 1997.

Poultry Production and Value: Final Estimates 1994 - 1997

EPA used data from this report to augment the poultry industry profile. The report presents national and state-level data for the top-producing states on production (number and pounds produced/raised), price per pound or egg, and value of production of broilers, chickens, eggs, and turkeys for 1994 through 1997.

Cattle: Final Estimates 1994 - 1998

EPA used data from this report to augment the beef industry profile. The report provides the number of and population estimates for beef feedlots that have a capacity of over 1,000 head of cattle, grouped by size and geographic distribution. This report also provides national and state-level data which include the number of feedlots, cattle inventory, and number of cattle sold per year by size class for the 13 top-producing beef states. In addition, the report presents the total number of feedlots that have a capacity of fewer than 1,000 head of cattle, total cattle inventory, and number of cattle sold per year for these operations. However, EPA did not use this report to estimate farm counts because it provided limited data. Instead, as discussed earlier in this section, EPA used data provided by USDA based on the *1997 Census of Agriculture*.

Milking Cows and Production: Final Estimates 1993 - 1997

EPA used data from this report to augment the dairy industry profile. The report presents national and state-level estimates of dairy cattle inventory and the number of dairy operations by size group. This particular report presents data for all dairy operations with over 200 mature dairy cattle in one size class. However, EPA did not use this report to estimate farm counts because it provided limited data. Instead, as discussed earlier in this section, EPA used data provided by USDA based on the *1997 Census of Agriculture*.

3.3.2 Animal and Plant Health Inspection Service National Animal Health Monitoring System (NAHMS)

APHIS provides leadership in ensuring the health and care of agricultural animals and plants, improving agricultural productivity and competitiveness, and contributing to the national economy and public health. One of its main responsibilities is to enhance the care of animals. In 1983, APHIS initiated NAHMS as an information-gathering program to collect, analyze, and disseminate data on animal health, management, and productivity across the United States. NAHMS conducts national studies to gather data and generate descriptive statistics and information from data collected by other industry sources. NAHMS has published national study reports for various food animal populations (e.g., swine, dairy cattle).

EPA gathered information from the following NAHMS reports:

- *Swine ’95 Part I: Reference of 1995 Swine Management Practices*
- *Swine ’95 Part II: Reference of Grower/Finisher Health & Management Practices*
- *Swine 2000 Part I: Reference of Swine Health and Management in the United States*
- *Layers ’99 Parts I and II: Reference of 1999 Table Egg Layer Management in the U.S.*
- *Dairy ’96 Part I: Reference of 1996 Dairy Management Practices*
- *Dairy ’96 Part III: Reference of 1996 Dairy Health and Health Management*
- *Beef Feedlot ’95 Part I: Feedlot Management Practices*
- *Feedlot ’99 Part I: Baseline Reference of Feedlot Management Practices*
- *Equine ’98 Parts I and II: Baseline Reference of 1998 Equine Health and Management*

EPA also collected information from NAHMS fact sheets, specifically the *Swine ’95* fact sheets, which describe biosecurity measures, vaccination practices, environmental practices/ management, and antibiotics used in the industry. The information EPA collected from these reports is summarized below.

Swine '95 Part I: Reference of 1995 Swine Management Practices

This report (USDA APHIS, 1995b) provides references on productivity, preventative and vaccination practices, biosecurity issues, and environmental programs (including carcass disposal). The data were obtained from a sample of 1,477 producers representing nearly 91 percent of the U.S. hog inventory from the top 16 pork-producing states. Population estimates are broken down into farrowing and weaning, nursery, grower/finisher, and sows.

Swine '95 Part II: Reference of Grower/Finisher Health & Management Practices

This report (USDA APHIS, 1996a) provides additional references on feed and waste management, health and productivity, marketing, and quality control. The data were collected from 418 producers with operations having 300 or more market hogs (at least one hog over 120 pounds) and represent about 90 percent of the target population. NAHMS also performed additional analyses for EPA that present manure management information for the swine industry in two size classes (fewer than 2,500 marketed head and more than 2,500 marketed head) and three regions (Midwest, North, and Southeast) (USDA APHIS, 1999).

Swine 2000 Part I: Reference of Swine Health and Management in the United States

Swine 2000 (USDA APHIS, 2001) was designed to statistically sample from operations with 100 or more pigs. The study included 17 of the major pork-producing states that account for 94 percent of the U.S. pig inventory. Data for this report were collected from 2,328 operations. This report provides information on feed and waste management, health and productivity, animal management, and facility management. In addition to this report, NAHMS also performed additional analyses for EPA that present the percent of sites where pit holding was the waste management system used most by region and herd size for farrowing and grow/finish operations (USDA APHIS, 2002b).

Layers '99 Parts I and II: Reference of 1999 Table Egg Layer Management in the U.S.

The Layers '99 study (USDA APHIS, 2000b) is the first NAHMS national study of the layer industry. Data were obtained from 15 states, which account for over 75 percent of the table egg layers in the United States. Part I of this report summarizes the study results including descriptions of farm sites and flocks, feed, and health management. Part II of this report summarizes biosecurity, facility management, and manure handling practices.

Dairy '96 Part I: Reference of 1996 Dairy Management Practices and Dairy '96 Part III: Reference of 1996 Dairy Health and Health Management

These reports (USDA APHIS, 1996b and 1996c) present the results of a survey distributed to dairies in 20 major states to collect information on cattle inventories; dairy herd management practices; health management; births, illness, and deaths; housing; and biosecurity. The results represent 83 percent of U.S. milk cows, or 2,542 producers. The reports also provide national data on cattle housing, manure and runoff collection practices, and irrigation/land application practices for dairies with more than, or fewer than, 200 mature dairy cattle. NAHMS provided the same information to EPA with the results reaggregated into three size classes (fewer than 500, 500 to 699, and more than 700 mature dairy cattle) and into three regions (East, West, and Midwest) (USEPA, 2002a).

Beef Feedlot '95 Part I: Feedlot Management Practices

This report (USDA APHIS, 1995a) contains information on population estimates, environmental programs (e.g., ground water monitoring and methods of waste disposal), and carcass disposal at small and large beef feedlots (fewer than and more than 1,000 head capacity). The data were collected from 3,214 feedlots in 13 states, representing almost 86 percent of the U.S. cattle-on-feed inventory.

Feedlot '99 Part I: Baseline Reference of Feedlot Management Practices

This report (USDA APHIS, 2000a) contains information on population estimates, environmental programs, and carcass disposal at beef feedlots. The data were collected from 1,250 feedlots in 12 states, representing 77 percent of all cattle on feed in the United States.

Equine '98 Parts I and II: Baseline Reference of 1998 Equine Health and Management

This report contains information on population demographics, as well as health and health management practices. Part II of the same report describes nutrition, pasture, housing, bedding, and manure management. NAHMS performed additional analyses for EPA to provide information on primary use and function by size class (USDA APHIS, 2002a).

3.3.3 Natural Resources Conservation Services

NRCS provides leadership in a partnership effort to help people conserve, improve, and sustain U.S. natural resources and the environment. NRCS relies on many partners to help set conservation goals, work with people on the land, and provide assistance. Its partners include conservation districts, state and federal agencies, NRCS Earth Team volunteers, agricultural and environmental groups, and professional societies.

NRCS publishes the *Agricultural Waste Management Field Handbook* (AWMFH) (USDA NRCS, 1992), which is an agricultural/engineering guidance manual that explains general waste management principles and provides detailed design information for particular waste management systems. The handbook presents specific design information on a variety of farm production and waste management practices at different types of feedlots. The handbook also provides runoff calculations under normal and peak precipitation as well as information on manure and bedding characteristics. NRCS also publishes Conservation Practice Standards for many waste handling and treatment operations. EPA used this information to develop its cost and environmental analyses. NRCS personnel also contributed technical expertise in the development of EPA's estimates of compliance costs and environmental assessment framework by providing EPA with estimates of manure generation in excess of expected crop uptake.

NRCS also analyzed the census data that EPA used for its analysis. In the draft February 23, 2002 *Profile of Farms with Livestock in the United States: A Statistical Summary* (USDA, 2002), NRCS presents estimates of the number of CAFOs by animal sector and size group, as well as the number of head at these farms. EPA used these estimates to calculate the average number of head and the number of CAFOs by animal sector and size group. In the case of beef feedlots, NRCS used a turnover rate of 2.5 to estimate capacity for all size operations. EPA recalculated the number of head at these operations using the turnover rates discussed above.

Another NRCS report (USDA, 2000), *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States* published in December 2000, provides background information on trends in animal agriculture and manure production based on information collected in the *1997 Census of Agriculture*. EPA used data on the percentage of farms with sufficient cropland, insufficient cropland, and no cropland to determine the number of CAFOs that require off-site transport of excess manure. EPA also used data from this report to determine the amount of excess manure at operations with an insufficient amount of cropland to agronomically land-apply all of the manure and wastewater generated on site.

Beginning in early 2002 the NRCS shared drafts of their report *Overview of Cost Analysis for Implementation of CNMPs On Animal Feeding Operations* with EPA. This report presents a cost analysis for planning, designing, implementing and following up on CNMPs on AFOs. The report also estimated the percentage of operations that have high, medium, and low requirements for the development and implementation of CNMPs. The scheduled release of the final document is October 2002. EPA used the data and appendices of information from these draft reports to refine baseline conditions for some portions of the CAFOs industry.

3.3.4 Agricultural Research Service (ARS)

ARS is the primary research agency working internally for the USDA. One of its many objectives is to heighten awareness of natural resources and the environment. EPA used information provided from ARS's *Agricultural Phosphorus and Eutrophication* report (USDA, 1999) to estimate the number of CAFOs that could be subject to a P-based regulation.

3.3.5 Economic Research Service (ERS)

ERS provides economic analyses on efficiency, efficacy, and equity issues related to agriculture, food, the environment, and rural development to improve public and private decision making. ERS uses data from the Farm Costs and Returns Survey (FCRS) to examine farm financial performance (USDA ERS, 1997). In this report, ERS grouped agricultural production in the United States into 10 broad geographic sectors: Pacific, Mountain, Northern Plains, Southern

Plains, Lake States, Corn Belt, Delta, Northeast, Appalachian, and Southern. EPA further consolidated the ten sectors into five regions in order to analyze aggregated Census of Agriculture data: Mid-Atlantic, South, Midwest, Central, and Pacific. These five aggregated regions are the geographic regions used throughout EPA's analyses.

ERS is also responsible for the Agricultural Resource Management Study (ARMS), USDA's primary vehicle for collecting information on a broad range of issues about agricultural resource use and costs, and farm sector financial conditions. The ARMS is a flexible data collection tool with several versions and uses. Information is collected via surveys, and provides a measure of the annual changes in the financial conditions of production agriculture.

3.4 Other Agency Reports

EPA used data from several EPA reports to develop emission factors used in the nonwater-quality impact analyses. The Office of Air Quality Planning and Standards (OAQPS) report entitled *Emissions from AFOs* (USEPA, 2001) summarizes data concerning air emissions from large AFOs including estimated emission factors. The Office of Air and Radiation report entitled *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2000* (USEPA, 2002b) provides methodologies for estimating methane and nitrous oxide emissions from manure management systems and agricultural land. The Office of Research and Development (ORD) provided literature summaries and possible approaches to quantifying pathogens in manure, their risks to human health, and potential reductions resulting from the various technology options and BMPs. ORD also provided the summary report *Regional/ORD Workshop on Emerging Issues Associated with Aquatic Environmental Pathogens* (September 5, 2001) and the memorandum *Human Health and Environmental Risks Associated with Runoff from Animal Feedlot Operations* (February 12, 2001).

3.5 Literature Sources

EPA performed several Internet and literature searches to identify papers, presentations, and other applicable materials to use in developing the proposed rule. Literature sources were identified from library literature searches as well as through EPA contacts and industry experts. Literature collected by EPA covers such topics as housing equipment, fertilizer and manure application, general agricultural waste management, air emissions, pathogens, and construction cost data. EPA used literature sources to estimate the costs of design and expansion of waste management system components at AFOs. EPA also used publicly available information from several universities specializing in agricultural research as well as existing computer models, such as the FarmWare Model that was developed by EPA's AgStar program, for industry profile information, waste management and modeling information, and construction cost data. The agency also reviewed industry magazines for useful information.

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CHAPTER 4

INDUSTRY PROFILES

4.0 INTRODUCTION

This chapter describes the current organization, production processes, and facility and waste management practices of the AFO and CAFO industries. Farm production methods, operation sizes, geographical distributions, pollution reduction activities, and waste treatment practices in use are described separately for the swine, poultry, beef, and dairy subcategories. Discussions of changes and trends over the past several decades are also provided.

Information on animal production was generally obtained from USDA 1997 Census of Agriculture, NASS, and information gathered from site visits and trade associations. For information obtained from the 1997 Census of Agriculture, EPA divided the U.S. into five production regions and designated them the South, Mid-Atlantic, Midwest, West, and Central Regions. Originally, the USDA ERS established ten regions so that it could group economic information. EPA condensed these regions into the five AFO regions because of similarities in animal production and manure handling techniques, and to allow for the aggregation of critical data on the number of facilities, production quantities, and financial conditions, which may otherwise not be possible due to concerns about disclosure[1]. The production regions are defined in Table 4-1. See the *Cost Report* for additional discussion of the sensitivity of EPA's models to the five AFO regions as used in the cost models.

4.1 Swine Industry Description

Swine feeding operations include facilities that confine swine for feeding or maintenance for at least 45 days in any 12-month period. These facilities do not have significant vegetation in the confinement area during the normal growing season, and include totally enclosed buildings, and open buildings with and without outside access. Swine pasture operations are generally not included. Facilities that have swine feeding operations may also include other animal and agricultural operations such as crop farming.

This section discusses the following aspects of the swine industry:

- 4.1.1: Distribution of the swine industry by size and region

[1]For example, USDA Census of Agriculture data are typically not released unless there is a sufficient number of observations to ensure confidentially. Consequently, if data were aggregated on a state basis (instead of a regional basis), many key data points needed to describe the industry segments would be unavailable.

- 4.1.2: Production cycles of swine
- 4.1.3: Swine facility types and management
- 4.1.4: Swine waste management practices
- 4.1.5: Pollution reduction
- 4.1.6: Waste disposal

Table 4-1. AFO Production Regions.

Region	States Included
Central	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oklahoma, Texas, Utah, Wyoming
Midwest	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin
Mid-Atlantic	Connecticut, Delaware, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia, West Virginia
Pacific	Alaska, California, Hawaii, Oregon, Washington
South	Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, South Carolina

The swine industry is a significant component of the domestic agricultural sector, generating farm receipts ranging from $9.2 billion to more than $11.5 billion annually during the past decade (USDA NASS, 1998a). Total annual receipts from the sale of hogs average approximately 12 percent of all livestock sales and 5 percent of all farm commodity sales. Annual swine output ranks fourth in livestock production value after cattle, dairy products, and broilers. During 1997, more than 17 billion pounds of pork were processed from 93 million hogs. The retail value of pork sold to consumers exceeded $30 billion. The National Pork Producers Council estimates that the pork industry supports more than 600,000 jobs nationally (NPPC, 1999).

As described in the following sections, the swine industry has undergone a major transformation during the past several decades. Swine production has shifted from small, geographically dispersed family operations to large “factory farms” concentrated primarily in 10 states in the Midwest and the South. The number of hog operations, which approached 3 million in the 1950s, had declined to about 110,000 by 1997. The rate of consolidation has increased dramatically in the last decade, which has seen more than a 50 percent decline in the number of swine operations (USDA NASS, 1999a). All indications are that this trend toward consolidation is continuing.

Swine production has also changed dramatically in terms of the production process and the type of animal produced. The hog raised for today's consumer is markedly different from the one produced in the 1950s. Today's hogs contain approximately 50 percent less fat and are the result of superior genetics and more efficient diets. The average whole-herd feed conversion ratio (pounds of feed per pound of live weight produced) used to be between 4 and 5 and has steadily decreased with current averages between 3.6 and 3.8. The most efficient herds have whole-herd feed conversion ratios under 3.0 (NPPC, 1999). Hence, a well-run swine operation can currently produce a 250-pound hog using only 750 pounds of animal feed during its lifetime.

The domestic hog industry is increasingly dominated by large, indoor, totally confined operations capable of handling 5,000 hogs or more at a time (USDA NASS, 1999b, and USDA NASS, 1999c). These operations typically produce no other livestock or crop commodities. In addition, there has been greater specialization as more swine operations serve only as nursery or finishing operations.

Another growing trend in the industry is that more hogs are being produced under contract arrangement whereby large hog producers, typically referred to as integrators or contractors, establish production contracts with smaller growers to feed hogs to market weight. The producer-integrator provides management services, feeder pigs, food, medicine, and other inputs, while the grower operations provide the labor and facilities. In return, each grower receives a fixed payment, adjusted for production efficiency. These arrangements allow integrators to grow rapidly by leveraging their capital. For example, instead of investing in all the buildings and equipment required for a farrow-to-finish operation, the integrator can invest in specialized facilities, such as farrowing units, while the growers pay for the remaining facilities, such as the nurseries and finishing facilities (Martinez, 1999). Occasionally other forms of contracts may be used.

According to a survey conducted for the USDA, 11 percent of the nation's hog inventory at the end of 1993 was produced under long-term contracts. This percentage was expected to increase to 29 percent by 1998 (Martinez, 1999). The Mid-Atlantic region has the greatest proportion of contracted hogs, with more than 65 percent of grown at facilities where the grower does not own the hogs (USDA NASS 1999c).

These changes at both the industry and farm levels represent a significant departure from earlier eras, when hogs were produced primarily on relatively small but integrated farms where crop production and other livestock production activities occurred and where animals spent their complete life cycle. The following sections describe the current production and management practices of domestic swine producers.

4.1.1 Distribution of Swine Operations by Size and Region

EPA's 1974 CAFO Effluent Limitations Guidelines and Standards generally apply to swine feeding operations with more than 2,500 head, but count only those swine weighing more than 55 pounds. (See Chapter 2 for the definition of a CAFO, and Chapter 5 for a discussion of the basis for revisions to the swine subcategory.) Most data sources cited in this section do not distinguish swine by weight, but may provide other information that distinguishes sows and other breeding pigs, feeder pigs, litters, and market pigs. Where numbers of head are presented in the following sections, feeder pigs were not included in the counts unless specified in the text.

4.1.1.1 National Overview

The estimated number of domestic swine operations has continuously declined since the 1950s. As recently as 1970, there were more than 870,000 producers of swine. By 1997, this number had decreased to about 110,000 (USDA NASS, 1999b)[2]. The decline has been especially dramatic over the past decade. As shown in Table 4-2, the number of operations has steadily decreased over the years.

Table 4-2. Changes in the Number of U.S. Swine Operations and Inventory 1982-1997.

Year	Operations	Inventory
1982	329,833	55,366,205
1987	243,398	52,271,120
1992	191,347	57,563,118
1997	109,754	61,206,236

Source: USDA NASS, 1999b.

As the number of operations has decreased, however, hog inventories have actually risen due to the emerging market dominance by larger operations. Inventories increased from 55.4 million head in 1982 to 61.2 million head in 1997 (USDA NASS, 1999b).

4.1.1.2 Operations by Size Class

The general trend in the U.S. swine industry is toward a smaller number of large operations (Table 4-3). As the percentage of smaller producers decreases, there is a consistent increase in the percentage of herds with a total inventory of 2,000 or more head. The increase in the number of large operations has predominantly occurred in conjunction with extended use of total confinement operations, which separate the three production phases described in 4.1.2.

[2] USDA defines an operation as any place having one or more hogs or pigs on hand at any time during the year.

Table 4-3. Percentage of U.S. Hog Operations and Inventory by Herd Size.

Year	0-1,999 Head		2,000-4,999 Head		More Than 5,000 Head	
	Operations	Inventory	Operations	Inventory	Operations	Inventory
1982	99.3	85.7	0.6	9.5	0.1	4.8
1987	98.9	79.0	1.0	12.9	0.2	8.1
1992	97.9	68.7	1.6	15.2	0.4	17.0
1997	94.4	39.3	3.9	20.8	1.7	40.2

Source: USDA NASS, 1999b.

In terms of farm numbers, small operations still dominate the industry; however, their contribution to total annual hog production has decreased dramatically in the past decade. For example, operations with up to 1,999 head, which produced 85.7 percent of the nation's hogs in 1982, raised only 39.3 percent of the total in 1997. In contrast, in 1982, the 0.1 percent of operations that reported more than 5,000 head produced approximately 5 percent of the swine; in 1997 these large operations (1.7 percent of all operations) produced over 40 percent of the nation's hogs.

4.1.1.3 Regional Variation in Hog Operations

Swine farming has historically been centered in the Midwest Region of the United States, with Iowa being the largest hog producer in the country. Although the Midwest continues to be the nation's leading hog producer (five of the top seven producers are still in the Midwest), significant growth has taken place in other areas. Perhaps the most dramatic growth has occurred in the Mid-Atlantic Region, in North Carolina. From 1987 to 1997, North Carolina advanced from being the 12^{th} largest pork producer in the nation to second behind only Iowa. Climate and favorable regulatory policies played a major role in the growth of North Carolina's swine industry.

North Carolina's winters are mild and summers are tolerable, and this has allowed growers to use open-sided buildings. Such buildings are less expensive than the solid-sided buildings made necessary by the Midwest's cold winters. Midwestern growers must also insulate or heat their buildings in the winter. Tobacco farmers, who found hogs a means of diversifying their operations, also fueled North Carolina's pork boom. The idea of locating production phases at different sites was developed in North Carolina. The state also has a much higher average inventory per farm than any of the states in the Corn Belt. Whereas Iowa had an average of fewer than 850 head per farm, North Carolina had an average of more than 3,200 head per farm in 1997. In recent years, significant growth has also occurred in the panhandle area of Texas and Oklahoma, Colorado, Utah, and Wyoming, in the Central Region; northern Iowa and southern Minnesota, in the Midwest Region.

Tables 4-4 through 4-7 present the distribution of different types of swine operations for the key producing regions. For the purposes of these tables, breeder operations, also known as farrowing operations, have large numbers of sows and sell or transfer the pigs when they have been weaned or grown to approximately 55 pounds (feeder pigs); some farrowing operations may also keep boars. Nursery operations receive weaned pigs and grow them to approximately 55 pounds. Grow-finish operations are operations that receive feeder pigs and grow them out to marketable weight; these pigs are often labeled "swine for slaughter." Combined operations perform all phases of production, known in the industry as "farrow-to-finish," or just the final two phases called "wean-finish." Note that no large independent nurseries are depicted by the 1997 census data. EPA is aware that several large nurseries have recently begun operation or are under construction. The considerable amount of growth in the Central (Southwest) Region that has occurred in the past 3 years is not reflected in the 1997 statistics presented in this section.

Table 4-4 shows the number of operations for six different size classes of facilities. Table 4-5 presents the average herd size by operation type, region, and operation size. Table 4-6 presents the percentage of total swine animal counts at combined and slaughter operations by region and operation size. Table 4-7 presents the distribution of different animal types in combined swine operations by region and operation size.

Table 4-4. Total Number of Swine Operations by Region, Operation Type, and Size in 1997.

<table>
<tr><th rowspan="2">Region [a]</th><th rowspan="2">Operation Type [b]</th><th colspan="7">Number of Swine Operations (Operation Size Presented by Number of Head)</th></tr>
<tr><th>>0–750</th><th>>750–1,875</th><th>>1,875–2,500</th><th>>2,500–5,000</th><th>>5,000–10,000</th><th>>10,000</th><th>Total</th></tr>
<tr><td rowspan="2">Mid-Atlantic</td><td>combined</td><td>6,498</td><td>421</td><td>82</td><td>185</td><td>130</td><td>135</td><td>7,451</td></tr>
<tr><td>slaughter</td><td>8,120</td><td>344</td><td>150</td><td>413</td><td>281</td><td>119</td><td>9,427</td></tr>
<tr><td rowspan="2">Midwest</td><td>combined</td><td>35,263</td><td>5,212</td><td>782</td><td>1,106</td><td>410</td><td>213</td><td>42,986</td></tr>
<tr><td>slaughter</td><td>27,081</td><td>2,194</td><td>425</td><td>521</td><td>142</td><td>48</td><td>30,411</td></tr>
<tr><td rowspan="2">Other</td><td>combined</td><td>10,821</td><td>359</td><td>74</td><td>135</td><td>60</td><td>5</td><td>11,494</td></tr>
<tr><td>slaughter</td><td>13,502</td><td>83</td><td>50</td><td>91</td><td>45</td><td>10</td><td>13,781</td></tr>
<tr><td rowspan="4">National</td><td>combined</td><td>52,582</td><td>5,992</td><td>938</td><td>1,426</td><td>600</td><td>393</td><td>61,931</td></tr>
<tr><td>slaughter</td><td>48,703</td><td>2,621</td><td>625</td><td>1,025</td><td>468</td><td>177</td><td>53,619</td></tr>
<tr><td>breeder</td><td>2,227</td><td colspan="2">15</td><td colspan="3">3</td><td>2,245</td></tr>
<tr><td>nursery</td><td colspan="4">83</td><td colspan="2">0</td><td>83</td></tr>
</table>

[a] Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Other = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK, WA, OR, WA, OR, CA, AK, HI, AR, LA, MS, AL, GA, SC, FL.
[b] Operation type: combined = breeding inventory, finishing (average of inventory and sold/2.8), and feeders (sold/10); slaughter = finishing (average of inventory and sold/2.8); breeder = (inventory); and nursery = (feeders sold/10).
Source: USDA NASS 1999c.

Table 4-5. Average Number of Swine at Various Operations by Region Operation Type, and Size in 1997.

Region [a]	Operation Type [b]	Average Swine Animal Counts (Operation Size Presented by Number of Head)						
		>0– 750	>750–1,875	>1,875–2,500	>2,500–5,000	>5,000–10,000	>10,000	All Operations
Mid-Atlantic	combined	74	1,182	2,165	3,509	5,021	28,766	851
	slaughter	32	1,242	2,184	3,554	6,877	13,653	641
Midwest	combined	209	1,137	2,152	3,444	6,761	27,403	637
	slaughter	135	1,161	2,124	3,417	6,791	19,607	355
Other	combined	51	1,255	2,150	3,455	7,052	59,172	410
	slaughter	13	1,291	2,215	3,626	6,830	14,901	85
National	combined	160	1,147	2,153	3,453	6,413	31,509	621
	slaughter	84	1,176	2,146	3,491	6,846	15,338	336

[a] Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Other = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK, WA, OR, WA, OR, CA, AK, HI, AR, LA, MS, AL, GA, SC, FL.
[b] Operation type: combined = breeding inventory, finishing (average of inventory and sold/2.8), and feeders (sold/10); and slaughter = finishing (average of inventory and sold/2.8).
Source: USDA NASS, 1999c.

Table 4-6. Distribution of Swine Herd by Region, Operation Type, and Size in 1997.

Region [a]	Operation Type [b]	Percentage of Total Swine Animal Counts by Size Group (Operation Size Presented by Number of Head)						
		>0–750	>750–1,875	>1,875–2,500	>2,500–5,000	>5,000–10,000	>10,000	Total
Mid-Atlantic	combined	1.25	1.30	0.46	1.69	1.70	10.10	16.50
	slaughter	1.45	2.37	1.82	8.16	10.74	9.03	33.56
Midwest	combined	19.14	15.42	4.38	9.91	7.21	15.18	71.24
	slaughter	20.26	14.16	5.02	9.89	5.36	5.23	59.92
Other	combined	1.44	1.17	0.41	1.21	1.10	6.93	12.26
	slaughter	0.94	0.60	0.62	1.83	1.71	0.83	6.52
National	combined	21.83	17.88	5.25	12.81	10.01	32.21	100.00
	slaughter	22.65	17.13	7.45	19.88	17.80	15.09	100.00

[a] Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Other = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK, WA, OR, WA, OR, CA, AK, HI, AR, LA, MS, AL, GA, SC, FL.
[b] Operation type: combined = breeding inventory, finishing (average of inventory and sold/2.8), and feeders (sold/10); and slaughter = finishing (average of inventory and sold/2.8).
Source: USDA NASS, 1999c.

Table 4-7. Distribution of Animal Type in Swine Herds at Combined Facilities by Region, Operation Type, and Size in 1997.

Region [a]	Swine Type [b]	Percentage of Breeding, Finishing, and Feeder Hogs at Combined Facilities (Operation Size Presented by Number of Head)						
		>0–750	>750–1,875	>1,875–2,500	>2,500–5,000	>5,000–10,000	>10,000	All Operations
Mid-Atlantic	Breeding	19.84	17.38	15.59	17.68	16.66	17.19	17.31
	Finishing	73.96	71.74	72.46	65.56	59.02	58.55	61.61
	Feeder	6.20	10.88	11.95	16.75	24.32	24.25	21.08
Midwest	Breeding	17.85	16.14	16.55	15.88	15.23	14.65	16.18
	Finishing	78.33	79.59	76.66	76.38	77.77	80.32	78.59
	Feeder	3.82	4.26	6.80	7.73	7.00	5.03	5.23
Other	Breeding	22.47	19.95	19.54	18.38	20.84	17.54	18.74
	Finishing	73.03	61.02	69.00	71.39	64.45	78.57	73.89
	Feeder	4.48	19.04	11.46	10.23	14.71	3.90	7.37
National	Breeding	18.27	16.50	16.70	16.36	16.16	16.10	16.66
	Finishing	77.73	77.70	75.66	74.44	71.78	72.63	74.91
	Feeder	4.00	5.79	7.63	9.21	12.05	11.27	8.40

[a] Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Other = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK, WA, OR, WA, OR, CA, AK, HI, AR, LA, MS, AL, GA, SC, FL.
[b] Swine type: Breeding = inventory; finishing = average of inventory and sold/2.8; and feeder = sold/10.
Source: USDA NASS, 1999c.

USDA NRCS (2002) also provided information to EPA on the number of swine operations based on the following classifications as shown in Table 4.8:

- Operation size: >=2,500 head, 1,250-2,499 head, and 750-1,249 head.
- Land availability: No excess (Category 1 farms with sufficient crop or pastureland). Excess, with acres (Category 2 farms with some land, but not enough land to assimilate all manure nutrients). Excess, no acres (Category 3 farms with none of the 24 major crop types identified by NRCS).
- Location: Eleven states or groups of states.
- Nutrient basis: Applications are based on N or P application rates.

In Illinois for example, there are 72 facilities with more than 2,500 head with none of the 24 major crop types identified by NRCS for application of animal wastes. There are 34 operations (with 2,500 or more head) with some land in Illinois, but not enough land to assimilate all manure nutrients using N-based application rates, and 184 Illinois operations (with 2,500 or more head) with enough land to assimilate all manure nutrients using N-based application rates.

Table 4-8. Number of Swine Facilities as Provided by USDA Based on Analyses of 1997 Census of Agriculture Database.

Location	Land availability category	Operation Size and Nutrient Basis					
		>=2,500		1,250–2,499		750–1,249	
		N	P	N	P	N	P
AR, KS, OK	No excess	52	21	76	50	101	80
AR, KS, OK	Excess, no acres	66	66	36	36	22	22
AR, KS, OK	Excess, with acres	113	144	78	104	40	61
IL							
IL	Excess, no acres	72	72	45	45	39	39
IL	Excess, with acres	34	123	31	105	21	77
IN	No excess	179	107	254	205	387	346
IN	Excess, no acres	68	68	53	53	50	50
IN	Excess, with acres	35	107	29	78	36	77
IO	No excess	411	164	1,155	796	1,587	1,346
IO	Excess, no acres	211	211	183	183	235	235
IO	Excess, with acres	120	367	89	448	51	292
MI, WI	No excess	57	25	97	65	169	136
MI, WI	Excess, no acres	31	31	30	30	29	29
MI, WI	Excess, with acres	19	51	19	51	8	41
MN	No excess	225	97	386	272	523	430
MN	Excess, no acres	152	152	83	83	69	69
MN	Excess, with acres	50	178	28	142	28	121
MO	No excess	54	32	104	87	203	183
MO	Excess, no acres	17	17	18	18	25	25
MO	Excess, with acres	59	81	48	65	33	53
NC	No excess	194	15	83	23	56	21
NC	Excess, no acres	185	185	71	71	33	33
NC	Excess, with acres	630	809	157	217	45	80
NE	No excess	40	15	164	141	279	245
NE	Excess, no acres	81	81	49	49	82	82
NE	Excess, with acres	32	57	29	52	29	63
OH	No excess	45	23	98	61	202	154
OH	Excess, no acres	23	23	33	33	31	31
OH	Excess, with acres	12	34	17	54	29	77
other	No excess	184	87	244	145	404	289
other	Excess, no acres	132	132	99	99	102	102
other	Excess, with acres	157	254	104	203	78	193

Source: USDA NRCS, 2002.

4.1.2 Production Cycles of Swine

Swine production falls into three phases. Pigs are farrowed, or born, in farrowing operations. Sows are usually bred for the first time when they are 180 to 200 days old. Farrowing facilities range from pasture systems to completely confined housing systems. A sow's gestation period is about 114 days. Farrowings are typically 9 to 11 pigs per litter, with a practical range of 6 to 13. The highest death losses in the pig-raising cycle occur within 3 to 4 days of birth. The average number of pigs weaned per litter in 1997 was 8.67 (see Table 4-9). Producers incur significant expenses in keeping a sow, so the survival of each pig is critical to overall profitability. Sows usually resume sexual activity within a week after a litter is weaned. Growers are able to roughly synchronize production by weaning all their baby pigs on the same day. When they do this, all the sows in a farrowing group become sexually active again at roughly the same time and may be bred again at the same time. The sows will then farrow at about the same time, over a period of about a week. In this way, growers are able to keep groups of pigs together as they move from one phase of production to another. Sows normally produce five to six litters before they are culled and sold for slaughter at a weight of 400 to 460 pounds.

Baby pigs are typically allowed to nurse from the sow, and then are relocated to a nursery, the second phase of swine production. In the nursery phase, pigs are weaned at 3 to 4 weeks of age and weigh 10 to 15 pounds. In the nursery, the pigs are raised to 8 to 10 weeks of age and 40 to 60 pounds. In practice, the weaning phase may take as few as 10 days, and may exceed 35 days.

During the third phase of production, growing pigs are raised to a market weight of 240 to 280 pounds. Finishing takes another 15 to 18 weeks, thus hogs are typically sent to market when they are about 26 weeks old (see Table 4-10). The growing and finishing phases were once separate production units, but are now combined in a single unit called grow-finish. In the growing–finishing unit, pigs are raised from 50 or 60 pounds to final market weight. The average grow-finish facility will produce approximately 2.8 turns (also called life cycles, herds, or groups) annually. Typically, finished pigs are from 166 to 212 days old. This results in a range of 2.4 to 3.4 turns (or groups) of pigs produced from the grow-finish unit per year. Average farrow-to-finish operations will produce 2.1 groups per sow per year. The range of annual turnover frequency at farrow-to-finish farms is from 1.8 to 2.5.

Table 4-9. Productivity Measures of Pigs.

Year	Number of Pigs Weaned per Litter	Per Breeding Animal per Year		Average Live Weight per Pig (pounds)
		Litters	Head to Slaughter	
1992	8.08	1.69	13.08	252
1993	8.13	1.68	13.06	254
1994	8.19	1.73	13.36	255
1995	8.32	1.68	13.64	256
1996	8.50	1.64	13.51	257
1997	8.67	1.72	13.79	260
Average	8.32	1.69	13.41	256

Source: NPPC, 1999.

Table 4-10. Age of Pigs Leaving Grow-Finish Unit in 1995.

Age of Pig on Leaving Grow-Finish Unit (days)	Percentage of Operations and Pigs	
	Percentage of Operations	Percentage of Pigs
120–160	12.5	12.2
160–165	16.7	12.6
166–180	49.6	45.8
181–209	16.3	24.9
210 or more	4.9	4.5
Weighted Average	173 days	175 days

Source: USDA APHIS, 1995.

In 1995, most operations had a farrowing facility, whereas slightly less than half of the facilities nationwide had a separate nursery facility. Most operations (85.6 percent) did have a finishing facility. Finishing operations get their pigs from on-site farrowing and nursery units (76.7 percent), off-site farrowing operations (10.2 percent), feeder pig producers under both contract and noncontract arrangements (13.8 percent), or livestock auctions or sales (5.9 percent). Large finishing operations (>10,000 head marketed) were more likely (56.3 percent) to get their pigs from off-site sources (USDA APHIS, 1995). Tables 4-11 and 4-12 present the frequency of the three major production phases by region and size. The sample profile of the *Swine ‘95* survey indicates that 61.9 percent of respondents were farrow-to-finish operations and that 24.3 percent were grow-finish operations. (At the time of writing, reports from the Swine 2000 survey did not provide equivalent statistics that allow comparisons based on region and operation size. Thus, Tables 4-11 and 4-12 present data from the *Swine ‘95* survey.)

Table 4-11. Frequency of Production Phases in 1995 on Operations That Marketed Less Than 5,000 Hogs in a 6-Month Period.

Production Phase	USDA APHIS Region[a]		
	Midwest	North	Southeast
Farrowing	76.6	68.6	69.3
Nursery	20.1	51	57.8
Finishing	78.8	79.7	93.4

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995

Table 4-12. Frequency of Production Phases in 1995 on Operations That Marketed 5,000 or More Hogs in a 6-Month Period.

Production Phase	USDA APHIS Region[a]		
	Midwest	North	Southeast
Farrowing	44.8	80.4	89
Nursery	75	67.1	97.4
Finishing	45.8	69.7	62.8

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

Although many large operations continue to have the full range of production phases at one facility, these operations are no longer the norm. More frequently, in new operations, several specialized farms are linked, or horizontally integrated, into a chain of production and marketing. Pigs begin in sowherds on one site, move to a nursery on another, and then move again to a finishing facility. Specialized operations can take advantage of skilled labor, expertise, advanced technology, streamlined management, and modern housing. However, the primary advantage of specialization is disease control. In a farrow-to-finish operation, a disease outbreak that begins in one phase of the operation can spread to the other phases. Physically separating the phases makes it easier to break this disease cycle. At the same time, separating phases spreads the cost of establishing swine operations, particularly if the different operations are owned by different persons.

Thus other categories of swine operations may comprise two or three of the three phrases described: combined farrow-nursery operations, which breed pigs and sell them at 40 to 60 pounds to finishing operations; wean-to-finish operations, which finish weaned pigs; and farrow-to-finish operations, which handle all phases of production from breeding through finishing. The emerging trend in the mid to late ‘90s was to produce pigs in two production phases rather than in three. In two-phase production, the weaned pigs may go straight into the grower building or finishing building, bypassing the nursery. The advantages of such practices are reduced transportation costs, lessened animal stress, and reduced animal mortality.

4.1.3 Swine Facility Types and Management

Table 4-13 summarizes the five major housing configurations used by domestic swine producers.

Although there are still many operations at which pigs are raised outdoors, the trend in the swine industry is toward larger confinement facilities where pigs are raised indoors. A typical confinement farrowing operation houses 3,000 sows, although some farrowing operations house as many as 10,000 sows at one location, and farms are being planned that will house as many as

15,000 sows at one location. Typical nursery operations are much smaller with a capacity of only about 1,500 head, but as stated earlier, separate nursery facilities are relatively uncommon.

Table 4-13. Summary of Major Swine Housing Facilities.

Facility Type[a]	Description	Applicability
Total confinement	Pigs are raised in pens or stalls in an environmentally controlled building.	Most commonly used in nursery and farrowing operations and all phases of very large operations. Particularly common in the Southeast.
Open building with no outside access	Pigs are raised in pens or stalls but are exposed to natural climate conditions.	Relatively uncommon but used by operations of all sizes.
Open building with outside access	Pigs are raised in pens or stalls but may be moved to outdoors.	Relatively uncommon, but used by some small to mid-sized operations.
Lot with hut or no building	Pigs are raised on cement or soil lot and are not confined to pens or stalls.	Used by small to mid-sized operations.
Pasture with hut or no building	Pigs are raised on natural pasture land and are not confined to pens or stalls.	Traditional method of raising hogs currently used only at small operations.

[a] These are the main facility configurations contained in the *Swine '95* Survey conducted by USDA APHIS, 1995.

The economic advantages of confined facilities have been the primary driving factor (especially at large operations) for farmers to abandon dry lot or pasture raising of hogs. Although controlled-environment buildings require a greater initial capital investment than traditional farm operations, labor costs per unit output are significantly reduced. Furthermore, these facilities allow for far greater control of the production process, protect both animals and workers from weather, and usually result in faster growth-to-market weight and better feed efficiency. Most controlled-environment facilities employ "all in, all out" production, in which pigs are moved in groups, and buildings are cleaned and disinfected between groups. It should be noted that the success of a controlled-environment operation is highly dependent on properly functioning ventilation, heating and cooling, and waste removal systems. A prolonged breakdown of any of these systems during extreme weather conditions can be catastrophic to the pig herd and economically devastating to the operator.

Facility requirements differ somewhat for each phase in a hog's life cycle, and hence farrowing, nursery, and growing-finishing facilities are configured differently. For example, farrowing operations require more intense management to ensure optimal production and reduce piglet mortality. A typical farrowing pen measures 5 by 7 feet, and the litter is provided with a protected area of approximately 8 square feet. The sow is relegated to a section of the pen and is separated from the piglets by low guard rails that reduce crushing but do not interfere with suckling. Floors are usually slatted under or to the rear of the sow area to facilitate waste removal (NPPC, 1996).

Newly born piglets require special care because of their vulnerability to injury and disease. Nursery systems are typically designed to provide a warm, dry, and draft-free environment in which animal stress is minimized to promote rapid growth and reduce injury and mortality. Nursery rooms are regularly cleaned and sanitized to reduce the piglets' exposure to pathogens. Nursery buildings are cleaned and disinfected thoroughly between groups of pigs to prevent the transmission of disease from one herd to another. Nursery pens usually hold 10 to 20 pigs. Pigs are held in the nursery from weaning until they are 8 to 12 weeks old (NPPC, 1996).

Finishing pigs at tend to require less intensive management than piglets and can tolerate greater variations in environmental conditions without incurring health problems. In an environmentally controlled building, growing and finishing pens hold 15 to 40 pigs and allow about 6 square feet per pig. Overcrowding leads to stress and aggressive behavior and can result in reduced growth rates and injury. Slatted concrete floors are the most common (NPPC, 1996).

Smaller facilities tend to use open buildings, with or without access to the outside. Usually, hogs raised in these buildings are also confined to pens or stalls. Depending on the climate, the building might require ventilation and mist sprayer systems to prevent heat stress in the summer. Bedding might be needed during the winter months to protect the animals from the cold.

Hogs raised on dry lots or pasture require care and management similar to that for animals raised indoors, plus additional measures to protect the herds from extreme weather conditions. They must be provided with sufficient shade to reduce heat stress in the summer. Where natural shade is not available, facilities can be constructed to protect the herd from the sun in the summer and from wind and cold during the winter. Windbreaks are used under certain environmental conditions.

The most comprehensive information on swine facility and waste management systems currently in use by farm type, size, and state location was collected in conjunction with USDA's *Swine '95* study (USDA APHIS, 1995). Included in the study were 16 major pork-producing states that accounted for almost 91 percent of the U.S. hog inventory and more than 70 percent of the pork producers. The samples for the major swine-raising operations were statistically designed to provide inferences to the nation's swine population. Although the survey was conducted by APHIS and focused on swine health issues, it contains information on swine production and facility and waste management. Tables 4-14 and 4-15 present information on the housing types used in the farrowing phase. Tables 4-16 and 4-17 present information on the housing types used in the nursery phase. Tables 4-18 and 4-19 present information on the housing types used in the finisher phase. These tables clearly demonstrate that the larger facilities tend to use total confinement in all regions. (At the time of writing, reports from the Swine 2000 survey did not provide equivalent statistics that allow comparisons based on region and operation size. Thus Tables 4-14 through 4-19 present data from the *Swine '95* survey.)

Table 4-14. Housing Frequency (in percent) in 1995 of Farrowing Facilities at Operations That Marketed Fewer Than 5,000 Hogs in a 6-Month Period.

Facility Type	USDA APHIS Region[a]		
	Midwest	North	Southeast
Total Confinement	22.6	53.1	56
Open Building; no outside access	13.1	8.0	8.8
Open Building; outside access	25.7	33.8	31.2
Lot	16.2	3.2	1.1
Pasture	22.4	1.9	2.8

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

Table 4-15. Housing Frequency (in percent) in 1995 of Farrowing Facilities at Operations That Marketed 5,000 or More Hogs in a 6-Month Period.

Facility Type	USDA APHIS Region[a]		
	Midwest	North	Southeast
Total Confinement	98.3	100	100

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

Table 4-16. Housing Frequency (in percent) in 1995 of Nursery Facilities at Operations That Marketed Fewer Than 5,000 Hogs in a 6-Month Period.

Facility Type	USDA APHIS Region[a]		
	Midwest	North	Southeast
Total Confinement	52.3	55.4	62
Open Building; no outside access	9.1	11.5	8.8
Open Building; outside access	27.7	33.8	31.2
Lot	7.0	not available	3.7

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA.. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

Table 4-17. Housing Frequency (in percent) in 1995 of Nursery Facilities at Operations That Marketed 5,000 or More Hogs in a 6-Month Period.

Facility Type	USDA APHIS Region[a]		
	Midwest	North	Southeast
Total Confinement	99	100	96.4

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA; Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

Table 4-18. Housing Frequency (in percent) in 1995 of Finishing Facilities at Operations That Marketed Fewer Than 5,000 Hogs in a 6–Month Period

Facility Type	**USDA APHIS Region[a]**		
	Midwest	**North**	**Southeast**
Total Confinement	19.9	36.5	23.4
Open Building; no outside access	15.4	14.1	9.5
Open Building; outside access	24.5	42.1	55.9
Lot	17.1	4.6	9.3
Pasture	23.0	2.5	1.9

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

Table 4-19. Housing Frequency (in percent) in 1995 of Finishing Facilities at Operations That Marketed 5,000 or More Hogs in a 6-Month Period.

Variable	**Region[a]**		
	Midwest	**North**	**Southeast**
Total Confinement	96.8	95.5	83.9

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA APHIS, 1995.

4.1.4 Swine Waste Management Practices

Removal of manure from the animals' living space is critical for animal and farm worker well-being. Odor, gases, and dust carried by ventilation exhaust air are also affected by the waste management system used. Swine waste management systems can be separated into collection, storage, and treatment practices. An overview of the major practices in each of these areas is presented below, and more detailed information on waste collection, storage, and treatment practices is provided in Section 8 of this document. Although the practices described below do not represent all of the waste management practices in use today, they are the predominant practices currently used at swine operations.

4.1.4.1 Swine Waste Collection Practices

Indoor raising of hogs requires that animals be physically separated from their waste products. Separation in larger facilities is usually accomplished through the use of concrete flooring with slots that allow the waste to drop below the living area and be transferred to a pit or trough beneath the pen. Smaller facilities hand clean pens to collect wastes.

The most frequently reported waste management system used in 1990 was hand cleaning (41.6 percent), which declined in use to 28.3 percent of operations in 1995 (USDA APHIS, 1995). This decrease in hand cleaning is highly correlated to the decrease in smaller facilities. Some facilities separate solid material from liquids before moving the material to storage. (A discussion of solid-liquid separation is presented in Section 8.) Slatted floors are now more commonly used to separate the manure from the animals at larger facilities. The waste is then deposited in an under-floor pit or gutter where it is stored or moved to another type of storage. There are two main types of under-floor collection practices in which the waste is moved for storage elsewhere.

- *Pit recharge*. Pit recharge is the periodic draining of the pit contents by gravity to storage, followed by recharging the pit with new or recycled water. Regular pit draining removes much of the manure solids that would otherwise settle and remain in the bottom of the pit. The regular dissolution of settled solids increases the likelihood the solids will be removed at the next pit draining. Recharge systems use a 16- to 18-inch-deep, in-house pit with 6 to 8 inches of water, which is emptied every 7 days to an anaerobic lagoon. Previously, 24-inch-deep pits were preferred, but now shallower pits are used with the hog slat system.
- *Flush*. Flush systems may use fresh water or recycled lagoon water for frequent removal of feces and urine from under-floor collection gutters or shallow pits. Like pit recharge systems, flush systems also improve animal health and performance as well as human working conditions in the swine houses by avoiding prolonged storage. Flush tanks with the capacity to release at least 1.5 gallons per 100 pounds of live animal weight per flush are placed at the end of the swine houses. Pit floors should be level from side to side, and wide pits should be divided into individual channels no wider than 4 to 5 feet. The floor slope for most flush systems is between 1 and 2 percent. Floors are flushed at least 1 to 12 times per day; the flush tanks are filled with new or recycled lagoon water before every flush. The flushed waste is collected and removed from the houses into storage through a system similar to that used in pit recharge systems.

4.1.4.2 Swine Waste Storage Practices

Waste storage is critical to the proper management of wastes from AFOs because manure nutrients are best applied to farmland only at certain times of the year, as determined by crops, climate, and weather. Storage practices include deep pits, anaerobic and aerobic lagoons, above and belowground slurry storage (tanks or pits), and dry storage. Most large hog farms (more than 80 percent) have from 90 to 365 days of waste storage capacity (see Table 4-20).

Table 4-20. Percentage of Swine Facilities With Manure Storage in 1998.

Annual Marketed Head	0–3 months	3–6 months	6–9 months	9–12 months	None or NA
NR	3.2	3.7	3.2	7.4	82.5
0-1,000	31.9	27.2	12.3	17.4	11.3
1,000-2,000	14.9	38.0	20.7	19.4	7.1
2,000-3,000	10.1	35.4	21.9	28.1	4.4
3,000-5,000	5.8	33.5	22.8	32.6	5.3
5,000-10,000	6.1	2	22.1	35.6	7.0
10,000-20,000	4.7	26.4	21.1	40.9	6.8
20,000-50,000	6.0	23.5	22.8	39.2	8.6
50,000 +	4.0	19.5	28.7	28.0	19.8

NA = Not reported/available. Source: NPPC, 1998.

An overview of common waste storage practices is provided below; more detailed information can be found in Section 8 of this document.

- *Deep pit manure storage*. Many operations use pits that are 6- to 8-feet deep and provide for up to 6 months of storage under the house. Commonly, slurry is removed from the pit twice a year. The slurry is disposed of through direct surface application or subsurface injection, transferred to an earthen storage facility, or pumped to an above or belowground storage tank. This slurry system produces a waste stream with higher dry matter content (4 to 5 percent) and higher nutrient content than other liquid manure systems. The above and belowground storage systems conserve more N than other systems (N loss of only 10 to 30 percent). Operations use this system to avoid problems associated with lagoons such as odor, ammonia volatilization, and ground water impact resulting from leaking lagoons.
- *Lagoon Systems.* Lagoon systems can serve as both storage and treatment units. Anaerobic lagoons are the most common type of lagoon and are characterized by anaerobic decomposition of organic wastes. When properly designed an anaerobic lagoon will have a minimum total capacity that includes appropriate design treatment capacity, additional storage for sludge accumulation, and temporary storage for rainfall and wastewater inputs. A lagoon should also have sufficient freeboard and an indicator of the highest safe water level, to prevent the wastewater from overflowing the embankment.
- Lagoons usually fill to capacity within 2 to 3 years of startup due to the accumulated waste volume and, depending on the region, rainfall in excess of evaporation. When the

lagoon is full, water overflow will occur unless the operator is in a position to apply the excess water to the land. Lagoon water drawdown by irrigation or other methods is usually begun before the water reaches the maximum wastewater storage level. Several states require that liquid level indicators be placed in the lagoon to be sure that the liquid stays below the level required to contain the 24-hour, 25-year storm.

In addition to anaerobic lagoons, there are aerobic lagoons (which mix and aerate waste via mechanical aerators or ozone generators), two-stage lagoons (typically a constant volume covered treatment cell followed by a storage cell), and multistage cell lagoons. Technical information and a discussion of the advantages and disadvantages of these types of lagoons is presented in Section 8 of this document.

- *Settling and evaporation ponds*. Earthen ponds are used by some swine operations for solids separation. These ponds are designed to remove 40 percent of the total solids (in a 6 percent solids form) based on 3 months of storage. The material is then moved to another earthen pit, which serves as a drying bed, or flow is diverted to a parallel solids removal pond. The slurry dries to about 38 percent solids and 3-inch thickness within 6 months. The material is then moved with a front-end loader into a box-type spreader and applied to the land. Solids drying ponds and beds are not covered and therefore exposed to rainfall. A floating pump is located half the lagoon distance from the inlet, with a screen over the intake to protect sprinkler nozzles. The supernatant is pumped and used to irrigate fields. Another variation is to use a single lagoon followed by an evaporation pond that is 6 feet deep and as big as possible. Some evaporation ponds dry up during the summer. Because of odor problems, there is a trend away from the earthen pond for solids separation to either a single anaerobic lagoon or an anaerobic lagoon and an evaporation pond.

  Waste runoff storage. The systems described above can also be associated with operations that maintain hogs on an outside lot for at least part of the time. Such operations might also use housing similar to the systems described above, but allow outside access for the animals. Dry lot areas may be paved or dirt, and manure is stored in piles that are created by tractor or scraping systems. Although controls might be in place to contain manure from enclosed areas through use of a deep pit or lagoon, they are not generally protective of the outside environment. Other typical runoff controls include surface diversions to prevent rainwater from running onto the lot, or a crude settling basin with a slotted overflow.

- Other. Other types of waste management practices currently used include above and belowground tanks (possibly covered or aerated), and hoop housing/deep bedding systems.

USDA APHIS (2001) performed a survey of swine operations with 100 or more pigs. The study included 17 of the major pork-producing states that account for 94 percent of the U.S. pig inventory. Data for that survey were collected from 2,328 operations. The report provided information on feed and waste management, health and productivity, animal management, and facility management. In addition to this report, NAHMS also performed additional analyses for EPA that present the percent of sites where pit holding was the waste management system used most by region and herd size for the farrowing and grow-finish phase (USDA APHIS, 2002a). Tables 4.21 and 4.22 indicate the percent of sites where pit holding was the waste management system used most.

Table 4-21. Percent of Sites Where Pit Holding was the Waste Management System used most by Region and Herd Size for Farrowing Phase.

States	Total Inventory (head)		
	Total	**750–2500**	**>2500 +**
Minnesota, Wisconsin, Michigan, Pennsylvania	37.3	50.3	49.3
Colorado, South Dakota, Nebraska, Kansas, Missouri	22.6	37.9	50.2
Iowa, Illinois, Indiana, Ohio	40.9	65.0	63.2
Texas, Oklahoma, Arkansas, North Carolina	16.0	14.4	23.9

Source: USDA APHIS, 2002a.

Table 4-22. Percent of Sites Where Pit Holding was the Waste Management System used most by Region and Herd Size for Grower-Finisher Phase.

States	Total Inventory (head)		
	Total	**750–2500**	**>2500 +**
Minnesota, Wisconsin, Michigan, Pennsylvania	59.9	77.5	83.3
Colorado, South Dakota, Nebraska, Kansas, Missouri	33.6	55.3	39.3
Iowa, Illinois, Indiana, Ohio	48.3	67.6	77.5
Texas, Oklahoma, Arkansas, North Carolina	27.7	26.3	37.5

Source: USDA APHIS, 2002a.

4.1.4.3 Swine Waste Treatment Practices

Many types of technology are used to treat swine wastes. These technologies work in a variety of ways to reduce the N, COD, and the volatile solids content of waste; or to change the form of the waste to make it more concentrated and thus easier to handle. The most common type of treatment practice is the anaerobic lagoon.

- *Lagoon treatment systems*. Lagoons designed to treat waste can reduce organic content and N by more than 50 percent (PADER, 1986). Anaerobic lagoons are generally preferred over aerobic lagoons because of their greater ability to handle high organic load. Nonetheless, incomplete anaerobic decomposition of organic material can result in offensive by-products, primarily hydrogen sulfide, ammonia, and intermediate organic acids, which can cause disagreeable odors. Therefore, proper design, size, and management are necessary to operate an anaerobic lagoon successfully.

  New lagoons are typically half filled with water before waste loading begins. Starting up during warm weather and seeding with bottom sludge from a working lagoon speeds establishment of a stable bacterial population. Proper lagoon maintenance and operation is absolutely necessary to ensure that lagoon liner integrity is not affected, that berms and embankments are stable, and the required freeboard and rainfall storage are provided.

Even when bacterial digestion is efficient, significant amounts of sludge accumulate in anaerobic lagoons. Although lagoons can be designed with enough storage to minimize the frequency of bottom sludge removals, at some point sludge accumulation will greatly diminish the treatment capacity of most lagoons. Without the proper treatment volume, anaerobic decomposition will be incomplete, and odors will usually become more pronounced. Inadequate maintenance of treatment volume is the single most common reason for the failure of lagoon treatment systems. The method used most frequently to remove sludge entails vigorous mixing of sludge and lagoon water by means of an agitator/chopper pump or propeller agitator. The operation of the agitator/chopper must be continuously monitored to prevent damage to the liner berms, or embankments, which could result in contamination of surface or ground water. The sludge mixture is then pumped through an irrigation system onto cropland.

Some lagoons are covered with a synthetic material. There can be multiple advantages to covering a lagoon. A cover will prevent rainfall from entering the system, which can result in additional disposal costs. Nitrogen volatilization is minimized, making the waste a more balanced fertilizer and potentially saving expenses for the purchase of N fertilizers. The EPA AgSTAR Program has demonstrated that biogas production and subsequent electricity generation from covered lagoons and digesters can be cost effective, help control odor, and provide for more effective nutrient management.

- *Digesters*. Conventional aerobic digestion is frequently used to stabilize biosolids at small municipal and industrial facilities as well as at some AFOs. Waste is aerated for relatively long periods of time to promote microbial growth. Substantial reductions in total and volatile solids, BOD, COD and organic N as well as some reduction in pathogen densities can be realized. Autoheated aerobic digesters use the heat released during digestion to increase reaction rates and allow for more rapid reduction of pathogens. The biosolids created by digesters concentrate solids, resulting in easier handling. Additional information on the operational considerations, performance, and advantages and disadvantages of digesters can be found in Section 8.
- *Sequencing batch reactors*. Manure is treated in sequence, typically in a vessel of metal construction. The vessel is filled, reacted (aeration cycled on and off), and then allowed to settle. Organic carbon and ammonia are reduced and P is removed through biosolids generation or chemical precipitation. The biosolids generated are in a concentrated form, allowing for ease in handling.
- *Other*. Many other practices are used separately or in combination with the practices listed above to treat swine wastes. Constructed wetland treatment cells, trickling filters, composting, oxidation ditches, are a few of the other ways to treat swine wastes. Systems being developed or under trial studies include Y- or V- shaped pits with scrapers for solid-liquid separation at the source, membrane filtration, chemical treatments, high-rise hog buildings, oligolysis, hydroponic cultivation, photosynthetic digesters, and closed loop water use systems using ultraviolet disinfection. Information on the operational considerations, performance, and advantages and disadvantages of these and other treatment practices can be found in Section 8.

4.1.4.4 Waste Management Practices by Operation Size and Geographical Location

The use of a particular waste management system is driven by the size of the operation and geographic considerations (e.g., climate). For example, operation of a confined facility with the use of a lagoon for treatment requires substantial capital investment. Below a certain number of head, such a system would be cost-prohibitive since the high start-up and maintenance costs of such a facility have to be spread over a large number of animals to ensure economic viability. Geographic considerations also play a role in waste management. Anaerobic lagoons are common in the Southeast, where factors such as land availability and climate conditions are favorable. Midwestern farms are more likely to use pit storage with slurry transport to above or belowground tanks. The *Swine '95* Survey (USDA APHIS, 1995) provides a detailed picture of swine management practices by operation type, size, and location. (At the time of writing, reports from the Swine 2000 survey did not provide equivalent statistics that allow comparisons based on region and operation size and is therefore not presented in this section.)

Waste Management Practice by Operation Size

As mentioned previously, large operations (greater than 2,000 head marketed in the past 12 months) are much more likely to use water for waste management than small operations. Small operations (less than 500 head) typically manage waste by hand cleaning or mechanical scraper/tractor. They also use pit-holding and flushing systems because of their relatively lower labor requirements. While larger operations also use pit storage and slurry storage in tanks, they are far more likely to move waste from the housing facility to a lagoon. Tables 4-23, 4-24, and 4-25 present the frequency of operations using the most common types of waste management systems for swine farrowing, nursery, and finishing phases, respectively. Table 4-26 presents the frequency of waste storage system use by size of operation. Table 4-27 presents the frequency of waste storage system use by region for operations that marketed 5,000 or more hogs in a 12-month period. It should be noted that the percentages do not add to 100 percent. This is because an operation may use more than one waste storage system. For example, many large facilities in the Southeast have below floor slurry storage that is then moved to lagoon storage.

Table 4-23. Frequency (in percent) of Operations in 1995 by Type of Waste Management System Used Most in the Farrowing Phase.

	Number of Hogs Marketed in Past 12 Months		
Variable	**<2,000**	**2,000–10,000**	**>10,000**
None	14.1	5.6	1.7
Pit-holding	24.4	53.9	49
Scraper/Tractor	12.3	3.6	6.0
Hand cleaned	39.7	0.6	0
Flush - under slats	4.6	20.8	39.3
Flush - gutter	3.0	2.7	2.6
Other	1.8	13	1.5

Source: USDA APHIS, 1995.

Table 4-24. Frequency (in percent) of Operations in 1995 by Type of Waste Management System Used Most in the Nursery Phase.

Variable	Number of Hogs Marketed in Past 12 Months		
	<2,000	2,000–10,000	>10,000
None	4.4	3.3	0
Pit-holding	32.3	55	48
Scraper/Tractor	18.5	3.9	1.7
Hand cleaned	31.7	1.6	0
Flush - under slats	8.7	19.6	10.2
Flush - gutter	2.1	1.7	3.4
Other	2.3	15	6.8

Source: USDA APHIS, 1995.

Table 4-25. Frequency (in percent) of Operations in 1995 by Type of Waste Management System Used Most in the Finishing Phase.

Variable	Number of Hogs Marketed in Past 12 Months		
	<2,000	2,000–10,000	>10,000
None	15.2	4.6	0
Pit-holding	22.1	53	45.3
Scraper/Tractor	25.5	8.6	11.4
Hand Cleaned	28.0	3.0	0
Flush - under slats	1.9	17.5	30.0
Flush - gutter	3.3	7.8	6.0
Other	4.0	5.5	7.4

Source: USDA APHIS, 1995.

Table 4-26. Frequency (in percent) of Operations in 1995 That Used Any of the Following Waste Storage Systems by Size of Operation.

Waste Storage System	Percentage of Operations by Number of Head Marketed for Slaughter		
	<2,000 Head	2,000–10,000 Head	>10,000 Head
Below-floor slurry	43.6	70.4	47.9
Aboveground slurry	4.1	10.3	8.3
Belowground slurry	17.3	25.6	26.8
Anaerobic lagoon with cover	2.2	0.5	2.0
Anaerobic lagoon without cover	17.4	29.2	81.8
Aerated lagoon	1.3	6.9	1.0
Oxidation ditch	2.9	0.1	0.0
Solids separated from liquids	4.1	5.9	4.7
Other	0.6	0.0	1.1

Source: USDA APHIS, 1995.

Table 4-27. Frequency (in percent) of Operations in 1995 That Used Any of the Following Waste Storage Systems by Region for Operations That Marketed 5,000 or More Hogs in a 12-Month Period.

	USDA APHIS Region[a]		
Waste Storage System	**Midwest**	**North**	**Southeast**
Below-floor slurry	21.5	28.5	85.7
Aboveground slurry	NA	NA	27.2
Belowground slurry	NA	NA	43.3
Anaerobic lagoon	91.2	4.8	33.3
Aerated lagoon	NA	X[b]	NA
Solids separated from liquids	NA	NA	14.4

[a] Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
The standard error for the aerated lagoons in the northern region as evaluated by NAHMS exceeds 21 percent and was therefore determined by NAHMS not to be statistically valid. Note that the aerated lagoon is reportedly found in roughly 70 percent of the operations in the north region.
Source: USDA APHIS, 1995.

With minor exceptions, there are consistent trends in operation management from one part of the country to another. The multisite model that separates production phases is being adopted across the country; finishing age and number of litters per year already tend to be the same from one part of the nation to another. With the exception of the Midwest, producers tend to farrow small groups of sows weekly (USEPA, 1998). In the Midwest, some producers farrow only twice a year, usually in the spring and fall. This is primarily done on smaller operations, where sows are maintained outdoors and then moved indoors for farrowing. The buildings in which pigs are housed in the Midwest tend to differ from those in more temperate parts of the country, and waste is managed differently in the Midwest than in other parts of the country. Confined, three-site operations predominate in the Southeast, South-Central, and West Regions, although there are some smaller outdoor operations in the South-Central and West Regions.

Most types of waste management systems are also similar across most regions with only minor deviations. For example, the pit-recharge systems with aboveground storage and land application are nearly identical among farms in the Midwest, the South-Central, and the Northeast Regions. The primary waste management system that has the most variation among and within regions is known as the hand wash system. Hand wash systems are found predominantly on operations with fewer than 500 pigs and most of those that use hand washing as their primary waste management system have fewer than 100 pigs. On these operations, it is in the farrowing house or nursery phases of production that hand washing is used to remove waste from the buildings. Either the wash water exits the building and enters the environment directly or a collection basin is located underneath or at one end of the building. In the case of collection, the wash water is stored and used for land application at a later time or is allowed to evaporate over time. Frequency of hand washing varies among operations from three times a day to once a week.

Another type of system identified as a primary waste management system on small operations in the Midwest and New England (USDA APHIS, 1995) uses a flat blade on the back of a tractor to scrape or remove manure from feeding floors. The popularity of this system has apparently waned, and the it no longer represents a major means for removing wastes from swine feeding operations (NCSU, 1998a).

Swine Waste Management Systems in the Pacific Region

Descriptive information about the waste management systems in this region is provided in Table 4-28. In general, the region is characterized by operations with fewer than 500 pigs that use hand washing and dry lots as their primary waste management system. In contrast, the majority of pigs are raised on operations with more than 1,000 animals that use either deep pit/aboveground storage or pit recharge/lagoon.

Table 4-28. Distribution of Predominant Waste Management Systems in the Pacific Region[a] in 1997.

Farm Size (number of pigs)	Primary Waste Management System
Fewer than 500	1. Hand Wash/Dry Lots 2. Scraper/Aboveground Storage/Land Application
500 to 1,000	1. Hand Wash/Dry Lots 2. Deep Pit/Aboveground Storage/Land Application
More than 1,000	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Covered Anaerobic Lagoon/Irrigation

[a] Alaska, California, Hawaii, Oregon, and Washington.
Source: NCSU, 1998a.

Swine Waste Management Systems in the Central Region

Table 4-29 presents information for the Central Region. It is the fastest-growing area of swine production in the nation at the present time. As a result, large operations (>2,000 head) account for almost all of the swine in these states. As a group, these large operations appear to rely on evaporation from lagoons, aeration of anaerobic lagoons, or biogas production from lagoons as the main means for storing and treating swine waste.

Circle 4, one of the largest operations in the country, uses a pit-recharge system that is emptied about three times per week. Wastewater treatment is by a two-stage evaporative lagoon system. The primary stage is designed for treatment of volatile solids, with additional volume for 20 years of sludge storage. The exact treatment volume design is operation- (or complex-) specific and takes into consideration the diet, feed digestibility, and absorption and conversion efficiency of the animal for each group of confinement houses. The primary stage is sized on the basis of volume per input of volatile solids plus an additional volume for 20 years of sludge storage. The secondary stage lagoon volume and surface area are specified to allow evaporation of all excess water not required for pit recharge. Waste management plans call for sludge removal every 20 years. Because the operation has not reached its design life at this time, this system cannot be evaluated.

Table 4-29. Distribution of Predominant Waste Management Systems in the Central Region[a] in 1997.

Farm Size (number of pigs)	Primary Waste Management System
Fewer than 500	1. Hand Wash/Dry Lots
500 to 1,000	1. Flush or Pit Recharge/Anaerobic Lagoon/Irrigation 2. Deep Pit/Aboveground Storage/Land Application
More than 1,000	1. Flush or Pit Recharge/Aeration of Anaerobic Lagoon/Irrigation 2. Flush or Pit Recharge/Covered Anaerobic Lagoon/Land Application 3. Pit Recharge/Evaporation from Two-Stage System

[a]Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oklahoma, Texas, Utah, Wyoming
Source: NCSU, 1998a.

Swine Waste Management Systems in the Mid-Atlantic Region

Table 4-30 summarizes descriptive information for the region. Only North Carolina and Pennsylvania grow a significant number of swine. The medium and large operations rely on either anaerobic lagoons and wastewater irrigation or aboveground storage and land application as their primary means of waste management. Operations in the remaining states typically have fewer than 500 animals each, and they use hand washing in conjunction with dry lots as their primary waste management system.

The design and operation of the anaerobic lagoon and irrigation system are different in the two key states. In Pennsylvania, lagoon loading rates are lower to accommodate the lower temperatures, and storage requirements must be increased to accommodate the longer inactive period during winter. Average yearly rainfall is about the same in the two states, with rainfall in excess of evapotranspiration requiring increased storage requirements.

Table 4-30. Distribution of Predominant Waste Management Systems in the Mid-Atlantic Region[a] in 1997.

Farm Size (number of pigs)	Primary Waste Management System
Fewer than 500	1. Hand Wash/Dry Lots 2. Gravity Drain/Collection Basin/Land Application
500 to 1,000	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Anaerobic Lagoons/Irrigation 3. Scraper/Aboveground Storage/Land Application
More Than 1,000	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Anaerobic Lagoons/Irrigation

[a]Connecticut, Delaware, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia, and West Virginia.
Source: NCSU, 1998a.

Swine Waste Management Systems in the South Region

Table 4-31 summarizes descriptive information for the region. Large operations (more than 1,000 head) represent only a small fraction of the operations in the states of the region. The predominant waste management system is a flush or pit-recharge system for removal of waste from buildings, an anaerobic lagoon for treatment and storage of waste, and reincorporation of treated wastewater back into the environment by irrigation. In these states, housing is usually enclosed, with ventilation and a concrete floor surface.

Table 4-31. Distribution of Predominant Waste Management Systems in the South Region[a] in 1997.

Farm Size (number of pigs)	Primary Waste Management System
Fewer than 500	1. Hand Wash/Dry Lots 2. Scraper System/ Aboveground Storage/Land Application
500 to 1,000	1. Flush or Pit Recharge/Anaerobic Lagoon/Irrigation
More Than 1,000	1. Flush or Pit Recharge/Anaerobic Lagoon/Irrigation

[a]Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, and South Carolina.
Source: NCSU, 1998a.

Swine Waste Management Systems in the Midwest Region

Table 4-32 summarizes descriptive information for this region. Small operations account for most of the operations in this region; however, recent construction of large units in Iowa, Minnesota, Missouri, and South Dakota indicate that the trend toward production in larger units seen in the southeastern United States is probably occurring in the Midwest Region as well. Primary waste management systems for operations with fewer than 500 pigs are hand wash coupled with dry lots with and without collection basins. In contrast, medium and large operations rely on storage of waste either under buildings with deep pits or in aboveground structures in conjunction with direct land application for crop production.

Table 4-32. Distribution of Predominant Waste Management Systems in the Midwest Region[a] in 1997.

Farm Size (number of pigs)	Primary Waste Management System
Fewer than 500	1. Hand Wash/Dry Lots 2. Hand Wash/Dry Lots and Collection Basin/Land Application 3. Deep Pit/Land Application
500 to 1,000	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Aeration of Anaerobic Lagoons/Irrigation 3. Deep Pit/Land Application
More than 1,000	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Covered Anaerobic Lagoon/Irrigation

[a]Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.
Source: NCSU, 1998a.

4.1.5 Pollution Reduction

4.1.5.1 Swine Feeding Strategies

Swine producers use a variety of feed ingredients to achieve a balanced diet for a pig at each phase of the animal's development. Various grain products, including corn, barley, milo, and sometimes wheat, form the foundation of the growing pig's diet and supply most of the carbohydrates and fat. Oilseed meals, which foster muscle and organ development, are the primary source of protein (NPPC, 1999). Producers also supplement the basic diet with minerals and vitamins as needed. A pig's diet changes as the animal grows. For example, finishing pigs typically receive a diet containing 13 to 15 percent crude protein versus the 20 to 22 percent protein diet received by young pigs. The *Swine '95* survey indicates that more than 96 percent of grow-finish operations use multiple diets from time of entry to market weight. Almost 70 percent of the operations feed their pigs three or more diets during this phase.

Swine operations can use feeding strategies both to maximize growth rates and to reduce excretion of nutrients. The following feeding strategies can be used to reduce N and P manure content.

Grinding. Fine grinding and pelleting are simple but effective ways to improve feed utilization and decrease N and P excretion. By reducing the particle size, the surface area of the grain particles is increased, allowing for greater interaction with digestive enzymes. When particle size is reduced from 1,000 microns to 400 microns, N digestibility increases by approximately 5 to 6 percent. As particle size is reduced from 1,000 microns to 700 microns, excretion of N is reduced by 24 percent. The current average particle size is approximately 1,100 microns; the recommended size is between 650 and 750 microns. Reducing particle size below 650 to 750 microns greatly increases the energy costs of grinding and reduces the throughput of the mill. The use of so small a particle size will also increase the incidence of stomach ulcers in the hogs (NCSU, 1998b).

Amino Acid Supplemental Diets. Supplementing the diet with synthetic lysine to meet a portion of the dietary lysine requirement is an effective means of reducing N excretion by hogs. This process reduces N excretion because lower-protein diets can be fed when lysine is supplemented. Research 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/ton of feed) without negatively affecting the performance of grow-finish pigs. Greater reductions in protein are possible, but only if threonine, tryptophan, and methionine are also supplemented.

Table 4-33 shows the theoretical effect of feeding low-protein, amino acid-supplemented diets on N excretion of finishing pigs. Note that reducing the protein level from 14 to 12 percent and adding 0.15 percent lysine results in an estimated 22 percent reduction in N excretion. Reducing the protein further to 10 percent and adding 0.30 percent lysine, along with adequate threonine, tryptophan, and methionine, reduces the estimated N excretion by 41 percent.

Although it is currently cost-effective to use supplemental lysine and methionine, supplemental threonine and tryptophan are too expensive to use in widespread diets. However, because of rapid technological advances in fermentation procedures for synthesizing amino acids, the price of threonine and tryptophan will likely decrease in the next few years.

Table 4-33. Theoretical Effects of Reducing Dietary Protein and Supplementing With Amino Acids on Nitrogen Excretion by 200-lb Finishing Pig[a,b]

Diet Concentration	14 CP	12 CP + Lysine	10 CP + Lysine + Threonine + Tryptophan + Methionine
N balance			
N intake, g/d	67	58	50
N digested and absorbed, g/d	60	51	43
N excreted in feces, g/d	7	7	7
N retained, g/d	26	26	26
N excreted in urine, g/d	34	25	17
N excreted, total, g/d	41	32	24
Reduction in N excretion, %	----	22	41
Change in dietary costs, $/ton[b]	0	-0.35	+$14.50

[a]Assumes an intake of 6.6 lb/d and a growth rate of 1.98 lb/d. [b]Costs used L-Lysine HCl, $2.00/lb; corn, $2.50/bushel; SBM, $250/ton; L-Threonine, $3.50/lb; DL-Methionine, $1.65/lb; Tryptosine (70:15, Lys:Tryp) $4.70/lb.
Source: NCSU, 1998b.
g/d = grams/day

Phase Feeding and Split-Sex Feeding. Dividing the growth period into more phases with less spread in weight allows producers to meet the pig's protein requirements more closely. Also, since gilts (females) require more protein than barrows (males), penning barrows separately from gilts allows lower protein levels to be fed to barrows without compromising leanness and performance efficiency in gilts. Feeding three or four diets, compared with only two diets, during the grow-finish period would reduce N excretion by at least 5 to 8 percent (NCSU, 1998b).

Formulating Diets on an Available Phosphorus Basis. A high proportion (56 to 81 percent) of the P in cereal grains and oilseed meals occurs as phytate. Pigs do not use P in this form well because they lack significant amounts of 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.

Because some feedstuffs are high in phytate and because there is some endogenous phytase in certain small grains (wheat, rye, triticale, and barley), there is wide variation in the bioavailability of P in feed ingredients. For example, only 12 percent of the total P in corn is available, whereas 50 percent of the total P in wheat is available. The P in dehulled soybean meal is more available than the phosphorus in cottonseed meal (23 percent versus 1 percent), but neither source of P is as highly available as the P in meat and bone meal (66 percent), fish meal (93 percent), or dicalcium phosphate (100 percent) (NCSU, 1998b).

Supplementing Diets with Phytase Enzyme. Supplementing the diet with the enzyme phytase is an effective means of increasing the breakdown of phytate P in the digestive tract and reducing the P excretion in the feces. Using phytase allows one to feed a lower P diet because the unavailable phytate phosphorus in the grain and soybean meal is made available by the phytase enzyme to help meet the pig's P needs. Studies at Purdue University, the University of Kentucky, and in Denmark indicate that the inclusion of phytase increased the availability of P in a corn-soy diet threefold, from 15 percent to 45 percent.

A theoretical example of using phytase is presented in Table 4-34. If a finishing pig is fed a diet with 0.4 percent P (the requirement estimated by NRC, 1988, cited in NCSU, 1998b), 12 grams of P would be consumed daily (3,000 grams times 0.4 percent), 4.5 grams of P would be retained, and 7.5 grams of P would be excreted. Feeding a higher level of P (0.5, 0.6, or 0.7 percent) results in a slight increase in P retention but causes considerably greater excretion of P (10.3, 13.2, and 16.2 g/d, respectively). Being able to reduce the P to 0.3 percent in a diet supplemented with phytase would reduce the intake to 9 grams of P per day and would potentially reduce the excreted P to 4.5 g/day (a 37 percent reduction in P excretion versus NRC's estimate). The percent reduction in excreted P is even more dramatic (56 percent) when one compares the 4.5 grams with the 10.3 grams of P excreted daily by finishing pigs fed at the 0.5 percent P level typically recommended by universities and feed companies. Bone strength can be completely recovered by supplementing a low-P diet with 1,000 phytase units per kilograms of feed, while most of the grain and feed efficiency is returned to NRC levels. In addition to returning bone strength and growth performance to control levels, there is a 32 percent reduction in P excretion. A summary of 11 experiments (Table 4-35) indicates that all the growth rate and feed efficiency can be recovered with the dietary supplementation of 500 phytase units and reduced-P diets. Some analyses have suggested that a 50 percent reduction in excreted P by pigs would mean that land requirements for manure applications based on P crop uptake would be comparable to manure applications based on N.

Previously, phytase was too expensive to use as a feed additive. However, this enzyme can now be effectively produced by recombinant DNA techniques and the cost has decreased. A cost evaluation indicates that under certain conditions replacing dietary P of an inorganic P source (e.g., dicalcium phosphate) with the phytase enzyme would be cost neutral. Swine require that phytase supplements be fed at different levels based on the age of the pig (Table 4-36). The

Table 4-34. Theoretical Effects of Dietary Phosphorus Level and Phytase Supplementation (200-lb Pig).

Dietary P (%)	Phosphorus (g/d) Intake	Phosphorus (g/d) Retained	Phosphorus (g/d) Excreted	Change From Industry Average (%)
0.70	21.0	4.8	16.2	+57
0.60	18.0	4.8	13.2	+32
0.50	15.0	4.7	10.3	0
0.40 (NRC, 1988)	12.0	4.5	7.5	-27
0.30	9.0	2.5	6.5	-37
0.30 + Phytase	9.0	4.5	4.5	-56

Source: Cromwell and Coffey, 1995, cited in NCSU, 1998b.

Table 4-35. Effect of Microbial Phytase on Relative Performance of Pigs.[a]

Growth Response	Negative Control	Positive Control	Effect of 500+ Phytase Units/kg
ADG	100	115 (+/- 6.5)	116.7 (+/ -10.6)
ADFI	100	105 (+/- 5.2)	107.6 (+/- 7.8)
Feed Conversion Ratio	100	93 (+/- 4.9)	93.2 (+/- 5.0)

[a]Eleven experiments with the negative control diets set at 100 percent and the relative change in pig growth performance to the control diets.
Source: Jongbloed et al., 1996, cited in NCSU, 1998b.

Table 4-36. Effect of Microbial Phytase on Increase in Phosphorus Digestibility by Age of Pigs and the Recommended Rates for Inclusion of Phytase in Each Phase.

	Nursery	Grower	Finisher	Gestation	Lactation
Approximate Increase (%)	13	17	17	7	20
Inclusion Level (Phytase Unit/lb)	454–385	385–227	27–113	227	227

Source: Jonbloed et al., 1996, cited in NCSU, 1998b.

different levels are based on phase of production and are likely related to the digestive enzymes and cecum of the younger pig being less developed.

4.1.5.2 Waste and Waste Water Reductions

Methods to reduce the quantity of wastewater generated at swine operations include advanced swine watering systems to reduce water spillage and recycling water in waste flush systems. The feeding strategies discussed in the previous section will also reduce the quantity of waste generated by ensuring that animals do not receive more feed than required for optimal growth. Additional information on feeding strategies for swine can be found in Chapter 8. Advanced swine breeding has resulted in animals that produce less waste per pound of meat produced.

Nipple water delivery systems reduce the amount of wastewater and are more healthy for the animals. Trough or cup waters are typically placed close to the floor of the pen. This allows the animal to spill water and add contaminates to the standing water. Nipple water delivery systems are placed higher in the pen and only deliver water to the animal when the animal is sucking on the nipple. Watering systems may also use water pressure sensors and automatic shutoff valves to reduce water spillage. The sensor will detect a sustained drop in water pressure resulting from a break in the water line. The sensor will then stop the water flow to the broken line and an alarm will sound. The operator can then fix the broken line and restore water to the animals with minimal water spillage. There is little information about the relative use of the various water delivery systems or the relative use of water pressure sensors and shutoff valves within the swine industry.

The use of recycled water in swine flush and pull plug waste management systems will also reduce the amount of wastewater generated at an operation. To obtain recycled water of appropriate quality an operation can use a variety of methods to remove pollutants from the waste stream. Such methods include solid-liquid separation, digesters, and multiple-stage lagoon systems. Multiple-stage lagoon systems or the use of an initial settling basin will allow settling of solids and biological processes to occur that can result in high quality water. One large operation in Utah claims to have a completely closed system in which all wastewater is treated in a multiple-stage lagoon system and then recycled back to the manure flush system.

4.1.6 Waste Disposal

Waste is disposed in either a liquid or solid form. Handling and disposal in a solid form has several advantages the more concentrated the waste. Hauling costs are reduced as the water content is reduced; however, most operations prefer to handle and dispose of waste in a liquid form because of the reduced labor cost of handling the waste in this manner. Table 4-37 shows the percentage of operations that use or dispose of manure and wastes as unseparated liquids and solids. Tables 4-38 and 4-39 show the percentage of operations that are using the most common disposal methods by USDA APHIS region. (At the time of writing, reports from the Swine 2000 survey did not provide equivalent statistics that allow comparisons based on region and operation size and is therefore not presented in this section.)

Table 4-37. Percentage of Operations in 1995 That Used or Disposed of Manure and Wastes as Unseparated Liquids and Solids.

Operation Size	USDA APHIS Region[a]		
	Midwest	North	Southeast
Operations marketing fewer than 5,000 hogs in 12 months	92.3	99.1	97.7
Operations marketing 5,000 or more hogs in 12 months	100	19.6[b]	98.5

[a]Midwest = SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
[b]The standard error on this measurement is 16.0, resulting in questions of its accuracy.
Source: USDA NAHMS, 1999.

