

**PROCESSED BASED AMMONIA
FARM EMISSIONS MODEL
DATA DOCUMENTATION**

Development of an Improved Process Based Ammonia Emission Model
For Agricultural Sources

Prepared For
Lake Michigan Air Directors Consortium
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Executive Summary

This report is the data documentation on the development of a process-based ammonia emissions model for agricultural sources, which was funded by the Lake Michigan Air Directors Consortium (LADCo). It lays out the preliminary framework and analytical approach that the project team is currently taking to collect the necessary input data for the overall ammonia emission model. This report also presents the technical background, input data requirements and data sources.

The scope of the final data document for this project is to develop a comprehensive document on data requirement based upon the mathematical equations developed to build a process based farm emissions model for predicting or estimating ammonia emission rates and factors from individual or a group of animal feeding operations at local, regional, and national levels. The following three components will be the sources of ammonia emissions from an animal feeding operation (AFO): animal housing, manure treatment and/or storage, land application (or manure utilization). The animal species to be included are Dairy Cattle, Beef Cattle, Swine, Poultry (Layers, Broilers, and Turkeys).

1. Introduction

The processed-based ammonia model will require a variety of data obtained from numerous sources. The necessary data will be collected to populate the animal allocation processor (AAP), provide the activity data for the farm emission model (FEM), provide the necessary emission factors for the fertilizer module in the farm emission model to compute “whole animal” ammonia emission estimates from the farm emissions model. A comprehensive data document is crucial to address the wide spectrum of data requirements.

The data requirements and data sources for the Animal Allocation Processor (AAP) are described in the “Development of an Improved Process Based Ammonia Emissions Model for Agricultural Sources – Design Document”. All the input variables required by the Farm Emissions Model (FEM) are spatially and temporally allocated by the AAP and outputted into ASCII tables to be imported by the FEM.

This data document is specifically written for the Farm Emissions Model (FEM) and will attempt to address the following issues: (1) to provide an overview of the agricultural waste management systems and agricultural waste characteristics; (2) to address data requirements and default values for dairy, beef, swine, and poultry at the animal excretion level; (3) to address data requirements and default values for the four major animal types in the housing, storage, land emissions models; and (4) data requirements and sources for meteorological variables used by FEM.

An overview of the agricultural waste management systems and agricultural waste characteristics are described in chapter 2 of this document. Contents, figures and table are from chapters 9 and 4 of the “Agricultural Waste Management Field Handbook, United States Department of Agriculture” (<http://www.wcc.nrcs.usda.gov/awm/awmfh.html>).

Data requirements at the animal excretion level are described in Chapter 3. This includes input data needed for excretion equations for dairy, beef, swine, and poultry (broilers, turkeys, and ducks). Nitrogen excretion from animals is influenced by the age, species, and diet of animals. Data required to accurately model these processes include information concerning animal populations, including age, and feed ratios. This chapter points out that a national database describing the diet composition and input at the farm level is non-existent in the United States. Therefore, a critical component to the input-output mass balance model is not available. There is the need for every producer to submit a nutrient balance report for his or her operation similar to what is required and implemented in Denmark.

Chapter 4 describes the data requirements at the post-excretion level for the housing model. Ammonia emissions from animal housing depend on the specific housing design and practices for each farm. In addition, the collection and storage of manure from housing operations varies by indoor and outdoor storage. Information concerning housing

design and operation for each specific farm treated by the module will be needed. As the design and operation of animal housing varies by species, age and climate, animal populations by age and climatic conditions for each farm location will be required.

Chapter 5 describes the data requirements at the post-excretion level for the storage model. Ammonia emissions associated with manure storage will vary by the type of manure. Dry manure storage is typical of beef cattle feedlot, dairy corrals, high-rise layer facility, broiler and turkey facilities. Wet manure storage is commonly used for manure collected in swine and layer facilities. For each farm, data concerning the type and number of storage facilities will be required. In addition environmental data will be required.

Chapter 6 describes the data requirements at the post-excretion level for the land application model. Ammonia emission rates from different land application practices vary by type of animal manure, crop management practices and climatic conditions. Data regarding the nutrient content of manure by animal type, specific application and crop management practices for each farm and environmental conditions will be required.

Chapter 7 describes the meteorological inputs required by the farm emissions model and the source of the hourly variable meteorological fields.

A data exchange format is also developed to handle future data transfer among state, local agencies for the Improved Process Based NH₃ Model.

2. Agricultural Waste Management

Contents, figures and table in this chapter are from chapters 9 and 4 of the “Agricultural Waste Management Field Handbook, United States Department of Agriculture” (<http://www.wcc.nrcs.usda.gov/awm/awmfh.html>)

2.1 Agricultural Waste Management Systems

An agricultural waste management system (AWMS) is a planned system in which all necessary components are installed and managed to control and use byproducts of agricultural production in a manner that sustains or enhances the quality of air, water, soil, plant, and animal resources.

Agricultural waste management systems must be developed using the total systems approach. A total system accounts for all the waste associated with an agricultural enterprise throughout the year from production to utilization. In short, it is the management of all the waste, all the time, all the way.

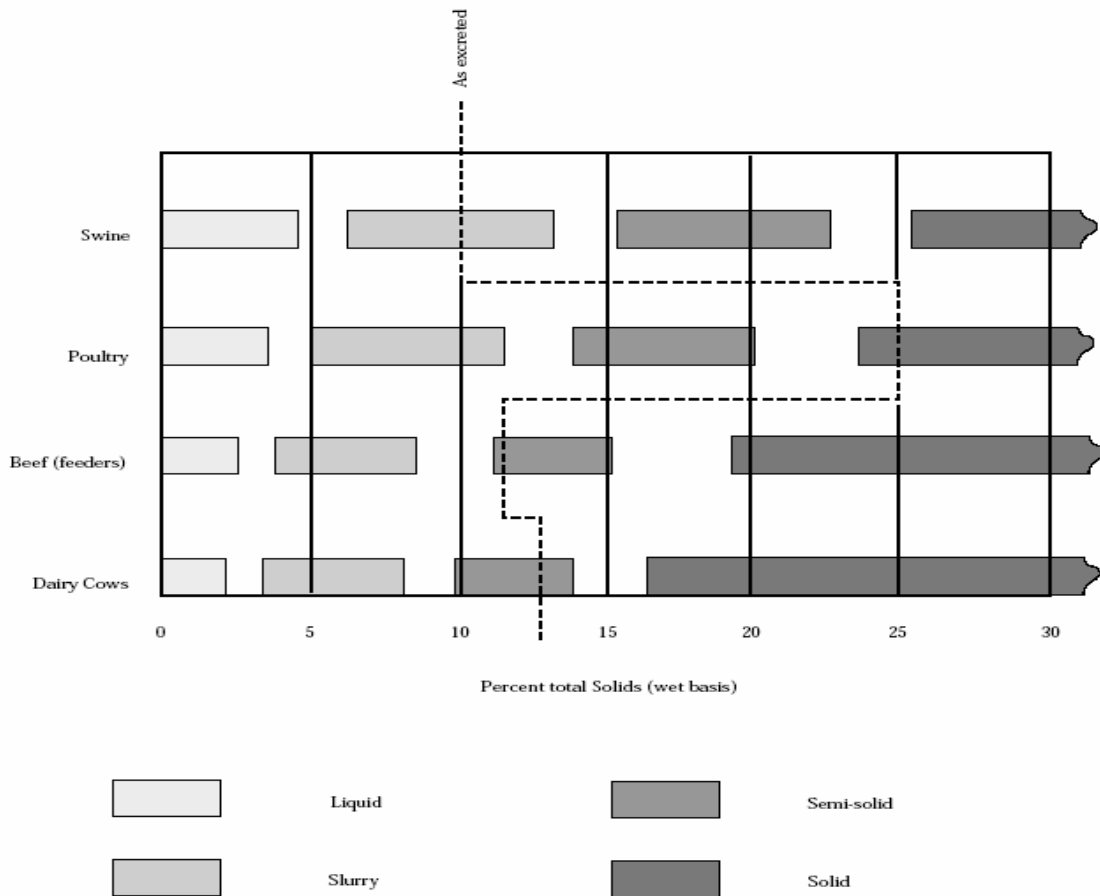


Figure 2.1 Relative handling characteristics of different kinds of manure and percent total solids

Waste of different consistencies requires different management techniques and handling equipment. Agricultural waste may be in the form of a liquid, slurry, semi-solid, or solid. Waste, such as manure, can change consistency throughout the system or throughout the year. The total solids (TS) concentration of manure is the main characteristic that indicates how the material can be handled.

Factors that influence the TS concentration of excreted manure include the climate, type of animal, amount of water consumed by the animal, and the feed type. In most systems the consistency of the waste can be anticipated or determined. The TS concentration of the waste can be increased by adding bedding to the waste, decreased by adding water, and stabilized by protecting it from additional water. Figure 2–1 illustrates how varying the TS concentration for different animal manures affects consistency. Additional information is in section 2.2.

The consistency of the waste should be selected and controlled for several reasons. Solid waste management systems have a reduced total volume of waste because of the reduction in the amount of water. Solid waste handling equipment may have lower cost and power requirements; however, the labor required for operation and management generally is greater than that for other methods.

Liquid waste management systems are often easier to automate and require less daily attention than those for solid wastes. However, the additional water needed increases the volume of waste requiring management, and the initial cost of the liquid handling equipment may be greater than that for solid waste systems.

Operator preference is also a factor. A landowner may select a method for managing waste because that method is popular in the community. It will be easier to learn from and share experiences with neighbors and, in case of equipment failure or other emergencies, the landowners can more easily assist each other.

Waste Management Functions

An agricultural waste management system consists of six basic functions (fig. 2–2):

- Production
- Collection
- Storage
- Treatment
- Transfer
- Utilization

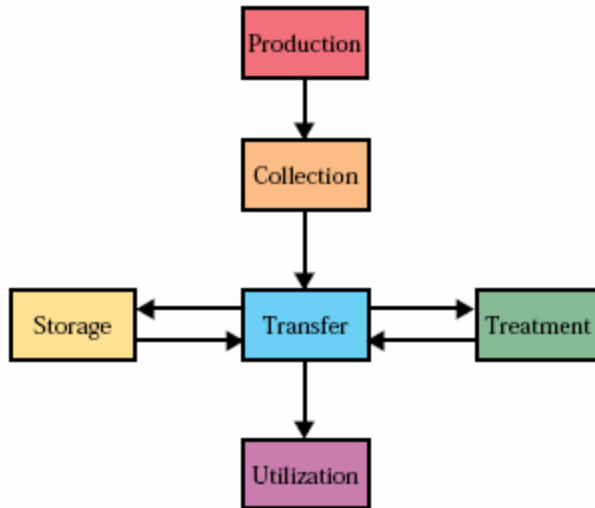


Figure 2.2 Waste Manamgent functions

For a specific system these functions may be combined, repeated, eliminated, or arranged as necessary.

Production

Production is the function of the amount and nature of agricultural waste generated by an agricultural enterprise. The waste requires management if quantities produced are sufficient enough to become a resource concern. A complete analysis of production includes the kind, consistency, volume, location, and timing of the waste produced.

The waste management system may need to accommodate seasonal variations in the rate of production. The production of unnecessary waste should be kept to a minimum. For example, a large part of the waste associated with many livestock operations includes contaminated runoff from open holding areas. The runoff can be reduced by restricting the size of open holding areas, roofing part of the holding area, and installing gutters and diversions to direct uncontaminated water away from the waste. A proverb to remember is, “Keep the clean water clean.” Leaking watering facilities and spilled feed contribute to the production of waste. These problems can be reduced by careful management and maintenance of feeders, watering facilities, and associated equipment. A record should be kept of the data, assumptions, and calculations used to determine the kind, consistency, volume, location, and timing of the waste produced. The production estimates should include future expansion.

Collection

This refers to the initial capture and gathering of the waste from the point of origin or deposition to a collection point. The AWMS plan should identify the method of collection, location of the collection points, scheduling of the collection, labor requirements, necessary equipment or structural facilities, management and installation

costs of the components, and the impact that collection has on the consistency of the waste.

Storage

Storage is the temporary containment of the waste. The storage facility of a waste management system is the tool that gives the manager control over the scheduling and timing of the system functions. For example, with adequate storage the manager has the flexibility to schedule the land application of the waste when the spreading operations do not interfere with other necessary tasks, when weather and field conditions are suitable, and when the nutrients in the waste can best be used by the crop. The storage period should be determined by the utilization schedule.

The waste management system should identify the storage period; the required storage volume; the type, estimated size, location, and installation cost of the storage facility; the management cost of the storage process; and the impact of the storage on the consistency of the waste.

Treatment

Treatment is any function designed to reduce the pollution potential of the waste, including physical, biological, and chemical treatment. It includes activities that are sometimes considered pretreatment, such as the separation of solids. The plan should include an analysis of the characteristics of the waste before treatment; a determination of the desired characteristics of the waste following treatment; the selection of the type, estimated size, location, and the installation cost of the treatment facility; and the management cost of the treatment process.

Transfer

This refers to the movement and transportation of the waste throughout the system. It includes the transfer of the waste from the collection point to the storage facility, to the treatment facility, and to the utilization site. The waste may require transfer as a solid, liquid, or slurry, depending on the total solids concentration. The system plan should include an analysis of the consistency of the waste to be moved, method of transportation, distance between points, frequency and scheduling, necessary equipment, and the installation and management costs of the transfer system.

Utilization

Utilization includes recycling reusable waste products and reintroducing nonreusable waste products into the environment. Agricultural wastes may be used as a source of energy, bedding, animal feed, mulch, organic matter, or plant nutrients. Properly treated, they can be marketable. A common practice is to recycle the nutrients in the waste through land application. A complete analysis of utilization through land application

includes selecting the fields; scheduling applications; designing the distribution system; selecting necessary equipment; and determining application rates and volumes, value of the recycled products, and installation and management costs associated with the utilization process.

2.1.1 Dairy Waste Management Systems

Dairy operations vary, and each operation presents its own unique problems (Figure 2-3).

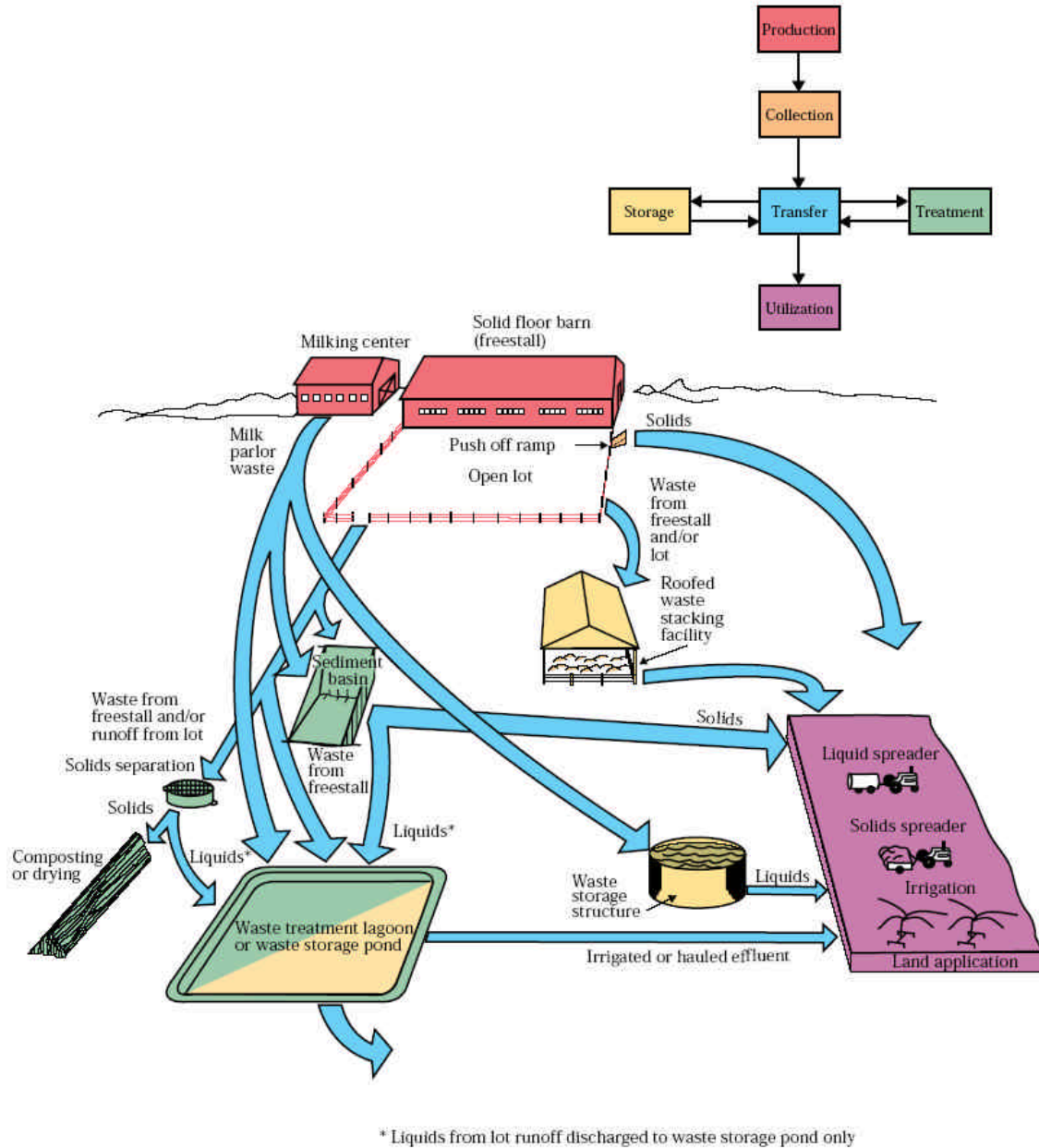


Figure 2-3 Waste handling option – dairy.

Dairy animals are typically managed on pastures in partial confinement. While animals are on pasture, their waste should not be a resource concern if stocking rates are not excessive, grazing is evenly distributed, manure from other sources is not applied, and grazing is not allowed during rainy periods when the soils are saturated. To prevent waste from accumulating in feeding, watering, and shade areas, the feeding facilities can be moved, the number of watering facilities can be increased, and the livestock can be rotated between pastures. To reduce deposition of waste in streambeds, access to the stream may be restricted to stable stream crossings and access points (fig. 2-4).

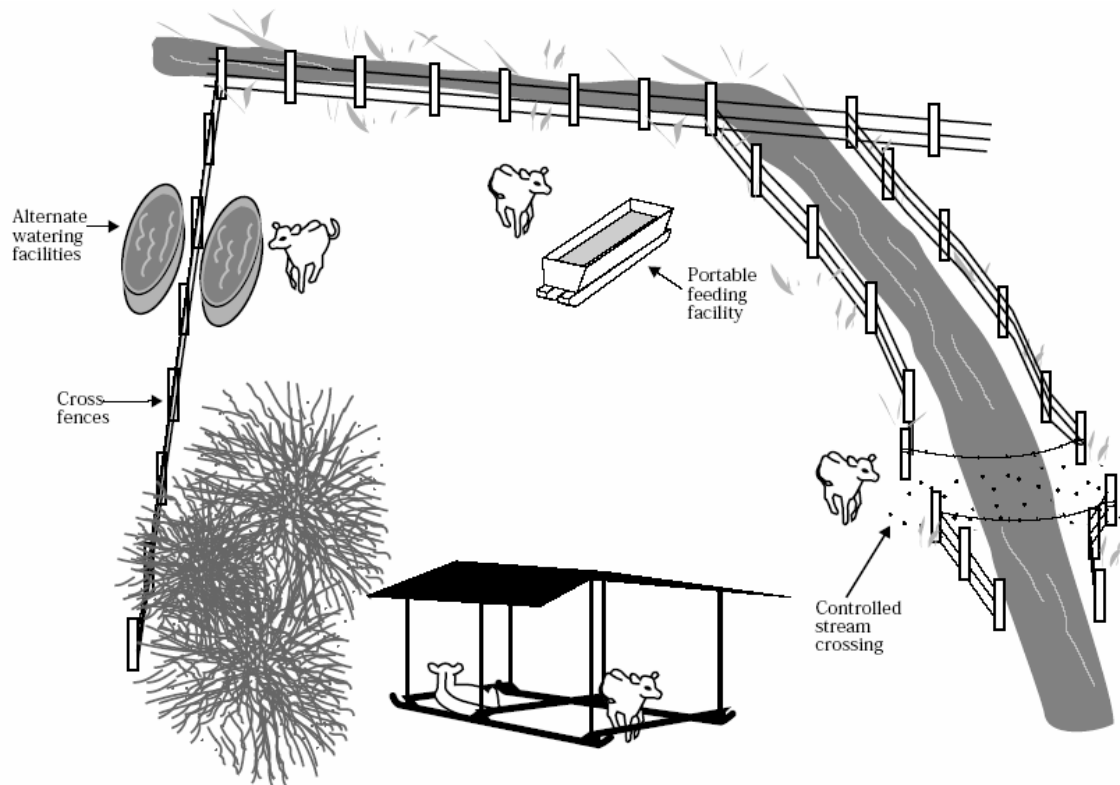


Figure 2-4 Livestock waste management on pasture includes cross fences for rotation, portable feeding facilities, shade areas away from streams, alternate water facilities, and controlled stream crossing

The manure in paved holding areas generally is easier to manage, and the areas are easier to keep clean. If the holding areas are unpaved, the traffic of the livestock tends to form a seal on the soil that prevents the downward movement of contaminated water. Care must be taken when removing manure from these lots so that damage to this seal is minimized.

