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Field Handbook**

Chapter 1 Laws, Regulations, Policy, and Water Quality Criteria

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Chapter 1 — Laws, Regulations, Policy, and Water Quality Criteria

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Chapter 1 Laws, Regulations, Policy, and Water Quality Criteria

651.0100 Federal laws

(a) Introduction

Laws, regulations, and policies associated with manure management change due to advances in science and technology, changes in social and political objectives, and from knowledge gained through experience with their implementation. This chapter provides a reasonable introduction, overview, and background to these laws and policies, but it should not be substituted for a direct familiarity of the legal and policy documents themselves.

Many environmental laws enacted by Congress are enforced by the U.S. Environmental Protection Agency (EPA). The EPA issues regulations for prevention of air and water pollution, protection of drinking water, proper solid waste management, and control of pesticide use. Their broad regulatory powers related to air and water pollution and solid waste management are of great interest to the agricultural producer and to agencies, such as the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), that provide technical assistance to producers. State public health and environmental control agencies generally are responsible for implementing Federal and State control programs.

(b) Air

Federal legislative efforts to regulate air pollution began with the passage of the Air Pollution Control Act in 1955. The Clean Air Act was originally passed in 1963 with significant amendments in 1970, 1977, and 1990. The 1990 Clean Air Act Amendments (CAAA) introduced sweeping changes to the Clean Air Act and is the basis for many of the existing air quality regulations in the United States.

Since the Clean Air Act is the underlying environmental law for air quality in the United States, regulatory agencies, such as the EPA and other State and local regulatory agencies, must promulgate specific regulations to implement the Clean Air Act. The Federal regulations promulgated by the EPA can be found in Title 40 of the Code of Federal Regulations (CFR). Each State and local regulatory agency must implement regulations that are as stringent as, or more stringent than, the Federal regulations. Each of these sets of regulations addresses air quality concerns from many different types of air pollutant emission sources.

Federal regulations implementing the Clean Air Act include the establishment of National Ambient Air Quality Standards (NAAQS), as well as emissions standards for various pollutants and sources. These regulations currently do not address odors or greenhouse gases; however, these pollutants may be regulated at the State or local level. On the Federal level, emissions of importance to agriculture, such as particulate matter and ozone, as well as their precursor emissions, are regulated.

There are currently no specific exemptions or exclusions for agriculture in the Federal Clean Air Act regulations.

(c) Water

Federal legislation for protection of water quality began with the Rivers and Harbors Act of 1886 and 1889. In 1948, the Federal Water Pollution Prevention Act set a national policy for prevention, control, and abatement of water pollution. It was amended in 1956. The Federal role in water pollution control was expanded by the Water Quality Act of 1965, Clear Water Restoration Act of 1966, and Water Quality Improvement Act of 1970.

The Federal Water Pollution Control Act of 1972, Public Law 92–500, was passed so that the effectiveness and speed of implementation of water pollution control could be improved. This is to be accomplished by increasing Federal responsibility for establishing standards and providing greater involvement in their implementation and enforcement. The objective is to restore the chemical, physical, and biological integrity of the Nation's water. To achieve this objective, the law set a national goal of no discharge of pollutants into the Nation's water by 1985. Water of the United States is defined in the 40 CFR, part 122, to include wetlands and intermittent streams, as well as conventional lakes, ponds, rivers, streams, and the territorial seas.

Under section 303(d) of the 1972 Clean Water Act, States, territories, and authorized tribes are required to develop lists of impaired waters. These impaired waters do not meet water quality standards that have been set for them, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop estimates of the Total Maximum Daily Load (TMDL) for these waters. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards.

The Clean Water Act of 1977, Public Law 95–217, changed the 1972 amendments by providing more easily attainable objectives and time schedules. It strengthened the 1972 law's basic requirement that operators of point source discharges, such as those from industrial and municipal facilities, feedlots, and other discrete significant sources, obtain a permit specifying allowable amounts and constituents of effluents and a schedule for achieving compliance. The permits are known as National Pollutant Discharge Elimination System (NPDES) permits (see section 651.0101(a) of this chapter). The Clean Water Act has been modified in several instances since 1977.

(d) Other Federal actions of interest to agriculture

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was enacted in 1980 to provide broad Federal authority to respond to releases of hazardous substances that might endanger public health. The CERCLA requires reporting to EPA when a facility releases to the ambient air or water greater than a "reportable quantity" (100 pounds in a 24-hour period) of a hazardous substance. The EPA is authorized to require long-term remedial action that permanently and significantly reduces threats to public health. Originally focused on hazardous wastes from industrial plants, the increased size and consolidation of animal feeding operations has raised the possibility that the emission of substances like ammonia and hydrogen sulfide from such operations may be subject to the notification provisions of CERCLA (EPA 2005).

The Emergency Planning and Community Right-to-Know Act (EPCRA) was enacted in 1986. It establishes requirements for Federal, State and local governments, Indian Tribes, and industry regarding emergency planning and "Community Right-to-Know" reporting on hazardous and toxic chemicals. The Community Right-to-Know provisions help increase the public's knowledge and access to information on chemicals at individual facilities, their uses, and releases into the environment. States and communities, working with facilities, can use the information to improve chemical safety and protect public health and the environment. The EPCRA was passed in response to concerns regarding the environmental and safety hazards posed by the storage and handling of toxic chemicals. These concerns were triggered by the disaster in Bhopal, India, in which more than 2,000 people suffered death or serious injury from the accidental release of methyl isocyanate. To reduce the likelihood of such a disaster in the United States, Congress imposed requirements on both States and regulated facilities.

The National Environmental Policy Act (NEPA) is the basic national charter for protection of the environment. The NEPA establishes a process used during planning to produce better decisions for protection and enhancement of the environment. The process uses Environmental Assessments and Environmental Impact Statements to ensure that Federal agencies use "all practical means and measures" to protect and improve the environment. The NRCS procedures for environmental evaluations of proposed animal waste control facilities will meet the intent of NEPA.

Criteria for Classification of Solid Waste Disposal Facilities and Practices, Federal Register, Vol. 44, No. 179, September 13, 1979, defines requirements for land application of organic materials.

Water Quality Criteria, Federal Register, Vol. 45, No. 231, November 28, 1980, established the criteria for 64 waterborne constituents, which provided updated values for "Quality Criteria for Water" published by EPA.

The 1986 Amendments to the Safe Drinking Water Act, Public Law 99–339, established requirements for a new series of regulations covering such topics as filtration, disinfection, bacteria, and virus control. This law also set maximum contaminant levels for a large number of organic and inorganic chemicals including nitrates/nitrites, selenium, and many agricultural pesticides.

National Coastal and Marine Policy, January 1989, asserts that the EPA will protect, restore, and maintain the Nation's coastal and marine waters to protect human health and sustain living resources.

Criteria for Identifying Critical Aquifer Protection Areas—Final Rule—40 CFR 149, Federal Register, Vol. 54, No. 29, February 14, 1989, among other things, defines a critical aquifer area as one that is vulnerable to contamination; contamination is reasonably foreseeable unless a control program is implemented; contamination would cause significant economic, environmental, or social costs; and all or part of a sole source aquifer.

The 1987 Amendments to the Federal Water Pollution Control Act, Public Law 100–4, February 4, 1987, reflect the continued interest Congress has in assuring that water quality needs of the country are met. The Amendments added Section 319, "Nonpoint Source Management Programs," which requires States to assess water quality conditions and prepare and submit assessment reports to the EPA administrator. Based on State assessment reports, States are to prepare and implement water quality management plans that deal with problems in an orderly fashion. The major provisions of the section 319 amendment require State management programs to:

- identify best management practices (BMP) and measures to be undertaken to reduce pollutant loadings
- identify programs to achieve implementation of the best management practices
- schedule annual milestones for using program implementation methods and implementing the best management practices
- certify that State laws provide adequate authority to implement management programs
- assure that sources of funds and other types of assistance are available to carry out the management program

Section 319 allows for demonstration projects and hydrologic unit areas to be selected for implementation. States are required to develop and implement management programs on a watershed basis to the maximum extent practicable.

The Coastal Zone Act Reauthorization Amendments of 1990 (Public Law 101–508, Budget Reconciliation Act) amended the Coastal Zone Act of 1972 (16 USC 1455) by including requirements for coastal and Great Lakes States to develop programs for nonpoint source pollution control. Control programs are to be carried out by implementing a prescribed set of management measures. Programs are to "...serve as an update and expansion of State nonpoint source management program developed under section 319 of the Federal Water Pollution Control Act...."

651.0101 Federal regulations and rules

(a) National Pollutant Discharge Elimination System

The EPA published policies and procedures for issuance of National Pollutant Discharge Elimination System (NPDES) permits on May 22, 1973, and final regulations on March 18, 1976. These regulations established conditions under which separate storm sewers and concentrated animal feeding operations are considered point sources of pollution subject to NPDES permit requirements. On June 18, 1976, final regulations were published for silvicultural activities. On July 12, 1976, final regulations were published for agricultural activities that, in effect, defined irrigation return flows as an agricultural point source of pollution. However, in 1977, this definition was changed by Public Law 95–217, which specifically excluded irrigation return flows from NPDES regulation.

The NPDES permit requirements were consolidated with those of other EPA permit programs on May 19, 1980. They are included in the CFR, Title 40, parts 122, 123, 124, and 125. Most agricultural activities are not point sources of pollution subject to NPDES permits; however, concentrated animal feeding operations (CAFO) that discharge (or plan to discharge) are considered point sources by the EPA, and they are required to have a NPDES permit.

Most States have been granted full NPDES permitting authority by the EPA with oversight of State operations provided by the EPA. Where States do not have permitting authority, a variety of arrangements for permitting have been made. They range from the EPA doing all permitting to the EPA issuing permits for certain categories of pollutants (or operations) and the State issuing the permits for other categories.

(1) Concentrated animal feeding operations

Under the EPA CAFO rule, an animal feeding operation (AFO) is a lot or facility where animals are confined for 45 days or more a year, and crops, vegetations, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility. Discharge from an AFO defined as as CAFO is subject to NDPES permit requirements. A CAFO may fall into one of three types: Large CAFO, Medium CAFO, or Small CAFO based on the actual number of animals at the operation.

A Large CAFO has more than a specified number of animals by type which are confined.

A Medium CAFO has more than a specified number of animals, but less than a Large CAFO, and the animals are in contact with surface water running through the confinement area, or a constructed ditch or pipe carrying manure or wastewater from the animal housing or feeding area, or the permitting authority has designated the operation as a CAFO. The regional administrator of the EPA or the director of the State program reserves the right to designate any feedlot in this size range as a point source of pollution after an onsite inspection.

A Small CAFO has less than the minimum number of animals for designation as a Medium CAFO, and the regional administrator of the EPA or the director of the State program, after onsite inspection, determines that animals are in contact with surface waters running through the production area, and pollutants are discharged into the water of the United States through a fabricated device or directly into such water flowing through a feedlot.

Animal numbers for Large, Medium, and Small CAFOs are presented in table 1–1.

(2) Concentrated aquatic animal production facilities

NPDES permit requirements for concentrated aquatic animal production applies to direct discharges of wastewater from the following existing and new facilities:

- Facilities that produce at least 100,000 pounds a year in flow-through and recirculating systems that discharge wastewater at least 30 days a year (used primarily to raise trout, salmon, hybrid striped bass, and tilapia).
- Facilities that produce at least 100,000 pounds a year in net pens or submerged cage systems (used primarily to raise salmon).

Note: State regulations that are more stringent supersede the above criteria.

(3) NPDES permits

Point sources of pollution can be regulated by individual or general permits. Owners or operators of most point sources are required to apply for individual permits. These include some concentrated AFOs, concentrated aquatic animal production facilities, and certain silvicultural activities.

Part 122, Title 40, CFR established conditions and procedures whereby point sources can be regulated under a general permit. General permits can be made applicable to any category of point sources if the category has similar characteristics throughout the area covered by the general permit. Owners and operators are required to comply with the conditions of the general permit, but they do not have to apply for a permit.

The EPA has set the permitting requirements for CAFOs under the NPDES (40 CFR Part 122) and Effluent Limitations Guidelines and Standards (ELG) (40 CFR Part 412).

(4) Nonpoint source pollution

While concentrated animal facilities that discharge are considered point sources of pollution, other potential agricultural sources of water pollution are considered to be nonpoint sources.

Each State's comprehensive water quality plan includes controls for point sources (PS) and nonpoint sources (NPS) of water pollution. Features of point and nonpoint sources of water pollution are shown in table 1–2.

Table 1–1 EPA CAFOs classified as Large, Medium, and Small according to species animal numbers

Species	Large CAFO	Medium CAFO	Small CAFO
Beef cattle	1,000 or more	300 to 999	Less than 300
Veal	1,000 or more	300 to 999	Less than 300
Mature dairy cattle	700 or more	200 to 699	Less than 200
Dairy heifers	1,000 or more	300 to 999	Less than 300
Swine (55 lb or more)	2,500 or more	750 to 2,499	Less than 750
Swine (<55 lb)	10,000 or more	3,000 to 9,999	Less than 3,000
Turkeys	55,000 or more	16,500 to 54,999	Less than 16,500
Laying hens or broilers 1/	30,000 or more	9,000 to 29,999	Less than 9,000
Laying hens 2/	82,000 or more	25,000 to 81,999	Less than 25,000
Chickens except laying hens	125,000 or more	37,500 to 124,999	Less than 35,500
Ducks 1/	5,000 or more	1,500 to 4,999	Less than 1,500
Ducks 2/	30,000 or more	10,000 to 29,999	Less than 10,000
Sheep or lambs	10,000 or more	3,000 to 9,999	Less than 3,000
Horses	500 or more	150 to 499	Less than 150

1/ Only applicable to poultry operations with liquid manure systems;
2/ Other than liquid manure systems
Note: State regulations that are more stringent supersede the above criteria.

Table 1–2 Typical features of point and nonpoint sources of water pollution

Point sources	Nonpoint sources
Relatively steady flow over time	Flows usually occur at random and intermittent intervals following rain, snow melt, or ground thaw events
Adverse impacts most severe during periods of low stream flow or cumulative in lakes	Adverse impacts most severe during or following storm events or cumulative in lakes
Pollutants enter watercourses at identifiable points	Pollutants enter watercourses at many, often unidentifiable, points

The prescribed approach used for control of NPS is often different from that used for PS. PS controls generally rely on collection and treatment of potential pollutants. NPS control methods, on the other hand, are typically based on management of potential pollutants including such practices as land application of manure.

Individual States have been given the responsibility by EPA to formulate a comprehensive water quality plan for control of various pollutants and specific steps for selecting systems of practices. The choice of particular practices from those approved by the State depends on the site-specific conditions. The selection of practices for a particular case is related to the pollutant or pollutants that need to be controlled, type of agricultural activity contributing the pollutant or pollutants, and site-specific characteristics.

Water pollution laws form the foundation for a control program by specifying broad objectives and providing mechanisms to obtain them. However, legislation cannot define the important details and methods of implementation for programs that are conducted by such natural resource management agencies as the NRCS. Legislation can specify goals, standards, criteria, and other guidelines, but each program must be individually developed at the local level.

(b) CERCLA/EPCRA reporting rule for air releases of hazardous substances from animal waste at farms

The EPA has established rules for reporting requirements and associated reporting exemptions of releases of hazardous substances to the Federal government and State and local governments as required by the CERCLA and EPCRA. These include the rules for reporting the release of ammonia and hydrogen from manure management facilities at AFOs and CAFOs.

651.0102 State responsibilities

All State laws dealing with air and water quality and disposal of solid wastes must meet the minimum requirements of the Federal laws. Most States have such laws. Many have laws, rules, or regulations specifically addressing management of agricultural wastes in terms of surface and ground water quality requirements, management facilities, land application, and odors. Many of the State laws, rules, and regulations are more stringent than those promulgated by the Federal Government. In the absence of State requirements, the EPA assumes enforcement. As mentioned previously, odors and greenhouse gases are not currently regulated on the Federal level, although States may have implemented rules and regulations for these air emissions.

651.0103 State laws and regulations

Each State should supplement this section with information on State laws and regulations or reference where this information is located (see 450–GM, Part 405.03).

651.0104 Owner/producer responsibilities

All work in which the NRCS assists farmers and landowners must meet the minimum requirements of Federal, State, and local laws, rules, and regulations. Landowners, producers, and operators are responsible for obtaining required approvals and permits and for operating facilities in accordance with these laws, rules, and regulations.

651.0105 Safety

Safety is an important aspect of planning, design, construction, and operation of an agricultural waste management system (AWMS). The NRCS policy as it pertains to an AWMS includes:

- notification of utility companies when utilities are in the vicinity of engineering investigations or construction activities (National Engineering Manual (NEM), part 503)
- incorporating safety measures into structures (NEM, part 503)
- informing decisionmaker and contractor of safety requirements at preconstruction conferences (NEM, part 512.13)
- safety requirements for construction activities under formal NRCS contracting (Federal Acquisition Regulations, Clause 52.236–13, and 29 CFR 1910 and 1926)
- safety requirements for construction contracts under locally awarded contracts (120–V–CG-CAM (National Contracts, Grants, and Cooperative Agreements Manual, part 516)
- safety requirements for construction by informal contracting acquired by the decisionmaker (110–GM (General Manual), part 402.4)
- withdrawing NRCS assistance if unsafe construction conditions are not corrected (110–GM, part 402.13)

651.0106 Policies—Federal, USDA, and NRCS

The policies that guide involvement of USDA agencies in pollution abatement activities are in the following documents:

(a) USDA nonpoint source water quality policy

This policy (Department Regulation 9500–7, December 5, 1986) gives the key instructions for agencies of the USDA to follow concerning nonpoint source pollution. Some of the instructions are:

- ensure that actions and programs conform with the nonpoint source water quality plans adopted by State and local governments
- coordinate water quality activities with appropriate public and private institutions
- promote the improvement, protection, restoration, and the maintenance of water quality to support beneficial uses
- integrate water quality concepts, considerations, and management techniques into appropriate programs, research, and modes of assistance to landowners and land users
- provide Federal assistance in accordance with overall environmental policy and other procedural directives developed by the USDA
- encourage the use of best management practices (BMP) as the mechanism to meet Federal, State, and local water quality requirements for agricultural and silvicultural lands
- train agency personnel in surface water and ground water quality concepts to a level commensurate with their responsibility

(b) USDA policy for ground water quality

The foundation of this policy, Department Regulation No. 9500–8, November 9, 1987, is in support of "prudent use and careful management of nutrients and other agricultural chemicals" and in advocating and fostering programs, activities, and practices to avoid ground water contamination. To bolster this position, USDA agencies will continue to conduct research, monitoring, assessment, and evaluation of chemical management; provide information, education, and technical assistance to private landowners in using practices that minimize risks; and provide information and education to people and communities in rural areas about protecting wells from pathogens and nutrients and other agricultural chemicals.

(c) NRCS water quality policy

General Manual (GM), title 460, part 401, subpart A, establishes responsibilities in support of implementing water quality activities from the NRCS Chief through the various national office levels to the NRCS state conservationists. Some of the more important requirements are that the State Conservationists have the responsibility to:

- assist local soil and water conservation districts, other Federal and State Government agencies, and the private sector to identify and treat nonpoint source pollution problems
- ensure that actions, investments, and programs conform with water quality nonpoint source pollution programs by State and local governments
- incorporate BMP as part of Resource Management Systems (RMS), which are the most effective and practical means of preventing or controlling pollutants from nonpoint sources
- encourage landowners and land users to treat each acre within its capability and according to its needs for both surface and ground water quality protection and improvement
- cooperate with local conservation districts in developing conservation plans that use RMS to minimize pollution problems from animal wastes, nutrients, pesticides, salts, sediments, and related pollutants
- maintain adequately trained personnel in surface water and ground water quality concepts and management techniques

(d) NRCS conservation planning policy

General Manual (GM), title 180, Part 409, establishes NRCS policy for providing conservation planning assistance to clients. The objective in conservation planning is to help each client attain sustainable use and sound management of soil, water, air, plant, and animal resources. The purpose is to prevent the degradation of resources and to ensure their sustained use and productivity, while considering the client's economic and social needs.

Conservation planning guidance makes recommendations on the appropriate levels of assistance that may be provided for managing such activities as livestock waste, food processing waste, pesticides, and municipal wastewater and sewage sludge.

Livestock waste—Inventory, planning, and application assistance may be provided for agricultural waste management systems if the wastes are to be used for a beneficial purpose, such as use of water, nutrients, and organic material.

Food processing waste—Inventory, planning, and application assistance may be provided to farmers, ranchers, and food processors for waste management systems that include beneficial use of water, nutrients, and organic material. The NRCS does not often provide planning and application assistance to large corporate food processors. Traditionally, inventory, planning, and application assistance have been provided to smaller, family owned and operated food processing companies that grow the products that they process.

Pesticides—Inventory and planning assistance can be provided for a wide range of activities related to use and management of pesticides and waste pesticides. Application according to label, equipment operator protection, spill cleanup, equipment cleaning, container disposal, storage and transport, and filling and mixing areas are included. The use and management of pesticide waste should be carried out using guidelines and procedures jointly developed with the Cooperative Extension Service, experiment stations, and the pesticide industry.

Municipal wastewater and sewage sludge—The NRCS generally does not provide independent planning where wastewater or sludge is applied to land owned or controlled by a municipality or industry or where land applications are used strictly for disposal. The NRCS may provide planners in the private sector with soils and conservation practice information that can used for erosion control, nutrient management, vegetation management, and irrigation management. The NRCS may provide planning assistance to private land owners of agricultural land receiving municipal or industrial waste. Municipal or industrial waste must be applied according to EPA regulations (40 CFR Parts 403 (Pretreatment), 503 (Biosolids), 257 (Industrial Sludges), and other State and/or local regulations regarding the use of biosolids as a nutrient source). This will require monitoring the accumulation of potential pollutants and heavy metals including arsenic, cadmium, copper, lead, mercury, selenium, and zinc. (Sludge from municipal wastewater treatment facilities is solid waste, which comes under the purview of Public Law 580, Solid Waste Disposal Act, or Resource Conservation and Recovery Act of 1976.)

(e) NRCS Comprehensive Nutrient Management Planning policy

Comprehensive nutrient management plans (CNMPs) are developed in accordance with NRCS CNMP policy. GM 190, Part 405 establishes NRCS policy for Comprehensive Nutrient Management Plans (CNMP); GM 190, Part 405.11 delivers Minimal Requirements Essential for Providing CNMP Technical Assistance; the Field Office Technical Guide, Section III contains the CNMP technical criteria associated with specific elements of a CNMP; and the National CNMP Field Handbook details the steps of CNMP development and implementation, associated software, and automation of the process. From GM 190 Part 405:

A. A CNMP is a conservation plan for an AFO or user of the by-products of an AFO that:

(1) Must include the following:

(a) The production area including the animal confinement, feed and other raw materials storage areas, animal mortality facilities, and the manure handling containment or storage areas; and

(b) The land treatment area, including any land under control of the AFO owner or operator, whether it is owned, rented, or leased, and to which manure or process wastewater is, or might be, applied for crop, hay, pasture production, or other uses;

(2) Meets NRCS FOTG Section III quality criteria for water quality (nutrients, organics, and sediments in surface and ground water) and soil erosion (sheet and rill, wind, ephemeral gully, classic gully, and irrigation induced natural resource concerns on the production area and land treatment area);

(3) Mitigates, if feasible, any excessive air emissions and/or negative impacts to air quality resource concerns that may result from practices identified in the CNMP or from existing on-farm areas/activities;

(4) Complies with Federal, State, Tribal, and local laws, regulations, and permit requirements; and

(5) Satisfies the owner/operator's production objectives.

(f) Federal policy on land application of municipal sewage sludge

The Federal Policy for Use of Municipal Sewage Sludge for the Production of Fruits and Vegetables was published in January 1981. It was jointly developed by the USDA, EPA, and Food and Drug Administration (FDA). NRCS technical assistance must be provided in conformance with the guidelines established in this document. The policy was an outgrowth of the EPA regulations, "Criteria for Classification of Solid Waste Disposal Facilities" [Federal Register, Vol. 44, No. 179 (40 CFR, Part 257), 9/13/79]. The regulation addresses land application of municipal wastewater sludge for food chain crop production. It states that through use of high quality sludge coupled with proper management procedures, the consumer should be protected from contaminated crops, and potential adverse environmental effects will be minimized.

(g) NRCS Electronic Field Office Technical Guide policy

General Manual, Section 450, Part 401, establishes the need to develop resource management plans that deal with agricultural wastes. This is supported by entries in the Electronic Field Office Technical Guide (eFOTG) "Waste Disposal Interpretations," Section II, Soil and Site Information, 401.3(b)(2), and "Animal Wastes and Agri-Chemical Management," Section III, Resource Management Systems, 401.3(b)(3).

RMS and BMP are similar, but they have some fundamental differences. Their differences are indicated by the following definitions:

RMSs are a combination of conservation practices and management identified by primary use of land or water that, if installed, will at a minimum protect the resource base by maintaining acceptable ecological and management levels for the five resource concerns in accordance with the FOTG.

BMP, as defined in 40 CFR, Part 130, are a practice or combination of practices determined by a State after problem assessment, examination of alternative practices and appropriate public participation, to be the most effective, practicable means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals. BMPs address one or more resource concerns.

(h) NRCS flood plain and wetland policy

NRCS environmental policy in GM–190, part 410, applies when waste management facilities on flood plains or wetlands are being planned. This policy restricts or requires special provision for certain agricultural waste management structures or activities within flood plains and wetlands. It is NRCS policy that flood plains be, to the extent practical, conserved, preserved, and restored to existing natural and beneficial value on base (100 year) flood plains as a part of technical and financial assistance in programs NRCS administers. A permit may be necessary to comply with the Clean Water Act, section 404(b)(1), if earth is filled or removed on the flood plain. If AWMS facilities encroach on a flood plain, a building permit may be required by local agencies. It is also NRCS policy to aid in protecting, maintaining, managing, and restoring wetlands.

(i) NRCS agricultural waste management conservation practice standards

National standards for agricultural waste management are in the National Handbook of Conservation Practice Standards. The field office standards are in section IV of the Field Office Technical Guide. Conservation practice standards (CPS) establish the minimum level of quality with which these practices are planned, designed, installed, operated, and maintained. The NRCS CPS can be used to address specific waste management needs of producers. Some examples are:

Waste Storage Facility (Code 313)—A waste storage impoundment made by constructing an embankment and/or excavating a pit or dugout, or by fabricating a structure. The purpose of the practice is to temporarily store wastes such as manure, wastewater, and contaminated runoff as a storage function component of an agricultural waste management system.

Animal Mortality Facility (Code 316)—An on-farm facility for the treatment or disposal of livestock and poultry carcasses. This practice may be applied as part of a conservation management system to support one of the following purposes: decrease nonpoint source pollution of surface and ground water resources, reduce the impact of odors that result from improperly handled animal mortality, decrease the likelihood of the spread of disease or other pathogens that result from the interaction of animal mortality and predators, and provide contingencies for normal and catastrophic mortality events.

Composting Facility (Code 317)—A facility to process raw manure or other raw organic by-products into biologically stable organic material. The purpose of the practice is to reduce the pollution potential of organic agricultural wastes to surface and ground water.

Waste Treatment Lagoon (Code 359)—An impoundment made by excavation or earthfill for biological treatment of animal or other agricultural wastes. The purpose of the practice is to reduce the pollution potential component of a waste management system.

Closure of Waste Impoundments (Code 360)—The closure of waste impoundments (treatment lagoons and waste storage ponds) that are no longer used for their intended purpose in an environmentally safe manner. The purposes of this practice are to protect the quality of surface water and ground water resources, eliminate a safety hazard for humans and livestock, and safeguard the public health.

Anaerobic Digester (Code 366)—An anaerobic digester is a component of a waste management system that provides biological treatment in the absence of oxygen. The purposes of this practice are to capture biogas for energy production, manage odors, reduce the net effect of greenhouse gas emissions, and reduce pathogens.

Roofs and Covers (Code 367)—A manufactured membrane, composite material, or roof structure placed over a manure management facility. Its purpose is to provide a roof or cover for water quality improvement, air quality improvement and odor reduction, capture of biogas for energy production, or to divert clean water from manure pack and/or manure storage facilities.

Roof Runoff Management (Code 558)—A facility for collecting, controlling, and disposing of runoff from roofs. The purpose of this practice is to divert noncontaminated runoff away from areas where waste accumulates to areas where clean water can be disposed of safely.

Nutrient Management (Code 590)—Managing the amount, form, placement, and timing of application of plant nutrients. The purpose of this standard is to assure that all sources of plant nutrients, including livestock waste, are included in a fertility program designed to supply plant nutrients for optimum yields, yet minimize nutrient losses to surface and ground water.

Amendments for the Treatment of Agricultural Waste (Code 591)—Applies where the use of a chemical or biological amendment will alter the physical and chemical characteristics of the waste stream as part of a planned waste management system. This practice will improve or protect air quality, water quality, animal health, and will alter the consistency of the waste stream to facilitate implementation of a waste management system.

Feed Management (Code 592)—Managing the quantity of available nutrients fed to livestock and poultry for their intended purpose in order to supply the quantity of available nutrients required by livestock and poultry for maintenance, production, performance, and reproduction; while reducing the quantity of nutrients, especially nitrogen and phosphorus, excreted in manure by minimizing the over-feeding of these and other nutrients. This action should improve net farm income by feeding nutrients more efficiently.

Waste Treatment (Code 629)—For the mechanical, chemical, or biological treatment of agricultural waste. The purpose is to use mechanical, chemical, or biological treatment facilities and/processes as part of an agricultural waste management system. This should improve ground and surface water quality by reducing the nutrient content, organic strength, and/or pathogen levels of agricultural waste; improve air quality by reducing odors and gaseous emissions; produce value added by-products; and facilitate desirable waste handling, storage, or land application alternatives.

Solid/Liquid Waste Separation Facility (Code 632)—A filtration or screening device, settling tank, settling basin, or settling channel used to separate a portion of solids from a liquid waste stream. The purpose of the practice is to partition solids, liquids, and their associated nutrients as part of a conservation management system to improve or protect air quality, water quality, or animal health or meet management objectives.

Waste Utilization (Code 633)—using animal or other agricultural wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources. The purpose of the practice is to safely recycle waste materials back through the soil-plant system.

Waste Transfer (Code 634)—A system using structures, conduits, or equipment to convey by-products (wastes) from agricultural operations to points of usage. The purpose of this practice is to transfer agricultural material associated with production, processing, and/or harvesting through a hopper or reception pit, a pump (if applicable), a conduit, and/or hauling equipment to a storage/treatment facility, loading area, and/or agricultural land for final utilization as a resource.

Vegetated Treatment Area (Code 635)—A component of an agricultural waste management system consisting of an area of permanent vegetation used for agricultural wastewater treatment. The purpose of this practice is to improve water quality by reducing loading of nutrients, organics, pathogens, and other contaminants associated with livestock, poultry, and other agricultural operations

Constructed Wetland (Code 656)—An artificial ecosystem of saturated soils and hydrophytic vegetation used for water treatment. The purpose of this practice if for treatment of wastewater and contaminated runoff from agricultural processing, livestock, and aquaculture facilities or for improving the quality of storm water runoff or other water flows lacking specific water quality discharge criteria.

Many other practice standards are used to support those listed, such as those for irrigation, tillage, and cropping systems. Other conservation practice standards will be developed as needed to supplement agricultural waste management systems based on proven research development.

(j) NRCS policy on biosecurity

The NRCS policy on biosecurity can be found in the Agency's General Manual at Title 130, Part 403, Subpart H, Biosecurity Preparedness and Response.

This policy states that: "During periods of outbreak of infectious animal diseases, NRCS employees shall not enter affected areas for normal planning and implementation purposes. Entry to those areas shall only be made in response to a request from the State Veterinarian or other responsible official in order to provide guidance and assistance for mortality disposal. In those situations, biosecurity measures as directed by the responsible official shall be followed."

651.0107 Water quality criteria and standards

Water quality objectives, criteria, and standards are interrelated, but different from one another. A water quality **objective** is a goal toward which a control program is aimed. For example, an objective of Public Law 92–500 was to eliminate discharge of all pollutants into navigable streams by 1985. Objectives often represent an ideal condition.

Water quality **criteria**, on the other hand, represent specific, though not necessarily precise, quality characteristics that research and experience indicate are generally necessary to support various water uses. They provide a measure of suitability of water quality for a particular use and what magnitude of change is needed to make it suitable.

Water quality **standards** differ from objectives and criteria in that they represent measures required by laws or regulations. They tend to be rigid and absolute and are either met or violated. Standards provide the "teeth" for water quality legislation and also the yardstick by which performance can be evaluated. Water quality standards generally are related directly to the specific quality criteria for uses to be protected.

(a) Water quality criteria

Water quality criteria provide the best estimate, based on available research and experience, of the characteristics necessary for various uses of water. These criteria provide a basis for determining if a specific body of water is suitable for a particular purpose. Unfortunately, because of the variability in factors that influence water quality criteria, they tend to be imprecise. Nevertheless, the criteria are based on the best information available and thus should be adhered to unless State or local guidelines based on the specific local situation suggest differently.

Generally, if water quality criteria, such as those published by the EPA, are met by a particular water source for a specific use, that source for that use will be safe over a fairly large range of circumstances.

Water that does not meet a particular criterion may be suitable for a specific use, but the margin of safety for that use is reduced.

In some cases, local information and experience allow criteria to be adjusted. Because water quality criteria are not legally binding, they can be modified by State or local agencies if experience suggests criteria different from those of the EPA are more appropriate for local conditions.

Water quality criteria are continually changing, so the summary of EPA criteria given in table 1–3 may change as new and better information becomes available. For a more complete listing of water quality criteria, refer to the EPA publication “Quality Criteria for Water” published in 1986.

(b) National water quality standards

Water quality standards are legally enforceable and set maximum allowable limits of concentration for various pollutant constituents or minimum limits of favorable constituents. Typically, standards relate to water quality in a receiving stream, for example, concentration of Biochemical Oxygen Demand (BOD). However, technology-based standards are established for use of the most effective control or treatment technologies available to prevent water pollution.

The early water quality standards, which related to health, were aimed at improving domestic drinking water supplies. If a particular water source was used for drinking, it had to meet the quality standards or be treated in some fashion so that it would meet those standards. Responsibility for meeting the standards

Table 1–3 Water quality criteria (EPA 1986)

Color	For aesthetic purposes, water shall be virtually free from substances producing objectionable color. The source of the color should not exceed 75 color units in the standard platinum-cobalt scale for domestic water supply. Increased color (in combination with turbidity) should not reduce the depth of the zone of effective photosynthetic oxygen production by more than 10 percent from the seasonally established norm for aquatic life.
Dissolved oxygen	Water should contain sufficient dissolved oxygen to maintain aerobic conditions in the water column and, except as affected by natural phenomena, at the sediment-water interface for aesthetic purposes. A minimum concentration of dissolved oxygen to maintain good fish populations is 5 mg/L.
Fecal coliform bacteria	For bathing, swimming, and other body contact water recreation based on a minimum of five samples taken over 30 days, the fecal coliform bacteria should not exceed a log mean of 200 per 100 ml, nor should more than 10 percent of the total samples taken during any 30-day period exceed 400 per 100 ml; and The median fecal coliform bacteria concentration should not exceed 14 MPN (most probable number) per 100 ml with not more than 10 percent of samples exceeding 43 MPN per 100 ml for the harvesting of shellfish.
Nitrate (NO_3)	For health reasons, domestic water supplies should not have nitrate nitrogen concentrations exceeding 10 mg/L (for humans).
Nitrite (NO_2)	For heath reasons, domestic water supplies to be used by infants should not have nitrite nitrogen concentrations exceeding 1 mg/L.
Phosphorus	Criteria for phosphorus from the EPA 1986 reference are explained in chapter 3 of this handbook. See 651.0302(a)(2)(ii), Effects of phosphorus in the aquatic environment.
Solids and turbidity	For freshwater fish and other aquatic life, settleable and suspended solids should not reduce the depth of the zone of photosynthetic oxygen production by more than 10 percent from the seasonally established norm.

has typically been assigned to the user. In general, the burden of meeting standards is now moving from the water user to the potential water polluter. Water quality standards are now aimed at control of potential pollutants at the source. This change in focus, in part, has resulted in the use of standards for point sources based not only on pollutant concentrations in water, but also on the **best available technologies** for control of water pollution.

Standards for confinement feedlots and agricultural NPS pollution are technology-based and specify particular design or procedural practices. For example, NPDES permits required for confinement feedlots specify design and operation standards.

Design standards are also necessary in the definition of NPS water pollution control practices, particularly if they are structural. Procedural standards for pollution control may, for example, include such management practices as proper manure spreading or fertilizer management.

The provisions of section 303 of the 1972 Federal Water Pollution Control Act Amendments require that the State agency designated responsibility for water pollution control adopt water quality standards that have been submitted to EPA for approval.

State water quality standards are established for water uses for specific watercourses. The identification of specific water uses for watercourses is often referred to as stream classification. Stream classification is carried out by the States following State-defined procedures. The procedures generally consider:

- needs and desires of the public
- present and future demands on the watercourse
- cost of maintaining different stream qualities
- benefits expected under different control alternatives

Not all streams are classified, and those that are may not be classified in a straightforward manner. Wide variations in classification can occur along the same stream. Classification is done not only for streams, but for all natural watercourses.

Table 1–4 gives an example of a designated area classification system. Classification systems vary from State to State.

Each water use classification requires a specific quality of water. Therefore, once a designated area is classified for specific uses by the State agency responsible for water pollution control, water quality standards are defined for that area. In some cases, the pollutant assimilative capacity, water quality requirements, and other stream characteristics are not directly used in determining standards. In such cases, technology-based effluent standards are used. An example of these is the NPDES permits required of feedlot operations.

Table 1–4 Example of a designated area classification system

Class	Water uses
I	Sources of water supply for drinking or food processing purposes, requiring principally disinfection. Any other usage requiring water of lower quality.
II	Sources of water supply for drinking or food processing purposes, requiring treatment in addition to disinfection. Any other usage requiring water of lower quality.
III	Sources not used for drinking or food processing purposes, but used for swimming or other body contact recreation. Any other usage requiring water of lower quality.
IV	Sources not used for drinking or food processing purposes or body contact recreation, but used for fishing or other non-body contact recreation. Any other usage requiring water of lower quality.
V	Sources used only for agriculture or industrial supplies, fish survival, or navigation.

651.0108 Agricultural impacts on the use of water

(a) Agricultural waste and its impact on water use

The value of water lies in its usefulness for a wide variety of purposes, and the quality determines its acceptability for a particular use. Therefore, a quality problem occurs when water is contaminated to a level where it is no longer acceptable for a particular use. Water quality criteria are often used to determine acceptability. Potential water pollutants derived from agricultural waste can be classified as nutrients, oxygen-demanding materials, bacteria that indicate potential presence of pathogens, sediment, suspended or dissolved materials, and agrichemicals and other organic and inorganic materials.

For water quality parameters to have meaning, they must be related to one or more beneficial uses of water. The uses include domestic, industrial, and agricultural water supplies; swimming, fishing, boating, and other forms of recreational use; and commercial navigation. Agricultural wastes are not likely to adversely affect commercial navigation.

(b) Impacts on domestic water supplies

Although only a very small amount of the water taken for domestic purposes is used for drinking, it is because of this use that domestic water is of the utmost concern and has the most stringent quality requirements.

Water withdrawn from surface watercourses for domestic or municipal supply is almost always treated to some degree to remove contaminants. In the case of individual home water supplies, this treatment might only involve chlorination to destroy pathogens or other organisms. Municipal water supplies are generally treated more extensively. Water quality concerns for domestic supplies should never be taken lightly. Failure of supplies to meet standards for even short periods of time can result in serious illness.

