Feedlot Industry Sector Profile
Revised Draft Report

December 30, 1998

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Acknowledgments

This document was prepared by Tetra Tech, Inc. under EPA Contract 68-C7-0014, Work Assignment 1-33 by staff located at the Fairfax, VA; Research Triangle Park, NC; and Las Cruces, NM offices. Chapter 9 and portions of Chapter 10 are an abridged version of Chapters 1 through 8 of *Draft Swine and Poultry Industry Characterization, Waste Management Practices and Model Detailed Analysis of Predominantly Used Systems*, prepared by North Carolina State University on September 30, 1998, under EPA Contract 68-C7-0014, Work Assignment 1-27. SAIC prepared selected summary tables that were derived from data collected in the 1992 Census of Agriculture under EPA Contract 68-C4-0046, Work Assignment 4-24 based on technical direction from Marla Smith. EPA staff, Anna Kinney and Paul Shriner, provided technical contributions to Chapter 11. Anna Kinney, Kurt Roos, and Warren McFall provided comments on the draft document.

1.0 Introduction

This study is part of a preliminary analysis of operations that breed and grow animals primarily for food stocks. Typical and alternative waste management technologies and practices are described for a variety of animal sectors. The information presented in this report is complemented by the technical information presented in the *Draft of Swine and Poultry Industry Characterization, Waste Management Practices and Model Detailed Analysis of Predominantly Used Systems* (NCSU, 1998).

1.1 Background

According to 40 CFR 122.23, an animal feeding operation (AFO) is a lot or facility (other than an aquatic animal production facility) where the following conditions are met:

< 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.

< Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

For purposes of 40 CFR 122.23, a concentrated animal feeding operation (CAFO) is an AFO that meets one of the criteria summarized in Table 1-1 or has been designated on a case-by-case basis by the Environmental Protection Agency (EPA). Criteria (a) in Table 1-1 are applicable for any facility while criteria (b) are applicable if one of the following conditions is met: 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 waters of the United States 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; provided, however, that no AFO is a CAFO if the AFO discharges only in the event of a 25-year, 24-hour storm event.

Table 1-1. Criteria from 40 CFR Part 122, Appendix B.

Animal Categories	Number of Animals	
	Criteria (a)	Criteria (b)
Slaughter and feeder cattle	1,000	300
Mature dairy cattle (whether milked or dry)	700	200
Swine each weighing over 25 kg (~55 pounds)	2,500	750
Horses	500	150
Sheep or lambs	10,000	3,000
Turkeys	55,000	16,500
Laying hens or broilers (continuous overflow watering)	100,000	30,000
Laying hens or broilers (liquid manure system)	30,000	9,000
Ducks	5,000	1,500
Animal units[a]	1,000	300

[a] According to 40 CFR Part 122, Appendix B, an animal unit is calculated as the number of slaughter and feeder cattle multiplied by 1.0, plus the number of mature dairy cattle multiplied by 1.4, plus the number of swine weighing over 25 kg multiplied by 0.4, plus the number of sheep multiplied by 0.1, plus the number of horses multiplied by 2.0.

An assessment of the number of operations that might be CAFOs was made using the 1992 Census of Agriculture.[1] Since the Census of Agriculture data are not directly comparable to the regulations summarized above, the methodology included various scenarios to qualify the sensitivity of the assessment. The scenarios are as follows:

< **Scenario 1:** Broiler and layer operations with fewer than 30,000 animals for criteria (a) or fewer than 9,000 animals for criteria (b) were excluded.

< **Scenario 2**: Broiler and layer operations with fewer than 100,000 animals for criteria (a) or fewer than 30,000 animals for criteria (b) were excluded.

< **Scenario 3**: Broiler and layer operations with fewer than 100,000 animals for criteria (a) or fewer than 30,000 animals for criteria (b) were excluded; grazed sheep and horses were excluded.

< **Scenario 4**: Broiler and layer operations were excluded; grazed sheep and horses were excluded.

Complete details about the assessment methodology are provided in Sections A.1 and A.2 of Appendix A. Table 1-2 presents the results of this assessment for 40 CFR Part 122. Scenario 4 excludes broilers and layers and has a consideration for grazed sheep and horses, resulting in the lowest total number of operations (5,845) that might be a CAFO based on criteria (a) from Table 1-1. Scenario 3 includes broiler and layer operations with more than 100,000 animals. Under this scenario, an additional 540 layer and 1,855 broiler operations might be a CAFO, for a total of 8,205 operations. In Scenario 2, grazing is not considered and the number of horse and sheep operations doubles. Scenario 1 includes layer and broiler operations with more than 30,000 animals, resulting in increases to 1,731 and 12,785 operations, respectively.

A similar assessment was performed for 40 CFR Part 412. The results from this assessment are the same as those presented in Table 1-2 for beef, dairy, swine, turkeys, layers, broilers, and ducks. In Scenarios 3 and 4, the number of horse operations decreased by 3 from the results presented in Table 1-2. There was an 80 percent decrease in the number of sheep operations for all scenarios using criteria (a); a 62 percent decrease in the number of sheep operations using criteria (b), Scenarios 1 and 2; and a 71 percent decrease in the number of sheep operations using criteria (b), Scenarios 3 and 4. There was also a decrease (between 5.6 and 7.9 percent) in mixed operations depending on criteria and scenario. Overall, there was a decrease of between 0.5 and 1.2 percent of total operations.

More recently, USDA and EPA have considered normalizing operation sizes by computing the number of animal units at a given operation using the same procedure. These computations are usually based on the number of animals corresponding to 1000 pounds of live weight and are usually based on assumptions of average animal weight. The results presented in Table 1-2 are based on EPA’s current animal unit definition. For the remainder of this report; however, the methodology developed by Lander et al. (1998) for dairy, beef, broilers, layers, and turkeys will be adopted and extended to other animal categories. The Lander et al. (1998) procedure was selected because it had already been designed to work with the Census of Agriculture data and included substantial work summarizing the most current literature.[2] The modified procedure is summarized in Section A.3 of Appendix A. Table 1-3 presents the results of this assessment for the range of animal categories summarized in the 1992 Census of Agriculture database.

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[1] The 1997 Census of Agriculture data were not available for preparation of this report.

[2] Discussions with the senior author indicate that USDA is considering modifications to this methodology, but such modifications are not available at this time.

Table 1-2. Estimation of operations that might be CAFOs derived from data collected in the 1992 Census of Agriculture.

Animal Category	Part 122, criteria (a)				Part 122, criteria (b)				Number of Operations Evaluated
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4	
	Broiler and layer operations with fewer than 30,000 animals excluded	Broiler and layer operations with fewer than 100,000 animals excluded	Broiler and layer operations with fewer than 100,000 animals excluded; grazed sheep and horses excluded	Broiler and layer operations excluded; grazed sheep and horses excluded	Broiler and layer operations with fewer than 9,000 animals excluded	Broiler and layer operations with fewer than 30,000 animals excluded	Broiler and layer operations with fewer than 30,000 animals excluded; grazed sheep and horses excluded	Broiler and layer operations excluded; grazed sheep and horses excluded	
Beef	967	967	967	967	2,678	2,678	2,678	2,678	147,201
Broilers	12,785	1,855	1,855	0	17,778	12,785	12,785	0	35,759
Dairy	952	952	952	952	5,565	5,565	5,565	5,565	155,339
Ducks	108	108	108	108	156	156	156	156	16,854
Horses	39	39	22	22	275	275	176	176	338,346
Layers	1,731	540	540	0	4,621	1,731	1,731	0	87,927
Sheep	114	114	53	53	674	674	197	197	83,650
Swine	2,879	2,879	2,879	2,879	19,613	19,613	19,613	19,613	202,315
Turkeys	689	689	689	689	2,402	2,402	2,402	2,402	15,591
Animal units[a]	221	221	215	215	1,739	1,739	1,694	1,694	735,812
Total[b]	20,339	8,289	8,205	5,845	54,614	46,922	46,301	32,047	791,627

[a] Uses EPA's current animal unit definition (see Table 1-1).
[b] Since an operation can be characterized as a CAFO for more than one animal category, the total number of operations might not equal the column total.

Table 1-3. Distribution of operations by animal category and size class derived from data collected in the 1992 Census of Agriculture.

	Size Class (Animal Units[a])								
Animal Category	**1-25**	**25-100**	**100-300**	**300-500**	**500-1,000**	**1,000-5,000**	**5,000-10,000**	**10,000 or More**	**Tot. Num. of Oper.**
Beef	612,458	314,125	77,239	12,982	7,749	3,665	256	240	1,028,714
Broilers	18,519	9,214	7,319	531	153	18	2	3	35,759
Dairy	41,111	73,864	33,901	3,579	1,764	1,090	25	5	155,339
Ducks	16,771	58	16	4	3	2			16,854
Geese	12,387	10	1						12,398
Goats	47,316	1,245	344	53	21	4			48,983
Horses	336,732	6,257	384	49	16	14	1		343,453
Layers	84,076	4,489	1,649	363	244	196	20	3	91,040
Mink	828	78	10						916
Mules, burros, donkeys	26,157	28	1						26,186
Other poultry	5,619	30	5	3	1				5,658
Pheasants	2,609	26	2	1					2,638
Pigeons	1,724	4							1,728
Quail	1,560	3	2						1,565
Rabbits	14,880	23	3		1				14,907
Sheep	81,869	3,179	924	152	93	36	1	1	86,255
Swine	138,860	49,661	14,499	1,840	963	328	21	12	206,184
Turkeys	12,251	274	1,128	810	766	344	10	8	15,591

[a] Lander et al. (1998) procedure for computing animal units was adopted and extended for this table and the remainder of this document.

1.2 Scope and Document Organization

Data gathering for this report was limited to a literature search of readily available sources (including U.S. Department of Agriculture documents, Census of Agriculture, U.S. EPA documents, academic documentation, and trade literature) and information voluntarily submitted by stakeholders. Based on the data presented in Table 1-3, geese, pigeons, pheasants, quail, other poultry, mules, burros, donkeys, rabbits, and mink are not considered in detail. These sectors were excluded since each represents less than 2.5 percent of the total 1,061,056 operations that raise livestock and more then 90 percent of the operations within each of these sectors is in the 1 to 25 animal unit size class. Ducks also meet this criteria but were not excluded since ducks are included in the existing regulation. It should also be noted that there was not much available data on the excluded sectors or any other sectors not specifically considered.

The next chapter in this report is an assessment of the manure generation by animal operations across the United States. Chapters 3 through 10 provide an animal sector profile summarizing key operational characteristics and trends of dairy, beef, sheep, horses, goats, ducks, swine, and poultry (broilers, turkeys, and layers). Operational characteristics include the type of animal handling, feeding, and waste handling practices and the advantages and drawbacks associated with these practices. The information presented in Chapters 9 (swine) and 10 (poultry) were abridged from the NCSU (1998) report that was prepared to support revisions to the pork and poultry subcategories of the regulation (40 CFR 122.23 and 40 CFR Part 412). Chapter 11 presents a summary of waste treatment technology effectiveness and cost data.

Throughout this report, data summaries have been prepared by region to better describe the geographic distribution of the various animal sectors. For consistency, these regions correspond to those shown in Figure 1-1 although future analyses might require different regional groupings for different animal sectors.

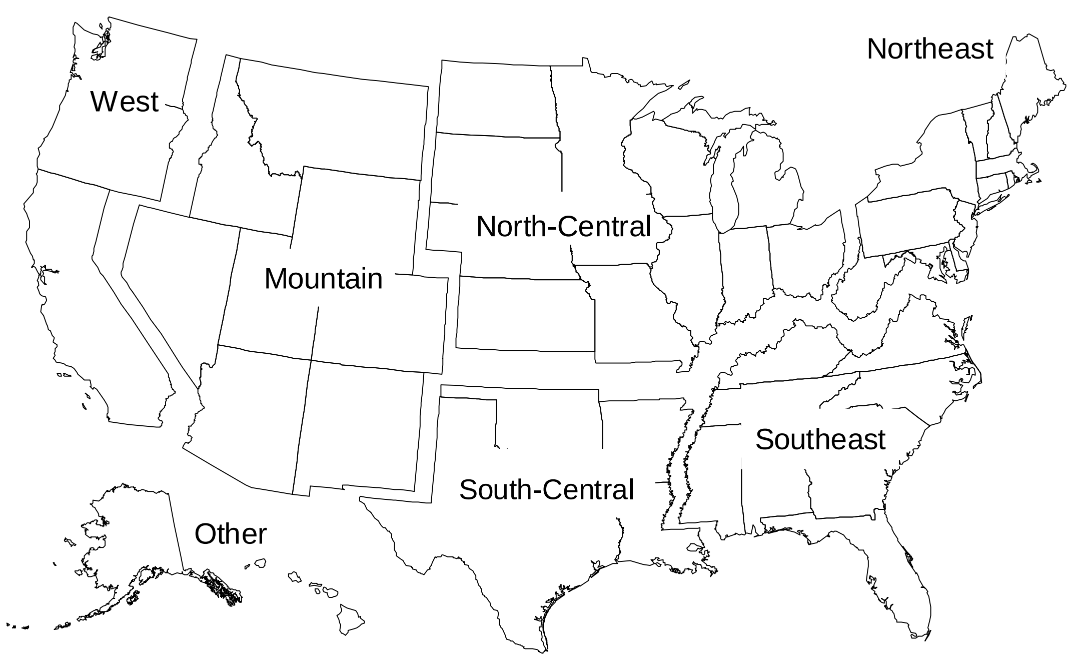

Figure 1-1. Regional grouping of states to facilitate data summaries presented in this report.

1.3 References

Lander, C.H., D. Moffitt, and K. Alt. 1998. *Nutrients Available from Livestock Manure Relative to Crop Growth Requirements.* U.S. Department of Agriculture, Natural Resources Conservation Service, Resource Assessment and Strategic Planning Working Paper 98-1. <http://www.nhq.nrcs.usda.gov/land/pubs/nlweb.html>. Accessed October 15, 1998.

NCSU. 1998. *Draft of Swine and Poultry Industry Characterization, Waste Management Practices and Model Detailed Analysis of Predominantly Used Systems*. North Carolina State University, Raleigh, North Carolina. September.

2.0 Animal Waste Production in the United States

2.1 Introduction

This chapter describes the procedures and results associated with estimating animal waste production in the United States. It is based on the methodology developed by Lander et al. (1998) and the 1992 Census of Agriculture data (Geographic Area Series 1B, U.S. Summary and County Level Data).

2.2 Approach

The Lander et al. (1998) approach for computing animal units, manure production, and nutrient availability was adopted for beef, dairy, swine, broilers, layers, and turkeys. The basic methodology was extended for other animal sectors through additional literature searches and assessment. The top portion of Table 2-1 summarizes the work from Lander et al. (1998); the bottom portion of the table documents the sources and assumptions used to extend their procedure to additional animal sectors.

For animals taken from birth to market weight in the same operation, a simple average weight between birth and market weight was used. These values were then converted into the number of animals per animal unit (Table 2-1, third column). Production length was set to 365 days per year, which tends to overestimate manure production for operations that have multiple cycles per year. In cases such as broilers, the amount of down time is not controlled by the individual producer. Manure generation and nutrient content as excreted were compiled from the *Livestock Waste Facilities Handbook* (Midwest Plan Service, 1985), *Agricultural Waste Management Field Handbook* (USDA-NRCS, 1992), *Livestock Manure Characterization Values From the North Carolina Database* (NCSU, 1990), and *Manure Production and Characteristics* (ASAE Standard D384.1). Local information generally proved to be local adaptations of nationally available information. According to Lander et al. (1998)

> The categories of nitrogen, phosphorus, and potassium content (after losses) in [Table 2-1] were added to provide a mechanism for estimating the amount of nutrients that would be present in land applied manure and effluent. There is no national or even regional perspective on what these values should be. The estimates shown are based on a three part assumption:
>
> < Nitrogen losses will exceed (greatly exceed) those of phosphorus and potassium primarily due to volatilization of nitrogen compounds.
>
> < As the quality (from an automation view) and numbers of manure management systems improve, the losses of nutrients, particularly nitrogen, may increase. In other words, as the manure management system becomes more automated, nitrogen losses through volatilization also increase.
>
> < Phosphorus and potassium amounts are present within the bottom sludge of lagoons and ponds, and even though the sludge is not removed on a regular basis, the phosphorus and potassium content must be considered in an application strategy; i.e., effluent composition may not reflect actual nitrogen, phosphorus and potassium in the lagoon or holding pond.
>
> Numerous individuals in USDA, at universities, and part of the industry groups were consulted to arrive at the national values for after losses. The discussions focused on the types of manure systems typically used by the industry in different parts of the country, the losses typically associated with these systems ..., and the portion of the nation's livestock raised in different parts of the country. The values shown in [Table 2-1] are estimates based on all these assumptions and considerations.

Table 2-1. Basic manure characteristics.

Animal Category	Census Variable Symbol	Animal /AU	Annual Manure Production Factors (Tons/ AU-yr)	Manure Nutrient Content Factors (lbs/ton)						Produc. Cycles (#/year)
				Nitrogen		Phosphorus		Potassium		
				as excreted	after losses	as excreted	after losses	as excreted	after losses	
Beef cows [a]	K804	1	11.50	10.95	3.3	3.79	3.23	8.25	7.44	1
Milk cows [a]	K805	0.74	15.24	10.69	4.3	1.92	1.65	6.70	6.04	1
Calves [a]	K804 or K805	4								
Heifers and heifer calves [a]	K806	1.82	12.05	6.06	1.82	1.30	1.10	5.03	4.53	1
Steers, steer calves, bulls, and bull calves [a]	K807	1.64	10.59	10.98	3.3	3.37	2.86	7.87	7.08	1
Fattened cattle sold [a]	K812	1.14	10.59	10.98	4.39	3.37	2.86	7.87	7.08	2.5
Breeding hogs/pigs [a]	K816	2.67	6.11	13.26	3.32	4.28	3.62	7.85	7.04	1
Other hog/pig [a]	K817	9.09	14.69	11.30	2.82	3.29	2.80	7.95	7.16	2
Hens/pullets laying age [a]	K892	250	11.45	26.93	18.46	9.98	8.50	10.44	9.40	1
Pullets>3 months, not laying [a]	K894	250	8.32	27.20	13.6	10.53	8.95	11.41	10.27	2
Pullets<3 months [a]	K896	455	8.32	27.20	13.6	10.53	8.95	11.41	10.27	2
Broiler [a]	K898	455	14.97	26.83	16.1	7.80	6.61	10.49	9.48	6
Turkeys for slaughter [a]	K900	67	8.18	30.36	16.18	11.83	10.06	11.61	10.44	2
Turkey hens for breed [a]	K902	50	9.12	22.41	11.2	13.21	11.23	7.60	6.84	1
Horse	K830	1 [b]	9.31 [b]	11.76 [b]	3.53 [n]	2.78 [b]	2.37 [p]	9.80 [b]	8.82 [q]	1
Donkeys/mules/burros	K833	1.7 [c]								1
Sheep	K824	16.7 [b]	7.30 [b]	21.00 [b]	6.30 [n]	4.35 [b]	3.70 [p]	16.00 [b]	14.40 [q]	1.5
Milk goats	K843	7.6 [b,d]	7.48 [b]	21.95 [b]	6.59 [n]	5.37 [b]	4.56 [p]	15.12 [b]	13.61 [q]	1
Angora goats	K847	10 [e]	7.48 [m]	21.95 [m]	6.59 [n]	5.37 [m]	4.56 [p]	15.12 [m]	13.61 [q]	1
Mink	K836	200 [f]	0.20							2 [l]
Rabbit	K854	154 [g]								2.5 [l]
Duck	K904	244 [b,h]	20.08 [b]	27.27 [b]	16.36 [o]	9.82 [b]	8.35 [p]	12.91 [b]	11.62 [q]	5 [l]
Geese	K906	101 [h]								2 [l]
Pigeons	K908	435 [i]								3 [l]
Pheasants	K910	357 [j]								4 [l]
Quail	K912	4760 [k]								5 [l]

[a] Lander et al. (1998)
[b] ASAE Standard (1998) D384.1
[c] L. Patton, personal communication 7/13/98
[d] http://uslink.net/~act/bmf/history.html
[e] http://members.aol.com/melodiehll/goats.html
[f] http://agri.gov.ns.ca/rs/greenplan/waste/061.html
[g] http://www.rabbit.org/faq/faq.txt
[h] http://eru.usask.ca/saf_corp/livestock/poultry/ducks_and_geese.html
[i] http://www.geocities.com/Athens/Acropolis/6450/ BASICPIGEONINFO.html
[j] http://ndsuext.nodak.edu/extpubs/alt-ag/pheasan.htm
[k] http://pages.prodigy.net/nightfalcon/bobwhite.htm
[l] Estimated based on ratio of animals sold to inventory from 1992 Census of Agriculture
[m] Estimated from milk goats
[n] Estimated as 30 percent of nitrogen excreted
[o] Estimated as 60 percent of nitrogen excreted
[p] Estimated as 85 percent of phosphorus excreted
[q] Estimated as 90 percent of potassium excreted

> To calculate the quantities of nutrients available from animal manure, it was necessary to estimate the quantities of recoverable manure for each of the animal categories studied ... In application, the recoverable manure factors are multiplied times the tons of manure per animal unit or by the total tons of manure produced by the entire population of an animal category to arrive at the value of recoverable manure. Nutrient values per ton [of recoverable manure] remain the same [as excreted manure] based on the assumption that the decrease in nutrients ... mirror[s] the reduction in the solids content [from excreted to] recoverable manure. This assumption is environmentally conservative and, for phosphorus and potassium, is relatively sound. For nitrogen, however, the assumption has some problems. Nitrogen, being relatively volatile in some forms, has a tendency to decrease rapidly as the manure is left unrecovered. Unfortunately, there is relatively little information to relate recoverable manure and recoverable nitrogen. It could vary both by animal

type and management style. The best estimate of manure nutrient content for land application comes from considering both recoverable manure and after losses together, i.e., neither taken separately tells the complete story.

Based on the typical nutrient losses developed by Lander et al. (1998), similar values were developed for the additional animal categories. For this report, manure as excreted and recoverable manure after losses are evaluated. The equations used in this analysis are summarized in Appendix A, Exhibits A-1 and A-2.

2.3 Waste Generation

Using state summary-level data from the 1992 Census of Agriculture, the number of animal units and amount of nutrients as excreted and recoverable after losses were estimated. State- and region-level results are presented in Appendix A, Tables A-7 and A-8. Table 2-2 presents a summary of this information.

Beef accounts for 62.6 percent (51,051,678 animal units) of the total number of farm-domesticated animal units. Dairy and swine follow with 18.1 and 9.6 percent of the total animal units, respectively. Layers, broilers, turkeys, horses, sheep, and goats account for the remaining 9.7 percent of the animal units.

Beef accounts for more than one-half (53 percent) of the nitrogen as excreted, but only 18.5 percent of the recoverable nitrogen after losses. Dairy accounts for nearly one-fifth (19.9 percent) of the excreted nitrogen, but 30.4 percent of the recoverable nitrogen after losses. Swine account for less than one-tenth (9.5 percent and 8.9 percent) of the excreted nitrogen and recoverable nitrogen after losses. Broilers, layers, and turkeys account for 14.1 and 37.2 percent of the excreted nitrogen and recoverable nitrogen after losses, respectively.

Beef accounts for more than one-half (58.8 percent) of the excreted phosphorus and about one-fourth (23.7 percent) of the recoverable phosphorus after losses. Dairy account for 12.5 percent of the excreted phosphorus and 21.9 percent of the recoverable phosphorus after losses. Swine account for 9.6 percent of the excreted phosphorus and 16.2 percent of the recoverable phosphorus after losses. Broilers, layers, and turkeys account for 16.5 and 32.5 percent of the excreted phosphorus and recoverable phosphorus after losses, respectively.

Horses, sheep, goats, and ducks account for less than 3.3 and 2.5 percent of the nitrogen and phosphorus as excreted, respectively. Assuming 100 percent recovery (a high estimate), horses, sheep, goats, and ducks account for 4.8 and 5.7 of the nitrogen and phosphorus after losses, respectively.

2.4 References

Lander, C.H., D. Moffitt, and K. Alt. 1998. *Nutrients Available from Livestock Manure Relative to Crop Growth Requirements.* U.S. Department of Agriculture, Natural Resources Conservation Service, Resource Assessment and Strategic Planning Working Paper 98-1. <http://www.nhq.nrcs.usda.gov/land/pubs/nlweb.html>. Accessed October 15, 1998.

Table 2-2. Estimate of animal units and nutrients from manure by animal category and region.

Animal Category	Animal Units		Nitrogen as Excreted		Recoverable Nitrogen after Losses		Phosphorus as Excreted		Recoverable Phosphorus after Losses		Potassium as Excreted		Recoverable Potassium after Losses	
	AU	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
Beef	51,051,678	62.6	2,991,126	53.0	213,334	18.5	977,468	58.8	150,560	23.7	2,244,666	59.3	370,701	24.6
Broilers	1,970,429	2.4	395,707	7.0	229,673	19.9	115,040	6.9	94,294	14.8	154,713	4.1	135,236	9.0
Dairy	14,756,164	18.1	1,124,909	19.9	350,093	30.4	207,227	12.5	139,083	21.9	718,387	19.0	504,932	33.5
Ducks[a]	15,059	0.02	4,123	0.07	2,473	0.2	1,485	0.09	1,262	0.2	1,952	0.05	1,757	0.1
Goats[a]	194,064	0.2	15,931	0.3	4,783	0.4	3,898	0.2	3,310	0.5	10,974	0.3	9,878	0.7
Horses[a]	2,049,522	2.5	112,197	2.0	33,678	2.9	26,523	1.6	22,611	3.6	93,497	2.5	84,147	5.6
Layers	1,246,034	1.5	182,971	3.2	114,557	9.9	68,224	4.1	55,098	8.7	71,734	1.9	61,257	4.1
Sheep[a]	673,154	0.8	51,597	0.9	15,479	1.3	10,688	0.6	9,091	1.4	39,312	1.0	35,381	2.3
Swine	7,814,778	9.6	538,467	9.5	101,952	8.9	160,096	9.6	103,160	16.2	367,121	9.7	250,560	16.6
Turkeys	1,836,468	2.3	221,911	3.9	85,650	7.4	92,161	5.5	57,437	9.0	83,628	2.2	54,886	3.6
Total	81,607,349		5,638,938		1,151,673		1,662,809		635,908		3,785,985		1,508,736	

Region	Animal Units		Nitrogen as Excreted		Recoverable Nitrogen after Losses[a]		Phosphorus as Excreted		Recoverable Phosphorus after Losses[a]		Potassium as Excreted		Recoverable Potassium after Losses[a]	
	AU	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
Mountain	9,902,263	12.1	606,993	10.8	72,458	6.3	184,408	11.1	42,036	6.6	445,571	11.8	121,245	8.0
North-Central	32,433,500	39.7	2,159,519	38.3	430,893	37.4	632,351	38.0	268,642	42.2	1,479,577	39.1	681,762	45.2
Northeast	4,544,869	5.6	374,712	6.6	127,936	11.1	91,808	5.5	58,479	9.2	225,245	5.9	147,498	9.8
South-Central	15,300,869	18.7	1,023,170	18.1	169,596	14.7	319,362	19.2	91,677	14.4	703,524	18.6	197,080	13.1
Southeast	13,216,785	16.2	1,027,891	18.2	246,784	21.4	316,102	19.0	126,316	19.9	639,576	16.9	224,879	14.9
West	6,056,642	7.4	437,060	7.8	102,857	8.9	115,843	7.0	48,103	7.6	285,571	7.5	134,557	8.9
Other	152,421	0.2	9,593	0.2	1,151	0.1	2,935	0.2	654	0.1	6,920	0.2	1,714	0.11
Total	81,607,349		5,638,938		1,151,673		1,662,809		635,908		3,785,985		1,508,736	

[a] Assumes all manure from horses, sheep, goats, and ducks is recoverable.

3.0 Dairy

3.1 Introduction

The care and management of the dairy cow depends on the animal's age, lactation and pregnancy status, and health, as well as the location, facilities, and surrounding environment. Nearly all dairy operations (93 percent) use holstein cows as the primary animal breed. Dairy operations that primarily use Jersey and Guernsey cows account for 4.1 and 1.7 percent of the dairies. Ayrshire, Brown Swiss, and other breeds account for the remaining 1.2 percent of dairy operations (APHIS, 1996a). Table 3-1 shows the distribution of calves, heifers, and mature cattle in a typical dairy herd.

Table 3-1. Distribution of calves, heifers, and mature cattle in a typical dairy herd.

Herd size (total mature cows)	75	100	250	400
Calves and heifers (total)	75	100	250	400
0-2 months, 150 lb	6	8	20	32
3-5 months, 250 lb	9	12	30	48
6-8 months, 400 lb	9	12	30	48
9-12 months, 600 lb	14	18	45	72
13-15 months, 800 lb	9	12	30	48
16-24 months, 1,050 lb	28	38	95	152
Dry cows (total)	13	17	43	68
Transition (first 4-14 days)	0-4	1-5	4-9	5-16
Next 40 days (divide in 2 groups)	8-9	11-12	28-30	45-48
Close-up (2-3 weeksprepartum)	2-5	3-6	8-15	16-24
Maternity (individual pens)	3-5	4-6	10-16	16-24
Fresh cows (0-7 days postpartum)	1-3	1-4	3-10	4-12
Two-year-olds (305 days lactation)	18-24	26-30	65-75	104-120
Three years and older (305 days lactation)	44	58	145	232
High producers (< 120 days)	15-18	20-24	50-60	80-96
Medium producers	12-15	16-20	40-50	60-72
Low producers	12-15	16-20	40-50	60-72
Sick cows	0-4	0-5	0-13	0-20

Source: Adapted from MWPS (1997). Numbers assume uniform calving year-around, 12-month calving interval, first calving at 24 months of age, all males sold at birth, a 30% culling rate, 0% mortality, and a stable herd size.

After calving, a dairy cow is normally milked two or three times a day for 10 to 12 months. Once milking is stopped, the cow is called a "dry" cow. This dry period, which usually begins 40 to 70 days (with an average of 61.7 days) prior to the next calving, allows for the regeneration of milk secretory tissue in the udder. On average, dairy cows have an average calving interval of 13 months, with the first calving at 25.5 months.

Most cows have access to outside areas. Table 3-2 summarizes the percentage of lactating and dry cows that have access to outside areas on a daily basis during the summer and winter months.

Each year, up to one-third of the lactating dairy cattle are culled from the herd. The average percentage of cows culled from the herd in 1995 (as a percent of January 1, 1996, dairy cow inventory) is 24 percent. The leading reasons for culling include reproductive problems, udder or mastitis problems, poor production, or lameness/injury. Operations that use milk production as a criterion for culling use an average of 33.4 pounds of milk per cow per day to determine when to cull non-pregnant dairy cows. Most culls (95.5 percent) go to slaughter, but some (4.5 percent) are purchased at auctions and relocated to other farms (APHIS, 1996a).

Table 3-2. Percent of operations and cows on those operations that had outside area accessible on a daily basis.

Type of Area	Lactating Cows				Dry Cows			
	Summer		Winter		Summer		Winter	
	Percent Oper.	Percent Cows	Percent Oper.	Percent Cows	Percent Oper.	Percent Cows	Percent Oper.	Percent Cows
Both pasture and dry lot	41.8	31.7	11.4	10.8	38.4	30.7	11.4	12.5
Pasture only	27.7	18.5	5.5	4.5	39.9	34.6	9.5	11.0
Dry lot only	21.6	37.5	57.5	59.6	18.4	32.0	56.7	56.3
Neither pasture nor dry lot	8.9	12.3	25.6	25.1	3.3	2.7	22.4	20.2

Source: APHIS, 1996c.

Many dairy operations use artificial insemination as the primary means for breeding cows. In fact, 45.4 percent of operations do not keep bulls in their inventory (APHIS, 1996a). Some dairies use bulls to breed cows that had difficulty conceiving through artificial insemination or aborted early in gestation. These bulls, referred to as “clean-up” bulls, are housed with cows in group corrals. Clean-up bulls are usually purchased from registered breeders to provide superior genetics for the herd. Sometimes semen is collected from the clean-up bulls and distributed to other dairies for artificial insemination.

Heifer calves are usually raised as replacements for lactating cows. Forty-five percent of heifer calves are separated from the mother immediately (no nursing), 27.4 percent are separated within 12 hours, 18.7 percent are separated within 12 to 24 hours, and 8.9 percent are separated after 24 hours. Weaning involves the transition from a milk-based diet to a forage or concentrate. On average weaning occurs at 8.7 weeks, with 94.2 percent of heifer calves weaned between 4 and 12 weeks (APHIS, 1996a). Usually, a healthy calf can be weaned successfully once it is eating at least 1.5 pounds of calf starter (dry feed). Nationally, 1.7 percent (7.8 percent in the West) of farmers have someone else raise their heifers on a contract basis (APHIS, 1993). Some bull calves are raised for veal or beef or are terminated soon after birth. The proportion of bull calves raised for veal or beef is geographically variable. From birth to weaning is the time of the greatest mortality and morbidity. About 10.8 percent of heifer calves die before weaning, primarily due to scours, diarrhea, digestive problems, or respiratory problems. Approximately 2.4 percent of weaned heifers die before first calving, and 3.8 percent of dairy cows die each year (APHIS, 1996a).

3.2 Housing

Most dairy operations provide separate housing for different groups of animals based on age (calf versus cow) and milking status (lactating versus dry). Figure 3-1 summarizes the percent of operations by housing facilities for dairy heifers and adult cows. Housing can also be characterized as cold versus warm housing. Cold housing is uninsulated, with natural ventilation designed as an integral part of the building. Indoor temperatures are closely related to outside temperatures. Cold housing systems are less expensive to build and are easily ventilated, allowing better disease control. During cold weather cold housing can make manure handling more difficult, as well as increasing feed consumption to maintain body heat. Warm housing, or environmentally controlled housing, tends to be less desirable since it is typically more expensive to construct and requires increased management.

3.2.1 Replacement Housing

Replacement housing can be grouped into the following categories: calf housing (0-2 months), transition housing (3-5 months), and heifer housing (6-24 months).

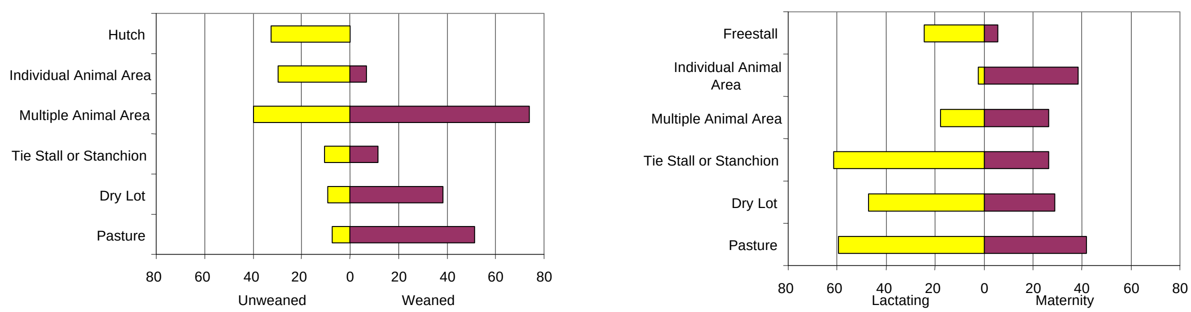

Figure 3-1. Percent of operations by housing facilities for dairy heifers and adult cows (Source: APHIS, 1996a).

3.2.1.1 Calf Housing

As mentioned earlier, the period from birth to weaning is the time of greatest mortality and morbidity, therefore, special care is taken to minimize environmental stress by ensuring that the housing provides protection from heat, cold, wind, and rain. Adequate space, comfort, and proper ventilation are also important when designing calf housing. Facilities are designed for complete cleaning and disinfecting on a regular basis to reduce the number of pathogens. The types of housing that can be used for calves include individual pens, hutches, and closed housing (Stull, 1996).

Individual pens. Individual pens separate calves and reduce the spread of communicable diseases. Individual pens also make it easier to observe changes in behavior, feed consumption, and waste production, which can indicate sickness. In cold housing systems, pens are typically 4 by 7 feet and removable. A cover on the back half of the pen may be added to give the calf additional protection in drafty locations. These pens are usually placed on crushed rock or concrete as a base for bedding. In warm housing systems, it is possible to use 2 by 4 foot expanded metal or slatted wood elevated pens. However, to avoid hock, leg, and joint problems sometimes associated with the metal pens, expanded metal is coated with plastic. Because these pens provide little shelter from drafts and cold in the winter, calves may suffer from cold stress, making it advisable to avoid individual pens for housing calves in colder climates. Pneumonia may also be associated with the elevated pens that are placed over flush systems for cleaning. These problems can be minimized if the pen size is doubled and a bedding box filled with straw or other comfortable materials is added.

Hutches. Most individual outside hutches are approximately 4 by 8 by 4 feet and made out of wood. One end of the hutch is left open, and wire fence is provided to allow the calf to move outside. Hutches are more labor-intensive than elevated metal pens, but they allow for complete separation of unweaned calves and better insulation from drafts. Hutches are easy to move and can be modified to account for temperature, sunlight, predominating winds, and direction of inclement weather. This mobility also allows for easier cleaning. Fiberglass or polyethylene hutches are easier to sanitize than wooden hutches or metal pens.

Closed housing. An enclosed barn containing individual pens constitutes “closed housing.” Problems of accumulating moisture and manure gases (methane, carbon dioxide, hydrogen sulfide, and ammonia) increase calves’ susceptibility to respiratory diseases, making it critical for closed housing to have adequate ventilation. Environmentally controlled closed housing is expensive to construct and operate, and it requires more management than the other types of calf housing.

3.2.1.2 Transition Housing

As calves age, group size may be increased. After about 150 days of age, calves may be placed on pasture or housed in groups of up to 100 to 200, sorted into uniform groups with individual calves having no more than about 10 percent weight variation from the mean of the group. Typical housing includes calf shelters or super hutches, transition barn, and calf barn.

Calf shelter or super hutches. These portable pens provide a feeder, water trough, and shelter for up to six calves, usually providing calves with 25 to 30 square feet each (Morrill et al., 1991 and Stull, 1996). Super hutches can be moved in a field or pasture when necessary to provide a clean surface for the calves.

Transition barn. A transition barn provides a series of pens (typically 10 by 24 feet) for calves up to 6 months old. Capacity is slightly higher if the entire pen is bedded (eight versus six animals). Transition barns usually have a single sloped roof and are open to the south or east to take advantage of sunlight. The back and end walls can be removed in the summer for natural ventilation.

Calf barn. A calf barn combines individual pens and transition group pens for calves in one building design. Pens are designed for easy dismantling and manure removal.

3.2.1.3 Heifer Housing

The most common types of housing for heifers after 6 months of age are freestall and bedded pack housing systems. In *freestalls*, young heifers are grouped in stalls that are sized to be compatible with the age or size of the heifer. Freestall housing requires less bedding than bedded pack housing, but more frequent manure removal from alleys. *Bedded pack housing* is often used with an outside feeding area. It is sized to allow for installation of a scrape alley and freestalls at a later date. The bedded area is roofed to provide a warm, draft-free resting surface and includes substantial amounts of bedding to keep animals clean and dry. Manure is removed as a solid two to four times a year.

3.2.2 Housing During Periparturient (around calving) Period

Sod pastures are often used for calving during the summer, but might become too muddy during the winter in some climates. Maternity and calving pens may also be used. In those operations where special housing is provided, cows are moved to a “close-up” pen for easier observation (usually 2 weeks before parturition). When parturition is very near, cows are moved to a maternity area for calving (Stull, 1996).

Close-up cow pens. Cow density in close-up cow pens is about one-half the density in lactating cow pens to allow the calving cows some space to segregate themselves from other cows.

Maternity area. A pasture can be used for the maternity area; small individual pens are also suitable. Pens are usually designed to allow at least 100 square feet per cow and maintain a well-ventilated but not drafty environment.

3.2.3 Housing for Lactating Dairy Cows

Nearly 70 (69.5) percent of operations use tie stall or stanchion type milking parlors. These account for 43.9 percent of the cows in the United States. Milking parlors are used in 28.8 percent of the dairy operations and account for 54.9 percent of the cows milked in the United States (APHIS, 1996a). Methods to house lactating cows include freestall barns and loose housing such as barns, corrals, or shades. The predominant flooring type for lactating cows is concrete (83.2 percent of cows), followed by dirt (9.6 percent), pasture (4.6 percent), and concrete slats (1.6 percent). About two-thirds (66.9 percent) of operations use straw and/or hay for bedding, followed by wood products (27.9 percent), rubber mats (27 percent), corn cobs or stalks (12.8 percent), sand (11.2 percent), and shredded newspaper (6.7 percent) (APHIS, 1996c). Composted manure, rubber tires, and mattresses were also identified as bedding.

Freestalls. Freestalls are individual cow bedding areas where comfort and sanitation are aided through partitions separating the cows. One stall is provided for each lactating cow, and in some cases more stalls may be added to accommodate herd growth and provide an escape area for subordinate animals to move away from more aggressive members of the herd.

Loose Housing. Loose housing units, such as barns, shades, and corrals, provide the dairy cow with thermal and physical comfort and minimize disease. Because overcrowding tends to intensify unfavorable conditions like excess moisture, manure accumulation, and reduced ventilation, which can lead to cow health problems such as mastitis and pneumonia, animal spacing is important under loose housing conditions. The recommended loafing space for each cow is 40 to 50 square feet of roofed area, in semi-arid conditions. In unpaved earthen exercise corrals, the recommended space for a group of 100 cows is 500 to 600 square feet per animal. When corrals are paved, space can be reduced to 100 square feet per animal. Alternatively, in cooler climates only 20 to 30 square feet of roofed area per animal is necessary for small breeds and 30 to 40 square feet for larger breeds (Stull, 1996). Surfaces in loose housing should contain scarified concrete areas that are 15 to 20 feet wide around water troughs, feed bunks, and entrances to give cows ample footing in these areas. The hard surfaces should also have a 4 percent slope for proper drainage. Dirt lots should slope at 4 percent or more, depending on the soil type and rainfall (Stull, 1996). Mud problems can be reduced in these areas with proper drainage and berming to control rainwater.

3.2.4 Dry Cow Housing

Dry cows are usually housed in groups for about 40 days. If using earthen corrals in semi-arid conditions, 500 to 600 square feet of loafing area and 40 to 50 square feet of shade are provided per cow. If using freestalls, one stall or 25 square feet is allocated per cow. Exercise pens are designed for 100 to 200 square feet per cow.

3.3 Demographics

3.3.1 National Change

The number of milk cows in the United States has continuously decreased since the peak of 24.1 million milk cows in 1940. According to the National Agricultural Statistics Service (NASS), there were approximately 9.7 million and 9.4 million milk cows in 1991 and 1996, respectively. The number of dairy operations has also decreased from 180,640 in 1991 to 140,090 in 1996 (APHIS, 1996b). Tables 3-3 and 3-4 present the percentage of U.S. dairy operations and milk cow inventory by size class from 1991 through 1995. The trend since 1991 has been that the proportion of smaller herds (1 to 49 head) has steadily decreased while the proportion of larger herds (50 or more head) has steadily increased.

Table 3-3. Percent of U.S. dairy operations by herd size.

Year	1-29 Head	30-49 Head	50-99 Head	100-199 Head	200 or More Head
1991	39.8	22.8	25.9	11.5[a]	–[a]
1992	38.9	22.1	26.0	13.0[a]	–[a]
1993	37.2	22.2	26.9	9.3	4.4
1994	35.8	22.0	27.7	9.9	4.6
1995	34.4	22.2	27.9	10.5	5.0

[a] The 100-199 size group includes 200 or more head.
Source: NASS data as presented by APHIS (1996b).

Table 3-4. Percent of U.S. milk cow inventory by herd size.

Year	1-29 Head	30-49 Head	50-99 Head	100-199 Head	200 or More Head
1991	6.3	16.6	31.7	45.4[a]	– [a]
1992	5.5	15.2	30.0	49.3[a]	– [a]
1993	5.0	14.8	29.2	19.2	31.8
1994	4.6	14.0	28.7	19.3	33.4
1995	4.0	13.0	28.0	20.0	35.0

[a] The 100-199 size group includes 200 or more head.
Source: NASS data as presented by APHIS (1996b).

3.3.2 Geographic Distribution

Dairy cattle are distributed in several regions in the United States. Table 3-5 summarizes the number of operations in each region by operation size class computed from the 1992 Census of Agriculture. In 1992, more than one-half of all operations were located in the North-Central Region, although more than one-half of the operations with 500 or more animal units were located in the West Region. Figure 3-2 presents a geographic distribution of the number of milk cows per county, and Figure 3-3 presents the geographic distribution of operations with 500 or more milk cows.

Table 3-5. Size distribution of all dairy operations derived from data collected in the 1992 Census of Agriculture.