Production

Waste associated with dairy operations include manure, contaminated runoff, milking house waste, bedding, and spilled feed.

Collection

The collection methods for dairy waste vary depending on the management of the dairy operation. Dairy animals may be partly, totally, or seasonally confined. Manure accumulates in confinement areas and in areas where the dairy animals are concentrated before and after milking.

Unroofed confinement areas must have a system for collecting and confining contaminated runoff. This can be accomplished by using curbs at the edge of the paved lots (fig. 2-5) and reception pits where the runoff exits the lots. Paved lots generally produce more runoff than unpaved lots. On unpaved lots, the runoff may be controlled by diversions, sediment basins, and underground outlets. The volume of runoff can be reduced by limiting the size of the confinement area, and uncontaminated runoff can be diverted if a roof runoff management system and diversions are used.

The manure and associated bedding accumulated in roofed confinement areas can be collected and stored as a solid. The manure can also be collected as a solid in unroofed lots in humid climates where the manure is removed daily and in unroofed lots in dry climates.

Manure can be removed from paved areas by a flushing system. The volume of contaminated water produced by the system can be greatly reduced if provisions are made to recycle the flush water.

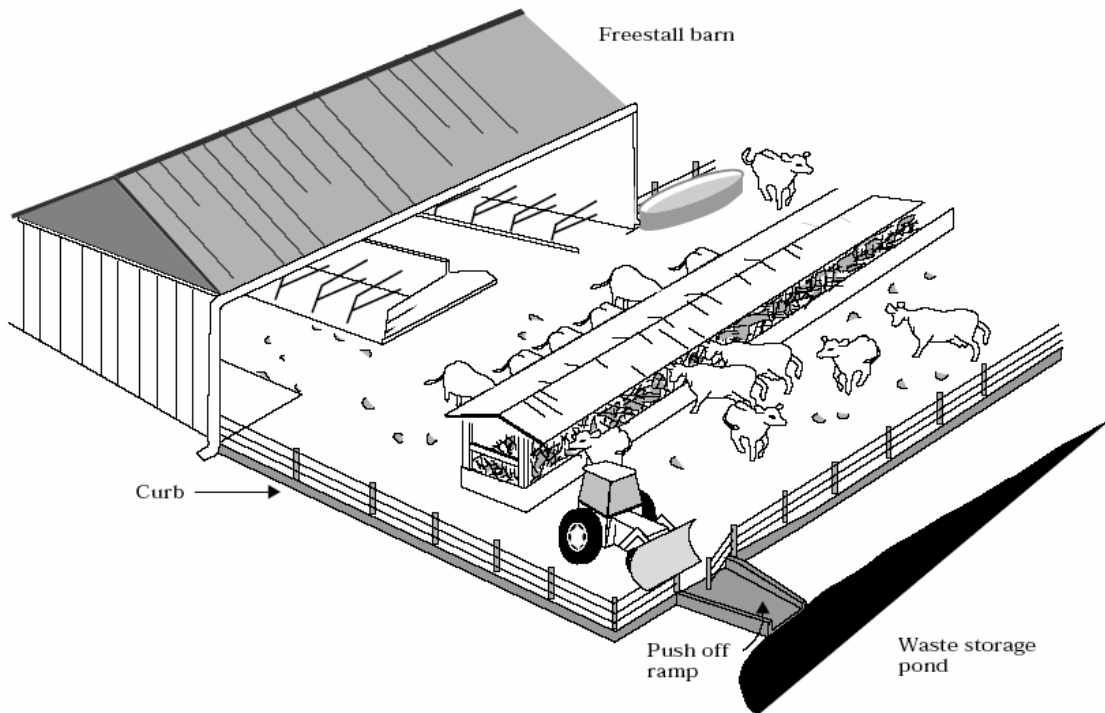


Figure 2-5 Confinement area with curbing

Storage

Milking house waste and contaminated runoff must be stored as a liquid in a waste storage pond or structure. Manure may be stored as a slurry or liquid in a waste storage pond designed for that purpose or in a structural tank (figs. 2-6 & 2-7). It can be stored as a semisolid in an unroofed structure that allows for the drainage of excess water and runoff or as a solid in a dry stacking facility. In humid areas the stacking facility should have a roof.

Treatment

Liquid waste can be treated in an aerobic lagoon, an anaerobic lagoon, or other suitable liquid waste treatment facilities. Solids in the waste can be composted.

Transfer

The method used to transfer the waste depends largely on the consistency of the waste. Liquid and slurry wastes can be transferred through open channels, pipes, or in a portable liquid tank (fig. 2-8). Pumps can be used to transfer liquid waste as needed. Solid and semi-solid waste can be transferred by mechanical conveyance equipment, in solid manure spreaders, and by pushing them down curbed concrete alleys. Semi-solid waste has been transferred in large pipes through the use of gravity, piston pumps, or air pressure.

Utilization

Dairy waste is used as bedding for livestock, marketed as compost, and used as an energy source, but the most common form of utilization is through land application. Waste may be hauled and distributed over the land in a dry or liquid manure spreader. Liquid waste can be distributed through an irrigation system. Slurries may be distributed through an irrigation system equipped with nozzles that have a large opening (fig. 2-9).

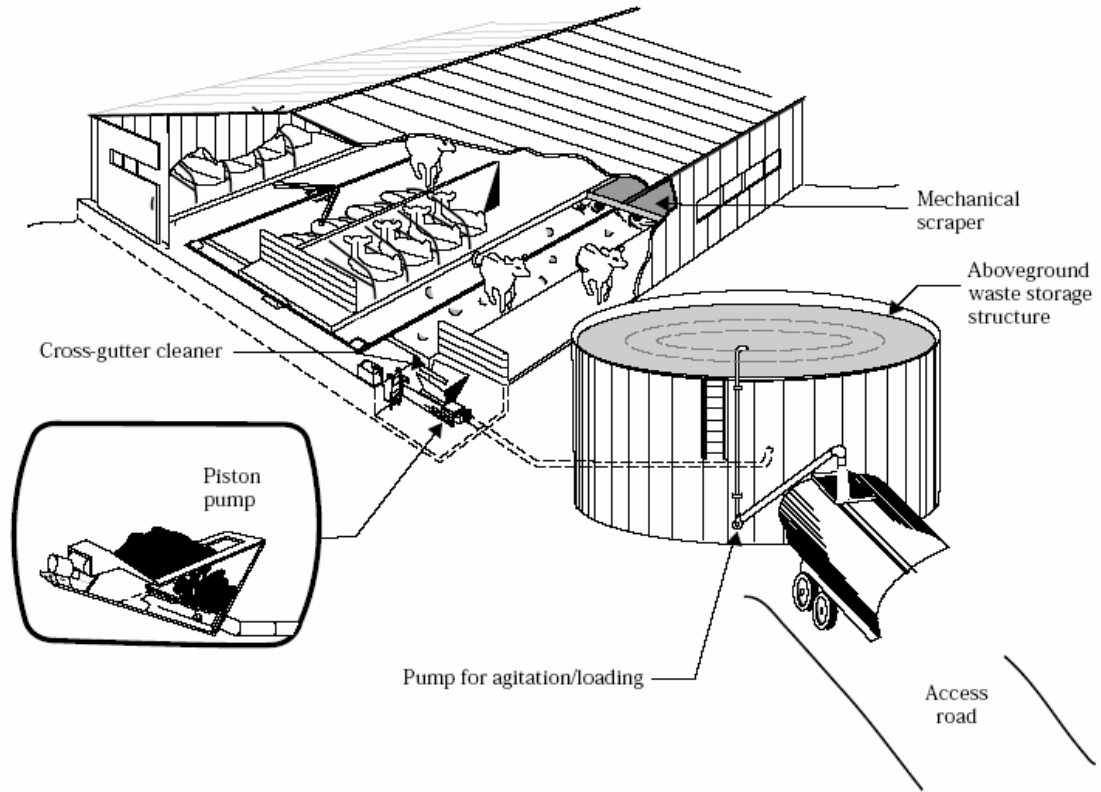


Figure 2-6 Aboveground waste storage structure

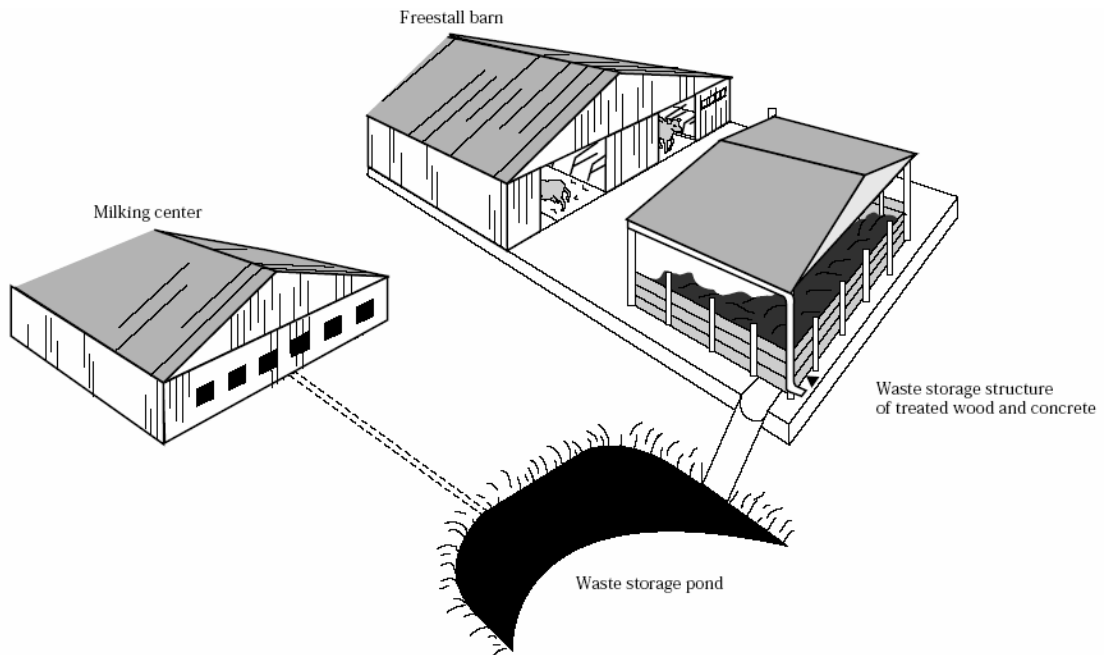


Figure 2-7 Storage Facilities

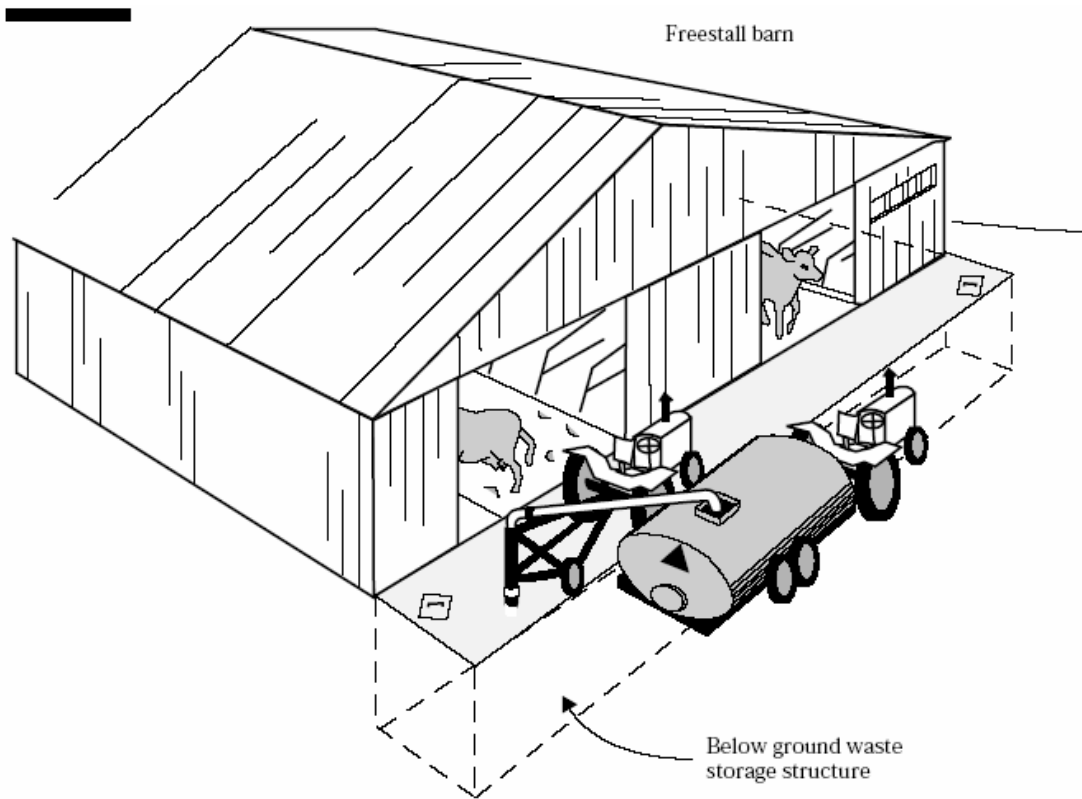


Figure 2-8 Tank wagon used to spread liquid wastes from below ground storage structure

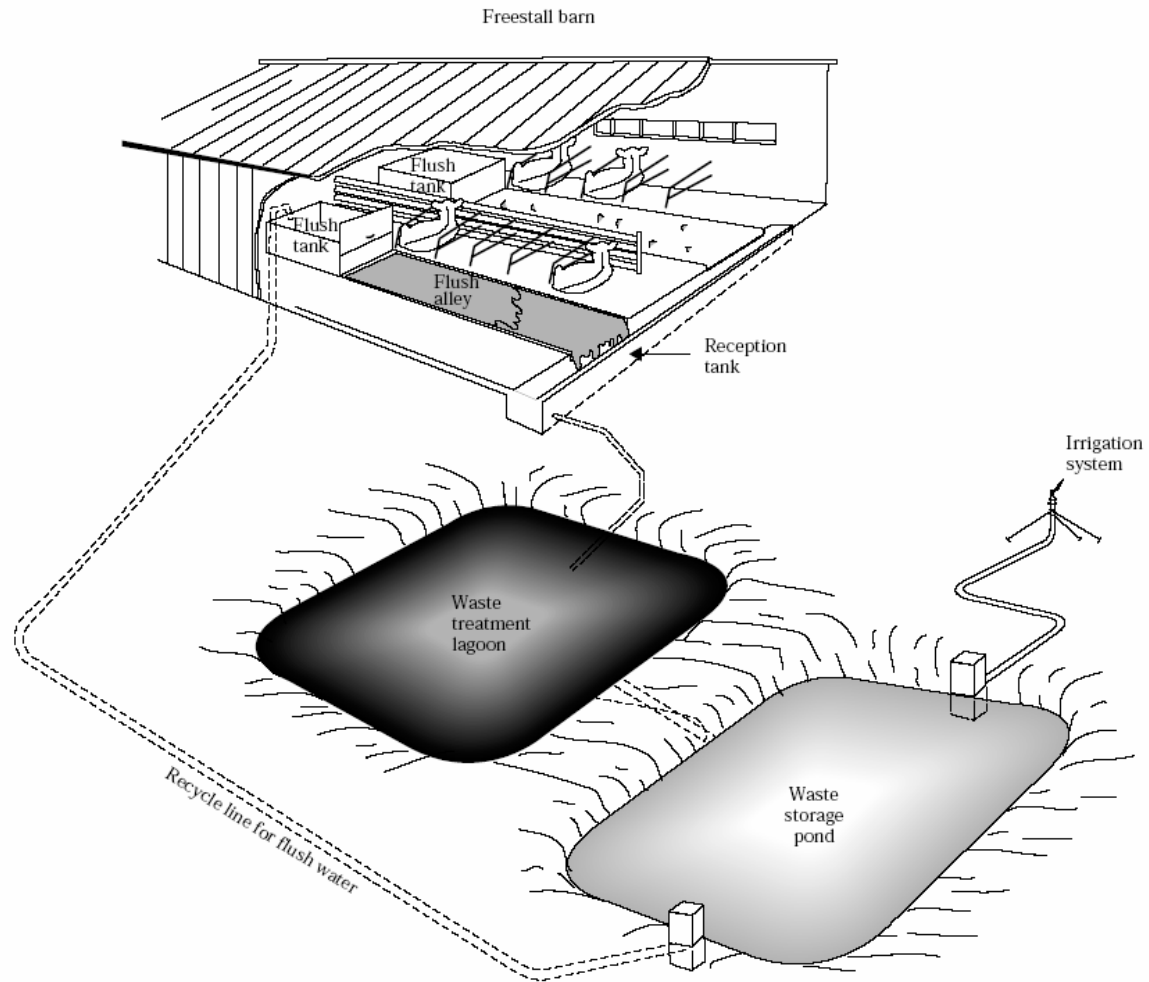


Figure 2-9 Freestall barn with flushing alleyway and irrigation system

2.1.2 Beef Waste Management System

Beef brood cows and the calves less than a year old are usually held on pastures or range. The calves are then finished in confined feeding facilities. While the animals are on pastures, their waste should not become a resource concern if the stocking rates are not excessive and the grazing is evenly distributed. To prevent waste from accumulating in feeding, watering, and shade areas, the feeding facilities can be moved, the number of watering facilities can be increased, and the livestock can be rotated between pastures. To reduce deposition of waste in streambeds, access to the stream may be restricted to stable stream crossings and access points. Figure 2-10 shows a paved beef feedlot operation.