Quality requirements for domestic drinking water are determined by the EPA and, in some instances, include modifications and additions from the State health department. Water quality regulations for domestic supplies can be divided into two categories: primary standards related to health concerns and secondary standards pertaining to aesthetic interests.

Health associated regulations often relate to toxic levels of artificial and natural substances. Under the 1986 amendments to the Safe Drinking Water Act, the EPA set primary standards for 83 contaminants. Some of the substances that are associated with agriculture include nitrate, bacteria, selenium, lindane, toxaphene, 2–4D, aldicarb, alachlor, carbofuran, simazine, atrazine, picloram, dalapon, diquat, and dinoseb. Those regulations aimed primarily at aesthetics include such substances as foaming agents, pH, and total dissolved solids.

The primary and secondary standards for drinking water for specific constituents are listed in table 1–5.

Table 1–5 Selected primary and secondary drinking water standards as specified by the EPA

Constituent	Maximum allowed
Primary standards	
Inorganic chemicals	
Nitrate-nitrogen	10 mg/L
Selenium	0.045 mg/L*
Synthetic organic chemicals	
Lindane	0.0002 mg/L*
Toxaphene	zero*
Alachlor	zero*
Aldicarb	0.009 mg/L*
Carbofuran	0.036 mg/L*
Total coliform bacteria	
Total coliform no more than 1 coliform-positive sample/month for systems that analyze fewer than 40 samples/month, and no more than 5 percent of samples positive if system analyzes more than 40 samples/month	
Fecal coliform bacteria	zero*
Secondary standards	
Color	15 units
Foaming agents	0.5 mg/L
Odor numbers	3 threshold odor
Total dissolved solids	500 mg/L

* EPA units under 1986 Safe Drinking Water Act Amendments.

Surface water, especially streams, often contains many complex mixes of pollutants that are difficult to remove because levels vary widely over time. Therefore, the 1986 Safe Drinking Water Act Amendments require that all public drinking supplies from surface water undergo filtration and disinfection treatment.

Ground water, however, tends to maintain a quality that remains relatively constant over time and some substances are not present or occur only at low levels. Soil filtration removes most turbidity, color, and microorganisms, and some chemicals can be absorbed by the soil. Because of the natural purification of water as it percolates through soil, ground water is often used as a domestic supply with little treatment. However, ground water monitoring programs have recently increased because of the growing concern that this water supply source may not always be as safe as previously assumed. One of the primary problems of using ground water for domestic purposes is the lack of localized water quality information. Furthermore, localized ground water quality can be radically affected by a local source of contaminant, such as nitrate from confined livestock or other NPS.

Some of the constituents in deep ground water aquifers are associated with agricultural chemicals, but generally not livestock waste. Nitrate is the primary constituent that can pollute ground water and have manure as its source. Water contaminated by nitrate can be treated with an ion exchange process to remove the contaminant, but this can be an expensive process and is not practical for many areas.

Under certain situations livestock waste can be a source of ground water pollution other than nitrate contamination. For example, shallow aquifers that supply dug wells can be contaminated by animal waste. Aquifers overlain by porous materials, such as gravel or some types of limestone, allow pollutants to be easily transported to the ground water. In some cases, poorly designed or constructed wells or earthen manure storage ponds can be the cause of ground water contamination from livestock waste.

(c) Impacts on industrial water supplies

Industry uses water for a wide variety of purposes, so it is not surprising that water quality requirements for industry also vary widely. Several broad categories of industrial water uses include separation processes, transport of materials, cooling, chemical reactions, and product washing.

Food processing industries are of particular concern because water used to wash food influences the quality of the final product. Water quality of the supply source, however, is less important for most industrial uses than for domestic or other uses because industry possesses the technology to treat water to acceptable levels. Because this treatment can be quite expensive, however, guidelines for upper limits or concentrations of selected constituents in water supplies for some industrial uses are identified. This allows industries to treat only to the acceptable level. Table 1–6 lists the maximum allowable concentrations of constituents in raw water supplies for several industrial operations as determined by the National Academy of Sciences (1974).

Table 1–6 Maximum allowable concentrations of selected constituents in raw water supplies for industrial use (mg/L)

Constituent	Petroleum	Chemical	Paper	Textile	Cooling water
Ammonia	40	—	—	—	—
Nitrate	8	—	—	—	30
Dissolved solids	3,500	2,500	1,000	150	1,000
Suspended solids	5,000	10,000	—	1,000	5,000
Color	25	500	360	—	—

(d) Impacts on agricultural uses

Farms require a domestic water supply in addition to water used for a variety of other purposes. Livestock farmers are especially concerned with water quality for health and product quality reasons (especially milk).

A water supply that is both potable (safe to drink) and palatable (nice to drink) is most desirable for livestock consumption, although the water generally does not need to be as pure as that for human consumption. Livestock farmers must be particularly careful that the farm water supply does not become contaminated by the livestock waste. Surface ponds or tanks to which livestock have ready access are always potential candidates for contamination.

The quality of water needed for livestock consumption varies with the type and age of animals. In general, young animals are less tolerant of water that has high nitrate or fecal coliform levels. Some animals, primarily lactating ones, have a relatively high daily intake of water as compared to their body weight. The daily intake for lactating cows, for instance, may be 25 to 35 gallons of water. High water intake increases the risk of health problems resulting from poor water quality. Table 1–6 gives recommended limits of concentrations of some potentially toxic substances in drinking water for livestock. Those substances that originate on livestock farms and that often contaminate livestock water supplies include nitrates, bacteria, organic materials, and suspended solids.

Nitrate-nitrogen standard for human consumption is 10 milligrams per liter. No standards for livestock are established, but it is generally accepted that nitrate-nitrogen levels of over 100 milligrams per liter can adversely affect the growth and health of livestock. Most young animals should be given water in which the nitrate level is much lower than 100 milligrams per liter. The size of the animal generally affects their sensitivity to nitrate-nitrogen. For example, poultry are less tolerant to nitrate-nitrogen than swine, which are less tolerant than cattle.

Fecal coliform count should be essentially zero for calves and less than 10/100 milliliters for adult animals. A high level of suspended solids and objectionable taste, odor, and color in water can cause animals to drink less than they should. Refer to tables 1–7, 1–8, and 1–9 for specific guidance.

Water used to wash food products or food handling equipment at the farmstead, including dairy utensils, must be contaminant free (potable water appropriate for domestic supply).

Irrigation, the largest consumptive use of water nationally, requires a water supply that does not contain substances that adversely affect plant growth. Typically, livestock waste is not the source of any waterborne

Table 1–7 Recommended limits of concentration of some potentially toxic substances in drinking water for livestock (based on Carson 1981)

Substance	Safe upper limit of concentration (mg/L)	
	EPA*	NAS**
Aluminum	5.0	
Arsenic	0.02 (0.05)	0.2
Barium	(1.0)	***
Beryllium	No limit	
Boron	5.0	
Cadmium	0.05 (0.01)	0.05
Chromium	1.0 (0.05)	1.0
Cobalt	1.0	1.0
Copper	0.5 (1.0)	0.5
Fluoride	2.0	2.0
Iron	No limit (0.3)	***
Lead	0.1 (0.05)	0.1
Manganese	No limit (0.05)	***
Mercury	0.001 (0.000144)	0.01
Molybdenum	No limit	***
Nickel	(0.6)	1.0
Nitrate-N	100 (10.0)	100.0
Nitrite-N		10.0
Selenium	0.05 (0.01)	
Vanadium	0.1	0.1
Zinc	25.0 (5.0)	25.0

* EPA (standards for human drinking water are shown in parenthesis)
** National Academy of Sciences
*** Not established/no limit. Experimental data available are not sufficient to make definite recommendations

Table 1–8 Desired and potential problem levels of pollutants in livestock water supplies*

Substances	Desired range	Problem range
Total bacterial/100 ml	<200	>1,000,000
Fecal coliform/100 ml	<1	>1 for young animals; >10 for older animals
Fecal strep/100 ml	<1	>3 for young animals; >30 for older animals
pH	6.8–7.5	<5.5 or >8.5
Dissolved solids mg/L	< 500	>3,000
Total alkalinity mg/L	<400	>5,000
Sulfate mg/L	<250	>2,000
Phosphate mg/L	<1	**
Turbidity Jackson units	<30	**

* Based on research literature and field experience in northeastern United States
** Not established

Table 1–9 Effect of salinity of drinking water on livestock and poultry (Water Quality Criteria 1972)

Soluble salt (mg/L)	Effect
<1,000	Low level of salinity; present no serious burden to any class of livestock or poultry
1,000 to 2,999	Satisfactory for all classes of livestock and poultry; may cause temporary, mild diarrhea in livestock; and water droppings in poultry at higher levels; no effect on health or performance
3,000 to 4,999	Satisfactory for livestock; may cause temporary diarrhea or be refused by animals not accustomed to it; poor water for poultry causing watery feces and, at high levels, increased mortality and decreased growth (especially in turkeys)
5,000 to 6,999	Reasonable safety for dairy and beef cattle, sheep, swine, and horses; avoid use for pregnant or lactating animals; not acceptable for poultry, causes decreased growth and production or increased mortality
7,000 to 10,000	Unfit for poultry and swine; risk in using for pregnant or lactating cows, horses, sheep, the young of these species, or animals subjected to heavy heat stress or water loss; use should be avoided, although older ruminants, horses, poultry, and swine may subsist for long periods under conditions of low stress
>10,000	Risks are great; cannot be recommended for use under any conditions

substances that would harm crop growth unless excessive amounts of wastes are applied. Manure provides nutrients needed for plant growth. Very high levels of nitrate (100 to 500 mg/L) can cause quality problems for certain crops that are irrigated by sprinkler systems. High coliform concentrations in water applied to fruits or vegetables to be marketed without further processing can also be a problem. Livestock can be the source of suspended matter and, indirectly, algae, both of which can interfere with the operation of sprinkler and trickle irrigation systems. In arid regions, soils that are already high in salts can have this condition aggravated by land application of livestock waste.

(e) Impacts on recreation

Kinds of water-based recreation vary, and each has slightly different water quality requirements. For example, swimmers generally prefer crystal clear water, but fishermen prefer that the water have some plant and algae growth, which promotes fish production. Many water quality requirements for recreational uses are highly qualitative and vary from one use to another and even from one user to another. Water-based recreation can be broadly separated into contact and noncontact activities. Obviously, the contact activities present greater health concerns, which relate primarily to disease-causing microbes. Requirements for noncontact recreational activities are similar to those for promotion of aquatic life and aesthetic considerations.

Typically, the acceptability of water for contact recreation is determined by measuring the level of an "indicator organism," such as fecal coliform bacteria, that denotes the likely presence or absence of other potentially harmful organisms. The degree of risk involved is associated with the level at which the organisms are present. Indicator organisms are used because the actual disease-causing organisms are extremely difficult to routinely measure. See table 1–3 for criteria for fecal coliform bacteria.

Surveys for E. coli and enterococci bacteria can be conducted if more rigorously investigated bacterial status of bathing waters is desired. For freshwater bathing, the geometric mean of bacterial densities for E. coli should not exceed 126 per 100 milliliters, or 33 per 100 milliliters for enterococci. For marine water bathing, the geometric mean of enterococci bacteria densities should not exceed 35 per 100 milliliters. Sufficient numbers of samples, generally not less than five spaced equally over a 30-day period, should be gathered and a confidence level applied to the test results according to the intensity of use of the water. This should be accomplished before making a final judgment about the acceptability of the water for bathing purposes.

(f) Impacts on aesthetics

Manure and other waste associated with livestock production can be important sources of aesthetic degradation. For example, they can be the source of objectionable deposits, floating scum, bad odors, and nutrients that promote growth of nuisance aquatic life. Local regulations are often aimed at maintenance of aesthetic quality of watercourses.

To maintain aesthetic water quality, all water should be free from substances that:

- settle to form objectionable deposits
- float as debris, scum, or other matter to form nuisances
- produce objectionable odor, color, taste, or turbidity
- injure, are toxic, or produce adverse physiological responses in humans, animals, or plants
- produce undesirable or nuisance aquatic life

651.0109 References

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United States
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**Soil
Conservation
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Agricultural
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Field Handbook

Chapter 2 Planning Considerations

Chapter 2 Planning Considerations

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Chapter 2 Planning Considerations

651.0200 Introduction

Planning an Agricultural Waste Management System (AWMS) involves the same process used for any type of natural resource management system, such as an erosion control system. Each system includes a group or series of practices planned, designed, and installed to meet a need. However, different resource concerns, management requirements, practices, environmental effects, and economic effects must be considered.

Planning an AWMS often requires the cooperation and combined efforts of a team of people. The team is made up of the decisionmaker of the property involved and may include Soil Conservation Service (SCS) specialists and conservationists, county agricultural extension agents, and professionals outside of government. Specialists include engineers, geologists, soil scientists, and agronomists. The SCS planner must establish a good working relationship with all members of the planning team.

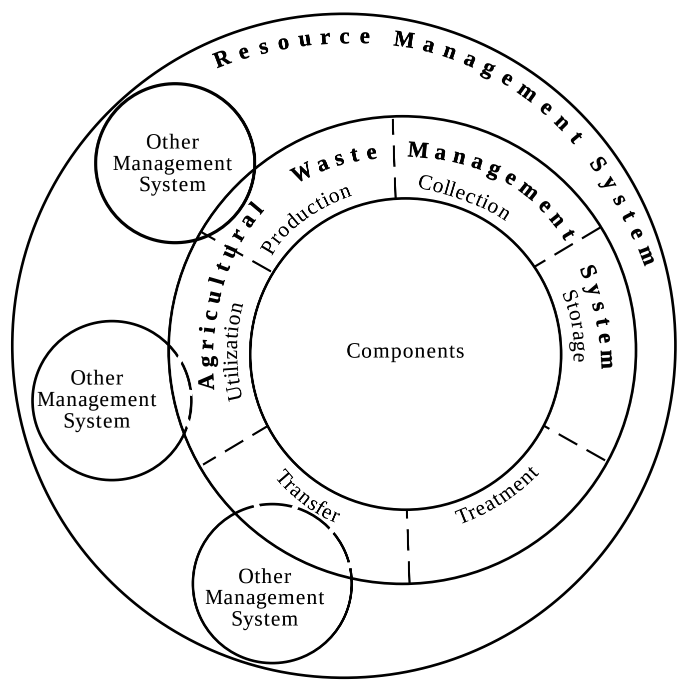
The planning process is often complex because of the number of alternatives to be considered; however, the AWMS selected should be as simple and easily managed as possible.

To successfully plan an AWMS, the planner should understand that it is planned under the umbrella of a Resource Management System (RMS) (fig. 2–1). An RMS is a unique combination of practices and management that when applied to a specific land use and problem situation will protect the resource base and environment. It also provides solutions to all identified resource problems and meets the decisionmaker's and public's resource use, conservation, and maintenance objectives. As such, an AWMS is a subsystem in an RMS that deals with an agricultural waste problem. In solving an agricultural waste problem, an AWMS will interface or relate to other subsystems in an RMS, such as a cropping system or a water management system.

The planner should view an AWMS as including the following functions: (1) production, (2) collection, (3) storage, (4) treatment, (5) transfer, and (6) utilization. This simplifies interpreting, analyzing, and evaluating the inventory data as well as the planning of alternatives.

The functions are accomplished by implementing components. The components may be an interrelated group of conservation practices, such as a waste storage pond, roof runoff water management, diversion, and waste utilization. Push-off ramps, manure pumps, transport equipment, grade control structures, and vegetative treatments are examples of component elements that support the functions.

Figure 2–1 Relationship of an Agricultural Waste Management System, other management systems, and the Resource Management System



651.0201 Planning for protection of natural resources

The major objective of SCS in planning an AWMS is to help the producer achieve wise use of natural resources. The key to doing this is to involve the decisionmaker in the planning process. The SCS must assure that the decisionmaker involved in planning an AWMS recognizes the nature, extent, and importance of the five resources—soil, water, air, plants, and animals (fig. 2–2). In addition to the resources, the social, cultural, and economic effects of alternative AWMS's on the human environment must be considered. A brief discussion of each of the planning aspects as they relate to an AWMS follows.

(a) Soil

The soil resource is a very important aspect of planning an AWMS as it is most often the medium used in the final assimilation of many of the agricultural waste products. The application of organic agricultural wastes has a beneficial influence on the soil condition by improving tilth, decreasing crusting, increasing organic matter, and increasing infiltration.

Waste must be applied to the soil so that the constituents in the waste do not exceed the soil's capacity to adsorb and store them. The rate at which wastes are applied must not exceed the soil's infiltration rate. Application of wastes at a rate that exceeds the soil's infiltration rate can result in runoff, which can cause erosion. Plant nutrients in solution or those attached to the soil particles along with bacteria, organic matter, and other agricultural material may be transported to the receiving water.

(b) Water

Maintaining or improving the quality of surface and ground water generally is an important aspect in the planning of an AWMS. Potential ground water contaminants from agricultural operations include nutrients, generally nitrates; salts; waste pesticides; and bacteria. Potential surface water contaminants from agricultural operations are nutrients, usually nitrates in solution; phosphorus and other agricultural chemicals attached to soil particles; organic matter; and bacteria.

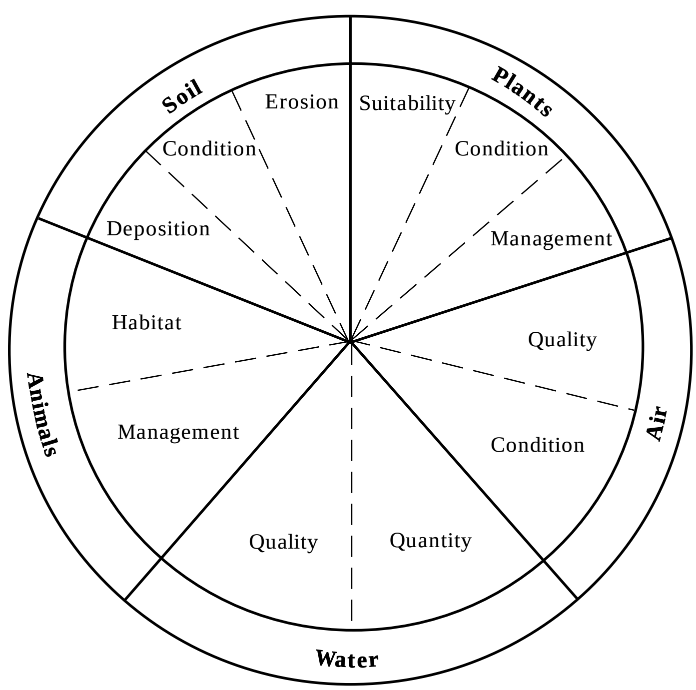
The usual objective in planning an AWMS is to exclude unneeded clean water and capture polluted water for storage or treatment for subsequent use when conditions are appropriate.

(c) Air

An AWMS often has an adverse impact on the air resource, so planning must consider ways to minimize degradation of air quality. Objectionable odors from confined livestock, waste storage areas, lagoons, and field application of wastes must be considered in planning an AWMS.

Emissions of ammonia and other gases from farming operations including livestock operations are associated with soil acidification via an acid-rain type phenomenon. These type emissions are also coming under scrutiny for their contribution to other environmental concerns, such as the greenhouse effect/global warming.

Figure 2–2 Resource considerations



Air movement, humidity, and the odors air may carry from the AWMS must be considered. Windbreaks, screens, or structure modification may be required to create conditions that minimize the movement of air.

(d) Plants

Plants are an important aspect of planning an AWMS. They are used to recycle the nutrients available in agricultural waste (often producing an economic return), screen undesirable views, channel or funnel wind, reduce noise, modify temperature, or prevent erosion. Plants selected for an AWMS must be adapted to the site conditions. If wastes are applied to agricultural fields, the application must be planned so that the available nutrients do not exceed the plant's need or contain other constituents in amounts that would be toxic to plant growth.

(e) Animals

Obviously, an AWMS for a livestock enterprise must be planned to be compatible with the type of animals involved. A healthy and safe environment is essential for these animals. Structures need to be planned to both protect the AWMS structure from the animals and the animals from the structure. Planning should also consider hazards from disease, parasites, and insects. Wildlife should also be considered.

Pollution of receiving water can have a significant effect on animals. Organic matter can drastically reduce dissolved oxygen levels in a stream, and high ammonia concentrations can kill fish. In addition, water overenriched by nutrients, contaminated by agricultural chemicals, or polluted by bacteria can result in an environment that has a very negative effect on animals.

(f) Social

The wide differences in perspective and perception in a community can effect how an AWMS is received. For example, how an AWMS system is viewed by an adjacent landowner who has a similar enterprise as compared to one who works in the city could be completely different. For this reason, planning must deal not only with complex technological considerations, but also social considerations.

An AWMS must be planned so that the social effect on a community is minimized. Measures to minimize odors and maximize landscape compatibility must be included. A public relations effort by the decisionmaker can also be helpful in assisting a community in understanding and accepting an AWMS.

Federal, State, and local laws and regulations must be considered in the development of an AWMS. Compliance with the laws and regulations may be the main objective of some decisionmakers.

Human safety must be considered in planning an AWMS. Potential hazards are numerous. Safety measures need to be incorporated into structures and must be stressed in operation and maintenance plans.

(g) Cultural

Any cultural resources discovered onsite during the planning process must be evaluated.

(h) Economic

To assist decisionmakers, economics should also be considered in planning and evaluating an AWMS. Average annual costs and associated benefits should be developed for the evaluation. Average annual costs are the initial costs amortized plus necessary operation, maintenance, and replacement costs.

The value of agricultural wastes must also be considered. The word "waste" has the connotation of being something left over that has little or no value. However, many agricultural wastes are valuable as soil building amendments. If the land user would account for animal waste applications, then purchased inputs (nutrients) could be reduced. If treated, the waste can be used for bedding and refeeding, and energy can also be produced.

651.0202 Conservation planning process

For an orderly approach to planning, SCS uses a 9-step planning process. The steps are (l) identify the problem; (2) determine the objectives; (3) inventory the resources; (4) analyze the resource data; (5) formulate alternative solutions; (6) evaluate alternative solutions; (7) client determines a course of action; (8) client implements the plan; and (9) evaluation of the results of the plan.

To learn the mental process involved, inexperienced planners should make a conscious effort to evaluate each of these steps. As experience is gained, however, the planner will find that even though each of the steps is considered mentally, some tend to blend so that in practice there are actually fewer planning steps. For example, step 4, analyze the resource data, may blend with step 5, formulate alternative solutions. To thoroughly and efficiently plan an AWMS, each planning step must be considered.

Individual contacts, newsletters, and the media can provide information on local situations that must be addressed in planning an AWMS. The information should stress voluntary action to correct problems and give details of programs that are available to the decisionmaker for both technical and financial assistance.

Decisionmakers request assistance in developing an AWMS for many reasons. Regulations, fear of fines, and complaints from the public motivate some decisionmakers. Others have an interest in reducing costs or labor associated with their current system. Some may desire to make use of nutrients available in agricultural wastes for crop production. Still others may be motivated by a genuine interest in protecting the environment. A decisionmaker's reason for requesting assistance does not change the planning process, but may influence the attitude and responsiveness to the plan presented.

Following is a discussion of the planner's activities and responsibilities in each planning step as it relates to an AWMS.

(a) Identify the problem

Decisionmakers need to know what problems, potential problems, and Federal, State, and local laws and regulations affect their operation. This information can help them recognize the need to develop an AWMS that will protect the resource base.

(b) Determine the objectives

Planning step 2, determine the objectives, is extremely important in the planning process. To plan an AWMS that is acceptable and will be implemented, the planner must determine the decisionmaker's objectives early in the planning process.

The objectives greatly influence the type of AWMS planned. For example, the type of AWMS planned would be significantly affected if the decisionmaker's primary objective is to use the waste for power generation rather than for land application. A decisionmaker's objective to bring the operation into compliance with laws and regulations may result in an AWMS that is not as extensive as one where the objective is to minimize the effect on the environment and enhance public acceptance of the system. A decisionmaker's objective to minimize management efforts would result in an AWMS significantly different from one that would emphasize the role of management.

(c) Inventory the resources

When the objectives are determined and documented, planning step 3, inventory the resources, is to be addressed. Some inventory data may have been developed during the process of determining objectives. However, at this point the planner must assure that the resource inventory data are complete to the extent that they can be used to develop alternatives for a proposed AWMS.

Planning an AWMS requires an inventory based on compilation of data from many different sources. Some of the required data can be physically measured. For example, the number of acres available for land application of waste can be determined from a map using a planimeter. Other data needed, such as the level of management, are less tangible and must be determined based on observation, discussions with the decisionmaker, and judgment of the planner.

Worksheets are convenient for organizing much of the inventory data needed for planning an AWMS. A partial list of items that must be inventoried or evaluated follows. These items are described in more detail in their specific chapter.

(1) Type of enterprise

The type of enterprise is an important factor to be evaluated during the inventory. A dairy enterprise is significantly different from a beef cattle feedlot. Agricultural operations that grow their own feed present an aspect different from that of operations that buy all their livestock feed. Handling of cannery wastes is significantly different from the handling of municipal wastes. Each type of enterprise has a different overall objective that must be established by evaluating the type of enterprise.

(2) Size of enterprise

The size and characteristics of the enterprise must be carefully evaluated to determine the amount and type of wastes generated. For livestock enterprises, the number, type, size of animals, management, and ration fed are important inventory factors. The type, source, and consistency of all wastes that must be managed should also be determined.

(3) Site location

A careful evaluation of the site should be made to determine the best location for components and practices of an AWMS. Aerial photographs are very helpful in site evaluation. If possible, those components that are not visually pleasing should not be located where they are routinely visible to neighbors or passersby. Some people can "smell" with their eyes. An AWMS that is managed correctly and has its components out of sight has few problems. Sites that are highly visible or conspicuous or that front on well-traveled roads should include visual barriers, special design, and good management practices.

The location of lakes, streams, wells, and other receiving water should be noted. An AWMS should be developed to minimize the negative effect on the water.

AWMS components should not be placed on flood plains; however, if alternative locations are not available, care should be taken to flood proof facilities according to requirements of Federal and State laws. In addition, land application of agricultural wastes should not be made during periods when flooding normally occurs unless the waste is injected or plowed down immediately.

(4) Present facilities

A careful inventory of existing livestock housing facilities and waste handling facilities should be made. Full consideration should be given to using existing facilities in the AWMS.

(5) Land availability

The amount of land available for an AWMS needs to be carefully determined. Adequate amounts of agricultural land are needed for application of nutrients and other constituents in agricultural wastes to assure crop utilization and protection. Space for expansion of the enterprise for additional components or the enlargement of components of an AWMS should also be evaluated. It may be appropriate to flag the approximate boundaries of the proposed AWMS components to aid the planner and decisionmaker in visualizing how components will integrate with the current facilities. This step may need to be repeated several times.

(6) Soil

Soils must be evaluated to determine if they are appropriate for AWMS components and activities, such as land application, construction, and trafficability. Features, such as soil physical and chemical characteristics, nutrient levels, water table level, and depth to bedrock, must be evaluated. Engineering characteristics may need to be evaluated for structural components. Soil reports, test holes, and soil tests are all useful in evaluating soil.

(7) Topography

Certain topography favors certain waste handling systems. A gravity flow system may be a good choice where elevation differences exist. On the other hand, dramatic elevation changes might create more complex problems for waste transport and land application. Topography may dictate the location of AWMS components and the method of land application of wastes. U.S. Geological Survey quadrangle sheets, stereoscopic aerial photograph pairs, and site visits can be used to evaluate topography.

(8) Climate

Climate information should be evaluated in the inventory phase of planning an AWMS. Weather often dictates when waste can be land applied and for how long it must be stored. Extremely low temperatures cause problems with equipment and freezing of wastes in storage and treatment facilities.

Long-term weather characteristics should be evaluated as related to climatic extremes in temperature or precipitation. The amount of precipitation for a location can dictate consistency of the waste and subsequent handling techniques and equipment needs. For instance, an unroofed waste storage structure in a humid climate can be expected to receive a certain amount of precipitation for a given season of the year. Knowledge of local weather records is essential for proper planning.

(9) Geology

The geology of a particular site always plays an important part in selecting an appropriate AWMS. For this reason, the geology of the area in which the AWMS will be located must be evaluated. The ground water table, variations in depth to bedrock or in soil depth, potential for sinkholes, and fractured or cavernous rock often eliminate use of some types of AWMS components. Geologic information, including depth to the water table and geologic reports, should be reviewed for any given site. Onsite geologic investigations with the assistance of a qualified geologist should be given a high priority, especially where storage or treatment components are involved.

(10) Crops

When developing an AWMS that uses the waste material on cropland, grassland, or hayland, the cropping schedule for all land that might be involved must be evaluated. To achieve appropriate use and avoid offsite pollution, the planner and decisionmaker must determine the best time for land application. A tentative schedule for land application of waste should be prepared during planning to determine if the system that has been selected will work. Once all the variables have been firmed up, detailed plans can be prepared.

(11) Labor availability

Some waste handling activities, such as frequent spreading of wastes, are labor intensive. Systems considered should be carefully evaluated to determine labor requirements throughout the year. An adequate labor supply should be available for waste handling without adversely affecting the other activities of the enterprise. The planner should consider all labor requirements of the enterprise. Scheduling conflicts between such operations as waste application and crop planting and harvesting should be avoided.

(12) Equipment

Existing waste handling equipment must be inventoried and evaluated as to its suitability for the alternative systems being planned. A list of necessary equipment including critical replacement parts should be developed during planning of an AWMS. How the existing equipment fits into the overall equipment needs should be determined. In planning equipment needs, such factors as the complexity of the machinery, the availability of service and parts, and the relative importance of the machine to the operation should be considered. As a rule, the amount and complexity of equipment should be minimized.

(13) Level of management

During the inventory phase, the level of management that will or can be provided by the decisionmaker must be assessed. An AWMS must be manageable by the decisionmaker. Some require intensive levels of management and good record keeping ability. Composting and anaerobic digesters are in this category. When a change in the waste handling system is being considered, it is necessary to evaluate any management changes that the desired system might present. For example, if a dairy farmer wants to switch from a solid to a slurry or liquid waste handling system, a modification in the amount and type of bedding used and equipment needed will most likely be necessary.

If possible, the planner and decisionmaker should visit several operational sites that have waste handling systems similar to those being considered.

(14) Adjacent land use

The adjacent land use should to be evaluated, especially in relationship to prevailing winds and views. Consideration should be given to the sensitivities of anyone living, traveling, or working near the site of the AWMS. For example, attitudes of the public regarding spillage, odors, flies, and unsightly conditions can have a negative effect on the given operation.

(15) Travel routes

Existing and potential haul routes should be inventoried. Many AWMS's require that wastes be transferred to fields for land application using equipment that can haul and spread the material. Although haul routes should be the shortest distance possible, roads should be located to avoid extreme cutting, filling, and potential erosion.

Where it is necessary to use public roads as haul routes, applicable State and local laws that govern their use must be followed. Use of public roads as haul routes requires that safety precautions be taken and hauling equipment that minimizes spillage and tracking of waste material, mud, and dirt be used. Aerial photographs and soil maps can be used to inventory haul routes.

(16) Laws and regulations

The planner must determine what Federal, State, and local laws apply to an AWMS. However, the decisionmaker must know how the laws affect planning and operation of the AWMS and must obtain the necessary permits and licenses.

The laws and regulations may require the decisionmaker to obtain permits to construct and operate an AWMS. They may also dictate the type of AWMS or that certain features be incorporated into the AWMS components. Undoubtedly, the decisionmaker will need to contact officials of various Federal, State, and local agencies to determine the requirements for compliance with laws and regulations. Officials to contact may include milk inspectors, local zoning authorities, and environmental regulatory personnel. Permits must be applied for well in advance of the actual date of beginning the installation of an AWMS.

(17) Water quality

SCS requires that an AWMS be planned to preclude offsite discharge for precipitation events that are equal to or less than the 25-year, 24-hour storm.

The sensitivity of lakes, streams, or ground water aquifers to contaminants in the agricultural waste should be evaluated and made part of the decision process of whether or not to allow discharge. Receiving water sensitivity must also be considered when establishing the intensity of management and level of efficiency needed to avoid or minimize accidental spills and to assure that the designated water use is protected.

(18) Utilities

All utilities that may be needed or affected by an AWMS must be determined. They include buried or overhead electrical wires, size of service and voltage needed, and types of motors to be serviced (single or three phase); other buried wires, such as telephone cables; gas lines; sewer lines; wells; and water lines. See Part 503 of the National Engineering Manual (NEM) for SCS policy on developing a plan to prevent damage to public or private utilities during engineering and construction activities.

(19) Landscape resources

Landscape features need to be evaluated during the inventory to make the AWMS compatible with the surrounding landscape. Earth mounds, fencing, vegetation, and position on the landscape are alternatives to enhance the landscape. In addition, structures can be painted to complement other farm buildings. Similarity in construction materials and texture should be promoted.

When planning AWMS components that will be visible, the planner should consider planting fast-growing trees or shrubs that screen the facility as soon as possible. An earthen barrier can also be constructed with or without trees or shrubs.

Areas not easily accessible for mowing should be protected with vegetation that requires minimal maintenance. Ground cover adds to the attractiveness of the site and reduces the potential for erosion.

An archaeological site that is identified during planning or during construction of structural components of an AWMS must be reported to the State Historic Preservation Officer.

(20) Expansion of the enterprise

Possible expansion of the enterprise should be explored with the decisionmaker during the inventory. Installation of facilities to meet expansion needs may be best accomplished to begin with rather than enlarging the facilities later. Such factors as increasing family size and the economy can dictate the need for expansion of an enterprise.

(21) Flexibility

The need for flexibility should be explored with the decisionmaker during the inventory. For example, providing for 180 days storage of wastes as compared to 90 days would give more flexibility in waste application to the land. Roofs over waste storage facilities with gutters and directional downspouts would provide flexibility in the amount and consistency of wastes to be handled. Another example of flexibility would be where the decisionmaker may prefer the labor saving advantages of a flush system for collection of wastes combined with scraping. During freezing weather, however, a flush system might seem inappropriate although it can be successfully operated if it is properly installed and managed. Having both a waste stacking facility and a waste storage pond would give the decisionmaker the flexibility to vary the collection method used.

(d) Analyze the resource data

In step 4 of the planning process, the resource data collected in the previous planning step is analyzed. This step can be best accomplished by viewing an AWMS as having six functions (figs. 2–1 & 2–3): production, collection, storage, treatment, transfer, and utilization. The inventory data are cataloged into one of the six functions and then interpreted, analyzed, and evaluated in preparation for developing alternatives. This may result in data in all of the functions or in only a few. Following is a brief explanation of each function of an AWMS.

(1) Production

The data cataloged in this function are the type, origin, amount, consistency, and constituents of the waste. For example, a dairy enterprise waste amount depends on the number of each type of stock in the herd and the amount of wash water used. The consistency of the waste is either a solid, semi-solid, slurry, or liquid. Wastes from a dairy could be generated in one or more of these consistencies. Components that exclude or introduce clean water also affect the consistency and amount of waste.

(2) Collection

Inventory data that apply to the collection and initial short-term holding of the waste are cataloged in this function. Using a dairy as an example, the manure may be collected by scraping, flushing, or some other method to a storage tank or other short-term storage facility for eventual transfer to longer term storage or treatment.

(3) Storage

Inventory data that apply to storage are cataloged in this function. For a dairy that has ample land for application of wastes, the waste can be stored in a waste storage pond or structure for application to cropland when soil and weather conditions are appropriate.

(4) Treatment

Inventory data that apply to treatment are cataloged in this function. For a dairy operation where enough land for application of wastes is not available, a waste treatment lagoon could be used to reduce concentration of nutrients in the part that is water.

(5) Transfer

Cataloged in this function of the AWMS is inventory data that apply to moving the waste from the point of collection to storage or treatment and the transfer of waste from storage or treatment to the point of land application or final use. For a dairy, liquids could be transferred through a pipeline from the point of collection to either a waste storage pond or waste treatment lagoon or to cropland for land application.

(6) Utilization

Data cataloged under this function are those that apply to utilization, such as land application, sacking dried manure for sale, feeding or bedding with treated manure, or generating energy. Inventory data that apply to this part would be the type of soil, existing land application equipment, amount of area for land application, crops, crop rotations, market for dried manure, and potential for use of energy on the farm and sale of excess energy.

(e) Formulate alternative solutions

Step 5 of the planning process, formulate alternative solutions, is used to develop alternative AWMS's based on the analysis of the inventory data as cataloged into one of the six functions of an AWMS.

(f) Evaluate alternative solutions

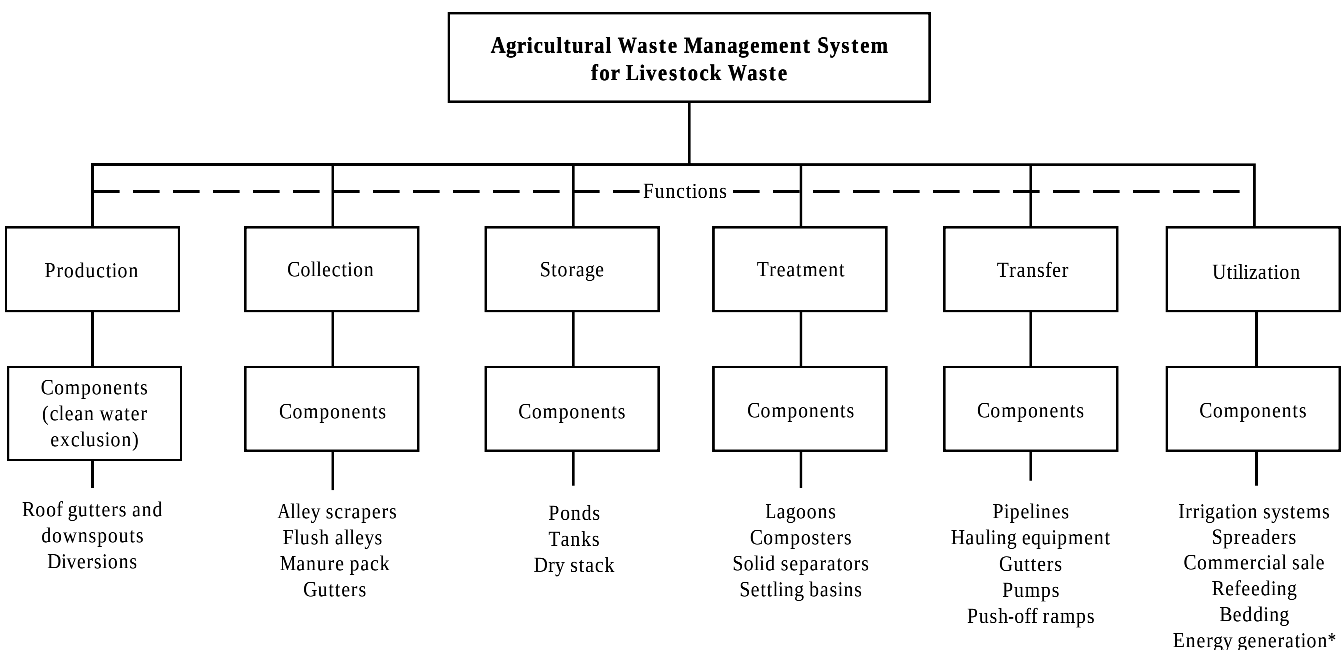
Alternative solutions need to be evaluated to determine if they meet the objectives, solve the problem, and are socially, culturally, and economically acceptable.

