Extracted from the NRCS "Agricultural Waste Management Field Handbook Part 651, Agricultural Wastes and Water, Air, and Animal Resources"

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United States Department of Agriculture
Natural Resources Conservation Service

Part 651
Agricultural Waste Management
Field Handbook

Chapter 3 Agricultural Wastes and Water, Air, and Animal Resources

Issued February 2012

Acknowledgments

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651.0300 Introduction

This chapter focuses on the effects that agricultural wastes can have on water, air, and animal resources. Special emphasis is placed on the reactions of particular contaminants within the aquatic environment (how they change and how they affect aquatic life and human health). The impact of contaminants on designated uses of water is not covered in detail here because it is adequately covered in chapter 1 of this handbook. The pollutant delivery process—the movement of pollutants from the source to a stream or water body—is described in this chapter.

651.0301 Pollution versus contamination

In addressing the subject of pollution, we must be aware that none of the natural resources, especially water and air resources, is completely pure. Air often contains pollen, dust, volcanic ash, and other particulates. In that sense, the air we breathe would rarely be "pure," even without the influence of humans.

Likewise, all natural water, including surface water, groundwater, and precipitation, contains foreign substances; it is not simply two parts hydrogen and one part oxygen (H_2O). Some foreign substances occur naturally, and some are there because of cultural contamination (human activity on the land).

Natural water might contain minerals, salts, algae, bacteria, gases, and chemicals and have an unpleasant taste, yet it still might not be considered polluted. Water generally is considered polluted only if foreign substances in the water result in impairment of a specific, designated use of the water. The determination of use impairment is based on the quality of water not meeting established limits for specific constituents (e.g., 5 mg/L of dissolved oxygen) and not necessarily on an obvious problem, such as an alga bloom or bad taste and odor.

Water may be contaminated by substances, but not be considered polluted with regard to meeting established standards. A farmer, for example, may fertilize the farm pond at recommended rates in the spring to enhance fish production. This purposeful addition of nutrients to the water and the subsequent minor enrichment do not constitute an act of pollution because the intended use of the water (fish production in this case) is not impaired; rather, fish production is enhanced.

On the other hand, if the water from that same farm pond was discharged to a stream having an inlet pipe for a municipal water supply immediately downstream, the discharge could be considered polluted if it contained a concentration of any substance that did not meet State standards for a water supply. The alga that served as a source of feed for aquatic organisms in the pond could become unwanted suspended solids and a potential problem at the water treatment plant.

In this chapter, pollution refers to a resource that has been contaminated beyond legal limits. Such limits are specifically designated by State agencies, but may be limited to only the water and air resources. However, limits can also be applied to soils and plants to prevent unsafe levels of heavy metals where municipal sludge is being applied. Fish and cattle (animal resources) may also be contaminated to unsafe levels with pesticides or other substances, but specific pollution limits for this resource may not be a part of State standards.

Chapter 1 of this handbook provides detailed information on the designated use classifications that most States use to establish pollution limits for water. Information on the ways in which each use can be affected by agricultural pollutants and the characteristics of nonpoint source pollution are also included in that chapter.

651.0302 Effects of animal waste on the water resource

Animal waste contains a number of contaminants that can adversely affect surface and groundwater. In addition, certain of the constituents in animal waste can impact grazing animals, harm terrestrial plants, and impair air quality. However, where animal waste is applied to agricultural land at acceptable rates, crops can receive adequate nutrients without the addition of commercial fertilizer. In addition, soil erosion can be substantially reduced and the water-holding capacity of the soil can be improved if organic matter from animal waste is incorporated into the soil.

(a) Constituents affecting surface water quality

The principal constituents of animal waste that impact surface water are organic matter, nutrients, and fecal bacteria. Animal waste may also increase the amount of suspended material in the water and affect the color either directly by the waste itself or indirectly through the production of algae. Indirect effects on surface water can also occur when sediment enters streams from feedlots or overgrazed pastures and from eroded streambanks at unprotected cattle crossings. The impact that these contaminants have on the aquatic environment is related to the amount and type of each pollutant entering the system and the characteristics of the receiving water.

(1) Organic matter

All organic matter contains carbon in combination with one or more other elements. All substances of animal or vegetable origin contain carbon compounds and are, therefore, organic.

When plants and animals die, they begin to decay. The decay process is simply the various naturally occurring microorganisms converting the organic matter—the plant and body tissue—to simpler compounds. Some of these simpler compounds may be other forms of organic matter or they may be compounds, such as nitrate and ortho-phosphate, or gases, such as nitrogen gas (N_2), ammonia (NH_3), and hydrogen sulfide (H_2S).

When manure or other organic matter is added to water, the decay process occurs just as it does on land. Microorganisms attack these organic materials and begin to consume and convert them. If the water contains dissolved oxygen, the organisms involved in the decay process are aerobic or facultative. Aerobic organisms require free (dissolved) oxygen to survive, while facultative organisms function in both aerobic (oxygen present) or anaerobic (oxygen absent) environments.

As the organisms consume the organic matter, they also consume free oxygen. The principal by-products of this aerobic digestion process are carbon dioxide (CO_2) and water (H_2O). Figure 3–1 is a schematic representation of the aerobic digestion cycle as it relates to nitrogenous and carbonaceous matter.

In a natural environment, the breakdown of organic matter is a function of complex, interrelated, and mixed biological populations. However, the organisms principally responsible for the decomposition process are bacteria. The size of the bacterial community depends on its food supply and other environmental factors including temperature and pH.

If a large amount of organic matter, such as manure, is added to a water body, the bacterial population begins to grow, with the rate of growth expanding rapidly. Theoretically, the bacterial population doubles with each simultaneous division of the individual bacteria; thus, one divides to become two, two becomes four, four becomes eight, and so forth. The generation time, or the time required for each division, may vary from a few days to less than 30 minutes. One bacterium with a 30-minute generation time could yield 16,777,216 new bacteria in just 12 hours.

Because each bacterium extracts dissolved oxygen from the water to survive, the addition of waste and the subsequent rapid increase in the bacterial population could result in a drastic reduction in dissolved oxygen in a stream. The point in a stream where the maximum oxygen depletion occurs can be a considerable distance downstream from the point where pollutants enter the stream. The level of oxygen depletion depends primarily on the amount of waste added; the size, velocity, and turbulence of the stream; the initial dissolved oxygen levels in the waste and in the stream; and the temperature of the water.

A turbulent stream can assimilate more waste than a slow, placid stream because the turbulence brings air into the water (re-aeration) and helps replenish the dissolved oxygen. In addition, cold water can hold more dissolved oxygen than warm water. For example, pure water at 10 degrees Celsius (50 °F) has 10.92 milligrams per liter of dissolved oxygen when fully saturated, while water at 30 degrees Celsius (86 °F) has 7.5 milligrams per liter at the saturation level.

An adequate supply of dissolved oxygen is essential for good fish production. Adding wastes to a stream can lower oxygen levels to such an extent that fish and other aquatic life are forced to migrate from the polluted area or die for lack of oxygen. The decomposition of wastes can also create undesirable color as well as taste and odor problems in lakes used for public water supplies.

The amount of organic matter in water can be determined with laboratory tests, including those for 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and volatile solids (VS). Table 3–1 illustrates BOD_5 values for a sampling of lagoon influents and effluents for various livestock facilities. The table is used for illustration only and shows how "strong" agricultural wastes can be, even after treatment. Concentrations will vary considerably from these values, depending on such factors as the age and size of the lagoon, characteristics of the waste, geographical location, and the amount of dilution water added.

The BOD_5 value for raw domestic sewage ranges from 200 to 300 milligrams per liter, while that for municipal wastewater treated to the secondary level is about 20 milligrams per liter. Because municipal waste is so much more dilute, the concentrations of BOD_5 are much lower than those in treated animal waste. Nevertheless, animal wastewater released to a stream, though smaller in total volume relative to municipal discharges, can be more concentrated and cause severe damage to the aquatic environment.

Figure 3–1 Aerobic cycle of plant and animal growth and decomposiyion as related to nitrogen and carbon

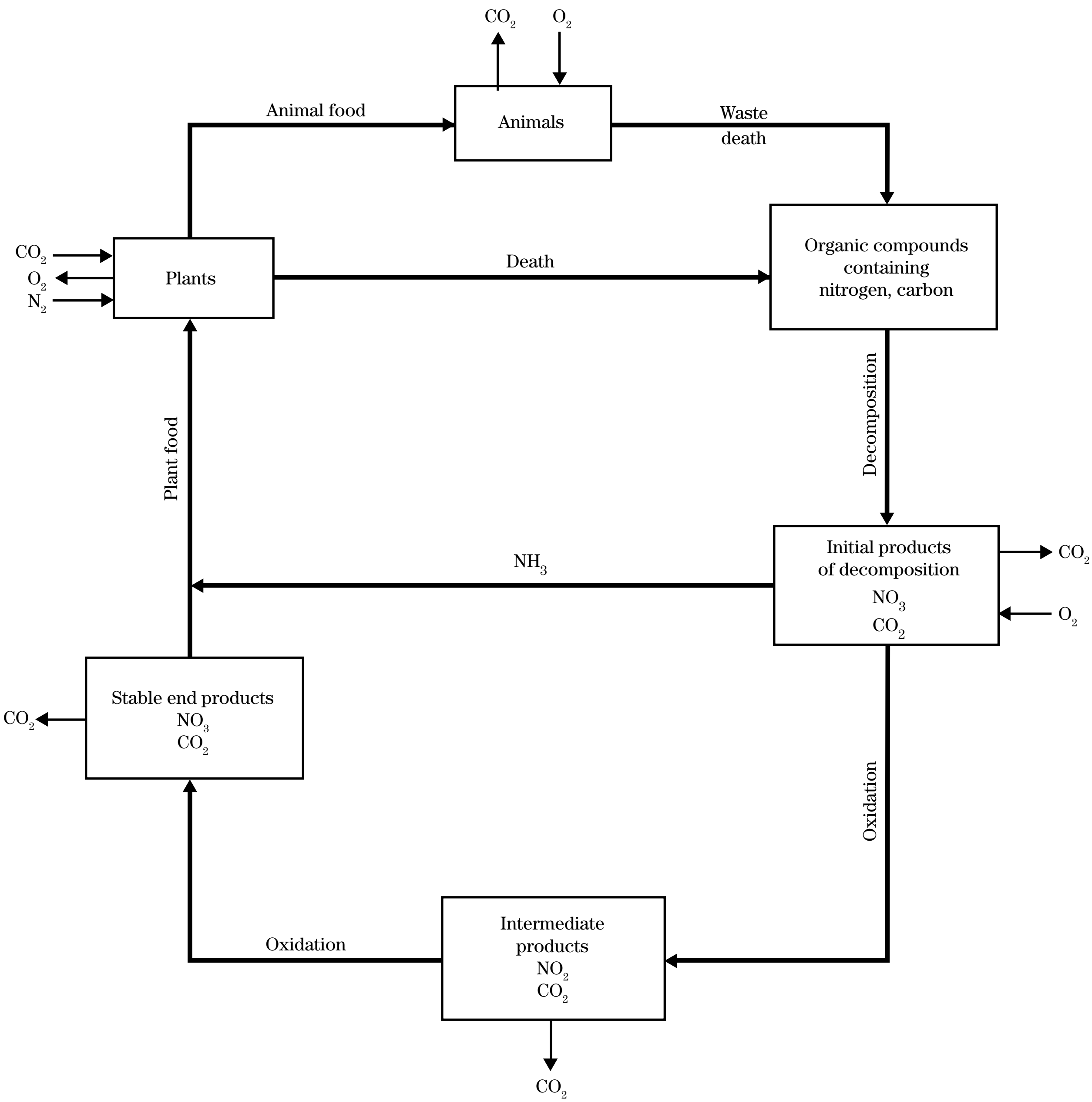


Table 3–1 A sampling of influent BOD_5 concentrations and range of effluent concentration for various types of anaerobic lagoons

Source	Lagoon influent	Lagoon effluent
	- - - - - - - mg/L	- - - - - - -
Dairy	6,000	200–1,200
Beef	6,700	200–2,500
Swine	12,800	300–3,600
Poultry	9,800	600–3,800

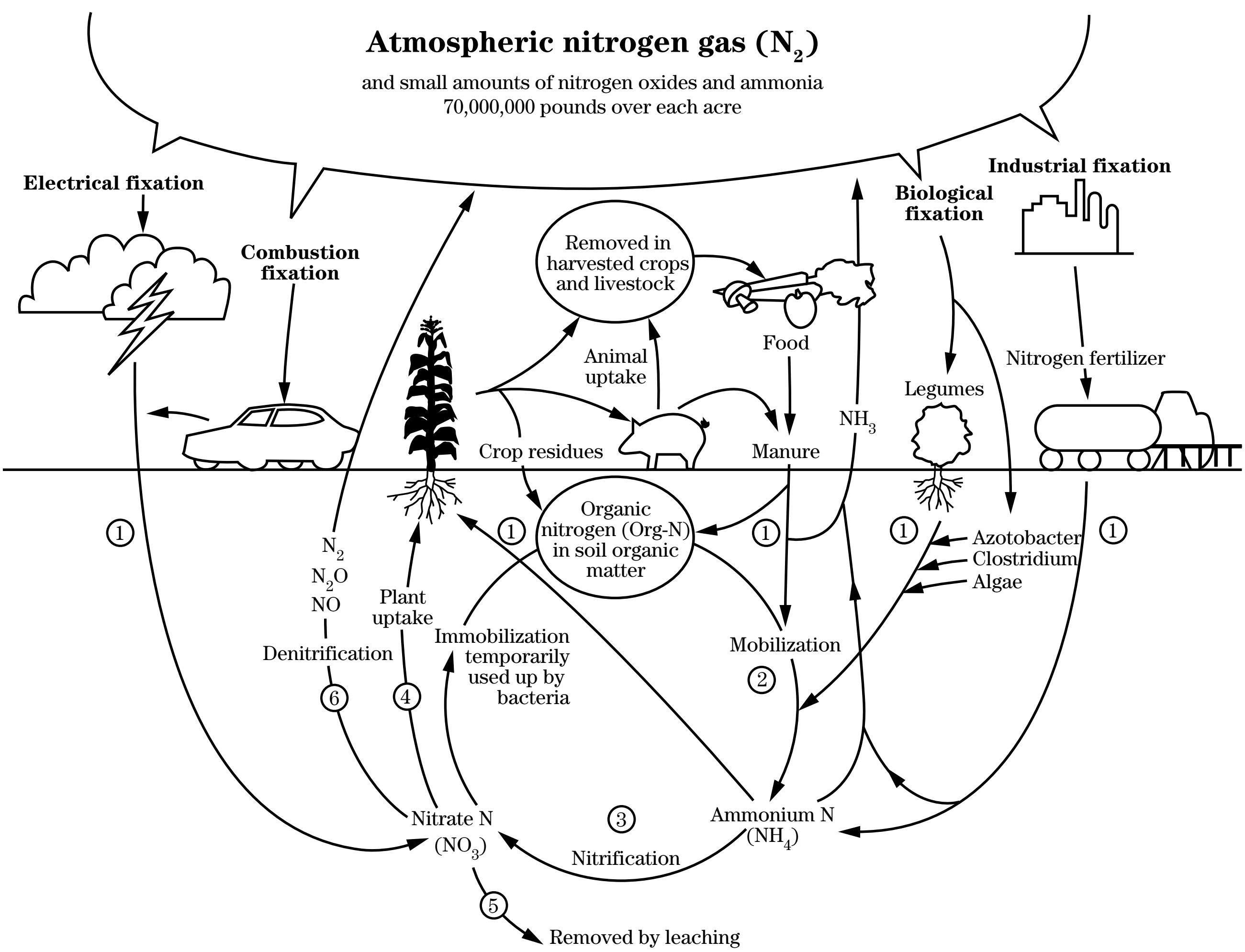
(2) Nutrients

The principal nutrients of concern in the aquatic environment are nitrogen (N) and phosphorus (P). An understanding of how these nutrients react in the environment is important to understanding the control processes described in later sections.

(i) Nitrogen—Nitrogen occurs throughout the environment—in the soil, water, and surrounding air. In fact, 78 percent of the air we breathe is N. It is also a part of all living organisms. When plants and animals die or when waste products are excreted, N returns to the environment and is cycled back to the land, water, and air and eventually back to other plants and animals.

Figure 3–2 depicts the N cycle. It shows the flow from one form of N to another. The various forms of N can have different effects on our natural resources—some good and some bad.

Figure 3–2 Site analysis diagram



The conversion from one form of N to another is usually the result of bacterial processes. Some conversions require the presence of oxygen (aerobic systems), while others require no oxygen (anaerobic systems). Moisture content of the waste or soil, temperature, and pH speed or impede conversions.

In water quality analyses, total nitrogen (TN) includes the organic (Org-N), total ammonia (NH_3 + (NH_4 (the ammonium ion)), nitrite (NO_2), and nitrate (NO_3) forms. Total Kjeldahl nitrogen (TKN) includes the total organic and total ammonia nitrogen. The NH_3, NO_2, and NO_3 forms of N may be expressed in terms of the concentration of N (NO_3–N or NH_4–N) or in terms of the concentration of the particular ion or molecule (NO_3 or NH_4). Thus, 45 milligrams per liter of NO_3 is equivalent to 10 milligrams per liter of NO_3–N. (See chapter 4 of this handbook for conversions and expressions.)

Organic nitrogen—Nitrogen in fresh manure is mostly in the organic form (60–80% of TN). In an anaerobic lagoon, the organic fraction is typically 20 to 30 percent of TN. Org-N in the solid fraction (feces) of most animal waste is usually in the form of complex molecules associated with digested food, while that in the liquid fraction is in the form of urea.

From 40 to 90 percent of the Org-N is converted to NH_3 within 4 to 5 months after application to the land. The conversion of Org-N to NH_3 (called mineralization) is more rapid in warmer climates. Under the right temperature and moisture conditions, mineralization can be essentially complete in 60 days. Conversion to NH_3 can occur either under aerobic or anaerobic conditions.

Org-N is not used by crops; however, it is not mobile once applied to the land unless runoff carries away the organic matter or soil particles to which it might be attached.

Ammoniacal nitrogen—This term is often used in a generic sense to refer to two compounds: NH_4 (the ammonium ion) and NH_3 (un-ionized ammonia). These forms of NH_3 exist in equilibrium, with the concentrations of each depending on pH and temperature.

Un-ionized NH_3 is toxic to fish and other aquatic life in very small concentrations. In one study, the concentration required to kill 50 percent of a salmonid (e.g., trout) population after 96 hours of exposure (the 96-hour LC_{50}) ranged from 0.083 to 1.09 milligrams per liter; for nonsalmonids the range was 0.14 to 4.60 milligrams per liter. Invertebrates are more tolerant of un-ionized NH_3 than fish, and phytoplankton and vascular aquatic plants are more tolerant than either the invertebrates or fish.

To protect aquatic life, the U.S. Environmental Protection Agency (EPA) has established a recommended allowable limit of 0.02 milligrams per liter for un-ionized NH_3. Table 3–2 shows, in abbreviated form, the relationship between un-ionized NH_3 and NH_4 as related to pH and water temperature. As water temperatures and pH rise, the amount of total NH_3 required to provide a lethal concentration of un-ionized NH_3 becomes smaller.

The concentration of un-ionized NH_3 from an overflowing lagoon or other storage structure with concentrated animal waste can exceed the EPA criterion by as much as 3,000 times. Runoff from a feedlot or overfertilized pasture can also have high levels of total ammonia nitrogen (NH_3 + NH_4).

Ammonium nitrogen is relatively immobile in the soil. The positively charged ammonium ion tends to attach to the negatively charged clay particles and generally remains in place until converted to other forms.

Ammonia can be lost to the atmosphere in gaseous form (volatilization), a process that is not a function of bacterial activity. As much as 25 percent of the NH_3 irrigated from an animal waste lagoon can be lost between the sprinkler head and the ground surface. Temperature, wind, and humidity will affect losses.

Table 3–2 Concentrations of total NH_3 (NH_3 + NH_4) in mg/L that contain an un-ionized NH_3 concentration of 0.020 mg/L NH_3

Temp (°C)	pH values						
	6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**
5	160	51	16	5.1	1.6	0.53	0.18
10	110	34	11	3.4	1.1	0.36	0.13
15	73	23	7.3	2.3	0.75	0.25	0.09
20	50	16	5.1	1.6	0.52	0.18	0.07
25	35	11	3.5	1.1	0.37	0.13	0.06

Ammonia can be converted to NO_2 and then to NO_3 (nitrified) only under aerobic conditions. For this reason, Org-N and ammonia nitrogen generally are the only forms of N in anaerobic lagoons and waste storage ponds. The NH_3 begins to nitrify when the waste from these structures is applied to the land where aerobic conditions exist.

Nitrite—This is normally a transitory phase in the nitrification and denitrification processes. Very little NO_2 is normally detected in the soil or in most natural waters.

Nitrites occasionally occur in significant concentrations in farm ponds and commercial fish ponds during a fall "overturn" or when the mud on the bottom of the pond is disturbed during commercial harvesting. If the bottom material is enriched with nutrients (from excess commercial feed, fish waste, or other sources of animal waste), the concentrations of nitrites in the overlying water can be raised enough to cause NO_2 poisoning or brown blood disease in fish when this mud is disturbed. The dead or dying fish have "chocolate" colored blood, which indicates that the hemoglobin has been converted to methemoglobin.

NO_2 concentrations at or below 5 milligrams per liter should be protective of most warm-water fish, and concentrations at or below 0.06 milligrams per liter should suffice for cold-water fish. Concentrations as high as these are unlikely to occur as a result of natural conditions in surface water.

The EPA has not recommended any special limits on nitrates in surface water; however, some States have criteria for NO_2 concentrations in finished or treated water (see chapter 1 of this handbook).

Nitrate—The NO_3 form of N is the end product of the mineralization process (the conversion of N from the NH_3 form to NO_2 and then to NO_3 under aerobic conditions). The NO_3 form of N is soluble in water and is readily used by plants.

Under anaerobic conditions, microbial activity can convert NO_3 to a gaseous form of N, a process called denitrification. N in animal waste that has been converted to NO_3 after land application can leach into the soil profile, encounter a saturated anaerobic zone, and then be denitrified through microbial activity. The gaseous forms of N created in this process can then migrate upward through the soil profile and be lost to the atmosphere.

The principal source of agricultural NO_3 in surface water is runoff from feedlots, cropland, and pastures. Table 3–3 illustrates the possible differences in dissolved N concentrations in runoff from fields that had manure surface applied at agronomic rates and those that had no manure applied.

The values in table 3–3 represent estimates of dissolved N only and do not represent amounts that could also be transported with sediment. Although these values were obtained from published data, they do not reflect the variability that could result from such factors as differences in rainfall in various geographic regions, slope of land, amount and age of manure on the ground surface, or extent of crop cover. Therefore, table 3–3 is presented only to illustrate the extent to which NO_3 concentrations can be increased in runoff from land that has received applications of manure.

Elevated NO_3 levels have also been observed in the spring runoff from fields where manure had been applied to snow-covered or frozen ground. In addition, the discharge from underground drainage lines in cropland fields can have elevated concentrations of nitrate.

Nitrates are toxic to fish only at very high concentrations—typically in excess of 1,000 milligrams per liter for most freshwater fish. Such species as largemouth bass and channel catfish, could maintain their normal growth and feeding activities at concentrations up to 400 milligrams per liter without significant side effects.

Table 3–3 Estimated concentrations of total dissolved nitrogen in runoff from land with and without livestock and poultry manure surface applied

Cropping conditions	Dissolved N concentration in runoff	
	With manure	Without manure
	---------- mg/L ----------	
Grass	11.9	3.2
Small grain	16.0	3.2
Row crop	7.1	3.0
Rough plow	13.2	3.0

Source: Animal Waste Utilization on Cropland and Pastureland (USDA 1979)

These concentrations would not result from natural causes and are not likely to be associated with normal agricultural activities.

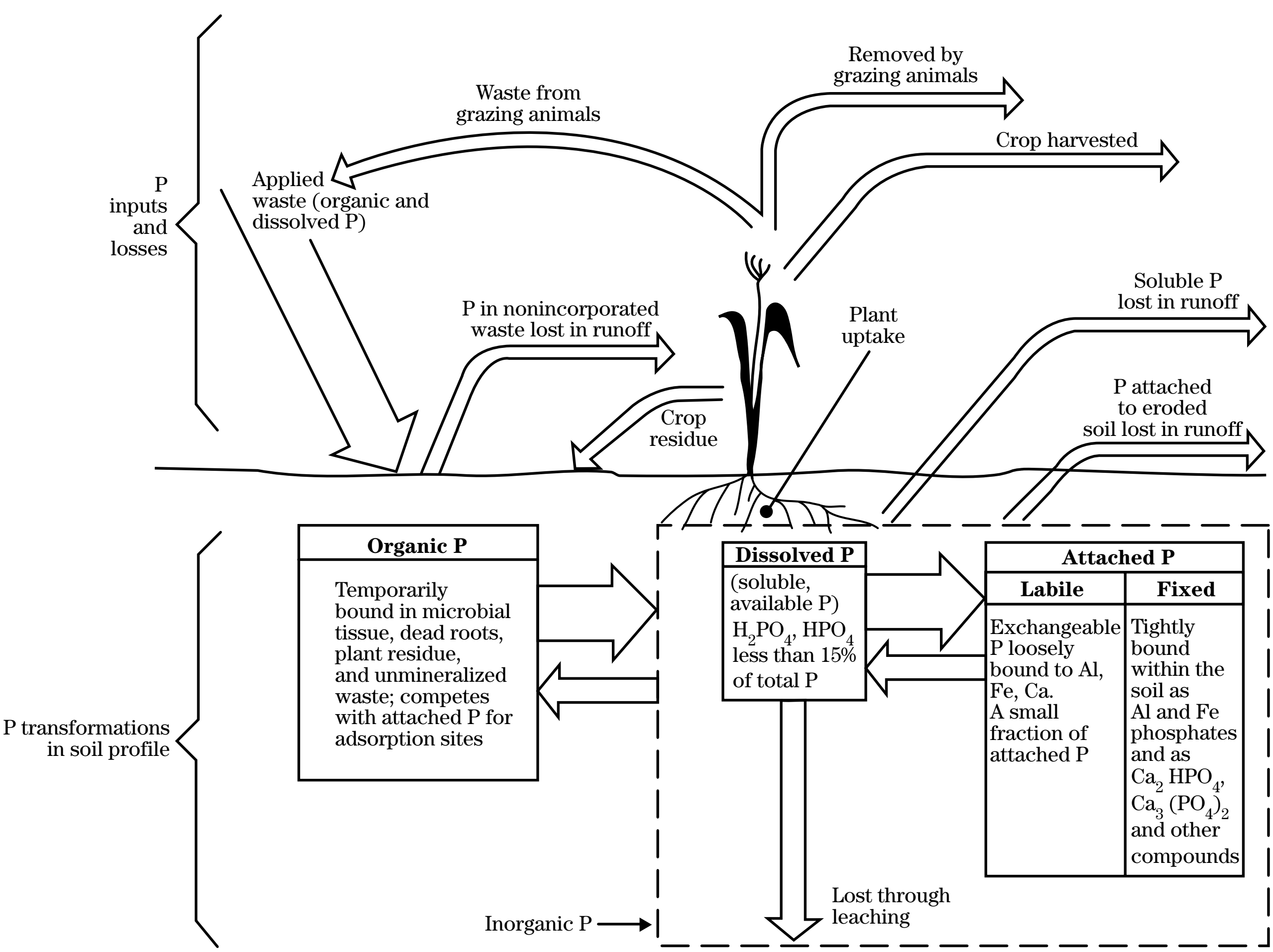
Although nitrates are not normally toxic to aquatic organisms, nitrate is a source of enrichment for aquatic plants. If an adequate supply of other essential nutrients is available (especially P), nitrates can help promote algae blooms and the production of other aquatic vegetation.

The EPA has not recommended any limiting criteria for nitrates as related to surface water. (See chapter 1, section 651.0107(b) for a description of limits related to drinking water as it comes from the tap.)

(ii) Phosphorus—Phosphorus is one of the major nutrients needed for plant growth, whether the plant is terrestrial or aquatic. Because P is used extensively in agriculture, the potential for pollution from this source is high.

Forms of Phosphorus—Water samples are often analyzed for only total P; however, total P can include organic, soluble, or "bound" forms. An understanding of the relationship among these forms is important to understanding the extent to which P can move within the environment and the methods for its control. Figure 3–3 depicts the relationship between the P forms and illustrates ways that P can be lost from waste application sites.

Figure 3–3 Phosphorus inputs and losses at a waste application site and P transformation within the profile (abbreviated P cycle)



Organic P is a part of all living organisms, including microbial tissue and plant residue, and it is the principal form of P in the metabolic by-products (wastes) of most animals. About 73 percent of the P in the fresh waste of various types of livestock is in the organic form

Soluble P (also called available or dissolved P) is the form used by all plants. It is also the form that is subject to leaching. The soluble form generally accounts for less than 15 percent of the total P in most soils.

Attached P includes those compounds that are formed when the anionic (negatively charged) forms of dissolved P become attached to cations, such as iron, aluminum, and calcium. Alum has been successfully used as an additive to poultry litter to capture dissolved P in attempts to prevent it from leaving application fields with stormwater runoff. Attached P includes labile, or loosely bound, forms and those that are "fixed," or tightly adsorbed, on or within individual soil particles.

It should be noted that the P that is loosely bound to the soil particles (labile P) remains in equilibrium with the soluble P. Thus, when the concentration of soluble P is reduced because of the removal by plants, some of the labile P is converted to the soluble form to maintain the equilibrium.

Factors affecting the translocation of Phosphorus—A number of factors determine the extent to which P moves to surface or groundwater. Nearly all of these factors relate to the form and chemical nature of the P compounds. Some of the principal factors affecting P movement to surface and groundwaters are noted.

Degree of contact with the soil—Manure that is surface applied in solid form generally has a higher potential for loss in surface runoff than wastewater applied through irrigation, especially in areas that have frequent, high-intensity storms. This also assumes the irrigation water infiltrates the soil surface. Because P readily attaches to soil particles, it is important that fields used for manure applications have low erosion potential. For some soils, the potential for loss in surface runoff may be reduced by incorporating land applied solid wastes into the soil profile. Before incorporation is used to reduce runoff potential, the potential damage to soil structure should be considered. Grasslands and soils under no-till commonly developed improved soil structure that increase infiltration and reduces runoff. Destroying soil structure that has developed through the absence of tillage by incorporation could inadvertently increase runoff potential.

Soil pH—After animal waste makes contact with the soil, the P will change from one form to another. Organic P eventually converts to soluble P, which is used by plants or converted to bound P. However, the amount of soluble P is related to the pH of the soil as illustrated in figure 3–4. In acid soils, the soluble P occurs primarily as dihydrogen phosphate ion (H_2PO_4), and when the pH increases above 7, the principal soluble form is HPO_4.

Figure 3–4 illustrates that most inorganic P occurs as insoluble compounds of aluminum, iron, calcium, and other minerals typically associated with clay soils. Therefore, these bound forms of P will generally remain in place only so long as the soil particles remain in place.

Soil texture—Phosphorus is more readily retained on soils that have a high clay fraction (fine-textured soils) than on sandier soils. As noted in figure 3–4, those soil particles that contain a large fraction of aluminum, iron, and calcium are very reactive with P. Thus, clay soils have a higher adsorption potential than that of sandy soils. Sand grains that have a coating of aluminum or iron oxides can also retain some amount of P.

Research has shown that soils with even a modest clay fraction have the potential to adsorb large amounts of P. For example, one study revealed that a Norfolk sandy loam soil receiving swine lagoon effluent at P application rates of 72, 144, and 288 pounds per year would require 125, 53, and 24 years to saturate the adsorption sites in the soil profile to a depth of 105 centimeters (41 in). This does not mean that all of the applied P would be adsorbed within the soil profile. Rather, the soil simply has the potential for such adsorption, assuming none is lost through other means.

Amount of waste applied—Organic P readily adsorbs to soil particles and tends to depress the adsorption of inorganic P, especially where organic P is applied at high rates. Thus, the concentrations of soluble and labile P increase significantly at high application rates of organic P.

When organic P and commercial superphosphate are applied at the same rates, the superphosphate P will be less effective in raising the concentration of soluble P than the P applied in manure or other organic waste. This occurs because the organic P competes for adsorption sites, resulting in more P staying in soluble form rather than becoming attached as labile P.

Long-term applications of organic P at rates that exceed the uptake rate of plants will result in saturation of the adsorption sites near the soil surface. This, in turn, results in greatly increased concentrations of both soluble and labile P. The excess soluble P can either leach downward to a zone that has more attachment sites and then be converted to labile P or fixed P, or it can be carried off the land in runoff water.

If soils that have high labile P concentrations reach surface water as sediment, they will continuously desorb or release P to the soluble form until equilibrium is attained. Therefore, sediment from land receiving animal waste at high rates or over a long period of time will have a high potential to pollute surface water.

Table 3–4 illustrates typical dissolved P concentrations reported in surface runoff from fields where animal waste was applied at recommended agronomic rates. Although this table is based on research findings, it is provided for illustration only because it does not necessarily represent concentrations that might occur in different regions of the country where the land slopes, soil types, waste application quantities and rates, or amounts of precipitation could be different than those for which the research was conducted.

Waste that is surface applied can produce total P concentrations in surface runoff higher than those shown in table 3–4, especially if the waste is applied at high rates, not incorporated, applied on snow-covered or frozen ground, or applied on fields with inadequate erosion control practices.

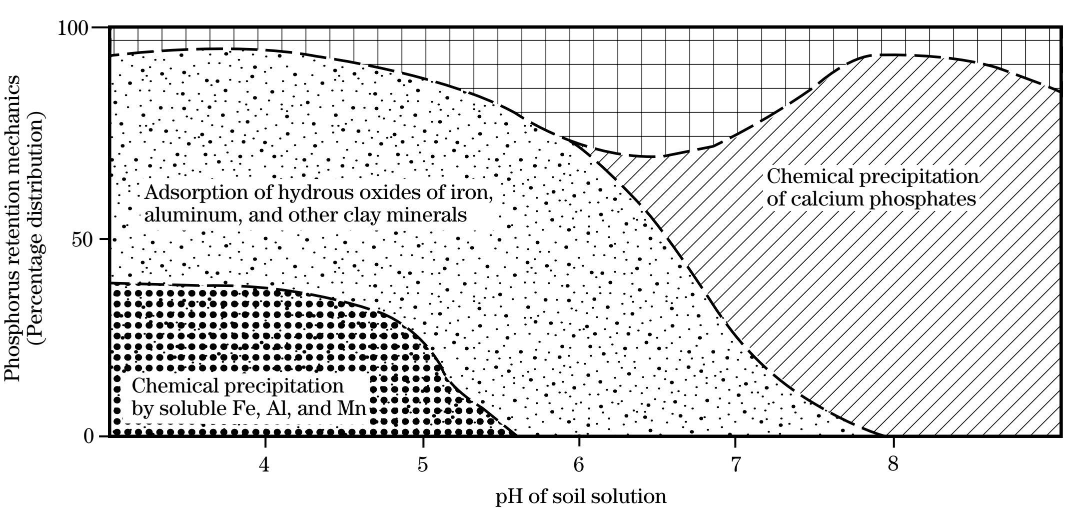
Erosion control measures—Although organic matter increases the water-holding capacity of soils and generally helps to reduce the potential for erosion,

Table 3–4 Estimated dissolved P concentrations in runoff from land with and without animal wastes surface applied

Cropping conditions	Dissolved P in runoff With manure	Without manure
	- - - - - - - - - - mg/L	- - - - - - - - - -
Grass	3.0	0.44
Small grain	4.0	0.40
Row crop	1.7	0.40
Rough plow	1.7	0.20

Source: Animal Waste Utilization on Cropland and Pastureland (USDA 1979).

Figure 3–4 P retention and solubility as related to soil pH



erosion can still occur on land receiving livestock and poultry wastes. If wastes are applied to satisfy the N requirements of the crops, the P concentrations in the soil may become extremely high. Because such soils generally have a high concentration of labile P, any loss of soil to surface water poses a serious threat to water quality in the receiving water, especially ponds and lakes. For this reason, good erosion control measures are essential on land receiving animal waste.

Phosphorus entrapment—Providing an adequate buffer zone between the source of organic contaminants (land spreading areas, cattle feedlots) and stream or impoundment helps provide settling and entrapment of soil particles with attached P. Forested riparian zones adjacent to streams form an effective filter for sediment and sediment related P. In addition, water and sediment control basins serve as sinks for sediment-attached P.

Animal waste lagoons are also very effective for P storage. Typically 70 to 90 percent of the P in waste that enters a waste treatment lagoon will settle and be retained in the sludge on the bottom of the lagoon. It should also be noted that this P accumulation will eventually need to be addressed.

Phosphorus retention—Sandy soils do not effectively retain P. If the groundwater table is close to the surface, the application of waste at excessive rates or at N-based rates will most likely contaminate the groundwater beneath those soils. However, groundwater that is below deep, clay soils is not likely to be contaminated by P because of the adsorptive capacity of the clay minerals.

P will change forms rapidly once contact is made with the soil. Equilibria can be established between the bound forms and those in solution within just a few hours. However, as time goes on, more of the P is converted to the fixed or tightly bound forms. The conversion to these unavailable forms may take weeks, months, or even years. Therefore, the soil has the potential to retain large amounts of P (to serve as a P "sink"), especially if given ample time between applications. Caution should be taken in that high P concentrations can inhibit both plant nutrient uptake and soil biological activity. Soil and manure can be treated with substances containing calcium, iron, or aluminum cations, like alum, to improve their ability to retain soluble P.

Aerobic conditions—Compounds of P, iron, manganese, and other elements react differently where oxygen is present or absent in the surrounding environment. This is true in the soil environment as well as in impoundments. Under anaerobic conditions, iron changes from the ferric to the ferrous form, thus reducing P retention and increasing P solubility.

Soils receiving frequent applications of wastewater can become saturated and anaerobic. Such soils will not be as effective at removing and retaining P as well-aerated soils.

Harvesting—Soluble P will be removed from the soil by plants. The amount removed depends on the amount required by the plant and the reserve of P in the soil. If the plants are removed through mechanical harvesting, all of the P taken up by the plant will be removed except that associated with the roots and unharvestable residue. If the plants are removed be grazing animals, only a part of the plant P will be removed because a large fraction of the P consumed will be returned to the land in the feces. If plants are not harvested and removed, either mechanically or through animal consumption, they will eventually die, decay, and return the P to its source. It then becomes available again as a source of plant food or pollution.

***Effects of phosphorus in the aquatic environment*—**When P enters the freshwater environment, it can produce nuisance growths of algae and aquatic weeds and can accelerate the aging process in lakes. Direct toxicity to fish and other aquatic organisms is not a major concern. Some algae species are toxic to animals if ingested with drinking water.

In the marine or estuarine environment, however, P in the elemental form (versus phosphates or other forms of combined P) can be especially toxic and can bioaccumulate in much the same way as mercury. For this reason, the EPA has established a criterion of 0.01 micrograms per liter (μg/L) of yellow (elemental) P for marine and estuarine water. This concentration represents a tenth of the level demonstrated to be lethal to important marine organisms. Other forms of P are virtually nontoxic to aquatic organisms.

Although no national criteria exist for other forms of P to enhance or protect fresh water, the EPA recommends that total phosphate concentrations not exceed 50 micrograms per liter (as P) in any stream at the point where it enters a lake or reservoir (EPA 1986). A desired goal for the prevention of plant nuisances in streams or other flowing water not discharging directly to lakes or impoundments is 100 micrograms per liter of total P.

Relatively uncontaminated lakes have from 10 to 30 micrograms per liter total P in the surface water. However, a phosphate concentration of 25 micrograms per liter at the time of spring turnover in a lake or reservoir may occasionally stimulate excessive or nuisance growths of algae and other aquatic plants.

The EPA reports these findings regarding P in natural water (EPA 1984):

- High P concentrations are associated with accelerated eutrophication of water when other growth-promoting factors are present.
- Aquatic plant problems develop in reservoirs and other standing water at P values lower than those critical in flowing streams.
- Reservoirs and lakes collect phosphates from influent streams and store part of them within consolidated sediment, thus serving as a phosphate sink.
- P concentrations critical to noxious plant growth vary, and nuisance growths may result from a particular concentration of phosphate in one geographic area, but not in another.

Whether or not P will be retained in a lake or become a problem is determined by nutrient loading to the lake, the volume of the photic (light-penetrating) zone, the extent of biological activity, the detention time of the lake, and level at which water is withdrawn from the lake. Thus, a shallow lake in a relatively small watershed and with only a surface water discharge is more likely to have eutrophication problems than a deep lake that has a large drainage area-to-lake volume ratio and bottom water withdrawal. This assumes that the same supply of nutrients enters each lake.

Figure 3–5 depicts average inflowing P concentrations into a lake versus hydraulic residence time, which is the time required for the total volume of water in the lake to be replaced with a "new" volume. The dotted lines represent P concentrations of 10, 25, and 60 micrograms per liter and roughly delineate the boundaries between oligotrophic, mesotrophic, eutrophic, and hyper-eutrophic conditions. Figure 3–5 is presented for purposes of illustration only because the delineations between the different trophic states cannot be precisely defined. The model used to develop figure 3–5 is only one of many models used to predict trophic state. Some are more useful in cool, northern climates, while others are best suited to warm-water lakes or lakes in which N rather than P is limiting.

(3) Fecal organisms

The excreta from warm-blooded animals have countless microorganisms, including bacteria, viruses, parasites, and fungi. Some of the organisms are pathogenic (disease causing), and many of the diseases carried by animals are transmittable to humans, and vice versa. Table 3–5 lists some of the diseases and parasites transmittable to humans from animal manure.