Table 4-38. Percentage of Operations in 1995 That Marketed Fewer Than 5,000 Hogs in a 12-Month Period and That Used the Following Methods of Use/Disposal by Region.

Waste Disposal Method	USDA APHIS Region[a]		
	Midwest	North	Southeast
Placed on own land	97.9	98.5	96.8
Given away	NA	11.0	2.6

[a]Midwest=SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast=MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA NAHMS, 1999.

Table 4-39. Percentage of Operations in 1995 That Marketed 5,000 or More Hogs in a 12-Month Period and That used the Following Methods of Use/Disposal by Region.

Waste Disposal Method	USDA APHIS Region[a]		
	Midwest	North	Southeast
Placed on own land	100	100	97.5
Sold	NA	NA	7.3
Given away	NA	NA	11.3

[a]Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA.
Source: USDA NAHMS, 1999.

Transport and land application of manure nutrients are necessary to realize the fertilizer benefit of such nutrients. Surface application and injection are common means of land application for slurry. Depending on the consistency of the manure, several types of equipment are available to apply the nutrients to the land. The common manure spreader is a low-maintenance, relatively inexpensive piece of equipment. The spreader is designed for solids and thick slurries; however, because of the characteristics of the equipment, the manure is hard to apply uniformly. This type of spreader requires loading equipment and usually takes longer to empty small loads. A flexible drag hose can be used on relatively flat landscapes. This system unloads the manure quickly, although it normally requires two tractors and a power unit on the pump. A flexible drag hose system is effective on regularly shaped fields, but the equipment is expensive. Tank wagon applications are used for liquid manure. The wagon is adaptable to either surface broadcast or injection, depending on the situation. Tank wagons apply liquid manure uniformly and are self-loading; however, the pump to discharge the manure requires a large amount of horsepower, which can be taxing on the tractor. Soil compaction is normally associated with tank wagons, and it usually takes longer to empty the storage facility. Tables 4-40 and 4-41 show the percentage of operations that disposed of manure and waste on owned or rented land using various methods. Operations may use more than one method, therefore columns do not add up to 100 percent.

Table 4-40. Method of Manure Application in 1995 on Land by Operations That Marketed Fewer Than 5,000 Hogs in a 12-Month Period.

Manure Application Method	USDA APHIS Region[a]		
	Midwest	North	Southeast
Irrigation	47.6	11.2	2.9
Broadcast	18.4	57.8	69.0
Slurry–surface	33.0	55.7	46.6
Slurry–subsurface	X[b]	26.6	22.9

[a]Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA.
[b]Operations in this region use this method, but NAHMS determined the standard error was too high to report statistically valid values.
Source: USDA NAHMS, 1999.

Table 4-41. Method of Manure Application in 1995 on Land by Operations That Marketed 5,000 or More Hogs in 12-Month Period.

Manure Application Method	USDA APHIS Region[a]		
	Midwest	North	Southeast
Irrigation	100	74.8	16.4
Broadcast	X[b]	X[b]	39.4
Slurry–surface	X[b]	6.3	68.1
Slurry–subsurface	X[b]	23.6	72.1

Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA.
[b]Operations in this region use this method, but NAHMS determined the standard error was too high to report statistically valid values.
Source: USDA NAHMS, 1999.

Most manure and waste is disposed of on land owned or rented by the operator, thus the amount of land available for land application of wastes is critical. Applying too much manure and waste to the same land year after year can result in a steady increase in the soil P content. Table 4-8 presents the number of swine operations with and without adequate crop and pastureland for manure application on an N- and P- basis at plant removal rates and operations that own no land. The operations that have no land were determined by running queries of the USDA 1997 Census of Agriculture data to identify facilities that did not grow any of the 24 major crops grown in the United States. Operations with no land available are assumed to haul their waste to land that can use the waste as a fertilizer resource.

Another waste product of swine farms is animal mortality. Mortalities are usually handled in an environmentally sound and responsible manner, but improper disposal may cause problems with odors, pathogens, biosecurity, and soil and water contamination. The 1995 USDA APHIS *Swine 95* study assessed the frequency of mortality disposal methods based on whether operations marketed more or fewer than 2,500 head in the prior 6 month period. (An operation that sold 2,500 head in the last 6 months corresponds roughly to an operation with 1,000 to 1,500 animal unit capacity.) Tables 4-42 and 4-43 show the percentage of operations by method of disposal for those operations which specified at least one pig had died in the 6 month period.

Table 4-42. Method of Mortality Disposal on Operations That Marketed Fewer Than 2,500 Hogs in a 6-Month Period in 1995.

Method of disposal	USDA APHIS Region[a]		
	Midwest	North	Southeast
Burial on operation	73.2	71.6	46.6
Burn on operation	9.1	7.2	15.2
Renderer entering operation	2.1	14.1	38.7
Renderer at perimeter of operation	2.7	4.2	8.7
Composting	10.3	6.4	13.0
Other	7.0	9.8	6.8

[a]Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA NAHMS, 1999.

Table 4-43. Method of Mortality Disposal on Operations That Marketed 2,500 or More Hogs in a 6-Month Period in 1995.

Method of Disposal	USDA APHIS Region[a]		
	Midwest	**North**	**Southeast**
Burial on operation	23.0	21.0	20.8
Burn on operation	9.9	10.2	17.1
Renderer entering operation	39.9	50.1	37.5
Renderer at perimeter of operation	27.9	23.2	31.4
Composting	X	X	11.1
Other	3.4	X	1.8

[a]Midwest = SD, NE, MN, IA, IL; North = WI, MI, IN, OH, PA; Southeast = MO, KY, TN, NC, GA. Only the 16 major pork states that accounted for nearly 91 percent of U.S. hog inventory were surveyed.
Source: USDA NAHMS, 1999.

4.2 Poultry Industry

Poultry feeding operations include facilities that confine chickens or turkeys for feeding or maintenance for at least 45 days in any 12-month period. These facilities do not have significant vegetation in the confinement area during the normal growing season, thus pasture and grazing operations are generally not included. Facilities at which poultry are raised may also include other animal and agricultural operations such as grazing, egg processing, and crop farming.

The specific poultry sectors are discussed in the following sections:

- 4.2.1: Broilers, roasters, and other meat-type chickens
- 4.2.2: Layers and pullets
- 4.2.3: Turkeys
- 4.2.4 Ducks

Up until the 1950s most of the nation's poultry production was conducted on small family farms in the Midwest. Midwestern states provided favorable climatic conditions for seasonal production of poultry and close proximity to major sources of grain feed. Eventually, with the improvement of the transportation and distribution systems, the poultry industry expanded from the Midwest to other regions. With the advent of climate-controlled systems, poultry production evolved to a year-round production cycle. By 1997, the value of poultry production exceeded $21.6 billion, and much of the poultry output was generated by corporate producers on large facilities producing more than 100,000 birds (USDA NASS, 1998a).

The poultry industry encompasses several subsectors including broilers, layers, turkeys, ducks, geese, and several other game fowl. This section focuses only on broilers, layers, and turkeys, which account for more than 99 percent of the annual farm receipts from the sale of poultry (USDA NASS, 1998a).

Together the annual sales of broilers, chicken eggs, and turkeys generate almost 10 percent of the value of all farm commodities. Although each of the poultry subsectors has experienced significant growth in output over the past two decades, broilers remain the dominant subsector, accounting for approximately 65 percent ($14.2 billion) of the $21.6 billion in poultry farm sales during 1997. Sales of eggs and turkeys accounted for 21 percent ($4.5 billion) and 13 percent ($2.9 billion), respectively. More than 15 million metric tons of poultry meat were produced in the U.S. during that year (USDA NASS, 1998c).

Poultry production (especially broiler production) is a highly integrated industry, and as a result, management strategies at the facility level tend to be more similar than in other sectors of AFOs. Contract growing began in the South during the 1930s, and by the 1950s the contracts had evolved to their current form. Thus, the integrated structure seen today was in place by the 1960s (Sawyer, 1971, cited in Aust, 1997). For example, more than 90 percent of all chickens raised for human consumption in the U.S. are produced by independent farmers working under contract with integrated chicken production and processing companies. The company provides some inputs such as the birds themselves, feed, medication, and monitoring of flock health by company service personnel. The farmer provides the grow-out buildings, electricity, water, fuel, bedding material ("litter"), and labor and management skills. The company provides the newly hatched chicks that the farmer raises to market age and weight, giving them the feed provided by the company. The farmer is paid largely on the basis of weight gained by the flock as compared with other flocks produced during the same span of time. When the birds reach market weight, the company picks them up and takes them to processing plants, where they are processed into food products. Most integrated companies are stand-alone chicken operations, although some also produce turkeys.

The poultry industry has continued to evolve in terms of the type and number of birds it produces. Genetically designed birds have been developed with the ability to mature quickly and reach market weight or lay eggs more rapidly. This has resulted in increased efficiency and overall poultry production. Facilities that grow the birds have incorporated the latest automated technology for the feed and watering systems as well as ventilation systems. The technological advances have transformed poultry raising into a modern, mechanized industry.

4.2.1 Broiler Sector

This section describes the following aspect of the broiler industry:

- 4.2.1.1: Distribution of the broiler industry by size and region
- 4.2.1.2: Production cycles of broilers
- 4.2.1.3: Broiler facility types and management4.2.1.4: Broiler waste management practices
- 4.2.1.5: Pollution reduction
- 4.2.1.6: Waste disposal

National Overview

Domestic broiler production has followed the same trend as swine and other livestock industries. Production has shifted from geographically diverse, small, family-run operations to large industrial production facilities concentrated in a few states. The number of broiler operations was quite stable between 1992 and 1997, with operations decreasing slightly from 23,949 broiler operations in 1992 to 23,937 operations in 1997, down less than 1 percent (USDA NASS, 1999b). However, between 1982 and 1992, more than 6,000 broiler operations, or 20 percent of the industry's producers, went out of business. As shown in Table 4-44, although the number of operations decreased over the past 20 years, total broiler production increased, with new large operations more than compensating for the small producers who have left the industry.

Table 4-44. Broiler Operations and Production in the United States 1982–1997.[a]

Year	Operations	Production
1982	30,100	3,516,095,408
1987	27,645	4,361,198,301
1992	23,949	5,427,532,921
1997	23,937	6,741,476,153

[a]Broilers are young chickens of the meat-type breeds, raised for the purpose of meat production. Estimates cover a 12-month period (Dec. 1 through Nov. 30) and exclude states with fewer than 500,000 broilers.
Source: USDA NASS, 1998a, 1998b.

4.2.1.1 Distribution of Broiler Operations by Size and Region

EPA's 1974 CAFO Effluent Limitations Guidelines and Standards generally apply to broiler operations with more than 100,000 birds and continuous overflow watering systems, and to broiler operations with 30,000 birds and a liquid manure system. (See Chapter 2 for the definition of a CAFO, and Chapter 5 for a discussion of the basis for revisions to the poultry subcategories.) Where numbers of birds are presented, all birds regardless of age (e.g., poult, laying age, or pullet) or function (i.e., breeder, layer, meat-type chicken) are included unless otherwise indicated in the text.

Large operations dominate broiler production. Although large production operations are characteristic of other livestock industries, such as the swine sector, the consolidation of the broiler industry began earlier and was well entrenched by the 1970s. By 1982, farms that produced fewer than 2,000 birds per flock numbered only 2,811, or about 5 percent of the total. This number decreased by two-thirds to about 1,000 farms a decade later (Abt, 1998). Compared with other livestock industries, such as swine, the broiler industry has the smallest proportion of small operators. For example, the smallest hog operations still accounted for more than 60 percent of all hog producers in 1992.

Regional Variation in Broiler Operations

Table 4-45 presents the 1997 distribution of broiler operations by region and operation size, and Table 4-46 presents the average flock size for these operations. In addition to being dominated by large producers, the broiler industry is concentrated in several states. Georgia, Arkansas, and Alabama, all in the South Region are some of the largest broiler-producing states. Table 4-47 presents the distribution of total chickens by region and operation size. It is important to note that

Table 4-45. Total Number of Broiler Operations by Region and Operation Size in 1997.

Region [a]	Number of Chicken Broiler Operations by Size Group [b] (Operation Size Presented by Number of Birds Spot Capacity)					
	>0-30,000	>30,000–60,000	>60,000–90,000	>90,000–180,000	>180,000	Total
Central	3,046	412	325	274	78	4,135
Mid-Atlantic	5,113	2,105	1,055	842	100	9,215
Midwest	7,910	207	96	141	43	8,397
Pacific	1,244	41	38	42	63	1,428
South	3,403	3,597	2,327	1,980	377	11,684
National	20,716	6,362	3,841	3,279	661	34,859

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.
[b] Broilers are young chickens of the meat-type breeds, raised for the purpose of meat production. Estimates cover a 12-month period (Dec. 1 through Nov. 30) and exclude states with fewer than 500,000 broilers.
Source: USDA NASS, 1999c.

Table 4-46. Average Number of Chickens at Broiler Operations by Region and Operation Size in 1997.

Region [a]	Average Chicken Broiler Animal Counts [b] (Operation Size Presented by Number of Birds Spot Capacity)					
	>0–30,000	>30,000–60,000	>60,000–90,000	>90,000–180,000	>180,000	All Operators
Central	1,494	44,224	73,084	119,026	332,030	25,402
Mid-Atlantic	6,178	44,193	73,590	115,281	303,155	35,771
Midwest	830	47,357	75,821	118,611	414,945	6,933
Pacific	608	44,041	73,695	132,560	624,380	35,200
South	12,538	43,998	73,776	117,581	281,453	60,897
National	4,158	44,187	73,717	117,347	332,073	35,993

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.
[b] Broilers are young chickens of the meat-type breeds, raised for the purpose of meat production. Estimates cover a 12-month period (Dec. 1 through Nov. 30) and exclude states with fewer than 500,000 broilers.
Source: USDA NASS, 1999c.

Table 4-47. Distribution of Chickens by Region and Operation Size in 1997.

Region [a]	Percentage of Total Chicken Broiler Counts [b] (Operation Size Presented by Number of Birds Spot Capacity)					
	>0-30,000	>30,00060–000	>60,000–90,000	>90,000–180,000	>180,000	Total
Central	0.36	1.45	1.89	2.60	2.06	8.37
Mid-Atlantic	2.52	7.41	6.19	7.74	2.42	26.27
Midwest	0.52	0.78	0.58	1.33	1.42	4.64
Pacific	0.06	0.14	0.22	0.44	3.14	4.01
South	3.40	12.61	13.68	18.56	8.46	56.71
National	6.86	22.41	22.57	30.67	17.49	100.00

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.
[b] Broilers are young chickens of the meat-type breeds, raised for the purpose of meat production. Estimates cover a 12-month period (Dec. 1 through Nov. 30) and exclude states with fewer than 500,000 broilers.
Source: USDA NASS, 1999c.

operations with more than 90,000 birds accounted for more than 48 percent of the broilers even though they represented only 11.3 percent of the broiler operations. Operations with fewer than 30,000 birds represented almost 60 percent of the operations but accounted for less than 7 percent of the total birds.

USDA NRCS (2002) provided information to EPA on the number of broiler operations based on the following classifications as shown in Table 4-48:

- Operation size: > = 100,000 head, 50,000–99,999 head, and 30,000–9,999 head.
- Land availability: No excess (Category 1–farms with sufficient crop or pastureland). Excess, with acres (Category 2 farms with some land, but not enough land to assimilate all manure nutrients). Excess, no acres (Category 3 farms with none of the 24 major crop types identified by NRCS).
- Location:Ten states or groups of states.
- Nutrient basis:Applications are based on N or P application rates.

In Alabama for example, there are 98 facilities with more than 100,000 head with none of the 24 major crop types identified by NRCS for application of animal wastes. There are 268 operations (with 100,000 or more head) with some land in Alabama, but not enough land to assimilate all manure nutrients using N- based application rates and 274 operations (with 100,000 or more head) with some land in Alabama, but not enough land to assimilate all manure nutrients using P- based application rates. An undisclosed number of facilities have enough land (i.e., no excess manure).

Table 4-48. Number of Broiler Facilities as Provided by USDA Based on Analyses of 1997 Census of Agriculture Database.

Location	Land availability category	Operation Size and Nutrient Basis					
		> = 100,000		50,000–99,999		30,000–49,999	
		N	P	N	P	N	P
AL	No excess	d	d	34	15	39	32
AL	Excess, no acres	98	98	227	227	217	217
AL	Excess, with acres	268	274	666	685	412	419
AR	No excess	d	d	58	49	104	93
AR	Excess, no acres	69	69	155	155	226	226
AR	Excess, with acres	260	263	797	806	672	683
GA	No excess	d	d	17	6	14	10
GA	Excess, no acres	169	169	319	319	194	194
GA	Excess, with acres	382	387	494	505	250	254
KT, TN, VA, WV	No excess	d	d	34	17	23	15
KT, TN, VA, WV	Excess, no acres	58	58	169	169	129	129
KT, TN, VA, WV	Excess, with acres	187	201	304	321	149	157
MD, DE	No excess	d	d	106	31	103	38
MD, DE	Excess, no acres	62	62	275	275	294	294
MD, DE	Excess, with acres	38	73	146	221	107	172
MS	No excess	d	d	10	8	14	14
MS	Excess, no acres	72	72	172	172	70	70
MS	Excess, with acres	230	230	437	439	143	143
NC, SC	No excess	d	d	61	12	59	19
NC, SC	Excess, no acres	105	105	287	287	290	290
NC, SC	Excess, with acres	177	198	394	443	292	332
OK, MO, KS	No excess	d	d	19	12	30	29
OK, MO, KS	Excess, no acres	26	26	49	49	32	32
OK, MO, KS	Excess, with acres	124	126	248	255	171	172
TX, LA	No excess	d	d	23	21	9	8
TX, LA	Excess, no acres	53	53	117	117	41	41
TX, LA	Excess, with acres	231	231	312	314	86	87
other	No excess	d	d	41	11	45	17
other	Excess, no acres	113	113	162	162	112	112
other	Excess, with acres	100	104	190	220	99	127

Source: USDA NRCS, 2002.
d = data not disclosed

4.2.1.2 Production Cycles of Broilers

Broilers are usually grown for 42 to 56 days depending on the market weight desired. Female broilers can also be grown to lay eggs for replacement stock, and these females are called broiler breeders. Roasters are usually grown separated by sex, with the females being harvested at 42 days of age and the males given the space in the entire house until they are sent to market several weeks later (USEPA, 1998). Other meat-type chickens (capons, game hens) comprise less than 1 percent of chickens raised for meat. Since they are raised in a similar manner to broilers, albeit with different market weights and ages, they are not usually differentiated in the data.

Chickens are produced to meet specific requirements of the customer which can be a retail outlet, fast-food chain, or institutional buyer, among others. A broiler is considered any chicken raised for meat products, though the industry further classifies chickens primarily by the size, weight, and age of the bird when processed.

- **Poussin** - Less than 24 days of age and about 1 pound or less.
- **Cornish Game Hens** - Less than 30 days of age and about 2 pounds.
- **Fast-food Broiler** - 2 pounds, 4 ounces to 3 pounds, 2 ounces (mostly 2 pounds, 6 ounces to 2 pounds, 14 ounces) and less than 42 days of age.
- **3's and Up** - 3 to 4 3/4 pounds and 40 to 45 days of age.
- **Broiler Roaster** - 5 to 6 pounds, hens usually 55 days.
- **Broiler for Deboning** - 5 to 6 pounds, males usually 47 to 56 days.
- **Heavy Young Broiler Roaster** - The typical roaster, 6 to 8 pounds, less than 10 weeks.
- **Capon** - 7 to 9 pounds, surgically desexed male broiler, 14 to 16 weeks.
- **Heavy Hens** - spent breeder hens, 5 to 5 ½ pounds, 15 months of age.

4.2.1.3 Broiler Facility Types and Management

The most common type of housing for broilers, roasters, pullets, and breeding stock is some type of enclosed housing with bedding derived from wood shavings, rice hulls, chopped straw, peanut hulls, or other products, depending on availability. The bedding absorbs moisture and dilutes the manure produced by the birds. Modern houses have an automatic feeding system to distribute the feed, a closed water system (automatic) to deliver the water for the birds, and a ventilation system to provide clean air. Some houses have side curtains that can be retracted to allow diffusion of air. Ventilation is typically provided using a negative-pressure system, with exhaust fans drawing air out of the house, and fresh air returning through ducts around the perimeter of the roof. The ventilation system uses exhaust fans to remove moisture and noxious gases during the winter season and excess heat during the summer. Advanced systems use thermostats and timers to control exhaust fans. These houses are also commonly integrated with an alarm signal to notify the operator of malfunctions and a back-up electric generator during power outages.

Broilers and Roasters. Houses for broilers and roasters are usually 40 feet wide and 400 to 500 feet long and typically designed for 25,000 to 30,000 broilers per flock. Older houses may be somewhat smaller, holding 20,000 to 25,000 birds. The houses contain an impermeable surface for the floor, typically clay. Wood shavings are initially added to the houses to a depth of approximately 4 inches. Between flocks, a small amount of litter referred to as cake (compacted and concentrated manure/litter mix) is removed and the remaining litter may be "top dressed" with an inch or so of new bedding material.

Pullets. Pullets are young chickens, usually less than 20 weeks of age, often raised for the purpose of egg production. Pullet houses are similar in construction to broiler houses. The houses are usually 40 to 45 feet in width and 300 to 500 feet in length. Most pullet houses are equipped with nipple, trough, or bell drinkers and often use mechanical feeders (drag chain, trough, or pan) to distribute feed to the birds. Pullets are usually raised on a floor covered with a bedding source, 1 to 4 inches deep. This litter mixture is either removed after each flock (20 to 21 weeks) or used for a second flock. If the litter is used for a second flock, a small amount of litter as cake is removed and the remaining litter is top dressed with an inch or so of new bedding material. When the house is totally cleaned out, the litter is pushed to the center of the house and a front loader places it in a litter spreader for land application or disposal. Regular and thorough house cleaning is required to minimize disease transmission.

Breeders. Houses are usually 40 to 45 feet in width and 300 to 600 feet in length. Most of the breeder houses contain two rows of slats for the birds to roost. The slats are panels of wood elevated 18 to 24 inches and laid across supports. The slats are spaced 1 inch apart to allow the feces material to fall to the floor. Equipment can access the center section of the house to aid in the clean-out between flocks. These slats cover two-thirds of the entire length of the house along the outside walls, with the center one-third of the building containing bedding litter.

The center third of the house is covered with 2 to 6 inches of a bedding source before young breeder layers are placed in the breeder house. Drinkers, mechanical feeders, and nests are placed over the slat section of the house, which allows most of the manure produced by the birds to fall beneath the slat area, keeping the area accessible to the birds cleaner.

4.2.1.4 Broiler Waste Management Practices

This section summarizes waste management practices for broiler, breeding stock, pullets, and roaster production facilities. Manure as excreted by the birds has a high water content, most of which evaporates. A typical broiler house with capacity for 22,000 birds at a time will produce 120 tons of litter per year. The litter consists mainly of wood chips or other organic plant matter even after it has been in place for a year (NCC, 1999).

Litter Clean-out Schedules. The litter (bedding and manure) of broiler, pullet, and roaster houses is typically cleaned out completely once a year, although there is a trend toward less frequent complete clean-outs. Between flocks, the feeders, waterers, and brooding equipment are winched to the ceiling. A machine is often used to clean out any clumps of litter (termed caking out) that may build up around waterers and feeders. When the broiler or roaster house is completely cleaned out, the litter is typically removed with a front-end loader or bobcat to a spreader truck or flail-type spreader. Spreader trucks are similar to lime-spreading trucks, with a moving bed that empties onto large, round metal plates that distribute the litter for use as fertilizer nutrients for pasture and crops. The rate of application is controlled by the rate at which the moving bed empties and the speed of the truck (NCSU, 1998a).

The common clean-out frequency in broiler breeder houses is once a year. When the house is cleaned, all the equipment (including slats) is removed from the house to allow a front-end loader to push all of the manure to the center litter section of the house. Then a front-end loader places the mixture of manure and litter into a spreader for land application. A thorough cleaning after each flock (essentially once a year) removes pathogens that could be transferred to the next flock. After removal of all organic matter, the house is disinfected.

Litter Storage. Litter is removed from houses in large quantities during annual clean-out. Thus, operators that have land try to time the annual clean-out to coincide with the time land is available for litter application. If this approach is successful, the facility will need only enough storage for cake out during the rest of the year. Traditionally, operators stack litter outside, near the poultry houses or at the edge of fields for spreading in the spring.

However, an increasing number of states are imposing restrictions on the outdoor storage of waste, although the stringency of these requirements varies from state to state. For example, under Virginia's Poultry Waste Management Program, stockpiled poultry litter must be (1) covered, (2) located to prevent storm water runoff, and (3) separated a minimum of 3 feet from the seasonally high water table or by the use of an impermeable barrier. Maryland's requirements for outdoor storage are less restrictive and require only that storage be protected from rainfall and runoff. The state of Delaware, which is also an important producer of poultry, is less restrictive than Maryland and allows for uncovered storage of poultry litter (Hansen, 2000).

There are several methods for storing poultry litter ranging from open stock piles to roofed storage structures. The size and type of method employed varies with location and size of the operation as well as applicable regulations. Open stockpiles are the least expensive alternative, but pose the greatest risk of contaminating the surrounding environment. Contamination risk is reduced if these stockpiles are put on top of ground liners. Other storage structures include bunker-type storage structures, which are permanent aboveground concrete slabs with two parallel walls of concrete identical to those used for storing silage on livestock farms (Brodie et al., 2000). Storage structures with permanent roofs offer both advantages and disadvantages. These structures eliminate the need for plastic covers and reduce the risk of runoff contamination; however, they require a higher level of investment and higher maintenance costs than the other types of structures. Also if these roof structures are not high enough, compacting becomes more difficult and reduces the operator's ability to use the full capacity of the structure (Goan, 2000).

4.2.1.5 Pollution Reduction

New technologies in drinking water systems result in less spillage and are equipped with automatic shutoff valves that help ensure that broiler litter stays drier. Feeding strategies reduce the quantity of waste generated by ensuring that broilers do not receive more feed than required for optimal growth. State regulations have also driven many broiler operations to handle mortalities in ways other than burials such as rendering and composting, which are increasing (see Section 4.2.1.6).

Nipple water delivery systems reduce the amount of wasted water and are healthier for the animals. Trough or bell type watering devices allow the animal to spill water and add contaminants to the standing water. Nipple water systems deliver water only when the animal is sucking on the nipple. Watering systems may also use water pressure sensors with automatic shutoff valves to reduce water spillage. The sensor will detect a sustained drop in water pressure resulting from a break in the water line. The sensor will then stop the water flow to the broken line and an alarm will sound. The operator can then fix the broken line and restore water to the animals with minimal water spillage.

Feeding strategies that reduce N and P can reduce the quantity of nutrients in the excreta. Dietary strategies designed to reduce N and P include enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility, more precise diet formulation, and improved quality control. Although N and P are currently the focus of attention, these strategies also have the potential to decrease other nutrients. Phytase is commonly added to broiler feed. Phytase additions are expected to achieve a reduction in P excretion of 20 to 60 percent depending on the P form and concentration in the diet (NCSU, 1998b). Protein content, calcium, other mineral content, vitamin B, and other factors identified in the literature influence the effectiveness of phytase use in feed. Additional information on feeding strategies for broilers can be found in Chapter 8.

Feeding Strategies. P excretion can be reduced by improving the utilization of feed nutrients through genetic improvements in poultry or by improving the availability of nutrients in the feed ingredients through processing or genetics. Absorption of some minerals is relatively poor and is dependent on the chemical form in the feed or supplement.

4.2.1.6 Waste Disposal

This section summarizes waste disposal practices for poultry production facilities. The two major categories of poultry waste are manure or litter (manure mixed with bedding) and dead animals. There is little variation in manure characteristics, but the litter composition varies by storage, composting management, and other practices. Poultry litter can be disposed of in several ways including land application, animal feed, and incineration. Waste may be pelletized before its applied to the land. Pelletizing produces a more uniform product that is lighter, easily transported in bulk, and spread more uniformly. Additional information on pelletizing poultry wastes and other waste disposal methods can be found in Chapter 8.

Land Application of Poultry Litter. Land application of poultry litter recovers nutrients that otherwise would be lost, and improves crop yields. Poultry manure slowly releases its nutrients, so annual applications are possible. Composting and bagging a pelleted poultry manure fertilizer produces a marketable product for the commercial horticulture industry. One main obstacle to greater commercialization of poultry manure as a fertilizer product has been the inconsistency in product quality from one facility to another.

Where land application is employed, operators commonly use broadcast spreaders and flail-type spreaders for litter. Recommended application rates are based on the nutrient content of the litter, crop type and yield goals, and current soil conditions.

Many producers with cropland apply their litter to their own crops. However, as operations have increased in size and become more specialized, this option is becoming more limited. In some cases, poultry production provides supplemental income to an otherwise small or nonagricultural household with little or no land. Further exacerbating the problem of poultry litter disposal is the fact that many areas of chicken production have a surplus of nutrient supply over crop needs (USDA NRCS, 1998). In these areas, poultry producers face difficulties in selling litter, giving litter away, or even paying local farmers to take the litter. Table 4-48 presents the number of broiler operations with and without adequate crop and pastureland for manure application on an N- and P- basis at plant removal rates and operations that own no land. The operations that have no land were determined by running queries of the USDA 1997 Census of Agriculture data to identify facilities that did not grow any of the 24 major crops grown in the United States. Operations with no land available are assumed to haul their waste to land that can use the waste as a fertilizer resource. More details on the national- and county-level nutrient balance are found in Chapter 6.

Use of Poultry Litter as Animal Feed. Data on the use of poultry litter as animal feed is inadequate to determine how prevalent it is as a waste disposal method. Anecdotal information indicates that use of poultry litter as a food supplement for beef herds may be common in the Mid-Atlantic and Southeast Regions.

Incineration of Poultry Wastes. Incineration of poultry wastes is not done on a large scale in the United States. The practice is being successfully implemented in the United Kingdom and is actively being investigated in this country. Additional information on centralized incineration of poultry wastes is presented in Chapter 8.

Disposal of Dead Animals. Concerns about possible ground water pollution from the burial of dead birds have caused the poultry industry to search for alternatives for dealing safely with dead stock. The most common methods of disposal of dead birds are composting, incineration, burial in deep pits, rendering, and disposal in landfills. Anecdotal information indicates that some broiler integrators have begun to distribute freezers to grower operations to store dead birds prior to picking them up for rendering. Technical information on practices for the disposal of dead animals is presented in Chapter 8. However, there is little information available on the relative use of these practices within the broiler industry.

4.2.2 Layer Sector

This section describes the following aspect of the layer industry:

- 4.2.2.1: Distribution of the layer industry by size and region
- 4.2.2.2: Production cycles of layers and pullets
- 4.2.2.3: Layer facility types and management
- 4.2.2.4: Layer waste management practices
- 4.2.2.5: Egg processing and wash water
- 4.2.2.6: Pollution reduction
- 4.2.2.7: Waste disposal

National Overview. Trends in the egg production subsector have paralleled those in other livestock industries—increasing overall production on fewer and larger farms. At the end of 1997, there were 69,761 operations with hens and pullets of laying age (layers 20 weeks and older) in the United States. This number represents a 19 percent decrease from the estimated 86,245 operations with egg-producing birds in 1992 (USDA NASS, 1999c). In the 10-year period from 1982 to 1992, the number of operations with hens and pullets declined from more than 212,000, a 60 percent decrease (Abt, 1998). Table 4-49 shows the number of operations and bird inventory for 1982, 1987, 1992, and 1997. The number of operations in each category of operation has decreased substantially while total production has increased. Table 4-49 also provides data on operations and inventory with birds below laying age. As with other sectors, specialization of production has gained a foothold, with a small but increasing number of operations producing only pullets.

Table 4-49. Operations With Inventory of Layers or Pullets 1982-1997.

Total Number of Farms with	1997		1992		1987		1982	
	Ops	Production	Ops	Production	Ops	Production	Ops	Production
Layers 20 weeks and older	69,761	313,851,480	86,245	301,467,288	141,880	316,503,065	212,608	310,515,367
Layer and pullets 13 weeks and older	72,616	366,989,851	88,235	351,310,317	144,438	373,577,186	215,812	362,464,997
Pullets between 13 and 20 weeks old	13,180	53,138,371	14,818	49,843,029	19,639	57,074,121	28,109	51,949,630
Pullets less than 13 weeks	5,122	51,755,985	4,938	44,567,993	6,753	47,409,798	8,726	40,705,085

Source: USDA NASS, 1999b.

One major difference between the layer and egg production sector and the broiler production sector is geographical distribution. Layer production, although primarily performed in 10 states, is much less geographically concentrated than the broiler industry. Hence, the key regions identified for the broiler industry in the previous section are not applicable to the layer and egg production sector. Overall, layer production has not increased as rapidly as has broiler production.

4.2.2.1 Distribution of Layer Operations by Size and Region

Layers are defined as chickens maintained for the production of table eggs. Eggs may be produced for human consumption in the shell form (sold in cartons) or may be used in the production of liquid, frozen, or dehydrated eggs. Laying hen operations include facilities that confine chickens for feeding or maintenance for at least 45 days in any 12-month period. These facilities do not have significant vegetation in the confinement area during the normal growing season. Facilities that raise pullets are generally included. Egg washing and egg processing facilities located at the same site as the birds are generally included. Facilities that have laying hen or pullet feeding operations may also include animal and agricultural operations such as grazing and crop farming.

EPA's 1974 CAFO ELG generally apply to laying hen operations with more than 100,000 birds and with continuous overflow watering systems, and to laying hen operations with 30,000 birds and with a liquid manure system. (See Chapter 2 for the definition of a CAFO, and Chapter 5 for a discussion of the basis for revisions to the poultry subcategories.) Where numbers of birds are presented, all birds regardless of age (e.g., poult, laying age, or pullet) or function (i.e., breeder, layer, meat-type chicken) are included unless otherwise indicated in the text.

Table 4-50 presents the number of layer, pullet, and combined operations by size class as well as the average bird count at each type of operation. Table 4-51 presents the number of operations with laying hens by operation size and region. Data on the three types of operations were obtained through special queries of the 1997 Census of Agriculture (USDA NASS, 1999c). Each operation is uniquely characterized, thus the sum of all three provides the total number of operations with layers or pullets or both (75,172 total operations). Pullet operations were assumed to be evenly distributed so as to support layer operations. Table 4-52 presents the distribution of egg laying chickens by facility size and region. It is important to note that in 1997 the 326 largest operations with laying hens were less than one half of a percent of the total operations (70,857) but had over 55 percent of the laying hens. Table 4-53 presents the number of layer facilities and total USDA-based AUs using the 1997 Census of Agriculture (USDA NRCS, 2002).

Table 4-50. Number of Operations in 1997 and Average Number of Birds at Operations with Layers or Pullets or Both Layers and Pullets in 1997.

National Item	Number of Layer, Pullet, and combined Layer and Pullet Operations and Average Bird Counts (Operation Size Presented by Number of Birds Spot Capacity)					
	>0–30,000	**>30,000–62,500**	**>62,500–180,000**	**>180,000–600,000**	**>600,000**	**Total**
Layer Ops	57,413	528	419	146	25	58,531
Layer Count	926	43,621	103,048	311,189	1,013,318	
Pullet Ops [a]	3,694	516	61	44		4,315
Pullet Count	5,010	51,162	133,303	305,679		
Layer and Pullet Ops	12,011	67	93	91	64	12,326
Layer and Pullet Count	218	45,963	112,377	358,580	1,367,476	

[a] Pullet size ranges vary from the others: >0-30,000; >30,000-100,000; >100,000-180,000; and >180,000.
Source: USDA NASS, 1999c.

Table 4-51. Number of Operations in 1997 With Laying Hens by Region and Operation Size in 1997.

Region[a]	Number of Chicken Egg Laying Operations (Operation Size Presented by Number of Layers in Inventory)					
	>0–30,000	>30,000–62,500	>62,500–180,000	>180,000–600,000	>600,000	Total
Central	15,067	76	41	28	9	15,221
Mid-Atlantic	17,445	150	133	48	15	17,791
Midwest	23,069	123	182	78	39	23,491
Pacific	6,509	38	66	39	17	6,669
South	7,334	208	90	44	9	7,685
National	69,424	595	512	237	89	70,857

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.
Source: USDA NASS, 1999c.

Table 4-52. Distribution of Chickens at Operations in 1997 With Laying Hens by Region and Facility Size.

Region[a]	Percentage of Total Chicken Egg Layer Counts (Operation Size Presented by Number of Layers in Inventory)					
	>0-30,000	>30,000–62,500	>62,500–180,000	>180,000–600,000	>600,000	Total
Central	1.62	1.12	1.27	3.08	2.29	9.38
Mid- Atlantic	5.51	2.21	4.41	4.77	5.24	22.14
Midwest	2.25	1.93	6.15	7.55	16.61	34.49
Pacific	0.26	0.57	2.27	3.75	4.79	11.65
South	9.29	2.79	3.04	4.48	2.79	22.34
National	18.92	8.62	17.14	23.63	31.69	100.00

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.
Source: USDA NASS, 1999c.

Table 4-53. Layer Facility Demographics from the 1997 Census of Agriculture Database.

Size Class (EPA AUs)	Number of Operations	Total USDA AUs	Size Class Interval (Number of Head)	
			Lower	Upper
300-500	776	95,648	30,000	49,999
500-750	446	88,817	50,000	74,999
750-1000	238	69,379	75,000	99,999
>1000	671[a]	922,558	100,000	up
Total	2,131	1,176,402		

Source: USDA NRCS, 2002.

4.2.2.2 Production Cycles of Layers and Pullets

A layer is a sexually mature female chicken capable of producing eggs. Egg production can be divided into two types, table and hatching. Table eggs are used for consumption, and hatching eggs are used to supply broiler or layer production operations.

Traditionally, layers are kept through 1 year of egg production and sold for meat at 18 to 20 months of age. Depending on market conditions (relative price of eggs to hens), it has become increasingly common to recycle layers through more than 1 year of production (Bradley et al., 1998). Producers will recycle their flocks into a second or even a third cycle of lay. Flock recycling involves stopping the flock's egg production, allowing a suitable rest period, and then bringing the flock back into production. The entire process (called "force molting") of recycling layers takes approximately 4 to 5 weeks. Producers stop egg production by reducing the length of day (lighting) and feed supply. This period typically takes 2 to 4 weeks and involves a 7-day fast followed by a period during which the flock is fed a low calcium diet. After this "rest period," the flock is returned to normal lighting conditions and a nutritionally balanced diet to support egg production (UCD, 1998). Once the flock is brought back into production, most layers will meet or exceed original levels of egg production. Under this regime, the flock's life is extended for 6 to 12 additional months.

4.2.2.3 Layer Facility Types and Management

Litter-based Housing. A few litter and slat/litter houses are used to produce table eggs. These same housing systems are used for the breeders that produce fertile eggs for the production of hatching eggs, which eventually replace the current flock of egg layers.

Non-litter Based Housing. Layers are often raised in cages arranged in two or four decks. Cages have been the preferred way of housing table egg layers since the mid-1940s (Bradley et al., 1998). They are popular because they provide good sanitation. When the birds are caged, flock nutrition can be better managed and products (eggs) kept cleaner. Cages are designed to separate the layers from their own feces and thereby eliminate many of the feces-related parasite and health problems. Most commercial layer facilities employ one of the following designs.

High-rise Cage Systems. Cage systems are two-story poultry houses with cages for the laying hens in the top story suspended over the bottom story, where the manure is deposited and stored. The house structure itself is usually 40 to 60 feet wide and from 400 to 500 feet long. The watering system is a closed (noncontinuous flow) nipple or cup system. The ventilation system is designed so that the external air is brought into the top story, through the cages where the birds are located, and then over the manure in the bottom story, exiting through fans in the bottom story side wall. The ventilation system is designed to dry manure as it is stored. With proper management of waterers to prevent water leaking to the bottom story, layer waste commonly has a moisture content of 30 to 50 percent.

Scrape-out and Belt Systems. Housing facilities for scrape-out and belt manure removal cage systems are the same dimensions as high-rise units except they have only one story. Watering systems in these operations are also closed, using nipple or cup waterers. Ventilation varies from fan-controlled to adjustable curtains in the side wall.

Cages in the scrape-out system are suspended over a shallow pit, which is scraped out to the end of the house by a small tractor or a pit scraper. Belt systems have a continuous belt under the different tiers of cages that moves the manure to the end of the house, where it is placed into a field spreader or some other suitable storage device. Some of the newer belt systems move air over the manure on the belt in an attempt to dry the manure before it is removed.

The manure from scrape-out and belt systems usually has a moisture content of between 70 and 85 percent. Therefore, the manure can be handled as a slurry, which is either injected or land applied to the land with a spreader that can handle the high-moisture manure.

Flush-Cage Housing. Housing, equipment, and ventilation in flush-cage housing are similar to the scrape-out system with the exception of how the manure is handled. Cages are suspended over a shallow pit as in the scrape-out system, but water is used to move the manure from under the cages to the end of the house, where the water and manure mixture is placed in an anaerobic lagoon. The water used to flush the manure pits is recycled from the lagoon. A variation of this system consists of solids separation by means of a primary lagoon and a secondary lagoon (NCSU, 1998a).

Although storage, management, and disposal practices are quite similar for broiler and layer operations, with the exception of layer operations using lagoon systems, there are regional differences in how operations manage waste. A survey conducted by the United Egg Producers during 1998 indicated significant regional differences in the way layer wastes are managed. These differences are shown in Table 4-54. This data was used with the data in Table 4-51 to estimate that the total number of layer operations that use water to move the wastes to a lagoon (referred to as wet layer systems) was approximately 3,100 operations.

Table 4-54. Summary of Manure Storage, Management, and Disposal.

	Percentage of Region With Practice				
Practice	Pacific	Central	Midwest	Mid-Atlantic	South
Storage sheds in addition to high-rise housing	0	0	10	0	0
Housing with 6-month or longer storage of dry manure	75	40	90	90	40
Export or sale of some or all of litter	100	40	100	75	50
Litter use other than land application (incineration, pelletization)	0	0	5	5	0
Farms with wet storage systems, such as lagoon	0	60	2	5	60

Source: UEP, 1998

4.2.2.4 Layer Waste Management Practices

Manure handling systems vary by region. In 1999 the USDA's APHIS completed the Layers '99 Study (USDA APHIS, 2000b), which looked at a 15-state target population to develop information on the nation's table egg layer population. The 15 states accounted for over 75 percent of the table egg layers in the United States on December 1, 1998. The information collected was summarized by four regions. The data collected on the manure-handling methods of layer facilities are presented in Table 4-55.

Table 4-55. Frequency of Primary Manure-Handling Method by Region.

Primary Manure-Handling Method	Great Lakes		Southeast		Central		West		All Farms	
	%	SE	%	SE	%	SE	%	SE	%	SE
High-rise (pit at ground level with house above	63.0	12.3	31.4	6.0	48.1	6.0	7.8	2.1	39.7	4.4
Deep pit below ground	0.0	--	0.0	--	6.4	3.9	7.3	2.5	2.9	1.0
Shallow pit (pit at ground level with raised cages)	23.4	9.6	19.9	7.3	1.6	1.2	24.1	7.2	18.9	4.4
Flush system to lagoon	0.0	--	41.0	5.9	0.0	--	12.0	3.6	12.5	2.5
Manure belt	13.6	6.7	4.3	2.1	20.2	4.9	5.2	1.5	10.6	2.7
Scraper system (not flush)	0.0	–	2.5	2.1	23.7	8.7	43.6	6.4	15.4	2.6
Total	100		100		100		100		100	

Great Lakes = IN, OH, and PA; Southeast = AL, FL, GA, and NC = Central = AR, IA, MN, MO, and NE; West = CA, TX, WA.
SE = Standard Error
Source: USDA APHIS, 2000b

4.2.2.5 Layer Egg Wash Water

The majority of eggs marketed commercially in the United States are washed using automatic washers. Cleaning compounds such as sodium carbonate, sodium metasilicate, or trisodium phosphate, together with small amounts of other additives, are commonly used in these systems. In addition, plants operating under the Federal Grading Service are required to rinse eggs with a sanitizer following washing (Moats, 1981). Wash water is contaminated with shell, egg solids, dirt, manure, and bacteria washed from the egg surface into the recycled water.

A study by Hamm et al. (1974), performed to characterize the wastewater from shell egg washers, calculated the pollutant load from 11 egg grading and egg breaking plants. Median waste concentrations in the wash waters at the grading plants were found to be 7,300 mg/L for COD, 9,300 mg/L for TSS, and 4,600 mg/L for volatile solids; median concentrations at the breaking plants were found to be 22,500 mg/L for COD, 27,000 mg/L for TSS, and 16,600 mg/L for volatile soilds.

Eggs may be washed either on or off farm. Operations that wash their eggs on farm may do so inline or offline. The frequency of egg processing by location is presented in Table 4-56. The frequency of egg processing by operation size is presented in Table 4-57. Eggs from over 80 percent of the operations are processed off site. Operations with fewer than 100,000 layers are more likely to have their eggs processed off site. Smaller poultry operations primarily haul their wash water to treatment centers or sell their eggs to larger operations for washing and processing (Thorne, 1999). On the other hand, larger egg production operations collect and store egg wash water on site in large tanks or lagoons for treatment and storage. This lagoon water may then be applied to fields using spray irrigation. These anaerobic lagoons are earthen structures designed to provide biological treatment and long-term storage of poultry layer waste. Treatment of waste occurs anaerobically, a process in which organic material is decomposed to carbon dioxide and water, while stabilized products, primarily humic substances, are synthesized. Where space is available, two-stage lagoons may be constructed for better wastewater treatment and greater management flexibility. The first stage contains only the treatment (permanent) volume and sludge volume while the second stage lagoon stores treated wastewater for irrigation and provides additional treatment that produces a higher quality effluent for recycling as flush water (Tyson, 1996).

Table 4-56. Percentage of Operations by Egg Processing Location and Region.

Primary Egg Processing Location	Great Lakes		Southeast		Central		West		All	
	%	SE	%	SE	%	SE	%	SE	%	SE
On farm in line	17.8	8.4	13.1	4.3	9.0	3.2	10.9	2.4	13.5	3.0
On farm off line	6.7	5.4	0.6	0.6	3.3	3.3	9.3	2.4	5.3	2.1
Off farm	75.5	8.1	86.3	4.4	87.7	4.5	79.8	3.6	81.2	3.2
Total	100	--	100	--	100	--	100	--	100	--

Regions: Great Lakes = IN, OH, and PA; Southeast = AL, FL, GA, and NC; Central = AR, IA, MN, MO, and NE; West = CA, TX, WA.
SE = Standard Error.
Source: USDA APHIS, 2000b.

Table 4-57. Percentage of Operations by Egg Processing Location and Operation Size.

Primary Egg Processing Location	Egg Laying Operations with <100,000 Layers		Egg Laying Operations with 100,000+ Layers	
	%	SE	%	SE
On farm in line	4.3	2.8	28.9	5.6
On farm off line	5.2	3.1	5.5	1.9
Off farm	90.5	4.1	65.6	6.0
Total	100	--	100	--

Regions: Great Lakes: IN, OH, and PA; Southeast: AL, FL, GA, and NC; Central: AR, IO, MN, MO, and NE; West: CA, TX, WA.SE = Standard Error.
Source: USDA NAHMS, 2000.

4.2.2.6 Waste and Wastewater Reductions

Methods to reduce the quantity of wastewater generated at layer operations include advanced watering systems to reduce water spillage and feeding strategies. The use of feeding strategies will reduce the quantity of waste generated by ensuring that animals do not receive more feed than required for optimal growth. Dietary strategies to reduce N and P content include developing more precise diets and improving the digestibility of feed ingredients through the use of enzyme additives and genetic enhancement of cereal grains. Information on feeding strategies for layer operations can be found in Chapter 8.

There are several types of water delivery systems used in layer operations. Nipple water delivery systems reduce the amount of wastewater and result in healthier birds. Trough or cup drinkers allow the bird to spill water and add contaminates to the standing water. Continual overflow watering systems reduce the health risk to the birds but produce a greater quantity of wastewater.

Nipple water delivery systems are placed in the cage and deliver water only when the bird is sucking on the nipple. Approximately 62 percent of all layer operations use nipple drinker systems (USDA APHIS, 2000b). However, for layer operations with more than 100,000 birds this number increases to approximately 81.5 percent (USDA NAHMS, 2000). Watering systems may also use water pressure sensors and automatic shutoff valves to reduce water spillage. The sensor will detect a sustained drop in water pressure resulting from a break in the water line. The sensor will then stop the water flow to the broken line and an alarm will sound. The operator can then fix the broken line and restore water to the animals with minimal water spillage. There is little information about the relative use of water pressure sensors within the layer industry.

4.2.2.7 Waste Disposal

Practices for the disposal of layer wastes are similar to those for other poultry litter. After removal from the housing facilities, waste can be directly applied to the land (if available), stored prior to final disposal, or pelletized and bagged for use as commercial fertilizer. Waste storage, application of litter, and other poultry waste disposal practices are discussed in detail in Section 4.2.1.6. The percentage of layer and pullet operations with and without enough land for application of manure on a N- and P- basis and operations with no land are shown in Tables 4-58 and 4-59. The facilities that have no land were determined by running queries of the USDA 1997 Census of Agriculture data to identify facilities that did not grow any of the 24 major crops grown in the United States.

Mortality and the disposal of dead hens is a potentially significant source of contamination at laying operations. A total of 6.5 percent of hens placed in the last completed flock (one flock per farm site) died by 60 weeks of age, and the overall average cumulative mortality was 14.6 percent (USDA APHIS, 2000b). The common methods of disposing of dead hens and frequency of use are presented in Table 4-60. Tables 4-61 and 4-62 present this information for operations with fewer than and more than 100,000 laying hens. Larger facilities are much more likely than smaller facilities to send dead birds to rendering plants (50.2 percent versus 21.1 percent). While smaller facilities are more likely than larger facilities to bury their dead birds (45.6 percent versus 9.1 percent).

Table 4-58. Percentage of Layer Dominated Operations With Sufficient, Insufficient, and No Land for Agronomic Application of Generated Manure.

Capacity (Number of Birds)	Sufficient Land		Insufficient Land		No Land
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	
1–29,999	12.2	9.2	49.1	53	41.1
30,000–59,999	6.8	1	60.3	65	33.2
60,000–179,999	6.2	0	52	62.2	36.8
180,000+	1.1	0	46.6	47.1	52.9
Total	10.5	6.9	49.5	57.5	38.8

Source: USDA NASS, 1999c.

Table 4-59. Percentage of Pullet Dominated Operations With Sufficient, Insufficient, and No Land for Agronomic Application of Generated Manure.

Capacity (Number of Birds)	Sufficient Land		Insufficient Land		No Land
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	
1–29,999	11.6	5.9	47.3	53	41.1
30,000–59,999	11.9	1.7	54.9	65	33.2
60,000–179,999	14.1	1.1	49.2	62.2	36.8
180,000+	2	0	45.1	47.1	52.9
Total	11.6	3.7	49.5	57.5	38.8

Source: USDA NASS, 1999c.

Table 4-60. Frequency of Disposal Methods for Dead Layers for All Facilities.

Method of Disposal	Farm Sites		Dead Hens	
	Percent	Std Error	Percent	Std Error
Composting	15.0	(3.5)	11.7	(4.1)
Incineration	9.0	(2.9)	10.4	(4.5)
Covered deep pit	32.0	(5.8)	17.9	(4.3)
Rendering	32.0	(4.9)	41.4	(8.6)
Other	16.1	(3.6)	18.6	(5.4)
Total	--		100.0	

Source: USDA APHIS, 2000b.

Table 4-61. Frequency of Disposal Methods for Dead Layers for Facilities With <100,000 Birds.

Method of Disposal	Farm Sites		Dead Hens	
	Percent	Std Error	Percent	Std Error
Composting	13.9	4.7	13.4	7.5
Incineration	9.3	4.2	19.8	9.8
Covered deep pit	45.6	7.2	36.4	8.3
Rendering	21.1	4.5	19.7	6.0
Other	14.0	4.7	10.7	3.8
Total	--	--	100.0	--

Source: USDA NAHMS, 2000.

Table 4-62. Frequency of Disposal Methods for Dead Layers for Facilities With ≥ 100,000 Birds.

Method of Disposal	Farm Sites		Dead Hens	
	Percent	Std Error	Percent	Std Error
Composting	16.8	4.6	10.6	4.4
Incineration	8.7	3.3	4.6	2.5
Covered deep pit	9.1	2.2	6.5	2.5
Rendering	50.2	7.2	54.8	10.9
Other	19.7	5.8	23.5	8.7
Total	--	--	100.0	--

Source: USDA NAHMS, 2000.

4.2.3 Turkey Sector

This section describes the following aspects of the turkey industry:

- 4.2.3.1: Distribution of the turkey industry by size and region
- 4.2.3.2: Production cycles of turkeys
- 4.2.3.3: Turkey facility types and management
- 4.2.3.4: Turkey waste management practices
- 4.2.3.5: Pollution reduction
- 4.2.3.6: Waste disposal

National Overview

Turkey production has increased steadily over the past 2 decades and, as in the other poultry sectors, there has been a shift in production to fewer but larger operations. Between 1982 and 1997, almost 21 percent of the turkey operations went out of business (USDA NASS, 1998b). As shown in Table 4-63, the number of turkey operations decreased from 12,708 operations in 1992 to 12,207 operations in 1997, a 4 percent decrease. The number of turkeys produced rose approximately 10 percent between 1992 and 1997. The number of hens held for breeding, however, decreased by almost 6 percent during the same period.

As in the broiler industry, most turkeys are produced under contract production arrangements. For each contract arrangement, an integrator company provides the birds, feed, medicines, bird transport, and technical help. The contract producer provides the production facilities and labor to grow the birds from hatchlings to market-age birds. In return, the contract producer receives a guaranteed price, which may be adjusted up or down based on the performance of the birds compared with that of other flocks produced or processed by the company during the same span of time. Some turkeys are raised by independent turkey producers. Even under this type of production, however, the independent producer may arrange for feed, poults, medical care, and possibly processing, through contracts. Finally, some turkeys are produced on farms owned by the integrator company. The integrator company may also be the company that processes the birds; however, some turkey integrators provide all services except the processing, which the integrator arranges with a processing company.

Table 4-63. Turkey Operations in 1997, 1992, 1987, and 1982 With Inventories of Turkeys for Slaughter and Hens for Breeding.

Total Farms With	1997		1992		1987		1982	
	Ops	Production	Ops	Production	Ops	Production	Ops	Production
Turkeys	6,031	307,586,680	6,257	279,230,136	7,347	243,336,202	7,498	172,034,935
Turkeys sold for slaughter	5,429	299,488,350	5,658	272,831,801	6,813	238,176,199	6,838	167,540,306
Turkey hens kept for breeding	747	8,098,330	793	6,398,335	761	5,160,003	1,040	4,494,629

Source: USDA NASS, 1998b.

4.2.3.1 Distribution of Turkey Operations by Size and Region

EPA's 1974 CAFO Effluent Limitations Guidelines and Standards generally apply to turkey operations with more than 55,000 birds. (See Chapter 2 for the definition of a CAFO, and Chapter 5 for a discussion of the basis for revisions to the poultry subcategories.) Where numbers of birds are presented, all birds regardless of age (e.g., poult, laying age, or pullet) or function (i.e., breeder, layer, meat-type birds) are included unless otherwise indicated in the text.

The consolidation of the turkey industry has mirrored that of other livestock industries. The number of turkey farms with fewer than 30,000 birds decreased from 5,113 in 1987 to only 3,378 in 1997 (USDA NASS, 1999b). Concurrently, the number of operations with more than 60,000 birds increased 26 percent from 1232 in 1987 to 1671 in 1997. Although these changes are not as dramatic as those for the swine or broiler industry, they are indicative of an industry that is undergoing a steady transformation into one dominated by large integrated operations.

Table 4-64 presents the number of turkey operations in 1997 by size and region. Table 4-65 presents the distribution of turkey production by size of operation and region. It is important to note that the 369 largest operations (2.7 percent) had 43.6 percent of the total turkey count. These tables reflect the use of 2.5 turns (flocks) per year. USDA NASS performed an analysis for EPA to estimate how variations in the estimated of number of turns per year would change the number of potential CAFOs (operations with more than 55,000 birds). This analysis showed that there would be only minor changes to the estimated number of CAFOs if the estimated number of turns was adjusted to two or three turns.

State-level data from the 1997 Census of Agriculture (USDA NASS, 1999b) indicate that states in the Midwest and Mid-Atlantic Regions account for more than 70 percent of all turkeys produced. Key production states (determined by number of turkeys produced) are North Carolina, Minnesota, Virginia, Arkansas, California, and Missouri. Other states with significant production include Indiana, South Carolina, Texas, Pennsylvania, and Iowa. Table 4-66 presents the number of turkey facilities and total USDA-based AUs using the 1997 Census of Agriculture (USDA NRCS, 2002).

Table 4-64. Number of Turkey Operations in 1997 by Region and Operation Size.

Region [a]	Number of Turkey Operations by Size (Operation Size Presented by Number of Birds Spot Capacity)				
	>0–16,500	>16,500–38,500	>38,500–55,000	>55,000	Total
Central	2,301	54	19	34	2,408
Mid-Atlantic	3,265	597	143	83	4,088
Midwest	4,016	493	121	142	4,772
Other	2,035	222	83	110	2,450
National	11,617	1,366	366	369	13,718

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Other = WA, OR, CA, AK, HI, AR, LA, MS, AL, GA, SC, FL.
Source: USDA NASS, 1999c.

Table 4-65. Distribution of Turkeys in 1997 by Region and Operation Size.

Region [a]	Percentage of Total Turkey Counts by Operation Size (Operation Size Presented by Number of Birds Spot Capacity)				
	>0–16,500	>16,500–38,500	>38,500–55,000	>55,000	Total
Central	0.64	1.22	0.80	5.20	7.85
Mid-Atlantic	4.93	13.18	5.73	7.15	30.99
Midwest	4.38	10.62	4.88	19.94	39.82
Other	1.48	5.18	3.35	11.34	21.34
National	11.43	30.20	14.75	43.62	100.00

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Other = WA, OR, CA, AK, HI, AR, LA, MS, AL, GA, SC, FL.
Source: USDA NASS 1999c.

Table 4-66. Turkey Facility Demographics from the 1997 Census of Agriculture Database.

Size Class (EPA AUs)	Number of Operations	Total USDA AUs	Size Class Interval (Number of Head)	
			Lower	Upper
300–500	875	360,475	16,500	27,499
500–750	478	306,632	27,500	41,249
750–1000	262	230,628	41,250	54,999
1000+	388	915,367	55,000	up
Total	2,003	1,813,102		

Source: USDA NRCS, 2002.

4.2.3.2 Production Cycles of Turkeys

The growth of a turkey is commonly divided into two phases: brooding and grow-out. The brooding phase is the period of the poult's life extending from 1 day to about 6 to 8 weeks. During this time, the poults are unable to maintain a constant body temperature and need supplemental heat. Brooder stoves are used to keep the ambient temperature at 90 to 95 °F when the poults arrive; thereafter, the producer decreases the temperature by 5 °F for the next 3 weeks until the temperature reaches 75 °F. Poults are extremely susceptible to disease and are typically administered special starter feeds containing antibiotics and a high percentage of protein. One difference between turkeys and broilers is that feeding strategies, such as the use of phytase to reduce P content in waste, are not employed with turkeys through the entire life cycle because phytase is thought by some to inhibit bone development in poults. As with the broiler industry, further research in diet, nutrition, and the complex relationships between calcium, vitamins, and P may overcome this limitation.

The grow-out phase is the period in a turkey's life between the brooding phase and the market or breeding phase. Depending on the sex of the birds, the grow-out phase typically lasts up to 14 weeks. Modern turkeys grow rapidly. A tom (male) poult weighs about ¼ pound at birth; at 22 weeks it weighs almost 37 pounds. Hens (females) are usually grown for 14 to 16 weeks and toms from 17 to 21 weeks before being marketed. Most operators start fewer toms than hens in a given house to allow more space for the larger birds.

4.2.3.3 Turkey Facility Types and Management

Market and breeder turkeys are raised in similar housing systems. Typically, young turkey poults are delivered to the operation on the day of, or the day after, hatching. The poults are placed in barns called brooder houses. The brooder houses for turkeys are usually as wide as broiler and pullet houses but are usually only 300 to 400 feet long. The houses have an impermeable floor surface made of either clay or cement. The floors are then covered with 3 to 4 inches of bedding.

As with broilers, ventilation is usually provided by a negative-pressure system, with exhaust fans drawing air out of the house and fresh air returning through ventilation ducts around the perimeter of the roof. Some turkey houses have side curtains that can be retracted to allow diffusion of air. More advanced ventilation systems use exhaust fans controlled by a thermostat and timer. Brooding heaters are normally present in one-third to one-half of the house, for the early stages of development. As the poults get older, they are usually released into the other two-thirds or half of the house and remain there until they are of market age. In some operations the poults are moved to a specially designed grower house, where they stay until they are of market age. Some operations will move poults to range.

The construction of the housing facilities varies by region and depends on climatic conditions and production practices. Generally, in the southern and southeastern U.S. the houses are more open. The side walls of the houses are 6 to 8 feet high, with a 4- to 5-foot-wide opening covered by wires and curtains. Since moderate winters are normal in the South and Southeast, the curtains can contain the heat necessary to maintain a reasonable temperature within the commercial poultry houses. In the northern and central states, most houses have solid side walls and contain considerable insulation to combat the colder temperatures. These houses rely on exhaust fans or moveable solid side walls during the hot summer days to diminish the effects of heat stress on the birds.

These traditional systems are called two-age farms because two ages of birds can be on the farm at one time. Once the poults have been moved to the grower barn, the brooder house is totally cleaned out for another group of poults. This cleanup includes removal of all litter used during the brooding phase. The second group of poults occupies the brooder house while the first group of birds is still in the grower barn. Operations in the Shenandoah Valley area of Virginia and West Virginia are known to use a modification of the typical two-age management system. Under this system the houses are longer. Poults may occupy one end of the house, while an older group is being grown out at the other end. The birds do not have to be moved as often under this system.

The two-age farm system has served the turkey industry for more than 20 years. Currently, however, there are efforts to modify this system because of morbidity and mortality. The modifications are directed at raising older birds in facilities removed from the poults. This approach provides an opportunity to break any disease cycle that might put the birds, especially the younger ones, at increased risk (USEPA, 1998).

4.2.3.4 Turkey Waste Management Practices

For brooder facilities, the litter is removed after every flock of brooded poults. This practice is necessary to provide the next group of poults with clean bedding to achieve the lowest possible risk of disease exposure. Poult litter may be composted between flocks to control pathogens and then reused in the grow-out houses. For grower systems, the litter is removed once a year. In between flocks, cake is removed and the old litter may be top-dressed with a thin layer of new bedding. For single-age farms, the bedding in the brooding section is moved to the grower section. New bedding is put in the brooder section, and the facilities are prepared for the next group of poults.

4.2.3.5 Pollution Reduction

New technologies in drinking water systems result in less spillage and ensure that turkey litter stays drier. Feeding strategies will also reduce the quantity of waste generated by ensuring that turkeys do not receive more feed than required for optimal growth. State regulations have also driven many turkey operations to handle mortalities in ways other than burial such as rendering and composting, which are on the rise (see Section 4.2.3.6).

Nipple water delivery systems reduce the amount of wasted water and are healthier for the animals. Trough or bell type watering devices allow the animal to spill water and add contaminants to the standing water. Nipple water systems deliver water only when the animal is sucking on the nipple. Watering systems may also use water pressure sensors and automatic shutoff valves to reduce water spillage. The sensor will detect a sustained drop in water pressure resulting from a break in the water line. The sensor will then stop the water flow to the broken line and an alarm will sound. The operator can then fix the broken line and restore water to the animals with minimal water spillage.

Feeding strategies can be used to reduce the quantity of nutrients in the excreta. Dietary strategies designed to reduce N and P include enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility, more precise diet formulation, and improved quality control. Although N and P are currently the focus of attention, these strategies also have the potential to decrease other nutrients. There is debate on the impacts of phytase feed supplements for turkey poults concerning bone growth and bone development. Phytase additions are expected to achieve a reduction in P excretion of 20 to 60 percent depending on the P form and concentration in the diet (NCSU, 1998b). Protein content, calcium, other mineral content, vitamin B, as well as other factors identified in the literature influence the effectiveness of phytase use in feed. Additional information on feeding strategies for turkeys can be found in Chapter 8.

4.2.3.6 Waste Disposal

Practices for the disposal of turkey litter are similar to those for other poultry litter. After removal from the housing facilities, waste can be directly applied to the land (if available), stored prior to final disposal, or pelletized and bagged for use as commercial fertilizer. Waste storage, application of litter, and other poultry waste management practices are discussed in detail in Section 4.2.1.4. The percentage of turkey operations with and without enough land for application of manure on a N- and P- basis and operations with no land are shown in Table 4-67. The facilities that have no land were determined by running queries of the USDA 1997 Census of Agriculture data to identify facilities that did not grow any of the 24 major crops grown in the U.S.

Disposal of dead birds can be handled through composting, incineration, burial in deep pits, rendering, and disposal in landfills. Technical information on practices for the disposal of dead animals is presented in Chapter 8; however, there is little information available on the relative use of these practices within the turkey industry.

Table 4-67. Percentage of Turkey Dominated Operations With Sufficient, Insufficient, and No Land for Agronomic Application of Generated Manure.

Capacity (Number of Birds)	Sufficient Land:		Insufficient Land:		No Land
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	
1–16,499	15.6	5.9	52.5	62.2	31.8
16,500–38,499	6.8	0.3	65.4	71.9	27.9
38,500–54,999	4.1	0	65.5	69.9	30.4
55,000+	3	0	58.1	61.1	38.9
Total	9.4	2.4	59.5	66.5	31.1

Source: USDA NASS, 1999c.

4.2.4 Duck Sector

The specialized husbandry for ducks has limited expansion due to the fact that duck production "know-how" has tended to remain within families or in a limited number of large companies (Scott and Dean, 1991). Duck farms must also be located in close proximity to processing plants specially adapted to handle ducks. These factors, as well as the specialized market for duck meat in the United States, have played an important role in limiting the expansion of the duck industry.

4.2.4.1 Distribution of the Duck Industry by Size and Region

The 1992 Census of Agriculture reported an inventory of nearly 3.5 million ducks in the United States (Table 4-68). This represented more than a 26 percent drop from 1987. The number of farms dropped from about 25,000 operations in 1987 to about 16,000 operations in 1992.

Table 4-68. Duck Inventory and Sales.

Category		1987	1992
Total ducks	Inventory	4,538,716	3,339,659
	Number of farms	24,664	16,312
Duck sales	Sold	26,041,817	16,391,031
	Number of farms	4,262	3,038

Source: 1992 Census of Agriculture.

Ducks were first produced commercially in the United States on Long Island, New York. The major producers are now located in the Midwest and California. Indiana produces the majority of commercial ducks, followed by Wisconsin, California, New York, and Pennsylvania (Table 4-69).

Table 4-69. 1992 Regional Distribution of Commercial Ducks.

State	Inventory	Farms
Indiana	1,170,154	388
Wisconsin	695,109	653
California	526,610	806
New York	312,523	524
Pennsylvania	152,855	653

Source: 1992 Census of Agriculture.

Based on data provided to EPA by Maple Leaf Farms (2001), most duck operations tend to be relatively small. Table 4-70 presents the number of operations by size class based on data from five of the seven companies that raise ducks commercially.

Table 4-70. Distribution of Commercial Duck Operations by Capacity.

Number of Facilities	Capacity per Site
48	2,500–3,000
65	4,000–10,000
33	11,000–15,000
31	16,000–25,000
7	26,000–30,000
11	31,000–50,000
2	90,000
3	117,000
2	144,000
2	165,000
1	190,000

Source: Maple Leaf Farms, 2001.

4.3 Dairy Industry

Dairy AFOs include facilities that confine dairy cattle for feeding or maintenance for at least 45 days in any 12-month period, and do not have significant vegetation in the area of confinement. Dairies may also perform other animal and agricultural operations that are not covered by the existing dairy effluent guidelines including grazing, milk processing, and crop farming.

- Section 4.3.1: The distribution of dairy operations by size of operation and region in 1997
- Section 4.3.2: Dairy production cycles
- Section 4.3.3: Stand-alone heifer raising operations
- Section 4.3.4: Dairy facility management practices
- Section 4.3.5: Dairy waste management practices
- Section 4.3.6 lists the references used in this section

4.3.1 Distribution of Dairy Operations by Size and Region

Current effluent limitations guidelines and standards apply to dairy operations with 700 or more mature dairy cattle (both lactating and dry cows), where the animals are fed at the place of confinement and crop or forage growth or production is not sustained in the confinement area.

Information presented in this section comes from USDA, NASS 1997 Census of Agriculture data, and from site visits and trade associations. The 1993 to 1997 NASS reports on dairy operations present the number of dairies by size class. Dairy operations with more than 200 mature dairy cattle are grouped in one size class; therefore, an analysis of dairy operations that fall under the current effluent guidelines regulations (i.e., those with more than 700 milking cows) cannot be completed with NASS data alone. Data from the 1997 Census of Agriculture provide some additional information on medium and large (more than 200 milking cows) dairy operations. Although the NASS and Census data do not match exactly, EPA has found that there is generally a good correlation between the two datasets. EPA used the Census data to estimate farm counts.

From 1988 to 1997, the number of dairies and milking cows in the U.S. decreased while total milk production increased. Improved feeding, animal health, and dairy management practices have allowed the dairy industry to continue to produce more milk each year with fewer milking cattle. Since 1988, the total number of milking cows has decreased by 10 percent and the total number of dairy operations has decreased by 43 percent, indicating a general trend toward consolidation (USDA NASS, 1995b; 1999d).

Between 1993 and 1997, the number of operations with fewer than 200 milking cows decreased, while the number of operations with 200 or more milking cows increased. Both NASS and the 1997 Census of Agriculture have collected data that quantify the changes by size class. Based on the NASS data, the number of operations with 200 or more milking cows increased by almost 7 percent between 1993 and 1997, while all smaller size classes decreased in numbers of operations. Table 4-71 shows the estimated distribution of dairy operations by size and region in 1997, and Table 4-72 shows the total number of milk cows and average cow herd size by size class in 1997. EPA derived the data in these tables from the Census data (ERG, 2000b).

According to Census of Agriculture data, of the 116,874 dairy operations across all size groups in 1997, Wisconsin had the most with 22,576 (19 percent), followed by Pennsylvania with 10,920 (9 percent), Minnesota with 9,603 (8 percent), and New York with 8,732 (7 percent). Table 4-73 presents the number of dairies by top-producing states for the following size groups:

- 1 to 199 milk cows
- 200 to 349 milk cows
- 350 to 700 milk cows
- more than 700 milk cows

Of the large dairies (more than 700 milking cows), California has the most operations (46 percent), and of the medium dairies (200 to 700 milking cows), California, New York, Wisconsin, and Texas have the most operations.

Table 4-74 shows the annual milk production in 1997 for the top-producing states. Although California has only 2,650 dairy farms in all, it is the largest milk-producing state in the U.S., according to NASS data and data received from the National Milk Producers Federation (National Milk Producers, 1999; USDA NASS, 1999d).

Table 4-71. Distribution of Dairy Operations by Region and Operation Size in 1997.

Region[a]	Number of Operations				
	0-199 Milk Cows	200-349 Milk Cows	350-700 Milk Cows	> 700 Milk Cows	Total
Central	9,685	593	433	404	11,115
Mid-Atlantic	32,490	870	487	81	33,928
Midwest	59,685	943	497	90	61,215
Pacific	2,875	722	725	786	5,108
South	5,001	253	170	84	5,508
National	109,736	3,381	2,312	1,445	116,874

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.

Table 4-72. Total Milk Cows by Size of Operation in 1997.

Size Class	Number of Operations	Total Number of Milk Cows	Average Milk Cow Herd Size
0–199 Milk Cows	109,736	5,186,000	47
200–349 Milk Cows	3,381[a]	795,000	235
350–700 Milk Cows	2,312[a,b]	1,064,000	460
> 700 Milk Cows	1,445[b]	2,050,455	1,419
Total	116,874	9,095,455	78

[a] Estimated value. Published Census of Agriculture data show 4,881 dairies with 200-499 milk cows. Assumes approximately 70 percent have 200-349 milk cows and 30 percent have 350-500 milk cows.
[b] Estimated value. Published Census of Agriculture data show 1,379 dairies with 500-999 milk cows. Assumes approximately 60 percent have 500-699 milk cows and the remainder have 700-1,000 milk cows.

Table 4-73. Number of Dairies by Size and State in 1997.

Location	Size Class				Total
	1-199 Milk Cows	200-349 Milk Cows	350-700 Milk Cows	>700 Milk Cows	
California	969	471	547	663	2,650
Florida	495	51	58	62	666
Idaho	1,105	119	90	90	1,404
Michigan	3,743	144	81	22	3,990
Minnesota	9,379	135	75	14	9,603
New York	8,162	319	194	57	8,732
Pennsylvania	10,693	148	71	8	10,920
Texas	3,562	266	188	97	4,113
Washington	925	175	130	72	1,302
Wisconsin	22,041	333	171	31	22,576
Total United States	109,736	3,381	2,312	1,445	116,874

Table 4-74. Milk Production by State in 1997

Location	Total Milk Production (million pounds)	Milk Produced Per Cow (pounds)
California	27,582	19,829
Florida	2,476	15,475
Idaho	5,193	19,092
Michigan	5,410	17,680
Minnesota	9,210	16,186
New York	11,530	16,495
Pennsylvania	10,662	16,951
Texas	5,768	15,259
Washington	5,305	20,968
Wisconsin	22,368	16,057
Total United States	156,091	16,871

4.3.2 Dairy Production Cycles

The primary function of a dairy is the production of milk, which requires a herd of mature dairy cows that are lactating. In order to produce milk, the cows must be bred and give birth. Therefore, a dairy operation may have several types of animal groups present, including

- Calves (0 to 5 months)
- Heifers (6 to 24 months)
- Cows that are close to calving (close-up cows)
- Lactating dairy cows
- Dry cows
- Bulls

Most dairies operate by physically separating and handling their animals in groups according to age, size, milking status, or special management needs. This separation allows each group to be treated according to its needs. Section 4.3.2.1 presents a description of the typical mature dairy herd, and Section 4.3.2.2 discusses the immature animal groups that may also be present at the dairy.

4.3.2.1 *Milk Herd*

The dairy milk herd is made up of mature dairy cows that have calved at least once. These mature cows are either lactating or “dry” (not currently producing milk). After a cow has calved, the milk she initially produces (called “colostrum”) contains higher amounts of protein, fat, minerals, and vitamins than normal milk. The colostrum is usually collected and fed to the calves. After about 4 days, the milk returns to normal and the cow rejoins the lactating cow herd.

After being milked for about 10 to 12 months after calving, the cows go through a dry period. These dry periods allow the cow to regain body condition and the milk secretory tissue in the udder to regenerate. The dairy industry has reported an average of 60.5 days of dry period per cow (USDA APHIS, 1996a).

Periodically, all dairies must cull certain cows that are no longer producing enough milk for that dairy. Cows are most often culled for the following reasons: reproductive problems, udder or mastitis problems, poor production for other reasons, lameness or injury, disease, or aggressiveness or belligerence. In 1995, an average of 24 percent of the herd was culled from all size operations (USDA APHIS, 1996a). Dairies in high milk-producing regions (e.g., California) have reported during site visits cull rates of up to 40 percent.

Some dairies decide when a cow is to be culled by determining a milk break-even level (pounds of milk per cow per day). Approximately 28 percent of dairies use this practice and reported an average milk break-even level of approximately 33 pounds per cow per day. The milk break-even levels ranged from 32.5 pounds per cow per day at small dairies (less than 100 head) up to 36.5 pounds per cow per day at larger dairies (200 or more head) (USDA APHIS, 1996a).

Nearly all culled cows (approximately 96 percent) are sent away for slaughter. Approximately 74 percent are sent to a market, auction, or the stockyards. Others (21 percent) are sold directly to a packer or slaughter plant, and the remaining 1 percent are sent elsewhere. Cows that are not sold for slaughter (approximately 4 percent) are usually sent to another dairy operation (USDA APHIS, 1996a).

4.3.2.2 Calves, Heifers, and Bulls

The immature animals at a dairy are heifers and calves. Typically, according to Census of Agriculture data, for dairies greater than 200 milking cows, the number of calves and heifers on site equals approximately 60 percent of the mature dairy (milking) cows. EPA assumes that there are an equal number of calves and heifers on site (30 percent each). Calves are considered to be heifers between the age of 6 months and the time of their first calving (between 25 and 28 months of age) (USDA APHIS, 1996a). Heifers tend to be handled in larger groups, and often they are divided for management purposes into a breeding group and a bred heifer group (Bickert et al., 1997). Heifers and cows are often bred artificially. They may be placed daily in stanchions for estrus (heat) detection with the aid of tail chalk or heatmount detectors. Heifers and cows in pastures or in pens without stanchions may be heat detected by observation and then bred in a restraining chute. Heifers that do not conceive after attempts with artificial insemination are often placed in groups with a breeding-age bull to allow natural service of those animals. Approximately 45 percent of dairy operations do not keep bulls on site, and approximately 35 percent of dairy operations keep one bull on site for breeding (USDA APHIS, 1996a).

Cows and heifers that are at the end of their pregnancy are considered to be “periparturient” or “close-up cows.” About 2 weeks before she is due, the heifer or cow is moved from her regular herd into a smaller pen or area where she can be observed and managed more closely. When the cow is very near to calving, she is often moved to an isolated maternity pen. Shortly after birth, the calves are separated from their mothers and are generally kept isolated from other calves or in small groups until they are about 2 months old. After the calves are weaned from milk (at about 3 months of age), they are usually moved from their individual pen or small group into larger groups of calves of similar age. Female calves are raised (as replacements) to be dairy cows at the dairy or sent to an off-site calf operation. Female calves (heifers) may also be raised as beef cattle. Male calves that are not used for breeding are either raised as beef cattle (see Section 4.4) or as veal calves (see Section 4.4.5).

4.3.3 Stand-Alone Heifer Raising Operations

Stand-alone, heifer-raising operations provide replacement heifer services to dairies. It has been estimated that 10 percent to 15 percent of all dairy heifers are raised by stand-alone heifer raisers (Gardner and Jordan 1999, personal communication). These heifer-raising operations often contract with specific dairies to raise those dairies’ heifers for a specified period of time, and many also provide replacement heifers to any dairy needing additional cows. The age at which dairies send their animals to heifer-raising operations varies significantly (USDA APHIS, 1996a). Table 4-75 shows the percentage of dairies that use heifer- raising operations, the median age at which heifers are received by these facilities, and the amount of time that the heifers remain at these facilities.

Table 4-75. Characteristics of Heifer-Raising Operations.

Age of Heifer	Percentage of Dairies Using Heifer Raisers	Median Age of Heifer	Time That Heifers Remain on Site
0–4 months	41.2	1 week	12 months
4 months–breeding	47.1	6 months	15 months
Breeding–first calving	11.8	Breeding age	9 months

There are a number of advantages for dairies to use heifer-raising operations. Specifically, dairies using heifer-raising operations could expand their herd size by 25 percent or more within existing facilities, specialize in milking cows or raising crops, and obtain healthier and better producing milking cows. In addition, raising calves off the farm may reduce risks of transmission of diseases for which older cows are the main source of infection. Some disadvantages include an increased risk of introducing disease into the herd and a shortage of replacement heifers if the raiser’s breeding results are less than adequate. Also, the costs associated with raising the heifers could run higher than what the dairies are paying if labor, feed, and other resources are not allocated profitably (USDA APHIS, 1993).

Custom raising of dairy heifers is becoming more common as dairy herds increase in size and dairy farmers do not have facilities to raise all their heifers (Noyes, 1999). Throughout the U.S., the level of specialization is increasing for dairy farms; in fact, some large dairy farms raise no crops, purchase all of their feedstuffs, or do not raise replacement heifers for the milking herd. Herd owners for these dairies must use other strategies to obtain herd replacements. As a result, enterprises that specialize in raising dairy calves and heifers are found in many western states (Faust, 2000). It is also believed that the poor beef market in the last few years has caused some beef feedlots to add pens of dairy heifers or switch to heifers entirely (Cady 2000, personal communication).

Stand-alone heifer operations use two primary methods for raising their animals. One method is to raise heifers on pasture, usually in moderate to warm climates where grazing land is available. The second is to raise heifers in confinement (on dry lots, as for beef cattle). Confinement is commonly used at operations in colder climates or areas without sufficient grazing land (Jordan 1999, personal communication).

The actual number of stand-alone, heifer-raising operations, as well as the number of confined operations, is unknown. However, based on information supplied by industry representatives (e.g., Professional Dairy Heifer Growers Association), EPA estimates that there may be 5,000 heifer-raising operations in the United States; 300 to 400 operations with more than 1,000 head, 750 to 1,000 with more than 500 head, and 4,000 with fewer than 500 head (most of them with around 50 head) (Cady 2000, personal communication). Most large dairy heifer-raising operations (those with more than 1,000 head) are confinement-based while smaller operations are often pasture-based (see above). Table 4-76 shows EPA's estimate of confined heifer-raising operations by size and region (ERG, 2000a; 2000b).

Table 4-76. Distribution of Confined Heifer-Raising Operations by Size and Region in 1997.

Region[a]	Number of Operations			
	300–499 Heifers	500–1,000 Heifers	> 1,000 Heifers	Total
Central	25	250	180	455
Mid-Atlantic	0	0	0	0
Midwest	200	100	0	300
Pacific	25	150	120	295
South	0	0	0	0
National	250	500	300	1,050

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.

The sizes of heifer-raising operations range from 50 head (typical "mom and pop" operations) to 25,000 head, and tend to vary geographically. The average size of a heifer operation located west of the Mississippi River is 1,000 to 5,000 head, while the average size in the upper Midwest, Northeast, and South is 50 to 200 head. Nationally, the median size of a dairy heifer-raising operation is approximately 200 head (Cady 2000, personal communication).

Stand-alone, heifer-raising operations are found nationwide with more heifer raisers located where cows are concentrated and in areas where the dairy industry is evolving toward more specialization (Bocher, 2000). EPA estimates that, of the number of heifers raised at stand-alone heifer operations, approximately 70 percent are managed in the West, 20 percent are managed in the South/Southeast, 7 percent are managed in the Northeast, and approximately 3 percent are managed in the upper Midwest. The upper Midwest is also believed to be the single largest growing region with respect to small heifer operations (see above).

4.3.4 Dairy Facility Management

This section describes factors that affect the facility management of a dairy operation including housing by type of animal, use of housing in the industry, flooring and bedding type, feeding and watering practices, milking operations, and rotational grazing.

4.3.4.1 Housing Practices

The purpose of dairy housing is to provide the animals with a dry and comfortable shelter, while providing the workers with a safe and efficient working environment. Optimal housing facilities accommodate flexibility in management styles and routines, enhance the quality of milk production, and allow for the protection of the environment, yet remain cost-effective (Adams et. al., 1995). The following subsections describe, housing for each type of animal group according to age, from milking cows to calves.

Milking Cows

The primary goal in housing lactating dairy cows is to provide an optimum environment for the comfort, proper nutrition, and health of the lactating cow for maximum milk productivity. It is also designed to allow for efficient milking processes. The most common types of lactating cow housing include freestalls, dry lots, tie stalls/stanchions, pastures, and combinations of these. The types of housing used for dry cows include loose housing and freestalls (Stull et al., 1998). These housing types are described in detail below.