(g) Client determines a course of action

The seventh step in the planning process is making decisions. The decisionmaker must select one system from among the alternatives developed by the planner; however, the planner needs to guide the decisionmaker by presenting cost effective, environmentally sound, and socially acceptable alternatives. If the preceding planning elements are properly carried out, the decisionmaker will have all of the information available, including the private and public objectives, on which to make the needed decision.

Numerous worksheets and guides are presented in various sections of this handbook to aid in documenting information used in planning. Resource information and data that need to be documented provide a basis for the decisions that are made. All engineering and design information must be in design folders as required in Part 511 of the National Engineering Manual. Operation and maintenance plans must be developed so the decisionmaker fully understands how the AWMS is to be operated safely and what

Figure 2–3 Analyzing resource data and formulating alternative solutions using the six functions of an Agricultural Waste Management System



*Energy generation is included under the utilization function because utilization of the waste material is the basic purpose of such operations. This is distinct from the treatment function in which the basic purpose is to change characteristics of the waste material. A substantial part of the original volume and strength of the waste material still remains after it has been used for energy generation. Consequently, waste material discharged after energy generation must be managed similarly to that which has not been used for energy generation. In the case of livestock manure, the management process could include transfer to storage and, from there, transfer to a second waste utilization function of application on the land.

facilities need to be inspected and maintained. Waste utilization plans and specifications including water budgets and plant nutrient budgets should be developed in accordance with the guidelines in chapter 11 and the requirements of the Field Office Technical Guide.

(h) Client implements the plan

In step 8 the client implements the plan. Well planned, economically sound, and acceptable plans have a much greater likelihood of being implemented. Decisionmakers ultimately have almost total control over implementation. The planner, however, can help decisionmakers by providing approved detailed construction drawings and specifications for facilities, specific operation and maintenance plan for each component, and information on cost sharing programs, low interest loans, and other opportunities or conditions, such as pending laws, that may affect the decision to implement the AWMS installation.

(i) Evaluation of the results of the plan

Changing demands, growth, and technological advances create a need to evaluate an AWMS to update objectives and modify plans. Plans developed but not implemented within a few years should be re-evaluated. This requires repeating some or all of the planning elements to maintain a viable plan. The implemented AWMS may need to be fine tuned not only because of technical advances, but because of what the decisionmaker has learned about the system. This planning element gives the planner an excellent opportunity to gain experience and knowledge that will be useful when providing planning assistance to other decisionmakers.

651.0203 AWMS plan

An Agricultural Waste Management System plan is prepared as an integral part of and in concert with conservation plans. It is prepared in consultation with the producer and is formulated to expressly guide the producer in the installation, operation, and maintenance of the AWMS. The AWMS plan must account for all management systems operating on the farm that relate to the AWMS operation. For example, manure nutrient management must be a part of the overall nutrient management. The plan must interface with other systems, such as the tillage, irrigation, and cropping systems.

(a) Purpose of the plan

The purpose of the AWMS plan is to provide the producer with all the information necessary to manage agricultural wastes in a manner to protect the air, soil, water, plant, and animal resources. The plan may be necessary to comply with State regulation or law. It must take into account such factors as the financial status and management capabilities of the producer.

(b) Contents of the plan

The AWMS plan should include:

- A description of all system components or practices planned
- The sequence and schedule of component installation
- The operation and maintenance requirements including a time schedule
- Engineering design and layout information on location, size, and amounts
- Waste spreading plans including an accounting of the nutrients available, crops and field where applied, and amount and timing of application
- Information showing the relationship between the AWMS and the other management systems

The plan is to guide the actions of the producer in a way that provides for protection of all natural resources. It must have adequate information to accomplish this purpose.

651.0204 Waste impoundment planning considerations

Waste impoundments include earthen waste storage ponds and waste treatment lagoons. See Chapter 10 for the design detail of these AWMS components. The planning of waste impoundments must consider the potential consequences if they fail. Safeguards or measures to reduce the potential for failure or the consequences of failure should be considered as warranted.

Not all waste impoundments are planned to have an embankment. Those that do must consider the risk to life and property should the embankment fail. The information that follows is limited to embankment impoundment sites where the potential risk is limited to physical damage of farm buildings, agricultural land, or township and county roads. This hazard criterion is the low hazard or class (a) classification for dams that will impound clean water. Waste impoundments, however, present additional risk beyond that of clean water impoundments because of the nature of material they contain. This material can be high in organic matter, nutrients, and micro-organisms. In addition, the wastewater may have offensive odors. As such, even though a waste impoundment is sited so the risk is limited to physical damage of property, there may still be a significant potential in failure to degrade soil, water, air, plant, and animal resources as well as negatively impact the human environment.

The purpose of this section is to describe the potential consequences of failure and excessive odors. Also described are the planning considerations for minimizing the potential of failure and the consequences should failure occur. The two major categories considered are:

- Embankment breach or accidental release
- Liner failure

(a) Potential risk from sudden breach of embankment or accidental releases of waste impoundments

Because of site conditions, waste impoundments are often planned and designed to have an embankment. These types of impoundments may have significant consequences if the embankment fails. Waste impoundments may also be designed to have a gravity outlet to facilitate emptying as a part of the transfer function of an AWMS. This type of outlet potentially can allow an accidental or unplanned release.

Significant consequences in the event of sudden embankment breach or accidental release may occur, particularly if there is impact to a surface waterbody. The primary consequence to a surface waterbody is contamination with micro-organisms, organic matter, and nutrients. This contamination may kill aquatic life and make the water unsuitable for its intended use. As a minimum the waterbody would most likely be discolored. Chapter 3 describes more completely the effects of animal waste on surface water.

The magnitude of the environmental impact from breach or accidental release to a surface waterbody is related to the amount and concentration of the released waste and to the quality and quantity of water and the biota in the receiving waterbody. The magnitude of the impact may also vary according to the time of year and such factors as the dilution capacity, reaeration coefficients, antecedent dissolved oxygen conditions, sensitivity to phosphorus and nitrogen loads, and the proximity of drinking water intakes and recreation areas. Exactly what the effect of released waste would be is difficult, if not impossible, to predict with any precision. Regardless of the impact, it must be recognized that releasing wastewater in any amount or concentration into a surface waterbody is seldom socially acceptable. For this reason, precautionary measures should be considered in planning and design to minimize the risk or consequences of embankment breach or accidental release if a hydraulic analysis indicates that a surface waterbody may be impacted. This would be even more important from a social acceptability aspect if the affected waterbody is off-farm.

Embankment breach or the accidental release of effluent from a waste impoundment may also cause severe erosion and destruction of cropland and critical habitat. Because animal waste potentially contains disease causing micro-organisms that are transmittable to humans (see table 3–5 for a listing), a release that would contaminate areas where people live can potentially lead to human health problems.

Features, safeguards, or management measures to minimize the risk of embankment failure or accidental release, or to minimize or mitigate impact of this type of failure, should be considered if one or more of the categories described in table 2–1 may be significantly impacted.

A substantive evaluation of the impact of sudden breach or accidental release from waste impoundments should be made on all waste impoundments. Waste impoundments planned with embankments where significant direct property damage may occur should be evaluated with an appropriate breach routing procedure, such as that in Technical Release No. 66, Simplified Dam Breach Routing Procedure. The following should be considered, either singly or in combination, to minimize the potential or the consequences of sudden breach of embankments if one or more of the categories shown in table 2–1 may be significantly impacted.

- An auxiliary (emergency) spillway
- Additional freeboard
- Accommodating the wet year rather than normal year precipitation
- Reinforced embankment, such as additional top width, flattened or armored downstream side slopes
- Secondary containment
- Permanent markers at critical wastewater elevations to indicate need for operational action

Table 2–1 Potential impact categories from breach of embankment or accidental release

Surface waterbodies—perennial streams, lakes, wetlands, and estuaries
Critical habitat
Farmstead or other areas of habitation
Off-farm property

The potential for accidental release exists whenever a gravity outlet is used to facilitate emptying the waste impoundment as part of the utilization function of an AWMS. Any one of many possibilities, including vandalism, may result in an accidental or unplanned release. Evaluation of the impact of this type release should be made by routing the outlet's maximum discharge. The following should be considered to minimize the potential for accidental release of gravity outlets from the required volume when one or more of the categories described in table 2–1 may be significantly impacted.

- Outlet gate locks or locked gate housing.
- Secondary containment.
- Alarm system.
- Do not use a gravity outlet. Use another means of emptying the required volume.

Development of an emergency action plan should be considered for waste impoundments where there is potential for significant impact from breach or accidental release. In addition, consideration should be given to actions to minimize damage from breach. Actions would include well head protection, dikes, and diversion channels. These actions should be taken to augment, not replace the measures to reduce the risk of breach.

(b) Potential hazard of liner failure for waste impoundments

Waste impoundments present a risk of contaminating underlying ground water aquifers and surface water that may be fed by these aquifers because of the nutrients and micro-organisms contained in the wastewater. To minimize this risk, NRCS practice standards require that waste impoundments be located in soils of acceptable permeability or be lined. Despite this, risk remains because of the possibility of poor performance of these measures in preventing the movement of contaminants to the ground water. Any of a number of causes could lead to nonperformance of liners. These causes would include such things as not being homogenous with lenses of more permeable material, being constructed with inadequate compaction, having desiccation cracks develop following impoundment emptying, and being damaged during agitation. Flexible membrane liners may fail by such things as cracks, tears, seam separation, or loosened connections. Concrete liners may leak if they crack or joint seals fail. The acceptability of the risk depends on the importance of the underlying aquifer, the location and type of aquifer, and geologic site conditions that may be unforgiving to poor performance.

The seepage protection planned for a waste impoundment should correspond to the risk involved. A thorough geologic investigation is essential as a prerequisite to planning seepage control for a waste impoundment. Special consideration should be given to seepage control in any one of the following conditions:

- Any underlying aquifer is at a shallow depth and not confined.
- The vadose zone is rock.
- The aquifer is a domestic water supply or ecologically vital water supply.
- The site is located in an area of carbonate rock (limestone or dolomite).

Should any of these conditions exist, consideration should be given to the following:

- A clay liner designed and installed in accordance with procedures of appendix 10D with a thickness and coefficient of permeability so that specific discharge is less than 1×10^{-6} centimeters per second.
- A flexible membrane liner over a clay liner.
- A geosynthetic clay liner flexible membrane liner.
- A concrete liner designed in accordance with the criteria for watertight slabs on grade.

The subsurface investigation for a waste impoundment site must be conducted so as to locate any subsurface drainage lines. If found, the lines must either be removed, rerouted, or replaced with nonperforated pipe with watertight joints

Some waste impoundments require foundation drains to lower the seasonal water table to an acceptable depth. These drains must be designed and installed to have an appropriate separation distance from the impoundment liner and outlet in nonsensitive areas. Functional failure of these drains may impact impoundment liner performance. As such, outlets should be guarded from damage and located so they can be inspected for proper operation. Dual outlets should be considered so a backup outlet is available if one fails.

Pumping and agitation, if used, can be destructive to liners, especially soil blanket liners. Plan for pumping and agitation at locations that will not result in damage to liners or for measures that will eliminate the possibility of damage.

(c) Potential impact from odors and gaseous emissions from waste impoundments

Potential odors from a livestock operation are not limited to waste impoundments. Other sources include buildings (e.g., housing units and milking parlors), open lots, the animals themselves, and operational activities, such as agitation and land application. When developing recommendations for minimizing odor, all sources must be dealt with effectively. This section describes AWMS odors and their impact assessment in general terms. However, the planning considerations given are limited to waste impoundments.

Assessment of the potential for offensive odor impact from an AWMS is complex. Several factors account for this complexity. Odors from an AWMS vary in intensity, frequency, and duration depending on time of year, time of day, weather conditions, and management activities underway. Physiographic characteristics of the site, including such items as topography, vegetation, and cultural features, can also affect the potential for impact. These characteristics interact to vary the distance to which odors may have an impact. Social factors, described in detail later in this section, also add significantly to the potential for odors to have an impact. All of these factors must be assessed in planning an AWMS and associated waste impoundments. Consider as many of the interacting factors as each individual situation necessitates.

The first planning consideration for minimizing the impact of odors from waste impoundments is choosing the best site possible. This siting will maximize separation distance and use prevailing wind direction, topography, buildings, and vegetative screens to direct and dissipate odors. See Chapter 8, Siting Agricultural Waste Management Systems, for more details on siting to minimize odors.

Assessment of the social factors related to odors is difficult because of the varied human response to odors. Odor sensation is a personal response. Odor is not observed by individuals with equal sensitivity nor is there always agreement among individuals as to whether an odor is objectionable when detected. Individuals respond differently to odors primarily because of variations of background. For example, someone raised in an urban setting would observe an odor from an AWMS differently than someone raised in a rural setting.

The social factors to consider in determining the extent that measures must be taken to minimize odors are related to who the owner or operator is, who the neighbors are, and the nature of the community in which the AWMS is located. Odors from an enterprise owned and operated by a person who has a long-standing presence in the community are more likely to be tolerated than a similar enterprise owned and operated by a newcomer, if local experience to the farm has been positive. Less likely to be tolerated would be a newly established, large enterprise owned and managed by someone who does not live on the farm. Odors that affect neighbors with similar enterprises are more likely to be tolerated. For example, odors from a dairy that is located in a rural area surrounded by other similar sized dairy farms would probably be tolerated. However, odors from a livestock operation that is much larger than the majority of neighboring farms and not considered to be part of the farming community may not be tolerated. An example would be a large corporate farm in the midst of smaller family farms.

Less tolerant of odors would be neighbors who have dissimilar enterprises, especially non-odor producing enterprises. An example is a hog operation located in a predominately corn growing area. A type of rural neighbor that would be even less tolerant of odors would be those who have migrated to the country from urban areas. Often people with this background have moved to the country for the fresh air and not necessarily to make a living. This neighbor, in all likelihood, would be less tolerant of odors, especially if they are intense and drawn-out. Those living in adjacent urban communities will generally not tolerate odors that they perceive to be objectionable regardless of intensity or duration.

An evaluation that would include, but not be limited to the following factors should be considered in determining the recommendations for minimizing AWMS odors:

Owner/operator assessment
- Tenure
- Type of enterprise
- Size of enterprise
- Future plans for expansion
- Perception of odors

Neighboring farms assessment
- Tenure
- Type of enterprise
- Size of enterprise
- Perception of odors

Non-farm neighbors assessment
- Tenure
- Perception of odors

Community assessment
- Composition - percent rural vs. percent urban
- Migration to community in the last 5 years
- Economic sectors
- History of odor complaints to community leaders

Sources of helpful information in evaluating these social factors and other related factors include, but are not be limited to the following:
- U.S. Census of Agriculture
- U.S. Census of Population and Housing
- Local land use planning reports
- Interviews with local health agencies
- Interviews with State health agencies
- Interviews with State environmental agencies
- Published information, such as reports and newspaper items

For sites where measures beyond siting are necessary to minimize odors, anaerobic lagoons should be considered instead of waste storage ponds. Lagoons with loading rates reduced to at least half the values shown in figure 10–22 should be used. The following measures should be considered for sites where the need to minimize odors is significant:
- Covering anaerobic waste treatment lagoons and storage ponds
- Using naturally aerated or mechanically aerated lagoons
- Using composting in conjunction with a solid waste system rather than a liquid or slurry system
- Using a methane recovery system

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Waste Management
Field Handbook

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

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

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. 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 man.

Likewise, all natural water, including surface water, ground water, and precipitation, contains foreign substances; it is not simply two parts hydrogen and one part oxygen (H_20). 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 (for example, 5 mg/L of dissolved oxygen) and not necessarily on an obvious problem, such as an algae 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 algae 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 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 ground water. 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 micro-organisms 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 nonorganic 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. Micro-organisms 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 °C (50 °F) has 10.92 mg/L of dissolved oxygen when fully saturated, while water at 30 °C (86 °F) has 7.5 mg/L 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.

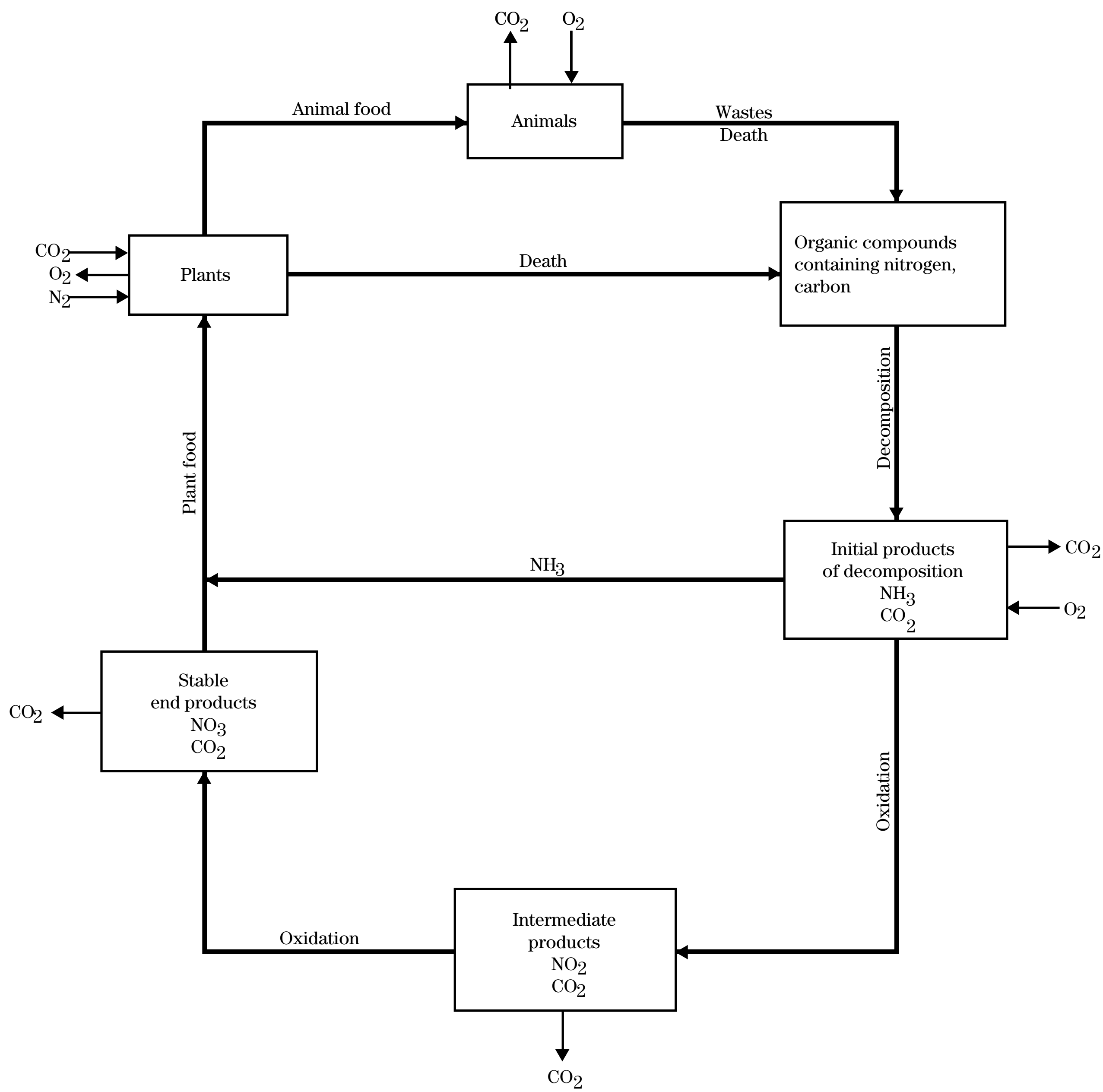
The amount of organic matter in water can be determined with laboratory tests, including those for 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and volatile solids (VS). Table 3–1 illustrates BOD_5 values for a sampling of lagoon influents and effluents for various livestock 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 mg/L, while that for municipal wastewater treated to the secondary level is about 20 mg/L. 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.

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

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



(2) Nutrients

The principal nutrients of concern in the aquatic environment are nitrogen and phosphorus. An understanding of how these nutrients react in the environment is important to understanding the control processes discussed 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 nitrogen. It is also a part of all living organisms. When plants and animals die or when waste products are excreted, nitrogen 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 nitrogen cycle. It shows the flow from one form of nitrogen to another. The various forms of nitrogen can have different effects on our natural resources—some good and some bad.

The conversion from one form of nitrogen 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 ($NH_3 + NH_4$), nitrite (NO_2), and nitrate (NO_3) forms. Total Kjeldahl Nitrogen (TKN) includes the total organic and total ammonia nitrogen. The ammonia, nitrite, and nitrate forms of nitrogen 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 mg/L of NO_3 is equivalent to 10 mg/L of NO_3–N. (See chapter 4 for conversions and expressions.)

Organic nitrogen—Nitrogen in fresh manure is mostly in the organic form (60–80% of total N). In an anaerobic lagoon, the organic fraction is typically 20 to 30 percent of total N. Organic nitrogen 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 organic N is converted to ammonia within 4 to 5 months after application to the land. The conversion of organic N to ammonia (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 ammonia can occur either under aerobic or anaerobic conditions.

Organic 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 ammonia exist in equilibrium, with the concentrations of each depending on pH and temperature.

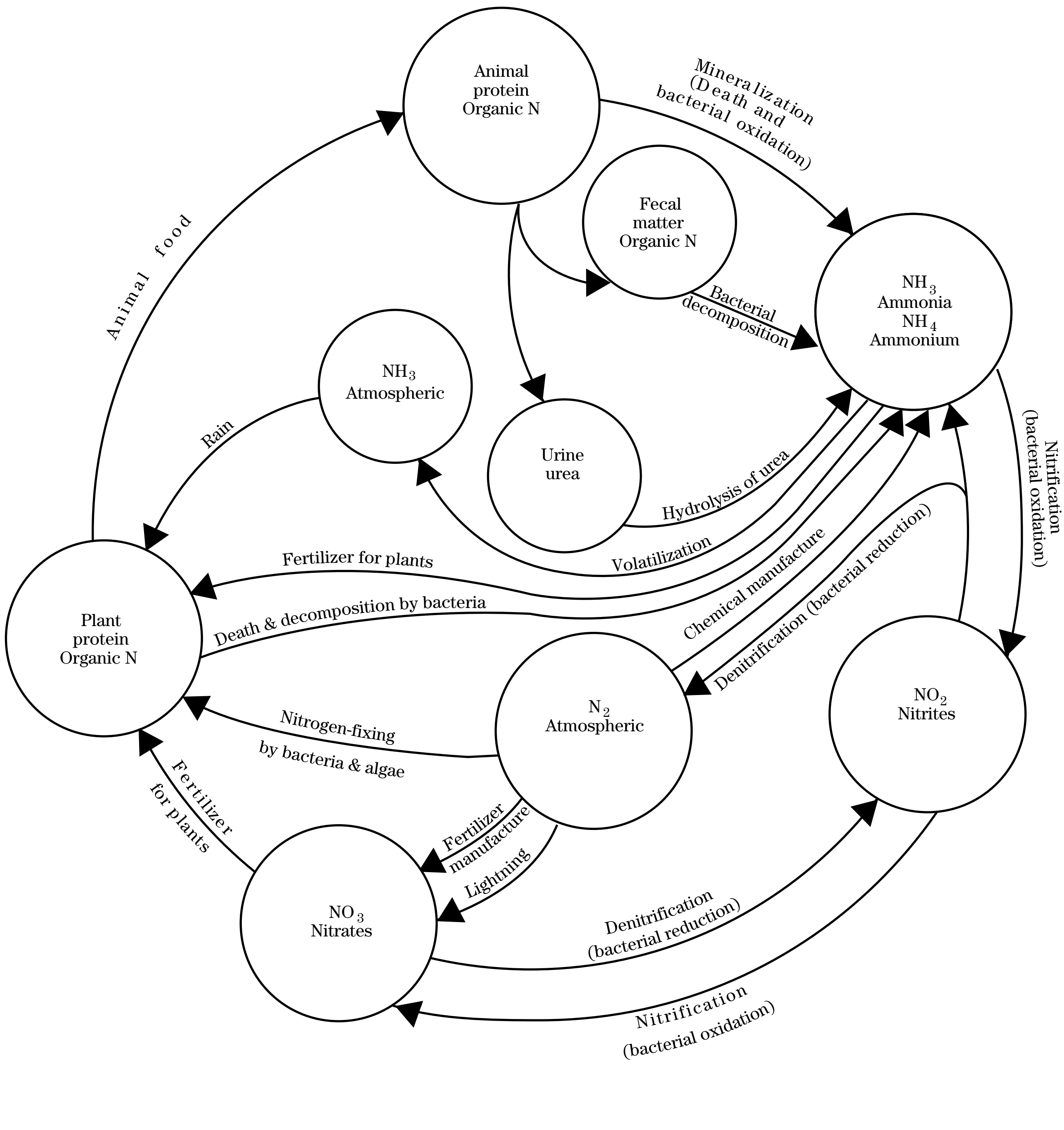
Un-ionized ammonia is toxic to fish and other aquatic life in very small concentrations. In one study, the concentration required to kill 50 percent of a salmonid (for example, trout) population after 96 hours of exposure (the 96-hour LC_{50}) ranged from 0.083 to 1.09 mg/L; for nonsalmonids the range was 0.14 to 4.60 mg/L. Invertebrates are more tolerant of 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 mg/L for un-ionized ammonia. Table 3–2 shows, in abbreviated form, the relationship between NH_3 and NH_4 as related to pH and water temperature. As water temperatures and pH rise, the amount of total ammonia required to provide a lethal concentration of NH_3 becomes smaller.

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

Figure 3–2 The nitrogen cycle



The concentration of 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 NH_4 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 ammonia irrigated from an animal waste lagoon can be lost between the sprinkler head and the ground surface. Temperature, wind, and humidity will affect losses.

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

Nitrite (NO_2)—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 nitrite 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.

Nitrite concentrations at or below 5 mg/L should be protective of most warmwater fish, and concentrations at or below 0.06 mg/L should suffice for coldwater 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 nitrites in surface water; however, some States have criteria for nitrite concentrations in finished or treated water (see chapter 1).

Nitrate (NO_3)—The nitrate form of nitrogen is the end product of the mineralization process (the conversion of N from the ammonia form to nitrite and then to nitrate under aerobic conditions). The nitrate 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. Nitrogen in animal waste that has been converted to nitrate 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 nitrates 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 the table 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

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).

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, the table is presented only to illustrate the extent to which nitrate concentrations can be increased in runoff from land that has received applications of manure.

Elevated nitrate 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 NO_3.

Nitrates are toxic to fish only at very high concentrations—typically in excess of 1,000 mg/L 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 mg/L without significant side effects. 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, NO_3 is a source of enrichment for aquatic plants. If an adequate supply of other essential nutrients is available (especially phosphorus), 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 651.0108(b), for a discussion of limits related to drinking water as it comes from the tap.)

(ii) Phosphorus—Phosphorus (P) is one of the major nutrients needed for plant growth, whether the plant is terrestrial or aquatic. Because phosphorus 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 phosphorus; however, total phosphorus can include organic, soluble, or "bound" forms. An understanding of the relationship among these forms is important to understanding the extent to which phosphorus can move within the environment and the methods for its control. Figure 3-3 depicts the relationship between the phosphorus forms and illustrates ways that P can be lost from waste application sites.

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

Soluble phosphorus (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 phosphorus in most soils.

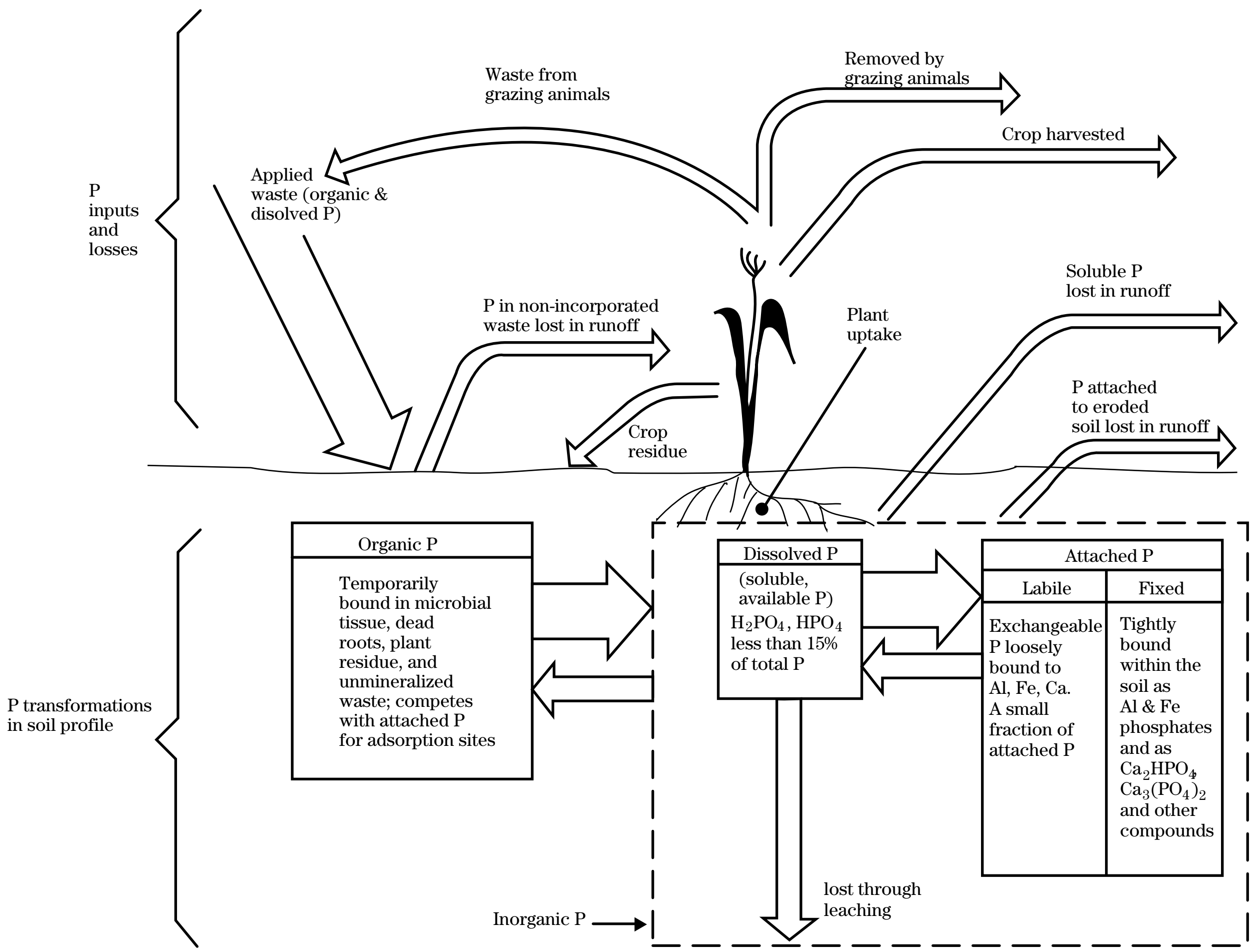
Attached phosphorus includes those compounds that are formed when the anionic (negatively charged) forms of dissolved P become attached to cations, such as iron, aluminum, and calcium. Attached phosphorus includes labile, or loosely bound, forms and those that are "fixed," or tightly adsorbed, on or 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 phosphorus moves to surface or ground water. Nearly all of these factors relate to the form and chemical nature of the phosphorus compounds. Some of the principal factors affecting P movement to surface and ground waters are noted below.

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 phosphorus readily attaches to soil particles, the potential for loss in surface runoff is greatly reduced by incorporating land applied solid wastes into the soil profile.

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



Soil pH. After animal waste makes contact with the soil, the phosphorus 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 H_2PO_4, and when the pH increases above 7, the principal soluble form is HPO_4.

Figure 3-4 illustrates that most inorganic phosphorus 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 phosphorus. Thus, clay soils have a higher adsorption potential than that of sandy soils.

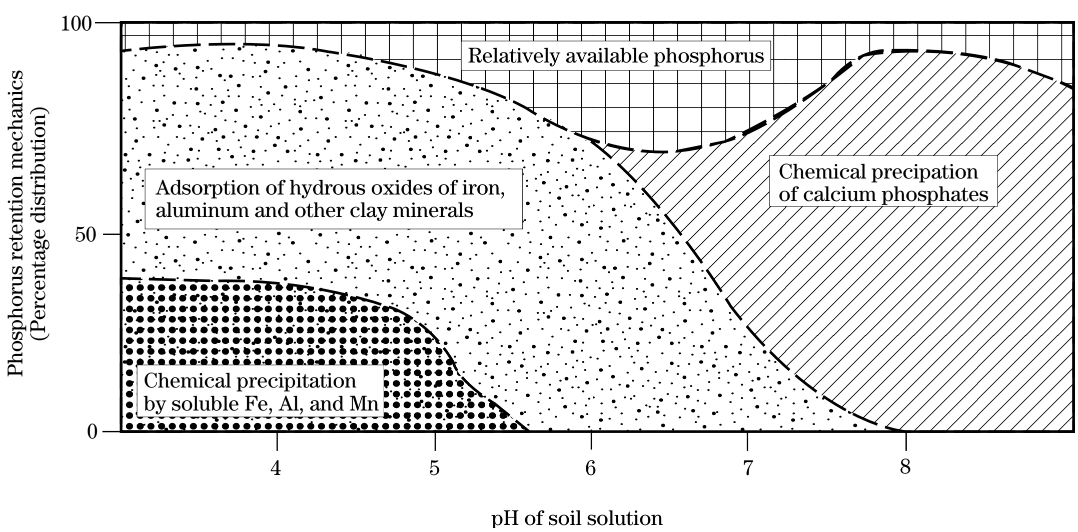
Research has shown that soils with even a modest clay fraction have the potential to adsorb large amounts of P. For example, one study revealed that a Norfolk sandy loam soil receiving swine lagoon effluent at phosphorus application rates of 72, 144, and 288 pounds per year would require 125, 53, and 24 years to saturate the adsorption sites in the soil profile to a depth of 105 cm (41 inches). 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 attach-

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



ment 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 phosphorus 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, erosion can still occur on land receiving livestock and poultry wastes. If wastes are applied to satisfy the nitrogen requirements of the crops, the phosphorus 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 phosphorus. In addition, water and sediment control basins serve as sinks for sediment-attached phosphorus.

Animal waste lagoons are also very effective for phosphorus storage. Typically 70 to 90 percent of the phosphorus in waste that enters a waste treatment lagoon will settle and be retained in the sludge on the bottom of the lagoon.

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

Phosphorus 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 phosphorus “sink”), especially if given ample time between applications.

Aerobic conditions. Compounds of phosphorus, iron, manganese, and other elements react differently where oxygen is present or absent in the surrounding

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

Cropping conditions	– Dissolved phosphorus 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).

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 phosphorus as well aerated soils.

Harvesting. Soluble phosphorus 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 phosphorus 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 phosphorus 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 phosphorus to its source. It then becomes available again as a source of plant food or of pollution.

Effects of phosphorus in the aquatic environment—When phosphorus 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, phosphorus 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, EPA has established a criterion of 0.01 μg/L (micrograms per liter) of yellow (elemental) phosphorus 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 phosphorus to enhance or protect fresh water, EPA recommends that total phosphate concentrations not exceed 50 μg/L (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 μg/L of total phosphorus.

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

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

- High phosphorus 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 phosphorus 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.
- Phosphorus 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 phosphorus 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 phosphorus 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 phosphorus concentrations of 10, 25, and 60 μg/L and roughly delineate the boundaries between oligotrophic, mesotrophic, eutrophic, and hyper-eutrophic conditions. This figure 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 warmwater lakes or lakes in which nitrogen rather than phosphorus is limiting.

(3) Fecal organisms

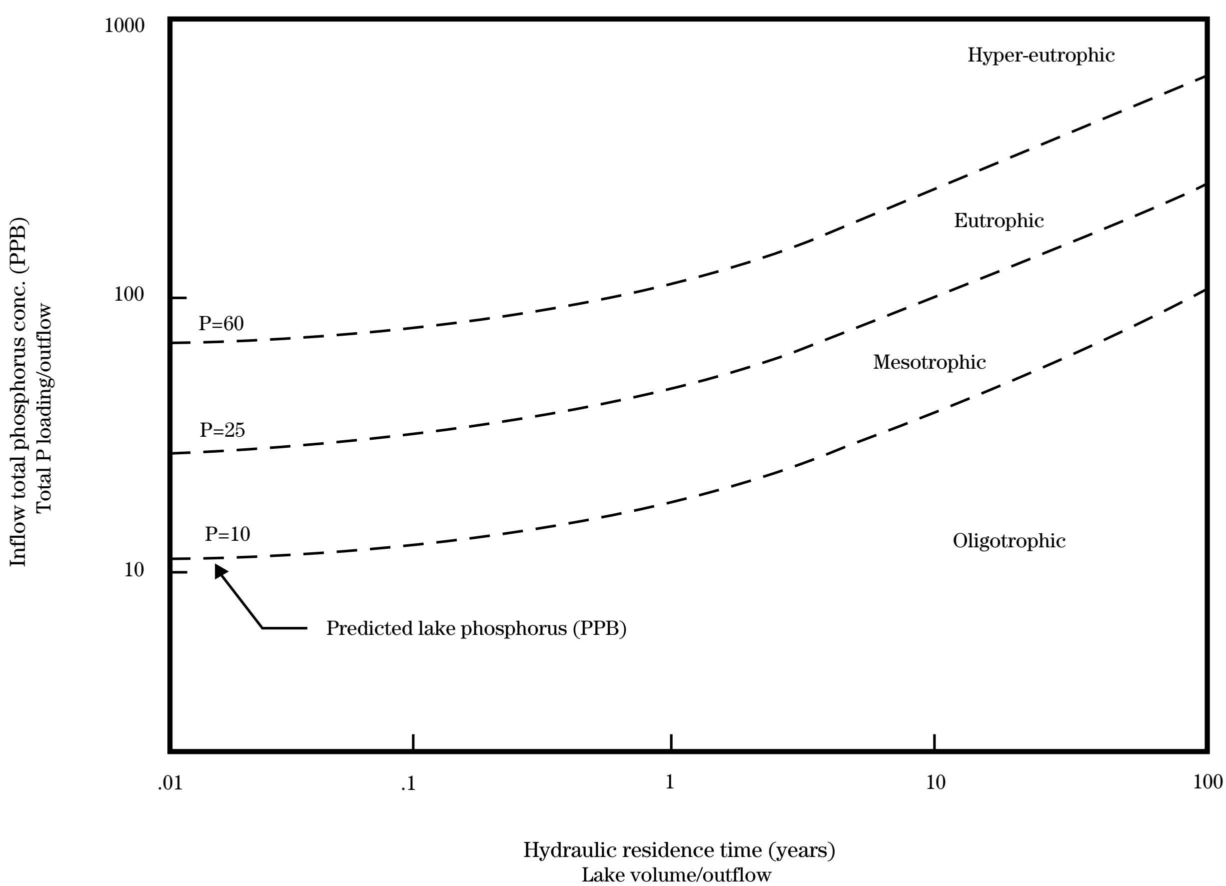
The excreta from warmblooded animals have countless micro-organisms, including bacteria, viruses, parasites, and fungi. Some of the organisms are pathogenic (disease causing), and many of the diseases carried by animals are transmittable to humans, and vice versa. Table 3–5 lists some of the diseases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

Many States use fecal coliform bacteria as an indicator of pollution from warmblooded animals, including man. The test for fecal coliforms 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 warmblooded 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.

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



- 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 warmblooded animals and with soils. However, the fecal coliform group represents a part of the total coliforms and is easily differentiated from the total coliforms during testing.