	Operations Categorized by Size Class (animal units[a])								
Location	1-25	25-100	100-300	300-500	500-1,000	1,000-5,000	5,000-10,000	10,000 or More	Total
Northeast	5,349 (13%)	15,925 (21.6%)	8,623 (25.4%)	642 (17.9%)	198 (11.2%)	40 (3.7%)	0 (0.0%)	0 (0.0%)	30,777 (19.8%)
Southeast	7,637 (18.6%)	4,595 (6.2%)	3,872 (11.4%)	599 (16.7%)	196 (11.1%)	93 (8.5%)	2 (8%)	2 (40%)	16,996 (10.9%)
North-Central	15,816 (38.5%)	49,947 (67.6%)	16,611 (49%)	772 (21.6%)	149 (8.4%)	16 (1.5%)	0 (0.0%)	0 (0.0%)	83,311 (53.6%)
South-Central	5,729 (13.9%)	1,881 (2.5%)	2,307 (6.8%)	483 (13.5%)	170 (9.6%)	71 (6.5%)	3 (12%)	1 (20%)	10,645 (6.9%)
Mountain	4,129 (10%)	1,027 (1.4%)	1,179 (3.5%)	288 (8%)	215 (12.2%)	165 (15.1%)	8 (32%)	1 (20%)	7,012 (4.5%)
West	2,388 (5.8%)	482 (0.7%)	1,304 (3.8%)	791 (22.1%)	829 (47%)	700 (64.2%)	12 (48%)	1 (20%)	6,507 (4.2%)
Other	63 (0.2%)	7 (0.0%)	5 (0.0%)	4 (0.1%)	7 (0.4%)	5 (0.5%)	0 (0.0%)	0 (0.0%)	91 (0.1%)
United States	41,111	73,864	33,901	3,579	1,764	1,090	25	5	155,339

[a] The procedure for estimating animal units was adopted from Lander et al. (1998).

One of the geographical shifts since 1992 has been the increased number of milk cows that have calved in many of the western and mountain states, with the largest increase being 88.1 percent in New Mexico. On the other hand, the largest decreases in the number of milk cows that have calved have occurred in the southeastern states, with the largest decrease (besides Wyoming, whose small numbers exaggerate decreases) occurring in Tennessee with a 27.3 percent decrease from 1992 to 1996. At the same time, the number of operations with milk cows has decreased across the board, except for no change in Alaska and New Hampshire. Herd size also increased from 1991 to 1996 in every state except Arkansas, New Hampshire, Alaska, and Wyoming. The most notable changes occurred in Alabama, New Mexico, and South Carolina, where herd sizes increased more than 100 percent (APHIS, 1996b).

Table 3-6 presents the most recent inventory of the number of dairy operations by size class for selected states for 1997 and 1998. Table 3-7 presents the most recent inventory of milk cows (as a percent of inventory) by size class for selected states in 1996 and 1997.

Table 3-6. Milk cows: number of operations by size group, selected states, and United States, 1997-1998.[a]

State	1-29 Head		30-49 Head		50-99 Head		100-199 Head		200+ Head		Total	
	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
Arizona	190	180	0	0	0	0	10	10	100	100	300	290
California	570	500	100	90	130	120	300	290	1,800	1,800	2,900	2,800
Colorado	630	610	30	40	50	50	70	70	120	130	900	900
Florida	340	350	10	10	30	30	40	40	180	170	600	600
Georgia	300	230	20	20	140	130	200	190	140	130	800	700
Idaho	430	350	150	130	280	250	250	250	290	320	1,400	1,300
Illinois	430	330	420	430	880	780	330	320	40	40	2,100	1,900
Indiana	2,100	1,700	500	500	700	700	250	250	50	50	3,600	3,200
Iowa	1,300	1,010	1,300	1,200	1,650	1,500	480	520	70	70	4,800	4,300
Kentucky	1,500	1,300	730	650	990	900	330	300	50	50	3,600	3,200
Maryland	190	160	130	130	480	440	240	220	60	50	1,100	1,000
Michigan	1,100	1,000	900	850	1,300	1,200	880	830	220	220	4,400	4,100
Minnesota	2,100	1,700	4,100	3,600	3,800	3,600	830	850	170	250	11,000	10,000
Missouri	1,800	1,500	700	680	900	800	540	560	60	60	4,000	3,600
New Mexico	550	340	0	0	10	10	10	10	130	140	700	500
New York	1,800	1,700	2,000	2,000	3,700	3,300	1,300	1,200	400	400	9,200	8,600
North Carolina	570	520	60	60	210	200	260	230	100	90	1,200	1,100
Ohio	3,800	3,200	800	800	1,400	1,400	400	500	100	100	6,500	6,000
Oregon	530	370	50	20	150	140	210	210	160	160	1,100	900
Pennsylvania	2,600	2,300	3,800	3,800	3,900	3,800	1,000	1,100	200	200	11,500	11,200
Tennessee	300	260	290	240	540	520	300	300	70	80	1,500	1,400
Texas	1,200	800	100	100	400	300	700	600	600	700	3,000	2,500
Utah	300	320	70	70	190	170	210	210	130	130	900	900
Vermont	150	150	450	400	1,000	950	350	350	150	150	2,100	2,000
Virginia	550	500	130	110	520	500	400	390	100	100	1,700	1,600
Washington	750	540	70	70	180	120	320	300	380	370	1,700	1,400
Wisconsin	5,000	4,600	9,500	8,500	9,600	8,900	2,530	2,550	370	450	27,000	25,000
Other States	8,700	6,900	2,000	1,800	3,800	4,000	2,000	2,250	700	740	17,200	15,690
Total	39,780	33,420	28,410	26,300	36,930	34,810	14,740	14,900	6,940	7,250	126,800	116,680

[a] An operation is any place having one or more head of milk cows on hand at any time during the year.
Source: NASS, 1998.

Table 3-7. Milk cows: percent of inventory by size group, selected states, and United States, 1996-1997.[a]

	1-29 head		30-49 head		50-99 head		100-199 head		200+ Head	
State	**1996**	**1997**	**1996**	**1997**	**1996**	**1997**	**1996**	**1997**	**1996**	**1997**
Arizona	0.2	0.2	-	-	-	-	0.8	0.8	99.0	99.0
California	0.1	0.1	0.3	0.3	0.8	0.8	3.8	3.8	95.0	95.0
Colorado	2.4	1.5	1.5	2.0	5.1	5.0	13.0	14.5	78.0	77.0
Florida	0.3	0.3	0.2	0.2	1.5	1.5	3.0	3.0	95.0	95.0
Georgia	1.1	1.0	0.9	1.0	11.0	10.0	30.0	29.0	57.0	59.0
Idaho	1.0	0.7	2.3	1.9	7.2	5.9	13.5	12.5	76.0	79.0
Illinois	3.0	2.0	11.0	11.0	49.0	47.0	28.0	30.0	9.0	10.0
Indiana	13.0	14.0	15.0	16.0	36.0	35.0	24.0	22.0	12.0	13.0
Iowa	8.0	6.5	19.0	19.0	43.0	40.0	23.0	26.0	7.0	8.5
Kentucky	8.5	7.0	17.0	16.0	42.0	41.0	25.0	27.0	7.5	9.0
Maryland	2.7	2.7	5.3	5.3	36.0	37.0	35.0	35.0	21.0	20.0
Michigan	5.0	4.0	11.0	10.0	28.0	27.0	35.0	35.0	21.0	24.0
Minnesota	7.0	6.0	26.0	23.0	41.0	41.0	17.0	17.0	9.0	13.0
Missouri	9.0	8.0	15.0	15.0	33.0	32.0	34.0	36.0	9.0	9.0
New Mexico	0.9	0.7	-	-	0.4	0.4	0.7	0.9	98.0	98.0
New York	2.7	2.6	11.3	11.4	37.0	35.0	28.0	28.0	21.0	23.0
North Carolina	1.5	1.5	2.5	2.5	17.0	16.0	41.0	41.0	38.0	39.0
Ohio	13.0	12.0	13.0	13.0	40.0	41.0	22.0	23.0	12.0	11.0
Oregon	2.0	2.0	2.0	1.0	13.0	12.0	31.0	30.0	52.0	55.0
Pennsylvania	6.0	5.0	23.0	22.0	41.0	41.0	20.0	22.0	10.0	10.0
Tennessee	3.5	2.5	9.5	7.5	33.0	33.0	37.0	36.0	17.0	21.0
Texas	1.2	0.9	1.0	1.1	7.8	7.0	24.0	23.0	66.0	68.0
Utah	1.3	1.3	2.7	2.7	16.0	14.0	31.0	31.0	49.0	51.0
Vermont	1.0	1.0	11.0	9.0	39.0	39.0	24.0	25.0	25.0	26.0
Virginia	3.0	3.0	4.0	4.0	30.0	29.0	40.0	40.0	23.0	24.0
Washington	0.9	0.7	1.1	1.0	5.0	3.3	20.0	19.0	73.0	76.0
Wisconsin	5.1	4.5	26.0	25.0	41.0	40.0	21.0	22.0	6.9	8.5
Other States	4.0	3.5	9.0	8.5	31.0	31.0	23.0	23.0	33.0	34.0
Total	4.0	3.5	12.0	11.5	27.0	26.0	20.0	20.0	37.0	39.0

[a] Percents reflect average distribution of various probability surveys conducted during the year but are based primarily on beginning-of-year and mid-year surveys.
Source: NASS, 1998.

3.4 Waste Management Systems

The type of housing system affects the quantity of bedding or dilution water used in a manure management system. This, in return, influences the manure characteristics and selection of collection, transfer, storage, and transport equipment. The basic components of dairy manure management systems are shown in Figure 3-4. In addition to the components shown by Veenhuizen et al. (1998), manure is also stockpiled in (or outside of) dry lots similarly to stockpiling for beef feedlots described in Chapter 4.

Solid wastes are usually associated with bedded loafing barns, stanchion stalls, and dry lots where the solids content is greater than 18 percent. Fresh manure has a solids content of 12 percent and can be handled as a semisolid or as a solid if bedding is added. (Semisolid manure has a solids content ranging from 10 to 16 percent. For fresh manure to be handled as a solid, 12 pounds of bedding would be needed for every 100 pounds of fresh manure.) Handling manure as a solid or semisolid minimizes the volume of manure that is handled. (Milking center wastes would typically be managed separately as a liquid.) Solid storage can include a stacking slab or covered storage. One or two walls are commonly provided to control leachate, ease load-out, reduce required

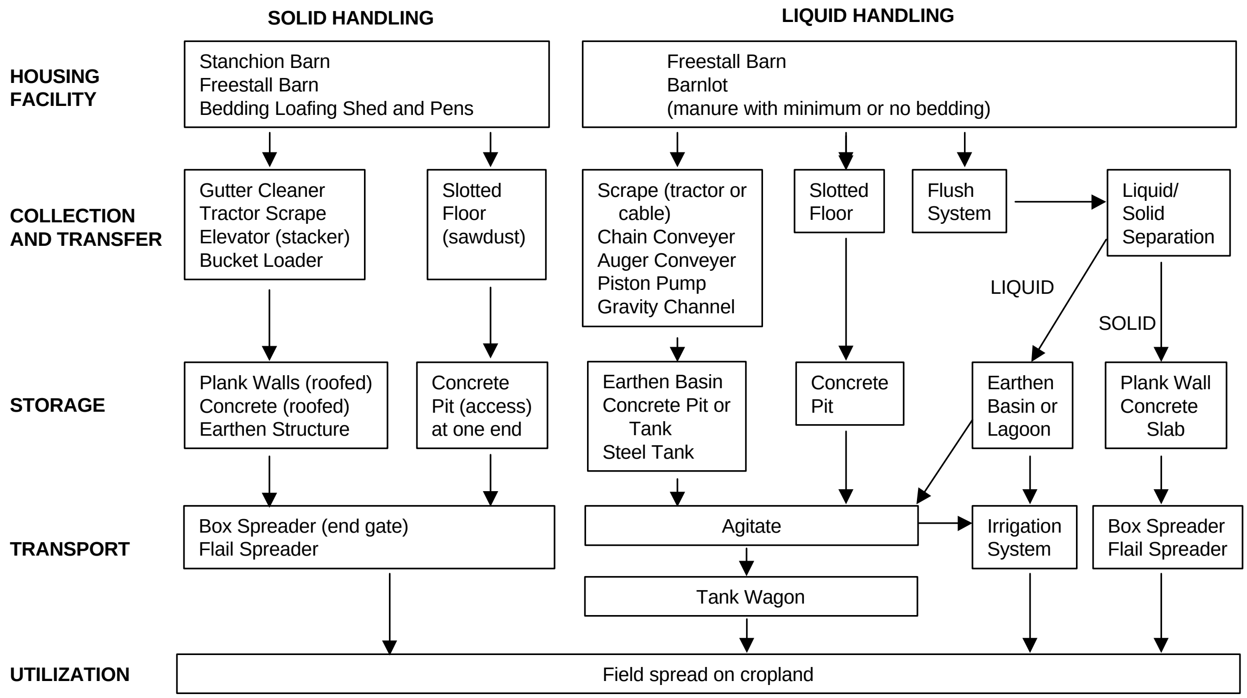

Figure 3-4. Basic components of solid and liquid manure systems for a dairy (Source: Veenhuizen et al., 1992).

floor area, and screen manure. In high-rainfall regions, roofing on storage can be used to keep precipitation out so that manure can continued to be handled as a solid or semisolid. Rainwater that does fall on uncovered storage can be drained with a picket-dam structure. Solid manure is usually transferred and loaded into storage using a tractor-mounted front-end loader, elevator stacker, or solid piston pump. Manure is then unloaded from storage using a front-end loader or is spread as a solid or semisolid in a box or flail spreader.

Fresh manure can be treated as a slurry if 30 gallons of dilution water (from precipitation, runoff, or milking center wastewater) is added per 100 gallons of the fresh manure, resulting in a solids content of 4 to 10 percent. Slurry systems maintain more plant nutrients from the waste than lagoons and are often used where geology is unsuitable for lagoons. Operations may switch from the solid to slurry system to reduce labor costs. Slurry systems are also known as liquid tank systems.

Manure with a solids content of less than 4 percent is considered liquid. This is usually the effluent from the liquid-solid separation process, milking centers, or supernatant from lagoons. If there is no solids separation performed, about 250 gallons of dilution water must be added per 100 gallons of fresh manure, to reduce the solids content to below 4 percent. Liquid systems are usually associated with the lagoon waste management system and are favored by large operations because labor costs are minimized and a flushing system can be used to collect and transport waste to the lagoon. Flushing systems have the primary advantage of being automated. Manure can also be collected and removed from the barn with a tractor-mounted scraper, mechanical alley scraper, flushing system, or slotted floor. Based on the site conditions, manure is stored in earthern basins, belowground tanks, or aboveground tanks. Liquid manure is transferred to storage using gravity pumps, large piston pumps, pneumatic pumps, and centrifugal chopper pumps. Some liquid-storage structures allow for agitating the waste prior to irrigating or loading a tank spreader (typical of belowground tanks). If solids are not agitated (common in lagoons), they will accumulate in the structure, reducing storage capacity.

The remainder of this section provides a more detailed description of the equipment and typical practices used to manage dairy manure.

3.4.1 Nutritional Strategies

Nutritional strategies for dairy cattle to minimize nutrient excretion have not been adequately reported in the literature at this time although anecdotal evidence suggests opportunities for decreased nutrient excretion exist. One objective of future research might be to optimize the balance between milk production and nutrient excretion. Surveys conducted on dairy farms in New York have shown that feed imports account for 62 to 86 percent of the total nitrogen input of a farm: 64 to 76 percent of this nitrogen remains on the farm in initial manure excretions. Likewise, feed accounts for 45 to 80 percent of the total phosphorus input to the farm, and 68 to 81 percent of the total phosphorus input remains on the farm. For potassium, 16 to 62 percent of the inputs are represented in the feed, while 67 to 89 percent of the potassium inputs remain on the farm (Grusenmeyer and Cramer, 1997).

3.4.2 Waste Collection

As shown in Table 3-8, about three-fourths (74 percent) of dairy operations with less than 100 milk cows and one-third (34.7 percent) of dairy operations with 100 to 199 milk cows use a *gutter cleaner* (APHIS, 1996c). Gutter cleaners 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 used to clean the gutters. Shuttle-stroke gutter cleaners are driven by electric motors. They have paddles that pivot on a drive rod, which travels alternately forward for a short distance and backwards, for the same distance. The paddles move the manure forward on the forward stroke, then collapse on the drive rod on the return stroke, forcing the manure down the gutter.

Table 3-8. Percent of operations by method of removing manure from cow housing areas.

Method	Fewer than 100 Head	100-199 Head	200 or More Head	Total
Gutter cleaner	74.0	34.7	9.0	63.2
Alley scraper (mechanical or tractor)	50.2	82.4	85.0	57.7
Alley flushed with water	0.2	4.3	26.6	2.8
Other	1.3	0.5	0.1	1.1

Source: APHIS, 1996c.

More than 80 percent of operations with more than 100 milk cows use a *mechanical or tractor scraper* (APHIS, 1996c). 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. The system is run by a 0.5- to 1-horsepower electric motor and controls. 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.

Outside lots usually produce semisolid or solid waste from lot scrapings and sheltered bedded packs, while lot runoff is liquid. The solids and semisolids can be moved to storage using a tractor scraper or front-end loader. Runoff is commonly drained to a settling basin and/or solids separator. The removed solids can be spread as fertilizer and soil conditioner, mixed as a feed for heifers, or composted and used for freestall bedding. The separated liquid wastes can be stored. Runoff from areas without livestock impact do not need to be handled in the manure management system. Instead, this runoff is diverted away from outside lots, reducing the total volume into the system.

Flush systems are suitable for cleaning freestall alleys, parlor floors, and holding areas when temperatures are above 25 EF. One-fourth (26.6 percent) of operations with more than 200 milk cows flush alleys with water (APHIS, 1996c). Required flush water volume varies according to alley width and slope (see Table 3-9). The values in Table 3-9 were developed to provide an initial flow depth of 3 inches, a velocity of 5 feet per second, and a 10-second flow duration for alley lengths up to 150 feet.

Typical freestalls with alley widths of 10 and 12 feet and a 2 percent floor slope would require about 2,750 gallons per flush. Thus, to flush the alley two or three times a day would require 5,500 to 8,250 gallons per day. To reduce the amount of fresh water needed for flushing, flush water can be recycled (MWPS, 1997). Of those operations that flush alleys, 54.4 percent recycle water for multiple flushings (APHIS, 1996c). A solids separation system is used if the flush water is recycled. Note that only fresh water is used to clean the milking parlor area.

Table 3-9. Flush parameters.

Alley Slope (%)	**Flow Depth (in)**	**Flow Rate (gpm/ft alley width)**	**Flush Volume (gal/ft alley width)**
1.0	7.0	1,306	220
1.5	5.0	933	156
2.0	4.0	747	125
2.5	3.4	635	106
3.0	3.0	560	94

Source: Adapted from MWPS (1997).

Milking center effluent is a liquid, but it contains milk solids, manure, grit, detergents, and sometimes feed. When dairy barn manure is handled and stored as a slurry or liquid, the milking center effluent 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 effluent may be added at the collection point in the barn.

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 through 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. Mechanical scrapers are not common under slotted floors because of the difficulty associated with repair and replacement (MWPS, 1997). The storage of animal and milking center waste in a pit beneath slotted floors combines manure collection, transfer, and storage. Problems may arise; however, if the pits cause manure gasses and moisture to build up in the animal environment. The excess gas and moisture can also be corrosive, causing premature deterioration of metal gusset plates on trusses. Other disadvantages include expensive construction and difficulties in proper solids removal (MWPS, 1997). If the gravity flow channel beneath the slotted floor has straight sides, the collected manure can be removed by flushing.

3.4.3 Waste Storage

Storage planning should consider all farmstead operations, building locations, and prevailing summer winds. The American Society of Agricultural Engineers (ASAE) indicates that manure storages are to be located at least 100 feet away from water supplies and 50 feet from the milking center (ASAE EP393.2 DEC97). According to a recent survey, three-fourths (73.8 percent) of dairy operations have a distance of 500 or more feet between manure storage and the nearest waterway or body of water, while 14.6 and 11.6 percent of dairy operations have a distance of 200 to 499 feet and less than 200 feet between manure storage and the nearest waterway or body of water. More than 80 (81.1) percent of dairy operations have a distance of 200 or more feet between manure storage and the nearest well (APHIS, 1996c). If storage units are located over shallow, creviced bedrock or in gravel beds, construction procedures and materials that prevent seepage to the ground water should be used (ASAE EP393.2 DEC97). Belowground storage units should be avoided in areas with high water tables unless drains are installed to permanently lower the water table (ASAE EP393.2 DEC97). ASAE also recommends that storage units have a storage capacity of up to 210 days in colder climates and as little as 45 days in warmer climates (ASAE EP393.2 DEC97).

Table 3-9 summarizes the percent of operations by waste storage system used. Operations with 200 or more milk cows have a larger proportion of operations with anaerobic lagoons without covers (46.7 percent), provide outside storage within dry lots or pens (22.0 percent), and provide slurry storage in tanks (17.5 percent) than operations with fewer than 200 milk cows. Operations with 200 or more milk cows also have a larger proportion of aerated lagoons

(8.3 percent) than other operations, but overall are a smaller percentage of operations than operations with anaerobic lagoons. Below-floor slurry/deep pits and slurry storage in earthen-basins are more prevalent in operations with 100 or more milk cows. For those operations with lagoons, 84 percent use a single-stage lagoon while 16.6 percent use a multiple-stage lagoon. Interestingly, only 2.3 percent of operations separate solid waste from liquids before placement in some type of storage tank or lagoon while 29.5 percent do not separate solids; 68.2 percent do not use storage tanks or lagoons (APHIS, 1996c).

Table 3-9. Percent of operations by waste storage system.

Method	Fewer than 100 Head	100-199 Head	200 or More Head	Total
Below-floor slurry or deep pit	4.7	19.6	16.9	7.9
Slurry storage in tanks	3.2	10.9	17.5	5.4
Slurry storage in earthen-basin	13.5	25.2	27.8	16.3
Anaerobic lagoon with cover	0.2	0.3	1.1	0.3
Anaerobic lagoon without cover	5.7	18.2	46.7	10.7
Aerated lagoon	0.5	3.3	8.3	1.5
Manure pack (inside barn)	22.3	20.4	14.1	21.4
Outside storage for solids (not in dry lot or pen)	37.9	33.0	30.1	36.6
Outside storage within dry lots or pens	14.8	11.5	22.0	14.9
Solids in a building without cattle access	2.8	4.1	2.4	3.0
Other	2.1	1.8	1.6	2.0

Source: APHIS, 1996c.

3.4.3.1 Solid and Semisolid Manure Storage Units

When bedding is used and water dilution is avoided, dairy manure can be stacked and stored on paved areas with appropriate controls for drainage. If solid manure from the bedded areas is combined with manure scraped from freestall or feeding alleys, the result is typically a semisolid mixture that needs to be confined by walls constructed from concrete or pressure-treated wood. These structures are filled using a bottom-loading piston pump or a push-off ramp, and they are emptied using a front-end loader or manure auger. If these storage units are not covered, picket dams or floor drains can be used to allow rainwater to drain to a holding tank or detention pond. Picket dams consist of vertical slots about ½ inch wide (ASAE EP393.2 DEC97) between standing planks or pickets holding solid manure but allowing liquids, such as rainwater, to drain. Detention ponds are designed for a 25-year, 24-hour return storm and 1-foot freeboard (ASAE EP393.2 DEC97). Manure from roofed storage units would typically be dryer than that from unroofed storage units.

3.4.3.2 Liquid and Slurry Storage Units

Milking centers may produce up to 50 percent of the waste volume, but because of the dilute nature of milking center effluent, only about 15 percent of the total solids. This is mainly due to the many cleaning and flushing procedures used to keep the milking area sanitary. About 5 to 10 gallons of fresh water per cow milked per day is used in milking centers where flushing does not occur. In milking centers that use manure flushing and automatic cow washing, water use can climb to 150 gal/d/cow with 10 percent of the water usage associated with parlor, cleanup, and sanitation; 30 percent with cow washing; 50 percent with manure flushing; and 10 percent with miscellaneous uses. Therefore, milking center wastes and runoff from corrals and open feeding areas are dilute enough to handle as a liquid that can be stored in steel or reinforced concrete tanks, earthen basins, or retention ponds.

The allowable storage depth of *belowground tanks* is limited by the soil mantle depth over bedrock, the water table elevation, and the pump's effective lift. *Aboveground tanks* range in size from 10 to 30 feet high and 30 to 120 feet in diameter. They are made of concrete staves, reinforced concrete, preformed concrete panels, and steel. Compared to earthen basins they are expensive and usually not used to store runoff or dilute wastes. However, in areas where basins are limited by space, high ground water, or shallow and creviced bedrock, or where earthen basins are not aesthetically acceptable, aboveground storage tanks are a good alternative.

Earthen basins allow long-term storage at low to moderate investment. Currently, these structures can be unlined or they can be lined, depending on location and unloading methods, with clay, a synthetic material, or concrete. The inside bank slopes common for most soils are from 2:1 to 3:1 (run:rise). The outside side slopes are typically 3:1. *Holding ponds* are used for temporary storage of runoff water from a settling basin, or the effluent from a solids separator. *Lagoons* that receive large quantities of manure, such as from the holding area or the cow feed yard, usually operate in an anaerobic mode. In the *anaerobic lagoon*, the nutrient concentration of the supernatant, or the upper liquid layer of the lagoon, is greater than that in an aerobic lagoon. Sludge accumulates at a rate of about 0.073 ft^3/lb of total solids added to the lagoon, or about 266 cubic feet per year for each 1,000-pound lactating cow equivalent. Lagoons receiving wastewater from only the milk house of the milking parlor generally exhibit a nonviscous supernatant and operate in an aerobic mode. Also, sludge accumulates at a slow rate in such lagoons.

3.4.4 Waste Disposal and Use

Table 3-10 summarizes the percentage of dairy operations that implement various manure disposal practices. Most (98.9 percent) operations apply manure to land owned or rented by the operator. Larger operations have also exploited other disposal options including selling, composting, and giving the manure away more than smaller operations. Larger operations also tend to analyze manure for nutrient content more than smaller operations, yet less than one-half of all operations establish manure application rates based on manure nutrients and/or crop needs (APHIS, 1996c). According to a study in Wisconsin of 1,179 farmers, less than 29.8 percent of operations made an effort to credit manure nitrogen on their most productive corn field. Of those operations that credited manure nitrogen, 66 percent underestimated manure nitrogen by 11 percent or more, 28 percent overestimated manure nitrogen by 11 percent or more, and 6 percent estimated manure nitrogen within 10 percent of the University of Wisconsin guidelines. In all, less than 2 percent of all farmers spreading manure on corn ground are crediting manure nutrients with any degree of accuracy (Nowak et al., 1998).

For those operations that applied manure to their own land, 30.4, 25.5, 10.8, and 33.3 percent of operations apply manure on a daily, weekly, monthly, or less frequent basis, respectively, during summer months. During winter months, 46.5, 14.7, 7.8, and 31.0 percent of operations dispose of manure on a daily, weekly, monthly, or less frequent basis, respectively (APHIS, 1996c).

Broadcast spreaders are the most prevalent equipment used to apply manure regardless of operation size, but they are more common on small operations and can be used for solid or semisolid waste. Box-type spreaders have moving aprons that move the load rearward to beaters. Flail-type spreaders use chains attached to a shaft that revolves at high speed to flail the manure out of the tank.

Larger operations have a higher frequency of irrigation systems such as center pivots, traveling guns, stationary hand-carried sprinklers, and gated pipe for disposing of liquid wastes. The type of system used depends on trade-offs related to operation size, capital costs, labor availability, and the type of land. Larger operations tend to use center pivots or traveling guns. Center pivots have the highest capital cost and lowest labor requirements. Traveling guns require less capital and more labor. Small operations can use stationary hand-carried sprinklers if labor is available. In certain circumstances, liquid wastes from milking centers or lagoons can be surface-irrigated with gated pipe. Gated pipe systems can be made from polyethylene pipe with holes drilled at 30- to 40-inch intervals. These holes should be small enough to allow flow to be distributed throughout the length of the pipe, but large enough to prevent clogging by small solids. Commercial systems with adjustable gates are also available. Conventional irrigation pumps or centrifugal pumps can used if installed to prevent surface debris and sludge from entering the intake.

Table 3-10. Percent of operations by waste disposal practice.

Method	Fewer than 100 Head	100-199 Head	200 or More Head	Total
Disposal Method				
Applied on land owned or rented by operator	99.4	98.6	94.7	98.9
Sold or received other compensation	0.8	2.7	17.5	2.3
Gave away	4.9	8.7	22.6	6.8
Composted	3.3	6.2	16.3	4.7
Application Method				
Irrigation	3.1	11.2	40.5	7.0
Broadcast/solid spreader	90.6	85.1	75.8	88.7
Slurry (surface application)	17.7	38.5	44.6	22.7
Slurry (subsurface injection)	3.6	5.9	8.6	4.3
Other method	0.0	0.4	1.0	0.1
Practices				
Analyzed nutrient content of manure	10.3	26.4	28.6	14.0
Established manure application rate based on manure nutrients and/or crop needs	41.7	50.5	43.3	43.2
Applied manure a minimum of 50 feet from waterbodies	77.9	77.2	82.5	78.1
Incorporated manure into soil within 24 hours after application	15.8	22.8	31.5	17.9

Source: APHIS, 1996c.

Settling tanks can also be used in combination with filter strips. Once the solids are removed, grass filter strips can provide surface disposal of the effluent. Filter strips are an effective means of wastewater treatment for dairy facilities producing less than 500 gallons per day from the milking center. The wastewater flows through the filter strip and the water evaporates while the fine solids and bacteria remain. Organic compounds are degraded aerobically so that little odor is given off, and phosphorus and nitrogen are consumed by plants. The soils most compatible with this disposal system are fine-textured soils with moderate permeability, such as sandy loam to clay loam. Filter strips might not be sufficient where the soil is too sandy. Good cover crops to use, because of their tolerance to moisture and ability to develop thick ground cover (thus reducing erosion), are tall fescue and reed canary grass. Other crops might be selected because of uptake characteristics or increased usefulness. The vegetation is periodically harvested and fed to livestock, used as a bedding or soil amendment, or used as a fuel.

Slurries can be pumped with chopper pumps into tank wagons drawn by tractors. Tank wagons have capacities of 1,000 to 3,000 gallons. For large operations or if longer hauls are necessary, a tank truck may be more cost-effective. Tank wagons spread the liquid on the soil or may be equipped with knives to inject the waste into the soil. Although injection reduces odors and nitrogen loss, substantial power is required to pull the tank wagon and injectors at a reasonable speed. Injection is not an option if the soil is frozen or too rocky.

In general, sludge should be removed when sludge levels have reached about two-thirds of the normal pond depth (NSW, 1994). There are several options for removing the sludge. The decision of which to use depends on producer preference, the availability of the necessary equipment and contractors, and the costs involved. Hydraulic dredging removes the sludge as a liquid/slurry by using a large-capacity pump to mix the whole pond contents and keep solids suspended while pumping the slurry. Sludge can then be transferred directly to a land disposal site, or a vacuum tanker can be used to distribute the wastes to land whenever desired. This type of sludge removal is often done by septic tank pump-out contractors or specialized waste management contractors. If liquid is pumped off and in-flow from the milking center is by-passed to contour drains or alternative disposal systems for a short time, the accumulated sludge will dry slightly, allowing removal as a semisolid with a long-arm excavator. Sludge removal is usually timed so that the sludge can be land applied immediately.

3.5 Example Systems

This section provides a summary of dairy waste management systems used today. Some examples, in particular those based on personal communication with knowledgeable experts, may be a general characterization of operations in that state or region rather than a specific system.

3.5.1 Connecticut (Neafsy, personal communication, 1998)

Dairy waste is usually handled as a liquid. Historically, the storage volume required in liquid systems was 6 months' capacity. Recently, it has become important to consider nutrient management as the basis for waste management systems. This has led to an increase in the suggested storage volume to 9 months' capacity. The typical storage unit has historically been earthen storage lagoons. Currently, however, polyethylene or PVC liners have been suggested to protect leaching from the lagoons to groundwater in cases where permeability of the surrounding soil is too high. Liquid waste is applied using irrigation if the crop is near the waste storage facility. The most common application method, however, is to use conventional spreaders. Application is done when the crops can best utilize the nutrients. For corn crops, application is completed in April or May. Once applied, the manure is immediately incorporated and corn is planted. For hay crops, a light application is performed after harvest.

Solids are a minor part of the typical dairy waste management systems in the Northeast. In fact, about 30 to 40 percent of producers put the milk room and silage leachate in with the manure so that all waste is handled as a liquid. In smaller operations where handling of solids is more practical, solids are composted and used as bedding.

Runoff is diverted using roofs, gutters, and graded land into settling basins and vegetative filter areas that are set up in a pattern described as an "ice cube tray." This pattern allows detention and infiltration of some of the water before the runoff enters any surrounding waterbodies.

3.5.2 Idaho (Shoemaker, personal communication, 1998)

In the wetter areas of the West, wastes are scraped from corrals, while in drier areas the wastes are left mounded in the corrals. Barn wash water and storm water that runs off from corrals are stored in earthen ponds designed for 6 months of storage. Liners are necessary in cases where permeability of the surrounding soils exceeds certain values. These earthen ponds are emptied in early spring just before the growing season. Sprinkler systems are the current trend for applying liquid waste because minimal labor is required.

Wastes from the holding pens are stacked as solids. The solids are applied to the land using manure spreaders. Solids application and immediate incorporation are usually performed in the fall after the crops have been harvested.

Storm water handling is most important through the winter period; therefore, clean water is diverted off site through earthen runoff diversions or pipe lines. Roofing or gutters to divert runoff have received limited acceptance due to the drier climate in the mountain region. Separators are not common due to the dry climate, but have recently become more important in some dairy operations during spring thaw.

3.5.3 Nebraska (Bodman, 1995)

In Nebraska, many dairy producers still rely on daily scrape/haul methods for managing manure. This is appropriate as long as land area is available to allow spreading throughout the year without exceeding agronomic nutrient needs and as long as runoff is controlled to prevent contaminated runoff from leaving the owner's property. Because of increasing herd sizes, which have increased environmental and water quality concerns and have created a need for more efficient use of labor, many dairy producers are considering various storage options. In Nebraska, a minimum of 180 days of storage is required. The storage options include underfloor storage, aboveground tub or tower silos, slotted dams, earthen-bank storage units, and lagoons.

Underfloor storage is used for operations where daily labor and equipment are minimized. Manure enters the storage through slotted floor or by scraping. The storage is constructed of reinforced concrete and is considered expensive. The underfloor storage is divided into individual cells up to 50 by 50 feet. To remove the manure from an underfloor storage system, the manure is agitated and handled as a slurry.

Aboveground tub or tower silos are used in areas with a shallow watertable or where bedrock exists. Costs and handling methods are similar to those for underfloor storage. If these storage units are not covered, the usable depth is 3 to 5 feet less than the total depth. Rainfall and duration of storage determine the volume available for storing manure. It is important to provide sufficient storage depth at all times to allow accumulation of rainfall and runoff from a 25-year, 24-hour precipitation event, which in Nebraska ranges from 3.5 inches to 5.7 inches from northwest to southeast Nebraska.

Slotted dam storage units use an earthen-bank enclosure to store manure solids. This enclosure has a concrete floor and access ramp. A separate earthen-bank impoundment is used to store the milking center effluent, precipitation, and runoff from both parts of the storage system. This type of storage works best for producers using fibrous bedding and fibrous feeds such as long hay and corn silage. Slotted dams are not well suited for operations that use sand bedding with a high haylage ration. If manure is a semisolid, it is hauled to the fields using open-top tanks, whereas liquid manure is usually land-applied via irrigation.

Earthen storage units are well suited to operations having a low to moderate amount of lot drainage or runoff. This is also the least expensive storage option. The storage unit should be agitated so the settled and floating solids are put into suspension. The resulting slurry is hauled to the fields using an enclosed tank spreader. Earthen-bank storages are designed with considerations for precipitation, runoff, manure production rate and duration of storage.

3.5.4 Kansas (Melton, personal communication, 1998)

Solid manure is scraped from the lots and stockpiled. It is handled with heavy equipment such as front-end loaders or scrapers and spread onto cropland or pastureland using a manure spreader.

Building washdown water, liquid manure, and lot runoff are directed into earthen ponds or concrete-lined holding tanks. No special lining considerations are usually necessary because the highly aggregated clay that makes up most of the soils in the area prevent-leaching. The holding tanks and ponds should be designed with a 1-year holding capacity due to the possibility of frozen ground during the winter months preventing application. Liquids are directed to the holding ponds by earthen diversions, open channels, or pipes. Holding tanks are emptied using “honey wagons” or liquid manure spreaders, while ponds are emptied using irrigation equipment.

3.5.5 Oregon (Moore and Hart, 1997)

Dairy manure is collected using tractor scrape units or hydraulic flush systems. In the more temperate areas, flushing is the main method used for larger herds. This system reduces labor, provides excellent barn cleaning, and is easily controlled. During wet weather or when soils are at or near saturation, field spreading is not possible so this system may require large storage units.

One of the most common treatment methods is the use of a mechanical separator. Most flush collection units have separators, which are used to remove the large particles from the waste stream. The most common separator is the static inclined screen. In such a separator, manure passes over an inclined screen. The liquid passes through the screen while the solids continue over and flow off the end of the screen. The solids can then be handled with other solid wastes. The purpose of the separator is to reduce the buildup of solids in ponds and lagoons. The separation also allows for the liquid to be more easily pumped and reduces clogging in piping and sprinkler heads.

In Oregon dairy manure application to cropland is usually limited by soil moisture content or nutrient loading rate. Along the Washington and Oregon coast, soil temperatures rarely drop below freezing so that manure nitrogen is slowly converted into the soluble nitrate form available to plants. The cool temperatures allow minor growth of pasture grass, but the presence of high winter rainfall makes this time one of the highest concerns in terms of runoff. Therefore, manure applications in late fall must match the limited uptake of the cover crop. By January and February the soil temperatures increase enough so that the growth of the cover crop is plentiful, allowing for up to 30 kg of nitrogen/month-ha to be spread. In the Willamette Valley, where some soil temperatures drop below freezing, dairy operators interseed rye in corn so that a growing fall-winter crop can be used to take up nitrate from fall and winter manure applications.

3.5.6 California (Meyer et al., 1997)

Regulations regarding manure storage capacity and use have existed in California since 1984. Nevertheless herd size has increased to 979 lactating and dry cows, total farm acreage has increased from 501 to 685 acres, and land available for manure application has increased from 379 to 505 acres. These regulations include a requirement that storage must have the capacity to store rainfall that has been contaminated by manure and maintain storage capacity for a 25-year, 24-hour storm event. The storage structure must also have the impermeability of a 10 percent clay soil. Manure application must be done at proper rates. Meyer et al. (1997) determined the most commonly used manure management practices were the following:

- The technique used most often for collecting manure is a combination of flushing and scraping (64.9 percent) or just flush collection (77.1 percent).
- The most common storage systems are holding or storage ponds (95.9 percent); 59.5 percent of producers have one pond and 24.3 percent have two ponds. The mean total storage capacity for waste liquids is 48.57 acre-ft, with a mean of 115,673 ft^2 of pond surface area. Evaporation ponds for temporary storage and disposal of waste are used by 9.5 percent of the producers. The most popular system for solid-liquid separation is settling ponds or basins (54.1 percent), while mechanical solid-liquid separators are used by 9.5 percent of the producers.

- Liquid manure and runoff that has accumulated in ponds are most often applied to the land through seasonal (29.7 percent) or year-round (33.8 percent) irrigation. Almost all (94.6 percent) producers include scraping solid manure into piles as part of their solid manure collection system. Solid manure is disposed of most often by field spreading or is sold.

3.5.7 Florida (Watts, personal communication, 1998)

Manure deposited on the pastures or on any unlined area is to be applied at an agronomic rate. If this is not possible, the manure should be collected and applied at recommended rates that depend on the crops planted and the estimated crop production rate. To collect all contaminated water and waste, which includes wash water, cooling water, and wastewater, the concrete area is curbed, inlet boxes are employed, waterways are lined or drain pipes used, and the waste is pumped to a waste storage facility.

Waste storage facilities are for temporary storage for contaminated water generated by the dairy. Facility storage volume includes water from the facility's drainage area that comes into contact with the animal activities, normal precipitation minus evaporation, waste water, manure, and the 25-year, 24-hour storm precipitation on the actual facility surface. Storage facilities are either an excavated pond with an approved liner, a fabricated structure, or a holding tank constructed of approved material.

The disposal method usually consists of a waste distribution system that includes a center pivot, a traveling gun, a solid-set irrigation system, a linear irrigation system, or a honey wagon. The waste is applied to the crop at planned agronomic rates. The soils at each waste application site are examined to determine whether to use nitrogen or phosphorus as the soil limiting nutrient for application. Some dairies scrape the manure and apply it to designated fields on the dairy; if not, the manure is hauled off site.

3.5.8 Texas (Walker, personal communication, 1998)

Because of the drastic differences in climate in different areas of Texas, waste management practices differ from one area to the next. The dairy farms tend to the larger, greater-than-1,000-head in Erath County and to the south and west of Fort Worth. In eastern Texas, the farms tend to be smaller, family-owned operations. In the east, where the rainfall amounts are generally higher and nutrient buildup on the land might lead to runoff, treatment lagoons based on 140 to160 days of storage are used. Often, these systems include a waste storage pond that the waste enters after the treatment lagoon. Then the waste is land-applied based on a water budget The storage ponds are built for 30 days' capacity to match crop demand, or they may need up to 3 months' storage capacity to carry over into the winter months when application is not feasible. Most of the large dairy farms in Texas are located in the western parts of the state where rainfall amounts are quite small. On these operations, storage ponds are designed for enough capacity to hold the water from a 25-year, 24-hour storm event and with enough settling time to allow the solids holding the majority of the phosphorus to settle out.

In eastern Texas where perched water tables might also be a problem, earthen storage units require liners made of treated local soil or proper soil imported from other areas. In western Texas where the climate is more arid, direct surface application of waste is possible, with the runoff being pumped back into the system using special channels and pipes surrounding the fields. Because of the climate in Texas, aboveground storage is not necessary except possibly during the winter and spring in the wettest areas of eastern Texas.

Land application is usually done in the spring. Farmers often plant a small seed crop, such as clover, between their regular crops to allow for plant uptake of nutrients. This makes it possible, in places such as southern Texas, to land-apply liquid waste year-round.

Because of the large amount of wastewater produced, the most common type of application system is using commercial pumping services to dewater the lagoons and apply the waste through traveling guns. Alternatively, some operations have their own pumping system with underground pipes, polyethylene hoses, and traveling gun or pivot sprinklers.

For the confined feedlot areas that collect waste in solid form, front-end loaders are typically used to collect and then stack the manure. This is the system used more often by the drier western Texas operations. The solid waste is field-applied using manure spreaders.

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4.0 Beef

4.1 Introduction

Beef production has two primary phases—the cow-calf phase, in which calves reach maturity (usually on pasture), and the finishing phase, in which cattle are generally confined and fed a strict diet to promote weight gain and to improve the quality of meat.

4.1.1 Cow-calf Operations

Most cow-calf operations use pasture for calving. Less than 10 percent of operations surveyed had a cow or heifer that calved in a calving lot or confined shed/barn, and only 21.1 percent of operations had a cow or heifer that calved in a special calving pasture or shelter (APHIS, 1997a). In 1993, 81.2 percent of the calves were born from January through May. About 2.9 percent of calves are born dead, 1.8 percent die within 24 hours, and 2.5 percent die by 3 weeks for a cumulative percentage of 7.2 (APHIS, 1994d). Calves from replacement heifers have a cumulative mortality in the first 3 weeks of 13.9 percent, while calves from cows have a cumulative mortality in the first three weeks of 5.9 percent (APHIS, 1994c). In 1996, the proportion of calves born during January through May of 1996 was 78.6 percent. Producers reported a 92.6 percent calving rate (APHIS, 1997a).

In 1992, the average calf weaning weight was 502.4 pounds (APHIS, 1994b). In 1996, the average weaning weights for steers/bulls and heifers were 526 and 484 pounds, respectively (APHIS, 1998a). Larger operations tend to wean calves at an older age and heavier weight. Most operations (93.6 percent) wean bulls and steer calves after they weigh at least 400 pounds, while nearly one-fourth (24.5 percent) wean bulls and steer calves at weights over 600 pounds. On average calves are weaned at 221 days with 77.3 percent of operations weaning calves between 170 and 259 days (APHIS, 1997a). If the cow-calf phase is confined, calves are typically raised in hutches for approximately 12 weeks and then sent to a corral for maturation for an additional 22 to 26 weeks. If calves are intended for veal, they are sent to slaughter at maturation; if not, the calves are confined for finishing and slaughter. Of the cattle or weaned calves that are sold, most (85.7 percent) are intended for slaughter (see Table 4-1). The operation average sale weights are presented in Table 4-2.

Table 4-1. Percent of beef cattle or weaned calves sold in 1996 by animal class and herd size.

	Herd Size, Number of Cows				
Animal Class	**Fewer than 50**	**50-99**	**100-299**	**300 or More**	**All Operations**
Steers	39.5	46.0	44.6	46.9	43.8
Heifers intended for breeding	10.8	9.3	8.5	6.5	9.0
Heifers intended for slaughter	23.5	29.2	29.9	30.0	27.8
Cows intended for breeding	5.0	1.3	4.9	2.6	3.9
Cows intended for slaughter	14.1	9.7	8.6	11.2	10.9
Bulls intended for breeding	1.5	1.8	1.2	1.2	1.4
Bulls intended for slaughter	5.6	2.7	2.3	1.6	3.2

Source: APHIS, 1997a.