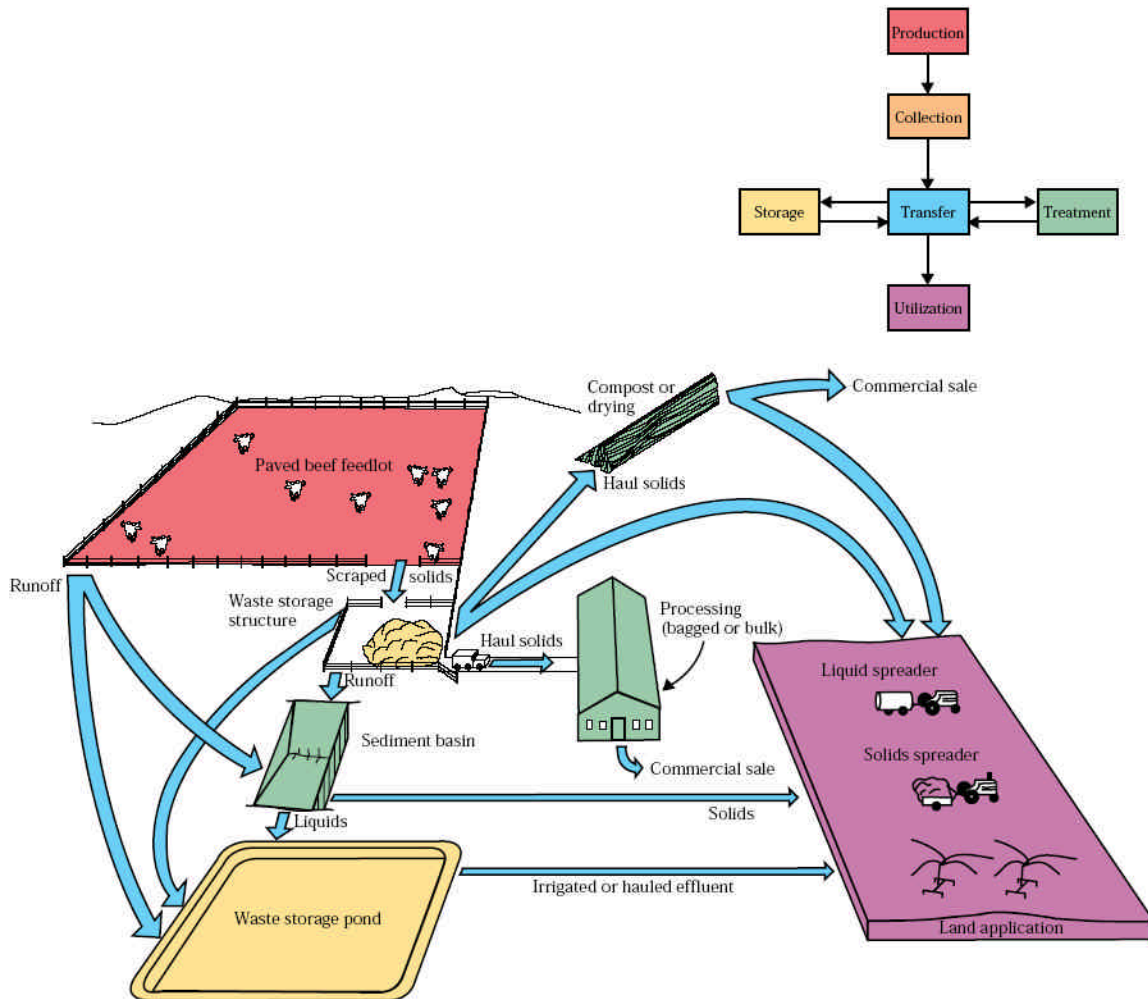


Figure 2-10 Waste handling option – beef.

Production

Waste associated with confined beef operations include manure, bedding, and contaminated runoff.

Collection

Beef cattle can be confined on unpaved (fig. 2–11), partly paved, or totally paved lots. If the cattle are concentrated near wells, adequate protection must be provided to prevent well contamination. Because much of the waste is deposited around watering and feeding facilities, paving these areas, which allows frequent scraping, may be desirable. On unpaved lots, the traffic of the livestock tends to form a seal on the soil that prevents the downward movement of contaminated water. Care must be taken when removing manure from these lots so that damage to this seal is minimized. The seal tends to break down after livestock are removed from the lot. To prevent possible contamination of ground water resources, all the manure should be removed from an abandoned lot.

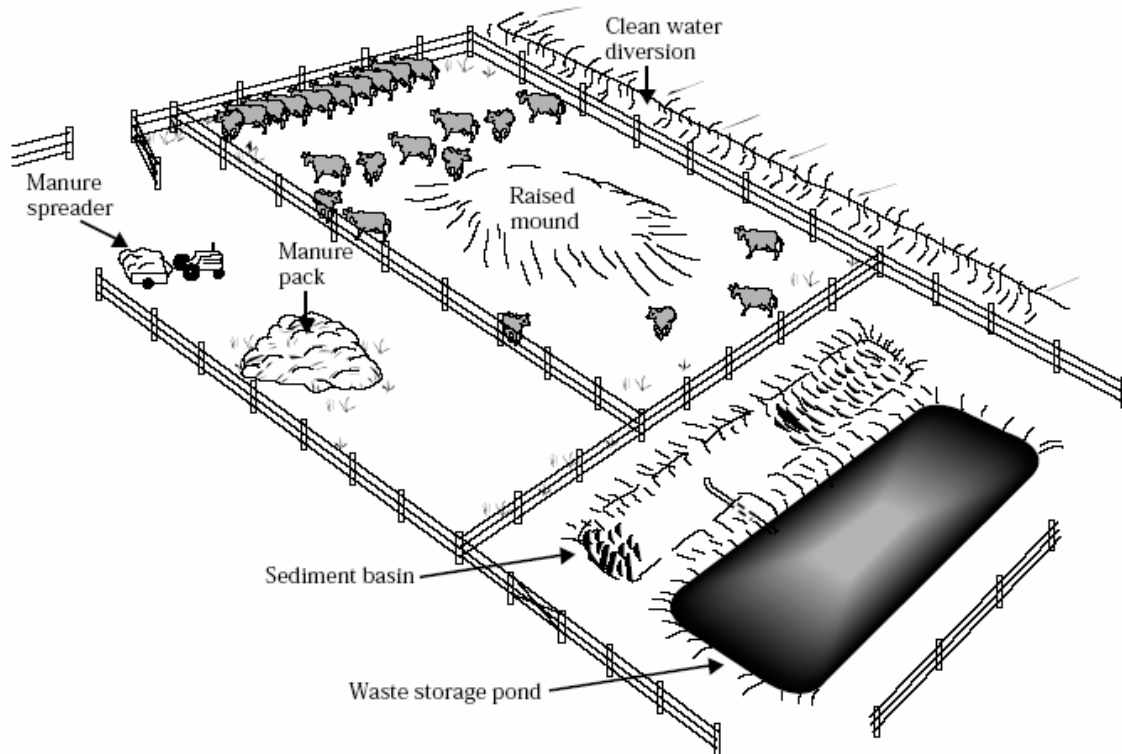


Figure 2-11 Waste collection from an unpaved beef feedlot.

Unroofed confinement areas must have a system for collecting and confining contaminated runoff. On unpaved lots the runoff can be controlled by using diversions, sediment basins, and underground outlets. Paved lots generally produce more runoff than unpaved lots, but curbs at the edge of the lots and reception pits where the runoff exits the lots help to control the runoff. Solid/liquid separators or settling basins can be used to recover some of the solids in the runoff. The volume of runoff can be reduced by limiting the size of the confinement area, and uncontaminated runoff can be excluded by use of diversions.

The manure in confinement areas that have a roof can be collected and stored as a solid. It may also be collected as a solid or semi-solid from open lots where the manure is removed daily and from open lots in a dry climate.

Storage

Manure can be stored as a bedded pack in the confinement area if bedding is added in sufficient quantities. Manure removed from the confinement area can be stored as a liquid or slurry in an earthen pond or a structural tank, as a semi-solid in an unroofed structure that allows drainage of excess water and runoff to a waste storage pond, or as a solid in a dry stacking facility designed for storage. In areas of high precipitation, dry stacking facilities should be roofed (fig. 2-12). Contaminated runoff must be stored as a liquid in a waste storage pond or structure.

Treatment

Treatment of the waste in a lagoon is difficult for some livestock systems because of the volume of solids in the waste, but many of the solids can be removed before treatment. Liquid waste may be treated in an aerobic lagoon, an anaerobic lagoon, or other suitable liquid waste treatment facilities. Solid waste can be composted.

Transfer

The method used to transfer the waste depends largely on the consistency of the waste. Liquid waste and slurries can be transferred through open channels or pipes or in a portable liquid tank. Pumps can be used as needed. Solids and semi-solids may be transferred by using mechanical conveyance equipment, by pushing the waste down curbed concrete alleys, and by transporting the waste in solid manure spreaders. Piston pumps or air pressure can be used to transfer semi-solid waste through large pipes.

Utilization

Beef cattle waste can be used as bedding for livestock, as an energy source, or it can be marketed as compost, but the most common form of utilization is land application. The waste can be hauled and distributed over the land in appropriate spreading devices. Liquid waste can be distributed through an irrigation system, and slurries can be applied using irrigation equipment with nozzles that have a large opening.

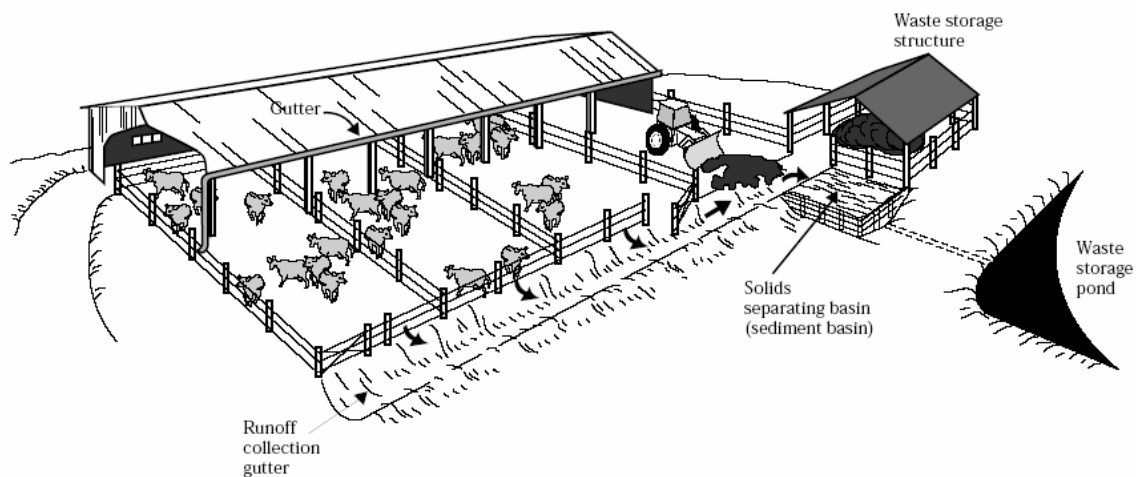


Figure 2-12 Storage facilities for wastes from paved feedlot in high precipitation area

2.1.3 Swine Waste Management System

Open systems (pastures, woodlots, and wetlands), feedlot systems, confinement systems, or a combination of these, are used for raising swine (fig. 2-13).

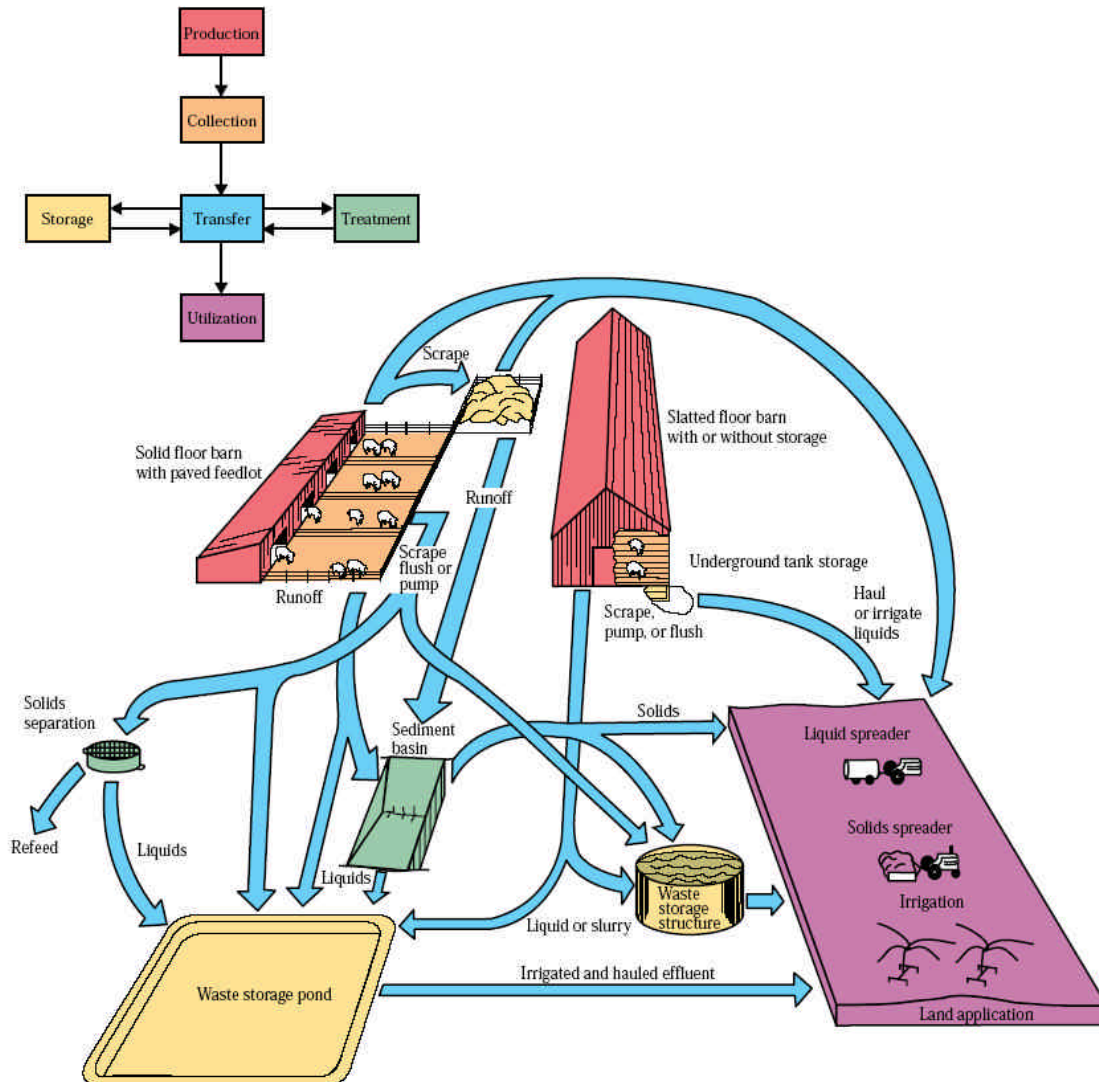


Figure 2-13 Waste handling options – swine.

Raising hogs in an open system may appear to have a low initial investment, but often results in animal health and pollution control problems. Even if sufficient land is available, hogs tend to congregate and concentrate their waste. This can be prevented by moving the feeding, watering, and housing facilities and by rotating the hogs through a series of open lots.

Hogs raised in an open system should not have unrestricted access to streams. Runoff is difficult to manage in an open system because of the large area and topographic limitations. Rather than invest the capital and time necessary to install and manage an extensive runoff management system, it may be more efficient to convert to a more concentrated operation.

Manure in feedlot systems can be handled as a solid if the feedlots are cleaned regularly, sufficient bedding is added to the manure, and the collected manure is protected from excessive precipitation. It can also be handled as a slurry or liquid, but measures must be

taken to manage contaminated runoff (fig. 2-14). Total confinement systems eliminate the need to manage contaminated runoff and may allow for more automation in waste management.

Undesirable odors are often associated with swine operations. A swine waste management system should incorporate odor control measures where possible. A clean, neat appearance; efficient management system (fig. 2-15); and positive public relations with those affected by the odors eliminate many complaints.

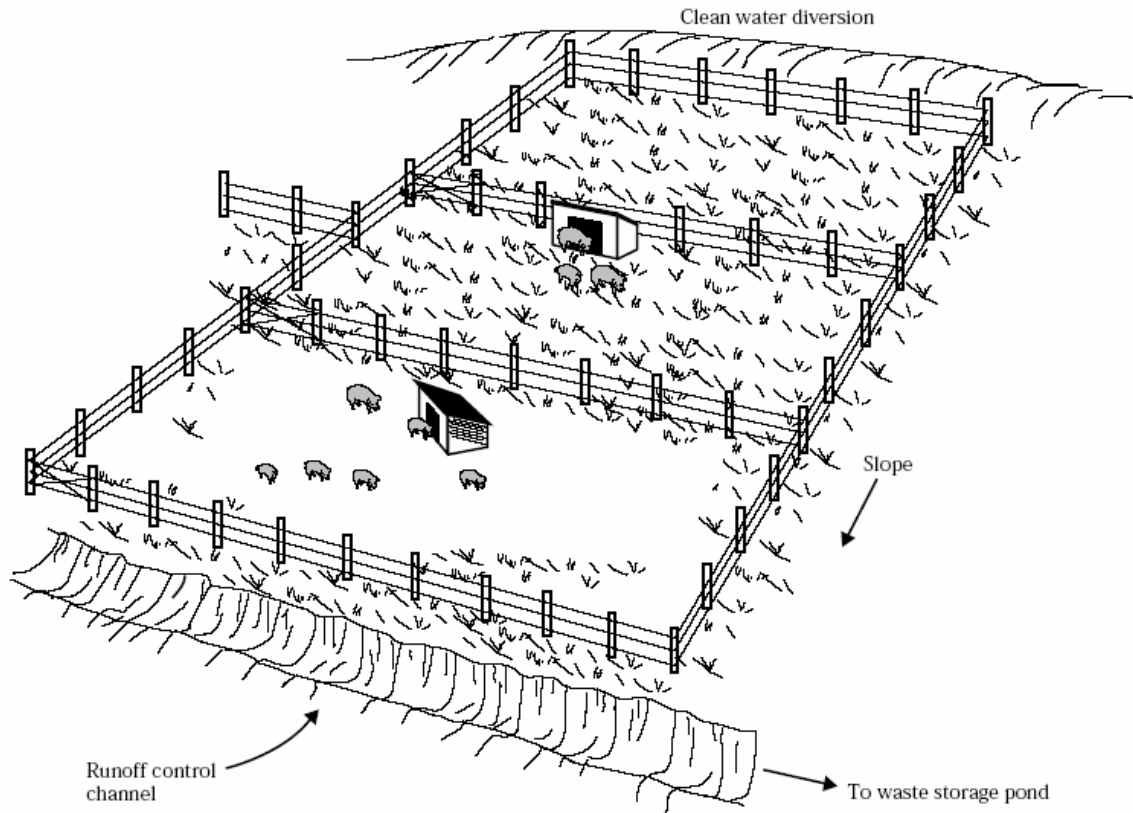


Figure 2-14 Runoff control

Production

Waste associated with swine operations include manure and possibly contaminated runoff. In some systems provisions must be made to manage flush water. Hogs tend to play with watering and feeding facilities, which can add to the waste load. The disposal of dead pigs may be a resource concern in some operations.

Collection

Swine manure can be collected by scraping or flushing. Scraped manure is collected as a solid or slurry, and flushed manure must be handled as a liquid. The flush water should be recycled if possible so that the volume of contaminated water is kept to a minimum.

The collection process can use automated equipment, or it can be as simple as raising swine on slatted floors over waste storage pits (fig. 2–16).

Storage

Swine manure can be stored as a solid, slurry, or liquid. If stored as a solid, it should be protected from precipitation. Above or below ground tanks (fig. 2–17) or an earthen waste storage pond can be used to store slurries or liquid waste.

Treatment

Liquid waste from a swine operation is commonly treated in an anaerobic lagoon, but it can also be treated in an aerobic lagoon (fig. 2–18) or oxidation ditch. Solid waste and dead pigs can be composted.

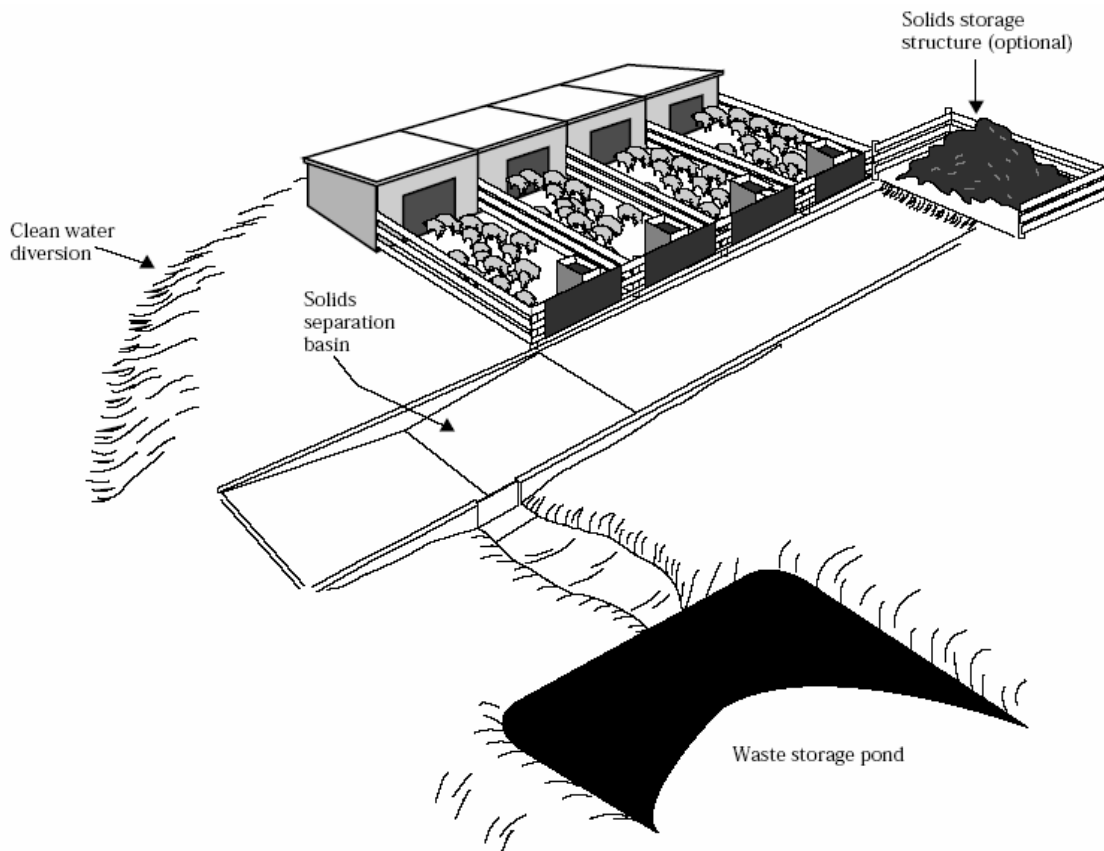


Figure 2-15 Manure scraped and handled as a solid on paved lot operation

Transfer

The method used to transfer the waste depends largely on the consistency of the waste. Liquid waste and slurries may be transferred through open channels, pipes, or in a

portable liquid tank. Pumps can transfer liquid waste as needed. Solids and semi-solids can be transferred by mechanical conveyance equipment. Piston pumps or air pressure can be used to transfer semi-solid waste through smooth pipes.