A positive test for fecal coliform bacteria is a clear indication that pollution from warmblooded animals exists. A high count indicates a greater probability that pathogenic organisms will be present.

Some fecal coliforms generally are in all natural water even without the influence of humans or their domestic animals. Birds, beaver, deer, and other wild animals contribute fecal coliforms to the water, either directly or in runoff. It is necessary, therefore, to have acceptable limits for fecal coliform bacteria, taking into account the beneficial use of the stream or water body. The EPA established water quality criteria for fecal coliform 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 fecal coliform (FC) to fecal streptococcus (FS) bacteria to help identify whether a suspected source of water pollution is from humans or other warmblooded 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

Table 3–5 Diseases and organisms spread by animal manure

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

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, EPA has established criteria for using Escherichia coli (E. coli) and enterococci as a measure of harmful levels of bacterial pollution in ambient waters. E. coli (a fecal coliform type) and enterococci are natural inhabitants of warmblooded 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 warmblooded 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 5 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 EPA.

(b) Constituents affecting ground water quality

Nitrates and bacteria are the primary constituents of animal waste that affect ground water quality. Phosphorus and potassium do not constitute a threat to public health through water supplies. In their common forms, phosphorus and potassium 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 phosphorus applied to the land will be quickly immobilized. 0nly a small fraction of the soluble inorganic phosphorus will be available for plants. (See previous discussion of the characteristics of P in this chapter.)

In addition to animal waste, other agricultural related wastes and their constituents can impact ground water quality. Salinity has long been recognized as a contaminant of ground water resulting from percolating irrigation application. Two mechanisms influence the amount of salt reaching the ground water. 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.

Table 3–6 Typical allowable limits for fecal coliform 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 fecal coliform to fecal streptococcus 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

Pesticides also have been identified as a contaminant of ground water. 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 ground water 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 (NO_3)

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

EPA established a criterion of 10 mg/L 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 nitrate is converted to nitrite in the alkaline environment of the baby's stomach. The nitrite 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 micro-organisms is a possible problem if wastes are spread on sandy soils. Studies in poultry growing areas of the Northeast and South indicate elevated fecal coliform and fecal streptococcus 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 ground water by fecal organisms is reduced considerably by the filtering action of the soil. The importance of soil filtering is discussed in the following section.

Well water should be tested regularly for contamination by fecal bacteria. The acceptable limit is zero for potable water (table 1–4).

651.0303 Factors affecting the pollution process

Water pollution occurs only when a contaminant finds a pathway from the source to the ground water 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 man.

(a) Pathways to pollution

The pathway that a contaminant follows to reach a stream or to enter ground water 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 phosphorus) 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 ammonia 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 nitrogen 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 ground water. 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 micro-organisms 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.

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

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

Some soils have a tremendous capacity to remove bacteria and protect the ground water 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.

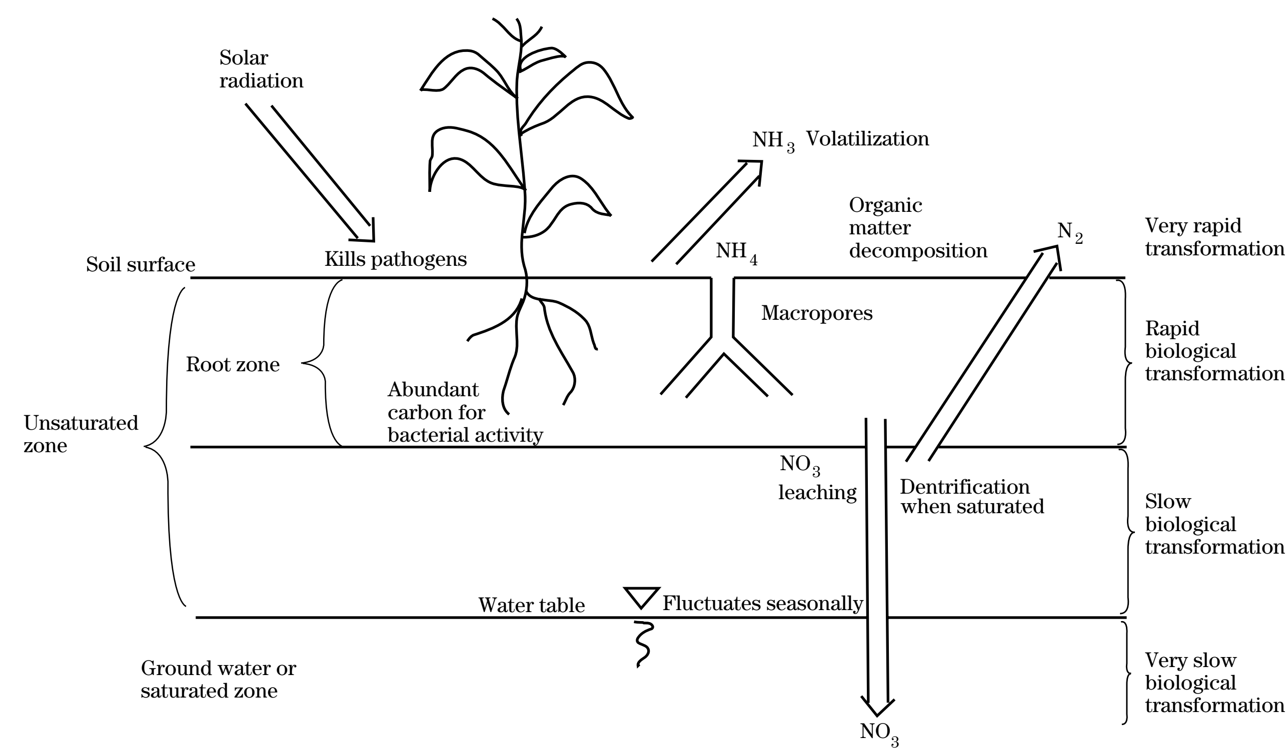
The unsaturated zone includes the root zone and an unsaturated area below the root zone. The root zone is characterized by an abundance of macropores, created in part by decaying roots and wormholes. The macropores allow rapid downward movement of substances carried by percolating water.

The root zone is also characterized by an abundance of carbon created by the decaying roots. Because micro-organisms 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 nitrate, which is available for a variety of other transformations within the root zone, can remain in the nitrate form for years below this zone of microbial activity.

Within the saturated zone or in the ground water, contaminants can remain unchanged for long periods because of the absence of micro-organisms. 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 nitrogen).

Figure 3–6 Transformations on or in the soil



651.0304 Controlling the pollution process

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

- 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 ground water.

These factors (availability, detachment, transport) must be addressed when attempting to prevent the movement of contaminants from land to water. A brief discussion 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?

Partitioning of the substance between soil and water—Is the substance in soluble form, such as NO_3, or is it adsorbed to soil particles?

Position of the substance on or in the soil profile—Is the manure incorporated immediately after application?

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 to be used are:

- Remove all animals from the watershed.
- Reduce the number of animals.
- Use cropping systems that require more nutrients throughout the year.
- 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.)
- Incorporate the manure, thus limiting the availability of particular constituents. P 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 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 phosphorus is an identified water quality problem, then practices must be applied to prevent detachment of phosphorus. 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 ammonia, 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. Lagoons, waste storage ponds, and settling basins are useful for this purpose.

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 filter strips and terraces are good examples of practices that interrupt the transport process.

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,
- health problems for animals in confined housing units,
- corrosion of materials; and
- the generation of deadly gases that can affect animals and humans.

Different gases are produced as animal waste is degraded by micro-organisms. Under aerobic conditions, carbon dioxide is the principal gas produced. Under anaerobic conditions, the primary gases are methane and carbon dioxide. About 60 to 70 percent of the gas generated in an anaerobic lagoon is methane, and about 30 percent is carbon dioxide. 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 methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), and hydrogen sulfide (H_2S). Table 3–9 provides a summary of the most significant characteristics of ammonia, carbon dioxide, hydrogen sulfide, and methane.

Methane is flammable, and in recent years interest in using it as a source of energy on the farm has increased. Because methane is also explosive, extreme care is required when attempting to generate and capture this gas for onfarm 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 chapter 2.)

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	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.
Carbon dioxide	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.
Hydrogen sulfide	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	Yes	None	Asphyxiant, flammable	Headaches at 500,000 ppm.

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 hydrogen sulfide 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, hydrogen sulfide 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. **H_2S 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 hydrogen sulfide. 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.

651.0306 Effects of animal waste on the animal resource

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 below. 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 nitrogen and potassium, and stress on the animal. Lactating cows grazing new growth of cool-season grasses or winter cereals are especially susceptible. Nonlactating cows and bulls 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.

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 address the role of soil and plant resources in agricultural waste management, these two resources are discussed in separate chapters in this handbook. The Conservation Practice Physical Effects in the Field Office Technical Guide 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 ground water, 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 the 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 the 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.

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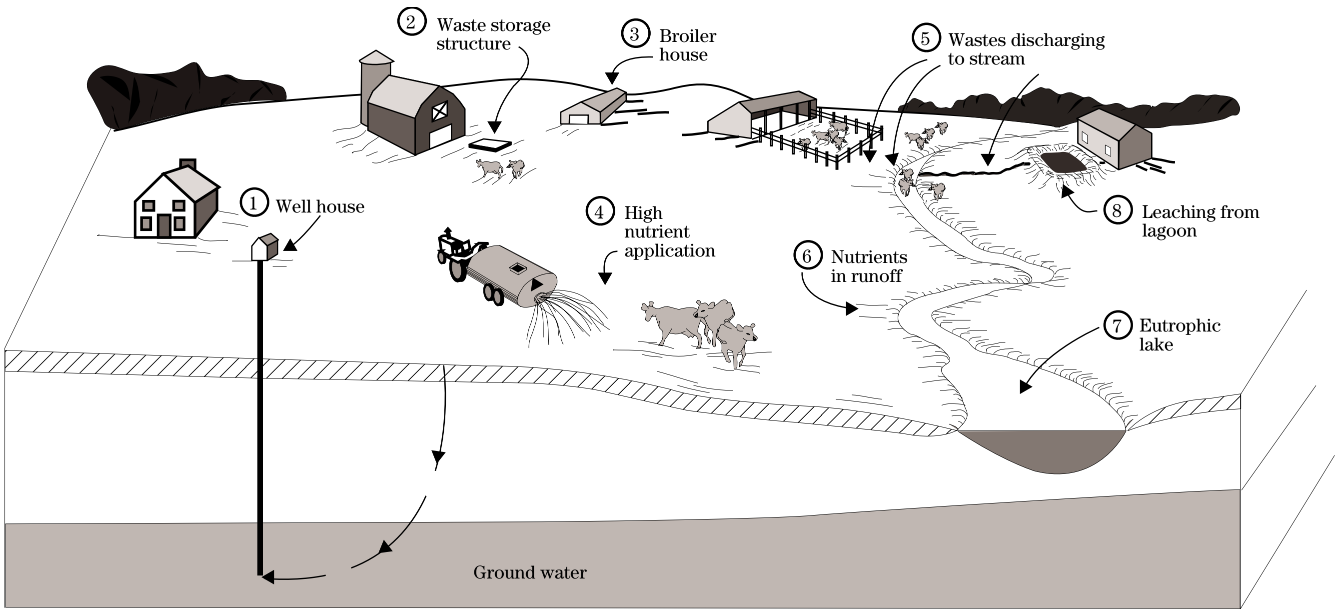
Figure 3–7 Possible danger points in the environment from uncontrolled animal waste



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 and other gases 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 micro-organisms through soil, fractured rock, and sinkholes.
5. Discharging lagoon, runoff from open feedlot, and cattle in creek: (a) Organic matter creates low dissolved oxygen levels in stream; (b) Ammonia 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 ground water or enter stream as interflow.

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Agricultural Waste Management Field Handbook

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.

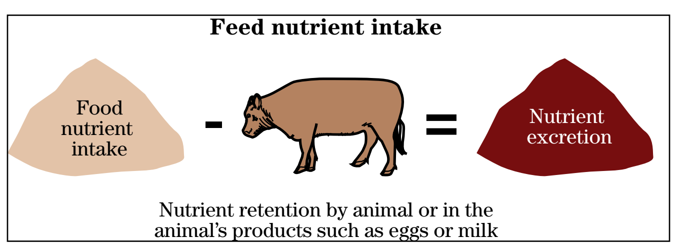
These equations allow an estimate of as excreted manure characteristics relevant to a wide range of dietary options and animal performance levels commonly observed in commercial production. Considered are factors related to the feed efficiency in animal performance and to feed intake including crude 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)

$$\begin{aligned} FS &= 20 \text{ grams} \\ VS &= TS - FS \\ &= 50 \text{ grams} - 20 \text{ grams} \\ &= 30 \text{ grams} \end{aligned}$$

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/ft³- - - - - -	
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:

$$\begin{aligned}
\text{Volume} &= 2.6\ \text{ft}^3\text{/d-a} \times 500 = 1{,}300\ \text{ft}^3\text{/d} \\
\text{N} &= 1.0\ \text{lb/d-a} \times 500 = 500\ \text{lb/d} \\
\text{P} &= 0.19\ \text{lb/d-a} \times 500 = 95\ \text{lb/d} \\
\text{K} &= 0.49\ \text{lb/d-a} \times 500 = 245\ \text{lb/d}
\end{aligned}$$

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

$$\begin{aligned}
\text{Volume} &= 1.9\ \text{ft}^3\text{/d/1000 lb AU} \times 500 \times \frac{1400}{1000} \\
&= 1{,}330\ \text{ft}^3\text{/d} \\
\text{N} &= 0.76\ \text{lb/d/1000 lb AU} \times 500 \times \frac{1400}{1000} \\
&= 532\ \text{lb/d} \\
\text{P} &= 0.14\ \text{lb/d/1000 lb AU} \times 500 \times \frac{1400}{1000} \\
&= 98\ \text{lb/d} \\
\text{K} &= 0.35\ \text{lb/d/1000 lb AU} \times 500 \times \frac{1400}{1000} \\
&= 245\ \text{lb/d}
\end{aligned}$$

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	ft^3/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	ft^3/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	Finishing cattle			
		Corn, no supplemental P	Corn with supplemental P	Corn with 25% wet distillers grains	Corn with 30% wet corn gluten feed
Weight	lb/f.a.	9,800	9,800		
Volume	ft^3/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	Finishing cattle			
		Corn, no supplemental P	Corn with supplemental P	Corn with 25%wet distillers grains	Corn with 30% wet corn gluten feed
Weight	lb/d/1000 lb AU	65	65		
Volume	ft^3/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		Boar 440 lb
		Gestating 440 lb	Lactating 423 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		Boar 3/
		Gestating 1/	Lactating 2/	
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 lb/f.a.

VS production for 1,000 animals =
99.00 lb/f.a. × 1000 f.a. = 99,000 lb
VS daily production = 99,000 lb/120 d = 825 lb/d

Using table 4–10d, select

VS = 5.4 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		
		Raw	Secondary	Raw	Digested	Compost[2/]
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			
		Poultry	Swine	Cattle	Wastewater sludge
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 leachate1/

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 silage1/

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

651.0406 References

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**Soil
Conservation
Service**

Agricultural
Waste Management
Field Handbook

Chapter 5 Role of Soils in Waste Management

(210-AWMFH, 4/92)

Chapter 5 Role of Soils in Waste Management

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Chapter 5 Role of Soils in Waste Management

651.0500 Introduction

Agricultural waste management system (AWMS) planning, design, implementation, and function are dependent on soil physical and chemical properties and landscape features. The AWMS planner and designer must understand agricultural waste related soil suitabilities and limitations. This chapter describes soil agricultural waste interactions and those soil properties and characteristics that affect soil suitability and limitations for an AWMS.

Soil data should be collected early in the planning process. Essential soil data include soil maps and the physical and chemical properties that affect soil suitability and limitations for an AWMS. Soil maps are in published soil surveys or, if not published, are available at the local Natural Resources Conservation Service field office. Soil suitability and limitation information can be obtained from published soil surveys, section II of the Field Office Technical Guide (FOTG), Field Office Communication System (FOCS), tables and soil data sets, soil interpretation records (SIR's), and the National Soils Handbook interpretation guides, part 603.

Soil information and maps may be inadequate for planning AWMS components. Agricultural waste management systems should not be implemented without adequate and complete soil maps or soil interpretive information. If soil data or maps are inadequate or unavailable, soil survey information must be obtained before completing an agricultural waste management system plan. This information will include a soil map of the area, a description of soil properties and their variability, and soil interpretive data.

651.0501 Soil phases

Soil is heterogeneous material made up of three major components: a solid phase, a liquid phase, and a gaseous phase. All three phases influence the supply of plant nutrients to the plant root.

The **solid phase** is the main nutrient reservoir. It holds nutrients in the cation form (positive charged ions), such as potassium, nitrogen (as ammonium), sodium, calcium, magnesium, iron, manganese, zinc, and cobalt on negatively charged clay and organic colloidal particles. Anionic (negatively charge ions) nutrients, such as nitrogen (as nitrate), phosphorus, sulfur, boron, and molybdenum, are largely held by the organic fraction or mineral complexes.

Nitrate is held very loosely to the anion exchange sites of the soil and move readily with percolating soil water. As the organic fraction is impoverished because of poor farming practices, the soil's ability to hold these elements is drastically reduced.

Phosphorus is often fixed to the mineral soil fraction containing iron, aluminum, and carbonates. It can be attached to hydrous aluminum, iron oxides, carbonates, and clays, particularly the kaolinitic type.

The amount of plant available nutrients held by a soil depends upon its unique chemical and physical makeup. This makeup can be ascertained by a soil's cation-exchange capacity, pH, organic matter content, clay minerology, and water holding capacity.

The **liquid phase** of the soil, the soil solution, is responsible for the transport of nutrients in the soil. Nutrients transported in the liquid phase are present in the solute form of the nutrient element. Oxygen and carbon dioxide can be dissolved in the soil solution and transported to and from the system. A large percentage of agricultural waste material is composed of water. Depending on the type, timing, and method of delivery of waste, this water can be used to supply part of the plant's moisture as well as nutrient requirements.

The **gaseous phase** mediates the exchange of gases that occurs among the numerous living organisms in the soil. Nitrogen, oxygen, water vapor, and carbon dioxide are the primary gaseous by-products of the soil and plant system. Gas exchange affects denitrification, mineralization of organic material, and soil micro-organism growth rate.

651.0502 Soil-agricultural waste interaction

Soil-agricultural waste interactions are a complex set of relationships that are dependent on the soil environment, microbial populations, and the chemical and physical properties of the soil and waste material. The following discussion describes some of these relationships.

(a) Filtration

Soil filtering systems are used to deplete Biological Oxygen Demand (BOD), consume or remove such biostimulants as phosphates and nitrates, provide long term storage of heavy metals, and deactivate pathogens and pesticides. Soils suitable for use as filtering systems have permeability slow enough to allow adequate time for purification of water percolating through the soil system.

A balance of air, water, and nutritive substances at a favorable temperature is important to a healthy microbial population and an effective filtration system.

Figure 5–1 Relationship between microbial respiration rate and temperature

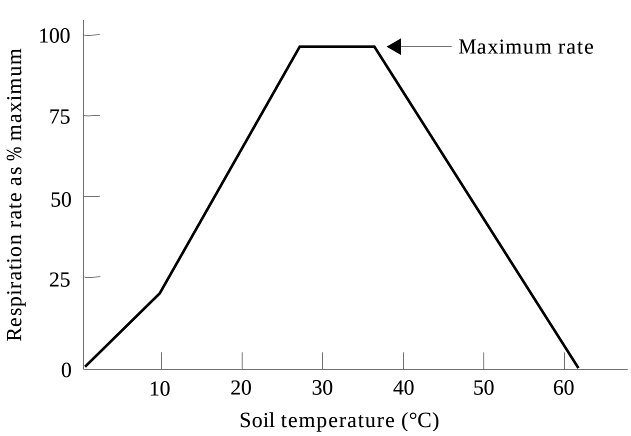
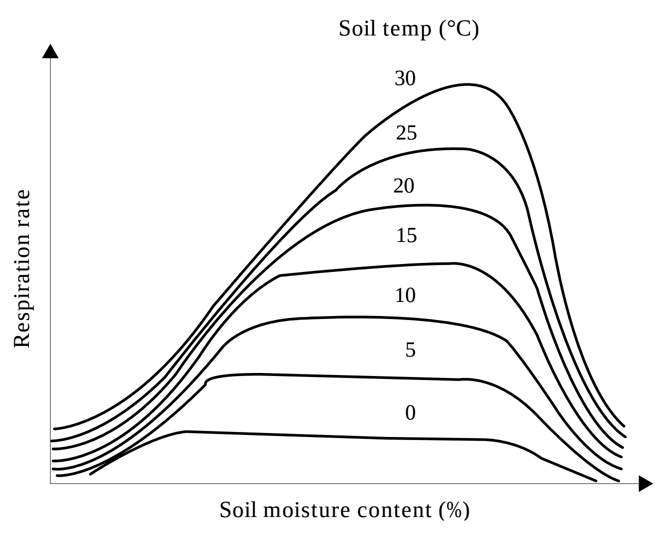


Figure 5–2 Relationship of microbial respiration rate to temperature and moisture



For example, overloading the filtration system with wastewater that has high amounts of suspended solids causes clogging of soil pores and a reduction of soil hydraulic conductivity. Management and timing of wastewater application are essential to maintaining soil filter systems. Climate, suspended solids in the wastewater, and cropping systems must be considered to maintain soil porosity and hydraulic conductivity.

The wastewater application rate should not exceed the waste decomposition rate, which is dependent on soil temperature and moisture content. Periods of wetting and drying increase microbial decomposition and by-product uptake by the crop and decrease potential soil pore clogging. In areas where the temperature is warm for long periods, the application rates may be higher if crops or other means of using the by-products of waste decomposition are available.

Tillage practices that maintain or improve soil tilth and reduce soil compaction and crusting should be included in the land application part of agricultural waste management systems. These practices help to maintain soil permeability, infiltration, and aeration, which enhances the biological decomposition processes.

(b) Biological degradation

Several factors affect biological degradation of various agricultural waste organics when the waste is applied to soil. These factors interact during the biological degradation process and can be partitioned into soil and organic factors.

Soil factors that affect biological degradation are temperature, moisture, oxygen supply, pH, available nutrients (N, P, K, and micronutrients), porosity, permeability, microbial population, and bulk density. Organic factors are carbon to nitrogen ratio (C:N), lignin content, and BOD.

The soil and organic factors interact and determine the environment for microbial growth and metabolism. The physical and chemical nature of this environment determines the specific types and numbers of soil micro-organisms available to decompose organic material.

The decomposition rate of organic material is primarily controlled by the chemical and biological composition of the waste material, soil moisture and temperature (figs. 5–1 & 5–2), and available oxygen supply. Rapid decomposition of organic wastes and mineralization of organic nitrogen and phosphorus by soil micro-organisms are dependent on an adequate supply of oxygen and soil moisture.

High loading rates or high BOD waste may consume most of the available oxygen and create an anaerobic environment. This process can cause significant shifts in microbial populations, microbial metabolisms, and mineralization by-products. Under anaerobic conditions, the by-products may be toxic and can be in sufficient concentrations to inhibit seed germination and retard plant growth, even after aerobic conditions have been restored. See section 651.0503(a).

(c) Chemical reactions

Management for utilization of organic waste material must take into account the chemical reactions that occur between the soil and the waste components. These reactions are broadly grouped as ion exchange, adsorption, precipitation, and complexation. The mechanisms and rates of these reactions are dependent upon physical, chemical, and biological properties of the soil and organic waste material.

Organic waste mineralization by-products consist of macro- and micro-plant nutrients, soluble salts, gases, and heavy metals. These by-products dissolve and enter soil water solutions as precipitation or irrigation water infiltrates the soil surface and percolates through the soil profile. The dissolved by-products are subject to the interactions of ionic exchange, adsorption, precipitation, or complexation. These processes store and exchange the macro- and micro-plant nutrient by-products of organic waste mineralization. They also intercept and attenuate heavy metals, salts, and other detrimental mineralization by-products that can adversely affect plant growth and crop production.

Ion exchange reactions involve both cations and anions (table 5–1). Ionic exchange and adsorption is the replacement or interchange of ions bonded electrostatically to exchange sites on soil particles and soil organic materials with similarly charged ions in the soil solution. This ionic interchange occurs with little or no alteration to exchanging ions.

Cation exchange is the adsorption and exchange of nonmetal and metal cations to negatively charged sites on soil particles and soil organic materials. Cation-exchange capacity (CEC) is the measure of a soil's potential to exchange cations and is related to soil mineralogy, pH, and organic matter content.

Anion exchange is the exchange and replacement of negatively charged ions to positively charged sites on soil particles. Anion exchange capacity is relatively low in most soils when compared to cation exchange; however, anion exchange is important because the anion exchange potential of the soil is related to its ability to retain and exchange nitrate nitrogen (NO_3–N), sulfate, chloride, boron, molybdenum, and phosphorus.

Adsorption and precipitation are processes that remove an ion from the soil solution. Sorption occurs as ions attach to the solid soil surface through weak chemical and molecular bonds or as strong chemical bonds. Precipitation is the deposition of soluble compounds in soil voids. It occurs when the amount of the dissolved compounds in the soil solution exceeds the solubility of those compounds.

Complexation is the interaction of metals with soil organic matter and some oxides and carbonates, resulting in the formation of large, stable molecules. This process extracts phosphorus and heavy metals from the soil solution. These stable complexes act as sinks for phosphorus, heavy metals, and some soil micronutrients.

651.0503 Soil-agricultural waste mineralization relationship

The mineralization of agricultural waste material is governed by the biological, chemical, and physical properties of soil and organic waste; the soil moisture; and the soil temperature. Organic waste mineralization is a process where microbes digest organic waste, reduce the waste material to inorganic constituents, and convert it to more stable organic materials. Inorganic materials released during this process are the essential plant nutrient (N, P, K), macronutrients and micronutrients, salts, and heavy metals.

(a) Microbial activity

Soil-agricultural waste material microbial composition and microbial activity greatly influence the rate of organic waste mineralization. Soil moisture, temperature, and aeration regulate soil microbial activity and thus are factors that influence the rate of waste mineralization.

Table 5–1 Common exchangeable soil cations and anions

Elements	Cations	Anions
Aluminum	Al^{+3}	
Boron		BO_3^{-3}
Calcium	Ca^{+2}	
Carbon		CO_3^{-2}, HCO_3^{-}
Chlorine		Cl^{-}
Copper	Cu^{+}, Cu^{+2}	
Hydrogen	H^{+}	OH^{-}
Iron	Fe^{+2}, Fe^{+3}	
Magnesium	Mg^{+2}	
Manganese	Mn^{+2}, Mn^{+3}	
Molybdenum		MoO_4^{-2}
Nitrogen	NH_4^{+}	NO_2^{-}, NO_3^{-}
Phosphorus		HPO_4^{-2}, $H_2PO_4^{-}$
Potassium	K^{+}	
Sulfur		SO_3^{-2}, SO_4^{-2}
Zinc	Zn^{+2}	

Soils that are warm, moist, and well aerated have the highest potential microbial activity and the highest potential rate of organic waste mineralization. Lower potential rates should be expected when soils are dry, cold, or saturated with water. (See figs. 5–1 & 5–2.)

Average annual soil surface temperature and seasonal temperature variations have a significant impact on the duration and rate of soil microbial activity. Average annual soil temperatures in the conterminous United States range from less than 32 °F (0 °C) to more than 72 °F (22 °C). Microbial activity is highest in soils that have high average annual soil temperature and lowest in soils that have low temperature.

In many areas, the mean winter soil temperature is 9 °F (5 °C) or more below the mean summer soil temperature. Microbial activity and organic waste mineralization in the soils in these areas are greatest during the summer months and least during the winter months. Thus, microbial activity decreases or increases as mean monthly soil temperature changes throughout the year.

Agricultural wastes applied to cold or frozen soils mineralize very slowly, are difficult or impossible to incorporate, and are vulnerable to surface runoff and erosion. Potential agricultural waste contamination of surface water is highest when agricultural wastes are applied under these conditions.

Microbial activity is also highly dependent on the soil moisture content. Soils that are dry throughout most of the growing season have a low organic matter mineralization rate. Microbial activity in these soils is greatest immediately after rainfall or irrigation events and decreases as soil moisture decreases. Conversely, soils that are moist throughout most of the growing season have higher microbial activity and more capacity to mineralize organic waste. Wet soils or soils that are saturated with water during the growing season have potentially lower microbial activity than moist soils. This is not caused by a lack of soil moisture, but is the result of low soil aeration when the soils are saturated.

(b) Nitrogen mineralization

Organic nitrogen is converted to inorganic nitrogen and made available for plant growth during the waste mineralization process. This conversion process is a two way reaction that not only releases nitrogen, but also consumes nitrogen.

Agricultural waste materials, especially livestock manure that has C:N ratios shown in chapter 4, increase the energy or food supplies available to the soil microbial population. This high energy stimulates soil microbial activity, which consumes more available nitrogen than the mineralization processes release. Thus, high microbial activity during initial waste mineralization can cause a reduction of available nitrogen below that needed for plant growth. Nitrogen deficiency also occurs if the waste mineralization cannot supply sufficient quantities of nitrogen to the plants during periods of rapid growth. This is most apparent in spring as the soil warms and crops exhibit a short period of nitrogen deficiency.

Ammonium nitrogen (NH_4^+) is the initial by-product of organic nitrogen mineralization. Ammonium is adsorbed to soil particles through the cation exchange. It can be used by plants or micro-organisms. Ammonium nitrogen is further oxidized by nitrifying bacteria to nitrate (NO_3^-). This form of nitrogen is not strongly adsorbed to soil particles nor easily exchanged by anion exchange.

Nitrate forms of soil nitrogen are susceptible to leaching and can leach out of the plant root zone before they can be used for plant growth. Nitrate can contaminate if leached below the soil root zone or transported off the field by runoff to surface water. Soils that have high permeability and intake rates, coarse texture, or shallow depth to a water table are the most susceptible to nitrate contamination of ground water. Those that have low permeability and intake rates, fine texture, or steep slopes have a high runoff potential and are the most susceptible to nitrogen runoff and erosional losses.

(c) Phosphate mineralization

Organic phosphorus in agricultural wastes is made available for plant growth through the mineralization process. Phosphorus is removed from the soil solution by adsorption to the surface of clay particles or complexation with carbonates, iron, aluminum, or more stable organic compounds.

Phosphorus mobility is dependent on the phosphorus adsorption and complexation capacity of a soil. Soils that have slow permeability and high pH, lime, Fe or Al oxides, amorphous materials, and organic matter content have the highest phosphorus adsorption capacity. Adsorbed phosphorus is considered unavailable for plant growth. Soil erosion and runoff can transport the sorbed and complexed phosphorus offsite and contaminate surface water. Adsorbed phosphorus in suface water may become available by changes in the water pH or redox potential. Conversely, soils that have rapid permeability, low pH, and low organic matter have low phosphorus adsorption capacity allowing phosphorus to leach below the root zone. However, this seldom occurs.

(d) Potassium, calcium, and magnesium mineralization

Potassium, calcium, and magnesium converted from organic to inorganic compounds during mineralization have similar reactions in the soil. Upon dissolution, they become cations that are attracted to negatively charged soil particles and soil organic matter. These minerals are made available for plant growth through the cation exchange process. Potassium is less mobile than nitrogen and more mobile than phosphorus. Leaching losses of potassium are not significant and have little potential to contaminate ground water. Calcium and magnesium can leach into ground water or aquifers, but they do not constitute a hazard to water quality.

(e) Heavy metal and trace element mineralization

Heavy metals and trace elements are by-products of the organic mineralization process. Municipal sludge applied on the land is often a source of heavy metals. They are strongly adsorbed to clay particles or complexed (chelated) with soil organic matter and have very little potential to contaminate ground water supplies and aquifers. This immobilization is strongest in soils that have a high content of organic matter, pH greater than 6.0, and CEC of more than 5. However, application of organic waste containing high amounts of heavy metals can exceed the adsorptive capability of the soil and increase the potential for ground water or aquifer contamination. See chapter 6 for the impact of heavy metals on plants.

Sandy soils that have low content of organic matter and low pH have a low potential for retention of heavy metals. These soils have the highest potential for heavy metals and trace element contamination of aquifers and ground water. Surface water contamination from heavy metals and trace elements is a potential hazard if agricultural wastes are applied to areas subject to a high rate of runoff or erosion.

651.0504 Soil characteristics

Soil suitabilities and limitations for agricultural waste application are based on the most severely rated soil property or properties. A severe suitability rating does not necessarily infer that agricultural wastes cannot be used. It does, however, infer a need for careful planning and design to overcome the severe limitation or hazard associated with one or more soil properties. Care must be taken in planning and designing agricultural waste management systems that are developed for soils that have a moderate limitation or hazard suitability rating. In general, moderate limitations or suitability ratings require less management or capital cost to mitigate than do the severe ratings.

Slight is the rating given soils that have properties favorable for the use of agricultural wastes. The degree of limitation is minor and can be overcome easily. Good performance and low maintenance can be expected.

Soil suitability for site specific agricultural waste storage or treatment practices, such as a waste storage pond, waste treatment lagoon, or waste storage structure, are not discussed in this section. Soil variability within soil map delineations and mapping scale generally prevent using soil maps for evaluation of these site specific agricultural waste management system components. Soil investigations conducted by a soil scientist or other qualified person are needed to determine and document site specific soil information, such as soil type, observed and inferred soil properties, and the soil limitations or hazards for the site specific components. See chapter 7 for site specific considerations.

Nonsite specific agricultural waste utilization practices are those that apply agricultural wastes to fields or other land areas by spreading, injection, or irrigation. The suitability, limitations, or hazards associated with these practices are dependent upon and influenced by the geographical variability of the soil and soil properties within the area of application. They are discussed in this chapter.

Soil suitability ratings for nonsite specific agricultural waste management system components and practices are determined from soil survey maps and FOTG interpretive tables, SIR, or National Soils Handbook interpretive guides. Soil variability within fields or geographical areas may require the collective assessment of soil suitability and limitation ratings for the application of agricultural wastes in the area under consideration. Soil features and their combined effect on the agricultural waste management system are important considerations when evaluating soil-agricultural waste suitability ratings for soils. A soil scientist should be consulted when assessing the effects of soil variability on design and function of an agricultural waste management system.

(a) Available water capacity

Available water capacity is a measure of the soil's capacity to hold water in a form available to plants. It is a function of soil porosity, texture, structure, organic matter content, and salinity. Available soil water is estimated as the difference between soil water content at 1/3 or 1/10 bar tension (field capacity) and 15 bar tension (permanent wilting point). The available water capacity is generally expressed as the sum of available water in inches to a specified soil depth. Generally, this depth is 5 feet or the depth to a root-restricting layer, whichever is less. Available water capacity infers the capacity of a soil to store or retain soil water, liquid agricultural wastes, or mineralized agricultural waste solids in the soil solution. Applying agricultural wastes increases soil organic matter content, helps to stabilize soil structure, and enhances available water capacity.

Limitations for agricultural waste applications are slight if the available water capacity is more than 6.0 inches per 5 foot of soil depth, moderate if it is 3.0 to 6.0 inches, and severe if it is less than 3.0 inches. Soils for which the limitations are moderate have reduced plant growth potential, limited microbial activity, and low potential for retaining liquid and mineralized agricultural waste solids. Lower waste application rates diminish the potential for ground water contamination and help to alleviate agricultural waste overloading.

Soils that have severe limitations because of the available water capacity have low plant growth potential, very low potential for retaining liquid or mineralized agricultural waste solids, low microbial activity, and high potential for agricultural waste contamination of surface and ground water. Reducing waste application rates, splitting applications, and applying waste only during the growing season diminish potential for ground and surface water contamination and help prevent agricultural waste overloading.

The volume of liquid agricultural waste application should not exceed the available water capacity of the root zone or the soil moisture deficit at the time of application. Low rates and frequent applications of liquid agricultural wastes on soil that has low available water capacity or during periods of high soil moisture deficit can reduce potential for ground water contamination.

(b) Bulk density

Bulk density, soil mass per unit volume, is expressed in grams per cubic centimeter. It affects infiltration, permeability, and available water capacity. Coarse textured soils have only a slight limitation because of bulk density. Medium to fine textured soils in which the bulk density in the surface layer and subsoil is less than 1.7 g/cm^3 have slight limitations for application of agricultural wastes. Medium to fine textured soils in which the bulk density in these layers is more than 1.7 g/cm^3 have moderate limitations.

Agricultural waste application equipment may compact the soil when the waste is applied to soil by spreading or injecting and soil moisture content is at or near field capacity. Agricultural wastes should be applied when soil moisture content is significantly less then field capacity to prevent compaction.

Agricultural wastes can be surface applied to medium to fine textured soils that have bulk density less than 1.7 g/cm^3. Liquid waste should be injected and application rates reduced when the bulk density of medium to fine textured soil is equal to or greater than 1.7 g/cm^3. Injection application and reduced application rates on these soils help to prevent liquid waste runoff and compensate for slow infiltration.

Incorporating wastes that have a high solids content with high levels of organic carbon reduces the soil surface bulk density and improves soil infiltration and surface permeability. The high bulk density associated with coarse textured soils does not impede or affect the application of agricultural wastes. The high permeability rate of coarse textured soils may affect the application rate because of the potential for ground water contamination. (See sections 651.0503(h) and 651.0503(i).)

(c) Cation-exchange capacity

Cation-exchange capacity (CEC) is an index of the soil's capacity to exchange cations with the soil solution. It affects the ability of the soil to adsorb and retain cations and heavy metals. Cations are held to the soil particles by adsorption and can be returned to the soil solution for plant use by the exchange process.

Soils that have high CEC and organic soils can exchange and retain large amounts of cations released by agricultural waste mineralization processes. Conversely, soils in which the CEC is low have low potential for exchanging and retaining these agricultural waste materials. The potential for agricultural waste contamination of underlying ground water and aquifers is highest for soils that have low CEC and lowest for those with high CEC.

The limitations for solid and liquid waste applications are slight for soils that have a cation-exchange capacity of more than 15, moderate for those with a capacity of 5 to 15, and severe for those for which it is less than 5. Underlying ground water supplies and aquifers can become contaminated when agricultural wastes are applied at high rates to soils that have moderate or severe limitations because of their CEC. Reducing agricultural waste application rates can reduce the hazard for ground water contamination.

(d) Depth to bedrock or cemented pan

The depth to bedrock or a cemented pan is the depth from the soil surface to soft or hard consolidated rock or a continuous indurated or strongly cemented pan. A shallow depth to bedrock or cemented pan often does not allow for sufficient filtration or retention of agricultural wastes or agricultural waste mineralization by-products. Bedrock or a cemented pan at a shallow depth, less than 40 inches, limits plant growth and root penetration and reduces soil agricultural waste adsorptive capacity. Limitations for application of agricultural wastes are slight if bedrock or a cemented pan is at a depth of more than 40 inches, moderate if it is at a depth of 20 to 40 inches, and severe at a depth of less than 20 inches.

Agricultural wastes continually applied to soils that have moderate or severe limitations because of bedrock or a cemented pan can overload the soil retention capacity. This allows waste and mineralization by-products to accumulate at the bedrock or cemented pan soil interface. When this accumulation occurs over fractured bedrock or a fractured cemented pan, the potential for ground water and aquifer contamination is high. Reducing waste application rates on soils that have a moderate limitation diminishes ground water contamination and helps to alleviate the potential for agricultural waste overloading. If the limitations are severe, reducing waste application rates and split applications will lessen overloading and the potential for contamination.