Heifers not confined for finishing are bred and are sent back to pasture or range. Tables 4-3 and 4-4 present the percentage of operations by type of grazing used, herd size, and location. After a year-long gestation period, bred cattle calve and either are sent back to pasture or range to be rebred or sent to slaughter. Of the breeding age females culled in 1992, the most common reasons for culling were pregnancy status (open or aborted) (32.7 percent), age/bad teeth (21.4 percent), and economics (drought, market, herd reduction) (15.2 percent) (APHIS,

Table 4-2. Operation average sale weight for beef cattle and weaned calves sold in 1996 by animal class and herd size.

Animal Class	Herd Size, Number of Cows			
	Fewer than 50	50-99	100-299	300 or More
Steers	584	645	660	674
Heifers intended for breeding	519	600	603	685
Heifers intended for slaughter	557	611	625	689
Cows intended for breeding	1,023	1,058	1,071	1,147
Cows intended for slaughter	996	1,055	1,055	1,073
Bulls intended for breeding	1,145	1,141	1,305	1,239
Bulls intended for slaughter	1,040	1,476	1,600	1,670

Source: APHIS, 1997a.

Table 4-3. Percent of cow-calf operations in 1996 by type of grazing used and herd size.

Type of Grazing	Herd Size, Number of Cows			
	Fewer than 50	50-99	100-299	300 or More
Grazed on public lands	1.4	6.5	18.0	36.4
Grazed in a grazing association	0.1	1.6	4.7	11.0
Grazed on leased, private land	30.6	49.1	68.0	68.0
Grazed on own land	95.8	96.1	97.3	95.5

Source: APHIS, 1998a.

Table 4-4. Percent of cow-calf operations in 1996 by type of grazing used and state.

Type of Grazing	State				
	California Colorado Montana New Mexico Oregon Wyoming	Kansas Nebraska North Dakota South Dakota	Oklahoma Texas	Arkansas Illinois Iowa Missouri	Alabama Florida Georgia Kentucky Mississippi Tennessee Virginia
Grazed on public lands	32.8	9.7	0.1	0.0	1.1
Grazed in a grazing association	7.1	2.7	0.1	0.0	0.0
Grazed on leased, private land	49.8	63.0	41.0	45.3	16.1
Grazed on own land	85.4	98.8	94.1	98.4	98.2

Source: APHIS, 1998a.

1994d). Most cow herds have access to pasture, ranging from 83.2 percent in January to 99.4 percent in July. During the winter months (November-January) 18 to 19 percent of the operations with cow herds had access to crop residues (APHIS, 1994d). Despite the high proportion of cow-calf operations that use pasture, a large number of operations also provide hay, silage, supplements, or grain depending on the season (see Table 4-5).

Table 4-5. Percent of cow-calf operations feeding hay, silage, supplements, or grain to the cow herd during 1993. (Value in parentheses corresponds to average pounds of feed per head per day for operations feeding the associated feedstuff.)

	Type of Additional Feed/Supplement			
Month	**Hay**	**Silage**	**Supplements**	**Grain**
January	95.6 (28.4)	3.5 (25.3)	53.1 (1.9)	40.0 (3.4)
March	88.1 (27.0)	3.6 (26.3)	50.2 (1.7)	34.9 (3.8)
May	14.9 (19.7)	0.9 (28.2)	24.9 (1.2)	8.1 (4.1)
July	0.8 (22.3)	0.0 (0.0)	18.5 (0.9)	4.1 (4.4)
September	11.8 (12.4)	0.4 (15.0)	24.0 (1.4)	6.4 (3.0)
November	63.9 (22.7)	0.1 (34.4)	42.7 (1.6)	22.9 (4.3)

Source: APHIS, 1994d.

Cow-calf operations use a variety of water sources including tanks, troughs, automatic waterers, rivers, streams, ponds, lakes, and other sources. As shown in Table 4-6, natural sources such as ponds/lakes and rivers/streams, followed by tanks/troughs, are the dominant water sources for most of the year. Table 4-7 summarizes the manure disposal methods used in cow-calf operations. Sweeten (1998) notes that in many cases the effect on nutrients of unconfined cow-calf operations on range or pasture cannot be distinguished from natural or background conditions although elevated bacteria and sediment would be the most common water quality change.

Table 4-6. Percent of cow-calf operations by water source and month.

	Month			
Water Source	**January**	**April**	**July**	**October**
Tank or trough	42.6	36.6	38.2	36.2
Automatic waterer	15.4	13.9	9.9	12.4
River/stream	45.5	47.9	46.6	48.1
Pond/lake	54.7	58.9	62.8	61.9
Other	4.7	3.9	4.6	5.4

Source: APHIS, 1994d.

Table 4-7. Percent of operations and beef cows where various methods were used to dispose of manure.

Manure Disposal Method	**Operations**	**Beef Cows**
Drag or harrow pastures	43.0	44.2
Hauled and spread onto land used for grazing or forage production for the operation	25.5	34.1
Hauled and spread onto other land	21.9	25.4
Other	2.5	1.7
No disposal	34.7	32.4

Source: APHIS, 1998a.

4.1.2 Finishing Operations

The finishing phase typically starts when the calves reach 6 months of age or weigh at least 400 pounds, and the phase can last up to 24 months of age. Typically, the annual average steer weight is from 1,100 to 1,300 pounds at slaughter while the annual average heifer weight is from 1,100 to 1,200 pounds (NASS, 1998). This phase is conducted in a confined area to control weight gain, feed fiber ratios, feed efficiency, feed costs, and animal health. In this phase, there is generally between 50 to 200 square feet of feedlot area per head of cattle, with the larger space allocations associated with unpaved lots or wetter conditions. Beef cows and bulls culled from the breeding stock are slaughtered at weights up to 1,400 pounds. Unlike grazed land, the runoff from feedlots contains high levels of nutrients, salts, bacteria, and organic matter (Sweeten, 1998).

From 1989 to 1994 for operations with more than 1,000 head, 38.4 and 42.1 percent of operations instituted a ground and surface water monitoring program, respectively. Nearly 70 (69.6) percent of these operations also changed their manure management program. Operations with fewer than 1,000 head instituted or changed these same actions less (instituted ground water monitoring, 10.1 percent; instituted surface water monitoring, 8.8 percent; changed manure management, 20.1 percent) (APHIS, 1995a).

In the same survey, nearly all (99.5 percent) operations with fewer than 1,000 head dispose of manure on their own land while only 88 percent of larger operations use their own land. Larger operations (those with 1,000 or more head) also give the manure away (23 percent), sell the manure (9.3 percent), pay someone to take the manure (6.6 percent), or dispose of it by some other method (4.1 percent). More than one-third (38 percent) of operations with more than 1,000 head test the manure nutrient content, while only 7.7 percent of smaller operations test manure for nutrient content. About 50 (48.6) percent of smaller operations and 70 (69.1) percent of operations with more than 1,000 head test the nutrient content of the soil. Of operations testing soil, only one-third (32.5 percent) of smaller operations and 62.4 percent of operations with more than 1,000 head use soil testing to determine manure application rates. Forty-five (44.9) percent of operations with more than 1,000 head, while a little more than one-tenth (10.5 percent) of smaller operations, test ground water. Nearly 95 (94.8) percent of dead animals are sent to a renderer for disposal, and 4.4 percent of dead animals are buried on the farm (APHIS, 1995a).

4.1.3 Housing and Related Facilities

Housing facilities for beef cattle operations include confined calving facilities, bull pens, artificial insemination areas, and feedlots (MWPS, 1987), all of which require manure management. As suggested earlier, many operations do not house their cow-calf operations and most finishing operations use feedlots.

Cow-Calf Feed Yard. Separate feed yards might be provided for mature cows, first calf heifers, bulls, and calves. Layouts and size vary depending on herd size, feed storage and handling equipment, and soil and drainage conditions. Lot size also depends on how long the cattle are confined. Up to 1,000 square feet per cow-calf unit is provided. More area is allocated if cattle are penned year-round; less area is allocated if cattle are grazed. Fence-line feed bunks are common for herds over 100 head, although mechanical feed bunks can be used for herds up to 500 head.

Calving Facility. Calving facilities are used for observing cows and heifers that are ready to calve and might require assistance. The building might consist of a shed with stalls in colder areas or an open, wind-protected pen in mild regions. There might be a loose housing observation area, individual pens ranging in size from 10 by 10 to 12 by 12 feet with three solid sides, and a chute for holding and treating cows. The barn or pen is sized to hold 5 to 10 percent of the herd, or more if the risk of severe weather is high, if several cows or heifers require observation at one time, or if heat synchronization and artificial insemination practices are used. Bedding is provided, as well as heated areas for the calves in cold or wet weather. Cows and calves are usually turned out 2 to 3 days after birth.

Bull Pens and Yards. Space is usually provided for one bull per 25 cows or heifers. Bulls are penned either separately or in groups of up to 10 to prevent fighting. Bulls can be kept outdoors if windbreaks and shade are provided, but a barn is usually available if extreme temperatures occur since such conditions adversely affect bull fertility.

Open Feedlots. Open feedlots can be paved, partially paved, or unpaved. Feedlots are sloped or graded from 4 to 6 percent to promote drainage away from the lot, typically to a retention pond. Inside the feedlot, mounds provide consistently dry areas for cattle to rest. Windbreaks and shade are provided in areas where weather can be extreme. Alleys for cattle are typically 12 feet wide. In areas of high rainfall or snowfall, more space is needed for drainage and/or snow storage. Heavily trafficked areas might be paved for easier cleaning and to prevent excessive erosion, especially near feedbunks and waterers. Table 4-8 presents typical space allocations based on lot slope. Runoff from feedlots is directed to retention ponds. In some feedlots, a solids separator (i.e., settling pond or sediment trap) is used as a pretreatment to a retention pond.

Table 4-8. Minimum lot space requirements for different lot slopes.

Slope of Feedlot	Minimum Area Requirement (ft^2/head)
4% or greater	150-250
2%-4%	250-400
Less than 2%	400-800

Source: MWPS, 1987.

Cattle Feeding Facility. Outdoor feedlots might have several pens with fence-line feed bunks located around a central office and feed storage area. Pens have rounded corners to facilitate cattle and equipment turning. The feedlot area depends on herd size, manure and snow storage, amount of paved area, soil type, drainage, rainfall, freezing and thawing cycles, and the type of equipment used, although in general lots contain 400 to 450 square feet per head.

Barn with Outdoor Pens. Semienclosed lots with three-sided barns are used in areas with severe weather or high rainfall, with outdoor space provided for exercise, resting, and manure storage. Feed, cattle, and equipment stay dry, promoting more regular feed intake and improved cattle comfort. The barn is designed to improve conditions within; for instance, a light-colored roof and northern exposure might be used in hot climates to keep the inside cooler, or a southern exposure and dark-colored roof might be used where heating is needed in colder climates. The floor is sloped toward the opening, heavily trafficked areas are paved, and bedding might be provided for a loafing area.

Confinement Feeding Barns. Confined feeding barns require less area per head and prevent problems associated with severe weather and high precipitation. Fence-line or mechanical bunks are used for feeding. Minimum space allocation is 18 ft^2/head in slotted floor pens and 30 ft^2/head in solid floor pens for 800- to 1,000-pound cattle. Slotted floors have the added advantages of easier manure collection and improved cattle cleanliness since cattle traffic works manure through the slots. Slats are typically concrete, but wood, plastic, and aluminum are also used. Slot spacing depends on cattle size.

4.2 National Distribution by Type and Size

Table 4-9 summarizes number of cattle and calves from 1989 through 1998. Although the number of milk cows has declined during this period, the number of beef cows has remained generally stable. Table 4-10 presents the number of operations in each region by operation size class computed from the 1992 Census of Agriculture. In 1992, more than one-third of all operations were located in the North-Central Region and more than 20 percent in the Southeast and South-Central Regions. Figure 4-1 presents a geographic distribution of the number of beef cows per county, and Figure 4-2 presents the geographic distribution of operations with 500 or more beef cows. Table 4-11 summarizes the number of operations by beef cow herd size by state for 1996 and 1997. Table 4-12 presents the number of cattle and calves on feed by states for 1996 through 1998.

Table 4-9. Number of cattle and calves by class and year in the United States.

Year	All Cattle and Calves (thousands)[a]	Cows and Heifers that Have Calved (thousands)		500 Pounds and Over (thousands)					Calves Under 500 Pounds (thousands)
				Heifers					
		Beef Cows	Milk Cows	Beef Cow Replace.	Milk Cow Replace.	Other	Steers	Bulls	
1989	96,740	32,488	10,138	5,325	4,117	7,631	15,431	2,150	19,461
1990	95,816	32,455	10,015	5,283	4,171	7,803	15,512	2,160	18,418
1991	96,393	32,520	9,966	5,443	4,093	8,102	15,967	2,196	18,107
1992	97,556	33,007	9,728	5,643	4,131	8,048	16,424	2,239	18,336
1993	99,176	33,365	9,658	6,092	4,176	8,550	16,940	2,278	18,118
1994	100,988	34,650	9,528	6,365	4,144	9,068	17,042	2,307	17,884
1995	102,755	35,156	9,487	6,475	4,141	9,275	17,463	2,390	18,369
1996	103,487	35,228	9,416	6,179	4,104	9,949	17,732	2,392	18,488
1997	101,460	34,271	9,309	6,056	4,057	10,199	17,320	2,339	17,909
1998[b]	99,501	33,683	9,191	5,745	3,982	10,018	17,197	2,266	17,418

[a] Total may not add due to rounding. [b] Preliminary.
Source: NASS, 1998.

Table 4-10. Size distribution of all beef operations derived from data collected in the 1992 Census of Agriculture.

Location	Operations Categorized by Size Class (animal units[a])								
	1-25	25-100	100-300	300-500	500-1,000	1,000-5,000	5,000-10,000	10,000 or More	Total
Northeast	56,254 (9.2%)	11,825 (3.8%)	1,142 (1.5%)	125 (1%)	41 (0.5%)	20 (0.5%)	0 (0.0%)	0 (0.0%)	69,407 (6.7%)
Southeast	155,861 (25.4%)	70,644 (22.5%)	10,220 (13.2%)	1,156 (8.9%)	569 (7.3%)	255 (7%)	12 (4.7%)	5 (2.1%)	238,722 (23.2%)
North-Central	216,941 (35.4%)	124,906 (39.8%)	32,396 (41.9%)	4,691 36.1%)	2,538 (32.8%)	1,180 (32.2%)	97 (37.9%)	92 (38.3%)	382,841 (37.2%)
South-Central	125,038 (20.4%)	75,539 (24%)	17,446 (22.6%)	2,964 (22.8%)	1,857 (24%)	942 (25.7%)	61 (23.8%)	80 (33.3%)	223,927 (21.8%)
Mountain	27,385 (4.5%)	20,739 (6.6%)	11,777 (15.2%)	3,045 (23.5%)	2,007 (25.9%)	905 (24.7%)	56 (21.9%)	39 (16.3%)	65,953 (6.4%)
West	30,382 (5%)	10,295 (3.3%)	4,189 (5.4%)	988 (7.6%)	724 (9.3%)	340 (9.3%)	30 (11.7%)	23 (9.6%)	46,971 (4.6%)
Other	597 (0.1%)	177 (0.1%)	69 (0.1%)	13 (0.1%)	13 (0.2%)	23 (0.6%)	0 (0.0%)	1 (0.4%)	893 (0.1%)
United States	612,458	314,125	77,239	12,982	7,749	3,665	256	240	1028,714

[a] The procedure for estimating animal units was adopted from Lander et al. (1998).

Table 4-11. Number of operations by beef cow size group in selected states and United States, 1996-97.[a]

State	1-49 Head		50-99 Head		100-499 Head		More than 500 Head	
	1996	1997	1996	1997	1996	1997	1996	1997
AL	27,000	23,000	3,200	3,200	1,750	1,750	50	50
AZ	1,500	1,500	330	230	400	500	170	170
AR	20,000	20,000	4,100	4,100	1,870	1,870	30	30
CA	11,700	11,600	1,200	1,200	1,800	1,700	300	300
CO	5,300	5,300	1,500	1,600	2,450	2,350	250	250
FL	15,300	16,400	1,700	1,600	1,650	1,700	350	300
GA	21,000	20,500	2,800	2,280	1,180	1,200	20	20
ID	5,000	5,100	1,100	1,000	1,280	1,280	120	120
IL	15,600	15,700	1,600	1,600	600	500		
IN	15,000	15,000	800	800	200	200		
IA	21,000	20,800	5,050	5,250	1,900	1,900	50	50
KS	20,000	19,000	5,900	5,500	3,980	4,350	120	150
KY	38,500	38,000	4,700	4,400	1,770	1,570	30	30
LA	13,400	13,200	1,700	1,600	1,400	1,400	100	100
MN	13,500	13,400	2,000	2,100	480	480	20	20
MS	25,000	24,000	3,000	3,000	960	950	40	50
MO	51,000	48,000	8,000	8,300	3,900	3,600	100	100
MT	4,300	4,800	2,650	2,150	4,200	4,300	550	550
NE	12,300	12,200	4,600	4,600	4,600	4,700	500	500
NM	3,900	3,900	1,000	1,000	1,300	1,300	300	300
ND	5,700	5,300	3,500	3,500	3,140	3,240	60	60
OH	20,000	19,000	780	760	220	240		
OK	41,000	42,000	8,400	8,000	4,400	3,800	200	200
OR	14,000	12,000	1,300	1,500	1,300	1,300	200	200
PA	11,500	11,000	380	380	120	120		
SD	8,200	7,200	4,500	4,500	5,000	5,000	300	300
TN	46,000	45,000	4,600	3,600	1,375	1,375	25	25
TX	104,000	104,000	17,500	17,500	10,500	10,500	1,000	1,000
UT	3,400	3,200	790	870	890	910	120	120
VA	22,000	23,000	2,800	2,700	1,170	1,260	30	40
WA	11,500	11,500	700	700	750	750	50	50
WY	1,800	1,700	1,000	1,000	1,800	1,800	300	400
Other	87,000	87,000	4,300	4,300	930	950	150	150
US	716,400	703,300	107,480	104,820	69,265	68,845	5,535	5,635

[a]An operation is any place having one or more cattle on hand during the year. Missing data combined with other size groups.
Source: NASS, 1998.

Table 4-12. Cattle and calves: total number on feed by state, 1996-98.[a]

State	1996 (thousands)	1997 (thousands)	1998 (thousands)
Alabama	5	5	4
Arizona	222	233	245
Arkansas	18	19	10
California	350	375	400
Colorado	1,070	1,130	1,140
Georgia	10	5	5
Idaho	270	270	295
Illinois	290	265	240
Indiana	200	220	170
Iowa	900	1,000	1,000
Kansas	2,210	2,220	2,370
Kentucky	25	20	20
Louisiana	3	3	1
Maryland	17	11	15
Michigan	200	200	200
Minnesota	335	300	275
Mississippi	4	4	3
Missouri	100	95	110
Montana	105	85	80
Nebraska	2,030	2,220	2,300
Nevada	22	25	24
New Jersey	4	6	4
New Mexico	136	137	123
New York	30	30	30
North Carolina	10	10	10
North Dakota	75	100	70
Ohio	235	200	165
Oklahoma	415	400	435
Oregon	80	80	60
Pennsylvania	75	75	75
South Carolina	8	6	7
South Dakota	330	320	320
Tennessee	20	20	20
Texas	2,630	2,630	2,860
Utah	60	50	40
Virginia	35	30	30
Washington	166	163	200
West Virginia	9	8	10
Wisconsin	150	150	155
Wyoming	95	80	85
Other	19	16	12
US	12,968	13,216	13,618

[a]Cattle and calves on feed are animals for slaughter market being fed a full ration of grain or other concentrates and are expected to produce a carcass that will grade Select or better.
Source: NASS, 1998.

4.3 Waste Management Technologies

Manure management is important in beef cattle facilities to

- Maintain good animal health
- Minimize pollution
- Maintain aesthetics
- Reduce odors and dust
- Control insects and pathogens
- Balance nutrient use

A manure management plan should consider methods for integrating collection, storage, transfer, and use.
One key aspect of designing a manure management plan is the manure consistency. In beef cattle operations, manure as excreted is semisolid with about 12 percent solids by weight. The advantages of solid handling are reduced total volume. Labor requirements may be greater in solid waste handling operations since waste handling cannot be easily automated. Liquid waste handling can be automated, requiring less labor, but equipment installation and maintenance costs are higher and the total volume of manure is higher due to water inputs. Operator preference is often the deciding factor in selecting which kind of system will be used. Figure 4-3 provides a schematic of waste handling alternatives for beef cattle management. The following section describes waste management technologies for both solid and liquid manure.

4.3.1 Waste Reduction

Waste storage volume can be reduced by diverting clean water (precipitation and surface flow) from contact with manure. Roofing animal housing areas and manure storage sites (with gutters to divert roof runoff) can be used to prevent contact with precipitation, while diversionary structures (berms), channels, and well-planned drainage patterns will keep clean surface runoff out of feedlot and waste storage and treatment areas.

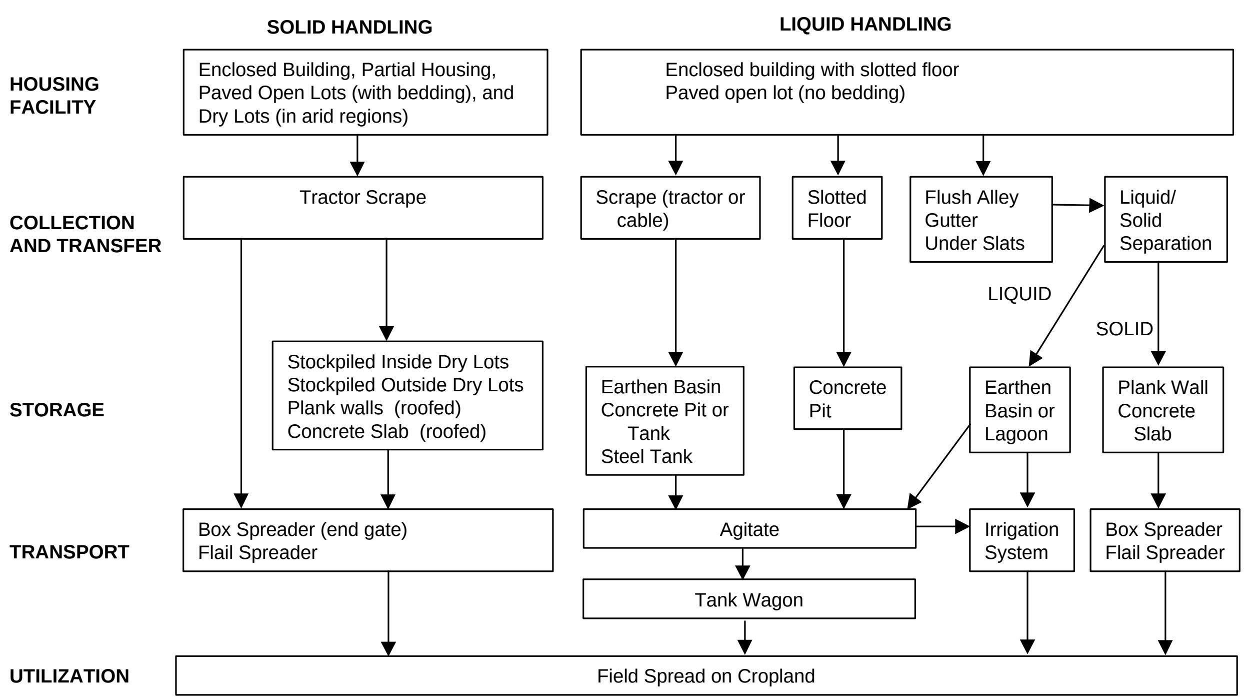

Figure 4-3. Handling alternatives for beef cattle manure (Source: After Veenhuizen et al., 1992).

Nutritional strategies are sometimes used for other livestock, such as swine or poultry, to reduce the nutrient content of manure. Although some research has been conducted to determine the relationship between feed quality and waste quantity and quality (Tamminga, 1996), this option has not been adequately reported in the literature at this time despite anecdotal evidence suggesting opportunities for decreased nutrient excretion.

4.3.2 Waste Collection, Storage, Treatment, and Use

4.3.2.1 Waste Collection

Scraping. Manure scraping is the most common method for collecting solid and semisolid manure from both barns and open lots. Collection can be done with tractors or mechanical systems. To scrape alleys, tractors can be fitted with a rubber or steel blade attached to the front or rear. Alternatively, a skid-steer tractor with a front-mounted bucket can be used to scrape alleys, large open areas, and convoluted spaces. Tractors have fewer problems than more mechanized systems and work better on frozen manure. Paving surfaces allow for improved scraping, although unpaved lots can be scraped if care is taken not to disrupt the natural surface seal formed by cattle traffic and microbial activity (this seal improves surface flow and helps protect against groundwater contamination).

Mechanical scrapers and barn cleaners can reduce labor requirements by automating the scraping process. Also, odor is reduced in enclosed areas by removing manure regularly (at least once a day). This equipment is limited to a single alley or gutter and is propelled electrically with cables or chains. Sometimes a single system can clean two parallel alleys in opposite directions. Alley scrapers are most often used in free stall barns and cover the entire length and width of the alley in one pass. The cable/chain is recessed into the floor to stabilize the blade and prevent a tripping hazard. They travel at 4 to 7 feet per minute and do not interfere with cattle in the alley or at the feedbunk. They can be equipped with automatic stopping systems if an animal or other obstruction gets caught and requires attention. Cold barns may need to be tractor scraped on very cold days.

Slotted Flooring. This method rapidly removes manure from the animal's space. Cattle traffic works the manure between the slats and keeps the floor surface relatively clean. Wide slats (4 to 8 inches) are recommended for beef cattle with spacing between slats of 1.5 to 1.75 inches. Slotted floors should not be used for breeding areas to ensure firm footing (stressed animals do not breed as well). Slats can be made of concrete, aluminum, or plastic. Each material has advantages and disadvantages with respect to cost, durability, and animal safety. Concrete is used most often in beef operations to support the weight of the large animals. Slats should have a textured surface for sure footing and tapered sides for improved cleaning. Solid manure can be removed from under the floor using mechanical scrapers or flushing systems.

Flushing systems. Beef cattle manure can be diluted with water to allow for automated handling. However, this approach increases the volume of manure to be handled, treated, and stored and requires a larger capital investment for equipment and storage facilities. A flushing system requires a large volume of water to carry manure down a sloped gutter (0.5 to 1.0 percent) to storage. This system is usually found under slotted floors in beef operations. Water can be discharged using a flush tank or a large-capacity pump. A small pump can be used to fill the flush tank. Typically 100 gallons per 1,000 pounds live weight per day is required for adequate cleaning. Large-capacity pumps are controlled by a time clock. Gutters should be pumped with 110 gpm/foot of gutter width for 3 to 5 minutes at least twice a day.

Liquid can be transferred to a storage lagoon or basin via a sump and pump at the end of collection gutters or with gravity transfer at a 1 to 5 percent slope through concrete, steel, or plastic pipes. Both systems are flushed with water to prevent clogging with solids, salts, or mineral deposits. Either clean water or recycled water from a lagoon, storage basin, or holding pond can be used. Pipe size, flushing frequency, and flush water volume are designed for a specific consistency and volume of manure to ensure that efficient scouring is achieved. In general, large diameter (20- to 36-inch) pipes work for manure with up to 3 lb/day of well-mixed, chopped, or fine bedding per 1,000-lb animal. Small (6- to 8-inch) pipes work well with liquid manure. There should be a 4- to 6-foot difference between the collection channel and the top of the storage, and the storage should be bottom-loaded to prevent gases from returning to the building.

Runoff from open feedlots, manure storage areas, and feeding facilities are another source of liquid wastes produced in beef cattle operations. Liquid wastes are directed toward a storage or treatment system. Runoff that has not come into contact with manure is normally diverted from the storage or treatment system. The size of a treatment system is dependent on the lot size; the rainfall duration, intensity, and frequency; and the quantity of manure on the lot. The last is determined based on the number of cattle present, the amount of time during which they have access to the lot, and the volume of manure produced per animal.

Separation. Runoff or liquid from flushing systems will contain suspended solids that can be removed before storage in a pond or lagoon or treatment in a vegetated filter area. Separation of liquids and solids reduces the solids entering a storage facility and extends its storage capacity. For example, a settling basin slows water velocity and removes solids by gravity (up to 50 to 85 percent removal) if detention time is at least 30 minutes. Baffles and porous dams can be used to slow the flow, and concrete basins tend to improve solids removal, although in arid regions where evaporation is high, earthen basins are used. The settling basin needs to be cleared of solids between runoff events. The solids from separation are cheaper to transport. Choosing a separation system is usually based on consideration of maintenance, operating, and installation costs; applicability; and benefits that may offset costs. Common methods to separate liquids and solids include the following:

- Settling basin—gravity separation (see above).
- Centrifuge—rapidly rotating devices that use centrifugal force to squeeze liquids from solids.
- Particle size screens, vibratory screens, strainers, and filters—liquids pass through screen.
- Belt pressure rollers—liquids pass through or out the belts while solids are scraped out.
- Screw presses—liquids pass through a screen while solids are discharged out the end of a cylinder that contains a screw that conveys the manure.
- Evaporation—common in arid regions where evaporation exceeds precipitation.

4.3.2.2 Waste Storage

Manure, if dry enough, can be stacked as a solid for storage. Storage areas can be located in the barn with the animals, in a separate, roofed structure, in an unroofed structure, in the feedlot, in a storage yard near the animal facility, or at the site of future land application (which would require more frequent or daily hauling). If the storage area is unroofed and precipitation can enter, runoff from the manure area can be collected and treated. Roofed structures keep out precipitation, and diversionary measures can be used to reduce surface runoff. Solids from settling ponds or other separation processes would generally be stored in a similar fashion.

Liquid wastes are typically stored in a waste storage pond or in some cases, a reception pit after separation. These storage structures are rectangular or circular and can be earthen, steel, or reinforced concrete. *Belowground storage tanks* are designed based on bedrock depth, water table elevation, and effective pump lift. Tanks made of concrete are designed to withstand internal and external pressures and potential uplift. Before use, 6 to 12 inches of water is added to tanks to keep solids submerged. *Earthen storage basins* can be lined with clay or a synthetic liner (in some cases both) to prevent leakage to ground water. The choice of liners depends on local regulations, soil and geologic conditions, cost, and pond emptying methods (for example, some agitation and pumping devices may tear plastics and geomembranes). In some cases clay liners are susceptible to channeling (macropores) and worm activity. Runoff that has not passed through areas with manure is excluded to reduce total storage requirements. Currently, design documents recommend that storage capacities accommodate the runoff from a 25-year, 24-hour storm event in addition to storing wastewater for a desired length of time and allowing for a 1-foot freeboard. Depending on climate and other agronomic issues, systems are designed for up to 10 to 12 months of storage (less in warmer climates), including dilution water from spilled waterers, precipitation, and water added to allow for irrigation of manure with pumps. Some storage basins are bottom loaded to promote crust formation that reduces odors and fly problems and to promote even distribution of solids. For bottom-loaded basins, the inlet pipe is at least 1 foot above the bottom of the basin. *Aboveground storage tanks* are expensive but may be desirable when earthen or pit storage is unacceptable due to poor geologic, hydrologic, or soil conditions or when alternative storage structures are not aesthetically acceptable. Aboveground tank sizes range from 10 to 60 feet in height and 30 to 120 feet in diameter. The tanks are constructed of concrete and steel.

4.3.2.3 Waste Treatment

Composting. Composting produces an excellent soil conditioner that improves organic matter content, soil tilth, and nutrient content and protects against cropland erosion. Composted manure contains about one-half the nitrogen of fresh manure; however, much of the nitrogen is in an organic form that is less susceptible to leaching and volatilization. In fact, only about 15 percent of the nitrogen in manure is available in the first cropping season. Nevertheless, if manure handling and application methods are inefficient in conserving nitrogen, compost might have more nitrogen than the field-applied manure. Composting can be labor-intensive and expensive. (Starting costs range from $20,000 to $125,000 and higher depending on operation size and technology chosen.) Some additives may be required (i.e., crop residues, sawdust, newspaper clippings, or yard waste) to adjust the carbon-to-nitrogen ratio and moisture content of the materials. The compost product can be sold to nurseries or cash crop farms to partially offset treatment costs. Runoff from the composting process should be diverted to retention basins, ground water infiltration should be minimized, and clean surface runoff should be excluded from treatment areas. Management practices vary seasonally, but composting can continue year-round even in cold climates.

Table 4-13 presents comparative costs (1994 dollars) of composting. Some compost piles are turned or aerated regularly to maintain optimal oxygen concentration and temperature. Other composting systems are mechanized and do not require turning, but capital investment and maintenance costs are higher. *Windrow composting* involves placing the manure mixture in long, narrow piles (windrows) that are turned on a regular basis. The windrows are approximately 3 feet high and 10 to 20 feet wide for dense manure. The shape of the windrow depends on the turning equipment used. The turning frequency depends on compost materials and climatic conditions. *Passively aerated windrows* eliminate the need for turning because air is supplied through open-ended, perforated PVC pipes embedded in the windrow. Air flow is maintained through two rows of 0.5-inch holes to control the heat produced by the decomposition process. Windrow materials should be thoroughly mixed when constructed and built on a base of straw, moss, or compost to absorb moisture and provide insulation. *Aerated static piles* are similar to passively aerated windrows, except that air is forced into the pile using pipes with blowers. This method allows for larger piles and turning is not required. In *in-vessel composting,* composting materials are confined within a building, container, or vessel. Forced aeration and mechanical turning techniques are used to speed the process (Minnesota Dept. of Agriculture, 1995).

Table 4-13. Comparative costs (1994 dollars) of composting methods.

Method	Estimated Cost per Ton of Incoming Material
Windrow composting using a loader for turning	$5-$10
Windrow composting using specialized windrow turners	$15-$30
Aerated static pile systems	$20-$50
In-vessel systems	$50-$100

Source: Minnesota Dept. of Agriculture, 1995.

Anaerobic Digestion. This process, appropriate for liquid manure, decomposes organic material in the absence of air. Both methane and carbon dioxide are given off. Collectively, they are referred to as biogas. Biogas, when collected, can be used as an energy source. The systems best suited for cattle manure include

- Anaerobic lagoon—covers for biogas recovery are considered expensive; biogas yields are low
- Plug-flow system—single tank system; relatively simple to operate; higher potential for loss of treatment
- Complete-mix systems—single tank with mixing systems to evenly distribute solids and increase surface area for bacterial activity; lower potential for loss of treatment; energy requirements may be high

Costs associated with these systems include materials handling, tank covers, heating and mixing equipment, gas handling equipment, and electricity generation. Odors can be a problem with poorly managed systems.

Aerobic Lagoons and Oxidation Ditches. These systems, also appropriate for liquid manure, allow both aerobic and anaerobic treatment in the same unit by physical aeration (by movement) in part of the ditch. Treatment effectiveness is determined by the treatment surface area and the oxygen provided by mixing equipment (or other supplemental oxygen source) based on daily BOD_5 loading per unit. These systems often rely on large surface areas or high equipment/energy costs to provide oxygen, resulting in the technology's not being cost-effective.

Vegetated Filter Strips and Infiltration Areas. Solids are removed before liquids are treated through a vegetated filter area since sediment would quickly overload the system. These systems work best for small quantities of runoff (relatively infrequent or low-intensity runoff events) since continuous application nullifies the ability of the filter strip to take up nutrients. The inflow is spread out using a concrete apron and a gravel spreader strip. This allows for further deposition of suspended solids and spreads the water evenly and thinly over the vegetated area. When the nutrient-rich water enters the soil, it is converted biologically and chemically to plant-available nutrients that are incorporated into the organic component of the soil or are taken up by plants. This transforms the nutrients into biomass that can be harvested. Vegetation generally consists of grasses, such as reed canarygrass, smooth bromegrass, and intermediate wheat used alone or in combination with bunch grasses. Species that tend to mat are usually avoided. Capital investment includes land, surface shaping, and vegetation establishment costs. Periodic harvesting or mowing is required. Gravel spreaders are replaced every 5 to 10 years to remove solids buildup. Flow-through time should be at least 15 minutes. The size of the vegetated area depends on feedlot size, slope, soil type, and rainfall.

4.3.2.4 Waste Use

Land Application. Solid manure can be loaded into manure spreaders (box- or flail-type), dump trucks, earthmovers, or wagons for *broadcast land application* as fertilizer or soil conditioner. To minimize nitrogen losses, solid manure is incorporated soon after application.

Feedlot runoff can be used to *water crops*, especially if the pond is located near the fields. Using appropriate design and management, water can be applied with minimal seepage to ground water. Storage capacity should account for climate (long enough to save up for the growing season). Since the water is nutrient-rich, applying it to crops will reduce the need for commercial fertilizer. Land application can be accomplished with tank sprayers or piped through irrigation systems if fields are near the storage site.

Spray or furrow irrigation systems can be used to transport liquids short distances to nearby fields for land application. High concentrations of solids may clog pumps, pipes, and sprinkler heads in these systems, so solids separation and/or dilution may be required (however, dilution increases the total volume and treatment requirements). Initial installation costs are high and equipment will require maintenance, but labor costs can be greatly reduced with the increased automation.

Depending on the operator, the sludge in the bottom of a lagoon can be removed using an excavator or agitated to mix with the supernatant. Agitation can be achieved by reversing the flow of the manure pump to facilitate horizontal and vertical mixing, ensuring not to damage the storage liner. Semisolid manure can be *injected* into the ground to reduce odors and nitrogen losses through volatilization.

The timing of liquid application is important to control nutrient losses. Manure should be applied as close to the time of crop needs as possible, during low rainfall periods, when the ground surface is not frozen, and when soil moisture is low enough to avoid compaction. In all cases, the rate of manure application can be determined by balancing crop uptake with existing soil nutrients.

Bedding and Livestock Feed. Dry manure can also be mixed with various bedding materials for loafing barns and resting areas, or it can be recycled as livestock feed.

4.4 Effectiveness of Waste Management Systems

Table 4-14 describes the quantity and nutrient quality of freshly excreted manure. Nutrients are lost in handling and storage at rates described in Table 4-15. Treatment methods further reduce the nutrient content of manure. The amounts of nutrients that are ultimately land applied also depend on soil and environmental conditions, as well as the timing and method of application. Table 4-16 shows that nutrient availability is greater when manure is applied in the spring, when the soil is finely textured, in areas of low precipitation, and when the manure is incorporated or injected rather than just surface applied. Land managers therefore have some flexibility in controlling nutrient inputs from manure to the soil.

Table 4-14. Fresh manure as excreted.

Animal Size (lb)	Total Manure Storage Allowance			Nutrient Content of Fresh Manure		
	lb/day	ft^2/day	gal/day	N (lb/day)	P (lb/day)	K (lb/day)
500	30	0.48	3.6	0.17	0.13	0.15
750	45	0.71	5.3	0.26	0.19	0.22
1000	60	0.95	7.1	0.34	0.25	0.30
1250	75	1.19	8.9	0.43	0.31	0.38

Source: MWPS, 1993.

Table 4-15. Nitrogen losses with different handling techniques.

Scrape and Haul	
Collection and storage	15-35% losses before application
Broadcasting solids	15-30% during and after application
Additional losses prior to crop use	5-10%
Liquid Handling	
Collection and storage	15-35% losses before application
Injection of liquid manure	0-2% losses
Additional losses prior to crop use	5-10% for fall application

Source: Legg and Easter, 1992.

4.5 Example Systems

The goal of this section is to compare and contrast waste management systems from different regions of the country. This is important because a particular system might be appropriate for one region but entirely ineffective for another. For example, a lagoon might be suitable for runoff treatment in a humid region where water is plentiful and a 6-foot depth is easily maintained, whereas in the arid southwest an evaporation or retention pond might be more appropriate. Some examples are general characterizations of operations in the state or region rather than descriptions of a specific system.

4.5.1 Ohio (Veenhuizen et al., 1992)

In Ohio, the typical cow/calf beef operation provides housing and bedding during winter and early-spring months. Solid-manure-handling systems are commonly used with both cow/calf operations and confined feeder operations. The common housing system for feeder beef cattle is an open-front shelter with an earthen or paved lot. Many feedlots are unpaved and require more total lot area for effective management. Paved lots are recommended to reduce the required lot area and ease manure collection and runoff control. Open-lot systems require two manure-handling methods. Lot scrapings are either solid or semisolid, and lot runoff is liquid. Solid manure is

Table 4-16. Estimated N availability (%) as a function of soil properties, environment, and application time and method for first year after application, assuming that 50% of the applied N is organic N and 50% is inorganic N.

Time of Application	Soil Texture	Rainfall	Application Methods			
			Broadcast w/o Incorporation	Broadcast w/ Incorporation	Knife Injection	Sweep Injection
Fall	Coarse	Low, Norm	30	55	45	55
		High	20	45	40	45
	Fine	Low, Norm	35	60	50	60
		High	30	55	45	55
Spring	Coarse	Low, Norm	40	55	50	55
		High	35	50	45	50
	Fine	Low, Norm	45	55	45	55
		High	45	55	40	50
Fall	Coarse	Low, Norm	30	35	50	60
		High	24	40	40	50
	Fine	Low, Norm	35	55	45	55
		High	35	50	40	50
Spring	Coarse	Low, Norm	40	50	50	55
		High	35	45	45	50
	Fine	Low, Norm	40	50	45	55
		High	40	50	40	50

Source: Schmitt, 1990.

moved from the lot to storage with a tractor scraper and front-end loader. Lot runoff is collected as part of the manure-handling system. Clean runoff should be diverted away from manured areas to reduce the total volume of liquid.

Beef cattle can be fed in solid or slotted-floor confinement buildings. Liquid-manure-handling systems are common with confinement housing. Manure is stored in a concrete tank under the building or in an outdoor earthen or concrete storage. It is transferred from the building with either a tractor or mechanical scraper, or by gravity flow.

Manure can be handled as a liquid, semisolid, or solid. The amount of dilution water or bedding influences the manure's form, but ultimately the choice of a manure handling and storage system is dictated by the landowner’s preference for a more automated liquid system with greater initial costs or a more labor-intensive solid system that requires less capital investment.

Storage capacity depends on the existing regulations, number and size of animals, quantity of bedding used, amount of dilution by spilled and cleaning water, amount of stored precipitation and runoff, and desired length of storage. The required length of storage can vary from farm to farm. Enough storage capacity and length of storage should be provided to allow spreading of manure when field conditions, weather, and local regulations permit. It is recommended that 3 to 6 months of storage capacity for liquid manure and at least 3 months of storage capacity for solid manure be allowed. Storage capacity of up to 12 months will provide more flexibility for scheduling field-spreading of manure.

4.5.2 Southeast Region (Alabama NRCS, 1998a, 1998b; Brantley, personal communication, 1998; Deal, personal communication, 1998; and Georgia NRCS, 1997)

Large confined beef cattle facilities are rare in the southeastern United States due to the distance from feed sources and slaughter houses, adverse cattle-raising conditions (very hot and humid), and problems with excessive runoff due to high rainfall rates. Although beef cattle are present in this area, stock density is very low. Often, little manure management is required unless several animals are confined in a small area where contaminated runoff drains to a stream or other water body. If this is the case, a filter strip or other instrument of nutrient removal should be installed between the lot and the water. Solid storage capacity of 30 to 45 days is recommended for a stacking facility, and at least 90 to 180 days of storage should be allowed for liquids in a holding pond. Storage capacity should also include precipitation directly into the storage unit, nondiverted runoff generated from the facility's drainage area during a 25-year, 24-hour precipitation event, and residual solids that are not pumped out when the liquids have been removed. Wastewater should not be applied within 2 days of a predicted rain or 2 days after a rain of 0.5 inch or more. The Southeast Regional NRCS office has several documents specifying standards for designing and operating waste management systems and their components, which can be found at their web site: http://www.ga.nrcs.usda.gov/reg/cps.html.

4.5.3 Northeast Region (University of Delaware, 1989; Graves, 1986; and Sato, personal communication, 1998)

There are few large feedlots in this area, although there are many smaller beef operations. Manure is considered a commodity, and nutrient management plans are written to apply the manure agronomically.

Runoff is diverted from manure lots using diversions and roof runoff management (gutters, downspouts, etc.). Lot runoff that has contacted manure is collected using curbing, grading, pipes, culverts, paving, and other collection methods. It is stored in holding ponds or storage tanks and is sometimes treated and disposed of using a vegetated filter strip. Storage capacity is determined by the accumulated runoff volume from the drainage area and rain volume over the storage structure. The liquids are stored in a holding pond and land applied using spray tankers at rates dictated by the nutrient management plan. Solids separation is used before the stored runoff is irrigated.

Solid manure can be stored in the same lot if it is under a roof, or it can be hauled to a separate facility. Daily land application is done when no storage is available. Solid storage capacity is generally designed for approximately 6 months if under a roof. Storage time varies depending on the size of the storage area, the availability of land for application, and local weather conditions (because manure should not be applied when the ground is frozen or wet). Solid manure treatment is not common in this region, although some landowners do use solids separation and composting. Land application is accomplished with manure spreaders prior to planting in spring or after harvest in fall. If the latter, conservation measures are taken to prevent surface water contamination.