Many States use fecal coliform (FC) bacteria as an indicator of pollution from warm-blooded animals, including man. The test for FCs is relatively simple and inexpensive compared to testing for specific pathogens. To test water for specific pathogens, such as salmonella, a number of samples of the suspect water must be collected to ensure that any pathogenic organisms in the water are actually captured.

The alternative to this impractical approach is to use an indicator organism that simply indicates when pollution from the waste of warm-blooded animals is present, thus providing a way to estimate the potential for the presence of pathogenic organisms. The indicator organism must have the following characteristics:

- It must exist in large numbers in the source (animals, humans) in far greater numbers than the pathogens associated with the source.
- The die-off or regrowth rate of the indicator organism in the environment should be approximately the same as most pathogens.
- The indicator should be found only in association with the source of waste; its presence, therefore, would be a definite indicator that pollution from that type of source is present.

One indicator organism used widely to check for the presence of pathogens is a family of bacteria known as the coliforms. The total group of coliforms is associated with both the feces of warm-blooded animals and with soils. However, the FC group represents a part of the total coliforms and is easily differentiated from the total coliforms during testing.

A positive test for FC bacteria is a clear indication that pollution from warm-blooded animals exists. A high count indicates a greater probability that pathogenic organisms will be present.

Some FCs generally are in all natural water even without the influence of humans or their domestic animals. Birds, beaver, deer, and other wild animals contribute FCs to the water, either directly or in runoff. It is necessary, therefore, to have acceptable limits for FC bacteria, taking into account the beneficial use of the stream or water body. The EPA established water quality criteria for FC bacteria in its Quality Criteria for Water (1976), which many States have adopted. Typical limits are shown in table 3–6.

Some planners have used the ratio of FC to fecal streptococcus (FS) bacteria to help identify whether a suspected source of water pollution is from humans or other warm-blooded animals. Table 3–7 shows the typical FC/FS ratios (as excreted) for different animal species.

Some questions remain regarding the usefulness of this method of identifying sources because the die-off rates between the two types of bacteria can differ significantly. Consequently, it would only have meaning when the sampling point is close to the source. For this reason, the FC/FS ratio should be used with extreme caution as a tool for determining sources of pollution.

In more recent years, the EPA has established criteria for using Escherichia coli (E. coli) and enterococci as a measure of harmful levels of bacterial pollution in

Figure 3–5 Lake trophic states based on model by Vollenweider (adapted from EPA 1990)

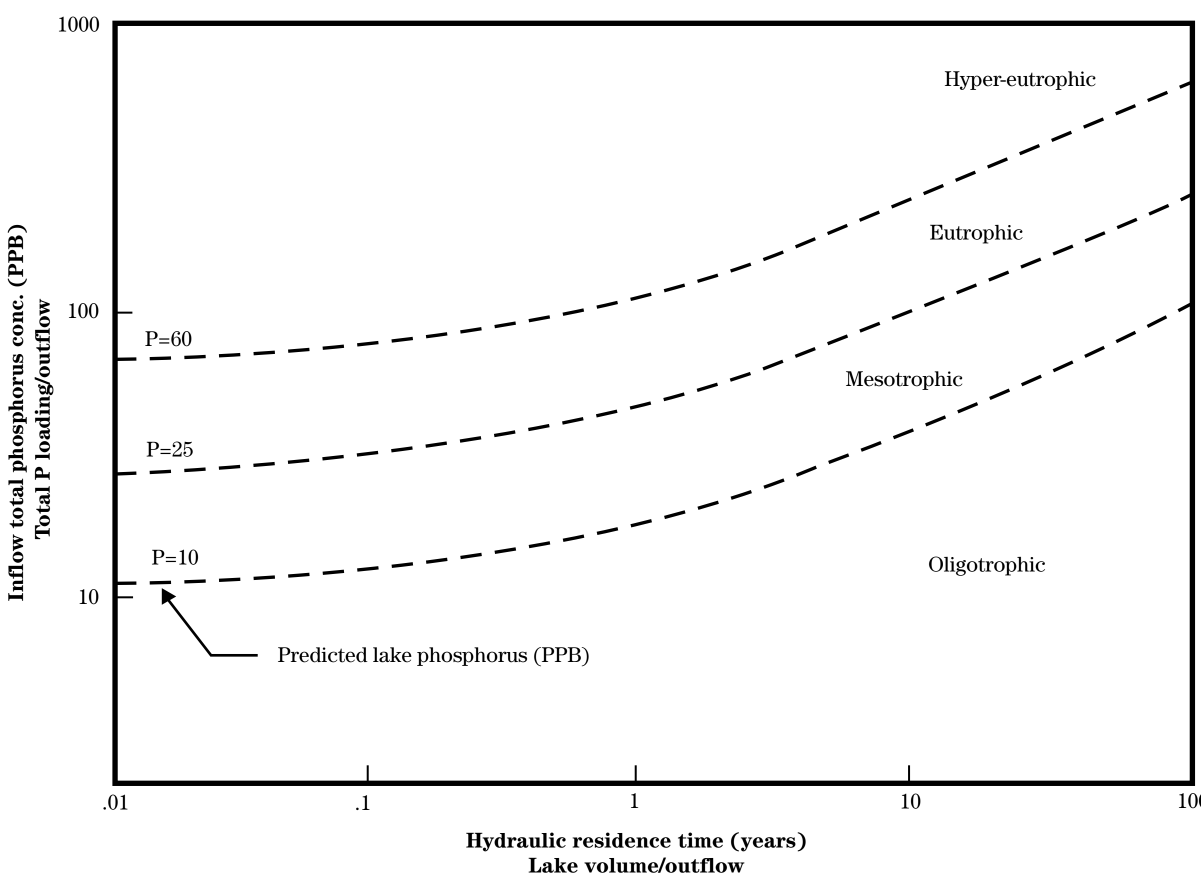


Table 3–5 Diseases and organisms spread by animal manure

Disease	Responsible organism
Bacterial	
Salmonella	Salmonella sp.
Leptospirosis	Leptospiral pomona
Anthrax	Bacillus anthracis
Tuberculosis	Mycobacterium tuberculosis
	Mycobacterium avium
Johnes disease	Mycobacterium aratuberculosis
Brucellosis	Brucella abortus
	Brucella melitensis
	Brucella suis
Listerosis	Listeria monocytogenes
Tetanus	Clostridium tetani
Tularemia	Pasturella tularensis
Erysipelas	Erysipelothrix rhusiopathiae
Colibacilosis	E. coli (some serotypes)
Coliform mastitis-metritis	E. coli (some serotypes)
Rickettsial	
Q fever	Coxiella burneti
Viral	
New castle	Virus
Hog cholera	Virus
Foot and mouth	Virus
Psittacosis	Virus
Fungal	
Coccidioidomycosis	Coccidoides immitus
Histoplasmosis	Histoplasma capsulatum
Ringworm	Various microsporum and trichophyton
Protozoal	
Coccidiosis	Eimeria sp.
Balantidiasis	Balatidium coli.
Toxoplasmosis	Toxoplasma sp.
Parasitic	
Ascariasis	Ascaris lumbricoides
Sarcocystiasis	Sarcocystis sp.

Table 3–6 Typical allowable limits for FC bacteria based on water use

Water use	Bacteria/100 ml sample
Public water supply (before treatment)	2,000 * 4,000 max
Swimming	100 coastal * 200 fresh water *
Fish and wildlife	2,000 max

* Based on a geometric mean of at least five samples collected over 30 days at intervals of no less than 24 hours.

Table 3–7 Typical FC to FS ratios (as excreted) for several animal species

Species	FC/FS ratio
Human	4.4
Ducks	0.6
Sheep	0.4
Pig	0.4
Chicken	0.2
Turkey	0.1

* Based on a geometric mean of at least five samples collected over 30 days at intervals of no less than 24 hours.

ambient waters. E. coli (a FC type) and enterococci are natural inhabitants of warm-blooded animals, and their presence in water samples is an indication of fecal pollution and the possible presence of pathogens. Some strains of enterococci are found outside warm-blooded animals.

The EPA reports that a direct relationship between the density of enterococci and E. coli in water and the occurrence of swimming-associated gastroenteritis has been established through epidemiological studies of marine and freshwater bathing beaches. The resulting criteria can be used to establish recreational water standards. The EPA criteria for freshwater bathing are based on a statistically significant number of samples (generally not less than five samples equally spaced over a 30-day period). The geometric mean of the indicated bacterial densities should not exceed one or the other of the following:

E. coli 126 per 100 ml
Enterococci 33 per 100 ml

These criteria should not be used without also conducting a statistical analysis based on information provided by the EPA.

(b) Constituents affecting groundwater quality

Nitrates and bacteria are the primary constituents of animal waste that affect groundwater quality. Phosphorus and potassium (K) do not constitute a threat to public health through water supplies. In their common forms, P and K are relatively insoluble and are not normally leached below the top several inches of most soils, especially those with a high clay fraction.

Phosphorus readily combines with aluminum and iron in acidic soils and with calcium in basic soils. Because these substances are relatively abundant in most soils, a large fraction of the total P applied to the land will be quickly immobilized. Only a small fraction of the soluble inorganic P will be available for plants (see previous description of the characteristics of P in this chapter).

In addition to animal waste, other agricultural-related wastes and their constituents can impact groundwater quality. Salinity has long been recognized as a contaminant of groundwater resulting from percolating irrigation application. Two mechanisms influence the amount of salt reaching the groundwater. The first is concentration of salt in the irrigation supplies. The process of evapotranspiration concentrates the salt in the root zone, making it available for solution and transport. The more salt in the irrigation supply, the more salt in the leachate. In addition, percolating water dissolves salts from marine shales, increasing the salinity of the aquifers in that manner.

Pesticides also have been identified as a contaminant of groundwater. The major source of contamination is associated with filling and washing application equipment in the proximity of the wellhead. However, concentrations of selected pesticides have been noted in the vicinity of application areas.

Oils and greases associated with the agriculture industry are also capable of contaminating groundwater supplies. Of most concern are leaking underground storage tanks for fuel oil, but percolating water is also capable of moving spilled oils from the soil surface into the soil profile.

(1) Nitrate

As noted in section 651.0302(a)(2), NO_3 is the soluble form of N and is easily leached beyond the root zone of plants. The principal sources of nitrates in groundwater from agricultural activities are animal waste and commercial fertilizers.

The EPA established a criterion of 10 milligrams per liter of NO_3–N for drinking water because of the health hazard that nitrates present for pregnant women and infants. Unborn babies and infants can contract methemoglobinemia, or blue baby syndrome, from ingesting water contaminated with nitrates. In extreme cases, this can be fatal. Blue baby syndrome generally effects only infants that are less than 6 months old. The disease develops when NO_3 is converted to NO_2 in the alkaline environment of the baby's stomach. The NO_2 then enters the bloodstream and interacts with the hemoglobin, converting it to methemoglobin.

Hemoglobin carries oxygen in the bloodstream, but methemoglobin does not. Therefore, as the amount of vitally needed hemoglobin is reduced in the bloodstream, less oxygen is carried to the body's organs, and symptoms of oxygen starvation begin to occur.

The baby's skin takes on a bluish tint. If the situation is not reversed, the baby could die of oxygen starvation.

Even after the baby discontinues consumption of the contaminated water, the buildup of normal hemoglobin can be slow. After the age of 6 months, the baby's stomach pH reaches adult levels, and the disease is rarely a problem.

(2) Fecal bacteria

Contamination of wells and springs by fecal bacteria or other waste-related microorganisms is a possible problem if wastes are spread on sandy soils. Studies in poultry growing areas of the Northeast and South indicate elevated FC and FS concentrations are possible where poultry litter has been applied at high rates.

A number of diseases can be transported between animals and man as noted in section 651.0302(a)(3); however, the potential for contamination of groundwater by fecal organisms is reduced considerably by the filtering action of the soil. The importance of soil filtering is described in the following section.

Well water should be tested regularly for contamination by fecal bacteria. The acceptable limit is zero for potable water (chapter 1, section 651.0108(b), table 1–5).

651.0303 Factors affecting the water pollution process

Water pollution occurs only when a contaminant finds a pathway from the source to the groundwater or to a stream or water body in such quantities that the designated use of the receiving water can no longer be met. However, the contaminant may not find such a pathway because of chemical or physical transformations affecting it in the environment or because the pathway is blocked by natural phenomena or by control processes imposed by humans.

(a) Pathways to pollution

The pathway that a contaminant follows to reach a stream or to enter groundwater depends on its physical and chemical characteristics as well as the surface and subsurface characteristics of the land. Many constituents of manure move as small organic particles (bacteria, viruses, suspended sediment), while others (i.e., ammonium or P) are adsorbed to organic particles or soil. The attached contaminants move in piggyback fashion only when the host material moves.

Sediment, organic particles, or substances adsorbed to particles can be physically detached at the soil surface by the impact of raindrops or by overland flow and then transported to surface water. Larger substances and attached substances are prevented from moving downward by the filtering action of the soil. However, soluble substances, such as nitrates, can move readily downward until impeded by a restricting layer. A fragipan or sandstone layer may cause soluble contaminants to migrate laterally as subsurface flow until they emerge along a streambank as part of bank flow.

(b) Transformations on the soil surface

Manure that is surface applied and not incorporated is exposed to solar radiation and aerobic drying conditions leading to volatilization and the death of pathogens. On warm and windy summer days, all of the initial ammonium in animal waste can be lost to the atmosphere within 24 to 48 hours. Mineralization and immobilization of N through adsorption can also occur rapidly under such conditions.

(c) Filtering in the upper soil layer

Many factors, including the soil's physical and chemical characteristics and the environment in the soil (table 3–8) affect the removal of fecal bacteria in the soil and prevent their movement into groundwater. The primary factors are filtration, adsorption, and die-off in the soil.

Bacteria passing through the soil matrix can be filtered as a result of three processes acting independently or in combination. These processes are:

- physical filtration or straining by the soil matrix
- sedimentation of bacteria in the soil pores
- "bridging," whereby previously filtered bacteria block or reduce the size of pores through which other bacteria would normally pass

Soil texture, structure, and pore size vary considerably among soils and influence the effectiveness of the filtering process. Adsorption of microorganisms onto clay particles and organic material effectively removes bacteria from liquids. Filtration and adsorption can remove over 90 percent of the bacteria applied in effluent in the first half inch of soil. Almost total removal can be accomplished in the first 2 inches of fine-textured soils.

Some soils have a tremendous capacity to remove bacteria and protect the groundwater resource. However, coarse-textured or disturbed soils do not provide the same level of treatment as undisturbed, fine-textured soils. In addition, overloading or constant saturation of the soil can greatly reduce its ability to remove bacteria.

(d) Transformations within the deep soil profile

The soil can be divided into saturated and unsaturated zones (fig. 3–6). The boundary between these zones varies seasonally and from year to year. In some locations, the saturated zone extends to the surface of the soil in early spring; at other times and locations, it may be hundreds of feet below the surface.

The unsaturated zone includes the root zone and an unsaturated area below the root zone. The root zone is characterized by an abundance of macropores, created in part by decaying roots and wormholes. The macropores allow rapid downward movement of substances carried by percolating water.

The root zone is also characterized by an abundance of carbon created by the decaying roots. Because microorganisms require carbon, biological transformations occur rapidly within the root zone, especially when the soil temperature is warm and adequate moisture is available.

Microbial activity is drastically reduced below the root zone. As a result, NO_3, which is available for a variety of other transformations within the root zone, can remain in the NO_3 form for years below this zone of microbial activity.

Table 3–8 Soil factors affecting infiltration and movement (leaching) of bacteria in soil

Physical characteristics	Environmental and chemical factors
Texture	Cation-exchange capacity
Particle size distribution	Chemical makeup of ions and their concentrations
Clay type and content	
Organic matter type and content	Bacterial density and dimensions
Pore size distribution	Nature of organic matter in waste effluent solution (concentration and size)
Temperature	
Moisture content	
Fragipan (hardpan)	pH
Surface compaction	

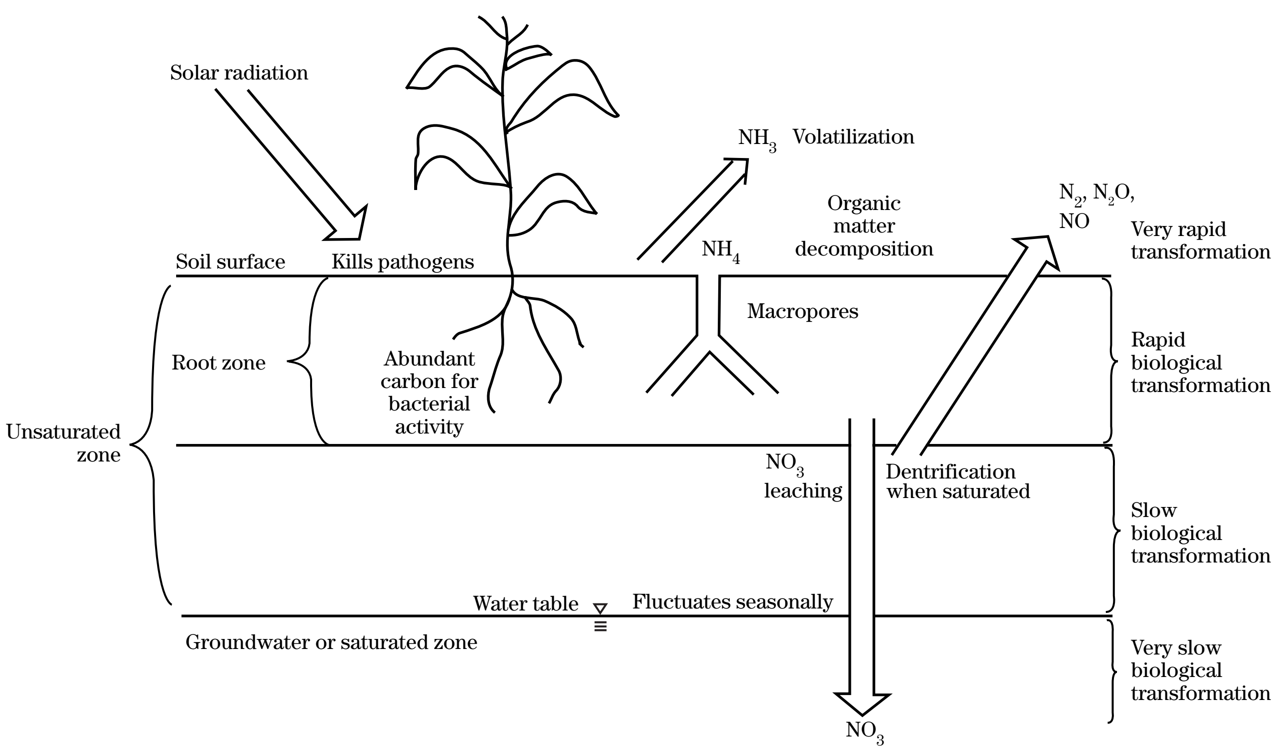
Within the saturated zone or in the groundwater, contaminants can remain unchanged for long periods because of the absence of microorganisms. However, in soils that have a seasonal high water table, the root zone can become saturated and anaerobic. In this environment, anaerobic bacteria can thrive, creating ideal conditions for denitrification (the conversion of nitrates to gaseous forms of N).

651.0304 Controlling the water pollution process

Manure is a valuable resource for crop production. It contains not only nutrients but also organic matter. A basic principle is that if manure is utilized to the maximum extent possible, discharge of pollutants to receiving waters will be minimized. The classic pollutant delivery process takes place in three stages: availability, detachment, and transport. Conservation practices that limit availability, prevent detachment, and interrupt transport should be used to prevent manure from contributing to water pollution.

Three elementary factors are required for a contaminant to reach a watercourse or enter the groundwater:

Figure 3–6 Transformations on or in the soil



- A contaminant must first be available. If pesticides, fertilizers, or animal waste are not used in a watershed, these contaminants are not available.
- If the contaminant is available, it must be detached or removed from its resting place.
- Once detached, the substance must be transported to the point where it is integrated into a stream or water body or leached into the groundwater.

These factors (availability, detachment, transport) must be addressed when attempting to prevent the movement of contaminants from land to water. A brief description of these factors and examples of controls for each factor follow. A variety of management, vegetative, and structural practices can be used to control pollution beyond those illustrated here.

(a) Limiting availability

Several factors must be known about a contaminant at the time of surface runoff or infiltration through the soil, including:

Amount of the substance available—Is the waste applied to the land in one large application or in split applications throughout the growing season? How much manure has been applied to the soil in the application area in previous years?

Partitioning of the substance between soil and water—Is the substance in soluble form, such as nitrate, or is it adsorbed to soil particles?

Position of the substance on or in the soil profile—Is the manure incorporated immediately after application? Are the soils managed to maximize infiltration?

Persistence of the substance on or in the soil— How long will it remain in place before being converted to another form or being lost through volatilization or leaching?

Animal waste can be deposited on pasture or rangeland, in streams where the animals congregate on hot days, or in confinement facilities where the waste must be removed and eventually returned to the land. In general, the more manure deposited by animals on pasture or feedlots or spread on the land, the greater the concentration of contaminants in runoff or percolating water.

The following examples illustrate how animal waste or the particular constituents within the waste (nutrients, bacteria) can be limited in a watershed or at land spreading sites, assuming a water quality problem has been identified and the source is a livestock operation. Measures that could be used are:

- Remove all animals from the watershed.
- Reduce the number of animals.
- Use cropping systems that require more nutrients throughout the year.
- Improve manure storage capacity to avoid spreading manure during critical runoff periods; for example, when the ground is frozen or covered with snow and ice.
- Apply wastes in split applications throughout the growing season, thereby making smaller amounts of manure available each time.
- Apply wastes over more acres at recommended rates. (Nutrient application rates far exceeding agronomic recommendations can result if, for convenience sake, wastes are applied to only the fields nearest the confinement facility.)
- Use cover crops to prevent erosion and to capture nutrients in the soil system between crops.
- Use reduced tillage systems and manage crop residues to build soil structure that will increase infiltration and decrease surface runoff.
- Incorporate or inject the manure, thus limiting the availability of particular constituents. Phorphorus and NH_4 will become bound within the soil profile and be less available for detachment.
- Collect and transport wastes to fields in other watersheds or bag the material for sale elsewhere.
- Compost the waste to reduce the availability of N.
- Treat the waste in a lagoon and land apply the waste only from the upper liquid zones of the

lagoon to reduce the amount of N. Some of the N will volatilize, and some will settle.

The Field Office Technical Guide (FOTG), Conservation Practice Physical Effects, lists the most common soil and water control practices used to prevent detachment and interrupt transport of contaminants to surface water.

(b) Preventing detachment

When the contaminants are on the land (already available), physical detachment generally results from the impact of raindrops or from shear forces in overland sheet flow or concentrated flow. Unprotected soil and surface-applied wastes, fertilizers, and pesticides may be detached in this way. Therefore, the primary control measures to prevent detachment are those that reduce the impact of raindrops, such as vegetative cover or mulch, and those that control the velocity of water moving across the landscape, such as minimum or no tillage.

An understanding of the particular contaminants and how they react on the land or in the environment is helpful in establishing proper methods of control. Preventing detachment can involve control of particular constituents within animal waste (see section 651.0302(a)). If P is an identified water quality problem, then practices must be applied to prevent detachment of P. If the problem is low dissolved oxygen in a stream or lake (possibly from excessive organic matter) or a fish kill from high concentrations of un-ionized NH_3, then controls for these constituents should be applied.

Weakly bonded substances, nitrates, and bacteria can be detached and transported by water moving through the soil. Management practices to control detachment include:

- applying less soluble fertilizers
- applying wastes in split applications to prevent too much N from being converted to nitrate at one time
- applying less irrigation water to fields when high levels of soluble substances are available

(c) Interrupting transport

If detachment of contaminants is inevitable, as with waste flushed from an open lot, then a method is needed to interrupt the transport process. For example, diversions can be designed to channel contaminated runoff into lagoons, waste storage ponds, and settling basins.

In the case of land-applied waste, a number of vegetative and structural practices can be used to intercept contaminants. Sediment basins are useful, especially if sandy soils are involved. Because the trap efficiency for clays can be relatively low, contaminants that are attached to clay particles are best controlled by controlling detachment rather than interrupting transport.

Vegetative and structural practices that slow the movement of water and allow for settling of solids are useful tools for interrupting transport of contaminants. Vegetative conservation buffers that function as filter strips at the edge of fields and infield practices like terraces and contour buffer strips are examples of practices that interrupt the transport process. Vegetative growth, especially a well-established winter cover crop, can take up nutrients that would otherwise be lost and can serve as a filter to trap sediment and adsorbed nutrients. For vegetative areas to be effective, they must slow runoff sufficiently to allow the sediment and organic materials to settle out in the filter and allow increased soil infiltration of runoff water.

651.0305 Effects of animal waste on the air resource

Livestock production facilities can be the source of gases, aerosols, vapors, and dust that, individually or in combination, can create such air quality problems as:

- nuisance odors
- particulate matter
- greenhouse gases
- ozone precursors
- animal health and asphyxiation

(a) Odors

Agricultural odors are a complex mixture of gases that can evoke a wide range of emotional and physiological responses when encountered via the sense of smell. While some odorous compounds can cause health problems, odors from livestock are mainly a community or individual perception issue. Many different compounds can be the potential cause of odors from agricultural operations. These compounds can generally be classified as volatile organic compounds (VOCs), odorous sulfur compounds (including H_2S) or NH_3. Odors may arise from animal operations in a number of ways, including:

- All living organisms (including animals) emit VOCs (including odorous compounds) naturally.
- The breakdown or decomposition of biological materials such as manure or feed can produce odorous compounds, including VOCs, odorous sulfur compounds, and NH_3.

(b) Particulate matter

Particulate matter (PM) is currently a "criteria air pollutant," which means that the EPA has identified PM as a pollutant that causes significant health (heart and lung) and environmental (deposition, visibility) effects. Particulate matter can be either solid particles or liquid droplets and come in a variety of sizes, shapes, and chemical composition. The EPA has currently established National Ambient Air Quality Standards (NAAQS) for the two forms of PM:

- Fine PM—currently regulated as PM2.5 (aerodynamic diameter less than or equal to 2.5 micrometers). **Note**: The diameter of the average human hair is 70 micrometers.
- Coarse PM—currently regulated as PM10 (aerodynamic diameter less than or equal to 10 micrometers), PM can be emitted directly (primary PM—dust, pollen, soot, etc.) or formed in the atmosphere (secondary PM—formed from the reactions and condensation of sulfates, nitrates, VOCs, and NH_3). Animal operations can influence PM in a variety of ways:
  - Animal activity can produce dust emissions that can be carried by wind or building ventilation.
  - Storage, handling, and the breakdown or decomposition of feed, bedding material, and manure can produce dust emissions as well as the emission of VOCs, NH_3, and oxides of nitrogen (NOx), which includes nitric oxide (NO) and nitrogen dioxide (NO_2).
  - Fuel combustion, or the burning of biological material, can produce fine PM as well as oxides of N and VOCs.
  - Manure decomposition and its application on the land can produce emissions of VOCs, NH_3, and oxides of N.

(c) Greenhouse gases

Greenhouse gases (GHGs) are compounds in the atmosphere that capture and retain energy reflected from the Earth's surface. They lead to a warming of the atmosphere that is popularly called the "greenhouse effect." Carbon dioxide, methane (CH_4), and nitrous oxide (N_2O) are the primary compounds associated with GHGs in agricultural operations. Common processes in animal operations that may produce GHGs are:

- Biological organisms (including animals) emit CO_2 and CH_4 naturally. Ruminants, such as cattle and sheep, produce more intestinal CH_4 than non-ruminants.

- The breakdown or decomposition of biological materials, such as manure, feed, or mortalities, can produce CO_2 (as a natural by-product of the breakdown/decomposition process), CH_4 (under anaerobic conditions), and N_2O (mainly from the nitrification/denitrification processes).
- Combustion in on-farm equipment or the burning of biological material also produces CO_2 as a natural by-product.

(d) Ozone precursors

Ozone is a gas composed of three oxygen atoms and is the primary component of smog. Although ozone in the upper atmosphere forms a layer that provides protection from ultraviolet radiation, ozone in the lower atmosphere and at ground level can be harmful. While ozone is not typically emitted directly from agricultural operations, it is formed in the lower atmosphere through the chemical reactions of VOCs and NOx, which are regulated as ozone precursors. Oxides of N and VOCs are known as ozone precursors because they are identified as pollutants that form ozone.

Some ways that animal operations can impact VOC and NOx formation are:

VOCs

- All living organisms (including animals) emit VOCs naturally.
- The breakdown or decomposition of biological materials such as manure or feed can produce VOCs.
- Incomplete fuel combustion or the burning of biological material can produce VOCs.

NOx

- Fuel combustion or the burning of biological material can produce NOx.
- The breakdown or decomposition (mainly nitrification/denitrification) of biological materials such as manure or feed can lead to NOx formation.

(e) Animal health and asphyxiation

A variety of gases can be generated in the operation of a livestock production facility that can cause asphyxiation, poisoning, and explosions. Some of these gases are toxic and can cause illness and even death at relatively low concentrations. Other gases are not toxic, but can displace oxygen and result in asphyxiation.

Different gases are produced as animal waste is degraded by microorganisms. Under aerobic conditions, CO_2 is the principal gas produced. Under anaerobic conditions, the primary gases are CH_4 and CO_2. About 60 to 70 percent of the gas generated in an anaerobic lagoon is CH_4, and about 30 percent is CO_2. However, trace amounts of more than 40 other compounds have been identified in the air exposed to degrading animal waste. Some of these include mercaptans (this family of compounds includes the odor generated by skunks), aromatics, sulfides, and various esters, carbonyls, and amines.

The gases of most interest and concern in manure management are CH_4, CO_2, NH_3, and H_2S. Table 3–9 provides a summary of the most significant characteristics of NH_3, CO_2, H_2S, and CH_4.

Methane is flammable, and in recent years, interest in using it as a source of energy on the farm has increased. Because CH_4 can be explosive, care is required when attempting to generate and capture this gas for on-farm use.

Carbon dioxide can be an asphyxiant when it displaces normal air in a confined facility. Because CO_2 is heavier than air, it remains in a tank or other well-sealed structure, gradually displacing the lighter gases.

Ammonia is primarily an irritant and has been known to create health problems in animals in confinement buildings. Irritation of the eyes and respiratory tract are common problems from prolonged exposure to this gas. It is also associated with soil acidification processes (see section 651.0302).

Hydrogen sulfide is deadly. Humans and farm animals have been killed by this gas after falling into or entering a manure tank or being in a building in which a manure tank was being agitated. Although only small amounts of H_2S are produced in a manure tank compared to the other major gases, this gas is heavier than air and becomes more concentrated in the tank over time.

When tanks are agitated in preparation for pump out, H_2S can be released to the area overhead. Where a tank is located beneath the animals in a building, forced-air ventilation in the building is imperative before operating the agitation equipment. An exhaust system should also be provided within the tank during agitation and pump out.

Hydrogen sulfide has the distinct odor of rotten eggs. At the first hint of this odor, the area around the tank should be immediately evacuated of all humans. Hydrogen sulfide deadens the olfactory nerves (the sense of smell); therefore, if the smell of rotten eggs appears to have disappeared, this does not indicate that the area is not still contaminated with this highly poisonous gas.

A person should never enter a manure storage tank even to help rescue someone else who has succumbed to the H_2S. Several lives have been lost attempting such rescues. If a tank must be entered, the air in the tank should first be evacuated using a forced-air ventilation system. Self-contained breathing apparatus, safety lines, and sufficient personnel to man the lines are needed in all cases. A mechanical hoisting device would be preferable (ASABE Standard S607, Ventilating Manure Storage to Reduce Entry Risk).

For more information on how animal waste affects the air resource, see the NRCS National Engineering Handbook, Part 629, Air Quality.

Table 3–9 Properties and physiological effects of the most important gases produced from animal wastes in an anaerobic environment

Gas	Lighter than air	Odor	Class	Comments
Ammonia (NH_3)	Yes	Sharp, pungent	Irritant	Irritation of eyes and throat at low concentrations. Asphyxiating, could be fatal at high concentrations with 30- to 40-minute exposure. PM precurser.
Carbon dioxide (CO_2)	No	None	Asphyxiant	<20,000 ppm=safe level; increased breathing, drowsiness, and headaches as concentration increases; could be fatal at 300,000 ppm for 30 minutes. Greenhouse gas.
Hydrogen sulfide (H_2S)	No	Rotten eggs	Poison	Headaches, dizziness at 200 ppm for 60 minutes. Nausea, excitement, insomnia at 500 ppm for 30 minutes; unconsciousness, death at 1,000 ppm.
Methane (CH_4)	Yes	None	Asphyxiant, flammable	Headaches at 500,000 ppm. Greenhouse gas.

651.0306 Effects of animal waste on the animal resource

The detrimental effects of the oxygen demand of organic matter and of the ammoniacal N that can come from manure on fish populations have been described previously in this chapter.

Animal mortality is part of all domestic animal feeding operations, and it is important to properly dispose of animal carcasses. Carcasses that are improperly disposed can become a feed source for undesirable predators like coyotes, and in their feeding on carcasses that can contribute to the spread of disease.

Wild turkeys are susceptible to blackhead disease from domestic poultry. Broiler breeder farms are commonly heavily contaminated with the cecal worm (*Heterakis gallinarum*) and their eggs, which can be transported to the field when spreading broiler breeder litter. For this reason, it is advisable to avoid spreading broiler breeder litter in areas where wild turkeys frequent.

Grazing animals can be adversely affected when animal waste is applied to forage crops at an excessive rate. Studies indicate that grass tetany, fescue toxicity, agalactia, and fat necrosis appear to be associated, in part, with high rates of fertilization from poultry litter on cool-season grasses (especially fescue). Highlights of these disease problems are provided. Additional details on the clinical signs of these diseases and methods to reverse or prevent their occurrence should be discussed with a veterinarian.

Grass tetany—Although this disease is associated mostly with low blood magnesium, conditions that increase the potential for its occurrence include low calcium, high uptake of N and P, and stress on the animal. Lactating cows grazing new growth of cool-season grasses or winter cereals are especially susceptible. Bulls and nonlactating cows are rarely affected.

Fescue toxicity—The precise cause of this disease is not well understood. Climatic conditions, molds and fungi, accumulation of ungrazed forage, and level of fertilization appear to be involved.

Agalactia—This term means absence of milk. Cows that have this condition are unable to lactate after giving birth. Not much is known about this disease, but it has often been observed in horses and cattle grazing on heavily fertilized tall fescue.

Fat necrosis—This disease is associated with mature cattle grazing tall fescue that has been heavily fertilized for a number of years with poultry litter. It appears to be a herd disease; although, it has occasionally been identified in individual animals. Cattle that have this disease generally have a restricted intestinal tract. In addition, the fat surrounding the birth canal can harden and prevent normal delivery.

Animal waste can be a repository for diseases and serves as a breeding ground for flies and other vectors. The transmission of diseases can be a problem.

Darkling beetles are a common problem in the litter of poultry houses. Left uncontrolled, they can spread disease between flocks and even between houses. Composting the litter in the poultry house between flocks and treatment with an insecticide can be an effective treatment against darkling beetles.

Fly problems are most prevalent where the waste is relatively moist. House flies thrive where the moisture content of the waste is 75 to 80 percent. Female flies generally will not lay eggs in manure in which the moisture content is less than 70 percent, and larvae develop poorly with less than 65 percent moisture. Therefore, fly production is reduced considerably if the waste is kept dry or is flushed regularly from confinement areas to a lagoon. Reducing fly populations will, in turn, reduce the chance for disease transmission within herds and flocks. It will also reduce the potential for nuisance complaints from neighbors.

651.0307 Conservation practice physical effects

Because of the amount of material available that addresses the role of soil and plant resources in agricultural waste management, these two resources are described in separate chapters in this handbook. The Conservation Practice Physical Effects in the FOTG should be consulted to evaluate the effects on water quality and quantity of conservation practices used in agricultural waste management systems on the soil, water, air, plant, and animal resources.

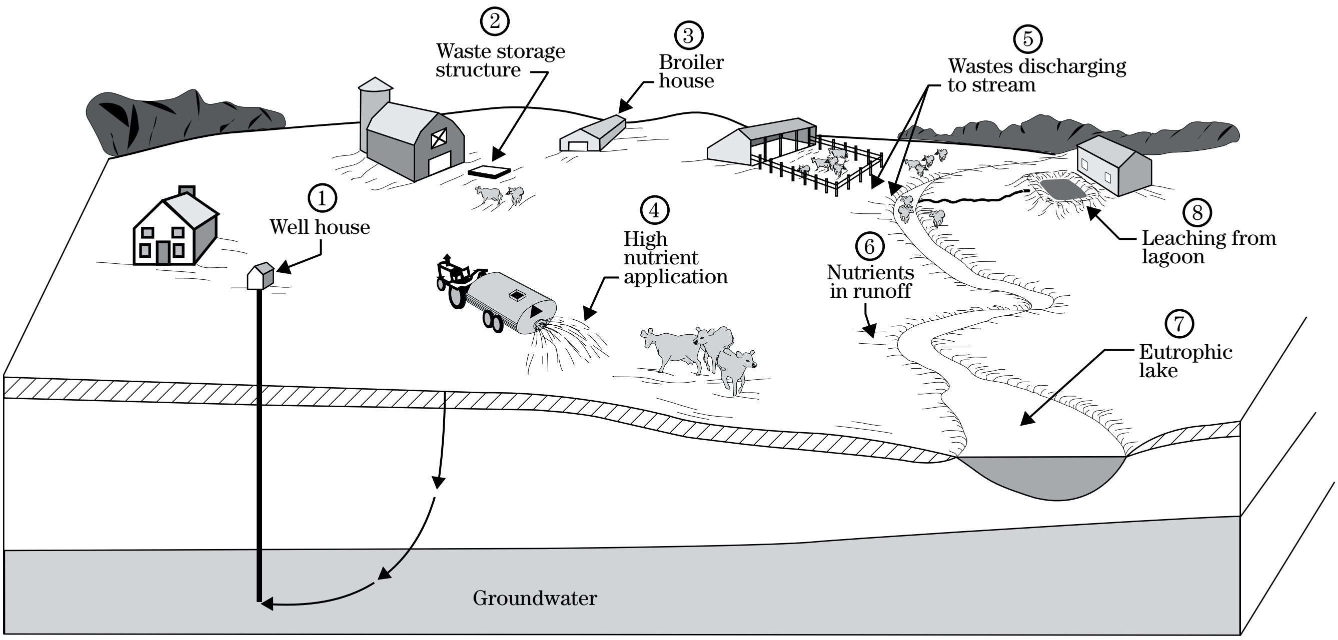
651.0308 Summary

Animal wastes can adversely affect water, air, and animal resources in a variety of ways. Nutrients can kill fish and create algae blooms in surface water. In groundwater, nitrates can make well water unfit for human consumption, particularly for infants. In addition, organic matter can cause dissolved oxygen problems in surface water, while bacteria and other microorganisms can contaminate wells and create health problems in recreational waters.

Certain constituents in animal waste can create health problems in animals grazing cool-season grasses. In addition, the gases that are produced can have a number of adverse effects on the air resource and on animals in confinement.

Figure 3–7 provides an abbreviated graphic summary of the impacts that animal wastes can have on water, air, and animal resources. This graphical depiction does not show all of the possible impacts and does not convey the complexity of the pollution process. Likewise, this chapter as a whole only introduces the pollution process as related to water, air, and animal resources. A more complete understanding of the interaction of animal wastes with the various resources and the methods for pollution control would take intensive study of the volumes already written on this topic in addition to a lot of field experience. Even then, all the answers are not in; more is being learned about the pollution process all the time.

Figure 3–7 Possible danger points in the environment from uncontrolled animal waste



1. Contaminated well: Well water contaminated by bacteria and nitrates because of leaching through soil. (See item 4.)
2. Waste storage structure: Poisonous and explosive gases in structure.
3. Animals in poorly ventilated building: ammonia, other gases, and particulates create respiratory and eye problems in animals and corrosion of metals in building.
4. Waste applied at high rates: Nitrate toxicity and other N-related diseases in cattle grazing cool-season grasses; leaching of NO_3 and microorganisms through soil, fractured rock, and sinkholes; loss of excess nitrogen via gaseous emissions.
5. Discharging lagoon, runoff from open feedlot, and cattle in creek: (a) Organic matter creates low dissolved oxygen levels in stream; (b) concentration reaches toxic limits for fish; and (c) Stream is enriched with nutrients, creating eutrophic conditions in downstream lake.
6. Runoff from fields where livestock waste is spread and no conservation practices on land: P and NH_4 attached to eroded soil particles and soluble nutrients reach stream, creating eutrophic conditions in downstream lake.
7. Eutrophic conditions: Excess algae and aquatic weeds created by contributions from items 5 and 6; nitrite poisoning (brown-blood disease) in fish because of high N levels in bottom muds when spring overturn occurs.
8. Leaching of nutrients and bacteria from poorly sealed lagoon: May contaminate groundwater or enter stream as interflow.

651.0309 References

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United States
Department of
Agriculture

Natural
Resources
Conservation
Service

Part 651
Agricultural Waste Management Field Handbook

Chapter 4 Agricultural Waste Characteristics

Issued March 2008

Acknowledgments

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Chapter 4 Agricultural Waste Characteristics

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Chapter 4 Agricultural Waste Characteristics

651.0400 Introduction

(a) Purpose and scope

Wastes and residues described in this chapter are of an organic nature and agricultural origin. Other by-products of nonagricultural origin that may be managed within the agricultural sector are also included. This chapter provides information for estimating characteristics of livestock and poultry manure and other agricultural residuals. The information provided is useful for the planning and design of agricultural waste management system (AWMS) components including:

- storage function components such as ponds and tanks
- treatment function components such as lagoons and composting
- utilization function components such as land application

The information may also be useful in formulating the environmental impact of manure and other agricultural wastes.