(e) Depth to high water table

Depth to high water table is the highest average depth from the soil surface to the zone of saturation during the wettest period of the year. This saturated zone must be more than 6 inches thick and persist for more than a few weeks. A shallow depth to high water table may not allow for sufficient filtration or retention of agricultural wastes or agricultural waste mineralization by-products. A high water table at a depth of less than 4 feet can limit plant and root growth and reduce the soil's agricultural waste adsorptive capacity.

Limitations for application of agricultural wastes are slight if the water table is at a depth of more than 4 feet, moderate at a depth of 2 to 4 feet, and severe if it is at a depth of less than 2 feet. Depth and type of water table, time of year, and duration data should be collected if agricultural wastes are to be applied to soils suspected of having a water table within 4 feet of the soil surface.

Agricultural wastes applied to soils that have moderate limitations because of the water table can overload the soil's retention capacity and percolate through the soil profile contaminating the water table. Reducing waste application rates on these soils helps to alleviate agricultural waste overloading and lessens the potential for ground water contamination.

The potential for contamination of shallow ground water is very high if agricultural wastes are applied to soils that have severe limitations. Careful application and management of agricultural wastes applied to these soils are recommended. Management should include frequent applications at very low rates.

(f) Flooding

Flooding is the temporary covering of the soil surface by flowing water. Ponded and standing water or flowing water during and shortly after rain or snowmelt are not considered flooding. Flooding events transport surface-applied agricultural wastes off the application site or field and deposit these materials in streams, rivers, lakes, and other surface water bodies.

Soils that have none or rare flooding potential (5 times or less in 100 years) have slight limitations for the application of agricultural waste. Occasional flooding (5 to 50 times in 100 years) is a moderate limitation for the application of agricultural waste, and frequent flooding (50 to 100 times in 100 years) is a severe limitation.

Agricultural wastes should be applied during periods of the year when the probability of flooding is low. Liquid agricultural waste should be injected, and solid agricultural waste should be incorporated immediately after application. Incorporating agricultural wastes and applying wastes when the probability of flooding is low reduce the hazard to surface water.

(g) Fraction greater than 3 inches in diameter—Rock fragments, stones, and boulders

Rock fragments, stones, and boulders are the soil fractions greater than 3 inches and are measured as a weight percent or estimated as a volume percentage of the whole soil. The upper size limit is undefined, but for practical purposes is about 40 inches. Stoniness is a soil surface feature that is defined as the percent of stones and boulders (rock fragments greater than 10 inches in diameter) that cover the soil surface. It is represented as classes 1 through 6.

Limitations for agricultural waste application are slight if stoniness is class 1 (less than 0.1 percent of the surface covered with stones and boulders), moderate if it is class 2 (0.1 to 3.0 percent of the surface covered with stones and boulders), and severe if it is classes 3, 4, 5, or 6 (more than 3 percent of the soil surface is covered with stones and boulders).

Rock fragments, stones, and boulders can restrict application equipment operations and trafficability and affect the incorporation of agricultural wastes. Incorporating agricultural wastes that have high solids content may be difficult or impractical where:

- Rock fragments between 3 and 10 inches in diameter make up more than 15 percent, by weight, (10 percent, by volume) of the soil
- Stones and boulders more than 10 inches in diameter make up more than 5 percent, by weight, (3 percent, by volume) of the soil
- The soil is in stoniness class 2 or higher

Because of this, agricultural wastes applied to these areas may be transported offsite by runoff and have the potential to contaminate the adjacent surface water. Local evaluation of the site is required to determine if the size, shape, or distribution of the rock fragments, stones, and/or boulders will impede application or incorporation of agricultural wastes.

(h) Intake rate

The intake rate is the rate at which water enters the soil surface. Initial water intake is influenced by soil porosity, bulk density, moisture content, texture, structure, and permeability of the surface layer. Continued water intake rate is controlled by the permeability of underlying layers. Water intake potential is inferred from hydrologic soil groups and inversely related to the hydrologic group runoff potential. If agricultural wastes that have large quantities of suspended solids are applied at high rates on soils that have high or moderate intake potential, soil macropore space can clog and the soil intake rate is reduced. Conversely, application and incorporation of agricultural wastes to soils that have slow water intake potential can increase soil structure and porosity, thus improving the potential water intake rate. The short-term effect may be pore clogging and resulting runoff if application rates are high on soils that have a slow intake rate.

Soils in hydrologic groups B and C have moderate intake potential and slight limitations for application of agricultural wastes. Soils in hydrologic group D have a slow intake potential, high runoff potential, and generally have moderate limitations for the applications of agricultural wastes. Incorporating agricultural wastes applied to hydrologic group D soils helps to prevent the removal and transport of wastes by runoff and water erosion and can reduce the potential for surface water contamination. Liquid waste application rates should not exceed irrigation intake rates for soils in hydrologic groups B, C, or D. Application rates that exceed the irrigation intake rate may result in runoff of agricultural wastes, which have the potential to contaminate adjacent surface water.

Soils in hydrologic group A generally have moderate limitations for the application of agricultural wastes that have high solids content, and severe limitations for liquid wastes. Rapid intake of liquid and mineralized waste solids has the potential to contaminate underlying aquifers and ground water supplies. Aquifer contamination potential can be reduced by reducing application rates, using split applications, and applying the waste only during periods of the year when evapotranspiration exceeds precipitation.

Soils in dual hydrologic groups, such as A/D, B/D, or C/D, have severe limitations for the application of agricultural wastes. Rapid and moderate infiltration of liquid and mineralized waste solids have the potential to contaminate underlying high water table and ground water supplies. Water table depth, type, time of year, and duration data should be collected if agricultural wastes are to be applied to soils in dual hydrologic groups. Aquifer and water table contamination can be lessened by reducing application rates, using split applications, and applying only during periods of the year when evapotranspiration exceeds precipitation.

(i) Permeability rate

Permeability (hydraulic conductivity) is the quality of soil that enables water to move downward through the soil profile. It generally is inferred from the permeability of the most slowly permeable horizons in the profile. Permeability is estimated from soil physical properties and is expressed in inches per hour. Permeability rates affect runoff, leaching, and decomposition rates of agricultural wastes that are applied to or incorporated in the surface layer. Application and incorporation of agricultural wastes improve soil surface intake and permeability; however, frequent applications at high rates can clog soil pores and reduce soil surface permeability and intake.

Agricultural wastes can be applied to soils that have only slight limitations because of permeability. Agricultural wastes applied to soils that have permeability of less than 0.2 inch per hour should be incorporated (solids) or injected (liquids) into the soil to reduce potential surface water contamination from erosion and runoff. Split rate applications of liquid wastes applied to soils that have permeability of more than 2 inches per hour reduce the potential for contamination of shallow aquifers. Reducing the rate of application and using split applications of waste solids on soils that have severe limitations for this use can reduce the potential for contamination of shallow aquifers. Table 5–2 shows the limitation ratings for solid and liquid wastes.

(j) Soil pH

Soil pH affects plant nutrient availability, agricultural waste decomposition rates, and adsorption of heavy metals. Soils in which the surface pH is less than 6.5 have lower potential for plant growth and low heavy metal adsorption.

Limitations and recommendations are based on the lowest pH value of the surface layer. Limitations for the application of agricultural wastes are slight if the pH in the surface layer is more than 6.5, moderate if it is 3.5 to 6.5, and severe if it is less than 3.5. Continuous, high application rates of agricultural wastes reduce soil pH. If large amounts of agricultural wastes are applied to small fields or land tracts, the soil pH should be monitored to prevent its reduction to levels that affect soil ratings and limitations for plant growth.

(k) Ponding

Ponding is standing water in a closed depression that is removed only by percolation, transpiration, or evaporation. Agricultural wastes applied to soils that are ponded have a very high potential for contaminating the ponded surface water. Application on these soils should be avoided if possible.

(l) Salinity

Salinity is the concentration of dissolved salts in the soil solution and is related to electric conductivity. Electrical conductivity is the standard measure of soil salinity and is recorded as Mmhos/cm. High soil salinity interferes with the ability of the plant to absorb water from the soil and to exchange plant nutrients. This interference reduces plant growth and seed germination and limits the choice of crops that can be successfully grown. If soil salinity is a potential hazard or limitation, crops that have a high tolerance to salinity should be used in the agricultural waste management system. For further information on the use of these crops, see chapters 6 and 11.

Table 5–2 Agricultural waste–soil permeability rate limitations

Waste	- - - - - Limitations - - - - -		
	Slight	Moderate	Severe
	- - - - - in/hr - - - - -		
Solids	< 2.0	2.0 – 6.0	> 6.0
Liquid	0.2 – 2.0	0.06 – 0.2 or 2.0 – 6.0	< 0.06 or > 6.0

Salinity ratings are for the electric conductivity of the soil surface. Limitations for the application of agricultural wastes are very slight if salinity is measured as less than 4 mmhos/cm, slight if it is 4 to 8 mmhos/cm, moderate if 8 to 16 mmhos/cm, and severe if more than 16 mmhos/cm.

Soils that have moderate limitations affect the choice of crops that can be grown and cause reduced germination. Agricultural wastes that have a high content of salt can be applied to moderately rated soils, but applications should be rotated among fields and rates should be reduced to prevent an increase in soil salinity and further degradation of plant growth.

Applying agricultural wastes that are high in salt to soils that have a severe rating should be avoided to prevent increasing soil salinity and further inhibiting plant growth and organic matter decomposition. However, limited amounts of agricultural wastes can be applied if applications are rotated among fields and soil salinity is monitored.

Agricultural wastes that have low salt content and a high C:N ratio can be applied and will have a beneficial impact on soils that have a moderate or severe salinity rating. Application of low salt, high C:N ratio agricultural wastes to these soils improves intake, permeability, available water capacity, and structure. It also reduces salt toxicity to plants.

(m) Slope

Slope is the inclination of the soil surface from the horizontal expressed as a percentage. The slope influences runoff velocity, erosion, and the ease with which machinery can be used. Steep slopes limit application methods and rates and machinery choices. Runoff velocity, soil carrying capacity of runoff, and potential water erosion increase as slopes become steeper.

Limitations for the application of agricultural wastes are slight if the slope is less than 8 percent, moderate if it is 8 to 15 percent, and severe if it is more than 15 percent. Agricultural wastes applied to soils that have moderate limitations should be incorporated. This minimizes erosion and transport of waste materials by runoff, thus reducing the potential for surface water contamination.

Soils that have severe slope limitations have limited cropping potential and are subject to excessive runoff and erosion. Agricultural wastes should be incorporated into these soils as soon as possible to reduce the potential for surface water contamination. Conservation practices that reduce potential water erosion and runoff help prevent the erosion and transport of agricultural wastes and should be incorporated in the agricultural waste management system.

(n) Sodium adsorption

Sodium adsorption is represented by the Sodium Adsorption Ratio (SAR), which is the measured amount of sodium relative to calcium and magnesium in a water extract from a saturated soil paste. A high and moderate SAR, more than 4, interferes with the ability of the plant to absorb water from the soil and to exchange plant nutrients. This interference reduces plant growth and seed germination and limits the choice of crops that can be successfully grown. An SAR of more than 13 has a detrimental effect on soil intake, permeability, and structure.

Limitations for the application of agricultural wastes are slight if SAR less than 4, moderate if it is 4 to 13, and severe if it is greater than 13. Soils that have moderate limitations affect the choice of crops that can be grown and reduce germination. To prevent increasing soil SAR and further degradation of soil properties, agricultural wastes that are high in sodium should not be applied to soils that have a moderate or severe rating. Agricultural wastes that have low sodium content and a high C:N ratio can be applied and will have a beneficial impact on soils that have a moderate or severe SAR rating. Application of agricultural wastes that have low salt conent and a high C:N ratio to these soils improves soil intake, permeability, and structure. It also reduces the plant toxicity effect of soil sodium.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Droughty	(inches)			
(Available water capacity)	> 6.0	Slight	Apply waste.	Improves available water capacity.
	3.0– 6.0	Moderate	(Low available water capacity and low retention). Reduce application rates.	Improves available water capacity. Contaminants can flow into ground water.
	< 3.0	Severe	(Very low available water capacity and very low retention). Reduce application rates and use split applications.	Improves available water capacity. Contaminants can flow into ground water and enter surface water.
Dense layer				
(Bulk density)	(grams/cc)			
Soil texture:				
Medium & fine	<1.7	Slight	Apply when soil moisture content is such that the field is in tillable condition.	Reduces bulk density and minimizes compaction.
Coarse	All			
Medium & fine	≥1.7	Moderate	(Compaction and runoff.) Apply when soil moisture content is such that the field is in tillable condition. Incorporate high solids content waste. Reduce application rate and inject liquid waste.	Reduces bulk density and minimizes compaction.
Low adsorption				
(Cation-exchange capacity)	(meq/100g of soil) > 15	Slight	Apply waste.	Increases cation-exchange capacity and organic matter content.
	5–15	Moderate	(Low adsorption and exchange of cations, and heavy metals.) Reduce application rates.	Contaminants can flow into ground water.
	< 5	Severe	(Very low adsorption and exchange of cations; heavy metals.) Reduce application rates.	Contaminants can flow into ground water.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Thin layer/ cemented pan				
(Depth to bedrock or cemented pan)	(inches) > 40	Slight	Apply waste.	None.
	20 – 40	Moderate	(Moderate soil depth and limited root zone.) Reduce application rates.	Contaminants can flow into ground water. Potential waste overloading of the soil if applied at high rates.
	< 20	Severe	(Shallow soil depth and root zone.) Reduce application rates and use split applications.	Contaminants can flow into ground water. Potential waste overloading of the soil if applied in a single application at high rates.
Wetness				
(Depth to high water table)	(feet) > 4	Slight	Apply waste.	None.
	2 – 4	Moderate	(Moderate soil depth and limited root zone.) Reduce application rates.	Contaminants can flow into ground water.
	< 2	Severe	(Shallow soil depth and root zone.) Application of agricultural wastes not recommended.	Contaminants can flow into ground water.
Flooding				
(Flooding frequency)	None, rare (5 times or less in 100 years.)	Slight	Apply waste.	None.
	Occasional (5 to 50 times in 100 years.)	Moderate	(Flooding and transport of waste offsite.) Apply and incorporate waste during periods when flooding is unlikely.	Contaminants can enter surface water.
	Frequent (50 to 100 times in 100 years.)	Severe	(Flooding and transport of waste offsite.) Apply and incorporate waste during periods when flooding is unlikely.	Contaminants will most likely enter surface water.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Too stoney or too cobbly (Fraction, > 3 inches in diameter; Rock fragments, 3 – 10 inches in diameter; Stones and boulders, >10 inches in diameter):				
	% by weight (volume)			
(Rock fragments) (Stones & boulders)	< 15 (< 10) < 5 (< 3)	Slight	Apply waste.	None.
(Rock fragments) (Stones & boulders)	15–35 (10–25) 5–15 (3–10)	Moderate	(Restricted equipment opera tion.) Apply waste at reduced rates.	Contaminants can enter surface water.
(Rock fragments) (Stones & boulders)	> 35 (> 25) > 15 (> 10)	Severe	(Restricted equipment trafficability and operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
(Stoniness)	Stoniness class			
	1	Slight	Apply waste.	None.
	2	Moderate	(Restricted equipment oper-ation.) Apply waste at reduced rates.	Contaminants can enter surface water.
	3, 4, 5	Severe	(Restricted equipment traffic-ability and operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
Intake (hydrologic soil group)				
Liquid & solid wastes	B and C	Slight	Apply solid waste. Do not exceed irrigation intake rates of liquid waste.	High application rates may cause clogged surface pores and reduced infiltra tion.
Solid wastes	A	Moderate	(Leaching of mineralized waste.) Reduce rate of application.	Application may clog surface pores and reduce infiltration.
Liquid wastes		Severe	(Rapid infiltration and leaching vulnerability.) Split applications and reduce application rates.	Contaminants can flow into ground water.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Intake (cont)				
Liquid & high solids waste	D	Moderate	(Slow infiltration and potential runoff.) Inject or incorporate agricul-tural wastes.	Improves infiltration and surface soil permeability. Contaminants can enter surface water.
Liquid & high solids waste	A/D, B/D, C/D	Severe	(Water table near the soil surface.) Reduce application rates.	Contaminants can flow into ground water.
Poor filter or percs slowly				
(Permeability)	(inches/hour)			
High solids waste	< 2.0	Slight	Apply waste.	Improves soil surface infil-tration and permeability.
Liquid waste	0.6 – 2.0	Slight	Apply waste.	Improves soil surface infil-tration and permeability.
Liquid waste	0.2 – 0.6	Moderate	(Slow permeability and poten-tial runoff vulnerability.)	Contaminants can enter surface water.
Liquid & high solids waste	2.0 – 6.0	Moderate	(Leaching vulnerability.) Inject liquid waste and incorporate high solids content waste.	Contaminants can flow into ground water.
Liquid waste	< 0.2	Severe	(Slow to very slow permeability and potential runoff contami-nation of surface water.) Inject liquid waste and incorporate high solids content waste.	Contaminants can enter surface water.
Liquid & high solids waste	> 6.0	Severe	(Rapid permeability and leaching vulnerability.) Split applications of liquid waste and reduce application rates of liquid and high solids content waste.	Contaminants can flow intoground water. Re-duced permeability from organic matter accumula-tion in pores.
Too acid				
(pH)	> 6.0	Slight	Apply waste.	Very high application rates of wastes may lower soil pH.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Too acid (cont.)				
	4.5 – 6.0	Moderate	(Increased availability of heavy metals and reduced plant growth potential.) Reduce application rates, apply lime, and incorporate.	Heavy metal contaminants can flow into ground water.
	< 4.5	Severe	(Increased availability of heavy metals, reduced plant growth, and limited crop selection.) Reduce application rates, apply lime, and incorporate.	Heavy metals contaminants can flow into ground water.
Ponding (Ponding)	All	Severe	(Ponded water.) Application of agricultural wastes not recommended.	Contaminants can enter surface water.
Excess salt (Salinity)	(mmhos/cm)			
	< 4	Slight	Apply waste.	None.
	4 – 8	Moderate	(Slight salinity—choice of crops and germination restricted.) Apply high C:N, low salt wastes. **Saline wastes:** Rotate application fields and reduce rates.	**High C:N & low salt wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Saline wastes:** May increase soil salinity if applied at continuous high rates.
	> 8	Severe	(Salinity, crops limited to salt-tolerant grasses.) Apply high C:N, low salt wastes. **Saline wastes:** Rotate application fields and reduce rates.	**High C:N & low salt wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Saline wastes:** May increase soil salinity if applied at continuous high rates.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Slope				
(Slope)	(percent)			
	< 8	Slight	Apply waste.	None.
	8 – 15	Moderate	(Moderately steep slopes, potential water erosion.) Incorporate liquid and high solids waste and control runoff.	Contaminants can enter surface water.
	> 15	Severe	(Steep slopes, water erosion, and limited cropping potential) Incorporate liquid and high solids waste and control runoff.	Contaminants can enter surface water.
Excessive sodium				
(Sodium adsorption)	(SAR)			
	< 4	Slight	Apply waste.	None.
	4 – 13	Moderate	(Slight sodicity, choice of crops and germination restricted.) Apply high C:N, low sodium wastes. Rotate application fields and reduce rates for sodic wastes.	**High C:N & low sodium wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Sodic wastes:** May increase soil sodicity if applied at continuous high rates.
	> 13	Severe	(Sodicity, limited to sodium-tolerant grasses.) Apply high C:N, low sodium wastes. Rotate applications of sodium wastes. Rotate application fields and reduce rates for sodic wastes.	**High C:N & low sodium wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Sodic wastes:** May increase soil sodicity if applied at continuous high rates.

651.0505 References

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United States
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**Soil
Conservation
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Agricultural
Waste Management
Field Handbook

Chapter 6 Role of Plants in Waste Management

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Chapter 6 Role of Plants in Waste Management

651.0600 Introduction

Many agricultural operations produce waste by-products. Animal manure is an example of a waste by-product that can be used as a plant nutrient. Properly managed and utilized agricultural wastes are a natural resource that can produce economic returns. Waste management systems properly planned, designed, installed, and maintained prevent or minimize degradation of soil, water, and air resources while providing chemical elements essential for plant growth.

The objectives of a complete system approach to waste management are to design a system that

- recycles nutrients in quantities that benefit plants,
- builds levels of soil organic matter,
- limits nutrient or harmful contaminant movement to surface and ground water,
- does not contaminate food crops with pathogens or toxic concentrations of metals or organics, and
- provides a method in the soil environment to fix or transform nonessential elements and compounds into harmless forms.

This chapter will provide the reader with an appreciation for the plant's role in management of nutrients in an agricultural waste management system. The function and availability of plant nutrients as they occur in agricultural wastes are discussed, and the effects of trace elements and metals on plants are introduced. General guidance is given so the components of the waste can be converted to plant available form and the nutrients harvested in the crop can be estimated. The impact of excess nutrients, dissolved solids, and trace elements on plants is given in relationship to agricultural waste application.

651.0601 Agricultural waste as a resource for plant growth

The primary objective of applying agricultural waste to land is to recycle part of the plant nutrients contained in the waste material into harvestable plant forage, fruit, or dry matter. An important consideration is the relationship between the plant’s nutrient requirement and the quantity of nutrients applied in the agricultural wastes. A plant does not use all the nutrients available to it in the root zone. The fraction of the total that is assimilated by the roots varies depending on the species of plant, growth stage, depth and distribution of its roots, moisture conditions, soil temperature, and many other factors. The uptake efficiency of plants generally is not high, often less than 50 percent. Perennial grasses tend to be more efficient in nutrient uptake than row crops. They grow during most of the year, and actively grow during the period of waste application, which maximizes the nutrient removal from the applied waste product.

Another major objective in returning wastes to the land is enhancing the receiving soil’s organic matter content. As soils are cultivated, the organic matter in the soil decreases. Throughout several years of continuous cultivation in which crop residue returns are low, the organic matter content of most soils decreases dramatically until a new equilibrium is reached. This greatly decreases the soil’s ability to hold the key plant nutrients of nitrogen, phosphorus, and sulfur. These nutrients may move out of the root zone, and crop growth will suffer. The amount of crop residue that is produced and returned to the soil is reduced.

651.0602 The plant–soil system

The plant-soil system has advantages in using the nutrients in waste products from agricultural systems. For centuries wastes have been spread on the soil to recycle nutrients because of the positive effect on plant growth. Soils have the ability to retain plant nutrients contained in the waste. Soil retention is an important storage mechanism, and the soil is enhanced by the organic matter supplied by waste. Plants absorb the nutrients in the waste, for the most part through the roots, and transform the soluble chemical elements, some of which are water contaminants, into plant tissue. This is the basis for addressing some of today's water quality concerns. Cropping systems and precisely calculated nutrient budgets can be tailored to meet planned waste application levels and crop nutrient needs and to reduce or eliminate losses from the plant-soil system.

(a) Nutrient transformation

Plant uptake is not the only form of nutrient transformation that takes place in the soil-plant system. The chemical compounds derived from waste material can be transformed by the following processes:

1. Absorbed by the roots and assimilated by the plant
2. Degraded by soil micro-organisms and become a part of the soil organic component, or broken down further into a gas, ion, or water
3. Fixed to soil minerals or attached to soil exchange sites
4. Solubilized and moved with runoff water.
5. Moved with eroded mineral or organic material
6. Leached downward through the soil toward the ground water
7. Escaped from plant tissue into the atmosphere

Plants can play a role in all of these processes. Processes 4, 5, 6, and 7 are nutrient escape mechanisms. Plant species and cultivars can be selected to interrupt many of these mechanisms. An example of process 4 is that cultivated crops that are conservation tilled and planted on the contour with grass sod improve removal of soluble nutrients by soil infiltration.

Other mechanisms might be active in the removal of some solid constituents. Many soil conservation actions reduce erosion, which interrupts process 5. Deep, fibrous-rooted plants or plants that can actively take up nutrients beyond the normal growing season of most agricultural crops interrupt process 6 by preventing escape of leaching soluble nutrients.

Plants can also be selected for their propensity to uptake a certain nutrient. Several crops are heavy users of nitrogen and accumulate nitrate, which is very soluble and leachable. Recent studies have shown that grass species vary significantly in their ability to remove and transform nitrogen within the soil. Alfalfa removes potassium and nitrogen in larger quantities and at a deeper rooting depth than most agricultural crops.

In other cases, plants may act as a catalyst or provide a better environment to promote the transformation processes. Plant growth moderates soil temperature, reduces evaporation from soil surface, provides an energy source of carbohydrates, and aggregates soil particles, which promotes high soil aeration. All this provides a better climate for a wide variety of soil micro-organisms, which aids process 2.

Process 3 is aided by plant growth as well, but generally this comes very slowly. The classic example is the difference in the cation-exchange capacity between a prairie soil and a forest soil derived from the same parent material. The surface layer of the prairie soil has a much higher organic matter content and cation-exchange capacity, at least double to sometimes nearly quadruple that of the forest soil (Jenny 1941). Yet, what takes centuries to build up can be quickly destroyed in less than two decades by erosion and excessive tillage (fig. 6–1). High residue crops in crop rotations help to prevent large decreases in soil organic matter content and have beneficial effects on nutrient retention (Wild 1988).

Denitrification is a classic example of nutrient transformation where microbial degradation and eventual escape of nitrogen gas occurs. It is an important process by which nitrogen in excess of crop requirement can be removed from the soil-plant system. This process requires the presence of nitrate-nitrogen, an organic carbon source, and anaerobic soil conditions. About one unit of organic carbon is required for each unit of nitrate-nitrogen to be denitrified (Firestone 1982).

Denitrification in land treatment systems is best accomplished if the nitrogen is in the nitrate form and the waste contains sufficient organic carbon to supply energy to the denitrifying micro-organism. Where the nitrogen in the waste material is in the organic or ammonium form, an aerobic condition must be present to convert the nitrogen to the nitrate form. During the aerobic process, the organic carbon will be oxidized by aerobic bacteria in the soil, leaving less carbon available for anaerobic microbial use when the system goes anaerobic.

Plant residue and roots are major sources of organic carbon for these microbial processes. The presence of living plants stimulates denitrification. This is attributed to two effects. First, low oxygen levels in the soil area immediately surrounding respiring plant roots creates the condition in which denitrifying anaerobes can exist. Second, root excretions can serve as a food source of decomposable organic carbon for the denitrifying bacteria.

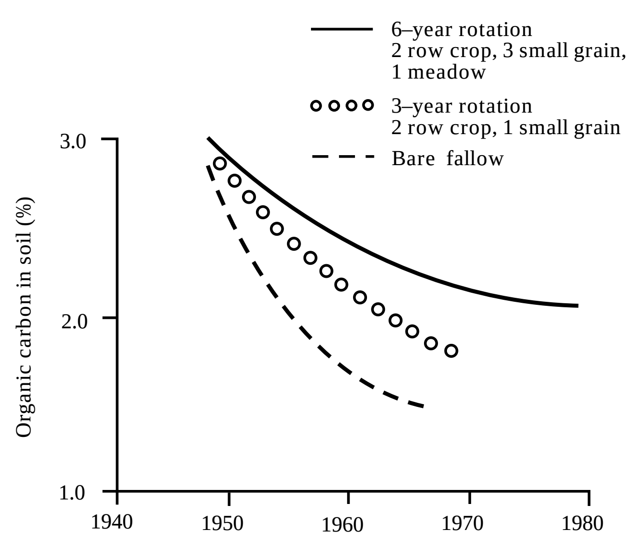
(b) Soil supports plant growth

Plant growth involves the interaction between soil and plant properties. Soil is the normal medium for terrestrial plant root growth. A plant's roots absorb nutrients and water from the soil. Roots anchored in the soil hold the plant erect. The soil must provide the environment in which roots can function.

Optimum plant growth depends on the soil having the biological, chemical, and physical conditions necessary for the plant root system to readily absorb nutrients and water. For instance, plants require soil pore space for root extension. Plant root metabolism also depends upon sufficient pore space to diffuse gases, such as oxygen and carbon dioxide. This allows for efficient root respiration, which keeps the root in a healthy condition for nutrient uptake. A decrease in soil pore space, such as that experienced with soil compaction, retards the diffusion of gases through the soil matrix, which greatly affects root growth.

Such inhibitory factors as toxic elements (aluminum or high concentrations of soluble salts) can limit or stop plant growth. Therefore, the plant's rate of absorption of nutrients involves many processes going on in the soil and plant roots.

Figure 6–1 The effects of different farming systems after three decades on the carbon content of soils from broken out sod ground



651.0603 Plant nutrient uptake

The process of element uptake by plants is complex and not totally understood. Some generally known points are:

- The process is not the same for all plants nor for all elements
- The complete process occurs within a healthy root system adequately supplied with carbohydrates and oxygen
- The essential elements must be in an available form in the root zone in balanced amounts
- Uptake varies from element to element and from crop to crop (see table 6–6)
- Soil conditions, such as temperature, moisture supply, soil reaction, soil air composition, and soil structure, affect the rate at which elements are taken up

(a) Essential plant nutrients

Plant growth can require up to 20 chemical elements. Plants get carbon, hydrogen, and oxygen from carbon dioxide and water. Nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium are needed in relative large quantities. These elements are called macronutrients. Boron, chlorine, cobalt, copper, iron, manganese, molybdenum, silicon, sodium, vanadium, and zinc are needed in small amounts, or not at all, depending on the plant (Tisdale et al. 1985). These elements are called micronutrients or trace elements.

Macronutrients and micronutrients are taken from the soil-water solution. Nitrogen is partly taken from the air by nitrogen- fixing plants associated with soil bacteria. As a whole, the 20 elements listed are termed essential elements; however, cobalt, silicon, sodium, and vanadium are essential elements for the growth of only particular plant species.

(b) Nonessential elements

Besides the 20 essential elements, other elements nonessential for plant growth must be monitored where municipal sludge is used as a soil amendment. These too are referred to as trace elements. Because these elements occur as impurities, they are often inadvertently applied to soils through additions of various soil amendments. Animal waste contains certain elements that can be considered nonessential. Nickel, arsenic, and copper have been found in poultry litter. Dairy manure has elevated levels of aluminum.

(c) Nitrogen

Nitrogen is the element that most often limits plant growth. About 98 percent of the planet's nitrogen is in the Earth's primary rock. Nearly 2 percent is in the atmosphere, but it is 79 percent inert.

Even though nitrogen is abundant, it is still the nutrient most frequently limiting crop production. This is because the plant available forms of nitrogen in the soil are constantly undergoing transformation. Crops remove more nitrogen than any other nutrient from the soil. The limitation is not related to the total amount of nitrogen available, but to the form the crop can use.

Most of the nitrogen in plants is in the organic form. The nitrogen is incorporated into amino acids, the building blocks of proteins. By weight, nitrogen makes up from 1 to 4 percent of the plant's harvested material.

Essentially all of the nitrogen absorbed from the soil by plant roots is in the inorganic form of either nitrate (NO_3) or ammonium (NH_4). Generally young plants absorb ammonium more readily than nitrate; however, as the plant ages the reverse is true. Under favorable conditions for plant growth, soil micro-organisms generally convert ammonium to nitrate, so nitrates generally are more abundant when growing conditions are most favorable. Once inside the root, ammonium and nitrate are converted to other compounds or transported to other parts of the plant.

(d) Phosphorus

Phosphorus concentration in plant leaves ranges between 0.2 and 0.4 percent (Walsh & Beaton 1972). Phosphorus is important for plant growth because of its role in ribonucleic acid (RNA), the plant cells genetic material, and its function in energy transfer with adenosine triphosphate (ATP).

Phosphorus is available for absorption by plants from the soil as the orthophosphate ion (H_2PO_4 and HPO_4). These ions react quickly with other compounds in the soil to become much less available for plant uptake. The presence of aluminum, iron, calcium, and organic matter links phosphorus in highly insoluble compounds. The concentration of orthophosphate ion in the soil solution is very low, less than 0.05 mg/L, so an equilibrium is established between the soluble ion and the adsorbed form in the soil.

Phosphorus immobility in soils is caused by several factors: presence of hydrous oxides of aluminum and iron; soils that have a high clay content, especially ones high in kaolin; soils high in volcanic ash or allophane; low or high soil pH; and high exchangeable aluminum. Of these factors, the one most easily manipulated is soil pH. Maintaining a soil pH between 6.0 and 6.5 achieves the most plant available phosphorus in a majority of soils. Knowing the extent each of the factors are at work in a particular soil gives the upper limit at which phosphorus loading can occur in the soil before soluble phosphorus leaching from the soil becomes a serious water quality concern.

The relative immobility of phosphorus in the soil profile allows some agricultural waste to be applied in excess of the crop’s nutrient needs, resulting in a soil phosphorus residual. Building a soil phosphorus residual can be beneficial in soils that readily fix phosphorus into an insoluble, unavailable form for plant uptake. This phosphorus reservoir, if allowed to rise, gives a corresponding rise in the soluble phosphorus content in the soil. This addition of total phosphorus has to be tempered with some restraint.

Manure applications can actually increase phosphorus leaching because organic phosphorus is more mobile through the soil profile than its inorganic counterparts. This would be particularly true on coarse textured soils that have a low cation-exchange capacity and low content of iron, aluminum, and calcium.

High phosphorus application rates appreciably increase the phosphorus concentration in the soil solution and availability for plant uptake into plant tissue, but this phosphorus rarely becomes toxic to the plant. Phosphorus toxicity depends on the plant species, phosphorus status of the plant, concentration of micronutrients, and soil salinity. Poor growth in plants that have high phosphorus levels can cause reduced nodulation in legumes, inhibition of the growth of root hairs, and a decrease in the shoot to root ratio (Kirkham 1985).

(e) Potassium, calcium, and magnesium

Potassium, calcium, and magnesium have similar reactions in the soil. The similar size and uptake characteristic can cause plant fertility problems. An excess of any one of these elements in the soil impacts the uptake of the others. It is, therefore, extremely important not to create nutrient imbalances by overapplying one of these elements to the exclusion of the others. Upon mineralization from the organic material, each element produces cations that are attracted to negatively charged particles of clay and organic matter.

Potassium is much less mobile than nitrogen, but more so than phosphorus. Leaching losses of potassium generally are insignificant except in sandy and organic soils. This is because sandy soils have a low cation-exchange capacity and generally do not have a clayey subsoil that can re-adsorb the leaching potassium. Potassium can leach from organic soils because the bonding strength of the potassium cation to organic matter is weaker than that to clay (Tisdale et al. 1985).

Some potassium is leached from all soils, even in the humid regions in soils that have strong fixing clays, but the losses do not appear to have any environmental consequences. Potassium leached from the surface soil is held in the lower horizons of the soil and returned to the surface via plant root uptake and translocation to above ground plant parts. Calcium and magnesium can occur in drainage water, but this has not been reported to cause an environmental problem. In fact, it can be beneficial in some aquatic systems. Total dissolved salts content may increase.

(f) Sulfur

Part of the sulfur applied to well drained soils ends up in sulfate form. Sulfur is oxidized by soil bacteria and fungi. The plant absorbs the oxidized sulfate ion. Sulfate concentrations between 3 and 5 mg/L in the soil are adequate for plant growth. Sulfates are moderately mobile and may be adsorbed on clay minerals, particularly the kaolinitic type, and on hydrous oxides of aluminum and to a lesser extent iron. If the soils in the waste management system are irrigated, sulfates can leach into the subsoil and even into ground water. Under poor drainage conditions, sulfates are converted mainly to hydrogen sulfide and lost to the atmosphere. In some instances, they are converted to elemental sulfur in waterlogged soils.

(g) Trace elements

Trace elements are relatively immobile once they are incorporated into the soil. The one nonmetal, boron, is moderately mobile and moves out of the rooting depth of coarse textured, acidic soils and soils that have a low organic matter content. The levels of plant available forms of all these elements are generally very low in relation to the total quantity present in soils. Some of these elements are not available for most plants to take up.

Soil reaction has the greatest influence on availability of trace elements that are taken up by plants. Except for molybdenum, the availability of trace elements for plant uptake increases as the soil pH decreases. The opposite occurs for molybdenum. For most agricultural crops, a pH range between 6.0 and 7.0 is best. As soil acidity increases, macronutrient deficiencies and micronutrient toxicity can occur depending on the nutrient, its total quantity available in the soil, and the plant in question. In alkaline soils, crops can suffer from phosphorus and micronutrient deficiencies.

Two nonessential elements of primary concern in municipal sludge are lead and cadmium. At the levels commonly found in soils or sludges, these elements have no detrimental effect on plant growth, but, they can cause serious health problems to the people or animals eating plants that are sufficiently contaminated with them. Lead can be harmful to livestock that inadvertently ingest contaminated soil or recently applied sludge while grazing. Cadmium, on the other hand, is taken up by some plants quite readily (table 6–1). If the plants are eaten, this element accumulates in the kidneys and can cause a chronic disease called proteinuria. This disease is marked by an increase of protein content in the urine.

Another nonessential element of concern is nickel. In high enough concentrations in the soil, it can become toxic to plants. Hydroxylic acid reacts with nickel to inhibit the activity of the urease molecule. This can interfere with plant metabolism of urea.

Table 6–1 Relative accumulation of cadmium into edible plant parts by different crops (USEPA 1983)*

High uptake	Moderate uptake	Low uptake	Very low uptake
Lettuce	Kale	Cabbage	Snapbean family
Spinach	Collards	Sweet corn	Pea
Chard	Beet roots	Broccoli	Melon family
Escarole	Turnip roots	Cauliflower	Tomato
Endive	Radish globes	Brussels sprouts	Pepper
Cress	Mustard	Celery	Eggplant
Turnip greens	Potato	Berry fruits	Tree fruits
Beet greens	Onion		
Carrots			

* The classification is based on the response of crops grown on acidic soils that have received a cumulative cadmium (Cd) application of 4.5 lb/ac. It should not be implied that these higher uptake crops cannot be grown on soils of higher Cd concentrations. Such crops can be safely grown if the soil is maintained at pH of 6.5 or greater at the time of planting because the tendency of the crop to assimilate heavy metals is significantly reduced as the soil pH increases above 6.5.

Two essential elements, zinc and copper, can also become toxic to plant growth if soil concentrations are excessive. These elements become toxic because they are mutually competitive as well as competitive to other micronutrients at the carrier sites for plant root uptake. Excessive concentrations of either element in the available form induces a plant nutrient deficiency for the other. High soil concentrations of copper or zinc, or both, can also induce iron and manganese deficiency symptoms (Tisdale et al. 1985).

In all, five elements of major concern have been targeted by the Environmental Protection Agency when sludge is applied to agricultural land. They are cadmium, copper, nickel, lead, and zinc. Table 6–2 shows their recommended cumulative soil limits in kilograms per hectare and in pounds per acre. Note that these loading limits depend on the soil's cation-exchange capacity and a plow layer pH maintained at 6.5 or above. Application of wastes that have these elements should cease if any one of the elements' soil limit is reached (USEPA 1983). Some states have adopted more conservative limits than those shown in table 6–2. State regulations should be consulted before designing a waste utilization plan.

Other trace elements have been identified as harmful to plant growth or potentially capable of occurring in high enough concentrations in plant tissue to harm plant consumers. They are aluminum, antimony, arsenic, boron, chromium, iron, mercury, manganese, and selenium. Generally, they do not occur in wastes, such as sludges, in high enough concentrations to pose a problem or they are only minimally taken up by crops (USEPA 1983).

As seen in table 6–1 for cadmium uptake, plants differ in their capacity to absorb elements from the soil. They also differ greatly in their tolerance to trace element phytotoxic effects. Tables giving specific tolerance levels for plant uptake are needed for individual plant species. Almost any element in the soil solution is taken into the plant to some extent, whether needed or not. An ion in the soil goes from the soil particle to the soil solution, through the solution to the plant root, enters the root, and moves from the root through the plant to the location where it is used or retained.