- Freestalls - This type of housing provides individual resting areas for cows in freestalls or cubicles, which helps to orient the cow for manure handling. Freestalls provide the cows with a dry and comfortable place to rest and feed. The cows are not restrained in the freestalls and are allowed to roam on concrete alleys to feeding and watering areas. Manure collects in the travel alleys and is typically removed with a tractor or mechanical alley-scraper, by flushing with water, or through slotted openings in the floor (refer to Section 4.3.5 for a more detailed description of waste handling) (Adams, 1995). Recently, there has been a trend toward using freestalls to house dairy cows and many loose housing units have been converted to freestalls (Bickert, 1997).

- Dry lots - Dry lots are outside pens that allow the animals some exercise, but do not generally allow them to graze. The use of dry lots depends upon the farm layout, availability of land, and weather conditions. Also, milking cows are not likely to spend their entire time on a dry lot, as they need to be milked at least twice a day at a tiestall or in a milking parlor.
- Tie Stalls/Stanchions - Tie stalls or stanchions confine the cow to a single stall where she rests, feeds, and is often milked. The tie stall prevents the cow from moving out of her stall with a chained collar, but allows her enough freedom to get up and lie down without interfering with her neighbors. Tie stalls are also designed to allow the cows access to feed and fresh water in a natural grazing position (Adams, 1995). Cows that are housed in tie stalls may be let out at certain times each day (e.g., between milkings) to graze in a pasture. Tie stalls are the most predominant type of dairy cow housing for lactating cows (USDA APHIS, 1996a); however, this is true of older, smaller dairies. The current preference, particularly for medium and large dairies, is freestalls.
- Loose Housing - Barns, shades, and corrals are considered loose housing. The design of these facilities depends upon the number of cows, climate, and waste-handling techniques. Overcrowding in this type of housing can lead to health problems and may reduce access to feed, water, or resting areas for some subordinate animals. Loose housing that is hard-surfaced typically has at least a 4 percent slope, depending on soil type and rainfall (Stull et al., 1998).
- Pastures - Depending on the farm layout, availability of pastureland, and weather conditions, heifers or cows may spend part or most of their day in a pasture. Milking cows do not spend all of their day outside, since they are milked at least twice per day in a parlor or from a tie stall. On some farms, the cows may be contained outdoors during the day, but are housed in a tie stall or freestall overnight.

Close-Up Cows

The primary objective in housing for cows that are close to calving is to minimize disease and stress to both the cow and calf. Sod pastures are often used in warmer climates or during the summer; however, the pastures can become too muddy in the winter in some climates, requiring additional worker time to keep watch over the cows. Alternatively, the cows may be housed in multiple-animal or individual pens prior to calving. About 2 weeks before the cow is due (i.e., 2 weeks prior to freshening), she is moved to a close-up pen. The cow density in close-up pens is about one-half the density in lactating cow pens to allow the calving cows some space to segregate themselves from other cows if they go into labor, although calving in close-up pens is usually avoided.

When birth is very near, cows are moved to a maternity area for calving. If the climate is sufficiently mild, pastures can be used for a maternity area; otherwise, small individual pens are used. Pens are usually designed to allow at least 100 square feet per cow and to provide a well-ventilated area that is not drafty (Stull et al., 1998).

Approximately 45 percent of all dairy farms have maternity housing apart from the housing used for the lactating cows. This feature is more prevalent in larger farms than in smaller farms. Approximately 87 percent of farms with 200 or more cows have separate maternity housing (USDA APHIS, 1996a).

Bulls

When bulls are housed on site at a dairy operation, they are typically kept in a pen or on pasture. If possible, bulls are penned individually with sufficient space for special care and to reduce fighting. When a bull is grazed on pasture, an electric fence is typically used to prevent the bull from escaping and causing danger (Bodman et al., 1987).

Heifers

According to information collected during site visits, the majority of heifers are kept on dry lots either on or off site. Heifers may also be kept in a pasture, in which the herd is allowed to move about freely and to graze. Pastures may be provided with an appropriate shelter. Heifer housing is typically designed for ease in:

- Animal handling for treatment (e.g., vaccinations, dehorning, pregnancy checks)
- Animal breeding
- Animal observation
- Convenient feeding, bedding, and manure handling (Bickert et al., 1997)

Weaned Calves (Transition Housing)

After calves are weaned, they are usually moved from individual pens or small group pens into housing for larger numbers of calves. This change causes a number of stresses due to new social interactions with other calves, competition for feed and water, and new housing. Therefore, the housing is designed such that the workers can monitor each calf's adjustment into the social group. Transition housing is used for calves from weaning to about 5 months of age. The most common types of housing used for weaned calves are calf shelters or superhutches, transition barns, and calf barns (Bickert et al., 1997). These types of housing are described below.

- Superhutches - Superhutches are open-front, portable pens that provide a feeder, water trough, and shelter for 5 to 12 calves. Superhutches typically provide 25 to 30 square feet per calf and can be moved in a field, dry lot, or pasture as needed to provide calves with a clean surface.

- Transition Barns - A transition barn is composed of a series of pens for groups of six to eight calves of up to 6 months old. Some transition barns are designed such that the back and end walls may be open or covered, depending on the weather conditions.
- Calf Barns - A calf barn combines both individual calf pens and transition barns within one building. The pens can be designed to be easily dismantled for waste removal, to minimize calf contact, or to provide draft protection (Bickert et al., 1997).

Calves

Sickness and mortality rates are highest among calves under 2 months of age; therefore, the housing for this group typically minimizes environmental stress by protecting the calves against heat, wind, and rain. Common calf housing types include individual animal pens and hutches, which are described below.

- Individual Pens - Pens are sized to house animals individually and separate them from others. Individual pens make it easier to observe changes in behavior, feed consumption, and waste production, which can indicate sickness. Calves may be raised in 2- by 4- foot expanded metal or slatted wood, elevated pens; however, these pens provide little shelter from drafts and cold in the winter (Stull, et al., 1998). Individual pens can be used inside a barn to provide isolation for each calf. Pens are typically 4- by 7- feet and removable. Solid partitions between pens and beyond the front of the pen prevent nose-to-nose contact between the calves. A cover over the back half of the pen gives the calf additional protection, especially in drafty locations. Pens can be placed on a crushed rock base or a concrete floor to provide a base for bedding (Bickert et al., 1997).
- Hutches - Hutches are portable shelters typically made of wood, fiberglass, or polyethylene and are placed in outdoor areas. Hutches allow for complete separation of unweaned calves since one calf occupies each hutch. One end of the hutch is open and a wire fence may be provided around the hutch to allow the calf to move outside. Lightweight construction materials improve hutch mobility and also allow for easier cleaning. Hutches are typically 4 feet by 8 feet by 4 feet and may be placed inside a shed or structure to provide protection from cold weather and direct sunlight (Bickert et al., 1997).

Use of Housing in Industry

Table 4-77 summarizes the relative percentages of U.S. dairies reporting various types of housing for their animals (USDA APHIS, 1996a). These data were collected in 1996 for activities in 1995 by USDA NAHMS. Note that some operations may have reported more than one type of housing being used for a particular group. The NAHMS data did not include housing type for dry cows. It is expected that dry cows are typically housed similarly to lactating cows (Stull et al., 1998).

Multiple age groups may be housed within a single building that allows for each group to be managed separately. Larger farms tend to place their animals in more than one building (Bickert et al., 1997). Superhutches, transition barns, calf barns, and loose housing were not specifically addressed in the NAHMS study, but may be considered specific types of multiple animal pens.

Dairies predominantly use some sort of multiple animal area for unweaned calves, weaned calves, and heifers.

Table 4-77. Percentage of U.S. Dairies by Housing Type and Animal Group in 1995.

Housing Type	Unweaned Calves	Weaned Calves and Heifers	Lactating Cows	Periparturient Cows
Dry lot	9.1	38.1	47.2	28.9
Freestall	2.5	9.7	24.4	5.6
Hutch	32.5	NA	NA	NA
Individual animal area	29.7	6.6	2.3	38.3
Multiple animal area	40.0	73.9	17.9	26.3
Pasture	7.4	51.4	59.6	41.9
Tie stall/stanchion	10.5	11.5	61.4	26.3

NA = Not applicable.

4.3.4.2 *Flooring and Bedding*

The flooring and bedding used in housing provide physical comfort for the cow, as well as a clean, dry surface to reduce the incidence of mastitis and other diseases. Tables 4-78 and 4-79 summarize the various types of flooring and bedding, respectively, that are used for lactating cows, as reported by U.S. dairies in the NAHMS study (USDA APHIS, 1996b).

The most predominantly used flooring is smooth concrete, reported by over 40 percent of the dairies. Other fairly common flooring types include grooved and textured concrete. The less common flooring types that were reported include slatted concrete, dirt, and pastures (USDA APHIS, 1996b). The flooring design is important in loose housing to maintain secure footing for the animals, as well as facilitate waste removal. The surfaces typically contain scarified concrete areas around water troughs, feed bunks, and entrances. Both hard-surface and dirt lots are sloped to allow proper drainage of waste and rainfall (Stull et al., 1998).

Table 4-78. Types of Flooring for Lactating Cows.

Type of Flooring	Percentage of Dairies Reporting
Smooth concrete	41.6
Grooved concrete	27.2
Textured concrete	16.2
Pasture	6.9
Dirt	5.8
Other	1.5
Slatted concrete	0.8

Table 4-79. Types of Bedding for Lactating Cows.

Type of Bedding	Percentage of Dairies Reporting
Straw and/or hay	66.9
Wood products	27.9
Rubber mats	27.0
Corn cobs or stalks	12.8
Sand	11.2
Shredded newspaper	6.7
Mattresses	4.7
Other	3.7
Composted manure	2.4
Rubber tires	1.0

More than one bedding type may be reported by a single dairy. The most commonly used bedding is straw or hay, or a combination of the two, while other common bedding includes wood products and rubber mats. Less frequently used are rubber tires, composted manure, mattresses, shredded newspaper, sand, and corn cobs and stalks (each reported by less than 13 percent of the dairies) (USDA APHIS, 1996b).

4.3.4.3 *Feeding and Watering Practices*

Feeding and watering practices vary for each type of animal group at the dairy. Most dairies deliver feed several times each day to the cows, and provide a continuous water supply. The type of feed provided varies with the age of the animal and the level of milk production to be achieved.

Milking cows - At dairies, mature cows are fed several times a day. Lactating cows are provided a balanced ration of nutrients including energy, protein, fiber, vitamins, and minerals (NRC, 1989). Dairies with greater than 200 milking cows typically feed a total mixed ration. In addition, most dairies in the U.S. feed grains or roughages (e.g., hay) that were grown and raised on the farm. Over half of all U.S. dairies reported that they pastured their dairy cows for at least 3 months of the year. Almost half of these dairies reported that grazing provided at least 90 percent of the total roughage for the cows while they were pastured (USDA APHIS, 1996a).

A lactating dairy cow consumes about 5 gallons of water per gallon of milk produced daily (Stull et al., 1998). Temperature can affect water consumption; therefore, actual consumption may vary. The predominant method for providing water to cows is from a water trough where more than one cow can drink at a time. Other watering methods frequently reported by small dairies (less than 200 cows) include automatic waterers for use by either individual cows or by a group of cows, at which only one cow drinks at a time (USDA APHIS, 1996b).

Heifers - Rations are balanced so heifers raised on site reach a breeding weight of 750 to 800 pounds by 13 to 15 months of age. Heifers are fed high-forage rations between breeding and calving, and are usually given enough manger space for all heifers to eat simultaneously (Stull et al., 1998).

Cows within 10 to 16 days of calving are normally fed as a separate group. They may be fed a few pounds of a grain concentrate mix in addition to forages. This practice avoids a sudden shift from an all-forage ration to a ration with a high proportion of concentrates, which is typical of that fed to cows in early lactation. If a postpartum cow is fed a total mixed ration, she may be fed about 5 pounds of long-stemmed hay in the ration for at least 10 days after calving to stimulate feed intake.

Calves - Calves are initially fed colostrum, the milk that is produced by the cow just prior to and during the first few days after calving. Colostrum contains more protein (especially immunoglobulins), fat, minerals, and vitamins than the milk normally produced, and less lactose (USDA BAMN, 1997). When calves are about 5 days old, their feed is switched to fresh whole milk or a milk replacer. Milk replacers are powdered products that contain predominantly dry milk ingredients. These are mixed with water to provide the optimum nutrition for the calf (Stull et al., 1998).

Calves are then weaned from a milk replacer or milk-based diet to a forage or concentrate diet. Calves are offered a starter ration in addition to milk or milk replacer when they are approximately 1 week old. Calves will consume 1 to 1.5 pounds of starter ration per day at weaning time, usually when they are 2 to 3 months old (Stull et al., 1998).

Because calves require more water than they receive from milk or milk replacer, water is typically available to them at all times.

4.3.4.4 Milking Operations

Lactating cows require milking at least twice a day and are either milked in their tie stalls or are led into a separate milking parlor. The milking parlors are often used in the freestall type of housing. The milking center typically includes other types of auxiliary facilities such as a holding area, milk room, and treatment area (Bickert, 1997).

Milking Parlor - Milking parlors are separate facilities, apart from the lactating cow housing, where the cows are milked. Usually, groups of cows at similar stages of lactation are milked at a time. The parlor is designed to facilitate changing the groups of cows milked and the workers' access to the cows during milking. Often, the milking parlors are designed with a worker "pit" in the center of a room with the cows to be milked arranged around the pit at a height that allows the workers convenient access to the cows' udders.

The milking parlor is most often equipped with a pipeline system. The milk is collected from the cow through a device called a "milking claw" that attaches to each of her four teats. Each milking claw is connected to the pipeline and the milk is drawn from the cow, through the claw, and into the pipeline by a common vacuum pump. The pipeline is usually constructed of glass or steel and flows into a milk receiver. From the receiver, the milk is pumped through a filter and into a bulk tank where it is stored until collection.

The milking parlor is typically cleaned several times each day to remove manure and dirt. Large dairies tend to use automatic flush systems, while smaller dairies simply hose down the area. Water use can vary from 1 to 3 gallons per day per cow milked (for scrape systems) to 30 to 50 gallons per day per cow milked (for flush systems) in the dairy parlor and holding area (Loudon et al., 1985).

Milking at Tie Stalls - Cows that are kept in tie stalls may be milked from their stalls. The housing is equipped with a pipeline system that flows around the barn and contains ports where the milking claws may be "plugged in" at each stall. The workers carry the necessary udder and teat cleaning equipment as well as the milking claws from one cow to the next.

Approximately 70 percent of dairy operations reported that they milk the cows from their tie stalls, while only 29 percent reported that they used a milking parlor; however, more than half of the lactating cow population (approximately 55 percent) is milked in a milking parlor (USDA APHIS, 1996a; 1996b). Therefore, it can be interpreted that many of the large dairies are using milking parlors, while the smaller dairies are typically using tie stalls.

Holding Area - The holding area confines cows that are ready for milking. Usually, the area is enclosed and is part of the milking center, which in turn, may be connected to the barn or located in the immediate vicinity of the cow housing. The holding area is typically sized such that each cow is provided 15 square feet and is not held for more than 1 hour prior to milking (Bickert et al., 1997). The cows' udders may sometimes be washed in this area using ground-level sprinklers.

Milk Room - The milk room often contains the milk bulk tank, a milk receiver group, a filtration device, in-line cooling equipment, and a place to wash and store the milking equipment (Bickert et al., 1997). To enhance and maintain milk quality and to meet federal milk quality standards, it is cooled from the first milking to 40° F or less within 30 minutes. Some commonly used milk cooling devices include precoolers, heat exchangers, bulk tank coolers, and combinations of these. The cooling fluid used is typically fresh or chilled service water. This water is still clean and may then be used to water the animals (Bickert et al., 1997), or more commonly as milk parlor flush water.

Milking equipment cleaning and sterilizing processes are often controlled from the milk room. Typically, the milking equipment is washed in hot water (95 to 160 °F) in prerinse, detergent wash, and acid rinse cycles. The amount of water used by an automatic washing system, including milking parlor floor washes, can vary from 450 to 850 gallons per day (Bickert et al., 1997).

Treatment Area - Treatment areas are used on farms to confine cows for artificial insemination, postpartum examination, pregnancy diagnosis, sick cow examination, and surgery. A single stall or a separate barn can be used as a treatment area.

Other Areas of the Milking Center - Milking and processing equipment is typically stored in a utility room. This equipment may include:

- Milk vacuum pump
- Compressor
- Water heater
- Furnace
- Storage

A separate room may also be used to store cleaning compounds, medical supplies, bulk materials, replacement milking system rubber components, and similar products. The storage room is often separated from the utility room to reduce the deterioration of rubber products, and is typically designed to minimize high temperatures, light, and ozone associated with motor operation (Bickert et al., 1997).

4.3.4.5 Rotational Grazing

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, 1988). This practice involves rotating grazing cows among several pasture subunits or paddocks to obtain maximum efficiency of the pastureland. Dairy cows managed under this system spend all of their time, except time spent milking, out on the paddocks during the grazing season.

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 required land 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 pastureland (Hannawald 2000, personal communication). Successful intensive rotational grazing, however, requires thorough planning and constant monitoring. All paddocks are typically monitored once a week. High-producing milk cows (e.g., more than 80 pounds of milk per 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).

Due to the labor, fencing, water, and land requirements for intensive rotational grazing, typically only small dairy operations (those with less than 100 head) use this practice (see above; USDA NRCS, 1996; CIAS, 2000a). Climate and associated growing seasons, however, make it very difficult for operations to use an intensive rotational grazing system throughout the entire year. These operations, therefore, must maintain barns or dry lots for the cows when they are not being grazed, or outwinter their milk cows. Outwintering is the practice of managing cows outside during the winter months. This is not a common practice as it requires farmers to 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, 2000b).

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 sacrifical 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, 2000c).

Advantages of rotational grazing compared to 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 (AAFC, 1999).
- 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 (USDA NRCS 1996). 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 (AAFC, 1999).
- Better land. Pastureland used in rotational grazing is often better maintained than typical pastureland. 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 to confined feeding operations, as one system can not readily switch to the other; however, assuming all things are equal, intensive rotational grazing systems have a number of advantages over confined feeding operation. These include:

- 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. 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 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. These include:
- Better rate of return. 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, 2000d).

There are a number of disadvantages associated with intensive rotational grazing compared with either conventional grazing or confined dairy operations. The major disadvantages are

- Limited applicability. Implementation of intensive rotational grazing systems depends upon available acreage, herd size, land resources (i.e., tillable versus steep or rocky), water availability, proximity of pasture area to milking center, and feed storage capabilities. Several sources indicate that this system is used by dairy farms with less than 100 cows. Typical confined dairy systems 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 cows 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 dairy operations cannot provide year-round grazing, they still must maintain barns and dry lot areas for their cows when they are not grazing, and dairy operations often prefer not to have to maintain two management systems.

- Reduced milk production levels. Studies indicate that dairy farmers using intensive rotational grazing have a lower milk production average than confined dairy farms (USDA NRCS, 1996). 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.
- Limited manure-handling options. Dairies using intensive rotational grazing systems may not be able to apply the wastewater and solid manure collected during the nongrazing seasons to their available pastureland as crops may not be growing.
- Increased likelihood of infectious diseases. Some infectious diseases are more likely to occur in pastured animals by direct or indirect transmission from wild animals or presence of an infective organism in pasture soil or water (Hutchinson, 1988).
- Limited flexibility. Intensive rotational grazing systems have limited flexibility for 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).

4.3.5 Dairy Waste Management Practices

Dairy waste management systems are generally designed based on the physical state of the waste being handled (e.g., solids, slurries, or liquids). Most dairies have both wet and dry waste management systems. Waste with 20 to 25 percent solids content can usually be handled as a solid while waste with less than 10 percent solids can be handled as a liquid (Loudon, 1985).

In a dry system, the manure is collected on a regular basis and stored where an appreciable amount of rainfall or runoff does not come in contact with it. Handling manure as a solid minimizes the volume of manure that is handled.

In a slurry or liquid system, manure is often diluted with water that typically comes from flushing system water, effluent from the solids separation system, or supernatant from lagoons. When dairy manure is handled and stored as a slurry or liquid, the milking center wastewater can be mixed in with the animal manure, serving as dilution water to ease pumping. If a gravity system is used to transfer manure to storage, milking center wastewater may be added at the collection point in the barn. Liquid systems are usually favored by large dairies for their lower labor cost and because the larger dairies tend to use automatic flushing systems.

4.3.5.1 Waste Collection

The collection methods for dairy manure vary depending on the management of the dairy operation. Dairy cows may be partially, totally, or seasonally confined. As previously mentioned, manure accumulates in confinement areas such as barns, dry lots, and milking parlors and in other areas where the herd is fed and watered. In wet climates, it is difficult to collect and store manure from unroofed areas as a solid, but it can be done if the manure is collected daily, stored in a roofed structure, and mixed with bedding. In arid climates, manure from unroofed areas can be handled as a solid if collection time can be flexible.

The following methods are used at dairy operations to collect waste:

- Mechanical/Tractor Scraper - Manure and bedding from barns and shade structures are collected normally by tractor or mechanical chain-pulled scrapers. Eighty-five percent of operations with more than 200 milking cows use a mechanical or tractor scraper (USDA APHIS 1996b). Tractor scraping is more common since the same equipment can be used to clean outside lots as well as freestalls and loose housing. A mechanical alley scraper consists of one or more blades that are wide enough to scrape the entire alley in one pass. The blades are pulled by a cable or chain drive that is set into a groove in the center of the alley. A timer can be set so that the scraper runs two to four times a day, or continuously in colder conditions to prevent the blade from freezing to the floor. Scrapers reduce daily labor requirements, but have a higher maintenance cost due to corrosion and deterioration.
- Flushing System - Manure can be collected from areas with concrete flooring by using a flushing system. A large volume of water is introduced at the head of a paved area, and the cascading water removes the manure. Flush water can be introduced from storage tanks or high-volume pumps. The required volume of flush water varies with the size of the area to be flushed and slope of the area. The total amount of flush water introduced can be minimized by recycling; however, only fresh water can be used to clean the milking parlor area. Flushing systems are predominantly used by large dairies with 200 or more head (approximately 27 percent) that tend to house the animals in a freestall-designed barn. These systems are much less common in dairies with fewer than 200 head (fewer than 5 percent reported using this system) (USDA APHIS, 1996b). These systems are also more common at dairies located in warmer climates.
- Gutter Cleaner/Gravity Gutters - Gutter cleaners or gravity gutters are frequently used in confined stall dairy barns. The gutters are usually 16 to 24 inches wide, 12 to 16 inches deep, and flat on the bottom. Either shuttle-stroke or chain and flight gutter cleaners are typically used to clean the gutters. About three-fourths (74 percent) of U.S. dairy operations with fewer than 100 milking cows and approximately one-third of U.S. dairy operations with 100 to 199 milking cows use a gutter cleaner (USDA APHIS, 1996b).
- Slotted Floor - Concrete slotted floors allow manure to be quickly removed from the animal environment with minimal labor cost. Manure falls through the slotted floor or is worked though by animal traffic. The waste is then stored in a pit beneath the floor or

removed with gravity flow channels, flushing systems, or mechanical scrapers. The storage of animal and milking center waste in a pit beneath slotted floors combines manure collection, transfer, and storage.

4.3.5.2 Transport

The method used to transport manure depends largely on the consistency of the manure. Liquids and slurries can be transferred through open channels, pipes, and in liquid tank wagons. Pumps can be used to transfer liquid and slurry wastes as needed; however, the greater the solids content of the manure, the more difficult it will be to pump.

Solid and semisolid manure can be transferred by mechanical conveyance or in solid manure spreaders. Slurries can be transferred in large pipes by using gravity, piston pumps, or air pressure. Gravity systems are preferred because of their low operating cost.

4.3.5.3 Storage, Treatment, and Disposal

Waste collected from the dairy operation is transported within the site to storage, treatment, and use or disposal areas. Typical storage areas for dairy waste include above and belowground storage tanks and storage ponds. Handling and storage methods used at dairy operations are discussed in detail in Section 8.2.

One common practice for the treatment of waste at dairies is solids separation. Mechanical or gravity solids separators are used to remove bulk solids from a liquid waste stream. This separation reduces the volume of solids entering a storage facility, which increases its storage capacity. Separation facilitates reuse of liquid in a flushing system which reduces clogging of irrigation sprinklers and waste volume going to treatment or land application sites. Manure slurry is often separated using mechanical separators, such as stationary screens, vibrating screens, presses, or centrifuges, all of which recover a relatively dry byproduct (Dougherty, 1998). Sedimentation by gravity settling is also used for solid/liquid separation.

Another common technology for the treatment of waste at dairies is an anaerobic lagoon. Anaerobic lagoons are biological treatment systems used to degrade animal wastes into stable end products. The advantage of anaerobic lagoons is their long storage times, which allow bacteria to break down solids. Disadvantages include odors produced during environmental or management changes, and sensitivity to sudden changes in temperature and loading rates. Anaerobic lagoons are designed to hold the following volumes: a minimum treatment volume (based on volatile solids loading), the volume of accumulated sludge for the period between sludge removal events, the volume of manure and wastewater accumulated during the treatment period, the depth of normal precipitation minus evaporation, the depth of the 25-year, 24-hour storm event, and an additional 1 foot of freeboard.

Typical manure and waste treatment technologies used at dairy operations are discussed in detail in Section 8.2.

The majority (approximately 99 percent) of small and large dairy operations (fewer than and more than 200 milking cows) dispose of their waste through land application (USDA APHIS, 1996b). The amount of cropland and pastureland that is available for manure application varies at each dairy operation. Generally, dairy operations can be categorized into three groups with respect to available cropland and pastureland: (1) those with sufficient land so that all manure can be applied without exceeding agronomic application rates, (2) those without sufficient land to apply all of their manure at agronomic rates, and (3) those without any available cropland and pastureland. Operations without sufficient land, or any land, often have agreements with other farmers allowing them to apply manure on their land. Depending on the size of the dairy operation, 1997 Census of Agriculture data indicate that the average age of cropland at dairies with at least 300 milking cows is approximately 350 acres, and the average age of pastureland is approximately 75 acres (Kellogg, 2000).

USDA conducted an analysis of the 1997 Census of Agriculture data to estimate the manure production at livestock farms (Kellogg, 2000). As part of this analysis, USDA estimated the number of confined livestock operations that produce more manure than they can apply on their available cropland and pastureland at agronomic rates for N and P, and the number of confined livestock operations that do not have any available cropland or pastureland. The analysis assumed land application of manure would occur on one of 24 typical crops or pastureland. Using the percentage of these facilities estimated by USDA against the total number of livestock facilities, one can also estimate the number of facilities that have sufficient cropland and pastureland for agronomic manure application. Table 4-80 summarizes the percentage of dairy operations that have sufficient, insufficient, and no land for manure application at agronomic application rates for N and P. EPA assumes that confined heifer operations have similar percentages.

Table 4-80. Percentage of Dairy Operations With Sufficient, Insufficient, and No Land for Agronomic Application of Generated Manure.

Size Class	Sufficient Land		Insufficient Land		No Land[a]
	Nitrogen Application	Phosphorus Application	Nitrogen Application	Phosphorus Application	
200–700 milking cows	50	25	36	61	14
> 700 milking cows	27	10	51	68	22

[a] No acres of cropland (24 crops) or pastureland.
Source: Kellogg, 2000.

4.4 <u>Beef Industry</u>

Beef feeding operations include facilities that confine beef cattle for feeding or maintenance for at least 45 days in any 12-month period. These facilities do not have significant vegetation on the beef feedlot during the normal growing season (i.e., the feedlot area does not include grazing operations). Facilities that have beef feedlot operations may also include other animal and agricultural operations not considered part of the feedlots, such as grazing and crop farming.

- This section discusses the following aspects of the beef industry:
- Section 4.4.1: Distribution of the beef industry by size of operation and region in 1997;
- Section 4.4.2: Beef production cycles
- Section 4.4.3: Beef feedlot facility management
- Section 4.4.4: Backgrounding operations
- Section 4.4.5: Veal operations
- Section 4.4.6: Cow-calf operations
- Section 4.4.7: Beef waste management practices

4.4.1 Distribution of the Beef Industry by Size and Region

EPA's current Effluent Limitations Guidelines and Standards apply to beef feedlot operations with 1,000 or more slaughter steers and heifers, where the animals are fed at the place of confinement and crop or forage growth or production is not sustained in the confinement area.

Information presented in this section comes from USDA NASS, 1997 Census of Agriculture data, and from site visits and trade associations. The 1994 to 1998 NASS reports on beef feedlots present annual estimates of beef operations that have a capacity of 1,000 head of cattle or more grouped in the following categories:

- Cattle inventory and calf crop
- Number of operations
- Inventory by class and size groups
- Monthly cattle on feed numbers
- Annual estimates of cattle on feed

NASS publishes only limited data for operations that have a capacity of fewer than 1,000 head of cattle (USDA NASS, 1999e). The 1997 Census of Agriculture collects information on cattle inventory and the number of cattle fattened for slaughter. NASS data on the number of beef feedlot facilites in each of EPA's size classes were limited; however, Census of Agriculture data provides the number of facilities by the number of head sold, or inventory. EPA used Census of Agriculture inventory data to estimate capacity. Then, EPA used these capacity data to estimate the percentage of total operations within each size class. These percentages were used with the NASS data to estimate total number of facilities in each size class. The capacity of a beef feedlot is the maximum number of cattle that can be held on site at any one time and can usually be determined by the amount of feedbunk space available for the cattle. On average, most beef feedlots operate at 80 to 85 percent of capacity over the course of a year, depending on market conditions (NCBA, 1999). In addition, most feedlots have cattle on site for 150 to 270 days (see Section 4.4.2); therefore, on average, the feedlot can run one and one half to two and one half turns of cattle each year. However, a feedlot may have anywhere from one to three and one half turnovers of its herd per year. For example, some feedlots only have cattle on site during the winter months (one turnover) when crops cannot be grown, while other feedlots move cattle through the feedyard more quickly (three and one half turnovers).

EPA estimated the maximum capacity of beef feedlots reported in the 1997 Census of Agriculture using the reported sales of cattle combined with estimated turnovers and average feedlot capacity (ERG, 2000b).

Maximum Feedlot Capacity (Head) = Cattle Sales (Head) * Average Feedlot Capacity (%) / Turnovers

For example, a feedlot that sold 1,500 cattle in 1997 and is estimated to operate at 80 percent capacity with one and one half turnovers has an estimated maximum capacity of 800 head.

In 1997, there were approximately 2,075 beef feedlots with a capacity of more than 1,000 head in the United States. (USDA NASS, 1999e). These operations represent only about 2 percent of all beef feedlots. EPA estimates that there were approximately 1,000 additional beef feedlots with a capacity of between 500 and 1,000 head (another 1 percent of beef feedlots), 1,000 beef feedlots with a capacity of between 300 and 500 head, and another 102,000 beef feedlots with a capacity of fewer than 300 head. Table 4-81 shows the estimated distribution of these operations by size and region. Table 4-82 shows the estimated number of cattle sold during 1997 by size class. EPA derived these data from the 1997 Census of Agriculture data and NASS data (ERG, 2000b).

Table 4-83 presents the number of beef feedlots by top-producing states and nationally for the following eight size categories:

- up to 299 head
- 300 to 999 head
- 1,000 to 1,999 head
- 2,000 to 3,999 head
- 4,000 to 7,999 head
- 8,000 to 15,999 head
- 16,000 to 31,999 head
- 32,000 head and greater

The data in this table were obtained from NASS and were also derived from the 1997 Census of Agriculture data. Note that in some cases the feedlots from several size groups have been aggregated to avoid disclosing details on individual operations for some states.

As one would expect, the number of feedlots decreases as the capacity increases. For example, there are 842 feedlots in the 1,000 to 1,999 size category but only 93 in the greater than 32,000 size category. Of the 106,075 beef feedlots across all size groups in 1997, the Midwest Region has the most with 71,183 (67 percent). Nebraska and Iowa have the most large beef feedlots (more than 1,000 head). Texas has the largest number of feedlots with a capacity of more than 32,000 head (41 percent).

Also included in the beef industry are veal operations, which are discussed in detail in Section 4.4.5. Veal operations are not specifically reported in the 1997 Census of Agriculture or NASS data. EPA conducted site visits to veal operations and requested distribution data from the industry to ultimately estimate the number of veal operations in the U.S., as shown in Table 4-84 (ERG, 2000b).

Table 4-81. Distribution of Beef Feedlots by Size and Region in 1997.

Region[a]	Feedlot Capacity					
	<300 Head	300–500 Head	500–1,000 Head	1,000–8,000 Head	>8000 Head	Total
Central	9,990	87	130	332	182	10,721
Mid-Atlantic	15,441	150	34	25	0	15,650
Midwest	68,235	685	810	1,236	217	71,183
Pacific	3,953	35	19	55	22	4,085
South	4,381	43	7	6	0	4,436
National	102,000[b]	1,000[b]	1,000	1,654	421	106,075

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.
[b] Estimated value. Assumes 98 percent of feedlots with fewer than 1,000 head have a capacity of fewer than 300 head, and 99 percent of all feedlots with fewer than 1,000 head have a capacity of fewer than 500 head.

Table 4-82. Cattle Sold in 1997.

Size Class	Number of Facilities	Cattle Sold	Average Cattle Sold
<300 Head Capacity	102,000	2,362,000[a]	23
300–500 Head Capacity	1,000	600,000[b]	600
500–1,000 Head Capacity	1,000	1,088,000[b]	1,088
>1,000 Head Capacity	2,075	22,789,000	10,983
All Operations	106,075	26,839,000	253

[a] Estimated value. Value presented is the difference between total sales for all feedlots with fewer than 1,000-head capacity, and the estimated sales for feedlots with 300- to 1,000- head capacity.
[b] Estimated value. Calculated from using the midpoint of the size range (e.g., 400 head for the 300–500 size class) and an average turnover rate of one and one half herds a year.

Table 4-83. Number of Beef Feedlots by Size of Feedlot and State in 1997.[a]

Location	Feedlot Capacity							
	1–299 Head	300–999 Head	1,000–1,999 Head	2,000–3,999 Head	4,000–7,999 Head	8,000–15,999 Head	16,000–31,999 Head	32,000+ Head
Arizona	151	4	-	3[b]	-	-	3	3
California	885	25	4[b]	-	4	4	5	7
Colorado	1,374	70	54	46	32	23	11	8
Idaho	894	13	19	15	9	17[b]	-	-
Iowa	11,839	435	200	110[b]	-	-	-	-
Kansas	2,563	160	45	28	30	34	41	17
Nebraska	4,700	359	270	181	118	64	25	7
New Mexico	318	6	-	-	6[b]	-	4[b]	-
Oklahoma	1,840	21	3[b]	-	9	5	3	6
South Dakota	2,652	124	50	41	17	6[b]	-	-
Texas	3,556	49	8	13	28	25	35	38
Washington	1,166	8	7[b]	-	-	4	5[b]	-
Other States	70,062	726	191	85	36	8	5	-
United States	102,000	2,000	842	504	308	191	137	93

[a] The number of feedlots is the number of lots operating at any time during the year. The U.S. totals show the actual number of feedlots in each size group. The sum of the numbers shown by states under a specified size group may or may not add to the U.S. total for that size group because some states size groups are combined to avoid disclosing individual operations.
[b] Lots from other size groups are included to avoid disclosing individual operations.

Table 4-84. Distribution of Veal Operations by Size and Region in 1997.

Region[a]	Capacity		Total
	300–500 Calves	> 500 Calves	
Central	5	3	8
Mid-Atlantic	1	1	2
Midwest	119	81	200
Pacific	0	0	0
South	0	0	0
Total United States	125	85	210

[a] Central = ID, MT, WY, NV, UT, CO, AZ, NM, TX, OK; Mid-Atlantic = ME, NH, VT, NY, MA, RI, CT, NJ, PA, DE, MD, VA, WV, KY, TN, NC; Midwest = ND, SD, MN, MI, WI, OH, IN, IL, IA, MO, NE, KS; Pacific = WA, OR, CA, AK, HI; South = AR, LA, MS, AL, GA, SC, FL.

4.4.2 Beef Production Cycles

Beef feedlots conduct feeding operations in confined areas to increase beef weight gain, control feed rations, increase feeding efficiency, reduce feed costs, and manage animal health. Calves are often brought in from backgrounding operations to the feedlot (Section 4.4.4). Calves usually begin the “finishing” phase when they reach 6 months of age or a weight of at least 400 pounds. Cattle are typically held on the feedlot for 150 to 180 days. As stated previously in this section, a beef feedlot may run anywhere from one to three and one half turnovers of its herd per year. The annual average steer weight at slaughter ranges from 1,150 to 1,250 pounds, while the annual average heifer weight at slaughter weight ranges from 1,050 to 1,150 pounds.

Some feedlots may bring in young calves at around 275 pounds and feed them on site for approximately 270 days. As a result, these feedlot operations have fewer turnovers of the herd per year. Based on site visits, this type of operation is typical at feedlots in southern California. Some operations may only bring in cattle during the winter months when no crops are being grown, also resulting in fewer turnovers of the herd per year. Other operations, the true “final finishing” operations, may bring cattle in at a heavier weight and require only approximately 100 days to feed cattle, resulting in more turnovers of the herd per year. These variations in turnovers often make it difficult to estimate farm counts if data only show cattle inventory.

4.4.3 Beef Feedlot Facility Management

This section describes factors that affect the facility management at a feedlot operation including the layout of feedlot systems, feeding and watering practices, water use and wastewater generation, and climate.

4.4.3.1 Feedlot Systems

Cattle traffic flow is an important factor in the design of a feedlot. These operations use separate vehicle and cattle traffic lanes when possible to minimize congestion, reduce the spread of parasites and disease, and promote drainage to make pen cleaning easier and to promote animal comfort and welfare. Outdoor feedlot systems comprise the following units which can be organized in various ways.

- <u>Office</u> - This is usually located on or near the main access road and has truck scales and facilities for sampling incoming feed. All bulk feed delivered to the lot enters at this point. Cattle trucks also use these scales for in and out weights (Thompson and O’Mary, 1983).
- <u>Feed Mill</u> - Truck traffic around the feed mill is typically heavy. A good design allows feed ingredients to be received while finished rations are trucked to the pens without traffic conflict. Feeding pens are often near the feed mill to reduce travel (Thompson and O’Mary, 1983).
- <u>Pens</u> - Pens are designed for efficient movement of cattle, optimum drainage conditions, and easy feed truck access. A typical pen holds 150 to 300 head but the size can vary substantially. Required pen space may range from 75 to 300 square feet of pen space per head, depending on climate (see Section 4.4.3.4). Space needs vary with the amount of paved space, soil type, drainage, annual rainfall, and freezing and thawing cycles.

- Large feedlots use cattle alleys behind the pens to keep the flow of cattle separate from the feed trucks. Smaller feedlots often use feeding alleys to move the cattle. The pens should allow for proper drainage of runoff to provide comfortable conditions. A grade of at least 3 percent is necessary to allow proper drainage in most areas (Thompson and O'Mary, 1983).
- Cattle Loading and Unloading Facilities - Feedlots locate these facilities to ensure the smooth flow of trucks to bring cattle in and out of the lot. Larger feedlots typically use two shipping areas, with the receiving area having hospital or separate processing facilities where cattle can receive various identification markers, vaccinations, and treatment for internal and external parasites, and are held until they are healthy enough to go to regular feeding pens (Thompson and O'Mary, 1983).
- Hospital Areas - These are facilities where cattle can be medically treated. Each facility normally has a squeeze chute, refrigerator, water, and medicine and equipment storage (Thompson and O'Mary, 1983). Approximately 10 percent of the cattle in a feedlot will be treated in hospital areas during the feeding period (NCBA, 1999).

The majority of beef feedlots are open feedlots, which are usually unpaved. These types of operations may use mounds in the pens to improve drainage and provide areas that dry quickly, because dry resting areas improve cattle comfort, health, and feed utilization. In open feedlots, protection from the weather is often limited to a windbreak near the fence in the winter and sunshade in the summer; however, treatment facilities for the cattle and the hospital area are usually covered. A concrete apron is typically located along feedbunks and around waterers, because these are heavy traffic areas (Bodman et al., 1987).

Open-front barns and lots with mechanical conveyors or fenceline bunks are common for feedlots of up to 1,000 head, especially in areas with severe winter weather and high rainfall. Confinement feeding barns with concrete floors are also sometimes used at feedlots in cold or high rainfall areas. These barns require less land and solve feedlot problems caused by drifting snow, severe wind, mud, lot runoff, and mound maintenance. Feeding is typically mechanical bunk feeding or fenceline bunks. Manure is usually scraped and piled in a containment area. If the barn has slotted floors, the manure is collected beneath slotted floors, and is scraped and stored or flushed to the end of the barn where it is pumped to a storage area for later application (Bodman et al., 1987).

4.4.3.2 Feeding and Watering Practices

At feedyards, all cattle are fed two or three times a day and are normally fed for 120 to 180 days, depending on their initial weight and type. Some operations may feed as long as 270 days if they receive young calves. Feedlots consider the following factors when determining feeding methods: the number of animals being fed; the type and size of grain and roughage storage; the equipment necessary to unload, meter, mix, and process feed; and the location and condition of existing feed storage (Bodman et al., 1987).

Beef feedlots use the following types of feeding methods:

- Fenceline feeding - Bunks are located along the side of a lot or pen. This method requires twice as much bunk length as bunks that feed from both sides, but the advantage is that feed trucks do not have to enter the pens with the cattle. Fenceline feedbunks have 6 to 14 inches of bunk space per head, and are typically used for feedlots with more than 100 head. Feedbunks are cleaned routinely to remove uneaten feed, manure, and other foreign objects.
- Mechanical bunk feeding - Bunks typically allow cattle to eat from both sides and are also used as pen dividers. This feeding method is common with continuous feed processing systems and small operations. Mechanical feedbunks are useful for feedlots of up to 500 head.
- Self-feeding - Feedlots use haystacks, feed from horizontal silos or plastic bags, and grain and mixed rations in bunks or self feeders with this feeding method. Portable silage and grain bunks are useful for up to 200 head (Bodman et al., 1987).

Twenty-four hour access to the water trough is required for the health of the animals and maximum production efficiency. Cattle water consumption varies, depending on such factors as animal size and season, and may range from 9 gallons per day per 1,000 pounds during winter to 18 gallons per day per 1,000 pounds during hot weather (Bodman et al., 1987). Typically, one watering space for each 200 head and a minimum of one watering location per pen of animals is provided (USDA NASS, 1999e). Some water may be required to add to the feed processing or to clean equipment.

4.4.3.3 Water Use and Wastewater Generation

The main source of wastewater to be managed is the runoff from rainfall events and snow melt. Surface runoff from rain and snow melt can transport manure, soil, nutrients, other chemicals (e.g., pesticides), and debris off the feedlot; therefore, it is important to divert clean water away from contact with manure, animals, feed processing and storage, and manure storage areas to reduce the total volume of contaminated wastewater. Runoff is affected by rainfall amount and intensity, feedlot maintenance practices, and soil type and slope. Runoff can be controlled by using diversions, sediment basins, and storage ponds or lagoons. Feedlots can also reduce the volume of runoff by limiting the size of confinement areas.

Typically, pens are constructed such that runoff is removed as quickly as possible, transported from the lot through a settling basin, and diverted into storage ponds designed to retain, at a minimum, the 24-hour, 25-year storm. Feedlots can reduce the runoff volume by preventing all runon water from entering clean areas and by diverting all roof runoff.

Only specially constructed barns use water to flush or transport manure. These barns are used by a very small percentage of the industry and typically at smaller feedlots.

4.4.3.4 Climate

Climate plays a large role in the design and operation of a feedlot. The metabolic requirement for maintenance of an animal typically increases during cold weather, reducing weight gain and increasing feed consumption to provide more net energy. Feed consumption typically declines under abnormally high temperatures, therefore reducing weight gain. Investigations in California have shown that the effects of climate-related stress could increase feed requirements as much as 33 percent (Thompson and O'Mary, 1983). As a result, waste (manure) generation would also increase.

In cold areas, feedlots typically provide a roof of some sort for the cattle. Sheltered cattle gain weight faster and more efficiently during winter than unsheltered cattle. Areas that receive substantial rainfall require mud control and paved feeding areas, since higher precipitation results in greater runoff volumes. In hot, semiarid areas, sun shades are typically provided for the cattle. A dry climate requires generally 75 square feet of pen space per head whereas a wet climate may require up to 400 square feet of pen space per head (Thompson and O'Mary, 1983). Feedlots typically use misting sprinklers or watering trucks to control dust problems in dry climates.

4.4.4 Backgrounding Operations

Backgrounding operations feed calves, after weaning and before they enter a feedlot using pasture and other forages. These operations allow calves to grow and develop bone and muscle without becoming fleshy or gaining fat covering. Weaned calves are typically sent to backgrounding operations to allow producers to:

- Develop replacement heifers.
- Retain rather than sell at weaning when prices are typically low.
- Use inexpensive home-grown feeds, crop residues, pasture, or a combination of these to put weight on calves economically.
- Put weight on small calves born late in the calving season before selling.
- Put minimal weight on calves during winter before grazing on pasture the following spring and summer.

Calves are normally kept at the operation from 30 to 60 days but can be kept up to 6 months (approximately 400 pounds) (Rasby et al., 1996). Typical diets consist of equal proportions of roughage and grains that produce a moderate gain of 2 to 2.5 pounds per day. Backgrounding operations typically keep calves on pasture during their entire stay; however, these operations may operate similarly to a beef feedlot, using pens to confine calves, and feedbunks to feed.

4.4.5 Veal Operations

Veal operations raise calves, usually obtained from dairy operations, for slaughter. Dairy cows must give birth to continue producing milk. Female dairy calves are raised to become dairy cows;

however, male dairy calves are of little or no value to the dairy operation. Therefore, these male dairy calves are typically sent to feedlots or veal operations. Calves are normally separated from the cows within 3 days after birth. Veal producers typically obtain calves through livestock auctions, although in some cases the calves may be taken directly from the dairy farm to the veal operation (Wilson et al., 2000).

The majority of veal calves are “special-fed” or raised on a low-fiber liquid diet until about 16 to 20 weeks of age, when they weigh about 450 pounds. Calves slated for “Bob” veal, which are marketed up to 3 weeks of age when they weigh about 150 pounds, constitute about 15 percent of the veal calves sold (USDA, 1998).

Calves are fed a milk-replacer diet composed of surplus dairy products including skim milk powder and whey powder. Their diet also includes plant- and animal-derived fats, proteins, and other supplements such as minerals and vitamins (Wilson et al., 2000). Calves spend their entire growing-out period on a liquid diet.

Veal calves are generally grouped by age in an environmentally controlled building. The majority of veal operations use individual stalls or pens. Floors are constructed of either wood slats or plastic-coated expanded metal, while the fronts and sides are typically wood slats. The slotted floors allow for efficient removal of waste. The back of the stall is usually open, and calves may be tethered to the front of the stall with fiber or metal tethers. Individual stalls allow regulation of air temperature and humidity through heating and ventilation, effective management and handling of waste, limited cross-contamination of pathogens between calves, individual observation and feeding, and, if necessary, examination and medical treatment (Wilson et al., 2000). The stalls provide enough room for the calves to stand, stretch, groom themselves, and lie down in a natural position.

Veal waste is very fluid, diluted by various volumes of wash water used to remove it from the building (see Section 6.4 for a discussion of veal manure characteristics). Therefore, manure is typically handled in a liquid waste management system. Manure, hair, and feed are regularly washed from under the stalls to reduce ammonia, odor, and flies in the room. Manure is typically washed out twice daily so that if the calf is having health problems, it is easily observed. Approximately 10 to 30 percent of the wastewater generated at a veal operation comes from scrubbing rooms and stalls after calves have been shipped to market.

The most common method for handling manure and wash water is using a sloping gutter under the rear of the stalls, allowing manure to continuously drain into a manure storage system. Tanks, pits, and lagoons are used to store manure until it is spread on fields. Storage pits may also be built directly under buildings; however, this produces higher levels of ammonia and other pit gases that require increased ventilation and higher fuel costs in the winter (Meyer, 1987).

4.4.6 Cow-Calf Operations

Cow-calf operations breed mature cows and yearling heifers with bulls to produce calves and can be located in conjunction with a feedlot, but they are more often stand-alone operations. A herd of mature cows, some replacement heifers, and a few bulls are typically maintained at cow-calf operations on a year-round basis. Offspring calves remain with the cows until weaned and then may be held in different pastures to grow until they weigh between 650 to 750 pounds when they are sold to feedlots as yearlings. These operations may also sell their calves to backgrounding operations or dairy operations. Artificial insemination is not commonly used at cow-calf operations. Bulls are typically used for breeding and are placed with cows at the proper time to ensure spring calves.

The number of bulls required at a cow-calf operation depends on the number of cows and heifers, size and age of bulls, crossbreeding program, available pasture, and length of breeding season. One bull is typically provided for each set of 25 cows or heifers. Bulls are usually pastured away from the cows, and they may be penned separately from each other to prevent fighting (Bodman, 1987).

Outdoor calving requires clean, well-drained, and wind-protected pastures. Separate feed areas are provided for mature cows, first calf heifers, bulls, and calves (Loudon, 1985). In cold climates, a calving barn may be needed to reduce the risk of death. These barns typically include a loose housing observation area, individual pens, and a chute for holding and treating cows. Typically, a barn is provided for 5 percent to 10 percent of the cow herd in mild climates, and for 15 to 20 percent of the herd in more severe weather or during artificial insemination (Bodman, 1987).

4.4.7 Waste Management Practices

Waste from a beef feedlot may be handled as a solid or liquid; both management methods have advantages and disadvantages. Waste from a veal operation is handled as a liquid. Solid waste is typically found in calving pens and in open lots with good drainage. Semisolid waste has little bedding and no extra liquid is added. Waste treated as a solid has a reduced total volume and weight because it contains less water; therefore, its management may cost less and require less power.

Slurry waste has enough water added to form a mixture that can be handled by solids handling pumps. Liquid waste is usually less than 8 percent solids, and large quantities of runoff and precipitation are added to dilute it. Wastes treated as a liquid are easier to automate and require less daily attention; however, the large volumes of added water increase the volume of waste. As a result, the initial cost of the liquid-handling equipment is greater (USDA NRCS, 1992).

4.4.7.1 Waste Collection

Beef cattle are confined on unpaved, partially paved, or totally paved lots, and much of their manure is deposited around feedbunks and water troughs. Feedlots typically collect these wastes from the feedlot surface after shipping each pen of cattle (Sweeten, n.d.).

The following methods are used in the beef industry to collect waste:

- Scraping - This is the most common method of collecting solid and semisolid manure from both barns and open lots. Solids can be moved with a tractor scraper and front-end loader. A tractor scraper may be used in irregularly shaped alleys and open areas. Mechanical scrapers are typically used in the pit under barns with slotted floors and propelled using electrical drives attached by cables or chains. Tractors have fewer problems and work better on frozen manure; however, mechanical scrapers reduce labor requirements. Removing manure regularly reduces odor in enclosed areas. Scraping is common for medium and large feedlots (Loudon, 1985).
- Slotted Flooring - This term refers to slats and perforated or mesh flooring and is a method of rapidly removing manure from an animal's space. Most slats are reinforced concrete, but can be wood, plastic, or aluminum, and are designed to support the weight of the slats plus live load, which includes animals, humans, and mobile equipment. Manure drops between slats, which keeps the floor surface relatively clean. Wide slats (between 4 and 8 inches) are commonly used with 1.5 to 1.75 inches between slats (Loudon, 1985).

Flushing System - This type of system dilutes manure from beef feedlots with water to allow for automated handling. Diluting the manure increases its volume and therefore requires a larger capital investment for equipment and storage facilities. 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. The amount of water typically used for cleaning is 100 gallons per head at least twice a day. Grade is critical for the flush alleys as is amount of water used (Loudon, 1985). This system is not very common for large feedlots; however, this type of system is widely used at veal operations.

Waste collection is easiest on paved lots. On unpaved lots, cattle traffic tends to form a seal on the soil that reduces the downward movement of contaminated water; however, deep scraping can destroy the interface layer that forms between the manure and the soil and acts as a seal to decrease the chance of pollutants from entering the ground water.

To reduce the production of unnecessary waste, clean water can be diverted away from the feedlot area. For example, uncontaminated water can be directed away from the waste and carried outside of the feedlot area. Roof runoff can be managed using gutters, downspouts, and underground outlets that discharge outside the feedlot area. Unroofed confinement areas can include a system for collecting and confining contaminated runoff. Paved lots will generally have more runoff per square foot than unpaved lots, but due to a smaller total area, they will have less total runoff per animal.

4.4.7.2 Transport

Waste collected from the feedlot may be transported within the site to storage, treatment, and use or disposal areas. Solids and semisolids are typically transported using mechanical conveyance equipment, pushing the waste down alleys, and transporting the waste in solid manure spreaders. Flail-type spreaders, dump trucks, or earth movers may also be used to transport these wastes. Liquids and slurries, typically found at veal operations, are transferred through open channels, pipes, or in a portable liquid tank. These wastes can be handled by relying on gravity or pumps as needed.

4.4.7.3 Storage, Treatment, and Disposal

Beef feedlot operations typically use a settling basin to remove bulk solids from the liquid waste stream, reducing the volume of solids before the stream enters a storage pond, thereby increasing storage capacity. A storage pond is typically designed to hold the volume of manure and wastewater accumulated during the storage period, the depth of normal precipitation minus evaporation, the depth of the 25-year, 24-hour storm event, and an additional 1 foot of freeboard. Solid manure storage can also range from simply constructed mounds to manure sheds that are designed to prevent runoff and leaching.

Beef feedlot operations may also use other types of technologies, such as composting or mechanical solids separation, when managing animal waste and runoff. Typical manure and waste handling, storage, and treatment technologies used at beef feedlots are discussed in detail in Section 8.2. The majority (approximately 83 percent) of beef feedlots dispose of their waste through land application (USDA APHIS, 2000a).

Veal operations typically use an underground storage pit or a lagoon for waste storage and treatment. Veal operations also typically dispose of their waste through land application.

The amount of cropland and pastureland that is available for manure application varies at each beef operation. Generally, operations in the beef industry can be categorized into three groups with respect to available cropland and pastureland: (1) those with sufficient land so that all manure can be applied without exceeding agronomic application rates, (2) those without sufficient land to apply all of their manure at agronomic rates, and (3) those without any available cropland and pastureland. Operations without sufficient land, or any land, often have agreements with other farmers allowing them to apply manure on their land. Depending on the size of the beef operation, 1997 Census of Agriculture data indicate that the average acreage of cropland at beef feedlots with at least 500 head is between 550 to 850 acres and the average acreage of pastureland is between 50 and 110 acres (Kellogg, 2000).

USDA conducted an analysis of the 1997 Census of Agriculture data to estimate the manure production at livestock farms. As part of this analysis, USDA estimated the number of confined livestock operations that produce more manure than they can apply on their available cropland and pastureland at agronomic rates for N and P and the number of confined livestock operations that do not have any available cropland or pastureland. The analysis assumed land application of manure would occur on 1 of 24 typical crop or pasturelands (Kellogg, 2000). Using the percentage of these facilities estimated by USDA against the total number of livestock facilities, one can also estimate the number of facilities that have sufficient cropland and pastureland for agronomic manure application. Table 4-85 summarizes the percentage of beef feedlots that have sufficient, insufficient, and no land for manure application at agronomic application rates for N and P. EPA assumes that all veal operations have sufficient land to apply their manure.

Table 4-85. Percentage of Beef Feedlots With Sufficient, Insufficient, and No Land for Agronomic Application of Manure.

Size Class	Sufficient Land		Insufficient Land		No Land[a]
	Nitrogen Application	Phosphorus Application	Nitrogen Application	Phosphorus Application	
300–1,000 head	84	62	9	31	7
1,000– 8,000 head	6	22	21	67	11
> 8,000 head	8	1	53	6	39

[a] No acreage of cropland (24 crops) or pastureland.
Source: Kellogg, 2000.

4.5 Horses

Today's horse industry is quite diverse, providing animals for pleasure, showing, breeding, racing, farm/ranch, and other uses. Because the horse industry is so diverse and much of the population is off farm, statistics on horse population sizes, distributions, and trends are much less available than they are for other agricultural livestock.

4.5.1 Distribution of the Horse Industry by Size and Region

In 1900, the Census of Agriculture indicated that 79 percent of all farms had horses, whereas by 1992 this percentage had dropped to 18 percent. Specifically, the 1992 Census of Agriculture reported 338,346 farms with 2,049,522 horses. The USDA estimates that up to 3 million of the approximately 5 million horses in the United States are raised off farms or on farms with too few animals to be reported in the Census data (USDA APHIS, 1996d). However, a survey of equids (domestic horses, miniature horses, ponies, mules, donkeys, and burros) was recently completed for 28 states representing more than three-fourths of the U.S. horse and pony inventory on farms (USDA APHIS, 1998a). In addition, 133 race tracks participated in portions of this survey. Participation from and accounting for race tracks is important since some facilities are very large. The Lone Star Park at Grand Prairie, Texas, located near Dallas/Fort Worth, has accommodations for up to 1,250 horses. It is also believed that since mules, donkeys, and burros represented only 4.7 percent of the animals surveyed, this survey is useful for characterizing the horse sector.

For the surveyed states, 40.1 percent of the equids are located in Texas, Oklahoma, Louisiana, Maryland, Virginia, Kentucky, Tennessee, Alabama, Georgia, and Florida; 13.0 percent are located in Ohio, Pennsylvania, New Jersey, and New York; 20.7 percent are located in Kansas, Missouri, Illinois, Indiana, Michigan, Wisconsin, and Minnesota; and 26.2 percent are located in Montana, Wyoming, Colorado, New Mexico, Washington, Oregon, and California. More than 95 (96.3) percent of the operations have from 1 to 19 equids on the operation, representing 73 percent of all equids. Less than 4 (3.7) percent of operations have 20 or more equids, representing 27 percent of all equids. Overall, boarding/training and breeding operations account for 3.7 and 5.2 percent of the operations respectively, yet account for more than 10 percent of the equids. Race tracks account for 53.4 percent of the operations with 20 or more equids, followed by boarding/training facilities (26.7 percent), breeding (22.7 percent), and farm/ranch (2.1 percent) (USDA APHIS, 1998a).

Farm or ranch use of equids represents 15.2 percent of all operations. Breeding as a primary use of equids represented 6.0 percent of operations. The categories of racing and showing/competition represented a total of 8.4 percent of all operations (USDA APHIS, 1998a).

According to the data presented in Table 4-86, pleasure was the primary use of equids on the largest percentage of operations regardless of region (66.8 percent). Larger percentages of operations in the Western and Southern Regions used equids primarily for farm/ranch work (20.6 and 18.4 percent, respectively) than in the Central (8.9 percent) and Northeast (5.7 percent) Regions. Outfitting, carriage horses, and teaching horses are examples of uses included in the "other" category. As shown in Tables 4-87 and 4-88, race tracks represent the primary use (more than 90 percent) at operations with 500 or more horses.

Table 4-86. Percent of Operations by Primary Use of Equids Present on January 1, 1998, and Region.

Primary Use of Equids	Southern	Northeast	Western	Central	All Operations
Pleasure	63.2	66.9	65.5	74.7	66.8
Showing/competition (not betting)	6.8	9.0	5.2	6.0	6.5
Breeding	6.3	6.3	3.5	7.9	6.0
Racing	2.7	2.9	1.0	0.9	1.9
Farm/ranch	18.4	5.7	20.6	8.9	15.2
Other	2.6	9.2	4.2	1.6	3.6
Total	100.0	100.0	100.0	100.0	100.0

Source: USDA APHIS, 1998a
Southern: Alabama, Florida, Georgia, Kentucky, Louisiana, Maryland, Oklahoma, Tennessee, Texas, and Virginia.
Northeast: New Jersey, New York, Ohio, and Pennsylvania.
Western: California, Colorado, Montana, New Mexico, Oregon, Washington, and Wyoming.
Central: Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, and Wisconsin.

Table 4-87. Percent of Operations by Primary Use of Equids Present on January 1, 1998, and Size Class.

Primary Use of Equids	<150 (n=2821)	150 - 499 (n=62)	500+ (n=21)
Pleasure	66.8	9.0	0.0
Showing/competition (not betting)	6.5	4.0	7.3
Breeding	6.0	53.3	0.0
Racing	1.9	13.5	92.7
Farm/ranch	15.2	16.6	0.0
Other	3.6	3.6	0.0
Total	100.0	100.0	100.0

Source: USDA APHIS, 2002b

Table 4-88. Percent of Operations by Primary Use of Equids Present on January 1, 1998, and Size Class.

Primary Function of Operation	<150 (n=2821)	150 - 499 (n=62)	500+ (n=21)
Boarding/training	3.7	17.6	7.3
Racetrack	0.0	6.7	92.7
Breeding farm	5.1	53.6	0.0
Farm/ranch	32.7	17.0	0.0
Residence with equids for personal use	54.7	0.0	0.0
Other	3.8	5.1	0.0
Total	100	100	100

Source: USDA AHPIS, 2002.

4.5.2 Waste Management Practices

Nationally, stalls are provided on two-thirds of operations (does not include race tracks). New England states provide stalls on 94.5 percent of their operations, while about one-half of operations in the western United States provide stalls. For those operations that do provide stalls, 71.3 percent had at least one stall per equid. About one-third (34.5 percent) of those operations with stalls clean them at least once a day, while 50.2 percent clean stalls once a week or less often. Straw, hay, wood shavings, chips, or sawdust are the most common type of bedding. Less than 40 (36.4) percent of operations indicate that they usually or sometimes compost manure or waste bedding on site. For those operations with more than 20 equids, the most common method of disposal was to apply the waste to fields where no animals graze (30.7 percent), followed by applying it to fields where livestock graze (29.7 percent), allowing manure/waste bedding to accumulate or leaving it to nature (15.1 percent), selling it or giving it away (11.5 percent), and hauling it away to someplace other than a landfill (8.9 percent) (USDA APHIS, 1998b).

Horse manure is usually handled as a solid. Many operations collect manure from stalls and paddocks regularly. This is usually done with a fork or shovel and a wheelbarrow, tractor-loader, or trailer. Daily maintenance of horses in a confined setting requires intense labor requirements to maintain sanitary conditions for the housed animals. Once manure and dirty bedding have been removed, wet areas might be treated with lime to maintain safe, clean, and odor-free conditions (Wheeler and Cirelli, 1995). Fresh bedding, typically composed of such materials as pine sawdust, peanut shells, peatmoss, rice hulls, and other absorbent materials, is added following removal of manure and soiled bedding to ensure clean, dry conditions. Simply adding fresh bedding and allowing manure and soiled bedding to accumulate in the horse stall results in dirty animals, provides excellent fly-breeding conditions, and may be unhealthy to horses (Graves, 1987). Depending on conditions, the runoff from paddocks, pens, corrals, and outdoor areas might need to be diverted to a settling basin or filter strip.

Manure management in pastures depends primarily on good distribution of manure across the pasture. Rotational grazing is a good option to avoid manure concentration in isolated spots in a pasture. Additionally, avoiding grazing during rainy periods when soils are saturated is important to avoid soil compaction and manure runoff. Restricted access to streams avoids manure deposition in or near water bodies. Also, damaging the grass stand increases the potential for manure runoff from pastures. The risk of this can be reduced by refraining from excessive stocking rates that lead to overgrazing (Colorado State University, 1996).

4.5.2.1 Waste Storage

Manure is typically stockpiled prior to use, providing greater flexibility for land application. The Government of British Columbia (1998) recommends not to stockpile manure directly on the ground for long-term storage where there is high rainfall or water tables. The size of any storage facility would depend on the number of animals housed. A facility 12 feet wide by 12 feet long by 6 feet high can hold a year's worth of manure for a 1,000-pound animal (USDA, 1997).

For horse operations that employ confined operations, an on-site storage facility is considered the most efficient way to collect and contain manure. Manure storage facilities should receive as much attention and planning as any other aspect of a horse operation (B.C. Government, 1998). Storage facilities are permanent structures designed and operated to contain all manure until it can be applied as a fertilizer or removed for use elsewhere. Basic siting and sizing considerations of storage facilities from the B.C. Government (1998) include the following:

- Located at least 15 meters (50 feet) away from any watercourse and at least 30 meters (100 feet) away from wells or domestic water sources.
- Located so that clean surface runoff from adjacent areas is excluded.
- Sized to provide enough storage to prevent having to spread manure during the fall and winter or at any time runoff is likely to occur.
- Of watertight construction.
- Structurally sound (with possible consideration of professionally engineered designs for both earthen and concrete structures).
- Sized and located to contain all of the runoff expected from local climatic conditions, using figures from the worst precipitation in 25 years.
- Adequately fenced to prevent the accidental entry of humans, animals, or machinery.
- Located out of sight and downwind from public places and neighboring residences (where possible).
- Covered in areas of the province receiving more than 600 millimeters (24 inches) of rainfall between October and April.

4.5.2.2 Waste Treatment and Disposal

For smaller operations, composting is commonly used to treat horse manure. Composting produces a relatively dry end-product that is easily handled and reduces the volume of the manure (40 to 65 percent less volume and weight than the raw material). Ideal conditions for composting include a carbon-to-nitrogen (C:N) ratio between 25:1 and 30:1, a moisture content between 40 and 60 percent, and good aeration. Horse manure as excreted has a C:N ratio of 19:1. With the addition of bedding, the C:N ratio usually increases to a level ideal for composting. Under normal composting conditions, the internal temperature will increase to between 135 °F and 160 °F, killing most pathogens, parasites, and weed seed. Properly constructed and maintained compost piles or windrows will finish composting in as few as 90 days, though the average time is approximately 120 days. When the composting process is complete, the temperature cools naturally.

Compost can be reused on horse pastures. However, experience has shown in the absence of careful management, this practice can spread internal parasites. Composted manure/bedding can also be used as a surface for riding areas when mixed with sand and wood products. Shavings-based stall waste can often be used by nurseries and do not require a complete composting process. Table 4-89 shows the average rates of horse manure application for forages and should follow normal practices for minimizing runoff and leaching that are applicable for all manures.

Table 4-89. Average Manure Application Rates and Area Requirements for Forages.

Forage	Yield (tons/acre)	Horse Manure (tons/acre)	Land Base Needed (acres/horse/yr)
Alfalfa	4	30	0.3
Alfalfa-Grass	4	20	0.4
Bentgrass	2	21	0.4
Big Bluestem	3	10	0.9
Birdsfoot Trefoil	3	25	0.4
Bluegrass	2	19	0.5
Bromegrass	3	19	0.5
Little Bluestem	3	11	0.8
Orchard Grass	4	20	0.5
Red Clover	3	20	0.4
Reed Canary Grass	4	18	0.8
RyeGrass	4	22	0.3
Switchgrass	3	12	0.8

Source: Colorado State University, 1996.

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CHAPTER 5

INDUSTRY SUBCATEGORIZATION FOR EFFLUENT LIMITATIONS GUIDELINES AND STANDARDS

5.0 INTRODUCTION

The Clean Water Act requires EPA to consider a number of different factors when developing Effluent Limitations Guidelines and Standards (ELGs) for a particular industry category. These factors include the cost of achieving the effluent reduction, the age of the equipment and facilities, the processes employed, engineering aspects of the control technology, potential process changes, nonwater quality environmental impacts (including energy requirements), and factors the Administrator deems appropriate. One way EPA takes these factors into account is by breaking down categories of industries into separate classes of similar characteristics. The division of a point source category into groups called “subcategories” provides a mechanism for addressing variations among products, raw materials, processes, and other parameters that result in distinctly different effluent characteristics. Regulation of a category by subcategory ensures that each subcategory has a uniform set of effluent limitations that take into account technology achievability and economic impacts unique to that subcategory.

The factors that EPA considered in the subcategorization of the CAFO point source category include:

- Animal production processes
- Waste management and handling practices
- Wastes and wastewater characteristics
- Waste use practices
- Age of equipment and facilities
- Facility size
- Facility location

EPA evaluated these factors and determined that subcategorization of this point source category is necessary. Based on these evaluations, the CAFO point source category has been divided into four subcategories for the purpose of issuing effluent limitations. These four subcategories are:

- Subcategory A (Subpart A): Horses and sheep

- Subcategory B (Subpart B): Ducks
- Subcategory C (Subpart C): Dairy and beef cattle other than veal calves
- Subcategory D (Subpart D): Swine, poultry, and veal calves

Section 5.1 briefly discusses the background of the subcategorization of the CAFO point source category including the 1974 Feedlots ELG. Section 5.2 discusses the subcategorization basis of the CAFO industry.

5.1 Background

Under the 1974 rulemaking, EPA divided the point source category into two subcategories: (1) Subpart A - all subcategories except ducks, and (2) Subpart B - ducks on dry lots and wet lots. Subcategories addressed under Subpart A include

- Beef cattle, open lot
- Beef cattle, housed lot
- Dairy cattle, stall barn with milk room
- Dairy cattle, free stall barn with milking center
- Dairy cattle, cowyard with milking center
- Swine, open dirt or pasture lots
- Swine, housed with slotted floor
- Swine, open or housed with solid concrete floor
- Chickens, broilers housed
- Chickens, layers (egg production) housed
- Chickens, layer breeding and replacement stock housed
- Turkeys, open lot
- Turkeys, housed lot
- Sheep, open lot
- Sheep, housed lot
- Horses, stables

This subcategorization was developed primarily on the basis of animal type and production processes employed. Secondary criteria were product produced, prevalence of the production process employed, and characteristics of waste produced.

On January 21, 2001 (66 FR 2960), EPA published a proposal to revise and update the ELG for feedlots (beef, dairy, swine, and poultry operations) that included two new subcategories:

- Subpart C: Dairy and beef cattle, other than veal calves, including heifer operations.
- Subpart D: Swine, poultry, and veal calves.

This subcategorization scheme explicitly addressed immature cattle and swine weighing less than 55 pounds, which were not explicitly included in the previous subcategorization scheme, and established new subcategories for swine, poultry, and cattle operations (separate from horses and sheep). The proposal did not affect Subpart B, and retained Subpart A for horses and sheep.

5.2 Subcategorization Basis for the Final Rule

The CAFO industry has changed operational practices considerably in the past few decades since promulgation of the 1974 ELG. During the development of this revised ELG, EPA determined that the basis for subcategorization needed to reflect current industry trends. In developing the final CAFO rule, EPA used information from USDA, industry, EPA site visits, data from EPA enforcement and inspection efforts, and public comments to evaluate each of the statutory factors listed above in Section 5.0 as they affect the current industry. EPA also considered maintaining the basis of subcategorization used in the 1974 ELG and refining the performance expectations for these facilities. Based on these analyses, EPA retained the subcategorization scheme proposed on January 21, 2001. The subcategories are

- Subpart A: Horses and sheep.
- Subpart B: Ducks.
- Subpart C: Dairy and beef cattle, other than veal calves, including heifer operations.
- Subpart D: Swine, poultry, and veal calves.

The remainder of this section discusses the factors considered for the subcategorization of the CAFO industry and those that were selected as the basis of the final subcategories.

5.2.1 Animal Production, Manure Management, and Waste Handling Processes

Production processes in the CAFO industry include all aspects of animal husbandry, animal housing, and type of animal operation. The type of production process, including animal type and housing, was one of the primary levels of subcategorizing the industry in the 1974 ELG. Furthermore, the waste handling and manure management practices at CAFOs are closely tied to housing practices and support the rationale for using these processes as a basis for subcategorization. As discussed in Chapter 4, Large beef feedlots, dairies, and heifer operations typically have outdoor confinement lots where animals are housed for all or at least a portion of their time. Large beef, dairy, and heifer operations keep animals in confinement on outdoor lots and generate and manage both solid manure and liquid process wastewater that are affected by climate, especially precipitation.

More specifically, the majority of Large beef feedlots are open feedlots, which are usually unpaved. These types of operations may use mounds in the pens to improve drainage and provide areas that dry quickly, because dry resting areas improve cattle comfort, health, and feed utilization, all of which contribute to efficient animal weight gain. In open feedlots, protection from the weather is often limited to a windbreak near the fence in the winter and sunshade in the summer; however, treatment facilities and hospital areas for the cattle are usually covered. Animals are fed two or three times daily, so a concrete apron is typically located along feedbunks and around waterers (i.e., heavy traffic areas). Wastes produced from beef feedlots include manure, bedding, spilled feed, and contaminated runoff. Unroofed confinement areas typically have a system for collecting and confining contaminated runoff. The runoff is typically managed in a storage pond and the manure from the open lots is often scraped and stacked into mounds or stockpiles. Beef feedlots typically use a settling basin to remove bulk solids from the liquid waste stream, reducing the volume of solids before the stream enters a storage pond.

The primary function of a dairy is the production of milk, which requires a herd of mature dairy cows that are lactating. In order to produce milk, the cows must be bred and give birth. Therefore, a dairy operation may have several types of animal groups present including calves, heifers, cows that are close to calving, lactating dairy cows, dry cows, and bulls. Animals at dairy operations may be confined in a combination of freestall barns, outdoor dry lots, tie stalls, or loose housing (barns, shades, and corrals). Some animals may be allowed access to exercise yards or open pastures. At dairies, the most common type of housing for lactating cows includes freestalls, dry lots, tie stalls/stanchions, pastures, and combinations of these. Freestalls are the housing systems used by practically all Large dairy operations. The cows are not restrained in the freestalls and are allowed to roam on concrete alleys to the feeding and watering areas. Manure collects in the travel alleys and is typically removed with a tractor or mechanical alley-scraper, by flushing with water, or through slotted openings in the floor (refer to Section 4.3.5 for a more detailed description of waste handling). Dry lots are outside pens that allow the animals some exercise, but do not generally allow them to graze. These milking cows are not likely to spend their entire time in a freestall or on a dry lot, as they need to be milked at least twice a day at a tiestall or in a milking parlor.

Most dairies have both wet and dry waste management systems. The dry waste (manure, bedding, and spilled feed) is typically collected from the housing and exercise areas by tractor scrapers and stored where an appreciable amount of rainfall or runoff does not come in contact with the waste. The wet waste (water from the barn and milking parlor cleaning operations, manure, and contaminated runoff) is typically stored in anaerobic lagoons. Like beef feedlots, dairies tend to use solid separators to remove bulk solids from a liquid waste stream. Waste associated with dairy production includes manure, contaminated runoff, milking parlor waste, bedding, spilled feed, and cooling water. Lactating cows require milking at least twice a day and are either milked in their tie stalls or are led into a separate milking parlor. The milking parlor is typically cleaned several times each day to remove manure and dirt via flushing or hosing and scraping.

Stand-alone, heifer-raising operations provide replacement heifer services to dairies. These heifer operations often contract with dairies to raise heifers for a specified period of time. Heifer-raising operations use two primary methods for raising their animals. One is to raise the cattle on pasture and the second is to raise heifers in confinement. These confined heifer operations tend to raise heifers in the same way that beef feedlots raise their cattle. The heifers are typically housed on unpaved open dry lots. Wastes produced from heifer operations include manure, bedding, and contaminated runoff. Unroofed confinement areas typically have a system for collecting and confining contaminated runoff. The runoff is typically managed in a storage pond and the manure from the open lots is often scraped and stacked into mounds or stockpiles. Heifer operations may also use a settling basin to remove bulk solids from the liquid waste stream.

In all cases, these open lots and outdoor pens expose large surface areas to precipitation, generating large volumes of storm water runoff contaminated with manure, bedding, feed, silage, antibiotics, and other process contaminants. Based on the similarity of the production, housing, and waste management processes for beef feedlots, dairies, and heifer operations, EPA developed a new subcategory, Subpart C, to address these operations under the revised ELG. EPA believes that these operations use similar technologies (e.g., storm water diversion, solid separation) to reduce effluent discharges from production areas given that all of these operations must manage storm water runoff from open lots as well as the storm water that contacts food or silage.

In contrast, nearly all Large swine, poultry, and veal calf operations use total confinement housing. These confinement buildings prevent contact of runoff and precipitation with the animals and manure. Furthermore, these operations are able to manage manure in a relatively dry form, or contain liquid wastes in storage structures such as lagoons, tanks, or under-house pits that are not greatly affected by precipitation. Operations using confinement housing differ most notably from operations using outdoor open lots in that they are constructed, or can be relatively easily configured, in a manner that prevents the generation of large volumes of contaminated storm water runoff. Thus they do not need to manage large, episodic volumes of storm water runoff. At most, operations using total confinement housing need only to manage the precipitation falling directly into manure-handling and storage structures (e.g., lagoon or open tank).

For example, swine operations may be categorized by six facility types based on the life stage of the animal in which they specialize: farrow-to-wean, farrow-nursery, nursery, grow-finish, farrow-to-finish, and wean-to-finish. Many operations have the traditional full range of pork production phases in one facility, known as farrow-to-finish operations. Most nursery and farrowing operations, as well as practically all large operations of any type, raise pigs in pens or stalls in environmentally controlled confinement housing. These houses commonly use slatted floors to separate manure and wastes from the animal. Swine waste includes manure, spilled feed, and water used to clean the housing area or dilute the manure for pumping. Most confinement hog operations use one of three waste handling systems: flush under slats, pit recharge, or deep under-house pits. The flushed manure and manure from pit recharge systems is typically stored in anaerobic lagoons or tanks while deep pit systems store manure under the confinement houses.

Based on the information in Chapter 4 as well as other information in the record, EPA is including operations with immature swine as CAFOs under Subpart D based on their production and waste-handling practices. Immature swine operations were not specifically addressed in the 1974 ELG because immature animals were typically raised at a farrow-to-finish operation and not at a separate operation like today. Although many large operations continue to have the full range of production phases at one facility, these are no longer the norm. Waste from immature operations is often flushed and managed in a lagoon or pit, just like operations that manage mature pigs. Due to the increased construction and reliance on immature swine operations, EPA maintains that these operations should be specifically addressed to ensure protection of surface water quality. Because the immature operations use virtually the same animal production and waste management processes and are expected to use similar effluent reduction practices and technologies as mature swine operations, EPA has included these immature operations under Subpart D.

Poultry operations can be classified into three individual sectors based on the type of commodity in which they specialize. These sectors include operations that breed or raise broilers, or young meat chickens, turkeys and turkey hens; and hens that lay shell eggs (layers). There are two types of basic poultry confinement facilities—those that are used to raise turkeys and broilers for meat, and those that are used to house layers. Both types use total confinement houses. Broilers and young turkeys are grown on floors on beds of litter shavings, sawdust, or peanut hulls, while layers are confined to cages suspended over a bottom story in a high-rise house, or over a pit, or a belt or scrape gutter. The majority of egg-laying operations use dry manure handling but some use liquid systems that flush waste to a lagoon. Poultry waste includes manure, poultry mortalities, litter, spilled water and feed, egg wash water, and also flush water at operations with liquid manure systems. Manure from broiler, breeder, some pullet operations, and turkey operations is allowed to accumulate on the floor where it is mixed with the litter. In the chicken houses, litter close to drinking water access forms a cake that is removed between flocks. The rest of the litter pack generally has low moisture content and is removed every 6 months to 2 years, or between flocks. The removed litter is stored in temporary field stacks, in covered piles, or in stacks within a roofed facility to help keep it dry.

Veal calf operations raise male dairy calves for slaughter. Veal calf are raised almost exclusively in confinement housing, generally using individual stalls or pens. Floors are constructed of either wood slats or plastic-coated expanded metal, while the fronts and sides are typically wood slats. The slotted floors allow for efficient removal of waste. Veal calves are raised on a liquid diet and their manure is highly liquid. Veal calf waste consists of manure, flushing water, and spilled liquid feed. Manure is typically removed from housing facilities by scraping or flushing from collection channels and then flushing or pumping into liquid waste storage structures, ponds, or lagoons. Veal calf manure is typically handled in a liquid waste management system like that used in swine operations and not like the outdoor stockpiled manure at beef feedlots. Veal calf operations maintain their animals in total confinement housing like swine and poultry operations as opposed to the outdoor lots used at most beef feedlots and dairies.

Nearly all Large swine, veal calves, and poultry operations confine their animals under roof, avoiding the use of open animal confinement areas that generate large volumes of contaminated storm water runoff. These operations differ most notably from beef and dairy operations in that they, in most cases, do not have to manage the large volumes of storm water runoff that must be collected at beef and dairy operations. While swine, veal calves, and certain poultry operations that manage wastes in uncovered lagoons must be able to accommodate precipitation, they are largely able to divert uncontaminated storm water away from the lagoons and minimize the volume of wastes they must manage. Furthermore, swine, poultry, and veal calf operations use similar technologies (e.g., reduction of fresh water use, storage of manure in covered or indoor facilities, recycle of flush water) to reduce effluent discharges.

Another basis for subcategorization is the type of production system in place. In the case of CAFOs that means the type of animal operation. For example, EPA considered whether the swine production pyramid of breeding, nursery, and finishing should be used as a basis of subcategorizing swine CAFOs, or whether subcategorization should be based on specific animal breeds, animal weights, type of feed, or other process-specific factors. In evaluating the information in the record, EPA determined there were too many life-cycle variables to allow reasonable subcategorization based on the type of production system, and that segmentation based on these variables was unlikely to result in substantially different effluent characteristics or effluent limitations for each subcategory. For example, such an approach as applied to chickens would result in over a dozen subcategorizations with considerable overlap. Yet the amount of litter and manure nutrients generated in 1 year by six flocks of broilers raised for 49 days each is not significantly different from that generated by seven flocks raised for 42 days (see Chapter 6 for additional information). Furthermore, such an operation could be subject to varying standards at different times of the year. EPA determined segmentation in this fashion would complicate rather than simplify the regulation.

5.2.2 Other factors

EPA analyzed data from USDA, universities, industries, and the literature on manure and waste characteristics for AFOs. Site-specific factors such as animal management, feeding regimens, and manure handling will affect the form and quantity of the final manure and waste products to some degree. However, for a given animal type, there is reasonably consistent manure generation, and similar pollutant generation. See Chapter 6 for more information. EPA considered, but rejected, basing subcategorization on the pollutant content of the wastes, in particular because this would not provide more effective control of CAFO discharges.

During the rulemaking, EPA evaluated subcategorization based on waste characteristics — one based on an expected nutrient content (e.g., P) of the manure or the mass of a particular nutrient. Although EPA believes that setting thresholds based on nutrient content of the manure may encourage the development of reduction strategies, it would not adequately reflect the form of the nutrient present in the manure (i.e., organic or inorganic, soluble fraction). Similarly, using the mass of the nutrient as the basis for subcategorization could possibly encourage manure management and nutrient conservation. See Chapter 2 for a discussion on the merits of P production as a metric for establishing regulatory thresholds. EPA believes using this same approach for subcategorization creates difficulties. For example, such an approach would significantly increase the complexity of identifying CAFOs (e.g., a facility is a CAFO if it produces "x" pounds of P) and cost of implementing the ELG (by requiring rigorous sampling, additional recordkeeping, and more frequent reporting). Furthermore, while some practices can be used to affect manure generation and nutrient outputs, others are only effective for select animal species (such as adding phytase to feed), or may provide limited benefit to overall manure management at the operation (for example, smaller feed pellets increase digestibility and may decrease nutrient excretion in the manure but will also decrease solid-liquid separation efficiency). The nutrient mass excreted can also change based on feeding strategies, feed supplements, and the amount of time elapsed before sampling. See Chapter 8 for more information. These factors make it harder for the CAFO to manage, and difficult for the permitting authorities to implement the regulation. Therefore, EPA rejected both of these approaches due to their limitations, increased costs, and complexity.