4.5.4 South-Central Region (Green, personal communication, 1998)

This region receives an average of 12 to 16 inches of rain per year. Cattle are kept in open, dry lots, where manure is frequently scraped and piled within the lot until it is removed as a solid and land applied using a manure spreader. The frequency of scraping and duration of storage depend on landowner preferences. Runoff control is achieved using diversions to prevent clean runoff from entering the feedlot, while feedlot runoff is channeled to a storage pond to be land applied.

Storage pond volume is designed for a minimum of 45 days’ storage of solids, liquids, precipitation, and runoff from a 25-year, 24-hour storm, and a 1-foot freeboard. Solids removal can be achieved with a settling basin or other solid separation mechanism, or both solids and liquids can be stored in the pond together. Either agitation to produce slurry for land application or irrigation of water and subsequent scraping and sludge application of solids can maintain the storage pond's capacity. Treatment lagoons are not practical in this area since it is difficult to maintain a minimum depth due to high evaporation rates. Treatment to reduce nitrogen is generally not necessary since manure is used as a crop fertilizer. The NRCS recommends land application from March to November when the crop is actively growing and when the ground is neither saturated nor snow-covered.

4.5.5 Colorado (Meyer, personal communication, 1998)

In Colorado, most beef cattle feedlots are located in the arid (approximately 10 inches of rain per year) eastern part of the state. These account for 85 percent of Colorado's cattle. The other 15 percent are found on smaller farms throughout the state. These feedlots act as a finishing center for cattle that are owned by smaller farms. When the finished cattle are returned, their owner is required to haul a quantity of manure from the feedlot in proportion to the number of cattle that were sent for finishing. This relieves part of the feedlot manager's burden of manure disposal.

At the feedlot, the cattle are penned in large, open lots that are frequently scraped of solids. Little effort is taken to control runoff since precipitation is low and the large feedlots are not located near waterways. However, berms and other diversions are used to keep clean runoff from storms from entering the lot. Storage ponds are generally not used for liquid waste since very little is produced. Evaporation is responsible for eliminating most of the liquid waste.

For the smaller confined beef operations, solid waste is scraped and stored temporarily until it can be land applied to crops with a manure spreader. Since Colorado rangeland is not lush with vegetation, manure applications for this type of land use are less than they would be in an area where more dense vegetation could use most of the nutrients. There have been limited efforts with windrow composting of solid manure to improve the quality of the manure materials.

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5.0 Sheep

5.1 Introduction

The sheep industry declined from approximately 30 million head in 1960 to less than 10 million head by the mid-1990s. The decrease in real prices for lamb is also resulting in structural changes as farmers diversify into other enterprises. The seasonality issues of lamb production, imports, and competing pricing of other commodities such as pork, poultry, and beef also have a major influence on the structure of the industry.

The sheep industry in the United States is diverse. Some operations produce farm flocks of 50 to 200 animals. Others have very large range operations of 1,000 to 5,000 sheep with shepherds to watch over the sheep and dogs (or other predator management practices) to guard the sheep from predators. Sheep can adapt to a wide range of climates and management systems and therefore can be raised all over the country.

In 1995 an average of 121.3 lambs were born alive per 100 ewes exposed. Smaller operations (flock sizes smaller than 50) had the highest number of lambs born alive with 138 per 100 ewes. There is a trend of fewer live lambs per ewe in larger operations. Operations with a flock size between 500 and 999 had an average of 121.1 live lambs per 100 ewes, and operations with a flock size of more than 1,000 had an average of 108 live lambs per 100 ewes. Approximately 9.4 percent of lambs born alive die before weaning. Mature sheep (those 1 year of age or older) are culled at a rate of 16.1 percent and die due to other causes at an annual rate of 5.1 percent (APHIS, 1996b).

Most sheep are raised in a grazing environment (Table 5-1), with only 2.3 percent of operations in the United States having intensive confinement, representing 6.4 percent of all sheep raised in that type of operation (APHIS, 1996b). During the 9-year period from 1988 to 1996, the average live weight of all sheep and lambs ranged from 124 to 128 pounds, with dressed weights of 63 to 64 pounds. During the same period, the number of sheep slaughtered per year range from 5.72 million in 1991 to 4.18 million in 1996 (NASS, 1998). Table 5-2 shows the percentage of operations that raise each breed of sheep and the distribution of the different breeds. Fine wool white face sheep are the most common, making up 41.8 percent of all sheep, but are raised in only 13 percent of sheep operations.

Table 5-1. Percent of operations and percent of sheep by primary flock type.

Flock Type	Percent Operations	Percent Sheep
Herded range flock	1.0	18.9
Fenced range flock	10.0	37.3
Farm flock	84.9	34.6
Intensive confinement	2.3	6.4
Multiple types	1.8	2.8

Source: APHIS, 1996b.

Feed and forage costs tend to be the single largest cost of producing lamb and wool. The housing and confinement structures for sheep are not usually very costly. Typically, sheep are placed in either a fenced in or herded area and can graze freely. Four typical management systems for rearing sheep include the following:

- Pastures–a plot of land for grazing; the solid manure can be dispersed, requiring no extra handling if there is enough land area; rotating land areas and avoiding steep slopes, streams, and drainage ways minimize runoff pollution. Sheep prefer to graze hillsides and steep slopes and can provide a means for improving forage utilization and fertility in those areas since they possess a great ability to convert a wide variety of forage and crop residues into meat and fiber.

Table 5-2. Percent of operations and percent of sheep by primary breed category.

Breed Category	Percent Operations	Percent Sheep
Colored wool	2.4	0.6
Fine wool white face	13.0	41.8
Medium wool white face	20.6	26.0
Black face	32.3	10.2
Crossbred	23.8	15.6
Hair sheep	1.0	0.4
Milk sheep	0.0	0.0
Multiple breeds	6.9	5.4
Total	100.0	100.0

Source: APHIS, 1996a.

- Open Lots for Sheep–open lots should be located away from streams, steep slopes; settling basins are recommended for lot runoff.

- Facilities with Slotted Floors–slats or perforated mesh flooring rapidly separates the animal from its manure improves cleanup, and reduces buildup of solids and the daily labor. Flooring can be made out of wood, concrete, steel, aluminum, or plastic.

- Bedded pens–bedded pens, with a manure pack, are the most common housing for sheep.

5.2 Demographics

5.2.1 National Change and Composition

The U.S. sheep and lamb inventory for 1996 was 8.46 million. Of these animals 60.6 percent are ewes 1 year old or older, 2.8 percent are rams, 10.2 percent are replacement lambs, and 26.4 percent are market sheep and lambs. Approximately 11.8 percent of the 82,000 operations with sheep in 1995 are not expected to have sheep in 2001 (APHIS, 1996b).

Table 5-3 summarizes how the sheep and lamb inventory has declined since 1989, when there were a total of 10.853 million head. In 1998, there were 7.616 million head. Table 5-4 summarizes breeding sheep operation size across the United States during 1997 and 1998. In 1997 there were an estimated 74,710 operations with sheep. More than 90 percent of the operations had fewer than 90 head, representing about one-fourth of the breeding inventory. Operations with 100 to 499 head represent a little more than 6 percent of the operations and one-fifth of the breeding inventory. A little more than 2 percent of the operations have more than 500 head and represent about 55 percent of the breeding inventory (NASS, 1998).

5.2.2 Geographic Distribution

Table 5-5 summarizes number of operations in each region by operation size class using the 1992 Census of Agriculture. Table 5-6 present the number of breeding and market sheep by state for 1997 and 1998. In 1998 the states with more than 200,000 breeding sheep and lambs include Texas (1,170,000), Wyoming (510,000), California (440,000), Montana (385,000), South Dakota (330,000), Utah (315,000), Colorado (240,000), Idaho (234,000), and New Mexico (215,000). The states with more than 100,000 market sheep and lambs include California (430,000), Colorado (335,000), Texas (330,000), and Wyoming (170,000). Figure 5-1 presents a geographic distribution of the number of sheep and lambs per county, and Figure 5-2 presents the geographic distribution of operations with 1,000 or more sheep and lambs. The number of operations with sheep and lambs from 1994 to 1997 is presented in Table 5-7.

Table 5-3. Sheep inventory and lamb crop (January 1 sheep inventory).

Year	All Sheep and Lambs (thousands)	Sheep and Lambs on Feed (thousands)	Breeding Sheep (thousands)				
			Total	Lambs		1 year and Over	
				Ewes	Wethers[e] and Rams	Ewes	Wethers[e] and Rams
1989	10,853	1,646	9,207	1,341	346	7,186	334
1990	11,358	1,762	9,596	1,322	311	7,608	355
1991	11,174	1,730	9,444	1,340	347	7,409	348
1992	10,797	1,832	8,965	1,166	320	7,129	350
1993	10,201	1,896	8,305	1,126	308	6,537	333
1994[a]	9,742	1,839	7,233	864	384	5,804	302
1995[a]	8,886	–[c]	6,436	878	–[d]	5,300	258
1996[a]	8,461	–[c]	6,228	863	–[d]	5,128	236
1997[a]	7,937	–[c]	5,850	794	–[d]	4,836	220
1998[ab]	7,616	–[c]	5,537	804	–[d]	4,527	206

[a] Includes new crop lambs. [b] Preliminary. [c] Discontinued. [d] Combined with ewes. [e] Castrated males.
Source: NASS, Livestock and Economics Branch.

Table 5-4. Breeding sheep: survey percent of operations by size group in 1997 and 1998.

Percent of Operations by Size Group							
1-99 Head		100-499 Head		500-4,999 Head		5,000 or More Head	
1997	1998	1997	1998	1997	1998	1997	1998
91.9	90.8	6.2	6.8	1.8	2.3	0.1	0.1
Percent of Inventory by Size Group							
1-99 Head		100-499 Head		500-4,999 Head		5,000 or More Head	
1997	1998	1997	1998	1997	1998	1997	1998
25.7	25.5	20.3	19.2	40.0	42.6	14.0	12.7

Source: NASS, 1998.

Table 5-5. Size distribution of all sheep operations derived from data collected in the 1992 Census of Agriculture.

Location	Operations Categorized by Size Class (animal units[a])								
	1-25	25-100	100-300	300-500	500-1,000	1,000-5,000	5,000-10,000	10,000 or More	Total
Northeast	9,643 (11.8%)	68 (2.1%)	5 (0.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	9,716 (11.3%)
Southeast	5,769 (7%)	46 (1.4%)	6 (0.6%)	0 (0.0%)	1 (1.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	5,822 (6.7%)
North Central	38,352 (46.8%)	887 (27.9%)	106 (11.5%)	10 (6.6%)	3 (3.2%)	2 (5.6%)	0 (0.0%)	0 (0.0%)	39,360 (45.6%)
South Central	9,244 (11.3%)	898 (28.2%)	259 (28%)	33 (21.7%)	12 (12.9%)	9 (25%)	0 (0.0%)	0 (0.0%)	10,455 (12.1%)
Mountain	9,991 (12.2%)	982 (30.9%)	458 (49.6%)	78 (51.3%)	51 (54.8%)	20 (55.6%)	1 (100%)	1 (100%)	11,582 (13.4%)
West	8,784 (10.7%)	292 (9.2%)	90 (9.7%)	31 (20.4%)	25 (26.9%)	5 (13.9%)	0 (0.0%)	0 (0.0%)	9,227 (10.7%)
Other	86 (0.1%)	6 (0.2%)	0 (0.0%)	0 (0.0%)	1 (1.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	93 (0.1%)
United States	81,869	3,179	924	152	93	36	1	1	86,255

[a] The procedure for estimating animal units was adopted from Lander et al. (1998).

Table 5-6. Number of breeding and market sheep and lambs by state during 1997 and 1998.

State	Breeding Sheep and Lambs		Market Sheep and Lambs[c]	
	1997 (thousands)	1998[b] (thousands)	1997 (thousands)	1998[b] (thousands)
Alabama	7.0	7.0	–[a]	–[a]
Alaska	1.4	1.3	0.2	0.1
Arizona	50.0	53.0	75.0	67.0
California	480.0	440.0	480.0	430.0
Colorado	250.0	240.0	325.0	335.0
Connecticut	6.2	6.1	0.8	0.9
Idaho	245.0	234.0	40.0	51.0
Illinois	69.0	68.0	10.0	11.0
Indiana	55.0	44.0	12.0	11.0
Iowa	188.0	158.0	97.0	77.0
Kansas	100.0	80.0	50.0	40.0
Kentucky	17.7	14.0	4.3	3.0
Louisiana	13.0	12.0	2.0	1.5
Maine	8.8	9.5	1.2	1.5
Maryland	27.6	28.2	4.4	4.8
Massachusetts	10.0	9.9	1.5	1.1
Michigan	65.0	60.0	33.0	30.0
Minnesota	130.0	110.0	50.0	60.0
Missouri	55.0	52.0	13.0	13.0
Montana	400.0	385.0	32.0	25.0
Nebraska	77.0	84.0	18.0	16.0
Nevada	74.0	70.0	11.0	10.0
New Hampshire	5.8	6.1	0.7	0.9
New Jersey	13.5	13.0	4.0	4.0
New Mexico	220.0	215.0	15.0	25.0
New York	48.0	53.0	12.0	12.0
North Carolina	11.5	10.0	1.7	1.0
North Dakota	105.0	84.0	30.0	26.0
Ohio	101.0	87.0	29.0	30.0
Oklahoma	60.0	56.0	15.0	14.0
Oregon	209.0	175.0	95.0	90.0
Pennsylvania	81.0	80.0	13.0	14.0
South Dakota	355.0	330.0	95.0	70.0
Tennessee	10.0	9.0	3.5	2.0
Texas	1,150.0	1,170.0	250.0	330.0
Utah	339.0	315.0	36.0	35.0
Vermont	14.3	11.5	2.1	2.5
Virginia	65.0	64.0	15.0	17.0
Washington	45.0	47.0	5.0	15.0
West Virginia	42.0	35.0	8.0	5.0
Wisconsin	57.0	58.0	12.0	12.0
Wyoming	550.0	510.0	170.0	170.0
Other States	38.1	42.1	14.8	15.0
US	5,849.9	5,536.7	2,087.2	2,079.3

[a] Data for this table are no longer available. [b] Preliminary. [c] Sheep and lambs on feed are animals being fattened for slaughter market on grain, other concentrates, or succulent pastures and are expected to produce a carcass that will grade Good or better.
Source: NASS, 1998.

Table 5-7. Operations with sheep and lambs (1994-1997).

State	1994	1995	1996	1997
Alabama	340	310	310	300
Alaska	40	40	40	40
Arizona	450	450	400	400
California	5,000	4,800	4,600	4,500
Colorado	1,600	1,300	1,300	1,200
Connecticut	480	350	350	350
Idaho	1,400	1,300	1,100	1,100
Illinois	3,700	3,500	3,300	3,100
Indiana	3,200	2,700	2,400	2,700
Iowa	6,500	6,300	6,000	5,800
Kansas	2,300	1,900	1,900	2,000
Kentucky	1,000	900	850	800
Louisiana	1,100	1,000	900	800
Maine	700	600	550	550
Maryland	1,100	1,000	1,000	1,100
Massachusetts	600	500	500	600
Michigan	2,100	2,000	2,000	2,100
Minnesota	3,600	3,500	3,300	3,000
Missouri	2,900	2,600	2,300	2,100
Montana	2,300	2,200	2,200	2,200
Nebraska	1,700	1,800	2,000	2,000
Nevada	350	350	350	350
New Hampshire	540	400	450	400
New Jersey	900	850	800	800
New Mexico	1,000	1,000	1,000	900
New York	1,800	1,700	1,800	1,700
North Carolina	600	600	600	620
North Dakota	1,400	1,200	1,000	1,000
Ohio	5,200	5,000	4,500	4,000
Oklahoma	2,000	1,700	1,700	1,700
Oregon	3,200	2,600	3,100	3,000
Pennsylvania	3,300	3,200	3,100	3,000
South Dakota	3,500	3,000	2,700	2,500
Tennessee	650	650	650	600
Texas	7,600	7,300	7,000	6,500
Utah	2,000	1,900	1,700	1,600
Vermont	720	750	600	600
Virginia	1,800	1,600	1,400	1,300
Washington	1,500	1,500	1,500	1,500
West Virginia	1,500	1,600	1,400	1,300
Wisconsin	2,500	2,400	2,300	2,100
Wyoming	1,200	1,100	1,100	1,100
Other States	1,780	1,620	1,460	1,400
Total U.S.	87,150	81,070	77,510	74,710

Source: NASS, 1998.

5.3 Waste Management Technologies

A market lamb weighing about 100 pounds produces about 4 pounds of manure daily. Table 5-8 gives the typical amount of manure and its constituents provided by 1,000 lb of sheep or lamb per day. In some areas of the country, sheep are used to graze leftover stalks and seeds after crops have been harvested. Crop residues, grass clippings, and food processing by-products are often feed to sheep. However, controlling sheep diets from a waste management perspective has not been considered in the literature at this time.

Table 5-8. Fresh manure production and characteristics per 1,000 pounds of live animal weight per day from ASAE Standard D384.1 DEC93.

Parameter	Sheep
Total Manure (lb)	40
Urine (lb)	15
Density (lb/cubic feet)	64
Total solids (lb)	11
Volatile solids (lb)	9.2
BOD_5 (lb)	1.2
COD (lb)	11
Total Kjeldahl Nitrogen (lb)	0.42
Total Phosphorus (lb)	0.087
Orthophosphorus (lb)	0.032

Source: ASAE, 1998.

Because of sheep manure's density and moisture content (75 percent water), the manure is almost always handled as a solid by scraping and hauling to the field. In fact, it is difficult to handle as a liquid because manure solids float (low density) to the surface. As stated earlier, only 2.3 percent of operations in the United States have intensive confinement, which represents 6.4 percent of all sheep raised (APHIS, 1996b). As a result, most sheep manure is dispersed onto pastures and requires no handling. For those operations that confine sheep, most of the waste management technologies will be similar to those presented for handling solid wastes from beef feedlots. A brief synopsis is provided here, but the reader is referred to Chapter 4 for further reading.

Open Lot with Shelter. Unpaved lots are scraped periodically and the manure is field spread; paved lots are scraped regularly, and the manure is field spread either immediately or after storage. Lot runoff is handled using holding ponds or vegetated infiltration areas to control runoff. Settling basins are recommended between the lot and holding pond or infiltrated area to remove large manure solids that either float or settle from runoff. The settling basin floor can be paved to facilitate cleaning. An expanded metal screen and a perforated pipe riser drain runoff water from settled solids. For most of the United States, 5 to 10 cubic feet of settling basin per 100 square feet of the lot area is sufficient. Sludge buildup in the pond tends to be greater with unpaved lots, with infrequent lot scraping, and where settling basins are not used (Hirning et al., 1994).

Vegetated Filter Strips and Infiltration Areas. A vegetated infiltration area is practical for many feedlots up to about 750 head if located next to grassland or other land kept out of crop production. Infiltration capacity is sharply reduced unless runoff is passed through a settling basin (Hirning et al., 1994).

Slotted Floors. Slotted floors significantly reduce daily labor for manure handling. Some of the more common floor materials used are green, undressed oak; concrete; flattened expanded metal X-plate; unflattened, expanded metal; metal and plastic slats; and kiln-dried pine. Floors and fleeces stay cleaner on more open floors and with high-roughage diets. Sheep are more sure footed and hooves wear more evenly on expanded metal than on other materials. Oak floors have irregular openings between slats that can trap lambs' feet. Pine floors soon show heavy wear. The choice of materials depends on cost, desired life expectancy, labor availability, cleanliness desired, and slipperiness (Hirning et al., 1994).

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6.0 Horses

6.1 Introduction

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. 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. 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 (APHIS, 1996). However, a study 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 (APHIS, 1998a). In addition, 133 race tracks participated in portions of this survey. Participation and accounting for race tracks is important since some facilities are very large. The Lone Star Park at Grand Prairie located near Dallas/Fort Worth, Texas, 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, 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, yet account for more than 10 percent of the equids (see Figure 6-1). 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) (APHIS, 1998a).

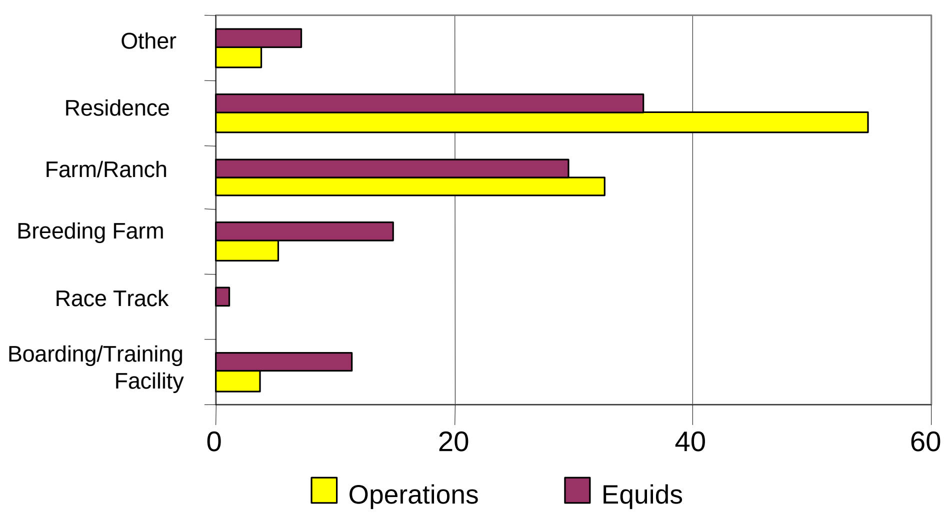

Figure 6-1. Percent of operations and equids by primary function of operation (Source: APHIS, 1998a).

Nationally, stalls are provided on two-thirds of operations (does not include race tracks). New England states provide stalls on nearly all (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, about 70 (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 about one-half (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 other than a landfill (8.9 percent) (APHIS, 1998b).

6.2 Waste Management Technologies

An average 1,000-pound horse generates approximately 9 tons of manure a year (51 pounds per day). Table 6-1 presents the characteristics of horse manure. 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.

Table 6-1. Horse "as excreted" manure characteristics.

Component	Concentration (lb/day/AU)
Weight	51
Total solids	15
Volatile solids	10
Total Kjeldahl nitrogen	0.30
Total phosphorus	0.071
Total potassium	0.25

Source: ASAE, 1998.

The characteristics of the 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 nitrogen-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 on pastures.

In general nitrogen is easily lost from horse manure. Decomposition rates depend on handling and storage methods. Horse manure should be kept compact and moist to prevent excessive losses. Manure left in loose heaps loses nitrogen rapidly to the atmosphere in the form of ammonia. Nutrients in urine are readily available for crop use. Additionally, bedding used in horse stalls absorbs and holds this valuable component well (Barney et al., 1990).

6.2.1 Waste Collection and Handling

Horse manure is best handled as a solid. As stated earlier, 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).

6.2.2 Waste Storage

Manure is typically stockpiled prior to use, providing greater flexibility for land application. The B.C. Government (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, Spring 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.

6.2.3 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 percent 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 EF and 160 EF, 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 practce 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 6-2 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 6-2. Average manure application rates and area requirements for forages.

Forage	**Yield (tons/acre)**	**Yield Annual 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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7.0 Ducks

7.1 Introduction

The most popular market duck raised for meat production in the United States is the Pekin duck. These ducks are relatively easy to raise because they are hardy and not susceptible to common poultry diseases. Small farms use barns or simple shelters to house the birds and often provide access to pastures or ponds for grazing and exercise. Large-scale operations, however, confine ducks year-round and seldom incorporate outside ranges or swimming (Hearn and Gouderham, 1988; Scott and Dean, 1991).

Modern confinement housing is similar to that used in the poultry industry for broilers and roasters, as described in Chapter 10. Barns are constructed with clear-span trusses and equipped with mechanical ventilation and heating systems. Common floor designs for duck houses include all wire mesh, solid floors with litter, or a combination of the two. Wire mesh floors are constructed over concrete pits that collect the duck manure. Solid floor systems are bedded with 4 to 6 inches of straw or wood shavings to help dry the waste and keep the animals comfortable. To keep the litter as dry as possible, solid floor systems should place drinkers over wire mesh. This helps to collect spilled water and waste and reduces the frequency of manure clean-out. Pelleted feeds and automatic hopper-type feeders are the standard for intensive duck operations. A constant supply of fresh water is essential because ducks consume about five times as much water by weight as food. Most conventional poultry drinking systems such as bell, trough, and nipple drinkers are suitable for ducks.

The housing floor design and age of the ducks dictate the amount of area required to raise each bird (Table 7-1). 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. Nest-boxes are commonly filled with bedding and provided at the rate of one space for every five or six ducks. Eggs are fertile about 3 days after the first mating and should be routinely collected from the nests, washed, and placed in incubators. When the ducklings hatch, they are moved to a separate brooder house or isolated from the rest of the flock behind a partition. Ducklings are brooded at a minimum temperature of 80 EF for the first week. The temperature in the brooder house is gradually reduced over the next 2 weeks until heating is no longer required. At 3 weeks of age the ducklings are moved to their rearing quarters, where they remain until selected for market (7 to 9 weeks of age) or added to the breeding stock. The benefits of modern confinement duck production are the ability to market the birds at an earlier age, improve feed conversion, obtain more predictable weight gain, and better control disease.

Table 7-1. Recommended indoor floor area per duck.

Age (weeks)	All Wire Floor (ft^2)	Wire and Litter[a] (ft^2)	All Litter[b] (ft^2)
1	0.25	0.25	0.3
2	0.4	0.5	0.6
3	0.6	0.9	1.1
4	0.9	1.2	1.5
5	1.1	1.5	1.9
6	1.3	1.8	2.25
7	1.5	2.0	2.5
Developing Breeders	Not Recommended	2.5	2.7
Laying Breeders	Not Recommended	3.0	3.0

[a] Wire covering 1/4 to 1/3 of the total floor area. [b] All litter except for narrow screen underwaterers.
Source: Scott and Dean, 1991.

7.2 Type and Size

7.2.1 National Distribution

The 1992 Census of Agriculture reported an inventory of nearly 3.5 million ducks in the United States (Table 7-2). 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. 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 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.

Table 7-2. 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.

7.2.2 Regional Distribution

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 7-3).

Table 7-3. 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.

7.3 Waste Management Technologies

7.3.1 Nutritional Strategies

Nutritional strategies followed by duck farmers are primarily designed for rapid growth and optimum egg production. The nutritional programs are not directly intended to reduce the quantity or nutrient content of the manure. One study, however, reported a 10 percent improvement in nitrogen utilization in ducks when their feeds were treated with both pectinase and hemicellulase enzymes (Scott and Dean, 1991).

7.3.2 Waste Collection

The two varieties of housing and floor design influence the waste collection process. The manure-litter mixture that accumulates in solid floor houses is completely cleaned out between flocks with power equipment, such as skid steers and front-end loaders. Houses with wire mesh floors collect manure in concrete pits. This waste is either collected with mechanical scrapers or pressure-washed and drained from the pit into storage tanks or lagoons.

7.3.3 Waste Storage, Handling, and Treatment

The proper use of duck manure can add to the fertility and productivity of cropland. If not managed properly, duck waste can cause odor and fly problems and pollute ground and surface waters. The best handling and treatment methods for preventing these problems depend on the type of housing and the characteristics of the manure collected. Fresh duck manure has a slightly different composition than other types of animal manure (Table 7-4). The manure can be handled and managed as either a dry litter (similar to broiler production) or a semisolid or liquid (similar to some layer production systems).

Table 7-4. Composition of fresh manure for a variety of animals.

Kind of Manure	% Water	% N	% P	% K
Duck	61	1.1	1.45	0.5
Goose	67	1.1	0.55	0.5
Hen	73	1.1	0.9	0.5
Turkey	74	1.3	0.7	0.5
Hog	87	0.55	0.3	0.45
Horse	80	0.65	0.25	0.5

Source: Florida Agricultural Information Retrieval System, 1998.

The amount of manure produced depends on the number of birds, the amount and type of feed, and the age of the birds. Table 7-5 presents estimates for manure production by poultry. Manure storage facilities should be sized to allow the waste to be spread when crop and field conditions are appropriate. There are many different types of dry litter storage facilities, including covered stockpiles, bunkers, and roofed structures.

Table 7-5. Approximate manure production by poultry.

Type of Bird	Market Wt. (lb)	Feed Eaten/Animal (lb/yr)	Manure Produced (lb/yr/animal)
Layer	4	77	15.4
Pullet	3	30	6.0
Broiler	4	54	10.8
Roaster	7	72	14.4
Turkey	20	120	24.0
Duck	7	114	22.8

Source: Jordan and Graves, 1996.

Covered stockpiles are the simplest and cheapest storage structures to design and construct. Manure is stacked on compacted material or a concrete pad located on high, well-drained ground. Plastic sheeting weighted with old tires is commonly used to cover the pile. Diversion ditches constructed around the pad further limit any contact with runoff. Bunker-style storage structures are built above the ground or into the ground and require similar pollution prevention measures. The bunkers are built with 6- to 10-foot-high parallel walls and a concrete floor that allows for easy loading and unloading. The most costly but effective dry litter storage facilities have a permanent roof. Construction estimates for these structures are between $3 and $5 per square foot for materials plus additional labor costs. Walls are typically constructed of pressure-treated wood or concrete. Roofs should be clear span with trusses 10 to 18 feet above the floor and support posts along the outside walls. This design allows the litter to be stacked high and permits easy access with power equipment. Manure collected as a semisolid or liquid is typically stored in tanks or lagoons outside the house.

Dry litter, duck manure, and carcasses can be treated by composting the materials. Composting aerobically reduces the organic content through microbial decomposition. The process requires a material with minimal compaction, proper temperatures (135 to 160 EF), 40 to 60 percent moisture content, and the appropriate carbon-to-nitrogen ratio

(25:1 to 30:1). The end-product looses more than one-half the initial volume due to losses of carbon dioxide and water to the atmosphere. Most nutrients are retained in the material along with organic matter that did not decompose during composting. This makes finished compost a valuable soil amendment that can be sold or added to the farmer's land.

Large-scale duck operations also use a variety of treatment technologies to manage semisolid or liquid wastes. These technologies have been implemented in other concentrated animal operations, including the chicken and turkey industries. Liquid waste treatment processes include anaerobic digestion in lagoons or tanks, aerobic digestion with mechanical aerators, constructed wetland systems, and scaled-down multistage treatment plants.

7.3.4 Waste Disposal and Use

Waste disposal techniques and environmental concerns are similar for the duck and poultry industries. Although older duck operations and small operations might still provide access to water, large-scale operations confine ducks year-round and seldom incorporate outside ranges or swimming (Hearn and Gouderham, 1988; and Scott and Dean, 1991). Thus, solid waste is typically disposed of by spreading it on hayland, pasture, or cropland with a wagon, box spreader, or flail spreader. The equipment should be calibrated to ensure proper application rates and to minimize pollution potential. The correct application rate takes into account the nutrient content of the soil and manure, as well as the type of vegetation that will use the nutrients. If the manure is not immediately worked into the soil by tillage, runoff potential increases and most of the volatile nitrogen compounds will be lost to the atmosphere as ammonia.

Liquid waste is also disposed of by applying it to land. Liquids can be pumped onto the land and irrigated, broadcast with tank wagons, or incorporated into the soil with subsurface injection equipment. Manure should not be applied to land near wells or springs or on slopes adjacent to surface waters. Vegetated buffer strips maintained along these waters and drainage ditches can provide additional surface water quality protection.

7.3.5 Examples of Typical Systems

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 and keep the animals comfortable. 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 and either sell the compost to sod farms or neighboring crop farms or apply the compost to their own land.

The large operations sometimes handle duck manure 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. This system is comparable to the system used with the production of broilers.

Newer duck housing facilities use wire floors over deep pits and handle the waste as a semisolid or liquid. These facilities do not use bedding, so the manure drops through the wire floor and collects into concrete pits. The manure is mechanically scraped or pressure washed from the pit and pumped to a holding tank or lagoon outside the house. This waste can be directly applied to land, stored, or sent to an on-site waste treatment system. Common systems include anaerobic digestion in lagoons or tanks, aerobic digestion with mechanical aerators, constructed wetland systems, and scaled-down multistage treatment plants.

Examples from Telephone Interviews

- A commercial duck farm on Long Island, New York, produces 800,000 to 900,000 birds per year (approximately the sixth largest producer in the United States). The ducks are housed on wire floors over a concrete base. The manure is scraped and pressure washed into a holding tank and then enters a treatment system. The waste is first processed in a primary clarifier and the effluent enters an activated sludge lagoon.

Solids from the clarifier are land injected or composted. Effluent that enters the lagoon is aerated mechanically (15-day retention) and eventually is pumped to 6 acres of artificial wetlands for finishing. The wastewater processed by the wetlands is reused as wash-down water or is emptied onto sand beds for groundwater infiltration.

- Maple Leaf Farms is the largest duck operation in the United States and raises nearly 70 percent of all the ducks produced. The company maintains three farms in Indiana, Wisconsin, and California along with smaller contract farms. Duck manure is managed as both a solid and a liquid depending on the age and design of the house. Solid-floor houses use bedding (pine shavings or curls), and the manure-litter mixture (40 to 60 percent moisture) is removed from the house. The manure-litter mixture is then stored on a concrete pad and composted. The compost is sold to sod farmers or neighboring farms or land applied off site. The bedded houses are more labor-intensive and are best suited for smaller operations (older facilities and family-run farms). Bedding costs are approximately $50 to $70 per ton.

- The Maple Leaf Farm facilities also manage duck waste in liquid form. In the newer houses, liquid waste is collected in deep pits under wire mesh floors. The liquid waste is scraped and washed from the pits to a 2000 to 5000-gallon holding tank outside the house. This waste either is land applied or enters a treatment system. The system (60,000 to 80,000 gallons treated per day) decants liquid off the top of the holding tank. The liquid waste goes to a rotor screen to remove solids and then enters a high-rate anaerobic digester. The digestor waste then goes to a digester clarifier, and the clarifier effluent enters an aerobic activated sludge plant. After being clarified, the final effluent is spray irrigated on canary grass, alfalfa, or corn. The process reduces BOD from 15,000 to less than 50 and total N from 25lb/1000gal to 100 to 200 ppm). All solids wasted from the process are land applied. The treatment facility costs are approximately $500,000 per year to treat 200 million gallons of waste. This cost covers transport, treatment, capital costs, etc.

7.3.6 Component/Unit Cost

Waste management system costs are not provided in the literature. The costs, however, would include the capital costs of housing and storage facilities, bedding material (straw or wood shavings), and handling equipment. Liquid waste systems would include additional costs for irrigation and/or injection equipment, pumping, and constructing and operating specialized treatment systems. Income-generating arrangements, such as selling compost to nearby farmers, could potentially reduce or offset some of these costs. Estimates from farmers, however, indicate that waste treatment costs can be very high, especially if land area for application is not abundant.

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8.0 Goats

8.1 Introduction

Goats are raised for a variety of purposes and provide consumers with milk, cheese, fiber, meat, and leather. In the United States, Angoras are by far the most popular goat commercially produced, followed by dairy goats. Goats raised for meat, such as the Spanish meat goat, the Boer goat, and sometimes the Angora, represent a relatively new and developing market.

Goats are ruminants and will readily forage on grasses, shrubs, and woody plants not preferred by sheep or cattle. Because of this feeding behavior, they can often be raised on marginal lands that are not fertile enough for other livestock. A large number of Angora and meat goats in the southwestern United States are maintained under range conditions, where they are grazed year-round in herds or loose grazed (unherded) in fenced areas. Both meat and Angora goats are extensively managed with minimal supplemental feed, limited or simple shelter, and minimal health care practices. Dairy goats, on the other hand, are intensively managed with special housing systems, supplemental feeds, and limited or no grazing area.

Goat husbandry techniques vary depending on the type of goat and the size of the farm. For large-scale meat and Angora operations, the male goats, called bucks, can be raised separately or herded year-round with the females, known as does. During the seasonal mating season from August to March, 3 to 4 bucks can be used to mate around 100 does in a herd. Pregnant does are given feed supplements and are eventually separated into clean straw-bedded pens to deliver the young, called kids. After a gestation period of about 21 weeks, domestic does usually give birth to one to three kids at a time. In commercial fiber and meat operations, kids are either separated into pens or corrals or remain with their mothers as a suckler herd until weaned at around 12 to 14 weeks. Replacement does that are not marketed for meat are returned to the breeding herd at about 1 year of age. Spanish and Boer meat goats are ready for market at 4 or 5 months of age, while Angoras are clipped for mohair every 6 months and then marketed for meat after 2 to 3 years (4 to 6 clippings).

Dairy operations typically keep bucks and does in separate pens until they are bred. One buck can mate with 30 or 40 does in a mating season. Some dairies use artificial insemination to better control the breeding period and limit the seasonal disruption to milk production. Pregnant does are given feed supplements and placed in maternity pens to deliver their kids. After a day or two, the kids are moved to kid pens.

The two main methods of housing dairy goats are loose housing and tie stalls or individual confinement. In loose housing, the goats rest together in a common area except at milking time (Figure 8-1). The goats have the freedom to exercise, and the building construction and maintenance costs are minimized. Stall housing confines the goats into rows of individual stalls and requires less space per animal (Figure 8-2). The advantage of confinement stalls is that the goats can be individually fed and cared for; the disadvantage is that the system increases housing and labor costs.

8.2 Type and Size

8.2.1 National Distribution

The 1992 Census of Agriculture reported an inventory of over 2.5 million goats (Table 8-1). Nearly 2 million of these were Angora goats. The U.S. milk goat inventory dropped from about 130,000 animals in 1987 to roughly 125,000 in 1992. The census reports that the number of dairy farms declined at an even greater percentage rate over the same period. The U.S. meat goat inventory is not specifically reported in the census, but it represents some portion of the “other goats” category in Table 8-1. This category of goat production grew by nearly 50 percent from 1987 to 1992.

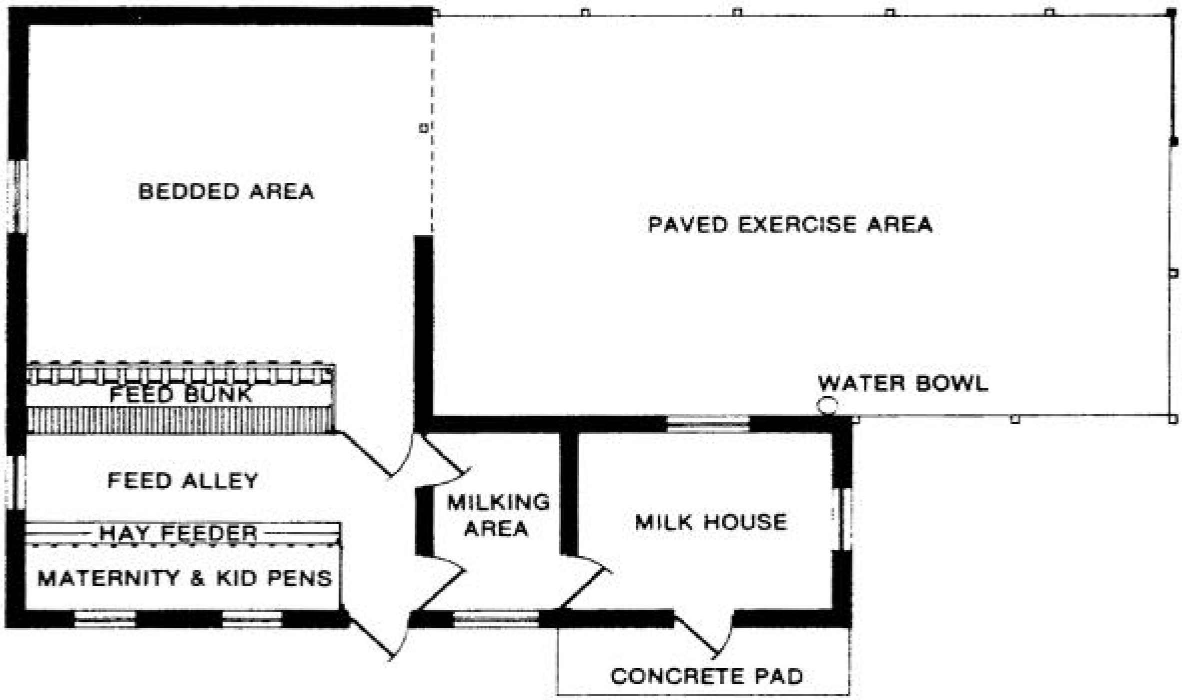

Figure 8-1. Loose housing for dairy goats (Source: Ensminger and Parker, 1986).

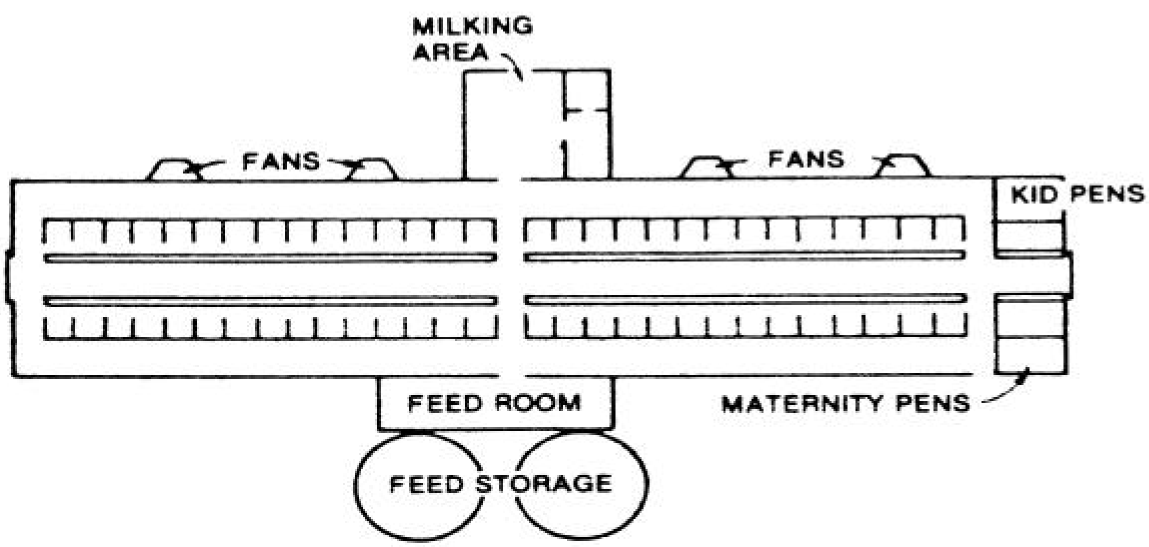

Figure 8-2. Individual stall housing for dairy goats (Source: Ensminger and Parker, 1986).

Table 8-1. Goat inventory and sales.

Goat Variety		1987	1992
Total goats	Inventory	2,246,587	2,515,541
	Number of farms	45,032	47,164
Angora goats	Inventory	1,702,166	1,799,280
	Number of farms	5,352	6,150
Milk goats	Inventory	129,225	124,718
	Number of farms	15,443	11,559
Other goats	Inventory	415,196	591,543
	Number of farms	29,354	34,901

Source: 1992 Census of Agriculture.

8.2.2 Regional Distribution

Angora goats are primarily raised in the southwestern United States. Texas produces the greatest number of Angoras by far, followed by Arizona, New Mexico, and Oklahoma (Table 8-2). Between 1987 and 1992, Texas and Oklahoma increased production, while Angora inventories in Arizona and New Mexico decreased.

Table 8-2. Regional distribution of angora goats.

State Producer	1987	1992	Percent Change
Texas	1,419,310	1,498,037	5.5
Arizona	109,529	73,164	(33.2)
New Mexico	81,064	62,648	(22.7)
Oklahoma	37,501	46,796	24.7

Source: 1992 Census of Agriculture.

Dairy goats are produced throughout the United States, with no region dominating the market. California is the number one producing state, closely followed by Texas, Wisconsin, and New York (Table 8-3).

Table 8-3. Regional distribution of dairy goats.

State Producer	1987	1992	Percent Change
California	16,055	16,593	3.3
Texas	10,559	11,727	11.1
Wisconsin	5,562	7,677	38.0
New York	5,234	5,746	9.8

Source: 1992 Census of Agriculture.

8.3 Waste Management Technologies

8.3.1 Nutritional Strategies

Nutritional management for Angora and meat goats raised on rangeland is minimal. Dairy goat nutrition is managed more intensively to maximize milk production. Neither nutritional management strategy, however, is used to reduce the quantity or nutrient content of the manure.

8.3.2 Waste Collection

The quantity of manure produced varies according to the number of animals, type of feed, and amount of bedding. Daily manure production (feces and urine) from goats of various weights is outlined in Table 8-4. Manure is collected from exercise yards, bedded pens or packs, stalls, or from pits below slatted floors. In either case, the manure is normally handled as a solid because it does not liquify well and is unsuitable for liquid manure handling and treatment systems. Goat manure produced daily equals about 5 percent of body weight and contains 60 to 70 percent moisture. Housing systems that use bedding of straw or wood shavings help to further dry the manure and create a pack. The pack is collected regularly by hand or power equipment, depending on the number of animals. Feeding and watering areas must be scraped more frequently (every 1 to 3 days) to remove clumps of litter and keep the goats clean and dry. Manure must also be collected from the milking parlor although dairy goats tend to deposit very little manure in this part of the facility. Milking parlor waste is either handled as a solid or washed as a semi-solid into an outside storage tank or lagoon. Goats raised on pasture or rangeland distribute their manure when grazing. This manure is normally not collected unless the land area is too small for the number of animals stocked.