This chapter includes table values for the typical characteristics of manure *as excreted* by livestock and poultry based on typical diets and animal performance levels in 2003. These typical values are most appropriate for use when:

- planning estimates are being made on a scale larger than a single farm such as county or regional estimate of nutrient excretion
- a rough estimate is needed for farm planning
- farm-specific information of animal performance and feed intake is not available

Much of the as excreted data included in the tables of this chapter were developed using equations that are now available for predicting manure content, primarily nitrogen and phosphorus, dry matter, and, depending upon species, other potential characteristics for beef, swine, and poultry excretion. The fundamental model (fig. 4–1) on which these equations are based is:

Nutrient excretion = Nutrient feed intake – Nutrient retention

$$\text{Dry matter excretion} = \text{Feed dry matter intake} \times \left(1 - \text{dry matter digestibility}\right) + \text{Dry matter in urine}$$

Of the total excreted solids, dry matter in urine typically contributes 10 to 20 percent of the volume.

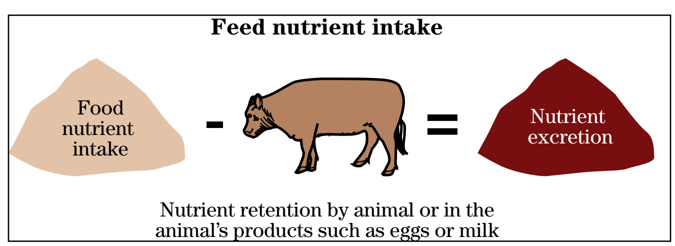
These equations allow an estimate of as excreted manure characteristics relevant to a wide range of dietary options and animal performance levels commonly observed in commercial production. Considered are factors related to the feed efficiency in animal performance and to feed intake including crude protein, phosphorus, and dry matter. A full presentation and description of these equations is beyond the scope of this chapter. They are, however, available in the American Society of Agricultural and Biological Engineers Standard D384.2. See *http://www.asabe.org/standards/index.html*.

For dairy and horses, regression analysis was performed on large data sets to determine appropriate equations.

In a number of situations, consideration should be given to using equations instead of the as excreted values presented in the tables of this chapter. Typical or average estimates of as excreted manure eventually become out-of-date due to changes in animal genetics, performance potential, feeding program strategies, and available feeds. If the timeliness of the data presented in this chapter becomes problematic, consideration should be given to computing values using equations. Other situations when use of equations should be considered are when:

- comprehensive nutrient management plans are being developed specific to a farm and its AWMS
- data is available for a livestock or poultry operation's feeding program and animal performance
- a feeding strategy or technology designed to reduce nutrient excretion is being used

Figure 4–1 Mass balance approach used for developing table values for beef cattle, swine, and poultry



The chapter also provides table values for the typical characteristics of manure at transfer from housing or from storage and treatment facilities. These values are useful for long-term planning for utilization of manure and other wastes; but, they should not be used in determining a field-specific application rate.

(b) Variations and ranges of data values

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.

Site-specific waste sampling, testing, and data collection are essential for the utilization function of an AWMS. Such sampling can result in greater certainty and confidence in amount of nutrients available. Care must be exercised to assure that samples are representative of the waste stream and arrive at the laboratory in a timely manner. Since manure and other waste products are in continual flux, it must also be kept in mind that the results from such testing are only valid for the time when the samples were taken.

651.0401 Definitions of waste characterization terms

Table 4–1 contains 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 physical properties—weight (Wt), volume (Vol), moisture content (MC), total solids (TS), volatile solids (VS), fixed solids (FS), dissolved solids (DS), and suspended solids (SS)—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. Of the chemical constituents, nitrogen (N), phosphorus (P), and potassium (K) are 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.

Volatile solids (VS) and 5-day Biochemical Oxygen Demand (BOD_5) are used in the planning and design of certain biological treatment procedures.

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.

When expressed in units of pounds per day or as a concentration, various solid fractions of manure, waste, or residue are often 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.

The term "agricultural waste" was coined by those who pioneered the technology. For them, the term seemed appropriate because it was generic and could be used in the context of the wide variety of materials under con-

Table 4–1 Definitions and descriptions of waste characterization terms

Physical characteristics

Term	Abbreviation	Units of measure	Definition	Method of measurement	Remarks
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. 1/; % d.w. 2/;	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 and dissolved solids
Volatile solids	VS, TVS	%, % w,b. 1/; % d.w. 2/;	That part of total solids driven off as volatile (combustible) gases when heated to 1,112 °F (600 °C); organic matter	Place total solids residue in furnace at 1,112 °F for at least 1 hour	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 1,112 °F (600 °C); ash	Weight (mass) of residue after volatile solids have been removed as combustible gases when heated at 1,112 °F for at least 1 hr is determined	Fixed solids equal total solids minus volatile solids
Dissolved solids DS; TDS	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 ºF	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

1/ % w.b. = percent wet basis
2/ % d.w. = percent dry weight basis

Table 4–1 Definitions and descriptions of waste characterization terms—Continued

Chemical properties

Term	Abbreviation	Units of measure	Definition	Method of measurement	Remarks
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. Recommended methods of manure analysis measures ammonium nitrogen (NH_4-N)
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	Digestion process which converts all organic nitrogen to ammonia	
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		Macro-nutrient for plants
Phosphorus	TP, SRP P P_2O_5	mg mg/L lb lb	Total phosphorus (TP) is a measure of all the forms of phosphorus, dissolved or particulate, that is found in a sample. Soluble reactive phosphorus (SRP) is a measure of orthophosphate, the filterable (soluble, inorganic) fraction of phosphorus, the form directly taken up by plant cells. P is elemental phosphorus. P_2O_5 is the fertilizer equivalent phosphorus	Laboratory procedure uses digestion and/or reduction to convert phosphorus to a colored complex; result measured by spectrophotometer or inductive coupled plasma	Critical in water pollution control; may be a limiting nutrient in eutrophication and in spreading of wastes
5-day Biochemical oxygen demand	BOD_5	lb of O_2		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
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

sideration. Now, the concern of many is that the word waste implies that the material is only suitable for disposal and as such, detracts from proper utilization. Even though another word or term might better convey the beneficial aspects, agricultural waste is so entrenched in the literature it would now be difficult to change. Further, a consensus replacement term that is appropriate in every context has not come to the forefront. It must be understood that it was neither the intent of those who initially developed the technology nor the authors of this chapter (with its continued use) to imply the materials being discussed are worthless and are only suitable for disposal. Rather, the materials are to be viewed as having value both monetarily and environmentally if properly managed, regardless of what they are called.

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 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. These are called solid manure or solid waste. Wastes that are between about 75 and 95 percent moisture content (25 and 5 percent solids) are semiliquid (slurry) or semisolid (chapter 9). 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.

The terms “manure,” “waste,” and “residue” are sometimes used synonymously. In this chapter, manure refers to materials that have a high percentage of feces and urine. Other material that may or may not have significant feces, and urine is referred to as waste or a related term such as wastewater. The term *as excreted* refers to feces and urine prior to any changes due to dilution water addition, drying, volatilization, or other physical, chemical, or biological processes. 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.

Because moisture content of manure is transitory, most testing laboratories report results in terms of dry weight (d.w.). However, equipment is calibrated and storage structures sized based upon wet weight. As such, it is important to understand the relationship of wet basis (w.b.) and dry basis (d.w.).

When test data is reported in terms of its wet basis, the base is its hydrated weight.

$$\text{Percent wet basis} = \frac{\text{weight of constituent}}{\text{wet weight of sample}}$$

When test data is reported in terms of its dry weight, the base is its dry weight.

$$\text{Percent dry basis} = \frac{\text{weight of constituent}}{\text{dry weight of sample}}$$

Residue after oven drying the sample is the total solids. Since the dry weight is equal to the total solids, they are always 100 percent d.w.

The fixed solids are the nonorganic portion of the total solids. The weight of fixed solids is determined by a test that involves heating a sample of the waste to 1,112 °F. The fixed solids are the ash that remains after the material driven off by the heating is the volatile solids.

Example 4–1

Given: A laboratory sample of manure weighing 200 grams is oven dried. After oven drying, the sample weighs 50 grams. Following oven drying, the remaining 50 grams is heated to 1,112 °F. After this heating, 20 grams remain.

Calculate:

Moisture content (MC)

$$\begin{aligned} MC &= \text{wet weight} - \text{dry weight} \\ &= 200 \text{ grams} - 50 \text{ grams} \\ &= 150 \text{ grams} \end{aligned}$$

Percent moisture (%MC)

$$\begin{aligned} \%\,MC &= \frac{MC}{\text{wet weight}} \times 100 \\ &= \left(\frac{150 \text{ grams}}{200 \text{ grams}}\right) \times 100 \\ &= 75\% \end{aligned}$$

Percent total solids dry basis (%TS)

$$\begin{aligned} \%TS \text{ w.b.} &= \left(\frac{\text{dry weight}}{\text{wet weight}}\right) \times 100 \\ &= \left(\frac{50 \text{ grams}}{200 \text{ grams}}\right) \times 100 \\ &= 25\% \end{aligned}$$

After the 50-gram dry sample (originally 200-gm wet sample) is heated to 1,112 °F, the sample now weighs 20 grams. Since the fixed solids are what remain, they are:

Percent fixed solids (%FS)

FS = 20 grams
VS = TS – FS
= 50 grams – 20 grams
= 30 grams

Percent volatile solids both wet basis and dry weight basis. (% VS w.b. and % VS d.w.)

$$\begin{aligned} \%VS \text{ d.w.} &= \frac{30 \text{ grams}}{50 \text{ grams}} \times 100 \\ &= 60\% \end{aligned}$$

Following are a number of relationships that may be used to evaluate the constituents of manure or other wastes.

$$\frac{\%\,\text{dw}}{\%\,\text{wb}} = \frac{\text{(oven dry weight of manure)}}{\text{(weight of manure at excreted moisture content)}}$$

$$\frac{\%\,\text{wb}}{\%\,\text{dw}} = \frac{\text{(weight of manure at excreted moisture content)}}{\text{(oven dry weight of manure)}}$$

$$\%\text{ dry matter} = \left(\frac{\text{dry weight}}{\text{wet weight}}\right) \times 100$$

$$\%\text{ moisture} = 100 - \%\text{ dry matter}$$

$$\%\text{ dry matter} = 100 - \%\text{ moisture}$$

$$\%\text{w.b.} = \%\text{ d.w.} \times \left(\frac{(100 - \%\text{ moisture})}{100}\right)$$

$$\%\text{ d.w.} = \left(\frac{\%\text{ w.b.} \times 100}{100 - \%\text{ w.b.}}\right)$$

$$\text{weight of manure (wet)} = \text{weight of total solids (dry)} + \text{weight of moisture}$$

Carbon is a component of all organic wastes. Quantifying it is important because of carbon's impact on soil quality and greenhouse gas emissions. Adding manure and other organic material to the soil improves the soil's structure and tilth and increases its nutrient storage capacity. As the soil sequesters the carbon in the manure, it reduces the emissions of carbon dioxide and methane into the air.

The carbon content of a material can be determined using the following equation if the material's volatile solids are known.

$$C = 0.55 \times VS$$

where:
C = carbon (% C d.w.)
VS = volatile solids (%VS d.w.)

Example 4–2

The testing laboratory reports that the manure's volatile solids on a dry weight basis are 60 percent. Compute the percentage d.w. carbon content of the sample.

$$\begin{aligned}\%\text{ C d.w.} &= 0.55 \times \%\text{ VS d.w.}\\ &= 0.55 \times 60\\ &= 33.0\ \%\text{ d.w.}\end{aligned}$$

The manure has a moisture content of 80 percent. Compute the percentage of carbon contained in the manure on a wet basis.

$$\begin{aligned}\%\text{ C w.b.} &= \%\text{ C d.w.} \times \frac{(100 - \%\text{ moisture})}{100}\\ &= 33.00 \times \frac{(100 \times 80)}{100}\\ &= 6.6\%\end{aligned}$$

Knowing the carbon to nitrogen ratio (C:N) can be important. For example, the C:N is an important aspect of the compost recipe (ch. 10). If the C:N is high, such as it might be in a manure containing organic bedding such as sawdust, the carbon can tie up nitrogen from the soil when land applied. The C:N can be determined using the following equation.

$$\text{C} : \text{N} = \frac{\text{C}}{\text{TN}}$$

where:
C:N = carbon to nitrogen ratio
C = carbon (%C d.w.)
TN = total nitrogen (%TN d.w.)

Example 4–3

Determine the C:N ratio for a manure that contains 2.1 percent d.w. of total nitrogen and a carbon content of 33.0 percent d.w.

$$\begin{aligned}\text{C:N} &= \frac{\text{C}}{\text{TN}}\\ &= \frac{33.0}{2.1}\\ &= 15.7 : 1\end{aligned}$$

The following are equations for converting nutrient levels reported on dry basis to a wet basis:

$$\text{nutrient level, wet basis} = \frac{\text{nutrient level, dry basis} \times (100 - \%\text{ moisture})}{100}$$

$$\text{nutrient level, wet basis} = \frac{\text{nutrient level, dry basis} \times \%\text{ dry matter total solids}}{100}$$

Example 4–4

A manure testing laboratory reports that the manure has a nitrogen content of 11.5 percent d.w. The manure sampled contained 85 percent moisture. Compute the pounds of nitrogen per ton of manure as it will be transferred for utilization.

$$\begin{aligned}\text{nutrient level, wet basis} &= \frac{\text{nutrient level, dry basis} \times (100 - \%\text{ moisture})}{100}\\ &= \frac{11.5 \times (100 - 85)}{100}\\ &= 1.725\%\end{aligned}$$

$$\begin{aligned}\text{lb N/ton} &= 1\text{ ton} \times 2{,}000\text{ lb/ton} \times \frac{1.725}{100}\\ &= 34.5\text{ lb/ton}\end{aligned}$$

651.0402 Units of measure

In this chapter, English units are used exclusively for weight, volume, and concentration data for manure, waste, and residue.

The table values for as excreted manure from livestock is expressed in three different formats. They are in terms of mass or volume per:

- day per 1,000 pounds of livestock live weight (lb/d/1000 lb)

and

- finished animal (f.a.) for meat producing animals

or

- day-animal (d-a) for other animals

Excreted manure table values are given in the NRCS traditional format of mass or volume per day per 1,000 pounds live weight for all livestock and poultry types and production groupings. The 1,000 pounds live weight or animal unit (AU) is often convenient because there is a commonality of expression, regardless of the species or weight of the individual species.

A 1,000-pound AU is 1,000 pounds of live weight, not an individual animal. For example, a 1,400-pound Holstein cow is 1.4 AU (1400/1000 = 1.4). A 5-pound laying hen would be 0.005 AU (5/1000 = 0.005). The challenge in using table values in this format is for young animals. Since these animals are gaining weight, an animal weight that is representative of the time period being considered must be determined.

As an alternative, table values for excreted manure from livestock and poultry being fed for an end result of meat production are given in terms of mass or volume per finished animal. The table values given in this format are the mass or volume for one animal's finishing period in the feeding facility. Manure production expressed in this manner eliminates the problems of determining a representative weight of the animal for its tenure at a facility. Breeding stock weight for beef or swine is not given in this format because the animal's weight is stable, and they are usually retained year-round.

Table values are also given in terms of mass or volume per day-animal for dairy animals, beef and swine breeding stock, and layer chickens. The young stock included in the tables with this format, such as dairy calves and heifers, are expressed as mass or volume per day-animal that is representative for the span of time when they are in this age category.

Food processing waste is recorded in cubic feet per day (ft^3/d), or the source is included such as cubic feet per 1,000 pounds of potatoes processed.

The concentration of various components in waste is commonly expressed on a milligram per liter (mg/L) basis or parts per million (ppm). One mg/L is milligrams of solute per liter of solution. One ppm is one part by weight of solute in one million parts by weight of solution. Therefore, mg/L equals ppm if a solution has a specific gravity equal to that of water (1,000,000 mg/L or 1 kg/L). 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/1,000g, 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 (µg/L). A microgram is one 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, can be expressed either on a wet basis (% w.b.) or on a dry weight basis (% d.w.). The percent w.b. is the "as is" or wet weight of the material, and the d.w. is with the moisture removed. The difference in these two bases 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 occasionally expressed in terms of the elemental nutrient form. However, laboratory analysis reports are more commonly expressing the nutrients in manure as a common fertilizer equivalent, P_2O_5 for P and K_20 for K. When comparing the nutrient content of a manure, waste, or residue with commercial fertilizer, the conversion factors listed in table 4–2 should be used, and comparisons on the basis of similar elements, ions, and/or compounds should be made. Nitrogen is always expressed as the nitrogen form such as Total N, NO_3-N, and NH_4-N).

Table 4–2 Factors for determining nutrient equivalency

Multiply	By	To get
NH3	0.824	N
NH4	0.778	N
NO3	0.226	N
N	1.216	NH_3
N	1.285	NH_4
N	4.425	NO_3
PO_4	0.326	P
P_2O_5	0.437	P
P	3.067	PO_4
P	2.288	P_2O_5
K_2O	0.830	K
K	1.205	K_2O

651.0403 Animal waste characteristics

Whenever locally derived values for animal waste characteristics are available, those values should be given preference over the more general data used in this chapter.

(a) As excreted manure

When compared to other types of manure data, the data given for as excreted manure characteristics is the most reliable. The properties of manure and other wastes will vary widely when modified by management actions. For example, manure that has been flushed, feedlot manure, and poultry litter will have material added and/or lost from the as excreted manure. Variations in other types of manure data in this chapter and other references result largely from additions/losses due to different management practices.

The primary concern of this chapter is livestock manure and waste produced in confinement and semiconfinement facilities. Not considered is manure produced by livestock and poultry on pasture or range. Manure produced in this manner is generally not collected for further management by transfer, storage, and treatment. As such, its management is significantly different than manure produced in confinement.

To determine the as excreted production of an animal using the table values given in units per day per 1,000 pounds livestock animal unit requires that a representative weight of the animal in question be determined. This approach is quite simple for mature animals that have reached their final weight. However, for feeder livestock and other immature livestock whose weight is changing daily, the challenge in using units of mass or volume/d/1,000 lb AU is to correctly determine the weight of the animal that is representative over the period of time being considered. For example, determining representative weight for an animal that has a beginning weight of 400 pounds and an ending weight of 800 pounds is much more complicated that merely averaging the two weights. Averaging in this manner does result in a conservative assumption. However, presentation of tabular data in units per finished animal eliminates this problem because a value is given for the animal's entire finishing period.

Facilities for meat-producing animals are rarely in full production 365 days per year due to uneven growth rates of animals, time required for facility cleaning after a group, and availability of animals for restocking a facility. Planning based on number of finished meat animals provides a more realistic planning estimate for annual manure volume and nutrient production.

The values given in the as excreted tables dairy, beef, swine, poultry, and equine were determined by one of the following two approaches.

- Use of a nutrient balance estimate of excretion that assumes feed intake minus animal retention equals excretion. This approach is used for all beef, swine, and poultry animal groups.
- Use of existing research data and regression analysis for dairy and equine.

Table values are estimated for dietary intake and animal performance levels common for livestock and poultry management in 2003 using the equations. Beef, poultry, and swine excretion characteristics are based on a calculation using equations that considers dietary nutrient intake minus animal nutrient retention using dietary and performance measurements typical for the industry at the time these data were published. Nutrient retention estimates followed common industry methodologies used for estimating animal nutrient requirements. Total nitrogen, total phosphorus, and dry matter excretion were estimated by these methods for all species. Available research data or models allowed additional excretion estimates for some species. Dry matter excretion is estimated to be a function of dry matter intake minus dry matter digestibility.

Dairy and equine manure characteristics were developed using existing research data and regression analysis to identify relationships between feeding programs, animal performance, and excretion. A regression analysis involves the study of relationships between variables.

For some values, particularly potassium, previously published excretion values were used instead of the equation methods used exclusively for nitrogen and phosphorus. As with most minerals, the amount of these nutrients (minerals) consumed can vary significantly due to regional differences. For example, some forages can be quite high in potassium because of high amounts of available potassium in the soil. In these situations, the amount of potassium consumed will be the major determinant in amount of potassium excreted. Development of modeling equations for estimating excretion of these other minerals is warranted, but they are not available at this time. Until these models are available, consideration should be given to adjusting the table values to a greater value if nutrient consumptions are very high.

Where dietary intake and animal performance level based excretion estimates could not be made, current references were reviewed, including the 1992 version of the NRCS Agricultural Waste Management Field Handbook (AWMFH); the American Society of Agricultural Engineers Standard D384.2; Manure Production and Characteristics, March 2005; and Manure Characteristics in Midwest Plan Service Publication MWPS–18, Section 1.

The as excreted table values for veal and sheep are from the 1992 version of the AWMFH.

As previously stated, table values given in this chapter are based on common dietary intake for livestock and poultry. If feed rations are atypical, excreted values should be computed by use of equations or by other means to more closely reflect actual values of the operation under consideration rather than using the table values. For example, table values may not be appropriate when by-products from the ethanol industry are included in feed rations. The rapid growth of the ethanol industry primarily for production of oxygenated fuel and, to a much lesser extent, the alcohol beverage industry, has resulted in its by-products being available as a competitively priced feed ingredient for dairy, beef, and, to some extent, swine and poultry. Use of these ethanol products may increase both nitrogen and phosphorus in the excreted manure beyond the values given in the tables.

Another example of when the table values are not appropriate is when beef cattle are fed high forage diets. Since beef cattle are ruminants, they can utilize forages, which are generally lower in digestibility, as well as concentrates, which are generally higher in digestibility. Depending upon the stage of production, the roughage-to-concentrate ratio can vary tremendously. When poorly digestible forages (fiber) are fed as compared to concentrates, volumes of manure produced are much greater than the values given in the tables.

(b) Common management modifications

How the manure is managed following excretion will often result in changes to its basic physical and chemical characteristics. These management actions include those related to wasted feed, wasted water, flush water, precipitation/evaporation, bedding (litter), soil, and biological activity. Management following excretion can also result in drying. For example, manure excreted in feedlots in arid parts of the country can lose substantial moisture because of evaporation. Dust, hair, and feathers from the livestock and poultry can also add to manure, but only in limited amounts.

(1) Wasted feed

Wasted feed can add nutrients and solids to the waste stream. Even though management can minimize the amount of feed wasted, a certain amount of feed that is presented to livestock and poultry will not be eaten. Correcting the excreted values to account for what could be considered normal wasted feed would usually be small compared to the range of values in the excreted manure that result from variations in diet intake and animal performance levels. However, if wasted feed appears to be excessive, the table values should be adjusted to account for it.

(2) Wasted water

Wasted water must be expected and controlled. Excess moisture content and increased waste volume can hamper equipment operation and limit the capacity of manure handling and storage facilities. Faulty waterers and leaky distribution lines cause severe limitations. Excess water from foggers and misters used for cooling stock in hot weather may also need to be accounted for in system design.

(3) Flush water

Flush water added to the waste stream will affect the consistency of the manure to the extent fresh water is added to the system. Using recycled water for flushing minimizes the amount of water added and needing to be managed.

(4) Precipitation/evaporation

Precipitation and evaporation can impact the physical characteristics of manure significantly, depending on the region. In regions of high precipitation, the added water can impact the consistency of the manure unless management excludes it. Evaporation, on the other hand can reduce the amount of water in the manure. But again, management of the manure will determine its impact. For example, allowing a crust to form on a waste storage pond will reduce evaporation.

(5) Bedding

Livestock producers use a wide range of bedding materials as influenced by availability, cost, and performance properties. Both organic and inorganic materials have been used successfully. Unit weights of materials commonly used for bedding dairy cattle are given in table 4–3.

Quantities of bedding materials used for dairy cattle are shown in table 4–4. The total weight of dairy manure and bedding is the sum of the weights of both parts. The total volume of dairy manure and bedding is the sum of the

Table 4–3 Unit weights of common bedding materials [1/]

Material	Loose	Chopped
	- - - - - -lb/ft^3- - - - - -	
Legume hay	4.3	6.5
Non legume hay	4.0	6.0
Straw	2.5	7.0
Wood shavings	9.0	
Sawdust	12	
Soil	75	
Sand	105	
Ground limestone	95	

1/ Adapted from the 1992 version of the AWMFH

Table 4–4 Daily bedding requirements for dairy cattle [1/]

Material	Barn type		
	Stanchion stall	Free-stall	Loose housing
	- - - - - - - - - lb/d/1000 lb - - - - - - - - - -		
Loose hay or straw	5.4		9.3
Chopped hay or straw	5.7	2.7	11
Shavings or sawdust		3.1	
Sand, or limestone		35 [2/]	

1/ Adapted from the 1992 version of the AWMFH
2/ Table 13, Manure Characteristics, Midwest Planning Service Section 1.

manure volume plus half of the bedding volume. Only half of the bedding volume is used to compensate for the void space in bedding materials. Typically, broiler producers replace the bedding material after three to six batches or once or twice a year. The typical 20,000-bird house requires about 10 tons of wood shavings for a bedding depth of 3 to 4 inches.

(6) Soil

Soil can also be added to manure after it is excreted. Its presence is most common on dairies and beef operations where cattle are confined in earthen feedlots or are pastured as a part of their routine. Dry soil adheres to the animals' bodies in limited amounts. Wet soil or mud adheres even more, and either falls off or is washed off at the dairy barn. Soil and other inorganic materials used for freestall base and bedding are also added to the manure. Soil or other inorganic materials commonly added to manure can result in a waste that has double the fixed solids content of as excreted dairy manure.

(7) Biological activity

Biological activity can begin almost immediately after manure has been excreted. This activity, of course, changes both the physical and chemical aspects of the manure. The manure can be managed to either increase or decrease biological activity. For example, manure can be treated in a waste treatment lagoon for the specific purpose of providing the environment for biological activity to reduce the pollution potential of the manure. Another example is managing the manure so that urine and feces mixes. This mixing initiates biological activity that releases ammonia resulting in a decrease in the nitrogen content of the manure. Separating urine and feces will eliminate this nutrient loss.

(c) Dairy

Manure characteristics for lactating and dry cows and for calves and heifers are listed in table 4–5.

Quantities of dairy manure vary widely from small cows to large cows and between cows at low production and high production levels. Dairy feeding systems and equipment often waste feed, which in most cases is added to the manure. 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 blend with those of the manure. Quantities of bedding materials added to cow stalls and resting areas are shown in table 4–4.

Dairy cattle excretion varies dramatically with milk production as illustrated in table 4–5. Higher producing herds will have higher feed intake and greater total manure and manure nutrient excretion. Recognition of herd milk production is critical to making reasonable estimates of manure excretion. Concentration of nutrients fed also varies significantly between herds. Farm management decisions on degree of addition of supplemental protein and minerals can have substantial impact on the quantity of nitrogen and phosphorus that must be addressed by a nutrient management plan. The equations should be used instead of the as excreted table values to reflect this variation.

Milking centers—The amount of water used by dairies ranges widely. Since the amount used will have a significant impact on the volume that must be managed, the preferred approach is to actually measure it. Table 4–6 provides a range of water usage for various operations. Table 4–7 gives typical characterization of milking center wastewater.

Example 4–5

Estimate the daily production of volume manure and pounds of N, P, and K for 500 lactating Holstein cows with an average weight of 1,400 pounds and with an average milk production of 100 pounds per day.

Using table 4–5(a), for 500 Holstein lactating cows:

Volume = 2.6 ft^3/d-a × 500 = 1,300 ft^3/d
N = 1.0 lb/d-a × 500 = 500 lb/d
P = 0.19 lb/d-a × 500 = 95 lb/d
K = 0.49 lb/d-a × 500 = 245 lb/d

Using table 4–5(b), for 500 Holstein lactating cows:

$$\text{Volume} = 1.9\ \text{ft}^3/\text{d}/1000\ \text{lb AU} \times 500 \times \frac{1400}{1000} = 1{,}330\ \text{ft}^3/\text{d}$$

$$\text{N} = 0.76\ \text{lb/d}/1000\ \text{lb AU} \times 500 \times \frac{1400}{1000} = 532\ \text{lb/d}$$

$$\text{P} = 0.14\ \text{lb/d}/1000\ \text{lb AU} \times 500 \times \frac{1400}{1000} = 98\ \text{lb/d}$$

$$\text{K} = 0.35\ \text{lb/d}/1000\ \text{lb AU} \times 500 \times \frac{1400}{1000} = 245\ \text{lb/d}$$

Table 4–5 Dairy manure characterization—as excreted

(a) In units per day-animal 1/

Components	Units	Lactating cow 2/ Milk production, lb/d				Milk-fed calf	Calf	Heifer	Dry cow 2/
		50	75	100	125	125 lb	330 lb	970 lb	
Weight	lb/d-a	133	148	164	179		27	54	85
Volume	ft³/d-a	2.1	2.4	2.6	2.9		0.44	0.87	1.4
Moisture	% wet basis	87	87	87	87		83	83	87
Total solids	lb/d-a	17	19	21	23		3.0	8.3	11.0
VS 3/	lb/d-a	14	16	18	20		3.0	7.1	9.3
BOD	lb/d-a	2.9						1.2	1.4
N	lb/d-a	0.90	0.97	1.04	1.11	0.017	0.14	0.26	0.50
P[a]	lb/d-a	0.15	0.17	0.19	0.21		0.02	0.04	0.07
K[a]	lb/d-a	0.41	0.45	0.49	0.52		0.04	0.11	0.16

1/ ASAE D384.2, March 2005
2/ Assumes 1,375 lb lactating cow and 1,660 lb dry cow. Excretion values for P and K not in bold are based on the assumption that intake is equal to excretion
3/ VS based on 85% of TS

(b) In units per day per 1,000 lb animal unit

Components	Units	Lactating cow milk production, lb/d				Milk-fed calf	Calf	Heifer	Dry cow
		50	75	100	125	125 lb	330 lb	970 lb	
Weight	lb/d/1000 lb AU	97	108	119	130		83	56	51
Volume	ft³/d/1000 lb AU	1.6	1.7	1.9	2.1		1.3	0.90	0.84
Moisture	% wet basis	87	87	87	87		83	83	87
Total solids	lb/d/1000 lb AU	12	14	15	17		9.2	8.5	6.6
VS	lb/d/1000 lb AU	9.2	11	12	13		7.7	7.3	5.6
BOD	lb/d/1000 lb AU	2.1						1.2	0.84
N	lb/d/1000 lb AU	0.66	0.71	0.76	0.81	0.11	0.42	0.27	0.30
P	lb/d/1000 lb AU	0.11	0.12	0.14	0.15		0.05	0.05	0.042
K	lb/d/1000 lb AU	0.30	0.33	0.35	0.38		0.11	0.12	0.10

(c) Jersey cows in units per day per 1,000-lb animal unit 1/

Components	Units	Lactating cow milk production, lb/d		
		45	60	75
Weight	lb/d/1000 lb AU	116	130	144
Total solids	lb/d/1000 lb AU	15	17	19
N	lb/d/1000 lb AU	0.72	0.80	0.88
P	lb/d/1000 lb AU	0.12	0.13	0.15
K	lb/d/1000 lb AU	0.42	0.46	0.50

1/ Excretion values were determined using intake based equations. Although the intake-based equations were developed for Holsteins, Blake et al. (1986) and Kauffman and St-Pierre (2001) found similar dry matter digestibility between breeds. Excretion estimates were determined using average dry matter intakes for Jersey cows (NRC 2001). Nutrient excretion estimates were based on cow consuming a diet containing 17 percent CP, 0.38 percent P, and 1.5 percent K.

Table 4–6 Dairy water use for various operations

(a) Milking center

Operation		Water use
Bulk Tank	Automatic	50–60 gal/wash
	Manual	30–40 gal/wash
Pipeline	In parlor	75–125 gal/wash
Pail milkers		30–40 gal/wash
Miscellaneous equipment		30 gal/d
Cow Preparation	Automatic	1–4.5 gal/wash/cow
	Estimated avg.	2 gal/wash/cow
	Manual	0.25–0.5 gal/wash/d
Parlor floor		
Cleaned with a hose		20–40 gal/milking
Flush		800–2100 gal/milking
Well water pre-cooler		2 gal/gal of milk cooled
Milkhouse		10–20 gal/d

(b) Alley flushing[2/]

Alley slope (%)	Flow depth (in)	Flow rate (gpm)[1/]	Flush volume (gal)[1/]
1.0	7.0	1,306	220
1.5	5.0	933	156
2.0	4.0	747	125
2.5	3.4	635	106
3.0	3.0	560	94

1/ Per foot of alley width
2/ Table adapted from the Midwest Plan Service Dairy Housing and Equipment Handbook, 2000

Table 4–7 Dairy waste characterization—milking center [1/]

Component	Units	Milking center [2/]			
		MH	MH+MP	MH+MP+HA [3/]	MH+MP+HA [4/]
Volume	ft^3/d/1000 lb	0.22	0.60	1.4	1.6
Moisture	%	100	99	100	99
TS	% w.b.	0.28	0.60	0.30	1.5
VS	lb/1000 gal	13	35	18	100
FS	lb/1000 gal	11	15	6.7	25
COD	lb/1000 gal	25	42		
BOD	lb/1000 gal		8.4		
N	lb/1000 gal	0.72	1.7	1.0	7.5
P	lb/1000 gal	0.58	0.83	0.23	0.83
K	lb/1000 gal	1.5	2.5	0.57	3.3
C:N ratio		10	12	10	7.0

1/ Adapted from the 1992 version of the AWMFH
2/ MH–Milk house; MP–Milking parlor; HA–Holding area
3/ Holding area scraped and flushed—manure excluded
4/ Holding area scraped and flushed—manure included

(d) Beef

Table 4–8 lists characteristics of as excreted beef manure. Feedlot manure varies widely because of climate, type of feedlot surface, and management. Typical values for feedlot manure are given later in table 4–16. Nutrient loss from feedlot manure is highly influenced by management factors such as moisture control, animal density, and cleaning frequency. The type of feedlot surface, earthen or paved, has impacts, as well. The soil in unsurfaced beef feedlots is readily incorporated with the manure due the animal movement and cleaning operations. Surfaced feedlots produce more runoff than unsurfaced lots. Runoff water from beef feedlots also exhibits wide variations in nutrient content character (table 4–9).

Moisture content of beef feedlot manure drops significantly over time from its as excreted 90 percent to about 30 percent. If the feedlot surface is too dry, dust will become a problem. If it remains too wet, odor may become a concern. Feedlot surface moisture of 25 to 35 percent will generally minimize odor, fly, and dust problems. For characteristics of manure solids from a beef feedlot, see table 4–16.

Nitrogen loss from feedlots can be by runoff, leaching, and ammonia volatilization. As much as 50 percent of the nitrogen deposited on feedlots may be lost as ammonia. The major source of ammonia is urea from urine, which can easily be converted to ammonia (NH_3), a gas. Urea may account for 40 percent to more than 50 percent of nitrogen excreted in manure; therefore, it has a potential for rapid loss. The volatilization of nitrogen as ammonia depends on temperature, moisture content, pH, air movement, and other factors. Ammonia is soluble in water, which could be a potential threat if feedlot runoff comes in contact with surface or ground water.

Once excreted, phosphorus is fairly stable. The usual path of phosphorus loss is through runoff. As such, feedlot runoff control measures will reduce the environmental impact of phosphorus.

Feeding of by-products from the food and corn processing industries is becoming common in beef cattle production. Use of distillers grains from the production of ethanol is growing rapidly in regions with significant corn production. Cattle diets commonly contain 20 percent distillers grains on a dry matter basis and 40 percent inclusion is becoming increasingly common. The distillers by-product contains a concentrated source of both protein and phosphorus. Use of these by-products can typically results in higher intakes of protein and phosphorus, resulting in higher excretion of nitrogen and phosphorus (table 4–8). Nutrient management plans will need to reflect the impact of by-product feeding.

Table 4–8 Beef waste characterization—as excreted

(a) Cow and growing calf in units per day-animal 1/

Components	Units	Beef cow in confinement	Growing calf confined 450–750 lb
Weight	lb/d-a	125	50
Volume	ft^3/d-a	2.0	0.8
Moisture	% w.b.	88	88
TS	lb/d-a	15	6.0
VS	lb/d-a	13	5.0
BOD	lb/d-a	3.0	1.1
N	lb/d-a	0.42	0.29
P	lb/d-a	0.097	0.055
K	lb/d-a	0.30	0.19

1/ Beef cow values are representative of animals during nonlactating period and first 6 months of gestation

(b) Cow and growing calf in units per day per 1,000 lb animal unit 1/

Components	Units	Beef cow in confinement 2/	Growing calf confined 450–750 lb 3/
Weight	lb/d/1000 lb AU	104	77
Volume	ft^3/d/1000 lb AU	1.7	1.2
Moisture	% w.b.	88	88
TS	lb/d/1000 lb AU	13	9.2
VS	lb/d/1000 lb AU	11	7.7
BOD	lb/d/1000 lb AU	2.5	1.7
N	lb/d/1000 lb AU	0.35	0.45
P	lb/d/1000 lb AU	0.08	0.08
K	lb/d/1000 lb AU	0.25	0.29

1/ Beef cow values are representative of animals during nonlactatin period and first 6 months of gestation
2/ Equals table 4–8a value x (1000 lb/1200 lb wt.)
3/ Equals table 4–8a value x (1000 lb/650 lb avg. wt.)

Table 4–8 Beef waste characterization—as excreted—Continued

(c) Finishing cattle excretion in units per finished animal [1/]

Components	Units	Corn, no supplemental P	Finishing cattle: Corn with supplemental P	Finishing cattle: Corn with 25% wet distillers grains	Corn with 30% wet corn gluten feed
Weight	lb/f.a.	9,800	9,800		
Volume	ft³/f.a.	160	160		
Moisture	% w.b.	92	92		
TS	lb/f.a.	780	780		
VS	lb/f.a	640	640		
BOD	lb/f.a.	150	150		
N	lb/f.a.	53	53	75	66
P	lb/f.a.	6.6	8.3	10	11
K	lb/f.a.	38	38		

1/ Assumes a 983 lb finishing animal fed for 153 days

(d) Finishing cattle in units per day per 1,000 lb animal unit [1/]

Components	Units	Corn, no supplemental P	Finishing cattle: Corn with supplemental P	Finishing cattle: Corn with 25%wet distillers grains	Corn with 30% wet corn gluten feed
Weight	lb/d/1000 lb AU	65	65		
Volume	ft³/d/1000 lb AU	1.1	1.1		
Moisture	% w.b.	92	92		
TS	lb/d/1000 lb AU	5.2	5.2		
VS	lb/d/1000 lb AU	4.3	4.3		
BOD	lb/d/1000 lb AU	1.0	1.0		
N	lb/d/1000 lb AU	0.36	0.36	0.50	0.44
P	lb/d/1000 lb AU	0.044	0.056	0.069	0.076
K	lb/d/1000 lb AU	0.25	0.25		

Table 4–9 Nitrogen content of cattle feedlot runoff (Alexander and Margheim 1974) [1/2]

Annual rainfall	Below-average conditions [3/]	Average conditions [4/]	Above-average conditions [5/]
	lb N/acre-in		
<25 in	360	110	60
25 to 35 in	60	30	15
>35 in	15	10	5

1/ Adapted from the 1992 version of the AWMFH

2/ Applies to waste storage ponds that trap rainfall runoff from uncovered, unpaved feedlots. Cattle feeding areas make up 90 percent or more of the drainage area. Similar estimates were not made for phosphorus and potassium. Phosphorus content of the runoff will vary inversely with the amount of solids retained on the lot or in settling facilities.

3/ No settling facilities are between the feedlot and pond, or the facilities are ineffective. Feedlot topography and other characteristics are conducive to high solids transport or cause a long contact time between runoff and feedlot surface. High cattle density—more than 250 head per acre.

4/ Sediment traps, low gradient channels, or natural conditions that remove appreciable amounts of solids from runoff. Average runoff and solids transport characteristics. Average cattle density—125 to 250 head per acre.

5/ Highly effective solids removal measures such as vegetated filter strips or settling basins that drain liquid waste through a pipe to storage pond. Low cattle density—less than 120 head per acre.

(e) Swine

Swine waste and waste management systems have been widely studied, and much has been reported on swine manure properties. Table 4–10 lists characteristics of as excreted swine manure from feeding and breeding stock. Breeding stock manure characteristics, also shown in table 4–10, are subject to less variation than those for growing animals.