Utilization

Swine waste is used as a feed supplement and an energy source through methane production. With proper ventilation and sufficient bedding, the solid manure can be composted in confinement facilities, and the heat generated from the composting process can be used to supplement heat in the buildings. The most common use of the nutrients in swine waste is through land application. The waste can be hauled and distributed over the land by spreading devices. If odors are a problem, liquid waste can be injected below the soil surface. It can also be distributed through an irrigation system. Slurries can be distributed through an irrigation system equipped with nozzles that have a large opening.

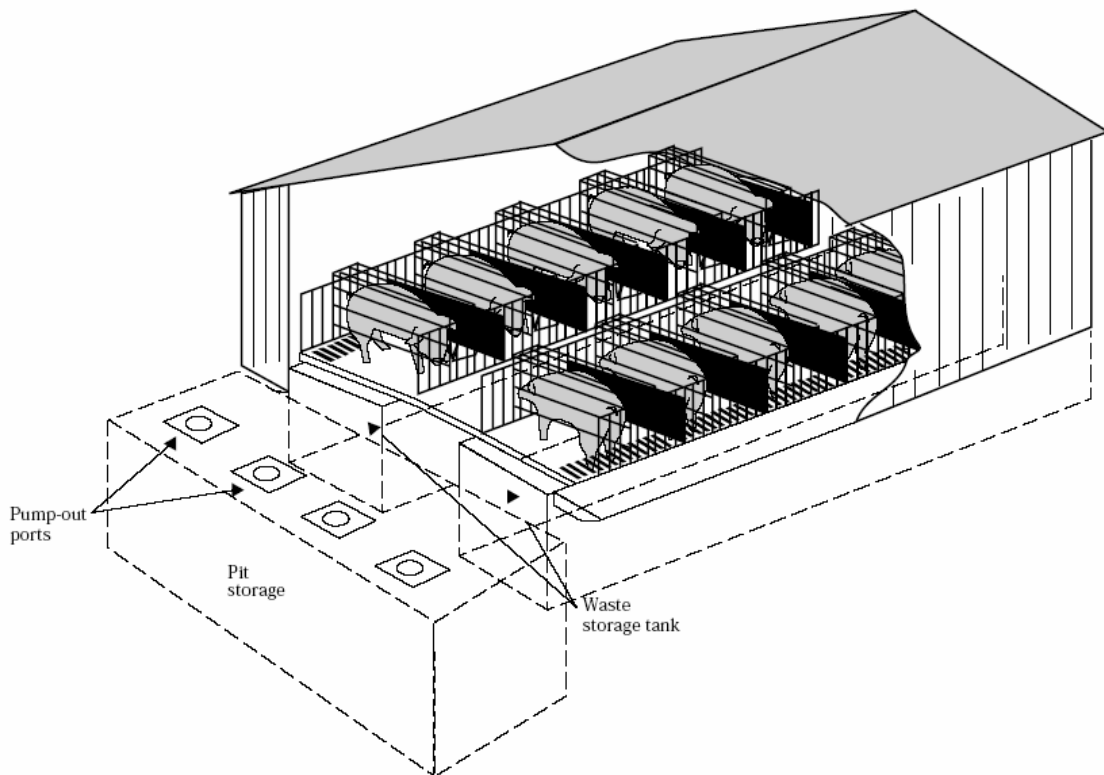


Figure 2-16 Confined housing with farrowing crates, partly slatted floor, pit storage, and liquid manure handling

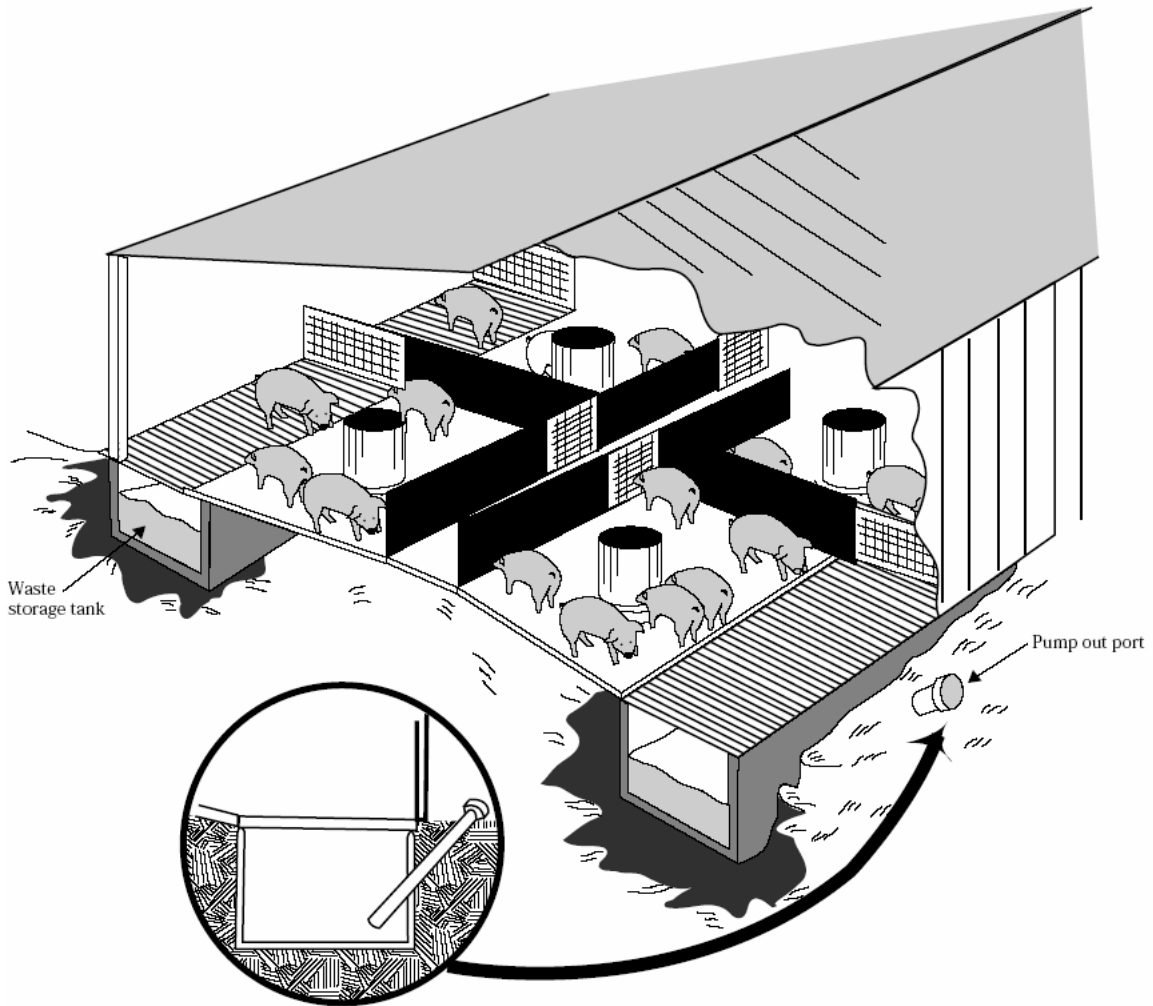


Figure 2-17 Fed hogs in confined area with concrete floor and tank storage liquid manure handling

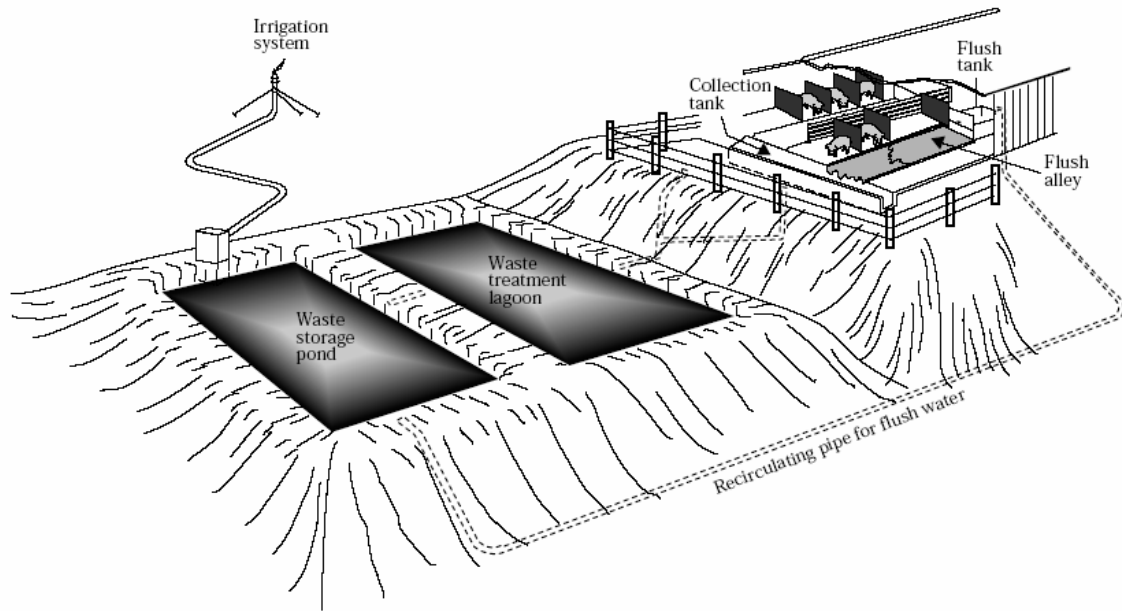


Figure 2-18 Two stage aerobic lagoon system for treatment of waste flushed from swine building

2.1.4 Poultry Waste Management System

The two basic poultry confinement facilities include those to raise turkeys and broilers used for meat (fig.2-19) and those to house layers. Broilers and young turkeys are grown on floors on beds of litter shavings (fig. 2-20), sawdust, or peanut hulls. Layers are confined to cages. Fly control around layers is important to prevent spotting of the eggs. Disease control is important in both systems.

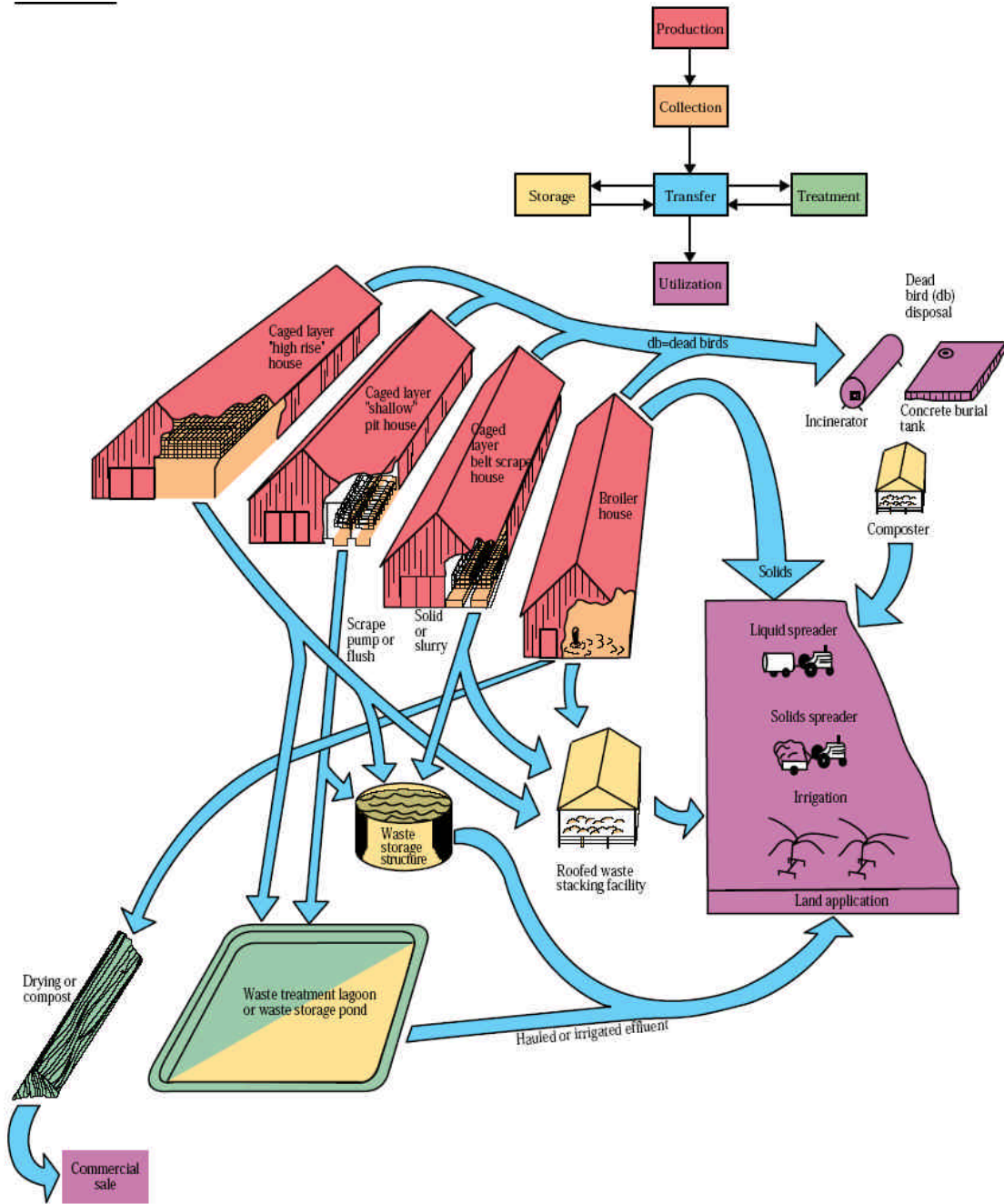


Figure 2-19 Waste handling options – poultry.

Production

Waste associated with poultry operations include manure and dead poultry. Depending upon the system, waste can also include litter, wash-flush water, and waste feed.

Collection

The manure from broiler and turkey operations is allowed to accumulate on the floor where it is mixed with the litter. Near watering facilities the manure litter pack forms a “cake” that generally is removed between flocks. The rest of the litter pack generally has low moisture content and is removed once a year in the spring. The litter pack can be removed more frequently to prevent disease transfer between flocks. In layer houses, the manure that drops below the cage collects in deep stacks (fig. 2–21) or is removed frequently using either a shallow pit located beneath the cages for flushing or scraping or belt scrapers positioned directly beneath the cages.

Storage

Litter from broiler and turkey operations is stored on the floor of the housing facility (fig. 2–22). When it is removed, it can be transported directly to the field for land application. If field conditions are not suitable or spreading is delayed for other reasons, the litter must be stored outside the housing facility. In some areas the litter may be compacted in a pile and stored in the open for a limited time; however, it generally is better to cover the manure with a plastic or other waterproof cover until the litter can be used. If the spreading is to be delayed for an extended period of time, the litter should be stored in a roofed facility. If the manure from layer operations is kept reasonably dry, it can be stored in a roofed facility. If it is wet, it should be stored in a structural tank or an earthen storage pond.

Treatment

Broiler and turkey litter can be composted. This stabilizes the litter into a relatively odorless mass that is easier to market and also helps to kill disease organisms so that the litter can be reused as bedding or supplemental feed to livestock. The litter can also be dried and burned directly as a fuel. Liquid manure may be placed into an aerobic digester to produce methane gas or it can be treated in a lagoon. The high volatile solid content of the layer manure may require an anaerobic lagoon of considerable size. If odors are a problem, the lagoon can be aerated.

Transfer

The method used to transfer the waste depends on the TS content of the waste. Liquid waste can be transferred in pipes, gutters, or tank wagons, and dried litter can be scraped (fig. 2–23), loaded, and hauled as a solid. If the distances between the poultry houses and the fields for application are great, the litter may need to be transported in a truck.

Utilization

The waste from poultry facilities can be applied to the land. If the owners of the poultry houses do not have enough land suitable for application, they should arrange to apply the waste to their neighbors’ land. Because of the high nutrient value of the litter, many landowners are willing to pay for the litter to be spread on their land. Whether on the owner’s land or the neighbor’s land, the waste must be spread according to an appropriate

waste utilization plan. Poultry waste can also be used for the production of methane gas, buried directly as a fuel, reused as bedding, or used as a feed supplement to livestock.

Dead poultry disposal

Because of the large numbers of dead birds associated with large poultry operations, the disposal of dead birds is a resource concern. Poultry facilities must have adequate means for disposal of dead birds in a sanitary manner. To prevent spread of disease, the dead birds are often collected daily by hand. Disposal alternatives include incineration, rendering, burial, dropping into a buried disposal tank, or composting. The dead birds are mixed with litter and straw, composted, and the composted material is stored until it can be applied to the land.