(h) Synthetic organic compounds

When dealing with municipal sludge, one other constraint to application rates should be addressed. Most sludge has synthetic organic compounds, such as chlorinated hydrocarbon pesticides, which can be slow to decompose and may be of concern from a human or animal health standpoint.

Polychlorinated biphenyls are in many sludges. Federal regulations require soil incorporation of any sludge that has more than 10 ppm of polychlorinated biphenyls wherever animal feed crops are grown. Polychlorinated biphenyls are not taken up by plants, but can adhere to plant surfaces and be ingested by animals and humans when the contaminated plant parts are eaten. Pesticide uptake by crops is minimal, and concentrations in wastes would be much less than that typically and intentionally applied to control pests on most cropland (USEPA 1983).

Table 6–2 Recommended cumulative soil test limits for metals of major concern applied to agricultural cropland[1] (USEPA 1983)

Metal	Soil cation-exchange capacity, meq/100g[2 3]		
	<5	5 to 15	>15
	lb/ac (kg/ha)		
Pb	500 (560)	1,000 (1,120)	2,000 (2,240)
Zn	250 (280)	500 (560)	1,000 (1,120)
Cu	125 (140)	250 (280)	500 (560)
Ni	125 (140)	250 (280)	500 (560)
Cd	4.4 (5)	8.9 (10)	17.8 (20)

1 Table 6-2 values should not be used as definitive guidelines for fruit and vegetable production.
2 Interpolation should be used to obtain values in CEC range 5-15.
3 Soil plow layer must be maintained at pH 6.5 or above at time of each sludge application.

651.0604 Balancing plant nutrient needs with waste application

Waste management must balance the capacity of the soils and plants to transform the chemical elements in the waste product by the amount that is applied or is residual in the system. A lack of plant nutrients in an available form for uptake can cause a deficiency in plants, and an excess of plant 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 or the environment. Those elements that are not transformed or retained in the soil can leave the system and become a contaminant to surface and ground water.

(a) Deficiencies of plant nutrients

The deficiency of nutrients to the plants from agricultural waste application can occur by either the shortage of supplied elements contained in the material or the interference in the uptake of essential nutrients caused by the excessive supply of another. In the first case, an analysis of the waste material is needed to determine the amount of plant nutrients being supplied, and this amount is balanced with the quantity required by the crop. Using the Nutrient Management Standard (590) with a nutrient budget worksheet will assure that all essential nutrients are being supplied to the crop. For the second case, an example in the section, "Excesses of plant nutrients, total dissolved solids, and trace elements," 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 accounted for in waste application 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 waste material 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.

Animal manure releases ammonia gas upon drying. Urea contained in manure is unstable. As manure dries, the urea breaks down into ammonium. The release of gaseous NH_3 from manure can result in ammonia toxicity. Exposure of corn seeds to ammonia during the initial stages of germination can cause significant injury to the development of seedlings. High levels of NH_3 and NH_4 in the soil interferes with the uptake of the calcium ion causing plants to exhibit calcium deficiency (Hensler et al. 1970; Olsen et al. 1970). Part of the ammonium 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 contributes to an increase in the soluble salt level as well as pH.

Proper handling of manure is necessary to prevent toxicity from occurring. Manure may contain high levels of ammonium nitrogen; up to 50 percent is in the NH_4 form. To prevent toxicity from occurring on young plant seedlings, the manure should be field spread and either immediately incorporated into the soil to adsorb the NH_4 on the cation exchange sites of the soil or allowed to air dry on the soil surface. Surface drying greatly reduces the level of ammonia by volatilization. Direct planting into the soil surface that is covered with manure, such as with no-till planting, can lead to germination problems and seedling injury unless rainfall or surface drying has lessened the amount of ammonia in the manure.

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 generally is sufficient to dissipate the high concentrations of NH_4 in the seed zone.

Sidedressing of manure on corn, either by injection or surface application, has been shown to be an effective way to apply the inorganic portion (NO_3 and NH_4) of nitrogen that is quickly made available for plant growth (Klausner and Guest 1981). Injecting manure into soil conserves more of the ammonium nitrogen during periods of warm, dry weather and prevents ammonia toxicity to the growth of plants (Sutton et al. 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, 6–4).

Some plant species are tolerant to salinity yet 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 are applied under a moisture deficit condition, salt concentrations can build up.

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

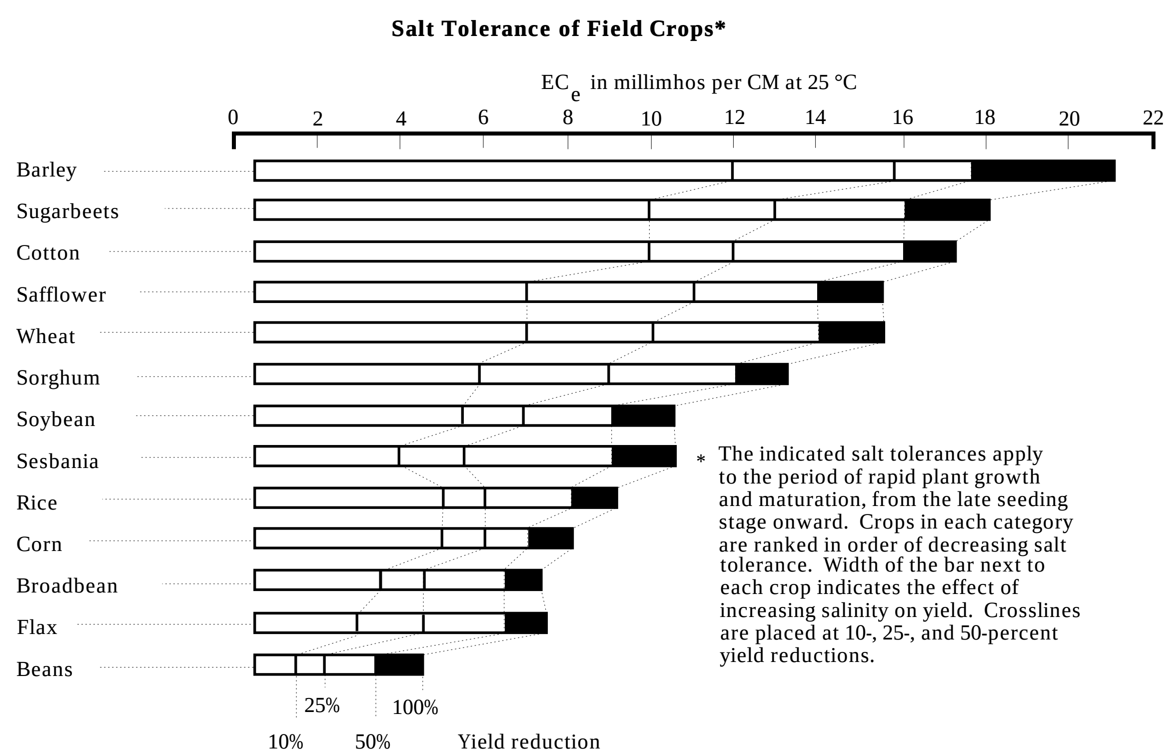
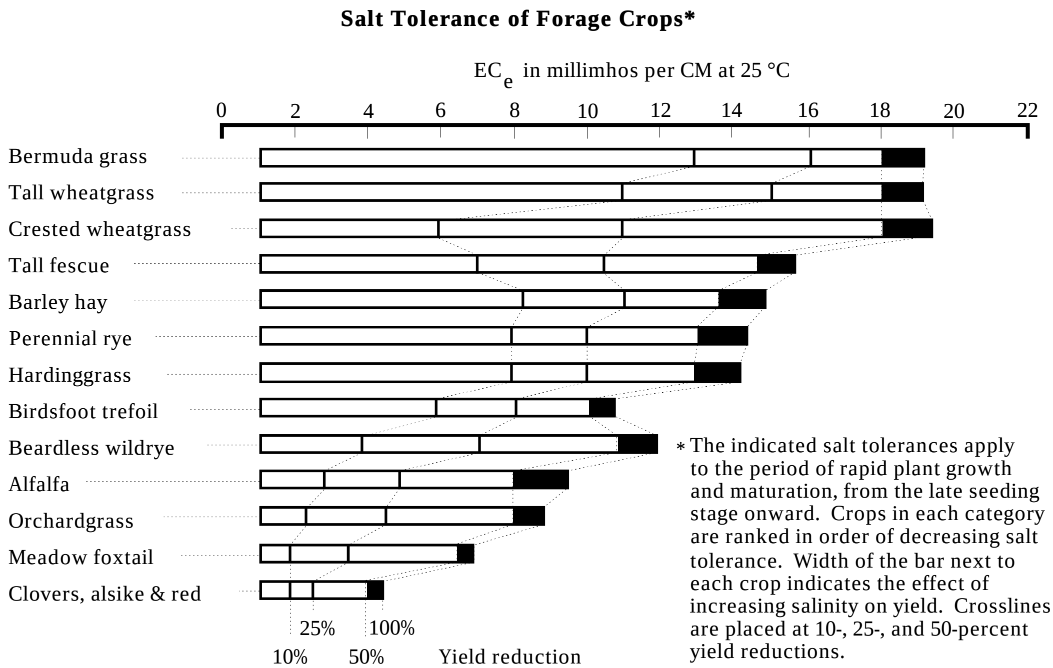
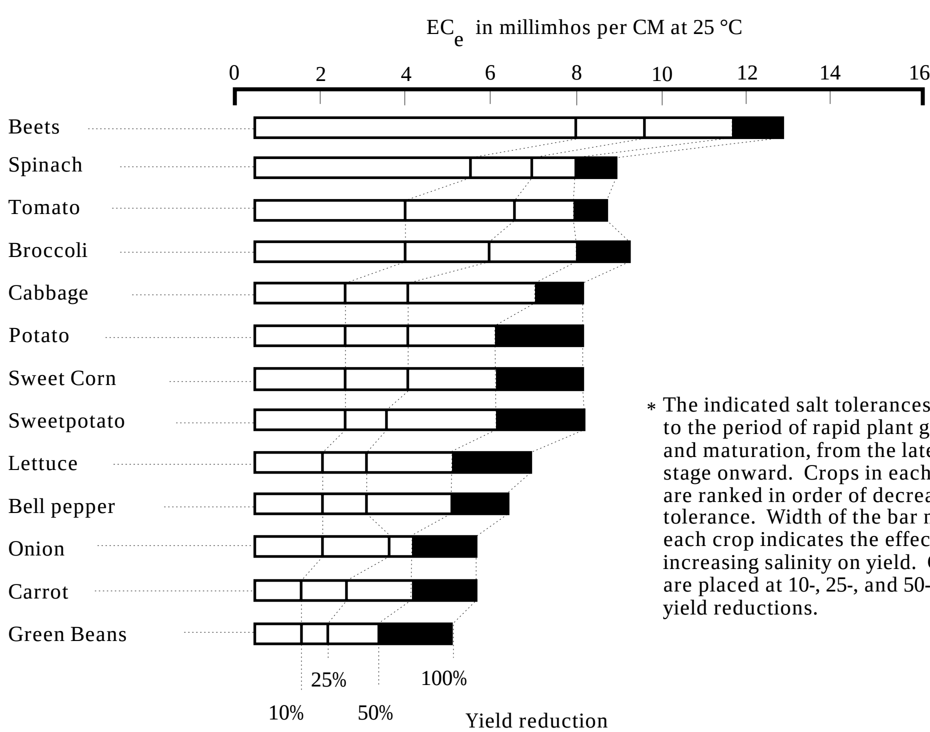


Figure 6–3 Effect of soil salinity on growth of forage crops



* 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.

A soil test, the electrical conductivity of saturated paste extract, is used to measure the total salt concentration in the soil. After prolonged application of manure, the soil electrical conductivity should be tested. 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, 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. Manure application rates may have to be adjusted (Stewart 1974).

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 that have elevated levels of trace elements are applied over a long period of time at significant rates, trace element toxicity can occur on 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 should 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 can be 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.

651.0605 Application of agricultural waste

(a) Field and forage crops

Manure and sewage have been used for centuries as fertilizers and soil amendments to produce food for human and animal consumption. Generally, manure and sludges are applied to crops that are most responsive to nitrogen inputs. Field crops that are responsive include corn, sorghum, cotton, tobacco, sugar beets, and cane.

Sewage sludge should not be used on tobacco. The liming effect of the sludge can enhance the incidence of root diseases of tobacco. It can also elevate cadmium levels in tobacco leaves, rendering it unfit for marketing (USDA 1986).

Cereal grains generally do not receive fertilizer application through manure because spreading to deliver low rates of nitrogen is difficult. Small grains are prone to lodging (tipping over en masse under wet, windy conditions) because of the soft, weak cell walls derived from rapid tissue growth.

Legumes, such as alfalfa, peanuts, soybeans, and clover, benefit less by manure and sludge additions because they fix their own nitrogen. The legumes, however, use the nitrogen in waste products and produce less symbiotically fixed nitrogen. Alfalfa, a heavy user of nitrogen, can cycle large amounts of soil nitrogen from a depth of up to 6 feet. Over 500 pounds per acre of nitrogen uptake by alfalfa has been reported (Schuman & Elliott 1978; Schertz & Miller 1972).

The great danger of using manure and sludges on legume forages is that the added nitrogen may promote the growth of the less desirable grasses that are in the stand. This is caused primarily by introducing another source of nitrogen, but it can also be a result of the physical smothering of legume plants by heavy application cover of manure.

Grass tetany, a serious and often fatal disorder in lactating ruminants, is caused by a low magnesium content in rapidly growing cool season grasses. Cattle grazing on magnesium deficient forage develop health problems. High concentrations of nitrogen and potassium in manure applications to the forages aggravate the situation. Because of the high levels of available nitrogen and potassium in manure, early season applications on mixed grass-legume forages should be avoided until the later-growing legume is flourishing because legumes contain higher concentrations of magnesium than grasses.

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

Element	Symptoms	Sensitive crop
Al	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 and 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.

Perennial grasses benefit greatly by the addition of manure and sludges. Many are selected as vegetative filters because of their efficient interception and uptake of nutrients and generally longer active growing season. Others produce large quantities of biomass and thus can remove large amounts of nutrients, especially nitrogen, from the soil-plant system.

Bermudagrass pastures in the South have received annual rates of manure that supply over 400 pounds of nitrogen per acre without experiencing excessive nitrate levels in the forage. However, runoff and leaching potentials are high with these application rates, and they must be considered in the utilization plan.

Grass sods also accumulate nitrogen. An experiment in England carried out for 300 years at Rothamsted showed a steady increase in soil nitrogen for about 125 years before leveling off when an old plowed field was retired to grass (Wild 1988). However, where waste is spread on the soil surface, any ammonia nitrogen in the waste generally is lost to the air as a gas unless immediately incorporated.

Grass fields used for pasture or hay must have waste spread when the leaves of the plants are least likely to be contaminated with manure. If this is done, the grass quality is not lessened when harvested mechanically or grazed by animals (Simpson 1986).

Spreading wastes immediately after harvest and before regrowth is generally the best time for hay fields and pastures in a rotation system. This is especially important where composted sludge is applied on pasture at rates of more than 30 tons per acre. Cattle and sheep ingesting the compost inadvertently can undergo copper deficiency symptoms (USDA 1986).

Some reports show that manure applied to the soil surface has caused ammonium toxicity to growing crops (Klausner and Guest 1981). Young corn plants 8 inches high showed ammonia burn after topdressing with dairy manure during a period of warm, dry weather. The symptom disappeared after a few days with no apparent damage to the crop. This is very similar to corn burn affected during sidedressing by anhydrous ammonia. Liquid manure injected between corn rows is toxic to plant roots and causes temporary reduction in crop growth. Warming soil conditions dissipate the high ammonium levels, converting the ammonium to nitrates, and alleviate the temporary toxic conditions (Sawyer and Hoeft 1990).

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	Al, 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
			Zn	Cd, Se, Mn, Fe, Ni, Cu	Ni, Cd
Mg	Al, Be, Ba, Cr, Mn, F, Zn, Ni, Co, Cu, Fe	Al, Zn	Cd	Zn, Cu, Al, Se, Mn, Fe, Ni	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	B	Si, Mo, Fe	Mo, Fe
			Al	Cu, Cd	(No evidence.)
			Pb	---	Cd
			Mn	Cu, Zn, Mo, Fe, Ar, Cr, Fe, Co, Cd, Al, Ni, Ar, Se	Cu, Cd, Al, Mo
K	Al, B, Hg, Cd, Cr, F, Mo, Mn, Rb	(No evidence.)	Fe	Zn, Cr, Mo, Mn, Co, Cu, Cd, B, Si	Cd, B
S	As, Ba, Fe, Mo, Pb, Se	F, Fe			
N	B, F, Cu	B, Cu, Fe, Mo	Mo	Cu, Mn, Fe, B	Mn, B. Si
Cl	Cr, I	(No evidence.)	Co	Mn, Fe	(No evidence.)
			Ni	Mn, Zn, Cu, Cd	Cu, Zn, Cd

(b) Horticultural crops

Vegetables and fruits benefit from applications of wastes; however, care must be taken because produce can be fouled or disease can be spread. Surface application of wastes to the soil around fruit trees will not cause either problem, but spray applications of liquid waste could.

Manure or sludge applied and plowed under before planting will not cause most vegetables to be unduly contaminated with disease organisms as long as they are washed and prepared according to good food industry standards. However, the scab disease may be promoted on the skin of potatoes with the addition of organic wastes. Well rotted or composted manure can be used to avoid excessive scabbing if it is plowed under before the potatoes are planted (Martin and Leonard 1949). Additional guidelines for the use of municipal sludge are in table 6–5.

Table 6–5 Summary of joint EPA/FDA/USDA guidelines for sludge application for fruit and vegetable production (USEPA 1983)

Annual and cumulative Cd rates:	Annual rate should not exceed 0.5 kg/ha (0.446 lb/ac). Cumulative Cd loadings should not exceed 5, 10, or 20 kg/ha, depending on CEC values of <5, 5 to 15, and >15 meq/100g, respectively, and soil pH.
Soil pH:	Soil pH (plow zone - top 6 inches) should be 6.5 or greater at time of each sludge application.
PCB's:	Sludges that have PCB concentrations of more than 10 ppm should be incorporated into the soil.
Pathogen reduction:	Sludge should be treated by pathogen reduction process before soil application. A waiting period of 12 to 18 months before a crop is grown may be required, depending on prior sludge processing and disinfection.
Use of high-quality sludge:	High-quality sludge should not contain more than 25 ppm Cd, 1,000 ppm Pb, and 10 ppm PCB (dry weight basis).
Cumulative lead (Pb) application rate:	Cumulative Pb loading should not exceed 800 kg/ha (714 lb/ac).
Pathogenic organisms:	A minimum requirement is that crops to be eaten raw should not be planted in sludge-amended fields within 12 to 18 months after the last sludge application. Further assurance of safe and wholesome food products can be achieved by increasing the time interval to 36 months. This is especially warranted in warm, humid climates.
Physical contamination and filth:	Sludge should be applied directly to soil and not directly to any human food crop. Crops grown for human consumption on sludge-amended fields should be processed using good food industry practices, especially for root crops and low-growing fresh fruits and vegetables.
Soil monitoring:	Soil monitoring should be performed on a regular basis, at least annually for pH. Every few years, soil tests should be run for Cd and Pb.
Choice of crop type:	Plants that do not accumulate heavy metals are recommended.

(c) Vegetated filter strips for agricultural waste treatment

Vegetated filter strips are designed strips or areas of vegetation growing downgradient of an animal production facility or cropland where animal waste has been applied. The strips can filter nutrients, sediment, organics, agrichemicals, and pathogens from runoff received from the contributing areas.

Four processes are involved in the removal of the elements in the run-on water. The first process is deposition of sediment (solid material) in the strip. A vegetated filter strip is composed of grasses or other dense vegetation that offers resistance to shallow overland flow. The decrease in flow velocity at the upslope edge of the vegetated filter strip greatly reduces the sediment transport capacity, and suspended solids are deposited.

In the second process the vegetation provides for surface run-on water to enter the soil profile. Once infiltrated into the soil, the elements are entrapped by the chemical, physical, and biological processes and are transformed into plant nutrients or organic components of the soil.

In the third process some soluble nutrients moving with the run-on water can be directly absorbed through the plant leaves and stems, and in the fourth, the thick, upright vegetation adheres solid particles that are being carried in the runoff, physically filtering them out.

In all of the processes, the nutrients taken from the run-on water by the plants transform a potential pollutant into vegetative biomass that can be used for forage, fiber, or mulch material.

Results from recent research show that vegetated filter strips have a wide range of effectiveness (Adam et al. 1986; Dillaha et at. 1988; Doyle et al. 1977; Schwer and Clausen 1989; Young et al. 1980). Variations in effectiveness are associated with individual site conditions, both the vegetated filter strip site and contributing area.

Land slope, soils, land use and management, climate, vegetation type and density, application rates for sites periodically loaded, and concentration and characteristics of constituents in incoming water are all important site characteristics that influence effectiveness. Operation and management of the contributing area, along with maintenance of the vegetated filter strip influence the ability of the total system to reduce the concentration and amount of contaminants contained in the runoff from the site. Knowledge of site variables is essential before making planning decisions about how well vegetated filter strips perform.

Research and operation sites exhibit certain characteristics that should be considered in planning a vegetated filter strip:

- Sheet flow must be maintained. Concentrated flow should be avoided unless low velocity grass waterways are used.
- Hydraulic loading must be carefully controlled to maintain desired depth of flow.
- Application of process generated wastewater must be periodically carried out to allow rest periods for the vegetated filter strip. Storage of wastewater is essential for rest periods and for climatic influences.
- Unless infiltration occurs, removal of soluble constituents from the run-on water will be minimal.
- Removal of suspended solids and attached constituents from the run-on can be high, in the range of 60 to 80 percent for properly installed and maintained strips.
- Vegetated filter strips should not be used as a substitute for other appropriate structural and management practices. They generally are not a stand-alone practice.
- Maintenance that includes proper care of the vegetation and removal of the accumulated solids must be performed.
- Proper siting is essential to assure uniform slopes can be installed and maintained along and perpendicular to the flow path.

The criteria for planning, design, implementation, and operation and maintenance of vegetated filter strips for livestock operations and manure application sites are in Conservation Practice Standard 393, "Filter Strip."

(d) Forest land for agricultural waste treatment

Forest land provides an area for recycling agricultural waste. Wastewater effluent has been applied to some forest sites over extended periods of time with good nutrient removal efficiency and minimal impact on surface or ground water. On most sites the soil is covered with layers, some several inches thick, of organic material. This material can efficiently remove sediment and phosphorus from the effluent. Nitrogen in the form of nitrates is partly removed from the wastewater in the top few feet of the soil, and the added fertility contributes to increased tree and understory growth. Caution must be taken not to over apply water that will leach nitrates out of the root zone and down toward the ground water. Digested sludge also has been applied to forest.

Considerable amounts of nutrients are taken up by trees. Many of these nutrients are redeposited and recycled annually in the leaf litter. Leaves make up only 2 percent of the total dry weight of northern hardwoods. Harvesting trees with leaves on increases the removal of plant nutrients by the following percentages over that for trees without leaves:

Calcium	= 12%
Potassium	= 15%
Phosphorus	= 4%
Nitrogen	= 19%

Whole tree harvesting of hardwoods removes almost double the nutrients removed when only the stemwood is taken. Stemwood, the usual harvested bole or log taken from the tree for lumber, makes up about 80 percent of the aboveground biomass (Hornbeck and Kropelin 1982).

Riparian forest buffers are effective ecosystems between utilization areas and water bodies to control transport of contaminants from nonpoint sources (Lowrance et al. 1985). No specific literature has been reported on using these areas for utilization of nutrients in agricultural waste. These areas should be maintained to entrap nutrients in runoff and protect water bodies. They should not be used for waste spreading.

Only 10 percent of the nitrogen in a 45-year-old Douglas fir forest ecosystem is in the trees. The greater part of the nutrient sink in a coniferous forest is in the tree roots and soil organic matter. Although nitrogen uptake in forests exceeds 100 pounds per acre per year, less than 20 percent net is accumulated in eastern hardwood forest. The greater part of the assimilation is recycled from the soil and litter. Continued application rates of agricultural waste should be adjusted to meet the long-term sustainable need of the forest land, which generally is a half to two thirds that of the annual row crops (Keeney 1980).

651.0606 Nutrient removal by harvesting of crops

The nutrient content of a plant depends on the amount of nutrients available to the plant and on the environmental growing condition. The critical level of nutrient concentration of the dry harvested material of the plant leaf is about 2 percent nitrogen, 0.25 percent phosphorus, and 1 percent potassium. Where nutrients are available in the soil in excess of plant sufficiency levels, the percentages can more than double.

In forage crops, the percent composition for nitrogen can range from 1.2 to 2.8 percent, averaging around 2 percent of the dry harvested material of the plant. The concentrations can reach as high as 4.5 percent, however, if the soil system has high levels of nitrogen (Walsh and Beaton 1973).

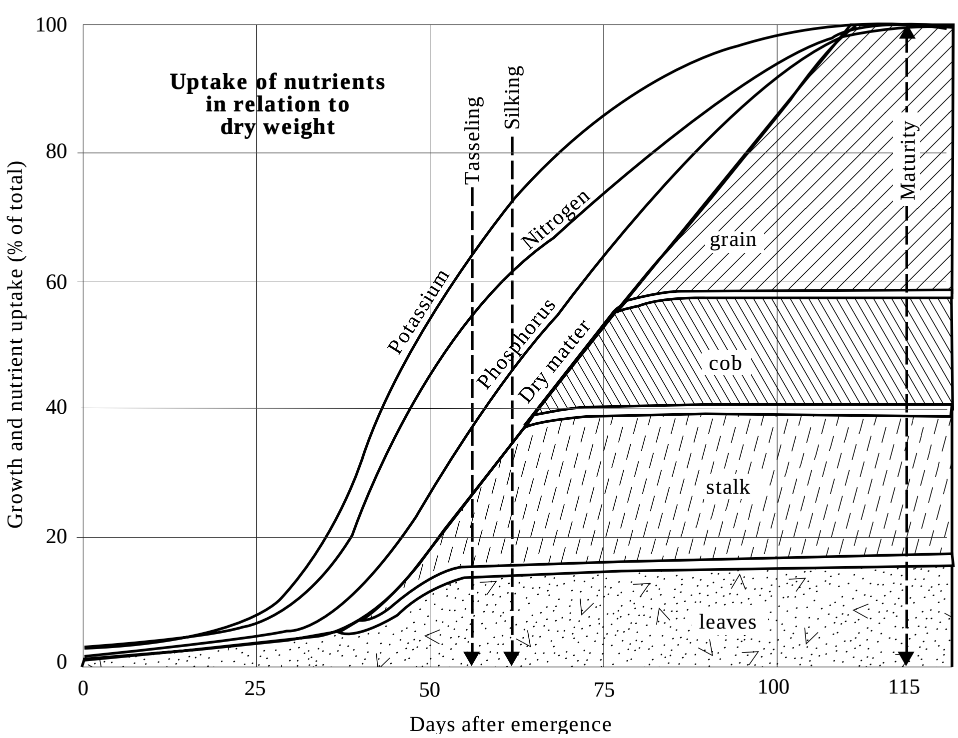
The total uptake of nutrients by crops from agricultural waste applications increases as the crop yields increase, and crop yields for the most part increase with increasing soil nutrients, provided toxic levels are not reached or nutrient imbalances do not occur. The total nutrient uptake continues to increase with yield, but the relation does not remain a constant linear relationship.

Two important factors that affect nutrient uptake and removal by crop harvest are the percent nutrient composition in the plant tissue and the crop biomass yield. In general, grasses contain their highest percentage of nutrients, particularly nitrogen, during the rapid growth stage of stem elongation and leaf growth.

Nitrogen uptake in grasses, like corn (fig. 6–5), follows an S-shaped uptake curve with very low uptake the first 30 days of growth, but rises sharply until flowering, then decreases with maturity.

Harvesting the forage before it flowers would capture the plant's highest percent nutrient concentration. Multiple cuttings during the growing season maximizes dry matter production. A system of two or three harvests per year at the time of grass heading would optimize the dry matter yield and plant tissue concentration, thus maximizing nutrient uptake and removal.

Figure 6–5 Growth and nutrient uptake by corn (adapted from Hanaway 1962)



(a) Nutrient uptake calculation

Table 6–6 can be used to calculate the approximate nutrient removal by agricultural crops. Typical crop yields are given only as default values and should be selected only in lieu of local information.

1. Select the crop or crops that are to be grown in the cropping sequence.
2. Determine the plant nutrient percentage of the crop to be harvested as a percentage of the dry or wet weight depending on the crop value given in table 6–6.
3. Determine the crop yield in pounds per acre. Weight to volume conversion are given.
4. Multiply the crop yield by the percentage of nutrient in the crop.

The solution is pounds per acre of nutrients removed in the harvested crop.

(b) Nutrient uptake example

Corn and alfalfa are grown in rotation and harvested as grain and silage corn and alfalfa hay. Follow the above steps to calculate the nutrient taken up and removed in the harvested crop.

1. Crops to be grown: corn and alfalfa

2. Plant nutrient percentage in harvested crop (table 6–6):

corn grain:	1.61% nitrogen
	0.28% phosphorus
	0.40% potassium
corn silage:	1.10% nitrogen
	0.25% phosphorus
	1.09% potassium
alfalfa:	2.25% nitrogen
	0.22% phosphorus
	1.87% potassium

3. Crop yield taken from local data base:

corn grain:	130 bu/ac @ 56 lb/bu = 7,280 lb.
corn silage:	22 tons/ac @ 2,000 lb/ton @ 35% dm = 15,400 lb
alfalfa hay:	6 tons/ac @ 2,000 lb/ton = 12,000 lb

4. Multiplying percent nutrients contained in the crop harvested by the dry matter yield:

corn grain:		
	1.61% N x 7,280 lb	= 117 lb N
	0.28% P x 7,280 lb	= 20 lb P
	0.40% K x 7,280 lb	= 29 lb K
corn silage:		
	1.10% N x 15,400 lb	= 169 lb N
	0.25% P x 15,400 lb	= 39 lb P
	1.09% K x 15,400 lb	= 168 lb K
alfalfa:		
	2.25% N x 12,000 lb	= 270 lb N
	0.22% P x 12,000 lb	= 26 lb P
	1.87% K x 12,000 lb	= 224 lb K

Nutrient values are given as elemental P and K. The conversion factors for phosphates and potash are:

$$\text{lb P x 2.3 = lb } P_2O_5$$
$$\text{lb K x 1.2 = lb } K_2O$$

Under alfalfa, nitrogen includes that fixed symbiotically from the air by alfalfa.

Table 6–6 shows the nutrient concentrations that are average values derived from plant tissue analysis values, which can have considerable range because of climatic conditions, varietal differences, soil conditions, and soil fertility status. Where available, statewide or local data should be used in lieu of the table values.

Table 6–6 Plant nutrient uptake by specified crop and removed in the harvested part of the crop (Kilmer 1982; Morrison 1956; Sanchez 1976; USDA 1985)

Crop	Dry wt. lb/bu	Typical yield/acre plant part	Average concentration of nutrients (%) N	P	K	Ca	Mg	S	Cu	Mn	Zn
Grain crops			% of the dry harvested material								
Barley	48	50 bu	1.82	0.34	0.43	0.05	0.10	0.16	0.0016	0.0016	0.0031
		1 T. straw	0.75	0.11	1.25	0.40	0.10	0.20	0.0005	0.0160	0.0025
Buckwheat	48	30 bu	1.65	0.31	0.45	0.09			0.0009	0.0034	
		0.5 T. straw	0.78	0.05	2.26	1.40		0.01			
Corn	56	120 bu	1.61	0.28	0.40	0.02	0.10	0.12	0.0007	0.0011	0.0018
		4.5 T. stover	1.11	0.20	1.34	0.29	0.22	0.16	0.0005	0.0166	0.0033
Oats	32	80 bu	1.95	0.34	0.49	0.08	0.12	0.20	0.0012	0.0047	0.0020
		2 T. straw	0.63	0.16	1.66	0.20	0.20	0.23	0.0008	0.0030	0.0072
Rice	45	5,500 lb	1.39	0.24	0.23	0.08	0.11	0.08	0.0030	0.0022	0.0019
		2.5 T. straw	0.60	0.09	1.16	0.18	0.10			0.0316	
Rye	56	30 bu	2.08	0.26	0.49	0.12	0.18	0.42	0.0012	0.0131	0.0018
		1.5 T. straw	0.50	0.12	0.69	0.27	0.07	0.10	0.0300	0.0047	0.0023
Sorghum	56	60 bu	1.67	0.36	0.42	0.13	0.17	0.17	0.0003	0.0013	0.0013
		3 T. stover	1.08	0.15	1.31	0.48	0.30	0.13		0.0116	
Wheat	60	40 bu	2.08	0.62	0.52	0.04	0.25	0.13	0.0013	0.0038	0.0058
		1.5 T. straw	0.67	0.07	0.97	0.20	0.10	0.17	0.0003	0.0053	0.0017
Oil crops			% of the dry harvested material								
Flax	56	15 bu	4.09	0.55	0.84	0.23	0.43	0.25		0.0061	
		1.75 T. straw	1.24	0.11	1.75	0.72	0.31	0.27			
Oil palm		22,000 lb	1.13	0.26	0.16	0.19	0.09		0.0043	0.0225	
		5 T. fronds & stems	1.07	0.49	1.69		0.36				
Peanuts	22-30	2,800 lb	3.60	0.17	0.50	0.04	0.12	0.24	0.0008	0.0040	
		2.2 T. vines	2.33	0.24	1.75	1.00	0.38	0.36		0.0051	
Rapeseed	50	35 bu	3.60	0.79	0.76		0.66				
		3 T. straw	4.48	0.43	3.37	1.47	0.06	0.68	0.0001	0.0008	
Soybeans	60	35 bu	6.25	0.64	1.90	0.29	0.29	0.17	0.0017	0.0021	0.0017
		2 T. stover	2.25	0.22	1.04	1.00	0.45	0.25	0.0010	0.0115	0.0038
Sunflower	25	1,100 lb	3.57	1.71	1.11	0.18	0.34	0.17		0.0022	
		4 T. stover	1.50	0.18	2.92	1.73	0.09	0.04		0.0241	

Table 6–6 Plant nutrient uptake by specified crop and removed in the harvested part of the crop — Continued

Crop	Dry wt. lb/bu	Typical yield/acre plant part	N	P	K	Ca	Mg	S	Cu	Mn	Zn
			Average concentration of nutrients (%)								
Fiber crops		% of the dry harvested material									
Cotton		600 lb. lint & 1,000 lb seeds	2.67	0.58	0.83	0.13	0.27	0.20	0.0040	0.0073	0.0213
		burs & stalks	1.75	0.22	1.45	1.40	0.40	0.75			
Pulpwood		98 cords	0.12	0.02	0.06		0.02				
		bark, branches	0.12	0.02	0.06		0.02				
Forage crops		% of the dry harvested material									
Alfalfa		4 tons	2.25	0.22	1.87	1.40	0.26	0.24	0.0008	0.0055	0.0053
Bahiagrass		3 tons	1.27	0.13	1.73	0.43	0.25	0.19			
Big bluestem		3 tons	0.99	0.85	1.75		0.20				
Birdsfoot trefoil		3 tons	2.49	0.22	1.82	1.75	0.40				
Bluegrass-pastd.		2 tons	2.91	0.43	1.95	0.53	0.23	0.66	0.0014	0.0075	0.0020
Bromegrass		5 tons	1.87	0.21	2.55	0.47	0.19	0.19	0.0008	0.0052	
Clover-grass		6 tons	1.52	0.27	1.69	0.92	0.28	0.15	0.0008	0.0106	
Dallisgrass		3 tons	1.92	0.20	1.72	0.56	0.40				
Guineagrass		10 tons	1.25	0.44	1.89		0.43	0.20			
Bermudagrass		8 tons	1.88	0.19	1.40	0.37	0.15	0.22	0.0013		
Indiangrass		3 tons	1.00	0.85	1.20	0.15					
Lespedeza		3 tons	2.33	0.21	1.06	1.12	0.21	0.33		0.0152	
Little bluestem		3 tons	1.10	0.85	1.45		0.20				
Orchardgrass		6 tons	1.47	0.20	2.16	0.30	0.24	0.26	0.0017	0.0078	
Pangolagrass		10 tons	1.30	0.47	1.87		0.29	0.20			
Paragrass		10.5 tons	0.82	0.39	1.59	0.39	0.33	0.17			
Red clover		2.5 tons	2.00	0.22	1.66	1.38	0.34	0.14	0.0008	0.0108	0.0072
Reed canarygrass		6.5 tons	1.35	0.18		0.36					
Ryegrass		5 tons	1.67	0.27	1.42	0.65	0.35				
Switchgrass		3 tons	1.15	0.10	1.90	0.28	0.25				
Tall fescue		3.5 tons	1.97	0.20	2.00	0.30	0.19				
Timothy		2.5 tons	1.20	0.22	1.58	0.36	0.12	0.10	0.0006	0.0062	0.0040
Wheatgrass		1 ton	1.42	0.27	2.68	0.36	0.24	0.11			
Forest		% of the dry harvested material									
Leaves			0.75	0.06	0.46						
Northern hardwoods		50 tons	0.20	0.02	0.10	0.29					
Douglas fir		76 tons	0.16								

Table 6–6 Plant nutrient uptake by specified crop and removed in the harvested part of the crop — Continued

Crop	Dry wt. lb/bu	Typical yield/acre plant part	Average concentration of nutrients (%) N	P	K	Ca	Mg	S	Cu	Mn	Zn
Fruit crops		% of the fresh harvested material									
Apples		12 tons	0.13	0.02	0.16	0.03	0.02	0.04	0.0001	0.0001	0.0001
Bananas		9,900 lb.	0.19	0.02	0.54	0.23	0.30				
Cantaloupe		17,500 lb.	0.22	0.09	0.46		0.34				
Coconuts		0.5 tons–dry copra	5.00	0.60	3.33	0.21	0.36	0.34	0.0010		0.0076
Grapes		12 tons	0.28	0.10	0.50		0.04				
Oranges		54,000 lb.	0.20	0.02	0.21	0.06	0.02	0.02	0.0004	0.0001	0.0040
Peaches		15 tons	0.12	0.03	0.19	0.01	0.03	0.01			0.0010
Pineapple		17 tons	0.43	0.35	1.68	0.02	0.18	0.04			
Tomatoes		22 tons	0.30	0.04	0.33	0.02	0.03	0.04	0.0002	0.0003	0.0001
Silage crops		% of the dry harvested material									
Alfalfa haylage (50% dm)		10 wet/5 dry	2.79	0.33	2.32	0.97	0.33	0.36	0.0009	0.0052	
Corn silage (35% dm)		20 wet/7 dry	1.10	0.25	1.09	0.36	0.18	0.15	0.0005	0.0070	
Forage sorghum (30% dm)		20 wet/6 dry	1.44	0.19	1.02	0.37	0.31	0.11	0.0032	0.0045	
Oat haylage (40% dm)		10 wet/4 dry	1.60	0.28	0.94	0.31	0.24	0.18			
Sorghum-sudan (50% dm)		10 wet/5 dry	1.36	0.16	1.45	0.43	0.34	0.04		0.0091	
Sugar crops		% of the fresh harvested material									
Sugarcane		37 tons	0.16	0.04	0.37	0.05	0.04	0.04			
Sugar beets		20 tons	0.20	0.03	0.14	0.11	0.08	0.03	0.0001	0.0025	
tops			0.43	0.04	1.03	0.18	0.19	0.10	0.0002	0.0010	
Tobacco		% of the dry harvested material									
All types		2,100 lb.	3.75	0.33	4.98	3.75	0.90	0.70	0.0015	0.0275	0.0035
Turf grass		% of the dry harvested material									
Bluegrass		2 tons	2.91	0.43	1.95	0.53	0.23	0.66	0.0014	0.0075	0.0020
Bentgrass		2.5 tons	3.10	0.41	2.21	0.65	0.27	0.21			
Bermudagrass		4 tons	1.88	0.19	1.40	0.37	0.15	0.22	0.0013		