Barns designed with slatted floors have more specialized manure collection systems. The manure falls through the slats and into a concrete pit or gutter, where it is removed manually or by a mechanical scraper. A mechanical scraper system has one or more scraping blades pulled by a chain or cable. Common scraper systems are gutter cleaners, below-slat scrapers, and alley scrapers. These systems allow more frequent removal of manure and can reduce daily labor requirements.

Table 8-4. Daily manure production by individual goats.

Goat Weight	Manure Weight (lb)	Manure Volume (in^3)
7	0.3	8
27	1.1	31
47	1.9	53
67	2.7	76
87	3.5	98
107	4.3	121
147	5.9	166
187	7.5	211

Source: Ensminger and Parker, 1986.

8.3.3 Waste Storage, Handling, and Treatment

The characteristics of goat manure influence the types of storage, handling, and treatment systems selected. Goat manure is handled by hand (shovel or fork) or power equipment, depending on the size of the operation. The waste is easiest to manage as a solid, especially when collected with bedding material. Large quantities of manure require storage facilities that can be accessed with power equipment, such as skid-steers and small front-end loaders. About 1 cubic foot per day of storage is needed for each 1,000 pounds of live goats. The total volume of storage should be adequate to coordinate land spreading with field and crop conditions.

There are many different types of litter storage facilities, including covered stockpiles, bunkers, and roofed structures. Covered stockpiles are the simplest and cheapest storage structures to design and construct. Manure is stacked on compacted material or a concrete pad located on high, well-drained ground. Plastic sheeting should be used to cover the pile and diversion ditches constructed around the pad in order to limit any contact with runoff. Bunker-style storage structures are built above the ground or into the ground. They have parallel walls 6 to 10 feet high and a concrete floor that allows for easy loading and unloading. Cover, such as plastic sheeting weighted with old tires, is commonly used to prevent the manure from coming into contact with and polluting runoff.

The most costly but effective storage facilities have a permanent roof. Construction estimates for these structures are between $3 and $5 per square foot for materials plus additional labor costs. Walls are typically constructed of pressure-treated wood or concrete. Roofs should be clear-span with trusses 10 to 12 feet above the floor and support posts along the outside walls. This design allows the litter to be stacked high and permits easy access with power equipment. Goat manure is typically not treated before being disposed of on land. An exception is composting, which is an aerobic treatment process controlled by microbial action. The process requires a material with minimal compaction, 40 to 60 percent moisture content, and the appropriate carbon-to-nitrogen ratio (25:1 to 30:1). Composting generates heat (120 to 160 EF) and decomposes the manure into a stable and dry humus-like material. The end-product is typically one-half the initial volume due to losses of carbon dioxide and water to the atmosphere. Most nutrients are retained in the material. This makes finished compost a valuable fertilizer and soil amendment that can be sold or land applied.

8.3.4 Waste Disposal and Use

The most common practice of manure disposal is applying the waste to hay fields, pasture, or cultivated land (Graves, 1986). Manure removed from the barns, milking parlor, and exercise yards is either disposed of directly or stored for future land application. To limit nutrient losses, odors, and pollution potential, manure must be applied correctly. Proper timing and application rates can reduce nutrient losses through mineralization, volatilization, denitrification, leaching, and erosion. Goat manure is best applied in the spring or throughout the growing season when plants can use the nutrients and minimize environmental impacts on surface and ground water. The waste should be applied to fields at agronomic rates suitable to the nutrient needs of the vegetation (Table 8-5).

Table 8-5. Nutrient removal rates for various crops.

		Nutrients Removed[a] (lb/unit production)	
Crop	**Units**	**N**	**P_2O_5**
Corn, grain	bu	1.0	0.4
Corn, stover	ton	20.6	7.5
Corn, silage	ton	7.4	2.9
Soybeans, grain[b]	bu	—	1.0
Soybeans, residue[b]	ton	—	6.5
Wheat, grain	bu	1.3	0.5
Wheat, straw	ton	13.0	3.6
Oats, grain	bu	0.7	0.3
Oats, straw	ton	12.4	4.6
Barley, grain	bu	1.0	0.4
Barley, straw	ton	13.5	4.7
Rye, grain	bu	1.0	0.5
Rye, straw	ton	10.0	6.0
Alfalfa[b]	ton	—	11.0
Orchardgrass	ton	50.0	16.6
Bromegrass	ton	33.2	13.2
Tall fescue	ton	55.0	18.6
Blue grass	ton	25.8	18.3
Clover grass[b]	ton	41.0	13.3
Sorghum-Sudan grass	ton	39.9	15.5

[a]Six sources listing nutrient removal for a given yield were averaged to estimate removal for a unit of production.
[b]Legumes fix a proportion of their required nitrogen depending on soil status.
Source: Fulhage, 1993.

Goat manure is spread onto the land with wagons, box spreaders, or flail spreaders. The equipment should be calibrated to ensure proper application rates and to minimize pollution potential. The correct application rate takes into account the nutrient content of the soil and manure, as well as the type of vegetation that will use the nutrients. If the manure is not immediately worked into the soil by tillage, runoff potential increases and most of the volatile nitrogen compounds will be lost to the atmosphere as ammonia (Table 8-6). Manure should not be applied to land near wells or springs or on slopes adjacent to surface waters. Vegetated buffer strips maintained along these waters and drainage ditches can also reduce water quality impacts.

Table 8-6. Manure nutrient loss by days until worked into soil.

Days Until Incorporation	% NH_3-N Available to Plants
0-2	80
2-4	60
4-7	40
>7	20

Source: Fulhage, 1993.

Some goat farms dispose of the manure by hauling it off site to other farms, where it is composted or applied to land. Transportation costs can be high, so this method is practical only if the farmer does not have enough land for proper disposal.

Milking parlor wash water is sometimes handled as a semisolid and is disposed of in different ways. If the waste is collected in storage tanks or lagoons, the solids are separated and land applied as mentioned above. The liquid waste can be irrigated onto the fields or spread by tank wagon. One method to reduce potential air and water quality problems is to incorporate the waste into the soil. This increases the amount of nutrients available to plants and reduces volatilization of ammonia. Subsurface injection, however, is suitable only for liquid waste, and it requires more time, labor, and costly equipment and maintenance than other disposal methods.

8.3.5 Examples of Typical Systems

Goat farms do not use a variety of intense waste management technologies common to other concentrated animal operations such as swine or poultry production. The manure, with or without bedding, has been easy for farmers to collect, handle, and manage as a solid. Typically, the waste management strategy is to dispose of the manure by applying it to land with little or no treatment. To limit potential impacts or air and water quality, litter may be stored until crop and soil conditions are appropriate for land application. Composting is a simple waste treatment processes and is one of the few used by the commercial goat industry. The most common waste management systems for different types of goats and farm sizes have already been presented. The following examples are provided as a general overview.

Smaller-sized goat operations house the animals in barns or sheds and use bedding to dry the manure pack and keep the animals comfortable. The litter is eventually removed from the barn manually or with power equipment and is either directly land applied or temporarily stored and then disposed of. Some operations compost the manure and apply it to their land or sell the compost as fertilizer to sod farms or neighboring crop farms. If land on the goat farm is sufficient for application or a market for compost is not readily available, composting becomes a less cost-effective management option.

Dairy goat operations of all sizes collect and handle the manure with the same solid waste management strategies. An exception is that some of the manure deposited in the milking parlor may be handled as a semisolid and washed from the building to a filter strip, storage tank, lagoon, or sanitary sewer. The volume of liquid waste is usually small and can be irrigated onto the land when it begins to reach the capacity of the tank or lagoon. Solids collected in the tank or lagoon can be separated and spread onto the land or composted.

Large commercial meat and Angora goat operations are generally operated on fenced pasture or rangeland. If the land area is large enough, manure is dispersed on the range and naturally decomposes without the need for further waste management. Because the goats are extensively managed, waste is seldom concentrated like it is with intensive confinement operations. Potential water quality problems, however, can exist if the animals have access to a stream or surface water. In these cases it is necessary to provide other watering sources and fence the animals out of streambank areas.

Examples from Telephone Interviews

- Coach Farms is a 1200-head dairy goat farm located in New York. The animals are kept in barns with bedding, and the litter is removed daily and spread on the fields. Milking parlor waste enters a settling tank before entering a holding lagoon. The settling tank is periodically pumped out by a commercial septic tank company. During the 15 years of operation, the lagoon has never been emptied and the waste applied to land.
- Redwood Hills Dairy is located in California and raises about 300 goats. The animals are housed in barns with straw bedding. The litter pack is removed twice each year (spring and fall) with a skid steer and is hauled off site to either be used directly as fertilizer or composted. Renting the skid steer is the only cost incurred.

- A dairy goat farm located in California raises about 500 goats. The manure is cleaned from the barn and stored in a bin. It is then picked up for free by an independent company to be composted and later sold. The goats are housed in open barns with pasture. Milking parlor wastewater is washed into a simple holding pond until it is pumped onto the land.

8.3.6 Component/Unit Cost

Waste management system costs are not provided in the literature. The costs, however, would include the capital costs of housing, bedding material (straw or wood shavings), and handling equipment. Income-generating arrangements, such as selling compost to nearby farmers, could potentially reduce or offset collection and handling costs. Dairy goat operations may have additional costs for lagoons or storage tanks used to store milking parlor wash water.

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9.0 Swine[3]

9.1 Introduction

Swine production typically falls into three phases. Pigs are farrowed, or born, in farrowing operations. Baby pigs are typically allowed to nurse for three to four weeks, then moved to a nursery, the second phase of swine production. Young pigs are usually moved to a nursery at about 15 pounds. They remain at the nursery for seven to eight weeks. They typically weigh about 60 pounds when they move from a nursery to a finishing operation. During finishing, pigs are raised to market weight, 240 to 280 pounds. Finishing typically takes 15 to 18 weeks; hogs are typically sent to market when they are 26 weeks old.

A farrow-to-finish operation includes all three production phases. A feeder pig operation is one that includes farrowing and a nursery at one site. While some large farms continue to include the full range of production, from farrow to finish, these 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 farm, move to a nursery on another, and then move again to a grow-out farm for finishing. As each operation specializes, it takes advantage of skilled labor, expertise, advanced technology, streamlined management, and modern housing. But 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 other phases. Physically separating the phases makes it easier to break this kind of 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.

Sows are usually bred for the first time when they are 180 to 200 days old. Artificial and natural insemination are probably used equally to breed sows, although the use of artificial insemination appears to be increasing. A pig's gestation period is 114 days. Sows usually average just over two litters per year, and an average litter is 10 or 11 pigs. A sow, therefore, usually gives birth to 23 or 24 pigs annually. 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 weaned 3 to 4 weeks after birth, and 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 then farrow at roughly 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. With the exception of some Midwestern farmers, growers usually farrow relatively small groups of sows weekly.

While there are still many farms on which relatively small numbers of pigs are raised outdoors, the trend in the swine industry is toward larger confinement farms where pigs are raised indoors. A typical confinement farrowing operation houses 3,000 sows, although there are farrowing operations that house as many as 10,000 sows at one location and farms that will house as many as 15,000 sows at one site are being planned.

The remainder of this section presents selected results from the Swine '95: Grower/Finisher Study that provides more details about swine production practices. In this study, owners of operations with at least 300 market hogs were interviewed twice. National estimates generated from this study were reported in *Swine '95 Part II: Reference of 1995 Grower/Finisher Health and Management* (May 1996). The states included in the two studies were Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Carolina, Ohio, Pennsylvania, South Dakota, Tennessee, and Wisconsin. Information collected during these two studies and a similar study done in 1990 provide an overview of environmental practices of U.S. pork producers.

Concerns about or regulations designed to protect environmental quality has led many producers to change or develop management schemes during the 5 years prior to the Swine '95 study. Nearly 21 percent of the producers

[3] This chapter is an abridged version of Chapters 1 through 4 of *Draft Swine and Poultry Industry Characterization, Waste Management Practices and Model Detailed Analysis of Predominantly Used Systems*, prepared by North Carolina State University on September 30, 1998, under EPA Contract 68-C7-0014, Work Assignment 1-27.

interviewed and more than one-half of the producers that market 10,000 or more hogs stated they had changed or developed manure management programs (Table 9-1).

About one-third (36 percent) of producers who marketed 10,000 or more hogs from December 1, 1994, to May 31, 1995, also changed their dust control programs during the 5-year period. Many of these operations also changed their programs for monitoring groundwater, surface water, and air quality (14.7, 18.8, and 9.8 percent, respectively). These changes and those shown for employee training programs indicate a growing producer awareness of responsible environmental management.

Table 9-1. Percent of swine operations that changed or developed waste management programs due to environmental concerns or regulations affecting environmental quality.[a]

Type of Program	All Operations	Operations That Marketed More Than 1,0000 Head
Manure management	20.9	52.6
Dust control in buildings	8.7	36.0
Surface water monitoring	5.7	18.8
Ground water monitoring	5.2	14.7
Employee training	4.6	43.2
Air quality monitoring	2.9	9.8

[a] Changes made during the 5 years prior to June 1995 interview.
Source: APHIS, 1995 and 1996.

Waste management systems used are shown for flooring type (Table 9-2) and waste storage (Table 9-3). The predominant floor types include concrete, slats, and partial slats. The predominant waste storage systems included anaerobic lagoon without cover, below-floor slurry or deep pit, and below-ground slurry storage. Below-floor slurry or deep pits are more prevalent for operations that marketed between 2,000 and 9,999 hogs while anaerobic lagoons without covers are more prevalent for operations that marketed more than 10,000 hogs.

Table 9-2. Waste management systems: types of flooring.[a]

Type of Flooring	Percent of Swine Operations that use Flooring	Percent of Grower/Finisher Pigs on this Flooring
Concrete slabs	26.3	38.8
Metal slats	3.6	0.8
Fiberglass or plastic slats	2.7	0.8
Slats and other flooring combined (partial slats)	33.0	23.9
Solid concrete	61.6	31.4
Dirt/pasture	12.1	3.2
Other	1.9	1.1

[a] Percentages based on number of pigs on hand on day of Swine '95 Interview.
Source: APHIS, 1995 and 1996.

Tables 9-4 through 9-7 summarize waste disposal methods used by swine operations. Nearly all operations dispose of their waste on their farm (Table 9-4). Interestingly, only 4 percent of the nation's hog operations separate the solid and liquid portions of waste. Tables 9-5 and 9-6 describes waste disposal by the operations that do not separate their waste and that do separate their waste, respectively. Table 9-7 describes wastewater disposal by size of operation.

Table 9-3. Percent of swine operations using different waste storage systems.

System	All Operations	Fewer Than 2,000 Head[a]	2,000-9,999 Head[a]	More Than 10,000 Head[a]
Below-floor slurry or deep pit	49.9	43.6	70.4	47.9
Above-ground slurry storage	5.6	4.1	10.3	8.3
Below-ground slurry storage	19.4	17.3	25.6	26.3
Anaerobic lagoon with cover	1.8	2.2	0.5	2.0
Anaerobic lagoon without cover	20.9	17.4	29.2	81.8
Aerated lagoon	2.6	1.3	6.9	1.0
Oxidation ditch	2.2	2.9	0.1	0
Solids separated from liquids	4.6	4.1	5.9	4.7
Other	0.4	0.6	0	1.1

[a] Number marketed for slaughter during the 12-month period beginning December 1, 1994.
Source: APHIS, 1995 and 1996.

Table 9-4. Swine operation waste disposal methods.

Method	Percent of Operations Using Method
Applied to owned or rented land	97.3
Sold	0.8
Given away	4.2
Pay someone to remove	0.5
Other	1.0

Source: APHIS, 1995 and 1996.

Table 9-5. Waste disposal methods of swine operations that do not separate solids and liquids.

Method	Percent of Operations Using Method
Applied to owned or rented land	95.7
Sold	0.3
Given away	2.7
Pay someone to remove	0.3
Other	1.0

Source: APHIS, 1995 and 1996.

Table 9-6. Waste disposal methods of swine operations that separate solids and liquids.

Method	Solids	Liquids
Applied to owned or rented land	94.2	95.4
Sold	0.8	0.3
Given away	4.2	4.3
Pay someone to remove	0.5	0
Other	1.0	0

Source: APHIS, 1995 and 1996.

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, when pit-holding was used most (Table 9-8). Table 9-9 presents the prevalence of waste management system by production phase. Producers disposed of animal carcasses most often by burying them, according to both the 1990 and 1995 studies (Table 9-10). Burning and use of renderers decreased significantly as carcass disposal methods from 1990 to 1995. On-site composting increased as a disposal method over the 5-year period.

Table 9-7. Waste disposal methods used to dispose of liquid on owned or rented land (by percent).

Method	All Operations	Fewer Than 2,000 Head[a]	2,000-9,999 Head[a]	More Than 10,000 Head[a]
Irrigation	12.8	8.8	24.1	55.3
Broadcast of solid spreader	57.9	63.3	41.9	10.5
Slurry (surface application)	46.0	42.6	58.3	33.2
Slurry (subsurface injection)	21.9	15.1	44.2	32.6
Other	0	0	0	0

[a] Number marketed for slaughter during the 12-month period beginning December 1, 1994.
Source: APHIS, 1995 and 1996.

Table 9-8. Most frequently used waste management systems.

Waste Management System	Percent of Producers Who Listed the System as Most Used	Standard Error
None	5.1	+/- 1.9
Pit-holding	41.1	+/- 2.9
Mechanical scraper/tractor	10.1	+/- 1.8
Hand cleaning	28.3	+/- 3.1
Flush-under slats	9.7	+/- 1.3
Flush-open gutter	3.2	+/- 0.9
Other	2.5	+/- 0.8

Source: APHIS, 1995 and 1996.

Table 9-9. Percent of operations using different waste management systems by production phase.

System	Farrowing	Standard Error	Nursery	Standard Error	Grower/ Finisher	Standard Error
None	13.8	+/-2.0	4.3	+/- 1.0	14.8	+/- 1.9
Pit-holding	25.5	+/- 2.1	33.7	+/- 2.4	23.2	+/- 1.9
Mechanical scraper/tractor	12.0	+/- 1.6	17.6	+/- 2.2	24.9	+/- 2.0
Hand cleaning	38.2	+/- 2.6	29.9	+/- 2.9	27.2	+/- 2.4
Flush-under slats	5.3	+/- 0.8	9.4	+/- 1.3	2.4	+/- 0.5
Flush-open gutter	3.0	+/- 0.9	2.1	+/- 0.7	3.4	+/- 1.0
Other	2.2	+/- 0.5	3.0	+/- 0.8	4.1	+/- 0.8

Source: APHIS, 1995 and 1996.

Table 9-10. Percent of producers using different methods of carcass disposal.

Method	1990 National Swine Survey	Standard Error	Swine '95 Total	Standard Error
Burial (on operation)	62.4	+/- 3.2	58.5	+/- 2.3
Burning (on operation)	21.6	+/- 2.1	12.3	+/- 1.4
Renderer entering operation	26.6	+/-2.5	25.1	+/-1.8
Renderer at perimeter of operation	29.0	+/- 3.3	6.9	+/- 0.9
Composting on operation	N/A	N/A	10.5	+/- 1.3
Other	17.6	+/- 2.2	7.2	+/- 1.3

Source: APHIS, 1995 and 1996.

9.2 Demographics

9.2.1 National Change

The general trend in the U.S. swine industry is toward a smaller number of large operations (Table 9-11 and 9-12). As the percentage of smaller producers decreases, there is a consistent increase in the percentage of herds with a total inventory of 1,000 or more head. The number of U.S. swine operations has decreased more than 30 percent since 1990. A steady decline in the number of operations has occurred each year, with nearly a 50 (48.3) percent decrease from 1990 to 1997 (Table 9-13). But the larger producers who are entering the industry raise more hogs, so the overall number of hogs is increasing. The increase in the number of large operations has predominantly occurred in conjunction with extended use of total confinement operations that separate the three production phases. On farms with fewer than 500 hogs, the animals are still typically maintained outdoors.

Table 9-11. Percent of U.S. hog operations by herd size, 1990-1995.

Year	1-99 Head	100-499 Head	500-999 Head	1,000-1,999 Head	More Than 2,000 Head
1990	63.9	25.0	7.1	4.0[a]	– [a]
1991	61.4	26.4	7.8	4.4[a]	– [a]
1992	60.2	26.5	8.1	3.6	1.6
1993	61.1	25.3	8.3	3.5	1.8
1994	59.9	25.5	8.5	3.9	2.2
1995	59.4	25.0	8.7	4.3	2.6

[a] The 1,000-1,999 size group includes the more than 2,000 head.
Source: NASS, 1998.

Table 9-12. Percent of U.S. hog inventory by herd size, 1990-1997.

Year	1-99 Head	100-499 Head	500-999 Head	1,000-1,999 Head	More Than 2,000 Head
1990	6.4	28.6	23.8	41.2[a]	– [a]
1991	5.5	27.2	23.4	43.9[a]	– [a]
1992	5.3	25.3	22.0	18.9	28.5
1993	5.0	23.0	21.5	17.5	33.0
1994	4.5	20.5	20.0	18.0	37.0
1995	3.5	18.0	17.5	17.0	44.0
1996	3.0	15.0	15.0	16.0	51.0
1997	3.0	12.0	14.0	16.0	55.0

[a] The 1,000-1,999 size group includes the more than 2,000 head.
Source: NASS, 1998.

Table 9-13. Changes in the Number of U.S. swine operations (1990-1997).

Year	Number	Percent of Previous Year	Percent of 1990
1990	268,140	89.1	100.0
1991	247,090	92.1	92.1
1992	240,150	97.2	89.6
1993	225,210	93.8	84.0
1994	207,980	92.3	77.6
1995	181,750	87.4	67.8
1996	156,250	85.9	58.3
1997	138,690	88.8	51.7

Source: NASS, 1998.

9.2.2 Regional Distribution

Swine farming historically has been centered in the Midwest in the United States; Iowa is far and away the largest hog producer in the country (Table 9-14). Although the Midwest continues to be the nation's leading hog producer, significant growth has taken place in other areas. Perhaps the most dramatic growth has occurred in North Carolina. Over a decade, North Carolina has gone from being the 12 th largest pork producer in the nation to second behind Iowa. Climate has played a major role in the growth of North Carolina's swine industry. Figure 9-1 presents a geographic distribution of the number of swine per county, and Figure 9-2 presents a geographic distribution of operations with 1,000 or more swine in 1992, respectively.

Winters are mild and summers are tolerable, which has allowed growers to use open-sided buildings, which are less expensive than the solid-sided buildings needed in the Midwest because of the cold winters. Midwestern growers must also insulate or heat their buildings in the winter. North Carolina's pork boom was also fueled by tobacco farmers who found hogs as a means of diversifying their operations. The idea of locating production phases at different sites was developed in North Carolina.

Growth has occurred elsewhere as well. There has been significant growth in recent years in the panhandle area of Texas and Oklahoma, as well as in northern Iowa and southern Minnesota. In the far West, hog farms have been established in Utah and Colorado. In the Southeast, North Carolina remains by far the largest producer, but the industry appears to be growing in Alabama and Mississippi.

Table 9-14. Number of swine operations in selected states by size group.[a]

State	1-99 Head		100-499 Head		500-499 Head		1,000-1,999 Head		2,000-4,999 Head		More Than 5,000 Head	
	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
Arkansas	2,100	1,900	230	240	60	60	100	90	70	70	40	40
Georgia	2,700	2,100	500	450	160	120	80	60	30	40	30	30
Illinois	2,900	2,600	3,300	2,600	1,300	1,200	830	660	370	340	100	100
Indiana	3,700	2,900	2,400	2,400	1,000	800	500	500	300	300	100	100
Iowa	4,600	4,500	8,900	6,800	4,300	3,500	2,300	2,000	700	980	200	220
Kansas	2,400	2,300	1,200	750	310	360	90	90	70	70	30	30
Kentucky	1,800	950	400	270	180	170	70	60	35	35	15	15
Michigan	3,200	2,800	750	820	170	180	150	150	100	120	30	30
Minnesota	5,000	4,900	3,300	3,100	1,400	1,400	800	850	350	400	150	150
Missouri	3,600	2,600	2,300	1,900	670	530	260	260	130	160	40	50
Nebraska	2,600	2,300	3,500	2,900	1,100	1,100	550	470	200	170	50	60
North Carolina	4,000	3,700	310	280	190	180	350	340	700	820	450	480
Ohio	7,000	6,500	2,200	1,700	490	490	200	200	90	90	20	20
Pennsylvania	3,800	3,400	800	600	220	200	180	160	80	115	20	25
South Dakota	1,200	950	1,600	1,200	450	400	150	150	60	60	40	40
Wisconsin	3,300	3,100	1,000	930	220	210	130	110	40	40	10	10
Other States[b]	37,700	34,800	3,500	3,000	780	730	450	420	115	130	105	110
United States	94,800	84,900	36,270	29,990	13,020	11,670	7,200	6,590	3,520	4,020	1,440	1,520

[a] An operation is any place having one or more hogs and pigs on hand any time during the year. [b] Individual state estimates are not available for the 34 states included in the Other States grouping.
Source: NASS, 1998.

9.3 Waste Management Systems

9.3.1 Nutritional Strategies

Grinding. Fine grinding and pelleting are simple but effective ways to improve feed utilization and decrease nitrogen and phosphorus 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, nitrogen digestibility increases by approximately 5 to 6 percent. As particle size is reduced from 1,000 microns to 700 microns, excretion of nitrogen is reduced by 24 percent. The industry average particle size is approximately 1,100 microns, with the recommended size being 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, as well as increasing the incidence of stomach ulcers.

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 nitrogen excretion by pigs. This process reduces nitrogen excretion because lower-protein diets can be fed when lysine is supplemented. Research studies have shown that protein levels can be reduced by 2 percentage points when the diet is supplemented with 0.15 percent lysine (3 pounds lysine-HC1/ton of feed) without negatively affecting performance of grow-finish pigs. Greater reductions in protein are possible, but only if threonine, tryptophan, and methionine are also supplemented.

Table 9-15 shows a theoretical model of the effect of feeding low-protein, amino acid-supplemented diets on nitrogen excretion of finishing pigs. Note that reducing the protein level from 14 percent to 12 percent and adding 0.15 percent lysine results in an estimated 22 percent reduction in nitrogen excretion. Reducing the protein further to 10 percent and adding 0.30 percent lysine, along with adequate threonine, tryptophan, and methionine, reduces the estimated nitrogen excretion by 41 percent.

Table 9-15. Theoretical model of the effects of reducing dietary protein and supplementing with amino acids on nitrogen excretion by 200-lb finishing pig.[ab]

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: as presented in NCSU, 1998.

Although it is currently cost-effective to use supplemental lysine and methionine (Table 9-15), supplemental threonine and tryptophan are currently too expensive to use in practical diets. However, because of the rapid technological advances in fermentation procedures for synthesizing amino acids, threonine and tryptophan will likely become sufficiently inexpensive in the next few years for use in practical diets.

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

Formulate diets on an available phosphorus basis. A high proportion (56 to 81 percent) of the phosphorus in cereal grains and oilseed meals occurs as phytate. Phosphorus in this form 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 phosphorus is added to the diet to meet the pig's growth requirements, but excessive phosphorus is excreted in the urine, increasing manure phosphorus concentrations.

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

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

A theoretical example of using phytase follows (Table 9-16). If a finishing pig is fed a diet with 0.4 percent phosphorus (the requirement estimated by NRC, 1988, cited in NCSU, 1998), 12 g of phosphorus would be consumed daily (3,000 x 0.4 percent), 4.5 g of phosphorus would be retained, and 7.5 g of phosphorus would be excreted. Feeding a higher level of phosphorus (0.5, 0.6 or 0.7 percent) results in a slight increase in phosphorus retention, but causes considerably greater excretion of phosphorus (10.3, 13.2, and 16.2 g/d, respectively). Being able to reduce the phosphorus to 0.3 percent in a diet supplemented with phytase would reduce the intake to 9 g of phosphorus per day and would potentially reduce the excreted phosphorus to 4.5 g/day (a 37 percent reduction in phosphorus excretion vs. NRC). The percent reduction in excreted phosphorus is even more dramatic (56 percent) when one compares the 4.5 g with the 10.3 g of phosphorus that is excreted daily by finishing pigs fed at the 0.5 percent phosphorus level typically being recommended by universities and feed companies. Bone strength can be completely recovered by supplementing a low-P diet with 1,000 phytase units/kg 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 phosphorus excretion. A summary of 11 experiments (Table 9-17) indicates that all the growth rate and feed efficiency can be recovered with the dietary supplementation of 500 phytase units and reduced phosphorus diets. Some analyses have suggested that a 50 percent reduction in excreted phosphorus by pigs would mean that land requirements for manure applications based on phosphorus crop uptake would be comparable to manure applications based on nitrogen.

Table 9-16. Theoretical model of effects of dietary phosphorus level and phytase supplementation (200-lb pig).

	Phosphorus (g/d)			Change From Industry Average (%)
Dietary P (%)	**Intake**	**Retained**	**Excreted**	
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, 1998.

Table 9-17. 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% and the relative change in pig growth performance to the control diets.
Source: Jongbloed et al., 1996, cited in NCSU, 1998.

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 can be performed by replacing an inorganic phosphorus source like dicalcium phosphate in the diet with phytase. Current phytase prices indicate that dietary phosphorus levels could be reduced by 0.1 percent and the phytase enzyme would be cost neutral. However, if the dicalcium phosphate price were $0.15/lb instead of $0.20/lb, dietary phosphorus would need to be reduced by 0.15 percent to be cost neutral. The pig requires that phytase supplementation be fed at different levels based on the age of the pig (Table 9-18). The different levels based on phase of production likely relate to the digestive enzyme and cecum development of the pig, the younger pig being less developed.

Table 9-18. 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, 1998.

9.3.2 Waste Collection and Storage

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 manure removal system. Slatted floors are commonly used to separate the manure from hogs. Underfloor flushing or pit recharge systems are commonly used with anaerobic lagoon systems.

Storage is a critical function of farm systems since manure nutrients can be applied to farmland only at certain times of the year as determined by crops, climate, and weather. Deep pits and slurry basins have been used with slurry systems. Storage capacity is one function served by anaerobic lagoons. Most hog farms have from 90 to 365 days of storage capacity. Transport and land application of manure nutrients is necessary to realize the fertilizer benefit of manure nutrients and to comply with nutrient management regulations designed to protect water quality. Surface application and injection are common means of land application for slurry. Transport of slurry is by "umbilical" hose and pump or by pump and haul in tanks. Transport and land application of anaerobic lagoon liquid is commonly done through irrigation. Transport and land application of anaerobic lagoon sludge may be done by irrigation or by pump and haul.

Water wash waste removal from swine houses. Typically, the floor surface in swine houses is slotted over manure collection pits. Because animals work the manure through floor slots, manure is separated quickly from the animals into the pits. Water wash systems, which recycle lagoon water, are used to remove wastes from the underfloor pits, which are 2 to 3 feet deep. Pits can be washed once a day or even more frequently. The more frequently the manure is removed from the houses, the more healthful the environment for both animals and workers.

Pit recharge. Pit recharge is the periodic draining of the pit contents by gravity to a lagoon, then recharging the pit with new lagoon 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. Zero slope is specified for the pit floor in pit recharge systems, but a minimum slope of 1:20 is used for constructing the pit to overcome an uneven floor surface, which could result in incomplete waste removal and associated problems. If the entire house is sloped, enough pit depth must exist to cover the upper end of the pit floor with at least 6 inches of water, while allowing enough storage below the air plenum openings on the lower end. The drains are located at the lower end of the pits, while the recharge locations are opposite the drain outlets. An average depth of 12 inches of recharge water and another 12 inches for waste accumulation between pit drainings is allowed. The maximum pit water level should be at least 4 inches below the air plenum openings or 12 inches below the slats. Generally, a 32-inch pit depth is the minimum between the slotted floor and pit floor. A gutter across the drain end of the pit floor directs waste to an exterior collection box, which is connected to an underground drainpipe leading to the lagoon. The pits are usually drained and recharged once a week.

This is the most common waste management system in the midwest. Specifically, these systems use a 16 to 18-inch-deep in-house pit with 6 to 8 inches of precharge water, which is emptied every 7 days to a single anaerobic lagoon. Previously, 24-inch deep pits were preferred, but now 16 to 18-inch-deep pits are used with the hog slat system. 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. These ponds are designed to remove 40 percent of the total solids on a 6 percent solids basis for 3 month's storage; the material is pumped 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. Material is then moved with a front-end loader into a box-type spreader and land applied. Solids drying ponds and beds are not covered to prevent the introduction of rainfall. The lagoon is based on 2 to 3 cubic feet per pound (ft^3/lb) and irrigation is through a center pivot system. A floating pump is located half the lagoon distance from the inlet with a screen over the discharge to protect sprinkler nozzles. The screen has to be cleaned, but this is easier than cleaning nozzles for traveling big guns. Another variation is to have a single lagoon (based on 2 to 3 ft^3/lb) followed by an evaporation pond that is 6 ft deep and as big as possible. Some of these evaporation ponds dry up during the summer.

One operation is installing a 16-inch-deep pit recharge system using 6 to 8 inches of precharge water and emptying it every 7 days. The operator had been using an older NRCS lagoon criteria of about 1 ft^3/lb but has now increased that to 2 ft^3/lb because of odor problems. Lagoon design is 1 year of storage in addition to the treatment volume. This type of a lagoon/center pivot irrigation system is more acceptable in states with a decreasing population density and an established center pivot irrigation system, such as Oklahoma, Kansas, and Iowa. The operation is taking advantage of the fertilizer value for corn. Future plans are to go beyond the 18-inch compact soil seal to synthetic liners and plastic covers, both for existing earthen solids drying beds and anaerobic lagoons.

Flush. Flush systems use recycled lagoon water for frequent removal of feces and urine from underfloor collection gutters or shallow pits. As with 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 of manure in the collection pits. Flush tanks with the capacity to release at least 1.5 gallons per 100 pounds of live animal weight per flush are adjacent to 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 to 2 percent. Floors should be flushed at least 4 to 6 times per day. The flush tanks are filled with recycled lagoon water before every flush. The flushed waste is collected and removed from the houses into the lagoon through a system similar to that used in pit recharge systems.

Deep pits. Many farms use deep pits that are 6 to 8 feet deep for up to 6 months storage of under the house. Twice a year a slurry is removed from the pit for surface application or subsurface injection, into an earthen storage facility, or pumped to a steel aboveground storage tank. This material is valued for its nutrient content and is applied to nearby land as fertilizer for corn and soybeans. Application is most often by surface spreading and tillage or by direct injection. This slurry system produces a waste stream with higher dry matter content (4 to 5 percent) and higher nutrient content than liquid manure systems. The aboveground storage system conserves more nitrogen than other systems (nitrogen loss of 10 to 30 percent). In this system, nutrients average 4.3 g/L N, 1.4 g/L P, and 2.2 g/L K (MWPS, 1985). Operations use this system to avoid problems associated with lagoons such as odor, ammonia volatilization, and ground water impact.

9.3.3 Anaerobic Lagoon Treatment

Treatment of manure to separate nutrients is economical in some situations when the cost of storing and hauling manure slurry exceeds its potential value as a fertilizer. Treatment becomes more attractive as crop yields decrease (and therefore land required for nutrient utilization increases). Treatment also becomes more attractive as hog farm size increases. No treatment occurs in typical slurry systems. Anaerobic digestion is the primary treatment in anaerobic lagoon systems. Plant-available nitrogen and phosphorus in land-applied anaerobic lagoon liquid may be at 10 percent of the nutrient concentration in the flush water entering the lagoon. Much of the nitrogen in swine manure is volatilized from the anaerobic lagoon or from the spray field. Much of the phosphorus in the manure settles in the lagoon sludge and attaches to the lagoon walls and bottom. Once every 5 to 15 years, anaerobic lagoon sludge can be applied to land other than the spray field receiving lagoon liquid. As a result, phosphorus is often spread over a greater area than the reduced quantity of nitrogen that is applied to a smaller spray field.

Anaerobic lagoons are the most common means of swine manure treatment in the southeastern region. Anaerobic bacteria, present in the intestinal tract of warm-blooded animals, can decompose more organic matter per unit lagoon volume than aerobic bacteria. However, incomplete anaerobic decomposition of organics can result in offensive by-products, primarily hydrogen sulfide, ammonia, and intermediate organic acids, which may cause disagreeable odors. Therefore, proper size and management are necessary to operate an anaerobic lagoon. The minimum total capacity of an anaerobic lagoon should include appropriate design treatment capacity, additional storage for sludge accumulation, temporary storage for rainfall and wastewater inputs, surface storage for a 25-year, 24-hour design rainfall event, and a freeboard, or indicator of the highest watermark, to prevent embankment overtopping. In North Carolina, the recommendation is 2 cubic feet of liquid volume per pound of live animal weight for a single anaerobic lagoon. A two-stage lagoon would have 1.5 cubic feet of volume per pound of live animal weight in the first stage and 0.5 cubic foot of volume per pound of live animal weight in the second stage. It is suggested that a lagoon to be located at least 1,000 feet from any residence or inhabited dwelling not owned by the producer. 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 ground water contamination.

New lagoons should be half filled with water before waste loading begins. Starting up during warm weather and seeding with bottom sludge from a working lagoon will speed establishment of a stable bacterial population. Under no circumstances should dead animals, molded feed, plastic gloves, long-stemmed vegetation, or other foreign material be allowed to enter a lagoon. Proper lagoon maintenance and operation is absolutely necessary to ensure that lagoon liner integrity is not affected and that berms and embankments are stable and provide the required freeboards and rainfall storage.

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 the treatment capacity of most lagoons will be diminished greatly as a result of accumulation. 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 for sludge removal must be continuously monitored to ensure that liner damage does not occur or that berms or embankments are damaged, which could result in contamination of surface or ground water. The sludge mixture is pumped through a gun-sprinkler slurry irrigation system onto cropland and disked into the soil.

Lagoons usually fill to capacity within 2 to 3 years of startup due to the added waste volume and rainfall that is in excess of evaporation. When the lagoon is full, water overflow will occur unless the operator is in a position to land apply the excess water. Since no overflow is permitted, excess water needs to be applied to cropland, grassland, or woodland at rates within the soil infiltration capacity and the fertilizer requirement of the vegetation. Sampling and analysis of the lagoon water is suggested to determine its nutrient content. Many states require a nutrient management program for which records regarding the amount of nitrogen applied to cropland must be kept to be sure fertilizer recommendations are not exceeded. Lagoon water drawdown by irrigation should begin 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.

9.4 Example Systems

There is also a trend toward consistency from one part of the country to another. The three-site model that separates production phases is being adopted across the country, while finishing age and number of litters per year tends 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. In the Midwest, some producers farrow only twice a year, usually in the spring and fall. This is usually done on smaller farms, where sows are maintained outdoors, then moved indoors for farrowing. Pigs are also finished in confinement. Of course, 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. In the Midwest and New England, the number of outdoor and confinement operations is roughly the same, but there are far more hogs raised in confinement operations.

Most types of waste management systems are similar across all 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, South-Central, and Northeast Regions. The primary waste management system that has the most variation among and within regions is that described as the hand wash system. Hand wash systems are found predominantly on operations with fewer than 500 pigs; most of the operations using hand washing as their primary waste management system have fewer than 100 pigs. On these operations, it is in the farrowing house and/or nursery phases of production in which hand washing is used to remove fecal material and urine from the buildings. For units using hand washing, the wash water either 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 may vary among operations from three times per day to once per week.

Another type of system identified as a primary waste management system on small operations in the Midwest and New England (NAHMS, 1995 and 1996) uses a flat blade on the back of a tractor to scrape or remove manure from feeding floors. The popularity of this system apparently has decreased over the last 3 years, and the system no longer represents a major avenue for removing wastes from swine feeding locations.

9.4.1 Systems in Alaska, California, Hawaii, Idaho, Montana, Nevada, Oregon, and Washington

Descriptive information about the number of pigs and types of operations in these states is contained in Table 9-19. These states contain 6.0 percent and 0.9 percent of the swine farms and total pigs in the United States, respectively. California and Montana account for 71 percent of the production within these states and are the only two states with significant numbers of farms with more than 2,000 animals. In general, these states are primarily composed of farms with fewer than 500 pigs (93 percent) that use hand washing and dry lots as their primary waste management system. In contrast, the majority of pigs (56.6 percent) are produced on farms with 500 to 2,000 animals that use either hand washing/dry lots or deep pit/aboveground storage/land application for reincorporation of swine waste back into the environment.

9.4.2 Systems in Arkansas, Arizona, New Mexico, Oklahoma, Texas, and Utah

Table 9-20 present information for Arkansas, Arizona, New Mexico, Oklahoma, Texas, and Utah which contain 10.2 percent and 5.9 percent of the swine farms and total pigs in the United States, respectively. Five of the six states have experienced a net increase in the number of pigs and large farms (more than 2,000 head) during the past 5 years. This area also accounts for the fastest growing area of swine production in the nation at the present time. As a result, the majority of the farms (53.3 percent) in these states contain more than 2,000 head and contain 90 percent of the pigs. As a group, these large farms seem to rely on aeration of anaerobic lagoons, biogas production from lagoons, or evaporation from lagoons as the main ways to treat swine waste and reincorporate it back into the environment.

Table 9-19. Distribution of pigs and predominant waste systems by farm size in Alaska, California, Hawaii, Idaho, Montana, Nevada, Oregon, and Washington.

Farm Size (number of pigs)	Number of Farms	Percent of Farms	Percent of Pigs	Primary Waste Management System
Fewer than 500	7,524	93.0	11.4	1. Hand Wash/Dry Lots 2. Scraper/Aboveground Storage/Land Application
500 to 2,000	485	6.0	56.6	1. Hand Wash/Dry Lots 2. Deep Pit/Aboveground Storage/Land Application
More than 2,000	81	1.0	32.0	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Covered Anaerobic Lagoon/Irrigation
Total	8,090			

Source: as presented in NCSU, 1998.

Table 9-20. Distribution of pigs and predominant waste systems by farm size in Arkansas, Arizona, New Mexico, Oklahoma, Texas, and Utah.

Farm Size (number of pigs)	Number of Farms	Percent of Farms	Percent of Pigs	Primary Waste Management System
Fewer than 500	4,022	28.5	0.8	1. Hand Wash/Dry Lots
500 to 2,000	2,563	18.2	9.2	1. Flush or Pit Recharge/Anaerobic Lagoon/Irrigation 2. Deep Pit/Aboveground Storage/Land Application
More than 2,000	7,515	53.3	90.0	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 Lagoon System
Total	14,100			

Source: as presented in NCSU, 1998.

Utah swine production. Circle 4 is the primary integrator in Utah. These operations use a pit-recharge system (depth of pit and volume of recharge water are unknown at this time) that is emptied about 3 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. Exact treatment volume design is farm- (or complex-) specific and includes consideration of diet, feed digestibility, and absorption and conversion efficiency of the animal. The primary stage is sized on the basis of volume per volatile solids input 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 on the order of 20 years. Land for agronomic application of biosolids is not required to be under the direct control of the farm owner/operator. No operation has reached its design life at this time to evaluate this procedure.

9.4.3 Systems in Connecticut, Delaware, Maryland, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia

Table 9–21 summarizes descriptive information for Connecticut, Delaware, Maryland, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia which contain 8 percent and 0.2 percent of the swine farms and total pigs in the United States, respectively. Of these states, Pennsylvania contains about 80 percent of the pigs and farms. It also contains the vast majority of the large-and-medium-size units. The medium and large farms rely on either anaerobic lagoons and irrigation or aboveground storage and land application as their primary means of waste management. Farms in the remaining 11 states typically have fewer than 500 animals each. Small operations constitute 57.8 percent of all farms in these states and use hand washing in conjunction with drylots as their primary waste management system.

Table 9-21. Distribution of pigs and predominant waste systems by farm size in Connecticut, Delaware, Maryland, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

Farm Size (number of pigs)	Number of Farms	Percent of Farms	Percent of Pigs	Primary Waste Management System
Less than 500	6,390	57.8	3.7	1. Hand Wash/Dry Lots 2. Gravity Drain/Collection Basin/Land Application
500 to 2,000	2,297	20.8	40.6	1 Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Anaerobic Lagoons/Irrigation 3. Scraper/Aboveground Storage/Land Application
More than 2,000	2,363	21.4	55.7	1 Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Anaerobic Lagoons/Irrigation
Total	11,050			

Source: as presented in NCSU, 1998.

The design and operation of the anaerobic lagoon and irrigation system are very similar to those of the system used in the southeast; however, there are some notable differences. Lagoon loading rates must be lowered to accommodate the lower temperatures of the region and storage requirements must be increased to accommodate the longer inactive period during winter. Although average yearly rainfall is about the same in the two regions, rainfall in excess of evapotranspiration is higher in these states, further increasing storage requirements. Emergency storage for the 25-year, 24-hour storm event is lower in these states than in the southeast. Design and operation of the above-ground storage/land application system are similar to those used in the Midwest. The primary difference is the site-specific realistic yield expectation of the fields accepting the nutrients. Differences in crop production techniques must also be considered.