EPA considered basing subcategorization on water use practices such as dairy, swine, and layer operations that employ technologies such as flush waste handling systems, deep pits, and scrapers. In considering these practices as a basis for subcategorization, EPA evaluated the cost for these sectors to comply with the various technology options, and concluded that water use practices did not prevent a facility from achieving the performance standards. (However, some technologies and practices for water use/reuse/recycle can be used to substantially reduce costs of certain technology options. See Chapter 8 and the Cost Report for more information.) EPA also determined that a subcategorization scheme based on water use practices could, in some cases, provide a disincentive for a facility to reduce fresh water consumption. Therefore, EPA did not select water use practices as a basis for subcategorization.

EPA evaluated the age of facilities as a possible means of subcategorization because older facilities may have different processes and equipment that could require the need for different or more costly control technologies to comply with regulations. EPA conducted site visits and consulted with EPA regions, enforcement officials, land grant and extension experts, and industry to collect information about AFOs and waste management practices. Specifically, EPA visited more than 115 beef feedlots; dairies; and swine, poultry, and veal calf operations throughout the United States. EPA visited a wide range of operations; including those demonstrating new and innovative technologies as well as old and new facilities were visited. EPA's analyses and site visits indicate that older facilities are similar to new facilities in a number of ways. Through retrofitting, expansions, and desire to maximize animal production, many older facilities have implemented technologies and practices used by the newer facilities in order to remain competitive. Even though confinement housing may have a 20- to 30-year useful life, modifications are continuously made to the internal housing structures at CAFOs such as replacement of floor materials, installation of new feeding systems, and improvements to drinking water equipment. These improvements and modifications are even more apparent at operations that have expanded the size of the facility. For example, many wet layer operations are retrofitting to dry manure systems, few, if any, Large swine facilities use open lots, and beef feedlots are diverting clean storm water away from the feedlot and manure storage areas. These and other examples of modifications are documented in the record (See W-00-27, Section 5.3). EPA determined that the age of the facility does not have an appreciable impact on the wastewater characteristics, especially the total amount of nutrients to be managed, and was not considered as a basis for subcategorization.

EPA also considered subcategorization on the basis of facility size and analyzed several size groups for each major livestock sector. Within each size group, EPA considered the predominant practices, and developed cost models to reflect these baseline practices. EPA found that all Large CAFOs used similar practices, though the smaller the operation, the more diverse the range of practices employed. EPA also determined that farm size did not consistently influence the ability of the operation to achieve the desired performance standards for each technology option. Additionally, EPA did not find that CAFO size consistently influenced the ability of the facilities to achieve the performance standards for each technology option (see the Economic Analysis document for more information on impacts). Finally, pollution potential from all AFOs within a broad size range is approximately the same per unit of animal production for all sizes of facilities. Therefore, to minimize confusion, potential inconsistencies, and administrative burden, EPA determined that the ELG applies to anyone defined as a Large CAFO and did not select to subcategorize further on the basis of facility size.

With respect to geographic location, EPA analyzed key production regions for each major livestock sector and considered the predominant practices within each of these regions. Next EPA identified different treatment, storage, and handling practices based on geographic location, and developed cost models to reflect these baseline practices. EPA acknowledges that geographic considerations, especially temperature and rainfall, may affect manure storage and handling, yet the practices employed by the industry do not vary considerably within a region. For example, while pits or lagoons may be used with different frequencies in any given region, these two technologies are used all over the country. EPA could not draw clear distinctions for each locale that would form a basis for subcategorization. Furthermore, EPA's cost analysis shows location does not prevent an operation from meeting the performance standards. See the Cost Report for more information. Therefore, there is no need to develop subcategorization by location. This is further supported by reported compliance rates by each EPA region; compliance did not vary by region. Therefore, EPA concludes subcategorization by location is difficult to implement, largely impractical, and, even if selected, would not provide for additional control of discharges.

EPA also evaluated pollution-control technologies currently being used by the industry as a basis for establishing regulations. The treatability of waste was not a factor for categorization since wastes from CAFOs are concentrated and present in such quantities that no direct discharge from the production area is currently allowed. Pollution-control technologies are often complementary to or directly part of the production or manure management process, therefore the rationale for using such processes as a basis for subcategorization is further supported by the potential use of pollution-control technologies as a basis for subcategorization. However, EPA believes that the use of pollution-control technologies only to segment the industry may result in disincentives for new and innovative treatment technologies, especially the transfer of technologies between animal sectors (for example, the recent application of high-rise housing to swine operations, a technology well established by layer hen operations). Although the current use of pollution-control technologies did assist EPA in identifying the best management practices addressed in the final ELG, EPA did not believe pollution-control technologies would serve as a better basis for subcategorization than the production of manure management processes.

Finally, EPA evaluated whether Nonwater Quality Impacts (NWQIs) could form a basis for subcategorization. NWQIs include changes in air emission and energy use at CAFOs such as those resulting from transportation of manure and wastes to off-site locations, and emissions of volatile organic compounds to the air. See the NWQI report for additional information. While NWQIs are of concern to EPA, the impacts are the result of individual facility practices and do not apply uniformly to different industry segments. To the extent there are similarities, these similarities do not lend themselves towards subcategorization of the industry in a way that provides better controls than the proposed approach. Therefore, NWQIs are not an appropriate basis for subcategorization.

CHAPTER 6

WASTEWATER CHARACTERIZATION AND MANURE CHARACTERISTICS

6.0 INTRODUCTION

This chapter describes waste streams generated by the animal feeding industry. Differences in waste composition and generation between animal types within each sector are highlighted.

The types of animal production and housing techniques determine whether the waste will be managed as a liquid, semisolid, or solid (Figure 6-1).The type of manure and how it is collected has a direct impact on the nutrient value of the waste, its value as a soil amendment, or other uses.

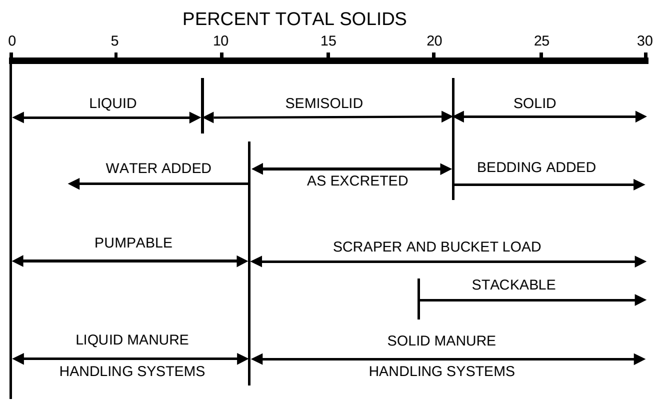

Figure 6-1.Manure characteristics that influence management options (after Ohio State University Extension, 1998).

6.1 Swine Waste

Swine waste contains numerous chemical and biological constituents such as nutrients, heavy metals, and pathogens that can potentially contaminate the environment. The composition of swine waste and the rate of its excretion by the pig varies with the stage of physical development, the pig's gender, and for females, whether she is farrowing. As noted in Chapter 4, during the course of their life cycle, pigs receive up to six different diets to maximize growth at each stage of physical development. Each diet is composed of a unique mix of nutrients and minerals, and these different diets are reflected in the different composition of manure generated.

Swine waste also undergoes physical and chemical changes after it has been excreted by the pig. For example, swine waste volume and composition change after the waste becomes mixed with water, feed, and bedding materials. Furthermore, microbial activity alters the chemical makeup of the waste by metabolizing organic matter and generating chemical by-products. Additional chemical changes can occur depending on how the waste is stored and whether it is treated.

For swine operations, typical manure-handling practices are designed to produce either a liquid or a semisolid. Thus, the nutrient component of manure usually becomes more dilute because of the addition of water used to aid in collection of the manure. In addition, ammonia volatilization reduces nitrogen (N) concentrations in both liquid and dry manure-handling systems. Phosphorus (P) concentrations increase in manure that is handled dry because the water content decreases.

As discussed in Chapter 4, swine manure is typically collected and stored by means of pit storage, lagoons, or a combination of the two. Most lagoons operate anaerobically. Aerated lagoons have received less attention because of their higher costs; however, their potential for decreased odor might increase their use. Svoboda (1995) achieved N removal, ranging from 47 to 70 percent (depending on aeration), through nitrification and denitrification in an aerobic treatment reactor using whole pig slurry. The proportion of P and potassium (K) typically remaining after storage is higher than N. However, up to 80 percent of the P in lagoons is found in the bottom sludge versus the water fraction (MWPS, 1993).

Jones and Sutton (1994) analyzed manure nutrient content in liquid manure pit and anaerobic lagoon samples just before land application. On a mass basis for pit storage, N decreases ranged from 11 to 47 percent; P, 9 to 67 percent; and K, 5 to 42 percent. In the water fraction of lagoons, N decreases ranged from 76 to 84 percent; P, 78 to 92 percent; and K, 71 to 85 percent. Nitrogen decreases in these two storage systems were primarily due to volatilization, whereas P and K decreases were due to accumulation in sludge. Boland et al. (1997) found that for deep pit systems almost four times as much land was needed when applying manure based on P rather than N, 2.5 times for tank storage, and 1.7 times for lagoon systems. These differences can be attributed to less ammonia volatilization in deep pit systems, and solids settling in lagoons.

A field study of Missouri swine lagoon surface-to-volume ratios found that large swine lagoons have significantly higher total N concentrations than small lagoons. This finding suggests that nutrient concentrations, and thus land application, of treated swine manure should be based on the design and performance characteristics of the lagoon rather than on manure production alone (Fulhage, 1998).

The use of evaporative lagoon systems has increased in arid regions. These systems rely on evaporation to reduce wastewater with pollutants accumulating in the lagoon sludge. This approach results in reduced or no land application of wastes. For example, due to a lack of adequate land disposal area in Arizona, Blume and McCleve (1997) increased the evaporation of wastewater from a 6,000-hog flush/lagoon treatment system by spraying the wastewater into the air. Although information on volatilization was not available, the evaporative increase from spraying and pond evaporation, versus pond evaporation alone, was 51 percent.

The following sections characterize swine waste in terms of generation rates, and chemical and biological contaminants. Differences between swine types and operations and changes to the waste after it leaves the pig are also characterized.

6.1.1 Quantity of Manure Generated

Table 6-1 shows the quantity of manure generated by different types of swine. Variation in these quantities can be attributed to different ages and sizes of animals within a group (USDA, 1992). Manure production can also vary depending on the digestibility of feed rations. For example, corn, which is 90 percent digestible, results in less total solids in manure than a less digestible feed such as barley, which is 70 percent digestible (USDA, 1992).

Table 6-1. Quantity of Manure Excreted by Different Types of Swine.

Type of Swine	Manure Mass (lb/yr/1,000 lb of animal mass)			
	Maximum Reported	Minimum Reported	USDA 1998 Value	
Grower-Finisher	44,327[a]	14,600[a]	Grower-Finisher 29,380[d]	Farrow to Finish 38,940[e]
Replacement Gilt	29,872[a]	11,972[a,b]		
Boar	31,527[a]	7,483[b]	Farrow 12,220[d]	
Gestating Sow	18,250[a]	9,928[b]		
Lactating Sow	32,120[a]	21,900[a,b]		
Sow and Litter	21,900[c]	21,900[c]		
Nursery Pig	54,142[a]	23,981[c]	---	

[a]NCSU, 1994.
[b]USDA, 1992.
[c]MWPS, 1993.
[d]USDA, 1998.
[e]Adapted from USDA, 1998.
---Not available.

As described in Chapter 3, there are three stages of swine production—farrow, nursery, and grower-finisher. Some swine operations encompass all three stages, whereas others specialize in just one. This section discusses the type of animal included in each operation and summarizes data on the quantity of manure produced by different operations.

Farrowing Operations

Farrowing operations include boars, gestating sows, lactating sows, and the sows' litters. Newborn pigs remain at the farrowing facility until they are weaned, which typically takes 3 to 4 weeks. Lactating sows and their litters produce the most manure, whereas boars produce the least. Manure production values for 1,000 lbs of animal in a farrowing operation range from 7,483 (USDA, 1992) to 32,120 lb/yr (NCSU, 1994), as shown in Table 6-2.

Nursery Operations

After farrowing and weaning, young pigs are moved to a nursery, when they reach approximately 15 pounds. They remain in the nursery for 7 to 8 weeks until they weigh approximately 60 pounds and are then transferred to a grower-finisher operation. Nursery pigs produce manure at rates of 23,981 (MWPS, 1993) to 54,142 lb/yr per/1,000 lbs of animal (NCSU, 1994) (Table 6-2).

Table 6-2. Quantity of Nitrogen Present in Swine Manure as Excreted.

	Nitrogen (lb/yr/1,000 lb of animal mass)		
Operation Type	**Maximum Reported**	**Minimum Reported**	**USDA 1998 Value**
Farrow to Finish	NA	NA	220.0[c]
Grower-Finisher	228.8[a]	87.6[b]	166.0[d]
Farrow	214.0[a]	54.8[b]	81.0[d]
Nursery	224.1[a]	134.0[a]	—

[a]NCSU, 1994.
[b]USDA, 1992.
[c]Adapted from USDA, 1998.
[d]USDA, 1998.
NA Not available.

Grower-Finisher Operations

In a finishing operation pigs are raised to market weight, which is approximately 240 to 280 pounds. This third stage of swine production is typically 15 to 18 weeks long, after which finished hogs are sent to market at approximately 26 weeks of age. A grower-finisher operation raises pigs over a relatively long period of time, during which their weight changes substantially. This weight change affects the quantity of manure produced (USDA, 1992). Values for manure production from growing-finishing pigs range from 11,972 (USDA, 1992) to 44,327 lb/yr per 1,000 lbs of animal (NCSU, 1994) (Table 6-2).

Farrow-to-Finish Operations

A farrow-to-finish operation includes all three stages of swine production. Because of the large variability in animal types presented in this type of operation, manure production values vary widely, from 7,483 lb/yr per/1,000 lbs of animal for boars (USDA, 1992) to 54,142 lb/yr per 1,000 lbs of animal for nursery pigs (NCSU, 1994) (Table 6-1).

6.1.2 Description of Waste Constituents and Concentrations

Swine waste contains substantial amounts of N, P, K, pathogens, and smaller amounts of other elements and pharmaceuticals. This section provides a summary of the constituents of swine waste as reported in the literature. There is significant variability in the generation rates presented below. This variability can be attributed to different nutritional needs for swine in the same operation type (e.g., sows and boars), and for swine of different ages and sizes grouped in the same operation. Also, as shown earlier in Table 6-1, different types of swine produce different quantities of manure.

Nitrogen

Nitrogen is usually measured as total N or as total Kjeldhal nitrogen (TKN). Although TKN does not include nitrate-nitrogen (NO_3-N), it may be considered equal to total N because NO_3-N is present only in very small quantities in swine manure (0.051 to 1.241 lb/yr per 1,000 lbs of animal) (NCSU, 1994; USDA, 1998). Published values for N production in swine manure range from 54.8 (USDA, 1992) to 228.8 lb/yr per 1,000 lbs of animal (NCSU, 1994), as shown in Table 6-2. In general, boars produce the least amount of N per 1000 pounds of animal, and grower-finisher pigs produce the most.

Phosphorus

The quantity of P excreted in swine manure for different types of swine operations is shown in Table 6-3. Phosphorus content ranges from 18.3 (USDA, 1992) to 168.2 lb/yr per 1,000 lbs of animal (NCSU, 1994)—boars excrete the least amount of P in manure per 1000 pounds of animal, whereas grower-finisher pigs excrete the most.

Table 6-3. Quantity of Phosphorus Present in Swine Manure as Excreted.

Operation Type	Phosphorus (lb/yr/1,000 lb of animal mass)		
	Maximum Reported	Minimum Reported	USDA 1998 Value
Farrow to Finish	NA	NA	64.1[d]
Grower-Finisher	168.2[a]	29.2[b]	48.3[e]
Farrow	68.3[a]	18.3[b]	26.2[e]
Nursery	93.4[a,b]	54.6[c]	—

[a]NCSU, 1994.
[b]USDA, 1992.
[c]MWPS, 1993.
[d]Adapted from USDA, 1998.
[e]USDA, 1998.
NA Not available.

Potassium

Table 6-4 shows the range of measured K quantities in manure for each type of swine operation. Boars produce the least amount of K at 36.50 lb/yr per 1,000 lbs of animal (USDA, 1992), whereas grower-finisher pigs produce the most at 177.4 lb/yr per 1,000 lbs of animal (NCSU, 1994).

Table 6-5 shows differences in the quantity of nutrients in manure at different stages of storage and handling. The data show a decrease in nutrient quantities from a manure slurry, which is untreated, to lagoon liquid and finally to secondary lagoon liquid. Lagoon sludge contains less N and K but more P, than lagoon liquid , because tends to be associated with the particulate fraction of manure, and N and K are usually in dissolved form. Table 6-6 shows the percent of manure nutrient content as excreted that is retained using different manure management systems. Table 6-7 shows manure nutrient concentrations in pit storage and anaerobic lagoons.

Table 6-4. Quantity of Potassium Present in Swine Manure as Excreted.

Operation Type	Potassium (lb/yr/1,000 lb of animal mass)		
	Maximum Reported	Minimum Reported	USDA 1998 Value
Farrow to Finish	NA	NA	154.79[d]
Grower-Finisher	177.4[a]	47.45[b]	116.79[e]
Breeder	136.6[a]	36.50[b]	47.96[e]
Nursery	130.6[a]	103.88[c]	---

[a]NCSU, 1994.
[b]USDA, 1992.
[c]MWPS, 1993.
[d]Adapted from USDA, 1998.
[e]USDA, 1998.
NA Not available.

Table 6-5. Comparison of Nutrient Quantity in Manure for Different Storage and Treatment Methods.

Nutrient	Mean Quantity in Manure (lb/yr/1000 lb of animal mass)					Land-Applied Quantity After Losses[b]	
	Paved Surface Scraped Manure[a]	Liquid Manure Slurry[a]	Anaerobic Lagoon Liquid[a]	Anaerobic Secondary Lagoon Liquid[a]	Anaerobic Lagoon Sludge[a]	Farrow	Grower
Nitrogen	137.65	164.44	34.71	28.79	6.57	20.29	17.23
Phosphorus	61.05	51.28	6.06	4.47	6.18	22.12	17.11
Potassium	79.81	78.20	29.84	23.13	1.46	43.01	43.75

[a]NCSU, 1994.
[b]USDA, 1998.

Table 6-6. Percent of Original Nutrient Content of Manure Retained by Various Management Systems.

Management System	Nitrogen	Phosphorus	Potassium
Manure stored in open lot, cool humid region.	55-70	65-80	55-70
Manure liquids and solids stored in an uncovered, essentially watertight structure.	75-85	85-95	85-95
Manure liquids and solids (diluted less than 50%) held in waste storage pond.	70-75	80-90	80-90
Manure stored in pits beneath slatted floor.	70-85	90-95	90-95
Manure treated in anaerobic lagoon or stored in waste storage pond after being diluted more than 50%.	20-30	35-50	50-60

Source: Adapted from Jones and Sutton, 1994.

Metals and Other Elements

Other elements present in manure include the micronutrients calcium, chlorine, magnesium, sodium, and sulfur; and heavy metals such as arsenic, cadmium, iron, lead, manganese, and nickel. Many of these elements are found in swine feed; others, such as heavy metals, are found in pharmaceutical feed additives. Table 6-8 shows the range of quantities of these elements in manure as excreted, after storage, at different stages of treatment, and when it is land applied.

Swine manure contains many kinds of bacteria, several of which are naturally present in the digestive systems of the animals. Others are in the pigs' general environment and can be ingested but are not a necessary component of digestion. Table 6-9 presents a summary of measured values of these bacteria in swine manure as excreted, and at various stages of treatment.

Table 6-7. Nutrient Concentrations for Manure in Pit Storage and Anaerobic Lagoons for Different Types of Swine.

Animal Type	Manure Produced 1000 gal/yr	Nitrogen (N) lb N/1000 gal/yr	Phosphorus (P) lb P/1000 gal/yr	Potassium (K) lb K/1000 gal/yr
Pit Storage				
Grower-Finisher	0.53	32.75	11.55	22.41
Lactating Sow	1.4	15.00	5.25	9.13
Gestating Sow	0.5	25.00	13.55	22.41
Nursery	0.13	25.00	8.44	18.26
Anaerobic Lagoon				
Grower-Finisher	0.95	5.60	1.639	3.486
Lactating Sow	2.10	4.10	0.874	1.660
Gestating Sow	0.90	4.40	1.857	3.320
Nursery	0.22	5.00	1.398	2.656

Source: Adapted from Jones and Sutton, 1994.

Table 6-8. Comparison of the Mean Quantity of Metals and Other Elements in Manure for Different Storage and Treatment Methods.

Element	Quantity produced in manure (lb/yr/1000 lb animal mass)					
	As Excreted	Paved Surface Scraped Manure[a]	Liquid Manure Slurry[a]	Anaerobic Lagoon Liquid[a]	Anaerobic Secondary Lagoon Liquid[a]	Anaerobic Lagoon Sludge[a]
Aluminum	1.340[a]	0.797	3.289	0.176	---	---
Arsenic	0.252[a]	---	0.003	0.004	---	---
Boron	1.132[b]-1.232[a]	0.239	0.086	0.042	0.037	0.004
Cadmium	0.010[a,b]	0.001	0.002	0.002	---	0.001
Calcium	120.45[b]-121.468[a]	117.932	48.433	7.547	6.459	6.373
Chlorine	93.335[a]-94.9[b]	90.615	27.073	18.571	---	0.378
Cobalt	0.014[a]	0.013	---	0.002	---	---
Copper	0.437[a]-0.438[b]	0.960	0.665	0.073	0.036	0.082
Chromium	---	---	---	---	---	0.007
Iron	5.84[b]-6.606[a]	16.858	4.643	0.486	0.292	0.713
Lead	0.030[a]-0.031[b]	0.019	---	0.033	---	0.007
Magnesium	25.55[b]-27.064[a]	33.766	16.884	2.461	1.587	1.837
Manganese	0.640[a]-0.694[b]	4.573	0.790	0.055	0.022	0.082
Molybdenum	0.010[a,b]	0.001	---	0.001	---	0.003
Nickel	0.029[a]	0.048	0.016	0.130	---	0.003
Selenium	---	---	---	0.000	---	---
Sodium	23.980[a]-24.455[b]	24.536	18.148	10.396	---	0.536
Sulfur	27.192[a]-27.74[b]	24.791	14.702	2.089	1.542	1.333
Zinc	1.825[b]-1.855[a]	2.414	2.210	0.191	0.036	0.212

[a]NCSU, 1994.
[b]ASAE, 1998.
NA Not available.

Table 6-9. Comparison of the Mean Concentration of Pathogens in Manure for Different Storage and Treatment Methods.

Type of Bacteria	Quantity Present in Manure (bacterial colonies per pound of manure)				
	Manure As Excreted	Paved Surface Scraped Manure	Liquid Manure Slurry	Anaerobic Lagoon Liquid	Anaerobic Lagoon Sludge
Enterococcus bacteria	3.128E+09	1.395E+09	3.839E+09	1.232E+06	---
Escherichia coliform bacteria	4.500E+07	5.400E+07	1.302E+08	---	---
Facultative bacteria	---	5.400E+11	5.164E+11	---	---
Fecal coliform bacteria	1.106E+09	4.800E+08	1.777E+07	2.502E+06	---
Fecal streptococcus bacteria	2.873E+10	---	2.276E+07	2.285E+06	---
Streptococcus bacteria	1.980E+08	2.205E+10	1.995E+10	---	---
Total aerobic bacteria	---	2.745E+11	1.269E+11	---	---
Total anaerobic bacteria	---	5.400E+11	1.092E+11	---	---
Total bacteria	---	---	---	3.885E+08	7.769E+09
Total coliform bacteria	2.445E+09	1.598E+09	9.551E+07	1.083E+07	---

Source: NCSU, 1994.
NA Not available.

Pharmaceuticals

To promote growth and to control the spread of disease, antibiotics and other pharmaceutical agents are often added to feed rations. Many of these chemicals are transformed or broken down through digestion and their components are excreted in manure. Table 6-10 lists several common pharmaceuticals added to swine feed and their frequency of use as reported in *Swine '95 Part I: Reference of 1995 Swine Management Practices* (USDA APHIS, 1995).

Table 6-10. Type of Pharmaceutical Agents Administered in Feed, Percent of Operations that Administer them, and Average Total Days Used.

Antibiotic/Agent in Feed	Percent Operations	Standard Error	Average Total Number Days	Standard Error
Chlortetracycline/Sulfathiazole/Penicillin	6.7	2.1	33.8	5.3
Chlorotetracycline/Sulfamethazine/Penicillin	6.4	2.0	23.6	3.6
Tylosin/Sulfamethazine	4.8	2.1	45.6	4.1
Carbadox	12.4	2.5	31.2	2.1
Lincomycin	4.3	1.4	60.3	17.6
Apramycin	2.8	1.2	50.9	22.7
Chlortetracycline	41.1	4.0	58.1	4.6
Oxytetracycline	9.6	2.2	39.2	6.6
Neomycin/Oxytetracycline	10.4	3.0	55.3	14.6
Tylosin	30.4	3.7	57.4	5.1
Bacitracin (BMD)	52.1	4.1	72.2	4.0
Virginiamycin	3.8	1.3	65.1	11.6
Zinc oxide	5.0	2.1	81.2	22.9
Copper sulfate	6.1	1.9	62.8	11.3
Other	4.6	2.2	97.6	11.8

Source: USDA APHIS, 1995.

Physical Characteristics

Tables 6-11 and 6-12 list several characteristics of swine manure as excreted by pigs, classified by different operation types, and with different types of storage and treatment methods.

Table 6-11. Physical Characteristics of Swine Manure by Operation Type and Lagoon System.

Characteristic	Physical Characteristics in Swine Manure (lb/yr/1000 lb unless otherwise noted)						
	Grower-Finisher as Excreted	**Farrow as Excreted**	**Farrow Finish as Excreted**	**Liquid Manure Slurry[b]**	**Anaerobic Lagoon Sludge[b]**	**Anaerobic Lagoon Liquid[b]**	**Anaerobic Secondary Lagoon Liquid[b]**
Manure	11,972[a]–33,830[b]	7,483[a]–27,313[b]	7,483[a]–39,586[b]	6,205	270	7,381	7,381
Urine	42.1[b]–49.0[b]	---	39.0[b]–74.0[b]	---	---	---	---
Density (lb/ft^3)	61.8[b]–62.8[b]	---	61.3–62.8	8.4	8.9	8.4	8.35
Moisture (%)	90[a]–91[a]	90[a]–97[a]	90[a]–97[a]	---	92[a]	100[a]	---
Total solids	3.28[a]–6.34[a]	1.9[a]–6.0[a]	1.9[a]–11.0[a]	---	7.60%[c]	0.25%[c]	---
Total dissolved solids	1.29[a]	---	1.29[a]	---	---	---	---
Volatile solids	2.92[a]–5.40[a]	1.00–5.40	1.00–8.80	---	379.89 [c] lb/1000 gal	10.00 [c] lb/1000 gal	---
Fixed solids	0.36[a]–0.94[a]	0.30[a]–0.60[a]	0.30[a]–1.80[a]	---	253.27 [c] lb/1000 gal	10.83 [c] lb/1000 gal	---
C:N ratio	6[a]–7[a]	3[a]–6[a]	3[a]–8[a]	---	8[a]	---	2[a]

[a]USDA, 1992.
[b]NCSU, 1994.
[c]USDA, 1996.
C Carbon

Table 6-12. Physical Characteristics of Different Types of Swine Wastes.

Physical Characteristic	lb/yr/1000 lb	lb/ 1000 gallons	
	Paved Surface Scraped Manure[a]	**Feedlot Runoff Water[b]**	**Settling Basin Sludge[b]**
Manure	21,089	---	---
Density (lb/ft^3)	62.4	---	---
Moisture (%)	---	98.50	88.8
Total solids	---	1.50	11.2

[A]NCSU, 1994
[b]USDA, 1996

6.2 Poultry Waste

Poultry wastes differ in composition between the three bird types addressed in this document — layers, broilers, and turkeys. Each bird type is raised for a specific role and is provided with a diet tailored to its nutritional needs. Hence, layers are fed diets to maximize egg production, whereas broilers are fed diets to promote growth and development. Within each subsector, however, variation in manure composition as excreted is quite small due to the high degree of integration, use of standardized feed, and total confinement (USEPA, 1999). However, there are differences in composition and quantity generated between operations due to variations in length and type of manure storage employed by the operation.

Broilers and turkeys have similar production regimes in terms of manure production, manure handling, and nutrient recovery. The floor of the house is covered with a bedding material that absorbs liquid. During the growth of the flock, continuous air flow removes ammonia and other gasses resulting in lower N content of the litter (manure and bedding). Another result of continuous air flow is a reduction in the moisture content of the litter over that of freshly excreted manure.

Manure produced by the laying industry typically includes no bedding. Two main types of manure handling are handling as excreted manure (with no bedding), and water-flushed collection. In high-rise cages or scrape-out/belt systems, manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored. Nutrients are more concentrated without bedding than with bedding. Flushing layer manure with water results in diluted nutrient concentrations, but increases the amount of waste that must be disposed.

As shown in Table 6-13, manure generation rates differ considerably between layers and broilers. The maximum reported generation rate for broilers is over 30 percent greater than for layers. Pullets have the lowest generation rate — almost half the rate of manure production for broilers, and only 70 percent of the production rate for layers.

Table 6-13. Quantity of Manure Excreted for Broilers.

Manure Mass (lb/yr/1,000 lb of animal mass)		
Minimum Reported	**Maximum Reported**	**USDA 1998 Value**
25,550[a]	31,025[b]	29,940[c]

[a]MWPS, 1993.
[b]ASAE, 1998.
[c]USDA, 1998.

6.2.1 Broiler Waste Characteristics

6.2.1.1 Quantity of Manure Generated

Manure production is frequently presented as volume or weight of manure produced per 1,000 pounds of animal mass. There is significant variation between the minimum and maximum reported values for manure generation in broilers. Table 6-13 contains the minimum, maximum, and 1998 USDA reported values for manure generation rates for broilers. The 1998 USDA reported values were used in EPA's analyses.

6.2.1.2 Description of Waste Constituents and Concentrations

Broiler waste contains N, P, K, and smaller amounts of other elements and pathogens. This section provides a summary of the constituents of broiler manure and litter as reported in the literature.

Table 6-14 shows selected physical and chemical characteristics for broiler manure as excreted, and after application of different storage practices. Manure quantity decreases under dry storage practices, especially when stored as a manure cake.

Table 6-14. Consistency of Broiler Manure as Excreted and for Different Storage Methods.

	Physical Characteristics of Manure (lb/yr/1,000 lb of animal mass unless otherwise noted)					
Physical Characteristic	**As Excreted**	**Broiler Litter[d]**	**Broiler House Litter[c]**	**Broiler House Manure Cake[c]**	**Broiler Litter Stockpile[c]**	**Broiler-Roaster House Litter[c]**
Manure/Litter	25,550[a]–31,025[b]	12,775	7,449	2,364	6,733	5,710
Density	63.0a–63.7[c]	---	31.7	34.3	33.1	29.0
Moisture	75d	24	---	---	---	---
Total solids	7,300d–8,030[b]	9,673	5,857	1,429	4,083	4,349
Volatile solids	5,475d–8,030[a]	7,811	4,666	1,110	2,903	3,349
Fixed solids	1,825[d]	1862	---	---	---	---
C:N ratio	8[d]	9	---	---	---	---

[a]ASAE, 1998.
[b]MWPS, 1993.
[c]NCSU, 1994.
[d]USDA, 1992.

Broilers excrete numerous nutrients including N, P, and K. As shown in Table 6-15, N is excreted at the highest rate of the three nutrients. In general, broilers produce more N and K per pound of bird than do layers, although K production rates are nearly equivalent on a time-averaged basis (USDA, 1998). These levels are altered when manure is stored or treated. Liquid manure volumes and nutrient concentrations are presented in Table 6-16 for raw and stored manure. Table 6-17 shows nutrient production as excreted and after loses. Storage as a manure cake significantly reduces nutrient content, especially N. Table 6-18 shows metals in broiler manure as excreted and for different storage and treatment methods. Microbial populations are very active in broiler litter and include enterococcus, fecal coliform, salmonella, and streptococcus. Table 6-19 shows bacteria levels per pound of manure.

Table 6-15. Nutrient Quantity in Broiler Manure as Excreted.

Nutrient	Quantity Present in Manure (lb/yr/1,000 lb of animal mass)		
	Minimum Reported	Maximum Reported	Time-Averaged Value
Nitrogen	310.25[a]	401.50b,[c]	401.65[e]
Phosphorus	71.68[a]	124.10[b]	116.77[e]
Potassium	139.27[d]	167.90[b]	157.04[e]

[a]MWPS, 1993.
[b]USDA, 1992.
[c]ASAE, 1998.
[d]NCSU, 1994.
[e]USDA, 1998.

Table 6-16. Broiler Liquid Manure Produced and Nutrient Concentrations for Different Storage Methods.

Storage Method	Manure Produced (1000 gal/yr)	Nutrient Concentration (lb nutrient/1000 gal)		
		Nitrogen	Phosphorus	Potassium
Raw manure	0.006	130.4	36.3	44.3
Pit storage [a]	0.010	63.00	17.48	24.07
Anaerobic lagoon storage [b]	0.016	8.50	1.88	2.91

Source: MWPS, 1993 as presented by Jones and Sutton, 1994.
[a] Includes dilution water.
[b] Includes rainfall and dilution water.

Table 6-17. Nutrient Quantity in Broiler Manure Available for Land Application or Utilization for Other Purposes

Nutrient	Quantity Present in Manure As Excreted and After Losses (lb/yr/1,000 lb of animal mass)	
	As Excreted	After Losses[a]
Nitrogen	410.6	241.0
Phosphorus	116.8	99.0
Potassium	157.0	141.9

Source: USDA NRCS, 2000.
[a] Manure nutrient losses during collection, storage, treatment, and transfer include volatilization of nitrogen, spillage, and manure nutrients carried from the confinement facilities by rainfall and runoff. Only waste treatment technologies that are in common practice were considered in estimating these losses.

Table 6-18. Quantity of Metals and Other Elements Present in Broiler Manure as Excreted and for Different Storage Methods.

Element	Quantity Present in Manure and Litter (lb/yr/1,000 lb of animal mass)				
	As Excreted	Broiler House Litter[a]	Broiler House Manure Cake[a]	Broiler Litter Stockpile[a]	Broiler-Roaster House Litter[a]
Aluminum	---	4.901	---	---	---
Arsenic	---	0.176	---	---	---
Barium	---	0.148	---	---	---
Boron	0.795[a]	0.211	0.052	0.131	0.133
Cadmium	0.017[a]	0.012	0.002	0.001	0.014
Calcium	136.626[a]–149.650[b]	158.424	40.197	212.888	117.184
Chlorine	296.537[a]	47.694	---	51.803	---
Cobalt	---	0.007	---	---	---
Copper	0.331[a]–0.358[b]	1.984	0.481	0.968	1.389
Chromium	---	0.566	0.185	0.006	0.942
Iron	29.509[a]	4.381	1.420	5.991	4.553
Lead	0.033[a]	0.151	0.054	---	0.204
Magnesium	50.336[a]–54.750[b]	32.871	8.225	27.596	24.046
Manganese	2.378[a]	2.957	0.815	2.344	2.170
Mercury	---	0.001	---	---	---
Molybdenum	0.134[a]	0.003	0.001	0.002	0.002
Nickel	0.111[a]	0.427	0.217	0.008	0.352
Selenium	---	0.002	---	---	---
Silicon	---	5.323	---	---	---
Sodium	50.336[a]–54.750[b]	48.668	12.390	22.290	37.143
Strontium	---	0.339	---	---	---
Sulfur	28.763[a]–31.025[b]	45.749	10.876	33.892	39.229
Zinc	1.208[a]–1.314[b]	2.652	0.713	2.112	1.932

[a]NCSU, 1994.
[b]ASAE, 1998.

Table 6-19. Concentration of Bacteria in Broiler House Litter.

Parameter	Concentration of Bacteria (bacteria colonies/lb manure)
Total bacteria	4.775E+11
Total coliform bacteria	2.285E+06
Fecal coliform bacteria	7.758E+06
Streptococcus bacteria	6.728E+09
Salmonella	2.048E+06
Total aerobic bacteria	7.107E+09

Source: NCSU, 1994.

6.2.2 Layer Waste Characteristics

6.2.2.1 Quantity of Manure Generated

Manure production is frequently presented as volume or weight of manure produced per 1,000 pounds of animal mass. There is less variation between the minimum and maximum reported values for manure generation in layers than in broilers. Table 6-20 contains the minimum, maximum, and 1998 USDA reported values for manure generation rates for layers. The 1998 USDA reported values for manure generation were used in EPA's analyses.

Table 6-20. Quantity of Manure Excreted for Layers.

Manure Mass (lb/yr/1,000 lb of animal mass)		
Minimum Reported	**Maximum Reported**	**USDA 1998 Value**
19,163[a]	23,722[b]	22,900[c]

[a]MWPS, 1993.
[b]NCSU, 1994.
[c]USDA, 1998.

6.2.2.2 Description of Waste Constituents and Concentrations

Layer waste contains N, P, K, and smaller amounts of other elements and pathogens. This section provides a summary of the constituents of layer manure as reported in the literature. Table 6-21 shows selected physical and chemical characteristics for layer manure as excreted, and after application of different storage and treatment practices. Manure quantity decreases under dry storage practices but increases significantly when converted to a slurry, or stored and treated in an anaerobic lagoon.

Table 6-21. Physical Characteristics of Layer Manure as Excreted and for Different Storage Methods.

Physical Characteristic	Physical Characteristics of Manure (lb/yr/1,000 lb of animal mass unless otherwise noted)						
	As Excreted	**High-Rise Litter[d]**	**Paved Surface Scraped Manure[b]**	**Unpaved Deep Pit Stored Manure[b]**	**Liquid Manure Slurry[b]**	**Anaerobic Lagoon Liquid[b]**	**Anaerobic Lagoon Sludge[b]**
Manure	19,163[a]–23,722[b]	14126	9877	32534	53598	9881	98805
Density (lb/ft^3)	60.0[a,c]–65.1[d]	62.4	51.3	7.8	8.4	8.4	8.4
Moisture (%)	74.8[a]–75.0[d]	---	---	---	---	---	---
Total solids	5,512[d]–6,019[b]	4979	5216	3646	265	1633	1633
Total suspended solids	2,477[b]	---	---	748	101	---	---
Volatile solids	3,942[d]–4,440[b]	3483	3137	2401	119	722	722
Volatile suspended solids	481[b]–4,380[c]	---	---	637	52	---	---
Fixed solids	1,570[d]	---	---	---	---	---	---
C:N ratio	7[d]	---	---	---	---	---	---

[a]MWPS, 1993.
[b]NCSU, 1994.
[c]ASAE, 1998.
[d]USDA, 1992.

Layers excrete numerous nutrients including N, P, and K. As shown in Table 6-22, N is excreted at the highest rate of these three nutrients. Nutrient concentrations of liquid manure are shown in Table 6-23. Table 6-24 shows nutrient production after application of storage or treatment practices. Table 6-25 shows metals in layer manure as excreted, and for different storage and treatment methods.

Table 6-22. Quantity of Nutrients in Layer Manure as Excreted.

Nutrient	Quantity Present in Manure (lb/yr/1,000 lb of animal mass)		
	Minimum Reported	Maximum Reported	Time-Averaged Value
Nitrogen	264.63[a]	315.43[b]	308.35[d]
Phosphorus	99.55[a]	113.15[c]	114.27[d]
Potassium	106.05[a]	124.10[c]	119.54[d]

[a]MWPS, 1993.
[b]NCSU, 1994.
[c]USDA, 1992.
[d]USDA, 1998.

Table 6-23. Annual Volumes of Liquid Layer Manure Produced and Nutrient Concentrations.

Storage Method	Manure Produced (1000gal/yr)	Nutrient (lb nutrient/1000 gal)		
		Nitrogen	Phosphorus	Potassium
Raw manure	0.011	110.2	35.4	37.7
Pit storage [a]	0.017	60.00	19.67	23.24
Anaerobic lagoon storage [b]	0.027	7.00	1.75	2.91

Source: MWPS, 1993 as presented by Jones and Sutton, 1994.
[a] Includes dilution water.
[b] Includes rainfall and dilution water.

Table 6-24. Nutrient Quantity in Layer Litter for Different Storage Methods.

Nutrient	Quantity Present in Manure and Litter (lb/yr/1,000 lb of animal mass)					
	High-Rise Litter[a]	Paved Surface Scraped Manure[b]	Unpaved Deep Pit Stored Manure[b]	Liquid Manure Slurry[b]	Anaerobic Lagoon Liquid[b]	Anaerobic Lagoon Sludge[b]
Nitrogen	199.44	165.79	238.42	42.35	24.63	24.63
Phosphorus	97.60	110.21	94.55	4.77	39.87	39.87
Potassium	114.40	107.96	114.40	54.75	9.60	9.60

[a]USDA, 1992.
[b]NCSU, 1994.

Table 6-25. Quantity of Metals and Other Elements Present in Layer Manure as Excreted and for Different Storage Methods.

Element	Quantity Present in Manure and Litter (lb/yr/1,000 lb of animal mass)						
	As Excreted	High-Rise Litter[c]	Paved Surface Scraped Manure[a]	Unpaved Deep Pit Stored Manure[a]	Liquid Manure Slurry[a]	Anaerobic Lagoon Liquid[a]	Anaerobic Lagoon Sludge[a]
Aluminum	9.987[a]	2.161	---	4.039	---	---	---
Arsenic	0.050[a]	---	---	---	0.002	---	---
Boron	0.651[a]–0.657[b]	0.157	0.178	0.125	0.059	0.041	0.041
Cadmium	0.014[a,b]	0.001	---	---	0.000	0.007	0.007
Calcium	474.500[b]–491.891[a]	288.598	375.753	138.050	6.945	55.653	55.653
Chlorine	204.400[b]–242.608[a]	28.394	---	27.554	21.777	---	---
Cobalt	0.029[a]	---	---	---	---	---	---
Copper	0.303[b]–0.308[a]	0.244	0.285	0.302	0.030	0.167	0.167
Chromium	---	0.114	0.188	---	0.002	---	---
Iron	21.900[b]–24.143[a]	2.936	14.008	7.089	0.387	5.727	5.727
Lead	0.270[b]–0.274[a]	0.135	0.656	---	0.005	0.023	0.023
Magnesium	51.100[b]–51.129[a]	58.577	28.306	16.495	2.188	13.629	13.629
Manganese	1.945[a]–2.227[b]	2.032	2.165	1.579	0.044	1.896	1.896
Mercury	---	---	---	---	0.000	---	---
Molybdenum	0.109[a]–0.110[b]	0.002	0.002	---	---	---	---
Nickel	0.091[a,b]	0.351	0.418	---	0.075	0.029	0.029
Selenium	0.010[a]	---	---	---	---	---	---
Sodium	36.500[b]–43.292[a]	19.646	16.268	20.082	11.755	3.958	3.958
Sulfur	51.053[a]–51.100[b]	49.971	23.554	16.762	3.918	8.414	8.414
Zinc	1.640[a]–6.935[b]	2.162	1.721	1.609	0.100	1.346	1.346

[a]NCSU, 1994.
[b]ASAE, 1998.
[c]USDA, 1992.

Microbial populations are quite active in layer litter and include enterococcus, fecal coliform, salmonella, and streptococcus. Table 6-26 shows bacteria levels per pound of manure. As shown in this table, converting the litter to a slurry substantially reduces the concentration of bacteria.

Table 6-26. Concentration of Bacteria in Layer Litter.

Type of Bacteria	Concentration in Manure (bacterial colonies/lb manure)	
	As Excreted	Layer Liquid Manure Slurry
Enterococcus bacteria	2.786E+13	---
Fecal coliform bacteria	1.552E+13	1.058E+06
Fecal streptococcus bacteria	3.375E+13	---
Salmonella	1.327E+10	---
Streptococcus bacteria	6.237E+13	---
Total aerobic bacteria	8.568E+15	---
Total bacteria	9.716E+16	---
Total coliform bacteria	1.835E+14	7.547E+06
Yeast	1.327E+15	---

Source: NCSU, 1994.

6.2.3 Turkey Waste Characteristics

Turkey operations usually separate and handle the birds in groups according to age, gender, size, or special management needs such as hatcheries or breeder farms. The types of animals are

- Poults (young turkeys)
- Turkey hens for slaughter
- Turkey toms for slaughter
- Hens kept for breeding

Although three major strains of turkeys are grown, the high degree of industry integration, standardized feed, and complete confinement has resulted in very little variation in manure characteristics. The exact quantity and composition of manure depends mostly on the specifics of farm management, such as precision feeding, control of wasted feed, and ammonia volatilization losses. Litter characteristics also vary according to material used for bedding.

6.2.3.1 Quantity of Manure Generated

Manure production is frequently presented as volume or weight of manure produced per 1,000 pounds of animal mass. Table 6-27 shows manure production as excreted for turkey hens for breeding and turkey hens and toms for slaughter.

Table 6-27. Annual Fresh Excreted Manure Production (lb/yr/1,000 lb of animal mass).

Animal Type	Range of Annual Manure Production Values	USDA 1998 Value
Turkeys for slaughter	15,914[a]-17,155[b]	16,360[c]
Hens for breeding		18,240[c]

[a]USDA, 1992.
[b]ASAE, 1998.
[c]USDA, 1998.

6.2.3.2 Description of Waste Constituents and Concentrations

Turkey waste contains N, P, K, and smaller amounts of other elements and pathogens. This section provides a summary of the constituents of turkey manure and litter as reported in the literature.

Composition of Manure

Exact manure composition depends on length and type of storage, as well as other management practices specific to each farm. Table 6-28 shows nutrients in turkey manure as excreted. Turkeys for slaughter produce more N and K in fresh, excreted manure, and breeding hens produce more P.

Table 6-28. Quantity of Nutrients Present in Fresh, Excreted Turkey Manure (lb/yr/1,000 lb of animal mass).

	Nitrogen		Phosphorus		Potassium	
Animal Type	**Range Includes Minimum**	**Maximum Reported**	**Minimum Reported**	**Range Includes Maximum**	**Range Includes Minimum**	**Maximum Reported**
Turkeys for slaughter	248.34[a]	270.1[b]	84[c]	96.77[a]	94.97[a]	102.20[b]
Hens for breeding	204.38[a]			120.48[a]	69.31[a]	

[a]USDA, 1998.
[b]USDA, 1992.
[c]ASAE, 1998.

Composition of Litter

The nutrient content of turkey litter is usually lower than that for broiler litter, and brooder litter contains less manure nutrients than grower house litter. Exact manure composition depends on length and type of storage, as well as other management practices specific to each farm. After stockpiling, litter may lose up to half of the total N excreted. When manure is combined with bedding materials, the waste litter absorbs water content from the manure. Table 6-29 displays the water absorption capacity of commonly used bedding materials. Because of different types of litter composition for turkey operations, nutrient quantities per ton of litter vary (Table 6-30).

Table 6-29. Water Absorption of Bedding.

Bedding Material	**Pounds of Water Absorbed per Pound of Bedding**
Wood	
Tanning Bark	4.00
Fine Bark	2.50
Pine	
Chips	3.00
Sawdust	2.50
Shavings	2.00
Needles	1.00
Hardwood Chips, Shavings or Sawdust	1.50
Corn	
Shredded Stover	2.50
Ground Cobs	2.10
Straw	
Flax	2.60
Oats	
Combined	2.50
Chopped	2.40
Wheat	
Combined	2.20
Chopped	2.10
Hay, Chopped Mature	3.00
Shells, Hulls	
Cocoa	2.70
Peanut, Cottonseed	2.50
Oats	2.00

Source: MWRA, 1993.

Table 6-30. Turkey Litter Composition in pounds per ton of litter.[a]

Manure Type	Nitrogen	Phosphorus	Potassium
Brooder house litter after each flock [b]	45	23	27
Grower house litter after annual cleanout [b]	57	31	33
Stockpiled litter [b]	36	30[e]-31	25[e]-27
Tom growout [c]	52	33	35
Hen growout [c]	73	38	38
Brood house [d]	51	14	27
Growout house [d]	65	28[e]-31	33[e]-38

[a]Zublena, 1993.
[b]NCSU, 1999.
[c]Pennsylvania
[d]Arkansas
[e]NCSU, 1994.
P_2O_5 converted to P by multiplication of 0.437.
K_2O converted to P by multiplication of 0.83.

In those cases where litter is recycled from the brooder barn and used in the growout barn, nutrient values of litter increase to roughly 60 pounds of available N and P per ton of litter. Table 6-31 presents some metal components of turkey litter.

Table 6-31. Metal Concentrations in Turkey Litter (pounds per ton of litter).

Manure type	Ca	Mg	S	Na	Fe	Mn	B	Mo	Zn	Cu
Turkey, brooder	28.0	5.7	7.6	5.9	1.4	0.52	0.047	0.00081	0.46	0.36
Turkey, grower	42.0	7.0	10.0	8.4	1.3	0.65	0.048	0.00092	0.64	0.51

Source: NCSU, 1998.

The physical characteristics and nutrient content of turkey manure and litter types are variable. As seen in Table 6-32, manure characteristics differ significantly from litter characteristics.

Fresh manure contains more nutrients than manure cakes, but litter from grower houses may exceed fresh manure K amounts. Table 6-33 shows metal quantities in excreted turkey manure and litter types by gender and age of bird.

Table 6-32. Waste Characterization of Turkey Manure Types (lb/yr/1,000 lb of animal mass).

Parameter	Turkey fresh manure	Turkey hen house manure cake[a]	Turkey tom house manure cake[a]	Turkey house litter[a]	Turkey poult (brooder) house litter[a]	Turkey breeder house litter[a]	Turkey stockpiled litter[a]
Manure	15,914[c]–17,155[d]	1905.3	1905.3	---	---	---	---
Litter	---	---	---	5960.5	6953.25	4967.65	5420.25
Volume (ft^3/yr/1000 lb)	251.85[c]	---	---	---	---	---	---
Density (lb/ft^3)	63[d]–63.49[a]	32.3	---	---	22.91	62.43	24.1
Total Solids (%wb)	4,179[a]–4,380[d]	1041.6	1041.6	4365.4	5527.96	3893.35	3316.90
Volatile Solids (%db)	3,205[a]–3,541[c]	845.2	845.3	3182.8	4297.07	-	-
TKN	226.3[d]–231.0[a]	42.74	42.74	165.13	138.12	87.97	85.67
NO_3–N	-	-	-	0.40	1.31		1.31
P	84.0[d]–87.8[a]	19.38	19.38	82.38	65.77	51.17	82.42
K	83.2[a]–87.6[d]	23.69	23.69	98.77	77.64	37.05	67.74

[a] NCSU, 1994.
[b] USDA, 1998.
[c] USDA, 1992.
[d] ASAE, 1998.

Table 6-33. Metals and Other Elements Present in Manure (lb/yr/1,000 lb of animal mass).

Metals/ Elements	Turkey fresh manure	Turkey hen house manure cake[a]	Turkey tom house manure cake[a]	Turkey house litter[a]	Turkey poult (brooder) house litter[a]	Turkey breeder house litter[a]	Turkey stockpiled litter[a]
Calcium	223.205[a]-230.0[b]	25.003	25.003	112.165	91.871	178.376	120.888
Magnesium	25.649[a]-26.6[b]	5.11	5.11	22.083	17.849	11.498	19.199
Sulfur	25.887[a]	5.986	5.986	25.477	21.207	18.287	20.039
Sodium	23.172[a]-24.0[b]	5.256	5.256	22.703	162.06	10.622	15.367
Chlorine	16.8407[a]	---	---	35.186	6.278	---	21.608
Iron	26.556[a]-27.4[b]	1.168	1.168	4.176	6.935	2.519	5.585
Manganese	0.853[a]-0.9[b]	0.548	0.5475	2.3725	1.825	1.059	2.044
Boron	0.452[a]	0.037	0.0365	0.146	0.146	0.073	0.110
Molybdenum	0.076[a]	0.001	0.001	0.004	0.003	---	0.003
Aluminum	---	0.694	0.694	2.263	5.037	---	---
Zinc	5.127[a]-5.5[b]	0.438	0.438	1.971	1.606	1.241	1.716
Copper	0.252[a]-0.3[b]	0.475	0.475	1.789	1.351	0.986	1.132
Cadmium	0.009[a]	---	---	0.001	0.001	---	0.001
Nickel	0.063[a]	---	---	0.018	0.007	---	0.007
Lead	0.190[a]	---	---	---	---	---	---

[a]NCSU, 1994.
[b]ASAE, 1998.

Data on bacterial concentrations in turkey manure or litter are generally sparse. However, Table 6-34 shows concentrations of fecal coliform and total bacteria for manure and litter. Land-applied quantities of turkey manure nutrients are shown in Table 6-35.

Table 6-34. Turkey Manure and Litter Bacterial Concentrations (bacterial colonies per pound of manure).

Bacteria Type	Excreted Manure	House Litter
Fecal coliform bacteria	1.31E+08	---
Total bacteria	---	2.53E+12

Source: NCSU, 1994.

Table 6-35. Turkey Manure Nutrient Composition After Losses–Land-Applied Quantities.

	Manure Composition (lb/yr/1,000 lb of animal mass)		
Animal	Nitrogen	Phosphorus	Potassium
Turkeys for slaughter	132.35 (116.0)	82.29 (14.5)	85.40 (9.6)
Hens for breeding	102.14 (102.2)	102.42 (18.1)	62.38 (6.9)

Source: USDA, 1998.
In parentheses are the differences between fresh, excreted manure content and after losses content.

6.2.4 Duck Wastes

The housing floor design and age of the ducks dictate the amount of area required to raise each bird. Age groups are kept isolated, either in separate buildings or in the same buildings with solid partitions between them. It is common for the female ducks and male drakes to be reared together. Breeding ducks are kept in breeder houses similar to turkey pole-barns. The mature ducks are typically bred at a ratio of one drake to five or six ducks.

6.2.4.1 *Quantity of Manure Generated*

The amount of manure produced depends on the number of birds, the amount and type of feed, and the age of the birds. Table 6-36 presents estimates for manure production by ducks. Table 6-37 presents the breakdown of nutrients available in the manure.

Table 6-36. Approximate Manure Production by Ducks.

Animal Type	Market Weight (Lbs)	Feed Eaten/Animal (lbs/year)	Manure Produced (lbs/year/animal)
Duck	7	114	22.8

Source: Jordan and Graves, 1996.

Table 6-37. Breakdown of Nutrients in Manure.

Animal Type	% Water	% N	% P	% K
Duck	61	1.1	1.45	0.5

Source: Florida Agricultural Information Retrieval System, 1998.

6.2.4.2 *Description of Waste Constituents and Concentrations*

Generally, ducks raised on small farms are housed in barns or poultry sheds with packed earthen or concrete floors. Bedding, such as straw or wood shavings, is used to dry the manure. The manure is removed manually or with power equipment at different intervals depending on the number of ducks and the season. The manure is then stored temporarily on a concrete pad or in a shed and then land applied. Some operations compost the manure.

Duck wastes in large operations are normally handled as a solid. Older barns or structures with solid floors accumulate a manure-litter mix that is removed between flocks with skid steers or front-end loaders. The solid manure is transported to a storage structure or directly applied to land.

6.3 <u>Dairy Waste</u>

This section describes the characteristics of dairy manure and waste. In this section, manure refers to the combination of feces and urine. Waste refers to manure plus other material, such as hair, bedding, soil, wasted feed, and water that is wasted or used for sanitary and flushing purposes. Due to the nature of dairy operations, however, even fresh manure may also contain small amounts of hair, bedding, soil, feed, and water.

6.3.1 Quantity of Manure Generated

Numerous analyses have estimated average manure quantities from dairy cattle. Four major data sources that contain mean values for dairy manure characteristics are identified below:

- ASAE Standard D384.1: *Manure Production and Characteristics*, 1999. This data source contains national fresh (as-excreted) manure characteristic values by animal type (e.g., dairy, beef, veal, swine).
- USDA, *Agricultural Waste Management Field Handbook (AWMFH)*, Chapter 4, 1996. This data source contains national manure characteristic values for fresh and managed manure (e.g., lagoon supernatant, feedlot runoff) by animal type including subtypes such as lactating and dry cows.
- NCSU, *Livestock Manure Production and Characterization in North Carolina*, 1994. This data source contains regional manure characteristic values for fresh and managed manure by animal type including subtypes.
- MWPS, *Livestock Waste Facilities Handbook*, 1985. This data source contains national fresh manure characteristic values by animal type and animal weight.

An analysis conducted by Charles Lander et al. of the USDA NRCS used a composite of three of these four data sources (Lander et al., 1998). Lander removed ASAE data before averaging to prevent double counting of the ASAE information that is included in the MWPS data. This analysis assumed that the average weight of a lactating cow is 1,350 pounds. EPA used data from the Lander analyses in estimating compliance cost for beef feedlots and dairies to be consistent with other USDA data used in the costing analyses. Table 6-38 presents the fresh manure estimates from all of these data sources for mature lactating dairy cows and calves.

Table 6-38. Weight of Fresh Dairy Manure.

Data Source	Quantity of Manure (wet basis) (lb/day/1,000-lb animal)	
	Lactating Cow	**Calf**
ASAE Standard	86	ND
USDA *Agricultural Waste Management Field Handbook*	80	ND
NCSU, *Livestock Manure Production and Characterization in North Carolina*	87.3	65.8
MWPS *Livestock Waste Facilities Handbook*	86	ND
USDA Lander analysis	83.5	ND

ND No data.

6.3.2 Waste Constituents and Concentrations

The composition and concentration of dairy waste varies from the time that it is excreted to the time it is ultimately used as a fertilizer or soil amendment. Nutrients and metals are expected to be present in dairy waste due to the constituents of the feed.

6.3.2.1 Composition of Fresh Manure

Manure characteristics for dairy cattle are highly variable and can be affected by the following: animal size, breed, and age; management choices; feed ration; climate; and milk production. For example, dairy feeding systems and equipment often produce considerable feed waste, which in most cases is added to the manure. In addition, dairy stall floors are often covered with organic and inorganic bedding materials (e.g., hay, straw, wood shavings, sawdust, soil, sand, ground limestone, dried manure) that improve animal comfort and cleanliness. Virtually all of this material will eventually be pushed, kicked, and carried from the stalls and added to the manure, and their characteristics imparted into the manure (Lander et al., 1998). In addition, the nutrient content (N, P, and K) of dairy manure can vary significantly due to differences in voluntary feed intake, differing supplemental levels, and differing amounts of nutrients removed during milking (USDA, 1992). Table 6-39 presents averages for fresh mature dairy cow and heifer manure characteristics that are reported in the four major data sources identified in Section 6.3.1. Data are presented for 16 nutrients and metals found in fresh dairy manure. Nitrogen is present in manure in four forms: ammonium-N, nitrate-N, nitrite-N, and organic-N. The total N is the sum of these four components, while the TKN is the sum of the organic-N and ammonium-N.

Phosphorus is present in manure in inorganic and organic form and presented as total P. Colonies of the pathogens coliform and streptococcus bacteria have also been identified in dairy manure.

Table 6-39. Fresh Dairy Manure Characteristics Per 1,000 Pounds Live Weight Per Day.

Parameter	Mean (mature dairy cow/dry cow)			
	ASAE	USDA	NCSU	MWPS
Moisture (%)	87.2	87.5/88.4	ND	87.3
Total solids (lb)	12	10 9.5	12.15/9.5	12
Volatile solids (lb)	10	8.5/8.1	10/6.64	10
Biochemical oxygen demand (BOD), 5-day (lb)	1.6	1.6/1.2	1.82/0.98	1.6
Chemical oxygen demand (COD) (lb)	11	8.9/8.5	11.17/6.97	ND
pH	7	ND	7	ND
TKN (lb)	0.45	0.45/0.36	0.45/0.34	0.43
Ammonium-N (lb)	0.079	ND	0.84/0.14	ND
Total P (lb)	0.094	0.07/0.05	0.22/0.13	0.17
Orthophosphorus (lb)	0.061	ND	0.14/ND	ND
K (lb)	0.29	0.26/0.23	0.36/0.2	0.34
Calcium (lb)	0.16	ND	0.17/0.12	ND
Magnesium (lb)	0.071	ND	0.075/ 0.05	ND
Sulfur (lb)	0.051	ND	0.052	ND
Sodium (lb)	0.052	ND	0.064	ND
Chloride (lb)	0.13	ND	0.13	ND
Iron (lb)	0.012	ND	0.012	ND
Manganese (lb)	0.0019	ND	0.0019	ND
Boron (lb)	0.00071	ND	0.00073	ND
Molybdenum (lb)	0.000074	ND	0.000075	ND
Zinc (lb)	0.0018	ND	0.0019	ND
Copper (lb)	0.00045	ND	0.00047	ND
Cadmium (lb)	0	ND	0	ND
Nickel (lb)	0.0003	ND	0.00028	ND
Total coliform bacteria (colonies)	500	ND	1.09E11 (colonies/100gm)	ND
Fecal coliform bacteria (colonies)	7.2	ND	7.45E10 (colonies/100gm)	ND
Fecal streptococcus bacteria (colonies)	42	ND	4.77E11 (colonies/100gm)	ND

Sources: ASAE, 1999; USDA, 1996; NCSU, 1994; MWPS, 1985.
ND No data.

Lander et al. averaged values from the MWPS, USDA, and NCSU datasets for N, P, and K. In all cases, EPA compared the averaged values to ASAE's data and determined them to be comparable to the lactating cow numbers. As stated earlier in this section, the milking status of dairy cattle can affect the excreted levels of N, P, and K. Lactating cows are expected to have a higher nutrient content in their manure because they typically are fed a higher energy diet. Table 6-40 presents the nutrient values in dairy manure from Lander's analysis that were used in the estimation of compliance costs for beef feedlots and dairies.

Table 6-40. Average Nutrient Values in Fresh Dairy Manure.

Parameter	Dairy Cow (lb/day/1,000-lb animal) [a]
TKN	0.45
Total P	0.08
K	0.28

Source: Lander et al., 1998.
Lander's analysis relied on 1990 NCSU data, while the NCSU data presented in this report is from 1994.

The volatile solids content of dairy manure varies depending on the age and lactation of the cow. The volatile solids content of manure for mature dairy cattle can be calculated by using data for lactating and dry cows and is presented in USDA's AWMFH. EPA's analysis assumes the dairy herd is made up of 83 percent lactating and 17 percent dry cows at any given time. Therefore, the volatile solids content for mature dairy cows, using USDA data, was calculated as

$$(8.5 \text{ lb/day/1,000 animal} \times 83 \text{ percent}) + (8.1 \text{ lb/day/1,000 animal} \times 17 \text{ percent}) = 8.45 \text{ lb/day/1,000 animal}$$

EPA used volatile solids data from USDA's AWMFH in the nonwater quality impact analyses to estimate emissions of methane.

6.3.2.2 Composition of Stored or Managed Waste

Dairy manure is often combined with large amounts of water and collected and stored in a number of different ways (see Section 4.3.5 for a detailed discussion of dairy waste management). This wastewater, therefore, has different physical properties than fresh manure. This section presents dairy waste values for waste from milking centers, and waste managed in lagoons.

Milking Centers

Approximately 15 percent of the manure generated at a dairy is produced in the milking center, which includes the milk room, milking parlor, and holding area. Milking centers that do not practice waste flushing use about 1 to 3 gallons of fresh water per day for each cow milked.

However, dairies that use flush cleaning and automatic cow washing use as much as 30 to 50 or more gallons pre day per cow (MWPS, 1985).

Waste associated with milking centers varies among the different rooms. Milk room waste typically consists of wash water associated with cleaning pipelines and holding tanks. This waste could be disposed of via septic tank systems, but many dairies include it in their manure waste management systems. Milk parlor waste typically consists of some manure and wash water from cleaning the milking equipment. Holding area waste generally contains more manure than the milk parlor and also contains wash water from cleaning the cows, and flush water from cleaning the area. Many dairies remove solids from milking center waste prior to storing the liquid waste in a lagoon. EPA used USDA data on milking center waste characteristics in the estimation of compliance costs for beef feedlots and dairies and NWQI analyses to calculate N loss during composting. Table 6-41 presents USDA data characterizing dairy waste from milking centers.

Table 6-41. Dairy Waste Characterization—Milking Centers.

		Milking Center			
Component	**Units**	**Milk Room**	**Milk Room + Milk Parlor**	**Milk Room + Milk Parlor + Holding Area[a]**	**Milk Room + Milk Parlor + Holding Area[b]**
Volume	ft^3/d/1,000#	0.22	0.6	1.4	1.6
Moisture	%	99.72	99.4	99.7	98.5
Total Solids	% wet basis	0.28	0.6	0.3	1.5
Volatile Solids	lb/1,000 gal	12.9	35	18.3	99.96
Fixed Solids	lb/1,000 gal	10.6	15	6.7	24.99
COD	lb/1,000 gal	25.3	41.7	ND	ND
BOD	lb/1,000 gal	ND	8.37	ND	ND
N	lb/1,000 gal	0.72	1.67	1	7.5
P	lb/1,000 gal	0.58	0.83	0.23	0.83
K	lb/1,000 gal	1.5	2.5	0.57	3.33
C:N ratio	unitless	10	12	10	7

Source: USDA/NRCS, 1992.
[a] Holding area scraped and flushed - manure removed via solids separator.
[b] Holding area scraped and flushed - manure included.
ND No data.

Lagoons

Lagoons that receive a significant loading of waste (e.g., from the holding area, freestall barn, and dry lots) generally operate in an anaerobic mode. Anaerobic dairy lagoon sludge accumulates at a rate of about 0.073 ft^3/lb of total solids. This is equivalent to about 266 ft^3/year per 1,000-lbs of lactating cow, assuming that 100 percent of the waste is placed in the lagoon (USDA, 1992).

Typically, storage or treatment reduces N in dairy manure by 30 to 75 percent through volatilization with only minor decreases in K and P. Although the values of K and P are low in the supernatant, which is removed on a regular basis, a disproportionate amount of the P and K is concentrated in the bottom sludge in lagoons and storage areas (Lander, 1999). EPA used USDA data on anaerobic lagoon waste characteristics in the estimation of compliance costs for beef feedlots and dairies and NWQI analyses. Table 6-42 presents USDA and NCSU data on dairy waste managed in lagoons.

Table 6-42. Dairy Waste Characterization—Lagoons.

Component	Units	Lagoon (USDA data/NCSU data)		
		Anaerobic - Supernatant	**Anaerobic - Sludge**	**Aerobic - Supernatant**
Moisture	%	99.75/ND	90/ND	99.95/ND
Total Solids	% wet basis	0.25/0.87	10/7.2	0.05/ND
Volatile Solids	lb/1,000 gal	9.16/52.4 % dry basis	383.18/56.7 % dry basis	1.67/ND
Fixed Solids	lb/1,000 gal	11.66/ND	449.82/ND	2.5/ND
COD	lb/1,000 gal	12.5/36.69	433.16/260.6	1.25/ND
BOD	lb/1,000 gal	2.92/7.8	ND	0.29/ND
N	lb/1,000 gal	1.67/4.86	20.83/19.16	0.17/ND
NH4-N	lb/1,000 gal	1.0/ND	4.17/ND	0.1/ND
P	lb/1,000 gal	0.48/2.76	9.16/41.8	0.08/ND
K	lb/1,000 gal	4.17/6.5	12.5/9.2	ND
C:N ratio	unitless	3/ND	10/ND	ND
Copper	lb/1,000 gal	ND/0.009	ND/0.46	ND
Zinc	lb/1,000 gal	ND/0.051	ND/0.74	ND

Sources: USDA NRCS 1992; NCSU, 1994.
ND No data.

6.3.2.3 Composition of Aged Manure/Waste

Dairy manure characteristics after excretion vary from operation to operation, and within the same operation during the year. Manure undergoes many changes after excretion including moisture change (dilution or consolidation), volatilization, oxidation, and reduction. These changes always affect the fresh manure characteristics. For example, it is estimated that as much as 50 to 60 percent of N in the urine portion of the manure can be lost during the first hours after excretion if some measure is not taken to preserve it (Lander, 1999). Phosphorus and potassium losses during storage are considered negligible except in open lots or lagoons. In open lots, about 20 to 40 percent of P and 30 to 50 percent of K can be lost by runoff and leaching. Up to 80 percent of the P in lagoons can accumulate in bottom sludges (USDA, 1998).

Characteristics of stored manure are either altered over time or conserved (mass). Nitrogen, for example, volatilizes as ammonia and is lost from the system. On the other hand, most of the compounds in manure (e.g., P, metals) remain in the manure over time and are considered to be conserved. Treating the manure often reduces the concentration of nonconservated elements, such as N and the organic compounds, thus reducing oxygen demands in further treatment (Lander, 1999).

Table 6-43 presents NCSU data on scraped dairy manure from a paved surface. NCSU data are used by EPA in the beef and dairy NWQI analyses.

Table 6-43. Dairy Manure Characteristics Per 1,000 Pounds Live Weight Per Day From Scraped Paved Surface.

Parameter	Unit	Value
Total solids	lb	13.7
Volatile solids	lb	11.5
TKN	lb	0.32
Ammonium-N	lb	0.077
Total P	lb	0.097
K	lb	0.22

6.4 Beef and Heifer Waste

This section describes the characteristics of beef and heifer manure and waste. In this section, manure refers to the combination of feces and urine, and waste refers to manure plus other material such as hair, soil, and spilled feed. Due to the nature of beef feedlots and heifer operations, however, even fresh manure may also contain small amounts of hair, soil, and feed.

6.4.1 Quantity of Manure Generated

Numerous analyses have estimated average manure quantities from beef cattle. Four major data sources that contain mean values for beef manure characteristics are identified below:

- American Society of Agricultural Engineers (ASAE) Standard D384.1: *Manure Production and Characteristics*, 1999. This data source contains national fresh (as-excreted) manure characteristic values by animal type (e.g., dairy, beef, veal, swine).
- USDA, *Agricultural Waste Management Field Handbook*, Chapter 4, 1996. This data source contains national manure characteristic values for fresh and managed manure (e.g., lagoon supernatant, feedlot runoff) by animal type including subtypes such as beef and heifer.

- North Carolina State University (NCSU), *Livestock Manure Production and Characterization in North Carolina*, 1994. This data source contains regional manure characteristic values for fresh and managed manure by animal type including subtypes.
- Midwest Plan Service-18 (MWPS): *Livestock Waste Facilities Handbook*, 1985. This data source contains national fresh manure characteristic values by animal type and animal weight.An analysis conducted by Charles Lander et al. of the USDA NRCS used a composite of three of these data sources (Lander et al., 1998). Lander removed ASAE data before averaging to prevent double counting of the ASAE information that is included in the MWPS data. Table 6-44 presents the fresh manure estimates from these five data sources for beef and heifer cattle.

Table 6-44. Weight of Beef and Heifer Manure.

Data Source	Quantity of Manure (wet basis) (lb/day/1,000-lb animal)		
	Steer, Bulls, and Calves	Beef Cows	Heifer
ASAE Standard	58	ND	ND
USDA *AWMFH*	55	63	82
NCSU *Livestock Manure Production and Characterization in North Carolina*	59	ND	68.4
MWPS *Livestock Waste Facilities Handbook*	60	63	ND
USDA Lander analysis	58	63	66

ND No data.

6.4.2 Waste Constituents and Concentrations

The composition and concentrations of beef and heifer waste varies from the time that it is excreted to the time it is ultimately used as a fertilizer or soil amendment. Nutrients and metals are expected to be present in beef and heifer waste due to the constituents of the feed.

6.4.2.1 Composition of "As-Excreted" Manure

Manure characteristics for beef and heifer cattle are highly variable and greatly influenced by the diet and age of the animals. Differences in weather, season, degree of confinement, waste collection systems, and overall management procedures used by feedlots across the nation add to the variability of manure characteristics in feedlots. The largest variable in fresh manure is moisture content, which significantly decreases over time. Another major variable is the ash content, which depends on the amount of soil entrained in the manure. Ash content also depends on the degree to which the manure has been degraded, which is a function of time since deposition, moisture conditions, temperature, and oxygen saturation (Sweeten et al., 1997). Ash content for fresh manure has been reported as 15.3 percent dry basis (Sweeten et al., 1995), while ash content for aged feedyard waste has been reported as high as 66 percent dry basis (TAES, 1996).

The N content of manure can begin to decrease rapidly after excretion. The urea-N part of the fecal protein rapidly converts to ammonia. Some measurements of ammonia concentrations in air around feedyards have indicated that about half of the N deposited in urine, or about one-fourth of the total N deposition of the feedlot surface, is lost to the atmosphere as ammonia gas (NH_3). The rate of ammonia emissions depends on temperature, pH, humidity, and moisture conditions, and has been found to nearly triple as manure dries after rainfall (Sweeten et al., 1997).

Table 6-45 presents data for 13 metals and nutrients found in fresh beef cattle manure, and Table 6-46 presents data on the constituents found in fresh heifer cattle manure. nitrogen is present in manure in four forms: ammonium-N, nitrate-N, nitrite-N, and organic-N. The total N is the sum of these four components, while the TKN is the sum of the organic-N and ammonium-N. phosphorus is present in manure in inorganic and organic forms and is presented as total P. Colonies of the pathogens coliform and streptococcus bacteria have also been identified in beef and heifer manure.

Table 6-45. Fresh Beef Manure Characteristics Per 1,000 Lbs. Live Weight Per Day.

Parameter	Mean (Beef)			
	ASAE	USDA	NCSU	MWPS
Moisture (%)	88.4	88.4	ND	88.4
Total solids (lb)	8.5	6.34	8.9	8.5
Volatile solids (lb)	7.2	5.74	7.3	7.2
BOD (5-day) (lb)	1.6	1.36	1.7	1.6
COD (lb)	7.8	5.86	7.9	ND
pH (lb)	7.0	ND	7.0	ND
TKN (lb)	0.34	0.30	0.36	0.34
Ammonium-N (lb)	0.086	ND	0.12	ND
Total P (lb)	0.092	0.10	0.22	0.25
Orthophosphorus (lb)	0.030	ND	0.07	ND
K (lb)	0.21	0.22	0.26	0.30
Calcium (lb)	0.41	ND	0.13	ND
Magnesium (lb)	0.049	ND	0.05	ND
Sulfur (lb)	0.045	ND	0.046	ND
Sodium (lb)	0.0030	ND	0.032	ND
Iron (lb)	0.0078	ND	0.0087	ND
Manganese (lb)	0.0012	ND	0.0012	ND
Boron (lb)	0.00088	ND	0.00095	ND
Molybdenum (lb)	0.000042	ND	0.000044	ND
Zinc (lb)	0.0011	ND	0.0010	ND
Copper (lb)	0.00031	ND	0.00033	ND
Total coliform bacteria (colonies)	29	ND	3E11 (colonies/100gm)	ND
Fecal coliform bacteria (colonies)	13	ND	1.3E11 (colonies/100gm)	ND
Fecal streptococcus bacteria (colonies)	14	ND	1.49E11 (colonies/100gm)	ND

Sources: ASAE, 1999; USDA, 1996; NCSU, 1994; MWPS, 1985
ND No data.

Table 6-46. Fresh Heifer Manure Characteristics Per 1,000 Lbs. Live Weight Per Day.

Parameter	Mean (Heifer)	
	USDA	**NCSU**
Moisture (%)	89.3	ND
Total solids (lb)	9.14	7.35
Volatile solids (lb)	7.77	5.34
BOD, 5-day (lb)	1.3	0.89
COD (lb)	8.3	5.67
TKN (lb)	0.31	0.23
Ammonium-N (lb)	ND	ND
Total P (lb)	0.04	0.38
Orthophosphorus (lb)	ND	ND
K (lb)	0.24	0.2
Calcium (lb)	ND	ND
Magnesium (lb)	ND	ND

Sources: USDA, 1996; NCSU, 1994.
ND No data.

EPA used beef waste characteristic data from USDA in the NWQI analyses. Lander et al. averaged values from the MWPS, USDA, and NCSU datasets for N, P, and K. EPA used Lander data in the estimation of compliance costs for beef feedlots and dairies. Table 6-47 presents Lander's averaged values for beef manure. EPA used USDA data in the estimation of compliance costs for heifer operations.

Table 6-47. Average Nutrient Values in Fresh (As-Excreted) Beef Manure.

Parameter	Beef (lb/day/1,000-lb animal)[a]
TKN	0.32
Ammonia	ND
Total P	0.098
K	0.23

Source: Lander et al., 1998.
[a] Lander's analysis relied upon 1990 NCSU data, while the NCSU data presented in this report is from 1994.
ND No Data.

6.4.2.2 Composition of Beef and Heifer Feedlot Waste

The characteristics of beef and heifer feedlot wastes vary widely because of differences in climate, rainfall, diet, feedlot surface, animal density, and cleaning frequency. Wasted feed and soil in unpaved feedlots is readily mixed with the manure because of animal movement and cleaning operations (Arrington et al., 1981). Therefore, due to the incorporation of more solids and exposure to the elements, the moisture content of beef feedlot waste is significantly lower than for fresh beef manure.

Table 6-48 presents characteristics of beef waste collected from unpaved and paved feedlots (USDA, 1992). Most feedlots are unpaved. However, for paved lots, concrete is the most common paving material, although other materials (e.g., fly ash) have been used (Suszkiw, 1999). EPA used this USDA data in the NWQI analyses to calculate N losses during composting. Table 6-49 presents NCSU data on scraped beef manure from an unpaved surface.

Table 6-48. Beef Waste Characterization—Feedlot Waste.

Component	Units	Unpaved Lot[a]	Paved Lot[b]	
			High-Forage Diet	High-Energy Diet
Weight	lb/d/1000lb	17.5	11.7	5.3
Moisture	%	45	53.3	52.1
Total Solids	% wet basis	55	46.7	47.9
Total Solids	lb/d/1000lb	9.6	5.5	2.5
Volatile Solids	lb/d/1000lb	4.8	3.85	1.75
Fixed Solids	lb/d/1000lb	4.8	1.65	0.76
N	lb/d/1000lb	0.21	ND	ND
P	lb/d/1000lb	0.14	ND	ND
K	lb/d/1000lb	0.03	ND	ND
C:N ratio	unitless	13	ND	ND

Source: USDA NRCS, 1992.
[a] Dry climate (annual rainfall less than 15 inches); annual manure removal.
[b] Dry climate; semiannual manure removal.
ND No data.

Table 6-49. Beef Manure Characteristics Per 1,000 Lbs. Live Weight Per Day From Scraped Unpaved Surface.

Parameter	Unit	Value
Total solids	lb	9.4
Volatile solids	lb	5.3
TKN	lb	0.20
Ammonium-N	lb	0.38
Total P	lb	0.062
K	lb	0.14

Source: NCSU, 1994.

Sweeten, et al., compiled and compared feedlot waste data representing "as-collected" waste, composted waste, and stockpiled waste from one area of the country (Sweeten et al., 1997). The Sweeten report was used in the estimation of compliance costs for beef feedlots and dairies and the NWQI report for calculations using the moisture content of manure. The agency also used the report's levels of annual costs, volatile solids, and N content of composting to determine emissions for the nonwater quality impact analysis.

6.4.2.3 Composition of Aged Manure

Beef cattle feedlots typically scrape and remove the manure that is deposited on the ground about every 120 to 365 days, as opposed to dairies that scrape or remove manure as often as every day. During this "aging" process, nutrients are lost due to ammonia volatilization, runoff, and leaching. Mathers et al. determined average nutrient concentrations in aged manure ready for land application from 23 beef cattle feedlots in the Texas High Plains (Mathers et al., 1972). Since EPA has not identified national data on aged manure characteristics, these local data are presented in Table 6-50 to demonstrate the significant difference in characteristics of fresh and aged manure.

These data show that the aged beef manure N concentration is 40.3 percent of the fresh manure concentration, while P and K in aged manure are 50.9 percent and 64.5 percent, respectively, of their concentrations in fresh manure. N losses as high as 50 percent have been reported in aged beef manure due to temperature, moisture, pH, and C:N ratio. Phosphorus and K losses are primarily due to runoff but may also occur because of leaching.

Table 6-50. Percentage of Nutrients in Fresh and Aged Beef Cattle Manure.

Parameter	Unit	Fresh Manure	Aged Manure
Moisture	%	88	34
N	% dry basis	5.08	2.05
P	% dry basis	1.59	0.81
K	% dry basis	3.55	2.29

Source: Mathers et al. 1972.

6.4.2.4 Composition of Runoff from Beef and Heifer Feedlots

As with feedlot wastes, constituent characteristics of beef and heifer feedlot runoff also vary across the country. The factors that are responsible for runoff waste variations are similar to those for feedlot wastes (i.e., climate, rainfall, diet, feedlot surface, animal density, and cleaning frequency). Paved feedlots produce more runoff than unpaved lots, and areas of high rainfall and low evaporation produce more runoff than arid areas.

Numerous analyses characterizing the runoff from beef feedlots have been conducted on a local level. However, manure characteristics data collected at a local level may not be representative of the beef industry as a whole. Since the constituent concentration of feedlot runoff varies among different areas of the country, this report presents only nationally available manure characteristics and regional estimates of feedlot runoff characteristics.

The USDA *AWMFH* characterizes both the supernatant and sludge from beef feedlot runoff lagoons. EPA used these data in the estimation of compliance costs for beef feedlots and dairies, and NWQI analyses. Table 6-51 presents these waste characteristics.

Table 6-51. Beef Waste Characterization—Feedlot Runoff Lagoon.

Component	Units	Runoff Lagoon	
		Supernatant	Sludge
Moisture	%	99.7	82.8
Total Solids	% wet basis	0.3	17.2
Volatile Solids	lb/1,000 gal	7.5	644.83
Fixed Solids	lb/1,000 gal	17.5	788.12
COD	lb/1,000 gal	11.67	644.83
N	lb/1,000 gal	1.67	51.66
NH_4-N	lb/1,000 gal	1.5	ND
P	lb/1,000 gal	ND	17.5
K	lb/1,000 gal	7.5	14.17
Copper	lb/lb	ND	1.94×10^{-4}
Zinc	lb/lb	ND	9.29×10^{-4}

Source: USDA NRCS, 1992; NCSU, 1994.
ND No data.

6.5 Veal Waste

This section describes the characteristics of veal manure and waste. In this section, manure refers to the combination of feces and urine, and waste refers to manure plus other material such as hair, soil, and spilled feed. Due to the nature of veal operations, however, even fresh manure may also contain small amounts of hair and feed.

This section discusses the following:

- Section 6.5.1: Quantity of manure generated; and
- Section 6.5.2: Waste constituents and concentrations.

6.5.1 Quantity of Manure Generated

National data on veal waste characteristics are available from the following three data sources:

- ASAE Standard D384.1: *Manure Production and Characteristics*, 1999. This data source contains national fresh manure characteristic values by animal type (e.g., dairy, beef, veal, swine).
- USDA, *AWMFH*, Chapter 4, 1996. This data source contains national manure characteristic values for fresh and managed manure (e.g., lagoon supernatant, feedlot runoff) by animal type including subtypes such as veal.
- NCSU, *Livestock Manure Production and Characterization in North Carolina*, 1994. This data source contains regional manure characteristic values for fresh and managed manure by animal type including subtypes.

Table 6-52 presents the average fresh manure characteristics for veal from these three data sources. EPA used USDA data in the estimation of compliance costs for veal operations.

Table 6-52. Average Weight of Fresh Veal Manure.

Data Source	Quantity of Manure (wet basis) (lb/day/1,000 lb animal)
ASAE Standard	62
USDA *AWMFA*	60
NCSU, *Livestock Manure Production and Characterization in North Carolina*	61.76

6.5.2 Waste Constituents and Concentrations

The composition and concentrations of veal waste vary from the time that it is excreted to the time it is ultimately used as a fertilizer or soil amendment. Nutrients and metals are expected to be present in veal waste due to the constituents of the feed. This section discusses the composition of fresh manure.