Table 4–10 Swine waste characterization—as excreted

(a) Mature swine in units per day-animal 1/

Components	Units	Sow Gestating 440 lb	Sow Lactating 423 lb	Boar 440 lb
Weight	lb/d-a	11	25	8.4
Volume	ft^3/d-a	0.18	0.41	0.13
Moisture	% w.b.	90	90	90
TS	lb/d-a	1.1	2.5	0.84
VS	lb/d-a	1.0	2.3	0.75
BOD	lb/d-a	0.37	0.84	0.29
N	lb/d-a	0.071	0.19	0.061
P	lb/d-a	0.020	0.055	0.021
K	lb/d-a	0.048	0.12	0.039

1/ Table 1.b, ASAE D384.2, March 2005

(b) Immature swine in units of per finished animal

Components	Units	Nursery pig 27.5 lb	Grow to finish 154 lb
Weight	lb/f.a	87	1200
Volume	ft^3/f.a.	1.4	20
Moisture	% w.b.	90	90
TS	lb/f.a.	10	120
VS	lb/f.a.	8.7	99
BOD	lb/f.a.	3.4	38
N	lb/f.a.	0.91	10
P	lb/f.a.	0.15	1.7
K	lb/f.a.	0.35	4.4

(c) Mature swine in units per day per 1,000 lb animal unit

Components	Units	Sow Gestating 1/	Sow Lactating 2/	Boar 3/
Weight	lb/d-1000 AU	25	59	19
Volume	lb/d-1000 AU	0.41	0.97	0.30
Moisture	% w.b.	90	90	90
TS	lb/d-1000 AU	2.5	5.9	1.9
VS	lb/d-1000 AU	2.3	5.4	1.7
BOD	lb/d-1000 AU	0.84	2.0	0.66
N	lb/d-1000 AU	0.16	0.45	0.14
P	lb/d-1000 AU	0.05	0.13	0.05
K	lb/d-1000 AU	0.11	0.28	0.09

1/ Table 4–10(a) value × (1000 lb/440 lb avg. wt.)
2/ Table 4–10(a) value × (1000 lb/423 lb avg. wt.)
3/ Table 4–10(a) value × (1000 lb/440 lb avg. wt.)

(d) Immature swine in units of per day per 1,000 lb animal unit

Components	Units	Nursery 1/	Grow to finish 2/
Weight	lb/d/1000 lb AU	88	65
Volume	ft^3/d/1000 lb AU	1.4	1.1
Moisture	% w.b.	90	90
TS	lb/d/1000 lb AU	10	6.5
VS	lb/d/1000 lb AU	8.8	5.4
BOD	lb/d/1000 lb AU	3.4	2.1
N	lb/d/1000 lb AU	0.92	0.54
P	lb/d/1000 lb AU	0.15	0.09
K	lb/d/1000 lb AU	0.35	0.24

1/ Table 4–10(c) value × (1000 lb/27.5 lb avg. wt.)/36 days fed
2/ Table 4–10(c) value × (1000 lb/154 lb avg. wt.)/120 days fed

Example 4–6

Estimate the total volatile and fixed solids produced daily in the manure of a grow-to-finish pig with an average weight of 154 pounds with a 120-day feeding period.

From table 4–10(b), in terms of mass per finished animal, read TS = 120 lb per finished animal and VS = 99 lb per finished animal.

To calculate the daily total solid production per day, divide the per finished animal VS value by the tenure of the animal in the feeding period.

$$\text{lb VS/d} = \frac{99}{120} = 0.82 \text{ lb VS/d}$$

To calculate FS daily production, the fixed solids per finished animal must be first determined.

$$\begin{aligned} FS &= TS - VS \\ &= 120 - 99 \\ &= 21 \text{ lb} \end{aligned}$$

The daily FS production is calculated by dividing the per finished animal FS production by the animal's tenure in the feeding period.

$$\text{lb FS/d} = \frac{21}{120} = 0.18 \text{ lb FS/d}$$

Example 4–7

Estimate the average daily volatile solids production in the manure of 1,000 grow-to-finish pigs with an average weight of 154 pounds over the 120 days feeding period.

Using table 4–10(b), select

$$VS = 99.00 \text{ lb/f.a.}$$

$$\text{VS production for 1,000 animals} =$$
$$99.00 \text{ lb/f.a.} \times 1000 \text{ f.a.} = 99{,}000 \text{ lb}$$
$$\text{VS daily production} = 99{,}000 \text{ lb}/120 \text{ d} = 825 \text{ lb/d}$$

Using table 4–10d, select

$$VS = 5.4 \text{ lb/d/1000 lb AU}$$

$$\begin{aligned} \text{VS lb/d} &= 5.36 \text{ lb/d/1000 AU} \times 1000 \text{ animals} \times 154 \text{ lb/animal} \\ &= 832 \text{ lb/d} \end{aligned}$$

(f) Poultry

Because of the high degree of industry integration, standardized rations, and complete confinement, layer and broiler manure characteristics vary less than those of other species. Turkey production is approaching the same status. Table 4–11 presents waste characteristics for as excreted poultry manure.

Table 4–16 lists data for poultry flocks that use 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 mass concentration 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 generally consists of the surface crust and wet spots that have clumped together. About 1 or 2 inches of new bedding is placed on the floor before the next flock.

When a grower manages for a more frequent, complete cleanout, the data in table 4–16 will require adjustment. The birds still 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. The nutrient concentrations may also be lower since there is less time for the nutrients to accumulate, and the ratio of bedding to manure may be higher. A further complication is that nitrogen is lost to the atmosphere during storage while fresh manure is being continually deposited. This can create significant variations based on litter management.

Table 4–11 Poultry waste characterization—as excreted

(a) Layer waste characterization in units of per day animal [1/]

Components	Units	Layers
Weight	lb/d-a	0.19
Volume	ft^3/d-a	0.0031
Moisture	% w.b.	75
TS	lb/d-a	0.049
VS	lb/d-a	0.036
BOD	lb/d-a	0.011
N	lb/d-a	0.0035
P	lb/d-a	0.0011
K	lb/d-a	0.0013

1/ Table 12(a) ASAE D384.2, March 2005

(b) Layer in units of per day per 1,000 lb animal unit

Components	Units	Layers [1/]
Weight	lb/d/1000 lb AU	57
Volume	ft^3/d/1000 lb AU	0.93
Moisture	% w.b.	75
TS	lb/d/1000 lb AU	15
VS	lb/d/1000 lb AU	11
BOD	lb/d/1000 lb AU	3.3
N	lb/d/1000 lb AU	1.1
P	lb/d/1000 lb AU	0.33
K	lb/d/1000 lb AU	0.39

1/ Table 4–11(a) value × (1000 lb/3 lb avg. wt.) × (0.90)

Table 4–11 Poultry waste characterization—as excreted—Continued

(c) Meat production poultry in units per finished animal [1/]

Components	Units	Broiler	Turkey (toms)	Turkey (hens)	Duck
Weight	lb/f.a.	11	78	38	14
Volume	ft^3/f.a.	0.17	1.3	0.61	0.23
Moisture	% w.b.	74	74	74	74
TS	lb/f.a.	2.8	20	9.8	3.7
VS	lb/f.a.	2.1	16	7.8	2.2
BOD	lb/f.a.	0.66	5.2	2.4	0.61
N	lb/f.a.	0.12	1.2	0.57	0.14
P	lb/f.a.	0.035	0.36	0.16	0.048
K	lb/f.a.	0.068	0.57	0.25	0.068

1/ Table 12(a) ASAE D384.2, March 2005

(d) Meat production poultry in units per day per 1,000 lb animal unit

Components	Units	Broiler [1/]	Turkey (toms) [2/]	Turkey (hens) [3/]	Duck [4/]
Weight	lb/d/1000 lb AU	88	34	48	102
Volume	ft^3/d/1000 lb AU	1.4	0.57	0.77	1.7
Moisture	% w.b.	74	74	74	74
TS	lb/d/1000 lb AU	22	8.8	12	27
VS	lb/d/1000 lb AU	17	7.1	9.8	16
BOD	lb/d/1000 lb AU	5.3	2.3	3.0	4.5
N	lb/d/1000 lb AU	0.96	0.53	0.72	1
P	lb/d/1000 lb AU	0.28	0.16	0.20	0.35
K	lb/d/1000 lb AU	0.54	0.25	0.31	0.50

1/ Table 4–11(c) value × (1000 lb /2.6 lb avg. wt.) / 48 days on feed
2/ Table 4–11(c) value × (1000 lb /17.03 lb avg. wt.) / 133 days on feed
3/ Table 4–11(c) value × (1000 lb /7.57 lb avg. wt.) / 105 days on feed
4/ Table 4–11(c) value × (1000 lb /3.51 lb avg. wt.) / 39 days on feed

Example 4–8

Determine the volume of litter and the amount N, P, and K produced for a 20,000-bird broiler house for six flocks between cleanouts. Assume the house is initially bedded with 10 tons of sawdust and that it is top-dressed with 5 tons between each flock.

Using table 4–11(c), select for broilers

$$\text{Volume} = 0.17 \text{ ft}^3/\text{f.a.}$$
$$N = 0.12 \text{ lb/f.a.}$$
$$P = 0.035 \text{ lb/f.a.}$$
$$K = 0.068 \text{ lb/f.a.}$$

For six 20,000-bird flocks the excreted amounts are:

$$\text{Volume} = 0.17 \text{ ft}^3/\text{f.a.} \times 6 \text{ flocks} \times 20{,}000 \text{ f.a./flock} = 20{,}400 \text{ ft}^3$$

$$N = 0.12 \text{ lb/f.a.} \times 6 \text{ flocks} \times 20{,}000 \text{ f.a./flock} = 14{,}400 \text{ lb}$$

$$P = 0.035 \text{ lb/fa} \times 6 \text{ flocks} \times 20{,}000 \text{ fa/flock} = 4{,}200 \text{ lb}$$

$$K = 0.068 \text{ lb/f.a.} \times 6 \text{ flocks} \times 20{,}000 \text{ f.a./flock} = 8{,}160 \text{ lb}$$

The sawdust used does not add nutrients, but it adds to the volume of the litter.

From table 4–3, select for sawdust 12 lb/ft^3

$$\text{Volume of sawdust placed} = (10 \text{ tons} + 5 \text{ top-dressings} \times 5 \text{ ton each}) = 35 \text{ tons}$$
$$(35 \text{ tons} \times 2000 \text{ lb/ton}) / 12 \text{ lb/ft}^3 = 5{,}833 \text{ ft}^3$$

As a rule of thumb, the volume of the sawdust will be reduced by approximately half due to volatilization of carbon, removal of cake, and consolidation and filling of voids with poultry excrement.

$$\text{Volume of sawdust added to manure} = 5{,}833 \text{ ft}^3 \times 0.5 = 2{,}916 \text{ ft}^3$$

$$\text{Total volume of litter} = \text{excreted volume} + \text{volume of sawdust} = 20{,}400 \text{ ft}^3 + 2{,}916 \text{ ft}^3 = 23{,}317 \text{ ft}^3$$

Layer lagoon sludge is much denser than pullet lagoon sludge because of its high grit or limestone content. Layer lagoon sludge accumulates at the rate of about 0.0294 cubic foot per pound of total solids added to the lagoon, and pullet lagoon sludge accumulates at the rate of 0.0454 cubic foot per pound total solids. This is equivalent to about 0.6 cubic foot per layer and 0.3 cubic foot per pullet annually.

(g) Veal

Data on manure characteristics from veal production are shown in table 4–12. Sanitation in veal production is an extremely important factor, and waste management facilities should be planned for handling as much as 3 gallons of wash water per day per calf.

(h) Sheep

As excreted manure characteristics for sheep are limited to those for the feeder lamb (table 4–13). In some cases, bedding may be a significant component of sheep waste.

(i) Horse

Table 4–14 lists characteristics of as excreted horse manure. Because large amounts of bedding are used in the stables of most horses, qualities and quantities of wastes from these stables generally are dominated by the kind and volume of bedding used.

Table 4–14 values apply to horses 18 months of age or older that are not pregnant or lactating. The representative number applies to 1,100-pound horses, and the range represents horses from 880 to 1,320 pounds. Sedentary would apply to horses not receiving any imposed ex-

Table 4–12 Veal waste characterization—as excreted [1/]

Component	Units	Veal feeder
Weight	lb/d/1000 lb AU	60
Volume	ft^3/d/1000 lb AU	0.96
Moisture	%	98
TS	% w.b.	2.5
	lb/d/1000 lb AU	1.5
VS	lb/d/1000 lb AU	0.85
FS	lb/d/1000 lb AU	0.65
COD	lb/d/1000 lb AU	1.5
BOD_5	lb/d/1000 lb AU	0.37
N	lb/d/1000 lb AU	0.20
P	lb/d/1000 lb AU	0.03
K	lb/d/1000 lb AU	0.25
C:N ratio		2.0

1/ Adapted from the 1992 version of the AWMFH

Table 4–13 Lamb waste characterization—as excreted [1/]

Component	Units	Lamb
Weight	lb/d/1000 lb AU	40
Volume	ft^3/d/1000 lb AU	0.63
Moisture	%	75
TS	% w.b.	25
	lb/d/1000 lb AU	10
VS	lb/d/1000 lb AU	8.3
FS	lb/d/1000 lb AU	1.8
COD	lb/d/1000 lb AU	11
BOD^5	lb/d/1000 lb AU	1.0
N	lb/d/1000 lb AU	0.45
P	lb/d/1000 lb AU	0.07
K	lb/d/1000 lb AU	0.30
C:N ratio		10

1/ Adapted from the 1992 version of the AWMFH

Table 4–14 Horse waste characterization—as excreted

(a) Horse in units/day-animal

Components	Units	Sedentary (1,100 lb)	Exercised (1,100) lb
Weight	lb/d-a	56	57
Volume	ft^3/d-a	0.90	0.92
Moisture	% w.b.	85	85
TS	lb/d-a	8.4	8.6
VS	lb/d-a	6.6	6.8
BOD	lb/d-a	1.1	1.1
N	lb/d-a	0.20	0.34
P	lb/d-a	0.029	0.073
K	lb/d-a	0.060	0.21

(b) Horse in units/d/1,000 lb animal unit

Components	Units	Sedentary[1/]	Exercised[1/]
Weight	lb/d/1000 lb AU	51	52
Volume	ft^3/d/1000 lb AU	0.82	0.84
Moisture	% w.b.	85	85
TS	lb/d/1000 lb AU	7.6	7.8
VS	lb/d/1000 lb AU	6.0	6.2
BOD	lb/d/1000 lb AU	1.0	1.0
N	lb/d/1000 lb AU	0.18	0.31
P	lb/d/1000 lb AU	0.026	0.066
K	lb/d/1000 lb AU	0.05	0.19

1/ Table 4–14(a) value × (1000 lb/1100 lb avg. wt.)

ercise. Dietary inputs are based on minimum nutrient requirements specified in Nutrient Requirements of Horses (NRCS 1989). Intense represents horses used for competitive activities such as racing. Dietary inputs are based on a survey of race horse feeding practices (Gallagher et al. 1992) and typical feed compositions (forage=50% alfalfa, 50% timothy; concentrate = 30% oats, 70% mixed performance horse concentrate).

(j) Rabbit

Some properties of rabbit manure are listed in table 4–15. The properties refer only to the feces; no urine has been included. Reliable information on daily production of rabbit manure, feces, or urine is not available.

Table 4–15 Rabbit waste characterization—as excreted [1/]

Components	Units	Rabbit
VS	% d.b.	0.86
FS	% d.b.	0.14
COD	% d.b.	1.0
N	% d.b.	0.03
P	% d.b.	0.02
K	% d.b.	0.03
C:N ratio		16

1/ Adapted from the 1992 version of the AWMFH

651.0404 Manure as transferred for utilization

Many physical, chemical, and biological processes can alter manure characteristics from its original as-excreted form. The as transferred for utilization production and characteristics values reported in table 4–16 allow for common modifications to excreted manure resulting from water addition or removal, bedding addition, and/or treatment processes. These estimates may be helpful for individual farm long-term planning prior to any samples being available and for planning estimates addressing regional issues. Whenever possible, site-specific samples or other more localized estimates should be used in lieu of national tabular estimates. To use table 4–16 to develop individual year nutrient management plans for defining field-specific application rates would be a misuse of the data. Where site-specific data are unavailable, this table may provide initial estimates for planning purposes until site-specific values are available. Chapter 11 of this handbook also presents another method of calculating as transferred for utilization values. The nutrient accounting methodology presented in chapter 11 adjusts as excreted nutrient values utilizing nutrient loss factors based on the type of management system in place.

Table 4–16 Manure as transferred for utilization

(a) Values [1/]

	Mass (lb/hd/d)	Moisture (% wb)	TS (% wb)	VS (% TS)	TKN (% wb)	NH3-N (% wb)	P (% wb)	K (% wb)
Beef								
Earthen lot	17	33	67	30	1.2	0.10	0.50	1.3
Poultry								
Leghorn pullets	No data	65	40		2.1	0.85	1.0	1.1
Leghorn hen	0.066	59	40		1.9	0.88	1.2	1.3
Broiler litter	0.044	31	70	70	3.7	0.75	0.60	1.4
Turkey litter	0.24	30			2.2		0.33	1.2
Dairy								
Scraped earthen lots	77	54	46		0.70		0.25	0.67
Scraped concrete lots	88	72	25		0.53		0.13	0.40
Lagoon effluent	234	98	2	52	0.073	0.08	0.016	0.11
Slurry (liquid)	148	92	8	66	0.30	0.14	0.13	0.40
Equine								
Solid manure								
Residential	71	43	65	26	0.76		0.24	0.99
Commercial	101							
Swine								
Finisher-Slurry, wet-dry feeders	6.6–8.8	91	9.0		0.70	0.50	0.21	0.24
Slurry storage-dry feeders	9.9	94	6.1		0.47	0.34	0.18	0.24
Flush building	35	98	2.0		0.20	0.14	0.07	0.17
Agitated solids and water		98	2.2		0.10	0.05	0.06	0.06
Lagoon surface water		99.6	0.40		0.06	0.04	0.02	0.07
Lagoon sludge		90	10		0.26	0.07	0.25	0.07

1/ Adapted from ASAE D384.2, table 19

Table 4–16 Manure as transferred for utilization—Continued

(b) Expressed as 1,000-lb animal units

Type of production	Mass in lb/AU/d, wet basis	Moisture, % wet basis [2/3]	Total solids % wet basis [3/]	Total solids, lb/AU/d	Volatile solids, % of TS	Volatile solids, lb/AU/d	Total Kjehldahl Nitrogen, % wet basis	Total Kjehldahl Nitrogen, in lb/AU/d [4/]	NH_3-N % wet basis	NH_3-N lb/AU/d	P % wet basis	P lb/AU/d	K % wet basis	K lb/AU/d
Beef earthen lot	17	33%	67%	11	30.2%	3.4	1.18%	0.20	0.10%	0.017	0.50%	0.084	1.25%	0.21
Poultry leghorn hen	17	59%	40%	6.6			1.85%	0.31	0.88%	0.15	1.21%	0.20	1.31%	0.22
Poultry broiler litter	17	31%	70%	12	70.0%	8.3	3.73%	0.63	0.75%	0.13	0.60%	0.10	1.37%	0.23
Poultry turkey litter	23[1/]	30%					2.18%	0.51			0.33%	0.077	1.23%	0.29
Dairy scraped earthen lots	57	54%	46%	26			0.70%	0.40			0.25%	0.14	0.67%	0.38
Dairy scraped concrete lots	65	72%	25%	16			0.53%	0.34			0.13%	0.084	0.40%	0.26
Dairy lagoon effluent	171	98%	2%	3.4	52.0%	1.8	0.07%	0.12	0.08%	0.14	0.02%	0.034	0.11%	0.19
Dairy slurry (liquid)	108	92%	8%	8.7	66.0%	5.7	0.30%	0.32	0.14%	0.15	0.13%	0.14	0.40%	0.43
Equine solid manure	64	43%	65%	42	26.3%	11	0.76%	0.49			0.24%	0.15	0.99%	0.64
Swine finisher, slurry w/ wet/ dry feeders	50	91%	9%	4.5			0.70%	0.35	0.50%	0.25	0.21%	0.11	0.24%	0.12
Swine slurry storage w/ dry feeders (sows)	23	94%	6%	1.4			0.47%	0.11	0.34%	0.077	0.18%	0.041	0.24%	0.054
Swine flush building (sows)	80	98%	2%	1.6			0.20%	0.16	0.14%	0.11	0.07%	0.056	0.17%	0.14

1/ Assuming raising an equal number of tom and hen turkeys
2/ Assuming moisture is equivalent to water, and whatever is not water is dry matter [TS+VS]
3/ Percent moisture plus percent TS can add up to more than 100% because solids estimates do not include solids in urine
4/ TKN includes ammonia N plus organic N. If the manure storage is aerobic, there would also be nitrate N

651.0405 Other wastes

(a) Residential waste

NRCS is seldom called on to provide assistance to municipalities; however, the information provided here may be useful in area-wide planning. Rural residential waste components are identified in tables 4–17 and 4–18. Table 4–17 lists the characteristics of human excrement. Household wastewater (table 4–18) can be categorized as graywater (no sanitary wastes included) and blackwater (sanitary wastewater). In most cases, a composite of both of these components will be treated in a septic tank. The liquid effluent from the septic tank generally is treated in a soil absorption field.

Municipal wastewater of residential origin is usually categorized into raw (untreated) and treated types (table 4–19). Secondary (biological) treatment is common for wastewater that is to be applied to agricultural land. Municipal wastewater sludge may also be in the raw, untreated form or in the treated (digested) form. Municipal compost is usually based on dewatered, digested sludge and refuse, but can contain other waste materials, as well.

Liquid and solid wastes of residential origin generally are not a source of toxic materials. Some industrial waste, however, may contain toxic components requiring careful handling and controlled distribution. Planning of land application systems for industrial waste must include thorough analyses of the waste materials.

(b) Food wastes and wastewater

Food processing can result in considerable quantities of solid waste and wastewater. Processing of some fruits and vegetables results in more than 50 percent waste. Many of these wastes, however, can be used in by-product recovery procedures, and not all of the waste must be sent to disposal facilities. Food processing wastewater may be a dilute material that has a low concentration of some of the components of the raw product. On the other hand, solid waste from food processing may contain a high percentage of the raw product and exhibit characteristics of that raw product.

Tables 4–20 and 4–21 present characteristics of wastewater and sludge from the processing of milk and milk products.

Characteristics of wastewater and sludge from the meat and poultry processing industries are listed in tables 4–22 and 4–23.

Table 4–17 Human waste characterization—as excreted [1/]

Component	Units	Adult
Weight	lb/d/1000 lb	30
Volume	ft^3/d/1000 lb	0.55
Moisture	%	89
TS	% w.b.	11
	lb/d/1000 lb	3.3
VS	lb/d/1000 lb	1.9
FS	lb/d/1000 lb	1.4
COD	lb/d/1000 lb	3.0
BOD_5	lb/d/1000 lb	1.3
N	lb/d/1000 lb	0.20
P	lb/d/1000 lb	0.02
K	lb/d/1000 lb	0.07

1/ Adapted from the 1992 version of the AWMFH

Table 4–18 Residential waste characterization—household wastewater [1/]

Component	Units	Graywater	Composite [2/]	Septage
Volume	ft^3/d/1000 lb of people	27	38	35
Moisture	%	99.92	99.65	99.75
TS	% w.b.	0.08	0.35	0.25
	lb/d/1000 lb of people	1.3	7.7	5.5
VS	% w.b.	0.024	0.20	0.14
FS	lb/d/1000 lb	0.056	0.15	0.11
N	lb/d/1000 lb	0.0012	0.007	0.0075
NH4-N	lb/d/1000 lb			0.0018
P	lb/d/1000 lb	0.0004	0.003	0.0019
K	lb/d/1000 lb		0.003	0.0025

1/ Adapted from 1992 version of the AWMFH
2/ Graywater plus blackwater

Table 4–19 Municipal waste characterization—residential[1/]

Component	Units	Wastewater		Sludge		Compost[2/]
		Raw	Secondary	Raw	Digested	
Volume	ft^3/d/1000 lb of people	90	85			
Moisture	%	99.95	99.95			40
TS	% w.b.	0.05[3/]	0.05[4/]	4.0	4.0	60
VS	"	0.035		3.0	2.1	
FS	"	0.015		1.0	0.90	
COD	"	0.045				
BOD_5	"	0.020	0.0025			
N	"	0.003	0.002	0.32	0.15	0.78
NH_4-N	"		0.001		0.08	
P	"	0.001	0.001	0.036	0.067	0.20
K	"	0.001	0.0012		0.010	0.17

Table 4–20 Dairy food processing waste characterization[1/]

Product/operation	Wastewater	
	Weight lb/lb milk processed	BOD_5 lb/1000 lb milk received
Bulk milk handling	6.1	1.0
Milk processing	4.9	5.2
Butter	4.9	1.5
Cheese	2.1	1.8
Condensed milk	1.9	4.5
Milk powder	2.8	3.9
Milk, ice cream, and cottage cheese	2.5	6.4
Cottage cheese	6.0	34
Ice cream	2.8	5.8
Milk and cottage cheese	1.8	3.5
Mixed products	1.8	2.5

1/ Adapted from 1992 version of the AWMFH

Table 4–21 Dairy food waste characterization—processing wastewater[1/]

Component	Units	Industry wide	Whey		Cheese wastewater sludge
			Sweet cheese	Acid cheese	
Moisture	%	98	93	93	98
TS	% w.b.	2.4	6.9	6.6	2.5
VS	% w.b.	1.5	6.4	6.0	
FS	% w.b.	0.91	0.55	0.60	
COD	% w.b.		1.3		
BOD5	% w.b.	2.0			
N	% w.b.	0.077	7.5		0.18
P	% w.b.	0.050			0.12
K	% w.b.	0.067			0.05

1/ Adapted from 1992 version of the AWMFH

Table 4–22 Meat processing waste characterization—wastewater[1/]

Component	Units	Red meat			Poultry [5/]	Broiler [6/]
		Harvesting [2/]	Packing [3/]	Processing [4/]		
Volume	gal/1000 lb[7/]	700	1,000	1,300	2,500	
Moisture	%					95
TS	% w.b.					5.0
	lb/1000 lb	4.7	8.7	2.7	6.0	
VS	lb/1000 lb					4.3
FS	lb/1000 lb					0.65
BOD^5	lb/1000 lb	5.8	12	5.7	8.5	
N	lb/1000 lb					0.30
P	lb/1000 lb					0.084
K	lb/1000 lb					0.012

1/ Adapted from 1992 version of the AWMFH
2/ Harvesting—Euthanizing and preparing the carcass for processing
3/ Packing—Euthanizing, preparing the carcass for processing, and processing
4/ Processing—Sectioning carcass into retail cuts, grinding, packaging
5/ Quantities per 1,000 lb product
6/ All values % w.b.
7/ Per 1,000 lb live weight harvested

Table 4–22 presents data on raw wastewater discharges from red meat and poultry processing plants. Table 4–23 describes various sludges. Dissolved air flotation sludge is a raw sludge resulting from a separation procedure that incorporates dissolved air in the wastewater. The data on wastewater sludge is for sludge from secondary treatment of wastewater from meat processing.

Table 4–24 presents raw wastewater qualities for several common vegetable crops on the basis of the amount of the fresh product processed. Characteristics of solid fruit and vegetable wastes, such as might be collected at packing houses and processing plants, are listed in table 4–25.

(c) Silage leachate

Silage leachate, a liquid by-product resulting from silage production typically from whole corn plants or sorghums, that drains from the storage unit must be considered in the planning and design of an AWMS. Silage is a forage-type livestock feed that is produced by fermentation at relatively high moisture contents and stored in airtight conditions. Oxygen depletion of surface water is the major environmental concern associated with silage leachate because of its high biological oxygen demand. This oxygen depletion is exacerbated because silage is usually produced in the late summer and early fall when streams are already low in total dissolved oxygen due to

Table 4–23 Meat processing waste characterization—wastewater sludge [1/]

Component	Units	Dissolved air flotation sludge			Wastewater sludge
		Poultry	Swine	Cattle	
Moisture	%	94	93	95	96
TS	% w.b.	5.8	7.5	5.5	4.0
VS	% w.b.	4.8	5.9	4.4	3.4
FS	% w.b.	1.0	1.6	1.1	0.60
COD	% w.b.	7.8			
N	% w.b.	0.41	0.53	0.40	0.20
NH_4-N	% w.b.	0.17			
P	% w.b.	0.12			0.04

1/ Adapted from the 1992 version of the AWMFH

Table 4–24 Vegetable processing waste characterization—wastewater [1/]

Component	Units	Cut bean	French-style bean	Pea	Potato	Tomato
Volume	ft^3/d/1000				270 [3/]	
TS	lb/1000 lb [2/]	15	43	39	53 [4/]	130
VS	lb/1000 lb [2/]	9	29	20	50 [4/]	
FS	lb/1000 lb [2/]	6	14	19	3 [4/]	
COD	lb/1000 lb [2/]	14	35	37	71 [5/]	96
BOD_5	lb/1000 lb [2/]	7	17	21	32	55

1/ Adapted from 1992 version of the AWMFH
2/ lb/1000 lb raw product
3/ ft^3/lb processed
4/ Total suspended solids
5/ Percent of TSS

Table 4–25 Fruit and vegetable waste characterization—solid waste [1/]

Fruit/vegetable	Moisture content	Total solids	Volatile solids	Fixed solids	N	P	K
Banana, fresh	84	16	14	2.1	0.53		
Broccoli, leaf	87	14			0.30		
Cabbage, leaf	90	9.6	8.6	1.0	0.14	0.034	
Cabbage core	90	10			0.38		
Carrot, top	84	16	14	2.4	0.42	0.03	
Carrot root	87	13	11	1.3	0.25	0.04	
Cassava, root	68	32	31	1.3	1.7	0.039	
Corn, sweet, top	80	20	19	1.2	0.7		
Kale, top	88	12	9.7	1.9	0.22	0.06	
Lettuce, top	95	5.4	4.5	0.9	0.05	0.027	
Onion top, mature	8.6	91	85	6.7	1.4	0.02	
Orange, flesh	87	13	12	0.6	0.26		
Orange pulp	84	16	15	1.0	0.24		
Parsnip, root	76	24			0.47		
Potato, top, mature	13	87	72	16	1.2		
Potato tuber					1.6	0.25	1.9
Pumpkin, flesh	91	8.7	7.9	0.8	0.12	0.037	
Rhubarb, leaf	89	11			0.20		
Rutabaga, top	90	10			0.35		
Rutabaga root	90	11			0.20		
Spinach, stems	94	6.5			0.07		
Tomato, fresh	94	5.8	5.2	0.6	0.15	0.03	0.30
Tomato, solid waste	89	11	10	0.9	0.22	0.044	0.089
Turnip, top	92	7.8				0.20	
Turnip root	91				0.34		

1/ Adapted from the 1992 version of the AWMFH seasonally high temperatures and low flow rates. Since 20 to 25 percent of the total nitrogen in silage leachate is in the form of nitrate, it is also has the potential of being a ground water contaminant.

Generally, the amount of leachate produced is directly influenced by the moisture content of the forage ensiled and the degree of compaction to which the forage is subjected. Silage leachate is typically 95 percent water. It has a pH that can range from 5.5 to 3.6. Table 4–26 lists the range for typical nutrient concentrations in silage leachate.

The range of uncertainty in nutrient content reflects the differences that can occur from year to year and from site to site. Management decisions based on these nutrient concentrations should also consider the associated volumes of leachate that are usually relatively small. In most instances, a practical design and plan for environmental containment should be based on a reasonably high concentration assumption. Operation and management decisions should be based on the results of timely sampling and testing at a specific site.

The factors that influence leachate production from silage include the degree to which the silage crop has been chopped and the amount of pressure applied to the leachate in the silo, but the greatest single factor is the percent of dry matter in the silage. The peak rate of silage leachate production has been measured with silage at 18 percent moisture as 0.5 cubic feet per ton of silage per day. The peak time of leachate production will usually be from 3 to 5 days following ensilage. Leachate production as a function of percent dry matter is given in table 4–27.

This variation in production can make a significant difference in the planning and design of systems to manage this effluent. The actual production rate used for a specific design should be a reasonable conservative estimate that is based on these numbers, local data, and the experience of the managers of the silos.

Table 4–26 Typical range of nutrient concentrations in silage leachate[1/]

Constituent	Concentration lb/ft^3
Total nitrogen	0.09–0.27
Phosphorus	0.02–0.04
Potassium	0.21–0.32

1/ Adapted from Stewart and McCullough

Table 4–27 Leachate production based on percent dry matter of silage[1/]

Dry matter content of silage %	Leachate produced of silage gal/ton
<15	100–50
15–20	50–30
20–25	30–5
>25	5–0

1/ Adapted from Stewart and McCullough

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651.0604 Balancing plant nutrient needs with manure application

Manure managers must balance the application of manure and residual elements in the soil with the need of the plants and the capacity of the microbes in the soil to transform the chemical elements into plant available forms. Lack of nutrients available in form for the plant to uptake can cause a deficiency in plants, and excess nutrients can cause toxicity. Both situations decrease plant growth. An excess can also find its way through the food chain and be hazardous to the consumer. Elements that are not transformed or retained in the soil can leave the system and become a contaminant to surface and groundwater. In applying manure to the land for plant nutrients, remember that the nutrient content of manure is highly variable, representative sampling is difficult, and laboratory procedures that indicate nutrient amounts are subject to errors. This is why it is difficult to apply manure nutrients with the precision of commercial fertilizer; however, with planned and measured applications of manure over several years, a landowner is able to achieve a reasonable balance between nutrients applied to the field by the manure and nutrients removed from the field by the crop.

(a) Deficiencies of plant nutrients

The deficiency of nutrients to the plants from manure applications can occur by either the shortage of supplied elements contained in the manure or by the interference in the uptake of a nutrient caused by the excessive supply of another nutrient. In the first case, an analysis of the manure can be used to help determine the amount of nutrients being supplied, and this amount is balanced with the crop's requirements. Using the NRCS National Conservation Practice Standard (CPS), Code 590, Nutrient Management with a nutrient budget worksheet will help assure that all essential nutrients are being supplied to the crop. For the second case, an example in the section 651.0604(b) shows the antagonism that excessive uptake of ammonium ion from manure has on the calcium ion. High levels of copper, iron, and manganese in the waste material can cause a plant deficiency of zinc caused by blockage of Zn uptake sites on the root by the other ions.

(b) Excesses of plant nutrients, total dissolved solids, and trace elements

The tolerance of plants to high levels of elements in plant tissue must also be considered when applying manure to cropland. Heavy applications of waste can cause elevated levels of nitrates in plant tissue that can lead to nitrate poisoning of livestock consuming that foliage. The ability to accumulate nitrates differs from plant to plant or even within cultivars of a species. Concentrations of nitrate nitrogen in plant dry matter less than 0.1 percent is considered safe to feed livestock. Large applications of manure on tall fescue, orchardgrass, and sudangrass can cause nitrate buildup. Cattle grazing these plants can, thus, be poisoned. When the concentration of nitrate nitrogen in the dry harvested material exceeds 0.4 percent, the forage is toxic.

Urea contained in manure is unstable. As manure dries, the urea breaks down into NH_4 and NH_3. The release of gaseous NH_3 from manure can result in NH_3 toxicity. Exposure of corn seeds to NH_3 during the initial stages of germination can cause significant injury to the development of seedlings. High levels of ammonium and NH_3 in the soil interferes with the uptake of the calcium ion, causing plants to exhibit calcium deficiency (Hensler, Olsen, and Attoe 1970). High levels of NH_4 and NH_3 also cause problems for earthworms and other soil organisms. Part of the NH_4 released is adsorbed on the cation exchange sites of the soil, releasing calcium, potassium, and magnesium ions into solution. High levels of these ions in the soil solution contribute to an increase in the soluble salt level and pH.

Up to 50 percent of manure nitrogen is in the NH_4 form. To prevent toxicity from occurring on young plant seedlings, the manure can be incorporated into the soil to absorb the NH_4 on the cation exchange sites or allowed to air dry on the soil surface. Surface drying greatly reduces the level of NH_4 by volatilization, but because this results in a loss of the nitrogen, this typically does not reflect efficiency in nutrient utilization. Applying manure at rates based on nitrogen requirements of the crop helps to avoid excess NH_4 buildup in the seed zone. A 0.25-inch rain or irrigation application should be sufficient to dissipate high concentrations of NH_3 in the seed zone. Side-dressing manure on corn is an effective way to apply inorganic nitrogen that is quickly available for plant growth (Klausner and Guest

1981). Injecting manure into soil conserves more of the NH_4 nitrogen during periods of warm, dry weather and prevents NH_3 toxicity to the growth of plants (Sutton, Nelson, Hoff, and Mayrose 1982).

The soluble salt content of manure and sludge is high and must be considered when these wastes are applied to cropland. The percent salt in waste may be estimated by multiplying the combined percentages of potassium, calcium, sodium, and magnesium as determined by laboratory analysis by a factor of two (USEPA 1979).

$$\% \text{ salts} = (\%K + \%Ca + \%Na + \%Mg) \times 2$$

Under conditions where only limited rainfall and irrigation are applied, salts are not adequately leached out of the root zone and can build up high enough quantities to cause plant injury. Plants that are salt sensitive or only moderately tolerant show progressive decline in growth and yields as levels of salinity increase (figs. 6–2, 6–3, and 6–4).

Some plant species are tolerant to salinity once established, but are sensitive during germination. If manure or sludge is applied to land in areas that receive moderate rainfall or irrigation water during the growing season, soluble salts in the waste will be dispersed through the profile or leached below the root zone. If manure or sludge is applied under a moisture deficit condition, salt concentrations can build up.

After prolonged application of manure, the soil electrical conductivity should be tested. A soil test of the electrical conductivity of saturated paste extract can be used to measure the total salt concentration in the soil. Conductivity values of 2 mmhos/cm or less are considered low in salts and suitable for all crops. Above values of 4 mmhos/cm, plant growth is affected except for all but the most tolerant crops (figs. 6–2, 6–3, and 6–4). At these high conductivity values, irrigation amounts need to be increased to leach salts. Added water percolating through the profile may then cause concern with leaching of nitrates, and manure application rates may have to be adjusted (Stewart 1974).

Figure 6–2 Effect of soil salinity on growth of field crops

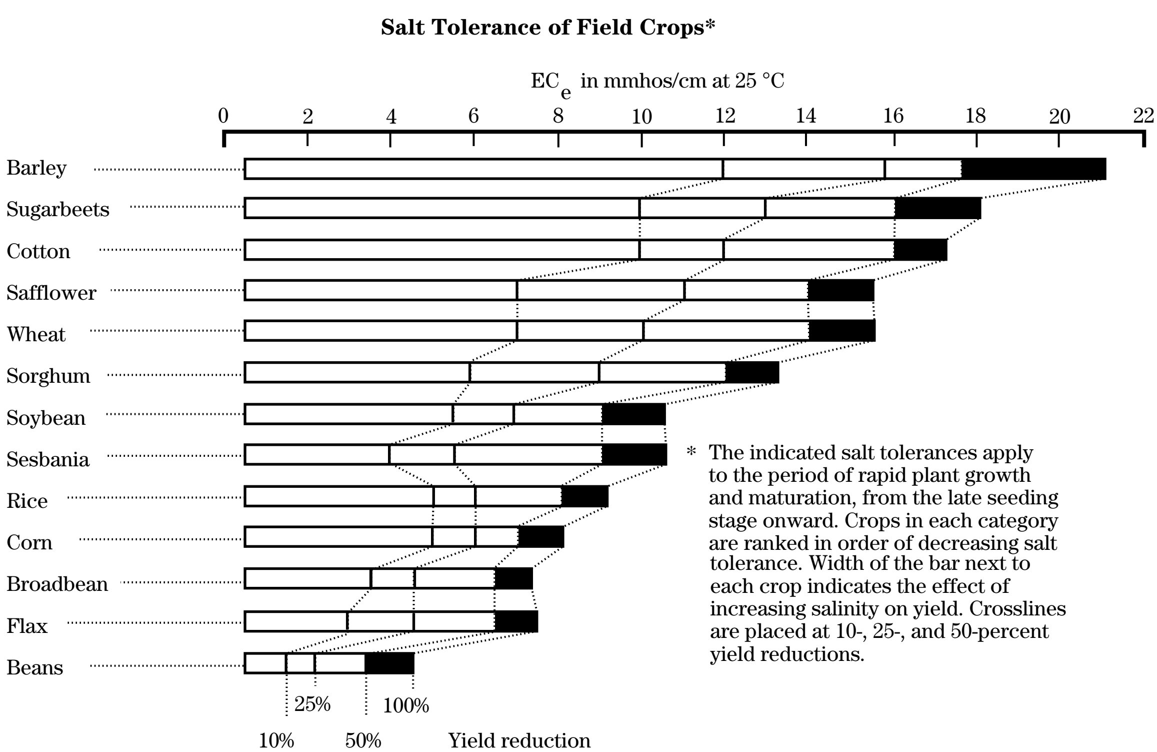
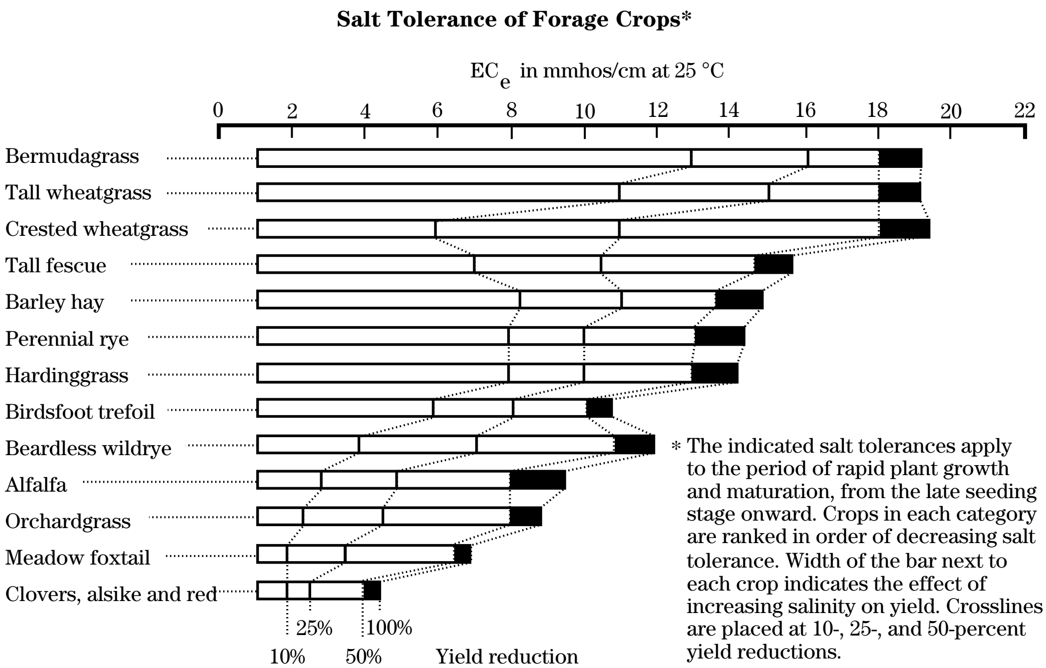
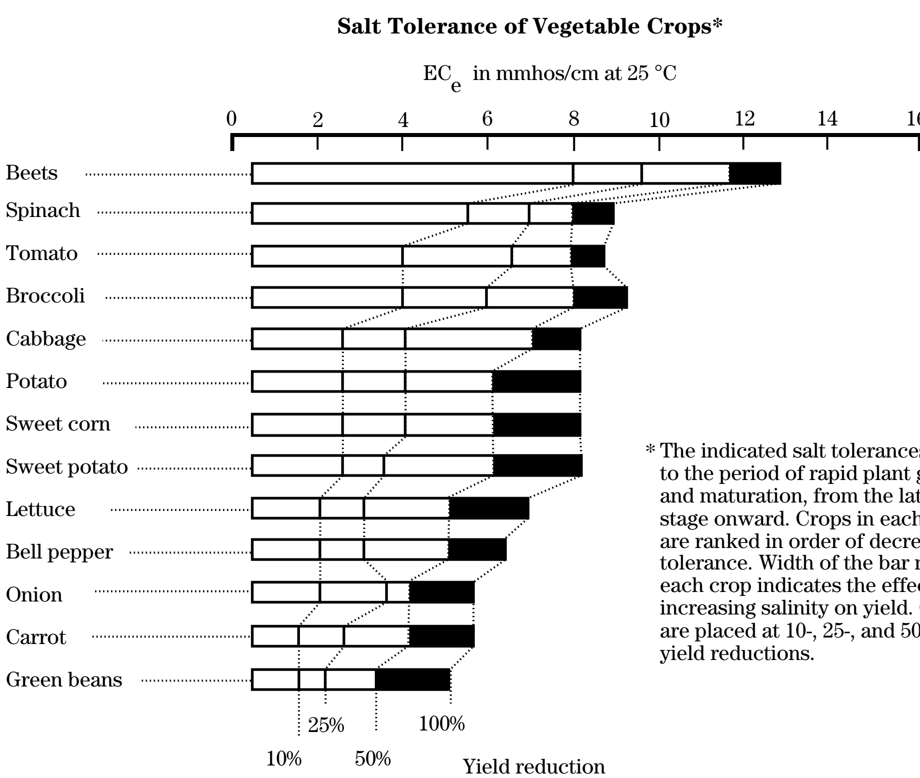


Figure 6–3 Effect of soil salinity on growth of forage crops



* The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seeding stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50-percent yield reductions.