9.4.4 Systems in Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia

Table 9-22 summarizes descriptive information for Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia which contains 17.7 percent and 21.3 percent of the swine farms and total pigs in the United States, respectively. Large operations (more than 2,000 head) represent 63.4 percent of the farms in these states and produce 92.5 percent of the pigs. North Carolina contains the largest number of farms with more than 2,000 animals and 77.1 percent of the region’s production. 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 waste back into the environment by irrigation. In these states, housing is usually enclosed with ventilation and concrete floor surface. A typical waste management practice for swine production farms includes a water wash system to remove wastes from swine houses, an anaerobic lagoon to treat the wastes, and a cropland irrigation system to use the nutrients in the lagoon water.

Table 9-22. Distribution of pigs and predominant waste systems by farm size in Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia.

Farm Size (number of pigs)	Number of Farms	Percent of Farms	Percent of Pigs	Primary Waste Management System
Less than 500	4,199	16.9	0.9	1. Hand Wash/Dry Lots 2. Scraper System/ Aboveground Storage/Land Application
500 to 2,000	3,883	15.9	6.6	1. Flush or Pit Recharge/Anaerobic Lagoon/Irrigation
More than 2,000	16,268	63.4	92.5	1. Flush or Pit Recharge/Anaerobic Lagoon/Irrigation
Total	24,350			

Source: as presented in NCSU, 1998.

9.4.5 Systems in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin

Table 9-23 summarizes descriptive information for Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin which contains 58.2 percent and 69.8 percent of the swine farms and total pigs in the United States, respectively. Numbers of small, medium, and large farms are fairly evenly distributed 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, as seen in the southeastern United States, is probably increasing in the Midwest. Primary waste management systems for farms with fewer than 500 pigs are hand wash coupled with drylots with and without collection basins. In contrast, medium and large farms rely on storage of waste either in buildings with deep pits or in above-ground structures in conjunction with direct land application for crop production.

Table 9-23. Distribution of pigs and predominant waste systems by farm size in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

Farm Size (number of pigs)	Number of Farms	Percent of Farms	Percent of Pigs	Primary Waste Management System
Less than 500	23,693	29.5	2.7	1. Hand Wash/Dry Lots 2. Hand Wash/Dry Lots and Collection Basin/Land Application 3. Deep Pit/Land Application
500 to 2,000	22,334	27.8	18.1	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Aeration of Anaerobic Lagoons/Irrigation 3. Deep Pit/Land Application
More than 2,000	34,273	42.7	79.8	1. Deep Pit/Aboveground Storage/Land Application 2. Pit Recharge/Covered Anaerobic Lagoon/Irrigation
Total	80,300			

Source: as presented in NCSU, 1998.

9.5 Example System Costs

This section summarizes the basic costs associated with a water flush/lagoon/spray field system in the southeast and a deep pit storage system in the Midwest (Table 9-24). The details of assumptions are presented recognizing that site-specific conditions could substantively change the results.

Table 9-24. Sample costs and benefits of typical manure management systems.

Category	Slurry (Midwestern) System ($/hog finished)	Anaerobic Lagoon (Southeastern) System ($/hog finished)
Storage, Treatment	$1.69	$0.42
Transport, Land Application	$1.164	$0.514
Sludge Removal, Land Application	NA	$0.05 to $0.90
Reduced Crop Income on Spray Field and Land Cost	NA	$0.121
Value of Fertilizer Saved	$2.438	NA
Net Cost	$0.416	$1.10 to $2.00

9.5.1 Water Flush/Lagoon/Spray Field System in the Southeast

Gravity flow in conjunction with slatted floors provides the mechanism for manure removal from the majority of southeastern swine facilities. A lagoon typically provides liquid and sludge storage for treatment by an anaerobic lagoon system. The excavated volume of the lagoon is 1.5 cubic feet per pound steady-state live weight or 810,000 cubic feet. Excavation and other costs are $1.10 per cubic yard. Total construction cost of the lagoon is $33,000. Annual ownership costs of the lagoon are $4,350 or $0.42 per hog finished.

Costs of lagoon liquid irrigation are estimated at $41.13 per acre-inch (0.001515 per gallon) for 130 acre-inches per year and an annual cost of $5,347. This equates to an irrigation cost of $0.514 per finished hog. Benefits of the water flush-anaerobic lagoon system include the value of fertilizer saved and application costs reduced compared to other systems. Income from crops cultivated on spray fields is diminished if the farmer plants a less profitable crop that uses higher levels of nitrogen. For example, a spray field of bermudagrass will result in a lost income that equals the difference between the most profitable crop or rotation and the income actually received from the benefit of bermudagrass and the net savings on fertilizer costs. Irrigation provides 330 and 90 lb/acre of nitrogen and phosphorus, respectively with an estimated value of $30.75 per acre. Considering the rental value of land occupied by the lagoon, the total cost for water flushing to an unaerated lagoon followed by land irrigation to coastal bermudagrass is $1.10 per finished hog.

Costs of removing sludge from the anaerobic lagoon depend heavily on the accumulation rate, the frequency of removal, the method of removal, and the distance transported. The lowest cost of sludge removal occurs if the sludge accumulates slowly, is removed after 15 years, and is removed by irrigation of sludge diluted 1:1 with lagoon liquid. The highest cost occurs when sludge accumulates quickly, is removed every 5 years, is removed by pump and haul, and is hauled more than 3 miles.

9.5.2 Deep Pit Storage System in the Midwest

This cost analysis is based on a typical midwestern waste system that allows for 6 months of storage of manure in the house and land application by direct injection. The system considered here is sized to serve a finishing pig operation with a 4,000-head one-time capacity. Manure removal is via slatted floors and gravity flow. The volume of manure and other water falling through the slats each day is 1.44 gallons per hog. Storage is in a concrete tank with a capacity of 180 days or 1,037,000 gallons or 138,356 cubic feet plus 10,643 cubic feet for a 1-foot freeboard. Construction cost is estimated at $113,633 including all excavation, concrete, labor, and plumbing. Amortized over 15 years at 8 percent (APR) and including 1.5 percent annually for property tax and insurance, the annual cost of owning the concrete tank is $17,617. Assuming a 4,000-head capacity and 2.6 groups finished per year, the cost per finished hog is $1.69.

Transport and land application are by pump, umbilical line and tractor-drawn injection for the slurry system. Custom rates for the slurry pump and injection system are $0.0071 per gallon plus $0.0028 per gallon per mile for distances greater than 1 mile. It is estimated that 563 acres of 120 bushel per acre corn land is needed to receive the annual slurry production for this operation. (This analysis assumes 144 lb nitrogen per acre, 47.5 plant-available nitrogen per 1,000 gallons of injected slurry, and 164 gallons slurry per hog finished). If this land area is available within 1 mile of the storage tank, the pumping and injection costs will be $1.164 per hog finished.

Benefits of the slurry system include the value of fertilizer saved. If the slurry provides all the fertilizer required by the crop, the cost of an application may also be saved. The 164 gallons of slurry applied to 120 bushels per acre continuous corn replaces $2.127 of fertilizer and may save $0.311 per hog finished in fertilizer application costs for a benefit of $2.438 per hog finished.

Net cost is the sum of cost less benefits. In this example, the cost of the slurry system on 120 bushel per acre corn land is less than the cost of the anaerobic lagoon system on less productive land producing bermudagrass. Considering a deep pit for up to 6 months storage of manure followed by land application by direct injection, a total cost of $0.41 per finished hog is accrued.

9.6 Bibliography

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10.0 Poultry[4]

10.1 Introduction

This chapter summarizes the demographics and waste management practices associated with broilers, layers, and turkeys.

10.2 Demographics

10.2.1 Broilers

Broiler production in the United States has steadily increased over the last decade (Table 10-1). Between 1987 and 1996, the number of broilers has increased by 52 percent, from approximately 5 billion to 7.6 billion. Accompanying the increased number of broilers, is an increase average live weight at slaughter from 4.3 to 4.8 pounds. Together these changes have yielded nearly a 70 (69.5) percent increase in live weight of broilers produced since 1987.

Table 10-1. Broiler production in the United States, 1987-96.[a]

Year	Number raised (thousands)	Pounds produced (live weight, 1,000 pounds)
1987	5,003,560	21,523,356
1988	5,237,901	22,464,479
1989	5,516,521	23,978,816
1990	5,864,150	25,630,960
1991	6,137,150	27,202,862
1992	6,402,490	28,828,872
1993	6,694,310	30,617,600
1994	7,017,540	32,528,500
1995	7,325,670	34,222,000
1996[b]	7,598,200	36,486,050

[a] Broilers are young chickens of the meat-type breeds, raised for the purpose of meat production. Estimates cover the 12-month period, Dec. 1 previous year through Nov. 30. Excludes states that produce fewer than 500,000 broilers. [b] Preliminary.
Source: NASS, 1998.

Table 10-2 displays broiler production by state for 1995 and 1996. The top five states in number of broilers raised in 1996 are Arkansas (1.155 billion), Georgia (1.154 billion), Alabama (873 million), North Carolina (681 million), and Mississippi (676 million). Texas, Maryland, Virginia, Delaware, and Missouri are ranked sixth through tenth in broiler production, respectively.

Figure 10-1 displays the number of broilers per county, and Figure 10-2 displays the number of operations per county with 200,000 or more broilers sold. Table 10-3 presents the number of broiler operations by size class and region. There are 9,214 operations (25.8 percent) that range in size from 25 to 100 animal units (11,400 to 45,500 broiler capacity), 7,319 operations (20.5 percent) that range in size from 100 to 300 animal units (45,500 to 136,500 broiler capacity), and 707 operations (2 percent) that are larger than 300 animal units (136,500 broiler capacity).

[4] Sections 10.3 and 10.4 of this chapter are an abridged version of Chapters 5 through 8 of *Draft Swine and Poultry Industry Characterization, Waste Management Practices and Model Detailed Analysis of Predominantly Used Systems,* prepared by North Carolina State University on September 30, 1998, under EPA Contract 68-C7-0014, Work Assignment 1-27.

Table 10-2. Broiler production by state, 1995 and 1996.[a]

State	1995		1996[b]	
	Number Raised (thousands)	Pounds Produced (live weight, 1,000 pounds)	Number Raised (thousands)	Pounds Produced (live weight 1,000 pounds)
Alabama	900,000	4,230,000	873,300	4,191,800
Arkansas	1,107,300	4,982,900	1,155,000	5,659,500
California	235,800	1,179,000	234,200	1,171,000
Delaware	263,100	1,394,400	257,600	1,416,800
Florida	139,800	615,100	131,400	591,300
Georgia	1,070,000	5,136,000	1,154,000	5,654,600
Hawaii	940	3,800	950	4,000
Iowa	15,000	72,000	17,200	77,400
Kentucky	64,500	258,000	77,000	331,100
Maryland	295,700	1,360,200	294,800	1,385,600
Michigan	630	2,850	550	2,200
Minnesota	48,000	249,600	47,500	251,800
Mississippi	644,000	2,962,400	675,900	3,109,100
Missouri	190,600	800,500	246,300	1,059,100
Nebraska	2,900	18,600	2,300	13,300
New York	1,400	6,900	1,500	8,000
North Carolina	670,100	3,417,500	681,100	3,541,700
Ohio	43,000	215,000	48,600	243,000
Oklahoma	198,300	852,700	204,000	877,200
Oregon	21,100	105,500	21,300	106,500
Pennsylvania	121,400	607,000	128,200	653,800
South Carolina	162,000	680,400	177,500	786,300
Tennessee	130,000	572,000	134,000	603,000
Texas	395,200	1,746,800	419,200	1,886,400
Virginia	260,100	1,196,500	259,100	1,243,700
Washington	40,300	197,500	40,000	196,000
West Virginia	88,900	391,200	89,700	394,700
Wisconsin	22,200	104,300	32,400	152,300
Other states[c]	193,400	863,350	193,600	874,850
Total	7,325,670	34,222,000	7,598,200	36,486,050

[a] Broilers are young chickens of the meat-type breeds, raised for the purpose of meat production. Estimates cover the 12-month period, Dec. 1 previous year through Nov. 30. Excludes states that produce fewer than 500,000 broilers. [b] Preliminary. [c] CT, IL, IN, LA, ND, and SD.
Source: NASS, 1998.

Table 10-3. Distribution of broiler operations derived from data collected in the 1992 Census of Agriculture.

Location	Operations Categorized by Size Class (animal units[a])								
	1-25	25-100	100-300	300-500	500-1,000	1,000-5,000	5,000-10,000	10,000 or More	Total
Northeast	2,384	1,358	878	58	12	1	1	0	4,692
	(50.8%)	(28.9%)	(18.7%)	(1.2%)	(0.3%)	(0.0%)	(0.0%)	(0.0%)	(13.1%)
Southeast	2,739	4,632	4,283	280	70	8	0	0	12,012
	(22.8%)	(38.6%)	(35.7%)	(2.3%)	(0.6%)	(0.1%)	(0.0%)	(0.0%)	(33.6%)
North-Central	8,541	330	246	18	1	3	0	0	9,139
	(93.5%)	(3.6%)	(2.7%)	(0.2%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(25.6%)
South-Central	2,223	2,806	1,817	142	35	3	1	1	7,028
	(31.6%)	(39.9%)	(25.9%)	(2.0%)	(0.5%)	(0.0%)	(0.0%)	(0.0%)	(19.7%)
Mountain	1,275	0	1	0	0	0	0	0	1,276
	(99.9%)	(0.0%)	(0.1%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(3.6%)
West	1,306	87	91	33	35	3	0	2	1,557
	(83.9%)	(5.6%)	(5.8%)	(2.1%)	(2.2%)	(0.2%)	(0.0%)	(0.1%)	(4.4%)
Other	51	1	3	0	0	0	0	0	55
	(92.7%)	(1.8%)	(5.5%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.2%)
United States	18,519	9,214	7,319	531	153	18	2	3	35,759

[a] The procedure for estimating animal units was adopted from Lander et al. (1998).

10.2.2 Turkeys

The turkey industry is substantially smaller than the broiler industry in the United States, but it has undergone a 25 percent increase in number of turkeys raised in the last decade (Table 10-4). The average live weight at slaughter also increased from 20.4 to 23.8 pounds, yielding an increase of 46.5 percent in total live weight production. Table 10-5 displays turkey production by state for 1996. The top five states in number of turkeys raised in 1996 are North Carolina (59.5 million), Minnesota (43.5 million), Arkansas (28 million), Virginia (25 million), and California (22.5 million). Figure 10-3 displays the number of turkeys per county, and Figure 10-4 displays the number of operations per county with turkeys.

Table 10-4. Turkey production in the United States, 1987-96.

Year	Number Raised[a] (thousands)	Pounds Produced (live weight, 1,000 pounds)
1987	240,438	4,894,858
1988	242,421	5,059,056
1989	261,394	5,467,629
1990	282,475	6,043,155
1991	284,910	6,114,620
1992	289,880	6,355,293
1993	287,650	6,432,577
1994	286,605	6,540,887
1995	292,856	6,779,277
1996[b]	301,378	7,171,527

[a] Total poults hatched less death loss of poults and young turkeys during the year. [b] Preliminary.
Source: NASS, 1998.

Table 10-5. Turkey production by state, 1996.[a]

State	Number Raised[b] (thousands)	Pounds Produced (live weight, 1,000 pounds)
Arkansas	28,000	526,400
California	22,500	492,750
Colorado	4,800	179,040
Connecticut	8	152
Georgia	550	16,995
Illinois	3,300	78,870
Indiana	14,000	351,400
Iowa	8,000	221,600
Kansas	1,750	49,000
Maryland & Delaware	330	6,653
Massachusetts	80	1,600
Minnesota	43,500	948,300
Missouri	22,000	578,600
New Hampshire	15	300
New Jersey	73	1,650
New York	520	12,792
North Carolina	59,500	1,457,750
North Dakota	2,100	46,200
Ohio	6,800	227,120
Pennsylvania	11,700	245,700
South Carolina	8,300	256,470
South Dakota	3,000	96,000
Vermont	35	630
Virginia	25,000	475,000
West Virginia	4,500	85,500
Other states[c]	31,017	815,055
Total	301,378	7,171,527

[a] Preliminary [b] Based on turkeys placed Aug.1, 1992, through, Jul. 31, 1993. Excludes young turkeys lost. [c] MI, NE, OK, OR, TX, UT, and WI combined to avoid disclosing individual operations.
Source: NASS, 1998.

Table 10-6 presents the number of turkey operations by size class and region. There are 12,525 operations (80.3 percent) that are smaller than 100 animal units (5,000 breeders or 6,700 turkeys for slaughter capacity), 1,128 operations (7.2 percent) that range in size from 100 to 300 animal units (5,000 to 15,000 breeders or 6,700 to 20,100 turkeys for slaughter capacity), 1,576 operations (10.1 percent) that range in size from 300 to 1,000 animal units (15,000 to 50,000 breeders or 20,100 to 67,000 turkeys for slaughter capacity), and 362 operations (2.3 percent) that are larger than 1,000 animal units (50,000 breeders or 67,000 turkeys for slaughter capacity).

Table 10-6. Distribution of turkey operations derived from data collected in the 1992 Census of Agriculture.

Location	Operations Categorized by Size Class (animal units[a])								
	1-25	**25-100**	**100-300**	**300-500**	**500-1,000**	**1,000-5,000**	**5,000-10,000**	**10,000 or More**	**Total**
Northeast	2,027 (89.6%)	46 (2.0%)	91 (4.0%)	52 (2.3%)	30 (1.3%)	16 (0.7%)	0 (0.0%)	0 (0.0%)	2,262 (14.5%)
Southeast	2,107 (66.4%)	32 (1.0%)	334 (10.5%)	318 (10.0%)	293 (9.2%)	87 (2.7%)	0 (0.0%)	1 (0.0%)	3,172 (20.3%)
North-Central	4,186 (75.6%)	159 (2.9%)	494 (8.9%)	299 (5.4%)	269 (4.9%)	124 (2.2%)	3 (0.1%)	5 (0.1%)	5,539 (35.5%)
South-Central	1,634 (80.0%)	10 (0.5%)	138 (6.8%)	104 (5.1%)	107 (5.2%)	48 (2.3%)	2 (0.1%)	0 (0.0%)	2,043 (13.1%)
Mountain	1,129 (92.8%)	14 (1.2%)	28 (2.3%)	18 (1.5%)	21 (1.7%)	6 (0.5%)	0 (0.0%)	1 (0.1%)	1,217 (7.8%)
West	1,142 (85.7%)	13 (1.0%)	43 (3.2%)	19 (1.4%)	46 (3.5%)	63 (4.7%)	5 (0.4%)	1 (0.1%)	1,332 (8.5%)
Other	26 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	26 (0.2%)
United States	12,251	274	1,128	810	766	344	10	8	15,591

[a] The procedure for estimating animal units was adopted from Lander et al. (1998).

10.2.3 Layers

Table 10-7 presents the number of layers and pullets in the United States from 1988 to 1997 (excluding broiler breeding stock). Since 1988 there has been a 12.7 percent increase in layers and a 13.8 percent increase in pullets. Table 10-8 presents the number of layer operations by size class and region. There are 84,076 operations (92.4 percent) that are smaller than 25 animal units (6,250 layers), 4,489 operations (4.9 percent) that range in size from 25 to 100 animal units (6,250 to 25,000 layers), 1,649 operations (1.8 percent) that range in size from 100 to 300 animal units (25,000 to 75,000 layers), and 826 operations (0.9 percent) that are larger than 300 animal units (75,000 layers). Figure 10-5 displays the number of hens and pullets per county, and Figure 10-6 displays the number of operations per county with 50,000 or more hens and pullets of laying age.

Layers and pullets are distributed across the country with less regional concentration than broilers (Table 10-9). California produces the greatest number of layers older than 1 year (15.27 million), followed by Iowa (11.66 million) and Ohio (10.86 million). The top three pullet-producing states are Arizona (3.49 million), Ohio (3.4 million), and Georgia (3.12 million). The top three egg-producing states are Ohio (6.98 billion), California (6.66 billion), and Pennsylvania (5.79 billion).

Table 10-7. Layer and pullet production in the United States, 1988-97.[a]

Year	Layers		Pullets	
	Older than 1 Year (thousands)	20 Weeks to 1 Year Old (thousands)	13 to 20 Weeks Old (thousands)	Under 13 Weeks Old (thousands)
1988	123,435	152,714	33,739	40,859
1989	118,839	153,230	35,769	43,415
1990	119,551	153,916	34,222	38,945
1991	117,178	162,943	34,272	42,344
1992	121,103	163,397	34,710	45,160
1993	131,688	158,938	33,833	47,941
1994	135,091	163,418	32,805	45,146
1995	133,537	165,216	32,786	45,446
1996	137,822	165,932	31,366	44,611
1997[b]	140,686	170,398	34,174	50,693

[a] Does not include commercial broilers. [b] Preliminary.
Source: NASS, 1998.

Table 10-8. Distribution of layer operations derived from data collected in the 1992 Census of Agriculture.

Location	Operations Categorized by Size Class (animal units[a])								
	1-25	25-100	100-300	300-500	500-1,000	1,000-5,000	5,000-10,000	10,000 or More	Total
Northeast	10,988	391	296	82	38	19	4	1	11,819
	(93.0%)	(3.3%)	(2.5%)	(0.7%)	(0.3%)	(0.2%)	(0.0%)	(0.0%)	(13.0%)
Southeast	15,652	2,246	588	93	58	44	1	0	18,682
	(83.8%)	(12.0%)	(3.1%)	(0.5%)	(0.3%)	(0.2%)	(0.0%)	(0.0%)	(20.5%)
North-Central	29,172	654	366	100	73	53	12	2	30,432
	(95.9%)	(2.1%)	(1.2%)	(0.3%)	(0.2%)	(0.2%)	(0.0%)	(0.0%)	(33.4%)
South-Central	13,262	1,115	293	42	26	30	0	0	14,768
	(89.8%)	(7.6%)	(2.0%)	(0.3%)	(0.2%)	(0.2%)	(0.0%)	(0.0%)	(16.2%)
Mountain	6,895	35	15	3	5	12	0	0	6,965
	(99.0%)	(0.5%)	(0.2%)	(0.0%)	(0.1%)	(0.2%)	(0.0%)	(0.0%)	(7.7%)
West	7,881	43	87	41	42	38	3	0	8,135
	(96.9%)	(0.5%)	(1.1%)	(0.5%)	(0.5%)	(0.5%)	(0.0%)	(0.0%)	(8.9%)
Other	226	5	4	2	2	0	0	0	239
	(94.6%)	(2.1%)	(1.7%)	(0.8%)	(0.8%)	(0.0%)	(0.0%)	(0.0%)	(0.3%)
United States	84,076	4,489	1,649	363	244	196	20	3	91,040

[a] The procedure for estimating animal units was adopted from Lander et al. (1998).

Table 10-9. Layer and pullet production by State, 1997.[a]

State	Layers		Pullets	
	Older than 1 Year (thousands)	20 Weeks to 1 Year Old (thousands)	13 to 20 Weeks Old (thousands)	Under 13 Weeks Old (thousands)
Alabama	4,292	6,200	2,066	2,500
Arkansas	6,070	8,351	3,486	3,976
California	15,270	11,010	1,000	3,080
Colorado	1,910	1,760	229	543
Connecticut	1,141	2,318	299	550
Delaware	150	250	0	0
Florida	6,216	4,522	1,045	1,133
Georgia	6,680	13,840	3,120	5,080
Hawaii	465	263	55	80
Idaho	546	385	30	223
Illinois	1,534	1,679	174	380
Indiana	10,238	12,076	1,355	3,479
Iowa	11,655	10,130	1,700	2,150
Kansas	505	843	245	256
Kentucky	1,550	1,650	380	820
Louisiana	940	963	165	370
Maine	2,256	2,523	621	1,495
Maryland	1,518	1,644	428	483
Massachusetts	72	473	3	155
Michigan	2,343	2,817	390	630
Minnesota	6,740	5,215	810	1,895
Mississippi	2,487	4,424	1,407	2,049
Missouri	3,490	3,605	675	1,490
Montana	35	240	45	69
Nebraska	6,011	3,979	563	1,573
New Hampshire	53	106	24	29
New Jersey	931	1,023	174	0
New Mexico	636	536	68	162
New York	1,070	2,400	540	470
North Carolina	4,307	7,306	1,920	2,952
North Dakota	125	140	3	40
Ohio	10,863	16,195	3,400	2,644
Oklahoma	1,910	1,700	310	710
Oregon	1,800	1,200	344	241
Pennsylvania	9,000	13,605	1,650	2,550
Rhode Island	10	61	17	1
South Carolina	2,205	2,424	438	446
South Dakota	800	1,370	175	205
Tennessee	316	922	246	442
Texas	5,630	11,545	2,315	2,700
Utah	849	669	198	151
Vermont	8	171	1	4
Virginia	704	2,759	582	428
Washington	2,900	2,221	1,090	805
West Virginia	285	760	322	292
Wisconsin	1,994	1,989	59	958
Wyoming	8	4	2	2
Other states[b]	168	132	5	2
US	140,686	170,398	34,174	50,693

[a] Preliminary. [b] AK, AZ, and NV combined to avoid disclosure of individual operations
Source: NASS, 1998.

10.3 Waste Management Systems

10.3.1 Broilers

Broiler and roaster housing. Houses used to rear broilers and roasters are usually 40 feet wide and 400 to 500 feet long. The houses are equipped with automatic feeding systems and automatic closed water systems (not a flow-through system). Ventilation varies from manual (side curtain) to complete fan ventilation controlled by thermostat and timer. Brooding (period when auxiliary heat is used) is often done in half to a third of the house and released to the remainder of the house, which has an impact on nutrient level in the litter in the brooding area. Broilers are usually grown for 42 to 56 days depending on market weight desired. 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 at 75 to 84 days of age.

Wood shavings are initially added to the houses at a depth of approximately 4 inches and top dressed with about 1-inch of new shaving between flocks. Litter (bedding and manure) is typically cleaned out completely annually, although there is a trend toward complete clean-out less often. Between flocks, 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 feeders, waterers, and brooding equipment are winched to the ceiling and litter is removed with a front loader or bobcat to a spreader trucks. 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. Rate of application is controlled by the rate at which the moving bed empties and the speed of the truck. In addition to land application, several other uses of litter are common, including feeding the litter to cattle as a protein source, composting it and using it as a soil amendment, using it as an ingredient for organic fertilizer, and burning it as fuel.

Broiler breeding and pullet housing. Pullet houses are generally 40 to 45 feet in width and 300 to 500 feet in length. Most houses are equipped with drinkers (nipple, trough, or bell type) and mechanical feeders (drag chain, trough, or pan type). Ventilation is mostly power ventilation; during the winter it is used to remove moisture and obnoxious gases, and during the summer it aids in removing excess heat produced by the birds.

The pullets are reared on a floor that is covered with a bedding source, 1 to 4 inches deep which can be wood shavings, rice hulls, chopped straw, peanut hulls, or another product depending on geographical availability. The bedding absorbs moisture and dilutes the manure produced by the birds when it mixes. This litter mixture is either removed after each flock (20 to 21 weeks) or used for a second flock, but a small amount of litter as cake (compacted and concentrated manure/litter mix) 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 to be used as a nutrient source for growing crops. Complete cleaning of the house is one of the procedures needed to practice good biosecurity and minimize of disease transmission.

Breeder houses are generally 40 to 45 feet in width and 300 to 600 feet in length. There will be a few variations to these dimensions. Most of the breeder houses are two-thirds slats and one-third litter. Occasionally some breeder organizations may use a totally littered floor. Slats are elevated (18 to 24 inches) panels of wood slats laid across supports with 1 inch of space between the slats that allows the fecal material to drop to the floor below. The slats generally cover one-third of each side of the house for the entire length of the house, with the center section free of equipment.

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. The breeder house is cleaned after the hens have finished the lay cycle. When the house is cleaned, all of 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 the front-end loader places the mixture of manure and litter into a litter spreader to be used as a nutrient source for growing crops. A thorough cleaning after each flock (essentially once per year) removes potentially harmful organisms that might be present to prevent them from infecting the next flock placed in the house. After removal of all organic matter, the house is disinfected.

Two decades ago, breeder layers were housed in systems that were 100 percent litter and had no slat area. Only a few of these systems are still in use, and litter is handled as described under the pullet system. An extremely small percentage of the breeder hens are housed in cages so that they can be artificially inseminated and so that detailed egg production records can be kept for purposes of genetic improvement by the primary breeder organizations. The manure in these facilities is handled similarly to that in a commercial cage layer facility.

10.3.2 Turkeys

Production systems. The production systems for turkey production are very similar to those for broilers with some minor, but significant, differences. Most turkeys are produced under contract. As with broilers, an integrated company provides birds, feed, medicines, bird transport, and technical help. The contract producer provides the production facilities and labor to grow the birds from hatchling to a market-age bird. For this, the contract producer receives a guaranteed price, which may be adjusted up or down based on the performance of the birds compared to other flocks produced or processed by the company during the same span of time. With this type of production, the contract turkey producer avoids much of the risk associated with production and market variation. In contrast to broiler production, which is about 99.9 percent integrated as just described, there are variations for turkey production. 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. In addition to independent production, some turkeys are produced on farms owned by the integrator company. The integrator turkey company may also be the company that processes the birds. However, some turkey integrators provide all services except the processing, which is arranged by the integrator with a processing company.

Housing equipment. Regardless of the contractual arrangement, all turkeys are produced in very similar housing and systems. Rearing and housing systems for breeder and market turkeys are very similar. Therefore, descriptions provided here may be construed to be descriptive of both market and breeder turkeys. Housing systems for turkey production are very similar across the United States and throughout the rest of North America.

The young turkey poults are received from the hatchery on the day of or the day after hatching. The poults are placed in barns called brooder houses. These barns are usually 40 to 50 feet wide and 300 to 400 feet long. The barns have dirt or clay floors covered with 3 to 4 inches of pine shavings or similar bedding. Once bedding has been used or even exposed to birds, it is usually called litter.

In southern climates, the side walls of these barns are 6 to 8 feet high with a 4- to 5-foot-wide opening that is covered by wire and curtains. These curtains may be opened or closed to provide ventilation. Ventilation can also be provided by side wall-mounted fans that pull air out of the barn. Inlets or opened curtains provide areas for air to then move into the barn. This is a negative-pressure air exchange system.

In northern climates the side walls may be solid, with all ventilation provided by side wall fans or movable solid side walls. The center of the barn may be 10 to 12 feet high. Each brooder house is equipped with gas-powered heaters or brooders, hence the name brooder house. Beneath each of these brooders, an 18- to 24-inch-high ring made of cardboard or a similar material is set up with a 12- to 14-foot diameter. This ring will keep the poults, approximately 300 per ring, in proximity to the brooder to make sure the poults are kept at the proper temperature. In addition, feed and water are provided in temporary flats and jugs.

In 5 to 9 days the rings, flats, and jugs are removed and the poults are trained to use permanent bell waterers and circular feed pans. Both water and feed systems are automatic or self-filling. Poults are placed in numbers to provide approximately 1 square foot per bird. Therefore, a brooder house that is 40 by 400 feet contains 16,000 square feet and can house up to 16,000 poults.

The poults are reared in the brooder house until 6 to 8 weeks of age. At that time, the poults are moved to range or grower barns, which are constructed very similarly to or the same as the brooder houses. In the grower house the male birds (toms) are provided approximately 1 square foot of space per 10 lb of live market weight per bird. Female birds (hens) are provided approximately 1 square foot of floor space for every 8 pounds of live market weight per bird. For example, toms expected to be marketed at 40 pounds live weight are provided 4 square feet per bird while hens expected to be marketed at 14 to 16 pounds live weight are provided 2 square feet per bird. These traditional systems as described are termed two-aged farms because two ages of birds can be on the farm at one time. Once the poults are moved to the grower barn, the brooder house is totally cleaned up for a second group of poults. This clean-up includes removal of all litter used during the brooding phase. This second group of poults occupies the brooder house while the first group of birds is still in the grower barn.

This two-age farm system has served the turkey industry for more than 20 years. Currently, however, there are efforts to modify and change this system due to increased morbidity and mortality, which has been difficult to control in some geographical areas of turkey production. These areas include but are not limited to North Carolina, South Carolina, Virginia, and Minnesota. These modifications are directed at raising older birds in facilities removed from the poults. This provides an opportunity to break any disease cycle that might put the birds, especially the younger birds, at increased risk for disease.

These current modifications include single-age farms, separate contract brooding farms, separate contract grower farms, and brood-and-move farms. Single-age farms are farms where poults are placed as described above. However, the poults are kept on the same farm for the entire production cycle. At 6 to 8 weeks of age, the birds are provided more floor space and properly sized equipment. Once the birds are transported to the processing plant, the entire facility is prepared for the next group of birds. Under separate brooding and growing contracts, birds are brooded by one contract producer and then moved to another farm owned by a second contract producer. In this way the birds are brooded and then reared on separate farms. Under one brood-and-move system, the poults are handled similarly but the same contract producer owns both the brooder and grower farm. In another brood-and-move system, the integrator company owns and operates the brooder farm and moves the poults to contract grower farms.

Litter handling systems. 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 for the lowest possible risk of disease exposure. For grower systems, the litter is removed once per year. In between flocks, caked manure 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.

Litter is usually removed by skid-steer tractors or tractors equipped with front-end loaders or scoops. The litter is dumped into trucks with lift beds or spreader trucks and transported to holding facilities or end users such as farmers who will use the litter on crop or pasture land.

10.3.3 Layers

High-rise cage systems. High-rise cage housing is a two-story poultry house 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 ventilation system is designed so that the external air is brought into the top story, brought through the cages where the birds are located, and then over the manure in the bottom story, and exits through fans in the bottom story side wall. The watering system is a closed (noncontinuous flow) nipple or cup system.

The ventilation system is designed to dry manure as it is stored. With proper management of waterers preventing water leaking onto the stored litter, litter moisture is commonly 30 to 50 percent. Litter of 30 percent to 50 percent can be stored for extended periods of time and handled and land applied similar to a litter product of broilers or turkeys. Usually clean-out of the high-rise is timed to coincide with availability of crop land for application or flock movement.

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 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 with a small tractor or a pit scraper. Another scraping system in use includes a wench and cable to supply the power to move the scraper from one end of the house to the other, scraping the manure in front of it to an unloading device at the end of the house, which places the manure in a field spreader.

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 attempt to move air over the manure on the belt in an attempt to dry the manure before its removal.

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

Flush cage housing. Housing, equipment, and ventilation are similar to the scrape-out system except with regard to 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. Lagoon levels are maintained so that sufficient storage is provided for the 25-year, 24-hour storm by irrigating liquid onto pasture or cropland. Some states require storage of more than the 25-year, 24-hour storm. North Carolina, for example, requires storage for the equivalent of two such storms.

Other systems. 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 production of hatching eggs, which will produce the commercial layer chicks that will eventually produce table eggs.

10.4 Economic Considerations

The predominant manure management system in all regions of the country involves the removal of poultry litter (wood shavings and manure) from production houses after one or more broods have been reared on the same litter. Equipment costs for a typical broiler operation are displayed here:

Item	Costs
Litter cruster machine (for removing cake between flocks)	$9,500.00
Tractor to pull cruster machine	$12,500.00
Front-end loader tractor (bobcat type)	$15,000.00
Spin spreader and truck	$32,000.00
Litter storage shed (40-ft by 160-ft to store annual production from four 40-ft by 500-ft production houses)	$22,000.00
Total Investment	$91,000.00 or $0.875/bird capacity based on a four-house family operation

Turkey operations follow the same basic manure management strategy as broiler operations with certain variations. Costs equate to $106,000 or $2.20 per bird, following the same criteria as above.

Costs for production houses and equipment (including fans and waterers) vary widely among regions. The 1997 cost of housing and equipment was more than $5 and $4.45 per square foot of building for broilers and turkeys, respectively, in North Carolina.

Maintaining good litter conditions inside the house results in a litter product containing optimum moisture and nutrient contents for land application. This nutrient resource has excellent physicochemical characteristics that can greatly improve the quality of cultivated soils. In addition to nutrients, poultry manure provides organic matter that enhances soil water-holding capacity, improves soil aeration, and increases retention of certain nutrients (Reeves et al., 1998, cited in NCSU, 1998). Some of the costs of poultry manure management will thus be defrayed by savings in fertilizer expenditures and invaluable soil properties that will enhance crop growth.

The high nutrient content of poultry manure presents alternative management strategies. Composting and bagging a pelleted poultry manure fertilizer produces a marketable product for the commercial horticulture industry. Ease of handling, lack of objectionable odor, and freedom from pathogens makes poultry manure an attractive soil amendment (Trumbaur et al., 1994, cited in NCSU, 1998).

The high concentration of phosphorus and protein in poultry manure has been capitalized upon as a dietary supplement for cattle in poultry-producing areas since the 1950s. Reeves et al. (1998, cited in NCSU, 1998) report that 20 to 25 percent of litter consists of crude proteins after five to six flocks. This translates into an $80 to $120 value per ton when formulated into a cattle feed (NSOE, 1996, cited in NCSU, 1998).

10.5 Bibliography

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11.0 Treatment Technology Efficiency Summary

11.1 Introduction

This chapter summarizes technologies and practices used to collect, store, treat, and dispose of manure with an emphasis on treatment efficiency and available information on cost. In earlier chapters it was demonstrated that the major manure disposal method for most operations is application on their own land. As animal feeding operations continue to consolidate (i.e., more large operations) to take advantage of specialized labor and equipment, applying manure on their own land at rates that balance crop uptake with existing soil nutrients will become more difficult. To encourage agronomic application of manure, some states have developed "manure banks" to help animal feeding operators find off-farm land for manure application. Some operators have built manure sheds to improve the ability to apply manure during more desirable times of the year. Because of the focus on nutrient management, most of the published treatment efficiency data is related to solids and nutrient removal or concentrations of major nutrients. Thus, the majority of the information presented in this chapter is related to solids and nutrients.

Several sources of literature provide national data summaries or typical values for a variety of common animal types and technologies. These data could be used to serve as a baseline for existing systems. In recent years, research has focused on odor control and improved nutrition strategies. Odor control research is largely driven by the need to maintain animal health and avoid nuisance odor liability. As odor controls are implemented there is likely to be a decrease in ammonia volatilization, the primary mechanism through which nitrogen is lost from stored manure. From an environmental perspective, this industry change might be advantageous since some research has shown that ammonia volatilization might contribute to atmospheric deposition in nearby watersheds (e.g., Paerl et al., 1995 and Fisher and Oppenheimer, 1991). Waste minimization technologies such as improved nutrition strategies (e.g., split-sex feeding, phytase addition) also show promise for reducing the production and nutrient content of manure. While split-sex feeding has been adopted by some operators, feed additives (e.g., phytase) have been cost neutral, in some instances. Anaerobic digestion and composting, both well-understood and value-added technologies, have reemerged due to programs such as EPA's AgStar Program for anaerobic digestion. However, Day and Funk (1998) state that there is still a need for continued research and demonstration of low-maintenance and less capital-intensive anaerobic digestion and development of compost systems that can receive and compost large volumes of high-moisture manure in a labor-efficient manner.

At the end of this chapter is an extensive bibliography of standard references and recent papers from proceedings, conferences, and journals that were considered for this chapter. Results from selected publications that included treatment efficiency or cost information are presented to supplement standard reference material. In most cases, information on novel and emerging technologies is based on a few studies, and further research is likely needed before these practices can be reliably implemented on a general basis. While it is reasonable to suspect that a technology proven effective for one animal type and location could be considered for a similar situation, it would be premature to assume that the technology could be transferred to other animal types and locations. Finally, exclusion or inclusion from this document does not imply disapproval or endorsement.

11.2 Waste Generation

The Midwest Planning Service, the American Society of Agricultural Engineers, and the USDA provide quantities and characteristics of manure excreted for a variety of animal types (Tables 11-1 through 11-3). Tables 11-4 through 11-6 provide general characteristics associated with milking center waste, poultry waste litter, and a comparison of animal waste with and without bedding, respectively. In states like Texas, feedlot operators estimate manure and constituent characteristics based on the mean plus one standard deviation (from Table 11-3) in order to obtain a permit (Sweeten, 1998). While excretion data exists for chemical parameters other than the major nutrients, relatively little has been published about the effect of different handling, storage, and treatment practices on chemical parameters other than nitrogen, phosphorus, and potassium. For example, hog manure includes copper and zinc, while broiler manure contains copper, zinc, and arsenic. Some concern has also been raised about organic compounds in manure such antibiotics, pesticides, and hormones, and their associated

Table 11-1. Annual volume and nutrient content of raw manure.

Animal Category	Manure Produced 1000 gal/yr.	Nutrients Produced (lb nutrient/1000 gal/yr) N	P	K
Farrow, per sow and litter	0.989	36.9	9.7	16.8
Nursery, per pig cap.	0.101	57.7	15.8	30.0
Grow-fin, per pig cap.	0.440	58.1	19.2	39.9
Breed-gestation, per sow cap.	0.396	59.9	24.2	36.8
Dairy cow, per mature cow	5.057	41.1	8.6	27.6
Dairy heifer, per hd cap.	2.639	42.2	9.1	28.4
Dairy calf, per hd cap.	0.528	41.5	9.1	28.7
Veal calf, per hd cap.	0.352	36.3	13.6	43.1
Beef cows, per hd cap.	2.770	47.4	12.7	34.2
Feeder calf (500#), per hd cap.	1.275	48.7	13.0	30.0
Fattening cattle, per hd cap.	2.551	48.7	13.0	30.0
Broilers, per bird cap.	0.006	130.4	36.3	44.3
Pullets, per bird cap.	0.007	116.2	31.4	45.9
Layers, per bird cap.	0.011	110.2	35.4	37.7
Tom-turkeys, per bird cap.	0.025	116.5	50.9	36.3
Hen-turkeys, per bird cap.	0.025	103.8	46.6	32.0
Ducks, per bird/yr.	0.014	80.3	42.1	24.5

Source: MWPS, 1993 as presented by Jones and Sutton, 1994.

by-products. For example, nonylphenol residue concentrations are similar to those found in municipal biosolids (Chaney, 1997). Although a comprehensive scan of pollutant parameters has not been performed, the leading issues related to ground and surface waters appear to be nitrogen and phosphorus.

Site-specific manure nutrient content is affected by numerous factors including rations, feed waste, water waste, nutrient loss, and bedding. The value of manure nutrients is dependent on the nutrient status of the field to which it is applied, the nutrient needs of the crop to be grown, the nutrient content of the manure, and the cost of purchased nutrients. The value of manure as a nutrient source is greatest when applied to a soil of low fertility. When applying manure at a rate to satisfy the N needs of a crop, P and K are usually applied in excess, and excess nutrients would not be given any value. In addition, continued build-up of soil P might be undesirable since it has resulted in some instances of increased dissolved P losses from fields (Sharpley, 1995). At the same time, manure has other benefits such as providing micronutrients and organic matter. Table 11-7 presents the average annual value (1994 dollars) of manure based on the nitrogen ($0.20/lb), phosphorus ($0.28/lb), and potassium ($0.16/lb) content for a variety of operations in Minnesota. Note, that in a 1995 study of dairy operations in the Chesapeake Bay, Ritter and Scarborough (1995) used nitrogen, phosphorus, and potassium costs of $0.22, $0.25, and $0.132 per pound.

In a more recent study, Lorimor and Xin (1998) evaluated poultry manure volume and nutrient production of layers from high-rise houses containing 80,400 to 124,500 birds at four commercial facilities in Iowa. Measured manure production was 10.5 tons/1000 birds/year with an average moisture content of 41 percent. Nutrient production was shown to be 385, 379, and 457 lb/1000 birds/year of N, P, and K, respectively. Different manure handling systems had a different effect on manure moisture content—manure had a higher moisture content when the manure dropped directly into storage rather than be allowed to remain on boards beneath the cages for a period of time before removal to a storage pile.