Table 6-53 presents data for nine metals and nutrients found in fresh veal manure. Veal manure is very fluid, with the consistency of a sloppy mortar mix, and is often diluted by large volumes of wash water (Meyer, 1987). The moisture content of fresh veal manure is approximately 98 percent (USDA, 1992).

Veal manure is typically stored in tanks, basins, and pits until it is pumped out onto the land as fertilizer. However, most of the fertilizer value of veal manure remains in the solids in a settling tank (Meyer, 1987). Over time, the most significant compositional change in veal manure, stored in pits, is the conversion of organic-N in fresh manure to ammonium-N and loss of total N to the atmosphere in the form of ammonia. Much of the high ammonia loss is due to microbial degradation of the organic matter including total N components (Sutton et al., 1989). EPA used USDA data in the estimating compliance costs and NWQI analyses for veal operations.

Table 6-53. Fresh Veal Manure Characteristics Per 1,000 Lbs. Live Weight Per Day.

		Mean (Veal)		
Parameter	**Unit**	**ASAE**	**USDA**	**NCSU**
Moisture	%	97.5	97.5	ND
Weight	lb	62	60	61.8
Total solids	lb	5.2	1.5	4.0
Volatile solids	lb	2.3	0.85	2.1
BOD (5-day)	lb	1.7	0.37	0.83
COD	lb	5.3	1.5	1.5
pH	lb	8.1	ND	7.7
TKN	lb	0.27	0.20	0.24
Ammonium-N	lb	0.12	ND	0.11
Total P	lb	0.066	0.03	0.053
K	lb	0.28	0.25	0.27
Calcium	lb	0.059	ND	0.059
Magnesium	lb	0.033	ND	0.33
Sodium	lb	0.086	ND	0.16
Iron	lb	0.00033	ND	0.00033
Zinc	lb	0.013	ND	0.013
Copper	lb	0.000048	ND	0.000048

Source: ASAE, 1999; USDA, 1996; NCSD, 1994.
ND No data.

6.6 Horse Waste

The horse industry raises animals for diverse uses, including pleasure, showing, breeding, racing, farm/ranch, and other minor uses. Because the horse industry is so diverse and much of the population is off farm, statistics on horse production are less available than other livestock.

6.6.1 Quantity of Manure Generated

An average 1,000-pound horse generates approximately 9 tons of manure a year (51 pounds per day). The volume of this solid excrement ranges from 0.75 to 1.0 cubic foot per day. Urine production ranges from 2.25 to 8 gallons per day depending upon diet, activity, and environmental conditions (Wheeler and Cirelli, 1995). Depending on practices, substantial amounts of bedding are added to the wastes.

6.6.2 Horse Waste Characteristics

The characteristics of horse waste will vary by the type of diet fed to the animal, which can range from low-nutrient crops such as Bermuda grass to N-rich forages such as clover, in addition to supplemental feeding. Since horses, unlike ruminants, are limited in their ability to use forages of low nutritive value, feeding regimes require a greater level of management, especially for horses raised primarily in pastures.

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CHAPTER 7

POLLUTANTS OF INTEREST

7.0 INTRODUCTION

Pollution generated at feedlot operations can arise from multiple sources. These sources, including animal waste, process wash waters, litter, animal carcasses, spills of pesticides, and pharmaceuticals, are the primary sources of potential environmental contamination.

Excreted animal waste contains undigested and partially digested feed, partially metabolized organic material, dead and living microorganisms from the digestive tract, cell wall material and other organic debris from the digestive tract, and excess digestive juices. Additional microorganisms may grow in the waste after it has been excreted. Depending on the type of feed provided to the animals and whether feed additives have been used, animal wastes can also contain pharmaceuticals (antibiotics and hormones), and trace inorganic elements.

Animal carcasses, which may contain pathogens, nutrients, and chemical toxicants, can pose an environmental problem, especially in the poultry industry where many operations have historically used burial as a means for disposal. For example, during 1990, several state agencies in Arkansas tested the management of dead-bird disposal pits and found high soil concentrations of ammonium (USEPA, 1999). Improper disposal of poultry carcasses has been implicated in ground water contamination; however, in recent years, greater regulation of animal disposal has reduced the risk of environmental contamination from buried animal carcasses. Arkansas, for example, has outlawed the use of dead-bird disposal pits. Other states have also issued guidelines or regulations for disposal of animal carcasses and require operators to use specific practices such as composting.

In the preliminary study on environmental impacts from animal feedlot operations, EPA (1998) identified and described the major animal waste constituents that can adversely affect the environment. Additional information on potential impacts can be found in the *Environmental Assessment of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and Effluent Limitations Guidelines for Concentrated Animal Feeding Operations* (USEPA, 2000). As demonstrated in Chapter 6, the physical and chemical characteristics of manure differ between animal sectors as well as within animal sectors. The following pollutants of interest identified by EPA in its preliminary feedlots study are described below:

- Nutrients (nitrogen, phosphorus)
- Total suspended solids (including sediment)
- Biochemical oxygen demand (BOD)

- Pathogen
- Chemical oxygen demand (COD)
- Other contaminants including salts, trace elements, and pharmaceuticals

Exposure pathways of contaminants in soil include direct ingestion, inhalation of dusts, ingestion of ground or surface water contaminated from migration of chemicals through soil or runoff from soil, dermal absorption, and ingestion of produce that has been contaminated through plant uptake (USEPA, 1996). Constituents in manure will have an impact on water quality if significant amounts reach surface or ground water. Management practices can reduce or block the potential transport of these constituents. Movement of constituents in manure is driven primarily by precipitation events, runoff and erosion of soluble and particulate components, leaching to ground water of soluble compounds, and wind erosion of dry material (USEPA, 2000).

7.1 Conventional Waste Pollutants

Biochemical Oxygen Demand

BOD is a measure of the oxygen-consuming requirements of organic matter decomposition. When animal waste is discharged to surface water, it is decomposed by aquatic bacteria and other microorganisms. Decomposing organic matter consumes oxygen and reduces the amount available for aquatic animals. Severe reductions in dissolved oxygen levels can lead to fish kills. Even moderate decreases in oxygen levels can adversely affect waterbodies through decreases in biodiversity as manifested by the loss of fish and other aquatic animal populations.

Total Suspended Solids

Suspended solids can clog fish gills and increase turbidity. Increased turbidity reduces penetration of light through the water column, thereby limiting the growth of desirable aquatic plants that serve as a critical habitat for fish, shellfish, and other aquatic organisms. Solids that settle out as bottom deposits can alter or destroy habitat for fish and benthic organisms. Solids also provide a medium for the accumulation, transport, and storage of other pollutants including nutrients, pathogens, and trace elements. Sediment-bound pollutants often have an extended interaction with the water column through cycles of deposition, resuspension, and redeposition.

Fecal Coliform Bacteria

Manure contains diverse microbial populations. Included are members of the normal gastrointestinal tract flora, such as members of the fecal coliform and fecal streptococcus groups of bacteria. These are the groups of bacteria commonly used as indicators of fecal contamination and the possible presence of pathogenic species. A discussion of pathogens found in the waste of AFOs is given in section 7.2.

7.2 Nonconventional Pollutants

Nutrients (Nitrogen, Phosphorus)

Because of its nutrient content, animal manure can serve as a valuable agricultural resource. In an area where the amount of nutrients in manure generated from AFOs is greater than the nutrient requirements of the crops grown in the area, excess land application has occurred, which can lead to increased nutrient runoff and seepage and subsequent degradation of water resources.

As noted in Chapter 6, wastes contain significant quantities of nutrients, particularly nitrogen (N) and phosphorus (P). Manure N occurs primarily in the form of organic-N and ammonia-N compounds. In its organic form, N is unavailable to plants. However, through bacterial decomposition, organic-N is transformed into ammonia, which is oxidized (by nitrification) to nitrite and ultimately to nitrate. Ammonia and nitrate are bioavailable and therefore have fertilizer value. These forms can also produce adverse environmental impacts when they are transported in excess quantities to the environment.

Ammonia. "Ammonia-N" includes the ionized form (ammonium) and the un-ionized form (ammonia). Ammonium is produced when microorganisms break down organic-N products in manure, such as urea and proteins. This decomposition can occur under aerobic or anaerobic conditions. Both forms are toxic to aquatic life, although the un-ionized form (ammonia) is much more toxic.

Ammonia is of environmental concern because it exerts a direct BOD on the receiving water. Ammonia can lead to eutrophication, or nutrient overenrichment, of surface waters. Ammonia itself is a nutrient and is also easily transformed to nitrate (another nutrient form of N) in the presence of oxygen. Although nutrients are necessary for a healthy ecosystem, the overabundance of nutrients (particularly N and P) can lead to nuisance algae blooms.

Nitrate. Nitrite is toxic to most fish and other aquatic species, but it usually does not accumulate in the environment because of its rapid conversion to nitrate in an aerobic environment. Nitrate is a valuable fertilizer because it is biologically available to plants. Excessive levels of nitrate in drinking water, however, can produce adverse human health and environmental impacts. For example, human infants exposed to high levels of nitrate can develop methemoglobinemia, commonly referred to as "blue baby syndrome" because the lack of oxygen can cause the skin to appear bluish in color. To protect human health, EPA has set a drinking water maximum contaminant level (MCL) of 10 mg/L for nitrate-N. N is the primary contributor to eutrophication in brackish and saline waters (USEPA, 2000).

N is interchanged among the atmosphere and organic matter and inorganic compounds in soil or water through the N cycle. The biological transformations of N that make up this process include N fixation, nitrate reduction, and denitification. Atmospheric nitrogen (N_2) can be bound by microorganisms with carbohydrates, water, and hydrogen to form ammonium and carbon dioxide in the process of N fixation. Aquatic microorganisms with the ability to fix atmospheric nitrogen include photosynthetic bacteria, *Azotobacter*, and some species of *Clostridium*. In soil, *Rhizobium* can fix atmospheric nitrogen in the root nodules of leguminous plants. Ammonium can be further converted by *Nitromonas* and *Nitrobacter* bacteria into nitrite and nitrate, respectively, in the process of nitrate reduction. This process provides most plants with the form of N they are able to absorb (nitrate). Ammonium present in animal manure can also be converted into nitrate by these bacteria for use by plants. Denitrification is the process by which fixed N present in soil or water is returned to the atmosphere by bacteria in the form of N_2, allowing the N cycle to begin again (Manahan, 1991).

Phosphorus. Animal wastes contain both organic and inorganic forms of P. P occurs almost exclusively in the form of inorganic and organic phosphates in natural waters. Organic phosphate is phosphate associated with a carbon-based molecule such as plant or animal tissue. Phosphate not associated with organic matter is inorganic, which is the form required for uptake by plants. Animals can use organic or inorganic phosphate. Both organic and inorganic forms can be dissolved in water or suspended (attached to particles in the water column). Sources of P include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations (USEPA, 2002a). The majority of P binds to mineral and organic particles in manure and is subject to runoff and erosion more than leaching except in very sandy soils with low P-binding capacity (USEPA, 2000).

P is of concern in surface waters because it is a nutrient that can lead to eutrophication and the resulting adverse impacts—fish kills, reduced biodiversity, objectionable tastes and odors, increased drinking water treatment costs, and growth of toxic organisms. At concentrations greater than 1.0 mg/L, P can interfere with coagulation in drinking water treatment plants (Bartenhagen et al., 1994).

P is of particular concern in fresh waters, where plant growth is typically limited by phosphorous levels. Under high pollutant loads, however, fresh water may become nitrogen-limited (Bartenhagen et al., 1994). Thus, both N and P loads may contribute to eutrophication.

P is interchanged in an aquatic ecosystem through the P cycle. Inorganic P from various natural and human sources is taken up by plants and converted to organic P. Animals graze on plants and thereby take up organic P. Organic P is released to the ecosystem in animal feces and in decaying animals and plants, generally to the bottom of the lake or stream. Bacterial decomposition converts organic P into inorganic P in both dissolved and suspended forms. Inorganic P is returned to the water column, allowing the P cycle to begin again, when the bottom of the waterbody is disturbed by animals, human activity, chemical interactions, or water currents. In streams, P tends to move downstream over time because the current carries decomposing plant and animal material and dissolved P downstream. P is stationary in waterbodies only when taken it is taken up by plants or bound to particles that settle to the bottom of pools (USEPA, 2002a).

Chemical Oxygen Demand

COD is another measure of oxygen-consuming pollutants in water. The COD test differs from the BOD test in that it measures the amount of oxygen required to oxidize all organic matter present in a sample regardless of how biologically assimilable the organic matter is because it uses a strong chemical oxidizing agent instead of microorganisms to oxidize the organic compounds in a sample (Masters, 1997). BOD only measures the oxygen required to oxidize biologically degradable material present in a sample. The COD test is used to measure oxygen-consuming pollutants in water because all organic compounds, with few exceptions, can be oxidized by the action of strong oxidizing agents under acidic conditions. The measured value of COD is generally greater than BOD in a sample, although these values are similar in samples containing easily biodegradable material. Because the COD test can be performed more quickly than the BOD test, it is sometimes used to estimate BOD.

Pathogens

Manure contains diverse microbial populations. There are many examples that demonstrate that pathogens from manure can be a problem. Other studies show that manured fields do not pose a significant threat to surface waters. Most pathogens present in animal manure are from the gastrointestinal tract and can be divided into those pathogens that are highly host-adapted and not considered to be pathogenic to humans and those that are capable of causing infection in humans (zoonoses). For example, most *Salmonellae* are zoonoses, but *S. pulloram* and *S. gallinarum*, which might be present in poultry manures, are not. However, each of these species may be included in gross estimates of *Salmonella* densities. The pathogens that might be present in poultry and swine manures can also be divided into those microorganisms which are commonly present and those which are less common. For example in poultry manures, *Campylobacter jejuni* is commonly present while *Mycobacterium avium* is less common. These distinctions are important in assessing the potential public health risks associated with poultry and swine operations, as well as other animal feeding operations.

The interactions between pathogens, cattle, and the environment are not well understood but current literature suggests that dairy and beef cattle shed pathogens that are known to be infectious to humans. The threat posed by pathogens in animal manure is influenced by the source, pH, dry matter, microbial, and chemical content of the feces. Solid manure that is mixed with bedding material is more likely to undergo aerobic fermentation in which temperature increases reduce the number of viable pathogens. However, some pathogens grow under a wide range of conditions that makes their control very difficult. Quantifying the risk associated with these pathogens is thus challenging. Rapidly changing pathogen numbers, changes in the infective status of the host, and survivability of the pathogens all make it increasingly difficult to determine how much of a threat animal-excreted pathogens are to society. Moreover, methods of pathogen detection produce varying results, making it difficult to compare studies that use different analyses (Pell, 1997).

The most common pathogens and found in animal manures and capable of causing disease in humans are *Salmonella*, *Escherichia coli*, *Bacillus anthracis, Mycrobacterium paratuberculosis*, *Brucella abortus, Leptospira* spp., *Chlamydia* spp., *Rickettsia* spp., and *Listeria monocytogenes* (Epstein, 1998). In addition, *Cryptosporidium parvum* oocysts (the eggs of a protozoan parasite that can cause gastrointestinal illness in humans) found in calf and pig manure (USDA, 1996) and *Giardia* oocysts in young dairy cattle manure (Pell, 1997) appear to be infectious to humans.

Unlike biosolids, the bacterial content of animal manure is currently not regulated; however, the Federal Part 257 regulation does include provisions regarding general management of these materials to help ensure that practices will not impact threatened or endangered species or habitat be either a direct discharge or a nonpoint source of pollutants or contaminate underground drinking water sources (USEPA, 2000). Fecal coliform, fecal streptococci, *Escherichia coli*, and enterococci are commonly used indicators of human and animal fecal contamination. These bacteria are not harmful in themselves but they indicate the possible presence of pathogenic bacteria, viruses, and protozoa that live in human and animal digestive systems. Because it is difficult to test for the pathogens themselves, tests for indicator bacteria are used instead (USEPA, 2002b).

EPA now recommends that enterococci and *Escherichia coli* be used as indicators of fecal contamination in fresh water and enterococci be used as an indicator of fecal contamination in salt water; however, several states continue to use fecal coliform as their indicator water quality standard (USEPA, 2002b). Indicator bacteria can be used to determine whether surface waters have been contaminated from manure applied to nearby fields. In the past, fecal streptococci and fecal coliform were monitored together and a ratio of fecal coliform to streptococci was calculated to determine whether the contamination was of human or nonhuman origin; however, this ratio is no longer recommended by EPA (USEPA, 2002b).

The levels of fecal coliform and fecal streptococci bacteria have been measured in the manure of several livestock animal types. Fecal coliform bacterial densities were measured in units of colonies/1,000 kg live animal mass per day at densities of 45 ± 27 for sheep; 18 ± 12 for swine; 7.5 ± 2.0 for layer chickens; and 16 ± 28 for dairy cows. Fecal streptococci bacterial densities were measured in units of colonies/1,000 kg live animal mass per day at densities of 62 ± 73 for sheep; 530 ± 290 for swine; 16 ± 7.2 for layer chickens; and 92 ± 140 for dairy cows (ASAE, 1999).

For additional information on pathogens see the *Environmental and Economic Benefit Analysis* and the *Environmental Assessment*.

Other Potential Contaminants

Animal wastes can contain other chemical constituents that could adversely affect the environment. These constituents include salts trace elements and pharmaceuticals, including antibiotics. Although salts are usually present in waste regardless of animal or feed type, trace elements and pharmaceuticals are typically the result of feed additives to help prevent disease or promote growth. Accordingly, concentrations of these constituents will vary with operation type and from facility to facility.

Salts and trace elements. Animal manure contains dissolved mineral salts. The major cations contributing to salinity are sodium, calcium, magnesium, and potassium; the major anions are chloride, sulfate, bicarbonate, carbonate, and nitrate. In land-applied wastes, salinity is a concern because salts can accumulate in the soil and become toxic to plants; they can also deteriorate soil quality by reducing permeability and contributing to poor tilth. Direct discharges and salt runoff to fresh surface waters contribute to salinization and can disrupt the balance of the ecosystem. Leaching salts can deteriorate ground water quality, making it unsuitable for human consumption. Trace elements such as arsenic, copper, selenium, and zinc are often added to animal feed as growth stimulants or biocides (Sims, 1995). When applied to land, these elements can accumulate in soils and become toxic to plants, and can affect human and ecological health.

Metals in potentially toxic concentrations in poultry, swine, and cow manures include arsenic, cadmium, copper, lead, molybdenum, nickel, selenium, and zinc (Overcash, et al., 1983). In promulgating standards for the disposal of sewage sludges by land application, EPA has established maximum allowable concentrations and cumulative loading limits for each of these metals as well as beryllium and mercury (Federal Register, 1989). It has generally been assumed that the metal concentrations in manure are well below those allowable for land application of wastewater treatment sludge; however, metal loadings may accumulate in cropland to which manure has been applied for many years.

Selenium and arsenic (as arsinilic acid) supplementation of complete feeds for poultry and swine is directly limited by EPA to 0.3 ppm and 90 ton of feed, respectively (21 CFR 573.920; 21 CFR 558.62). Copper and zinc are fed to swine as growth stimulants at levels significantly above nutritional requirements (Dritz et al., 1997). Arsenic is fed as a growth stimulant to broiler chickens. Drugs administered either prophylactically or therapeutically can also contain metals. Also, concentrated sources of macrominerals such as calcium might contain metals such as copper, manganese, and zinc, as well as other metals with no biological value. Copper and zinc in freshly excreted poultry and swine waste has been measured at concentrations between 12 and 15 mg/kg of total solids and between 42 and 310 mg/kg of total solids, respectively (Barker and Zublena, 1995).

Unlike poultry and swine, cattle are typically not fed excess amounts of metals because these metals do not have a growth-promoting effect on cattle. Zinc and copper in dry manure have been measured at concentrations of 50 mg/kg and 180 mg/kg, respectively in dairy cattle, and 25 mg/kg and 110 mg/kg, respectively in beef cattle. The differences in manure concentrations most likely occurred because enriched mineral supplements were supplied to the dairy cattle but not to the beef cattle (Nicholson, 1999).

Metals not essential for plant or animal nutrition are a concern because they do not degrade over time, they are relatively immobile, and they accumulate in the upper layers of the soil (Rutgers Cooperative Extension, 2000). Heavy metal concentrations in various fertilizers differ and large variabilities in concentration occur within the same fertilizer type. Researchers at Rutgers Cooperative Extension used measured metal concentrations in manure from existing studies to predict the concentrations of metals in soil after 100 years of application at rates of 6.2, 3.2, and 1.8 dry tons for dairy, poultry, and swine manure, respectively. From their model results, the researchers predicted that copper, lead, and zinc would persist in the soil.

According to a draft study performed by the Water Environment Research Foundation (WERF), farmers apply 120 million dry tons of animal manure on their farmlands annually. The draft WERF study results show that metal concentrations in swine and poultry manures are comparable to those in biosolids. The bioavailability and mobility of metals in soil is dependent on their form. Oxide-bound and organically bound metals largely remain immobile and are not absorbed by plants, while water soluble forms are more likely to be taken up by plants or to be carried off-site in runoff. The investigators for the WERF study are planning to perform more research on the metal leachability of manures, biosolids, and fertilizers (Spicer, 2002). This information will help to determine the impact of these heavy metals on humans and on the environment.

Researchers have found that aberrations and damage occurred in a high percentage of sperm cells from earthworms (*Eisenia fetida*) with elevated body burdens of heavy metals. The researchers exposed these earthworms to metals in their feed by placing them in cattle manure to which either 0.01 percent of lead or 1,000 micromoles/gram of manganese salts were added (Reinecke and Reinecke, 1997). High metal concentrations in soil may affect the ability of earthworms to reproduce and consequently affect soil fertility.

Heavy metals in soil can also adversely affect plant growth and survival and can accumulate in plants and subsequently affect the health of humans and animals who eat or use the plant products. Cadmium in soil is readily absorbed by tobacco, mushrooms, spinach, and other leafy vegetables. When tobacco is smoked, much of the cadmium is taken up by the human body. The National Research Council has recommended that the cadmium content of crops used to feed animals should be 0.5 mg/kg or less to reduce the cadmium concentration in meat (Cornell University, 1993). Symptoms of acute toxicity from ingestion of cadmium in humans include nausea, vomiting, and abdominal pain. Long-term effect of low-level exposure to cadmium are lung disease, emphysema, and kidney disease (Klaasen, 1996). Lead and arsenic are generally not absorbed by field crops; however, an accumulation of lead or arsenic in the soil may pose a risk to children and animals that might eat the soil (Klaasen, 1996). Lead exposure can adversely affect the nervous system, especially in children, which can lead to neurological, neurobehaviorial, and developmental impacts. Ingestion of large doses of arsenic (70 to 80 mg) can cause fever, anorexia, and heart arrhythmia, and can lead to death in humans. Long-term exposure to low concentrations of arsenic can cause adverse effects to the nervous system, peripheral vascular disease, and liver injury (Klaasen, 1996). Copper and zinc are toxic to plants in large concentrations (Cornell University, 1993). Ingestion by humans of copper and zinc in soil in large enough quantities to cause toxicity is unlikely.

Antibiotics and hormones. A number of pharmacologic agents are used in the production of poultry and swine, among them a variety of antibiotics and hormones. Nonantibiotic antimicrobials, such as sulfonamides, and some antibiotics, such as streptomycin, are used primarily to cure existing infections (therapeutic use). However, most of the antibiotics used in both the swine and the poultry industries are used both therapeutically and nontherapeutically as feed additives to promote growth, to improve feed conversion efficiency, and to prevent disease (Mellon et al., 2001). When antibiotics are used for nontherapeutic uses the dosage rates are substantially lower than when they are administered for therapeutic use.

Mellon and other investigators (2001) estimate that 24.6 million pounds of antibiotics are used annually by livestock producers for nontherapeutic purposes, of which approximately 10.3 million pounds are used in hog production, 10.5 million pounds are used in poultry production, and 3.7 million pounds are used in cattle production. Tetracycline, penicillin, erythromycin, and other antibiotics are commonly used for these nontherapeutic purposes (Mellon, et al., 2001). The antibiotics in manure applied to soil can persist in soil for 1 day to several weeks or longer. The rate of inactivation of these antibiotics is related to the temperature of the soil and the chemical structure of the antibiotic (Gavalchin and Katz, 1994).

Despite the fact that there is little information in the literature about concentrations of antibiotics in poultry and swine manures, it is known that the primary mechanisms of elimination are in urine and bile (Merck and Company, 1998). Approximately 25 to 75 percent of antibiotics administered to feedlot animals could be excreted in the feces (Chee-Sanford, et al., 2001). The form excreted, the unchanged antibiotic or metabolites or some combination thereof, is antibiotic specific, as is the mass distribution among mechanisms of excretion. These compounds may pose risks to humans and the environment. For example, chronic toxicity may result from low-level discharges of antibiotics. For example, chronic toxicity may result from low-level discharges of antibiotics (Merck and Company, 1998).

Use of antibiotics in agriculture might contribute to antimicrobial resistance. The main route of transmission of drug resistance is considered to be consumption of contaminated food. Drug resistance can also be transmitted through natural waters and soil. Lagoons and pit systems are commonly used for waste disposal in animal agriculture operations. Antibiotic and antibiotic-resistant microorganisms have the potential to seep from these waste lagoons into ground water (Chee-Sanford, et al., 2001). The large quantities of antibiotics entering the environment from manure and other sources allow for survival of antibiotic-resistant strains of microorganisms that can start to predominate the microbial population, which can cause certain diseases in humans and animals to be more difficult to treat than they were in the past (Mellon, et al., 2001). For example, an outbreak of salmonellosis in humans has been linked to infection by antibiotic-resistant *Salmonella newport* (Gavalchin and Katz, 1994). Antibiotics introduced in soil through manure application can also affect the bacterial populations of the soil (Gavalchin and Katz, 1994), which might lead to decreased soil fertility.

Specific hormones are used to increase productivity in the beef and dairy industries but hormones are not used in the poultry or swine industries. Thus, hormones present in poultry and swine manures are only in naturally occurring concentrations. U.S. farmers raise 36 million beef cattle per year of which two-thirds are given hormones. Some steer receive androgens to build their muscle mass and some cows receive female sex hormones to free up resources that would have otherwise been used for the reproductive cycle (Raloff, 2002).

A large portion of hormones passes through cattle in their feces. Waterborne androgen hormones have been detected in waterbodies downstream of animal feedlots. Investigators have found that male fish raised in water obtained from these waterbodies had significantly reduced testicle size in comparison to fish raised in water not containing these hormones, indicating that these waterborne hormones caused male fish to produce less testosterone and to be less fertile than male fish raised in water not containing these hormones. The investigators also suggested that these effects could have been caused by natural androgens and estrogens in manure in addition to or instead of being caused by the synthetic hormones given to the livestock (Raloff, 2002). Also, estrogen hormones in the environment have been implicated in the drastic reduction in sperm counts among men (Sharpe and Skakkebaek, 1993) and reproductive disorders in a variety of wildlife (Colburn et al., 1993).

Hormones in manure applied to soil might be degraded by soil bacteria and photochemical reactions. In addition, hormones might be leached by rain into lower soil horizons or washed directly into surface waters. Dissolved organic matter can bind steroids and enhance their solubility and mobility in the water (Schiffer, et al., 2001), increasing the potential of ground water and surface waters contamination by these compounds.

Schiffer and other investigators (2001) studied the residue and degradation of two growth promoting hormones used in cattle in the United States and Canada, trenbolone acetate and melegestrol acetate, in animal dung, liquid manure, and soil. The researchers found that trenbolone acetate concentrations were 5 to 70 times higher in solid manure than in liquid manure. Trenbolone acetate was determined to have a half-life of 267 days in liquid manure and was partially degraded in solid manure after 4.5 months of storage. The researchers found that trenbolone acetate was not detected in soil fertilized with liquid manure containing this hormone after 40 days; however, they did detect trenbolone acetate in soil 58 days after in had been fertilized with stored solid dung which contained lower concentrations of this hormone than the liquid manure. The researchers suggested that the trenbolone acetate might have adsorbed to the straw material present in the solid dung, which may have protected this hormone from leaching or degrading. The investigators also found that residues of melegestrol acetate in solid dung were more stable than trenbolone acetate because melegestrol acetate concentrations in dung did not decrease significantly after 4 months. They were able to detect melegestrol acetate in soil fertilized with solid manure from the spring until the end of cultivation (Schiffer, et al., 2001).

7.3 Priority Pollutants

The CWA requires states to adopt numeric criteria for priority toxic pollutants if EPA has published criteria guidance and if the discharge or presence of these pollutants could reasonably be expected to interfere with the designated uses of the state's waters. EPA currently lists a total of 126 toxic priority pollutants in 40 CFR 122, Appendix D. Other metal and organic chemicals, however, can cause adverse impacts.

Animal wastes may contain a variety of priority pollutants including the potentially toxic metals: arsenic, cadmium, chromium, copper, lead, molybdenum, nickel, selenium, and zinc (Overcash et al., 1983; ASAE, 1999). In promulgating standards for the disposal of sewage sludges by land application, EPA has established maximum allowable concentrations and cumulative loading limits for each of these metals. Although information about the concentrations of these metals in poultry and livestock manures, and its variability, is quite limited, it generally has been assumed that these concentrations are well below those allowable for land application of wastewater treatment sludges. However, the issue of cumulative loading has been raised periodically in light of long-term use of cropland for manure disposal, especially in areas where poultry and livestock production is concentrated (Sims, 1995).

Given the degree of vertical integration that has occurred in both the poultry and the swine industries, much of the feed manufacturing for these industries is controlled by integrators. Thus, information about the current use of trace mineral supplements in formulating both poultry and swine feeds is difficult to obtain because the integrators consider it proprietary. However, it appears to be a reasonable assumption that arsenic, copper, selenium, and zinc are typically added to poultry feeds and that copper, selenium, and zinc are common components of trace mineral premixes used in the manufacturing of swine feeds. It is probable that commonly used feed supplements also contain some manganese.

Feed amendments of selenium (0.3 part per million) and arsenic (90 grams per ton of feed) are regulated by the U.S. Food and Drug Administration (FDA) (Title 21, Part 573.920 of the Code of Federal Regulations). Levels of other trace minerals as feed supplements are regulated only indirectly by the FDA through maximum allowable concentrations in specified tissues at slaughter or in eggs.

Currently available information about metal concentrations in poultry and swine manures almost exclusively dates back to the 1960s and 1970s (Barker and Zublena, 1995). Kornegay's (1996) data are also somewhat dated, because they are averages over a 14-year period prior to 1992. When compared with Barker and Zublena's data for swine, Kornegay's data suggest that the concentrations of copper and zinc in swine manure have increased significantly over time. However, little is known about the current concentrations of trace metals in poultry and swine manures except that the variations in concentrations are substantial.

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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).

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

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

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 grow-finish 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 and 25 percent for the two weight classes, while total P excretion was reduced by 39 and 38 percent, respectively. The study also modeled the impact of reductions in dietary protein and P over the complete grow-finish 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 grow/finish 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 grow-finish operations that fed 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 greatly increases 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 to 53.5 percent. They also demonstrated that phytase addition improved the digestibility of other nutrients in the feed such as Ca, Zn, 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 grow-finish 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 the animals' nutritional requirements more precisely, 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: P, 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 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. P 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).

[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.

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 excess 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 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 because P plays a central role as a limiting nutrient in many soils; evidence indicates that dairy operators, as a whole, are oversupplying P in dairy diets; and there is an imbalance in the N to P ratio 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 2001 edition of the National Research Council's (NRC) nutrient requirements for dairy cows recommends dietary P levels of 0.32 to 0.44 percent of dry matter for dairy cows in lactation depending on breed and milk production rate (NRC, 2001). 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 0.48 percent P or more (Satter and Wu, 2000). 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):

$$\text{Manure P} = 9.6 + 0\,.472 \text{ x (Intake P)} + 0.00126 \text{ x (Intake P)}^2 \text{ B } 0.323 \text{ x Milk}$$

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 on average 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.

	Daily		Manure P (lb)		Reduction from Baseline (0.53%)		
Percentage of P in Diet	**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 0.48 percent P or more (Satter and Wu, 2000), much higher than the NRC recommendation of 0.44 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 suggest feeding about 15 percent less protein to a herd at the same level of production for certain conditions (Kohn, 1996). Evaluations of the CNCPS model's performance have been mixed, and further research is needed.

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.

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. Nitrogen 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 to 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 generally does not apply to these operations.

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 groove 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 ASAE has defined several types of gravity separation techniques (ASAE, 1998):

- 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 N (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 P with settled swine solids. The study also reported that 60 to 75 percent of the sodium, K, 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 TS 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	0–15	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 TS 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 TS. Chastain et al. (1998) noted, however, that a screw press did not separate well unless the TS 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 TS. 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 TS. 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-RiseJ 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 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.

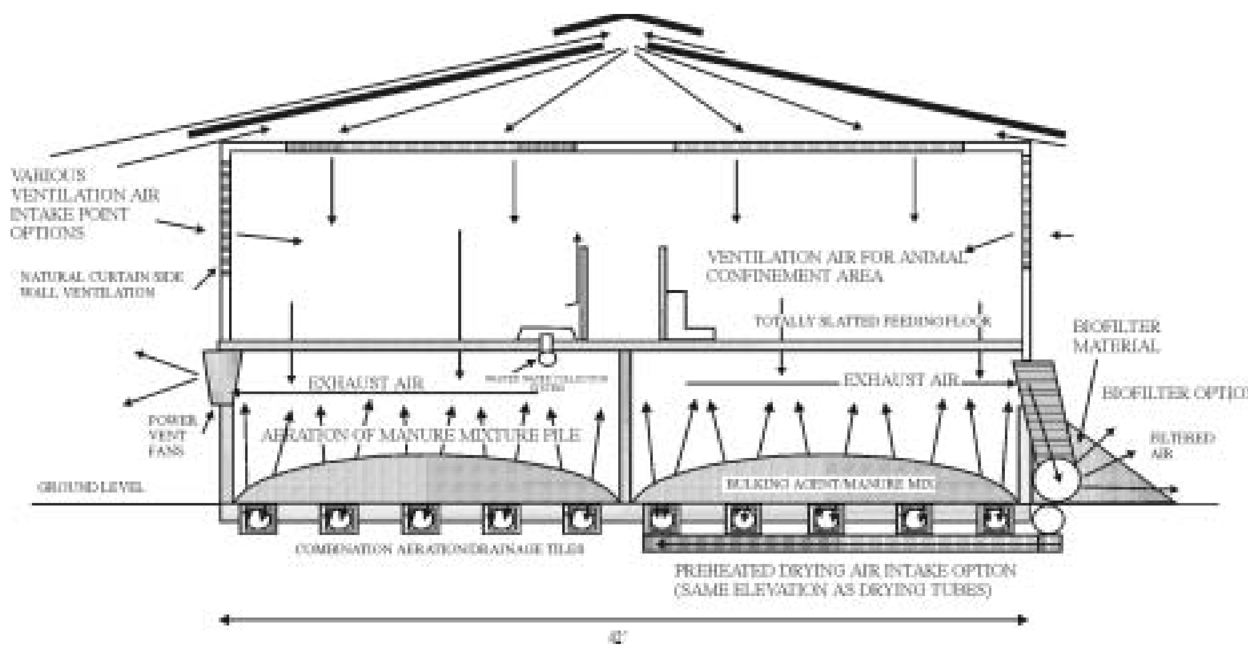

Figure 8-1. High-Rise Hog Building

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. N 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. NH_3 measurements on the swine housing level averaged from 0 to 8 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. NH_3 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. NH_3 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).

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).

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

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

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 NH_3 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 NH_3 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).

N 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 in 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 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.

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 to 28 percent of the wastewater volume generated from a flushing dairy operation comes from the milking center and 72 to 77

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

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 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
1419	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
1419	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
2628	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
43805	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. Pastureland used in rotational grazing is often better maintained than typical pastureland. 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. They are:

- 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.

- Better rate of return. 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

- Limited applicability. 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.

- Reduced milk production levels. 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.
- Reduced weight gain. 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.
- Increased likelihood of infectious diseases. 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).
- Limited flexibility. 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 eight to ten 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 2 to 3 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
- 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
- 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 APHIS - 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
- 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
- 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

Manure is often used as a nutrient source and soil amendment, and can be used effectively by itself or along with other nutrient sources such as commercial fertilizer. In some cases surplus manure can be treated, processed, or repackaged to increase its value as a nutrient resource (such as compost, pelletized litter, or a fertilizer blend). When manure is generated in excess of what can be locally utilized either as a nutrient source or some other alternative use, it is often treated as a waste. EPA believes manure is most effectively used as a resource, and the use of the term waste in the following sections is not meant to imply to the contrary.

The term "waste" as it relates to AFOs includes manure, bedding material, spilt or waste feed, animal carcasses, and other by products. There are a variety of methods for handling, storing, and treating waste. Waste may be handled both 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. Water may also be used for cleaning and disinfection, especially at dairies and egg-producing facilities. 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.

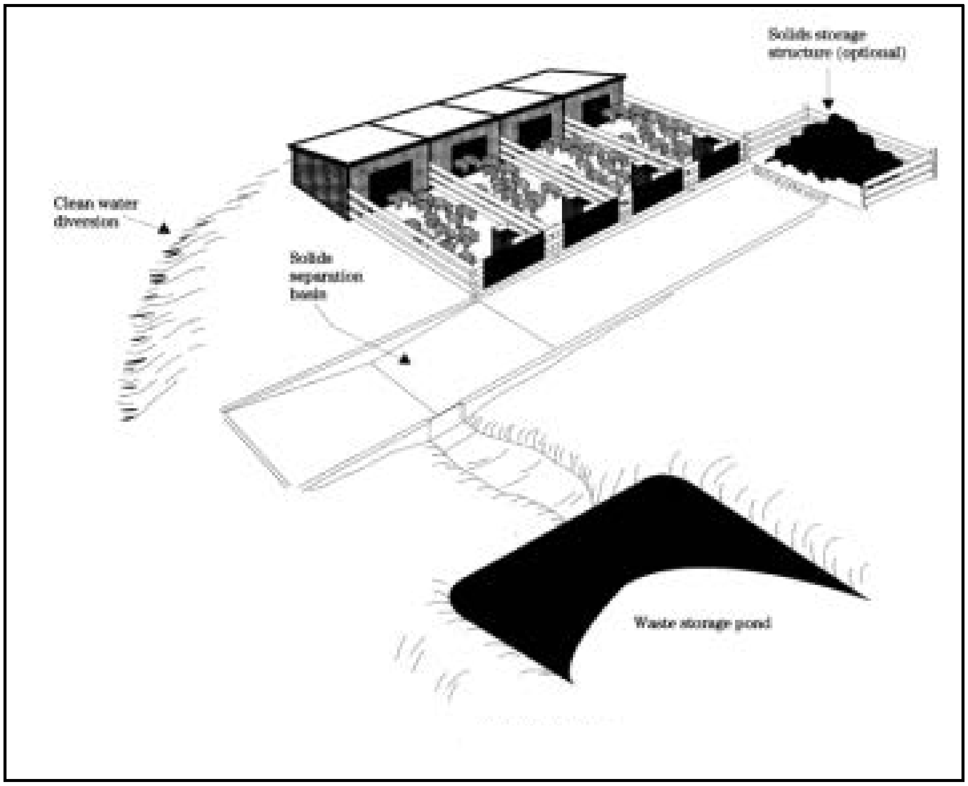

Figure 8-2. Manure scraped and handled as a solid on a paved lot operation (USDA NRCS, 1996).

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 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, 1996a), removal of manure by hand is used most often in all types of operations (farrowing 38.2 percent, nursery 29.9 percent, and grow-finish 27.2 percent). Mechanical scrapers and tractors are also used for solids handling (farrowing 12.0 percent, nursery 17.6 percent, and grow-finish 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.

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 BOD, COD, total solids (TS), P, calcium Ca, magnesium (Mg), and copper (Cu). Sixty per cent of the total TKN and forty percent of the 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., n.d.). 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., n.d.).

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 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.

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.

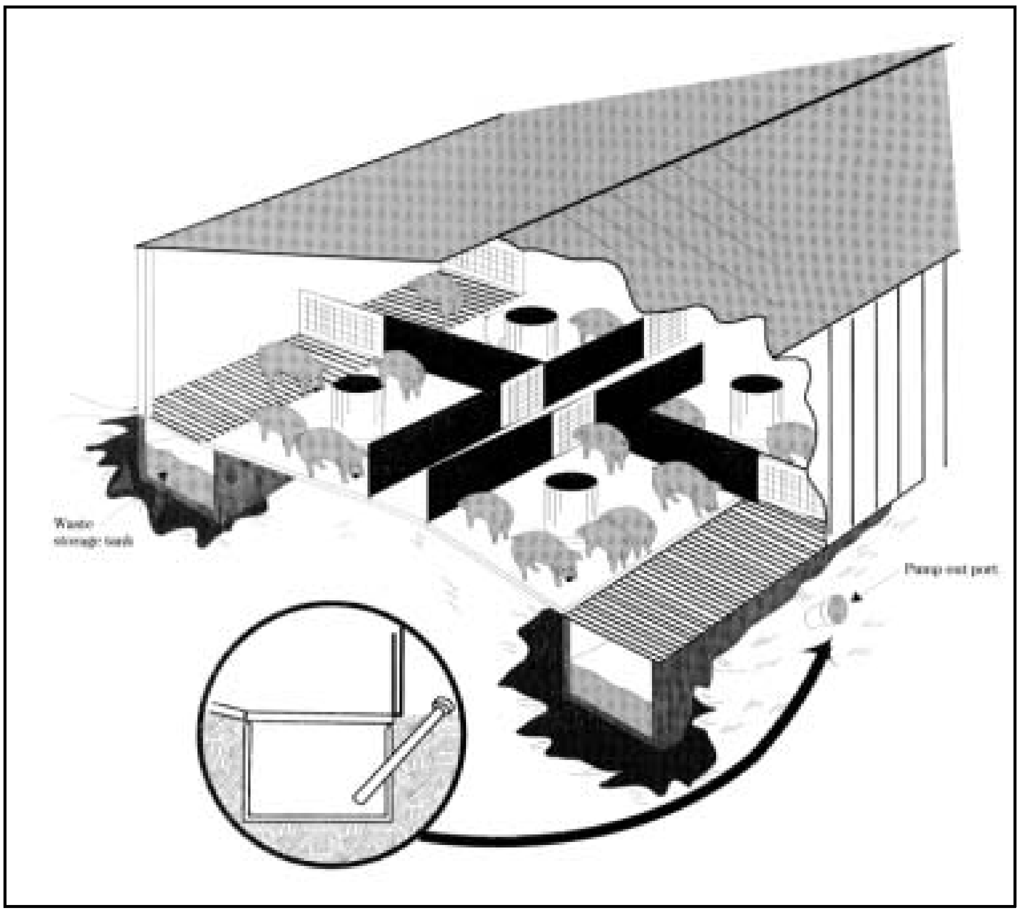

Figure 8-3. Fed hogs in confined area with concrete floor and tank storage liquid manure handling (USDA NRCS, 1996).

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, 1996a) 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 grow-finish 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, 2000).

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 percent 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 wastewater 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 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):

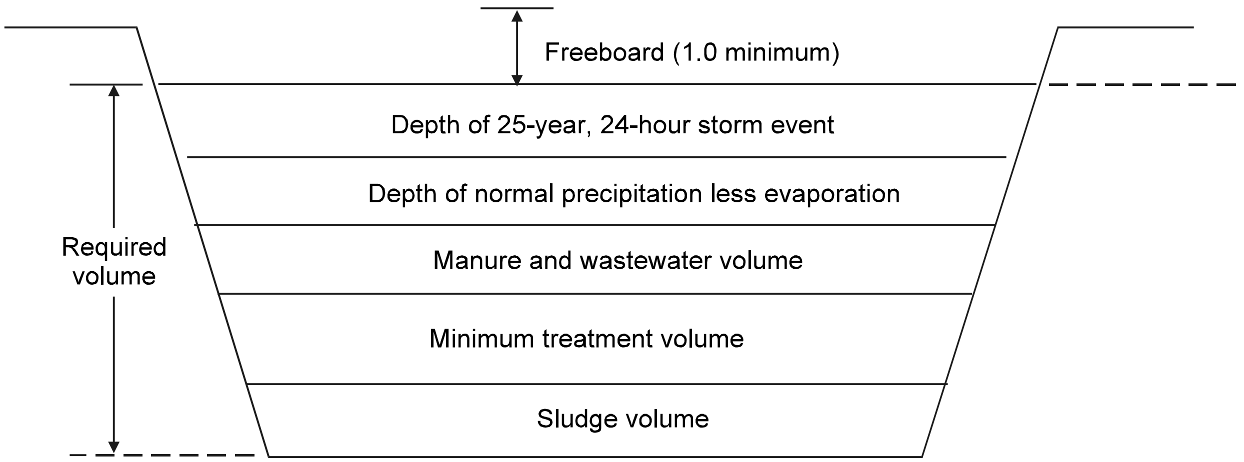

Figure 8-4. Cross section of anaerobic lagoons (USDA NRCS, 1998a)

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. P 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, 1998 Van Horn, 1999). 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 COD, TS, volatile solids (VS), total N, P, and K 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 (USDA NRCS, 2000). 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 VSLR 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 grow-finish swine operations. Of these, swine operations with 10,000 or more head use uncovered lagoons most frequently (81.8 percent) (USDA APHIS, 1996a). 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 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. For example, solids settling or solids separation prior to the storage pond reduces the rate of sludge accumulation.

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 for the storage period (usually the drylot area at AFOs).

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 AFO 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 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. P 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 dry lots. 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, 1996b). 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 (1.2 dilution versus 3.0 dilution for lagoon storage) while maximizing fertilizer value (1.7 times the N versus lagoon storage). Below-floor storage systems 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 provides 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 most commonly done at swine operations. *Swine ’95* (USDA APHIS, 1996a) reports that pit holding accounts for 25.5, 33.7, and 23.2 percent of farrowing, nursery, and grow-finish operations, respectively. Queries of the *Swine 2000* (USDA APHIS. 2002) data provided information on the use of pits by region, operation type, and size. Swine operations in the Midwest Region use pits most often, with 70.7 percent of the large and 67.7 percent of the medium grow-finish and 56.4 percent of the large and 54.9 percent of the medium farrow-to-finish operations using pits. Swine operations in the Mid-Atlantic Region use pits to a lesser degree, with 37.5 percent of the large and 26.3 percent of the medium grow-finish operations and 23.9 percent of the large and 14.4 percent of the medium farrow-to-finish operations using pits.

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

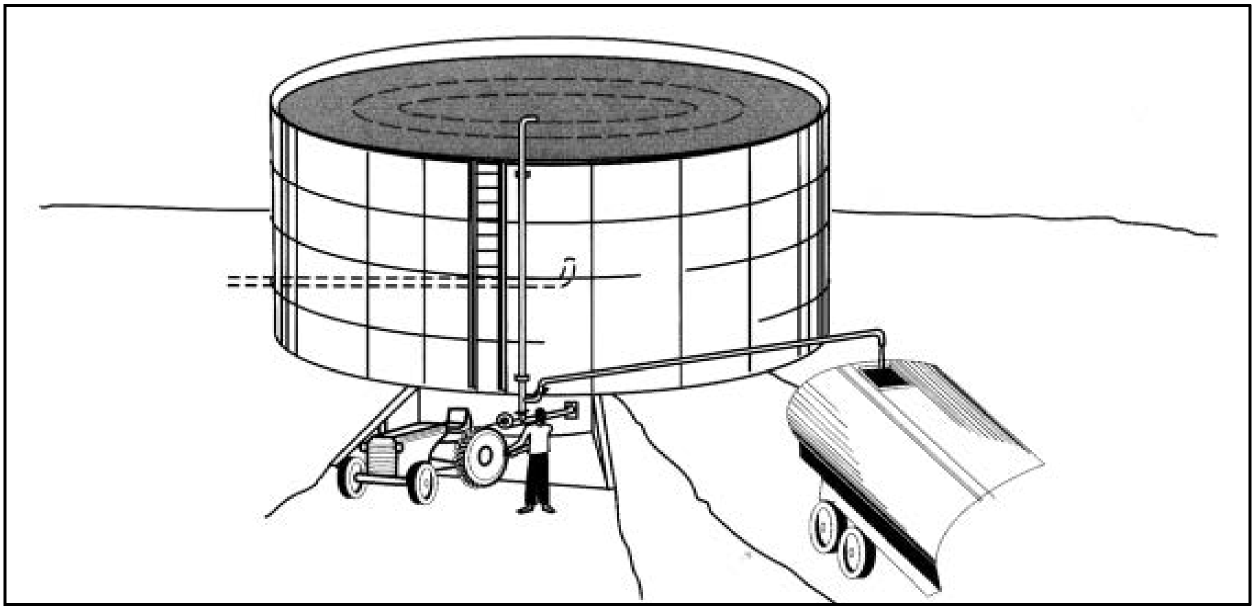

Figure 8-6. Aboveground waste storage tank (USDA NRCS, 1996).

high cost of storage volume, prefabricated storage tanks are generally used to contain only waste, but not runoff, from the livestock facility.

Below 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 because 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.

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 above or belowground storage tanks. Installation costs usually dictate that capacity be limited to manure storage requirements. Thus, water conservation is often practiced by facilities that use above 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.

Above 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. N 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, above 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

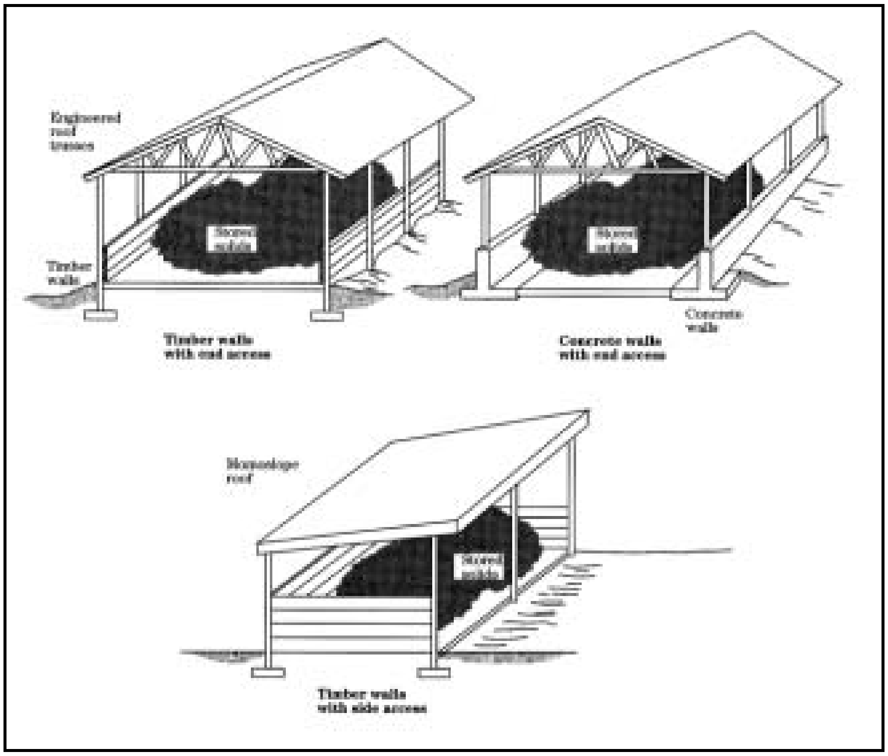

Figure 8-7. Roofed solid manure storage (USDA NRCS, 1996).

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.

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 are typically 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, 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, is probably 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 (Michele 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 semiliquid 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 AFOs to provide a surface on which to store solid and semisolid 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

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

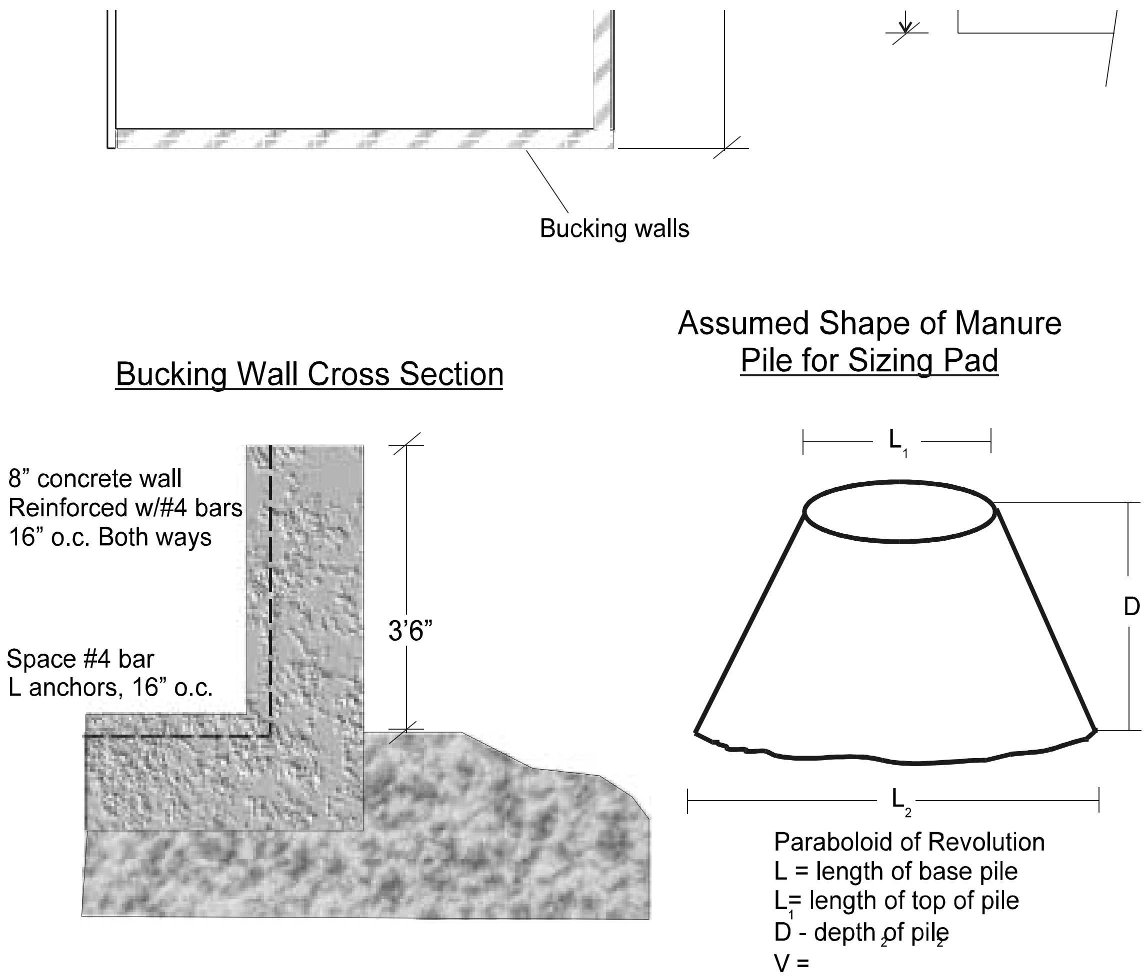

Figure 8-8 Concrete pad design.

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 semisolid 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 AFOs. 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 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 wash water, and flushed hog manure. Complete-mix digesters can be used to decompose animal manures with 3 to 10 percent TS. Plug-flow digesters are used to digest thick wastes (11 to 13 percent TS) 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 VS from dairy manure and 60 percent of the VS 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 BOD and TSS by 80 to 90 percent, and virtually eliminate 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 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.

Table 8-11. Anaerobic Unit Process Performance.

	Percentage Reduction						
Digester type	**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.

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 Na, K, and ammonium N, tended to be distributed evenly throughout the lagoon. Humenik et al. (1972) found that 92 to 93 percent of the copper(Cu) and zinc(Zn) 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 grow-finish 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 USDA NRCS (1999) developed 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 et al., 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.

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 et al., 1999.

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 Org-N to NH_3-N. Cheng et al., (1999) found that 30 percent of the total TKN (which includes ammonia and organic N) entering the covered first cell of a two-cell lagoon was retained in that cell, probably as Org-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 et al., (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.

Cheng (1999) found pathogen reduction through a North Carolina covered lagoon to be 2 to 3 orders of magnitude. 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 is also 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 several days 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 TS, and VS, BOD, COD, and Org-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 is typically 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.

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 Inc., 1991.

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 COD, and a 20 to 40 percent reduction in 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 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 substantially increase 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 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 °F (30 °C) or higher, can typically be maintained even in cold climates, and thermophilic temperatures as high as 131 to 149 °F (55 to 65 °C) 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 TS 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 TS concentration increases, the potential for achieving thermophilic temperatures also increases. Influent TS concentrations of between 3 and 5 percent are necessary to attain thermophilic temperatures.

With proper process design and operation, the previously discussed reductions in BOD_5, COD, TS, and total N that can be realized with conventional aerobic digestion also can be realized with autoheated aerobic digestion (Martin, 1999). Autoheated aerobic digestion can also provide significant reductions in pathogen densities in a relatively short 1- to 2-day treatment period. 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, 1999).

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, COD, TS, 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 (1999).

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, 1999). Feasibility also has been demonstrated in several studies with cattle manure, including studies by Terwilliger and Crauer (1975) and Cummings and Jewell (1977). 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, the 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.

P 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 (SBR) (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 to 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.
- 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: An 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.

React Phase: 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 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 HRT, 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 mg/L (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 Europe have 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 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 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 TS 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. N is considered volatile in the ammonia form, but some Org-N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-Org-N fraction of total 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 VS/TS. VS are a portion of the TS 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 NH_3 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 NMPs. 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. P 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 to 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 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 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.

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

Source: USDA NRCS 1996.

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 TS 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 VS/TS ratio. VS are a portion of the TS that can be biologically destroyed, and as they are destroyed, the VS/TS ratio declines. Some Org-N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-organic N fraction of TKN in settled solids.

As anaerobic digestion of manure changes the solution chemistry in a lagoon, materials such as NH_3 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 NMPs. 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. P 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 an SAV in its lagoon design calculations. Table 8-15 shows USDA's ratios of sludge accumulated per pound of 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 accumulate 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 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.

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

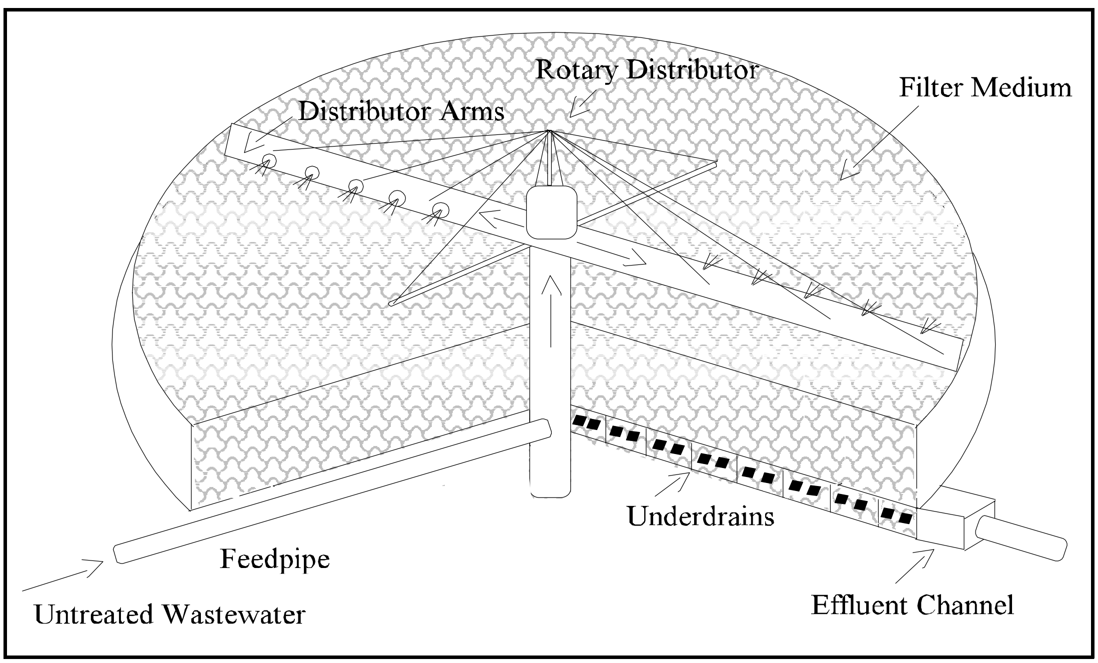

Figure 8-9. Trickling filter.

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. These systems look more like towers than conventional rock-media systems. It is also common to have single- 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 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 NH_3 to nitrite N, which is then converted to nitrate N by other microorganisms. Nitrate N is less toxic to fish and can be converted to N_2, 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 to 25°C range. A high wastewater temperature increases biological activity, but may result in odor problems. Cold wastewater (e.g., 5 to 10°C) can significantly reduce the efficiency BOD removal (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.

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 Inc., 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 Inc., 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.

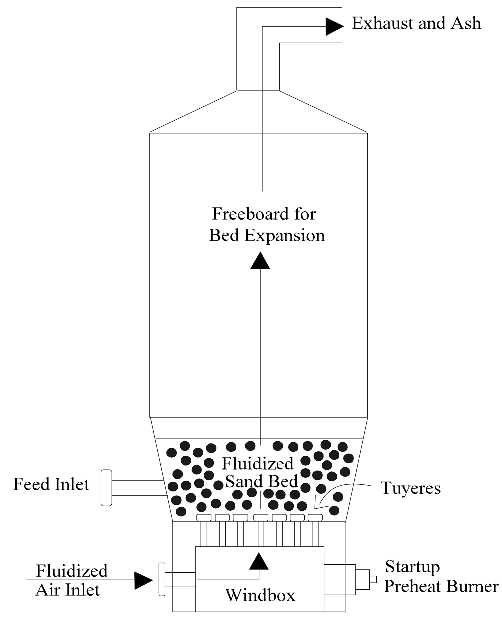

Figure 8-10. Fluidized bed incinerator.

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. 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, BOD_5, fecal coliform, and nutrients such as N and P. 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.

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, Org-N is converted to NH_3 (ammonification), which is used by plants as a nutrient; NH_3 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). NH_3 may be removed through volatilization, uptake by plants and microbes, or oxidized to nitrate. Volatilization of NH_3 in CWs appears to be the most significant mechanism for N removal for animal waste treatment (Payne Engineering and CH2M Hill, 1997).

P removal is achieved mainly by fixation by algae and bacteria, plant uptake, and (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, and 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 NH_3-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 NRCS (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 NPDES.

A performance summary of CWs used for treating animal waste indicates a substantial reduction of TSS (53 to 81 percent), fecal coliform (92 percent), BOD_5 (59 to 80 percent), NH_3-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, TSS, 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 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 TSS, and <10 mg/L NH_3-N. The NRCS *Field Test Method* is based on

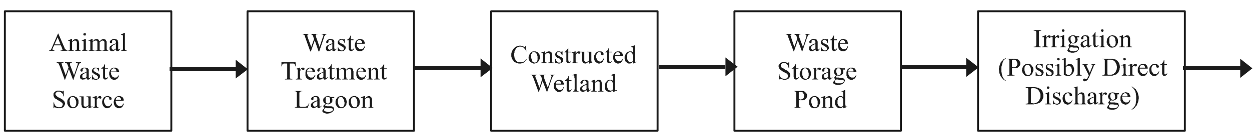

Figure 8-11. Schematic of typical treatment sequence involving a constructed wetland.

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 AFOs. The filters are designed with adequate length and limited flow velocity to promote filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilization of contaminants. These filters consist of three parts: a sediment basin, a flow distribution device, and a filter strip area (Harner, 2000).

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 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

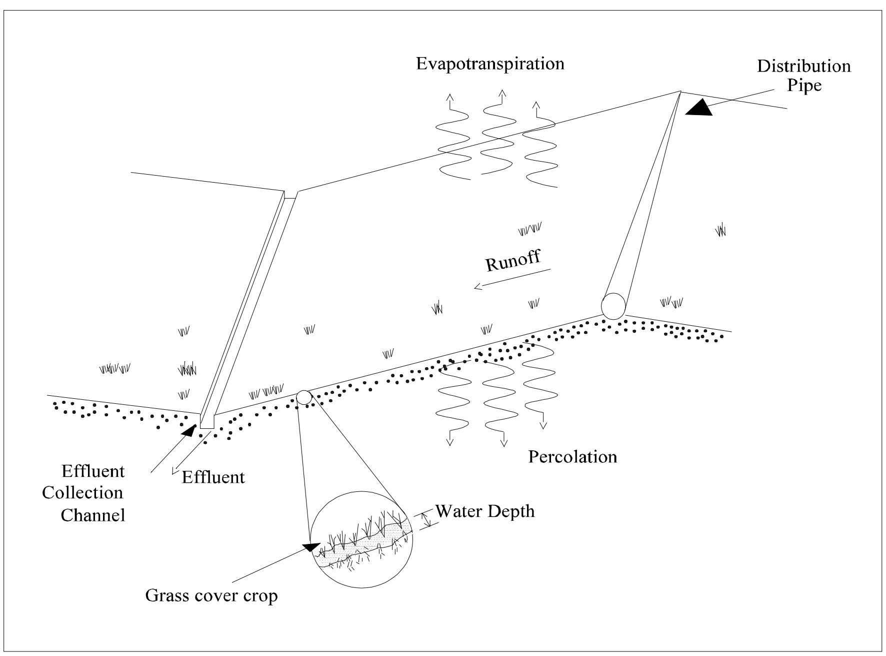

Figure 8-12. Schematic of a vegetated filter strip used to treat AFO wastes.

12 to 16 hours of drying. NH_3 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 NH_3. 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. The shape and area of the field being drained changes the filter strips effectiveness, as does the method of installation (Franti, 1997). It is best for runoff from areas of clean storm water to avoid passing through the filter. Allowing storm water into the filter strip could overwhelm the system causing inadequate filtration on the wastewater (Harner, 2000).

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.

Vegetated filter strips can be unsuccessful if the plants are not absorbing enough nutrients. Plants must be healthy, dense, swift growing, have fibrous roots to fight erosion, and be perennials. The plants must also endure being waterlogged and grow well in the spring and fall. The most effective type of plants to use are sod-forming grasses (Harner, 2000).

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 TSS, total P, and TKN 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 (Nebraska Cooperative Extension, 1997).

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. The filter's performance is limited by the level and duration of rainfall and the type of vegetation (EPA, 2001).

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. Sediment accumulation should be inspected (Harner, 2000). In addition, the slope needs to be periodically inspected and regraded to ensure a level flow surface and prevent channeling and erosion. When sparse plant coverage is observed, it should be reseeded. Undesirable plants in the filter should be managed (Harner, 2000).

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 NH_3 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 (Carbon:Nitrogen) 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).

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 off site, the raw material content will greatly affect its market value.

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 C:N ration 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.

Table 8-18. Desired Characteristics of Raw Material Mixes.

Characteristic	Reasonable Range	Preferred Range
C:N Ratio	20:1–40:1	25:–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.

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.

C and N 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 N 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 NH_3 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 N 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 N-rich, excessively wet, and has a C:N 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 NH_3 concentrations from dairy manure and rice hulls composted with various aeration rates (Hong et al., 1997). Temperature and NH_3 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 NH_3 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. NH_3 emissions were 39 percent lower from the intermittent aeration treatments, and N 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 N loss and NH_3 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, n.d.). 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, 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 10 to 15 percent, a slight odor may be noted. Crude protein levels of 17 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 10 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., Cu, arsenic, Zn) 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 NH_3 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 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 N is oxidized) and only secondarily on the amount of N in the fuel. In fact, the high NH_3 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 (K and Na) 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 NH_3 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 to 30 percent had a caloric content ranging from 7,600 Btu per pound to 4,700 Btu per pound. 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 NH_3 over nitrate (Monselise and Kost, 1993), transforms nutrients to a protein-rich (25 to 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 better understand 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 N_2. 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 NH_3 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 ^{o}C, with 150 ppm BOD and 250 ppm TKN, could nitrify 90 percent of the NH_3 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 NH_3, and could reduce the loss of NH_3-N to the atmosphere. When set up and operated properly, the treatment can convert 90 percent of the NH_3-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 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: NCSU 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-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 treatments have been applied to facility wastewater, animal waste, or directly to soils. A number of chemical amendments have been evaluated, mainly metal salts or by-products containing Al, Fe, or Ca, similar to methods used to remove P in municipal wastewater treatment. The P fixation capacity of soils is positively correlated with the Al content; Al and orthophosphate ions interact strongly to form either stable surface complexes or insoluble Al phosphate minerals (Moore and Miller 1994). Precipitation reactions with Fe and Ca form insoluble iron and calcium phosphates. Moore and Miller (1994) conducted laboratory studies of 100 different treatments with various Al, Fe, and Ca compounds at different rates and found that many of these compounds drastically reduced soluble P levels in poultry litter.

Amendments reported in the literature, mostly from laboratory or plot studies, include:

- **Water treatment residuals (WTR).** WTR, also known as alum sludge or alum hydrosolids (HS), are wastes generated from drinking water pretreatment. Peters and Basta (1996) added HS to soils previously treated with poultry litter and reported 50–60 percent reductions in Mehlich-III P. Haustein et al. (2000) found that high rates of both WTR and HiClay Alumina (HCA) applied directly to test plots decreased Mehlich-III soil test P levels due to the increased levels of soil Al.

- **Ferric Chloride ($FeCl_3$).** Ferric Chloride additions to poultry litter decreased P solubility at lower rates of about 20–50 g Fe/kg litter, but increased solubility at higher rates (Moore and Miller 1994). Barrow et al. (1997) reported that adding high levels of ferric chloride to dairy wastewater improved sedimentation of P by almost 50 percent. Sherman et al. (2000) reported significant P removal from dairy flushwater using ferric chloride.

- **Coal combustion byproducts**. Stout et al. (1998) reported that addition of fluidized bed combustion flyash (FBC) and flue gas desulfurization product (FGD) to soils significantly reduced Mehlich-III P (45 percent), Bray-I P (50 percent), and water extractable P (72 percent) due to converting readily desorbable soil P to less soluble Ca-, Al-, or Fe-bound forms. Dao (1999) observed that application of Class C fly ash to cattle manure reduced water-extractable P by 85-93 percent and Mehlich-III P concentrations by up to 98 percent. FBC and FGD additions reduced water soluble inorganic P in by fresh dairy and swine manure by 50–80 percent (Toth et al. 2001a). Dou and Ferguson (2002) reported water soluble P reductions of 23–59 percent in swine and dairy manure treated with FBC and FGD. It should be noted that these byproducts can contain significant concentrations of heavy metals that may be toxic to plants and the loadings of these elements must be considered in the use of combustion byproducts.

- **Zeolite.** Lefcourt and Meisinger (2001) reported that addition of zeolite (primarily Si, AL, Na, and K oxides) to dairy slurry reduced soluble P content by over 50 percent.

- **Polyacrylamide (PAM).** PAM has been used to reduce sediment, nutrients, and pesticides in furrow-irrigated agriculture. In lab and field studies, PAM alone or in combination with Al and Ca reduced PO_4 by 47–64 percent in soil column leachate when manure was applied and by about 50 percent in water flowing over surface-applied cattle manure (Entry and Sojka 2000).

- **Limestone Dust.** Barrington and Gelinas (2002) reported precipitating about 93 percent of total P in swine manure into a sludge by the addition of 2 percent fine limestone dust.

- **Wollastonite.** Application of wollastonite (alkaline calcium and ferrous silicates) to soils has been proposed as a means to reduce P solubility in hydrologically sensitive areas (Willett et al. 1999). However, no experimental data have been reported.

By far, the most widely proposed and most thoroughly evaluated manure amendment is aluminum sulfate ($Al_2(SO_4)_3$), commonly called alum.

Alum Treatment

Although alum has been used for P precipitation in wastewater treatment for several decades, the use of alum additions to animal waste has been studied extensively only since the early 1990s. Applications have ranged from pretreatment of agricultural wastewaters, manure treatment, and soil amendment. While the majority of the studies have focused on effects on P solubility and runoff, significant effects on nitrogen volatilization and runoff of metals have also been documented.

Alum treatment for P control. Alum is thought to reduce soluble P through two mechanisms, formation of relatively insoluble aluminum phosphate compounds:

$$AL_2(SO_4)_3\text{-}14H_2O + 2H_3PO_4 \rightarrow 2AlPO_4 + 6H^+ + 3SO_4^{2-} + 14H_2O$$

or sorption of P by amorphous aluminum hydroxides:

$$AL(OH)_3 + H_3PO_4 \rightarrow AL(OH)_3\text{-}H_3PO_4$$

Over time, amorphous aluminum phosphate could be transformed to crystalline minerals such as variscite or wavellite, which are stable under acid conditions (Moore et al. 1998).

Much of the work on alum treatment has been done on poultry litter. Poultry litter is a particular problem because most P in litter occurs in the soluble form and intensive poultry production often occurs with a limited land base for waste application. Moore and Miller (1994) conducted early laboratory studies of alum additions to poultry litter and reported that alum additions decreased water soluble P from 2,000 to about 1 mg P/kg and concluded that treating litter prior to field application could significantly reduce soluble P runoff. In another study, the soluble P content of poultry litter amended with alum was reduced by up to 94 percent, from 2022 mg/kg to 111 mg/kg (Moore et al. 1995).

Shreve et al. (1995) evaluated the effects of alum treatment of poultry litter on runoff P and on forage production. Amending poultry litter with alum resulted in an 87 percent reduction in soluble P concentrations in runoff from plots compared with untreated litter in the first runoff event after application, and a 63 percent reduction for the second runoff event. Runoff soluble P load in the first runoff event was reduced 86 percent by alum addition. Litter application increased fescue yields, with yield having the greatest response to alum-amended litter, probably due to increased available N resulting from decreased NH_4 volatilization from the alum-treated litter. Based on these field trials, the authors concluded that alum treatment for poultry litter had significant promise for use as an environmental and economic management practice in the poultry industry.

A subsequent examination of long-term solubility of P in soils receiving treated poultry litter reported that after addition of litter containing 200 mg alum/kg, soil soluble P decreased from initial concentrations of 4.5-11.5 mg P/kg to about 1 mg P/kg after about 100 days over a wide pH range and remained low through nearly 300 days (Shreve et al. 1996).

Moore et al. (1997) determined the effect of alum treatment of poultry litter on phosphorus runoff from field-scale watersheds. Soluble reactive P concentrations in runoff averaged 1.05 and 3.23 mg P/L for the alum-treated and untreated litter, respectively; alum reduced soluble P runoff by 67 percent during the first year after application. Total P concentrations responded similarly (average 1.49 and 4.23 mg P/L for alum-treated and untreated litter, respectively). Soluble P concentrations averaged 74 percent lower from alum-treated litter runoff during the second year after application. Overall, soluble reactive P concentrations were decreased 70 percent with alum.

Moore et al. (1997) also assessed agronomic rates of alum-treated poultry litter. The authors observed that application of normal poultry litter resulted in dramatic increases in water soluble P in soils, whereas application of alum-treated litter did not. Data showed that P bound by alum does not re-solubilize with time, indicating that litter application rates can be based on N, rather than P, if alum-treated litter is used, without risk of increasing soil test P levels. The study also found that the pH of soils fertilized with alum-treated litter was slightly higher than unfertilized soils, indicating that the use of alum in litter will not result in soil acidification.

Pre-treatment of poultry litter with alum significantly affects soil P as well as runoff. After three years of treating grass plots with alum-amended litter, no significant differences in soil water soluble P were observed when compared to the unfertilized control (Self-Davis et al. 1998, Moore et al. 2000). Water-soluble P levels in plots receiving untreated litter, however, increased each year. Alum-amended litter plots had significantly lower Mehlich-III P values compared to equivalently-managed untreated litter plots after two years of litter applications.

In an evaluation of treatment to fields already excessively high in soil test P, Haustein et al. (2000) applied water treatment residuals (WTR, composed of coagulated alum mixed with sand, silt, bacteria, and other compounds removed from raw water in the water treatment process) to grassed plots high in P. High rates of WRT (9–18 Mg/ha) decreased Mehlich-III soil test P levels 44–50 percent due to increased soil Al levels. Dissolved P in runoff from treated plots were less than or equal to levels in runoff from the control (no litter) plot.

A recent on-farm evaluation of alum as a poultry litter amendment showed that a poultry litter alum-treatment BMP can be effectively implemented under a wide range of real-world conditions (Sims and Luka-McCafferty 2002). Alum was applied over a 16-month period to 97 poultry houses on working poultry farms on the Delmarva peninsula, with 97 other houses serving as controls. Alum decreased water soluble P concentrations in litter by about 70 percent, from an average of 1475 mg P/kg in untreated litter to an average 405 mg P/kg in alum treated litter.

While the effects of alum treatment on P in other animal wastes have received considerably less evaluation, results seem to be similar to those observed with poultry litter. Alum addition to stockpiled and composted cattle waste reduced water-extractable P in the waste by 85–93 percent (Dao 1999). Sherman et al. (2000) demonstrated removals of 11–17 mg P/ mmol Al^{+3} added to flush waters containing 1 percent dairy manure solids. Alum has been shown to be very effective in reducing soluble P in dairy manure (Lefcourt and Meisinger 2000). Even a 0.4 percent addition rate reduced soluble P about 75 percent compared to the control; a 6.25 percent addition reduced soluble P by about 97 percent. Toth et al. (2001b) reported that alum addition significantly reduced soluble P in dairy manure (by 36–99 percent), and, to a lesser extent, in swine manure (7–80 percent). Addition of alum at 0.5 percent by volume to a swine waste settling basin improved P removal from the liquid fraction to 75 percent, compared to 38 percent without alum (Worley and Das 2000).

Addition of alum to horse bedding prior to application to grass plots decreased runoff soluble P concentrations by 97 percent, which was less than the mean soluble P concentration in runoff from control plots (Bushee et al. 1998). Alum addition to horse manure decreased P concentrations by >50 percent in plot runoff; runoff P concentrations from alum-treated application did not differ significantly from runoff from non-manured plots (Edwards et al. 1999).

Alum treatment effects on nitrogen. Ammonia (NH_3) volatilization from poultry litter results in accumulation of atmospheric NH_3 in the poultry house, which is detrimental to human and bird health and reduces poultry productivity. Ammonia loss from litter and other animal waste also reduces the N content of the manure and can contribute to both acid deposition and eutrophication (Kithome et al. 1999).

Numerous studies have confirmed that addition of alum to poultry litter can reduce NH_3 volatilization up to 99 percent (e.g., Moore et al. 1995, 1998, and 2000). Alum reduces NH_3 losses because the acid generated in the hydrolysis of alum reduces litter pH; the H^+ produced in this reaction will react with NH_3 to form non-gaseous NH_4^+, which can react with sulfate ions to form ammonium sulfate, a water-soluble fertilizer.

Moore et al. (1995) documented 36-99 percent reductions in NH_3 volatilization with alum application to poultry litter, noting that the preservation of N in the litter added to its fertilizer value. The authors attributed a lower poultry mortality rate in alum-treated litter due to decreased levels of atmospheric NH_3 in the house. Shreve et al. (1995) observed a higher forage yield with alum-treated litter compared to untreated litter, an effect they attributed to improved N content due to reduced NH_3 loss.

Moore et al. (1999, 2000) reported results of field trials where alum was applied to broiler litter. Alum applications lowered litter pH significantly during the entire growout period. Reductions in litter pH decreased NH_3 volatilization and resulted in significant reductions in atmospheric NH_3 in the alum-treated houses. Alum applications reduced NH_3 fluxes from litter by 97 percent for the first four weeks of the growout and by 75 percent for the full 6-week period. Additional benefits of the reduction of NH_3 loss included improved growth of broilers, improved feed conversion, lower mortality, and lower energy costs for ventilating and heating.

Addition of alum to poultry litter during composting has been shown to be effective in conserving nitrogen. Addition of 20 percent alum to poultry litter resulted in a 26 percent reduction in NH_3 loss (Kithome et al. 1999), resulting in a final compost significantly higher in total N and NH_4^+ compared to untreated compost.

In farm-scale evaluations of alum treatment, Sims and Luka-McCafferty (2002) reported that litters from alum-treated poultry houses had higher total N, NH_4-N concentrations and therefore a higher fertilizer value.

Again, relatively little work has been reported on alum amendment to other animal wastes for the reduction of ammonia volatilization. Lefcourt and Meisinger (2000) reported that the addition of 2.5 percent alum to dairy slurry reduced ammonia emissions by about 60 percent. In a laboratory test of potential amendments to reduce ammonia emissions from beef cattle feedlots, Shi et al. (2001) reported that alum application reduced NH_3 volatilization by up to 98 percent.

Alum treatment effects on metals. Poultry litter often contains significant concentrations of heavy metals such as As, Co, Cu, Mn, Se, and Zn. Trace metals are added to feed to prevent disease and improve feed conversion; most of the metals added pass directly through the bird, which leads to elevated metal levels in the manure. Research has indicated that the potential exists for nonpoint source metal pollution from fields receiving poultry litter (Moore et al. 1998).

Moore et al. (1997 and 1998) conducted plot studies to determine if alum treatment reduces metal runoff and uptake by plants from poultry litter; the authors present extensive data on alum effects on copper, zinc, arsenic, aluminum, selenium, and other elements. Concentrations and loads of water-soluble metals (Al, As, Ca, Cu, Fe, K, Mg, Na, and Zn) increased with increasing litter application rates, regardless of litter type. The metal of greatest concern was copper, which was found in high concentrations in runoff from untreated litter. Alum treatment significantly reduced concentrations of As, Cu, Fe, and Zn compared to untreated litter, but increased Ca and Mg levels. Reductions in trace metal runoff due to alum were thought to be related to reduction in concentrations of soluble organic carbon (SOC) due to alum treatment. The authors concluded that metal runoff from alum-treated litter is less likely to cause environmental harm than from untreated litter because the water quality impacts of Ca and Mg are far less than those caused by Cu, As, and Zn. The study also showed that aluminum runoff and uptake by plants was not affected by alum treatment.

Little work on the effects of alum on metals associated with other animal waste has been reported in the literature. Edwards et al. (1999) studied the runoff of metals from alum-treated horse manure and found few detectable effects on metals in runoff from manured plots. Runoff concentrations of Al, S, Ca, and K increased in response to alum.

Summary: Alum Treatment

Benefits of alum treatment. Alum treatment of animal waste, particularly poultry litter, has important beneficial effects as a P management BMP. These direct effects include:

- **Reduced P solubility in waste.** Reductions in water-soluble P content of poultry litter and other animal wastes of 70 to >90 percent have been cited (e.g., Moore and Miller 1994, Moore et al. 1995, Lefcourt and Meisinger 2000, Sims and Luka-McCafferty 2002). This effect has been documented from the laboratory to the farm scale.

- **Reduced soil P levels.** Use of alum-treated poultry litter significantly reduces soil P. For example, after three years of treating grass plots with alum-amended litter, no significant differences in soil water soluble P were observed when compared to the unfertilized control (Self-Davis et al. 1998, Moore et al. 2000). Alum-amended litter plots had significantly lower Mehlich-III P values compared to equivalently-managed untreated litter plots after two years of litter applications. Use of treated litter can also reduce soil test P on soils already excessively high in soil test P (Haustein et al. 2000).

- **Reduced runoff P.** Use of alum-treated animal waste can dramatically reduce P runoff losses compared to untreated waste. Reductions of about 60–90 percent in soluble P concentrations in runoff have been widely reported from alum-treated poultry litter and other animal wastes (Shreve et al. 1995, Moore et al. 1997, Bushee et al 1998). In several reported cases, P concentrations in runoff from land-applied alum-treated waste were not significantly different from P levels in runoff from un-manured land (Self-Davis et al. 1998, Edwards et al 1999, Moore et al. 2000).