Figure 6–4 Effect of soil salinity on growth of vegetable crops



* The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seeding stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50-percent yield reductions.

Trace element toxicity is of concern with waste application on agricultural land. Animal manure can have elevated amounts of aluminum, copper, and zinc. Sewage sludge can have elevated concentrations of several elements, most notably aluminum, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc. The element and concentration in the sludge depends on the predominant industry in the service area. If wastes with elevated levels of trace elements are applied over a long period of time at significant rates, trace element toxicity can occur in plants. Micronutrient and trace element toxicity to animals and humans can also occur where cadmium, copper, molybdenum, and selenium levels in plant tissue become elevated.

Table 6–3 lists some general crop growth symptoms and crops most sensitive to the given trace elements. If such symptoms should occur, a plant tissue test can be done to confirm which element is at fault. Many of the symptomatic signs are similar for two or more elements, making it extremely difficult to know with certainty which element is in excess from observation of outward symptoms. Much of the toxicity of such trace elements is because of their antagonistic action against nutrient uptake and use by plants. Table 6–4 shows the interaction among elements within plants and adjacent to the plant roots.

Table 6–3 General effects of trace element toxicity on common crops (Kabata and Pendias 1984)

Element	Symptoms	Sensitive crop
A1	Overall stunting; dark green leaves; purpling of stems; death of leaf tips; and coralloid and damaged root system	Cereals
As	Red-brown necrotic spots on old leaves; yellowing and browning of roots; depressed tillering	(No information)
B	Margin or leaf tip chlorosis; browning of leaf points; decaying growing points; and wilting and dying-off of older leaves	Cereals, potatoes, tomatoes, cucumbers, sunflowers, mustard
Cd	Brown margin of leaves; chlorosis; reddish veins and petioles; curled leaves; and brown, stunted roots	Legumes (bean, soybean), spinach radish, carrots, and oats
Co	Interveinal chlorosis in new leaves followed by induced Fe chlorosis and white leaf margins and tips; and damaged root tips	(No information)
Cr	Chlorosis of new leaves; injured root growth	(No information)
Cu	Dark green leaves followed by induced Fe chlorosis; thick, short, or barbed-wire roots; depressed tillering	Cereals and legumes, spinach, citrus, seedlings, and gladiolus
F	Margin and leaf tip necrosis; chlorotic and red-brown points of leaves	Gladiolus, grapes, fruit trees, and pine trees
Fe	Dark green foliage; stunted growth of tops and roots; dark brown to purple leaves of some plants ("bronzing" disease of rice)	Rice and tobacco
Hg	Severe stunting of seedlings and roots; leaf chlorosis; and browning of leaf points	Sugarbeets, corn, and roses
Mn	Chlorosis and necrotic lesions on old leaves; blackish-brown or red necrotic spots; accumulation of MnO_2 particles in epidermal cells; drying tips of leaves; and stunted roots	Cereals, legumes, potatoes, and cabbage
Mo	Yellowing or browning of leaves; depressed root growth; depressed tillering	Cereals
Ni	Interveinal chlorosis in new leaves; gray-green leaves; and brown, stunted roots	Cereals
Pb	Dark green leaves; wilting of older leaves; stunted foliage; and brown, short roots	(No information)
Rb	Dark green leaves; stunted foliage; and increasing amount of shoots	(No information)
Se	Interveinal chlorosis or black spots at Se content at about 4 mg/L and complete bleaching or yellowing of younger leaves at higher Se content; pinkish spots on roots	(No information)
Zn	Chlorotic and necrotic leaf tips; interveinal chlorosis in new leaves; retarded growth of entire plant; injured roots resemble barbed wire	Cereals and spinach

Table 6–4 Interaction among elements within plants and adjacent to plant roots

Major elements	Antagonistic elements	Synergistic elements	Trace elements	Antagonistic elements	Synergistic elements
Ca	AI, B, Ba, Be, Cd, Co, Cr, Cs, Cu, F, Fe, Li, Mn, Ni, Pb, Sr, Zn	Cu, Mn, Zn	Cu	Cd, Al, Zn, Se, Mo, Fe, Ni, Mn	Ni, Mn, Cd
Mg	Al, Be, Ba, Cr, Mn, F, Zn, Ni, Co, Cu, Fe	Al, Zn	Zn	Cd, Se, Mn, Fe, Ni, Cu	Cu, Zn, Pb, Mn, Fe, N
P	Al, As, B, Be, Cd, Cr, Cu, F, Fe, Hg, Mo, Mn, Ni, Pb, Rb, Se, Si, Sr, Zn	Al, B, Cu, F, Fe, Mn, Mo, Zn	Cd	Zn, Cu, Al, Se, Mn, Fe, Ni	Cu, Zn, Pb, Mn, Fe, N
K	Al, B, Hg, Cd, Cr, F, Mo, Mn, Rb	(No evidence)	B	Si, Mo, Fe	Mo, Fe
S	As, Ba, Fe, Mo, Pb, Se	F, Fe	Al	Cu, Dc	(No evidence)
N	B, F, Cu	B, Cu, Fe, Mo	Pb	—	Cd
C1	Cr, I	(No evidence)	Mn	Cu, Zn, Mo, Fe, Ar, Cr, Fe, Co, Cd, Al, Ni, Ar, Se	Mo
			Fe	Zn, Cr, Mo, Mn, Co, Cu, Cd, B, Si	Cd, B
			Mo	Cu, Mn, Fe, B	Mn, B, Si
			Co	Mn, Fe	(No evidence)
			Ni	Mn, Zn, Cu, Cd	Cu, Zn, Cd

Chapter 10 Agricultural Waste Management System Component Design

651.1000 Introduction

Ideally, the by-products of agricultural operations would be immediately returned to the soil from where they were generated. Unfortunately, this is usually not possible or economically justifiable. By-products of animal operations such as manure are biologically and chemically active, often requiring intermediate steps before final utilization. In addition, land application of manure is labor intensive and may be difficult or prohibited while the ground is frozen, crops are at certain growth stages, or when the ground is saturated. Temporary storage may reduce the potential for water pollution by allowing final utilization to occur at optimal times and by preventing runoff from entering ground water or surface water. However, the nutrient content of manure degrades over time, requiring a balance between convenience and the economics of nutrient utilization. Design considerations must include location, installation, and operation and maintenance.

Possible alternatives for manure management are available for any given agricultural operation. A manure management system may consist of any one or all of the following functions: production, collection, storage, treatment, transfer, and utilization. These functions are carried out by planning, applying, and operating individual components.

(a) Planning considerations

A successful manure management system must address production, operation, regulatory guidelines, and environmental considerations. The needs of the owner and/or decisionmaker are also vital considerations. The National Planning Procedures Handbook (NPPH) describes the nine-step process for planning.

(1) Landowner/decisionmaker desires

Input from the owner, operator, and/or decision-maker is critical for success of any planned operation. Managerial ability and long-range plans, in addition to current resources, must be considered. Also, financial considerations may determine the selected alternative.

(2) Regulatory requirements

Local, State, and Federal regulations must be considered at all stages. Environmental laws and specific State and Federal program requirements may impact current or potential activities and alternatives.

(3) Existing structure assessment and evaluation

Inventorying existing equipment and structures is an important part of planning. Using available resources may reduce the cost of system installation, but constrain the possible alternatives considered. An evaluation of the best alternative should consider both short- and long-term costs of operation and maintenance.

(4) Vulnerability and risk

Operating a livestock facility creates an environmental risk for pollution. Climatic conditions and operating procedures can lead to an accidental discharge into surface waters. Foundation problems can result in seepage into subsurface waters. Location of a facility is an extremely important consideration during the planning process to minimize exposure to vulnerability and risk.

(b) Selected alternative

Alternatives may consist of components like a piece of equipment, such as a pump; a structure, such as a waste storage tank; or an operation, such as composting. A system should consist of the best combination of the components that allows the flexibility needed to efficiently handle all forms of agricultural by-products generated for a given enterprise. In addition, the components must be compatible and integrated within the system. All components should be designed to be simple, manageable, and durable, and they should require low maintenance. In this chapter, components are discussed under section headings that describe the function that they are to accomplish.

(c) Design, installation, and operation

Any facility must be designed and installed according to locally acceptable engineering standards and regulatory requirements. Proper operation and maintenance are required to achieve desired results. The design must address the methods of production, collection, storage, treatment, transfer, and utilization.

651.1001 Production

Components that affect the volume and consistency of agricultural waste produced are included in the production function. Roof gutters and downspouts and diversion to exclude clean water from areas of waste are examples of components that reduce the volume of waste material that needs management. Fences and walls that facilitate collection of waste confine the animals, thus increase the volume.

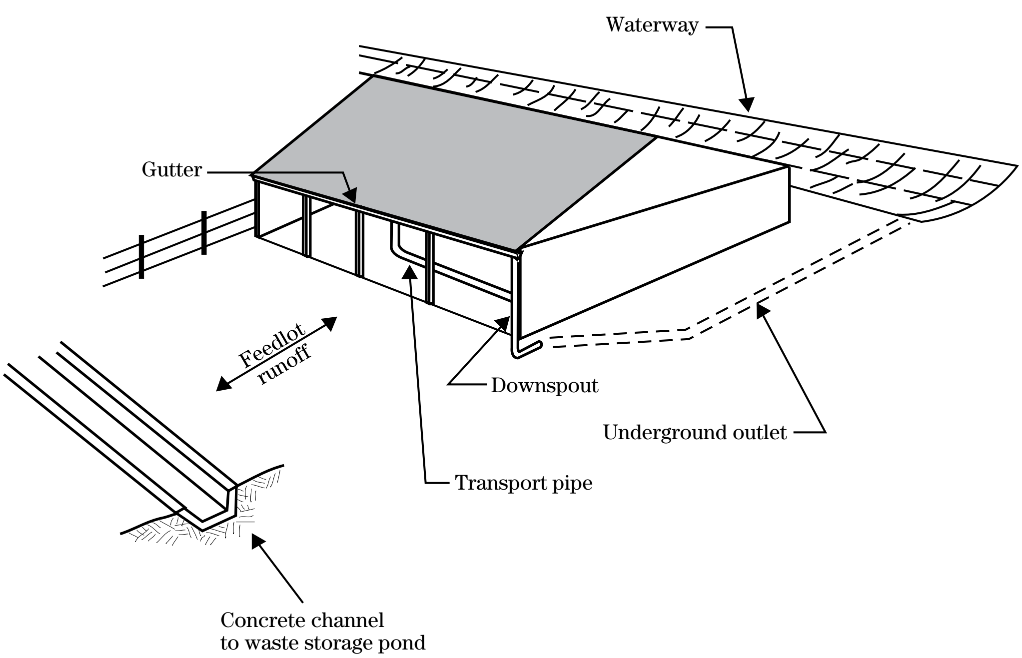
(a) Roof runoff management

Roof runoff should be diverted from feedlots and manure storage areas unless it is needed for some use, such as dilution water for waste storage ponds or treatment lagoons. This can be accomplished by roof gutters and downspouts with underground or open channel outlets (fig. 10–1). Roof runoff structures should be planned and designed according to NRCS Conservation Practice Standard 588, Roof Runoff Structure. Gutters and downspouts may not be needed if the roof drainage will not come into contact with areas accessible to livestock.

The area of a roof that can be served by a gutter and downspout system is controlled by either the flow capacity of the gutter (channel flow) or by the capacity of the downspout (orifice flow). The gutter's capacity may be computed using Manning's equation. Design of a gutter and downspout system is based on the runoff from a 10-year frequency, 5-minute rainfall except that a 25-year frequency, 5-minute rainfall is used for exclusion of roof runoff from waste treatment lagoons, waste storage ponds, or similar practices.

Rainfall intensity maps are in appendix 10B. Caution should be used in interpolating these maps. Rainfall probabilities are based on measured data at principal weather stations that are mostly in populated regions. The 10-year, 5-minute rainfall in the 11 Western States was based on NOAA Atlas 1, and that in the 37 Eastern States was based on the National Weather Service HYDRO 35. Both of these publications state their limitations in areas of orographic effect. In the Western States, the 10-year, 5-minute rainfall generally is larger in mountain ranges than in valleys. Rainfall in all mountain ranges could not be shown on these maps because of the map scale and readability considerations. Many of these differences were in the range of 0.05 inch and fall within the contour interval of 0.10 inch.

Figure 10–1 Roof gutter and downspout



A procedure for the design of roof gutters and downspouts follows:

Step 1 Compute the capacity of the selected gutter size. This may be computed using Manning's equation. Using the recommended gutter gradient of 1/16 inch per foot and a Manning's roughness coefficient of 0.012, this equation can be expressed as follows:

$$q_g = 0.01184 \times A_g \times r^{0.67}$$

where:
q_g = capacity of gutter, ft^3/s
A_g = cross-sectional area of gutter, in^2
r = A_g / wp, in
wp = wetted perimeter of gutter, in

Step 2 Compute capacity of downspout. Using an orifice discharge coefficient of 0.65, the orifice equation may be expressed as follows:

$$q_d = 0.010457 \times A_d \times h^{0.5}$$

where:
q_d = capacity of downspout, ft^3/s
A_d = cross-sectional area of downspout, in^2
h = head, in (generally the depth of the gutter minus 0.5 in)

Step 3 Determine whether the system is controlled by the gutter capacity or downspout capacity and adjust number of downspouts, if desired.

$$N_d = \frac{q_g}{q_d}$$

where:
N_d = number of downspouts

If N_d is less than 1, the system is gutter-capacity controlled. If it is equal to or greater than 1, the system is downspout-capacity controlled unless the number of downspouts is equal to or exceeds N_d.

Step 4 Determine the roof area that can be served based on the following equation:

$$A_r = \frac{q \times 3,600}{P}$$

where:
A_r = area of roof served, ft^2
q = capacity of system, either q_g or q_d, whichever is smallest, ft^3/s
P = 5-minute precipitation for appropriate storm event, in

This procedure is a trial and error process. Different sizes of gutters and downspouts should be evaluated along with multiple downspouts to determine the best gutter and downspout system to serve the roof area involved.

Design example 10–1 Gutters and downspouts

Mrs. Linda Worth of Pueblo, Colorado, has requested assistance in developing an agricultural waste management system for her livestock operation. The selected alternatives include gutters and downspouts for a barn having a roof with a horizontally projected area of 3,000 square feet. The 10-year, 5-minute precipitation is 0.5 inch. The procedure above is used to size the gutter and downspouts.

Step 1 Compute the capacity of the selected gutter size. Try a gutter with a 6-inch depth and 3-inch bottom width. One side wall is vertical, and the other is sloping, so the top width of the gutter is 7 inches. Note that a depth of 5.5 inches is used in the computations to allow for 0.5 inch of freeboard.

$$
\begin{aligned}
A_g &= (3 \times 5.5) + (0.5 \times 3.67 \times 5.5) \\
&= 26.6\ \text{in}^2 \\
wp &= 3 + 5.5 + \left(3.67^2 + 5.5^2\right)^{0.5} \\
&= 15.1\ \text{in} \\
r &= \frac{A_g}{wp} \\
&= \frac{26.6}{15.1} \\
&= 1.76\ \text{in} \\
q_g &= 0.01184 \times A_g \times r^{0.67} \\
&= 0.01184 \times 26.6 \times 1.76^{0.67} \\
&= 0.46\ \text{ft}^3/\text{s}
\end{aligned}
$$

Step 2 Compute capacity of downspout. Try a 3-inch-diameter downspout.

$$
\begin{aligned}
H &= \text{depth of gutter } - 0.5\ \text{in}^2 \\
&= 5.5\ \text{in} \\
A_d &= 3.1416 \times \left(\frac{3}{2}\right)^2 \\
&= 7.07\ \text{in}^2 \\
q_d &= 0.010457 \times 7.07 \times 5.5^{0.5} \\
&= 0.17\ \text{ft}^3/\text{s}
\end{aligned}
$$

Step 3 Determine whether the system is controlled by the gutter capacity or downspout capacity and make adjustments to number of downspouts if desired. By inspection, it can be determined that the gutter capacity (0.46 ft^3/s) exceeds the capacity of one downspout (0.17 ft^3/s). Unless a larger downspout or additional downspouts are used, the system capacity would be limited to the capacity of the downspout. Try using multiple downspouts. Determine number required to take advantage of gutter capacity.

$$
\begin{aligned}
N_d &= \frac{q_g}{q_d} \\
&= \frac{0.46}{0.17} \\
&= 2.7
\end{aligned}
$$

N_d is greater than 1; therefore, with one downspout, the system would be downspout controlled. With three, it would be controlled by the gutter capacity, or 0.46 cubic feet per second. Use three downspouts to take full advantage of gutter capacity.

Step 4 Determine the roof area that can be served based on the following equation:

$$
\begin{aligned}
A_r &= \frac{q \times 3{,}600}{P} \\
&= \frac{0.46 \times 3{,}600}{0.5} \\
&= 3{,}312\ \text{ft}^2
\end{aligned}
$$

This exceeds the roof area to be served; therefore, the gutter dimension selected and the three downspouts with dimensions selected are okay.

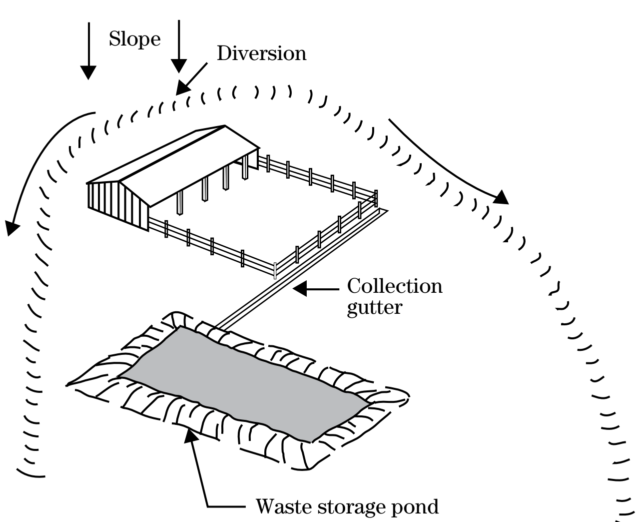
(b) Runoff control

Essentially all livestock facilities in which the animals are housed in open lots or the manure is stored in the open must deal with runoff. Clean runoff from land surrounding livestock facilities should be diverted from barns, open animal concentration areas, and manure storage or treatment facilities (fig. 10–2). Runoff from feedlots should be channeled into manure storage facilities.

Appendix 10C presents a series of maps indicating the amount of runoff that can be expected throughout the year for paved and unpaved feedlot conditions. Clean runoff should be estimated using information in chapter 2 of the NRCS NEH 650, Engineering Field Handbook or by some other hydrologic method.

Diversions are to be designed according to NRCS Conservation Practice Standard 362, Diversion. Diversion channels must be maintained to remain effective. If vegetation is allowed to grow tall, the roughness increases and the channel velocity decreases, causing possible channel overflow. Therefore, vegetation should be periodically mowed. Earth removed by erosion from earthen channels should be replaced. Unvegetated, earthen channels should not be used in regions of high precipitation because of potential erosion.

Figure 10–2 Diversion of clean water around feedlot



(c) Air quality considerations

Emissions of several pollutants from agricultural waste management systems can also affect air quality, including particulate matter (dust), odors, and other gases. Proper planning, design, operation, and maintenance of the agricultural waste management system can help to alleviate these air quality impacts. Siting of the system can significantly affect air quality. A manure storage facility should be located as far as possible from neighboring homes. Local and State regulatory agencies usually require a minimum distance. In addition, the facility should utilize terrain, vegetation, and meteorology to direct emissions away from nearby housing. Livestock may be adversely affected by high concentrations of gases, especially during manure agitation and pumping. Proper sanitation, housekeeping, feed additives, and moisture control, as well as frequent removal and land application of manure from buildings and storage facilities, can reduce emissions of dust, odors, and other gases, in addition to minimizing fly production.

651.1002 Collection

Livestock and poultry manure collection often depends on the degree of freedom that is allowed the animal. If animals are allowed freedom of movement within a given space, the manure produced will be deposited randomly. Typically, the manure must be collected for transportation to storage or treatment. Also, the design and operation of the facility affects whether the manure is collected as a solid, semisolid (slurry), or liquid. For example, a scrape system will contain more concentrated manure, while a flush system may produce a more dilute mixture.

Solid: (>20% solids content) Manure with higher solids content is usually collected with a scraper or front-end loader and stored in a dry stack facility. The solids content can be increased by drying and/or adding bedding material.

Liquid: (<10% solids content) Liquid manure is usually collected and transported by pumping into a storage pond or lagoon. Dilution water or solids-liquid separation is usually required to achieve the low solids content.

Semisolid or slurry: (10–20% solids content) Fresh manure is usually a semisolid. It can be pumped with a large diameter manure pump or collected by a vacuum pump. Solid-liquid separation may allow for easier management of the solids and liquids separately.

Descriptions of components that provide efficient collection of animal waste include paved alleys, gutters, and slatted floors with associated mechanical and hydraulic equipment follow.

(a) Alleys

Alleys are paved areas where the animals walk. They generally are arranged in straight lines between animal feeding and bedding areas. On slatted floors, animal hoofs work the manure through the slats into the alleys below, and the manure is collected by flushing or scraping the alleys.

(1) Scrape alleys and open areas

Two kinds of manure scrapers are used to clean alleys (fig. 10–3). A mechanical scraper is dedicated to a given alley. It is propelled using electrical drives attached by cables or chains. The drive units are often used to power two mechanical scrapers that are traveling in opposite directions in parallel alleys in an oscillating manner. Some mechanical scrapers are in alleys under slatted floors.

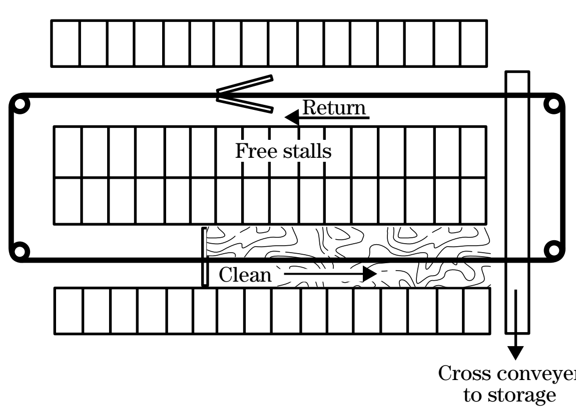
A tractor scraper can be used in irregularly shaped alleys and open areas where mechanical scrapers cannot function properly. It can be a blade attached to either the front or rear of a tractor or a skid-steer tractor that has a front-mounted bucket.

The width of alleys depends on the desires of the producer and the width of available equipment. Scrape alley widths typically vary from 8 to 14 feet for dairy and beef cattle and from 3 to 8 feet for swine and poultry.

(2) Flush alleys

Alleys can also be cleaned by flushing. Grade is critical and can vary between 1.25 and 5 percent. It may change for long flush alleys. The alley should be level perpendicular to the centerline. The amount of water used for flushing is also critical. An initial flow depth of 3 inches for underslat gutters and 4 to 6 inches for open alleys is necessary.

Figure 10–3 Scrape alley used in dairy barns



The length and width of the flush alley are also factors. Most flush alleys should be less than 200 feet long. The width generally varies from 3 to 10 feet depending on animal type. For underslat gutters and alleys, channel width should not exceed 4 feet. The width of open flush alleys for cattle is frequently 8 to 10 feet.

Flush alleys and gutters should be cleaned at least twice per day. For pump flushing, each flushing event should have a minimum duration of 3 to 5 minutes, at a flow rate between 5 and 10 feet per second.

Tables 10–1 and 10–2 indicate general recommendations for the amount of flush volume. Table 10–3 gives the minimum slope required for flush alleys and gutters. Figures 10–4 and 10–5 illustrate flush alleys.

Table 10–1 Recommended total daily flush volumes (MWPS 1985)

Animal type	Gal/head
Swine	
Sow and litter	35
Pre-nursery pig	2
Nursery pig	4
Growing pig	10
Finishing pig	15
Gestating sow	25
Dairy cow	100
Beef feeder	100

Table 10–2 Flush tank volumes and discharge rates (MWPS 1985)

Initial flow depth, in	Tank volume, gal/ft of gutter width	Tank discharge rate, gal/min/ft of gutter width	Pump discharge, gal/min/ft of gutter width
1.5	30	112	55
2.0	40	150	75
2.5	45	195	95
3.0	55	255	110
4.0	75	615	150
5.0	100	985	175
6.0	120	1,440	200

Table 10–3 Minimum slope for flush alleys (MWPS 1985)

	Underslat alley	Open alley narrow width (<4 ft)			Open alley wide width (>4 ft)		
Initial flow depth, in	3.0	1.5	2.0	2.5	4.0	5.0	6.0
Slope, %	1.25	2.0	1.5	1.25	5.0	4.0	3.0

Figure 10–4 Dairy flush alley

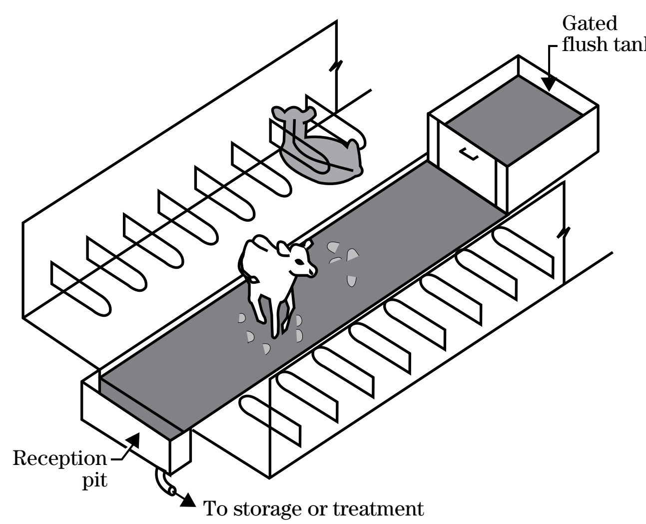
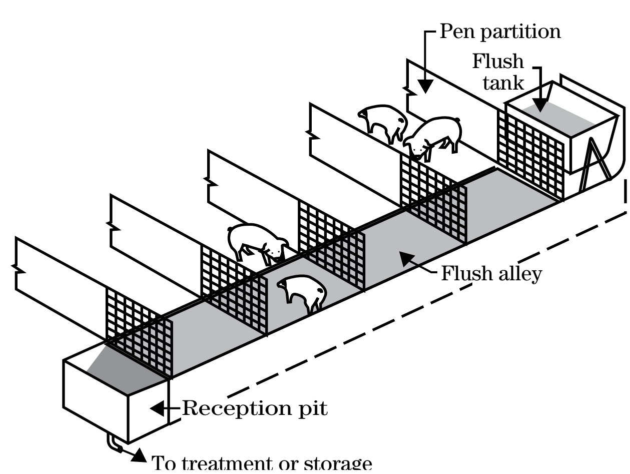


Figure 10–5 Swine flush alley



Several mechanisms are used for flushing alleys. The most common rapidly empties large tanks of water or use high-volume pumps. Several kinds of flush tanks are used (fig. 10–6). One known as a tipping tank pivots on a shaft as the water level increases. At a certain design volume, the tank tips, emptying the entire amount in a few seconds, which causes a wave that runs the length of the alley.

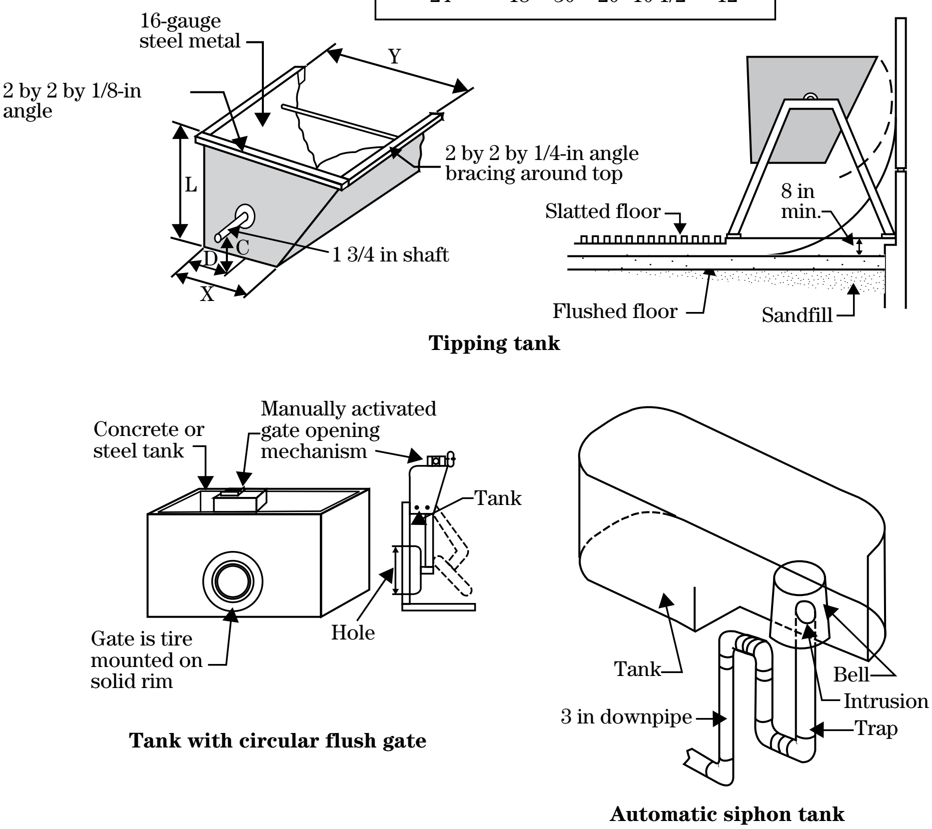
Some flush tanks have manually opened gates. These tanks are emptied by opening a valve, standpipe, pipe plug, or flush gate. Float switches can be used to control flushing devices.

Another kind of flush tank uses the principle of a siphon. In this tank, the water level increases to a given point where the head pressure of the liquid overcomes the pressure of the air trapped in the siphon mechanism. At this point the tank rapidly empties, causing the desired flushing effect.

Most flush systems use pumps to recharge the flush tanks or to supply the necessary flow if the pump flush technique is used. Centrifugal pumps typically are used. The pumps should be designed for the work that they will be doing. Low volume pumps (10–150 gal/min) may be used for flush tanks, but high volume pumps (200 to 1,000 gal/min) are needed for alley flushing. Pumps should be the proper size to produce the desired flow rate. Flush systems may rely on recycled lagoon water for the flushing liquid.

Figure 10–6 Flush tanks

Gal/ft of tank length	Tank dimensions in X	Y	L	C	D
40	18	36	30	15 1/2	14 1/2
30	18	33	24	12 1/2	13
24	18	30	20	10 1/2	12



In some parts of the country where effluent is recycled from lagoons for flushwater, salt crystals (struvite) may form inside pipes and pumps and cause decreased flow. Use of plastic pipe, fittings, and pumps that have plastic impellers can reduce the frequency between cleaning or replacing pipes and pumps. If struvite formation is anticipated, recycle systems should be designed for periodic clean out of pumps and pipe. A mild acid, such as dilute hydrochloric acid (1 part 20 mole hydrochloric acid to 12 parts water), can be used. A separate pipe may be needed to accomplish acid recycling. The acid solution should be circulated throughout the pumping system until normal flow rates are restored. The acid solution should then be removed. Caution should be exercised when disposing of the spent acid solution to prevent ground or surface water pollution.

(b) Gutters

Gutters are narrow trenches used to collect manure and bedding. They are often employed in confined stall or stanchion dairy barns and in some swine facilities.

(1) Gravity drain gutters

Deep, narrow gutters can be used in swine finishing buildings (fig. 10–7). These gutters are at the lowest elevation of the pen. The animal traffic moves the waste to the gutter. The gutter fills and is periodically emptied. Gutters that have Y, U, V, or rectangular cross-sectional shapes are used in farrowing and nursery swine facilities. These gutters can be gravity drained periodically.

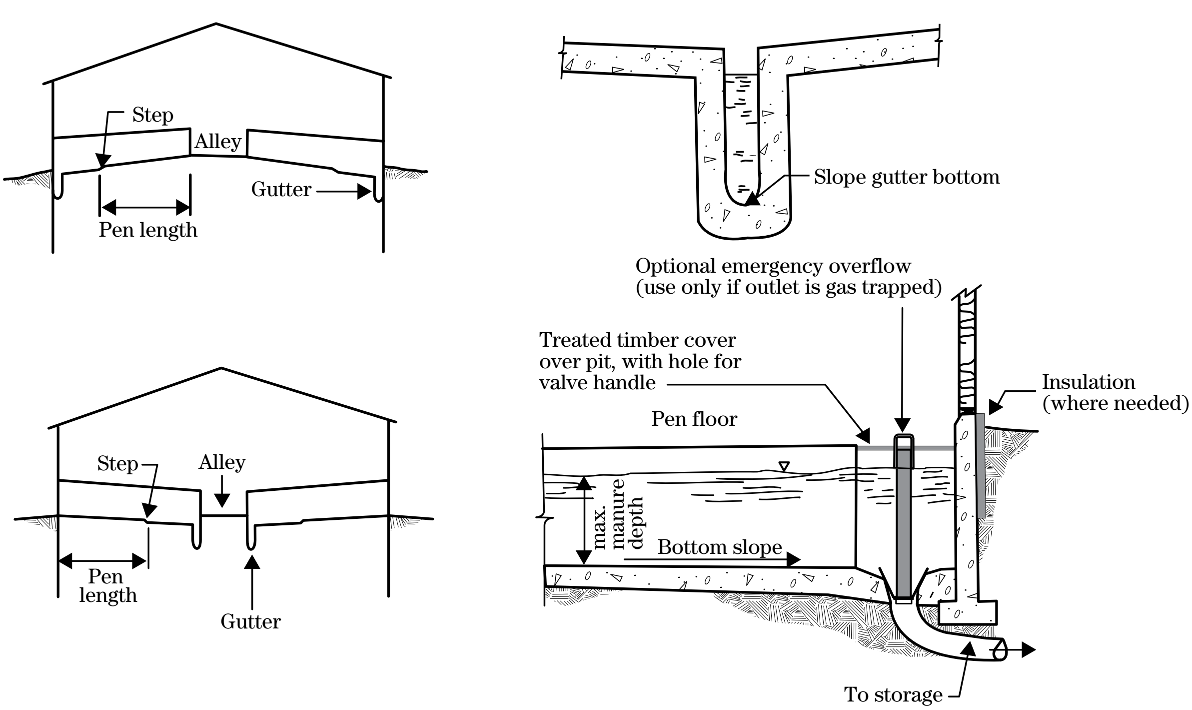
(2) Step-dam gutters

Step-dam gutters, also known as gravity gutters or gravity flow channels provide a simple alternative for collecting dairy manure (fig. 10–8). A 6-inch-high dam holds back a lubricating layer of manure in a level, flat-bottomed channel. Manure drops through a floor grate or slats and flows down the gutter under its own weight. The gutter is about 30 inches wide and steps down to a deeper cross channel below the dam.

(3) Scrape gutters

Scrape gutters are frequently used in confined stall dairy barns. The gutters are 16 to 24 inches wide, 12 to 16 inches deep, and generally do not have any bottom

Figure 10–7 Flush and gravity flow gutters for swine manure



slope. They are cleaned using either shuttle-stroke or chain and flight gutter cleaners (figs. 10–9 and 10–10). Electric motor driven shuttle stroke gutter cleaners have paddles that pivot on a drive rod. The drive rod travels alternately forward for a short distance and then backwards for the same distance. The paddles are designed to move manure forward on the forward stroke and to collapse on the drive rod on the return stroke. This action forces the manure down the gutter. Shuttle stroke gutter cleaners can only be used on straight gutters.

Chain and flight scrapers are powered by electric motors and are used in continuous loops to service one or more rows of stalls.

(4) Flush gutters

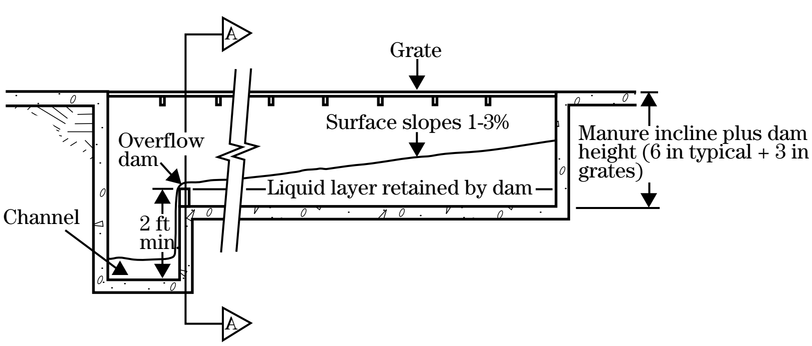
Narrow gutters can also be cleaned by flushing. Flush gutters are usually a minimum of 2 feet deep on the shallow end. The depth may be constant or increase as the length of the gutter increases. The bottom grade can vary from 0 to 5 percent depending on storage requirements and clean out technique. Flushing tanks or high volume pumps may be used to clean flush gutters (refer to the section on flush alternatives for alleys).

(c) Slatted floors

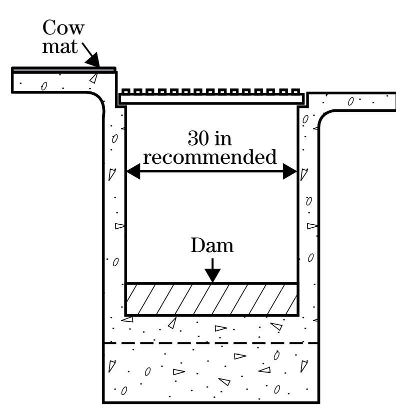
Manure and bedding are worked through the slats by the animal traffic into a storage tank or alley below. Most slats are constructed of reinforced concrete (fig. 10–11); however, some are made of wood, plastic, or aluminum. They are manufactured either as individual units or as gangs of several slats. Common slat openings range from 3/8 to 1 3/4 inches, depending on animal type. For swine, openings between 3/8 and 3/4 inch are not recommended.

Slats are designed to support the weight of the slats plus the live loads (animals, humans, and mobile equipment) expected for the particular facility. Reinforcing steel is required in concrete slats to provide needed strength.