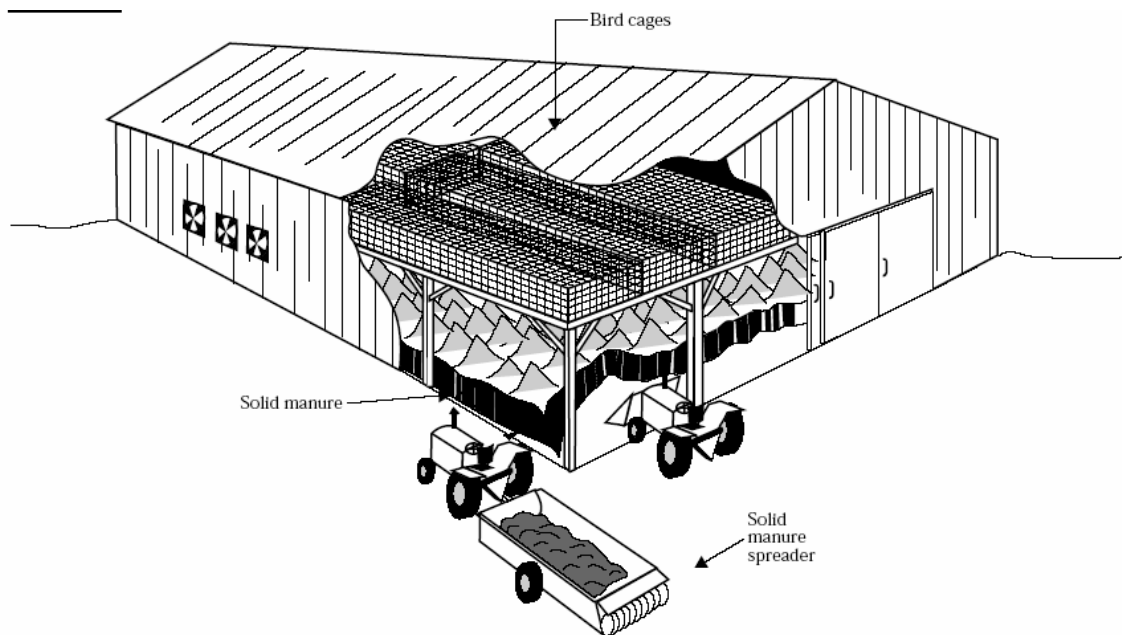


Figure 2-21 Manure accumulates under cages in “high-rise” house for layers

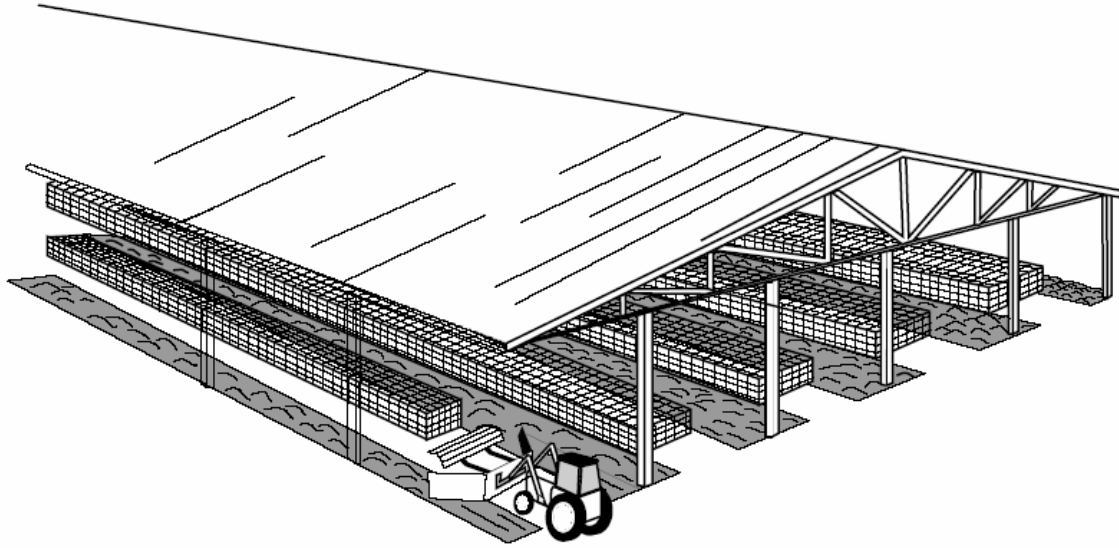


Figure 2-22 Litter from poultry operations may be stored on the floor of the facility until scraped after several cycles of birds

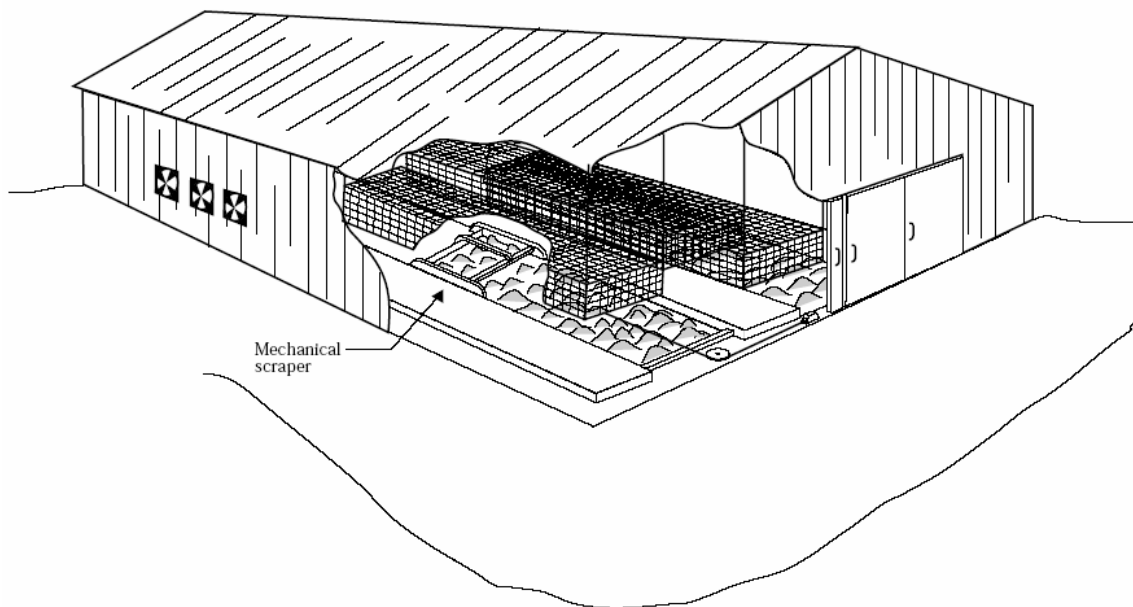


Figure 2-23 Solid waste may be scraped regularly (possibly by mechanical scraper) from facility for transport to the field

2.2 Agricultural Waste Characteristics

Wastes and residue described in this chapter are of an organic nature and agricultural origin. Some other wastes of nonagricultural origin that may be managed within the agricultural sector are also included. Information and data presented can be used for planning and designing waste management systems and system components and for selecting waste handling equipment.

In most cases a single value is presented for a specific waste characteristic. This value is presented as a reasonable value for facility design and equipment selection for situations where site specific data are not available. Waste characteristics are subject to wide variation; both greater and lesser values than those presented can be expected. Therefore, much attention is given in this chapter to describing the reasons for data variation and to giving planners and designers a basis for seeking and establishing more appropriate values where justified by the situation.

Onsite waste sampling, testing, and data collection are valuable assets in waste management system planning and design and should be used where possible. Such sampling can result in greater certainty and confidence in the system design and in economic benefit to the owner. However, caution must be exercised to assure that representative data and samples are collected. Characteristics of “as excreted” manure are greatly influenced by the effects of weather, season, species, diet, degree of confinement, and stage of the production/reproduction cycle. Characteristics of stored and treated wastes are strongly affected by such actions as sedimentation, flotation, and biological degradation in storage and treatment facilities.

2.2.1 Definitions of waste characterization terms

Table 2–1 gives definitions and descriptions of waste characterization terms. It includes abbreviations, definitions, units of measurement, methods of measurement, and other considerations for the physical and chemical properties of manure, waste, and residue.

The first four physical properties—weight (Wt), volume (Vol), total solids (TS), and moisture content (MC)—are important to agricultural producers and facility planners and designers. They describe the amount and consistency of the material to be dealt with by equipment and in treatment and storage facilities. The first three of the chemical constituents—nitrogen (N), phosphorus (P), and potassium (K)—are also of great value to waste systems planners, producers, and designers. Land application of agricultural waste is the primary waste utilization procedure, and N, P, and K are the principal components considered in development of an agricultural waste management plan.

Total solids and the fractions of the total solids that are volatile solids (VS) and fixed solids (FS) are presented. Volatile solids and fixed solids are sometimes referred to, respectively, as total volatile solids (TVS) and total fixed solids (TFS). Characterization of these solids gives evidence of the origin of the waste, its age and previous treatment,

its compatibility with certain biological treatment procedures, and its possible adaptation to mechanical handling alternatives.

Table 2.1 Definitions and descriptions of waste characterization terms (% w.b. is percent measured on a wet basis, and % d.b. is percent measured on a dry basis)

Term	Abbreviation	Units of measure	Definition	Method of measurement	Remarks
Physical Properties					
Weight	Wt	lb	Quantity or mass.	Scale or balance.	
Volume	Vol	ft ³ ; gal	Space occupied in cubic units.	Place in or compare to container of known volume; calculate from dimensions of containment facility.	
Moisture content	MC	%	That part of a waste material removed by evaporation and oven drying at 217 °F (103 °C).	Evaporate free water on steam table and dry in oven at 217 °F for 24 hours or until constant weight.	Moisture content (%) plus total solids (%) equals 100%.
Total solids	TS	% % w.b.; % d.w.	Residue remaining after water is removed from waste material by evaporation; dry matter.	Evaporate free water on steam table and dry in oven at 217 °F for 24 hours or until constant weight.	Total of volatile and fixed solids; total of suspended & dissolved solids.
Volatile solids	VS; TVS	% % w.b.; % d.w.	That part of total solids driven off as volatile (combustible) gases when heated to 1112 °F (600 °C); organic matter.	Place total solids residue in furnace at 1112 °F for at least 1 hr.	Volatile solids determined from difference of total and fixed solids.
Fixed solids	FS; TFS	% % w.b.; % d.w.	That part of total solids remaining after volatile gases driven off at 1112 °F (600 °C); ash.	Determine weight (mass) of residue after volatile solids have been removed as combustible gases when heated at 1112 °F for at least 1 hr.	Fixed solids equal total solids minus volatile solids.
Dissolved solids	DS; TDS	% % w.b.; % d.w.	That part of total solids passing through the filter in a filtration procedure.	Pass a measured quantity of waste material through 0.45 micron filter using appropriate procedure; evaporate filtrate and dry residue to constant weight at 217 °F.	Total dissolved solids (TDS) may be further analyzed for volatile solids and fixed dissolved solids parts.
Suspended solids	SS TSS	% % w.b.; % d.w.	That part of total solids removed by a filtration procedure.	May be determined by difference between total solids and dissolved solids.	Total suspended solids may be further analyzed for volatile and fixed suspended solids parts.

Table 2.1 Definitions and descriptions of waste characterization terms — Continued

Term	Abbreviation	Units of measure	Definition	Method of measurement	Remarks
Chemical Properties					
Ammoniacal nitrogen (total ammonia)		mg/L μg/L	Both NH ₃ and NH ₄ nitrogen compounds.	Common laboratory procedure uses digestion, oxidation, and reduction to convert all or selected nitrogen forms to ammonium that is released and measured as ammonia.	Volatile and mobile nutrients; may be a limiting nutrient in land spreading of wastes and in eutrophication.
Ammonia nitrogen	NH ₃ -N	mg/L μg/L	A gaseous form of ammoniacal nitrogen.		
Ammonium nitrogen	NH ₄ -N	mg/L μg/L	The positively ionized (cation) form of ammoniacal nitrogen.		Can become attached to the soil or used by plants or microbes.
Total kjeldahl nitrogen	TKN	mg/L μg/L	The sum of organic nitrogen and ammoniacal nitrogen.		
Nitrate nitrogen	NO ₃ -N	mg/L μg/L	The negatively ionized (anion) form of nitrogen that is highly mobile.		Nitrogen in this form can be lost by denitrification, percolation, runoff, and plant microbial utilization.
Total nitrogen	TN N	%; lb	The summation of nitrogen from all the various nitrogen compounds listed above.		Macro-nutrient for plants.
Phosphorus	P	%; lb	Acid-forming element that combines readily with oxygen to form the oxide P ₂ O ₅ . As a plant nutrient, it promotes rapid growth, hastens maturity, and stimulates flower, seed, and fruit production.	Laboratory procedure uses digestion and/or reduction to convert phosphorus to a colored complex; result measured by spectrophotometer.	Critical in water pollution control; may be a limiting nutrient in eutrophication and in spreading of wastes.
Potassium	K	%; lb	As a plant nutrient, available potassium stimulates the growth of strong stems, imparts resistance to disease, increases the yield of tubers and seed, and is necessary to form starch, sugar, and oil and transfer them through plants.	Laboratory digestion procedure followed by flame photometric analysis to determine elemental concentration.	
5-day Biochemical Oxygen Demand	BOD ₅	lb of O ₂	That quantity of oxygen needed to satisfy biochemical oxidation of organic matter in waste sample in 5 days at 68 °F (20 °C).	Extensive laboratory procedure of incubating waste sample in oxygenated water for 5 days and measuring amount of dissolved oxygen consumed.	Standard test for measuring pollution potential of waste materials that could be discharged to surface water.
Chemical Oxygen Demand	COD	lb of O ₂	Measure of oxygen consuming capacity of organic and some inorganic components of waste materials.	Relatively rapid laboratory procedure using chemical oxidants and heat to fully oxidize organic components of waste.	Estimate of total oxygen that could be consumed in oxidation of waste material.

Waste that has a very high water content may be characterized according to the amounts of solids that are dissolved and/or suspended. Dissolved solids (DS) or total dissolved solids (TDS) are in solution. Suspended solids (SS) or total suspended solids (TSS) float or they are kept buoyant by the velocity or turbulence of the wastewater.

Wastes are often given descriptive names that reflect their moisture content, such as liquid, slurry, semisolid and solid. Wastes that have a moisture content of 95 percent or more exhibit qualities very much like water and are called liquid waste or liquid manure. Wastes that have moisture content of about 75 percent or less exhibit the properties of a solid and can be stacked and hold a definite angle of repose. They are called solid manure or solid waste. Wastes that have between about 75 and 95 percent moisture content—25 and 5 percent solids—are semi-liquid (slurry) or semi-solid. Because wastes are heterogeneous and inconsistent in their physical properties, the moisture content and range indicated above must be considered generalizations subject to variation and interpretation.

Table 2–1 also lists physical and chemical properties of livestock and other organic agricultural wastes. Data on biological properties, such as numbers of specific micro-organisms, are not presented in this chapter. Micro-organisms are of concern as possible pollutants of ground and surface water, but they are not commonly used as a design factor for no-discharge waste management systems that use wastes on agricultural land.

The terms manure, waste, and residue are sometimes used synonymously. In this section **manure** refers to combinations of feces and urine only, and **waste** includes manure plus other material, such as bedding, soil, wasted feed, and water that is wasted or used for sanitary and flushing purposes. Small amounts of wasted feed, water, dust, hair, and feathers are unavoidably added to manure and are undetectable in the production facility. These small additions must be considered to be a part of manure and a part of the “as excreted” characteristics presented. **Litter** is a specific form of poultry waste that results from “floor” production of birds after an initial layer of a bedding material, such as wood shavings, is placed on the floor at the beginning of and perhaps during the production cycle.

Because of the high moisture content of “as excreted” manure and treated waste, their specific weight is very similar to that of water—62.4 pounds per cubic foot. Some manure and waste that have considerable solids content can have a specific weight of as much as 105 percent that of water. Some dry wastes, such as litter, that have significant void space can have specific weight of much less than that of water. Assuming that wet and moist wastes weigh 60 to 65 pounds per cubic foot is a convenient and useful estimate for planning waste management systems. Odors are associated with all livestock production facilities. Animal manure is a common source of significant odors, but other sources, such as poor quality or spoiled feed and dead animals, can also be at fault. Freshly voided manure is seldom a cause of objectionable odor, but manure that accumulates or is stored under anaerobic conditions does develop unpleasant odors. Such wastes can cause complaints at the production facility when the waste is removed from storage or when it is spread on the fields. Manure-covered animals and ventilation air

exhausted from production facilities can also be significant sources of odor. The best insurance against undesirable odor emissions is waste management practices that quickly and thoroughly remove wastes from production facilities and place them in treatment or storage facilities or apply them directly to the soil.

2.2.2 Units of Measure

Waste production from livestock is expressed in pounds per day per 1,000 pounds of livestock live weight (lb/d/1000#). Volume of waste materials is expressed in cubic feet per day per 1,000 pounds of live weight (ft³/d/1000#). Food processing waste is recorded in cubic feet per day (ft³/d), or the source is included as in cubic feet per 1,000 pounds of apples processed. In this chapter English units are used exclusively for weight, volume, and concentration data for manure, waste, and residue.

The concentration of various components in waste is commonly expressed as milligrams per liter (mg/L) or parts per million (ppm). One mg/L is 1 milligram (weight) in 1 million parts (volume); for example, 1 liter. One ppm is 1 part by weight in 1 million parts by weight. Therefore, mg/L equals ppm if a solution has a specific gravity equal to that of water.

Generally, substances in solution up to concentrations of about 7,000 mg/L do not materially change the specific gravity of the liquid, and mg/L and ppm are numerically interchangeable. Concentrations are sometimes expressed as mg/kg or mg/1000g, which are the same as ppm.

Occasionally, the concentration is expressed in percent. A 1 percent concentration equals 10,000 ppm. Very low concentrations are sometimes expressed as micrograms per liter (mg/L). A microgram is 1 millionth of a gram.

Various solid fractions of a manure, waste, or residue, when expressed in units of pounds per day or as a concentration, generally are measured on a wet weight basis (% w.b.), a percentage of the “as is” or wet weight of the material. In some cases, however, data are recorded on a dry weight basis (% d.w.), a percentage of the dry weight of the material. The difference in these two values for a specific material is most likely very large. Nutrient and other chemical fractions of a waste material, expressed as a concentration, may be on a wet weight or dry weight basis, or expressed as pounds per 1,000 gallons of waste.

Amounts of the major nutrients, nitrogen (N), phosphorus (P), and potassium (K), are always presented in terms of the nutrient itself. Only the nitrogen quantity in the ammonium compound (NH₄) is considered when expressed as ammonium nitrogen (NH₄-N). Commercial fertilizer formulations for nitrogen, phosphorus, and potassium and recommendations are expressed in terms of N, P₂O₅, and K₂O.

2.2.3 Animal waste characteristics

“As excreted” manure

Daily “as excreted” manure production data are presented where possible in pounds per day per 1,000 pounds livestock live weight (lb/d/1000#) for typical commercial animals and birds. Units of cubic feet per day per 1,000 pounds live weight (ft³/d/1000#) allow waste production to be calculated on a volumetric basis. Moisture content and total solids are given as a percentage of the total wet weight (% w.b.) of the manure. Total solids are also given in units of lb/d/1000#. Other solids data and the nutrient content of the manure are presented in units of lb/d/1000# on a wet weight basis.

“As excreted” manure characteristics are the most reliable data available. Manure and waste properties resulting from other situations, such as flushed manure, feedlot manure, and poultry litter, are the result of certain “foreign” materials being added and/or some manure components being lost from the “as excreted” manure. Much of the variation in livestock waste characterization data in this chapter and in other references results largely from the uncertain and unpredictable additions to and losses from the “as excreted” manure.

Livestock manure and waste produced in confinement and semi-confinement facilities are of primary concern and are given the greatest consideration in this chapter. Manure from unconfined animals and poultry, such as those on pasture or range, are of lesser significance because handling and distribution problems are not commonly encountered.

Foreign material in manure

Foreign material commonly added to manure in the production facility are 1) bedding (litter), 2) wasted and spilled feed and water, 3) flush water, 4) rainfall, and 5) soil. These are often added in sufficient quantities to change the basic physical and chemical characteristics of the manure. The resulting combination of manure and foreign material is called waste. Dust, hair, and feathers are also added to manure and waste in limited amounts. Hair and feathers, especially, can cause clogging problems in manure handling equipment and facilities though the quantities may be small. Other adulterants are various wood, glass, and plastic items, and dead animals and birds.

Dairy

Manure characteristics for lactating and dry cows and for heifers are listed in table 4–5. These data are appropriate for herds of moderate to high milk production. Quantities of dairy manure vary widely from small cows to large cows and between cows at low production and high production levels. Figure 2–1 more accurately reflects these quantities of “as excreted” manure total solids and volatile solids where more precise data are desired. Dairy feeding systems and equipment often allow considerable feed waste, which in most cases is added to the manure. Feed waste of 10 percent can result in an additional 40 percent of total solids in a dairy waste. Dairy cow stalls are often covered with bedding materials that improve animal comfort and cleanliness. Virtually all of the organic and inorganic bedding materials used for this purpose will eventually be pushed,

kicked, and carried from the stalls and added to the manure. The characteristics of these bedding materials will be imparted to the manure.

Milking centers—the milk house, milking parlor, and holding area—can produce about 50 percent of the waste volume, but only about 15 percent of the total solids in a dairy enterprise. Because this very dilute wastewater has different characteristics than the waste from the cow yard, it is sometimes managed by a different procedure. About 5 to 10 gallons of fresh water per day for each cow milked are used in a milking center where flushing of wastes is not practiced. However, where manure flush cleaning and automatic cow washing are used, water use can be 150 gal/d/cow or more.

Lagoons that receive a significant loading of manure, such as from the holding area or the cow feed yard, generally operate in an anaerobic mode. Supernatant (upper liquid layer of the lagoon) concentration in an anaerobic lagoon is much greater than that in an aerobic lagoon. Anaerobic dairy lagoonsludge accumulates at a rate of about 0.073 cubic foot per pound of total solids added to the lagoon. This is equivalent to about 266 cubic feet per year for each 1,000 pound lactating cow equivalent (100% of waste placed in lagoon).

Beef

Beef wastes of primary concern are those from the feedlots. The characteristics of these solid wastes vary widely because of such factors as climate, diet, feedlot surface, animal density, and cleaning frequency. The soil in unsurfaced beef feedlots is readily incorporated with the manure because of the animal movement and cleaning operations.