- **Reduced ammonia loss.** Numerous studies have shown that addition of alum to poultry litter can reduce NH_3 volatilization up to 99 percent (e.g., Moore et al. 1995, 1998, and 2000). Reduction in ammonia loss from poultry litter not only reduces airborne ammonia inside the poultry house but improves the fertilizer value of the litter by conserving N. Higher N content in alum-treated litter has been widely documented (Shreve et al. 1995, Kithome et al. 1999, Sims and Luka-McCafferty 2002).

- **Reduced runoff losses of metals.** Alum amendment decreases litter pH and the solubility of metals such as As, Cu, and Zn, which should reduce the movement of these soluble forms into surface or ground waters (Sims and Luka-McCafferty 2002). Runoff losses of some trace metals that pose significant environmental risk (e.g., copper) have been shown to be lower from land application of alum-treated poultry litter, compared to conventional litter (Moore et al. 1997 and 1998).

These documented effects of alum treatment have led to the conclusion that alum treatment offers great promise as an animal waste management BMP, particularly for poultry production (Moore et al. 1999, Sims and Luka-McCafferty 2002). Long-term studies of alum use have reported few negative impacts. The aluminum-phosphate minerals formed when alum is added to manure are believed to be stable for geologic time periods (Moore at al. 1999). Soil acidfication from alum use does not appear to be a problem, as increases in soil pH have been reported with alum-treated litter (Moore et al. 1997, 2000).

At typical rates of addition, alum treatment would not be expected to raise soil Al content significantly for several centuries (Moore et al. 2000). Even then, alum additions would not generally increase Al concentrations in runoff because soil pH does not typically become low enough for Al to be soluble. Thus, increases in Al in runoff from application of alum-amended waste would not be expected (Moore et al. 1999, 2000). In one reported case, however, elevated

Al levels were found in runoff from plots that received high-aluminum water treatment residuals in direct application; this was attributed to washing of freshly applied material from the soil or plant surface (Haustein et al. 2000).

Moore et al (1997) reported no significant differences in aluminum levels in plants due to application of alum treated litter. This is expected because alum-treated litter contains only trace quantities of soluble Al; most Al in treated litter and soil occurs as insoluble minerals.

Treatment of poultry litter with alum has a number of potential indirect benefits, including:

- **Improved fertilizer value.** Reduction of N losses and decreases in soluble P changes the N:P ratio of the litter. If alum-treated litter is used, it may be possible to apply litter based on N needs of a crop, rather than P, without risk of increasing soil P levels. Improved fertilizer value could also increase the economic feasibility of animal waste export or transport to facilitate nutrient trading.

- **Odor control.** Reduction of ammonia volatilization from animal waste, particularly poultry litter, may offer significant benefits in reduction of odor problems with animal production.

- **Health and productivity.** The reduction of ammonia production in poultry litter by alum has many important benefits to human and bird health and to productivity. Reduced ammonia levels in poultry houses will reduce exposure of farm workers to harmful levels of ammonia. Reductions in flock mortality, improved weight gains and feed conversion, and reduction in incidence of disease have all been documented in response to alum treatment of litter in poultry houses (Moore et al. 1999). Reduction in energy costs due to decreases in need for ventilation and heating have also been documented in response to reduced ammonia levels.

- **Solids separation.** The ability of alum to precipitate P in liquid dairy or swine waste may facilitate solids separation for composting and manure transportation.

- **Recycling of byproducts.** Use of Al-based materials like alum hydrosolids, water treatment residue, or flyash are used for waste treatment may replace expensive landfill disposal of these byproducts.

In addition to the broad environmental benefits, alum use seems likely to be a cost-effective practice to poultry growers and integrators. Moore et al. (1999) estimated a benefit:cost ratio of 1.96 for alum treatment of poultry litter, accounting for the cost of the alum treatment and the savings associated with improved productivity, lower mortality, and lower energy costs.

Cautions. While the benefits of alum treatment of animal waste have been clearly documented and few serious environmental risks have been identified, a few qualifications and concerns remain that must be considered.

- The reported reduction in P loss in runoff due to alum treatment generally assumes that erosion from source areas is minimized. Erosion and soil loss would transport particulate P in runoff, which may pose a long-term threat to water quality despite reductions in solubility due to alum treatment.

- Alum amendment of animal waste must be done in the context of a sound nutrient management program. Use of alum treatment as a BMP would be of little value if nutrients continue to be applied in excess of crop requirements.

- The effectiveness of alum may be lower than reported for poultry litter in other wastes if more of the P is already in a stable (nonsoluble) form, e.g., biosolids.

- Alum treatment is not an unlimited solution to the problem of excessive P loading from animal waste. For example, even when high P soils were treated to reduce soil test P by about 50 percent, the level of plant-available P remaining in the soil was twice that required for maximum crop production (Haustein et al. 2000).

- Because alum treatment conserves N in animal waste, there may be an increased potential for N loss in runoff or leaching.

- Whereas alum-treated animal wastes are neutral or alkaline, untreated aluminum sulfate may result in undesirable soil acidification and lead to release of toxic levels of dissolved Al (Peters and Basta 1996).

- Alum dose must be carefully controlled; excess alum addition can increase soluble Al in manure slurries (Lefcourt and Meisinger 2001); excessive application of some alum could immobilize enough P so that crop yields suffer from induced P deficiency.

- Although most studies have indicated that P compounds formed with Al are quite stable, some authors have suggested that the effects of changing redox potential on long-term stability of these compounds should be evaluated (Shreve et al. 1996).

- Because Al solubility is controlled by pH, soil pH may need to be monitored in areas vulnerable to acid deposition or if alum-treated manure applications are discontinued and replaced by inorganic N fertilizers, which tend to reduce soil pH.

- While alum will decrease the solubility of elements such as P, As, Cu, and Zn, it will have little or no effect on the total quantity of these elements in the waste. Research is needed on long term stability, transformations, and potential mobility of P and trace metals in soils amended with alum-treated animal waste (Sims and Luka-McCafferty 2002).

Chemical Treatment for Pathogen Reduction

Treatment of manure with lime (calcium hydroxide, calcium oxide) has been proposed as a means to reduce pathogens in animal waste. There is scant information in the scientific literature directly concerning animal waste treatment; most of the justification for this proposed treatment comes from the use of lime materials to reduce pathogens and odors in biosolids. It is important to note that the lime discussed here is not the same material as the limestone (calcium carbonate, "agricultural lime") that is used to raise the pH of agricultural soils.

Biosolids treatment

Federal regulations classify biosolids into two classes, based on pathogen content; these classes specify the degree of treatment the biosolids must receive before land application or disposal. To meet Class A requirements (very low pathogen concentrations), biosolids must be treated by thermal drying (80 ºC, dried to ≥90 percent solids), composting (55 ºC for three days, aerobic conditions), or lime stabilization. Lime stabilization to meet Class A requirements requires that pH be raised to ≥12 for 2 hours and be maintained at pH 11.5 for 22 hours, combined with high temperatures (70 ºC for 30 minutes). Lime stabilizaton involves addition of dry quicklime (CaO) to raise the pH and temperature of the biosolids.

In a comparison of stabilization techniques, Rothberg, Bamburini & Winsor, Inc. (undated), cited a number of advantages of lime stabilization, including pathogen reduction to Class A levels, low capital cost, dilution of metals concentrations, fixing of metals under alkaline conditions, and value of end product as a soil liming agent. Disadvantages cited include high annual cost, odor problems for ammonia offgas, and product applicability to alkaline soils. Currently, almost 20 percent of biosolids in the U.S. are treated with lime.

Lime inhibits pathogens by controlling environmental conditions required for bacterial growth. At pH >12, cell membranes of microorganisms are destroyed; hydrated lime (calcium hydroxide) is capable of creating pH levels as high as 12.4 (NLA 2001). Furthermore, use of quicklime (calcium oxide) involves an exothermic reaction with water, potentially raising temperatures to levels inimical to microorganisms.

Lime as an agricultural disinfectant

Lime is reportedly used in Europe as a disinfectant for barn and milking center floors, for disease control in carcass disposal, and for disinfection of animal wastes (NLA 2001).

Cooper Hatchery, Inc. (1987) reported that total bacteria counts, molds, and coliform bacteria were decreased in turkey litter after three days of fermentation following addition of hydrated lime.

Shand and Associates (1998) conducted a project to test the effectiveness of a lime pasteurization process to partially dehydrate and stabilize organic wastes in the Fraser River Basin (Canada). Although no pathogen data were reported, it is interesting to note that addition of lime accelerated ammonia emissions from animal wastes (probably due to elevated pH in the waste). This ammonia offgassing has been cited as a possible agent of disinfection in alkaline treatment of waste (Logan 1999).

Hogan et al. (1999) reported that hydrated lime effectively inhibited bacteria in recycled dairy manure bedding in 1 day. Lime was effective on reducing gram-negative bacteria, coliform counts, *Klebsiella spp*., and *streptococci*.

Logan (1999) reported mixed results of pathogen reductions in animal waste using a proprietary alkaline stabilization process; the process apparently did not use lime. Several different waste types were tested in a processing plant where alkaline materials (unspecified coal-burning byproducts) were mixed with animal waste. The process achieved reductions in fecal coliform of one to three orders of magnitude in digested dairy manure; however fecal coliform counts were still as high as 10^3–10^4/g after treatment. Alkaline treatment was effective in treating undigested manures, reducing fecal coliform counts from 10^6/g to 10^1/g in dairy manure and from 10^4/g to 10^1/g in beef manure. However, fecal streptococci, total aerobic bacteria, and gram-negative organisms were relatively unaffected by the treatment. Treatment of turkey manure was highly effective, reducing fecal coliform counts from 10^5/g to $<10^2$/g. The applicability of this proprietary, facility-based process to the farm scale was not addressed.

Given the lack of specific data on the ability of lime addition to reduce pathogen counts in animal waste, it is worth noting that environmental factors such as temperature, pH, moisture, nutrient supply, and solar radiation have significant effects on bacteria survival outside their host (Moore et al. 1988). Waste storage alone results in a significant reduction of bacteria numbers compared to those in fresh waste; reduction of 2–3 orders of magnitude in fecal coliform are typical with storage for 2–6 months (Patni et al. 1985, Moore et al. 1988**.** Microorganisms in land-applied waste are subject to mortality from high temperatures, dessication, UV light, and other stresses (Moore et al. 1988).

Summary: Lime Treatment

Given the lack of specific, objective literature on the subject, it is difficult to recommend the use of lime to reduce pathogens in animal waste at this time. More research is needed that specifically focuses on the effectiveness of lime treatment on reduction of indicator and pathogenic microorganisms in animal waste and on the practical application of lime addition at the farm scale as a practical BMP. There is insufficient data on these subjects at present.

Possible benefits of lime treatment:

- Proven effective and widespread use to achieve Class A biosolids standards

- Documented reductions of some microorganisms in some animal wastes
- Fixation of metals and phosphorus
- Odor control of hydrogen sulfide (NLA 2001)
- Potential value of end product in soil pH management

Major unknowns or possible disadvantages

- Little solid performance data specific to animal waste
- Possible ineffectiveness of alkaline treatment on some organism groups
- Variation in effectiveness on different waste types
- Acceleration of NH_3 generation reduces N content of final product and may pose environmental or health risks
- Unknown scalability to cost-effective farm management

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 engines). 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 material-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 AFOs 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 material-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 CAFOs. 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 (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 is raised in temperature to a maximum of 140 °F (60 °C) by microbes. Litter with a moisture content exceeding 25 percent may reach temperatures above 140 °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 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 (VS) 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 NH_3 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 beef cattle fed poultry litter-amended rations may increase, depending on the dry matter digestibility and the ash content of the litter (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 were also 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 prewean 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 prewean 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: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 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: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 preceding section 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, 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 poultry carcass disposal options, such as composting and rendering, is the complete destruction of pathogens. Another advantage is the relatively small mass of 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 degrades protein quality. 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 (NMP) 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— nitrogen (N), phosphorus (P), and potassium (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 elevate 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 to minimize transport of these nutrients from the field by using conservation practices that reduce erosion and runoff. These approaches also aid in preventing N losses, but N management must also include proper handling, storage, treatment, and timing of manure application and incorporation into the soil.

Sources of nutrients applied for crop production include commercial fertilizer, animal manure, and process wastewater. Nutrient application, manure management planning, erosion control, and other management practices are 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 not requiring all CAFO operators to develop and implement a CNMP. However, EPA recommends the use of USDA NRCS's *Comprehensive Nutrient Management Planning Technical Guidance* (National Planning Procedures Handbook Subpart E, Parts 600.50-600.54 and Subpart F, Part 600.75).

In 1999, the USDA NRCS published a National Conservation Practice Standard on Nutrient Management (Code 590) that provides guidance on managing the amount, source, placement, form and timing of the application of nutrients and soils amendments (e.g., manure). Several methods are presented for determining that proper nutrient application rates are used. Section 8.3.2.4 discusses some of these methods including: the P threshold, the P index, and soil testing. During the period 2001-2002, all states developed nutrient management standards that are in compliance with USDA's 590 standard. Most states developed a state-specific variation of the P index but the soil test method was used by one state to comply with the 590 standard (Landers personal communication, 2002).

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 (Recordkeeping), however, all six of the CNMP components 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 a 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: Recordkeeping: 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 recordkeeping 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 N to P ratio closer to that required by crop and forage plants.

Other information that should be part of an NMP 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, recordkeeping, 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.

NMPs 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 an NMP.

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, NMPs 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 results in improved nutrient use efficiency, that is, providing for profitable crop production while minimizing nutrient losses and water quality impacts.

Numerous studies have reported significant decreases in N and P applications to cropland due to nutrient management, particularly in areas of concentrated livestock production. Significant reductions in nutrient losses in runoff or leaching often accompany reductions in inputs. However, nutrient management may yield other environmental benefits as well.

Nutrient management may affect N and P availability in soils even more than N and P losses. In a study of nutrient management on Virginia farms, average annual mineral N availability was reduced by 53 kg/ha, while N losses were reduced by 21 kg/ha; average annual phosphate availability was reduced by 29 kg/ha, while average P losses were reduced by only 4 kg/ha (VanDyke et al. 1999). By reducing available nutrients not used by the crop, nutrient management can also reduce immobilized N and P that are subject to loss with eroded sediment in subsequent years.

In rare cases, nutrient management may result in no net decrease (or even an increase) in some nutrient applications on a farm due to redistribution of manure or fertilizer among fields or to optimization of nutrient applications for crop production. In livestock operations, for example, fields nearest the waste storage facility may have received excessive amounts of manure while remote fields received little or none. In such cases, nutrient management will promote more uniform manure application, which will reduce potential water quality impacts by decreasing excessive nutrient levels on some fields and insuring an adequate nutrient supply for crop production on others.

Furthermore, in the process of nutrient management, the producer may discover that he/she had been under fertilizing and additional nutrients are required to produce a good crop. Existence of a healthy crop contributes to good erosion control and nutrient uptake, while poor crop cover would expose soil to erosion and perhaps leave unused nutrients in the soil for leaching or runoff.

Nutrient management can improve the overall efficiency in the use of resources for crop production. Use of animal waste effectively recycles nutrients that might otherwise become water pollutants. Effective use of manure nutrients can lead to reduced demands for commercial N and P fertilizers including reduced energy demands for natural gas intensive N fertilizers (Risse, et al. 2001). More efficient animal waste and fertilizer management may improve the efficiency of equipment and machinery use on the farm.

Numerous studies have shown that nutrient management can yield increased farm income as over-application of purchased nutrients is avoided and better use is made of animal waste for crop production.

Improved use of animal waste has significant benefits to the maintenance of soil quality. With a good NMP, adequate soil fertility and soil organic matter content are maintained on all farm fields. There are ample data to show that the use of animal waste to improve and maintain soil quality has produced substantial reductions in soil erosion (13 to77 percent) and runoff (1 to 68 percent) across the country (Risse and Gilley 2000)

Finally, efficient use of animal waste in an NMP may contribute to reductions in greenhouse gas emissions. Nitrous oxide and methane from manure and fertilizer account for about 5 percent of total U.S. emissions of greenhouse gasses, notably where nutrients are applied to cropland in excess of recommended amounts (USEPA, 1998). Improving management and use of animal waste could therefore reduce emissions of nitrous oxides and methane and increase organic carbon storage in soil (Ogg 1999).

Advantages and Limitations: A good NMP 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 NMPs because of the cost. Only 4 to 22 percent of respondents indicated that they have an NMP.

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 NMP 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 NMP. For example, an NMP 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. 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 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 an NMP. 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 they 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 NMP 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:

- Determine crop yield goals based on site-specific conditions (e.g., soil characteristics).
- Determine crop nutrient needs based on individual yield goals.
- Determine nutrients available in manure and from other potential sources (e.g., irrigation water).
- 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 an NMP. 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 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:

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

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 over application 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 AFOs, 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, C:N 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. NH_3 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 NMPs for periods longer than 3 years (Wilkinson, 1992).

In Ohio, only about one-third of the Org-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 Org-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 when 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 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 NH_3, is the major N component of urine. Org-N, excreted in feces, is a result of unutilized feed, microbial growth, and metabolism in the animal.

$$\text{Total N} = NH_3 \text{ (ammonia)} + \text{Org-N}$$

The ratio of NH_3 to Org-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 Org-N can be mineralized to inorganic forms, which then can be lost to the atmosphere or into the soil profile. N can be lost from manure in the following three ways:

1. NH_3 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 Org-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 NH_3 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 NH_3-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.

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.

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.

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

Dairy Specific Information

Because of the variety of housing and production options associated with dairies, many dairies have a combination of solid-, liquid-, 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 8-21. 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-size 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.

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, and bull calves, as excreted)	pounds/ton	11.0	—	3.4	7.9
USDA NRCS, 1998a (steers, calves, bulls, and 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.

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.

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 can also 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 an 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 NMPs (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 NMPs 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. P 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 or ground water 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.

P Threshold - 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.

Phosphorus Index The concept of a P index is still evolving, but it is a tool that assesses the potential risk of P movement to water bodies. Both natural (e.g., rainfall, soil type, slope) and human (e.g., farming practices) factors influence the transformation and ultimate fate of P in the agricultural landscape. The P index looks at site-specific characteristics to identify where corrective soil and water conservation practices can be used to reduce the movement of P into surface water and thus reduce the threat of eutrophication. These characteristics are assigned a value based upon the site vulnerability and are weighted according to their assumed relative effect on potential P loss. Table 8-24 presents a list of nine site characteristics that may be used

Table 8-24. The P index.

Site characteristic (Weighting factor)	Loss rating (value)				
	None	Low (1)	Medium (2)	High (4)	Very high (8)
Soil erosion (1.5)	N/A	<5 tons/acre	5 to 10 tons/acre	10 to 15 tons/acre	>15 tons/acre
Irrigation erosion (1.5)	N/A	Infrequent irrigation on well-drained soils	Moderate irrigation on soils with slopes <5%	Frequent irrigation on soils with slopes of 2 to 5%	Frequent irrigation on soils with slopes of >5%
Soil runoff class (0.5)	N/A	Very low or low	Medium	Optimum	Excessive
Distance from watercourse (1.0)	> 1,000 ft	1,000 to 500 ft	500 to 200 ft	200 to 30 ft	<30 ft
Soil test P (1.0)	N/A	Low	Medium	Optimum	Excessive
P fertilizer application rate, lb P/acre (0.75)	None applied	<15	16 to 40	41 to 65	>65
P fertilizer application method (0.5)	None applied	Placed with planter deeper than 2 inches	Incorporated immediately before crop	Incorporated >3 months before crop or surface applied <3 months before crop	Surface applied to pasture or applied >3 months before crop
Organic P source application rate, lb P/acre (1.0)	None applied	<15	16 to 40	41 to 65	>65
Organic P source application method (0.5)	None applied	Injected deeper than 2 inches	Incorporated immediately before planting	Incorporated >3 months before crop or surface applied <3 months before crop	Surface applied to pasture or applied >3 months before crop

Source: USDA ARS, 1999.

to develop a P index (USDA ARS, 1999). Also presented are suggested weighting factors and loss ratings. The USDA continues to perform extensive research on factors that may be used in the development of a P index. Most states have developed customized P indexes to account for site-specific conditions that influence both soluble P losses and particulate P losses resulting from erosion.

The vulnerability of the site to P loss is estimated by multiplying the ratings value for each characteristic by the weighting factor and then summing all the weighted values to produce the P index for the site. Table 8-25 presents generalized interpretation of the P index. Site-specific factors will have a large impact on P loss. USDA recommends that efforts by farmers, extension agronomists, and soil conservation specialists be coordinated to identify management options that can reduce P loss to surface waters. Management options recommended by USDA include soil testing, soil conservation, and nutrient management. Actions become progressively proactive as the P index of a site increases.

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 implementing a management program. Such a site would need a comprehensive long-term P management plan including no application of fertilizer or manure for 3 or more years. Fields with a lower P index would require less severe management options and manure and fertilizer application programs could be developed accordingly.

Table 8-25. Generalized Interpretation of the P index.

P index	General vulnerability to P loss
< 8	**Low** potential for P loss. If current farming practices are maintained, there is a low probability of adverse impacts on surface waters.
8 to 14	**Medium** potential for P loss. The chance for adverse impacts on surface waters exists, and some remediation should be taken to minimize the probability of P loss.
15 to 32	**High** potential for P loss and adverse impacts on surface waters. Soil and water conservation measures and P management plans are needed to minimize the probability of P loss.
> 32	**Very high** potential for P loss and adverse impacts on surface waters. All necessary soil and water conservation measures and a P management plan must be implemented to minimize the P loss.

Source: USDA ARS, 1999.

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. N 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.

P 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.

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.

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.

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 NMPs (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 an N credit from manure when determining commercial fertilizer needs (Stevenson, 1995).

8.3.3 Recordkeeping

The key to a successful nutrient management system is sound recordkeeping. Such a recordkeeping regime should include the following:

Practice: Recordkeeping

Description: Recordkeeping 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: Recordkeeping applies to all farms and all land to which nutrients are applied. Recordkeeping 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 recordkeeping, 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).

Recordkeeping 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: Recordkeeping can be performed using pencil and paper, personal computers, portable computers, or GIS-based systems.

Demonstration Status: Recordkeeping 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 NMPs.

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.

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 CCAs.

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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.

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 N losses, a good BMP is to apply manure as near as possible to planting time or to the crop growth stage during which N 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 N loss, depending on soil type, climate, and crop) than spring application, especially when the manure is not incorporated into the soil (MWPS, 1993). These N losses are a result of NH_3 volatilization and conversion to nitrate, which may be lost by denitrification and leaching. However, 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 N, the Org-N fraction will still contribute to the plant-available N 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 potential. In northern areas where frozen soil and snow cover are common conditions, winter manure application should be avoided. Winter manure application is prohibited in a number of northern states and in most Canadian provinces. There may be some limited local justification for winter manure application, such as reduced NH_3 volatilization and odor problems (Steenhuis et al., 1979), reduced runoff due to a mulching effect of solid manure (Young and Holt, 1977; Clausen, 1990), enhanced die-off of some microorganisms in freeze-thaw cycles (Kibbey et al., 1978; Stoddard et al., 1998), avoidance of soil compaction, and simplified farm management schedules. However, considerable research has demonstrated that runoff from manure application on frozen or snow-covered ground has a high risk of water quality impact.

Extremely high runoff N and P concentrations have been reported from plot studies of winter-applied manure: 23.5 – 1086.0 mg TKN/L and 1.6 – 15.4 mg total P/L (Thompson et al., 1979; Melvin and Lorimor, 1996). In two Vermont field studies, Clausen (1990, 1991) reported 165 to 224 percent, increases in total P concentrations, 246 to 1480 percent, increases in soluble P concentrations, 114 percent increases in TKN concentrations, and up to 576 percent increases in NH_3-N following winter application of dairy manure. Mass losses of up to 22 percent of applied N and up to 27 percent of applied P from winter-applied manure have been reported (Midgeley and Dunklee, 1945; Hensler et al., 1970; Phillips et al., 1975; Converse et al., 1976; Klausner et al., 1976; Young and Mutchler, 1976; Clausen, 1990 and 1991; Melvin and Lorimer, 1996). Much of this loss can occur in a single storm event (Klausner et al., 1976). Such losses may represent a significant portion of annual crop nutrient needs.

On a watershed basis, runoff from winter-applied manure can be an important source of annual nutrient loading to water bodies. In a Wisconsin lake, 25 percent of annual P load from animal waste sources was estimated to arise from winter spreading (Moore and Madison, 1985). In New York, snowmelt runoff from winter-manured cropland contributed more P to Cannonsville Reservoir than did runoff from poorly managed barnyards (Brown et al., 1989). Clausen and Meals (1989) estimated that 40 percent of Vermont streams and lakes would experience significant water quality impairments from the addition of just two winter-spread fields in their watersheds.

Winter application of manure can increase microorganism losses in runoff from agricultural land compared to applications in other seasons (Reddy et al., 1981). Cool temperatures enhance survival of fecal bacteria (Reddy et al., 1981; Kibby et al., 1978). Although some researchers have reported that freezing conditions are lethal to fecal bacteria (Kibby et al., 1978; Stoddard et al., 1998), research results are conflicting. Kudva et al. (1998) found that *E. coli* can survive >100 days in manure frozen at –20 °C. Vansteelant (2000) observed that freeze/thaw of soil/slurry mix only reduced *E. coli* levels by about 90 percent. Studies have found that winter-spreading of manure does not guarantee die-off of *Cryptosporidium* oocysts (Carrington and Ransome, 1994; Fayer and Nerad, 1996). Finally, because incorporation or injection of manure is impossible in winter applications, filtration and adsorption through soil contact, important mechanisms for attenuating microorganism losses (Gerba et al., 1975; Patni et al., 1985), is prevented.

There are several additional disadvantages to winter manure application. Runoff from winter-spread fields, whether during winter thaws or in spring snowmelt, would occur before the growing season when riparian buffers or vegetated filter strips are relatively inactive and ineffective in removing pollutants from runoff before delivery to surface waters. In cases where winter spreading is carried out because of lack of adequate manure storage, the loss of management flexibility makes good nutrient management difficult.

Although several studies have reported little water quality impact from winter-spread manure (Klausner, 1976; Young and Mutchler, 1976; Young and Holt, 1977), such findings typically result from fortuitous circumstances of weather, soil properties, and timing/position of manure in the snowpack. The spatial and temporal variability and unpredictability of such factors makes the possibility of ideal conditions both unlikely and impossible to predict.

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 N, depending on soil temperature and moisture. N is lost through volatilization of NH_3 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, P and K losses are negligible, regardless of application method. However, some P and K 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 N available for crops by limiting volatilization, denitrification, and surface runoff. Incorporation also reduces odor and encourages mineralization of Org-N by microbial action in the soil, thereby increasing the amount of N 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.
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.

Application Method	Description	Advantages	Disadvantages
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 hp 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 require 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. N 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			
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 percent. 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.

Application Method	Description	Advantages	Disadvantages
Hand-moved sprinklers	Manure transported through rigid irrigation pipe, 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 pipe, including a mainline and one or more aluminum 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.
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: MWPS, 1993; and Bartok, 1994.
hp = horsepower

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 grow-finish 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 grow-finish 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 incorporate 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-size 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 N and odorous gases to the atmosphere, and place nutrients near the plant's root zone where they are needed. 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 grow-finish 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-size 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 not to 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 espread 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, N 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 grow-finish operations which dispose of their waste on owned or rented land. Nearly 80 percent of grow-finish 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 N and P, 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.

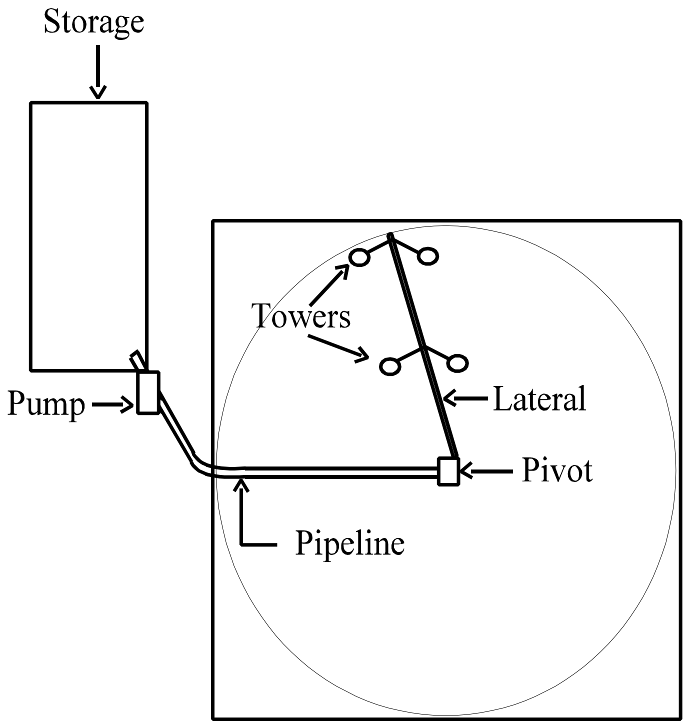

Figure 8-15. Schematic of a center pivot irrigation system.

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 N 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.

Planning manure application based on plant P requirements may result in application rates below the capability of some manure-spreading equipment. However, a general consensus among selected extension service specialists and equipment manufacturers indicates that box spreaders and liquid spreaders can be reliably calibrated to application rates as low as 2 to 3 tons/acre and 1,500 to 2,000 gallons/acre, respectively (Tetra Tech, 2001). This will allow for P-based application of manure under most conditions.

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 an 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 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 NMPs (Marketing Directions, 1998).

Practice: Transportation of Waste Off Site

Description: Animals at an AFO 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 AFOs 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 or liquid waste to fields before they apply solid waste. The distance manure must be hauled to be properly managed depends on the proximity of operations 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 nonwater-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 AFOs 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 6 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., N and P) and some pathogens. Excessive manure application can cause increased nitrate concentration in water. If the rate of manure application exceeds plant or crop N 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 P and N, 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. N is water-soluble and moves largely with the flow of water. Injecting or incorporating manure into the land however, significantly reduces the amount of N transported with runoff. Yet N can still move with ground water or subsurface water flow.

Reducing P levels in surface water is the best way to limit algae growth. Most of the P 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.

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

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.

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 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 PM 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 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 N requirements due to an increase in residue that has a high C:N 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 which 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 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, which usually requires 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 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 or 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 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 N for the next year’s crop.

Actively growing cover crops use available nutrients in the soil, especially N, 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 water body. They provide a buffer between a contaminant source and water bodies. 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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CHAPTER 9

ESTIMATION OF REGULATED OPERATIONS AND UNFUNDED MANDATES

9.0 INTRODUCTION TO NPDES PROGRAM

Under the National Pollutant Discharge Elimination System (NPDES) permit program, all point sources that discharge pollutants to waters of the United States must apply for an NPDES permit and may discharge pollutants only under the terms of that permit. Such permits include nationally established technology-based effluent discharge limitations. In the absence of national effluent limitations, NPDES permit writers must establish technology-based limitations and standards on a case-by-case basis, based on the permit writer's best professional judgment.

In addition to the technology-based effluent limits, permits may also include water quality-based effluent limits where technology-based limits are not sufficient to ensure compliance with the water quality standards or to implement a Total Maximum Daily Load (TMDL). Permits may include specific BMPs to achieve effluent limitations, typically included as special conditions. In addition, NPDES permits normally include monitoring and reporting requirements, as well as standard conditions that apply to all permits (such as duty to properly operate and maintain equipment).

EPA's analysis of the final rule includes estimates of the incremental costs and benefits of changes in the NPDES permit regulations in 40 CFR 122. To obtain incremental values, EPA developed estimates of the number of regulated operations for a baseline compliance scenario and a compliance scenario based on the final rule. Section 9.1 describes how EPA derived baseline estimates. Section 9.2 provides the estimates of the number of operations affected under the final rule. Section 9.3 provides estimates of the new expenditures states are expected to incur when they implement the final rule.

9.1 <u>Industry Baseline Compliance with 1976 Regulations</u>

EPA promulgated the original NPDES regulations for CAFOs in 1976. For the purposes of this analysis, EPA assumes that all operations covered by the 1976 regulations are currently in compliance with the existing regulatory program. This assumption generates the baseline number of regulated operations estimated for the final rule.

More specifically, EPA assumes that all operations are fully complying with the existing regulations because they fall into one of two categories. The first category consists of those operations that are defined or designated as CAFOs and that have in fact obtained a permit. EPA assumes, for purposes of costing the new regulations, that these CAFOs are in full compliance with their existing permits. The second category consists of all of the other unpermitted AFOs. EPA assumes that these operations do not need a permit because they do not meet the definition of a CAFO. For example, they might not meet the criteria for being defined as a Medium CAFO, or for Large CAFOs they might meet the criteria, but are excluded from the definition because they do not discharge except in the event of a 25-year, 24-hour storm. In reality, however, there are probably a number of unpermitted operations that are subject to the regulations and should have a permit (for example, they incorrectly claim they are a “no discharge” facility, as discussed in the preamble).

The following sections present EPA’s approach and assumptions for estimating the population of AFOs that are subject to permitting under the 1976 NPDES CAFO permitting regulations. The universe of AFOs and CAFOs is discussed by livestock category, size of operation, and production region. EPA’s assumptions about what is needed to comply with the current CAFO regulations are consistent with EPA’s views as stated in its 1995 CAFO guidance manual, *Guidance Manual on NPDES Regulations for Concentrated Animal Feeding Operations* (USEPA, 1995; USEPA, 1999).

9.1.1 Total Medium and Large Animal Feeding Operations

EPA’s estimates of Large and Medium AFOs by livestock category are provided in Table 9-1. The breakdowns by size are based the following animal thresholds, which are from the 1976 NPDES CAFO regulation. The discussion in this section pertains to which operations in these categories are considered effectively regulated by the 1976 rule.

Large operations that stable or confine more than:

- 1,000 beef cattle
- 700 mature dairy
- 2,500 swine over 55 pounds
- 55,000 turkeys
- 500 horses
- 5,000 ducks
- 30,000 laying hens or broilers using liquid manure systems

Medium operations that stable or confine:

- 300 to 1,000 beef cattle
- 200 to 700 mature dairy

- 750 to 2,500 swine over 55 pounds
- 16,500 to 55,000 turkeys
- 150 to 500 horses
- 1,500 to 5,000 ducks
- 9,000 to 30,000 laying hens or broilers using liquid manure systems

AFO estimates for additional animal categories that will be regulated under the final rule have also been included in Table 9-1 to provide a summary of all Medium and Large AFOs potentially regulated as CAFOs. In addition to breakdowns by livestock or poultry category and facility size, Table 9-1 shows that the primary livestock or poultry sectors have been divided into five production regions consistent with development of the Cost Models. The designation and use of production regions allows for the aggregation of critical data on the number of facilities, production quantities, and financial conditions, which might otherwise not be possible because of concerns about disclosure[1]. The facilities listed below as medium AFOs include all AFOs in that size range and are not limited to those facilities that may be defined or designated under current conditions or the final rule.

Table 9-1. Total 1997 Facilities with Confined Animal Inventories by Livestock or Poultry Sector, Operation Size, and Region.

Sector	Region	Medium Operations	Large Operations
Beef	Central	326	557
	Mid-Atlantic	100	11
	Midwest	2,198	1,124
	Pacific	44	74
	South	14	0
	Total	2,682	1,766
Dairy	Central	1,034	401
	Mid-Atlantic	1,407	103
	Midwest	1,503	96
	Pacific	1,406	759
	South	430	91
	Total	5,780	1,450
Swine	Central	153	82
	Mid-Atlantic	905	1,220
	Midwest	8,484	2,431
	Pacific	31	15

[1] For example, USDA Census of Agriculture data are not typically released unless there is a sufficient number of observations to ensure confidentially. Consequently, if data were aggregated on a state basis (instead of a regional basis), many key data points needed to describe the industry segments would be unavailable.

	South	328	176
	Total	9,901	3,924
Layer	Central	301	143
	Mid-Atlantic	394	211
	Midwest	346	312
	Pacific	110	125
	South	819	321
	Total	1,970	1,112
Broiler	Central	694	164
	Mid-Atlantic	2,892	413
	Midwest	411	56
	Pacific	184	15
	South	6,221	984
	Total	10,402	1,632
Turkey	Central	67	36
	Mid-Atlantic	692	88
	Midwest	574	149
	Pacific	110	45
	South	172	70
	Total	1,615	388
Heifers[1]	Central	195	145
	Mid-Atlantic	0	0
	Midwest	395	0
	Pacific	134	97
	South	0	0
	Total	724	242
Veal[1]	Central	3	0
	Mid-Atlantic	1	0
	Midwest	53	12
	Pacific	0	0
	South	0	0
	Total	57	12
Horses	Total	1,123	195
Ducks	Total	71	21
	Grand Total	34,325	10,742

[1]New livestock category in the final rule.

9.1.2 Baseline Compliance Estimates

The following subsections describe the livestock or poultry categories that EPA assumes are in full compliance with current NPDES regulations for CAFOs. In general, the large operations shown in Table 9-1 are currently defined as CAFOs, unless they are exempt because they have no discharges except in the event of a 25-year, 24-hour storm. Therefore, subsequent estimates of large operations currently in compliance include the large AFOs shown in Table 9-1. The exception for large layer and broiler operations is discussed below. The medium operations in Table 9-1 may be defined as CAFOs if either of the following conditions apply:

- Pollutants are discharged into navigable waters through a man-made ditch, flushing system, or other similar man-made device (the "MMD discharge" condition).
- Pollutants are discharged directly into waters of the United States, which originate outside of and pass over, across, or through the facility, or otherwise come into direct contact with the animals confined in the operation (the "direct contact" condition).

The number of medium operations meeting either condition is not known with any great degree of certainty. EPA derived estimates of the medium livestock operations that might meet either condition based on the best available information from USDA Extension personnel, state water quality staff, industry representatives, and other stakeholders, and BPJ judgement. The estimates are generally based on best estimates of the share of operations that might meet at least one condition. EPA multiplied these percentages by the estimate of total medium operations to derive the number of CAFOs for the medium category. In some instances, information supported different percentages across regions. The following sections provide EPA's estimates of the number of medium CAFOs under current regulations.

9.1.2.1 Beef

The beef industry is concentrated in the Midwest Region. The second largest production area is the Central Region.

EPA's estimates of the number of medium-size beef AFOs with a direct discharge or stream running through part of the production area were developed through various contacts with state agricultural and environmental personnel and USDA contacts. There are very limited data addressing these criteria, and opinions vary even within production regions. Information obtained from key states in each region indicates that the share of AFOs potentially meeting either criterion ranges from approximately 3 percent (Funk, 2002) to less than 6 percent in the Midwest (Lawrence, 2002). The share is less than 10 percent in the Central and Pacific Regions (Johnson, 2002), and close to 0 percent in the Mid-Atlantic and South Regions (Kniffen, 2002; Sadler, 2002). Using conservative values to account for some uncertainty regarding conditions in other states, EPA assumed that 6 percent of Medium AFOs in the Midwest Region would meet the CAFO definition and that 10 percent would meet it in the Central and Pacific Regions. The assumption for the Mid-Atlantic and South should be close to zero, but EPA assumed a nonzero value to allow for the possibility of some Medium CAFOs in the states not contacted. There are 114 Medium AFOs in these regions and EPA assumed that 4 percent of regional AFOs would meet the CAFO definition, which generates approximately 5 CAFOs throughout both regions. Table 9-2 reports the number of Medium CAFOs that EPA estimates may be defined as CAFOs under the 1976 NPDES CAFO regulations, by region, based on these assumptions.

Table 9-2. Regulated Beef Feeding Operations by Size Category Assuming Full Compliance.

Region	Total	Medium Facilities	Large Facilities
Central	590	33	557
Mid-Atlantic	15	4	11
Midwest	1,255	131	1,124
Pacific	79	5	74
South	1	1	0
Total	1,940	174	1,766

9.1.2.2 Dairy

Compared to other livestock categories, dairies are relatively evenly distributed across all regions except the South. The large dairies tend to be concentrated in the Central and Pacific Regions, while the Midwest and Mid-Atlantic have the most medium dairies. Many of these dairies were designed and built on or near waters of the United States and, therefore, have direct contact. Others have some type of MMD discharge. Estimates for the percentage of dairies in the Midwest Region with direct contact or MMD discharge have a large range. Bickert (1999) estimated less than 10 for each criteria and Groves (1999) estimated a range of 25 percent to 75 percent for the direct contact criterion and almost zero percent for the MMD discharge. Holmes (1999) estimated that 15 percent of operations would have direct contact and 40 to 50 percent would have an MMD discharge. EPA assumed that, on average, 45 percent for the medium-size dairies throughout the Midwest would meet either criterion. This estimate places greater weight on the estimates of Holmes (<20 percent across criteria) and Bickert (55 to 65 percent across criteria). EPA assumed a slightly higher percentage of 55 percent for the Mid-Atlantic to reflect a higher propensity for direct contact in that region. According to Johnson (1999), less than 10 percent of medium-size operations in California will have either direct contact or an MMD discharge. EPA assumed that 10 percent of operations throughout the Pacific Region would be defined CAFOs. EPA assumed that the CAFO share in the Central Region is 20 percent, and 35 percent in the South. These are BPJ estimates based on the belief that operations in these regions are less likely than Midwest operations to meet either criterion, but more likely than Pacific Region operations.

Table 9-3 reports EPA’s estimates of medium dairy CAFOs. Nationwide, approximately one-third of all medium operations are defined as CAFOs. Table 9-3 also shows that all large operations should be effectively regulated by the existing requirements either because they have a discharge permit or because they have no discharge except in the event of the 25-year, 24-hour storm event.

Table 9-3. Regulated Dairy Feeding Operations by Size Category Assuming Full Compliance.

Region	Total	Medium Facilities	Large Facilities
Central	608	207	401
Mid-Atlantic	877	774	103
Midwest	773	677	96
Pacific	900	141	759
South	241	150	91
Total	3,399	1,949	1,450

9.1.2.3 Swine

The swine industry is heavily concentrated in the Midwest. This is particularly true for medium-size operations. The Mid-Atlantic is the second largest production region, followed by the South Region.

Table 9-4 shows that all large swine AFOs are assumed to be effectively regulated under the 1976 NPDES CAFO regulations because they are either permitted or exempt because they have no discharges except in the event of a 25-year, 24-hour storm. Based on contacts with USDA Extension personnel, EPA assumes that approximately 15 percent of facilities in this size category (across all regions) have direct contact or use an MMD (Greenless, et al., 1999; Steinhart, 1999).

Table 9-4. Regulated Swine Operations by Size Category Assuming Full Compliance.

Region	Total	Medium Operations	Large Operations
Central	105	23	82
Mid-Atlantic	1,355	135	1,220
Midwest	3,704	1,273	2,431
Pacific	20	5	15
South	225	49	176
Total	5,409	1,485	3,924

9.1.2.4 Layers

Under the 1976 NPDES CAFO regulations, a layer operation is defined as a large CAFO if it confines more than 30,000 birds and uses a wet manure management system, or if it maintains more than 100,000 birds using continuous overflow watering and has the potential to discharge pollutants to waters of the U.S. EPA recognizes that continuous overflow watering is an outdated technology that has fallen out of favor in the layer industry. Therefore, EPA's estimates of the effectively regulated baseline large CAFO operations is based on those that use a wet manure management system.

The estimates of large layer CAFOs include operations with actual wet manure-handling systems and operations that create a crude wet manure-handling system. Currently, as many as 60 percent of the operations in the South and Central Regions use a wet manure-handling system, whereas only 0 to 5 percent of the operations use a wet system in the other regions.

As noted in EPA's 1995 permitting guidance, dry poultry operations are subject to the NPDES regulations if they establish a "crude liquid manure system" by stacking manure or litter in an outside area unprotected from rainfall and runoff. Including these operations as defined large CAFOs brings the total for the South and Central Regions to approximately 70 percent of large operations and approximately 7 percent of operations in other regions. These additions based on storage practices are based on conversations with industry personnel, who indicate that layer operations generally have long-term (> 6 months) storage, after which the manure is either sold or land applied (Funk, 1999; Jacobson, 1999; Patterson, 1999; Thomas, 1999; Tyson, 1999; York, 2000). The large CAFO estimates in Table 9-5 reflect the number of operations having either type of wet manure system.

For medium-size operations, either the MMD discharge or the direct contact condition must apply for operations that either have a wet manure-handling system or create a crude one. The regulated medium-size layer operations in Table 9-5 reflect combined estimates for both types of operations.

For operations with wet manure-handling systems, EPA obtained estimates from experts in the five states that have the largest regional shares of operations. These estimates indicate that the CAFO conditions are rarely met, bordering on 0 percent of operations in any region (Carey, 2002; Ramsey, 2002; Parsons, 2002; Hopkins, 2002; Johnson, 2002, Earnst, 2002, and Solainian, 2002). EPA derived a share estimate by assuming a worst-case average of two CAFOs per state, the total of 10 CAFOs equals approximately 3 percent of the 349 Medium AFOs in these states. Applying this percentage to all medium-sized wet layer AFOs generates a total CAFO estimate of 24.

Similarly, experts for key states in the Central, Mid-Atlantic, Midwest, and South Regions indicated that very few, if any, medium-sized dry operations stored manure outside of the production houses in a manner that might meet either of the CAFO conditions (Carey, 2002; Ramsey, 2002; Parsons, 2002; Hopkins, 2002; Jones, 2002; and Solainian, 2002). Rather than assume there are no Medium CAFOs in these regions, EPA derived a share estimate by assuming that an average of two operations per state stored manure outside (i.e., eight total in the four states) and in all cases the practice led to either a direct contact condition or an MMD condition.

The resulting number of CAFOs accounts for 2 percent of medium-sized AFOs in these states. EPA applied this percentage to all AFOs in these regions. EPA used a slightly higher estimate of 5 percent for the Pacific Region based on information provided by Johnson (2002) and Earnst (2002). These assumptions generate a total of 26 Medium CAFO operations.

Table 9-5. Regulated Layer Operations by Size Category Assuming Full Compliance.

Region	Total	Medium Operations	Large Operations
Central	107	8	99
Mid-Atlantic	26	8	18
Midwest	28	7	21
Pacific	13	5	8
South	259	22	237
Total	433	50	383

9.1.2.5 Broilers

Under the 1976 NPDES CAFO regulations, broiler operations with more than 30,000 birds are defined as CAFOs only if they use a liquid manure-handling system; operations with 9,000 to 30,000 birds and a liquid manure-handling system would also need to meet either the MMD discharge or the direct contact condition to be defined a CAFO. Because few, if any, broiler operations use a liquid manure-handling system, the only way by which a broiler operation is defined as a CAFO currently is if, through its manure-handling practices, it creates a form of liquid manure-handling system (Carey, 1999). As noted, dry poultry operations may establish a "crude liquid manure system" by stacking litter in an outside area unprotected from rainfall or runoff. This analysis assumes that at most 10 percent of the large broiler operations and 5 percent of the medium operations stack litter temporarily, in a manner consistent with EPA's interpretation of a liquid manure handling system and, therefore, would be defined as CAFOs (York, 2000). Furthermore, EPA assumed that no broiler operations would otherwise have direct contact with waters of the U.S. (WOUS) or an MMD based on information provided by regional experts (Carey, 1999; Gale, 1999; Lory, 1999; Patterson, 1999; Thomas, 1999; Tyson, 1999). Table 9-6 presents regulated broiler operation numbers.

Table 9-6. Regulated Broiler Operations by Size Category Assuming Full Compliance.

Region	Total	Medium Operations	Large Operations
Central	51	35	16
Mid-Atlantic	186	145	41
Midwest	26	20	6
Pacific	11	9	2
South	409	311	98
Total	683	520	163

9.1.2.6 Turkeys

EPA assumes turkey operations with more than 55,000 birds (1,000 AUs) are in compliance, being either permitted or exempt because they have no discharges except in the event of a 25-year, 24-hour storm. The only other turkey AFOs subject to the NPDES program are those having between 16,500 and 50,000 birds and an MMD discharge; no operations meet the direct contact conditions. Because virtually all turkey operations use dry litter systems (Battaglia, 1999; Carey, 1999; Jones, 1999), the only that have the potential to discharge are those operations that have established a crude liquid manure system through the use of waste management practices that allow contact between manure and rainwater. EPA assumed that 5 percent of the medium operations in the South Region and 2 percent in the other regions have established crude liquid systems. Table 9-7 presents the number of turkey feeding operations in full compliance by region and size.

Table 9-7. Regulated Turkey Operations by Size Category Assuming Full Compliance.

Region	**Total**	**Medium CAFOs**	**Large CAFOs**
Central	38	2	36
Mid-Atlantic	102	14	88
Midwest	160	11	149
Pacific	47	2	45
South	78	8	70
Total	425	37	388

9.1.2.7 Designated Operations

A medium facility that is not defined a CAFO may be designated a CAFO under the 1976 NPDES CAFO regulations if a permit authority determines that it is a significant contributor of pollutants to waters of the United States. A small facility can be designated a CAFO only if pollutants are discharged into navigable waters through a man-made ditch, flushing system or other similar man-made device, or pollutants are discharged directly into WOUS that originate outside of and pass over, across, or through the facility, or otherwise come into direct contact with the animals confined in the operation.

EPA has historically made very limited use of the designation provisions of the NPDES CAFO regulation that was promulgated in 1976. It is understood that only a few operations have been designated CAFOs over a 25-year span of existing NPDES CAFO regulations. Because the final rule does not alter the conditions for designation, EPA assumes that designation will continue to occur in a limited number of cases where an AFO does not meet the regulatory definition of a CAFO, but is determined to be a significant contributor of pollutants to WOUS based on site-specific conditions.

EPA does not possess any location-specific information regarding which AFOs may meet the conditions for designation. Furthermore, EPA expects that many of these operations that have conditions that might make them candidates for designation would be able to seek out technical assistance through voluntary programs to alter those conditions and avoid designation. These two factors make estimating future designations difficult, but the ability to prevent being designated a CAFO should minimize the number of designations.

Based on the limited use of this provision under the current regulation and the ability of operators to address conditions that might lead to designation, EPA assumed no more than 0.5 percent of all medium AFOs would be designated CAFOs. Table 9-8 shows the estimates of designated Medium CAFOs under the current rule by sector.

Designation would in almost all cases be the tool of last resort to address small operations that are found to be significant contributors of pollutants. Most, if not all, of these operations would be able to avoid designation through technical assistance offered by USDA and other voluntary programs. Although a lack of empirical data regarding discharge conditions at small operations makes it difficult to derive designation estimates, EPA believes designation of Small CAFOs will occur in only a very limited number of cases, if at all. Given this, EPA assumed a very small number of designations be assigned to each sector for the purposes of estimating cost and burdens for the final rule.

Table 9-8 Estimated Small and Medium Designated CAFOs over a 5-Year Period by Sector.

Sector	Medium Designated CAFOs	Small Designated CAFOs
Beef	13	2
Dairy	28	2
Swine	50	2
Layer	8	2
Broiler	50	2
Turkey	8	2
Heifers	3	0
Total	160	12

9.1.2.8 Summary of Baseline Compliance Estimates by Size and Type

The estimated number of regulated AFOs based on an assumption of full compliance with the existing regulations is presented in Table 9-9. The estimates include the large and medium beef, dairy, swine, broiler, layer, and turkey operations that are CAFOs by definition or that meet the 25-year, 24-hour storm exemption and the medium-size operations that potentially meet either the MMD discharge or the direct contact condition. The estimates also include the 195 horse operations that have 500 or more horses and, therefore, meet the definition of a large CAFO, and 157 large duck operations that meet current CAFO definitions. The horse CAFOs comprise 50 farms, 45 racetracks, and 100 fairgrounds (Tetra Tech, 2002). EPA does not have information to indicate that any of the 1,123 medium horse AFOs will meet either condition to be CAFOs by definition, and EPA does not expect any medium or small horse AFOs to be designated CAFOs. For ducks, EPA assumed that all facilities greater that 5,000 head were either permitted or claimed the storage exemption. EPA assumed no duck operations in the medium category met the current definition of a CAFO. Finally, the estimates in Table 9-9 include the medium and small designated CAFOs.

Table 9-9. Summary of Effectively Regulated Operations by Size and Livestock Sector

Livestock Category	Total	Defined CAFOs		Designated CAFOs	
		Medium CAFOs	Large CAFOs[1]	Medium	Small
Beef	1,955	174	1,766	13	2
Dairy	3,429	1,949	1,450	28	2
Swine	5,461	1,485	3,924	50	2
Layer	443	50	383	8	2
Broiler	735	520	163	50	2
Turkey	435	37	388	8	2
Horse	195	0	195	0	0
Duck	157	0	157	0	0
Heifers	3	0	0	3	0
Total	12,813	4,215	8,426	160	12

[1]Includes permitted CAFOs and Large AFOs that are in current compliance because they do not discharge except in the instance of the 25-year, 24-hour storm event.

This summary of animal operations that should currently have NPDES permits does not correspond with the number of NPDES permits issued to date. Most sources place the estimate of the number of operations covered by NPDES permits at approximately 4,100 (SAIC, 1999).

There are two main reasons for the large disparity between these numbers. First, many of the large operations opt out of the NPDES program because they claim they do not discharge except in the event of a 25-year, 24-hour storm. Second, many authorized states have declined to issue NPDES permits for CAFOs, relying instead on regulatory mechanisms other than the NPDES program to regulate CAFOs.

9.2 Affected Entities under the Final Rule

The final rule will increase the number of regulated operations as well as the number of operations needing to obtain an NPDES permit, which will include newly covered operations and large operations currently claiming the storm exemption. It will also affect the permit requirements of facilities already operating under permit coverage.

9.2.1 Final Rule Provisions that Affect the Number of Regulated Operations

EPA estimates that the final rule increases the potential number of regulated entities by about 2,500 facilities. These facilities are predominantly large, dry poultry operations. Operations that confine immature animals are the second largest component of change. EPA assumes that the number designated under the 1976 rule, assuming full compliance, will be same as the number designated under the final rule. The new sectors and size threshold changes in the final rule that affect the number of regulated operations are:

Large operations that stable or confine:

- 1,000 heifers
- 1,000 veal
- 10,000 small swine under 55 pounds
- 82,000 layers using other than a liquid manure-handling system
- 125,000 broilers using other than a liquid manure handling system
- 30,000 ducks (dry operations)

Medium operations that stable or confine:

- 300 to 1,000 heifers
- 300 to 1,000 veal
- 3,000 to 10,000 small swine under 55 pounds
- 25,000 to 82,000 layers using other than a liquid manure-handling system
- 37,500 to 125,000 broilers using other than a liquid manure-handling system
- 10,000 to 30,000 ducks (dry operations)

In addition, the following revisions to 40 CFR 122 in the final rule may affect currently and newly regulated operations:

- Clarify the definition of an AFO
- Eliminate the 25-yr, 24-hr storm exemption
- Implement duty-to-apply requirement
- Eliminate the mixed animal multiplier
- Include facility closure requirements.

9.2.2 Number of Operations Required to Apply for Permit

The primary impact on the number of NDPES permits issued to CAFOs will come from the addition of dry poultry operations; stand-alone, immature animal operations; and operations previously exempt due to the 25-yr, 24-hr storm provision. As a result of removing the storm exemption, all of the large beef, dairy, swine, wet layer, turkey, and horse AFOs reported in Section 9.1 are considered CAFOs and will need to obtain a permit except in cases where the permitting authority makes a determination that there is no potential to discharge. Table 9-10 provides a summary of the total expected permitted facilities by sector based on the final rule. Many of the estimates are the same as those in Table 9-9. Additions are explained below.

Table 9-10. Summary of CAFOs by Livestock Sector and Region Required to Apply for Permit.

Livestock Category	Total	Defined CAFOs		Designated CAFOs	
		Medium CAFOs	Large CAFOs	Medium	Small
Beef	1,955	174	1,766	13	2
Dairy	3,429	1,949	1,450	28	2
Swine	5,461	1,485	3,924	50	2
Layer	1,172	50	1,112	8	2
Broiler	2,204	520	1,632	50	2
Turkey	435	37	388	8	2
Heifers	475	230	242	3	0
Veal	16	4	12	0	0
Horse	195	0	195	0	0
Duck	25	4	21	0	0
Total	15,367	4,453	10,742	160	12

The inclusion of all poultry operations, regardless of manure handling system, brings in all large broiler and dry layer feeding operations. The number of large broiler CAFOs increases from 163 to 1,632. The medium broiler CAFO estimate is unchanged from the baseline estimate because the dry operations that met the medium CAFO conditions before will continue to meet those conditions. Similarly, the number of large layer CAFOs increases from 383 to 1,112, but the Medium CAFO estimates are unchanged because the conditions that define CAFOs in this size category have not changed.

The thresholds for duck operations with dry manure-handling systems were changed from 5,000 to 30,000 ducks for large operations, and from 1,500 to 10,000 ducks for medium operations. These changes were based on data EPA received from Purdue University, The Indiana Poultry Association, and duck producers. The threshold for duck operations with wet manure-handling systems is has not changed and remains 5,000 ducks for large operations and 1,500 ducks for medium operations. Because almost all operations use dry manure-handling systems, the number of large duck CAFOs under the revised size thresholds of the final rule is 21. EPA assumed that the share of medium dry duck operations that meet either the MMD discharge or direct contact condition is the same as the broiler share. Thus, there are four Medium duck CAFOs.

Finally, final rule provisions for stand-alone, immature animal operations adds 488 newly regulated large and medium operations. The Large CAFOs comprise 242 heifer operations and 12 veal operations. EPA assumes that the incidence of medium-sized veal and heifer CAFOs would be the same as the regional percentages in the baseline descriptions for beef and dairy, respectively. These assumptions add 230 medium heifer CAFOs and four medium veal CAFOs to the estimate of regulated operations under the final rule.

9.3 Unfunded Mandates

This section provides EPA's estimates of the new expenditures States are expected to incur when they implement the final rule. These administrative expenditures are based primarily on estimates of the amount of labor time needed to incorporate new regulatory requirements into existing State NPDES programs and to administer CAFO permits on an annual basis. EPA obtained the labor burden estimates used in this analysis from various sources including communications with staff at EPA regional offices and a small sample of State agencies, previous NPDES-related cost and burden analyses, and comments on the proposed rule. Then EPA asked State agency and EPA regional staff to evaluate whether those estimates were appropriate for administering NPDES permits for CAFOs.

EPA's cost analysis presumes that States issue fewer than 100 percent of the permits because EPA has responsibility for issuing permits in States that do not have approved NPDES programs. For informational purposes, this section will also show cost estimates pertaining to EPA's portion of the NPDES permits for CAFOs.

EPA estimated administrative costs for States with approved NPDES programs (hereafter "approved States") for four categories of activities:

- NPDES rule modification
- NPDES program modification request
- implementation for general permits
- implementation for individual permits.

Rule modification is a one-time activity in which approved States modify their NPDES programs to incorporate the new requirements contained in the final rule. EPA received substantial comment in this area at proposal and believes that this analysis fully recognizes the types of activities that would be required and their associated burden. Specific actions will vary across States because CAFO permitting practices vary widely. Forty-three States have approved NPDES base programs through which CAFO permits can be issued.[2] EPA's State Compendium (2001) demonstrates that State permitting programs for CAFOs vary substantially. Some State programs utilize a combination of NPDES and non-NPDES permits while others issue only one or the other type of permit to CAFOs.

Rule modification may involve a variety of activities such as reviewing the final rule requirements, revising regulatory or statutory language, conducting public outreach to solicit inputs or make the public aware of program changes, conducting formal public notification hearings to solicit comments on draft changes, and finalizing and publishing regulatory statutory revisions. For some approved States, rule modification may be as simple as incorporating the final rule by reference. For others, regulatory changes may require a lengthy stakeholder process or changes to state statutes.

Information provided by State agencies suggests that the labor hours required to develop or modify regulations may range from 0.10 full time equivalents (FTEs) to 1.57 FTEs.[3] Hammerberg (2002) indicated that Maryland completes approximately two major rules and several minor rules per year with a staff of three, which suggests a range of 0.25 to 1.0 FTEs per rule depending on the level of complexity. Consistent with the lower end of this range, Allen (2002) agreed with a midpoint estimate of 750 hours or 0.36 FTEs and Coats (2002) provided an estimate of 500 hours or 0.20 FTEs for States in EPA Region 2. At the high end, Sylvester (2002) estimated that a final rule similar to the proposed rule would require 1.57 FTEs to implement in Wisconsin, with approximately one-third of the time devoted to initial drafting, one-third to hearings, and one-third to responding to comments and finalizing the rule. EPA believes that the final CAFO rule is less complex than the proposed rule and most States are not likely to require this level of effort to implement rule revisions. In particular, the final rule will not change the definition of a medium-size CAFO or the designation criteria for small CAFOs, and it will not require the ELG be applied to medium-size CAFOs. Also, it will not require CAFOs to have certified permit NMPs or that those plans be submitted to permitting authorities along with permit applications. Therefore, EPA placed greater weight on the Maryland and EPA Region 2 estimates than the Wisconsin estimate to derive a weighted average of 0.41 FTEs or approximately 850 hours (0.45×0.20 FTE + 0.45×0.36 FTE + 0.10×1.57 FTE).

Following rule development, the approved States will need to request EPA approval for the modifications made to their NPDES programs in response to the final rule. These applications consist of a narrative program description including enforcement and compliance plans; a legal

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[2] Six States—Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico—do not have approved NPDES programs. A seventh state, Oklahoma, has an approved base program, but is not authorized to administer the CAFO portion of the NPDES program; EPA Region 6 has responsibility for CAFO permits.

[3] One FTE is equivalent to 2,080 hours.

certification that the State has authority to implement the program (Attorney General's statement); a compilation of relevant statutes, regulations, guidance, and tribal agreements; and copies of permit application forms, permit forms and reporting forms. In general, the amount of labor time required to prepare the application will vary. EPA's labor hour estimate is based on program modification and approval burdens in an active NPDES ICR ("NPDES and Sewage Sludge Management State Program Requirements," OMB NO. 2040-0057, EPA ICR 0168.07), which estimates 250 hours per State to prepare and submit a request for NPDES Program Modification under 40 C.F.R. Part 123.62. Allen (2002) and Sylvester (2002) concurred with this estimate, but Coats (2002) noted that 80 hours might be sufficient.

Table 9-11 summarizes EPA's labor assumptions for these one-time costs and provides unit expenditure estimates based on an hourly loaded wage rate of $29.78 (in 2001 dollars).[4]

Table 9-11. State Administrative Costs for Rule Development and NPDES Program Modification Requests. (costs in 2001 dollars)

Administrative Activity	Unit Hours	Labor Cost	O&M Cost[1]
State Administrative Costs			
Rule Development	850 per State	$25,310	$2,120
NPDES Program Modification Requests	250 per State	$7,450	

1. States may incur public notification costs twice (i.e., for draft and final rules) while revising their regulations. The O&M cost estimate is based on the same assumption of $1,000 per public notice that was used for the proposed rule. That estimate assumed that public notices would be placed in four newspapers and each notice cost $250. The $1,000 was converted from 1999 dollars to 2001 dollars using the Consumer Price Index (1000 × 177.1/166.6 = 1060) (BLS, 2002a). This estimate is consistent with a cost estimate for public notification expenses provided by Tilley and Kirkpatrick (2002).

Approved States will incur annual costs to administer their permit programs. To administer State general permits, permitting authorities will need to:

- Update their general permits to incorporate final rule requirements.

- Review Notice of Intent (NOI) forms submitted by CAFO operators seeking coverage under a general permit.

[4] This estimate was based on the mean hourly wage rate of $20.53 for Conservation Scientists (SOC 19-1031) employed in the public sector (BLS, 2001) because employees in this occupation will most likely conduct permit review and facility inspections, which account for most of the burden hours. The rate was escalated from 2000 dollars to 2001 dollars using the Employment Cost Index, which indicates a 3.6 percent increase in wages and salaries for state and local government workers from December 2000 to December 2001 (BLS, 2002c). Then, the escalated wage rate ($21.27 = $20.53 × 1.036) was converted to a loaded wage rate using a total compensation-to-wage ratio of 1.4, which was the ratio in 2001 for all state and local workers (BLS, 2002b).

- Inspect CAFOs covered by the general permit.
- Review annual reports submitted by CAFOs covered by general permits.

To administer individual permits, State agencies will need to:

- Review application forms (i.e., Forms 1 and 2B)
- Request public comment prior to issuing a permit
- Conduct public hearings, as needed
- Inspect CAFOs covered by individual permits
- Review annual reports submitted by CAFOs covered by individual permits.

To update their general permits, the 43 approved States will need to revise the general permit conditions affected by the final rule (or develop a general permit for CAFOs in the 21 approved States that currently do not have such permits). For example, general permits will need to specify the method(s) that the permit authority is requiring the CAFO owner or operator to use to calculate the rate of appropriate manure application as a special condition, as well as incorporate the NMP requirements listed in 40 C.F.R. 122.42(e)(1). They may also need to reflect changes to animal thresholds between large, medium, and small CAFOs if current permits use the AU approach in the CAFO definition.

EPA estimated that States may need 300 hours to revise their general permits to reflect new provisions of the final rule. Information provided by State contacts indicated that initial general permit development was a contentious process that took two (Allen, 1999) to four years (KauzLoric, 1999) to complete. EPA does not believe that the changes necessitated by the final rule (e.g., adding the NMP requirements; adding new recordkeeping or reporting requirements; switching from size thresholds based on AU to animal counts; and altering the ELG, BPJ, or special conditions where necessary) will require the same magnitude of effort as initial permit development. Furthermore, EPA will develop a model permit that States can adopt in whole or part to minimize the costs of permit revisions. Sylvester (2002) estimated that revising Wisconsin's general permit may take 456 hours and Coats (2002) estimated that States in Region 2 would need 160 hours to revise their general permits. EPA's estimate of 300 hours or 0.14 FTE is the approximate midpoint between these estimates. Allen (2002) considered EPA's 300-hour estimate to be acceptable.

Revised general permits will be subject to public comment. EPA estimated costs for the proposed rule based on public notice, comment review, and response requiring 160 hours or 0.08 FTE. Comments from State employees in South Dakota (Pirner, 2001) and Illinois (Willhite, 2001) indicated that costs would be higher because the process for selecting the type of facilities that may be eligible under a general permit will be contentious. Subsequent information obtained by EPA indicates a wide range of time from as little as 100 hours (Coats, 2002) to as much as 968 hours (Sylvester, 2002); Allen (2002) considered EPA's revised estimate of 180 hours to be acceptable. EPA assumed that the 180-hour estimate reflects labor requirements for the 22 States that already provide general NPDES permit coverage for CAFOs (US EPA, 2001) because these States have already resolved the applicability issue, which should not be substantially affected by the final rule. For the 21 States with approved programs that do not currently provide coverage under a general permit, EPA used the high estimate of 968 hours provided by Sylvester (2002) to incorporate additional time for the decision making process regarding which CAFOs would qualify for general permit coverage. The weighted average across all 43 States is approximately 570 hours (0.51 × 180 + 0.49 × 968) or 0.27 FTE.

Finally, States may conduct hearings regarding general permit revisions (or development for the States that do not provide general permit coverage for CAFOs). For the proposed rule, EPA derived costs for 240 hours based on the assumption that a State holds four hearings, each requiring 60 hours of labor time. Allen (2002) and Coats (2002) considered that assumption acceptable. Sylvester (2002) recommended an alternative estimate of 616 hours based on 12 hearings requiring 48 staff hours each plus an additional 40 hours for material preparation. For the final rule, EPA assumed that its original 240-hour estimate is sufficient for the 22 States that only need to revise existing general permits, and that the 21 States that do not provide general permit coverage for CAFOs will conduct additional hearings. For those States, EPA used the 616-hour estimate. The weighted average across all States is approximately 420 hours (0.51 × 240 + 0.49 × 616).

Adding together the three labor estimates for general permit development, EPA obtained a total estimate of 1,290 hours per general permit. For the 22 States that already provide general permit coverage, aggregate hours would be 720 hours. For the 21 States that would need to provide general permit coverage and determine which CAFOs are eligible, aggregate hours would be approximately 1,880 hours. It is possible that some of the States not currently providing general permit coverage will continue to rely solely on individual permits for CAFOs. Thus, EPA's cost analysis assumption that all 43 States will incur general permit revision costs provides an upper bound cost estimate.

CAFOs seeking coverage under a State's (or EPA's) general permit will submit completed NOI forms that the permitting authority will need to review and make a determination of coverage. For the proposed rule, EPA estimated that NOI review would require 1 hour. Comments indicated that the labor requirement would be substantially higher. For example, a Wisconsin State employee (Bazzell, 2001) indicated an expected expenditure of approximately 100 hours to review the NOI and accompanying documents. Ohio employees (Jones, et al., 2001) indicated that the estimates provided in the proposed rule did not allow time to ensure that the facilities were meeting all permit conditions. Willhite (2001) also indicated that costs for review of the NOI would be substantially higher. EPA believes that much of the concern regarding its proposed rule estimate centered on review of the proposed permit nutrient plan. For example, 60 hours of the 96-hour Wisconsin estimate pertained to reviewing the content of the NMP (Sylvester, 2002); 32 hours were allocated for review and approval of manure storage and runoff management systems, and 4 hours for general review for completeness of information. The final rule does not require a CAFO to submit this plan with the permit application, so this concern does not pertain to the final rule.

Nevertheless, EPA has revised the information requirements for the NOI and subsequently increased its estimate of the amount of time required for review. The final rule requires the following information be provided on the revised NOI and Form 2B: name and address of operator; manure storage mode and capacity; physical location including latitude and longitude of the production area; number of animals by type; estimated amount of manure generated per year; acreage available for agricultural use of manure, or litter and wastewater (under the control of the owner or operator); estimated amount of manure, or litter and wastewater to be transferred off site; and date for development of NMP, and expected date for full implementation. Reviews of the revised NOI forms to ensure completeness and accuracy of this required information should not take longer than 4 hours. This estimate is consistent with the one provided by Sylvester (2002). Furthermore, Allen (2002), Coats (2002), and Domingo (2002) indicated four hours would be adequate for NOI review. The annual reports that CAFOs are now required to submit (regardless of permit type) will contain updates for some of the information provided on the NOI form. Consequently, EPA assumed that the State burden to review an annual report, enter data as needed, and maintain CAFO records is the same as the NOI review estimate—4 hours.

EPA assumed that compliance inspections for CAFOs covered by a general permit would require an average of 16 hours, which includes 6 hours for round-trip travel time, 2 hours to prepare for the inspection, 4 hours to conduct the on-site portion of the inspection, and 4 hours for reporting and record keeping. This estimate is slightly greater than the recommendation of 12 hours made by Sylvester (2002), which included 8 hours for the inspection and travel time and 4 hours for reporting and data entry. EPA's estimate also equals the average of two inspection burden estimates in an active NPDES ICR (“Pollutant Discharge Elimination System and Sewage Sludge Management State Programs,” OMB NO. 2040-0057, EPA ICR 0168.07). The reconnaissance inspection has a burden estimate of 8 hours and the compliance evaluation inspection has a burden estimate of 24 hours. On average, CAFO inspections will require less time than a typical compliance evaluation inspection, which includes inspection of effluent and receiving waters and discharge monitoring records. A reconnaissance inspection often does not include review of onsite records. Thus, a CAFO inspection that includes review of onsite records in addition to a visual inspection of the operation will most likely require more than eight hours.

State administration costs for individual permits include 100 hours per permit to review Forms 1 and 2B, issue public notices, and respond to comments. EPA increased this estimate from the 70 hours used in its analysis of the proposed rule in response to comments (Muldener, 2001). Sylvester (2002) and Allen (2002) concurred with this estimate; Harsh (2002) thought it might be low, but Coats (2002) considered it to be twice the time needed.

EPA estimated that the hearing time for an individual permit would require 200 hours based on estimates from Washington State (KauzLoric, 1999), which indicated that a hearing required approximately 100 to150 hours of State employee time. Using BPJ, EPA assumed an average of two hearings per permit and an average requirement of 100 hours per hearing. This is higher than the estimate per hearing provided by Sylvester (2002). Nevertheless, Sylvester agreed with the estimate, as did Coats (2002) and Allen (2002). Harsh (2002) provided an alternative estimate of 22 to 33 hours. EPA decided to retain an average estimate of 200 hours because some individual permits may attract numerous participants and require multiple hearings.

EPA assumed that the inspection time and annual report review and subsequent recordkeeping costs for operations with individual permits would be the same as operations with general permits. The average inspection time will most likely be the same because most of the 16-hour estimate is spent on activities that will not vary across permit types. Similarly, the annual report content requirements are the same for all CAFOs regardless of permit type. Thus, the labor requirement is 4 hours.

Table 9-12 summarizes EPA's assumptions for general permit administration and Table 9-13 provides the assumptions used to develop State costs for individual permits. The same State wage rate is used to estimate unit costs. These tables also provide unit cost estimates for EPA, which is the permitting authority in some States.[5]

States may also need to undertake enforcement actions, but EPA has adopted the standard analytical assumption of full compliance for the purposes of estimating State and private sector expenditures. Given CAFO costs that reflect full compliance assumptions, there should be no need for enforcement actions. Therefore, this analysis excludes enforcement costs.

Although, the overall unit costs for permitting are generally higher than those used in proposal, due to a decrease in the universe of potential permittees under the final rule, States will incur much smaller permitting costs compared to either of the regulatory alternatives considered for EPA's proposed rule. For the proposed rule, EPA coproposed the following:

- A three-tier alternative in which all Tier 2 facilities would be required to either apply for an NPDES permit or submit certification that they did not meet any conditions necessitating a permit.

- A two-tier alternative that lowered the threshold for AFOs that were automatically defined as CAFOs from 1000 AU to 500 AU.

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[5] EPA used an hourly wage rate for a GS12, Step One Federal employee to estimate the cost of EPA staff. The U.S. Office of Personnel Management 2001 General Schedule reported a base annual salary of $51,927. EPA divided this by 2,080 hours to obtain an hourly rate of $24.96. Multiplying this rate by 1.6 to incorporate typical Federal benefits (OPM, 1999), EPA obtained a final hourly rate of $39.94 .

Table 9-12. State and Federal Administrative Costs Associated With General Permits. (costs in 2001 dollars)

Administrative Activity	Unit Hours	Labor Cost	O&M Cost[1]
State Administrative Costs			
General Permit Development	1,290 per State	$38,420	$1,060
- Revise Permit	300 per State		
- Public Notice/Response to Comments	570 per State		
- Public Hearing(s)	420 per State		
Review and Approval of NOIs	4 per CAFO	$120	
Review Annual Reports	4 per CAFO	$120	
Facility Inspections	16 per CAFO	$480	
Federal Administrative Costs[2]			
Review and Approval of NOIs	4 per CAFO	$160	
Review Annual Reports	4 per CAFO	$160	
Facility Inspections	16 per CAFO	$640	

1. States may incur public notification costs for the general permit. The O&M cost estimate is based on the same assumption of $1,000 per public notice that was used for the proposed rule. That estimate assumed that public notices would be placed in four newspapers and each notice cost $250. The $1,000 was converted from 1999 dollars to 2001 dollars using the Consumer Price Index ($1000 \times 177.1/166.6 = 1060$) (BLS, 2002a). This estimate is consistent with a cost estimate for public notification expenses provided by Tilley and Kirkpatrick (2002).

2. EPA employees will incur the same hourly burden for these activities as their State counterparts.

Table 9-13. State and Federal Administrative Costs Associated with Individual Permits. (in 2001 dollars)

Administrative Activity	Unit Hours	Labor Cost	O&M Cost[1]
State Administrative Costs			
Application Review/Public Notification/Response to Comments	100 per CAFO	$2,980	$1,060
Public Hearing	200 per CAFO	$5,960	$1,060
Review Annual Reports	4 per CAFO	$120	
Facility Inspections	16 per CAFO	$480	
Federal Administrative Costs[2]			
Application Review/Public Notification/Response to Comments	100 per CAFO	$3,990	$1,060
Public Hearing	200 per CAFO	$7,990	$1,060
Review Annual Reports	4 per CAFO	$160	
Facility Inspections	16 per CAFO	$640	

1. States may incur public notification costs for each individual permit and hearing. The O&M cost estimate is based on the same assumption of $1,000 per public notice that was used for the proposed rule. That estimate assumed that public notices would be placed in four newspapers and each notice cost $250. The $1,000 was converted from 1999 dollars to 2001 dollars using the Consumer Price Index ($1000 \times 177.1/166.6 = 1060$) (BLS, 2002a). This estimate is consistent with a cost estimate for public notification expenses provided by Tilley and Kirkpatrick (2002).

2. EPA employees will incur the same hourly burden for these activities as their State counterparts.

EPA estimated that 31,930 facilities would be affected under the proposed three-tier option. Under the proposed two-tier option, 25,540 facilities would have required NPDES permits. Based on the provisions of the final rule, EPA estimates that approximately 15,400 operations will require a permit. This estimate includes more than 10,700 large CAFOs, almost 4,500 medium operations defined as CAFOs, and almost 200 designated CAFOs. Because States incur most of their program costs through ongoing permit administration, EPA's final rule will be more cost effective and less burdensome than either of its proposed alternatives.

Of the 15,400 CAFOs requiring NPDES permits, EPA estimates that approximately 13,000 should have permits or meet the 25-year, 24-hour exemption under the 1976 regulations. EPA estimates, however, that only 4,100 permits have been issued, which implies that the permitting impact above the actual compliance baseline is approximately 11,300 permits.

EPA also recognizes that the final rule may affect permit conditions for those CAFOs that already have (or should have) permits. This could affect state costs for issuing permits and conducting inspections. Furthermore, revisions to the permit application forms may increase State review time as well as increase the time it takes producers to complete the forms. Thus, States may incur incremental costs for the baseline CAFOs that do (or should) have NPDES permits now. To simplify the analysis, EPA estimated an upper-bound impact that includes total permitting and inspection costs for all 15,400 CAFOs, although States are already incurring some portion of cost on 4,100 CAFOs. Actual new expenditures, therefore, will be lower than EPA's estimate suggests.

Operators or owners of a large CAFO may submit documentation that there is no potential to discharge in lieu of applying for a permit. The permitting authority would need to review the documentation and make a determination of whether there is a potential to discharge. Although there are no estimates of how many operations may pursue this option, given the stringent requirements, EPA believes that few, if any, operations will claim no potential to discharge. Therefore, EPA's cost analysis assumes that all CAFOs obtain NPDES permits. If any operation chooses to request a no-potential-to-discharge determination, then presumably doing so is as cost effective or more cost effective in the long run than obtaining a permit. Therefore, EPA concludes that its analysis may overstate costs should any CAFOs obtain an exemption based on no potential to discharge.

As noted above, only the approved States will incur costs. To derive State costs, EPA needed to estimate how often the States activities would occur. First, EPA estimated that 97 percent of the permitted CAFOs are located in these States based on its analysis of USDA livestock operation data. Second, EPA assumed that 70 percent of these CAFOs will request coverage under a State general permit (or EPA's general permit). The remaining 30 percent will obtain individual permits. EPA believes that the split between the two permit types is conservative (i.e., tending to overestimate costs) because the permit conditions for CAFOs are amenable to the use of a general permit. In particular, there are no facility-specific discharge limits that would require individual permitting. Third, EPA assumed that 12 percent of individual permits will require public hearings. The hearing percentage for individual permits is an average of estimates provided for Kansas (4 to 8 percent) and Indiana (15 to 20 percent). Finally, using best professional judgement, EPA assumed that each CAFO is inspected once within each 5-year permit period, which implies an annual inspection rate of 20 percent. The final rule contains no inspection frequency requirements and for NPDES purposes, this is a relatively high inspection rate because CAFOs fall into the category of nonmunicipal, minor dischargers, which have an annual inspection rate closer to 1 percent. States have indicated, however, that they inspect CAFOs more frequently to ensure compliance with multiple State requirements (US EPA, 2001). Although these frequent inspections may not be necessary to ensure NPDES compliance, inspectors can assess NPDES compliance status. Consequently, EPA increased its inspection rate estimate from 10 percent (used in the proposed rule) to 20 percent to reflect at least one NPDES-related inspection per CAFO every 5 years. This inspection rate includes the inspection required to designate a small or medium AFO, a CAFO.

Table 9-14 shows how the total estimate of 15,400 CAFOs and preceding assumptions generate the CAFO estimates for each of the permit-related costs shown in Tables 9-12 and 9-13. NPDES permits are valid for up to 5 years. Thus, States incur application review costs for each CAFO once every five years. To derive average annual costs, EPA assumed these costs would be incurred for 20 percent of total CAFOs each year. The annual CAFO column in Table 9-14 reflects this assumption.

Table 9-14. Derivation of CAFO Estimates Used to Calculate Annual Administrative Costs.[1]

Category	Total	Annual[1]
Total CAFOs	15,400	3,080
State-Issued Permits[2]	14,923	2,985
• General Permits	10,446	2,089
– Inspections	2,089	2,089
• Individual Permits	4,477	895
– Hearings	537	107
– Inspections	895	895
EPA-Issued Permits[2]	477	95
• General Permits	334	67
– Inspections	67	67
• Individual Permits	143	29
– Hearings	17	3
– Inspections	29	29

Detail may not add to totals because of independent rounding. The total CAFO estimate has been rounded to the nearest hundred for the purpose of this UMRA analysis.

1. Annual CAFO estimates for permit review costs equal total divided by 5 because permits are renewed every 5 years. Annual CAFO estimates for inspections equal 20 percent of total CAFOs.

2. EPA estimated the number of CAFOs in the 43 states with approved NPDES programs based on its analysis of USDA livestock operation data. EPA used this estimate to split total CAFOs between those receiving State-issued permits and EPA-issued permits.

To obtain the annual State costs reported in Table 9-15, EPA multiplied the one-time unit costs in Table 9-11 by the number of States expected to incur those costs. These one-time costs were then annualized over 5 years at a 7 percent discount rate.[6] Recurring annual permitting and inspection costs were derived by multiplying the unit costs in Tables 2 and 3 by their respective annual CAFO estimates in Table 9-14. Total annual State administrative costs are the sum of annualized one-time costs and annual permitting costs. The annual cost estimate for all States is $8.5 million. Federal costs for administering a portion of permits are shown in Table 9-16 for information purposes.

Table 9-15. Annual State Administrative Costs. (in 2001 dollars)

Administrative Activity	Unit Cost	Units	Total Cost ($millions)
Up-front State Costs			
Rule Development[1]	$27,430	43 States	$1.18
NPDES Program Modification Request	$7,450	43 States	$0.32
General Permit Development[1]	$39,480	43 States	$1.70
		Up-front Total	**$3.20**
		Annualized up-front Costs[2]	**$0.73**
Average Annual Implementation Costs for Permits and Inspections			
Review and Approve NOIs for General Permits	$120	2,089 CAFOs per year	$0.25
Review Applications/Public Notices/Respond to Comments for Individual Permits[1]	$4,040	895 CAFOs per year	$3.61
Public Hearings for Individual Permits[1]	$7,020	107 CAFOs per year	$0.75
Review Annual Reports (General and Individual Permits)	$120	14,923 CAFOs per year	$1.78
Facility Inspections (General and Individual Permits)	$480	2,984 CAFOs per year	$1.42
		Annual Permit Costs	**$7.81**
		Total Annual Costs	**$8.54**

Detail may not add to totals due to independent rounding.
1. Includes O&M costs.
2. Total up-front costs annualized over 5 years at a 7 percent discount rate.

[6] Assuming a 5-year annualization period generates a conservative annual estimate that tends to overstate costs because it treats these one-time activities as though they recur every five years, which is unlikely to be the case.