Table 11-2. Livestock waste characterization as excreted manure.[c]

Animal Category	Weight lb/d/1000#	Volume ft^3/d/1000#	Moisture %	TS % w.b.	TS lb/d/1000#	VS lb/d/1000#	FS lb/d/1000#	COD lb/d/1000#	BOD_5 lb/d/1000#	N lb/d/1000#	P lb/d/1000#	K lb/d/1000#	C:N ratio
Dairy[a]													
Cow, Lactating	80.00	1.30	87.50	12.50	10.00	8.50	1.50	8.90	1.60	0.45	0.07	0.26	10
Cow, Dry	82.00	1.30	88.40	11.60	9.50	8.10	1.40	8.50	1.20	0.36	0.05	0.23	13
Heifer	85.00	1.30	89.30	10.70	9.14	7.77	1.37	8.30	1.30	0.31	0.04	0.24	14
Beef[b]													
Feeder													
High forage diet	59.10	0.95	88.40	11.60	6.78	6.04	0.74	6.11	1.36	0.31	0.11	0.24	11
High energy diet	51.20	0.82	88.40	11.60	5.91	5.44	0.47	5.61	1.36	0.30	0.094	0.21	10
450 - 750 lb	58.20	0.93	87.00	13.00	7.54	6.41	1.13	6.00	1.30	0.30	0.10	0.20	12
Cow	63.00	1.00	88.40	11.60	7.30	6.20	1.10	6.00	1.20	0.33	0.12	0.26	10
Swine[b]													
Grower (40-220 lb)	63.40	1.00	90.00	10.00	6.34	5.40	0.94	6.06	2.08	0.42	0.16	0.22	7
Replacement gilt	32.80	0.53	90.00	10.00	3.28	2.92	0.36	3.12	1.08	0.24	0.08	0.13	7
Sow, gestation	27.20	0.44	90.80	9.20	2.50	2.13	0.37	2.37	0.83	0.19	0.063	0.123	6
Sow, lactation	60.00	0.96	90.00	10.00	6.00	5.40	0.60	5.73	2.00	0.47	0.15	0.30	6
Boar	20.50	0.33	90.70	9.30	1.90	1.70	0.30	1.37	0.65	0.15	0.05	0.10	6
Nursing/nursery pig (0 - 40 lb)	106.00	1.70	90.00	10.00	10.60	8.80	1.80	9.80	3.40	0.60	0.25	0.35	8
Poultry[a]													
Layer	60.50	0.93	75.00	25.00	15.10	10.80	4.30	13.70	3.70	0.83	0.31	0.34	7
Pullet	45.60	0.73	75.00	25.00	11.40	9.70	1.70	12.20	3.30	0.62	0.24	0.26	9
Broiler	80.00	1.26	75.00	25.00	20.00	15.00	5.00	19.00	5.10	1.10	0.34	0.46	8
Turkey	43.60	0.69	75.00	25.00	10.90	9.70	1.25	12.30	3.30	0.74	0.28	0.28	7
Duck	–	–	–	–	12.00	7.00	5.00	9.50	2.50	0.70	0.30	0.50	6
Other livestock[a]													
Veal	60.00	0.96	97.50	2.50	1.50	0.85	0.65	1.50	0.37	0.20	0.03	0.25	2
Sheep	40.00	0.63	75.00	25.00	10.00	8.30	1.76	11.00	1.00	0.45	0.07	0.30	10
Horse	50.00	0.80	78.00	22.00	11.00	9.35	1.65	–	–	0.28	0.05	0.19	19

[a] Increase solids and nutrients by 4% for each 1% feed waste more than 5%.
[b] Average daily production for weight range noted. Increase solids and nutrients by 4% for each 1% feed waste more than 5%.
[c] 1000# refers to 1,000 lb of animal live weight.
Source: USDA, 1992.

Table 11-3. Fresh manure production and characteristics per 1,000 lb live animal mass per day. Values in table are parameter mean (standard deviation).

	Animal Type										
Parameter	**Dairy**	**Beef**	**Veal**	**Swine**	**Sheep**	**Goat**	**Horse**	**Layer**	**Broiler**	**Turkey**	**Duck**
Total manure, lb	86 (17)	58 (17)	62 (24)	84 (24)	40 (11)	41 (8.6)	51 (7.2)	64 (19)	85 (13)	47 (13)	110
Urine, lb	26 (4.3)	18 (4.2)		39 (4.8)	15 (3.6)		10 (0.74)				
Density, lb/ft^3	62 (4)	63 (4.7)	62	62 (1.5)	64 (4)	63	63 (5.8)	60 (2.4)	63	63	
Total solids, lb	12 (2.7)	8.5 (2.6)	5.2 (2.1)	11 (6.3)	11 (3.5)	13 (1)	15 (4.4)	16 (4.3)	22 (1.4)	12 (3.4)	31 (15)
Volatile solids, lb	10 (0.79)	7.2 (0.57)	2.3	8.5 (0.66)	9.2 (0.31)		10 (3.7)	12 (0.84)	17 (1.2)	9.1 (1.3)	19
BOD_5, lb	1.6 (0.48)	1.6 (0.75)	1.7	3.1 (0.72)	1.2 (0.47)		1.7 (0.23)	3.3 (0.91)		2.1 (0.46)	4.5
COD, lb	11 (2.4)	7.8 (2.7)	5.3	8.4 (5.3)	11 (2.5)			11 (2.7)	16 (18)	9.3 (1.2)	27
pH	7 (0.45)	7 (0.34)	8.1	7.5 (0.57)			7.2	6.9 (0.56)			
Total Kjeldahl nitrogen, lb	0.45 (0.096)	0.34 (0.073)	0.27 (0.045)	0.52 (0.21)	0.42 (0.11)	0.45 (0.12)	0.3 (0.063)	0.84 (0.22)	1.1 (0.24)	0.62 (0.13)	1.5 (0.54)
Ammonia nitrogen, lb	0.079 (0.083)	0.086 (0.052)	0.12 (0.016)	0.29 (0.1)				0.21 (0.18)		0.08 (0.018)	
Total phosphorus, lb	0.094 (0.024)	0.092 (0.027)	0.066 (0.011)	0.18 (0.1)	0.087 (0.03)	0.11 (0.016)	0.071 (0.026)	0.3 (0.081)	0.3 (0.053)	0.23 (0.093)	0.54 (0.21)
Orthophsphorus, lb	0.061 (0.058)	0.03		0.12	0.032 (0.014)		0.019 (0.0071)	0.092 (0.016)			0.25
Potassium, lb	0.29 (0.094)	0.21 (0.061)	0.28 (0.1)	0.29 (0.16)	0.32 (0.11)	0.31 (0.14)	0.25 (0.091)	0.3 (0.072)	0.4 (0.064)	0.24 (0.08)	0.71 (0.34)
Calcium, lb	0.16 (0.059)	0.14 (0.11)	0.059 (0.049)	0.33 (0.18)	0.28 (0.15)		0.29 (0.11)	1.3 (0.57)	0.41	0.63 (0.34)	
Magnesium, lb	0.071 (0.016)	0.049 (0.015)	0.033 (0.023)	0.07 (0.035)	0.072 (0.047)		0.057 (0.016)	0.14 (0.042)	0.15	0.073 (0.0071)	
Sulfur, lb	0.051 (0.01)	0.045 (0.0052)		0.076 (0.04)	0.055 (0.043)		0.044 (0.022)	0.14 (0.066)	0.085		
Sodium, lb	0.052 (0.026)	0.03 (0.023)	0.086 (0.063)	0.067 (0.052)	0.078 (0.027)		0.036	0.1 (0.051)	0.15	0.066 (0.012)	
Chloride, lb	0.13 (0.039)			0.26 (0.052)	0.089			0.56 (0.44)			
Iron, lb	0.012 (0.0066)	0.0078 (0.0059)	0.00033	0.016 (0.0097)	0.0081 (0.0032)		0.016 (0.0081)	0.06 (0.049)		0.075 (0.028)	
Manganese, lb	0.0019 (0.00075)	0.0012 (0.00051)		0.0019 (0.00074)	0.0014 (0.0015)		0.0028 (0.0021)	0.0061 (0.0022)		0.0024 (0.00033)	
Boron, lb	0.00071 (0.00035)	0.00088 (0.000064)		0.0031 (0.00095)	0.00061 (0.0003)		0.0012 (0.00048)	0.0018 (0.0017)			
Molybdenum, lb	0.000074 (0.000012)	0.000042		0.000028 (0.00003)	0.00025 (0.00038)		0.000083 (0.000033)	0.0003 (0.000057)			
Zinc, lb	0.0018 (0.00065)	0.0011 (0.00043)	0.013	0.005 (0.0025)	0.0016 (0.001)		0.0022 (0.0021)	0.019 (0.033)	0.0036	0.015 (0.012)	
Copper, lb	0.00045 (0.00014)	0.00031 (0.00012)	0.000048	0.0012 (0.00084)	0.00022 (0.000066)		0.00053 (0.00039)	0.00083 (0.00084)	0.00098	0.00071 (0.0001)	
Cadmium, lb	0.000003			0.000027 (0.000028)	0.0000072		0.0000051	0.000038 (0.000032)			
Nickel, lb	0.00028						0.00062	0.00025			
Lead, lb				0.000084 (0.000012)	0.000084			0.00074			

All values in table are wet basis. All nutrients and metals values are given in elemental form. Typical live animal masses for which manure values represent are dairy, 1,400 lb; beef, 800 lb; veal, 200 lb; swine, 135 lb; sheep, 60 lb; goat, 140 lb; horse, 1000 lb; layer, 4 lb; broiler, 2 lb; turkey, 15 lb; and duck, 3 lb. Parameter means within each animal species are comprised of varying populations of data. Maximum numbers of data points for each species are dairy, 85; beef, 50; veal, 5; swine, 58; sheep, 39; goat, 3; horse, 31; layer, 74; broiler, 14; turkey, 18; and duck, 6.
Source: ASAE, 1998, ASAE Standard D384.1 DEC93.

Table 11-4. Dairy waste characterization of milking center.

Components	Units	Milking center			
		Milk house	Milk house and milking parlor	Milk house, milking parlor and holding area[a]	Milk house, milking parlor and holding area[b]
Volume	ft3/d/1000#	0.22	0.60	1.40	1.60
Moisture	%	99.72	99.40	99.70	98.50
TS	% w.b.	0.28	0.60	0.30	1.50
VS	lb/1000 gal	12.90	35.00	18.30	99.96
FS	lb/1000 gal	10.60	15.00	6.70	24.99
COD	lb/1000 gal	25.30	41.70		
BOD_5	lb/1000 gal		8.37		
N	lb/1000 gal	0.72	1.67	1.00	7.50
P	lb/1000 gal	0.58	0.83	0.23	0.83
K	lb/1000 gal	1.50	2.50	0.57	3.33
C:N ratio		10	12	10	7

[a] Holding area scraped and flushed - manure excluded. [b] Holding area scraped and flushed - manure included.
Source: USDA, 1992.

Table 11-5. Characterization of poultry waste litter.

Component	Units	Layer high-rise[a]	Broiler	Broiler breeder[b]	Turkey	Duck[b]
Weight	lb/d/1000#	24.00	35.00		24.30	
Moisture	%	50.00	24.00	34.00	34.00	11.20
TS	% w.b.	50.00	76.00	66.00	66.00	88.80
	lb/d/1000#	12.00	26.50		16.10	
VS	lb/d/1000#		21.40			58.60
FS	lb/d/1000#		5.10			30.20
N	lb/d/1000#	0.425	0.68	1.06	0.88	2.31
NH4-N	lb/d/1000#				0.01	
P	lb/d/1000#	0.275	0.34	1.32	0.40	
K	lb/d/1000#	0.30	0.40	1.19	0.45	
C:N ratio			9			14

[a] No bedding or litter added to waste.
[b] All values are precent wet basis.
Source: USDA, 1992.

Table 11-6. Approximate fertilizer nutrient values of animal manure as applied to land solid handling systems.

Type of System		Nutrient Content (lb/ton)			
		Total N	NH_4	P_2O_5	K_2O
Swine	No Bedding	10	6	9	8
	Bedding	8	5	7	7
Beef Cattle	No Bedding	21	7	14	23
	Bedding	21	8	18	26
Dairy Cattle	No Bedding	9	4	4	10
	Bedding	9	5	4	10
Poultry	Without Litter	33	26	48	34
	With litter	56	36	45	34
	Deep pit (compost)	68	44	64	45

Table 11-7. Approximate value (1994 dollars) of nutrients in animal manure as produced from a solid manure handling system in Minnesota.

Type of operation		Approx. Value	N (lb/ton)	P_2O_5 (lb/ton)	K_2O (lbs/ton)
60 head dairy at 1,300 lb with replacements, 50% increase from replacements	Without Bedding	$8,370	9	4	10
	With Bedding	$10,245			
100 head Beef at 1,000 lb	Without Bedding	$6,730	21	14	23
	With Bedding	$8,076	21	18	26
200 head finishing pigs at 200 lb	Without Bedding	$3,561	10	9	8
	With Bedding	$3,820	8	7	7
27,500 layers at 4 lb	Without Litter	$16,060	27	20	17
	With Litter	$17,666	20	16	13

20 percent increase in manure produced because of bedding, N=$0.20/lb, P=$0.28/lb, K=$0.16/lb
Source: Reichow, 1995.

11.3 Waste Reduction Through Feeding Practices

Wasted feed can increase the waste generated. For example, for each 1 percent of feed wasted above 5 percent, the solid and nutrient values presented in Table 11-2 are increased by 4 percent. To reduce waste some swine growers have switched to pelletized feed. The design of feeders and waterers are being improved to reduce waste and overflow. For example, some poultry houses have alarms that indicate when there is a water line break.

Numerous advances have also been made to improve feeding efficiency, thereby reducing waste. Knowledge about animal nutrition requirements and feed composition has allowed operators to customize feeding to animal type and performance. For example, some swine operations have already implemented multi-phase and/or split-sex feeding. Swine and poultry are better able to digest feed if it is more finely ground. Other studies have shown that typical copper supplements in poultry feed exceed requirements, resulting in enlargement of the proventriculus in broilers (Wideman, 1996). At the University of Kentucky, reductions in dietary zinc and copper in nursery pigs had no impact on pig performance (Cromwell, 1998). At Purdue University, sulfurous volatile organic carbons have been reduced 63 percent by controlling dietary protein intake (Sutton, in progress). Amino acid additions to pig feed such as lysine allow a reduction in the total protein intake, which results in lower excretion of total nitrogen and up to 45 percent less ammonia (Sutton, in progress). Section 9.3.1 provides more details about dietary manipulation to reduce nutrient excretion from swine operations. Section 9.3.1 also provides a preliminary cost analysis of some alternatives that demonstrate dietary manipulation to be cost neutral in some situations (NCSU, 1998). Boland et al. (1997) found that phytase adoption is likely to have little economic impact for swine producers under current conditions. Some anecdotal evidence also suggests that phosphorus loading from beef and dairy cattle waste can be reduced by changing the form and type of feed, although published results were not found during this literature review.

Digestability and degradability of typical feeds have also been extensively examined. Broilers, for instance, absorb about 20 to 30 percent of the phosphorus in the corn and soybeans they ingest. Food additives such as phytase allow animals to assimilate more phosphorus resulting in decreased phosphorus in manure. The inter-relationships between phosphorus, phytase, calcium, Vitamins D and E, and magnesium are now better understood. Additives for rumen and hindgut micrflora may alter digestability and in some cases reduce volatility and odor. A genetically engineered corn contains a phosphorus compound that is more readily assimilated, resulting in half the normal amount of phosphorus excreted by poultry (Farm Journal, 1998) and two-thirds the normal amount in pigs (Spencer, 1998). Subsequent land application of broiler litter on tall fescue plots resulted in 22 percent less phosphorus runoff as compared to unaltered corn. Phosphorus runoff decreased by 26 percent when genetically engineered corn and phytase were used (Moore, 1995). Manure with less phosphorus will tend to have a nitrogen-to-phosphorus ratio more in line with crop nutrient requirements. In addition, some plants naturally contain or have been modified to produce antibiotic compounds, reducing the need to directly add these substances to animal feed.

11.4 Comparison of Common Waste Collection, Storage, and Treatment Practices

A variety of technologies are used for waste collection including

< Scrapers and front-end loaders for paved outside feeding areas and freestalls and unpaved beef feedlots and a growing number of dairies in arid regions.

< Front-end loaders and other specialized equipment for bedded or litter systems common in dairy loafing sheds, turkeys for slaughter, pullets, broilers, and hoop structures for swine.

< Control structures for runoff.

< Flush systems for dairies, swine, and layers.

< Under-house collection common to swine and layers.

The selection of animal production and housing techniques determines whether the waste will be managed as a liquid, semisolid, or solid (see Figure 11-1) and ultimately determines the selection of storage, treatment, and disposal technologies used. Other factors that effect selection include location, capital versus labor cost, automation, operator preference, dust and odor control, and, as demonstrated in a number of surveys, ground and surface water protection. The type of manure and how it is collected has a direct impact on the nutrient value of the waste and its value as a soil amendment or for other uses.

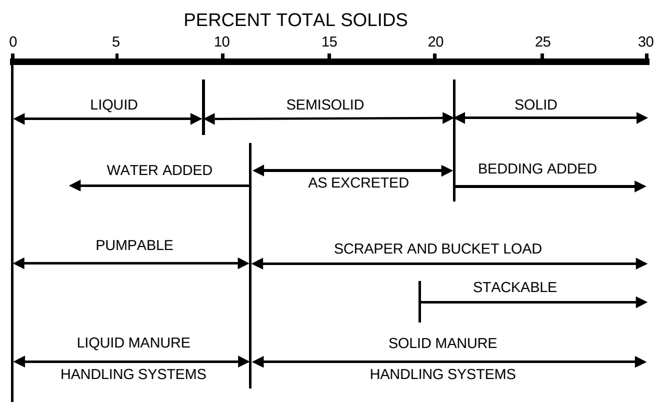

Figure 11-1. Manure characteristics that influence management options (after Ohio State University Extension, 1998).

Solid manure storage can range from simply-constructed mounds inside feedlots to manure sheds that are designed to prevent runoff and leaching. In liquid manure handling systems, the manure is typically stored under house, in aboveground or belowground steel or concrete tanks, or in lagoons. In addition to storage, lagoons also provide treatment. Most lagoons operate anaerobically (although a lagoon receiving only milking parlor waste will usually operate aerobically). Aerated lagoons have received less attention due to increased costs; however, decreased odor might increase their use. Svoboda (1995) achieved nitrogen removal from 47 to 70 percent depending on aeration through nitrification and denitrification in a 24 m^3 aerobic treatment reactor using whole pig slurry in Scotland. Secondary, or biological, treatment (such as oxidation ditches, activated sludge, and rotating biological contactors) can be used to treat manure in the same way as it is used to treat human wastes. However, it is an expensive technology in comparison to what is currently in use, and does not eliminate the resulting liquid effluent and solid sludge.

Lagoons may be either lined (clay or synthetic material) or unlined, depending on factors considered prior to construction. Some lagoons were designed assuming they would “self-seal.” Other lagoons have leaked due to disturbing the bottom liner during lagoon pumpout. Lagoon sidewalls have also cracked after repeated drying and wetting cycles that occur following lagoon emptying. Some farmers have reported worm holes in the sidewalls of a lagoon that contribute to leaching. In an evaluation of an earthen-lined dairy manure storage basin in Wisconsin, physicochemical and biological mechanisms were responsible for creating macropores resulting in preferential flow and leakage (McCurdy, 1993).

The effect of some lagoons on ground water has been fairly well documented. For example, in a targeted survey of 34 lagoons built on swine operations before the 1993 North Carolina requirement to meet NRCS standards, 13 lagoons were shown to have seepage losses such that ground water samples 125 ft from the lagoon had strong to very strong levels of NO_3-N. Another 9 lagoons had ground water samples that exceeded the NO_3-N drinking water standard, but were expected to dissipate quickly with increasing distances from the lagoon. Surface water samples indicated that 1 of 16 lagoons was the likely cause of nearby surface water nutrient enrichment, while 8 of 16 lagoons are potentially contributing to nearby surface water nutrient enrichment (Huffman and Revels, 1998). At a clay-lined swine waste lagoon located on the Delmarva Peninsula, ammonium nitrogen was above 1,000 mg/l N at shallow wells around the lagoon; chlorides and TDS were also high (Ritter, 1990). Some research has been done to evaluate the application of surfactants for enhancing soil liner materials in animal waste storage and treatment lagoons. In a laboratory experiment on sandy loam soil, optimum surfactants were found to reduce saturated hydraulic conductivity and did not negatively impact mechanical compaction characteristics; however, no influence on nitrate mobility was observed (Allred and Brandvold, 1998).

The proportion of phosphorus and potassium remaining in manure after storage is generally higher than nitrogen except when considering open lots or lagoons. Runoff and leaching from open lots can range from 20 to 40 percent of the phosphorus and 30 to 50 percent of the potassium. If runoff control systems such as settling basins and holding ponds are employed, much of the phosphorus and potassium can be recovered. It is also possible for up to 80 percent of the phosphorus in lagoons to accumulate in bottom sludges (MWPS, 1993). Table 11-8 is a comparison of livestock waste characteristics in anaerobic, aerobic, and runoff ponds, and Table 11-9 presents the percent of original nutrient content of manure retained by various management systems (USDA, 1992). Sweeten (1998) also provides a summary of beef feedlot runoff characteristics.

Jones and Sutton (1994) analyzed manure nutrient content just before land application. Table 11-10 shows the nutrient concentrations obtained from liquid manure pit samples. These concentrations were compared to those presented in Table 11-1 to determine the change in nutrient value. For example, nitrogen as excreted from a nursery-sized pig can be estimated as $0.101 \times 57.7 = 5.83$ lb-N/year. From Table 11-10, the nitrogen after storage would be $0.130 \times 25.00 = 3.25$ lb-N/year or a 44 percent decrease. On a mass basis for pit storage, nitrogen decreases range from 11 to 47 percent; phosphorus, 9 to 67 percent; and potassium, 5 to 42 percent. Comparable values from Table 11-9 (i.e., manure stored in pits beneath slatted floors) indicate that nitrogen decreases range from 10 to 30 percent, and phosphorus and potassium decreases range from 5 to 15 percent. Table 11-11 shows the nutrient concentrations obtained from anaerobic lagoon samples. These concentrations were compared to those presented in Table 11-1 to determine the change in nutrient value. On a mass basis for a lagoon, nitrogen decreases range from 76 to 84 percent; phosphorus, 78 to 92 percent; and potassium, 71 to 85 percent. Comparable values from Table 11-9 (i.e., manure treated in anaerobic lagoon) indicate that nitrogen

Table 11-8. Livestock waste characterization in anaerobic, aerobic, and runoff ponds.

		Anaerobic Lagoon								Aerobic Lagoon	Feedlot Runoff Pond	
		Supernatant				Sludge				Supernatant	Supernatant	Sludge
				Poultry				Poultry				
Component	**Units**	**Dairy**	**Swine**	**Layer**	**Pullet**	**Dairy**	**Swine**	**Layer**	**Pullet**	**Dairy**	**Beef**	
Moisture	%	99.75	99.75	99.50	99.70	90.00	92.40	86.90	92.60	99.95	99.70	82.80
TS	% w.b.	0.25	0.25	0.50	0.30	10.00	7.60	13.10	7.40	0.05	0.30	17.20
VS	lb/1000 gal	9.16	10.00	18.33	10.83	383.18	379.89	404.06	314.09	1.67	7.50	644.83
FS	lb/1000 gal	11.66	10.83	23.32	14.17	449.82	253.27	687.32	302.42	2.50	17.50	788.12
COD	lb/1000 gal	12.50	10.00			433.16	538.18			1.25	11.67	644.83
BOD_5	lb/1000 gal	2.92	3.33							0.29		
N	lb/1000 gal	1.67	2.91	6.25	3.00	20.83	25.00	32.50	24.17	0.17	1.67	51.66
NH_4-N	lb/1000 gal	1.00	1.83	4.58	2.24	4.17	6.33	7.66	4.91	0.10	1.50	
P	lb/1000 gal	0.48	0.63	0.83	0.75	9.16	22.50	45.82	27.49	0.08		17.50
K	lb/1000 gal	4.17	3.16	8.33	7.00	12.50	63.31	6.00	6.17		7.50	14.17
C:N ratio		3	2	2	2	10	8	7	7			

Source: USDA, 1992.

Table 11-9. Percent of original nutrient content of manure retained by various management systems.

Management System	Beef			Dairy			Poultry			Swine		
	N	P	K	N	P	K	N	P	K	N	P	K
Manure stored in open lot, cool humid region	55-70	70-80	55-70	70-85	85-95	85-95				55-70	65-80	55-70
Manure stored in open lot, hot, arid region	40-60	70-80	55-70	55-70	85-95	85-95						
Manure liquids and solids stored in a covered, essentially watertight structure	70-85	85-95	85-95	70-85	85-95	85-95				75-85	85-95	85-95
Manure liquids and solids stored in an uncovered, essentially watertight structure	60-75	80-90	80-90	65-75	80-90	80-90				70-75	80-90	80-90
Manure liquids and solids (diluted less than 50%) held in waste storage pond				65-80	80-95	80-95						
Manure and bedding held in roofed storage				65-80	80-95	80-95	55-70	80-95	80-95			
Manure and bedding held in unroofed storage, leachate lost				55-75	75-85	75-85						
Manure stored in pits beneath slatted floor	70-85	85-95	85-95	70-85	90-95	90-95	80-90	90-95	90-95	70-85	90-95	90-95
Manure treated in anaerobic lagoon or stored in waste storage pond after being diluted more than 50%	20-35	35-50	50-65	20-35	35-50	50-65	20-30	35-50	50-60	20-30	35-50	50-60

Source: USDA, 1992.

Table 11-10. Liquid manure nutrient concentrations in pit storage.

Animal Category	Manure Produced[b] 1000 gal/yr.	Nutrients lb nutrient/1000 gal/yr (% decrease from Table 11-1)[a]					
		Nitrogen		Phosphorus		Potassium	
Farrow, per sow and litter	1.400	15.00	(42%)	5.24	(24%)	9.13	(23%)
Nursery, per pig cap.	0.130	25.00	(44%)	8.44	(31%)	18.26	(22%)
Grow-fin, per pig cap.	0.530	32.75	(32%)	11.55	(28%)	22.41	(32%)
Breed-gestation, per sow cap.	0.500	25.00	(47%)	13.55	(29%)	22.41	(23%)
Dairy cow, per mature cow	6.000	31.00	(11%)	6.56	(9%)	15.77	(32%)
Dairy heifer, per hd cap.	3.000	32.00	(14%)	6.12	(24%)	23.24	(7%)
Dairy calf, per hd cap.	0.700	27.00	(14%)	6.12	(11%)	19.92	(8%)
Veal calf, per hd cap.	0.400	26.50	(17%)	9.61	(20%)	33.20	(12%)
Beef cows, per hd cap.	3.600	20.00	(45%)	6.99	(28%)	19.92	(24%)
Feeder calf (500#), per hd cap.	1.550	27.00	(33%)	7.87	(26%)	19.92	(19%)
Fattening cattle, per hd cap.	3.100	29.00	(28%)	7.87	(26%)	21.58	(13%)
Broilers, per bird cap.	0.010	63.00	(19%)	17.48	(20%)	24.07	(9%)
Pullets, per bird cap.	0.011	60.00	(19%)	15.30	(23%)	24.9	(15%)
Layers, per bird cap.	0.017	60.00	(16%)	19.67	(14%)	23.24	(5%)
Tom-turkeys, per bird cap.	0.034	53.00	(38%)	17.48	(53%)	24.41	(9%)
Hen-turkeys, per bird cap.	0.028	60.00	(35%)	16.61	(60%)	26.68	(7%)
Ducks, per bird/yr.	0.030	22.00	(41%)	6.56	(67%)	6.64	(42%)

[a] Percentage decrease based on decrease mass (i.e., accounts for increased dilution) from Table 11-1.
[b] Includes dilution water.
Source: after Jones and Sutton, 1994.

decreases range from 65 to 80 percent, phosphorus decreases range from 50 to 85 percent, and potassium decreases range from 35 to 50 percent. (Recall that phosphorus and potassium decreases for lagoons are related to sludge accumulation and nitrogen losses are due to volatilization.)

Fulhage (1994b) compared nutrient production from dairy lagoon/flush and slurry systems (see Tables 11-12 and 11-13). Based on an economic analysis, Boland et al. (1997) found that swine operations should use storage and application systems that minimize the cost of handling the manure. They also found that for deep pit systems

Table 11-11. Liquid manure nutrient concentrations in anaerobic lagoons.

Animal Category	Manure Produced[b] 1000 gal/yr.	Nutrients lb nutrient/1000 gal/yr (% decrease from Table 11-1)[a]		
		Nitrogen	Phosphorus	Potassium
Farrow, per sow and litter	2.100	4.10 (76%)	0.874 (81%)	1.660 (79%)
Nursery, per pig cap.	0.220	5.00 (81%)	1.398 (81%)	2.656 (81%)
Grow-fin, per pig cap.	0.950	5.60 (79%)	1.639 (82%)	3.486 (81%)
Breed-gestation, per sow cap.	0.900	4.40 (83%)	1.857 (83%)	3.320 (79%)
Dairy cow, per mature cow	11.000	4.20 (78%)	0.765 (81%)	2.490 (80%)
Dairy heifer, per hd cap.	6.000	4.25 (77%)	0.874 (78%)	2.490 (80%)
Dairy calf, per hd cap.	1.200	3.00 (84%)	0.437 (89%)	2.075 (84%)
Veal calf, per hd cap.	1.000	3.00 (77%)	0.437 (91%)	2.490 (84%)
Beef cows, per hd cap.	6.000	4.00 (82%)	1.311 (78%)	3.320 (79%)
Feeder calf (500#), per hd cap.	2.700	4.00 (83%)	1.311 (79%)	2.905 (79%)
Fattening cattle, per hd cap.	5.300	5.00 (79%)	1.748 (72%)	4.150 (71%)
Broilers, per bird cap.	0.016	8.50 (83%)	1.879 (86%)	2.905 (83%)
Pullets, per bird cap.	0.017	8.50 (82%)	1.748 (86%)	2.905 (85%)
Layers, per bird cap.	0.027	7.00 (84%)	1.748 (88%)	2.905 (81%)
Tom-turkeys, per bird cap.	0.060	8.00 (84%)	1.748 (92%)	3.735 (75%)
Hen-turkeys, per bird cap.	0.060	8.00 (82%)	1.748 (91%)	3.320 (75%)
Ducks, per bird/yr.	0.035	5.00 (84%)	1.311 (92%)	2.075 (79%)

[a] Decrease based on decrease mass (i.e., accounts for increased dilution) from Table 11-1. [b] Includes rainfall and dilution water.
Source: after Jones and Sutton, 1994.

Table 11-12. Nutrients produced for a dairy lagoon system.

Nutrients produced (lbs/yr)	Herd Size					
	100	200	300	500	750	1000
NH4 – N	2623	3912	4876	7130	9384	11960
Organic N	1312	1956	2438	3565	4692	5980
P	1994	2973	3710	5425	7140	9100
K	6838	10198	12770	18600	24480	31200

Source: Fulhage, 1994b

Table 11-13. Nutrients produced for a dairy liquid manure tank system.

Nutrients produced (lbs/yr)	Herd Size					
	100	200	300	500	750	1000
NH4 – N	7027	14054	21031	35135	52703	70270
Organic N	11225	22450	33675	56125	84188	112250
P	4212	8424	12636	21060	31590	42120
K	15444	30880	46332	77220	115830	154440

Source: Fulhage, 1994b.

almost four times as much land was needed when applying manure based on phosphorus rather than nitrogen; 2.5 and 1.7 times as much land would be needed for liquid tank and lagoon systems, respectively. These differences are due 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 TKN concentrations than small lagoons, and lagoons with specific surface areas of 0.0221 and 0.0498 m^2/kg pig exhibited average TKN levels of 1,300 mg/L (300 lb/acre-inch) and 550 mg/L (12 lb/acre-inch), respectively.

This suggests that land application of treated swine manure might need to be based on the design and performance characteristics of the lagoon rather than animal weight alone (Fulhage, 1998b).

Laboratory studies using a two-stage anaerobic sequencing batch reactor (ASBR) system were conducted on swine and dairy manure. Volatile solids were reduced by 54.7 percent for swine waste and 26.1 to 47.5 percent for dairy waste. Odor was negligible and H_2S and mercaptans were not detectable after anaerobic treatment for both waste types. Thermophilic-mesophilic treatments removed 6 to 15 percent more volatile solids than mesophilic-mesophilic treatments, indicating that a temperature-phased ASBR might be an attractive modification for treatment of animal waste (Tao et al., 1998).

A pilot swine waste treatment system composed of two upflow aerated biofilters in series with two polishing tanks also in series was tested for 1 year. The plant, with a 8 m^3/day capacity, removed approximately 88 percent BOD, 75 percent COD, and 82 percent suspended solids from flushed swine wastes containing 5.7 kg COD/day per m^3 of biofilter media. Total Kjeldahl nitrogen, total ammonia, and total nitrogen concentrations were decreased by 84, 94, and 61 percent, respectively although increased organic matter and lower temperatures decreased the efficiency of the system (Westerman et al., 1998).

Due to the 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. A solid set irrigation system was aligned on top of plastic ground covers so that any non-evaporating water could be collected and directed back into the lagoon. Although information on volatilization was not available, the evaporative increase from spraying and pond evaporation was 51 percent greater than pond evaporation alone.

Table 11-14 is a cost comparison (1994 dollars) of storage systems in Minnesota. This table is based on the same amount of storage required for different systems. They are approximations based on the following assumptions:

< Storage is for manure and runoff.
< The basins are excavated and no drainage problems exist.
< All systems, excluding the round tanks, are square.
< The clay liner is 2.4 feet thick and material for it is available on site.
< Two agitating pads plus a runoff ramp are included in all the basin cost comparisons.
< Collection pits, pumps, or pipe that may be needed for transfer to storage systems are not included.
< $3,000 has been included for components such as waterways, diversions, and fences.

Table 11-14. Cost comparison (1994 dollars) of manure systems in Minnesota.

System	Investment
Earthen basin	$10,000 - $50,000
Waste storage structure, concrete/below ground	$60,000 - $75,000
Prestressed concrete above ground storage	$60,000 - $75,000
Solid manure stacking slab & runoff pond	$40,000 - $55,000
Slurry storage/steel tank	$100,000 - $150,000
Used slurry	$70,000 - $80,000
Rotational grazing (if the producer has enough acreage)[a]	$40 - $100 per acre, includes water system, fencing, and livestock lanes

[a]Data based on average cost obtained throughout Minnesota by the NRCS Office, St. Paul, USDA
Source: Reichow, 1995.

System costs would also include the cost of pumping versus hauling, which includes labor costs as well as agitation requirements, capital, maintenance, and fuel costs. For example, Reichow (1995) estimated that for a dairy operation with a 34,000 ft^3 storage basin and a 1,000 gallon tank it would take 255 loads to empty the basin. Assuming 17 minutes to fill the tank, apply the manure to the field, and return it would take a total of 72 hours to empty this basin at a cost of between $1,600 and $2,500 (Reichow, 1995).

NCSU (1998) estimates the typical costs of constructing a lagoon to be $0.04/ft ^{3}. Pit storage was estimated at $0.82/ft ^{3}. In an example analysis, NCSU (1998) estimated the annual storage and treatment cost to be $1.69 and $0.42 per hog finished for a slurry (pit storage) system and an anaerobic lagoon, respectively. Related transportation and land application costs were estimated at $1.164 and $0.514 per hog finished for a slurry and lagoon system, respectively. Additional costs related to lagoon sludge removal and reduced income for a spray field combined with the value of fertilizer saved for a slurry system yielded a net cost of $0.416 and $1.10 to $2.00 per hog finished for slurry and lagoon systems, respectively.

Liang and Paquin (1997) have designed a variety of bioreactors for small swine operations made of high density polyethylene (HDPE) in Hawaii that are inexpensive, mobile, and capable of aerobic, anaerobic, or facultative waste treatment. The main limitations are due to the strength of HPDE which restricts the size of storage facilities (maximum 4 ft high and 16 ft wide). Costs of HDPE facilities are $0.45 per gallon compared to typical cone bottom polyolefin tanks ($1.8/gallon) or concrete block ($2/gallon).

11.5 Solid-Liquid Separation

Physical treatment by separation of solid and liquid wastes is used to minimize the solids loading to lagoons, to facilitate reuse of the liquid in a flushing system, to reduce clogging of irrigation sprinklers, or when volume reduction aids treatment. Separation can be achieved through sedimentation (gravity), centrifuging, or screening (Day and Funk, 1998). Settling basins are common when runoff is collected from feedlots or similar areas. If the detention time in a basin is about 30 minutes, 50 to 85 percent of the solids can be removed from runoff in the settling basin before passing to a retention pond. Lorimor et al. (1995) found that settling basins removed 64.2 percent of total solids below an earthen lot and 39 and 52.9 percent of total solids below two concrete feedlots studied in Iowa.

Sedimentation was also demonstrated when Stowell and McKenney (1998) analyzed dairy wastewater from an Ohio second-stage storage pond to characterize solid content in flushwater used to clean manure from dairy facilities. Total solids were found to range from 0.94 to 3.17 percent as water flowed from the first to the second storage pond. Solids in the second pond ranged from 1.045 to 3.21 percent for the top 1 m of water, 2.15 to 4.12 percent for the top 2 m, and 3.17 to 5.81 percent for the full pond depth.

The most common mechanical separation methods include (in general order of increasing cost): static inclined screens, vibrating screens, belt pressure rollers, screw presses, rotary strainers, vacuum filters, and centrifuges. In a study by Shutt et al. (1975, cited in Day and Funk, 1998), a static inclined screen, a vibrating screen, a liquid cyclone, and a settling chamber were evaluated. Using flushed swine waste, the static inclined screen removed 35 percent of total solids while the vibrating screen and cyclone removed 22 and 26 percent, respectively. Chiumenti et al. (1987, cited in Day and Funk, 1998) compared a horizontal decanter, vertical decanter, centrifugal separator, rotorpress, and an experimental pressure filter using cattle manure. They found that the horizontal decanter achieved 81 percent total solids removal and the centrifugal separator removed 32 percent of total solids. In another study, a vibrating screen separator was used to increase solids content from a flushed swine waste from 3 percent to 5-10 percent to optimize anaerobic digestion and methane production (Holmberg, 1983). A dairy manure solids separation research facility was installed in Sessums, Mississippi for an alley-flush type waste removal system with free stalls bedded with sand. A gravitational settling basin (GSB) alone or in combination with a mechanical screen separator (MSS) installed upline were used to separate solids whereby the effluent was transferred to a three stage anaerobic/facultative lagoon system. The objective was to separate manure solids, sand, and liquid, although some manure was collected in the GSB even with MSS treatment. End product nutrient concentrations were not affected by either treatment scenario (Burcham et al., 1997). Fulhage et al. (1998) found that an inclined, stainless steel bar screen type separator for a 160-cow freestall barn removed 45.5 percent of dry matter, 50.1 percent of volatile solids, 17.1 percent of total Kjeldahl nitrogen, 8.28 percent of ammonia-N, 11.0 percent of phosphorus, 9.93 percent of potassium, and 19.0 percent of organic-N. The separated solids had a 23.1 percent dry matter content.

Metal salts such as aluminum sulfate and calcium and iron salts can also be used to precipitate solids. Polymers such as polyacrylamide (PAM) can be used to precipitate nutrients. PAM has been demonstrated to remove 80 percent TSS, organic nitrogen, and phosphorus. PAM costs $2.50/kg for use in solid-liquid separation. Henriksen et al.

(1998) evaluated several flocculating agents and ion exchange to separate liquid swine manure. It was possible to flocculate 14-day old manure, but fresh swine manure was difficult to flocculate at best.

A screw press separator was installed at a 6,400-head swine facility in South Carolina to examine the removal of solids and nutrients from liquid waste. The separator, an alternative to strict gravity separation, had a 0.5 mm screen and 40 kg weights on each pressure plate arm. It was determined that the screw press was capable of removing total solids, volatile solids, TKN, organic-N, and total P by 16, 21, 12.5, 16, and 16 percent, respectively, from pit-recharge buildings with pre-settling (Chastain et al., 1998).

A mobile tangential flow separator (TFS) system was tested using chemical amendments to recover swine waste solids and phosphorus in North Carolina. The system reduced phosphorus from pre-screened flushed waste by greater than 90 percent when lime, ferric chloride, and polymer were added. Anaerobic lagoon liquid phosphorus was reduced by approximately 80 percent. End products were 25 percent sludge by volume with total solids of 4 to 5 percent (Westerman and Bicudo, 1998).

Some Asian pig producers separate the solid and liquid fractions of manure at the source (Tengman, 1997). An example of such separation occurs in an under house pit where the floor under the slats is sloped or v-shaped. The solids are scraped and the liquid fraction either flows by gravity or is pumped to storage. Such practices are being studied and gradually implemented at facilities in the United States. The solids fraction contains over 90 percent of the phosphorus and 37-76 percent of the nitrogen. The solid fraction (65 percent moisture, 14:1 C:N ratio) is about one-third of the total manure mass, and allows for increased economical transportation distance of manure.

Mechanical separators range from less than $20,000 to well over $100,000 although some operations might be able to erect their own version of a functional separator for a fraction of the cost. Other costs include power requirements, labor, and maintenance costs. A portion of the costs can be deferred based on the end product value, provided that a consumer is readily available. Avoidance costs are also present if the liquids and solids are land applied due to the concentrating of nutrients, the reduction in volume of solids, and reduction and ease of application of the liquids. One study (Bio/Resource News, Spring 1995) comparing separation with land application determined the cost per gallon of separating pig slurry was $0.005 while the cost per gallon of land spreading was $0.017.

11.6 Anaerobic Digestion

Anaerobic digestion is a biological process that decomposes organic material in the absence of air. During the decomposition process, biogas, which is a mixture of about 70 percent methane and 30 percent carbon dioxide is given off. Biogas contains about 60 percent of the energy value of the same amount of natural gas. In temperate to warmer climates, some lagoons are operated anaerobically with a synthetic cover. An existing lagoon that is covered can only digest manure containing less than 2 percent solids. More sophisticated equipment can be used, such as a complete mix digester, to process manures containing 3 to 8 percent solids. Plug flow digesters can handle dairy manures up to 11 percent solids, producing around 40 ft^3 of methane per cow per day (USEPA, 1997). Anaerobic digestion provides both odor and BOD reduction. In fact, a plug flow operation can produce up to a 90 percent reduction in BOD, more than 99 percent reduction in pathogens, and up to 95 percent reduction in solids. It also converts up to 70 percent of organic nitrogen to ammonia, a more available form for crop uptake. What remains is a semisolid effluent that is relatively odor-free and contains all the nitrogen, phosphorus, and potassium originally present in the animal manure (Day and Funk, 1998 and USEPA, 1997). In these systems, a storage lagoon is provided following anaerobic treatment and prior to final use or disposal.

Capital costs for anaerobic digesters can be broken down into the following major components:

- Materials handling, including equipment to move material into and out of the digester.
- Digester tanks including heating equipment and mixing equipment.
- Gas handling equipment.
- Electrical generation equipment if used.

Yang and Can (1997) investigated an anaerobic swine manure treatment prototype to determine its effects on odor, byproduct utilization, and wastwater reuse in Hawaii. Initial costs for facility construction are high and profit margins were decided by the efficiency of biogas electric production and wastewater irrigation. Profits were calculated for swine operations greater than 850 pigs. Strict wastewater reuse policies in Hawaii were achieved with this system by reduction in COD (89 to 95 percent), TKN (82 to 89 percent), and total phosphorus (81 percent) and little or no odor. An integrated system with anaerobic biofilm digester and intermittent aeration tank was tested for treatment of swine waste in North Carolina. Using plastic ballast rings as a medium, the anaerobic digester reduced COD, TOC, TSS, and VSS by 66, 56, 68, and 72 percent, respectively. The aeration tank further reduced organics and maintained strong nitification; however, no significant denitrification was determined in the intermittent aeration process (Cheng and Liu, 1998).

Berge and Hansen (1998) describes initial bench-scale experiments to remove ammonia, which inhibits bacteria activity, from anaerobic digesters. Using household ammonia and citric acid, ammonia removal was 9.58 mg/min/L. Similar experiments achieved ammonia removal rates of 4.4 mg/min/L from fish processing waste with ammonia concentrations above 2,500 mg/L.

Three leachbed-UASB closed-loop anaerobic digestion treatment systems were compared in a laboratory study to test alternatives for poultry mortality disposal (Chen, 1998).

The three leachbeds (Lbs), which carry out the hydrolysis/acidification phase of treatment, differed in their initial solids contents (4.4, 7.5, 13.3 percent). The UASBs accomplish the methanogenesis phase and serve as a vessel for continuous inoculum production for the LBs. All systems performed very well with little operational problems, but overall the system with an initial total solids in the LB of 7.5 percent performed best. After 118 days of anaerobic digestion in the LB-UASB system, about 86 percent of the poultry mortalities were biodegraded, and methane accounted for 83.7 percent of the total COD. The LBs accounted for at least 63 percent of the bioconversion in each system. System capacity can be further expanded by scheduling several LBs in sequence for one UASB in order to fully exploit the UASB potential as a high-rate digestor.

Zucker et al. (1997) used EPA’s Ag Star software to identify the cost effectiveness of anaerobic digestion for methane and electricity production for several independent dairy farms in the York, NY area and with a conglomerated manure facility. Inputs for the Ag Star model, such as farm type, size, location, and electrical expenses, were obtained by a survey from 30 dairies located in the area. Break-even costs are dependent on the value of electricity and any additional benefits from the anaerobically digested manure. Economies of scale apply to farms of 850 or more cows.

Williams et al. (1998) describe the design, construction, and anticipated operation of a lagoon-type methane recovery system for a California dairy facility expected to have 300 to 600 cows. The 16,000 cubic meter lagoon will be covered with a flexible membrane designed to float on the surface. Assuming 350 animals create an average of 370 cubic meters of biogas per day, a gas collection system is predicted to produce 25 kW using a micro-turbine electric generator. This system is estimated to annually produce 170,000 kWh and 77,000 KJ of hot water worth $16,000.

An anaerobic digester (anticipated 1000 cows) and a wetland system (anticipated 300 cows) were investigated as treatment alternatives for dairy waste in New York. The anaerobic digester was designed for monetary returns on the $365,000 initial cost through electric generation ($24,000 per year) and for sale of solids collected as a nutrient supply ($32,445 per year). The wetland treatment system initially cost $94,919 and obtained $6,000 per year on solids sold. Wright and Perschke (1998) determined that both systems were feasible options for treatment of dairy waste.