Wasted feed is an important factor in the characterization of beef wastes. Beef feedlot runoff water also exhibits wide variations in character. The influencing factors that are responsible for feedlot waste variations are similar to those listed for solid wastes. Surfaced feedlots produce more runoff than unsurfaced lots.

Swine

Swine waste and waste management systems have been widely studied, and much has been reported on swine manure properties. Wasted feed significantly changes manure characteristics. A 10 percent feed waste increases manure total solids by 40 percent. Ration components can make a significant difference in manure characteristics. Corn, the principal grain in swine rations, has a high digestibility (90%). Wasted feed further increases the necessary size of storage units and lagoon facilities needed for manure from rations of lower digestibility.

A common procedure for collecting and storing swine waste under slatted floors is in deep or shallow tanks that may be allowed to overflow to lagoons or longer-term storage units. Daily accumulation of such waste cannot be accurately predicted.

Swine waste storage structures and facilities must make allowances for wasted water. Small pigs, especially, play with automatic waterers and can waste up to 3 gallons of

water per day per head. Anaerobic lagoons have been used extensively for swine waste in the United States. Supernatant, the upper liquid layer, of properly operating swine lagoons is often brownish, chocolate, or purple. Sludge accumulates in a good anaerobic swine lagoon at a rate of 0.0485 cubic foot per pound of total solids placed in the lagoon. This is about 12 cubic feet per grower/finisher equivalent annually.

Poultry

In a litter (floor) system, bedding materials, whether wood, crop, or other residue, are largely organic matter that has little nutrient component. Litter moisture in a well-managed house generally is in the range of 25 to 35 percent. Higher moisture levels in the litter result in greater weight and reduced levels of nitrogen.

Most broiler houses are now cleaned out one or two times a year. Growers generally have five or six flocks of broilers each year, and it is fairly common to take the "cake" out after each flock. The cake is generally 1 to 2 inches of material. About 2 or 3 inches of new litter is placed on the floor before the next flock. Much of the waste characterization data for broiler litter are based on five or six cycles per year. The birds produce the same amount of N, P, and K per day. However, the density and moisture content of the litter is different with a more frequent cleanout and the nutrients are less concentrated. The amount of nutrients is less compared to the litter volume because less time is allowed for the nutrients to accumulate. A further complication is that nitrogen is lost to the atmosphere during storage while fresh manure is being continually deposited.

High-rise layer houses use no bedding and store manure for up to a year. Bird densities in high-rise houses have increased greatly in recent years, and the manure characteristics have been subject to great change. Use of current data for high-rise manure characterization is important. As in other livestock operations, feed waste greatly increases the volume and organic content of the waste. A 10 percent wastage of feed, when added to the manure, increases total solids by 42 percent.

Digestibility of DM	-	-	-	-	-	-	-
Digestibility of N			-				
Body Weight	-	-					
Days in Milk	-						
Milk True Protein	-						
Conc. CP diet	-	-	-	-	-	-	-
N Assump.	-	-	-	-	-	-	-
Init. Body Wt.		-		-	-		
Final BW		-		-	-		
DOF		-		-	-		
Moist. manure	-	-	-	-	-	-	-
Stand. Ref. Wt.		-					
Kcal (i,h, m)				-			
egg wt; prod				??			
gest. Length						-	
litter size						-	
gest. lean tissue						-	
ave. daily FI				-	-	-	-
ave fat free lean %					-		
ave. daily gain					-		
DM conc.				-	-	-	-
ave fat free gain				-			
Lean tissue gain,							-
lact. Length							-
litter wt at birth							-
litter wt at weaning							-

3.2 Dairy:

In the United States about half the animals on a dairy farm are not capable of milking because they have not had their first calf. If you have 100 “milking cows” on a dairy, then you have about 100 heifers that are not milking. So, if the database only contains milking cows then you need to calculate the cows that are not milking and younger. Also, out of the 100 “milking cows” in the example above, about 15% of those cows are dry (not milking) and pregnant. If the database includes dry and milking cows, then you need to split the number into true lactating and dry cows. However, if the database only provides actual milking cows, the further calculations are necessary. For example, if you are given a number of say 170 actual milking cows, then this would constitute about 85% of the milking cows that number 200 cows. Also, the heifers would be about 200 cows. Therefore, the cows in the herd are 400 (200 heifers, 170 milking, 30 dry). You might

also be given just the number of cows and the total milk produced. One needs to determine from the database if the cows given are all the cows, the milking and dry cows, or just the actual milking cows. Appropriate calculations should follow to obtain the correct number of cows that are milking, dry, and non-lactating heifers.

Some of the equations for the dairy DMe (dry matter excreted) and Ne (nitrogen excreted) estimates are based on regression equations and to double check the data the following system will be used.

Assumptions:

1. Energy requirements: 10 Mcal/day for maintenance; 0.78 Mcal/kg milk.
2. Feed energy concentration on average: 1.65 Mcal/kg DM.
3. Crude protein (CP) concentration of feed: 0.175 g CP/g feed
4. CP to N in milk: 6.38g CP/g N or 0.15674 g N/g CP
5. CP to N in feed: 6.25g CP/g N or 0.16 g N/g CP
6. Milk CP concentration: 0.032 g CP/g milk
7. Body stores: at equilibrium
8. Proportion of excreted N in urine and feces: 44.3 % in urine, 55.7% in feces.
9. N urea as % of total N in urine: 70%

One can calculate the DM intake as shown in the following example. Assume that:

1. the energy requirement for maintenance is 10 Mcal/day and
2. the energy requirements for milk is 0.78 Mcal/kg.
3. on the average feed energy concentration is 1.65 Mcal/kg DM.
4. 30 kg milk/day is taken from the database.

The energy requirements would be $10 + 30 \times 0.78 = 33.4$ Mcal/day. The DM intake would then be $33.4 / 1.65 = 20.24$ kg DM/day. Assume the crude protein content is 0.175 g protein/g feed DM. Then total protein intake would be $20.24 \times 0.175 = 3.542$ kg/day or 3,542 g/day of crude protein (CP). Convert this to g N per day by dividing by 6.25 (assuming protein is 16% N). Grams of N intake per day = $3,542 / 6.25 = 566.7$ g N intake/day. Milk CP content is about 0.032 g CP/g milk. The total CP in the milk is $30 \times 0.032 = 0.96$ kg or 960 g CP or $960 / 6.38 = 150.5$ g N in milk. Therefore the total N excreted is N intake – N milk = $566.7 - 150.5 = 416.2$ g N excreted.

One assumes that over the lactation the total body N stores are in equilibrium. The big assumption that is probably the most difficult is what proportion of the N excreted ends up in the urine and what proportion ends up in the feces. For now let's assume (Broderick, JDS. 2003. 86:1370-1381) that 44.3% of the N excreted ends up in the urine and 55.7% ends up in the feces. We can also assume that about 70% of the N in the urine is associated with urea.

Top states for milk production are California, Wisconsin, New York, Pennsylvania, and Minnesota. In general, milk production is not seasonal.

Input data needed for excretion equations for dairy (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animals on the dairy (total lactating and non-lactating)	see above for discussion
Milk Production	Usually provided
Dry matter intake	This is usually based on body weight and average body weights are used.
Dry matter digestibility	This number is not known and 60-65% is usually used. 60% currently used.
Body weight:	Not provided. Averages used (624, 755, 437 kg used for lactating, dry and heifers respectively)
Days in milk	normally not in national databases.
Milk true protein	Normally not provided. Can be estimated from crude protein (CP) in milk that is estimated at 3.2% but this is just an estimate.
Concentration of crude protein in diet:	Not given. Estimated at 0.175 g CP/g feed for lactating, 0.144 g CP/g feed for dry cows and 0.1106 g CP/g feed for heifer diets.
Nitrogen and urea assumptions	Assume (Broderick, JDS. 2003. 86:1370-1381) that 44.3% of the N excreted ends up in the urine and 55.7% ends up in the feces. Assume that about 70% of the N in the urine is associated with urea.
Moisture content of manure	Information not available. Estimated to be 87% moisture

The complete set of variables and default values used for dairy:
(All references to equations and pages are to Proposal for ASAE D384.1)

Variable	Description	Units				defaults	defaults	defaults
			Lactating	Dry	Heifer	Lactating	Dry	Heifer
Animal Number	number of animals	animal numbers	x	x	x			
Milk	Milk production	kg/animal/day	x			40	0	0
MTP	Milk true protein	g/g of milk/day	-			0.035	0	0
DIM	days in milk	Days	-			100	0	0
BW	average live body weight	Kg	-	-	-	624	755	437
DMI ^a	Dry matter intake	kg dry feed/animal/day	-	-	-	21.216	10.57	8.3467
Ccp	concentration of crude protein of total ration	g crude protein/g dry feed	-	-	-	0.17534	0.14428	0.11058
DMD ^b	Dry matter digestibility	% digestibility			-	60	60	60
CPintake	grams of crude protein/day	crude protein intake				3720	1525	923

Manure moisture	moisture content of manure	fraction	-	-	-	0.87	0.87	0.87
Nitrogen 1	Urine N:fecal N	proportion	-	-	-	50:50	50:50	50:50
Nitrogen 2	Urea in urine as N	fraction	-	-	-	0.70	0.70	0.70
DM _E	Dry matter (solids) excretion	kg DM/animal/day						
N _E	Total nitrogen excretion	g N/animal/day						

3.3 Beef:

Beef operations in the US can be broken into three main segments: cow-calf, calf after weaning, and finishing. The cow-calf segment is about 7 months or 210 days and the calves are about 250 kg when weaned. About one third of the calves weaned go directly into the finishing phase (feedlots) for about 250 days. About two thirds of the calves weaned go to many different feeding operations where the diets range from poor to very good. These calves are fed from 90 to 200 days and then moved into feedlots for finishing where they stay for about 150 days. Some of these 2/3 calves may be returned the breeding program and become part of the cow-calf operation.

A break down of the numbers of animals in each segment can be seen from the following description from Jim Oltjen: *About 33 million mother beef cows, another 11 million dairy cows. At any one time about 11 million steers and heifers on feed, with another 16 million on grass or something else. Note that about 80% of the mother cows wean a calf.* From this information one can neglect the dairy cows because they are accounted for in the Dairy system above. About 60 million animals (33+11+16) remain. Depending on what data is available. If finishing animals are available in the database, then one can assume they comprise about 18.3% of the beef cows. The beef cows (mothers) comprise about 55% of the animals and the remaining 26.7% is the most difficult to determine. If the data are available, we can use all three categories, if not, then we will need to make further assumptions.

Cow-calf and post weaning operations are throughout the US but the finishing (or feedlot) operations are only in a few locations. The top states for beef production are Texas, Missouri, Nebraska, and Oklahoma. Beef production might be seasonal to some extent where more beef is consumed during summer months.

Input data needed for excretion equations for beef (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	Information available depends on database and some estimates will be made based on above discussion.
Dry matter digestibility	Not known. Assume to be 80%. Might be high for non-finishing animals.

Dry matter intake	Not known. Calculate based on 2% of body weight.
Body Weight	Not known. Assume average body weight to be 446 kg for finishing animal. Assume body weight to be 550 kg for cow. Assume body weight to be 250 kg for animal at weaning.
Body Weight	Assume final body weight – initial body weight is zero for cow on maintenance. Assume final body weight – initial body weight is 250 kg for cow with calf.
Initial body weight	Not known. Assume to be 338 kg.
Final body weight	Not known. Assume to be 554 kg.
Days on feed for finishing	Not known. Assume to be 153 days.
Standard reference weight for expected body fat	Not known. Assume to be 478 kg.
Nitrogen and urea assumptions	Assume (Broderick, JDS. 2003. 86:1370-1381) that 44.3% of the N excreted ends up in the urine and 55.7% ends up in the feces. Assume that about 70% of the N in the urine is associated with urea.
Moisture content of manure	Assume moisture content is 92%.

The complete set of variables and default values used for beef:
(All references to equations and pages are to Proposal for ASAE D384.1)

Variable	Description	Units	defaults					
			Finishin	Cow-calf	Maintena			
			g	pairs	nce	Finishing	pairs	Maintena
Animal Number	number of animals	animal numbers	x	x	x			
BWf ²	Live body weight at finish of feeding period (market weight)	kg	-			554	550	550
BWi ²	Live body weight at start of feeding period (purchase weight)	kg	-			338	250	550
SRW ³	Standard reference weight for expected final body fat	478 kg for Choice (28% marbling) 462 kg for Select (26.8% marbling)	-			478		
DMI	Dry matter intake	g dry feed / day (2% of BWa)	-	-	-	8920	2700	2200
DMD	Dry matter digestibility of total	% of DMI	-	-	-	80	80	80

	ration							
Ccp	Concentration of crude protein of total ration	g of protein / g of dry feed	-	-	-	0.1345	0.1345	0.1345
DOF	Days on feed for individual ration	days	-	-	-	153	205	150
BWa	Average BW	kg	-	-	-	446	550+250	550
Manure moisture	moisture content of manure	Fraction	-	-	-	0.92	0.92	0.92
Nitrogen 1	Urine N:fecal N	proportion	-	-	-	50:50	50:50	50:50
Nitrogen 2	Urea in urine as N	Fraction	-	-	-	0.70	0.70	0.70
Urine Fraction	Fraction of urine in total manure	fraction	-	-	-	0.31	0.31	0.31
Dens_manure	Manure density	Kg/m ³	-	-	-	1000	1000	1000
water	Water addition to manure	M ³ /animal	-	-	-	0	0	0
DM _E	Dry matter excretion per animal per day	g of dry matter/day/animal						
DM _{E-T}	Total dry matter excretion per finished animal	g of dry matter/finished animal						
N _{E-T}	Total nitrogen excretion per finished animal	g of nitrogen/finished animal						

3.4 Swine:

The swine industry is a specialized industry similar to poultry. The four categories of swine are weaning, finishing, gestating sows and lactating sows. More than one diet can be used in each category complicating the exact N excretion on a daily basis. Equations are for days on feed so the equations used for swine must be divided by days on feed to convert to daily excretion.

Input data needed for excretion equations for weaning pigs (5-20 kg) (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	From database.
Nitrogen and urea assumptions	Not certain. Assume 30% N in feces, 70% in urine. Urea is 70% of N in urine.
Moisture content of manure	Manure moisture content assumed to be 90%.

Variables and default values below used for weaning pigs.

Variable	Description	Units	Swine Weaning	defaults Weaning
Animal Number	number of animals	animal numbers	x	
BWi-n	initial body weight	kg	-	5
BWf-n	final body weight	Kg	-	20
DOFn	days on feed to finish animal	Days	-	36
FFLGg	average fat-free lean gain	G	-	300
ADFI_n	average daily feed intake over finishing period (as fed)	g/day	-	625
FI_n	Feed intake per finished animal (nursery phase)	g/finished animal	-	22500
Ccp	concentration of crude protein in total wet ration	%	-	21.92
Cdm	dry matter concentration of diet	%	-	88
DMD	dry matter digestibility of total ration	%	-	80
Manure moisture	moisture content of manure	fraction	-	0.90
Nitrogen 1	Urine N:fecal N	Proportion	-	2.33
Nitrogen 2	Urea in urine as N	fraction	-	0.70
Manure fraction	Fraction of urine in total manure	fraction	-	0.31
Dens_manure water	Manure density	Kg/m ³	-	1000
	Water addition to manure	M ³ /animal	-	0.038
DM _{E-T}	Total dry matter excretion per finished animal or period (e. g. lactation)	g/ finished animal or g/period		
N _{E-T}	Total nitrogen excretion per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{I-T}	Nitrogen intake per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{R-T}	Nitrogen retained per finished animal or period (e. g. lactation)	g/finished animal or g/period		

Input data needed for excretion equations for finishing pigs (20-120 kg) (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	From database.
Nitrogen and urea assumptions	Not certain. Assume 30% N in feces, 70% in urine. Urea is 70% of N in urine.
Moisture content of manure	Manure moisture content assumed to be 90%.

Variables and default values below used for finishing pigs.

Variable	Description	Units	Swine Finishing	Defaults Finishing
Animal Number	number of animals	animal numbers	x	
Bwi	initial body weight	Kg	-	20
BWf	final body weight	Kg	-	120
DOFg	days on feed to finish animal	Days	-	120
DPf	average dressing percent	%	-	75
FFLPf	average fat free lean % at final weight	%	-	50
ADFIg	average daily feed intake over finishing period (as fed)	g/day	-	2346.591
Fig	feed intake per finished animal (as fed)	g/finished animal	-	281590.909
Ccp	concentration of crude protein in total wet ration	%	-	15.81
Cdm	dry matter concentration of diet	%	-	88
DMD	dry matter digestibility of total ration	%	-	82
Ave BW	average body weight	Kg		70
Manure moisture	moisture content of manure	Fraction	-	0.90
Nitrogen 1	Urine N:fecal N	Proportion	-	2.33
Nitrogen 2	Urea in urine as N	Fraction	-	0.70
Manure fraction	Fraction of urine in total manure	fraction	-	0.31
Dens_manure	Manure density	Kg/m ³	-	1000
water	Water addition to manure	M ³ /animal	-	0.0152
DM _{E-T}	Total dry matter excretion per finished animal or period (e. g. lactation)	g/ finished animal or g/period		
N _{E-T}	Total nitrogen excretion per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{I-T}	Nitrogen intake per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{R-T}	Nitrogen retained per finished animal or period (e. g. lactation)	g/finished animal or g/period		

Input data needed for excretion equations for gestating sows (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	From database.

Nitrogen and urea assumptions	Not certain. Assume 30% N in feces, 70% in urine. Urea is 70% of N in urine.
Moisture content of manure	Manure moisture content assumed to be 90%.

Variables and default values below used for gestating pigs.

Variable	Description	Units	Swine Gestating	defaults Gestating
Animal Number	number of animals	animal numbers	x	
GLTG	gestation lean tissue gain	kg /115 days	-	17.6
GL	gestation period length	days	-	115
LITTER	number of pigs in a litter	number	-	12
ADFIgs	average daily feed intake during gestation (as fed)	g/day, FI = 1% of BW %, CP intake =	-	2272.73
Ccp	concentration of crude protein	259g/d	-	11.4
Cdm	dry matter concentration of diet	%	-	88
DMD	dry matter digestibility of total ration	%	-	82
BW	average body weight	kg		200
Manure moisture	moisture content of manure	Fraction	-	0.90
Nitrogen 1	Urine N:fecal N	proportion	-	2.33
Nitrogen 2	Urea in urine as N	fraction	-	0.70
Manure fraction	Fraction of urine in total manure	fraction	-	0.31
Dens_manure	Manure density	Kg/m ³	-	1000
water	Water addition to manure	M ³ /animal	-	0.019
DM _{E-T}	Total dry matter excretion per finished animal or period (e. g. lactation)	g/ finished animal or g/period		
N _{E-T}	Total nitrogen excretion per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{I-T}	Nitrogen intake per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{R-T}	Nitrogen retained per finished animal or period (e. g. lactation)	g/finished animal or g/period		

Input data needed for excretion equations for lactating sows (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	From database.

Nitrogen and urea assumptions	Not certain. Assume 30% N in feces, 70% in urine. Urea is 70% of N in urine.
Moisture content of manure	Manure moisture content assumed to be 90%.

Variables and default values below used for lactating pigs.

Variable	Description	Units	Swine Lactating	defaults Lactating
Animal Number	number of animals	animal numbers	x	
LLTG	lactation lean tissue gain	kg	-	-5.3
LL	lactation length	Days	-	20
LW wean	litter weight at weaning	kg	-	50
LW birth	litter weight at birth	kg	-	1.25
ADFI lact	average daily feed intake during lactation (as fed)	g/day	-	5672.73
Ccp	concentration of crude protein (as % as fed)	%	-	17.046
Cdm	dry matter concentration of diet	%	-	88
DMD	dry matter digestibility	%	-	82
BW	average body weight	kg		192
Manure moisture	moisture content of manure	Fraction	-	0.90
Nitrogen 1	Urine N:fecal N	Proportion	-	2.33
Nitrogen 2	Urea in urine as N	Fraction	-	0.70
Manure fraction	Fraction of urine in total manure	fraction	-	0.31
Dens_manure water	Manure density	Kg/m ³	-	1000
	Water addition to manure	M ³ /animal	-	0.038
DM _{E-T}	Total dry matter excretion per finished animal or period (e. g. lactation)	g/ finished animal or g/period		
N _{E-T}	Total nitrogen excretion per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{I-T}	Nitrogen intake per finished animal or period (e. g. lactation)	g/finished animal or g/period		
N _{R-T}	Nitrogen retained per finished animal or period (e. g. lactation)	g/finished animal or g/period		

3.5 Poultry (broilers, turkeys, ducks):

Poultry can be considered broilers, turkeys, layers and other birds such as ducks. We may or may not use ducks for this project but they are included below. Most birds have

several diets during their phase of growth and all equations below are based on the total phase. For example, broilers may have 4 diets: a pre-starter, a starter, a grower and a finisher (or withdraw). But in the equations below the total intake is based on the entire phase not adjusting for the different nutrient contents of every diet. This is probably more of a problem with ruminants but still exist with poultry. Also, some birds, like ducks may be concentrated in certain counties such that most of the duck numbers are in a relatively small geographical area.