Table 9-16. Federal Administrative Costs.
(in 2001 dollars)

Administrative Activity	Unit Cost	Units	Total Cost ($millions)[1]
Average Annual Implementation Costs for Permits and Inspections			
Review and Approve NOIs for General Permits	$160	67 CAFOs per year	$0.01
Review Applications/Public Notices/Respond to Comments for Individual Permits[2]	$3,990	29 CAFOs per year	$0.15
Public Hearings for Individual Permits[2]	$7,990	3 CAFOs per year	$0.03
Review Annual Reports (General and Individual Permits)	$160	477 CAFOs per year	$0.08
Facility Inspection (General and Individual Permits)	$640	95 CAFOs per year	$0.06
		Annual Permit Costs	**$0.32**

Detail may not add to totals due to independent rounding.
1. EPA used an hourly wage rate for a GS12, Step One Federal employee to estimate the cost of the Agency staff. The U.S. Office of Personnel Management (OPM, 2001) General Schedule reported a base annual salary of $51,927 in 2001. EPA divided this by 2,080 hours to obtain an hourly rate of $24.96. Multiplying this rate by 1.6 to incorporate typical Federal benefits (OPM, 1999), EPA obtained a final hourly rate of $39.94.
2. Includes O&M costs.

New State expenditures as a result of the final rule are expected to differ across States. Although all approved States will incur up-front costs to revise their rules and implement programs, States with more CAFOs will incur more annual costs. EPA estimated that almost 50 percent of permitted CAFOs are located in seven States: approximately 9 percent in both Iowa and North Carolina; approximately 6 percent in both Georgia and California; and between 5 and 6 percent in each of Nebraska, Minnesota, and Texas. Thus, these States are likely to incur much higher annual costs than other States. State costs will also vary depending on the rate at which they utilize general versus individual permits.

States can use existing sources of financial assistance to revise and implement the final rule. Section 106 of the CWA authorizes EPA to provide federal assistance (from Congressional appropriations) to States, Tribes, and interstate agencies to establish and implement ongoing water pollution control programs. Section 106 grants offer broad support to States to administer programs to prevent and abate surface and ground water pollution from point and nonpoint sources. States may use the funding for a variety of activities including permitting, monitoring, and enforcement. Thus, State NPDES permit programs represent one type of State program that can be funded by Section 106 grants. The total appropriation for Section 106 grants for fiscal year 2002 was $192,476,900. On average, eligible States may receive between $60,000 to $9,000,000 of the total appropriation.

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CHAPTER 10

TECHNOLOGY OPTIONS CONSIDERED

This section describes the combinations of treatment technologies and best management practices (BMPs) that EPA configured as technology options for consideration as bases for the Concentrated Animal Feeding Operation (CAFO) effluent limitations guidelines and standards (ELGs). EPA developed technology options for the following:

- Best practicable control technology currently available (BPT);
- Best conventional pollutant control technology (BCT);
- Best available technology economically achievable (BAT); and
- New source performance standards (NSPS).

Technology bases for each option for each regulation were selected from the treatment technologies and BMPs described in Chapter 8. Sections 10.1 through 10.4 discuss the regulatory options that were considered for each of the regulations listed above.

10.0 INTRODUCTION

The regulations applicable to Large CAFOs are ELGs which are applied to individual operations through National Pollutant Discharge Elimination System (NPDES) permits issued by EPA or authorized states under Section 402 of the Clean Water Act (CWA). For Large CAFOs under Subparts C and D, the final ELG regulations prohibit the discharge of manure, litter, and other process wastewater, except for allowing discharge when rainfall causes an overflow from a facility designed, maintained, and operated to contain all process wastewaters, including storm water, plus runoff from the 25-year, 24-hour rainfall event.

All of these regulations are based upon the performance of specific technologies but not require the use of any specific technology.

10.1 Best Practicable Control Technology Currently Available (BPT)

The BPT effluent limitations control conventional, priority, and nonconventional pollutants when discharged from CAFOs to surface waters of the United States. Generally, EPA determines BPT effluent levels based upon the average of the best existing performances by plants of various sizes, ages, and unit processes within each industrial category or subcategory. In industrial categories where present practices are uniformly inadequate, however, EPA may determine that BPT requires higher levels of control than any currently in place if the technology to achieve those levels can be practicably applied.

In addition, CWA Section 304(b)(1)(B) requires a cost assessment for BPT limitations. In determining the BPT limits, EPA must consider the total cost of treatment technologies in relation to the effluent reduction benefits achieved. This inquiry does not limit EPA's broad discretion to adopt BPT limitations that are achievable with available technology unless the required additional reductions are "wholly out of proportion to the costs of achieving such marginal level of reduction." See Legislative History, op.cit. p. 170. Moreover, the inquiry does not require the Agency to quantify benefits in monetary terms. See e.g., American Iron and Steel Institute v. EPA, 526 F. 2d 1027 (3rd Cir., 1975).

In balancing costs against the benefits of effluent reduction, EPA considers the volume and nature of expected discharges after application of BPT, the general environmental effects of pollutants, and the cost and economic impacts of the required level of pollution control. In developing guidelines, the CWA does not require or permit consideration of water quality problems attributable to particular point sources, or water quality improvements in particular bodies of water. Therefore, EPA has not considered these factors in developing the final limitations. See Weyerhaeuser Company v. Costle, 590 F. 2d 1011 (D.C. Cir. 1978).

10.1.1 BPT Options for the Subpart C Subcategory

EPA incorporated the following BMPs into all BPT technology options:

Production Area BMPs

- Perform weekly inspections of all storm water diversion devices, runoff diversion structures, animal waste storage structures, and devices channeling contaminated storm water to the wastewater and manure storage and containment structure;
- Perform daily inspections of all water lines, including drinking water or cooling water lines;
- Install depth markers in all surface and liquid impoundments (e.g., lagoons, ponds, tanks) to indicate the design volume and to clearly indicate the minimum capacity necessary to contain the 25-year, 24-hour rainfall event, including additional freeboard requirements, or in the case of new sources subject to Subpart D, the runoff and direct precipitation from 100-year, 24-hour rainfall event;
- Correct any deficiencies found as a result of daily and weekly inspections as soon as possible;
- Do not dispose of mortalities in liquid manure or storm water storage or treatment systems, and mortalities must be handled in such a way as to prevent discharge of pollutants to surface water unless alternative technologies are approved; and
- Maintain on-site a complete copy of the records specified in 40 CFR 412.37(b). These records must be maintained for 5 years and if requested, be made available to the permitting authority.

Land Application BMPs

- Land-apply manure, litter, and other process wastewaters in accordance with a nutrient management plan that establishes application rates for each field based on the nitrogen requirements of the crop, or on the phosphorus requirements where necessary because of soil or other field conditions.
- Account for other sources of nutrients when establishing application rates, including previous applications of manure, litter, and other process wastewaters; residual nutrients in the soil; nitrogen credits from previous crops of legumes; and application of commercial fertilizers, biosolids, or irrigation water.
- Collect and analyze manure, litter, and other process wastewaters annually for nutrient content, including nitrogen and phosphorus.
- Calibrate manure application equipment annually.
- Applications of manure, litter, and other process wastewaters are prohibited within 100 feet of any down-gradient surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters. As a compliance alternative to the 100-foot setback, the CAFO may elect to establish a 35-foot vegetated buffer where application of manure, litter, or other process wastewaters is prohibited. The CAFO may also demonstrate to the permitting authority that a setback or vegetated buffer is unnecessary because implementation of alternative conservation practices or site-specific conditions will provide pollutant reductions equivalent to or better than the reductions that would be achieved by the 100-foot setback.
- Maintain on-site the records specified in 40 CFR 412.37(c). These records must be maintained for 5 years and if requested, be made available to the permitting authority.

In addition, BPT options for Subpart C operations (dairy and beef cattle other than veal which includes heifer operations) include the following technology bases:

Option 1: Zero discharge from a facility designed, maintained, and operated to hold manure, litter, and other process wastewaters, including direct precipitation and runoff from a 25-year, 24-hour rainfall event. In addition, determine the maximum allowable nitrogen-based application rates based on the nitrogen requirement of the crop to be grown and realistic crop yields that reflect the yields obtained for the given (or similar) field in prior years. Manure, litter, and other process wastewater applications must not exceed the nitrogen-based application rate.

Option 1A: The same elements as Option 1, with the addition of storage capacity for the chronic storm event (10-year, 10-day storm) above any capacity necessary to hold manure, litter, and other process wastewaters, including direct precipitation and runoff from a 25-year, 24-hour rainfall event.

Option 2: The same elements as Option 1, except nitrogen-based agronomic application rates are replaced by phosphorus-based agronomic application rates when dictated by site-specific conditions. In addition, at least once every three years, collect and analyze representative soil samples for phosphorus content from all fields where manure, litter, and other process wastewaters are applied.

Options 3A/3B: The same elements as Option 2, plus ground-water monitoring, concrete pads, synthetically lined lagoons and/or synthetically lined storage ponds for operations located in environmentally sensitive areas such as karst terrain where ground water contamination is likely and an assessment of the ground water's hydrologic link to surface water for all other operations.

Options 3C/3D: The same elements as Option 2, plus permeability standards for lagoons and storage ponds for operations located in environmentally sensitive areas such as karst terrain. No additional requirements are placed on operations not located in environmentally sensitive areas.

Option 4: The same elements as Option 2, plus costs for additional surface water monitoring.

Option 5A: The same elements as Option 2, plus implementation of a drier manure management system (i.e., composting).

Option 6: For Large dairy operations only, the same elements as Option 2, plus implementation of anaerobic digestion with energy recovery.

Option 7: The same elements as Option 2, plus timing restrictions on land application of animal waste to frozen, snow-covered, or saturated ground.

In addition to the technology options described above, EPA conducted several sensitivity analyses of costs include the requirement that all operations use a phosphorus-based agronomic rate as opposed to only when dictated by site-specific conditions, and all recipients of manure from a CAFO prepare nutrient management plans.

10.1.2 BPT Options for the Subpart D Subcategory

BPT options for Subpart D operations (swine, poultry, and veal calves) are the same as those described in Section 10.2.1 for Subpart C operations for Options 1, 1A, 2, 3A/3B, 3C/3D, 4, and 7. Option 5A is replaced by Option 5 and Option 6 is modified to address the operations under Subpart D. Descriptions of Options 5 and 6 for Subpart D operations are described below.

Option 5: The same elements as Option 2, but based on zero discharge with no overflow under any circumstances (i.e., total confinement and covered storage).

Option 6: For Large swine operations, the same elements as Option 2, plus implementation of anaerobic digestion with energy recovery.

10.2 Best Conventional Pollutant Control Technology (BCT)

BCT limitations control the discharge of conventional pollutants from direct dischargers. Conventional pollutants include BOD, TSS, oil and grease, and pH. BCT is not an additional limitation, but rather replaces BAT for the control of conventional pollutants. To develop BCT limitations, EPA conducts a cost reasonableness evaluation, which consists of a two-part cost test: 1) the POTW test, and 2) the industry cost-effectiveness test.

In the POTW test, EPA calculates the cost per pound of conventional pollutants removed by industrial dischargers in upgrading from BPT to a BCT candidate technology and then compares this to the cost per pound of conventional pollutants removed in upgrading POTWs from secondary to tertiary treatment. The upgrade cost to industry, which is represented in dollars per pound of conventional pollutants removed, must be less than the POTW benchmark of $0.25 per pound (in 1976 dollars). In the industry cost-effectiveness test, the ratio of the incremental BPT to BCT cost, divided by the BPT cost for the industry, must be less than 1.29 (i.e., the cost increase must be less than 29 percent).

In developing BCT limits, EPA considered whether there are technologies that achieve greater removals of conventional pollutants than for BPT, and whether those technologies are cost-reasonable according to the BCT Cost Test. In each subcategory, EPA considered the same technologies and technology options when developing BCT options as were developed for BPT.

10.3 Best Available Technology Economically Achievable (BAT)

The factors considered in establishing a BAT level of control include: the age of process equipment and facilities, the processes employed, process changes, the engineering aspects of applying various types of control techniques to the costs of applying the control technology, non-water quality environmental impacts such as energy requirements, air pollution and solid waste generation, and such other factors as the Administrator deems appropriate (Section 304(b)(2)(B) of the Act). In general, the BAT technology level represents the best existing economically achievable performance among facilities with shared characteristics. BAT may include process changes or internal plant controls which are not common in the industry. BAT may also be transferred from a different subcategory or industrial category.

In each subcategory, EPA considered the same technologies and technology options when developing BAT options as were developed for BPT.

10.4 New Source Performance Standards (NSPS)

NSPS under Section 306 of the CWA represent the greatest degree of effluent reduction achievable through the application of the best available demonstrated control technology for all pollutants (i.e., conventional, nonconventional, and toxic pollutants). NSPS are applicable to new industrial direct discharging facilities. Congress envisioned that new treatment systems could meet tighter controls than existing sources because of the opportunity to incorporate the most efficient processes and treatment systems into plant design. Therefore, Congress directed EPA, in establishing NSPS, to consider the best demonstrated process changes, in-plant controls, operating methods, and end-of-pipe treatment technologies that reduce pollution to the maximum extent feasible.

In each subcategory, EPA considered the same technologies and technology options for all animal sectors when developing NSPS options as were developed for BPT. In addition, at proposal, EPA considered a zero discharge option with no exception for storm overflows, based on maintaining animals in total confinement.

CHAPTER 11

MODEL FARMS AND COSTS OF TECHNOLOGY BASES FOR REGULATION

This section describes the methodology used to estimate engineering compliance costs associated with implementing the regulatory options for the concentrated animal feeding operations (CAFOs) industry. The information contained in this section provides an overview of the methodology and assumptions built into the cost models. More detailed information on the cost methodology and specific technologies and practices is contained in the *Cost Methodology for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations* (2002).

The following information is discussed in this section:

- Section 11.1: Overview of cost methodology;
- Section 11.2: Development of model farm operations;
- Section 11.3: Design and cost of waste and nutrient management technologies;
- Section 11.4: Development of frequency factors;
- Section 11.5: Summary of estimated industry costs by regulatory option; and
- Section 11.6: References.

11.1 Overview of Cost Methodology

To assess the economic impact of the effluent limitations guidelines and standards on the CAFOs industry, EPA estimated costs associated with regulatory compliance for each of the regulatory options described in Section 10. The economic burden is a function of the estimated costs of compliance to achieve the requirements, which may include initial fixed and capital costs, as well as annual operating and maintenance (O&M) costs. Estimation of these costs typically begins by identifying the practices and technologies that can be used to meet a particular requirement. The Agency then develops a cost model to estimate costs for their implementation.

EPA used the following approach to estimate compliance costs for the CAFOs industry:

- EPA collected data from published research, meetings with industry organizations, discussions with USDA cooperative extension agencies, review of USDA's Census of Agriculture data, and site visits to swine, poultry, beef, veal, and dairy CAFOs. These data were used to define model farms and to determine waste generation and nutrient concentration, current waste and nutrient practices, and the viability of waste management technologies for the model farms.

- EPA identified candidate waste and nutrient management practices and grouped appropriate technologies into regulatory options. These regulatory options serve as the bases of compliance cost and pollutant loading calculations.
- EPA developed technology frequency factors to estimate the percentage of the industry that already implements certain operations or practices required by the regulatory options (i.e., baseline conditions).
- EPA developed cost equations for estimating capital costs, initial fixed costs, and 3-year recurring costs, 5-year recurring costs, and annual O&M costs for the implementation and use of the different waste and nutrient practices targeted under the regulatory options. Cost equations were developed from information collected during the site visits, published information, vendor contacts, and engineering judgment.
- EPA developed and used computer cost models to estimate compliance costs and nutrient loads for each regulatory option.
- EPA used output from the cost model to estimate total annualized costs and the economic impact of each regulatory option on the CAFOs industry (presented in the *Economic Analysis*).

Table 11-1 presents the regulatory options and the waste and nutrient management components that make up each option.

Table 11-1. Summary of Regulatory Options for CAFOs

	Options									
Technology or Practice	**1**	**1A**	**2**	**3A/ 3B**	**3C/ 3D**	**4**	**5**	**5A**	**6**	**7**
Feedlot best management practices (BMPs), including storm water diversions, lagoon/pond depth markers, periodic inspections, and records	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mortality handling requirements (e.g., rendering, composting)[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nutrient management planning and recordkeeping (sample soils once every 3 years, sample manure twice per year)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Land application limited to nitrogen-based agronomic	✓	✓								
Land application limited to phosphorus-based agronomic application rates where dictated by site-specific conditions, and nitrogen-based application elsewhere			✓	✓	✓	✓	✓	✓	✓	✓
No manure application within 100 feet of any surface water, tile drain inlet, or sinkhole	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ground water requirements, including assessment of hydrologic link, monitoring wells (four per facility), impermeable pads under storage, impermeable lagoon/pond liners, and temporary/modified storage during upgrade				✓						
Ground water requirements including performance based standards for lagoons					✓					
Additional capacity for 10-year, 10-day chronic storm event		✓								
Surface water monitoring requirement, including four total grab samples upstream and downstream of both feedlot and land application areas, 12 times per year. One composite sample collected once per year at stockpile and surface impoundments. Samples are analyzed for nitrogen, phosphorus, and total suspended solids.						✓				
Drier manure technology basis[2,3]							✓	✓		
Anaerobic digestion									✓	
Timing requirements for land application (resulting in regional variation in storage periods)										✓

[1] There are no additional compliance costs expected for beef and dairy operations related to mortality handling requirements.
[2] Option 5 mandates "drier waste management." For beef feedlots and dairies, this technology basis is composting. For swine, poultry and veal operations, drier systems include covered lagoons.
[3] Option 5B mandates "no overflow" systems. For swine operations, the technology basis is high-rise housing for hogs, and for poultry operations the technology basis is dry systems.
(ERG, 2000a; Tetra Tech, Inc., 2000a)

11.2 <u>Development of Model Farm Operations</u>

For the purpose of estimating total costs and economic impacts, EPA calculated the costs of compliance for CAFOs to implement each of the regulatory options being considered. These costs reflect the range of capital costs, annual operating and maintenance costs, start-up or first year costs, as well as recurring costs that may be associated with complying with the regulations. EPA traditionally develops either facility-specific or model facility costs. Facility-specific compliance costs require detailed process information about many, if not all, facilities in the industry. These data typically include production, capacity, water use, wastewater generation, waste management operations (including design and cost data), monitoring data, geographic location, financial conditions, and any other industry-specific data that may be required for the analyses. EPA then uses each facility's information to determine how the potential regulatory options will impact that facility, and to estimate the cost of installing new pollution controls.

When facility-specific data are not available, EPA develops model facilities to provide a reasonable representation of the industry. Model facilities are developed to reflect the different characteristics found in the industry, such as the size or capacity of operations, types of operation, geographic locations, modes of operation, and types of waste management operations. These models are based on data gathered during site visits, information provided by industry members and their trade associations, and other available information. EPA estimates the number of facilities that are represented by each model. Cost and financial impacts are estimated for each model farm, then industry-level costs are calculated by multiplying model farm costs by the number of facilities represented by each particular model. Because of the amount and type of information that is available for the CAFOs industry, EPA has chosen a model-facility approach to estimate compliance costs.

EPA estimated compliance costs using a representative facility approach based on more than 1,700 farm-level models that were developed to depict conditions and to evaluate compliance costs for select representative CAFOs. The major factors used to differentiate individual model CAFOs include the commodity sector, the farm production region, the facility size (based on herd or flock size or the number of animals on site), and performance of the operation. EPA's model CAFOs primarily reflect the major animal sector groups, including beef cattle, dairy, hog, broiler, turkey, and egg laying operations. Practices at other subsector operations are also reflected by the cost models, such as replacement heifer operations, veal operations, flushed caged layers, and hog grow-finish and farrow-to-finish facilities. Model facilities with similar waste management and production practices were used to depict operations in regions that were not separately modeled.

Another key distinguishing factor incorporated into EPA's model CAFOs is the availability of cropland and pastureland to apply manure nutrients to land. For this analysis, nitrogen and phosphorus rates of land application are evaluated for three categories of cropland use: Category 1 CAFOs that have sufficient land for all on-farm nutrients generated, Category 2 CAFOs that have insufficient land, and Category 3 CAFOs that have no land. The number of CAFOs within a given category of land availability is drawn from 1997 USDA data and varies depending on which nutrient (nitrogen or phosphorus) is used as the basis to assess land application and nutrient management costs. For Category 2 and 3 CAFOs, EPA evaluated additional technologies that may be necessary to balance on-farm nutrients. These technologies may also be used to reduce off-site hauling costs associated with excess on-farm nutrients. Such technologies may include best management practices (BMPs) and various farm production technologies, such as feed management strategies, solid-liquid separation, composting, anaerobic digestion, and other retrofits to existing farm technologies.

EPA's model CAFOs also take into account such production factors as climate and farmland geography, as well as land application and waste management practices and other major production practices typically found in the key producing regions of the country. Required practices under existing state regulations are also taken into account. Model facilities reflect major production practices used by larger confined animal farms, generally those with more than 300 animal units. Therefore, the models do not reflect pasture and grazing type farms, nor do they reflect typical costs to small farms. EPA's cost models also reflect cost differences within sectors depending on manure composition, bedding use, and process water volumes.

11.2.1 Swine Operations

EPA developed the parameters describing the model swine farms using information from the National Agriculture Statistics Service (NASS), site visits to swine farms across the country, discussions with the National Pork Producers Council, and the USDA Natural Resources Conservation Service (NRCS). Dscriptions of the various components that make up the model farms are presented in the following discussion, and the sources of the information used to develop that piece of the model farm are noted.

11.2.1.1 Housing

Swine are typically housed in total confinement barns, and less commonly in other housing configurations such as open buildings with or without outside access and pastures (USDA, 1995). On many farms, small numbers of pigs (fewer than the number covered by this regulation) are raised outdoors; however, the trend in the industry is toward larger confinement farms at which pigs are raised indoors (North Carolina State University, 1998). For these reasons, the model swine farm is assumed to house its animals in total confinement barns.

11.2.1.2 Waste Management Systems

The characteristics of waste produced at an operation depends on the type of animals that are present. In farrow-to-finish operations, the pigs are born and raised at the same facility. Therefore, the manure at a farrow-to-finish farm has the characteristics of mixed excreta from varying ages. In grow-finish facilities, young pigs are first born and cared for at a nursery in another location, and then brought onto the finishing farm. Therefore, the manure at a grow/finish farm has characteristics of older pigs 7 weeks to slaughter weight. These are the two predominant types of swine operations in the United States from the size classes that would be covered under the final rule.

Swine houses with greater than 750 head typically store their wastes in pits under the house or flush the wastes to outside lagoons. Slatted floors or flush alleys are used to separate manure and wastes from the animal. It is common to allow manure to collect in a pit and wash the pit one to six times per day with water to move the waste to a lagoon. The waste is stored in the lagoon until it is applied to land or transported off site. Storing the waste in an anaerobic lagoon provides some treatment during storage, conditioning the wastewater for later land application, and reducing odors (NCSU, 1998). EPA developed model farms for farrow-to-finish and grow/finish operations in the Mid-Atlantic and Midwest regions that are assumed to use pits or flush alleys and anaerobic lagoon storage.

In the Midwest, a deep pit storage system is more common. Deep pit systems start with several inches of water in the pit, and the manure is collected and stored under the house until it is pumped out for field application, typically twice a year. This system uses less water, creating a manure slurry that has higher nutrient concentrations than the flush system described earlier. A survey of swine operations in 2000 shows that both lagoons and deep pits are commonly used for waste storage in the Midwest region (USDA APHIS, 2002). For purposes of developing the cost models, EPA estimated, from the USDA APHIS (2002) data, the percentage of farrow-to-finish and grow/finish operations in the Mid-Atlantic and Midwest regions that use pit storage. EPA developed model farms for farrow-to-finish and grow/finish operations in the Mid-Atlantic and Midwest regions that are assumed to use pit storage pumped twice per year.

Although not present in the statistics that were available to the EPA at the time of this analysis, EPA recognizes the increasing number of large swine operations in the Central region. Many of these larger operations in the Central region use evaporative lagoons instead of traditional anaerobic lagoons found in the Mid-Atlantic and Midwest. Thus, EPA developed model farms for large facilities in the Central region and assumed evaporative lagoons are used for waste storage.

EPA's swine model farms under Option 5 assume that all lagoons are covered with a synthetic cover. Facilities that use deep pit storage are not assumed to need any additional practices to comply with Option 5.

Figure 11-1 presents these waste management systems used for the model swine farms in this cost model.

11.2.1.3 Size Group

The general trend in the U.S. swine industry is toward a smaller number of large operations that have a larger number of animals on site. The number of smaller facilities, which tend to house the animals outdoors, has significantly decreased over the past 10 years (North Carolina State University, 1998). The trend in the larger operations is toward extended use of confinement operations.

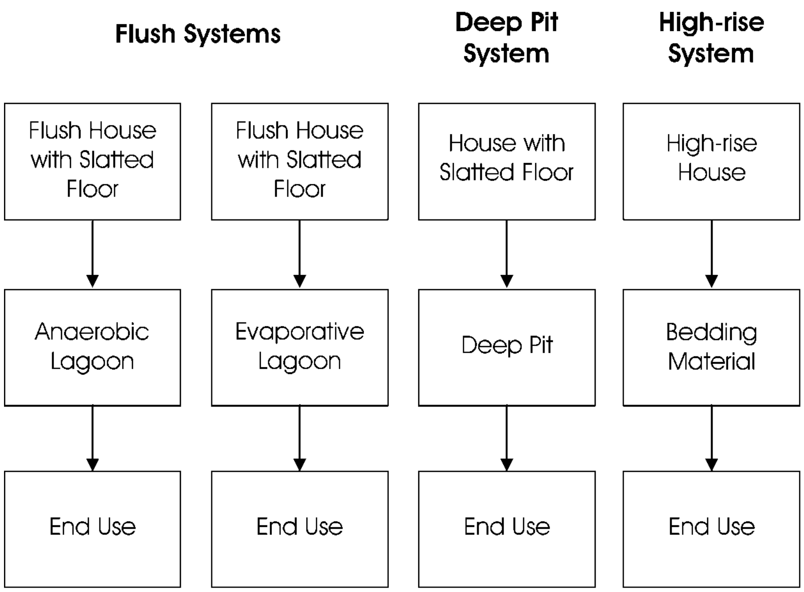


Figure 11-1. Swine Model Farm Waste Management System

For this regulation, five size groups were modeled for each type of model farm. The size groups are provided in Table 11-2.

Table 11-2. Number of Swine per Facility based on Modeled Region, Land Availability Category, Operation Size for Phosphorus-Based Application of Manure

Region	Land Availability Category	Medium 1	Medium 2	Medium 3	Large 1	Large 2
Central	No excess	NA	NA	NA	2,500	6,037
Central	Excess, with acres	NA	NA	NA	3,304	9,890
Central	Excess, no acres	NA	NA	NA	4,999	34,944
Mid-Atlantic	No excess	883	1,346	1,888	2,500	6,390
Mid-Atlantic	Excess, with acres	964	1,496	2,077	4,134	12,375
Mid-Atlantic	Excess, no acres	976	1,477	2,051	4,424	14,929
Midwest	No excess	863	1,311	1,885	2,500	5,094
Midwest	Excess, with acres	926	1,415	1,965	2,878	9,172
Midwest	Excess, no acres	976	1,522	2,114	4,463	16,636

NA - Not applicable.

11.2.1.4 Region

Data from site visits and North Carolina State University's draft *Swine and Poultry Industry Characterization* indicate that the predominant type of waste management system at swine operations varies from region to region (NCSU, 1998). EPA decided to develop model farms for the Mid-Atlantic and Midwest regions because over 93 percent of the facilities with more than750 head were located in these two regions in 1997 (USDA NASS, 1999). EPA added additional model farms in the Central region based on comments received on the proposed rule that many large facilities had recently located in states in the Central region.

As previously mentioned, flush-to-lagoon waste storage systems are more common in the Mid-Atlantic region while deep-pit storage systems are common in the Midwest. Given the regional variances in waste management systems, other variations in farming practices (e.g., crop rotations), and differences in climate, swine operations with both type of waste storage systems were modeled in both regions. Large swine operations that use evaporative lagoons for waste storage were modeled in the Central region. Operations located in other regions were split among the modeled regions to fully account for operations in a given size class. Allocating operations from one region to another was necessary since the census data could not be obtained for all desired regions and size groups (USDA NASS, 1999).

11.2.2 Poultry Operations

EPA developed four model farms to represent poultry operations in the United States. The model farms are broiler, turkey, dry layer, and wet layer operations. EPA developed the parameters describing the model poultry farms using information from NASS, site visits to poultry farms across the country, and the USDA NRCS. A description of the various components of each model farm is presented in the following discussion, and the sources of the information used to develop each piece of the model farm are noted.

11.2.2.1 Housing

Broilers and turkeys are typically housed in long barns (approximately 40 feet wide and 400 to 500 feet long; NCSU, 1998) and are grown on the floor of the house. The floor of the barn is covered with a layer of bedding, such as wood shavings, and the broilers or turkeys deposit manure directly onto the bedding. Approximately 4 inches of bedding are initially added to the houses and top dressed with about 1 inch of new bedding between flocks.

Layers are typically confined in cages in high-rise housing or shallow pit flush housing. In a high-rise house, the layer cages are suspended over a bottom story, where the manure is deposited and stored. EPA used this configuration to model housing for dry layer model farms. In shallow pit flush housing, a single layer of cages is suspended over a shallow pit. Manure drops directly into the pit, where it is flushed out periodically using recycled lagoon water. EPA used this configuration to model housing for wet layer model farms.

These poultry housing systems are considered typical systems in the poultry industry (NCSU, 1998). Therefore, the cost model uses these farm housing systems in the model farms.

11.2.2.2 Waste Management Systems

Manure from broiler and turkey operations accumulate on the floor where it is mixed with bedding, forming litter. Litter close to drinking water forms a cake that is removed between flocks. The rest of the litter in a house is removed periodically (6 months to 2 years) from the barns, and then transported off site or applied to land. Typically, broiler and turkey operations are completely dry waste management systems (NCSU, 1998). Therefore, EPA used this waste management configuration in modeling both broiler and turkey model farms.

Layer operations may operate as a wet or a dry system. Approximately 12 percent of layer houses use a liquid flush system, in which waste is removed from the house and stored in a lagoon (USDA APHIS, 2000). Operations that use this type of waste management system are referred to as wet layers. The remaining layer operations typically operate as dry systems, with manure stored in the house for up to a year. A scraper is used to remove waste from the collection pit or cage area (NCSU, 1998). Operations that use this type of waste management system are referred to as dry layers. The lagoon wastewater and dry manure are stored until they are applied to land or transported off site. Figure 11-2 presents the waste management systems for poultry.

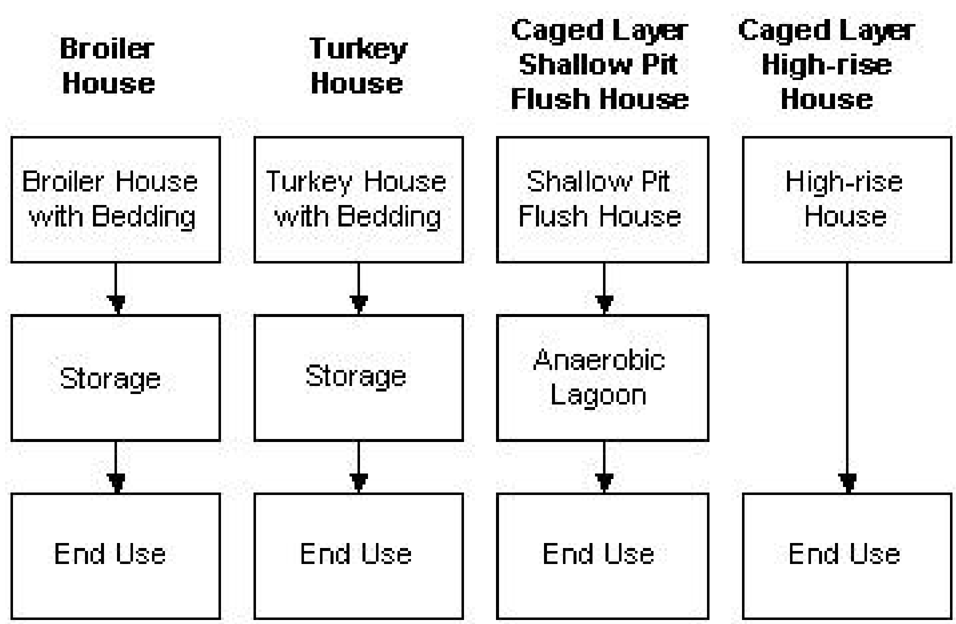


Figure 11-2. Poultry Model Farm Waste Management System

11.2.2.3 Size Group

For the final regulation, EPA modeled four size groups for broiler and dry layer operations, two size groups for wet layer operations, and four size groups for turkey operations. The size groups are presented in Tables 11-3, 11-4, and 11-5.

Table 11-3. Number of Broilers per Facility Based on Modeled Region, Land Availability Category, Operation Size for Phosphorus-Based Application of Manure.

Region	Land Availability Category	Medium 1	Medium 2	Medium 3	Large 1	Large 2
Mid-Atlantic	No excess	39,642	55,618	85,355	125,000	219,247
Mid-Atlantic	Excess, with acres	39,851	58,110	89,171	132,696	326,246
Mid-Atlantic	Excess, no acres	39,609	56,176	86,342	149,292	385,154
South	No excess	38,845	53,886	82,820	125,000	219,247
South	Excess, with acres	39,427	57,644	88,596	135,091	312,224
South	Excess, no acres	39,419	57,557	88,516	132,017	325,838

Table 11-4. Average Head Count for Layer Operations.

Size Class	Size Class Interval (Number of Head)		Average Head Count per Operation
	Lower	Upper	
Dry Layer Operations			
Medium 1	25,000	49,999	36,068
Medium 2	50,000	74,999	61,734
Medium 3	75,000	81,999	78,546
Large 1	82,000	599,999	291,153
Large 2	$\geq$600,000		856,368
Wet Layer Operations			
Medium 1	9,000	29,999	19,500
Large 1	$\geq$30,000		146,426

Table 11-5. Turkey Facility Demographics from the 1997 Census of Agriculture Database.

Size Class	Size Class Interval (Number of Head)		Average Head Count per Operation
	Lower	Upper	
Medium 1	16,500	27,499	22,246
Medium 2	27,500	41,249	34,640
Medium 3	41,250	54,999	47,534
Large 1	$\geq$55,000		127,396

Source: USDA NRCS, 2002.

11.2.2.4 Region

Data from site visits and North Carolina State University's draft *Swine and Poultry Industry Characterization* indicate that the predominant type of waste management system at poultry operations varies from region to region (NCSU, 1998). Most of the broiler operations in the United States are located in the South and Mid-Atlantic regions, while most of the egg-laying operations are located in the Midwest and South regions. Therefore, the model broiler farm reflects the South and Mid-Atlantic regions, and the model layer farm reflects the Midwest and South regions. State-level data from the 1997 Census of Agriculture indicate that states in the Midwest and Mid-Atlantic regions of the United States account for over 70 percent of all turkeys produced. For this reason, model turkey farms are located in the Mid-Atlantic and Midwest regions (USDA NASS, 1999).

11.2.4 Dairy Operations

EPA developed two model farms to represent medium- and large-sized dairies in the United States: a flush dairy and a hose/scrape dairy. EPA developed the parameters describing the dairy model farms from information from USDA, 1997 Agricultural Census data, data collected during site visits to dairy farms across the country, meetings with USDA extension agents, and meetings with the National Milk Producers Federation and Western United Dairymen. Description of the various components that make up the model farms are presented below, with the sources of the information used to develop each piece of the model farm.

11.2.4.1 Housing

To determine the type of housing used at the model farm, the type of animals on the farm were considered. In addition to the mature dairy herd (including lactating, dry, and close-up cows), there are often other animals on site at the dairy, including calves and heifers. The number of immature animals (i.e., calves and heifers) at the dairy is proportional to the number of mature cows in the herd, but further depends on the farm's management. For example, the dairy may house virtually no immature animals on site and obtain their replacement heifers from off-site operations, or the dairy could have close to a 1:1 ratio of immature animals to mature animals. Site visits suggest the trend that the largest dairy managers want to focus on milk production only, and prefer not to keep heifers on site.

Typically, according to Census of Agriculture data, for dairies greater than 200 milking cows, the number of calves and heifers on site equals approximately 60 percent of the mature dairy (milking) cows (USDA, 1997). EPA assumes that there are an equal number of calves and heifers on site (30 percent each) at the dairy model farms. Based on this information, the number of calves on site is estimated to be 30 percent of the number of mature cows on site, as are the number of heifers on site. The percentage of bulls is typically small (USDA, 1997), as most dairies do not keep them on site. For this reason, EPA assumed that their impact on the model farm waste management system is insignificant, and did not consider bulls in the dairy model farm.

The most common types of housing for mature cows include freestall barns, tie stalls/stanchions, pasture, drylots, and combinations of these (Stull, 1998). Based on site visits, most medium- to large-sized dairies (>200 mature dairy cattle) house their mature dairy cows in freestall barns; therefore, it is assumed that mature dairy cows are housed in freestall barns for the dairy model.

The most common types of calf and heifer housing are drylots, multiple animal pens, and pasture (USDA, 1996c). Based on site visits, most medium- to large-sized facilities use drylots to house their heifers and calves; therefore, it is assumed that calves are housed in hutches on drylots and heifers are housed in groups on drylots at dairies described in the model. EPA calculated the size of the drylot for the model farm using animal space requirements suggested by Midwest Plan Service (MWPS, 1995).

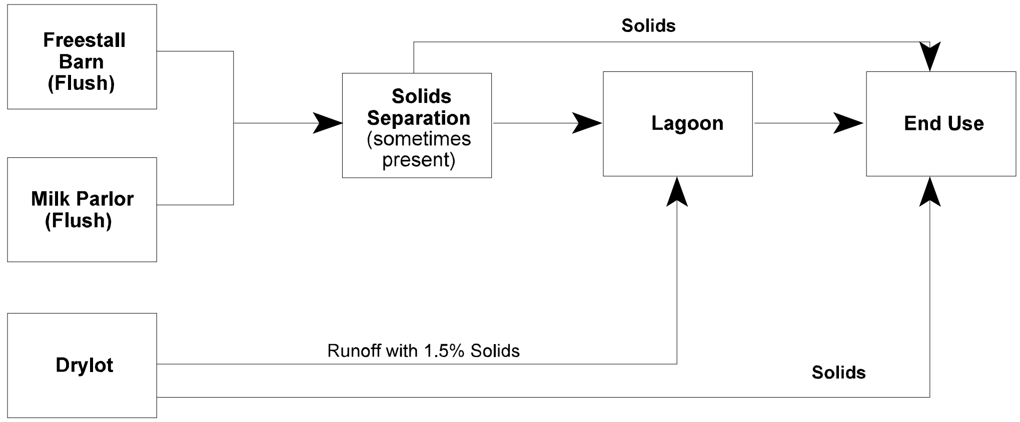
11.2.4.2 Waste Management Systems

Waste is generated in two main areas at dairies: the milking parlor and the housing areas. Waste from the milking parlor includes manure and wash water from cleaning the equipment and the parlor after each milking. Waste from the confinement barns includes bedding and manure for all barns, and wash water if the barns are flushed for cleaning. Waste generated from the drylots includes manure and runoff from any precipitation that falls on the drylot.

Based on site visits, most dairies transport their wastewater from the parlor and flush barns to a lagoon for storage and treatment. Some dairies use a solids separator (either gravity or mechanical) to remove larger solids prior to the wastewater entering the lagoon. Solids are removed from the separator frequently to prevent buildup in the separator, and they are stockpiled on site. Solid waste scraped from a barn is typically stacked on the feedlot for storage for later use or transport. Solid waste on the drylot is often mounded on the drylot for the cows and is later moved for transport or land application. Wastewater in the lagoon is held in storage for later use, typically as fertilizer on cropland either on or off site. Figure 11-4 presents the waste management systems used for model dairy farm.

The amount of waste generated at a dairy depends on how the operation cleans the barn and parlor on a daily basis. Some dairies clean the parlor and barns by flushing the waste (a flush dairy); others use less water, hosing down the parlor and scraping the manure from the barns (a hose/scrape dairy). EPA estimated the percentage of total dairies that operate as a flush dairy or a hose/scrape dairy using USDA data (USDA APHIS, 1996). Both flush and hose/scrape dairy systems are modeled separately as two model facilities.

Flush Dairy



Scrape/Hose Dairy

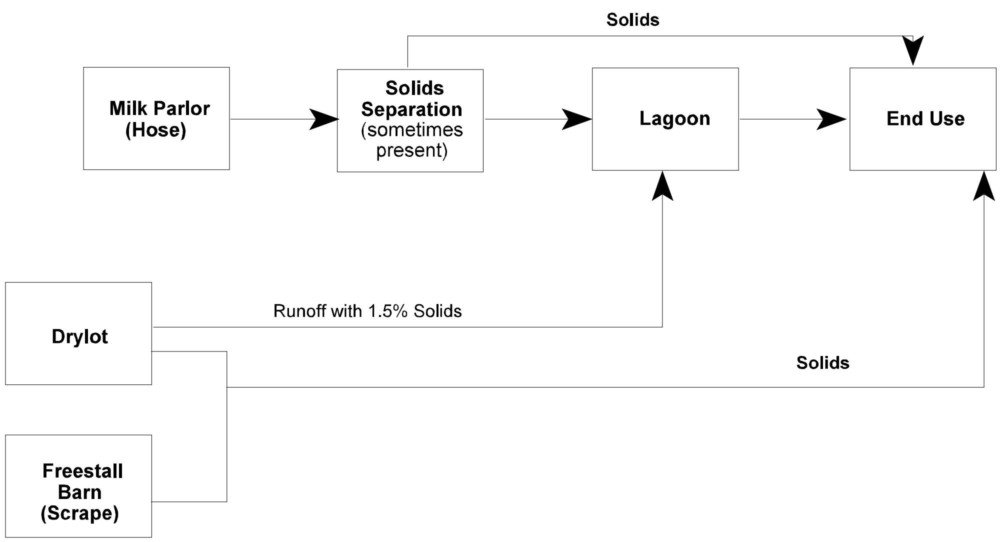


Figure 11-4 Dairy Model Farm Waste Management Systems

11.2.4.3 Size Group

Data collected during site visits indicate that dairies operate differently depending on their size. For example, larger dairies tend to already have lagoon storage, while moderate-sized dairies may have only a small amount of storage. Also, because feedlots with more than 700 animals are already regulated under the current rule, it was assumed for the cost model that these facilities are already in compliance with many of the components of the final rule. Therefore, four different size groups were used to model dairy operations with more than 200 animals. The size groups are presented in Table 11-6.

Table 11-6. Size Classes for Model Dairy Farms.

Size Class	Size Range	Average Head
Medium 1	200-349	250
Medium 2	350-524	425
Medium 3	525-699	600
Large 1	≥ 700	1,430

11.2.4.4 Region

Data from site visits indicate that dairies in varying regions of the country have different characteristics. These differences are primarily related to climate. For example, a dairy in the Pacific region receives a greater amount of rainfall annually than a dairy in the Central region; therefore, the Pacific dairy produces a higher amount of runoff to be contained and managed. Because operating characteristics may change between regions, dairies are modeled in five distinct regions of the United States: Central, Mid-Atlantic, Midwest, Pacific, and South.

11.2.5 Beef Feedlots and Heifer Operations

EPA developed one type of model farm to represent medium- and large-sized beef feedlots and heifer operations in the United States. The parameters describing the beef and heifer model farm were developed from information from USDA, data collected during site visits to beef feedlots across the country, meetings with USDA extension agents, the National Cattlemen’s Beef Association, and the National Milk Producers Federation, and discussions with the Professional Heifer Growers Association. Descriptions of the various components that make up the model farm are presented below, with the sources of the information used to develop that piece of the model farm referenced.

11.2.5.1 Housing

The vast majority of beef feedlots and heifer operations in the United States house their cattle on drylots (USDA, 1995a). Some smaller operations use confinement barns at beef feedlots. However, since the majority of operations, including most new ones, use open lots, EPA used drylots as the housing for the beef and heifer model farm. Some operations raise their heifers on pasture, but because this regulation addresses only confined operations, the heifer model farm accounts only for animals housed on drylots. The size of the drylot is calculated using animal space requirements suggested by Midwest Plan Service (MWPS, 1995).

11.2.5.2 Waste Management System

Based on site visits, the drylot is the main area where waste is produced at beef feedlots and heifer operations. Waste from the drylot includes solid manure, which has dried on the drylot, and runoff, which is produced from precipitation that falls on the drylot and open feed areas.

Most beef operations in the United States divert runoff from the drylot to a storage pond (USDA, 1995a). Heifer operations typically operate like beef feedlots (Cady, 2000). As such, EPA assumed that runoff from the drylot is channeled to a storage pond at both beef and heifer operations. Some operations use a solids separator (typically an earthen basin) to remove solids from the waste stream prior to the runoff entering the pond. Solid waste from the drylot is often mounded on the drylot to provide topography for the cattle and is later moved from the drylot for transportation off site or land application on site (USDA, 1995a).

The beef and heifer model farm was developed following these typical characteristics of beef feedlots and heifer operations. Figure 11-5 presents the waste management system used as part of the beef and heifer model farm.

11.2.5.3 Size Group

Data collected during site visits indicate that beef feedlots and heifer operations operate differently depending on their size. For example, larger feedlots frequently have solid separators prior to a holding pond, while moderate sized facilities are less frequently equipped with solids separators. Moreover, feedlots with more than 1,000 beef cattle are already regulated under the current rule. EPA, therefore, assumes that these facilities are already in compliance with many components of the final rule. To account for these differences, five different size groups were used to model beef feedlots with more than 300 animal units and four different size groups were used to model heifer operations with more than 300 animals. The size groups are presented in Tables 11-7 and 11-8.

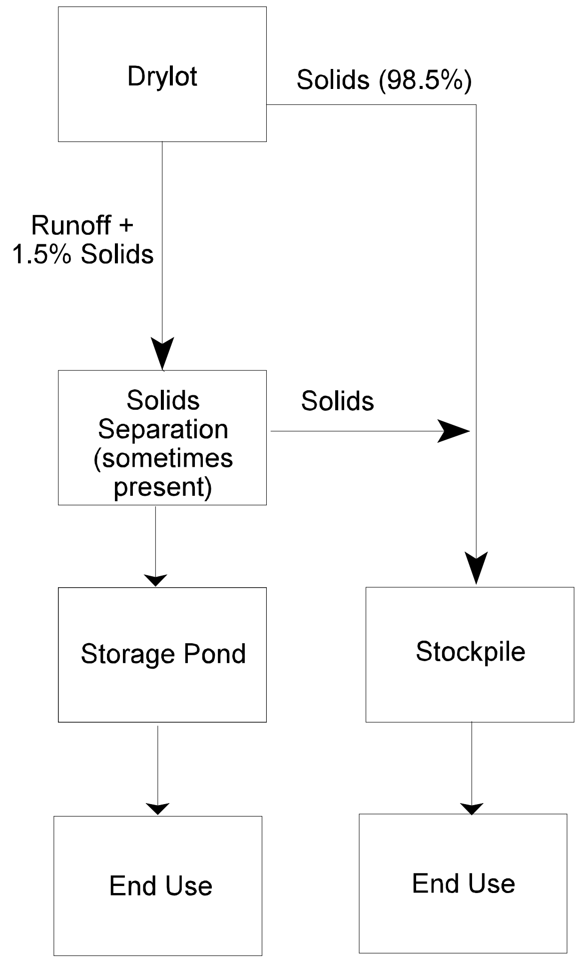


Figure 11-5. Beef and Heifer Model Farm Waste Management System

Table 11-7. Size Classes for Model Beef Farms

Size Class	Size Range	Average Head
Medium 1	300-499	370
Medium 2	500-749	552
Medium 3	750-999	766
Large 1	1,000-7,999	1,839
Large 2	≥ 8,000	25,897

Table 11-8. Size Classes for Model Heifer Farms

Size Class	Size Range	Average Head
Medium 1	300-499	400
Medium 2	500-749	625
Medium 3	750-999	875
Large 1	≥ 1,000	1,500

11.2.5.4 Region

Data from site visits indicate that beef feedlots in varying regions of the country have different characteristics. These differences are primarily related to climate. For example, a beef feedlot in the Midwest region receives a greater amount of rainfall annually than a beef feedlot in the Central region; therefore, the Midwest feedlot produces a greater volume of runoff to be contained and managed. Because operating characteristics may change between regions to accommodate these climatological differences, beef feedlots are modeled in five diverse regions of the United States: Central, Mid-Atlantic, Midwest, Pacific, and South, as described in Section 1.1. Data from USDA indicate that heifer operations are located in similar areas as beef feedlots and would have similar characteristics as the beef feedlots.

11.2.6 Veal Operations

EPA developed one model farm to represent medium- and large-sized veal operations in the United States. The parameters describing the veal model farm are developed from information collected during site visits to veal operations in Indiana and discussions with the American Veal Association. Descriptions of the various components that make up the model farm are presented below, with the sources of the information used to develop that piece of the model farm referenced.

11.2.6.1 Housing

Veal calves are generally grouped by age in environmentally controlled buildings. The majority of veal operations in the United States utilize individual stalls or pens with slotted floors, which allow for efficient removal of waste (Wilson, 1995). Because this type of housing is the predominant type of housing used in the veal-producing industry, individual stalls in an environmentally controlled building is designated as the housing for the veal model farm.

11.2.6.2 Waste Management Systems

Based on site visits, the only significant source of waste at veal operations is from the veal confinement areas. Veal feces are very fluid; therefore, manure is typically handled in a liquid waste management system. Manure and waste that fall through the slotted floor are flushed regularly out of the barn. Flushing typically occurs twice daily. Most veal operations have a lagoon to receive and treat their wastewater from flushing, although some operations have a holding pit system in which the manure drops directly into the pit. The pit provides storage until the material can be land applied or transported off site. Wastewater in the lagoon is held in storage for later use as fertilizer off site.

EPA developed the veal model farm used in the cost model from these general characteristics. The animals are totally confined; therefore, the only source of wastewater is from flushing the manure and waste from the barns. Direct precipitation is also collected on the lagoon surface, if the lagoon is uncovered. Figure 11-6 presents a diagram of the veal model farm waste management system.

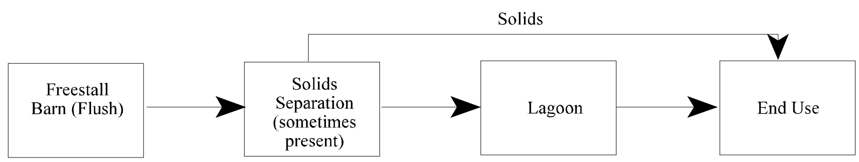


Figure 11-6. Veal Model Farm Waste Management System

11.2.6.3 Size Group

The veal industry standard operating procedures do not vary significantly based on the size of the operation, according to data collected during site visits and discussions with the American Veal Association (Crouch, 1999). The size groups are presented in Table 11-9.

Table 11-9. Size Classes for Model Veal Farm

Size Class	Size Range	Average Head
Medium 1	300-499	400
Medium 2	500-749	540
Medium 3	$\geq$750	1080

11.2.6.4 Region

The American Veal Association indicates that veal producers are located predominantly in the Midwest and Central regions (Crouch, 1999); therefore, only these two regions are modeled as part of the veal model farm.

11.3 Design and Cost of Waste and Nutrient Management Technologies

Two separate models were created to estimate compliance costs associated with regulatory options for CAFOs: one model to generate beef, dairy, heifer, and veal costs, and another model to generate swine, broiler, turkey, and layer costs. The cost models calculate model farm costs in three major steps:

1) Costs are calculated for each technology or practice that makes up each regulatory option for each model farm, based on model farm characteristics, including number of head, waste characteristics, and facility characteristics.

2) The costs for each technology or practice are then weighted for the entire model farm population, using frequency factors to indicate the portion of the model farm population that will incur that cost. These frequency factors define the performance of a model farm as having low, medium, or high requirements to comply with the regulatory option.

3) The weighted costs for each model farm population are summed, resulting in an average model farm cost for each model population in each performance category.

The resulting model farm cost represents the average cost that all of the operations within that model population are expected to incur within a performance category. The compliance costs that a single model farm incurs may be more or less than this average cost; however, the performance categories are expected to encompass the approximate range of compliance costs.

The cost estimates generated contain the following types of costs:

- **Capital costs** - Costs for facility upgrades (e.g., construction projects);

- **Fixed costs** - One-time costs for items that cannot be amortized (e.g., training);

- **Annual operating and maintenance (O&M) costs** - Annually recurring costs, which may be positive or negative. A positive O&M cost indicates an annual cost to operate, and a negative O&M cost indicates a benefit to operate, due to cost offsets;

- **Three-year recurring O&M costs** - O&M costs that occur only once every three years;

- **Five-year recurring O&M costs -** Application fees and reporting costs that occur only once every five years; and

- **Annual fertilizer costs -** Costs for additional commercial nitrogen fertilizer needed to supplement the nutrients available from manure application.

These costs provide the basis for evaluating the total annualized costs, cost effectiveness, and economic impact of each regulatory option.

The following sections discuss the six primary components of the costing methodology:

- Manure and nutrient production at each operation;
- Cropland acreage;
- Nutrient management planning;
- Facility upgrades;
- Land application; and
- Off-site transportation of manure.

Further detail on the cost methodology and data inputs to the cost model may be found in the *Cost Methodology for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations (2002).*

11.3.1 Manure and Nutrient Production

The manure produced at each model farm provides the basis for the design of the technology components and model farm parameters, including determining farm acreage, nutrient management practices, equipment sizes, and the agronomic rate of applying waste to land. The quantity and characteristics of the waste for each model farm are calculated from values provided in the *Agricultural Waste Management Field Handbook* and the *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States* (USDA NRCS, 1996; USDA NRCS, 2000).

The quantity of manure generated from a feedlot operation depends on the animal type and the number of mature and immature animals that are present. Nutrient production at each model farm is calculated using waste characteristics data for excreted manure for each animal type. The mass production of each of these nutrients is calculated using the average weight of the animal while housed at the model farm, the waste concentration data, and the number of animals on site.

11.3.2 Available Acreage

Data on the amount of cropland and pastureland available to facilities for land application of manure are limited. Therefore, EPA classified the model farms into three categories that define how much land they have available and how the operation ultimately manages its waste:

- **Category 1:** Facilities with sufficient land to apply all of their generated manure at appropriate agronomic rates. No manure is transported off site.
- **Category 2:** Facilities without sufficient land to apply all of their generated manure at appropriate agronomic rates. The excess manure after agronomic application is transported off site.
- **Category 3:** Facilities without any available land for manure application. All of the manure is transported off site regardless of the regulatory options considered by EPA.

EPA defines Category 1 operations as having a sufficient amount of land, and at a minimum, the available land equals the amount of land required to agronomically apply all of the manure generated at the operation. Category 2 acreages are based on a 2000 USDA analysis that calculated the amount of nutrients present in manure that exceeded the amount that could be applied agronomically (Kellogg, 2000). EPA assumes Category 3 operations have no available land.

11.3.2.1 Agronomic Application Rates

Under all regulatory options considered, all operations are required to implement nitrogen-based agronomic application rates when applying animal waste or wastewater. Under Options 2 through 7, however, operations that are located in areas with certain site conditions (e.g., phosphorus-saturated soils) are required to follow more stringent phosphorus-based agronomic application rates. Costs for nitrogen-based application are different than costs for phosphorus-based application. These costs are weighted for a model farm using a “nutrient-based application factor” to account for these different costs, based on the percent of facilities in that region that would apply on a phosphorus-basis verses a nitrogen-basis. The nutrient-based application factors vary according to the type of facility (beef, dairy, swine, or poultry).

Agronomic application rates are calculated using crop yields, crop uptakes, and crop utilization factors. These crops vary by region and animal type. EPA selected representative crops for each model farm by contacting USDA state and county cooperative extension services and incorporating data from USDA’s *Agricultural Waste Management Field Handbook* (USDA NRCS, 1996). EPA does not expect crops to vary significantly based on the size of the animal operation. Because veal operations are located predominantly in the Midwest, EPA developed only one set of crop assumptions for veal that reflect the Midwest region.

$$\text{Crop N Requirements (lb/acre)} = \text{Crop Yield (tons/acre)} \times \text{Crop Uptake (lb/ton)}_{\text{nitrogen}}$$

$$\text{Crop P Requirements (lb/acre)} = \text{Crop Yield (tons/acre)} \times \text{Crop Uptake (lb/ton)}_{\text{phosphorus}}$$

The average annual nitrogen and phosphorus crop removal and application rates were calculated by dividing the total crop requirements over the time to complete a full crop rotation. The cost model estimates that 70 percent of the nitrogen and 100 percent of the phosphorus in cattle manure that is applied to land is available for crop uptake and utilization over time (Lander, 1998); therefore, the agronomic application rate is calculated as the total crop nutrient requirements divided by the appropriate utilization factor.

$$\text{Manure Application Rate}_{\text{Nitrogen}}\text{ (lb/acre)} = \text{Total Crop Nitrogen Requirements (lb/acre)} \div 70\%$$

$$\text{Manure Application Rate}_{\text{Phosphorus}}\text{ (lb/acre)} = \text{Total Crop Phosphorus Requirements (lb/acre)} \div 100\%$$

When more than one crop is present, the agronomic rate is presented as the average of the individual agronomic rates for each crop. These agronomic rates for nitrogen- and phosphorus-based application scenarios are used as inputs to the cost model.

11.3.2.2 Category 1 Acreage

Category 1 acreages are calculated using the agronomic application rates, number of animals, manure generation estimates, nutrient content of the manure, and manure recoverability factors:

$$\text{Category 1 Acreage} = \frac{\text{\#Animals x Manure Generation (tons/head) x Nutrient Content (lbs/ton manure) x Recoverability Factor}}{\text{Agronomic application rate (lb/acre)}}$$

EPA defines recoverability factors as the percentage of manure, based on solids content, that it would be practical to recover. Recoverability factors are developed for each region, using USDA state-specific recoverability factors, and are based on the assumption that the decrease in nutrient value per ton of manure mirrors the reduction in solids content of the recoverable manure (Lander, 1998).

11.3.2.3 Category 2 Acreage

Category 2 acreages are calculated using Category 1 acreages, the estimate of excess manure from USDA's analysis, and acres required to apply excess manure to land (Kellogg, 2000):

Average Excess Nutrients (lbs/yr)	=	Excess Nutrients (lbs/yr)÷Number of Category 2 Facilities
Excess Acreage (acres)	=	Average Excess Nutrients (lbs/yr)÷Agronomic Application Rate (lb/acre)
Category 2 Acreage (acres)	=	Category 1 Acreage - Excess Acreage

11.3.3 Nutrient Management Planning

To minimize the release of nutrients to surface and ground waters, confined animal feeding operations must prevent excess application of manure nutrients on cropland through the process of nutrient management planning. Confined animal feeding operations apply manure nutrients to the land in the form of solid, liquid, or slurry. Manure is also stored prior to application in stockpiles, tanks, pits, storage ponds, or lagoons. Confined animal feeding operations prevent excess application by developing and abiding by appropriate manure application rates that are designed to add only the nutrients required by the planned crops at the expected yields. Nutrient management planning may also minimize releases of nutrients by specifying the timing andlocation of manure application.

Six nutrient management practices are evaluated as part of the costing methodology:

1. **Nutrient management plan -** a practice in which a documented plan is developed for each facility to ensure agronomic application of nutrients on cropland and management of waste on site. The plan includes costs for development of the plan, manure sampling and analysis (collecting samples from solid and liquid waste before each land application period), soil sampling and analysis (once every 3 years), hydrogeologic assessment for facilities located in ground water protection areas, periodic inspections of on-site facility upgrades, identification and protection of crop setback areas to protect waterfront areas, calibration of the manure spreader before each application period, and ongoing recordkeeping and recording. The plan is updated at least once every 5 years.

2. **Surface water monitoring** - a practice in which surface water samples are periodically collected and analyzed for indications of contaminated runoff into adjacent waters. Costs account for twelve sampling events per year, including four grab samples and one quality assurance sample per event, measuring for nitrate-nitrite, total Kjeldahl nitrogen, total phosphorus, and total suspended solids.

3. **Ground water assessment** - a practice for facilities to conduct a hydrogeologic assessment to determine if a direct hydrogeologic link exists between ground water and surface water.

4. **Ground water monitoring** - a practice for operations where ground water has a direct hydrogeologic link to surface water. Costs include installation of four 50-foot ground water wells and the collection of a sample from each well twice annually for indications of ground water contamination from the feedlot operation.

5. **Feeding strategies -** a practice in which the animal feed is monitored and adjusted to reduce the quantity of nutrients that are excreted from the animal. Costs include feeding strategies to reduce nitrogen and phosphorus in excrement from poultry and swine.

6. **Timing restrictions -** a practice in which manure is only land applied during times that the land and crops are most amenable to nutrient utilization. Costs for this practice are calculated for all animal sectors.

Further detail on the design of each practice may be found in the *Cost Methodology for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations (2002).*

11.3.4 Facility Upgrades

Section 8.0 of this report describes treatment technologies and facility upgrades that are presented as part of this cost methodology. These facility upgrades include:

- Anaerobic digestion with energy recovery;
- Anaerobic lagoons;
- Field runoff controls;
- Lagoon covers;
- Lined manure storage;
- Liners for lagoons and ponds;
- Litter storage sheds;
- Manure composting equipment;
- Recycle flush water;
- Retrofit options;
- Screen solid-liquid separation;
- Sludge removal;
- Solids separation (settling basin);
- Storage ponds; and
- Storm water diversions (berms).

An overview of the costs and applicability of each of these upgrades to each of the animal sectors is presented below:

- **Anaerobic digestion with energy recovery**: Option 6 requires the use of anaerobic digestion for Large dairy and swine CAFOs, prior to discharge to a storage lagoon. The digester is designed to receive waste from all flushing, hose, and scrape operations, and combines this waste into a reactor to produce methane for energy use at the operation. Covered lagoon digesters are costed for large flush dairies and swine operations, and complete mix digesters are costed for large hose dairies. Runoff from the dairy feedlot is collected separately into a storage pond or lagoon.

- **Anaerobic lagoons:** Costs for anaerobic lagoons are included for facilities that collect mixtures of water and manure, such as dairies, veal operations, swine, and wet layer operations. Lagoons receive wastewater from flush barns, flush and hose milking parlors (for dairies), and runoff from drylots. They are designed to include process wastewater, plus the capacity for the 25-year, 24-hour storm event and average rainfall for the storage period.

- **Field runoff controls:** Under all options, costs are included to implement and maintain setbacks along waterbodies contained within land-applied cropland for all animal operations. The size and therefore the cost of the setback were calculated based on national estimates of land area and stream miles and the average size and cost of filter strips (USEPA, 2000; USEPA, 1993).

- **Lagoon covers:** Under Option 5, the regulation requires that facilities have zero potential for discharge from the feedlot. This requirement may be met by covering liquid storage basins and preventing direct precipitation from entering and adding to the storage volume. Swine, wet layers, and veal operations under Option 5 have costs for lagoon covers.

- **Lined manure storage:** The cost model includes costs for the installation and maintenance of concrete pads as part of the waste management system for beef, heifer, and dairy operations under Option 3. The pads are designed to store waste from drylots, separated solids, and scraped manure.

- **Liners for lagoons and ponds:** Under the ground water options, operations that store animal waste (e.g., runoff and/or process water) in a lagoon or pond are required to have a liner in place if they are located in an area where ground water has a hydrogeologic connection to surface water. The liner is composed of two parts: a synthetic portion and a clay portion. The liner is designed to cover the floor of the pond or lagoon, including sloped sidewalls. Costs are calculated for all animal sectors to install liners in their lagoons and ponds.

- **Litter storage sheds:** Litter storage is included in the costing for all dry poultry operations. Requirements for poultry litter storage structures are similar to those for mortality composting facilities in that they require a roof, foundation, and floor, and suitable building materials for side walls.

- **Manure composting equipment:** EPA designed windrow composting systems to treat and manage manure waste from drylots, separated solids, and scraped manure under Option 5A for beef, dairy, and heifer operations. Mortality composting systems are designed for swine and poultry operations to manage mortality waste under all options.

- **Recycle flush water:** In liquid-based systems, fresh water can be used for flushing or water from a secondary lagoon can be recycled as flush water. This technology is applied to Category 2, lagoon-based swine operations for all Options except Option 5.

- **Retrofit options:** In addition to the use of lagoon covers to comply with the requirements of Option 5, EPA investigated retrofitting swine and wet layer systems to replace lagoons as the waste management practice. Retrofitting to a "scraper system" was assessed for swine and wet layers facilities. In addition, retrofitting to a high-rise and hoop house for swine operations was assessed.
- **Screen solid-liquid separation:** The cost model includes costs for swine operations to install and operate screen separation. Screens are used to separate the solids from the liquids, allowing the solids to be handled more economically.
- **Sludge removal:** Sludge must be removed from lagoons periodically to keep storage capacity available. The cost model accounts for sludge cleanout annually for beef feedlots, dairies, and heifer operations and once every five years for liquid-based swine operations for all considered options.
- **Solids separation (settling basin):** The cost model includes solids separation as part of facility upgrades for beef and dairy operations, to facilitate the management of manure waste by separating the solid portion from the liquid portion. EPA costed earthen separators for beef feedlots, where runoff is the largest expected flow through the separator, and concrete-lined separators for dairy operations, where large amounts of flush water are expected through the separator. Concrete is used to prevent erosion of the side slopes of the separator.
- **Storage ponds:** The cost model includes costs for storage ponds for facilities that collect runoff from the feedlot, such as beef facilities in which the cattle are confined on dry lots, and as a holding pond for effluent from an anaerobic digester in Option 6. The storage pond receives waste from drylot runoff only and is designed to include capacity for the 25-year, 24-hour storm event and average rainfall for the storage period. Under Option 1A, the cost model also includes capacity for the 10-year, 10-day storm event.
- **Storm water diversions (berms):** Under all regulatory options, EPA requires that all animal operations contain any runoff collecting in potentially contaminated areas. EPA assumes that Large CAFOs already have stormwater diversions in place, because it is required by the current regulation.

EPA calculated costs for facility upgrades using design specifications in combination with cost estimates for each portion of the upgrade (e.g., excavation, compaction, gravel fill, etc.). Design specifications were obtained from various sources, including the Natural Resources Conservation Service (Conservation Practice Standards), the Midwest Plan Service, the *Agricultural Waste Management Field Handbook*, and other engineering design sources. EPA combined these design specifications with model-farm information, such as the animal type, manure generation, housing methods, and the type of farm, to calculate the required size of the component as well as the materials and labor required to construct and operate the upgrade. Then, cost-estimation guides, including *Means Building Construction Cost Data*, *Means Heavy Construction Cost Data*, *Richardson's*, EPA's *FarmWare* Model, and vendor-supplied cost data, were used to determine the costs for each of these items that comprise the upgrade.

11.3.5 Land Application

The cost model calculates costs for land application of manure and other waste for those operations that have land, but are not currently applying their waste. Based on site visits, EPA estimates that all beef, dairy, veal, and heifer operations that have land already have equipment to apply dry waste. However, some facilities are assumed to need liquid land application equipment as well. Land application costs are based on installation and operation of a center pivot irrigation system, or a traveling gun system, based on vendor supplied cost data (Zimmatic, Inc., 1999, Rifco, Inc., 2001). For swine and poultry operations, EPA estimated (based on site visits) that all facilities already land apply their waste, and no additional costs would be incurred under the regulatory options.

11.3.6 Off-Site Transport of Manure

Animal feeding operations use different methods of transportation to remove excess manure waste and wastewater from the feedlot operation. The costs associated with transporting excess waste off site were calculated using two methods: contract hauling waste or purchasing transportation equipment. For poultry and swine operations, EPA based transportation costs on operations contract hauling their waste. For beef and dairy operations, EPA based transportation costs on either contract hauling or purchasing equipment to self-haul waste (whichever was least expensive).

Contract Hauling

EPA evaluated contract hauling as a method for the transport of manure waste off site. In this method, the animal feeding operation hires an outside company to transport the excess waste. This method is advantageous to facilities that do not have the capacity to store excess waste on site, or the cropland acreage to agronomically apply the material. In addition, this method is useful for facilities that do not generate enough excess waste to warrant purchasing their own waste transportation trucks.

No capital costs are associated with contract hauling; only the operating cost to haul the waste. For beef and dairy operations, EPA calculated a set rate per mile for solid waste and for liquid waste, using vendor-supplied quotations and the average hauling distance for each region (ERG, 2000b; Tetra Tech, Inc., 2000b). For swine and poultry operations, EPA extracted costs for contract hauling solid waste and liquid waste from multiple published articles (Tetra Tech, Inc., 1999).

Purchase Equipment

Another method evaluated for the transport of manure waste off site was purchasing transportation equipment. In this method, the feedlot owner is responsible for purchasing the necessary trucks and hauling the waste to an off-site location. Depending on the type of waste to be transported, a solid waste truck, a liquid tanker truck, or both types of trucks would be required. In addition, the feedlot owner is responsible for determining a suitable location to transport the waste, as well as all costs associated with loading and unloading the trucks, driving the trucks to the off-site location, and maintaining the trucks. EPA did not base compliance costs for swine and poultry operations on purchasing transportation equipment, and therefore no costs are calculated for these facilities under this transportation option.

The capital and annual costs associated with the purchase and operation of a truck for waste transport depend on the type of waste (solid or liquid) and quantity of waste to be transported. The cost model includes an evaluation on the amount of solid and/or liquid waste the operation will ship off site, and a determination of the capital costs based on that information. Annual costs are also calculated using the quantity of liquid or solid waste, as well as the hauling distance, maintenance costs, labor, fuel rates, and other parameters (ERG, 2000b).

11.4 Development of Frequency Factors

EPA recognizes that most individual farms are currently implementing certain waste management techniques or practices that are called for in the regulatory options considered. Only costs that are the direct result of the regulation are included in the cost model. Therefore, costs already incurred by operations are not attributed to the regulation.

To reflect baseline industry conditions, EPA developed technology frequency factors to describe the percentage of the industry that already implements particular operations, techniques, or practices required by the final rule. In some cases, these frequency factors are based on an assumed performance category (i.e., high, medium, and low performance) as estimated by USDA. EPA also developed ground water control frequency factors based on the location of the facility and current state requirements for permeabilities of waste management storage units. In addition, EPA developed nutrient basis frequency factors describing the distribution of farms that would apply manure to soils on a nitrogen or phosphorus basis, land availability frequency factors describing the distribution of farms with and without sufficient cropland to land apply the manure and wastewater generated at the farm, and transportation frequency factors describing the distribution of farms transporting excess manure and wastewater off site.

Some technologies included in the cost model, including composting and anaerobic digestion, were assumed not to be present under baseline industry conditions. Therefore, EPA assumed all of the facilities incur the cost of implementing the technologies and did not develop frequency factors for these technologies.

EPA estimated frequency factors based on the sources below (each source was considered along with its limitations):

- **EPA site visit information -** This information was used to assess general practices of animal feeding operations and how they vary between regions and size classes.

- **Observations from industry experts** - Experts on animal feeding operations were contacted to provide insight into operations and practices, especially where data were limited or not publicly available.
- **USDA Agricultural Phosphorus and Eutrophication document (USDA, 1999)** - This source provides information on the phosphorus content in state soils using the soil test P. EPA used this information to determine the percentage of facilities in each state that would require nitrogen-based versus phosphorus-based application rates.
- **USDA, Animal Plant and Health Inspection Service (APHIS)/National Animal Health Monitoring System (NAHMS)** - This source provides information on animal housing practices, facility size, and waste system components sorted by size class and region. These data have limited use because of the small number of respondents in the size classes of interest.
- **State Compendium: Programs and Regulatory Activities Related to AFOs** - This summary of state regulatory programs was used to estimate frequency factors based on current waste-handling requirements that already apply to animal operations in various states and in specific size classes. Operations located in states whose requirements meet or exceed the option requirements would already be in compliance and would not incur any additional cost.
- **USDA, Estimation of Private and Public Costs Associated with Comprehensive Nutrient Management Plan Implementation: A Documentation** - This source provides frequency factors for three performance-based categories of facilities (low-performing; medium-performing, and high-performing) for a series of "representative" farms defined by USDA in eight USDA defined regions. USDA defined high performers to be 25 percent of the facilities, medium performers to be 50 percent of the facilities, and low performers to be 25 percent of the facilities.

11.5 Summary of Estimated Model Farm Costs by Regulatory Option

A summary of the estimated regulatory compliance costs is provided in the following tables. Capital, fixed, annual, three-year recurring costs, and five-year recurring costs are included for each animal sector for Options 1, 2, and 5. Costs are presented in 1997 dollars.

- Table 11-10: Summary of Industry Costs for Option 1
- Table 11-11: Summary of Industry Costs for Option 2
- Table 11-12: Summary of Industry Costs for Option 5

Table 11-10. Summary of Industry Costs for Option 1

Animal Type	Manure Type	Operation Type	Capital	Annual	Fixed	3-YearRecurring	5-YearRecurring
Beef	Solid/Liquid	Beef	$66,271,376	$8,689,062	$4,305,153	$592,050	$2,530,516
Dairy	Solid/Liquid	Flush	$262,639,714	$45,358,315	$2,626,098	$183,113	$894,258
Dairy	Solid/Liquid	Hose	$33,153,994	$4,072,126	$2,461,447	$2,798,726	$739,387
Heifers	Solid/Liquid	Heifers	$13,452,388	$1,319,976	$694,719	$204,401	$82,858
Veal	Liquid	Flush	$0	$30,553	$38,948	$2,422	$10,090
Chicken	Liquid	LW	$9,118,438	$1,296,980	$132,432	$19,525	$81,264
Chicken	Solid	BR	$93,407,347	$4,060,985	$2,184,684	$74,888	$1,009,264
Chicken	Solid	LA	$32,664,307	$1,746,196	$356,844	$51,695	$247,758
Swine	Evapor	FF	$108,469	$150,883	$84,495	$3,970	$35,289
Swine	Evapor	GF	$111,079	$154,573	$86,411	$4,054	$36,036
Swine	Liquid	FF	$5,308,843	$1,686,581	$844,688	$30,149	$241,083
Swine	Liquid	GF	$4,017,456	$1,135,603	$527,369	$22,505	$171,891
Swine	Pit	FF	$360,663	$1,497,912	$889,058	$30,374	$272,588
Swine	Pit	GF	$334,852	$1,720,540	$957,771	$38,814	$329,614
Turkey	Solid	SL	$31,170,087	$1,668,463	$701,880	$27,143	$450,698

Table 11-11. Summary of Industry Costs for Option 2.

Animal Type	Manure Type	Operation Type	Capital	Annual	Fixed	3-YearRecurring	5-Year Recurring
Beef	Solid/Liquid	Beef	$96,942,128	$38,651,376	$7,672,585	$1,496,851	$9,179,452
Dairy	Solid/Liquid	Flush	$147,690,591	$115,353,998	$3,188,393	$334,556	$2,017,898
Dairy	Solid/Liquid	Hose	$35,758,320	$8,280,186	$3,066,584	$2,961,250	$1,916,937
Heifers	Solid/Liquid	Heifers	$16,559,995	$2,305,508	$842,928	$243,437	$312,186
Veal	Liquid	Flush	$0	$30,553	$38,948	$2,422	$10,090
Chicken	Liquid	LW	$14,047,475	$1,491,472	$144,601	$22,435	$93,337
Chicken	Solid	BR	$93,515,959	$4,120,237	$2,303,023	$83,562	$1,127,487
Chicken	Solid	LA	$32,642,246	$1,929,765	$333,911	$47,230	$224,575
Swine	Evapor	FF	$109,151	$151,249	$128,484	$8,945	$79,289
Swine	Evapor	GF	$112,054	$155,285	$131,852	$9,178	$81,337
Swine	Liquid	FF	$6,645,012	$1,803,879	$1,358,438	$86,947	$6,894,239
Swine	Liquid	GF	$4,934,234	$1,196,853	$855,210	$61,344	$5,231,336
Swine	Pit	FF	$505,620	$13,907,671	$1,398,631	$82,198	$781,926
Swine	Pit	GF	$454,228	$19,817,425	$1,538,482	$101,262	$910,429
Turkey	Solid	SL	$31,276,907	$2,864,728	$835,304	$35,254	$584,319

Table 11-12. Summary of Industry Costs for Option 5.

Animal Type	Manure Type	Operation Type	Capital	Annual	Fixed	3-Year Recurring	5-Year Recurring
Chicken	Liquid	LW	$22,224,957	$1,711,084	$200,193	$35,781	$148,929
Chicken	Solid	BR	$184,992,580	$4,120,237	$2,303,023	$83,562	$1,127,487
Chicken	Solid	LA	$32,642,246	$1,929,765	$333,911	$47,230	$224,575
Swine	Evapor	FF	$43,483,000	$1,830,320	$138,485	$10,060	$89,300
Swine	Evapor	GF	$44,603,942	$1,877,631	$142,109	$10,321	$91,605
Swine	Liquid	FF	$341,161,677	$10,805,902	$1,458,059	$98,623	$838,708
Swine	Liquid	GF	$250,152,138	$7,850,690	$920,791	$69,564	$552,835
Swine	Pit	FF	$37,452,731	$12,278,113	$1,398,631	$82,198	$781,926
Swine	Pit	GF	$46,434,556	$18,034,408	$1,538,482	$101,262	$910,429
Turkey	Solid	SL	$31,276,907	$2,864,728	$835,304	$35,254	$584,319
Veal	Liquid	Flush	$1,036,004	$82,351	$38,948	$2,422	$10,090

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CHAPTER 12

POLLUTANT LOADING REDUCTIONS FOR THE REVISED EFFLUENT LIMITATIONS GUIDELINES FOR CONCENTRATED ANIMAL FEEDING OPERATIONS

12.0 INTRODUCTION

Section 301(d) of the Clean Water Act (CWA) directs Environmental Protection Agency (EPA) to periodically review and revise, if necessary, Effluent Limitations Guidelines and Standards (ELGs) promulgated under CWA Sections 301, 304, and 306. Animal feeding operations (AFOs) have been identified as a major source of pollutants impairing surface water and ground water in the United States; therefore, EPA is revising the existing effluent guidelines for AFOs. The final regulation requires beef, dairy, veal, heifer, poultry, and swine AFOs to handle their manure in a more environmentally sound manner including upgrading facilities to reduce the runoff potential from feedlots, limiting land application of manure based on nitrogen (N) and phosphorus (P) agronomic rates, and encouraging other technologies (e.g., treatments that lower environmental impact or reduce the manure water content).

12.1 Computer Model Simulations

To support its rule revision, EPA performed computer model simulations of 13,500 different Sample Farms representing land application of manure by AFOs. Each Sample Farm represents various combinations of animal type, farm size, location, soil type, waste management and storage, incorporation technique, etc. For each Sample Farm, EPA estimated edge-of-field pollutant loadings (in pounds per year per acre of cropland) to serve as a basis for summing the national average annual pollutant reductions over a 25-year period of analysis. In sum, the interaction of these AFO facilities with the environment is based on approximately 228 million simulated days of Sample Farm performance. In addition to edge-of-field load reductions, EPA's assessment incorporated pollutant loadings from feedlots and manure storage structures, representing discharges from AFO production areas. These discharges generally include runoff from the feedlot or manure storage areas due to precipitation events, but also include, where actual discharge data was available, a limited number of discharges attributed to storage system failures and improper management.

The *Pollutant Loading Reductions for the Revised Effluent Limitations Guidelines for Concentrated Animal Feeding Operations*, or "Loads Report", describes the methods used by EPA to analyze these AFO and environment interactions, generate total pollutant loads, and then calculate potential pollutant load reductions associated with revisions to the existing CAFO

ELGs. These load reductions form the basis of potential benefits attributed to each technology option. Note, potential benefits associated with estimated national pollutant loads reductions are detailed in *Environmental and Economic Benefit Analysis of Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations* (or "Benefits Document"), and the economic impacts of rule revisions for each option is documented in *Economic Analysis of the Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations* ("Economic Analysis").

Finally, since this loads analysis reflects load reductions over a range of NPDES-permitting scenarios that could define CAFOs at different thresholds, all AFOs with more than 300 AUs were evaluated. Variations in farm size were also selected to correspond to different potential applicability thresholds for the revised ELG. These farm size variations allow load reductions to be calculated for the subset of AFOs defined as CAFOs, as well as the subset of CAFOs for which the ELG would apply. See the *Cost Report* for more information on the size thresholds evaluated.

12.2 Delineation of Potentially Affected Farm Cropland

EPA's loads assessment estimates the national sediment, nutrient, pathogen, and metals loadings to surface waters and ground water under the current effluent limitations guidelines (also called "pre-revised regulation" or "baseline") and after the implementation of various effluent limitations guidelines technology options (also referred to as "post-regulation" scenarios). EPA's national assessment starts with estimates of manure generation consistent with the methodology published by USDA in the 2002 "*Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients*." The next step estimates of fertilizer-based (both manure and synthetic) edge-of-field loads. See Section III.H of the Loads Report for more information.

Key to assessing the edge-of-field pollutant loads is a reasonable representation of land application of manure to croplands. Croplands are the primary destination for AFO generated manure (including treated or processed manure such as compost or pelletized litter). Analytical and mathematical models can be used to estimate pollutant loading from agricultural areas by simulating the physical, chemical, and biochemical processes that govern the transport of water and sediment. For example, field-scale models such as Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) (Knisel et al., 1993) and Erosion-Productivity Impact Calculator (EPIC) (Sharpley and Williams, 1990) provide estimates of pollutants in runoff and sediments that are leaving the field boundaries. Field-scale models permit a detailed assessment of pollutant load generation and the influence of various management technologies, but generally require detailing of variation in soil and crop type. In total, EPA used 13,500 different Sample Farms as inputs to GLEAMS to calculate the edge-of-field loads.

To provide a consistent basis for comparison, EPA evaluated pollutant loads at both AFO and non-AFO facilities for a cropland area totaling 21 million acres nationally. EPA used P-based fertilization, i.e., fertilization of cropland by applying manure at a P-based rate to calculate 21 million total acres for this analysis. In general, P-based fertilization at agronomic levels using manure requires about seven times the acreage needed than when applying manure N-based. Within the 21 million acres are multiple categories of AFO and non-AFO farms that reflect differences in fertilizer requirements and, therefore, application rates. Note, EPA's postrevision options do not affect the total generation of manure (i.e., production rates are constant), but rather the management of the AFO manure nutrients generated. Figure 12-1 indicates how, for baseline and three technology options (potential revised effluent guidelines technology options are described below), EPA maintained a constant total of 21 million acres in its assessment, to enable evaluation of AFO and non-AFO acres.