Figure 10–8 Gravity gutter for dairy manure



Cross section along stalls



Cross section AA

Figure 10–9 Shuttle-stroke gutter cleaner

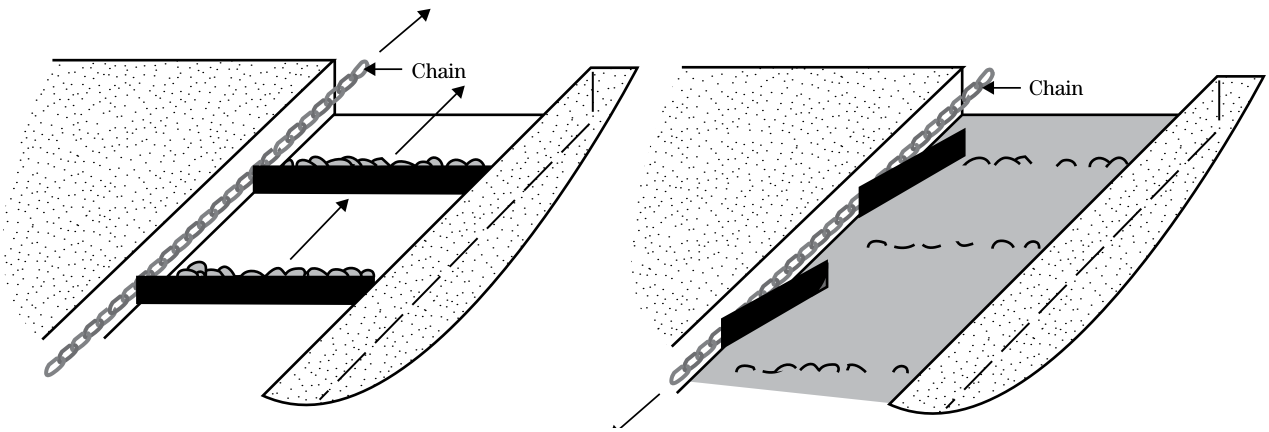


Figure 10–10 Chain and flight gutter cleaner

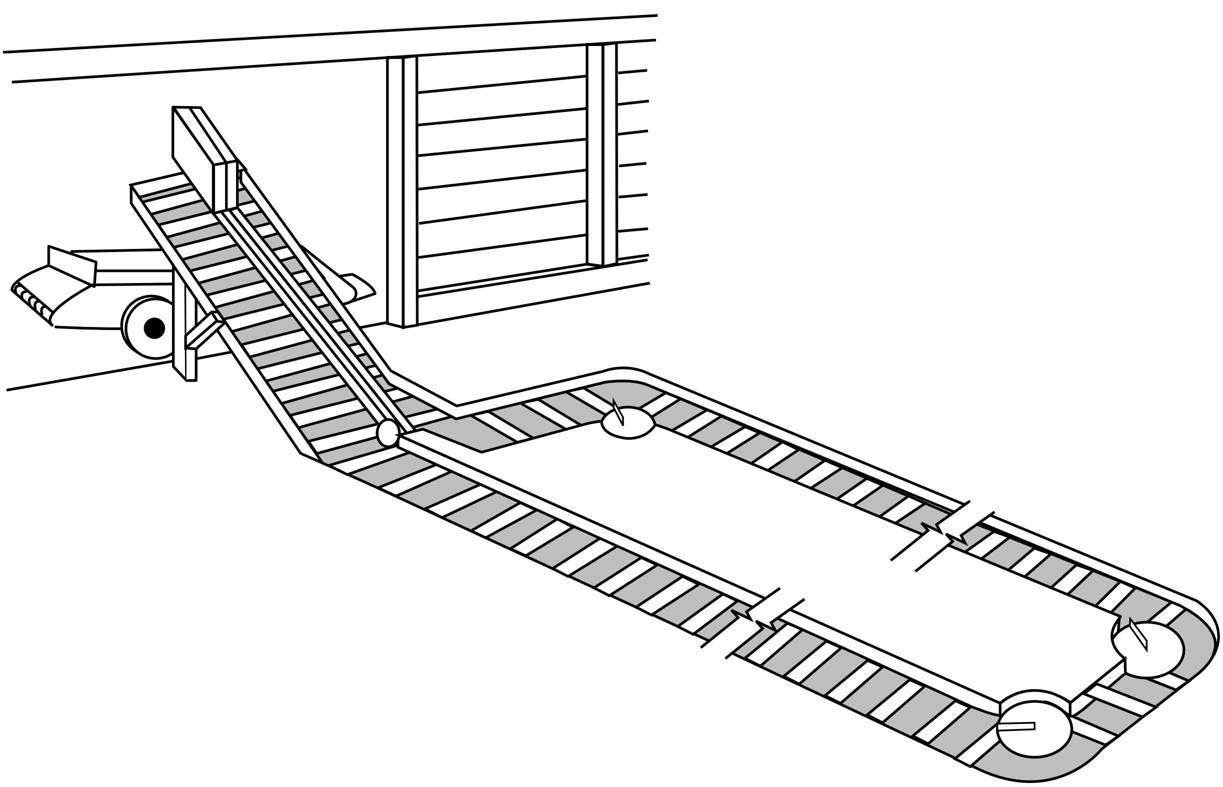
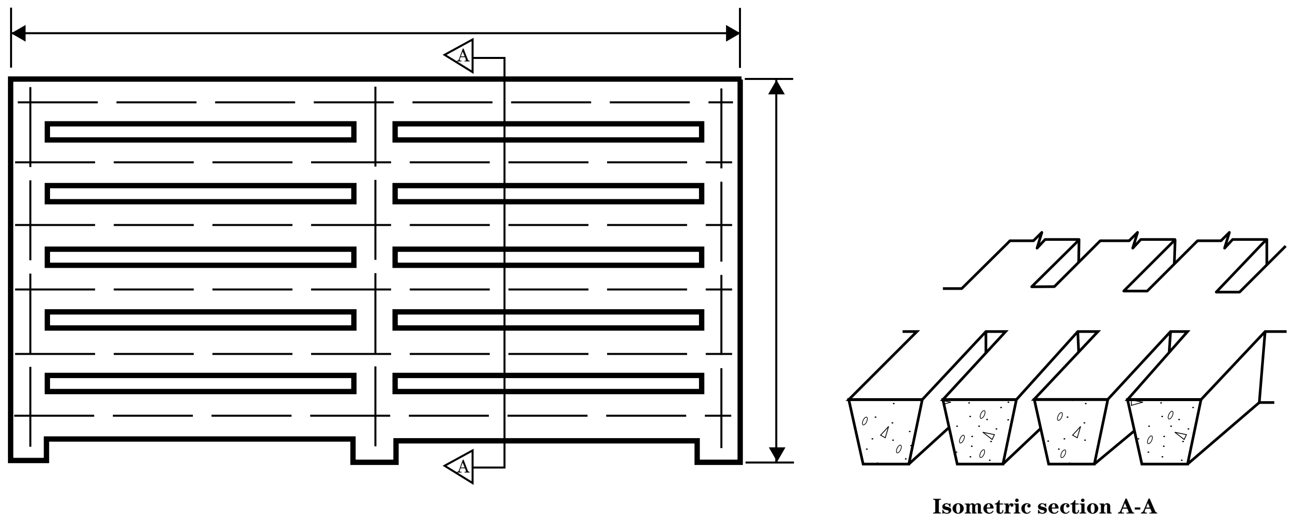


Figure 10–11 Concrete gang slats



651.1003 Transfer

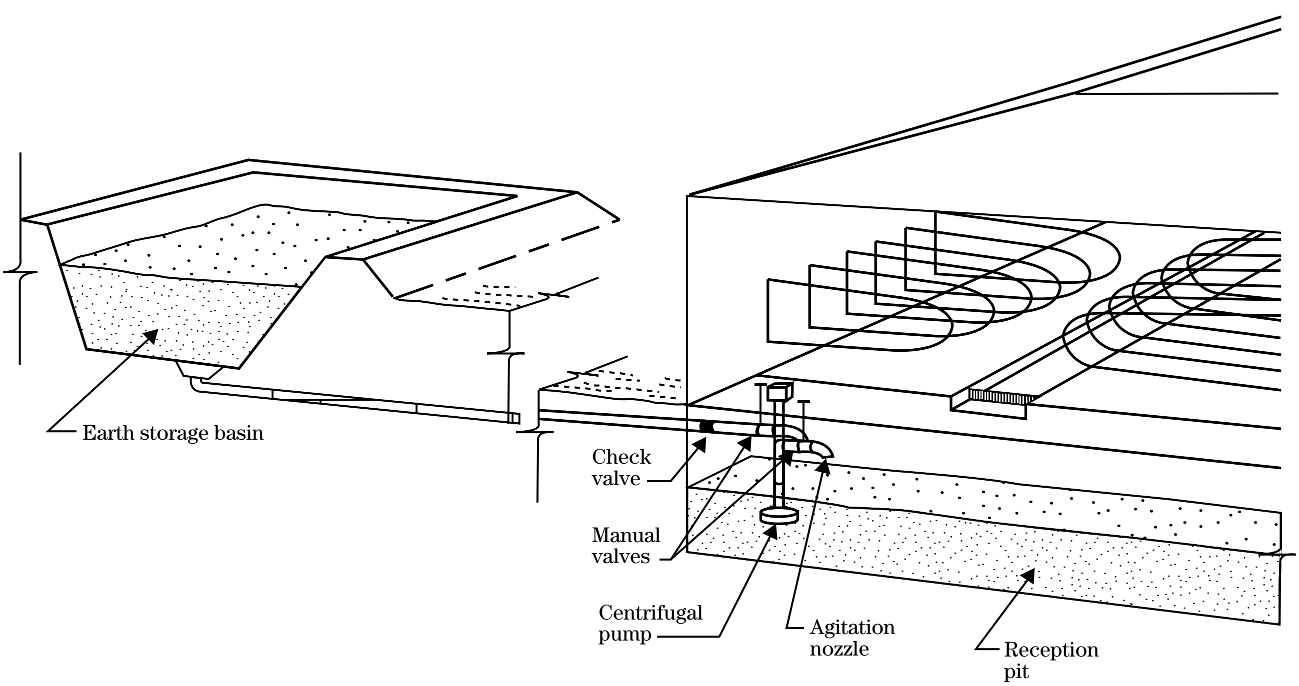
Manure collected from within a barn or confinement area must be transferred to the storage or treatment facility. In the simplest system, the transfer component is an extension of the collection method. More typically, transfer methods must be designed to overcome distance and elevation changes between the collection and storage facilities. In some cases, gravity can be used to move the manure. In many cases, however, mechanical equipment is needed to move the manure. Transfer also involves movement of the material from storage or treatment to the point of utilization. This may involve pumps, pipelines, and tank wagons. Transfer systems should be planned and designed in accordance with NRCS Conservation Practice Standard 634, Waste Transfer.

(a) Reception pits

Slurry and liquid manure collected by scraping, gravity flow, or flushing are often accumulated in a reception pit (fig. 10–12). Feedlot runoff can also be accumulated. These pits can be sized to hold all the manure produced for several days to improve pump efficiency or to add flexibility in management. Additional capacity might be needed for extra liquids, such as milk parlor water or runoff from precipitation. For example, if the daily production of manure and parlor cleanup water for a dairy is estimated at 2,500 gallons and 7 days of storage is desired, then a reception pit that has a capacity of 17,500 gallons (2,500 gal/d × 7 d) is the minimum required. Additional volume should be allowed for freeboard emergency storage.

Reception pits are rectangular or circular and are often constructed of cast-in-place reinforced concrete or reinforced concrete block. Reinforcing steel must be added so that the walls withstand internal and external loads.

Figure 10–12 Reception pit for dairy freestall barn



Manure can be removed with pumps or by gravity. Centrifugal pumps can be used for agitating and mixing before transferring the material. Both submersible pumps and vertical shaft pumps that have the motor located above the manure can be used. Diluted manure can be pumped using submersible pumps, often operated with float switches. The entrance to reception pits should be restricted by guard rails or covers.

Debris, such as pieces of metal and wood and rocks, must sometimes be removed from the bottom of a reception pit. Most debris must be removed manually, but if possible, this should be done remotely from outside the pit. The pit should be well ventilated before entering. If manure is in the pit, a self-contained breathing apparatus must be used. Short baffles spaced around the pump intake can effectively guard against debris clogging the pump.

In cold climates, reception pits need to be protected from freezing. This can be accomplished by covering or enclosing it in a building. Adequate ventilation must be provided in all installations. In some installations, hoppers and either piston pumps or compressed air pumps are used instead of reception pits and centrifugal pumps. These systems are used with semisolid manure that does not flow readily or cannot be handled using centrifugal pumps.

(b) Gravity flow pipes

Liquid and slurry manure can be moved by gravity if sufficient elevation differences are available or can be established. For slurry manure, a minimum of 2 feet of elevation head should exist between the top of the collection pit or hopper and the surface of the material in storage when storage is at maximum design depth.

Gravity flow slurry manure systems typically use 18- to 36-inch-diameter pipe. In some parts of the country, 4- to 8-inch-diameter pipe is used for the gravity transport of low (<3%) total solid (TS) concentration waste. The planner/designer should exercise caution when specifying the 4- to 8-inch pipe. Smooth steel, plastic, concrete, and corrugated metal pipe are used. Metal pipes should be coated with asphalt or plastic to retard corrosion, depending upon the type of metal. All joints must be sealed so that the pipe is water tight.

Gravity flow pipes should be designed to minimize changes in grade or direction over the entire length. Pipe slopes that range from 4 to 15 percent will work satisfactorily, but 7 to 8 percent slope is preferable. Excessive slopes allow separation of liquids and solids and increase the chance of plugging. The type and quantity of bedding and the amount of milkhouse waste and wash water added have an effect on the flow characteristics and the slope needed in a particular situation. Straw bedding should be discouraged, especially if it is not chopped. Smooth, rounded transition from reception pit to pipe and the inclusion of an air vent in the pipeline aid the flow and prevent plugging.

Figure 10–13 illustrates the use of gravity flow for manure transfer. At least two valves should be located in an unloading pipe. Proper construction and operation of gravity unloading waste storage structures are extremely important. Containment berms should be considered if the contamination risk is high downslope of the unloading facility.

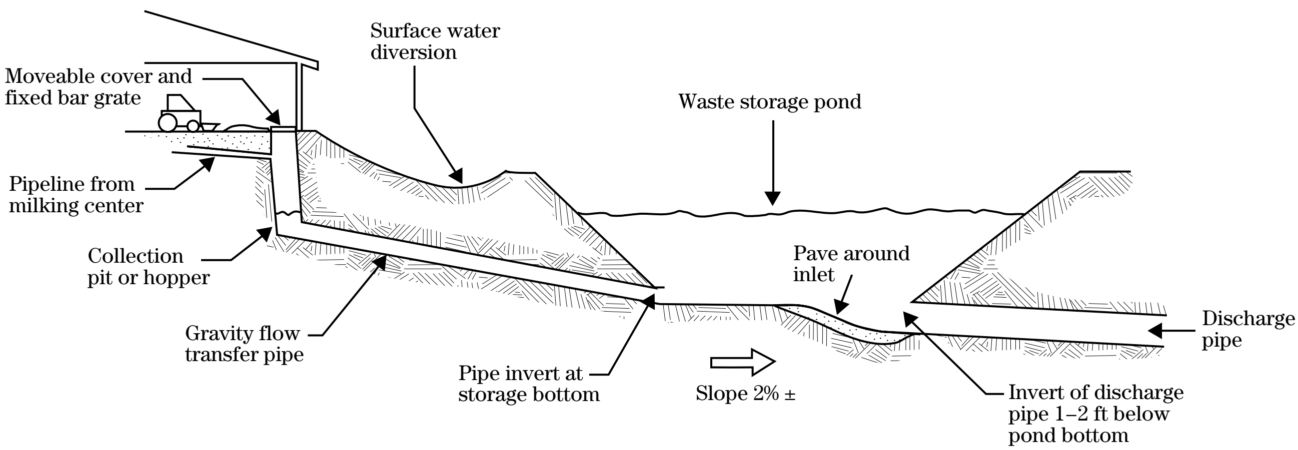
(c) Push-off ramps

Manure that is scraped from open lots can be loaded into manure spreaders or storage and treatment facilities using push-off ramps (fig. 10–14) or docks. A ramp is a paved structure leading to a manure storage facility. It can be level or inclined and usually includes a retaining wall. A dock is a level ramp that projects into the storage or treatment facility. Runoff should be directed away from ramps and docks unless it is needed for waste dilution. Ramp slopes should not exceed 5 percent. Push-off ramps and docks should have restraints at each end to prevent the scraping tractors from accidentally going off the end.

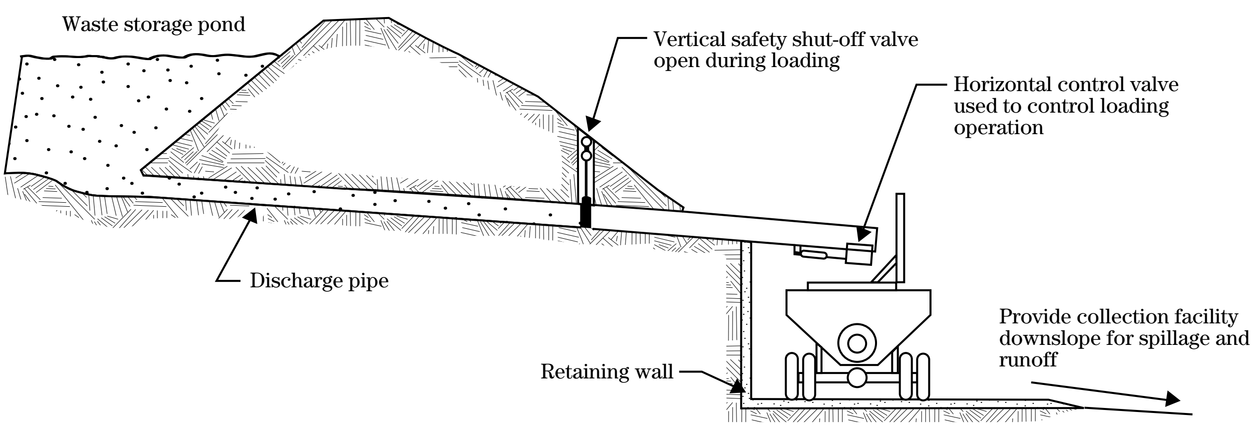
(d) Pumps

Most liquid manure handling systems require one or more pumps to either transport or agitate manure. Pumps are in two broad classifications—displacement and centrifugal. The displacement group includes piston, air pressure transfer, diaphragm, and progressive cavity pumps. The first two are used only for transferring manure; however, diaphragm and progressive cavity pumps can be used for transferring, agitating, and irrigating manure.

Figure 10–13 Examples of gravity flow transfer



Gravity flow transfer



Gravity flow from storage

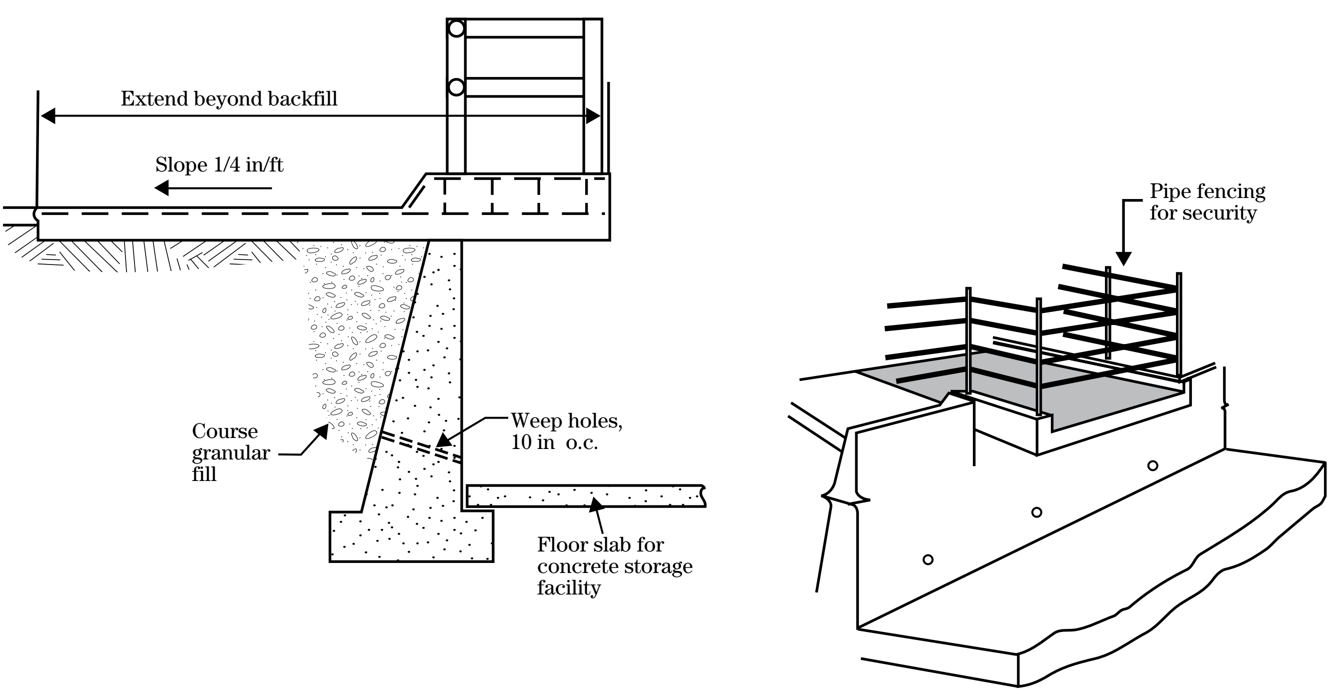
The centrifugal group includes vertical shaft, horizontal shaft, and submersible pumps. They can be used for agitation and transfer of liquid manure; however, only vertical and horizontal shaft pumps are used for irrigation because of the head that they can develop.

Pump selection is based on the consistency of the material to be handled, the total head to be overcome, and the desired capacity (pumping rate). Pump manufacturers and suppliers can provide rating curves for a variety of pumps.

(e) Equipment

Other equipment used in the transfer of agricultural by-product includes a variety of pumps including chopper/agitator, centrifugal, ram, and screw types. Elevators, pipelines, and hauling equipment are also used. See Agricultural Waste Management Field Handbook (AWMFH), 651.12 for information about specific equipment.

Figure 10–14 Push-off ramp



651.1004 Storage

Manure generally must be stored so that it can be used when conditions are appropriate. Storage facilities for manure of all consistencies must be designed to meet the requirements of a given enterprise.

Determining the storage period for a storage facility is crucial to the proper management of a manure management system. If too short a period is selected, the facility may fill before the material can be used in an environmentally sound manner. Too long a period may result in an unjustified expenditure for the facility and loss of nutrient value.

Many factors are involved in determining the storage period. They include the weather, crop, growing season, equipment availability, soil, soil condition, labor requirements, and management flexibility. Generally, when nutrient utilization is by land application, a storage facility must be sized so that it can store the manure during the nongrowing season. A storage facility that has a longer storage period generally will allow more flexibility in managing the manure to accommodate weather variability, equipment availability, equipment breakdown, and overall operation management. Storage facilities should be planned and designed in accordance with NRCS Conservation Practice Standard 313, Waste Storage Facility.

(a) Manure storage facilities for solids

Storage facilities for solid manure include storage ponds and storage structures. Storage ponds are earthen impoundments used to retain manure, bedding, and runoff liquid. Solid and semisolid manure placed into a storage pond will most likely have to be removed as a liquid unless precipitation is low or a means of draining the liquid is available. The pond bottom and entrance ramps should be paved if emptying equipment will enter the pond.

(1) Stacking facilities

Storage structures can be used for manure that will stack and can be handled by solid manure handling equipment. These structures must be accessible for loading and hauling equipment. They can be open or covered. Roofed structures are used to prevent or reduce excess moisture content. Open stacks can be used in either arid or humid climate. Seepage and runoff from dry stack facilities must be managed. Structures for open and covered stacks often have wooden, reinforced concrete or concrete block sidewalls.

Some operations store the manure at the point of generation. Examples of dairy facilities include dry packs and hoop buildings. The amount of bedding material often dictates whether or not the manure can be handled as a solid. Poultry operations often store and compost the litter in-place between flocks. Only part of the cake may be removed before the next flock is introduced to the building.

In some instances, manure must be stored in open stacks in fields or within a feedlot. Runoff and seepage from these stacks must be managed to prevent movement into streams or other surface or ground water. Figures 10–15 and 10–16 show various solid manure storage facilities.

Design considerations—Storage facilities for solid manure must be designed correctly to ensure desired performance and safety. Considerations include materials selection, control of runoff and seepage, necessary storage capacity, and proper design of structural components such as sidewalls, floors, and roofs.

The primary materials used in constructing timber structures for solids storage are pressure-treated or rot-resistant wood and reinforced concrete. These materials are suitable for long-term exposure to manure without rapid deterioration. Structural grade steel is also used, but it corrodes and must be protected against corrosion or be periodically replaced. Similarly, high quality and protected metal fasteners must be used with timber structures to reduce corrosion problems.

Seepage and runoff, which frequently occur from manure stacks, must be controlled to prevent access into surface and ground water. One method of control is to channel any seepage into a storage pond. At the same time uncontaminated runoff, such as that from the roof and outside the animal housing and lot area, should be diverted around the site.

Concrete ramps are used to gain access to solid manure storage areas. Ramps and floors of solid manure storage structures need to be designed so that handling equipment can be safely operated. Ramp slopes of 8 to 1 (horizontal to vertical) or flatter are considered safe. Slopes steeper than this are difficult to negotiate. Concrete pavement for ramps and storage units should be rough finished to aid in traction. Ramps need to be wide enough that equipment can be safely backed and maneuvered.

Factors to consider in the design of storage facilities for solids include type, number and size of animals, number of days storage desired, and the amount of bedding that will be added to the manure. Equation 10–1 can be used to calculate the manure storage volume:

$$\text{VMD} = \text{AU} \times \text{DVM} \times \text{D} \qquad \text{(eq. 10–1)}$$

where:

VMD = volume of manure production for animal type for storage period, ft^3

AU = number of 1,000-pound animal units (AU) by animal type

DVM = daily volume of manure production for animal type, ft^3/AU/d

D = number of days in storage period

The bedding volume to be stored can be computed using:

$$\text{BV} = \frac{\text{FR} \times \text{WB} \times \text{AU} \times \text{D}}{\text{BUW}} \qquad \text{(eq. 10–2)}$$

where:

FR = volumetric void ratio (ASAE 1982) (values range from 0.3 to 0.5)

WB = weight of bedding used for animal type, lb/AU/d

BUW = bedding unit weight, lb/ft^3

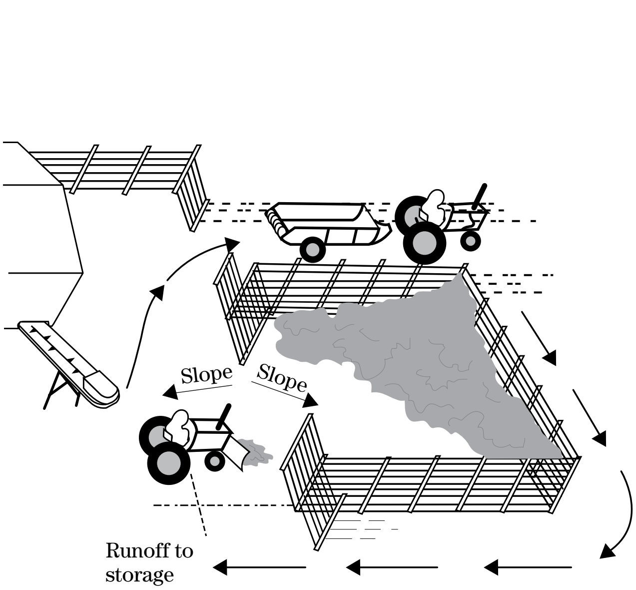
Using the recommended volumetric void ratio of 0.5, the equation becomes:

$$\text{BV} = \frac{0.5 \times \text{WB} \times \text{AU} \times \text{D}}{\text{BUW}}$$

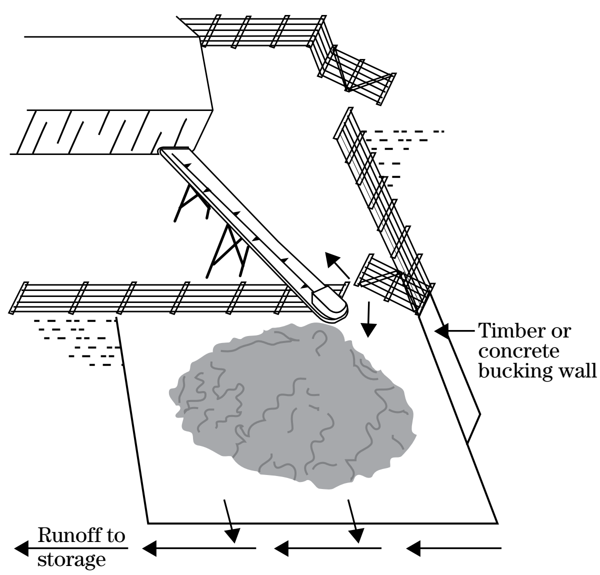
Characteristics of manure and bedding are described in AWMFH, chapter 4. Other values may be available locally or from the farmer or rancher.

Allowance must be made for the accumulation of precipitation that may fall directly into the storage. Contaminated runoff should be handled separately from a solid manure storage facility. Uncontaminated runoff should be diverted from the storage unit.

Figure 10–15 Solid manure stacking facilities

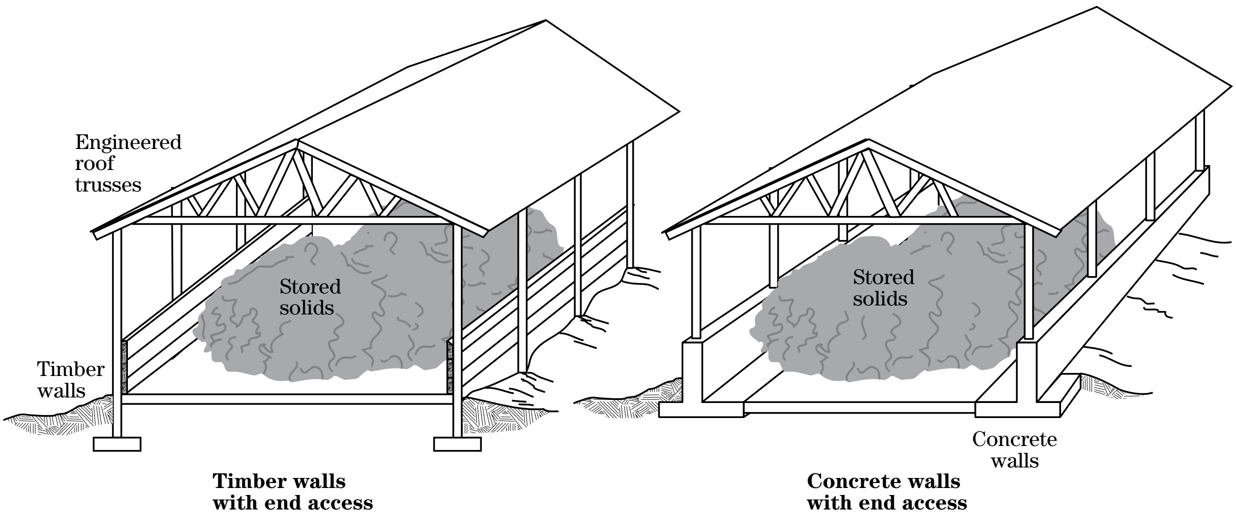


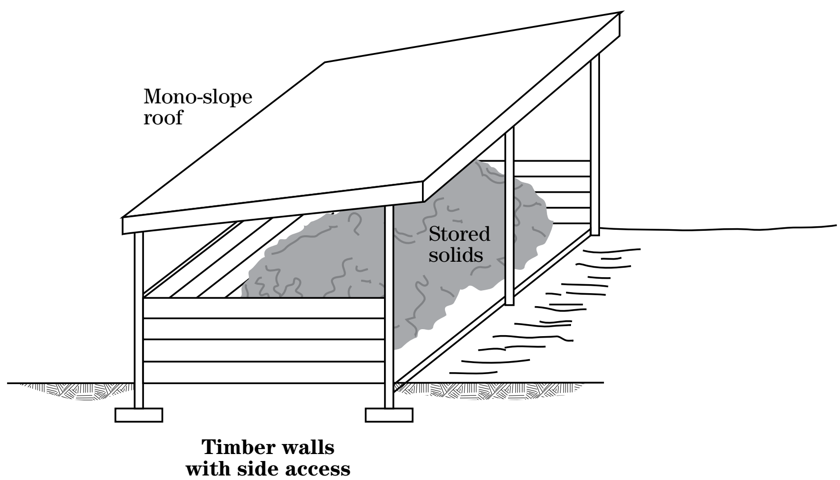
Barn cleaner to spreader or tractor stacking



To storage and/or spreader from elevator stacker

Figure 10–16 Roofed solid manure storage





Design example 10–2 Waste stacking facility

Mr. Ralph Kilpatrick of Hoot Ridge, Kentucky, has requested assistance in developing a manure management system. He selected an alternative that includes solid manure storage for his Holstein dairy herd of 52 heifers and 100 milking cows with an average milk production of 75 pounds per day. His nutrient management plan indicates the need for 90 days storage. He uses sawdust bedding for both the milking cows and the heifers. Because of space limitations, the storage can be no wider than 50 feet. He would prefer that the facility be stacked no more than 7 feet high. The structure will not be roofed, so stacking above sidewalls will not be considered in design. Determine the necessary volume and facility dimensions using worksheet 10A–1.

Manure production—the animal descriptions, average weight, and numbers are entered on lines 1 and 2. The number of equivalent animal unit (AU) for each animal type is calculated and entered on line 4. Daily manure production (line 4) is in table 4–5(b) of AWMFH, chapter 4. The number of days in storage is entered on line 6. The manure volume (line 7) is calculated using equation 10–1. Add the calculated manure volume for each animal type (VMD), and enter the sum (TVM) on line 8.

Wastewater volume—because this design example involves a waste stacking facility, it would not be appropriate to include wastewater in the storage facility. Therefore, lines 9, 10, and 11 are not involved in estimating the waste volume for this example.

Bedding volume—the weight of bedding used daily per animal unit for each animal type found in table 4–4 is entered on line 12. The bedding unit weight, which may be taken from table 4–3 in AWMFH, chapter 4, is entered on line 13. The bedding volume for each animal type for the storage period is calculated using equation 10–2 and entered on line 14. The total bedding volume (TBV) is the sum of the bedding volume for all animal types. Sum the calculated bedding volume (BV) for each animal type and enter it on line 15.

Waste volume—the total waste volume (WV) (line 16) is the sum of the total manure production (TVM) and the total bedding volume (TBV). The storage width (WI) and height (H) can be adjusted for site conditions and common building procedures (usually dimensions divisible by 4 or 8), so the length (line 17) is calculated by trial and error using the equation:

$$L = \frac{WV}{WI \times H}$$

A waste storage structure for solids should be designed to withstand all anticipated loads. Loadings include internal and external loads, hydrostatic uplift pressure, concentrated surface and impact loads, water pressure because of the seasonal high water table, and frost or ice pressure.

The lateral earth pressure should be calculated from soil strength values determined from results of appropriate soil tests. If soil strength tests are not available, the minimum lateral earth pressure values indicated in the NRCS Conservation Practice Standard 313, Waste Storage Facility, are to be used.

Timber sidewalls for storage structures should be designed with the load on the post based on full wall height and spacing of posts.

Worksheet 10A-1—Waste storage structure capacity design

Decisionmaker: Ralph Kilpatrick | Date: 6/13/91

Site: Hoot Ridge, KY

Animal units

1. Animal type: Milkers | Heifer
2. Animal weight, lbs (W): 1,400 | 1,000
3. Number of animals (N): 100 | 52
4. Animal units, $AU = \frac{W \times N}{1000}$ = 140 | 52

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM) = 1.7 | 0.9
6. Storage period, days (D) = 90
7. Total volume of manure production for animal type for storage period, ft^3 VMD = AU x DVM x D = 21,420 | 4,212
8. Total manure production for storage period, ft^3 (TVM) = 25,632

Wastewater volume

9. Daily wastewater volume per AU, ft^3/AU/day (DWW) =
10. Total wastewater volume for animal description for storage period, ft^3 WWD = DWW x AU x D =
11. Total wastewater volume for storage period, ft^3 (TWW) = 0

Bedding volume

12. Amount of bedding used daily for animal type, lbs/AU/day (WB) = 3.1 | 3.1
13. Bedding unit weight, lbs/ft^3 (BUW) = 12
14. Bedding volume for animal type for storage period, ft^3 (BV) = 1,628 | 604

$$BV = \frac{0.5 \times WB \times AU \times D}{BUW}$$

15. Total bedding volume for storage period, ft^3 (TBV) = 2,232

Waste volume requirement

16. Waste volume, ft^3 (WV) = TVM + TWW + TBV = 25,632 + 0 + 2,232 = 27,864

Waste stacking structure sizing

17. Structure length, ft $L = \frac{WV}{WI \times H}$ = 79.6 (USE 84)
18. Structure width, ft $WI = \frac{WV}{L \times H}$ = 47.4 (USE 48)
19. Structure height, ft $H = \frac{WV}{L \times WI}$ = 7

Notes for waste stacking structure:

1. The volume determined (WV) does not include any volume for freeboard. It is recommended that a minimum of 1 foot of freeboard be provided for a waste stacking structure.
2. The equations for L, WI, and H assume manure is stacked to average height equal to the sidewall height. Available storage volume must be adjusted to account for these types of variations.

Tank sizing

20. Effective depth, ft. (EH)

Total height (or depth) of tank desired, ft (H)

Less precipitation for storage period, ft. –
(uncovered tanks only)

Less depth allowance for accumulated solids, ft –
(0.5 ft. minimum)

Less depth for freeboard (0.5 ft. recommended), ft –

Effective depth, ft (EH) =

21. Surface area required, ft^2 $SA = \frac{WV}{EH}$ =

22. Rectangular tank dimensions

Total height, ft (H) = Selected width, ft (WI)=

Length, ft $L = \frac{SA}{WI}$ =

23. Circular tank dimensions

Total height, ft H =

Diameter, ft $DIA = (1.273 \times SA)^{0.5}$ =

Notes for waste storage tank structure:

1. Final dimensions may be rounded up to whole numbers or to use increments on standard drawings.
2. Trial and error may be required to establish appropriate dimensions.

(2) Picket dams

Scraped manure that has considerable bedding added can be stored as a solid or semisolid in a picket dam (also know as a picket fence) structure. However, precipitation can accumulate in the storage area if the manure is stored uncovered. The picket dam can also be used to drain runoff from the storage area while retaining the solid manure and bedding within the storage area. Any water drained should be channeled to a storage pond. The amount of water that drains from the manure depends on the amount of precipitation and the amount of bedding in the manure. Water will not drain from manure once the manure and water are thoroughly mixed. Picket dams will not dewater liquid manure; bedding is essential to create void spaces for drainage within the manure.

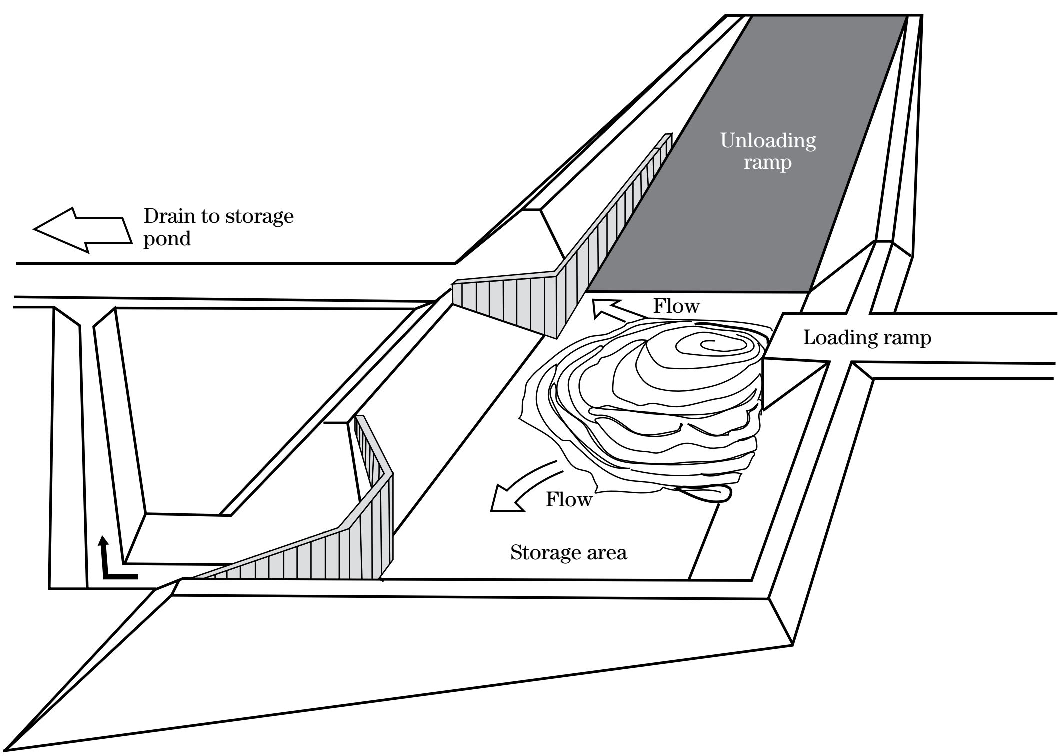
The picket dam should be near the unloading ramp to collect runoff and keep the access as dry as possible. It should also be on the side of the storage area opposite the loading ramp. Water should always have a clear drainage path from the face (leading edge) of the manure pile to the picket dam.

The floor of the storage area using a picket dam should have slope of no more than 2 percent toward the dam. Picket dams should be made of pressure-treated timbers that have corrosion-resistant fasteners. The openings in the dam should be about 0.75-inch-wide vertical slots. Figure 10–17 shows different aspects of picket dam design.