Input data needed for excretion equations for broilers, turkeys and ducks (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	From database.
Feed intake	Default dry matter intake numbers used from report assuming 88% moisture in feed: 4,047, 36,720, 17,550, and 5,508 grams for broilers, turkeys (male), turkeys (female), and ducks respectively.
Dry matter retention	0.6884, 0.7479, 0.7479, and 0.6937 for broilers, turkeys (male), turkeys (female), and ducks respectively.
Crude protein concentration (wet basis)	0.1816, 0.2007, 0.1973, and 0.1792 for broilers, turkeys (male), turkeys (female), and ducks respectively.
Nitrogen retention factor	0.6020, 0.5880, 0.5880, and 0.6570 for broilers, turkeys (male), turkeys (female), and ducks respectively.
Nitrogen and uric acid assumptions	Not certain. Assume N excreted contains: 70% uric acid, 3 % urea and 5 % ammonia with the remainder as intact protein, mostly of microbial origin.
Moisture content of manure	Manure moisture content assumed to be 74%.

Input data needed for excretion equations for layers (most values not known; use default values from ASAE D384.1)

Variable	Description
Total animal numbers in each category	From database.
Nitrogen and uric acid assumptions	Not certain. Assume N excreted contains: 70% uric acid, 3 % urea and 5 % ammonia with the remainder as intact protein, mostly of microbial origin.
Moisture content of manure	Manure moisture content assumed to be 75%.

Variables and default values below used for layers.

Variable	Description	Units	Layer	defaults
				Layer

Animal Number	number of animals	animal numbers	x	
FI	feed intake per phase. D.M. intake =88% of FI	kg feed/phase (wet basis) g/day	-	87.238
KCALi	Kcal intake for light layer strains	Kcal	-	270
KCALi	Kcal intake for heavy layer strains	Kcal	-	292
KCALm	Kcal requirement for maintenance	Kcal	-	100
KCALh	Kcal requirement for heat increment	Kcal	-	40
KCALe	Kcal requirement for one egg production	Kcal	-	53
Egg wt	Egg weight for light layers	Grams	-	60
Egg wt	Egg weight for heavy layers	Grams	-	63
Egg prod	fraction of days that eggs are produced	Fraction	-	0.8
Ccp	Crude protein of total ration	g of protein / g of feed (wet)	-	0.1774
Cpro	Crude protein consumption	kg of protein / phase g/day	-	15.4771
Phase	20-80 weeks	Days	-	420
Manure moisture	moisture content of manure	Fraction	-	0.75
Nitrogen 2	Uric acid as percent of N excreted	fraction	-	0.70
Urea_ammonia	Urea and ammonia as percent of N excreted	fraction	-	0.08
Dens_manure	Manure density	Kg/m ³	-	1000
water	Water addition to manure	M ³ /animal	-	0
DM _E	Dry matter excretion per hen per day	g of dry matter/hen - day	-	
N _E	Total nitrogen excretion per hen per day	g of nitrogen/ hen - day	-	

Variables and default values below used for broilers.

Variable	Description	Units	defaults	
			Broiler	Broiler
Animal Number	number of animals	animal numbers	x	
FI	feed intake per phase in DM grams	g feed/phase (dry matter)	-	4047
FI	feed intake per phase. D.M. intake =88% of FI	g feed/phase (wet basis)	-	4599
Cpro	crude protein consumption per day	g crude protein/day	-	835.1
Ccp	concentration of crude protein of total ration	g of protein/g of wet fed	-	0.1816
n	number of phases fed		-	1

DMrf	retention factor for dry matter	fraction	-	0.6884
Nrf	retention factor for nitrogen	fraction	-	0.602
DOF	days on feed	days		47.7
Manure moisture	moisture content of manure	Fraction	-	0.74
Nitrogen 2	Uric acid as percent of N excreted	Fraction	-	0.70
Urea_ammonia	Urea and ammonia as percent of N excreted	fraction	-	0.08
Dens_manure	Manure density	Kg/m ³	-	1000
water	Water addition to manure	M ³ /animal	-	0
DM _E	Dry matter excretion per phase	g of dry matter/phase		
DM _{E-T}	Total dry matter excretion per finished animal	g of dry matter/finished animal		
N _E	Nitrogen excretion per phase	g of nitrogen/phase		
N _{E-T}	Total nitrogen excretion per finished animal	g of nitrogen/finished animal		

Variables and default values below used for male and female turkeys.

Variable	Description	Units	Turkey (male)	Turkey (female)	defaults Turkey (male)	defaults Turkey (female)
Animal Number	number of animals	animal numbers	x	x		
FI	feed intake per phase in DM grams	g feed/phase (dry matter)	-	-	36720	17550
FI	feed intake per phase. D.M. intake =88% of FI	g feed/phase (wet basis)	-	-	41727	19943
Cpro	crude protein consumption per day	g crude protein/day			8373	3935
Ccp	concentration of crude protein of total ration	g of protein/g of wet fed	-	-	0.2007	0.1973
n	number of phases fed		-	-	1	1
DMrf	retention factor for dry matter	fraction	-	-	0.7479	0.7479
Nrf	retention factor for nitrogen	fraction	-	-	0.588	0.588
DOF	days on feed	days			133	105
Manure moisture	moisture content of manure	fraction	-	-	0.74	0.74
Nitrogen 2	Uric acid as percent of N excreted	Fraction	-	-	0.70	0.70
Urea_ammonia	Urea and ammonia as percent of N excreted	fraction	-	-	0.08	0.08
Dens_manure	Manure density	Kg/m ³	-	-	1000	1000

water	Water addition to manure	M ³ /animal	-	-	0	0
DM _E	Dry matter excretion per phase	g of dry matter/phase				
DM _{E-T}	Total dry matter excretion per finished animal	g of dry matter/finished animal				
N _E	Nitrogen excretion per phase	g of nitrogen/phase				
N _{E-T}	Total nitrogen excretion per finished animal	g of nitrogen/finished animal				

4. Housing Emissions Model

4.1 Data for different animal types

The design of housing emission sub-model considers the variation of structural, environmental control, and manure collection methods between different growth stage and species of animals and climatic conditions. For a given type of houses, three different types of manure collection and storage methods can be used, including long term deep pit for indoor manure storage, and scraping and flushing for outside manure storage. The housing emission sub-model will calculate the emissions from a combination of housing and manure collection methods that are commonly used for animal farms.

Key inputs for mechanical and natural ventilation housing models include:

1. Environment conditions:
 - a. dry bulb temperature: temperature taken with a thermometer that's dry, unit is in Kelvin.
 - b. wind speed: wind speed that is measured at the surface and/or 8-meters, unit is in m/s
 - c. relative humidity (if we have to account for manure water loss): An indication of how moist the air is. The amount of water vapor in the air at any given time is usually less than that required to saturate the air. The relative humidity is the percent of saturation humidity generally calculated in relation to saturated vapor density. unit is in %.
 - d. total solar radiation on a horizontal surface (if we have to calculate inside temperature): also called "global irradiance", and is the sum of incident diffuse radiation plus the direct normal irradiance projected onto the horizontal surface.
2. Structure
 - a. surface area covered with manure (floor area occupied by animals)
 - b. ventilation type (mechanical, natural)
 - c. velocity of air above floor
 - d. velocity of air above manure storage pit
 - e. depth and surface area of storage pit
 - f. method used to remove manure from structure (scraper, flush water)
 - g. source and volume of water recycle water
 - h. building dimensions
 - i. under-floor pits
3. Animals
 - a. population in house as function of time
 - b. urination and defecation rates
 - c. concentration of urea in urine
4. Operation
 - a. frequency of manure removal from structure
 - b. frequency of manure removal from storage pit

4.2 Variables and default values for dairy

Variable	Description	Units	Defaults
TimeInConfinement	Proportion of time spent by swine in confinement	proportion	1
TimeOnFeedlot	Proportion of time spent by swine on open feedlot	proportion	0
PitDepth	depth of storage pit	m	1.02
PitSurfaceArea	surface area of storage pit (per animal?)	m ² /sow	2.35
FMRSTRUC	frequency of manure removal from structure	time between clean outs (hours)	24
FMRSPIT	frequency of manure removal from storage pit	time between clean outs (days)	180
animal_capacity	Nominal cow population in single barn	number	120
total_farm_animals	Total number of swine on this farm	number	610
animal_weight	Average single swine weight (kg)	kg	148
animals_exit	Can all swine leave building during day? (1=yes, 0=no)	number	0
clock_time_animals_out	Standard time that animals let out of building (24hr clock)	HH:MM military time	6:00
clock_time_animals_in	Standard time that animals let back into building (24hr clock)	HH:MM military time	20:00
lat_site	Site latitude (deg)	deg	38.5
long_site	Site longitude (deg)	deg	120.5
std_long	Standard longitude for site (deg)	deg	120
build_length	Building length (m)	m	28
build_width	Building width (m)	m	10.1
eave_height	eave height (m)	m	2.49
roof_type	Building roof type (1=gable, 2=monoslope)	number	1
roof_slope	Building roof slope (decimal)	decimal	0.25
building_orientation	angle between building long axis and true north	deg	90
under_floor_pit	Does building have manure pit under (slatted) floor? (1=yes,0=no)	number	0
floor_pit_depth	depth of pit under floor	m	1.02
floor_pit_length	length of pit under floor	m	28
floor_pit_width	width of pit under floor	m	10.1
U_roof	U value for roof (W/m ² -C)	W/m ² -C	0.27
U_sidewall	U value for sidewalls (W/m ² -C)	W/m ² -C	0.43
U_endwall	U value for endwalls (W/m ² -C)	W/m ² -C	0.43
Perim_heat_factor	Perimeter heat loss factor (W/m-C)	W/m ² -C	1.5
mech_or_nat	Mechanical or Natural ventilation (1=mechanical, 2=natural)	number	1
min_vent_per_wt	required for mech vent only - Minimum mech. Vent. rate per animal (m ³ /s/animal)	m ³ /s/animal	0.0057
set_pt_temp	required for mech vent only - Set point temperature (C)	C	20
del_TC	required for mech vent only - Band width of ventilation control unit (C)	C	4
frac_sidewall_open_cold	required for natural ventilation only - fraction sidewall is open - cold weather	decimal	0
frac_sidewall_open_mild	required for natural ventilation only - fraction sidewall is open - mild weather	decimal	0.2

frac_sidewall_open_hot	required for natural ventilation only - fraction sidewall is open - hot weather	decimal	0.35
frac_endwall_open_cold	required for natural ventilation only - fraction endwall is open - cold weather	decimal	0
frac_endwall_open_mild	required for natural ventilation only - fraction endwall is open - mild weather	decimal	0.2
frac_endwall_open_hot	required for natural ventilation only - fraction endwall is open - hot weather	decimal	0.35
nat_vent_Cd	Discharge coefficient for vent openings	decimal	0.6
mu_max_urine	Michaelis-Menten parameter (kg/m ³ s)	kg/m ³ s	0.003
K_urine	Michaelis-Menten parameter (kg/m ³)	kg/m ³	0.056
ph_urine	pH of urine	ph units	8.6
frac_area_urine	Fraction for floor area covered with urine (decimal)	decimal	0.8

4.3 Variables and default values for beef

Variable	Description	Units	Defaults
TimeInConfinement	Proportion of time spent by swine in confinement	proportion	1
TimeOnFeedlot	Proportion of time spent by swine on open feedlot	proportion	0
PitDepth	depth of storage pit	m	1.02
PitSurfaceArea	surface area of storage pit (per animal?)	m ² /sow	2.35
FMRSTRUC	frequency of manure removal from structure	time between clean outs (hours)	24
FMRSPIT	frequency of manure removal from storage pit	time between clean outs (days)	180
animal_capacity	Nominal cow population in single barn	number	120
total_farm_animals	Total number of swine on this farm	number	610
animal_weight	Average single swine weight (kg)	kg	148
animals_exit	Can all swine leave building during day? (1=yes, 0=no)	number	0
clock_time_animals_out	Standard time that animals let out of building (24hr clock)	HH:MM military time	6:00
clock_time_animals_in	Standard time that animals let back into building (24hr clock)	HH:MM military time	20:00
lat_site	Site latitude (deg)	deg	38.5
long_site	Site longitude (deg)	deg	120.5
std_long	Standard longitude for site (deg)	deg	120
build_length	Building length (m)	m	28
build_width	Building width (m)	m	10.1
eave_height	eave height (m)	m	2.49
roof_type	Building roof type (1=gable, 2=monoslope)	number	1
roof_slope	Building roof slope (decimal)	decimal	0.25
building_orientation	angle between building long axis and true north	deg	90
under_floor_pit	Does building have manure pit under (slatted) floor? (1=yes,0=no)	number	0
floor_pit_depth	depth of pit under floor	m	1.02
floor_pit_length	length of pit under floor	m	28

floor_pit_width	width of pit under floor	m	10.1
U_roof	U value for roof (W/m ² -C)	W/m ² -C	0.27
U_sidewall	U value for sidewalls (W/m ² -C)	W/m ² -C	0.43
U_endwall	U value for endwalls (W/m ² -C)	W/m ² -C	0.43
Perim_heat_factor	Perimeter heat loss factor (W/m-C)	W/m ² -C	1.5
mech_or_nat	Mechanical or Natural ventilation (1=mechanical, 2=natural)	number	1
min_vent_per_wt	required for mech vent only - Minimum mech. Vent. rate per animal (m ³ /s/animal)	m ³ /s/animal	0.0057
set_pt_temp	required for mech vent only - Set point temperature (C)	C	20
del_TC	required for mech vent only - Band width of ventilation control unit (C)	C	4
frac_sidewall_open_cold	required for natural ventilation only - fraction sidewall is open - cold weather	decimal	0
frac_sidewall_open_mild	required for natural ventilation only - fraction sidewall is open - mild weather	decimal	0.2
frac_sidewall_open_hot	required for natural ventilation only - fraction sidewall is open - hot weather	decimal	0.35
frac_endwall_open_cold	required for natural ventilation only - fraction endwall is open - cold weather	decimal	0
frac_endwall_open_mild	required for natural ventilation only - fraction endwall is open - mild weather	decimal	0.2
frac_endwall_open_hot	required for natural ventilation only - fraction endwall is open - hot weather	decimal	0.35
nat_vent_Cd	Discharge coefficient for vent openings	decimal	0.6
mu_max_urine	Michaelis-Menten parameter (kg/m ³ s)	kg/m ³ s	0.003
K_urine	Michaelis-Menten parameter (kg/m ³)	kg/m ³	0.056
ph_urine	pH of urine	ph units	8.6
frac_area_urine	Fraction for floor area covered with urine (decimal)	decimal	0.8

4.4 Variables and default values for swine

Variable	Description	Units	Defaults
TimeInConfinement	Proportation of time spent by swine in confinement	proportion	1
TimeOnFeedlot	Proportation of time spent by swine on open feedlot	proportion	0
PitDepth	depth of storage pit	m	1.02
PitSurfaceArea	surface area of storage pit (per animal?)	m ² /sow	2.35
FMRSTRUC	frequency of manure removal from structure	time between clean outs (hours)	24
FMRSPIT	frequency of manure removal from storage pit	time between clean outs (days)	180
Animal_capacity	Nominal cow population in single barn	number	120
total_farm_animals	Total number of swine on this farm	number	610
Animal_weight	Average single swine weight (kg)	kg	148
animals_exit	Can all swine leave building during day? (1=yes, 0=no)	number	0
clock_time_animals_out	Standard time that animals let out of	HH:MM military time	6:00

	building (24hr clock)		
	Standard time that animals let back into		
clock_time_animals_in	building (24hr clock)	HH:MM military time	20:00
lat_site	Site latitude (deg)	deg	38.5
long_site	Site longitude (deg)	deg	120.5
std_long	Standard longitude for site (deg)	deg	120
build_length	Building length (m)	m	28
build_width	Building width (m)	m	10.1
eave_height	eave height (m)	m	2.49
	Building roof type (1=gable,		
roof_type	2=monoslope)	number	1
roof_slope	Building roof slope (decimal)	decimal	0.25
	angle between building long axis and		
building_orientation	true north	deg	90
	Does building have manure pit under		
under_floor_pit	(slatted) floor? (1=yes,0=no)	number	0
floor_pit_depth	depth of pit under floor	m	1.02
floor_pit_length	length of pit under floor	m	28
floor_pit_width	width of pit under floor	m	10.1
U_roof	U value for roof (W/m2-C)	W/m2-C	0.27
U_sidewall	U value for sidewalls (W/m2-C)	W/m2-C	0.43
U_endwall	U value for endwalls (W/m2-C)	W/m2-C	0.43
Perim_heat_factor	Perimeter heat loss factor (W/m-C)	W/m2-C	1.5
	Mechanical or Natural ventilation		
mech_or_nat	(1=mechanical, 2=natural)	number	1
	required for mech vent only - Minimum		
	mech. Vent. rate per animal		
min_vent_per_wt	(m3/s/animal)	m3/s/animal	0.0057
	required for mech vent only - Set point		
set_pt_temp	temperature (C)	C	20
	required for mech vent only - Band		
del_TC	width of ventilation control unit (C)	C	4
	required for natural ventilation only -		
frac_sidewall_open_cold	fraction sidewall is open - cold weather	decimal	0
	required for natural ventilation only -		
frac_sidewall_open_mild	fraction sidewall is open - mild weather	decimal	0.2
	required for natural ventilation only -		
frac_sidewall_open_hot	fraction sidewall is open - hot weather	decimal	0.35
	required for natural ventilation only -		
frac_endwall_open_cold	fraction endwall is open - cold weather	decimal	0
	required for natural ventilation only -		
frac_endwall_open_mild	fraction endwall is open - mild weather	decimal	0.2
	required for natural ventilation only -		
frac_endwall_open_hot	fraction endwall is open - hot weather	decimal	0.35
	required for natural ventilation only -		
nat_vent_Cd	Discharge coefficient for vent openings	decimal	0.6
mu_max_urine	Michaelis-Menten parameter (kg/m3 s)	kg/m3 s	0.003
K_urine	Michaelis-Menten parameter (kg/m3)	kg/m3	0.056
ph_urine	pH of urine	ph units	8.6
	Fraction for floor area covered with urine		
Frac_area_urine	(decimal)	decimal	0.8

4.5 Variables and default values for poultry

Variable	Description	Units	Defaults
TimeInConfinement	Proportation of time spent by swine in confinement	proportion	1
TimeOnFeedlot	Proportation of time spent by swine on open feedlot	proportion	0
PitDepth	depth of storage pit	m	1.02
PitSurfaceArea	surface area of storage pit (per animal?)	m ² /sow	2.35
FMRSTRUC	frequency of manure removal from structure	time between clean outs (hours)	24
FMRSPIT	frequency of manure removal from storage pit	time between clean outs (days)	180
animal_capacity	Nominal cow population in single barn	number	120
total_farm_animals	Total number of swine on this farm	number	610
animal_weight	Average single swine weight (kg)	kg	148
animals_exit	Can all swine leave building during day? (1=yes, 0=no)	number	0
clock_time_animals_out	Standard time that animals let out of building (24hr clock)	HH:MM military time	6:00
clock_time_animals_in	Standard time that animals let back into building (24hr clock)	HH:MM military time	20:00
lat_site	Site latitude (deg)	deg	38.5
long_site	Site longiture (deg)	deg	120.5
std_long	Standard longitude for site (deg)	deg	120
build_length	Building length (m)	m	28
build_width	Building width (m)	m	10.1
eave_height	eave height (m)	m	2.49
roof_type	Building roof type (1=gable, 2=monoslope)	number	1
roof_slope	Building roof slope (decimal) angle between building long axis and true north	decimal	0.25
building_orientation	Does building have manure pit under (slatted) floor? (1=yes,0=no)	deg	90
under_floor_pit	depth of pit under floor	number	0
floor_pit_depth	length of pit under floor	m	1.02
floor_pit_length	width of pit under floor	m	28
floor_pit_width	U value for roof (W/m ² -C)	m	10.1
U_roof	U value for sidewalls (W/m ² -C)	W/m ² -C	0.27
U_sidewall	U value for endwalls (W/m ² -C)	W/m ² -C	0.43
U_endwall	Perimeter heat loss factor (W/m-C)	W/m ² -C	0.43
Perim_heat_factor	Mechanical or Natural ventilation (1=mechanical, 2=natural)	W/m ² -C	1.5
mech_or_nat	required for mech vent only - Minimum mech. Vent. rate per animal	number	1
min_vent_per_wt	(m ³ /s/animal)	m ³ /s/animal	0.0057
set_pt_temp	required for mech vent only - Set point temperature (C)	C	20
del_TC	required for mech vent only - Band width of ventilation control unit (C)	C	4
frac_sidewall_open_cold	required for natural ventilation only - fraction sidewall is open - cold weather	decimal	0
frac_sidewall_open_mild	required for natural ventilation only - fraction sidewall is open - mild weather	decimal	0.2
frac_sidewall_open_hot	required for natural ventilation only - fraction sidewall is open - hot weather	decimal	0.35

	required for natural ventilation only -		
frac_endwall_open_cold	fraction endwall is open - cold weather	decimal	0
	required for natural ventilation only -		
frac_endwall_open_mild	fraction endwall is open - mild weather	decimal	0.2
	required for natural ventilation only -		
frac_endwall_open_hot	fraction endwall is open - hot weather	decimal	0.35
	required for natural ventilation only -		
nat_vent_Cd	Discharge coefficient for vent openings	decimal	0.6
mu_max_urine	Michaelis-Menten parameter (kg/m ³ s)	kg/m ³ s	0.003
K_urine	Michaelis-Menten parameter (kg/m ³)	kg/m ³	0.056
ph_urine	pH of urine	ph units	8.6
	Fraction for floor area covered with urine		
frac_area_urine	(decimal)	decimal	0.8

5. Storage Emissions Model

5.1 Data for different animal types

Manure storage facilities can be generally divided into **solid and liquid manure storages**. Solid manure storage is commonly used for manure collected in beef cattle feedlot, dairy corrals, high-rise layer facility, broiler and turkey facilities. Liquid manure storage is commonly used for manure collected in swine, dairy and layer feeding operations, using recycle water to facilitate manure movement from buildings. Liquid manure storage structures include above ground steel or concrete tanks and below ground earthen ponds or basins, under-floor pits, and lagoons (note: Lagoons primarily are meant for treatment but they have some storage capacity). The storage emission sub-model includes a solids storage module and a liquid-storage module. Mathematical equations have been developed to calculate ammonia emission rate from each storage type as a function of manure characteristics, climatic conditions, and time.