Additional information on the characterization of cropland acres potentially affected by EPA's rule revision is provided in Table 12-1. Category I AFO manure generation does not exceed the agronomic fertilizer requirements of their cropland acreage. Therefore, Category I farms are generally less affected by the various regulatory scenarios for land application. Category II AFOs have insufficent cropland to make full use of the manure they generate, so under baseline they either overapply manure to their croplands (a common occurrence according to site visits, compliance reports, literature, and state inspection reports in EPA's record). In most cases, this results in application rates 2 or 3 times the N application rate. For a limited number of sample

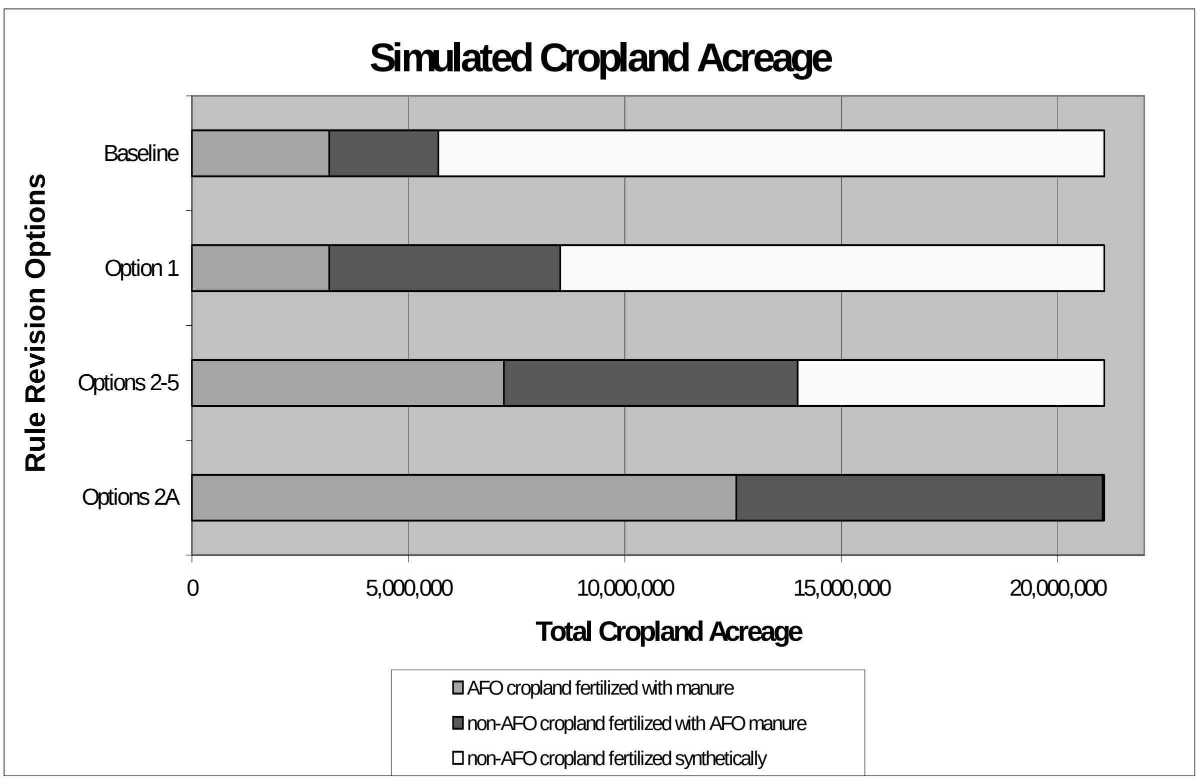

Figure 12-1. Delineation of cropland potentially affected by rule revisions

Table 12-1. Characterization of Farm Cropland Potentially Affected by Rule Revision, Based on Farm Conditions.

Farm Condition	Agronomic Limit based on Crop Selection	Baseline Acres (Prerevision)	Option 1 Acres	Option 2–5 Acres	Option 2A Acres
Category I - AFO cropland where manure is applied at agronomic rates.					
	N-based	1,415,812	1,415,812	784,137	0
	P-based	0	0	1,976,708	4,893,744
Category II - AFO cropland for facilities where manure application exceeds agronomic rates.					
	N-based within AFO facilities	1,755,734	1,755,734	910,503	0
	P-based within AFO facilities	0	0	3,571,789	7,840,241
	N-based for off-site non-AFO facilities	350,284	3,171,869	4,543,510	6,137,784
Category III - AFO farms with no land for manure application (Values are for non-AFO acreage receiving manure from AFOs).*					
	N-based	2,165,781	2,165,781	2,165,781	2,165,781
Total national acres in N-based condition (AFO manure fertilized)		5,687,611	8,509,196	8,403,931	8,303,565
Total national acres in P-based condition (AFO manure fertilized)		0	0	5,548,497	12,733,985
Non-AFO farms using commercial fertilizer (Used to ensure an consistent total acreage for cropland when comparing rule-revision options).					
	N-based and P-based	15,387,767	12,566,182	7,122,950	37,837
Total National Acreage Simulated		21,075,378	21,075,378	21,075,378	21,075,387

* Farms without available acreage to dispose of manure are assumed to disperse their manure to croplands of non-AFO farms at a rate less than five times N-based agronomic levels.

farms (34 out of 435 models), this would result in manure application at rates several times higher than the N rate. These higher manure application rates are likely to negatively affect crop responses. Based on land grant university application rates and the lower limit application attainable by certain land application designed for more concentrated animal manure (such as the limitations of poultry litter with broadcast spreaders), EPA set a limit of five (5) times the N rate for manure application rates at Category II operations. In the small number of cases where the Category II operations still had excess manure, the excess manure was transferred offsite to non-AFO cropland. Note that although 8 percent of the Sample Farms fall under this description, the number of CAFOs represented by these Sample Farms is small, such that these farms account for less than 4 percent of the total national loads. Finally, Category III AFO facilities have 10 or fewer acres of cropland, and all of the manure is transferred offsite to non-AFO croplands. The above described conditions for the three Categories of land availability comprise “baseline” conditions.

All manure transferred offsite is always assumed to be land-applied at an N-based rate. This assumption results in conservative (i.e. lower bound) estimates of load reductions, because load reductions are higher under P-based application rates, and some non-AFOs may be willing to accept manure and land apply manure at less than N-based rates. However, this assumption is deemed appropriate for this analysis as EPA expects very few non-AFO farms (such as row crop farmers) would accept manure as a fertilizer substitute if that farmer had to travel the same croplands more than once for fertilizer applications (i.e., once for manure applied at a P rate and once for supplemental N fertilizer to meet total crop requirements for N) . This analysis does not reflect alternative uses of manure because the processed, treated, or value-added manure is still ultimately land-applied (examples include compost, pelletized litter, digested manure, residual ash after incineration, etc.).

12.3 Modeled Changes from Baseline

For the post-regulation scenarios described below, departure from baseline conditions entails decreasing the over application of manure by linking application rates to crop requirements. As shown in Table 12-1, EPA's assessment differentiates between N-based and P-based fertilized cropland. Under the options considered, use of AFO manure at agronomic rates results in a decrease in synthetic (commercial) fertilizer needed to sustain crop yields on non-AFO cropland acres. This reduction in synthetic fertilizer affects the total estimated national pollutant loads, as detailed below. Note that application of manure on an agronomic N basis generally results in an overapplication of P, which over time can result in the buildup of soil P levels and increase P in the runoff. High levels of P in runoff is known to cause deleterious effects in surface waters. Additionally, application of manure at agronomic P rates results in a deficit of N. When assessing rule revisions, EPA assumed crops would receive the necessary commercial fertilizer to fulfill the total crops' N requirements. EPA also considered direct application to field surfaces versus incorporation of the manure. These two application methods have been shown to have quite different effects on sediment and nutrient transport, so this methodology considers the frequency of both application methods and the subsequent changes in loads.

Based on the farm categories defined in Table 12-1, Table 12-2 outlines what the rule-revision options entail in terms of nutrient application for AFO and non-AFO acres. Table 12-2 indicates how potential options establish requirements for agronomic fertilizing that is either N-based or P-based, and changes the categorization of cropland acres under management. In particular, the number of Category I farms (i.e. farms with sufficient cropland to assimilate all manure produced on the farm) under N-based application rates is lower than the number of Category I farms under P-based application rates. The total number of farms under all scenarios remains constant.

Technology Option 1 establishes manure application standards that prohibit application of manure in excess of the agronomic N rate. This scenario differs from baseline conditions in the decrease (about 3 million acres) in cropland receiving manure in excess of crop nitrogen requirements, and in the increased use of manure instead of synthetic fertilizer at non-AFO cropland. In other words, Category I farms continue to apply manure at a N based rates, Category III farms continue to transfer manure offsite, and Category II farms will spread manure over more acres. Options 2 through 5 establish manure application rates based on the limiting nutrient, either N or P. EPA used soil P test maps and USDA data to determine the percent of facilities in each state that would require N-based versus P-based application rates. This approach is based on a recent informal NRCS survey where 49 out of 50 states (all states except Idaho) reported an intention to use the Phosphorus Index (PI) to meet the NRCS Nutrient Management Standard 590.

Table 12-2. Overview of Regulatory Options.

Description of Assessed Regulatory Condition	**Description of Major Features**	
	AFO Acreage (On site)	**Non-AFO Acreage**
Baseline (prerevised regulatory baseline)	Category I, II, and III land receiving manure at N- to 5N-based rates or commercial fertilizer	Manure applied at agronomic N-based rate. Cropland not receiving manure has commercial fertilizer applied as needed to track a fixed total acreage.
Option 1	Category I, II, and III land receives manure at N-based rates or commercial fertilizer	
Options 2—5	Category I, II, and III land receives manure at N- or P-based rates depending on current soil P levels or commercial fertilizer	
Option 2a	Category I, II, and III land receives manure at P- based rates or commercial fertilizer	

Under Option 2 there are fewer Category I farms and correspondingly more Category II farms. The Category I farms apply commercial fertilizer N in addition to the manure to meet the total crop requirements for N. In addition, because P is used as the limiting nutrient for Options 2 through 5, an additional 6 million acres (8 million acres of cropland in total) are affected by a change in application rates at Category II facilities. Under Option 2A, all AFOs are assumed to apply manure to onsite cropland at the P-based rate with supplemental N added to bring the N applied to the crop removal rate. Option 2A was done as a sensitivity analysis to determine the upper bound load changes if all onsite manure was applied on a P-basis. Under Option 2, from 12 percent to 60 percent (on average roughly half) of all AFOs apply manure at a P-based rate, while the remaining AFOs continue to apply at a N-based rate identical to Option 1. See Chapter 1 of the *Loads Report* for a more detailed description of the model.

12.4 <u>Methodology for Production Area Loads</u>

EPA established a separate methodology for computing runoff and other discharges from the production area. EPA assumes CAFOs subject to the current ELG are in full compliance, therefore there are no runoff load reductions for these facilities. Medium size facilities (AFOs less than 1,000 AUs) may have runoff from the feedlot or manure storage areas. For purposes of this analysis, EPA assumes liquid waste storage facilities (ponds and lagoons) are designed in accordance with the NRCS Code 313 Waste Storage Facility or NRCS Code 359 Waste Treatment Lagoon. The storage capacity (days of storage) for each type of AFO is based on

USDA NAHMS data, site visits, and inspection/compliance reports. EPA then uses 25-year daily weather station precipitation and evaporation data from the county the Sample Farm is located in to represent the climate. Weather, manure generation, and process wastewater are tracked daily for 25 years to estimate the average annual overflow for each Sample Farm. Note that many Sample Farms, especially swine, poultry, and dairy operations, experienced no overflows using this methodology. The complete methodology and an example of the calculations for liquid storage overflows may be found in *Methodology for Estimating BAT Overflow from a Liquid Waste Storage Facility* in Appendices B and C of the *Loads Report*. In a similar manner, the runoff from stacked manure or uncovered litter stockpiles is calculated. See the *Loads Report* for more information.

Next, EPA reviewed available state inspection and discharge reports and university studies to determine the frequency of discharges occurring each year that are not attributable to precipitation at the time of the discharge. For example, one North Carolina study identified the probability of occurrence of permit violations on swine facilities in three North Carolina counties and identified the engineering and management factors that may relate to their occurrence. These discharges are generally infrequent, and when distributed across all Sample Farms, the load reductions attributable to these discharges are small. However, since many discharges are not thoroughly documented in state inspection/compliance reports, EPA believes the methodology is conservative and understates total discharges.

Finally, EPA evaluated the contribution of pollutants to surface waters through ground water with a direct hydrologic connection. Comprehensive studies conducted in North Carolina (Sheffield 2002) and Iowa (ISU 1999) conclude that all liquid impoundments leak, though the rate of leakage varies by soil type and liner construction (if any). Most studies of the lagoon leakage estimated ground water loads by simulating transport of pollutants through ground water aquifers. For its Sample Farm models, EPA assumed that 2,000 pounds per acre per year leaked from manure storage structures lined with silt loam soils. This reference value was used to develop direct and indirect manure storage structure leakage loadings for other soil types (i.e., soil permeability) based on work by Clapp and Hornberger (1978). However, these leakage values are for ammonium, which is not mobile in soils. For ammonium to mobilize, oxygen must be present to oxidize the ammonium to nitrate. Once nitrate is formed it can leach into ground water. Because soil under lagoons generally remains wet and anaerobic, only the outer fringe of the lagoon plume may oxidize and leach. Therefore, EPA assumed that 10 percent of the ammonia-nitrogen that reaches groundwater by leaching from the bottom of the manure storage structure reaches ground water in the form of nitrate-nitrogen. Sobecki and Clipper (1999) determined how many manure storage structures had direct seepage losses by evaluating the ground water pollution potential of AFO manure storage structures according to AFO region land characteristics. For these structures with a direct surface link, pollutant loads were assumed to directly connect with surface water and it was assumed that no ground water aquifer pollutant assimilation took place. See the *Loads Report* for more information.

12.5 Converting Site-specific Loads to National Loads

Each Sample Farm model represents a single combination of animal type, farm size, manure application technique, manure application rate, and farm location. Each Sample Farm model is also evaluated across the three categories of land availability and several soil types. EPA's estimate of the annual national total pollutant load was calculated by assigning the per farm pollutant loads from the suite of Sample Farm models to every AFO facility nationwide. Thus each Sample Farm model represents the behavior of a small fraction of the total AFO population. Sample Farm loads were subsequently extrapolated to the AFO region (See Chapter 4 for a description of EPA's regions) and eventually to national pollutant loads.

To orchestrate the feeding of sample model data into GLEAMS, EPA developed a processor (using the FORTRAN programming language), referred to as the Loadings Estimate Tool (LET). This program extracts data from several large databases, forms an input data file suitable for GLEAMS, feeds the data into GLEAMS, and then regulates GLEAMS output. LET also integrates pollutant loadings estimates from open-air feedlots, manure piles, runoff, and leaking lagoons, to estimate the average annual total pollutant loadings. These per facility production area pollutant loads or per acre land application loads were multiplied by the number of facilities specific to that particular state, farm size, animal type, and waste management system to obtain regional pollutant loads. These regional pollutant loads were then summed to obtain national pollutant loads. The following tables provide a summary of results for each pollutant parameter evaluated.

Tables 12-3 through 12-8 reflect the edge-of-field pollutant loads for Large CAFOs, and Tables 12-9 through 12-14 show the edge-of-field pollutant load reductions for Large CAFOs. Tables 12-15 through 12-20 reflect the edge-of-field loads from all Medium AFOs. Tables 12-21 through 12-26 show the edge-of-field load reductions from the permitted Medium AFOs *only*. No edge-of-field pollutant reductions occurred from the unpermitted Medium AFOs

Table 12-3. Edge-of-field nitrogen loads from Large CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	106	60	58	51	58
Dairy	45	31	30	27	30
Swine	89	87	85	75	110
Poultry	189	159	152	150	147
Total	428	338	325	304	345

Table 12-4. Edge-of-field phosphorous loads from Large CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	105	89	82	82	82
Dairy	19	16	14	14	14
Swine	26	26	22	22	18
Poultry	80	71	61	61	59
Total	230	202	178	178	173

Table 12-5. Edge-of-field sediment loads from Large CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	14,374	12,850	12,850	12,850	12,850
Dairy	2,351	2,225	2,225	2,225	2,225
Swine	3,726	3,726	3,583	3,583	4,311
Poultry	15,042	15,011	14,776	14,776	14,731
Total	35,493	33,813	33,434	33,434	34,118

Table 12-6. Edge-of-field *Fecal coliform* loads from Large CAFOs in 10^{19} colony forming units.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	437	424	423	423	423
Dairy	54	53	53	53	53
Swine	139	139	70	70	1
Poultry	64	57	29	29	0.7
Total	695	672	576	576	478

Table 12-7. Edge-of-field *Fecal streptococcus* loads from Large CAFOs in 10^{19} colony forming units.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	196	190	190	190	190
Dairy	214	206	207	207	207
Swine	4,103	4,087	2,068	2,068	39
Poultry	576	150	89	89	29
Total	5,089	4,633	2,554	2,554	465

Table 12-8. Edge-of-field metals loads from Large CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	2.8	2.7	2.6	2.6	2.6
Dairy	2.5	2.4	2.3	2.3	2.3
Swine	3.5	3.5	3.4	3.4	3.7
Poultry	11.2	10.9	10.7	10.7	10.6
Total	20.0	19.5	18.9	18.9	19.2

Table 12-9. Edge-of-field nitrogen load reductions from Large CAFOs in millions of pounds per year. Numbers in ( ) indicate negative values.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	45.2	47.9	54.3	47.9
Dairy	14.1	14.7	17.9	14.7
Swine	0.3	4.0	13.6	(21.3)
Poultry	29.9	36.4	38.1	41.6
Total	89.6	103.0	123.8	82.9

Table 12-10. Edge-of-field phosphorous load reductions from Large CAFOs in millions of pounds per year.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	15.6	23.1	23.1	23.1
Dairy	3.2	5.0	5.0	5.0
Swine	0.1	4.7	4.7	8.1
Poultry	8.5	19.2	19.2	20.4
Total	27.4	52.1	52.1	56.5

Table 12-11. Edge-of-field sediment load reductions from Large CAFOs in millions of pounds per year. Numbers in ( ) indicate negative values.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	1,524	1,524	1,524	1,524
Dairy	126	126	126	126
Swine	0	143	143	(585)
Poultry	31	266	266	311
Total	1,681	2,059	2,059	1,376

Table 12-12. Edge-of-field *Fecal coliform* load reductions from Large CAFOs in 10^{19} colony forming units.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	14.0	14.0	14.0	14.0
Dairy	1.3	1.3	1.3	1.3
Swine	0.5	69.1	69.1	138.0
Poultry	6.8	35.0	35.0	63.2
Total	22.7	119.5	119.5	216.6

Table 12-13. Edge-of-field *Fecal streptococcus* load reductions from Large CAFOs in 10^{19} colony forming units.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	6	6	6	6
Dairy	8	7	7	7
Swine	16	2,035	2,035	4,064
Poultry	426	487	487	547
Total	456	2,535	2,535	4,624

Table 12-14. Edge-of-field metals load reductions from Large CAFOs in millions of pounds per year. Numbers in ( ) indicate negative values.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	0.14	0.22	0.22	0.22
Dairy	0.03	0.14	0.14	0.14
Swine	0.01	0.13	0.13	(0.23)
Poultry	0.33	0.55	0.55	0.63
Total	0.51	1.04	1.04	0.76

Table 12-15. Edge-of-field nitrogen loads from Mediums CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	24	23	23	23	23
Dairy	60	56	55	53	55
Swine	101	101	100	98	102
Poultry	173	172	172	172	172
Total	358	353	351	347	353

Table 12-16. Edge-of-field phosphorous loads from Mediums CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	17	17	17	17	17
Dairy	24	23	22	22	22
Swine	22	22	21	21	20
Poultry	79	78	78	78	78
Total	141	140	137	137	136

Table 12-17. Edge-of-field sediment loads from Mediums CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	4,582	4,580	4,562	4,562	4,562
Dairy	2,885	2,882	2,827	2,827	2,827
Swine	3,910	3,910	3,890	3,890	3,898
Poultry	20,094	20,092	20,088	20,088	20,087
Total	31,470	31,464	31,367	31,367	31,374

Table 12-18. Edge-of-field *Fecal coliform* loads from Mediums CAFOs in 10^{19} colony forming units.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	22	10	10	10	10
Dairy	44	36	36	36	36
Swine	240	240	222	222	204
Poultry	40	40	40	40	39
Total	346	325	307	307	289

Table 12-19. Edge-of-field *Fecal streptococcus* loads from Mediums CAFOs in 10^{19} colony forming units.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	10	4	4	4	4
Dairy	254	201	201	201	201
Swine	7,057	7,055	6,530	6,530	6,003
Poultry	1,177	1,125	1,124	1,124	1,124
Total	8,498	8,385	7,859	7,859	7,332

Table 12-20. Edge-of-field metals loads from Mediums CAFOs in millions of pounds per year.

Sector	Baseline	Option 1	Option 2	Option 3	Option 5
Cattle	0.4	0.4	0.4	0.4	0.4
Dairy	3.4	3.4	3.3	3.3	3.3
Swine	2.9	2.9	2.9	2.9	2.8
Poultry	8.9	8.9	8.9	8.9	8.9
Total	15.7	15.7	15.6	15.6	15.6

Table 12-21. Edge-of-field nitrogen load reductions from Medium CAFOs in millions of pounds per year.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	0.17	0.22	0.22	0.22
Dairy	4.59	5.03	7.34	5.03
Swine	0.03	0.98	3.11	(0.59)
Poultry	0.81	0.88	0.90	0.95
Total	5.60	7.10	11.56	5.60

Table 12-22. Edge-of-field phosphorous load reductions from Medium CAFOs in millions of pounds per year.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	0.05	0.27	0.27	0.27
Dairy	1.33	2.55	2.55	2.55
Swine	0.01	0.70	0.70	1.50
Poultry	0.26	0.72	0.72	0.73
Total	1.66	4.24	4.24	5.05

Table 12-23. Edge-of-field sediment load reductions from Medium CAFOs in millions of pounds per year.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	1	20	20	20
Dairy	3	57	57	57
Swine	0	20	20	12
Poultry	2	6	6	7
Total	6	104	104	96

Table 12-24. Edge-of-field *Fecal coliform* load reductions from Medium CAFOs in 10^{19} colony forming units.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	12.1	12.1	12.1	12.1
Dairy	8.2	8.2	8.2	8.2
Swine	0.1	17.9	17.9	35.8
Poultry	0.1	0.5	0.5	0.8
Total	20.4	38.6	38.6	56.9

Table 12-25. Edge-of-field *Fecal streptococcus* load reductions from Medium CAFOs in 10^{19} colony forming units.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	5	5	5	5
Dairy	54	54	54	54
Swine	2	527	527	1,054
Poultry	52	53	53	54
Total	113	639	639	1,166

Table 12-26. Edge-of-field metals load reductions from Medium CAFOs in thousands of pounds per year.

Sector	Option 1	Option 2	Option 3	Option 5
Cattle	0.9	1.9	1.9	1.9
Dairy	23.2	80.3	80.3	80.3
Swine	0.1	18.5	18.5	42.4
Poultry	6.1	9.6	9.6	10.6
Total	30.2	110.2	110.2	135.1

12.6 References

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CHAPTER 13

NON-WATER QUALITY IMPACTS

13.0 INTRODUCTION

Eliminating or reducing one form of pollution may create or aggravate other environmental problems. Sections 304(b) and 306 of the Clean Water Act (CWA) require that the U.S. Environmental Protection Agency (EPA) consider the non-water quality environmental impacts (NWQI) of effluent limitations guidelines and standards. This chapter presents the methodology and estimates from EPA's NWQI analysis of seven primary regulatory options that were considered for concentrated animal feeding operations (CAFOs), including beef (includes heifer) operations, dairies, veal, swine, broiler, layer, and turkey operations. These impacts include:

- Air emissions from the animal production area, including animal housing and manure storage and treatment areas;
- Air emissions from application of manure to land;
- Air emissions from vehicles, including those involved in off-site transport of manure and in on-site composting operations; and
- Energy impacts from land application activities, the use of digesters, and the transportation of manure.

Typically, NWQI also include estimates of the generation of solid waste. Because manure is considered a by-product of animal feeding operations and is not regulated directly, the solid waste NWQI of the manure are not considered. In addition, although the chemical content of the manure may change, the amount of manure generated is not expected to change under any of the regulatory options being considered; therefore, this chapter does not discuss solid waste NWQI.

The remainder of this chapter contains the following information:

- Section 13.1 presents an overview of the analysis and pollutants;
- Section 13.2 discusses the methodology for estimating air emissions from animal feeding operations;
- Section 13.3 discusses the methodology for estimating air emissions from land application activities;
- Section 13.4 discusses the methodology for estimating air emissions from vehicles;
- Section 13.5 discusses the methodology for estimating energy impacts;

- Section 13.6 summarizes the industry-level non-water quality impacts for Large and Medium CAFOs; and
- Section 13.7 lists the references used in this section.

EPA's Office of Air Quality Planning and Standards also conducted an in-depth study of air emissions from animal feeding operations and prepared a draft report in August 2001. The National Academy of Sciences subsequently reviewed this report, and since that time, EPA has updated the available data used to develop air emission factors. This chapter presents results based on available data and methodologies developed as of September 2002. A more detailed description of the analysis is provided in the report *Non-Water Quality Impact Estimates for Animal Feeding Operations* (ERG, 2002a).

13.1 Overview of Analysis and Pollutants

A number of factors affect the energy use at and the pollutant emissions from CAFOs. Most of the substances emitted are the products of microbial processes that decompose the complex organic constituents in manure. The microbial environment determines which substances are generated and at what rate. This section describes the chemical and biological mechanisms that affect the formation and release of emissions.

The pollutants included in this analysis are:

- Ammonia. Ammonia is a by-product of the microbial decomposition of the organic nitrogen compounds in manure. Nitrogen occurs as both unabsorbed nutrients in manure and as either urea (mammals) or uric acid (poultry) in urine. Urea and uric acid hydrolyze rapidly to form ammonia and are emitted soon after excretion. Urea plus ammonia nitrogen from urine usually accounts for 40 to 50 percent of the total nitrogen excreted in manure (Van Horn et al., 1994).

  Ammonia continues to form during the microbial breakdown of manure under both aerobic and anaerobic conditions. Because it is highly soluble in water, ammonia accumulates in manure handled as liquids and semisolids or slurries, but volatilizes rapidly with drying from manure handled as solids. In aqueous solution, ammonia reacts with acid to form ammonium, which is not gaseous. The chemical equilibrium in an acid environment promotes rapid conversion of ammonia to ammonium with little release of ammonia to the atmosphere. Because most animal manure, lagoons, and feedlot surfaces have a pH greater than 7.0 (i.e., a nonacidic environment), ammonia is rapidly lost to the atmosphere. Consequently, ammonia losses from animal manure can easily exceed 50 percent (Van Horn et al., 1994).

- Nitrous oxide. Nitrous oxide can also be produced from the microbial decomposition of organic nitrogen compounds in manure. Unlike ammonia, however, nitrous oxide is emitted only under certain conditions. Nitrous oxide is emitted only if nitrification occurs and is followed by denitrification. Nitrification is the microbial oxidation of ammonia to nitrites and nitrates, and the process requires an aerobic environment. Denitrification is most commonly a microbially mediated process where nitrites and nitrates are reduced under anaerobic conditions. The principal end product of denitrification is dinitrogen gas (N_2). However, small amounts of nitrous oxide as well as nitric oxide also can be generated under certain conditions. Therefore, for nitrous oxide emissions to occur, the manure must first be handled aerobically and then anaerobically.

Research indicates that aerobic manure storage, such as composting, produces more nitrous oxide than anaerobic storage, such as lagoons (AAF Canada, 2000). In general, manure that is handled as a liquid tends to produce less nitrous oxide than manure that is handled as a solid. The quantity of nitrous oxide generated is typically small and varies significantly depending on environmental conditions such as pH, drainage, and plant uptake.

- Methane. With respect to livestock emissions, methane is produced in the normal digestive processes of animals and during the decomposition of animal manure. This analysis assesses only the amount of methane produced in manure decomposition. Livestock manure is principally composed of organic material. When this organic material decomposes in an anaerobic environment, methanogenic bacteria, as part of an interrelated population of microorganisms, produce methane. Methane is insoluble in water. Thus, methane volatilizes from solution as rapidly as it is generated. Concurrent with the generation of methane is the microbially mediated production of carbon dioxide, which is only sparingly soluble in water. The mixture of these two gases is commonly referred to as biogas.

  The principal factors affecting methane emission from animal manure are the methane-producing potential of the waste and the portion of the manure that decomposes anaerobically. The second factor depends on the biodegradability of the organic fraction and how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, pits), it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid (e.g., in stacks or pits) or when it is deposited on pastures and rangelands, it tends to decompose aerobically, producing little or no methane (IPCC, 2000).

- Hydrogen sulfide. Hydrogen sulfide is produced and subsequently emitted from animal manure only under anaerobic conditions and results from the mineralization of organic sulfur compounds and the reduction of the more oxidized inorganic forms of sulfur, including sulfites and sulfates. In animal manure, the principal organic sulfur compounds are the sulfur amino acids, and the principal sources of inorganic sulfur are minerals, such as copper and zinc, which are added to diets to correct nutritional deficiencies or to serve as growth stimulants. High concentrations of hydrogen sulfide can be released by agitation and pumping of liquid wastes. Although only small amounts of hydrogen sulfide are produced in a manure tank compared with the other major gases, this gas is heavier than air and becomes more concentrated in the tank over time. Research has determined that hydrogen sulfide production from animal feeding operations depends on the average outside air temperature, the size of the housing or waste management areas, the air retention time in the housing areas, and the daily sulfur intake of the animals.

- Criteria air pollutants. Criteria air pollutants are those pollutants for which a national ambient air quality standard has been set. Animal feeding operations that transport their manure off site and/or compost their manure on site use equipment (e.g., trucks, tractors) that release criteria air pollutants when operated. These pollutants are also released when biogas, generated from energy recovery systems for anaerobic digesters, is used for fuel (e.g., in an engine or flared). The criteria air pollutants included in this analysis are volatile organic compounds, nitrogen oxides, particulate matter, sulfur dioxide, and carbon monoxide.

- Energy usage. CAFOs also use energy when transporting manure off site, applying manure to land, and performing on-site operations such as composting. In some cases, the CAFO may generate energy from capturing and using biogas. Energy usage included in this analysis is expressed in kilowatt hours (kW-hr) and in consumed fuel (gallons). Energy use also includes production of fertilizer. Though CAFOs do not generate commercial fertilizer, the manure is used as a fertilizer replacement. Since the criteria air pollutants analysis reflects NWQI due to increased hauling distances and spreading of manure, an energy usage NWQI estimate is used to reflect national reductions in fertilizer consumption. This analysis of reductions in commercial fertilizer use are included in the memorandum entitled “Commercial Fertilizer Analysis” (ERG, 2002).

Where possible, the NWQI estimates for each regulatory option are presented in relation to the baseline conditions under which animal feeding operations generate air emissions and use energy (i.e., prior to implementation of a regulatory option). In some cases, however, there were insufficient data to quantify baseline NWQI. In these cases, the impacts presented in this chapter reflect only the change in impacts expected to result from implementation of the regulatory options from baseline.

13.2 Air Emissions from Animal Feeding Operations

Animal feeding operations generate various types of animal wastes, including manure (feces and urine), waste feed, water, bedding, dust, and wastewater. Air emissions are generated from the decomposition of the wastes from the point of generation through the management and treatment of these wastes on site. The rate at which emissions are generated varies as a result of a number of operational variables (e.g., animal species, type of housing, waste management system) and weather conditions (e.g., temperature, humidity, wind, time of release).

EPA evaluated air releases from animal confinement areas and manure management systems under baseline conditions and seven regulatory options considered by the Agency. Little data exist to allow for a complete analysis of all possible compounds; therefore, this analysis focused on the release of ammonia, hydrogen sulfide, and greenhouse gases (methane and nitrous oxide) from animal confinement areas and manure management systems and certain criteria air pollutants (carbon monoxide, nitrogen oxides, and volatile organic compounds) from energy recovery systems.

This section summarizes the methodology used for the following air emission calculations from the animal feeding operation:

- Section 13.2.1 - Ammonia and hydrogen sulfide from animal confinement areas and manure management systems;
- Section 13.2.2 - Greenhouse gases from animal confinement areas and manure management systems; and
- Section 13.2.3 - Criteria air pollutants from energy recovery systems.

A detailed description of the data inputs and equations used to calculate these air emissions is provided in the report *Non-Water Quality Impact Estimates for Animal Feeding Operations* (ERG, 2002a).

13.2.1 Ammonia and Hydrogen Sulfide Emissions From Animal Confinement Areas and Manure Management Systems

Animal housing and manure management systems produce ammonia and hydrogen sulfide emissions. Nitrogen is the primary component of animal waste most likely to generate air emissions. Total nitrogen comprises organic nitrogen, ammonia, nitrite, and nitrate. The primary form of nitrogen emissions from animal feeding operations to the atmosphere occurs as ammonia. For this analysis, EPA calculated emissions of ammonia for drylots, confinement houses, ponds and lagoons, and composted manure.

Hydrogen sulfide is produced by anaerobic decomposition of organic wastes such as animal manure. High concentrations can be released by agitation and pumping of liquid wastes. Research has determined that hydrogen sulfide production from animal feeding operations depends on the average outside air temperature, the size of the housing or waste management areas, the air retention time in the housing areas, and the daily sulfur intake of the animals. EPA estimated hydrogen sulfide emissions for confinement houses operating deep-pit systems, as these are production areas with anaerobic conditions.

The Agency based emission rates of ammonia and hydrogen sulfide on the emission factor and the amount of nitrogen or sulfur in the excreted manure. Emission factors depend upon the animal species as well as the type of animal confinement and manure management area. Because only swine emission factors for hydrogen sulfide have been published in the literature, EPA transferred these data to other animal types.

Livestock may be confined in a number of different ways that impact the type and amount of ammonia emissions. Some animals are housed in traditional confined housing (e.g., tie stall barns, freestall barns), while others are confined in outdoor areas (e.g., drylots, paddocks). Studies have shown that the method of confinement directly affects the emission of ammonia (Jacobson et al., 2000). Management of waste within the confinement area (e.g., litter system, deep-pit, freestall) also influences emissions of both ammonia and hydrogen sulfide. For instance, deep-pit systems are associated with a higher nitrogen emission factor because waste remains in the pit for a longer period of time, increasing ammonia volatilization.

Anaerobic lagoons and waste storage ponds are major components of the waste management systems at many animal feeding operations. These systems rely on microbes that biodegrade organic nitrogen to ammonium and ammonia. The ammonia continuously volatilizes from the surface of lagoons and ponds. The high sulfur content of swine, dairy, veal, and layer waste also results in hydrogen sulfide emissions from lagoons. Settling basins, used as a technology basis for several regulatory options, are estimated to remove 50 percent of manure solids at an operation. The remaining 50 percent reach the pond or lagoon. It is assumed that these basins remove approximately 12 percent of nitrogen and 50 percent of sulfur; therefore, 88 percent of the nitrogen and 50 percent of the sulfur excreted in manure enters the storage pond or lagoon.

The seven regulatory options, based on the implementation of different types of waste management systems, influence whether emissions of ammonia and/or hydrogen sulfide will increase or decrease when compared to baseline.

13.2.2 Greenhouse Gas Emissions from Animal Confinement Areas and Manure Management Systems

Manure management systems, including animal confinement areas, produce methane (CH_4) and nitrous oxide (N_2O) emissions. Data used to estimate greenhouse gas emissions include: animal weight, volatile solids excretion rate, nitrogen excretion rate, maximum methane-producing potential, runoff solids generation, and manure composted. The maximum methane-producing potential is the maximum volume of methane that can be produced per kilogram of volatile solids and is based on the type of animal and its diet. The methane and nitrous oxide emissions were estimated based on the guidance developed for international reporting of greenhouse gas emissions (IPCC, 2000) and used by EPA's Office of Air and Radiation.

Methane production is directly related to the quantity and quality of waste, the type of waste management system used, and the temperature and moisture of the waste (EPA, 1992). In general, manure that is handled anaerobically will produce more methane, while manure that is handled aerobically produces little methane. For example, liquid and slurry systems result in higher methane production because they promote anaerobic conditions. Certain animal populations, such as beef cattle on feedlots, may produce more methane if they are fed higher energy diets. Methane is also produced from the digestive processes of ruminant livestock as a result of enteric fermentation. However, because the regulatory options do not establish requirements dictating specific feeding strategies that affect diet, the effect on enteric fermentation methane emissions is difficult to predict and is not discussed further.

Nitrous oxide is produced as part of the nitrogen cycle through the nitrification and denitrification of the organic nitrogen in livestock manure and urine. The emission of nitrous oxide from manure management systems is a function of the nitrogen content of the manure, as well as the length of time the manure is stored and the specific type of system used. In general, the amount of nitrous oxide emitted from manure management systems tends to be small because conditions are often not suitable for nitrification to occur; however, when nitrous oxide is generated, manure that is handled as a liquid tends to produce less nitrous oxide than manure handled as a solid. The amount of emitted nitrous oxide depends upon the nitrogen excreted by the animal, and emission factors are assumed not to vary regionally.

13.2.3 Criteria Air Emissions From Energy Recovery Systems

Criteria air pollutants are those pollutants for which a national ambient air quality standard has been set. The criteria pollutants evaluated as non-water quality impacts from energy recovery systems include oxides of nitrogen (NOx), which are precursors to ozone, as well as carbon monoxide (CO) and sulfur dioxide (SO_2). These criteria pollutants are formed from the flaring and combustion of biogas.

NOx emissions result from the oxidation of nitrogen compounds in biogas and from thermal formation during the flaring and combustion processes. No emission factors incorporate both situations; therefore, EPA estimated emissions using an emission factor for each situation and a subsequent calculation estimating the amount of volatilized ammonia oxidized to NOx. EPA calculated sulfur dioxide emissions under the assumption that the sulfur compounds in biogas are completely oxidized in both the flare and gas turbines and estimated carbon monoxide emissions associated with the incomplete combustion of methane and other organic compounds.

Criteria pollutant air emissions from flaring and energy recovery systems are expected under Options 5 and 6. Under Option 5, anaerobic lagoons at all swine, chicken, and veal operations are modeled as covered, and the biogas is vented to a flare. Option 6 is based on the implementation of anaerobic digestion systems with energy recovery for Large swine operations and dairies. Options 5 and 6 greatly reduce the emissions of methane through the capture of biogas; however, flaring the biogas or using it in an energy recovery system will increase emissions of the criteria pollutants NOx, SO_2, and CO. These pollutants are generated from oxidation of nitrogen (from NH_3), sulfur (from H_2S), and carbon compounds (from organics and methane).

13.3 <u>Air Emissions from Land Application Activities</u>

Applying animal manure from animal feeding operations to cropland generates air emissions. These emissions result primarily from the volatilization of ammonia at the point the material is applied to land (Anderson, 1994). Additional emissions of nitrous oxide are released from cropland when nitrogen applied to the soil undergoes nitrification and denitrification. Loss through denitrification depends upon the oxygen levels of the soil to which manure is applied. Low oxygen levels, resulting from wet, compacted, or warm soil, increase the amount of nitrate-nitrogen released into the air as nitrogen gas or nitrous oxide (OSUE, 2000). However, a study by Sharpe and Harper (1997), which compared losses of ammonia and nitrous oxide from the sprinkler irrigation of swine effluent, concluded that ammonia emissions contributed more to airborne nitrogen losses. This analysis of air emissions from land application activities focuses on the volatilization of nitrogen as both ammonia and nitrous oxide and quantified both on- and off-site emissions.

The amount of nitrogen released into the environment from the land application of animal waste is affected by the rate and method by which it is applied, the quantity of material applied, and site-specific factors such as air temperature, wind speed, and soil pH. There were insufficient data to quantify the effect of site-specific factors; therefore, they were not addressed in this analysis.

Ammonia emissions depend on the ammonia volatilization rate and the amount of manure applied on and off site. The ammonia volatilization rates used to estimate total ammonia emissions are animal-specific and are based on the application method and the rate of incorporation. Ammonia losses were calculated separately for beef feedlots, dairies, and poultry and swine operations, and total emissions were estimated by summing the volatilization from solid and liquid application. Nitrous oxide emissions were calculated based on the methodology described in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000*, EPA 236-R-02-003 (EPA, 2002). This methodology estimated that 1.25 percent of the nitrogen that is land applied, but does not volatilize to ammonia, will be emitted as nitrous oxide, and that one percent of the nitrogen that volatilizes as ammonia will eventually become nitrous oxide. Like ammonia, the total amount of nitrous oxide emitted on and off site was calculated by summing the emissions resulting from both solid and liquid waste application.

Although ammonia volatilization may be reduced by implementing application techniques aimed at conserving nitrogen, this is not required by any regulatory option. However, Option 5, which mandates total confinement and covered lagoon storage, results in an increased concentration of applied nitrogen and elevated ammonia and nitrous oxide emissions from land application activities. The composting requirement of Option 5A is expected to result in increased emissions of ammonia and nitrous oxide, due to drier manure handling and windrow turning.

13.4 Air Emissions From Vehicles

Animal feeding operations that transport their manure off site and/or compost their manure on site use equipment (e.g., trucks, tractors) that release criteria air pollutants when operated. The NWQI analysis evaluated the increased emissions from off-site transportation and from composting manure on site.

Criteria air emissions from the off-site transportation of animal manure were evaluated for each of the regulatory options considered by EPA, as all options will result in an increase of off-site transportation of manure at some operations. The analysis examined three types of facilities: Category 1 operations have sufficient cropland to apply all manure on site; Category 2 operations do not have enough cropland to apply all waste on site and may or may not currently transport waste; and Category 3 operations have no cropland and currently transport all manure off site. Because Category 1 operations emit no criteria air pollutants from vehicles at baseline, nor will any regulatory option induce them to do so, there are no current or projected emissions in criteria air emissions for this category. Category 2 operations, however, incur costs for transporting more manure off site, leading to an increase in the amount of criteria air pollutants generated by these operations. Although Category 3 facilities currently transport their manure, a regulation that requires phosphorous-based rather than nitrogen-based application may cause facilities to transport their excess manure a further distance; therefore, there may also be an increase in the amount of criteria air pollutants generated by these operations for options that require phosphorus-based application. EPA calculated air emission estimates for the off-site transportation of manure from all Category 2 facilities, as well as from Category 3 facilities that are expected to follow phosphorus-based application.

Two different waste transportation options were also analyzed. One considered the cost of purchasing trucks to transport waste, and the other evaluated the cost of paying a contractor to haul the waste off site. Because of the different methods used to estimate the costs of the two transportation options, two methods were used to calculate air emissions. Criteria pollutant emissions from operations purchasing waste transportation vehicles were based on an estimate of the number of trucks purchased and the annual number of miles traveled. Contract hauling emissions were based on an estimate of the annual amount of waste generated, the annual number of miles traveled, and truck sizes.

Transportation emissions are reported as the incremental increase in criteria air pollutants from baseline for Category 2 and Category 3 operations. Additional criteria air pollutants are released in all cases.

Farm equipment used for on-site composting activities also affects the generation of air emissions. Composting of waste can result in a reduction in transportation air emissions if the volume or weight of material composted is reduced; however, the mere use of composting equipment contributes to criteria air emissions. Option 5A for beef (includes heifer) operations and dairies is based on all operations composting their waste; therefore, criteria air emissions from on-site composting of manure were estimated only for these CAFOs under Option 5A. The amount of waste composted was based on the amount of excreted semisolid waste. Pollutant emissions were determined using vehicle emission factors and miles traveled along the length of the windrow. On-site emissions of criteria air pollutants due to composting activities increase under Option 5A for all for beef (includes heifer) operations and dairies.

13.5 Energy Impacts

Certain regulatory options evaluated for animal feeding operations entail the use of different waste management systems and land application practices that may increase or decrease energy usage. Energy impacts related to land application for animal feeding operations were evaluated under baseline conditions and under the seven regulatory options considered by EPA. Energy impacts related to the use of anaerobic digesters were evaluated for all Large dairies and swine operations under Option 6.

Some beef (includes heifer) operations and dairies do not currently collect and land apply their liquid waste. The regulatory options implementing a no-discharge policy would force these operations to collect and land apply their liquid waste using pivot irrigation systems or traveling guns, depending on the amount of acreage available for application. As a result of the addition of these application systems, the energy requirements of these operations would increase.

Transporting manure off site and composting manure on site requires the use of equipment such as trucks and tractors. The fuel consumption resulting from using these vehicles contributes to the energy impacts associated with land application activities. The estimation of fuel consumption by transportation vehicles used the number of miles traveled per year and the vehicle fuel efficiency as data inputs.

Option 6 includes the use of anaerobic digesters with energy recovery to manage animal waste for the Large dairies and swine operations. Digesters require a continuous input of energy to operate the holding tank mixer and the engine that converts captured methane into energy (Jewell, 1997). The energy required to continuously operate these devices and the amount of energy generated by the system have been determined from EPA's *FarmWare* model. CAFOs using anaerobic digesters with energy recovery systems are expected to have a net decrease in electricity use.

13.6 Industry-Level NWQI Estimates

This section summarizes the industry-level NWQI estimates for each of the regulatory options considered by EPA. To evaluate the impact of the regulation on NWQI, model farm emissions were extrapolated to the population of animal feeding operations covered by the rule. Industry-level impacts for each animal sector (i.e., beef (includes heifer), dairy, veal, swine, and poultry) were estimated for Medium and Large CAFOs throughout the United States. Large facilities are considered CAFOs if they fall within the size range presented in Table 13-1. Medium AFOs are defined as CAFOs only if they fall within the size range presented in Table 13-1 and they meet one of the two specific criteria governing the method of discharge: (1) pollutants are discharged through a man-made ditch, flushing system, or other similar man-made device; or (2) pollutants are discharged directly into waters of the United States that originate outside the facility and pass over, across, or through the facility or otherwise come into direct contact with the confined animals.

Table 13-1. Summary of Size Thresholds for Large and Medium CAFOs.

Sector	Large	Medium[a]
Mature dairy cattle	More than 700	200 - 700
Veal calves	More than 1,000	300 - 1,000
Cattle or cow/calf pairs	More than 1,000	300 - 1,000
Swine (weighing 55 pounds or more)	More than 2,500	750 - 2,500
Swine (weighing less than 55 pounds)	More than 10,000	3,000 - 10,000
Turkeys	More than 55,000	16,500 - 55,000
Chickens (liquid manure handling system)	More than 30,000	9,000 - 30,000
Chickens other than laying hens (other than a liquid manure handling system)	More than 125,000	30,000 - 125,000
Laying hens (other than a liquid manure handling system)	More than 82,000	25,000 - 82,000

[a] Must also meet one of two criteria to be defined as a CAFO.

13.6.1 Summary of Air Emissions for Beef (Includes Heifer) Operations and Dairies

Tables 13-2 and 13-3 present estimates for Large CAFOs, and Tables 13-8 and 13-9 present estimates for Medium CAFOs.

Option 1

Option 1 is expected to result in a change in precursor pollutant (i.e., ammonia and hydrogen sulfide) emissions from CAFOs. Total ammonia emissions from beef (includes heifer) operations and dairies, including both the production area and land application activities, decrease under Option 1. Production area emissions decrease due to the added step of solids separation in waste management. Option 1 also requires agronomic application of manure, litter, and other process wastewater on site, which results in decreased application of manure nitrogen to cropland on site and decreased on-site land application ammonia emissions. However, off-site application of manure nitrogen increases, which also increases the off-site land application ammonia emissions. Hydrogen sulfide emissions from the production area decrease for dairies also because of the practice of solids separation, which allows for increased aerobic decomposition and the inhibition of hydrogen sulfide formation.

In addition, Option 1 is expected to result in a change in greenhouse gas emissions. For Large beef (includes heifer) and dairy CAFOs, methane emissions decrease due to the added step of solids separation in the waste management system. The separated solids are stockpiled rather than held in waste storage ponds or anaerobic lagoons. This drier method of manure handling reduces anaerobic conditions and the potential for volatile solids to convert to methane. This approach also results in greater conversion of nitrogen to nitrous oxide; thus, nitrous oxide emissions from dairies increase. For Medium beef (includes heifer) CAFOs, methane emissions increase due to increased liquid storage from baseline.

Due to the requirement under Option 1 to apply manure, litter, and other process wastewater at nitrogen-based agronomic rates, CAFOs with insufficient land on which to apply their waste at these rates will transport the excess manure off site. Due to this increase in transportation, emissions of criteria air pollutants increase from baseline for beef (includes heifer) and dairy CAFOs.

Options 2-4 and 7

Options 2-4 and 7 also result in changes to precursor and greenhouse gas emissions as discussed for Option 1. However, these options require manure, litter, and other process wastewater to be applied at agronomic rates for phosphorus for some operations.

Therefore, criteria air emissions increase compared to baseline and Option 1 due to an increase in the amount of manure nutrients transported off site.

Option 5A

Option 5A requires the implementation of composting at beef (includes heifer) and dairy CAFOs. Under Option 5A, ammonia emissions increase for these operations. Ammonia volatilizes rapidly from drying manure, resulting in an increase in emissions as more manure is handled as a solid rather than a liquid or slurry. In addition, composting practices release more emissions than stockpiles because the windrows are turned regularly, exposing more manure to the air. Stockpiles tend to form outer crusts that reduce the potential for volatilization.

Under a composting option, production area methane emissions increase as a result of the addition of organic material to the waste prior to composting. This material decomposes and contributes to increased methane emissions compared to other options and baseline. Nitrous oxide emissions also increase for these operations, as aerobic storage enhanced by windrow turning promotes the release of this gas.

Option 5A also results in an increase in criteria air emissions. The practice of composting requires turning equipment, which consumes fuel and generates additional air emissions. However, this increase is not as large as the increase under Options 2-4, 6, and 7. The additional criteria pollutants emitted by composting equipment is partially offset by reductions in transportation emissions, resulting from a decrease in the weight and/or volume of the composted material.

Option 6

Under Option 6, emissions of pollutants do not differ from Option 2 for all beef (includes heifer) CAFOs, and for Medium dairy CAFOs. However, for Large dairy CAFOs, this option results in changes to greenhouse gas and criteria air emissions. Methane and nitrous oxide emissions from the production area of Large dairy CAFOs decrease substantially, due to the addition of an anaerobic digester with energy recovery. Generated methane is collected as biogas and converted to energy, and nitrous oxide is oxidized during the combustion process. Emissions of nitrogen oxides, carbon monoxide, and sulfur dioxide increase due to combustion of the biogas.

13.6.2 Summary of Air Emissions for Swine, Poultry, and Veal Operations

Tables 13-4 through 13-7 present estimates for Large swine, poultry, and veal CAFOs, and Tables 13-10 through 13-13 present estimates for Medium swine, poultry, and veal CAFOs.

Option 1

Emissions of precursor pollutants and greenhouse gases do not change for veal, swine, and poultry operations under Option 1, as this option does not result in changes to the production area waste management procedures. However, criteria air pollution increases for swine and poultry operations due to the nitrogen-based application requirements and the associated increases in transportation of manure nutrients off site. Emissions for veal operations do not change from baseline because it is assumed that they have adequate cropland to apply all waste on site and consequently do not transport any manure.

Options 2-4 and 7

Under these options, emissions of precursor pollutants and greenhouse gases do not change from baseline for all veal, swine, and poultry operations, as waste handling practices are not expected to change.

As in Option 1, there is no increase in criteria air pollutant emissions for veal operations because they are not expected to transport manure off site. However, there is an increase in these pollutant emissions for swine and poultry operations when compared to baseline and Option 1 because of the increased transport of waste necessitated by the phosphorus-based application requirement.

Option 5

Option 5 requires zero discharge, with no allowance for overflow. It is expected that operations will implement total confinement and covered storage, in addition to the requirements of Option 2, for all swine, poultry, and veal operations. Under this option, ammonia emissions decrease for veal, swine, and chicken operations. Usually, ammonia in the effluent from the covered lagoon is released upon exposure to air. Option 5, however, is based on covered storage at all times; thus, depending on the application methods (e.g., if the waste is incorporated into the soil), ammonia emissions could substantially decrease. The use of a covered lagoon lowers the production area ammonia emissions. It should be noted, however, that ammonia emissions increase from material applied to land both on site and off site. Ammonia emissions from turkey operations do not change compared to baseline. Emissions of hydrogen sulfide decrease for veal and swine and drop to zero for wet-layer operations due to the practice of covered storage.

Methane and nitrous oxide emissions from the production area decrease for all veal, chicken, and swine operations as a result of total confinement and covered storage. However, nitrous oxide emissions increase from material applied to land both on site and off site.

Veal operations emit a larger quantity of nitrogen oxides, carbon monoxide, and sulfur dioxide compared with baseline and all other options due to flaring. Wet layer and swine operations also emit additional criteria air pollutants compared to baseline because of this practice. However, compared to Options 2-4 and 7, these operations emit a smaller amount of VOCs, nitrogen oxides, particulate matter, and carbon monoxide but a larger amount of sulfur dioxide. For turkey operations, criteria air emissions increase from baseline to the same level that results from Options 2-4, 6 and 7.

Option 6

Under Option 6, emissions of precursor pollutants do not differ from Option 2 for all veal and poultry CAFOs and for Medium swine CAFOs. However, for Large swine CAFOs, this option results in changes to greenhouse gas and criteria air emissions. Methane and nitrous oxide emissions from the production area of Large swine CAFOs decrease substantially, due to the addition of an anaerobic digester with energy recovery. Generated methane is collected as biogas and converted to energy, and nitrous oxide is oxidized during the combustion process. Emissions of nitrogen oxides, carbon monoxide, and sulfur dioxide increase due to combustion of the biogas.

13.6.3 Energy Impacts

The regulatory options evaluated for CAFOs are based on the use of certain waste management systems and land application practices that may impact electricity and fuel usage. Both energy usage indicators were estimated in relation to baseline, with electricity usage in units of megawatt-hours per year (MW-hr/yr) and fuel usage in gallons.

Increased electricity usage occurs at beef (includes heifer) and dairy CAFOs under all options. Surface runoff from the feedlot must be collected and stored before it can be land applied. These additional measures require an increase in electricity expenditures. Because veal, poultry, and swine are confined in houses, these operations do not experience elevated electricity demands, as there are no additional runoff controls expected. In addition, the land application of waste consumes electricity during the operation of the irrigation system. It is assumed that swine and poultry operations already land apply their waste and therefore do not experience additional electricity needs. However, some beef (includes heifer) operations and dairies do not currently collect and land apply their liquid waste, and a zero discharge policy would likely result in these operations collecting and land applying this waste using new irrigation systems. As a result, the energy requirements of these operations are expected to increase.

Under Option 1, all operations except veal operations experience an increase in fuel usage due to the requirement that manure be land applied according to agronomic rates for nitrogen. This requirement is expected to result in excess manure nutrients being transported to off-site land application sites. This fuel usage grows under Options 2-4, 6 and 7 because of the more stringent phosphorus-based requirement and the resultant increase in the amount of manure to be transported. Veal operations are assumed to apply all waste on site no matter the option and thus do not incur additional energy costs.

Under Option 5, swine and chicken operations use less fuel as a result of the total confinement and covered storage requirements. Fuel consumption at veal and turkey operations does not change from baseline under any option.

Under Option 5A, which requires composting at beef (includes heifer) and dairy CAFOs, fuel usage by transportation vehicles decreases due to a decrease in the weight and/or volume of the waste. Nevertheless, because of the fuel demands of the composting equipment, total fuel usage at beef and heifer operations increases compared to other options. Because all beef (includes heifer) waste is deposited on the drylot, a large amount of waste is available for composting. The additional fuel usage of composting equipment at these operations offsets the decrease from lower transportation fuel requirements. At dairies, however, much of the manure is in liquid and slurry form and less solid waste can be composted. Consequently, the energy demands of the composting equipment do not outweigh the energy saved from a reduction in transportation, and the overall fuel usage for dairies decreases under Option 5A.

Overall electricity use decreases at those operations that use anaerobic digesters under Option 6. Large swine and dairy CAFOs that digest their waste and recover and use the biogas to operate an engine generate excess energy, which can be sold or used to operate other machinery.

Table 13-2. NWQI for Beef (Includes Heifers) - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	385,256	383,154	383,154	383,154	383,154		505,713	383,154	383,154
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC		NC	NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.93	0.86	0.86	0.86	0.86		1.13	0.86	0.86
Nitrous Oxide (N_2O)	7.72	7.72	7.72	7.72	7.72		7.93	7.72	7.72
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	1.4	18.6	18.6	18.6		18.7	18.6	18.6
Nitrogen Oxides (NOx)	Baseline	29.3	387.5	387.5	387.5		389.8	387.5	387.5
Particulate Matter (PM)	Baseline	1.0	12.9	12.9	12.9		13.0	12.9	12.9
Carbon Monoxide (CO)	Baseline	7.6	103.8	103.8	103.8		104.4	103.8	103.8
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	37,986	37,986	37,986		38,257	37,986	37,986
Fuel Usage (gallons/yr)	Baseline	178,069	2,280,586	2,280,586	2,280,586		2,295,467	2,280,586	2,280,586

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-3. NWQI for Dairy - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	151,595	147,591	147,591	147,591	147,591		162,576	147,591	147,591
Hydrogen Sulfide (H_2S)	5,986	3,611	3,611	3,611	3,611		3,611	3,611	3,611
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	5.85	3.60	3.60	3.60	3.60		3.68	0.02	3.60
Nitrous Oxide (NOx)	1.46	1.95	1.95	1.95	1.95		2.72	0.56	1.95
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	42.4	90.8	90.8	90.8		88.7	90.8	90.8
Nitrogen Oxides (NOx)	Baseline	850.3	1820.1	1820.1	1820.1		1779.0	1841.3	1820.1
Particulate Matter (PM)	Baseline	26.5	56.8	56.8	56.8		55.5	56.8	56.8
Carbon Monoxide (CO)	Baseline	240.5	514.3	514.3	514.3		502.7	519.7	514.3
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	20.1	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	14,430	14,430	14,430		14,430	(1,009,331)	14,430
Fuel Usage (gallons/yr)	Baseline	4,682,297	10,031,078	10,031,078	10,031,078		9,805,490	10,031,078	10,031,078

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-4. NWQI for Veal - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	149	149	149	149	149	104		149	149
Hydrogen Sulfide (H_2S)	10	10	10	10	10	2		10	10
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.001	0.001	0.001	0.001	0.001	0.00002		0.001	0.001
Nitrous Oxide (N_2O)	0.0017	0.0017	0.0017	0.0017	0.0017	0.0021		0.0017	0.0017
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Nitrogen Oxides (NOx)	Baseline	Baseline	Baseline	Baseline	Baseline	0.41		Baseline	Baseline
Particulate Matter (PM)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Carbon Monoxide (CO)	Baseline	Baseline	Baseline	Baseline	Baseline	0.36		Baseline	Baseline
Sulfur Dioxide (SO_2)	Baseline	Baseline	Baseline	Baseline	Baseline	0.41		Baseline	Baseline
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-5. NWQI for Swine - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	183,732	183,732	183,732	183,732	183,732	109,037		183,732	183,732
Hydrogen Sulfide (H_2S)	13,036	13,036	13,036	13,036	13,036	2,150		13,036	13,036
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	12.46	12.46	12.46	12.46	12.46	2.27		0	12.46
Nitrous Oxide (NOx)	0.29	0.29	0.29	0.29	0.29	0.52		0.20	0.29
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	1.9	32.8	32.8	32.8	16.9		31.5	32.8
Nitrogen Oxides (NOx)	Baseline	38.5	655.4	655.4	655.4	404.7		700.8	655.4
Particulate Matter (PM)	Baseline	1.2	20.4	20.4	20.4	10.5		19.6	20.4
Carbon Monoxide (CO)	Baseline	10.9	185.9	185.9	185.9	154.1		196.8	185.9
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	66.0		66.0	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		(2,217,565)	Baseline
Fuel Usage (gallons/yr)	Baseline	210,840	3,593,589	3,593,589	3,593,589	1,855,656		3,459,148	3,593,589

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-6. NWQI for Chickens - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	205,038	205,038	205,038	205,038	205,038	200,755		205,038	205,038
Hydrogen Sulfide (H_2S)	1,146	1,146	1,146	1,146	1,146	0		1,146	1,146
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	1.19	1.19	1.19	1.19	1.19	0.27		1.19	1.19
Nitrous Oxide (N_2O)	2.30	2.30	2.30	2.30	2.30	2.40		2.30	2.30
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	1.9	7.5	7.5	7.5	6.9		7.5	7.5
Nitrogen Oxides (NOx)	Baseline	41.0	161.7	161.7	161.7	152.7		161.7	161.7
Particulate Matter (PM)	Baseline	1.5	5.8	5.8	5.8	5.4		5.8	5.8
Carbon Monoxide (CO)	Baseline	10.4	40.8	40.8	40.8	39.8		40.8	40.8
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	2.6		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	256,763	1,015,976	1,015,976	1,015,976	952,584		1,015,976	1,015,976

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-7. NWQI for Turkeys - Large CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	35,599	35,599	35,599	35,599	35,599	35,599		35,599	35,599
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC	NC		NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.09	0.09	0.09	0.09	0.09	0.09		0.09	0.09
Nitrous Oxide (N_2O)	1.05	1.05	1.05	1.05	1.05	1.05		1.05	1.05
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.2	1.6	1.6	1.6	1.6		1.6	1.6
Nitrogen Oxides (NOx)	Baseline	4.6	35.3	35.3	35.3	35.3		35.3	35.3
Particulate Matter (PM)	Baseline	0.2	1.3	1.3	1.3	1.3		1.3	1.3
Carbon Monoxide (CO)	Baseline	1.2	8.8	8.8	8.8	8.8		8.8	8.8
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	NC		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	29,706	225,701	225,701	225,701	225,701		225,701	225,701

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-8. NWQI for Beef (Includes Heifers) - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	3990	3964	3964	3964	3964		5386	3964	3964
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC		NC	NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.012	0.013	0.013	0.013	0.013		0.016	0.013	0.013
Nitrous Oxide (N_2O)	0.08	0.08	0.08	0.08	0.08		0.10	0.08	0.08
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.012	0.067	0.067	0.067		0.070	0.067	0.067
Nitrogen Oxides (NOx)	Baseline	0.3	1.4	1.4	1.4		1.5	1.4	1.4
Particulate Matter (PM)	Baseline	0.009	0.049	0.049	0.049		0.051	0.049	0.049
Carbon Monoxide (CO)	Baseline	0.07	0.37	0.37	0.37		0.39	0.37	0.37
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	1,640	2,821	2,821	2,821		2,822	2,821	2,821
Fuel Usage (gallons/yr)	Baseline	1,613	8,668	8,668	8,668		9,071	8,668	8,668

NC - Not calculated.
[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-9. NWQI for Dairy - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	39,837	39,185	39,185	39,185	39,185		48,337	39,185	39,185
Hydrogen Sulfide (H_2S)	1,068	598	598	598	598		598	598	598
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.97	0.64	0.64	0.64	0.64		0.67	0.64	0.64
Nitrous Oxide (N_2O)	0.585	0.589	0.589	0.589	0.589		0.818	0.589	0.589
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.9	4.3	4.3	4.3		4.0	4.3	4.3
Nitrogen Oxides (NOx)	Baseline	18.4	87.5	87.5	87.5		82.8	87.5	87.5
Particulate Matter (PM)	Baseline	0.6	2.8	2.8	2.8		2.7	2.8	2.8
Carbon Monoxide (CO)	Baseline	5.1	24.1	24.1	24.1		22.7	24.1	24.1
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC		NC	NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	970	4,228	4,228	4,228		1,667	4,228	4,228
Fuel Usage (gallons/yr)	Baseline	103,764	498,686	498,686	498,686		473,028	498,686	498,686

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-10. NWQI for Veal - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	12	12	12	12	12	8		12	12
Hydrogen Sulfide (H_2S)	0.7	0.7	0.7	0.7	0.7	0.2		0.7	0.7
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.0001	0.0001	0.0001	0.0001	0.0001	0.000001		0.0001	0.0001
Nitrous Oxide (N_2O)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002		0.0001	0.0001
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Nitrogen Oxides (NOx)	Baseline	Baseline	Baseline	Baseline	Baseline	0.04		Baseline	Baseline
Particulate Matter (PM)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Carbon Monoxide (CO)	Baseline	Baseline	Baseline	Baseline	Baseline	0.04		Baseline	Baseline
Sulfur Dioxide (SO_2)	Baseline	Baseline	Baseline	Baseline	Baseline	0.04		Baseline	Baseline
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-11. NWQI for Swine - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	10,596	10,596	10,596	10,596	10,596	7,090		10,596	10,596
Hydrogen Sulfide (H_2S)	616	616	616	616	616	183		616	616
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.68	0.68	0.68	0.68	0.68	0.19		0.68	0.68
Nitrous Oxide (N_2O)	0.02	0.02	0.02	0.02	0.02	0.03		0.02	0.02
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.0	0.6	0.6	0.6	0.3		0.6	0.6
Nitrogen Oxides (NOx)	Baseline	0.6	11.9	11.9	11.9	7.5		11.9	11.9
Particulate Matter (PM)	Baseline	0.0	0.4	0.4	0.4	0.2		0.4	0.4
Carbon Monoxide (CO)	Baseline	0.2	3.4	3.4	3.4	3.1		3.4	3.4
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	1.6		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	3,266	65,369	65,369	65,369	31,852		65,369	65,369

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-12. NWQI for Chickens - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	6,287	6,287	6,287	6,287	6,287	6,276		6,287	6,287
Hydrogen Sulfide (H_2S)	3.1	3.1	3.1	3.1	3.1	0.0		3.1	3.1
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.040	0.040	0.040	0.040	0.040	0.038		0.040	0.040
Nitrous Oxide (N_2O)	0.1427	0.1427	0.1427	0.1427	0.1427	0.1430		0.1427	0.1427
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.07	0.43	0.43	0.43	0.43		0.43	0.43
Nitrogen Oxides (NOx)	Baseline	1.47	9.40	9.40	9.40	9.47		9.40	9.40
Particulate Matter (PM)	Baseline	0.05	0.34	0.34	0.34	0.43		0.34	0.34
Carbon Monoxide (CO)	Baseline	0.37	2.33	2.33	2.33	2.32		2.33	2.33
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	0.11		NC	NC
Baseline + Energy Usage[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	9,404	60,024	60,024	60,024	59,844		60,024	60,024

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

Table 13-13. NWQI for Turkeys - Medium CAFOs

NWQI	Baseline	Regulatory Option							
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 5A	Option 6	Option 7
AIR EMISSIONS									
Precursor Pollutants (tons per year)									
Ammonia (NH_3)	603	603	603	603	603	603		603	603
Hydrogen Sulfide (H_2S)	NC	NC	NC	NC	NC	NC		NC	NC
Greenhouse Gases (Tg/yr CO_2 - Equiv)									
Methane (CH_4)	0.002	0.002	0.002	0.002	0.002	0.002		0.002	0.002
Nitrous Oxide (N_2O)	0.018	0.018	0.018	0.018	0.018	0.018		0.018	0.018
Criteria Air Pollutants (tons per year)[a]									
Volatile Organic Compounds (VOCs)	Baseline	0.00	0.04	0.04	0.04	0.04		0.04	0.04
Nitrogen Oxides (NOx)	Baseline	0.09	0.82	0.82	0.82	0.82		0.82	0.82
Particulate Matter (PM)	Baseline	0.00	0.03	0.03	0.03	0.03		0.03	0.03
Carbon Monoxide (CO)	Baseline	0.02	0.20	0.20	0.20	0.20		0.20	0.20
Sulfur Dioxide (SO_2)	Baseline	NC	NC	NC	NC	NC		NC	NC
BASELINE + ENERGY USAGE[a]									
Electricity Usage (MW-hr/yr)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline		Baseline	Baseline
Fuel Usage (gallons/yr)	Baseline	596	5,213	5,213	5,213	5,213		5,213	5,213

NC - Not calculated.

[a]Energy estimates reflect the incremental change in usage from baseline.

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CHAPTER 14

GLOSSARY

aeration	the process of bringing air into contact with a liquid by one or more of the following methods: (1) spraying the liquid in the air, (2) bubbling air through the liquid, and (3) agitating the liquid to promote absorption of oxygen through the air liquid interface
aerobic	having or occurring in the presence of the free oxygen
aerobic lagoon	a holding and/or treatment pond that speeds up the natural process of biological decomposition of organic waste by stimulating the growth and activity of bacteria that degrade organic waste in an oxygen-rich environment
Ag Census	the census of agriculture conducted every 5 years; a major source of information about the structure and activities of agricultural production at the national, state, and county levels
agitation	thorough mixing of liquid or slurry manure at a storage structure to provide a more consistent fertilizer material and allow the producer to empty as much of the storage as possible
agronomic rates	the land application of animal wastes at rates of application that provide the crop or forage growth with needed nutrients for optimum health and growth
air emissions	release of any pollutant into the air
ammonia volatilization	the loss of ammonia gas to the atmosphere
anaerobic	the absence of molecular oxygen, or capable of living and growing in the absence of oxygen, such as anaerobic bacteria
anaerobic lagoon	a holding and/or treatment pond that speeds up the natural process of biological decomposition of organic waste by stimulating the growth and activity of bacteria that degrade organic waste in an oxygen-depleted environment

animal feeding operation (AFO)	a lot or facility (other than an aquatic animal production facility) where animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and the animal confinement areas do not sustain crops, vegetation, forage growth, or postharvest residues in the normal growing season. Two or more animal feeding operations under common ownership are a single animal feeding operation if they adjoin each other or if they use a common area or system for the disposal of wastes.
APHIS	Animal and Plant Health Inspection Service, United States Department of Agriculture
baffle	a device (as a plate, wall, or screen) to deflect, check, or regulate flow (fluid, light, or sound)
barrow	a castrated male pig
berm	a narrow shelf, path, or ledge typically at the top or bottom of a slope; a mound or wall of earth
best available technology (BAT)	the best available technology that is economically achievable established under 301(b) and 402 of the Federal Water Pollution Control Act as amended, also known as the Clean Water Act, found at 33 USC 1251 et seq. The criteria and standards for imposing technology-based treatment requirements are listed in 40 CFR 125.3.
best conventional technology (BCT)	the best conventional pollutant control technology that is economically achievable established under 301(b) and 402 of the Federal Water Pollution Control Act as amended, also known as the Clean Water Act, found at 33 USC 1251 et seq. The criteria and standards for imposing technology-based treatment requirements are listed in 40 CFR 125.3.
best management practice (BMP)	a practice or combination of practices found to be the most effective, practicable (including economic and institutional considerations) means of preventing or reducing the amount of pollution generated
bioavailability	the degree and rate at which a substance is absorbed into a living system or is made available at the site of physiological activity
biochemical oxygen demand (BOD)	an indirect measure of the concentration of biodegradable substances present in an aqueous solution. Determined by the amount of dissolved oxygen required for the aerobic degradation of the organic matter at 20 °C. BOD_5 refers to that oxygen demand for the initial 5 days of the degradation process

biogas	a mixture of methane and carbon dioxide produced by the bacterial decomposition of organic wastes and used as a fuel
biosecurity	a defensive health plan and hygiene procedures that can help keep an animal feeding operation disease free
biosolids	solid organic matter recovered from a sewage treatment process and used especially as fertilizer
BPJ	best professional judgement
BPT	best practicable technology
broadcasting	method of application (seed or fertilizer) to the soil surface
broilers	chickens of either sex specifically bred for meat production and marketed at approximately 8 weeks of age
carcass-weight	weight of the dead body of an animal, slaughtered and gutted
certified specialist	someone who has been certified to prepare Comprehensive Nutrient Management Plans (CNMPs) by USDA or a USDA sanctioned organization
compaction	an increase in soil bulk density, limiting both root penetration, and water and nutrient uptake induced by tillage- and vehicular-traffic
composting	a process of aerobic biological decomposition of organic material characterized by elevated temperatures that, when complete, results in a relatively stable product suitable for a variety of agricultural and horticultural uses
concentrated animal feeding operation (CAFO)	an "animal feeding operation" that meets the criteria in 40 CFR Part 122, Appendix B, or an operation designated as a significant contributor of pollution pursuant to 40 CFR 122.23
costing	a systematic method or procedure used to develop the estimated costs of a technology or practice
cover crop	a close-growing crop, whose main purpose is to protect and improve the soil and use excess nutrients or soil moisture during the absence of the regular crop, or in the nonvegetated areas of orchards and vineyards

crop removal rate	the application rate for manure or wastewater which is determined by the amount of phosphorus which will be taken up by the crop during the growing season and subsequently removed from the field through crop harvest. Field residues do not count towards the amount of phosphorus removed at harvest.
crop rotation	a planned sequence of crops
denitrification	the chemical or biological reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen (N_2) or as an oxide of nitrogen (N_2O)
detention pond	a basin whose outlet has been designed to detain the storm water runoff from a design storm (e.g., 25 year/24 hour storm) for some minimum time to allow particles and associated pollutants to settle
digestion	the process whereby organic matter breaks down into simpler and/or more biologically stable products, e.g., ammonia to organic nitrogen
disking	cultivating with an implement that turns and loosens the soil with a series of discs
dry lots	open feedlots sloped or graded from 4 to 6 percent to promote drainage away from the lot to provide consistently dry areas for cattle to rest
effluent	the liquid discharge from a waste treatment process
endogenous	growing or produced by growth from deep tissue (e.g., plant roots)
ephemeral erosion	a shallow, concentrated flow path that develops as a response to a specific storm and disappears as a result of tillage or natural processes
erosion	the wearing away of the land surface by water, wind, ice, or other geologic agents and by such processes as gravitational creep
ERS	Economic Research Service, United States Department of Agriculture
evapotranspiration	the loss of water from an area by evaporation from the soil or snow cover and transpiration by plants
farrowing	the act of giving birth to pigs by the sow
farrow-to-finish	contains all three hog production phases: farrow, nursery, finish
fecal coliform	the bacterial count (Parameter 1) at 40 CFR 136.3 in Table 1A, which also cites the approved methods of analysis.

feedlot	a concentrated, confined animal or poultry growing operation for meat, milk, or egg production, or stabling, in pens or houses wherein the animals or poultry are fed at the place of confinement and crop or forage growth or production is not sustained in the area of confinement, and is subject to 40 CFR 412
fertilizer value	the value of noncommercial fertilizer (e.g., manure)
flushing system	a system that collects and transports or moves waste material with the use of water, such as in washing of pens and flushing of confinement livestock facilities
freeboard	the height above the recorded high-water mark of a structure (as a dam) associated with the water
FRN	federal registrar notice
frequency factor	the regional compliance of animal feeding operations with BMPs associated with a nutrient management plan, facility upgrades, or strategies to reduce excess nutrients
FORTRAN	one of the most widely used programming languages for solving problems in science and engineering
gilt	a young or immature female pig
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
ground water	water filling all the unblocked pores of underlying material below the water table
hen	a mature female chicken
incorporation	mixing manure into the soil, either by tillage or by subsurface injection, to increase manure nutrient availability for use by crops
injection	a tillage implement that cuts into the soil depositing liquid or slurry
integrators	poultry companies, under contract with growers, who supply birds, feed, medicines, transportation, and technical help
irrigation	application of water to lands for agricultural purposes (Soil Conservation Society of America, 1982)

lagoon	an all-inclusive term commonly given to a water impoundment in which organic wastes are stored or stabilized, or both. Lagoons may be described by the predominant biological characteristics (aerobic, anaerobic, or facultative), by location (indoor, outdoor), by position in a series (primary, secondary, or other), and by the organic material accepted (sewage, sludge, manure, or other)
land application	application of manure, sewage sludge, municipal wastewater, and industrial wastes to land for reuse of the nutrients and organic matter for their fertilizer and soil conditioning values
land application area	any land under the control of the CAFO operator, whether it is owned, rented, or leased, to which manure and process wastewater is or may be applied
layer	a mature hen that is producing eggs
leaching	(1) the removal of soluble constituents, such as nitrates or chlorides, from soils or other material by the movement of water; (2) the removal of salts and alkali from soils by irrigation combined with drainage; (3) the removal of a liquid through a non-watertight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surrounding permeable soil
load	quantity of substance entering the receiving body
macronutrient	a chemical element required, in relatively large amounts, for proper plant growth
manure	the fecal and urinary excretions of livestock and poultry
micronutrient	a chemical element required, in relatively small amounts, for proper plant growth
mulch	any substance that is spread on the soil surface to decrease the effects of raindrop impact, runoff, and other adverse conditions and to retard evaporation
NAHMS	National Animal Health Monitoring System, United States Department of Agriculture
NASS	National Agricultural Statistics Service, United States Department of Agriculture

new source	a source that is subject to subparts C or D of 40 CFR 412 and, not withstanding the criteria codified at 40 CFR 122.29(b)(1): (i) is constructed at a site at which no other source is located; or (ii) replaces the housing including animal holding areas, exercise yards, and feedlot, waste handling system, production process, or production equipment that causes the discharge or potential to discharge pollutants at an existing source; or (iii) constructs a production area that is substantially independent of an existing source at the same site. Whether processes are substantially independent of an existing source, depends on factors such as the extent to which the new facility is integrated with the existing facility; and the extent to which the new facility is engaged in the same general type of activity as the existing source.
nitrification	the biochemical transformation by oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) or nitrate (NO_3^-)
nitrogen	a chemical element, commonly used in fertilizer as a nutrient, that is also a component of animal wastes. Plant available nitrogen forms include nitrate (NO_3^-) and ammonium (NH_4^+).
no-till	a planting procedure that requires no tillage except that done in the immediate area of the crop row
NRCS	Natural Resource Conservation Service, United States Department of Agriculture
NSPS	New Source Performance Standards are uniform national EPA air emission and water effluent standards that limit the amount of pollution allowed from new sources or from modified existing sources
nutrient management	a planning tool used to control the amount, source, placement, form, and timing of the application of nutrients and soil amendments (USDA, 1999)
nutrient management plan	an approach for managing the form, rate, timing, and method of application of nutrients, including nutrients from biosolids, being applied to the soil in a manner that provides adequate plant nutrition but minimizes the environmental impact of these nutrients
nutrient removal rate	the removal of nutrients in harvested material on a per acre basis
NWPCAM	National Water Pollution Control Assessment Model
organic matter	the organic fraction of the soil exclusive of undecayed plant and animal residue

overflow	the process wastewater discharge resulting from the filling of wastewater or liquid manure storage structures to the point at which no more liquid can be contained by the structure
permit nutrient plan (PNP)	a plan developed in accordance with 40 CFR 412.33 (b) and §412.37. This plan shall define the appropriate rate for applying manure or wastewater to crop or pasture land. The plan accounts for soil conditions, concentration of nutrients in manure, crop requirements and realistic crop yields when determining the appropriate application rate.
phosphorus	one of the primary nutrients required for the growth of plants. Phosphorus is often the limiting nutrient for the growth of aquatic plants and algae.
phosphorus level	a system of weighing a number of measures that relate the potential for phosphorus loss due to site and transport characteristics. The phosphorus index must at a minimum include the following factors when evaluating the risk for phosphorus runoff from a given field or site: (1) Soil erosion. (2) Irrigation erosion. (3) Run-off class. (4) Soil phosphorus test. (5) Phosphorus fertilizer application rate. (6) Phosphorus fertilizer application method. (7) Organic phosphorus application rate. (8) Method of applying organic phosphorus.
phosphorus threshold (TH level)	a specific soil test concentration of phosphorus established by states. The concentration defines the point at which soluble phosphorus may pose a surface runoff risk.
photoperiod	the time between sunrise and sunset
phytase	an enzyme effective at increasing the breakdown of phytase phosphorus in the digestive tract and reducing the phosphorous excretion in the feces
point source	the release of a contaminant or pollutant, often in concentrated form, from a conveyance system, such as a pipe, into a waterbody
porous dam	a runoff control structure that reduces the rate of runoff so that solids settle out in the settling terrace or basin. The structure may be constructed of rock, expanded metal, or timber arranged with narrow slots.

potassium	one of the primary nutrients required for the growth of plants
poult	a young, immature turkey
precipitation	a deposit on the earth of hail, mist, rain, sleet, or snow; *also* **:** the quantity of water deposited
pretreatment	a process used to reduce, eliminate, or alter the nature of wastewater pollutants from nondomestic sources before they are discharged into publicly owned treatment works
process wastewater	water directly or indirectly used in the operation of the CAFO for any or all of the following: spillage or overflow from animal or poultry watering systems; washing, cleaning, or flushing pens, barns, manure pits, or other CAFO facilities; direct contact swimming, washing or spray cooling of animals; litter or bedding; dust control; and stormwater which comes into contact with any raw materials, products or by-products of the operation.
production area	that part of the CAFO that includes the animal confinement area, the manure storage area, the raw materials storage area, and the waste containment areas. The animal confinement area includes but is not limited to open lots, housed lots, feedlots, confinement houses, stall barns, free stall barns, milkrooms, milking centers, cowyards, barnyard, exercise yards, animal walkways, and stables. The manure storage area includes but is not limited to lagoons, sheds, under house or pit storage, liquid impoundments, static piles, and composting piles. The raw materials storage area includes but is not limited to feed silos, silage bunkers, and bedding materials. The waste containment area includes but is not limited to settling basins, and areas within berms, and diversions which separate uncontaminated stormwater . Also included in the definition of production area is any egg washing or egg processing facility.
production phase	the animal life cycles grouped into discreet categories based on age and maturity
protease	any of numerous enzymes that hydrolyze proteins and are classified according to the most prominent functional group (as serine or cysteine) at the active site
PSES	Pretreatment Standards for Existing Sources
PSNS	Pretreatment Standards for New Sources
pullet	an immature female chicken

reduced-till	a management practice whereby the use of secondary tillage operations is significantly reduced
residue cover	unharvested material left on the soil surface designed to reduce water and wind erosion, maintain or increase soil organic matter, conserve soil moisture, stabilize temperatures, and provide food and escape cover for wildlife
RFA	Regulatory Flexibility Analysis
rill erosion	an erosion process in which numerous small channels of only several centimeters in depth are formed; occurs mainly on recently cultivated soils
runoff	the part of precipitation or irrigation water that appears in surface streams of waterbodies; expressed as volume (acre-inches) or rate of flow (gallons per minute, cubic feet per second)
SBA	Small Business Administration
SBREFA	Small Business Regulatory Enforcement Fairness Act
setback	a specified distance from surface waters or potential conduits to surface waters where manure and wastewater may not be land applied. Examples of conduits to surface waters include, but are not limited to, tile line intake structures, sinkholes, and agricultural well heads.
sheet erosion	soil erosion occurring from a thin, relatively uniform layer of soil particles on the soil surface; also called interrill erosion
side-dressing	the application of fertilizer alongside row crop plants, usually on the soil surface. Nitrogen materials are most commonly side-dressed.
sludge	settled sewage solids combined with varying amounts of water and dissolved materials that are removed from sewage by screening, sedimentation, chemical precipitation, or bacterial digestion
slurry	a thin mixture of a liquid and finely divided particles
soil test phosphorus	the measure of the phosphorus content in soil as reported by approved soil testing laboratories using a specified analytical method
sow	a mature female hog
spreader	a farm implement used to scatter fertilizer
supernatant	the liquid fraction in a lagoon

surface runoff	the portion of precipitation on an area that is discharged from the area through stream channels
surface water	all water whose surface is exposed to the atmosphere (Soil Conservation Society of America, 1982)
suspended solids	(1) undissolved solids that are in water, wastewater, or other liquids and are largely removable by filtering or centrifuging; (2) the quantity of material filtered from wastewater in a laboratory test, as prescribed in APHA Standard Methods for the Examination of Water and Wastewater or similar reference
tanker	a vehicle constructed to transport bulk liquids
tom	a male turkey
total suspended solids (TSS)	the weight of particles that are suspended in water. Suspended solids in water reduce light penetration in the water column, can clog the gills of fish and invertebrates, and are often associated with toxic contaminants because organics and metals tend to bind to particles. Differentiated from total dissolved solids by a standardized filtration process whereby the dissolved portion passes through the filter.
USDA	United States Department of Agriculture
volatilization	the loss of gaseous components, such as ammonium nitrogen, from animal manure
waste management system	a combination of conservation practices formulated to appropriately manage a waste product that, when implemented, will recycle waste constituents to the fullest extent possible and protect the resource base in a nonpolluting manner
wastewater	the spent or used water from a home, a community, a farm, or an industry that contains dissolved or suspended matter
water quality	the excellence of water in comparison with its intended use or uses