Overall, the costs of anerobic digesters vary with the size and type of system to be used. A digester for a 120-head dairy or a 150-head hog operation should cost between $125,000 and $175,000. Economic viability for anaerobic digesters is strongly dependent on the operator’s ability to use the biogas and the price placed on odor control cost avoidance (Minnesota Dept. of Agriculture, 1995). Several operations have installed some form of digester for gas recovery. In general, only larger facilities have installed a large-scale digester, but a few hundred dairy head have been shown to be sufficient for a reasonable return (EPA, 1995). In 1993 dollars, capital and installation costs for gas recovery equipment ranges from $100 to $380/head for dairy and $40 to $170/head for pigs. The gas utilization equipment for a 5,000-head hog farm is about $21/pig. Annual operating and maintenance costs range from $2 to $6/head for complete mix digesters, and about $4/head for plug flow digesters. At $0.07/kWh electricity costs, annual benefits are estimated at $8/head for dairy, $13/head for pigs, and up to $34/head for a complete mix digester.

According to an AgStar Fact Sheet (EPA, 1995), a 500-head dairy operation installed a covered concrete lagoon to collect methane for both electrical energy and heat. The manure collection method for this facility is tractor scraping. The facility experienced an operating and maintenance (O&M) cost reduction of $53,000 with an annual rate of return of 21 percent. Another 270-head dairy installed a complete mix digester for $500,000 with an annual operating cost of $4,125 (EPA, 1997). The farm sells gas that is equivalent to 17,000-18,000 gallons per year of fuel oil to a neighboring retirement home and heats its digester with the biogas, saving $10,000 per year. The resulting land-applied effluent is valued at $25,000 per year. In addition, a 1,000-sow farrow-to-finish operation covered part of an existing lagoon to collect methane for electricity and heat. Their O&M costs decreased by $36,000 with a 34 percent annual rate of return. Another 1,500-sow farrow-to-finish operation installed a complete mix digester for $250,000 and demonstrated reduced O&M costs of $65,000 per year. Table 11-15 provides additional examples documented in EPA's AgStar program.

Table 11-15. Comparison of digester costs.

Size and Type of Operation	Type of Digester	Costs	Benefits/Break-even
300 sow farrow-to-feeder	covered lagoon	$16,000 capital <$500 O&M	12-13 gallons propane equiv/day
700 sow farrow-to-finish	covered lagoon		provides 80-90% of electricity demand (about $70,000 per year); reduces dust, odor, flies
1,000 sow farrow-to-finish	partial cover on existing lagoon		$36,000 electricity & heat (34% annual rate of return)
1,500 sow farrow-to-finish	complete mix digester	$250,000 capital	$65,000 electricity & heat per year (4 to 5 years)
150-head dairy	covered lagoon	$44,000 capital	$9,350 per year hot water (4.9 years)
270-head dairy	complete mix digester	$500,000 capital $4,125 O&M	$10,000/year heat + sells 17,000-18,000 gal/yr fuel oil equivs. (Land applied effluent valued @ $25,000/yr.)
350-head dairy	plug flow digester	$185,000	$40,000/yr. Electricity (solids sold blended as soil amendment)
400-head dairy	plug flow digester	$200,000	$51,000/year electricity & heat (digested solids sold as mulch for $6,000/yr.) Reduced clean-outs saved $9,000/yr. (5 years)
500-head dairy (scraped)	covered concrete lagoon		$53,000 electricity & heat; fewer lagoon cleanings; solids sales (21% annual rate of return)
1,000-head dairy	covered lagoon	$254,000 capital $10,000 O&M	$56,000 electricity (5.5 years, 18% rate of return)
5,000-head dairy (manure from 1,500 to 2,000 cows)	3 plug flow digesters	$300,000 $12,000 to $15,000 O&M	$125,000 to $160,000/yr. energy (6 years)

Source: USEPA, 1995, 1996, 1997a, 1997b.

11.7 Composting

Composting turns potentially nuisance-causing waste products into a more easily handled and valuable commodity. It is an excellent soil conditioner, and when applied to cropland, it adds organic matter, improves soil tilth, reduces fertilizer requirements, and reduces the potential for soil erosion (NRAES, 1992). Composted material also contains some natural plant disease suppression characteristics.

Although the composted product's value is higher than raw manure, composting can be relatively expensive and labor intensive. As a result, agricultural operations usually only consider composting when a marketable product is created that will remove excess nutrients from the farm. If transportation distances are long, composting might reduce transportation costs since composted material is typically one-half the uncomposted volume. Compost can also be used for the disposal of dead animals, yard waste from municipalities, sawdust and wood chips from lumber mills, food wastes from food processing facilities, paper mill sludge, etc. In some cases compost operators can charge a tipping fee for disposal of the wastes that would otherwise be disposed in a land fill, improving the economics of composting.

Some compost piles are turned or aerated regularly to maintain optimal oxygen concentration and temperature. Other composting systems are mechanized and do not require turning, but capital investment and maintenance costs are higher. *Windrow composting* involves placing the manure mixture in long, narrow piles (windrows) that are turned on a regular basis. The windrows are approximately 3 feet high and 10-20 feet wide for dense manure. The shape of the windrow depends on the turning equipment used. The turning frequency depends on compost materials and climatic conditions. *Passively aerated windrows* eliminate the need for turning because air is supplied through open-ended, perforated PVC pipes embedded in the windrow. Air flow is maintained through two rows of 0.5-inch holes to control the heat produced by the decomposition process. Windrow materials should be thoroughly mixed when constructed and built on a base of straw, moss, or compost to absorb moisture and provide insulation. *Aerated static piles* are similar to passively aerated windrows, except that air is forced into the pile using pipes with blowers. This method allows for larger piles and turning is not required. In *in-vessel composting,* composting materials are confined within a building, container, or vessel. Forced aeration and mechanical turning techniques are used to speed the process (Minnesota Dept. of Agriculture, 1995).

Different types of in-house deep litter manure management systems were tested in a 100,000-chicken commercial high-rise layer operation in Georgia. Composting was conducted using raw manure, a manure and leaf mixture, and manure and woodchip mixtures of 0.12 m, 0.25 m, and 0.38 m. The in-house composting was found to more efficiently reduce weight and volume of wastes than conventional methods of stacking manure under the house. Woodchip and leaf manure compost displayed similar properties, decreasing moisture content and concentrating nutrients compared to the raw manure. The composting process was found to be enhanced by regular turning of the manure mixtures (Thompson et al., 1998).

Five treatment combinations of composted cattle feedyard manure and liquid phosphate (10-34-0) were applied to provide 100 percent of the phosphorus requirement for full-season corn hybrid crops. 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 provide adequate substitute for chemical fertilizers. These findings may have been confounded by water limitations during the growing season and conclusions need to be verified (Auvermann and Marek, 1998).

Hong et al. (1997), in an unreplicated study in Ohio, measured ammonia concentrations from dairy manure and rice hauls composted with continuous aeration rates of 53, 73, and 90 L m^{-3} min^{-1}. Temperature and ammonia concentrations peaked 48 days after initiation of aeration and then declined steadily, approaching an asymptote after 150 hours. The highest ammonium removal occurred at the 73 L m^{-3} min^{-1} aeration rate.

The feasibility of using sawdust and chopped fescue hay as a low cost or waste carbon source to compost with separated swine manure solids was investigated using 21 L vessels and bin composting units. Manure and fescue hay produce the lowest C:N ratio in both small (11.5) and large composting units (26). The percent TKN (1.84 percent) and K (1.84 percent) were also higher for the fescue hay matrix. Percent phosphorus was greater for the sawdust material (0.84 percent). Temperature trends were used as indications of biological activity. Although labor intensive, composting manure with a carbon source was recommended because the product was easy to transport, odor stable, and appropriate for transport through residential areas (Hoehne et al., 1998).

The effect of intermittent aeration on composting swine waste was studied to determine changes in ammonia emissions and dry matter loss. Continuous and intermittent aeration treatments (4 each) were conducted on composting hog manure amended with sawdust in pilot-scale 200 L vessels run for a three week trial. Internal temperature was maintained in the continuous sequence using feedback control air flow fans while intermittent treatments received a cycle of 5 minutes of airflow and 55 minutes of rest. Ammonia emissions were 39 percent less from the intermittent aeration treatments, with nitrogen loss as ammonia-N consisting of 25.9 and 14.3 percent for continuous and intermittent aeration, respectively, although these differences were not statistically significant. Dry solids loss and other physicochemical properties were similar between the two treatments. It was concluded that intermittent aeration may be a practical method to reduce nitrogen loss and ammonia emissions during composting of swine manure with sawdust (Hong et al., 1998).

To reduce the bulk of swine manure slurries, Panti and Kinsman (1997) measured water loss after irrigation of swine manure slurry on existing swine manure:straw (3:1 w/w) compost piles when pile temperatures exceeded 50 EC. After 60 days, water in the control pile (with no added irrigation) was reduced by 75 percent. Including the additional water added to the compost pile by irrigation, the treatment piles removed about 340 percent of the water compared to the control pile during the same period.

Two waste products from a municipal and a dairy source were composted in the lab under controlled temperature and air flow rates. Maintaining high and constant temperatures (50 to 70 EC) destroys pathogens and accelerates decomposition. Air flow as low as 4 L/min was sufficient for decomposition of waste sources (Hall and Aneshansley, 1997).

The influence of ammonium sulfate (AS) amendments intended to increase nitrogen content in poultry manure was studied in pilot scale reactor vessels. Partially composted poultry waste (30 to 40 days old) received 80.6 gAS/kg compost (wet basis) and were monitored for two weeks. Treatments receiving AS retained 81-100 percent of the initial nitrogen content and demonstrated a 1 percent increase in final nitrogen concentration over non-amended compost. Sequential additions of AS exhibited greater ammonia emissions than a one-time application. Carey et al. (1998) concluded that ammonium sulfate could be added in one application to improve nitrogen content while experiencing minimal ammonia loss.

To compost swine carcasses in Missouri, Fulhage (1998) recommends the addition of 2.8 m^3 (100 ft^3) sawdust per 450 kg (1000 lb) of swine carcass (6 months total composting time). He estimated that one-third of the nitrogen and one-half of the dry matter and water in the raw ingredients are lost as products of respiration when swine are composted with sawdust, leaving 18 lb N and 2000 lb of finished compost (wet weight) per 1000 lb of animal carcass. These estimates are useful in sizing the soil-plant filter for carcass composting and in determining the land area needed for disposing of the compost product based on its nutrient content and the desired application rate.

Ekinci et al. (1998) investigated poultry litter composting as a function of the C/N ratio and pH of starting materials. They mixed short paper fiber, which has a high C:N ratio (> 200) and is slow to decompose, with broiler litter, which has a low C:N ratio (10-12) and emits too much ammonia when composted alone. An evaluation of ammonia emissions showed that NH_3-N losses decreased substantially as the C:N ratio increased. NH_3-N losses decreased significantly at pH > 7 and increased significantly at pH > 8. They also found that the initial temperature of the compost material (> 1°C) did not significantly affect the time needed for the material to reach the desired temperature of 45°C.

When assessing the cost of using composting as part of a waste management system, it is necessary to consider the availability and price of raw materials, the amount of land available for composting, the expected markets for the finished compost, local costs of labor and fuel, and location factors. There are also different composting methods. Composting equipment costs for starting an on-farm composting operation can range from $20,000 to $125,000 and higher, depending on the size of the operation and the level of technology chosen. Some smaller operations may use existing equipment, however, to help keep start-up costs low. Table 11-16 is a comparison of their costs. Note that costs include labor and equipment expenditures, and may vary widely depending on the size of the operations and the materials being handled.

11.8 Odor Control

Much research in the past decade has been aimed at odor (and dust) control. The extent to which odor control practices influence ammonia volatilization is important because the amount of ammonia volatilized can be significant. For example, ammonia emission from a new, grow-finish swine facility with a 2.4 m deep pit was

Table 11-16. Comparative costs of composting methods.

Composting Method	Estimated Cost (1995 dollars) per Ton of Incoming Material
Windrow composting using a loader for turning	\$5 - \$10
Windrow composting using specialized turners	\$15 - \$30
Aerated static pile systems	\$20 - \$50
In-vessel systems	\$50- \$100

Source: Minnesota Dept. of Agriculture, 1995.

measured from June 26 through September 25, 1997. Gaseous concentrations, temperature, and pig number were continuously recorded. The measured 122 ±8 g-ammonia/day/500 kg pig weight emission rate was higher than published literature values. This was likely the result of warm weather and high ventilation rates. The flux of ammonia from the building was directly proportional to ventilation rate, pig weight, and indoor temperature (Ni et al., 1998b). The 7.0 ± 0.9 g-hydrogen sulfide/day/500 kg pig weight emission rate measured was also higher than published literature values (Ni et al., 1998a). Recent research has tended to focus on biofilters and waste amendments. The remainder of this section describes some of this work.

Four biofilters constructed of yard waste compost and brush chips were tested to determine the effect of residence time on swine waste treatment. Odor was reduced by 87 and 91 percent for 4- and 8-second residence times, respectively. Hydrogen sulfide emissions were reduced 96 and 97 percent and ammonia emissions were reduced 74 and 82 percent. No significant difference between the 4- and 8-second test biofilters was determined. In conjunction with information from other studies, the current recommended minimum residence time for an open face biofilter is 4 to 5 seconds (Nicolai and Janni, 1998).

Chen et al. (1997) identified the presence of purple sulfur bacteria in 4 of 8 swine lagoons sampled. Purple sulfur bacteria are known to reduce odors from lagoons, but the reasons for their presence and growth are speculative. Characteristics of lagoons with and without purple sulfur bacteria indicated that amounts of alkalinity, BOD, salinity, or ammonium were significantly lower in purple lagoons. Sulfide concentrations were not significantly different in purple and non-purple lagoons.

A laboratory study to determine the odor reduction of swine and dairy manure was conducted using algae, powdered lava rock, a mixture of algae and powdered lava rock, and various thicknesses of rapeseed oil surface coatings. The algae extract increased ammonia release by 13 percent, while lava rock and the mixture reduced ammonia release by 3 percent and 2 percent, respectively. Rapeseed oil thickness of 24, 40, and 60 L/m^2 reduced ammonia emissions by 56, 53, and 64 percent and odor release by 67, 75, and 78 percent, respectively (Büscher et al., 1997).

A plenum covered with dairy and poultry compost and kidney bean straw was established outside an exhaust fan (2,200 cfm) from a manure storage pit under a swine farrowing barn in Minnesota. Average annual reductions of odor (78 percent), H_2S (86 percent), and NH_3 (50 percent) were measured between the inside and outside of the biofilter. The cost of this biofilter based on a 10-year life and compost/straw replacement frequency of 3 years was \$0.28/piglet produced (Nicolai and Janni, 1997).

Amendments of materials to dairy waste during composting was investigated to determine their influence on odor emissions. Rice husks (control) and finished dairy waste compost mixed with rice husks (treatment) were added to a stainless-steel tank in a 1:1 weight ratio with dairy manure. The odor emission rate was reduced by 64 and 40 percent between the control and treatment during the first and second weeks, respectively. Sulfur emissions were reduced by 54.8, 28.9, and 17.5 percent for methylmercaptan, dimethyl sulfide, and dimethyl disulfide, respectively. There was no significant reduction in average ammonia emissions (Tanaka et al., 1998).

Potassium permanganate, used in municipal and industrial wastewater treatment, has been used to reduce sulfides, mercaptans, and other odor causing agents in manure storage structures, particularly lagoons. Cement kiln and power-plant alkaline by-products have also been used to reduce volatilization and odor.

The treatment costs of several odor-control chemicals were compared with costs of operating an oxidation ditch. The oxidation ditch was three times more expensive to treat 1,000 gallons of waste than any of the chemicals evaluated. The cost of treating liquid manure with hydrogen peroxide at the 12.5 ppm level, which is sufficient to control sulfides during waste removal and land spreading, was less than treatment with any of the other chemical agents tested.

The costs of other odor-control chemicals, including Enviro-chem CX, Pit Boss, Micro-Aid, INHIBODOR, OD-R-ADE, LIQUIDATOR, NOXDOWN, MANU-RX, and De Odorase, range from $22 to $150 per gallon and treat various quantities of waste. Disk granulates are around $13 per disk and treat 1,000 square feet of surface area, or $5.40 per pound.

The cost of several oxidants, absorbents, and five proprietary odor control products (TNK, AGCO, Odor Control Plus, Micro-AID, and SANZYME) for beef feedlot manure ranged from $300 to $600 per acre for treatment during the odor production season. Feed additives, such as Micro-Aid and OD-R-ADE cost between $1.50 to $3.00 per ton of complete feed (Minnesota Dept. of Agriculture, 1995).

11.9 Wetlands and Vegetative Filter Strips

Constructed wetlands and vegetative filter strips use plants to take up nutrients and capture suspended solids from animal waste. Liquids percolate more slowly through wetland soils, resulting in more treatment. For example, Hunt et al. (1995) found that when swine wastewater containing 14 kg/ha-day of nitrogen was applied to a wetland combined with a grass filter strip over 95 percent N removal was achieved. Using the waste from a 140 mature milking cow herd, Moore et al. (1995) achieved fecal coliform removal of 89-95 percent; COD, 53-65 percent; BOD, 59-72 percent; total solids, 51-56 percent; total Kjeldahl nitrogen, 45-60 percent; and total phosphorus 54-69 percent from a constructed wetland in Oregon.

Three constructed wetlands in Ohio were sampled for the following water quality parameters: P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, B, NO_3-N, NH_4-N, SO_4-S, Cl^-, pH, EC, and TDS (Zimmermann, 1998). The wetlands were used for the disposal and treatment of milkhouse wash water from dairy farms with 40 to 60 cows. Results showed that the water in the third cell of the wetland was as good as or better than drinking water quality standards for all the parameters that had standards except for Fe and Mn. Although the wetlands were an effective method for disposal and treatment of milkhouse wash water, their effectiveness decreased with age due to overloading of various nutrients. This decrease in effectiveness can be avoided by removing wetland vegetation before overloading occurs or remedied by removing both the vegetation and the soil after overloading has occurred.

Buffer strips or vegetative zones serve as a barrier between manure-applied land and waterbodies. Typically, filter strips reduce runoff volume and velocity due to increased infiltration. This reduces sediment and suspended solids (SS) by increased deposition, chemical degradation, and transformation. Also, some nutrients are absorbed. In general, research has shown that filter strips can remove 56-95 percent of the sediment load depending on flow conditions, soil, slope, and filter width. Nutrient removal tends to be highly variable, although Clausen and Meals (1989) measured reductions in phosphorus runoff of 86 percent. Forest buffers can also be effective in reducing nutrients. An 80-90 percent nutrient removal (N,P,K) occurred when dairy feedlot runoff was passed through a forest buffer (Doyle et al., 1975). Table 11-17 presents filter strip effectiveness in simulated rainfalls (Leeds et al., 1994).

An experimental study was conducted in Georgia to determine the feasibility of using riparian buffer systems to remove nitrogen and phosphorus from swine lagoon effluent. Hubbard et al. (1998) showed that the systems were effective at removing nitrogen, but that phosphorus levels in shallow groundwater increased over time. Nitrogen concentration increased over time at the top ends of the plots but showed little increase at the bottom ends. An experimental study was conducted in Virginia to determine the effectiveness of vegetative filter strips at removing sediment, nutrients, bacteria, and pesticides from surface runoff (Barone et al., 1998). They found that 8.5 m filters trapped 23 percent of the incoming runoff, 96.7 percent TSS, 91 percent NH_4-N, 84 percent TKN, 96 percent total phosphorus, 88 percent atrazine, and 92 percent metolachlor. The 4.3 m filters trapped 39 percent of the incoming runoff, 96.7 TSS, 85 percent NH_4-N, 79 percent TKN, 81 percent total phosphorus, 84 percent

Table 11-17. Filter strip effectiveness.

Soil Texture	Slope (%)	Flow Conditions	Filter Width (ft)	Sediment Removal (%)	Total N (%)	Total P (%)
silt loam	11-16	shallow uniform overland flow	15	70	54	61
			30	84	73	79
silt loam	11-16	concentrated flow	15	83	83	85
			30	93	82	87
sandy loam	3-4	shallow uniform overland flow	15	66	0	27
			30	83	48	46

Source: Leeds et al., 1994.

atrazine, and 82 percent metolachlor. The filters did reduce levels of bacteria, although not below primary contact water standards, and they did not reduce NO_3-N concentration. The authors felt that the small differences in trapping efficiency between the 4.3 m strip and the 8.5 m strip do not justify the additional cost of installing the wider strip.

Murphy and George (1997) created an organic (bark bed) filter that flowed into a constructed wetland in Pennsylvania. The organic filter effectively reduced odors, but residual ammonia concentrations remained too high for the constructed wetland to remove enough N for discharge into surface waters. Evapotransipiration from the wetland removed much of the wastewater, and an average of 80 percent reduction in nutrients was observed in both dormant and growing seasons.

In a replicated study, nine constructed wetlands were amended with nitrogen from dairy manure at loading rates of 5,000, 10,000, and 20,000 kg N ha^{-1} yr^{-1} with a 7-day hydraulic residence time. Nitrogen was reduced by about 50 percent for each manure loading rate indicating that the system was not N-saturated. Average COD was reduced by 75 percent. COD and N reduction was enhanced in summer and diminished in winter. Solar radiation, rather than temperature, controls the rates of N and COD reductions. The cost of this type of system is $3-4/month/animal (Raman et al., 1997).

11.10 Waste Disposal

Land application is the primary disposal method used by most operators. In general, waste should be applied at rates, and with a timing, that balance crop uptake with existing soil nutrients. It should be noted, however, that applying manure in accordance with a sound nutrient management plan does not eliminate nutrients from leaving fields. In an Iowa field-plot study, for example, Kanwar et al. (1998) found that NO_3-N concentrations in subsurface drains were significantly higher from manured continuous-corn plots compared with corn-soybean rotation, fecal coliform bacteria were detected in drain water from both manure and non-manured plots with higher numbers for manured plots, and NO_3-N concentrations in subsurface drain water were higher for manure plots.

Depending on the soil characteristics, application method, application time, and weather conditions, the amount of nitrogen available during the first year of application is variable (see Table 11-18). Table 11-18 shows that broadcasting without incorporation is the application method that results in the most volatilization and the least amount of nitrogen available for crop use. Substantial amounts of the available or inorganic nitrogen are lost through volatilization. This occurs within a few days after application on warmer spring and fall days, or within a few weeks on winter days. If the manure is incorporated into the soil within a day or two after the broadcasting, volatilization losses are greatly reduced. Incorporation into the soil also allows thorough mixing of the manure into the soil, promoting conditions for organic N mineralization. Injection can be done with chisel-type knives, reducing volatilization losses, but the potential for denitrification losses exist. To avoid these denitrification losses from conventional injector systems, a sweep knife injection system can be used to reduce the concentrated zones of manure beneath the soil surface. Instead of creating a vertical band of manure where a knife shank runs through the soil, a broad horizontal band is created, reducing volatilization potential and encouraging rapid breakdown in the soil because of the more complete mixing of manure and soil.

Table 11-18. Estimated N availability, assuming 50 percent of N is organic N and 50 percent is ammonium N.

Organic Matter	Application Time	Soil Texture	Rainfall	Application Methods: Broadcast w/o incorp	Broadcast w/ incorp	Knife Injection	Sweep Injection
Low	Fall	Coarse	Low, Norm	30	55	45	55
			High	20	45	40	45
		Fine	Low, Norm	35	60	50	60
			High	30	55	45	55
	Spring	Coarse	Low, Norm	40	55	50	55
			High	35	50	45	50
		Fine	Low, Norm	45	55	45	55
			High	45	55	40	50
High	Fall	Coarse	Low, Norm	30	35	50	60
			High	25	40	40	50
		Fine	Low, Norm	35	55	45	55
			High	35	50	40	50
	Spring	Coarse	Low, Norm	40	50	50	55
			High	35	45	45	50
		Fine	Low, Norm	40	50	45	55
			High	40	50	40	50

Source: Schmitt, 1990.

In addition to manure's value for macronutrients, manure also provides micronutrients and improves soil condition as demonstrated in a field study to evaluate the effectiveness of biosolid application for improving water penetration in heavy clay soils planted with alfalfa and sudangrass in the Imperial Valley, California (Bali et al., 1998). Applying biosolids at rates ranging from 9-27 Mg/ha prior to the first irrigation in the season resulted in significantly increased infiltration rates. The increased infiltration was accompanied by a reduction in the irrigation time needed for a typical application depth of 10 cm. While increasing infiltration might be desirable, it might not be appropriate for surface irrigated fields due to decreased application uniformity or where increased chemical (e.g., atrazine) transport is a concern. In a laboratory study, Abu-Zreig and Rudra (1998) found that manure application increased the quantity and rate of atrazine leaching, especially when manure was applied immediately before a rainfall. The movement of atrazine was also greater and faster in undisturbed soils than in disturbed soils due to the presence of macropores. These results indicate that land application of manure results in an increase in chemical transport processes through the soil. To counter this affect, other researchers added poultry manure/paper pellets to shrinking/swelling soils to reduce cracking and limit preferential flow of water and solutes to groundwater in a Texas A&M field study. Organic matter additions are known to improve soil structure, thereby reducing cracking and allowing a substrate to absorb harmful contaminants. Treatments with pellets adsorbed more atrazine than control plots (McClure and Munster, 1997). Changes in infiltration rates were not expected until the pellet weathered further.

In addition to applying manure to agricultural fields, some researchers have proposed application to rangeland (Phillips, 1998) or investigated application to woodlands. Dickens et al. (1998) are evaluating the long-term effect on ground water of applying swine lagoon effluent as a seedling tree nutrient source. Loblolly pine, longleaf pine, and sycamore trees grown on a clayey soil typical of the South Caroline Piedmont region received a variety of weed control and effluent treatments at a rate of 0, 50, or 100 lb/plant available nitrogen. Tree survival was good, ranging from a mean of 87.1 percent (loblolly pine) to 93.9 percent (sycamore). Monitoring of soil nutrient status is currently underway and further studies are planned or in progress using broiler litter, turkey litter, dairy effluent, and swine effluent on both recently planted and more mature stands. In another study, five species of trees (box elder, green ash, sweetgum, swamp black gum, later replaced by sycamore due to high mortality, and bald cypress) were treated with swine effluent in North Carolina to show the effective utilization of nutrients by hardwood species. Application of swine waste at 200 and 400 lb N/acre resulted in increased survival for all seedling species, except for sycamore. Tree growth was increased by the 400 lb N/acre treatment for all species except bald cypress; the 200 lb/acre treatment exhibited no influence on growth. Box elder and green ash appeared to most effectively accumulate nutrients (Frederick et al., 1998).

There are opportunites to improve manure application technology. It has been estimated, for example. that a computer-directed liquid-manure applicator with GPS technology could be used for precision manure spreading. Equipment modifications to exisiting liquid-manure equipment would cost about $5,000. Glancey et al. (1997) developed a precision spreader for broadcasting solid waste in Delaware to accurately spread a range of manure (1 to 5 tons/acre) on various grid sizes (>0.5 ac) with infrequent calibration. The spreader has computer-controlled adjustable flow rates and GPS to enable accurate record keeping that facilitates manure application mapping. Capitals costs for Vee and Tanker spreaders in 1996 in York, New York are listed in Table 11-19 (Wright, 1997).

Table 11-19. Costs (1996 dollars) for vee and tanker spreaders.

Vee Spreader					
Capacity,gal	912	1,255	1,621	2,239	3,000
Capital Cost, $	7,500	10,000	12,500	$16,700	20,000
Tanker Spreader					
Capacity, gal	2,250	3,250	4,500	5,000	6,000
Capital Cost, $	$9,000	$9,500	$14,000	$15,500	$18,500

Source: Wright, 1997.

Powell (1994, cited in Sweeten, 1998) measured manure harvesting from feedlots of 53 tons/hour using a box scraper and 87 tons/hour using wheel loaders. In 1985, a survey of contractors in Texas found that farmers received up to $1.20 or paid as much as $0.60 per ton of manure removed. In 1989, hauling costs were found to be $2.61 per ton plus $0.055 per ton-mile (Sweeten, 1998). In 1996, manure could be purchased from contractors at about $30 per tractor trailer load for local hauls or $0.85 to $1.00 per mile in Doña Ana County, New Mexico. Other costs for commercial application of liquid and solid manure are summarized in Tables 11-20 and 11-21, respectively.

A survey on the economics of manure application and fertilizer value was presented to 97 York, New York area dairy farmers (33 surveys were returned). Although many manure land application systems were identified, some trends were evident. Farms are spending more money to apply manure than the concomitant cost of commercial fertilizer. Economies of scale allow large farms to reduce overall manure disposal costs, and analysis of manure and valuation of the nutrients will further reduce costs. The average cost of spreading manure is $77 per acre while net returns ranged from $-225 to $37 per acre. For the larger dairies studied, spreading costs were approximately $50 per cow per year or $45 per acre per year. Farms with storage had lower spreading costs despite the additional precipitation (Wright, 1997).

Ritter and Scarborough (1995) estimated that the annual cost of daily manure spreading in the Chesapeake Bay Watershed was $198.17, $159.27, and $127.75 per cow for 50-, 100-, and 200-cow dairy herds, respectively. The estimated annual collection, storage, and disposal costs for a 200-cow dairy herd were $150.59, $158.99, $185.03, $189.23, $201.07, and $150.88 per cow when using an earthen basin, earthen basin lined, belowground concrete storage, aboveground storage, aboveground steel storage, and anaerobic lagoon, respectively.

Some researchers have added a nitrate-based solution to lagoons just prior to land application to promote nitrifying bacteria growth. Additives such as PEG have been added to animal bedding, storage structures, and fields designated to receive manure. The additives bind nutrients, metals, and organic compounds. In some cases binding is slowly reversible; in other cases, long-term studies indicate binding is strong or relatively permanent. Other long-term studies are underway to determine the effects of these additives on the environment.

Aluminum, calcium, and iron compounds have also been used to decrease the amount of water-soluble phosphorus in poultry manure and to decrease nitrogen loss (Moore et al., 1995). Plots amended with this chemically-treated manure result in 87 percent lower phosphorus runoff concentrations. One study measured runoff from one-acre

Table 11-20. Costs of commercial application of liquid or slurry manure. (Values include costs of manure mixing, hauling, and land application.)

Location and Method of Application (if applicable)	Hauling and Application	Umbilical Cord attached to applicator	Extra Charges	Comments
	$ / gallon			
Iowa[a]				
Broadcast				
Maximum	0.011	0.007	0.0025	2 miles free
Average	0.0067	0.0065	0.0012	1 mile free
Minimum	0.003	0.006	0.0005	0.5 miles free
Injection				
Maximum	0.012	0.007	0.0025	2 miles free
Average	0.0077	0.0065	0.0012	1 mile free
Minimum	0.005	0.006	0.0005	0.5 miles free
Iowa[b]	0.01	no data	0.0013	1 mile free
Midwest[c] (injected)	0.0071	no data	0.0028	
Southeast[c] (irrigation)	0.0015	no data	no data	
North Carolina[d]	0.01	no data	no data	
Ontario Canada[e]	0.086	no data	no data	

[a] Lorimor, J. 1998. Commercial Manure Applicator Directory. www.ae.iastate.edu/manurdir98.htm

[b] Livestock Industry Facilities & Environment. 1995. You Can't Afford Not to Haul Manure. Iowa State University, University Extension, Ames, IA. Pub. No. Pm-1609.

[c] NCSU. 1998. EPA National Guidelines for Swine and Poultry Waste Management.

[d] Barker, J.C. 1996. Water Quality & Waste Management. Utilization of Dairy Manure as Fertilizer. Pub. No. EBAE 133-88.

[e] Ontario Federation of Agriculture. 1994. Best Management Practices: Livestock and Poultry Waste Management. Ministry of Agriculture and Food, Ontario, Canada.

Table 11-21. Costs of commercial application of solid manure. (Values include costs of hauling and land application.)

Location	Cost
Georgia[a] (average)	$20/ton
Oklahoma[b]	$0.10/mile/ton
Delaware[c]	$0.08/mile/ton
Maryland[d]	
90 mile transport	$0.23/mile/ton
150 mile transport	$0.18/mile/ton

[a] from Vest, L., B. Merka, W.I. Segars. 1994. Poultry Waste: Georgia's 50 Million Dollar Forgotten Crop.

[b] from Johnson, G.V. H. Zang, W.R. Ruan, N.J. Basta, and J.A. Hatter. 1889. Animal Waste Management: Economics of Nutrient Recycling. Southern Soil Fertility Conference, Memphis, TN.

[c] from Martin, J.H., J.G. Farrel, J.E.A. MacKenzie. 1998. An Analysis of Nutrient Utilization Efficiency by Agriculture in Delaware's Inland Bays Drainage Basin. Final Project Report. The Center for Inland Bays. Nassau, DE.

[d] Parker, D. 1998. Alternative Uses for Poultry Litter. Economic Viewpoints Vol. 3 No. 1. University of Maryland, Cooperative Extension Service.

watersheds at two commercial broiler farms. The watersheds were equipped with flumes and automatic water samplers. Untreated poultry litter (control) and litter treated with alum were applied to grass pastures and runoff was monitored. The runoff concentrations are provided in Table 11-22.

Table 11-22. Change in runoff concentrations with alum use, mg/L.

	Soluble P	Total P	NH_3	Nitrate	TKN	Total K	Total As	Total Cu
Control litter	3.23	4.23	2.14	1.55	4.94	17.6	0.04	0.05
Alum-treated litter	1.05	1.49	2.13	1.80	3.89	12.8	0.09	0.04

Source: Moore, 1998.

Aluminum sulfate has also been demonstrated to decrease runoff of metals such as As, Cu, Fe, and Zn in poultry litter, whereas Ca and Mg concentrations in the runoff increased (Moore, 1998). Ferrous sulfate was also effective in reducing soluble P in the runoff from land-applied poultry litter, but is not favored as an option for use inside poultry houses because chickens might ingest the toxic substance.

11.11 Other Technologies

Throughout the world, research continues in nearly all aspects of animal waste management. This section presents some of these technologies. In most cases, information discussed here is based on a few studies and further research is likely needed before these practices could be reliably implemented on a general basis. While it is reasonable to suspect that a technology proven effective for one animal type and location could be considered for a similar situation, it would be premature to assume that the technology could be transferred to other animal types and locations. Finally, exclusion or inclusion from this document does not imply disapproval or endorsement.

< Some countries have been experimenting with digging trenches around fields that accept manure and filling the trenches with an iron compound. This compound captures phosphorus that runs off the field.

< A two-stage reactor that uses red and green algae has been used to remove nutrients from the wastewater. BOD removal from 25,000 mg/L raw waste to less than 10 mg/L in the effluent was achieved. Full scale demonstration of technology on swine waste is being implemented in the New England area. Equipment and system installation costs are high, approaching $1 million for a 2,500- to 5,000-head facility. A 5-year payback is estimated using the algae as a feed (protein) source.

< Chemical oxidation processes, particularly ozonation, are used to reduce organics, pathogens, and color in wastewater. Other oxidants include chlorine and chlorine dioxide, but their use is of concern due to the generation of trihalomethanes and chlorinated organics. In Japan, pig producers make extensive use of ozonation to treat urine and wastewater following an under-house pit solid-liquid separation process; the solid fraction is composted. Ozonation processes are currently being studied at a large scale U.S. farrow-to-finish operation.

< Microbial inactivation in swine waste was laboratory tested using several coagulants for solids removal followed by a UV radiation treatment. Four coagulants (two polyacrylamides, ferric chloride, and a polyaluminum chloride) were used, with the two metal salts lowering total suspended solids most effectively (70-95 percent). UV exposure did not reduce microbial populations sufficiently for many water reuse activities. It was found that UV treatment following the polyaluminum chloride application of waste diluted by a factor of 15 was capable of meeting Hawaii water reuse regulations (Pauin, 1998).

< USDA/ARS has been evaluating encapsulated nitrifiers as part of an alternative treatment sequence for animal waste. This technology is in use at the Pegasus project in Osaka, Japan. Research on municipal wastewater with nitrifying microorganisms suspended in a polyethylene glycol resin demonstrated a nitrification rate 2.6-3.8 times as high as activated sludge (the denitrification rate of activated sludge was 1.5 times higher than conventional biological denitrification processes). Overall, a pilot system combining traditional denitrifying with encapsulated nitrifiers resulted in nitrogen removal greater than 70 percent and an effluent BOD_5 of less than 20 mg/L (Tanaka, 1991). In another project, removal of ammonia nitrogen from swine wastewater by nitrifying bacteria was tested in bench experiments with loading rates of 418 mg N/L/day and a hydraulic

residence time of 12 hours. Nitrification efficiencies of 95 percent were obtained using nitrifiers encapsulated in polyvinyl alcohol gel. These encapsulated microbes were then added to a pilot plant built at a North Carolina swine facility. Nitrification activity increased from 21 to 200 g N/M^3/day in 30 days using a 48-hour retention time (Vanotti and Hunt, 1998).

- In addition to microbial digestion, systems have been developed that use algae (photosynthetic fermentors), fish (grass carp), or aquatic plants (duckweed, water hyacinths) to remove nutrients from the wastewater. For example, in a bench-scale experiment on duckweed using swine wastewater, *Lemna gibba* removed ammonia and phosphate by 99.8 and 99 percent, respectively, from wastewater in a 1:1 dilution with tap water. Greater dilution of wastewater did not appear to enhance nutrient removal capabilities (Cheng et al., 1998). The effluent is used for recycle, or in some cases animal drinking water. The plants are harvested for use as an animal feed. One system used in India involves integration of a fish pond under the slats of a goat confinement house. Both the goats and fish are sold, and very little manure management is needed.

- Alternative uses of manure are another option beyond new treatment technologies. Some possibilities that have not been widely adopted include using manure as a fuel, a commercial fertilizer additive, and an animal feed component (Steele, 1995). Flachowsky and Hennig (1995) found that poultry and pig excrement can be used as low-quality feed for ruminants. They also found that deep stacking of poultry litter might destroy potential pathogens and improve feed value while urea treatment preserved wet pig-slurry solid, and sodium hydroxide increased digestibility. Manure can also be dried and incinerated, or mixed with cement, kiln by-products, or glass to create a floor tile product.
- Crystallization or freezing processes have been used to treat wastewater. By turning the wastewater to snow, the volatile gases are readily stripped from the water. Other contaminants are precipitated from the water in a process called *atomizing freeze-crystallization*. In a pilot test program, the meltwater had reductions of 60 percent of the nutrients, and almost 100 percent of pathogens were killed (MacAlpine, 1997). Options to capture the stripped gases are being explored. The system appears to be especially suitable for colder climates, where typical bacterial digestion and treatment processes are slowed by the temperature.

- Ion exchange is a process by which one ion is displaced from a insoluble material or resin by ions of a different species. The process can be operated continuously or in a batch mode. The used resin is regenerated and reused. The process is used to remove ammonium, some nitrate and nitrite, TDS, and SS. Zeolite, a volcanic mineral, is frequently used for its cation properties and to reduce odor.

- The thermochemical conversion (TCC) process of altering the chemical structure of organic matter was tested in a bench-scale processor to change swine waste into oils and gases (He et al., 1998). COD was reduced by 94 percent and 8.5 percent of the volatile solids were converted to oils. It was concluded from these preliminary results that the TCC process could be an alternative treatment option of swine waste.

11.12 Other Effectiveness and Cost Information

Table 11-23 presents a relative comparison of common waste treatment systems developed by NCSU (1998). Values of 1 indicate most effective and 3 indicate least effective. Costs are rated as high (H), medium (M), and low (L).

Table 11-24 shows the average costs in the state of Pennsylvania for some of the most common manure management systems. It was compiled by the Bureau of Land and Water Management of the Pennsylvania Department of Environmental Resources in 1993. The cost data can be highly variable between sources, years, and regions. BMP costs can also vary between farms.

Table 11-23. Effectiveness and cost of waste treatment system components.

System Component	Nitrogen Reduction	Phosphorus Reduction	Oxygen Demand Reduction	Pathogen Reduction	Odor Emission Reduction	Ammonia Emission Reduction	Cost
Covered Reactors	3	2	1	2	1	1	H
Solids Separation	2	2	2	2	2	2	M
Composting	N/A	N/A	N/A	1	2	2	M
Anaerobic Digester	3	2	1	2	1	1	H
Anaerobic Lagoon	2	2	1	2	2	3	L
Aerated Lagoon	2	2	1	1	1	1	H
Sequencing Batch Reactor	1	2	1	1	1	1	H
Fixed-media Aerated Biofilters	2	2	1	1	1	1	H
Activated Sludge	1	2	1	1	1	1	H

Source: NCSU, 1998.

Table 11-24. Cost data (1993 dollars) for Pennsylvania state averages for manure management practices.

Management Practice	Cost[a] ($)	Benefits	Maintenance Requirements	Coordinating Structures/Practices
Terrace (grassed) **Gradient** **Storage**	 $1.38/LF $2.20/LF	Slows runoff to allow sediment eposition; reduces the volume of runoff to enter a filter strip; assists the collection of clean or dirty runoff	Remove sediment buildup and debris; protect from animal access; seed as necessary to maintain vegetation	Collection facility for contaminated runoff; transportation of clean runoff; off-site treatment of polluted runoff
Reduce Barnyard Surface Area	move fencing	Enables runoff containment with curbing and basins; reduces the volume of barnyard runoff	Frequent scrapings to reduce manure buildup; attention to animal occupancy time	Runoff collection practices; storage and treatment structure
Roof Barnyard	$5.50/SF	Enables diversion of clean roof water to prevent contamination; reduces the amount of barnyard waste to be treated	Snow removal; monitor for leakage	Roof runoff management system; gutters and downspouts
Diversion	$1.58/LF	Protects uncontaminated water from barnyard contaminants; reduces volume of contaminated water runoff	Remove sediment buildup and debris; seed as necessary to maintain vegetation; protect from animal access	Channel to move clean runoff off-site; collection facility for contaminated runoff
Grassed Waterways	$2082.34/AC	Allows transportation of clean or contaminated water	Seed as necessary to maintain vegetation; protect from animal access; remove sediment buildup and debris	Channel to move clean runoff off-site; collection facility for contaminated runoff
Subsurface Tile Drainage	$1.44/LF	Improves absorption of rainwater at barnyard surface; helps contain barnyard pollutants	Check drains for clogging; monitor transport of polluted drainage	Collection and treatment of liquid waste drainage; collection of undrained runoff from lot surface
Roof Runoff Management System	$4.64/LF	Diverts clean roof water, prevents contamination; reduces the amount of barnyard waste to be treated	Monitor for leakage; snow removal; remove debris	Collection of diverted clean water; transportation of clean roof runoff off-site
Downspout (4" diam)	$1.41/LF	Enables diversion of clean roof water to prevent contamination; enables reduction of barnyard waste to be treated	Remove debris; monitor for leakage	Collection of diverted clean water; transportation of clean roof runoff off-site

Table 11-24. Cost data (1993 dollars) for Pennsylvania state averages for manure management practices.

Management Practice	Cost[a] ($)	Benefits	Maintenance Requirements	Coordinating Structures/Practices
Curbing (concrete)	$7.37/LF	Provides containment of barnyard wastes; enables collection of all effluent and solids	Monitor to ensure working order	Collection of solid and liquid waste; transportation of waste to storage and treatment
Barnyard Paving (concrete)	$106.37/CY	Enables better cleaning of barnyard surface; improved herd health due to cleaner animals	Frequent scrapings to reduce manure buildup; check surface and repair damages	Runoff collection practices; storage and treatment structure
Waste Storage Pond (10-20,000 cu.ft.)	$3.17/CF	Provides containment and storage of barnyard wastes; waste may be removed as needed for spreading	Removal of solids for spreading or composting; transportation of fluids for treatment	Fluid waste treatment facility; composting facility; transport system of waste to the storage pond
Vegetative Filter Strip	$295/AC	Provides an effective way to treat fluid portion of waste	Seed as necessary to maintain vegetation; ensure level soil surface to prevent channelling; harvest grass to remove nutrients from site	Sediment basin to separate solids prior to strip treatment
Sediment Detention Basin	$217.92/LF	Allows waste water recycling; enables use of filter strips for treatment of liquid	Removal of sediment; maintain outflow of fluids onto treatment areas	Treatment of polluted fluid runoff; treatment or use of sediment
Ag. Waste Stacking & Handling Pad	N/A	Compost may be sold; provides a means of separating solids for treatment or use; provides an effective way to separate and treat fluid waste	Maintain filter strip; maintain level pad surface-fill as needed; prevent spillage of solids from pad onto filter; maintain even flow across interface to filter	Filter strip or storage pond; compost storage area; transport of waste to pad site
Composting	N/A	Compost may be sold; compost serves as an excellent soil conditioner	Turn windrow stacks to maintain aeration; check temperature to ensure working condition	Compost storage area; treansport of waste to compost site
Maintain Riparian Wetlands:		Improves population of insect pest predators; treatment of surface and subsurface runoff waters; improves biodiversity on property	Intermittant harvesting to maximize productivity	Upslope separation and removal of solids
Tree Plantation	$142.24/AC			
Streambank Protection	$21.25/LF			

[a] LF=Linear Foot, SF=Square Foot, CF=Cubic Foot, AC=Acre, CY=Cubic Yard

Source: Evans and Sandman, 1997. Barnyard Runoff Management: An Information Source for Dairy Farmers.

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