Table 6–6 Plant nutrient uptake by specified crop and removed in the harvested part of the crop — Continued

Crop	Dry wt. lb/bu	Typical yield/acre plant part	Average concentration of nutrients (%) N	P	K	Ca	Mg	S	Cu	Mn	Zn
Vegetable crops			% of the fresh harvested material								
Bell peppers		9 tons	0.40	0.12	0.49		0.04				
Beans, dry		0.5 ton	3.13	0.45	0.86	0.08	0.08	0.21	0.0008	0.0013	0.0025
Cabbage		20 tons	0.33	0.04	0.27	0.05	0.02	0.11	0.0001	0.0003	0.0002
Carrots		13 tons	0.19	0.04	0.25	0.05	0.02	0.02	0.0001	0.0004	
Cassava		7 tons	0.40	0.13	0.63	0.26	0.13				
Celery		27 tons	0.17	0.09	0.45						
Cucumbers		10 tons	0.20	0.07	0.33		0.02				
Lettuce (heads)		14 tons	0.23	0.08	0.46						
Onions		18 tons	0.30	0.06	0.22	0.07	0.01	0.12	0.0002	0.0050	0.0021
Peas		1.5 tons	3.68	0.40	0.90	0.08	0.24	0.24			
Potatoes		14.5 tons	0.33	0.06	0.52	0.01	0.03	0.03	0.0002	0.0004	0.0002
Snap beans		3 tons	0.88	0.26	0.96	0.05	0.10	0.11	0.0005	0.0009	
Sweet corn		5.5 tons	0.89	0.24	0.58		0.07	0.06			
Sweet potatoes		7 tons	0.30	0.04	0.42	0.03	0.06	0.04	0.0002	0.0004	0.0002
Table beets		15 tons	0.26	0.04	0.28	0.03	0.02	0.02	0.0001	0.0007	
Wetland plants			% of the dry harvested material								
Cattails		8 tons	1.02	0.18							
Rushes		1 ton	1.67								
Saltgrass		1 ton	1.44	0.27	0.62						
Sedges		0.8 ton	1.79	0.26		0.66					
Water hyacinth				3.65	0.87	3.12					
Duckweed			3.36	1.00	2.13						
Arrowweed			2.74								
Phragmites			1.83	0.10	0.52						

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Chapter 7 Geologic and Groundwater Considerations

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Chapter 7 Geologic and Groundwater Considerations

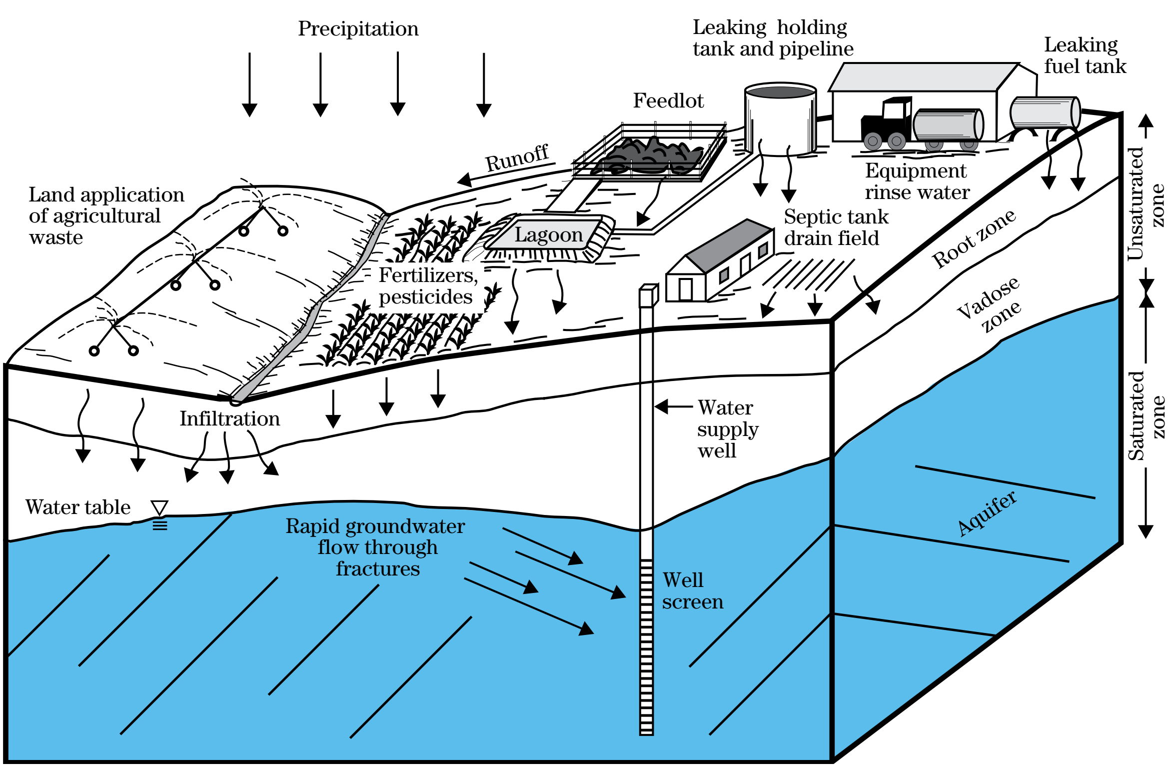
651.0700 Introduction

Chapter 7 covers geologic and groundwater considerations that may affect the planning, design, and construction of an agricultural waste management system (AWMS). Two main issues are addressed:

- engineering suitability of the soil and foundation characteristics of the site
- potential for an AWMS component to contaminate groundwater

Storing, treating, or utilizing agricultural wastes at or below the ground surface has the potential to contaminate groundwater (fig. 7–1). Many agricultural waste management components can be installed on properly selected sites without any special treatment other than good construction procedures. The key is to be able to recognize and avoid potentially problematic site conditions early in the planning process. An appropriately conducted onsite investigation is essential to identify and evaluate geologic conditions, engineering constraints, and behavior of earth materials. The requirements for preliminary (planning) and detailed (design) investigations are explained in this chapter. This chapter provides guidance in a wide variety of engineering geologic issues and water quality considerations that may be found in investigation and planning of an AWMS.

Figure 7–1 Agricultural sources of potential groundwater contamination



651.0701 Overview of geologic material and groundwater

(a) Geologic material

The term "geologic material," or earth material, covers all natural and processed soil and rock materials. Geologic material ranges on a broad continuum from loose granular soil or soft cohesive soil through extremely hard, unjointed rock.

(1) Material properties

Material properties of soil or rock are either measured in the laboratory using representative samples or assessed in the field on in-place material. Common examples of material properties include mineral composition, grain size, consistency, color, hardness (strength), weathering condition, porosity, permeability, and unit weight. Some properties may be inferred by index tests of samples; for example, permeability may be roughly inferred in soils from their gradation and plasticity values.

(2) Mass properties

Mass properties of geologic materials are large scale features that can only be observed, measured, and documented in the field. They typically cannot be sampled. These properties include regional features such as geologic structure or karst topography. Geologic structure refers to the orientation and deformation characteristics such as faults and joints. Karst topography is formed primarily in limestone terrain and characterized by joints that have been widened by dissolution. Mass properties also include discontinuities that are distinct breaks or abrupt changes in the mass. The two broad types of discontinuities are stratigraphic and structural, depending on mode of formation (see Title 210, Technical Release (TR)–78), The Characterization of Rock for Hydraulic Erodibility). The presence of discontinuities complicates the design of an AWMS.

Stratigraphic discontinuities originate when the geologic material is formed under distinct changes in deposition or erosion. They are characterized by abrupt lateral or vertical changes in composition or other material property such as texture or hardness. These features apply to all stratified soil and rocks and can occur in many shapes described with common geologic terms such as blanket, tongue, shoestring, or lens. Abrupt changes in composition or material property can result in contrasting engineering behavior of the adjacent geologic materials. A common example of a stratigraphic discontinuity is the soil/bedrock interface.

Structural discontinuities are extremely common in almost any geologic material. They include fractures of all types that develop some time after a soil or rock mass has formed. Almost all types of bedrock are fractured near the Earth's surface. Forces acting on the mass that cause deformation include physical geologic stresses within the Earth's crust; biological, such as animal burrows or tree roots; or artificial, such as blasting. Fractures in rock materials may be systematically oriented, such as joint sets, fault zones, and bedding plane partings, or may be randomly oriented. In soil materials, fractures may include soil joints, desiccation cracks, and remnant structure from the parent bedrock in residual soils.

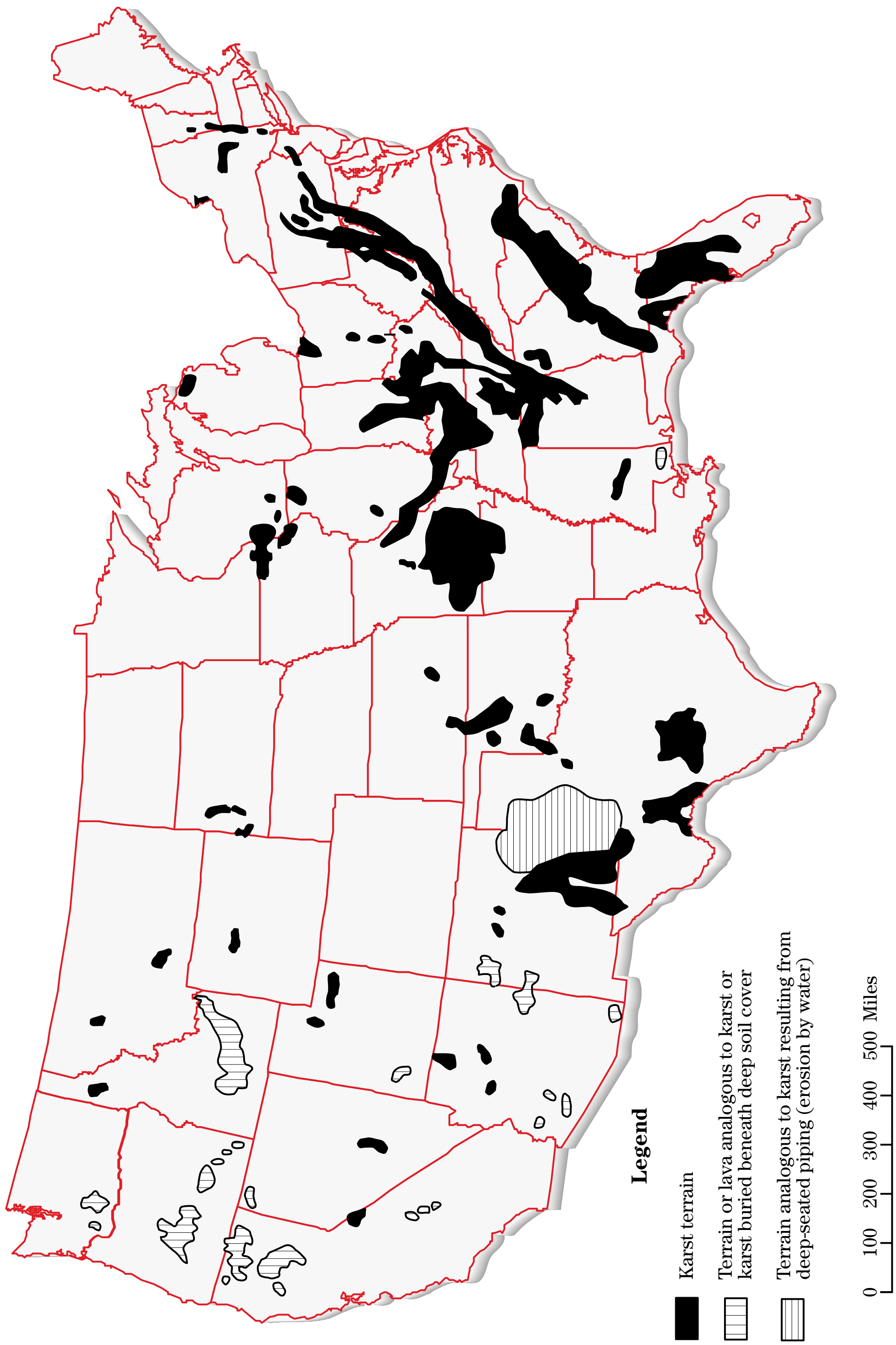
Many rural domestic wells, particularly in upland areas, derive water from fractures and joints in bedrock. These wells are at risk of contamination from waste impoundment facilities if fractured bedrock occurs within the excavation limits, within feedlots or holding areas, and in waste utilization areas. Fractures in bedrock may convey contaminants directly from the site to the well and significantly affect water quality in a local aquifer. Although karst topography (fig. 7–2) is well known as a problem because of its wide, interconnected fractures and open conduits, almost any near-surface rock type will have fractures that can be problematic unless treated in design.

(b) Groundwater

Many U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) programs deal with the development, control, and protection of groundwater resources. The planners of agricultural waste management practices should be familiar with the principles of groundwater. NRCS references that include information on groundwater are Title 210, National Engineering Handbook (NEH), Section 16, Drainage of Agricultural Lands, Part 631, Chapter 30, Groundwater Hydrology and Geology, Chapter 31, Groundwater Investigations; Chapter 32, Well Design and Spring Development, and Chapter 33, Groundwater Recharge, and Part 650, Engineering Field Handbook (EFH), Chapter 12, Springs and Wells and Chapter 14, Water Management (Drainage).

Figure 7–2 Karst areas in the United States

Generalized map of areas of karst and analogous terrains in the conterminous United States

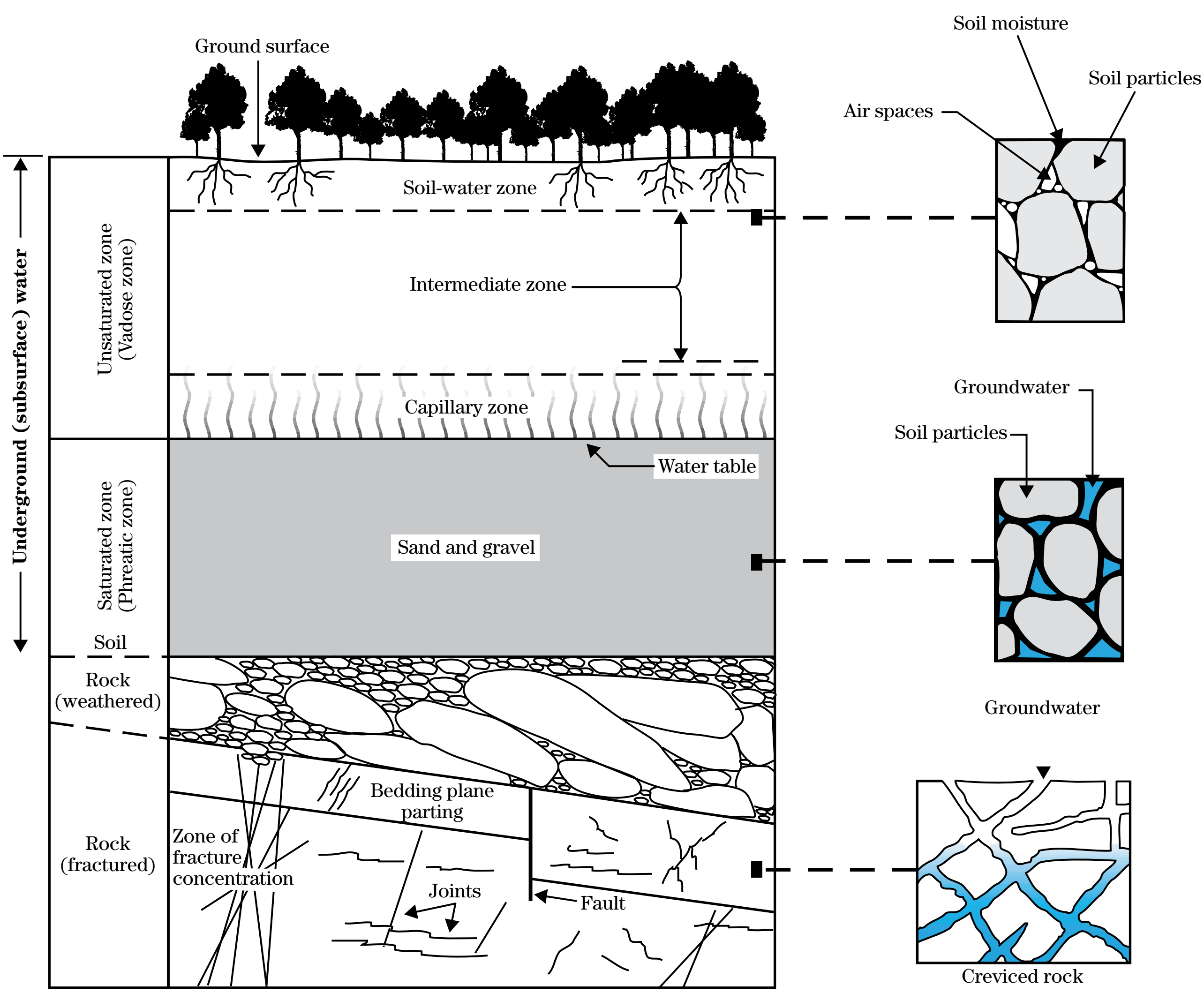


(1) Zones of underground water

All water beneath the surface of the Earth is called underground water, or subsurface water. Underground water occurs in two primary zones: an upper zone of aeration called the vadose or unsaturated zone and a lower zone of saturation called the phreatic or saturated zone. The vadose zone contains both air and water in the voids, and the saturated zone is where all interconnected voids are filled with water (fig. 7–3). The term "groundwater" applies to the saturated zone. Groundwater is the only underground water available for wells and springs.

The vadose zone has three components with differing moisture regimes: the soil-water zone, intermediate zone, and basal capillary zone (fig. 7–3). The soil-water zone extends from the ground surface to slightly below the depth of root penetration. Water in this zone is available for transpiration and direct evaporation, and the zone is unsaturated except during rainfall or irrigation events. Depending on the depth of the vadose zone, there may be an intermediate zone where water moves either downward under gravity or is held in place by surface tension. There are areas in the country where the intermediate zone is hundreds of feet thick.

Figure 7–3 Zones of underground water (AIPG 1984; Heath 1983; and Todd 1980)



Directly above the water table there can be a saturated zone called the capillary zone or fringe. Water in the capillary fringe overlies the water table, where the fluid pressure in the pores is exactly atmospheric pressure; therefore, the pore pressure above the water table is less than atmospheric. Surface tension and capillary action cause water in this zone to rise. It can rise between a few inches to more than a few feet above the water table, depending on the soil type. Capillary rise increases as the pore spaces decrease and the plasticity of the soil increases.

(2) Aquifers

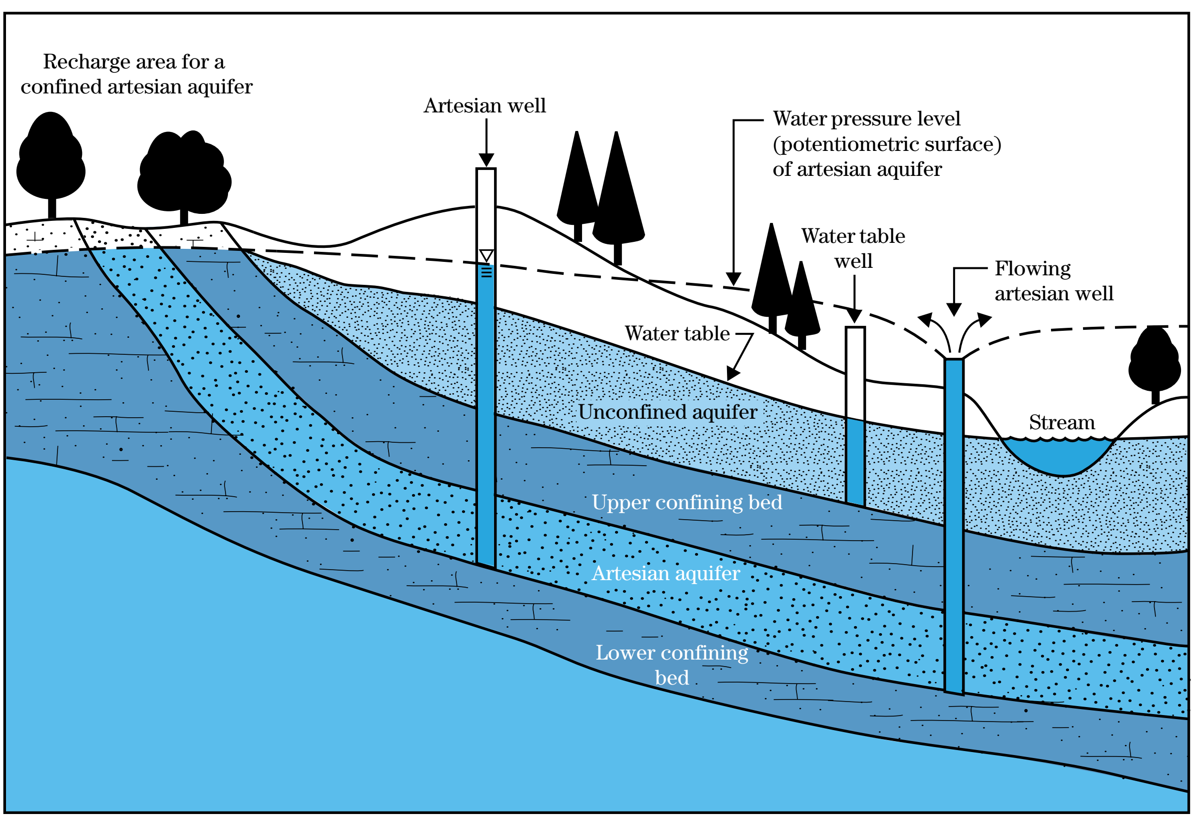
An aquifer is a saturated, permeable geologic unit capable of storing and conveying usable amounts of groundwater to wells or springs. When designing any agricultural waste management component, it is important to know:

- what type(s) of aquifers are present and at what depth
- the use classification of the aquifer, if any

Aquifers occur in many types of soil or rock materials. Productive aquifers include coarse-grained alluvial deposits; glacial outwash; coarse-grained, highly porous or weakly cemented sandstones and conglomerates; and limestones that dissolve into karst conditions. An aquifer need not be highly productive to be an important resource. For example, there are millions of private domestic wells throughout the country that yield 10 gallons per minute or less. In upland areas, often the only source of water available to wells occurs in fractured bedrock within about 300 feet of the surface. Below this depth, it is likely that the weight of the overlying rock materials will hold fractures closed and limit the volume of water they can convey.

An aquifer may be unconfined, confined, or perched (fig. 7–4). An unconfined aquifer, also known as a water table aquifer, occurs in relatively homogeneous, permeable materials that extend to a deeper, less permeable zone (fig. 7–5). It occurs near the ground surface and is affected only by atmospheric pressure and the weight of the water; it is generally recharged

Figure 7–4 Aquifers (AIPG 1984)



locally. The water table is the undulating surface that marks the top of an unconfined aquifer; it usually follows the general topography although with lesser relief. The water table, or static water level, is the elevation at which water stabilizes in a well under atmospheric pressure, although a well-developed capillary fringe will extend the saturated zone above the water table. Changing atmospheric pressures during heavy storms can cause relatively large changes in the water levels in shallow, unconfined aquifers.

A confined aquifer occurs at depth and is bounded above and below by geologic materials with lower permeabilities (fig. 7–6) known as an aquiclude. An aquiclude is a saturated geologic unit that is incapable of transmitting water, whereas an aquitard can transmit small volumes of water, but very slowly. The static water level in a confined aquifer, known as the potentiometric surface, will rise above the elevation at the top of the confining unit in a tightly cased, well penetrating the aquifer materials. It is controlled by the potentiometric pressure at the recharge area, which must be higher in elevation than that of the well. Recharge areas can be a long distance away. Slowly leaking aquitards overlying a confined aquifer can also create potentiometric pressures.

Figure 7–5 Unconfined aquifer (AIPG 1984)

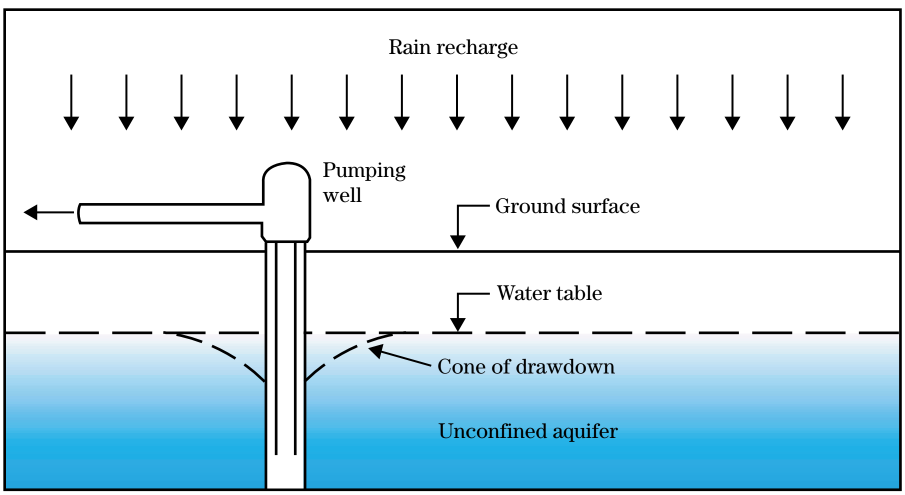
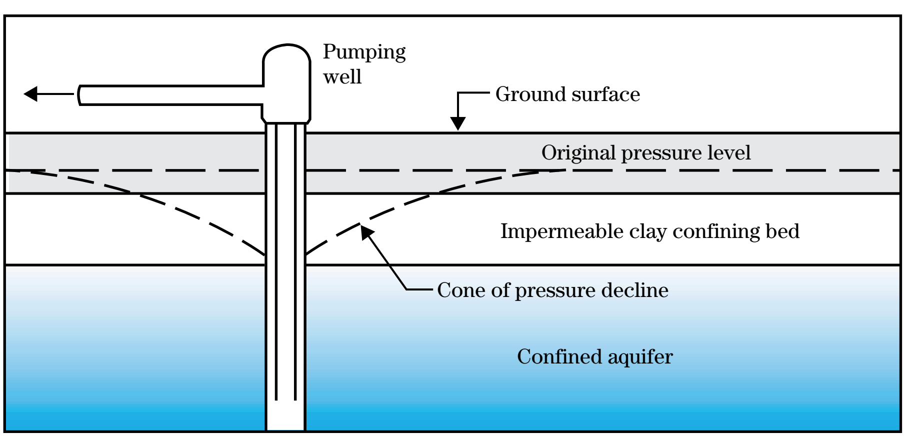


Figure 7–6 Confined (artesian) aquifer (AIPG 1984)



Confined aquifers are also known as artesian aquifers. Any well in which the static water level rises above the elevation at the top of the confining unit is called an artesian well (fig. 7–7). An artesian well that flows at the surface is called a flowing artesian well; not all artesian wells flow. To flow, the elevation of the surface of the well must lie below that of the potentiometric surface.

A perched aquifer (fig. 7–8) is a local zone of unconfined groundwater occurring at some level above the regional water table, with unsaturated conditions existing above and below it. They form where downward-percolating groundwater is blocked by a zone of lesser permeability and accumulates above it. This lower confining unit is called a perching bed, and they commonly occur where clay lenses are present, particularly in glacial outwash and till. These perched aquifers are generally of limited lateral extent and may not provide a long-lasting source of water. Perched aquifers can also cause problems in construction dewatering and need to be identified during the site investigation.

The U.S. Environmental Protection Agency (EPA), under the provisions of the Safe Drinking Water Act (1974), has the authority to designate aquifers as "sole source aquifers." A sole source aquifer is an aquifer that provides the primary, or sole, source of drinking water to an area. No Federal funds can be committed to any project that the EPA finds would contaminate a sole source aquifer and cause a significant health hazard.

An individual State may designate groundwater use classifications, in addition to their designated surface water use classifications. These designated use classifications protect aquifers for future use. There are States that regulate against groundwater overdraft, where pumping exceeds aquifer recharge.

(3) Porosity

Most materials within a few hundred feet of the Earth's surface contain solids and voids. Downward percolating water collects in voids and becomes available for wells and springs. Porosity is defined as the ratio of the volume of voids to the total volume of a soil or rock mass, expressed as a percentage.

$$\text{Porosity }(\%) = \frac{\text{Volume of voids in a given mass }(L^3)}{\text{Volume of given soil mass }(L^3)}$$

Figure 7–7 Cross section through stream valley showing groundwater flow lines and flowing (artesian) well from unconfined aquifer (Fetter 1980)

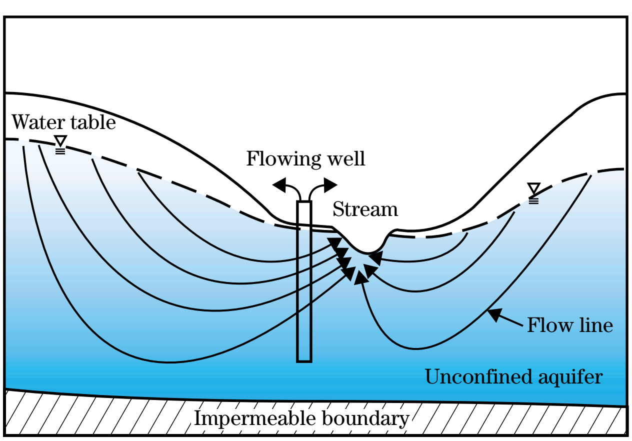
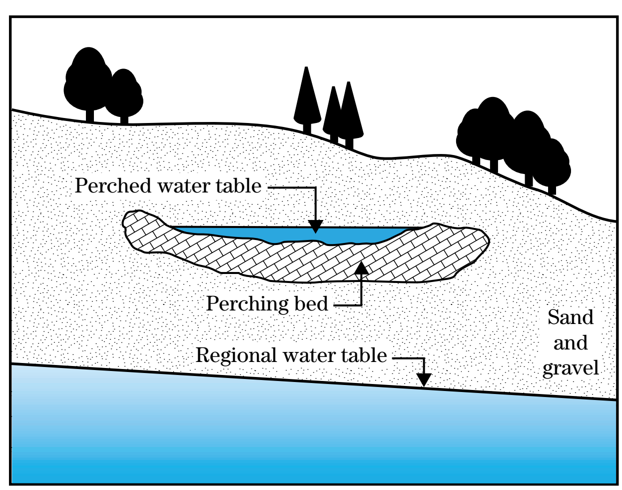


Figure 7–8 Perched aquifer



The two main types of porosity are primary and secondary (fig. 7–9).

Primary porosity refers to openings that developed at the time the material was formed or deposited. An example of primary porosity is the voids between particles in a sand and gravel deposit. Primary porosity of soil depends on the range in grain size (sorting) and the shape of the grains and is independent of particle size. Thus, a bathtub full of bowling balls has the same porosity as the same tub full of BBs. This assumes the arrangement (packing) is the same for balls and BBs. However, the tub full of a mixture of bowling balls and BBs will have a lower porosity than either the BBs or the bowling balls because BBs will occupy space between the bowling balls. Secondary porosity refers to openings formed after initial formation or deposition of a material. Processes that create secondary porosity include physical weathering (freezing-thawing, wetting and drying, heating and cooling), chemical or biological action, and other stresses that produce fractures and joints. Secondary porosity is extremely common in most geologic materials near the Earth's surface. This type of porosity enables contaminants to move with little attenuation (reduction) or filtration.

(4) Specific yield

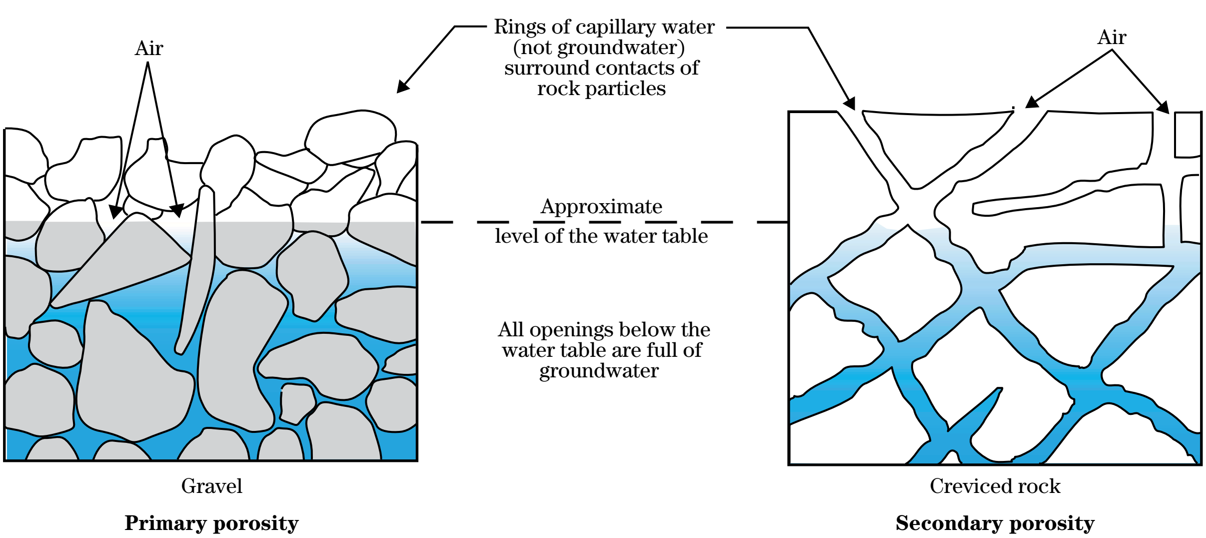
Specific yield is the ratio of the volume of water that an unconfined aquifer (soil or rock) releases by gravity drainage to the volume of the soil or rock mass. A material that has high porosity, such as clay, does not necessarily yield a high volume of water if the material also has low permeability (see section 651.0702 (h), Permeability of aquifer material). Such a material has low specific yield. See table 7–1 for comparison of porosity and specific yield of some geologic materials.

$$\text{Specific yield } (\%) = \frac{\text{Volume of water drained } (L^3)}{\text{Volume of given geologic material } (L^3)}$$

Table 7–1 Porosity and specific yield for various geologic materials (from Sterrett 2007)

Geologic material	Porosity (%)	Specific yield (%)
Soil:		
Gravel (mix)	25–40	15–30
Sand (mix)	25–40	10–30
Silt	35–50	5–10
Clay	45–55	1–10
Sand, silt, clay mixes	25–55	5–15
Sand and gravel mixes	10–35	10–25
Rock:		
Fractured or porous basalt	5–50	5–50
Fractured crystalline rock	0–10	0–10
Solid (unfractured) rock	0–1	0
Karst topography	5–50	5–50
Sandstone	5–30	5–15
Limestone, dolomite	1–20	0.5–5
Shale	0–10	0.5–5

Figure 7–9 Porosity—how groundwater occurs in geologic materials



651.0702 Engineering geology considerations in planning

This section provides guidance in determining what engineering geology considerations may need to be investigated for various waste management components (table 7–2). The significance of each consideration is briefly described with some guidance given on how to recognize it in the field. Most issues serve as signals or red flags that, if found, justify requesting assistance of a geologist or other technical specialist.

(a) Corrosivity

Soil is corrosive to many materials used in AWMS components. Soil survey data available through Soil Data Mart (SDM) (for GIS users) and Web Soil Survey (WSS) give corrosion potentials for steel and concrete for soil map units. Note that data for map units normally apply only to the top 60 inches of soil.

(b) Location of water table

The elevation and shape of the water table may vary throughout the year. High water tables and perched water tables in borrow areas can create access problems for heavy machinery. Rising water tables can also crack, split, and lift concrete slabs and rupture impoundment liners. The occurrence of a high water table may restrict the depth of excavation and require installation of relief or interceptor drainage systems to protect the practice from excessive uplift pressures. A preliminary field investigation will identify estimates of the depth to high water table using soil survey data available through SDM (for GIS users) and WSS. Site-specific groundwater depths may vary from values given in these sources. Stabilized water levels observed in soil borings or test pits provide the most accurate determination in the field. Seasonal variations in the water table also may be inferred from the logs of borings or pits. Recording soil color and redoximorphic features is particularly important. Redoximorphic features indicate seasonal changes in soil moisture. Perennially saturated soil is typically gray. Perennially aerated soil is typically various shades of red, brown, or yellow.

(c) Depth to rock

The selection of components that make up an AWMS may be restricted by shallow depth to bedrock because of physical limitations or State and local regulations.

The occurrence of hard, dense, massive, or crystalline rock at a shallow depth may require blasting or heavy excavators to achieve the designed grade. If the rock surface is irregular, differential settlement can be a hazard for steel tanks and monolithic structures, such as reinforced concrete tanks. Vegetative practices, such as filter strips, may be difficult to establish on shallow soil or exposed bedrock. Waste applied in areas of shallow or outcropping bedrock may contaminate groundwater because fractures and joints in the rock provide avenues for contaminants.

For waste impoundments, shallow bedrock generally is a serious condition requiring special design considerations. Bedrock of all types is nearly always jointed or fractured when considered as a unit greater than 0.5 to 10 acres in area. Fractures in any type of rock can convey contaminants from an unlined waste storage pond or treatment lagoon to an underlying aquifer. Fractures have relatively little surface area for attenuation of contaminants. In fact, many fractures are wide enough to allow rapid flow. Pathogens may survive the passage from the site to the well and thereby cause a health problem. Consider any rock type within 2 feet of the design grade to be a potential problem. The types of defensive design measures required to address shallow rock conditions depend on site conditions and economic factors. Design options include linings, waste storage tanks, or relocating to a site with favorable foundation conditions.

Sinkholes or caves in karst topography or underground mines may disqualify a site for a waste storage pond or treatment lagoon. Sinkholes can also be caused by dissolving salt domes in coastal areas. The physical hazard of ground collapse and the potential for groundwater contamination through the large voids are severe limitations.

Table 7–2 Engineering geology consideration for selected waste management components

Agricultural Waste Management Component	**Engineering geology considerations** Corrosivity	Location of water table (uplift pressures)	Depth to rock	Stability for embankment and excavation cut banks	Excavatability	Seismic stability	Dispersion	Permeability	Puncturability	Settlement potential	Shrink/swell	Topography	Availability and suitability of borrow material
1. Waste empoundments												X	
A. Earthfill embankment		X	X	X		X	X	X	X	X	X		X
B. Excavated cutbank		X	X	X	X		X	X	X		X		
C. Clay liners		X									X		
2. Waste storage structure (tanks and stacking facilities)	X	X	X		X	X			X	X	X	X	X
3. Vegetative filter strips							X	X				X	
4. Waste utilization area (land application)	X	X					X	X				X	
5. Constructed wetland		X					X	X	X		X	X	X
6. Composting facility										X		X	
7. Waste transfer - (e.g., concrete lined waterways, buried piplines)	X											X	
8. Heavy use area protection	X	X	X		X	X			X	X	X	X	X
9. Waste separation facility/components	X	X	X		X	X			X	X	X	X	X

(d) Stability for embankment and excavated cut slopes

Embankments and excavated cut slopes must remain stable throughout their design life. Control of groundwater prevents stability problems related to excessive pore pressure. Subsurface interceptor drains, relief drains, or open ditches may be needed to control excessive water pressure around structures. The foundation must be free-draining. This will prevent increased loads caused by the static or dynamic weight of a component from causing downslope sliding or slumping, especially for a clay foundation with low shear strength.