(3) Weeping walls

Flushed manure that contains significant amounts of bedding and sand can also be stored as a solid or semisolid in a weeping wall structure. A long, narrow structure with one long, perforated wall allows sand to settle at the inlet end while solids tend to settle toward the opposite end. The perforated wall (15–30% openings) allows the liquids to drain into a channel and be transferred for storage. Typically, these structures have concrete bottoms and access ramps or removable walls for solids removal. Gravity dewaters the manure and differential settling removes 60 to 70 percent of the sand. However, plugged perforations can be a significant operation and maintenance challenge.

Figure 10–17 Solid manure storage with picket dam



(b) Liquid and slurry manure storage

Liquid and slurry manure can be stored in storage ponds or in aboveground or belowground tanks. Solids separation of manure and bedding is a problem that must be considered in planning and design. Solids generally can be resuspended with agitation before unloading, but this involves a cost in time, labor, and energy. Another option allows solids to accumulate if the bottom is occasionally cleaned. This requires a paved working surface for equipment.

Earthen storage is frequently the least expensive type of storage; however, certain restrictions, such as limited space availability, high precipitation, water table, permeable soils, or shallow bedrock, can limit the types of storage considered. Table 10–4 provides guidance on siting, investigation, and design considerations. Storage ponds are earthen basins designed to store manure and runoff (figs. 10–18, 10–19, and 10–20). They generally are rectangular, but may be circular or any other shape that is practical for operation and maintenance. The inside slopes range from 1.5 to 1 (horizontal to vertical) to 3 to 1. The combined slopes (inside plus outside) should not be less than 5 to 1 for embankments. The soil, safety, and operation and maintenance need to be considered in designing the slopes. The minimum top width of embankments shall be in accordance with NRCS Conservation Practice Standard 313, Waste Stroage Facility; however, greater widths should be provided for operation of tractors, spreaders, and portable pumps.

Storage ponds should provide capacity for normal precipitation and runoff (less evaporation) during the storage period. Appendix 10C provides a method for determining runoff and evaporation volumes. A minimum of 1 foot of freeboard is provided.

Inlets to storage ponds can be of any permanent material designed to resist erosion, plugging, or, if freezing is a problem, damage by ice. Typical loading methods are pipes and ramps, which are described in AWMFH 651.1003. Flow of material away from the inlet should be considered in selecting the location of the inlet.

Gravity pipes, pumping platforms, and ramps are used to unload storage ponds. A method for removing solids should be designed for the storage pond. If the contents of the pond will be pumped, adequate access must be provided to thoroughly agitate the material. A ramp should have a slope of 8 to 1 or flatter and be wide enough to provide maneuvering room for unloading equipment.

Pond liners are used in many cases to compensate for site conditions or improve operation of the pond. Concrete, geomembrane, and clay linings reduce permeability and can make an otherwise unsuitable site acceptable. Table 10–4 provides criteria on selection between types of liners. See Appendix 10D, Geotechnical Design and Construction Guidelines for earthen liner information. Also, see Appendix 10E, Synthetic Liner Guidelines for nonearthen liner information.

Figure 10–18 Cross section of waste storage pond without a watershed

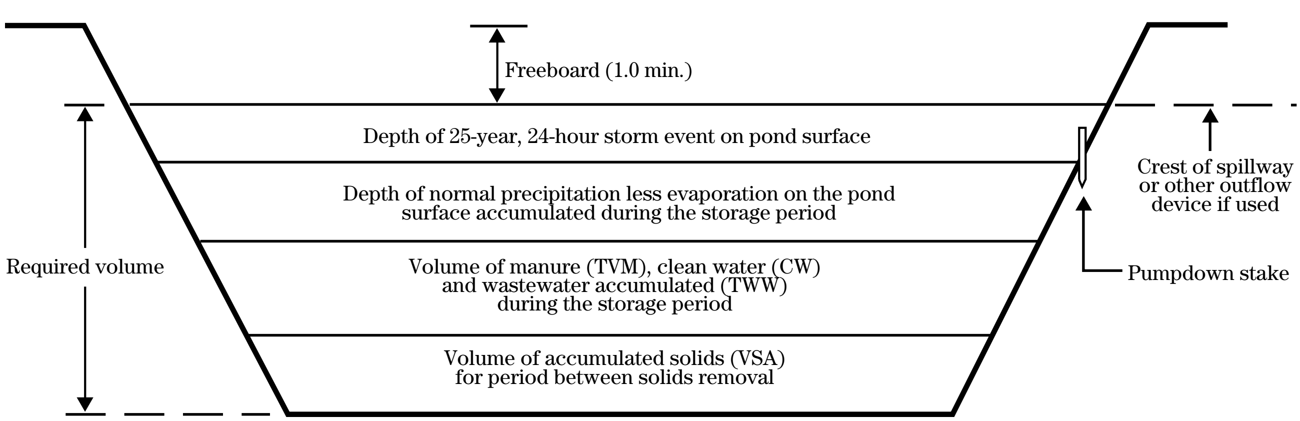
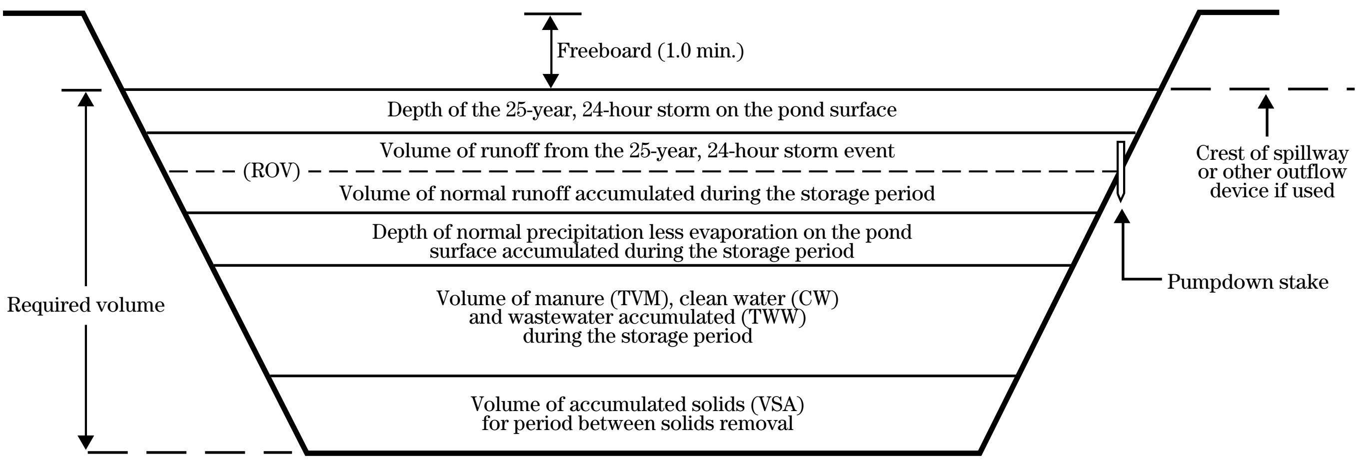
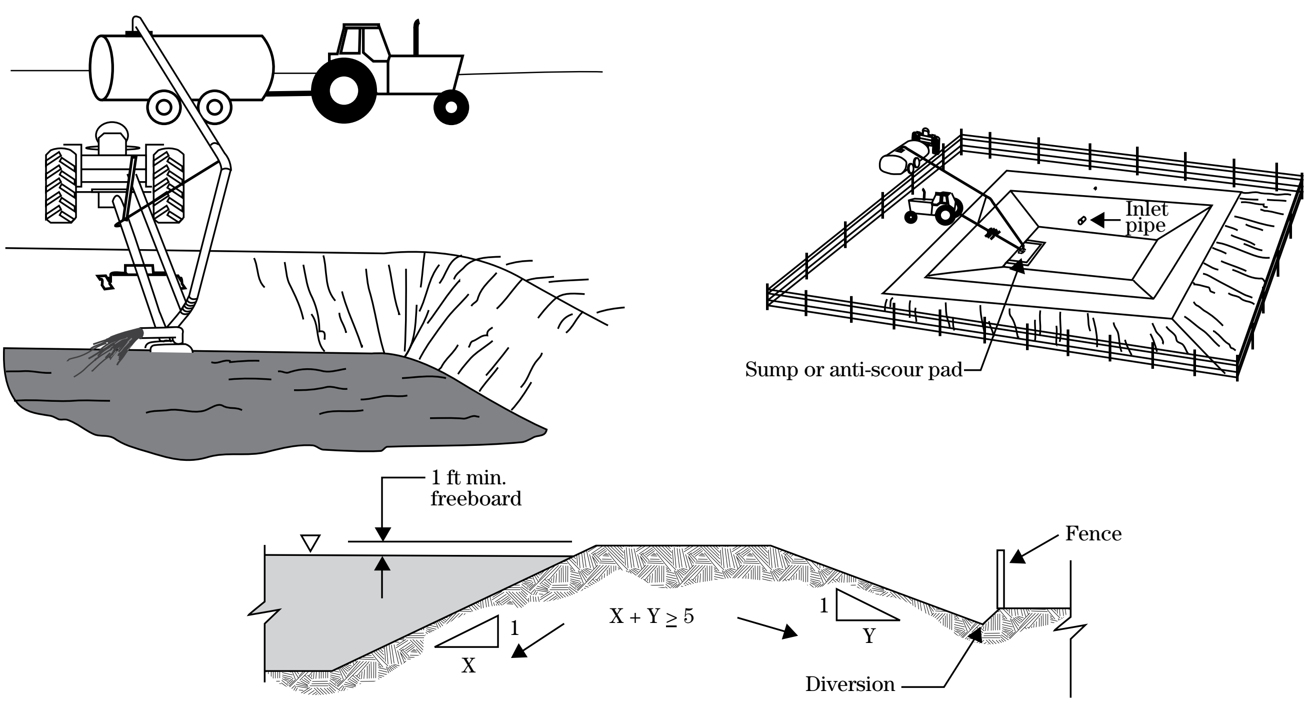


Figure 10–19 Cross section of waste storage pond with watershed



*or other outflow device

Figure 10–20 Waste storage ponds



Cross-section earth embankment

Table 10–4 Criteria for siting, investigation, and design of liquid manure storage facilities

Risk→ **Vulnerability ↓**	**Very high** <1,500 ft from public drinking water supply wells; **OR** <100 ft from any domestic well or Class 1 stream	**High** Does not meet Very High Risk criteria; **AND** Recharge areas for Sole Source aquifers; **OR** 100 to 600 ft from unconfined domestic water supply well (or where degree of aquifer confinement is unknown) or Class 1 stream	**Moderate** Does not meet High Risk criteria; **AND** 600 to 1,000 ft from unconfined domestic well (or where degree of aquifer confinement is unknown) or Class 1 stream; **OR** <600 ft from unconfined nondomestic water supply well (or where degree of aquifer confinement is unknown) or Class 2 stream	**Slight** Does not meet Moderate Risk criteria; **AND** >1,000 ft from unconfined domestic well (or where degree of aquifer confinement is unknown) or Class 1 stream; **AND** >600 ft from unconfined nondomestic water supply well (or where degree of aquifer confinement is unknown) or Class 2 stream
Very high Large voids (e.g., karst, lava tubes, mine shafts); **OR** Highest anticipated ground water elevation within 5 ft of invert; **OR** <600 ft from improperly abandoned well*	**Evaluate other storage alternatives** * (or properly seal well and reevaluate vulnerability)	**Evaluate other storage alternatives** * (or properly seal well and reevaluate vulnerability)		
High Does not meet Very High Vulnerability criteria: **AND** Bedrock (assumed fractured) within 2 ft of invert; **OR** Coarse soils/parent material (Permeability Group I soils as defined in AWMFH, always including GP, GW, SP, SW); **OR** Highest anticipated groundwater elevation is between 5 to 20 ft below invert; **OR** 600 to 1,000 ft from improperly abandoned well*		**Synthetic liner required** * (or properly seal well and reevaluate vulnerability) No additional site characterization required	**Liner required** * (or properly seal well and reevaluate vulnerability) Specific discharge $\le 1\times10^{-6}$ cm^3/cm^2/s No manure sealing credit Earthen liner design includes sampling and testing of liner material (Classification, Standard Proctor compaction, Permeability)	**Liner required** * (or properly seal well and reevaluate vulnerability). Specific Discharge $\le 1\times10^{-6}$ cm^3/cm^2/s No manure sealing credit Earthen liner design includes sampling and classification testing of liner material Published permeability data and construction method specifications may be used
Moderate Does not meet High Vulnerability criteria; **AND** Medium soils/parent material (Permeability Group II soils as defined in AWMFH, usually including CL-ML, GM, SM, ML); **OR** Flocculated or blocky clays (typically associated with high Ca); **OR** Complex stratigraphy (discontinuous layering); **OR** Highest anticipated ground water elevation is between 21 to 50 ft below invert; **OR** 600–1,000 ft from improperly abondoned well*	**Evaluate other alternatives or synthetic liner as allowed** Local regulations may apply Consult with area engineer	**Further evaluate need for liner** Specific discharge $\le 1\times10^{-6}$ cm^3/m^2/s No manure sealing credit Earthen liner/no liner design includes sampling and testing of liner/in-place material (Classification, Standard Proctor compaction/in-place density, Remolded/ Undisturbed sample Permeability)	**Further evaluate need for liner** Specific discharge $\le 1\times10^{-6}$ cm^3/cm^2/s No manure sealing credit Earthen liner/no liner design includes sampling and testing of liner/in-place material (Classification, Standard Proctor compaction/ in-place density, Remolded/Undisturbed sample Permeability)	**Further evaluate need for liner** Specific discharge $\le 1\times10^{-6}$ cm^3/cm^2/s No manure sealing credit Earthen liner/no liner design includes sampling and classification testing of liner/ in-place material + in-place density Published permeability data and construction method specifications may be used
Low Does not meet Moderate Vulnerability criteria; **AND** Fine soils/parent material (Permeability Group III and IV soils as defined in AWMFH, usually including GC, SC, MH, CL, CH); **AND** Highest anticipated ground water elevation is >50 ft below invert		**Further evaluate need for liner** Specific discharge $\le 1\times10^{-6}$ cm^3/cm^2/s No manure sealing credit Earthen liner/no liner design includes sampling and testing of liner/ in-place material (Classification, Standard Proctor compaction/ in-place density, Remolded/ Undisturbed sample Permeability) Scarify and recompact surface to seal cracks and break down soil structure as appropriate	**Liner not required** Specific discharge $\le 1 \times 10^{-6}$ cm^3/cm^2/s Field classification and published permeability data may be used Construction method specifications may be used Scarify and recompact surface to seal cracks and break down soil structure as appropriate	

*See local regulations

Concrete can be used to provide a wear surface if unloading equipment will enter the pond.

Figures 10–21, 10–22, and 10–23 represent various kinds of storage ponds and tanks.

Liquid manure can be stored in aboveground (fig. 10-22) or belowground (fig. 10–23) tanks. Liquid manure storage tanks are usually composed of concrete or glass-lined steel. Belowground tanks can be loaded using slatted floors, push-off ramps, gravity pipes or gutters, or pumps. Aboveground tanks are typically loaded by a pump moving the manure from a reception pit. Tank loading can be from the top or bottom of the tank depending on such factors as desired agitation, minimized pumping head, weather conditions, and system management.

Storage volume requirements for tanks are the same as those for ponds except that provisions are normally made to exclude outside runoff from storage tanks because of the relative high cost of storage. Of course, if plans include storage of outside runoff, accommodation for its storage must be included in the tank's volume.

Tanks located beneath slatted floors can sometimes be used for temporary storage with subsequent discharge into lagoons or other storage facilities. Recycled lagoon effluent is added to a depth of 6 to 12 inches in underslat pits to reduce tendency for manure solids to stick to the pit floor. Manure and bedding are allowed to collect for several days, typically 1 to 2 weeks, before the pits are gravity drained.

(1) Design considerations

Tank material types—the primary materials used to construct manure tanks are reinforced concrete and glass-lined steel. Such tanks must be designed by a professional engineer and constructed by experienced contractors. A variety of manufactured, modular, and cast-in-place tanks are available from commercial suppliers. NRCS concurs in the standard detail drawings for these structures based on a review and approval of the drawings and supporting design calculations. A determination must be made that the site conditions are compatible with the design assumptions on which the design is based. Structures can also be designed on an individual site-specific basis.

Figure 10–21 Layout of waste storage ponds

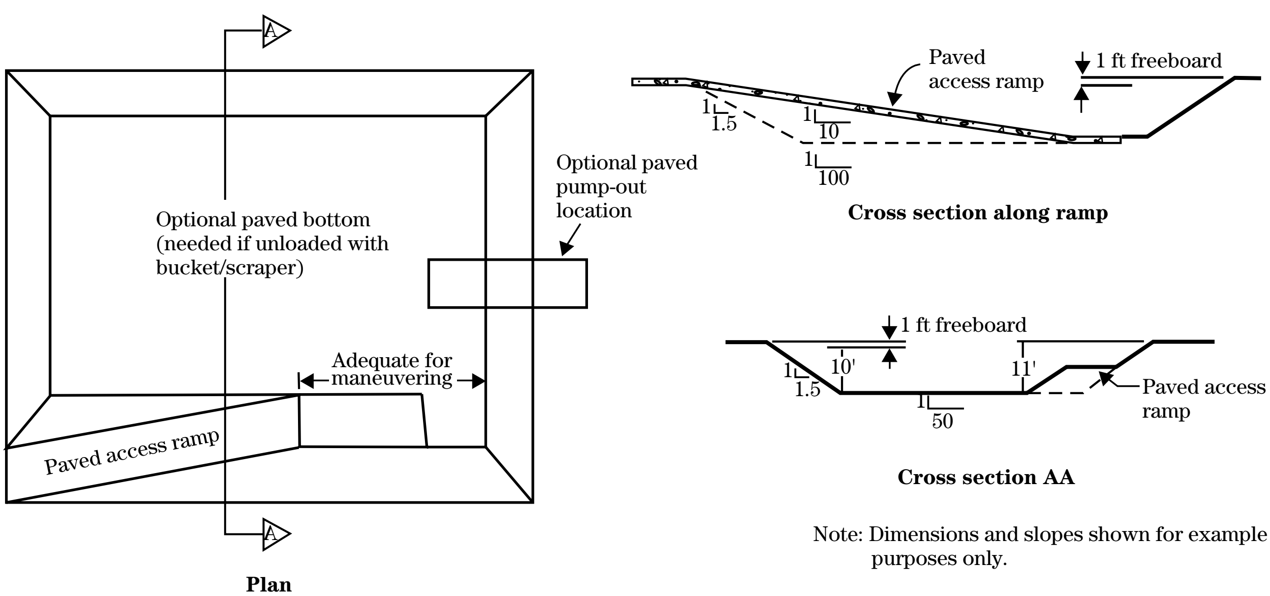


Figure 10–22 Aboveground waste storage tank

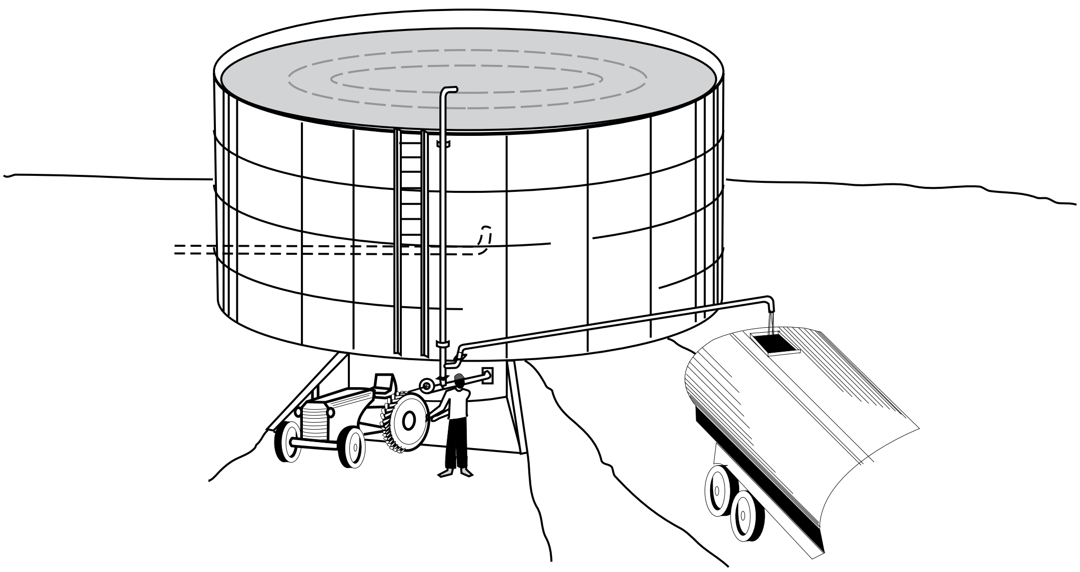
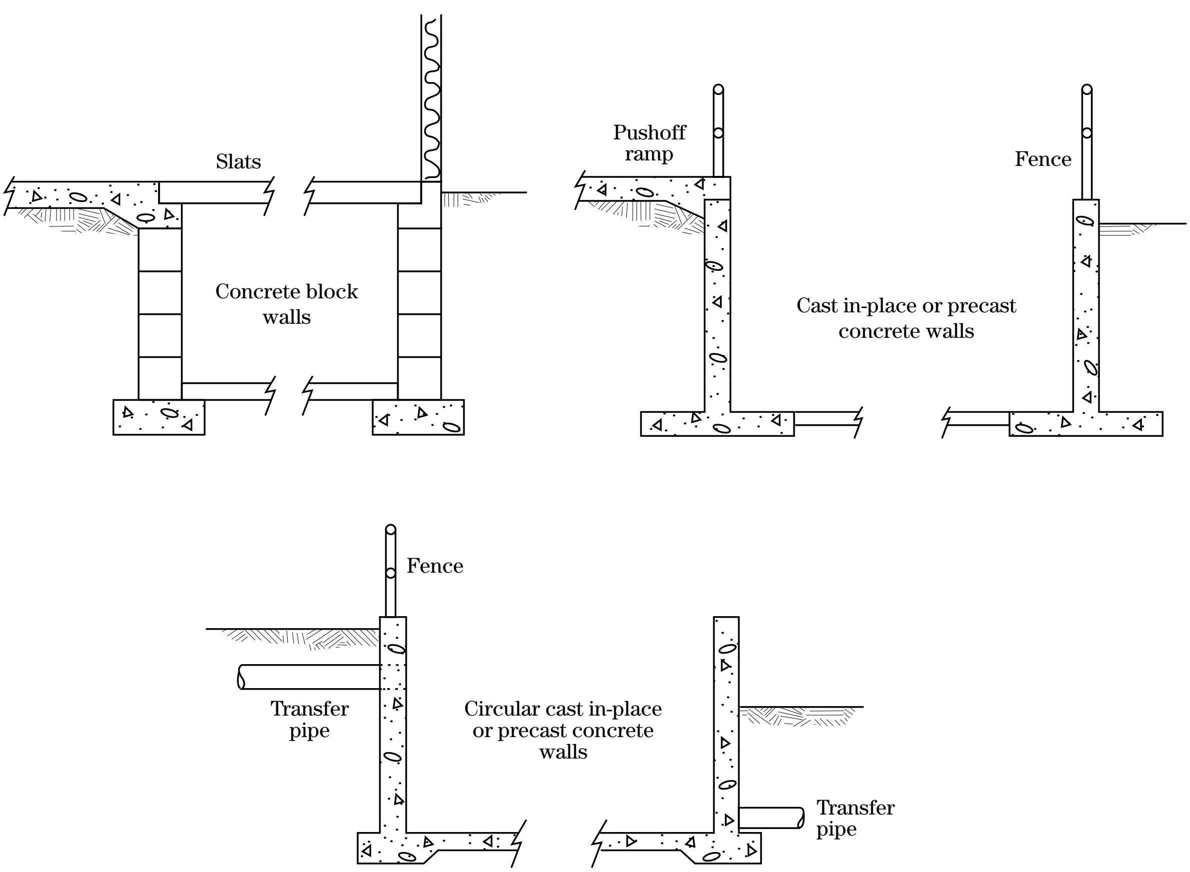


Figure 10–23 Belowground waste storage structure



Cast-in-place, reinforced concrete, the principal material used in belowground tanks, can be used in aboveground tanks, as well. Tanks can also be constructed of precast concrete panels that are bolted together. Circular tank panels are held in place with metal hoops. The panels are positioned on a concrete foundation or have footings cast as an integral part of the panel. Tank floors are cast in-place slabs.

Other aboveground tanks are constructed of metal. Glass-fused steel panels are widely used. Such tanks are manufactured commercially and must be constructed by trained crews. Other kinds of metal panels are also used.

Sizing—storage ponds and structures should be sized to hold all of the manure, bedding, washwater from the milkhouse; flushing; and contaminated runoff that can be expected during the storage period. Equation 10–3 can be used to compute the waste volume:

$$WV = TVM + TWM + TBV \qquad \text{(eq. 10–3)}$$

where:

WV = waste volume for storage period, ft^3

TVM = total volume of manure for storage period, ft^3 (see eq. 10–1)

TWW= total wastewater volume for storage period, ft^3

TBV = total bedding volume for storage period, ft^3 (see eq. 10–2)

Data on manure production are available in AWMFH, chapter 4 or from the farmer or rancher. Appendix 10C provides a method of estimating contaminated runoff volume.

In addition to the waste volume, storage tanks must, if uncovered, provide a depth to accommodate precipitation less evaporation on the storage surface during the most critical storage period. The most critical storage period is generally the consecutive months that represent the storage period that gives the greatest depth of precipitation less evaporation. Appendix 10C gives a method for estimating precipitation less evaporation. Storage tanks must also provide a depth of 0.5 feet for material not removed during emptying. A depth for freeboard of 0.5 feet is also recommended.

Storage ponds must also provide a depth to accommodate precipitation less evaporation during the most critical storage period. If the pond does not have a watershed, the depth of the 25-year, 24-hour precipitation on the pond surface must be included. Appendix 10B includes a map giving the precipitation amount for the 25-year, 24-hour precipitation. Frequently, storage ponds are designed to include outside runoff from watersheds. For these, the runoff volume of the 25-year, 24-hour storm must be included in the storage volume.

Appendix 10C gives a procedure for estimating the runoff volume from feedlots. The NRCS NEH 650, Engineering Field Handbook, chapter 2, or by some other hydrologic method may be used to estimate runoff volumes for other watershed areas.

(2) Design of sidewalls and floors

The information on the design of sidewalls and floors on solid manure storage material in AWMFH 651.1004(a) is applicable to these items used for liquid manure storage. All possible influences, such as internal and external hydrostatic pressure, flotation and drainage, live loads from equipment and animals, and dead loads from covers and supports, must be considered in the design.

Pond sealing—storage ponds must not allow excess seepage. The soil in which the pond is to be located must be evaluated and, if needed, tested during planning and design to determine need for an appropriate liner. Refer to AWMFH 651.07 for more detailed information on determining the need for and design of liners.

Design example 10–3 Storage tank

Mr. Bill Walton of Middlesburg, Tennessee, has requested assistance on a manure management system. The selected alternative includes a below-ground, covered, slurry storage tank for his Holstein dairy herd. He has 75 heifers that are about 1,000 pounds each and 150 milkers (average milk production of 75 lb/d) that average 1,400 pounds. Bedding material is not used with these animals. Based on crop utilization of the nutrients, storage is needed for 75 days. The critical storage periods are January 1 to March 15 and July 1 to September 15. The washwater from the milkhouse and parlor is also stored. No runoff will be directed to the storage. Worksheet 10A–1 shows how to determine the necessary volume for the storage tank and several possible sets of tank dimensions. It also shows how to estimate the total solids content of the stored material.

Manure production—the animal type, average weight, and number are entered on lines 1, 2, and 3. The equivalent 1,000-pound animal unit (AU) for the animal type is calculated and entered on line 4. The daily volume of manure (DVM) production for each animal type is selected from table 4–5(b) and entered on line 5. The storage period (D) is entered on line 6. The total manure volume (VMD) is calculated for each animal type and entered on line 7. Add the VMD for each animal type and enter the sum (TVM) on line 8.

Wastewater volume—the daily milking center wastewater volume per animal unit description (DWW) is selected from table 4–7 of AWMFH, chapter 4, and entered on line 9. The wastewater volume for the animal type for the storage period (WWD) is calculated and entered on line 10. Add the wastewater volumes for each animal type and enter the sum (TWW) on line 11.

Bedding volume—bedding is not used in this example. If bedding were used, however, its volume for the storage period would be determined using lines 12 through 15.

Waste volume—WV is the total volume of waste material that will be stored including total manure (TVM), total wastewater (TWW), and total bedding volume (TBV). Provisions are to be made to assure that outside runoff does not enter the tank. In addition, if the tank is not covered, the depth of precipitation less evaporation on the tank surface expected during the most critical storage period must be added to the depth requirements.

Total depth available—the desired depth is the total planned depth based on such considerations as foundation condition, tank wall design, and standard drawing depth available.

Surface area—the surface area (SA) (line 21) dimensions are calculated using the equation for SA.

Tank dimensions—because tanks are rectangular or circular, various combinations of length and width can be used to provide the SA required. If the depth is held constant, only one solution for the diameter of a circular tank is possible. The dimensions of either shape can be rounded upward to match a standard detail drawing or for convenience.

Worksheet 10A-1—Waste storage structure capacity design

Decisionmaker: Bill Walton | Date: 6/13/87

Site: Middlesburg, TN

Animal units

1. Animal type: Milkers | Heifers
2. Animal weight, lbs (W): 1,400 | 1,000
3. Number of animals (N): 150 | 75
4. Animal units, $AU = \frac{W \times N}{1000}$ = 210 | 75

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM) = 1.7 | 0.9
6. Storage period, days (D) = 75
7. Total volume of manure production for animal type for storage period, ft^3 VMD = AU x DVM x D = 26,775 | 5,063
8. Total manure production for storage period, ft^3 (TVM) = 31,838

Wastewater volume

9. Daily wastewater volume per AU, ft^3/AU/day (DWW) = 0.6 | 0
10. Total wastewater volume for animal description for storage period, ft^3 WWD = DWW x AU x D = 9,450 | 0
11. Total wastewater volume for storage period, ft^3 (TWW) = 9,450

Bedding volume

12. Amount of bedding used daily for animal type, lbs/AU/day (WB) =
13. Bedding unit weight, lbs/fb^3 (BUW) =
14. Bedding volume for animal type for storage period, ft^3 =

$$VBD = \frac{0.5 \times WB \times AU \times D}{BUW}$$

15. Total bedding volume for storage period, ft^3 (TBV) = 0

Minimum waste storage volume requirement

16. Waste storage volume, ft^3 (WV) = TVM + TWW + TBV = 31,838 + 9,450 + 0 = 41,288

Waste stacking structure sizing

17. Structure length, ft $L = \frac{WV}{WI \times H}$ =
18. Structure width, ft $WI = \frac{WV}{L \times H}$ =
19. Structure height, ft $H = \frac{WV}{L \times WI}$ =

Notes for waste stacking structure:

1. The volume determined (WSV) does not include any volume for freeboard. It is recommended that a minimum of 1 foot of freeboard be provided for a waste stacking structure.
2. The equations for L, WI, and H assume manure is stacked to average height equal to the sidewall height. Available storage volume must be adjusted to account for these types of variations.

Tank sizing

20. Effective depth, ft. (EH)

Total height (or depth) of tank desired, ft (H) 12

Less precipitation for storage period, ft. (uncovered tanks only) – 0

Less depth allowance for accumulated solids, ft (0.5 ft. minimum) – 0.5

Less depth for freeboard (0.5 ft. recommended), ft – 0.5

Effective depth, ft (EH) = 11

21. Surface area required, ft^2 $SA = \frac{WV}{EH}$ = 3,753

22. Rectangular tank dimensions

Total height, ft (H) = 12 Selected width, ft (WI) = 28

Length, ft $L = \frac{SA}{WI}$ = 134 (USE 136)

23. Circular tank dimensions

Total height, ft H = 12

Diameter, ft $DIA = (1.273 \times SA)^{0.5}$ = 69.1 (USE 70)

Notes for waste storage tank structure:
1. Final dimensions may be rounded up to whole numbers or to use increments on standard drawings.
2. Trial and error may be required to establish appropriate dimensions.

Design example 10–4 Storage pond

Mr. Joe Green of Silverton, Oregon, has requested assistance in developing a manure management system for his dairy. He has selected an alternative that includes a storage pond component. He has a Holstein herd composed of 500 milkers weighing 1,400 pounds with an average milk production of 75 pounds per day, 150 dry cows averaging 1,400 pounds; and 150 heifers averaging 1,000 pounds. He has a freestall barn that has flush alleys. He uses foam pads for bedding. The alternative selected includes land application. A storage period of 180 days is required for storage through the winter months of high precipitation. A solid separator will be used to minimize solid accumulation in the storage pond and to allow recycling of the flushwater. Water from the milkhouse and parlor will be stored in the pond. Use worksheet 10A-2 to determine the required capacity and size of the pond.

Manure production—the animal type, average weight, and numbers are entered on lines 1, 2, and 3. The number of 1,000-pound animal unit (AU) for each animal type is calculated and entered on line 4. The volume of daily manure production (DVM) from table 4–5(b) in AWMFH, chapter 4, is entered on line 5. The storage period (D) is entered on line 6. The manure volume for the storage period for each animal type (VMD) is then calculated and entered on line 7. The total volume (TVM) is added and then entered on line 8.

Wastewater volume—in this example, only the wastewater from the milkhouse and parlor is accounted for in the waste storage volume requirements because the alley flushwater is recycled. The daily wastewater volume per animal unit (DWW) from table 4-6 in AWMFH, chapter 4, is entered on line 9. The wastewater volume for each animal type for the storage period (WWD) is calculated using the equation and entered on line 10. The wastewater volume from each animal type (WWD) is added, and the sum (TWW) is entered on line 11.

Clean water volume—in this example, no clean water is added. However, if clean water (CW) is added for dilution, for example, the amount added during the storage period would be entered on line 12.

Runoff volume—for this example, the storage pond does not have a watershed and storage for runoff is not needed. However, storage ponds are frequently planned to include the runoff from a watershed, such as a feedlot. The ponds that have a watershed must include the normal runoff for the storage period and the runoff volume for the 25-year, 24-hour storm. The runoff volume from feedlots may be calculated using the procedures in appendix 10C. For watersheds or parts of watersheds that have cover other than feedlots, the runoff volume may be determined using the procedure in chapter 2 of the NEH 651, Engineering Field Handbook. The value for watershed runoff volume (ROV) is entered on line 13. Documentation showing the procedure and values used in determining the volume of runoff should be attached to the worksheet.

Volume of accumulated solids—this volume is to accommodate the storage of accumulated solids for the period between solids removal. The solids referred to are those that remain after the liquid has been removed. An allowance for accumulated solids is required mainly for ponds used to store wastewater and polluted runoff. Solids separation, agitation before emptying, and length of time between solids removal all affect the amount of storage that must be provided. Enter the value for accumulated solids (VSA) on line 14. In this example, the solids from the manure are separated and solids accumulation will be minimal. No storage is provided for accumulated solids. *(Continued)*

Design example 10–4 Storage pond—Continued

Waste volume—the total waste storage volume (WV) is determined by adding the total volume of manure (TVM), total wastewater volume (TWW), clean water added (CW), and volume allowance for solids accumulation (VSA). Storage ponds that have a watershed must also include the normal runoff volume for the storage period and the volume of the 25-year, 24-hour storm runoff (ROV). WSV is calculated on line 15. The storage pond must be sized to store this volume plus additional depth as explained in "depth adjustment."

Storage pond sizing—the storage pond is sized by trial and error for either a rectangular or circular shaped pond by using the procedure on **line 16**.

Depth adjustment—the depth required for the storage volume with the selected pond dimensions must be adjusted by adding depth for the precipitation less evaporation and the depth of the 25-year, 24-hour storm on the pond surface. The minimum freeboard is 1 foot. The adjustment for final depth is made using line 17**.**

Completed worksheet for Design example 10–4

Worksheet 10A-2—Waste storage pond design

Decisionmaker: Joe Green | Date: 10/4/90

Site: Silverton, OR

Animal units

1. Animal type: Milkers | Dry | Heifers
2. Animal weight, lbs (W): 1,400 | 1,400 | 1,000
3. Number of animals (N): 500 | 150 | 150
4. Animal units, $AU = \frac{W \times N}{1000}$ = 700 | 210 | 150

Manure volume

5. Daily volume of manure production per AU, ft^3/AU/day (DVM) = 1.7 | 0.84 | 0.9
6. Storage period, days (D) = 180
7. Total volume of manure production for animal type for storage period, ft^3 VMD = AU x DVM x D = 214,200 | 31,752 | 24,300
8. Total manure production for storage period, ft^3 (TVM) 270,252

Wastewater volume

9. Daily wastewater volume per AU, ft^3/AU/day (DWW) = 0.6 | 0 | 0
10. Total wastewater volume for animal description for storage period, ft^3 WWD = DWW x AU x D = 75,600
11. Total wastewater volume for storage period, ft^3 (TWW) 75,600

Clean water volume

12. Clean water added during storage period, ft^3 (CW) 0

Runoff Volume

13. Runoff volume, ft3 (ROV) (attach documentation) 0
Includes the volume of runoff from the drainage area due to normal runoff for the storage period and the runoff volume from the 25-year, 24-hour storm.

Solids accumulation

14. Volume of solids accumulation, ft^3(VSA) 0

Waste volume requirement

15. Waste volume, ft^3 (WV) = TVM + TWW + CW + ROV + VSA
= 270,252 + 75,600 + 0 + 0 + 0 = 345,852

Pond sizing

16. Sizing by trial and error

Side slope ratio, (Z) = 3 V must be equal to or greater than WV = 345,852 ft^3

Rectangular pond,

$$V = \left(\frac{4 \times Z^2 \times d^3}{3}\right) + \left(Z \times BL \times d^2\right) + \left(Z \times BW \times d^2\right) + \left(BW \times BL \times d\right)$$

Circular pond,

$$V = (1.05 \times Z^2 \times d^3) + (1.57 \times W \times Z \times d^2) + (0.79 \times W^2 \times d)$$

Trial no.	Bottom width ft (BW)	Bottom length ft (BL)	Depth* ft (d)	Volume ft^3 (V)		Trial no.	Bottom diameter (DIA)	Depth* ft (d)	Volume ft^3 (V)
1	100	500	6	367,392					
2	100	450	6	331,992					
3	100	450	6.2	345,286					
4	100	455	6.2	348,963	≈	WSV OK			

* Depth must be adjusted in Step 17.

Depth adjustment

17. Depth adjustment

Depth, ft (d) 6.2

Add depth of precipitation less evaporation (For the storage period) + 2.3

Add depth of 25-year, 24-hour storm + 0.3

Add for freeboard (1.0 foot minimum) + 1.0

Final depth 9.8

651.1005 Treatment

In many situations, manure treatment is necessary before final utilization. Adequate treatment reduces pollution potential of the manure through biological, physical, and chemical processes using such components as lagoons, oxidation ditches, composting, and constructed wetlands. These types of components reduce nutrients, reduce pathogen counts, and reduce total solids. Composting also reduces the volume of the material. Treatment may also include solids separation, drying, and dilution that prepare the material for facilitating another function. By their nature, treatment facilities require a higher level of management than that of storage facilities.

(a) Primary treatment

Primary treatment includes the physical processes such as solids-liquids separation, moisture adjustment, and dilution. Although not required, primary treatment is often followed by secondary treatment prior to storage or land application.

(1) Drying/dewatering

If the water is removed from freshly excreted manure, the volume to handle can be reduced. The process of removing water is referred to as dewatering. In the arid regions of the United States, most manure is dewatered (dried) by evaporation from sun and wind. Some nutrients may be lost in the drying process.

Dried or dewatered manure solids are often sold as a soil conditioner or garden fertilizer. These solids may also be used as fertilizer on agricultural land. They are high in organic matter and can be expected to produce odors if moisture is added and the material is not re-dried or composted. Because the water is removed, the concentrations of some nutrients and salts will change. Dried manure should be analyzed to determine the nutrient concentrations before land application.

In humid climates, dewatering is accomplished by adding energy to drive off the desired amount of moisture. Processes have been developed for drying manure in greenhouse-type facilities; however, the drying rate is dependent on the temperature and relative humidity. The cost of energy often makes the drying process unattractive.

(2) Solid/liquid separation

Animal manure contains material that can often be reclaimed. Solids in dairy manure from animals fed a high roughage diet can be removed and processed for use as good quality bedding. Some form of separation must be used to recover these solids. A mechanical separator or settling basin is typically employed. Separators are also used to reduce solids content and required storage volumes.

Separators also facilitate handling of manure. For example, solid separation can allow the use of conventional irrigation equipment for land application of the liquids. Separation eliminates many of the problems associated with the introduction of solids into storage ponds and treatment lagoons by reducing solids accumulation and minimizing agitation requirements. Separation facilities should be planned and designed in accordance with NRCS Conservation Practice Standard 632, Solid/Liquid Waste Separation Facility.

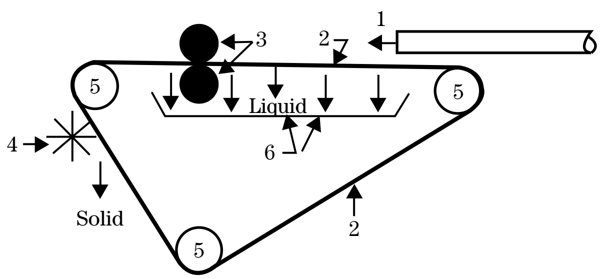
Mechanical separation—Several kinds of mechanical separators can be used to remove by-products from manure (fig. 10–24). One kind commonly used is a screen. Screens are statically inclined or in continuous motion to aid in separation. The most common type of continuous motion screen is a vibrating screen. The TS concentration of manure to be processed by a screen should be reduced to less than 5 percent. Higher TS concentrations reduce the effectiveness of the separator.