The types of storage and treatment structures include:

1. Storage tank,
2. storage pond,
3. anaerobic lagoon,
4. aerobic lagoon, and
5. stock pile
6. Under-floor pits

The variables required for storage and treatment structures include:

1. Dimensions – length, width, depth, side slopes – should be able to use this information to calculate the volume of manure in storage and the area of the surface exposed to the atmosphere.
2. Storage cover and cover type
3. Manure feeding rates (Volumetric)
4. Manure outflow rates from treatment and storage structures (volumetric)
5. Manure properties (for both inflow and out flow)
 - a. TKN (Total ammonium nitrogen + Organic nitrogen) – TKN is needed in conjunction with TAN to calculate organic nitrogen content of the manure. Subsequent ammonia generation in storage and treatment structures comes from organic nitrogen.
 - b. TAN (Total ammonium nitrogen)
 - c. Other N species e.g. nitrates and nitrites
 - d. Total Solids
 - e. Volatile solids
 - f. Suspended solids (or Dissolved Solids)
 - g. PH
 - h. Temperature
6. Environmental Conditions (Weather)
 - a. Dry bulb temperature
 - b. Wind speeds (note the height at which this is measured)

- c. Rainfall
- d. Evaporation/ Evapotranspiration rates
- 7. Time when data was collected (to reflect the season)
- 8. Measurement methods
- 9. Animal numbers and weights associated with the manure in storage
- 10. Period manure storage (age)
- 11. Sludge accumulation and properties similar to manure listed in 5 above.

5.2 Variables and default values for dairy

Variable	Description	Units	Defaults
OpenFeedlotManure	Proportion of manure collected on open feedlot (corrals)	proportion	0.5
storageLiquidManure	Proportion of Manure collected into liquid storage	proportion	0.5
SurfaceArea	Surface area of open feedlot (corrals)	m ² /animal	4.65
SolidManure	Proportion of manure collected in solid form	proportion	0.5
LiquidManure	Proportion of manure collected in liquid form	proportion	0.5
StoragePeriod	Total manure storage operiod before storage is emptied	days	180
StorageType	Manure storage type, cumulating volume vs. constant volume		cumulating
StorageGeometry	Manure storage geometry (cylindrical, rectangle, or pond)		pond
Diameter	Diameter of storage if it is circular	m	33
BottomLength	Bottom length of storage if it is a rectangular pond	m	67
BottomWidth	Bottom width of storage if it is a rectangular pond	m	33
BottomDiameter	Bottom diameter of storage if it is a cicular pond	m	33
SideSlope	Side slope of storage if it is a rectangular or circular pond	m	2
ManureMoisture	Manure moisture	proportion	0.9
ManurePH	Manure pH		7
VolumeEmptied	Volume emptied from the storage during the time step	m ³	0
TimeStep	Time step	s	3600
MineralizationRate	Organic nitrogen mineralization rate at 20°C	1/day	0.06
TempCoeff	Temperature coefficient used in the mineralization rate eqn		1.036

5.3 Variables and default values for beef

Variable	Description	Units	Defaults
OpenFeedlotManure	Proportion of Manure collected on open feedlot (corrals)	proportion	0.5
StorageLiquidManure	Proportion of Manure collected into liquid storage	proportion	0.5
SurfaceArea	Surface area of open feedlot (corrals)	m ² /animal	4.56
SolidManure	Proportion of manure collected in solid form	none	0.5

LiquidManure	Proportion of manure collected in liquid form	none	0.5
StoragePeriod	Total manure storage period before storage is emptied	days	180
StorageType	Manure storage type, cumulating volume vs. constant volume	none	cumulating
StorageGeometry	Manure storage geometry (cylindrical, rectangle, or pond)	none	pond
Diameter	Diameter of storage if it is circular	m	33
BottomLength	Bottom length of storage if it is a rectangular pond	m	67
BottomWidth	Bottom width of storage if it is a rectangular pond	m	33
BottomDiameter	Bottom diameter of storage if it is a circular pond	m	33
SideSlope	Side slope of storage if it is a rectangular or circular pond	m	2
ManureMoisture	Manure moisture	proportion	0.9
ManurePH	Manure pH	none	7
VolumeEmptied	Volume emptied from the storage during the time step	m3	0
TimeStep	Time step (1 hour)	s	3600
MineralizationRate	Organic nitrogen mineralization rate at 20°C	1/day	0.06
TempCoeff	Temperature coefficient used in the mineralization rate eqn		1.036

5.4 Variables and default values for swine

Variable	Description	Units	Defaults
StoragePeriod	Total manure storage period before storage is emptied	days	180
StorageType	Manure storage type, cumulating volume vs. constant volume	none	cumulating
StorageGeometry	Manure storage geometry (cylindrical, rectangle, or pond)	none	pond
Diameter	Diameter of storage if it is circular	m	33
BottomLength	Bottom length of storage if it is a rectangular pond	m	67
BottomWidth	Bottom width of storage if it is a rectangular pond	m	33
BottomDiameter	Bottom diameter of storage if it is a circular pond	m	33
SideSlope	Side slope of storage if it is a rectangular or circular pond	m	2
ManurePH	Manure pH	none	7
VolumeEmptied	Volume emptied from the storage during the time step	m3	0
TimeStep	Time step	s	3600
MineralizationRate	Organic nitrogen mineralization rate at 20°C	1/day	0.06
TempCoeff	Temperature coefficient used in the mineralization rate eqn		1.036

5.5 Variables and default values for poultry

Variable	Description	Units	Defaults
SolidManure	Proportion of manure collected in solid form	proportion	1
storageLiquidManure	Proportion of manure collected in liquid form	proportion	1
StoragePeriod	Total manure storage operiod before storage is emptied	days	180
StorageType	Manure storage type, cumulating volume vs. constant volume	none	cumulating
StorageGeometry	Manure storage geometry (cylindrical, rectangle, or lagoon)	m	cumulating
Diameter	Diameter of storage if it is circular	m	33
BottomLength	Bottom length of storage if it is a rectangular pond	m	67
BottomWidth	Bottom width of storage if it is a rectangular pond	m	33
BottomDiameter	Bottom diameter of storage if it is a cicular pond	m	33
SideSlope	Side slope of storage if it is a rectangular or circular pond	m	2
ManureMoisture	Manure moisture	proportion	0.9
ManurePH	Manure pH	none	7
VolumeEmptied	Volume emptied from the storage during the time step	m3	0
TimeStep	Time step	s	3600
MineralizationRate	Organic nitrogen mineralization rate at 20°C	1/day	0.06
TempCoeff	Temperature coefficient used in the mineralization rate eqn	none	1.036

6. Land Emissions Model

6.1 Data for different animal types

Different methods, schedule, and rates are used for land application of animal manure depending on the solids and nutrient contents of animal manure, crop management practices, and climatic conditions. Ammonia emission rate from different land application practices will be different. The land application emission model developed considers common manure application practices used on different livestock farms.

Land application methods can be divided according to the forms of manure: solids, slurry, and liquid. Solids manure is typically surface spread. Slurry manure is surface spread or injected. Liquid manure is irrigated with center pivot, sprinkler, or furrow irrigation techniques. A thorough literature review will be conducted regarding the methodologies for measuring and calculating ammonia emissions from different land application practices. New calculation methods and emission data available in the literature will be used for predicting the ammonia emission rate from different land application practices.

The variables required to compute ammonia from land application include:

1. Properties of manure being applied to land
 - a. TKN
 - b. TAN
 - c. Other N species e.g. nitrates and nitrites
 - d. Total Solids
 - e. Volatile solids
 - f. Suspended solids (or Dissolved Solids)
 - g. pH
 - h. Temperature
2. Rainfall activity before and after land application.
3. Environmental conditions
 - a. temperature,
 - b. wind speeds
4. Application rates
5. Runoff
6. Leaching of ammonium nitrogen in the soil
7. Crop yields
 - a. nitrogen contents of plants
8. Inorganic N applied
9. Land application method
10. Time data was taken.
11. Measurement methods
12. Deposition from the atmosphere
13. Properties of the soil the manure is being applied
 - a. pH,
 - b. moisture content,
 - c. soil type, etc.

6.2 Variables and default values for dairy

Variable	Description	Units	Defaults
NPH	Manure - pH		7
Mdensity	Manure Density (g)	kg/m3	1000
CropType	Crop type		corn
Grain	N Uptake -corn (grain, 150 bu per ac)	kg/m2	0.0207
Silage	N uptake-corn (silage, 16 tons per ac)	kg/m2	0.0146
Soybean	N Uptake -Soybean (50 bu per ac.)	kg/m2	0.0288
Wheat	N Uptake-Wheat (60 bu. Per ac)	kg/m2	0.0140
Alfalfa	N Uptake -Alfalfa (4 tons per ac.)	kg/m2	0.0202
Bermuda	N Uptake - Bermuda grass (4 tons per ac.)	kg/m2	0.0252
Soil_application	soil infiltration rate	m/d	0.48
CropHeight	Crop or weed canopy height (h)	m	0.1000
FrictionHeight	Height above ground where friction velocity is calculated	m	2.0000
DryMineralizationRate	Mineralization rate (k)for dry soil	week-1	0.477
WetMineralizationRate	Mineralization rate (k) for wet soil	week-1	0.132

6.3 Variables and default values for beef

Variable	Description	Units	Defaults
NPH	Manure - pH		7
Mdensity	Manure Density (g)	kg/m3	1000
CropType	Crop type	none	corn
Grain	N Uptake -corn (grain, 150 bu per ac)	kg/m2	0.0207
Silage	N uptake-corn (silage, 16 tons per ac)	kg/m2	0.0146
Soybean	N Uptake -Soybean (50 bu per ac.)	kg/m2	0.0288
Wheat	N Uptake-Wheat (60 bu. Per ac)	kg/m2	0.0140
Alfalfa	N Uptake -Alfalfa (4 tons per ac.)	kg/m2	0.0202
Bermuda	N Uptake - Bermuda grass (4 tons per ac.)	kg/m2	0.0252
Soil_application	Soi infiltratiron rate	m/d	0.48
CropHeight	Crop or weed canopy height (h)	m	0.1000
FrictionHeight	Height above ground where friction velocity is calculated	m	2.0000
DryMineralizationRate	Mineralization rate (k)for dry soil	week-1	0.477
WetMineralizationRate	Mineralization rate (k) for wet soil	week-1	0.132

6.4 Variables and default values for swine

Variable	Description	Units	Defaults
NPH	Manure - pH		7
Mdensity	Manure Density (g)	kg/m3	1000
CropType	Crop type		corn
Grain	N Uptake -corn (grain, 150 bu per ac)	kg/m2	0.0207

Silage	N uptake-corn (silage, 16 tons per ac)	kg/m2	0.0146
Soybean	N Uptake -Soybean (50 bu per ac.)	kg/m2	0.0288
Wheat	N Uptake-Wheat (60 bu. Per ac)	kg/m2	0.0140
Alfalfa	N Uptake -Alfalfa (4 tons per ac.)	kg/m2	0.0202
Bermuda	N Uptake - Bermuda grass (4 tons per ac.)	kg/m2	0.0252
Soil_application	Soil infiltration rate	m/d	0.48
CropHeight	Crop or weed canopy height (h)	m	0.1000
FrictionHeight	Height above ground where friction velocity is calculated	m	2.0000
DryMineralizationRate	Mineralization rate (k)for dry soil	week-1	0.477
WetMineralizationRate	Mineralization rate (k) for wet soil	week-1	0.132

6.5 Variables and default values for poultry

Variable	Description	Units	Defaults
NPH	Manure - pH		7
Mdensity	Manure Density (g)	kg/m3	1000
CropType	Crop type	none	corn
Grain	N Uptake -corn (grain, 150 bu per ac)	kg/m2	0.0207
Silage	N uptake-corn (silage, 16 tons per ac)	kg/m2	0.0146
Soybean	N Uptake -Soybean (50 bu per ac.)	kg/m2	0.0288
Wheat	N Uptake-Wheat (60 bu. Per ac)	kg/m2	0.0140
Alfalfa	N Uptake -Alfalfa (4 tons per ac.)	kg/m2	0.0202
Bermuda	N Uptake - Bermuda grass (4 tons per ac.)	kg/m2	0.0252
Soil_application	Soil infiltration rate	m/d	0.48
CropHeight	Crop or weed canopy height (h)	m	0.1000
FrictionHeight	Height above ground where friction velocity is calculated	m	2.0000
DryMineralizationRate	Mineralization rate (k)for dry soil	week-1	0.477
WetMineralizationRate	Mineralization rate (k) for wet soil	week-1	0.132

7. Meteorology Data

Meteorological data is available from MM5 model simulations for 2002 on the National RPO modeling domain (Figure 5.1). The RPO National Grid is defined on a Lambert conformal projection, with true latitudes at 33°N and 45°N, and the central latitude and longitude at 40°N and 97°W, respectively. The grid point spacing is 36 km. The continental expanse of this domain results in a grid of 165 (eastwest) by 129 (north-south) dot points, and 164 (east-west) by 128 (north-south) cross points. Overall, the domain covers 5904 km by 4608 km. Data available include wind speeds, temperatures, soil temperatures and moistures, rain, relative humidity, boundary layer parameters such as PBL heights, surface heat flux, surface moisture flux, etc.

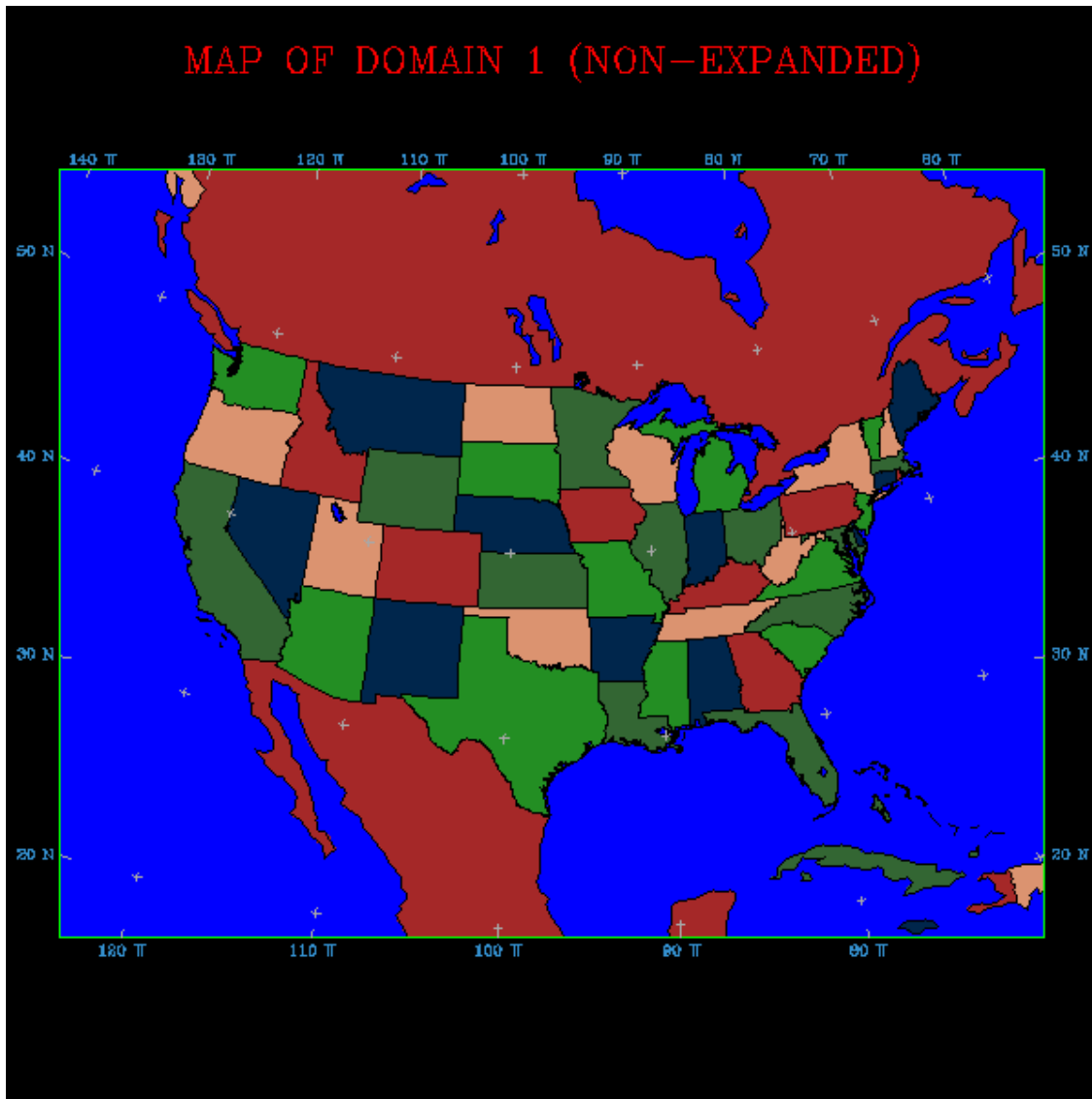


Figure 7.1 National RPO 36-km domain.

The meteorological variables used by the Farm Emissions Model include the following:

Variable name	Unit
total radiation	W/m ²
Temperature	K
10 meter temperature	K
1.5 meter temperature	K
wind speed	M/s
10 meter wind speed	M/s
wind direction	Degree
convective rain	Cm
non-convective rain	Cm
evaporation rate	
absolute humidity	%
barometric pressure	Pa
cloud cover	%
soil moisture	M ³ /M ³
soil temperature	K
U*	M/s
Roughness length	M

References

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