A centrifuge separator uses centrifugal force to remove the solids, which are eliminated from the machine at a different point than the liquids. In addition, various types of presses can be used to force the liquid part of the manure from the solid part.

Several design factors should be considered when selecting a mechanical separator. One factor is the amount of liquid manure that the machine can process in a given amount of time. This is referred to as the "throughput" of the unit. Some units have a relatively low throughput and must be operated for a long time. Another very important factor is the TS content required by the given machine. Centrifuges and presses can operate at a higher TS level than can static screens.

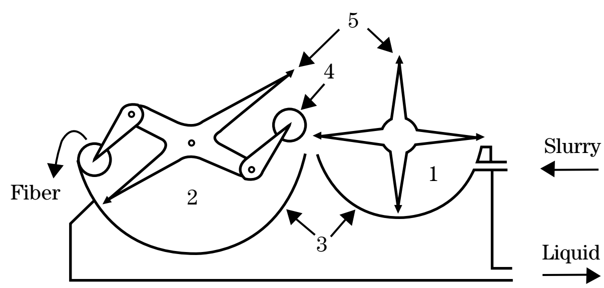
Figure 10–24 Schematic of mechanical solid-liquid separators

Flat belt separator



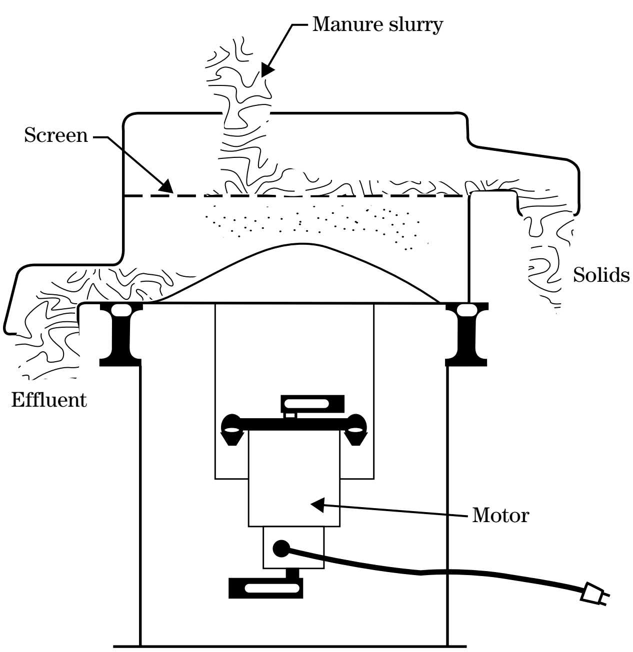
1 Slurry input
2 Polyester mesh belt
3 Press rollers
4 Rotary brush
5 Belt guide rollers
6 Liquid collection trough

Roller-press separator

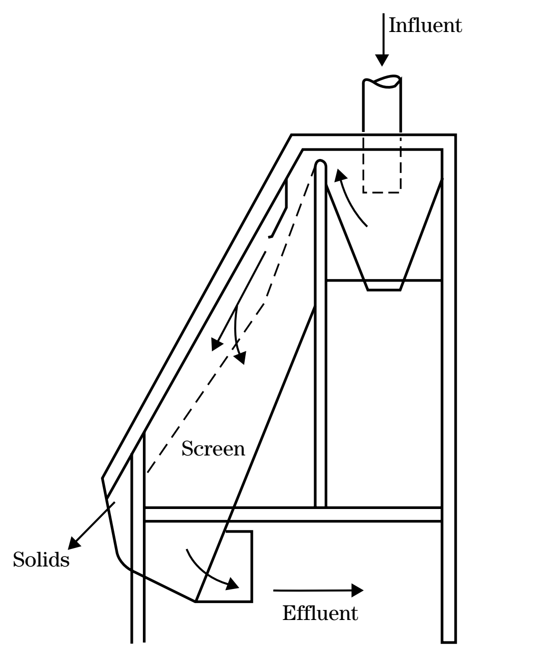


1 Screening stage
2 Roller pressing stage
3 Screens
4 Spring loaded press roller
5 Brushes

Vibrating screen separator



Stationary inclined screen separator



Consideration should be given to handling the separated materials. Liquid can be collected in a reception pit and later pumped to storage or treatment. The separated solids will have a TS concentration of 15 to 40 percent. While a substantial amount of nutrients is removed with the solids, the majority of the nutrients and salt remain in the liquid fraction. In many cases, water drains freely from piles of separated solids. This liquid needs to be transferred to storage to reduce odors and fly breeding.

Typically, solids must still be processed before they can be used. If they are intended for bedding, the material should be composted or dried.

A planner/designer needs to know the performance characteristics of the separator being considered for the type of manure to be separated. The best data, if available, would be that provided by the separator manufacturer. If that data is not available, the manufacturer or supplier may agree to demonstrate the separator with material to be separated. This can also provide insight as to the effectiveness of the equipment.

If specific data on the separator is not available, tables 10–5 and 10–6 can be used to estimate performance characteristics. Table 10–5(a) gives data for separating different materials using different separators, and table 10–6 presents general operational characteristics of mechanical separators.

Settling basins—In many situations, removing manure solids, soil, and other material from runoff from livestock operations is beneficial. The most common device to accomplish this is the settling or solids

Table 10–5 Operational data for solid/liquid separators (a); settling basin performance (b)

(a) Operational data for solid/liquid separators

Animal type	Separator	TS concentration (%)			% Retained in separated solids				
		Raw waste	· · · Separated · · ·						
			liquids	solids	TS	VS	COD	N	P
Dairy	Vibrating screen								
	16 mesh	5.8	5.2	12.1	56	—	—	—	—
	24 mesh	1.9	1.5	7.5	70	—	—	—	—
	Decanter centrifuge 16-30 gal/min	6–8	4.9–6.5	13–33	35–40	—	—	—	—
	Static inclined screen								
	12 mesh	4.6	1.6	12.2	49	—	—	—	—
	32 mesh	2.8	1.1	6.0	68	—	—	—	—
	Screw press	2–7	1–4	20–30	26–34	—	—	—	—
Beef	Static inclined screen	4.4	3.8	13.3	15	—	—	—	—
	Vibrating screen	1–2	—	—	40–50	—	—	—	—
Swine	Decanter centrifuge 3 gal/min	7.6	2.6	37	14	—	—	—	—
	Vibrating screen 22 gal/min/ft^2								
	18 mesh	4.6	3.6	10.6	35	39	39	22	26
	30 mesh	5.4	3.5	9.5	52	56	49	33	34
	Screw press	2–5	—	22–34	16–30	—	—	—	—

separation basin. A settling basin used in association with livestock operations is a shallow basin or pond that is designed for low velocities and the accumulation of settled materials. When the basin is positioned between the source and the storage or treatment facilities, settling will occur if the velocity of the liquid is below 1.5 feet per second.

Settling basins should have access ramps that facilitate removal of settled material. Outlets from settling basins should be located so that sediment removal is not restricted. Chemical additives are sometimes used to aid differential settling by flocculation. Flocculants are outside the scope of this document. Table 10–5(b) provides settling basin performance, wet basis.

(3) Dilution

Dilution is often used to facilitate another function. This process involves adding clean water or water that has less total solids to manure, resulting in a mixture that has a desired percentage of total solids. A common use of dilution is to prepare the manure for land

Table 10–5 Operational data for solid/liquid separators (a); settling basin performance (b)—Continued

(b) Settling basin performance (results in wet basis) (LPES 2001)

Manure	Input solids, %	% removal from liquid				
		Solids	**COD**	**TKN**	**N-org**	**TP**
Flushed dairy	3.83	55 (VS)	61	—	26	28
Dairy	1.1	65	—	40	—	—
Poultry, beef, dairy, swine, horse	-1	45–76*	28–67*	—	—	—
Feedlot runoff	1–3	40–64	—	84	—	80
Flushed swine	0.2	12	—	33	—	22
Feedlot runoff	1–3	13	—	0.7	—	0.3

* 10-minute setting time

Table 10–6 Characteristics of solid/liquid separators (Barker 1986)

Characteristic	Decanter centrifuge (%)	Vibrating screen	Stationary inclined screen
Typical screen opening	—	20 mesh	10–20 mesh
Maximum waste TS concentration	8	5	5
Separated solids TS concentration	to 35	to 15	to 10
TS reduction*	to 45	to 30	to 30
COD reduction*	to 70	to 25	to 45
N reduction*	to 20	to 15	to 30
P reduction*	to 25	—	—
Throughput (gal/min)	to 30	to 300	to 1,000

* Removed in separated solids

application using a sprinkler system. Figure 10–25 is a design aid for determining the amount of clean dilution water required to lower the TS concentration.

(b) Secondary treatment

Secondary treatment includes biological and chemical treatment such as composting, lagoons, oxidation ditches, and vegetative treatment areas. This additional treatment step reduces the pollution potential prior to land application by reducing the nutrient contents of the material. Secondary treatment facilities should be planned and designed in accordance with the applicable Conservation Practice Standards.

(1) Amendments for treatment

Biological and chemical additives are sometimes used to alter the characteristics of manure and other by-products of agricultural operations to facilitate secondary treatment. Use of these additives should be in accordance with the NRCS Conservation Practice Standard 591, Amendments for Treatment of Agricultural Waste.

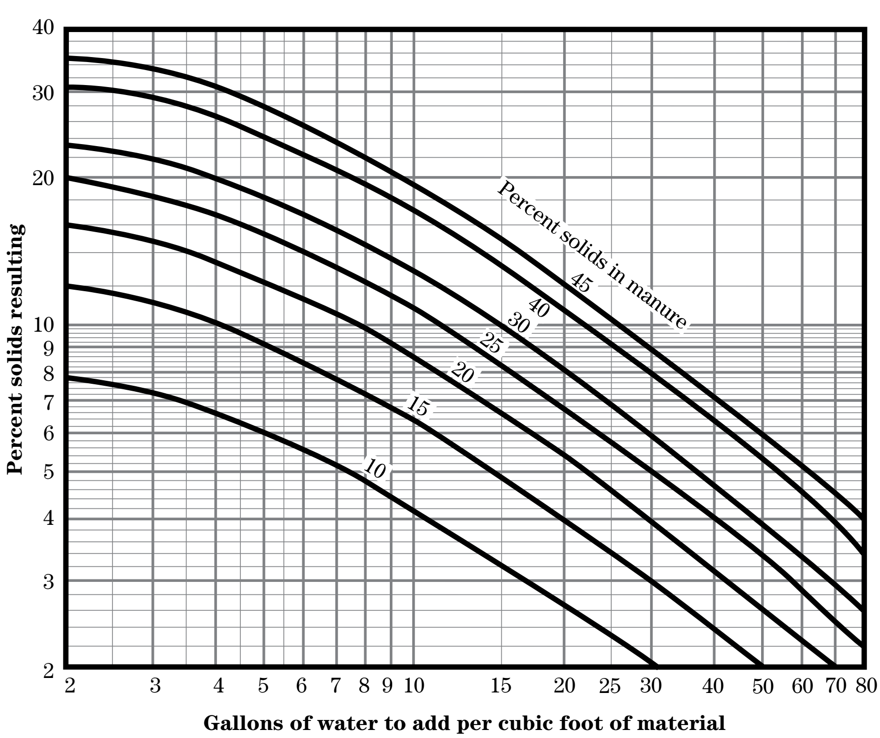
(2) Anaerobic lagoons

Anaerobic lagoons are widely accepted in the United States for the treatment of manure. Anaerobic treatment of manure helps to protect water quality by reducing much of the organic concentration (BOD, COD) of the material. Anaerobic lagoons also reduce the nitrogen content of the material through ammonia volatilization and effectively reduce manure odors if the lagoon is managed properly. Anaerobic lagoons should be planned and designed in accordance with NRCS Conservation Practice Standard 359, Waste Treatment Lagoon.

Design—The maximum operating level of an anaerobic lagoon is a volume requirement plus a depth requirement. The volume requirement is the sum of the following volumes:

- minimum treatment volume, ft^3 (MTV)
- manure volume, wastewater volume, and clean water, ft^3 (WV)
- sludge volume, ft^3 (SV)

Figure 10–25 Design aid to determine quantity of water to add to achieve a desired TS concentration (USDA 1975)



The depth requirement is the normal precipitation less evaporation on the lagoon surface.

Polluted runoff from a watershed must not be included in a lagoon unless a defensible estimate of the volatile solid loading can be made. Runoff from a watershed, such as a feedlot, is not included in a lagoon because loading would only result during storm events and because the magnitude of the loading would be difficult, if not impossible, to estimate. As a result, the lagoon would be shocked with an overload of volatile solids.

If an automatic outflow device, pipe, or spillway is used, it must be placed at a height above the maximum operating level to accommodate the 25-year, 24-hour storm precipitation on the lagoon surface. This depth added to the maximum operating level of the lagoon establishes the level of the required volume or the outflow device, pipe, or spillway. A minimum of 1 foot of freeboard is provided above the outflow and establishes the top of the embankment. Should State regulation preclude the use of an outflow device, pipe, or spillway or if for some other reason the lagoon will not have these, the minimum freeboard is 1 foot above the top of the required volume.

The combination of these volumes and depths is illustrated in figure 10–26. The terms and derivation are explained in the following paragraphs.

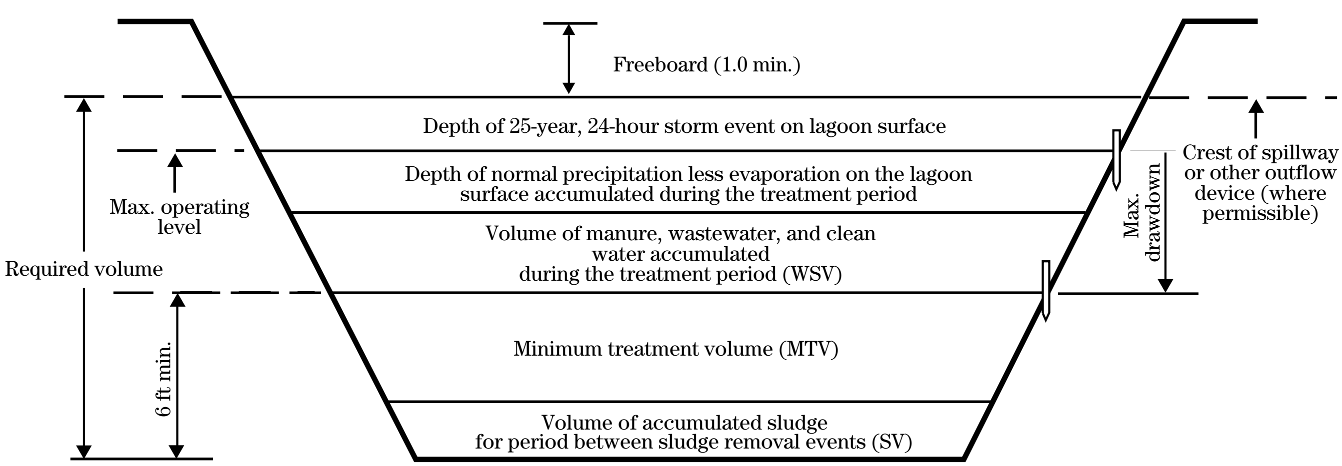
Anaerobic waste treatment lagoons are designed on the basis of volatile solids loading rate (VSLR) per 1,000 cubic feet. Volatile solids represent the amount of solid material in wastes that will decompose as opposed to the mineral (inert) fraction. The rate of solids decomposition in anaerobic lagoons is a function of temperature; therefore, the acceptable VSLR varies from one location to another. Figure 10–27 indicates the maximum VSLRs for the United States. If odors need to be minimized, VSLR should be reduced by 25 to 50 percent.

The MTV represents the volume needed to maintain sustainable biological activity. The MTV for volatile solids (VS) can be determined using equation 10–4.

$$\mathrm{MTV} = \frac{\mathrm{TVS}}{\mathrm{VSLR}} \qquad \text{(eq. 10–4)}$$

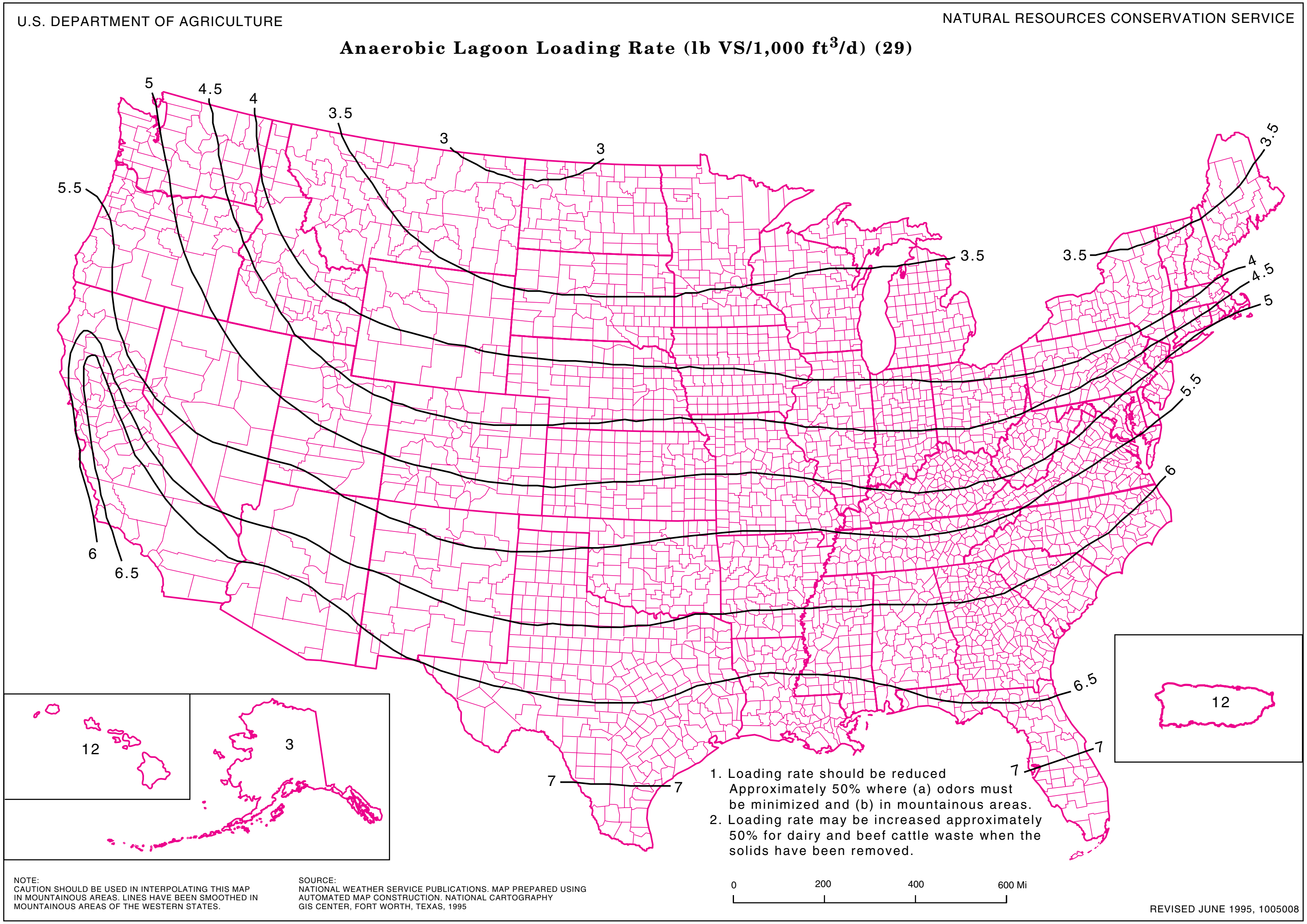
where:
- MTV = minimum treatment volume, ft^3
- TVS = total daily volatile solids loading (from all sources), lb/d
- VSLR = volatile solids loading rate, lb/1,000 ft^3/d (from fig. 10–27)

Figure 10–26 Anaerobic lagoon cross section



Note: The minimum treatment volume for an anaerobic waste treatment lagoon is based on volatile solids.

Figure 10–27 Anaerobic lagoon loading rate (lb VS/1,000 ft^3/d)



Soil properties

The permeability of soils at the boundary of a waste storage pond depends on several factors. The most important factors are those used in soil classification systems such as the Unified Soil Classification System (USCS). The USCS groups soils into similar engineering behavioral groups. The two most important factors that determine a soil's permeability are:

- The percentage of the sample which is finer than the No. 200 sieve size, 0.075 millimeters. The USCS has the following important categories of percentage fines:
  - Soils with less than 5 percent fines are the most permeable soils.
  - Soils with between 5 and 12 percent fines are next in permeability.
  - Soils with more than 12 percent fines but less than 50 percent fines are next in order of permeability.
  - Soils with 50 percent or more fines are the least permeable.
- The plasticity index (PI) of soils is another parameter that strongly correlates with permeability.

When considered together with percent fines, a grouping of soils into four categories of permeability is possible. The following grouping of soils is based on the experience of NRCS engineers. It may be used to classify soils at grade as an initial screening tool. Estimating permeability is difficult because so many factors determine the value for a soil. For *in situ* soils, the following factors, in addition to percent fines and PI, affect the permeability of the natural soils:

- The dry density of the natural soil affects the permeability. Soils with lower dry densities have higher percentage of voids (porosity) than more dense soils.
- Structure strongly affects permeability. Many clay soils, particularly those with PI values above 20, develop a blocky structure from desiccation. The blocky structure creates preferential flow paths that can cause soils to have an unexpectedly high permeability. Albrecht and Benson (2001) and Daniel and Wu (1993) describe the effect of desiccation on the permeability of compacted clay liners.
- While not considered in the USCS, the chemical composition of soils with clay content strongly affects permeability. Soils with a preponderance of calcium or magnesium ions on the clay particles often have a flocculated structure that causes the soils to be more permeable than expected based simply on percent fines and PI. Soils with a preponderance of sodium or potassium ions on the clay particles often have a dispersive structure that causes the soils to be less permeable than soils with similar values of percent fines and PI. The NRCS publication TR–28, Clay Minerals, describes this as follows:

  > *In clay materials, permeability is also influenced to a large extent by the exchangeable ions present. If, for example, the Ca (calcium) ions in a montmorillonite are replaced by Na (sodium) ions, the permeability becomes many times less than its original value. The replacement with sodium ions reduces the permeability in several ways. For one thing, the sodium causes dispersion (disaggregation) reducing the effective particle size of the clay minerals. Another condition reducing permeability is the greater thickness of water adsorbed on the sodium-saturated montmorillonite surfaces which diminishes the effective pore diameter and retards the movement of fluid water.*

- Alluvial soils may have thin laminations of silt or sand that cause them to have a much higher horizontal permeability than vertical permeability. This property is termed anisotropy and should be considered in flow net analyses of seepage.
- Other types of deposits may have structure resulting from their mode of deposition. Loess soils often have a high vertical permeability resulting from their structure. Glacial tills may contain fissures and cracks that cause them to have a permeability higher than might be expected based only on their density, percent fines and PI of the fines.

The grouping of soils in table 10D–3 is based on the percent passing the No. 200 sieve and PI of the soils. Table 10D–4 is useful to correlate the USCS groups to one of the four permeability groups.

Table 10D–3 Grouping of soils according to their estimated permeability. Group I soils are the most permeable, and soils in groups III and IV are the least permeable soils

Group	Description
I	Soils that have less than 20 percent passing a No. 200 sieve and have a PI less than 5
II	Soils that have 20 percent or more passing a No. 200 sieve and have PI less than or equal to 15. Also included in this group are soils with less than 20 percent passing the No. 200 sieve with fines having a PI of 5 or greater
III	Soils that have 20 percent or more passing a No. 200 sieve and have a PI of 16 to 30
IV	Soils that have 20 percent or more passing a No. 200 sieve and have a PI of more than 30

Table 10D–4 Unified classification versus soil permeability groups [1/]

Unified Soil Classification System Group Name	Soil permeability group number and occurrence of USCS group in that soil			
	I	II	III	IV
CH	N	N	S	U
MH	N	S	U	S
CL	N	S	U	S
ML	N	U	S	N
CL–ML	N	A	N	N
GC	N	S	U	S
GM	S	U	S	S
GW	A	N	N	N
SM	S	U	S	S
SC	N	S	U	S
SW	A	N	N	N
SP	A	N	N	N
GP	A	N	N	N

1/ ASTM Method D–2488 has criteria for use of index test data to classify soils by the USCS.
A = Always in this permeability group
N = Never in this permeability group
S = Sometimes in this permeability group (less than 10 percent of samples fall in this group)
U = Usually in this permeability group (more than 90 percent of samples fall in this group)

Permeability of soils

Table 10D–5 shows an approximate range of estimated permeability values for each group of soils in table 10D–3. The ranges are wide because the classification system does not consider other factors that affect the permeability of soils, such as the electrochemical nature of the clay in the soils. Two soils may have similar percent finer than the No. 200 sieves and PI values but have very different permeability because of their different electrochemical makeup. The difference can easily be two orders of magnitude (a factor of 100). The most dramatic differences are between clays that have a predominance of sodium compared to those with a preponderance of calcium or magnesium. High calcium soils are more permeable than high sodium soils.

Table 10D–5 summarizes the experienced judgment of NRCS engineers and generally used empirical correlations of other engineers. The correlations are for *in situ* soils at medium density and without significant structure or chemical content. Information shown in figure 10D–5 is also valuable in gaining insight into the probable permeability characteristics of various soil and rock types.

Some soils in groups III and IV may have a higher permeability than indicated in table 10D–5 because they contain a high amount of calcium. High amounts of calcium result in a flocculated or aggregated structure in soils. These soils often result from the weathering

Table 10D–5 Grouping of soils according to their estimated permeability. Group I soils are the most permeable and soils in groups III and IV are the least permeable soils.

Group	Percent fines	PI	Estimated range of permeability, cm/s	
			Low	High
I	< 20	< 5	3×10^{-3}	2
II	≥ 20	≤ 15	5×10^{-6}	5×10^{-4}
	< 20	≥ 5		
III	≥ 20	16 ≤ PI ≤ 30	5×10^{-8}	1×10^{-6}
IV	≥ 20	> 30	1×10^{-9}	1×10^{-7}

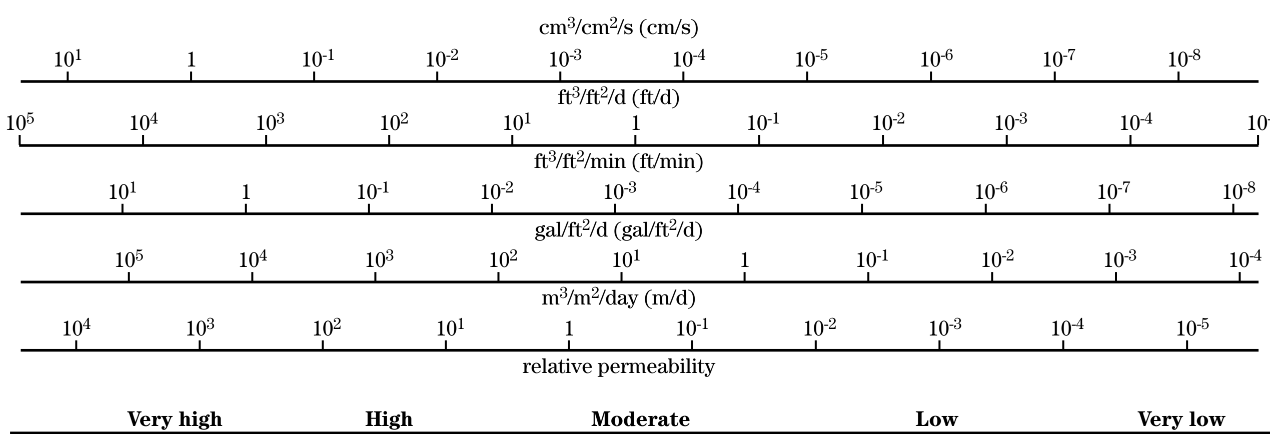
of high calcium parent rock, such as limestone. Soil scientists and published soil surveys are helpful in identifying these soil types.

High calcium clays should usually be modified with soil dispersants to achieve the target permeability goals. Dispersants, such as tetrasodium polyphosphate, can alter the flocculated structure of these soils by replacement of the calcium with sodium. Because manure contains salts, it can aid in dispersing the structure of these soils, but design should not rely on manure as the only additive for these soil types.

Soils in group IV usually have a very low permeability. However, because of their sometimes blocky structure, caused by desiccation, high seepage losses can occur through cracks that can develop when the soil is allowed to dry. These soils possess good attenuation properties if the seepage does not move through cracks in the soil mass. Soils with extensive desiccation cracks should be disked, watered, and recompacted to destroy the structure in the soils to provide an acceptable permeability. The depth of the treatment required should be based on design guidance given in the section **Construction considerations for compacted clay liners.**

High plasticity soils like those in group IV should be protected from desiccation in the interim period between construction and filling the pond. Ponds with intermittent storage should also consider protection for high PI liners in their design.

Figure 10D–5 Permeability of various geologic material (from Freeze and Cherry 1979)



Representative materials

	Very high	High	Moderate	Low	Very low
Soil types	Clean gravel (GP)	Clean sand, clean sand and gravel mixes (GW, GP, SW, SP, SM)	Fine sand, silty sand and gravel mixes (SP, SM, GM, GW–GM, GP–GM, SW–SM, SP–SM)	Silt, clay, and sand-silt-clay mixes, organic silts, organic clays (GM, GC, SM, SC, MH, ML, ML–CL, OL, OH, GW–GC, GC–GM, SW-SC, SP–SC, SC–SM)	Massive clay, no soil joints or other macropores (CL, CH)
			Any soil mass with joints, cracks or other macroporosity		
Rock types		Cavernous and karst limestones and dolomites, permeable basalts	Limestones, dolomites, clean sandstones	Interbedded sandstones, siltstones, and shales	Most massive rocks, unfractured and unweathered
			Fractured igneous and metamorphic rocks		

In situ soils with acceptable permeability

For screening purposes, NRCS engineers have determined that if the boundaries of a planned pond are underlain on the sides and bottom both by a minimum thickness of natural soil in permeability groups III or IV, the seepage from those ponds is generally low enough to cause no degradation of ground water. This assumes that soils do not have a flocculated structure. Unless State regulations or other requirements dictate a more conservative method of limiting seepage, it is the position of NRCS that special design measures generally are not necessary where agricultural waste storage ponds or treatment lagoons are constructed in these soils, provided that:

- at least 2 feet of natural soil in groups III or IV occur below the bottom and sides of the lagoon
- the soils are not flocculated (high calcium)
- no highly unfavorable geologic conditions, such as karst formations, occur at the site
- the planned depth of storage is less than 15 feet

Ponds with more than 15 feet of liquid should be evaluated by more precise methods. If the permeability and thickness of horizons beneath a structure are known, the predicted seepage quantities may be estimated more precisely. In some cases, even though a site is underlain by 2 feet of naturally low permeability soil, an acceptably low seepage rate satisfactory for some State requirements cannot be documented. In those cases, more precise testing and analyses are suggested. The accumulation of manure can provide a further decrease in the seepage rate of ponds by up to 1 order of magnitude as noted previously. If regulations permit considering this reduction, a lower predicted seepage can be assumed by designers.

Definition of pond liner

Compacted clay liner—Compacted clay liners are relatively impervious layers of compacted soil used to reduce seepage losses to an acceptable level. A liner for a waste impoundment can be constructed in several ways. When soil alone is used as a liner, it is often called a clay blanket or impervious blanket. A simple method of providing a liner for a waste storage structure is to improve a layer of the soils at the excavated grade by disking, watering, and compacting the soil to a thickness indicated by guidelines in following sections. Compaction is often the most economical method for constructing liners if suitable soils are available nearby or if soils excavated during construction of the pond can be reused to make a compacted liner. Soils with suitable properties can make excellent liners, but the liners must be designed and installed correctly. Soil has an added benefit in that it provides an attenuation medium for many types of pollutants. NRCS Conservation Practice Standard (CPS) 521D, Pond Sealing or Lining Compacted Clay Treatment, addresses general design guidance for compacted clay liners for ponds.

If the available soils cannot be compacted to a density and water content that will produce an acceptably low permeability, several options are available, and described in the following section. The options involve soil additives to improve the permeability of the soils and adding liners constructed of materials other than natural soils.

Treat the soil at grade with bentonite or a soil dispersant—Designers must be aware of which amendment is appropriate for adding to specific soils at a site. In the past, bentonite has been inappropriately used to treat clay soils and soil dispersants have inappropriately been used to treat sands with a small clay content.

The following guidelines are helpful and should be closely followed.

- ***When to use bentonite***—Soils in groups I and II have unacceptably high permeability because they contain an insufficient quantity of clay or the clay in the soils is less active than required. A useful rule of thumb is that soils amenable for treatment with bentonite will have PI values less than 7, or they will have less than 30 percent finer than the No. 200 sieve, or both.

  Bentonite is essentially a highly concentrated clay product that can be added in small quantities to a sand or slightly plastic silt to make it relatively low in permeability. CPS 521C, Pond Sealing or Lining Bentonite Treatment, covers this practice. NRCS soil mechanics laboratories have found it important to use the same type and quality of bentonite planned for construction in the laboratory permeability tests used to design the soil-bentonite mixture. Both the quality of the bentonite and how finely ground the product is before mixing with the soil will strongly affect the final permeability rate of the mixture. It is important to work closely with both the bentonite supplier and the soil testing facility when designing treated soil liners.

- **When to use soil dispersants**—Soils in groups III and IV may have unacceptably high permeability because they contain a preponderance of calcium or magnesium on the clay particles. Unfortunately, field or lab tests to determine when soils are likely to have this problem are not available. High calcium soils often occur when parent materials have excessive calcium. Many soils developed from weathering of limestone and gypsum may have this problem. See the section Design and construction of clay liners treated with soil dispersants, for more detail. Some States require the routine use of soil dispersants in areas that are known to have high calcium clay soils.

Use of concrete or synthetic materials such as geomembranes and geosynthetic clay liners (GCLs)—Concrete has advantages and disadvantages for use as a liner. A disadvantage is that it will not flex to conform to settlement or shifting of the earth. In addition, some concrete aggregates may be susceptible to attack by continued exposure to chemicals contained in or generated by the waste. An advantage is that concrete serves as an excellent floor from which to scrape solids. It also provides a solid support for equipment such as tractors or loaders.

Figure 10D–6 Agricultural waste storage impoundment lined with a geomembrane *(Photo credit NRCS)*

Geomembranes and GCLs are the most impervious types of liners if designed and installed correctly. Care must be exercised both during construction and operation of the waste impoundment to prevent punctures and tears. The most common defects in these liners arise from problems during construction. Forming seams in the field for geomembranes can require special expertise. GCLs have the advantage of not requiring field seaming, but overlap is required to provide a seal at the seams. Geomembranes must contain ultraviolet inhibitors if exposed to sunlight. Designs should include provision for protection from damage during cleaning operations. Concrete pads, double liners, and soil covering are examples of protective measures. Figure 10D–6 shows an agricultural waste storage facility with a geomembrane liner with ultraviolet inhibitors.

When a liner should be considered

A constructed liner may be required if any of the conditions listed are present at a planned impoundment.

Proposed impoundment is located where any underlying aquifer is at a shallow depth and not confined and/or the underlying aquifer is a domestic or ecologically vital water supply—State or local regulations may prevent locating a waste storage impoundment within a specified distance from such features. Even if the pond bottom and sides are underlain by 2 feet of naturally low permeability soil, if the depth of liquid in the pond is high enough, computed seepage losses may be greater than acceptable. The highest level of investigation and design is required on sites like those described. This will ensure that seepage will not degrade aquifers at shallow depth or aquifers that are of vital importance as domestic water sources.

Excavation boundary of an impoundment is underlain by less than 2 feet of suitably low permeability soil, or an equivalent thickness of soil with commensurate permeability, over bedrock—Bedrock that is near the soil surface is often fractured or jointed because of weathering and stress relief.

651.1008 Safety

Much of this material was taken from the publication *Safety and Liquid Manure Handling* (White and Young 1980).

Safety must be a primary consideration in managing animal waste. It must be considered during planning and designing of waste management system components, as well as during the actual operation of handling wastes. The operator must be made aware of safety aspects of any waste management system components under consideration. Accidents involving waste management may be the result of:

- poor design or construction
- lack of knowledge or training about components and their characteristics
- poor judgment, carelessness, or lack of maintenance
- lack of adequate safety devices, such as shields, guard rails, fences, or warning signs

The potential for an accident with waste management components is always present. However, accidents do not have to happen if components are properly designed, constructed, and maintained and if all persons involved with the components are adequately trained and supervised.

First aid equipment should be near storage units and lagoons. A special, easily accessible area should be provided for storing the equipment. The area should be inspected periodically to ensure that all equipment is available and in proper working condition. The telephone numbers of the local fire department and/or rescue squad should be posted near the safety equipment and near all telephones.

(a) Confined areas

Manure gases can accumulate when manure is stored in environments that do not have adequate ventilation, such as underground covered waste storage tanks. These gases can reach toxic concentrations and displace oxygen. The four main gases are ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and methane (CH_4). The gases produced under anaerobic conditions and the requirements for safety because of these deadly gases are described in AWMFH, chapter 3. Because of the importance of safety considerations, the following repeats and elaborates on these safety requirements.

Ammonia is an irritant at concentrations below 20 parts per million. At higher levels it can be an asphyxiant.

Carbon dioxide is released from liquid or slurry manure. The rate of release is increased with agitation of the manure. High concentrations of carbon dioxide can cause headaches and drowsiness and even death by asphyxiation.

Hydrogen sulfide is the most dangerous of the manure gases and can cause discomfort, headaches, nausea, and dizziness. These symptoms become severe at concentrations of 800 parts per million for exposures over 30 minutes. Hydrogen sulfide concentrations above 800 parts per million can lead to unconsciousness and death through paralysis of the respiratory system.

Methane is also an asphyxiant; however, its most dangerous characteristic is that it is explosive.

Several rules should be followed when dealing with manure stored in poorly ventilated environments:

- Safety equipment can include air packs and face masks, nylon line with snap buckles, safety harness, first-aid kits, flotation devices, safety signs, and hazardous atmosphere testing kits or monitors. All family members and employees should be trained in first-aid, CPR techniques, and safety procedures and policies. The following material discusses specific safety considerations.
- Do not enter a manure pit unless absolutely necessary and only then if the pit is first ventilated, air is supplied to a mask or a self-contained breathing apparatus, a safety harness and attached rope is put on, and there are two people standing by.
- If at all feasible, construct lids for manure pits or tanks and keep access covers in place. If an open, ground-level pit or tank is necessary, put a fence around it and post “Keep Out” signs.

- Do not attempt without assistance to rescue humans or livestock that have fallen into a manure storage structure or reception pit.
- Move all the animals out of the building, if possible when agitating manure stored beneath that building. If the animals cannot be removed, the following steps should be taken:
  – If the building is mechanically ventilated, turn fans on full capacity when beginning to agitate, even in the winter.
  – If the building is naturally ventilated, do not agitate unless there is a brisk breeze blowing. The animals should be watched when agitation begins, and at the first sign of trouble, the pump should be turned off. The critical area of the building is where the pumped manure breaks the liquid surface in the pit. If an animal drops over because of asphyxiation, do not try to rescue it. Turn off the pump, and allow time for the gases to escape before entering the building.
- Do not smoke, weld, or use an open flame in confined, poorly ventilated areas where methane can accumulate.
- Keep electric motors, fixtures, and wiring near manure storage structures in good condition.

(b) Aboveground tanks

Aboveground tanks can be dangerous if access is not restricted. Uncontrolled access can lead to injury or death from falls from ladders and to death from drowning if someone falls into the storage tank. The following rules should be enforced:

- Permanent ladders on the outside of aboveground tanks should have entry guards locked in place or the ladder should be terminated above the reach of individuals.
- A ladder must never be left standing against an aboveground tank.

(c) Lagoons, ponds, and liquid storage structures

Lagoons, ponds, and liquid storage structures present the potential for drowning of animals and humans if access is not restricted. Floating crusts can appear capable of supporting a person's weight and provide a false sense of security. Tractors and equipment can fall or slide into storage ponds or lagoons if they are operated too close to them. The following rules should be obeyed:

- Rails should be built along all walkways or ramps of open manure storage structures.
- Fence around storage ponds and lagoons, and post signs reading "Caution Manure Storage (or Lagoon)." The fence keeps livestock and children away from the structure. Additional precautions include a minimum of one lifesaving station equipped with a reaching pole and a ring buoy on a line.
- Place a barrier strong enough to stop a slow-moving tractor on all push-off platforms or ramps.
- If manure storage is outside the livestock building, use a water trap or other device to prevent gases in the storage structure from entering the building, especially during agitation.

(d) Equipment

All equipment associated with waste management, such as spreaders, pumps, conveyors, and tractors, can be dangerous if improperly maintained or operated. Operators should be thoroughly familiar with the operator's manual for each piece of equipment. Equipment should be inspected frequently and serviced as required. All guards and safety shields must be kept in place on pumps, around pump hoppers, and on manure spreaders, tank wagons, and power units.

(e) Fences

Fences are an important component in some agricultural waste management systems. They are planned and designed in accordance with Conservation Practice Standard 382, Fencing. As they apply to agricultural waste management, fences are used to:

- Confine livestock so that manure can be more efficiently collected.
- Exclude livestock from surface water to prevent direct contamination.