Embankments and excavated cutbanks may be vulnerable to failure when wastewater is emptied or pumped out of a waste impoundment. Rapid drawdown of wastewater may leave the soil in the bank above the liquid level saturated, which may then lead to bank caving. Designers must consider this in determining the stable side slope of embankments and cut banks and in designing the liner thickness. Consideration should be given in operation and maintenance plans to addressing the maximum rate that wastewater should be withdrawn from waste impoundments to minimize this problem.

(e) Excavatability

Excavation characteristics of the geologic materials at the site determine the type and size of equipment needed and the class of excavation, either common or rock, for pay purposes (table 7–3). Commonly avail-

Table 7–3 Excavation characteristics

Classification elements	Class I	Class II	Class III
	Very hard ripping to blasting	**Hard ripping**	**Easy ripping**
	Rock material requires drilling and explosives or impact procedures for excavation may classify 1/ as rock excavation (NRCS Construction Spec. 21). Must fulfill **all** conditions below:	Rock material requires ripping techniques for excavation may classify 1/ as rock excavation (NRCS Construction Spec, 21). Must fulfill **all** conditions below:	Rock material can be excavated as common material by earthmoving or ripping equipment may classify 1/ as common excavation (NRCS Construction Spec. 21). Must fulfill **all** conditions below:
Headcut erodibility index, k_h (210–NEH, Part 628, Chapter 52)	$k_h \geq 100$	$10 < k_h < 100$	$k_h \leq 10$
Seismic velocity, approximate (ASTM D 5777 and Caterpillar Handbook of Ripping, 1997)	≥ 2,450 m/s (≥ 8,000 ft/s)	2,150–2,450 m/s (7,000–8,000 ft/s)	≤ 2,150 m/s (≤ 7,000 ft/s)
Minimum equipment size(flywheel power) required for to excavate rock. All machines assumed to be for heavy-duty, track-type blasting, for backhoes or tractors equipped with a single tine, rear-mounted ripper.	260 kW (350 hp), for $k_h < 1,000$ 375 kW (500 hp), for $k_h \leq 10,000$ Blasting for $k_h > 10,000$	185 kW (250 hp)	110 kW (150 hp)

1/ The classification implies no actual contract payment method to be used nor supersedes NRCS contract documents. The classification is for engineering design purposes only.

able equipment may not be suitable in some situations. Blasting or specialized high horsepower ripping equipment may be required. Cemented pans, dense glacial till, boulders, an irregular bedrock surface, or a high water table can all increase the difficulty and cost of excavation.

(f) Seismic stability

Projects located in seismic zones 3 and 4, as defined in 210–TR–60, Earth Dams and Reservoirs, require special geologic investigations. These include investigations to determine the liquefaction potential of noncohesive strata, including very thin beds and the presence of any faults that have been active in the Holocene Epoch, which began 11,500 years ago.

These considerations are used in the design of embankment slopes, cut slopes, zoned fill, or internal drainage. A foundation consisting of loose, saturated, fine-grained, relatively clean sand is most susceptible to liquefaction during seismic events. Most well compacted embankments consisting of fine-grained plastic soils are inherently resistant to seismic shock. Determine the seismic zone of a site using the map in 210–TR–60 Earth Dams and Reservoirs. Other geologic hazards may be identified in Section I of the Field Office Technical Guide (FOTG) and local geologic reports and maps and other local technical references.

(g) Dispersion

Dispersive clay soils are unusually erodible and have been responsible for a significant amount of damage to NRCS channels and structures. Dispersive clay soils are distinguished from typical clay soils by differing electrochemical properties. Normal clays are composed primarily of calcium, magnesium, and potassium cations and have two positive charges. Dispersive clays are characterized by higher sodium contents, and have only one positive charge. With only one positive charge, the electrochemical forces are imbalanced. The imbalance causes the individual particles in a dispersive clay soil to be repulsed rather than attracted to one another. Because these particles are very small, they are easily detached and transported by even slow moving water. Small flows can erode significant volumes of material.

Typical characteristics of dispersive soils:

- They often occur in layers or lenses within a soil profile rather than as a mappable unit with consistent mineral, structural, and hydraulic characteristics. Color is not a reliable indicator of dispersive characteristics.
- They have high erodibility. Clay and colloidal fractions go readily into suspension and remain there. In small ponds and puddles, the colloidal clay particles stay suspended for long periods of time, and the water will remain turbid. The water may rarely clear up, if ever.
- Surface exposures, including streambanks and cut slopes, have the appearance of melted sugar. Gullying and rilling are extensive, forming a "badland" topography of jagged ridges and deep, rapidly-forming channels and tunnels. Lush vegetation does not prevent erosion on earthfill embankments.
- They have high shrink-swell potential and are thus subject to severe cracking when dried. "Jugging" can occur when rainfall and runoff concentrate in a crack. The crack is eroded from the bottom up, eroding a larger volume of the underlying soil than at the surface opening. The result is a jug-shaped feature; erosion to a depth of 4 to 8 feet is common.

(h) Permeability

Permeability or hydraulic conductivity refers to rate at which water flows through a material. The permeability of the underlying material is an important geologic consideration in the planning process. For example, permeability of the soil material at the excavation limits of a waste impoundment is an important factor in determining the need for a liner. Permeability can also affect the attenuation of contaminants that are land applied in waste utilization. Soils with lower permeability may allow the time needed for transformation and plant uptake of nutrients while soils with high permeability may leach contaminants. Permeability can be measured in the laboratory or estimated based on the characteristics of the material. Further description of permeability is given in 210–NEH, Part 651, Agricultural Waste Management Field Handbook (AWMFH), Chapter 10, Appendix D, Design and Construction Guidelines for Waste Impoundments Lined with Clay or Amendment-treated Soil.

(i) Puncturability

Puncturability is the ability of foundation materials to puncture a flexible membrane liner or steel tank. Angular rock particles greater than 3 inches in diameter may cause denting or puncturing in contact with a tank. Angular particles greater than 0.5 inch can puncture plastic and synthetic rubber membranes. Sharp irregularities in the bedrock surface itself also can cause punctures. Large angular particles can occur naturally or be created by excavation and construction activity.

(j) Settlement potential

Monolithic structures are designed to behave as a structural unit, and they are particularly vulnerable to settlement. Examples include tanks made out of steel and poured-in-place reinforced concrete. Differential settlement occurs when settlement is uneven across the entire foundation.

The potential for differential settlement can be an important design consideration in certain earthfill and concrete waste impoundment structures. Although the potential for differential settlement may be less significant, some segmentally designed structures may be susceptible to settlement as well.

Segmentally designed structures are built of structurally independent units such as precast, reinforced concrete retaining wall units. The designer should be familiar with the 210–NEH, Part 650, EFH, Chapter 4, Elementary Soil Engineering.

The six common geologic conditions that cause settlement to occur are:

- Abrupt, contrasting soil boundaries—A foundation is susceptible to differential settlement if underlain by zones, lenses, or beds of widely different soil types with boundaries that change abruptly either laterally or vertically.
- Compressible soil—Some layers or zones of materials over 1 foot thick may settle excessively when loaded by an embankment or concrete structure. These include soft clays and silts, peat and organic-rich soil (OL and OH in the Unified Soil Classification System (USCS)), and loose sands.
- Areas that have been active or abandoned underground mines and areas with high rates of groundwater withdrawal
- Steep abutments—Differential settlement of embankments may occur on abutment slopes that are steeper than 1 horizontal to 1 vertical. Compaction must be done by hand to achieve the density necessary to limit settlement and provide the necessary bond to retard leakage along the interface. Settlement cracks may occur in the fill in the area where the base of a steep abutment joins the flood plain.
- Uneven rock surfaces—A foundation may settle if it is constructed on soil materials overlying a highly irregular, shallow bedrock surface or other uneven, unyielding material. As a rule, consider a foundation problematic if the difference between the maximum and minimum thickness of compressible soil above an uneven rock surface divided by the maximum observed thickness is greater than 25 percent. This thickness ratio is expressed as:

$$100\left(\text{max. thickness} - \frac{\text{min. thickness}}{\text{max. thickness}}\right)$$
$$= \text{thickness ratio (percent)}$$

- Collapsible soil—This soil condition is common, particularly in the arid areas of the Western United States. These soils collapse or consolidate rapidly in the presence of water. They are characterized by low densities and low water contents and are generally fine-grained (CL, ML, CL-ML and MH, with an occasional SM). There are several types of soils which are water-sensitive and several causes of their unstable structure. They are:
  - — Fine-grained alluvial deposits with a random and unstable configuration that have not been saturated since their deposition—Most were deposited as debris flows from unvegetated watersheds in events with heavy rain. When they are eventually saturated, they collapse under their own weight.
  - — Wind-blown silt deposits known as loess that are very loose and contain appreciable voids—They characteristically have clay ma-

terial acting as a binding agent, which rapidly looses strength when wetted loaded.

— Gypsiferous soils in which the gypsum has been dissolved and then recrystallized—They form a porous mass which collapses easily.

(k) Shrink/swell

Soil containing montmorillonite clay may undergo substantial changes in volume when wetted and dried. Some minerals found as components in rock, such as gypsum or anhydrite, also may change volume dramatically when wetted and dried. Soil that has a high shrink/swell hazard is identified in Soil survey data available through SDM (for GIS users) and WSS. Field investigations and previous experience in the area may often be the only ways to foresee this problem.

(l) Topography

Recognition of land forms and their associated problems is a valuable asset when planning a component for an AWMS. For example, flood plain sites generally have a higher water table compared to that of adjacent uplands, are subject to surface flooding, and can indicate presence of permeable soils, as the alluvium may be more permeable.

Topography can indicate the direction of regional groundwater flow. Uplands may serve as aquifer recharge areas; valley bottoms, marshes, and lowlands serve as groundwater discharge areas.

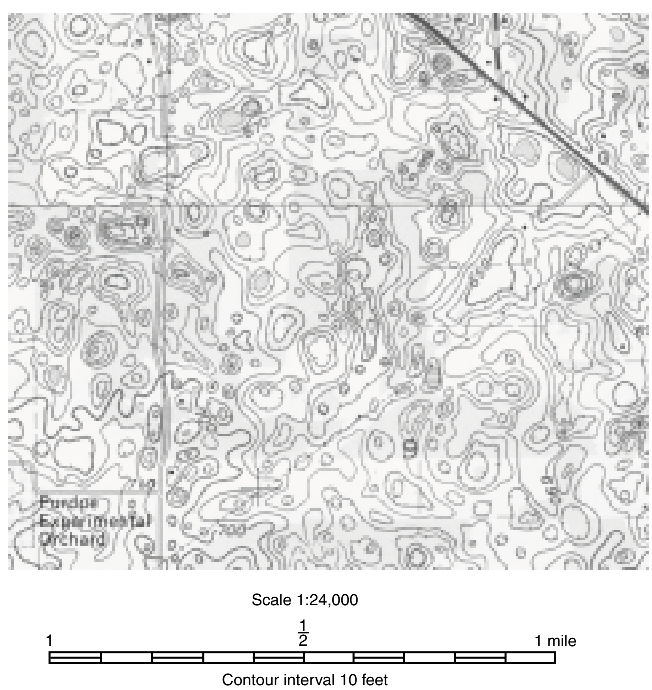
Steep slopes restrict use for some structural and vegetative measures. Potential hazards include landslides and erosion.

Karst topography is formed on limestone, gypsum, or similar rocks by dissolution and is characterized by sinkholes, caves, and underground drainage. Common problems associated with karst terrain include highly permeable foundations and the associated potential for groundwater contamination, and sinkholes can open up with collapsing ground. As such, its recognition is important in determining potential siting problems. Figure 7–10 illustrates karst topography near Mitchell, Indiana. Note the lack of stream development and the formation or presence of numerous sinkholes and depressions.

(m) Availability and suitability of borrow material

Borrow must meet gradation, plasticity, and permeability requirements for its intended use and be in sufficient quantity to build the component. Losses routinely occur during handling, transport, placement, and consolidation of fill materials. To compensate, as much as 150 percent of the design fill requirements should be identified within an economical hauling distance. Conditions of the borrow area itself may limit its use as borrow materials. Limitations may include such things as moisture content, thickness, location, access, land use, vegetation, and/or cultural resources.

Figure 7–10 Karst topography



(n) Presence of abandoned wells and other relics of past use

The site and its history should be surveyed for evidence of past use that may require special design considerations of the site relocation. If there is an abandoned well on the site, special efforts are required to determine if the well was sealed according to local requirements. An improperly sealed well can be a direct pathway for contaminants to pollute an aquifer.

Other remnants of human activity, such as old foundations, trash pits, or filled-in areas, require special AWMS design or site relocation. See section 651.0704 for guidance in planning investigations.

651.0703 Factors affecting groundwater quality considered in planning

(a) Attenuation potential of soil

Many biological, physical, and chemical processes break down, lessen the potency, or otherwise reduce the volume of contaminants moving through the soils in the root zone. These processes, collectively called attenuation, retard the movement of contaminants into deeper subsurface zones. See 210–NEH, Part 651, AWMFH, Chapter 3, Section 651.0303, Factors affecting the pollution process, for more details. The degree of attenuation depends on the time a contaminant is in contact with the material through which it travels. It also depends on the distance through which it passes and the total amount of surface area of particles of the material. Attenuation potential increases as clay content increases, soil depth increases, and distance increases between the contaminant source and the well or spring. Organic materials in the soil also increase the attenuation potential.

(1) Clay content
Increased clay content increases the opportunity for attenuation of contaminants because of its cation exchange capacity and its effect of reducing permeability. Clay particles hold a negative charge that gives them the capacity to interchange cations in solution and have a very low permeability (see fig. 7–11). As such, clay can absorb contaminant ions and thus attenuate the movement of contaminants.

(2) Depth of soil
Deeper soil increases the contact time a contaminant will have with mineral and organic matter of the soil. The longer the contact time, the greater the opportunity for attenuation. Very shallow (thin to absent) soil overlying permeable materials provides little to no protection against groundwater contamination.

(3) Distance between contaminant source and groundwater supply
Both the depth and the horizontal distance to a groundwater supply affect the attenuation of contaminants. The greater the horizontal distance between the source of the contamination and a well, spring, or the

groundwater supply, the greater the time of travel will be with increased potential for attenuation of contaminants.

(b) Groundwater flow direction

A desirable site for a waste storage pond or treatment lagoon is in an area where groundwater is not flowing away from the site toward a well, spring, or important underground water supply.

The direction of flow in a water table aquifer generally follows the topography, with lesser relief. In most cases, the slope of the land indicates the groundwater flow direction. In humid regions, the shape of the water table is a subdued reflection of surface topography. Unconfined groundwater moves primarily from topographically higher recharge areas down gradient to discharge areas. Lower areas serve as discharge points where groundwater rises and merges with perennial streams and ponds, drainage ditches, or flows as springs. Radial flow paths and unusual subsurface geology can too often invalidate this assumption. Consider the case where secondary porosity governs the flow. A common example is bedrock in upland areas where the direction of groundwater flow is strongly controlled by the trend of prominent joint sets or fractures. Fracture patterns in the rock may not be parallel to the slope of the ground surface. Thus, assuming that groundwater flow is parallel to the topography can be misleading in terrain where flow is controlled by bedrock fractures.

Appendix 7A demonstrates a method of calculating groundwater flow direction in a water table aquifer.

(c) Permeability of aquifer material

Permeability is a material property that is determined by laboratory analysis, but is also commonly determined as a mass property through field testing. The mass property is more accurately known as the aquifer's hydraulic conductivity, which integrates all of the aquifer's characteristics to conduct water.

The time available for attenuation in aquifer materials decreases as the permeability of the materials increases. Permeability may vary significantly between different types of materials or at different places within the same material. Permeability is often many times greater laterally than vertically. Ignored or undetected, a thin (0.5 inch or less) clay or shale seam in an otherwise uniform soil or rock aquifer can profoundly alter the outcome of mathematical analyses and design assumptions. Figure 7–11 shows the permeability of various geologic materials.

(d) Hydraulic conductivity

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient.

Hydraulic conductivity is one of the hydraulic properties of the soil; the other involves the soil's fluid retention characteristics. These properties determine the behavior of the soil fluid within the soil system under specified conditions. More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition.

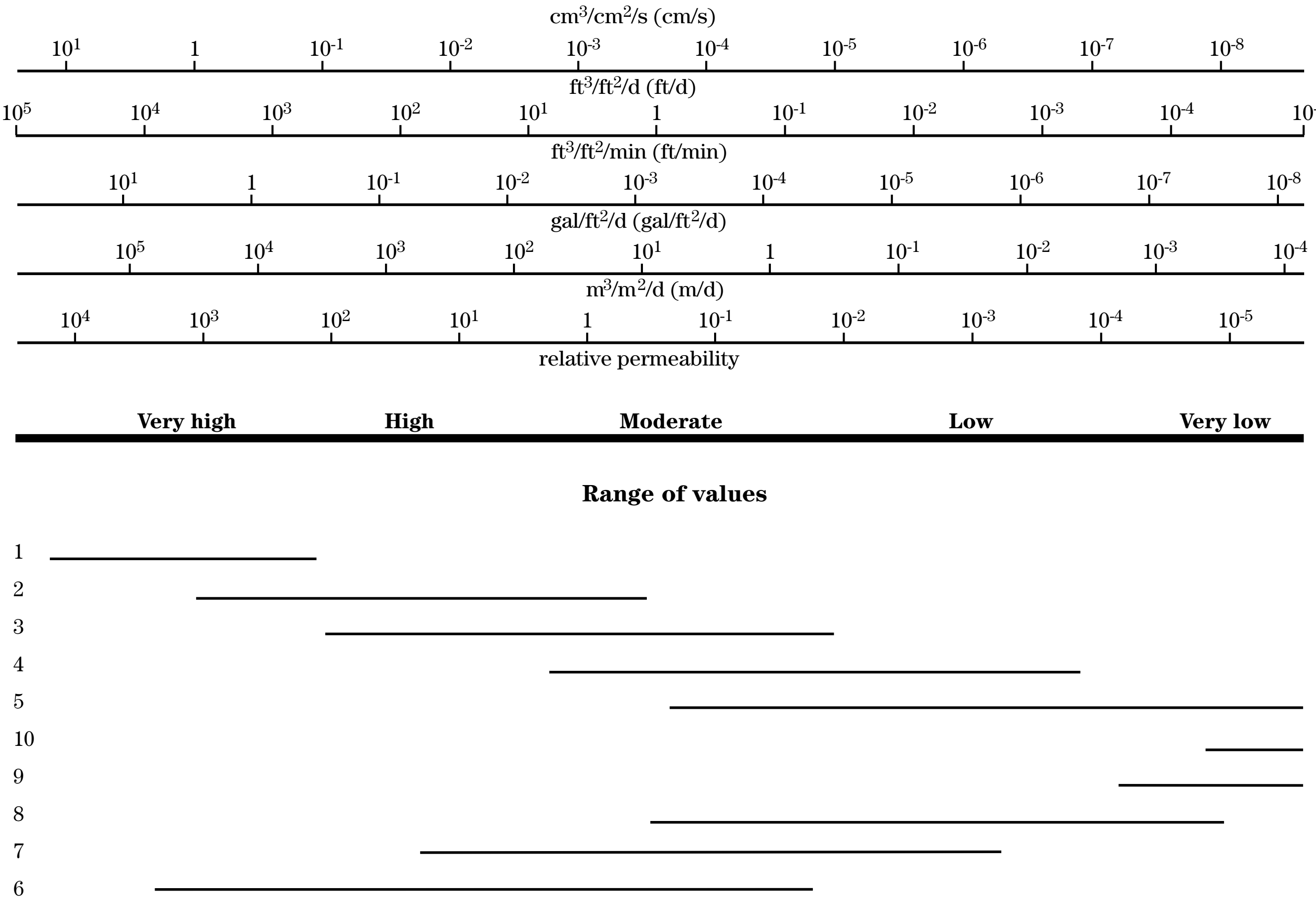
The hydraulic conductivity depends on the soil grain size, structure of the soil matrix, type of soil fluid, and relative amount of soil fluid (saturation) present in the soil matrix. The important properties relevant to the solid matrix of the soil include pore size distribution, pore shape, tortuosity, specific surface, and porosity.

Hydraulic conductivity is an important soil property when determining the potential for widespread groundwater contamination by a contaminating source. Soils with high hydraulic conductivities and large pore spaces are likely candidates for far reaching contamination.

(e) Hydraulic head

Hydraulic head is the energy of a water mass produced mainly by differences in elevation, velocity, and pressure, expressed in units of length or pressure. Groundwater moves in the direction of decreasing hydraulic head. Hydraulic head in an aquifer is measured using piezometers. For more information, see 210–NEH, Part 631, Chapter 32, Well Design and Spring Development.

Figure 7–11 Permeability of various geologic materials (from Freeze and Cherry 1979)



Representative materials

Numbers

Soil types

1. Clean gravel (GP)
2. Clean sand, clean sand and gravel mixes (GW, GP, SW, SP, SM)
3. Fine sand, silty sand and gravel mixes (SP, SM, GM, GW–GM, GP–GM, SW–SM, SP–SM)
4. 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)
5. Massive clay, no soil joints or other macropores (CL, CH)

Rock types

6. Cavernous and karst limestones and dolomites, permeable basalts
7. Fractured igneous and metamorphic rocks
8. Limestones, dolomites, clean sandstones
9. Interbedded sandstones, siltstones, and shales
10. Most massive rocks, unfractured and unweathered

(f) Hydraulic gradient

The hydraulic gradient is the change in hydraulic head per unit distance of flow in a given direction; it is expressed in units of height (elevation) per length (distance). Groundwater velocity is a function of the hydraulic gradient. Most water in an unconfined aquifer moves slowly unless it has been developed during the well construction process. Well development is a procedure that alters the physical characteristics of the aquifer near the borehole so that water will flow more freely to the well.

Pumping water from a well can steepen local hydraulic gradients drawdown. This results in acceleration of flow toward the well, carrying any contaminants with it. Appendix 7A provides a method to calculate the hydraulic gradient in water table aquifers.

(g) Hydrogeologic setting

Hydrogeology is the study of the occurrence, movement, and quality of underground water. The hydrogeologic setting of an AWMS component includes all the various geologic factors that influence the quality and quantity of underground water. Information on the hydrogeologic setting of a site is in the following sources:

- State water quality management and assessment reports of surface and groundwater use designations and impairments
- geologic maps showing rock types and structures
- regional water table maps and, if available, tables of static water levels in wells
- groundwater vulnerability maps

(h) Land topography

Topographic features that impound contaminated runoff water increase the potential for groundwater contamination by infiltration. Examples include seasonal wetlands and level terraces. The hazard of contaminating surface water flowing across the ground increases as the slope and slope length increase.

(i) Proximity to designated use aquifers, recharge areas, and well head protection areas

State water management and assessment reports and the following maps should be reviewed to ascertain the proximity of sensitive groundwater areas:

- sole source or other types of aquifers whose uses have been designated by the State
- important recharge areas
- wellhead protection areas

(j) Type of aquifer

See section 651.0701, Overview of geologic material and groundwater, for details on unconfined, confined, and perched aquifers.

(k) Vadose zone material

The types of material in the vadose (unsaturated) zone affect the flow path and rate of flow of water and the contaminants percolating through it. Flow rate is a function of the permeability of the material (fig. 7–11). Flow rate in the mass is greatly increased by macropores such as soil joints. The time available for attenuation in this zone decreases as the permeability of the materials increases. Permeability rates may be inferred from the types of materials.

651.0704 Site investigations for planning and design

(a) Preliminary investigation

The purpose of a preliminary site investigation is to establish feasibility for planning purposes. A preliminary site investigation also helps determine what is needed in a detailed investigation. A site investigation should be done only after local regulations and permit requirements are known. The intensity of a field investigation is based on several factors including:

- quality of information that can be collected and studied beforehand
- previous experience with conditions at similar sites
- complexity of the AWMS or site

Clearly defined objectives for investigation are essential in this phase. Table 7–2 may be useful in defining objectives. For example, the objectives for investigating a site for a steel storage tank are significantly different from those for an earthen structures. The tanks involve consideration of differential settlement of the foundation, while the objectives of the subsurface investigation of earthen structures involves consideration of excavatability and permeability of foundation materials.

For many sites the preliminary investigation and experience in the area are adequate to determine the geologic conditions, engineering constraints, and behavior of the geologic materials. Hand-auger borings and site examination often provide adequate subsurface information so that a detailed subsurface investigation is not required. A detailed investigation must be scheduled if reliable information for design cannot be obtained with the tools available during the preliminary investigation phase.

An initial field evaluation should be performed on the potential layout(s) of the component, access to the site, and location of active or abandoned wells, springs, and other such features.

All wells and well records near the site should be examined for proper construction. The condition of the concrete pad and, if possible, the annular seal or grout around the well casing also need to be examined. See the Field Office Technical Guide (FOTG) for the National Conservation Practice Standard (CPS), Code 642, Water Well. Some State water agencies may have more restrictive minimum requirements.

Valuable background information about a proposed site is obtained from the following sources:

- soil survey reports—Provide soil map units, aerial photos, information on seasonal flooding and the water table, and engineering interpretations and classification of soils
- topographic maps—USGS topographic quadrangles or existing survey data from the site provide information about slopes, location of forested areas, topographic relief, and distances to identified resource features such as wells, watercourses, houses, roads, and other cultural features
- aerial photos—Provide information on vegetation, surface runoff patterns, erosion conditions, proximity to cultural features, and other details.
- local geologic maps and reports—Provide information on depth to and types of bedrock, bedrock structure, location of fault zones, characteristics of unconsolidated deposits, depth to water table, aquifer characteristics, and other geologic and groundwater information
- conservation plans and associated logs

(b) Detailed investigation

The purpose of a detailed geologic investigation is to determine geologic conditions at a site that will affect or be affected by design, construction, and operation of an AWMS component. Determining the intensity of detailed investigation is the joint responsibility of the designer and the person who has engineering job approval authority. Complex geology may require a geologist. Detailed investigations require application of individual judgment, use of pertinent technical references and state-of-the-art procedures, and timely consultation with other appropriate technical disciplines. Geologic characteristics are determined through digging or boring, logging the types and characteristics of the materials, and securing and testing representative samples. An onsite investigation should always be conducted at a proposed waste impoundment location. State and local laws should be followed in all cases.

(1) Investigation tools

Soil probes, hand augers, shovels, backhoes, bulldozers, power augers, and drill rigs all are used to allow direct observations for logging geologic materials, collecting samples, and access for field permeability testing. Soils that have been drilled with an auger are considered to be disturbed, and soil zones can be mixed, obscuring thin layers of potential permeability. Test pits expose a detailed view of the subsurface conditions; however, they cannot be safely excavated below the water table.

Geophysical methods are indirect techniques that are used in conjunction with direct methods of investigation such as test pits and soil borings. They require trained and experienced specialists to operate the equipment and interpret the results. The data must be ground truthed at a particular site, and the geology must be well understood to interpret the additional information accurately. These methods include electromagnetic induction, resistivity, refraction seismographs, ground penetrating radar, and cone penetrometer testing (see Soil Mechanics Note 11: The Static Cone Penetrometer: the Equipment and Using the Data).

(2) Logging geologic materials

During a geologic investigation, all soil and rock materials at the site or in borrow areas are identified and mapped. From an engineering standpoint, a mappable soil or rock unit is defined as a zone that is consistent in its mineral, structural, and hydraulic characteristics and sufficiently homogeneous for descriptive and mapping purposes. A unit is referred to by formal name such as Alford silt loam or Steele shale, or is set in alphanumeric form such as Sand Unit A–3.

The NRCS classifies rock material using common rock type names as given in 210–NEH, Part 631, Chapter 12, Rock Material Field Classification System and Part 628, Chapter 52, Field Procedures Guide for the Headcut Erodibility Index; and 210–TR–78, The Characterization of Rock for Hydraulic Erodibility. Soils are classified for engineering purposes according to the USCS, ASTM D 2488, Standard Practice for Description and Identification of Soils, Visual Manual Procedure. Appendix 7B provides criteria for identifying soils by the USCS. Any geologic material, regardless of origin, that meets the criteria in this standard practice is considered soil for classification purposes.

When greater precision is needed, representative samples are analyzed in a soil mechanics laboratory. The laboratory uses ASTM D 2487, Standard Test Method for Classification of Soils for Engineering Purposes. Laboratory determinations of particle characteristics and Atterberg limits (liquid limit and plasticity index) are used to classify soils.

Use standard NRCS log sheets, such as NRCS–533, or the soil log sheet and checklists in appendix 7B. Logs also may be recorded in a field notebook. Be methodical when logging soils.

Identify and evaluate all applicable parameters according to criteria given in ASTM D 2488. Thorough logging requires only a few minutes on each boring or test pit and saves a trip back to the field to gather additional or overlooked information. Also, be prepared to preserve a test hole or pit to record the stabilized water table elevation after 24 hours.

Each log sheet must contain the name of the project, location, date, investigator's name and title, and type of equipment used (backhoe) including make and model, and test pit or boring identification number, or each soil type found in a test pit or drill hole, record the following information, as appropriate.

- station and elevation of test hole or pit
- interval (depth range through which soil is consistent in observed parameters)
- particle size distribution by weight, for fraction less than 3 inches
- percent cobbles and boulders by volume, for fraction greater than 3 inches
- angularity of coarse material
- color of moist material including presence of redoximorphic feature which occur in the zone of water table fluctuation
- relative moisture content
- structure

- consistency in saturated fine-grained materials or relative density in coarse-grained materials
- plasticity of fines
- group name and USCS symbol according to ASTM D 2488 flow charts
- geologic origin and formal name, if known
- sample (size, identification number, label, depth interval, date, location, name of investigator)
- other remarks or notes (mineralogy of coarse material, presence of mica flakes, roots, odor, pH)
- depth (or elevation) of water table after stabilizing; give date measured and number of hours open
- depth to rock, "refusal" (where the equipment meets resistance and cannot penetrate any further) or total depth of hole

For more details, see 210–NEH, Part 650, EFH, Chapter 4, Elementary Soil Engineering.

(3) Samples

Samples of soil and rock materials collected for soil mechanics laboratory testing must meet minimum size requirements given in Geology Note 5, Soil Sample Requirements for Soil Mechanics Laboratory Testing. Sample size varies according to testing needs. Samples must be representative of the soil or rock unit from which they are taken. A geologist or engineer should help determine the tests to be conducted and may assist in preparing and handling samples for delivery to the lab. Test results are used in design to confirm field identification of materials and to develop interpretations of engineering behavior.

(4) Guide to detailed geologic investigation

For foundations of earthfill structures, use at least four test borings or pits on the proposed embankment centerline, or one every 100 feet, whichever is greater. If correlation of materials between these points is uncertain, use additional test borings or pits until correlation is reasonable. The depth to which subsurface information is obtained should be no less than equivalent maximum height of fill, or to hard, unaltered rock or other significant limiting layer. For other types of waste storage structures, the depth should be to bedrock, dense sands or gravels, or hard fine-grained soils. Report unusual conditions to the responsible engineer or State specialist for evaluation. These conditions are listed in table 7–2.

For structures with a pool area, use at least five test holes or pits or one per 10,000 square feet of pool area, whichever is greater. These holes or pits should be as evenly distributed as possible across the pool area. Use additional borings or pits, if needed, for complex sites where correlation is uncertain. The borings or pits should be dug no less than 2 feet below proposed grade in the pool area or to refusal (limiting layer). Log the parameters listed in this section. Report unusual conditions to the responsible engineer or other specialist for further evaluation. Pay special attention to perched or high water tables and highly permeable materials in the pool area.

Borrow areas for embankment type structures and clay liners should be located, described, and mapped. Locate at least 150 percent suitable borrow of the required fill volume. Soil samples for natural water content determinations should be obtained from proposed borrow and clay liner sources. Samples should be collected and maintained in moisture proof containers. The parameters listed in this section should be logged.

Consult soil survey reports and local surficial geologic maps to help identify potential borrow areas for investigation. Some designs may require bentonite or chemically treated soil to reduce permeability (see 210–NEH, Part 651, AWMFH, Chapter 10, Appendix 10D). A qualified soil mechanics engineer should be consulted for guidance.

Depth to the water table in borrow areas is an important consideration. Dewatering a borrow area is usually impractical for small components such as waste structures. Installing drainage or excavating and spreading the materials for drying before placement generally is not cost-effective. It may be necessary to do so, however, when suitable borrow is limited. Adhere to any State or local requirements for back filling test pits or plugging borings.

651.0705 References

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Appendix 7A Determining Groundwater Flow Direction and Hydraulic Gradient

If a published water table map is not available for the area, but several wells and springs are nearby, a contour map of the water table should be developed. Plot on a topographic map (at an appropriate scale) a sufficient number of points of static levels of water wells, observation wells, and test pits. Include spot elevations of perennial streams, ponds, and lakes. Using an appropriate contour interval, contour the data points to produce a useful water table map. Record dates of observations to allow comparison over time, from season to season, or in areas of suspected water table fluctuations.

If information on water table depths is not available and the aquifer is controlled by primary porosity, such as alluvium and glacial outwash, sketch several lines perpendicular to the elevation contours in the area of interest. The pattern that develops will indicate general groundwater flow directions. Groundwater discharge areas occur where the lines converge, such as most valleys, perennial streams, and ponds. Recharge areas, such as hilltops and upland areas converge, occur where the lines diverge.

For planning purposes, the general groundwater flow direction and hydraulic gradient of the water table should be calculated using data from three wells located in any triangular arrangement in the same unconfined aquifer (Heath 1983). They may be observation wells, test holes, test pits, or water wells. Also, the elevation of a perennial pond or stream can serve as an observation point. There is an 8-step procedure for this planning method, and figure 7A–1 gives an example.

Step 1—Obtain a detailed topographic map of the site, such as a USGS quadrangle or a field survey map. Be sure the map has a north arrow.

Step 2—Plot the position of the proposed AWMS component and all springs, wells within at least a half-mile radius. If the existence of wells is unknown, assume every rural house or farm/ranch headquarters represents the location of a well. Black squares on USGS quadrangles symbolize houses.

Step 3—Select three wells not in a line, and measure the static (nonpumping) levels using a commercial water depth meter or a lead weight on a measuring tape. Record on the map the head (elevation of the water table) for each well. Use consistent units (meters or feet above mean sea level or an arbitrary datum plane) throughout this exercise.

Step 4—Measure the distance between the wells with the highest and lowest water level elevations, and record on the map.

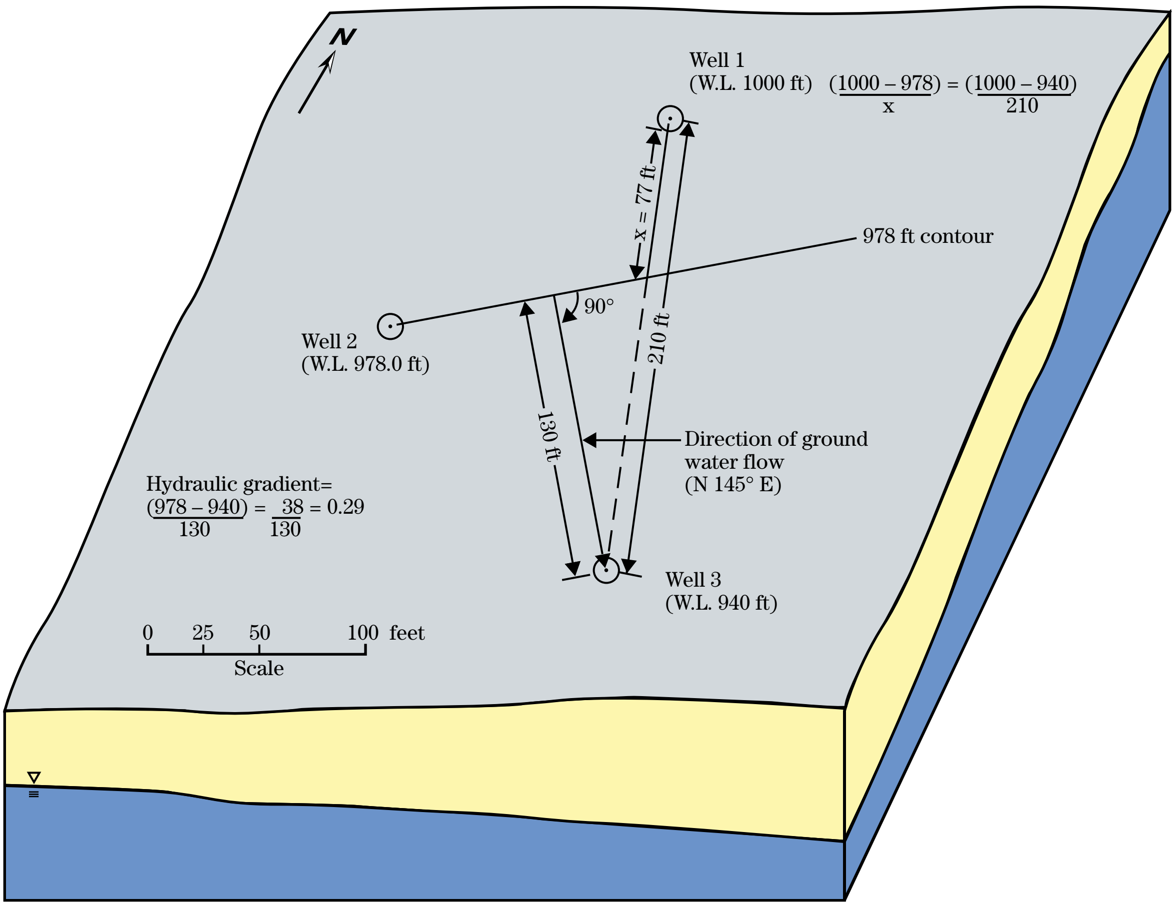
Step 5—Using the map, identify the well with the intermediate water table elevation (that is, neither the highest nor the lowest). Interpolate the position between the well with the highest head and the well with the lowest head where the head is equal to that in the intermediate well. Mark this point on the map. Measure the distance between this point and the well with the lowest water level.

Step 6—Draw a straight line between the intermediate well and the point identified in step 5. This line represents a segment of a water table contour along which the head is the equal to that in the intermediate well.

Step 7—Draw a line perpendicular from this contour to the lowest head well, and measure the distance. This line is parallel to the groundwater flow direction. Using the north arrow as a guide, orient a protractor to measure the compass direction of the line. Express the orientation of the groundwater flow direction in degrees azimuth (clockwise east from north).

Step 8—Subtract the head of the lowest well from that of the intermediate well. Divide the difference by the distance measured in step 7. The result is the hydraulic gradient.

Figure 7A–1 Determining direction of groundwater flow and hydraulic gradient (from Heath 1983)



Appendix 7B

Identifying Soils for Engineering Purposes

Soil Log Sheet

Project________________________ Location________________________________ Date____________

Investigator_____________________ Title_______________________ Equipment_____________________

Interval (feet)	Particle size distribution by weight			Particle size distribution by volume		Angularity (coarse fraction)	Color (when moist)	Relative moisture content	Saturated consistency of fines	Density (coarse fraction)	Group name	Unified symbol	Geologic origin	Sample no.
	Percent fines	Percent sand	Percent gravel	Percent cobbles	Percent boulders									

Notes:

Test hole no.________ Station________ Elevation________ Water table elevation________ after______hours Sheet_____of_____

The following tables are derived from ASTM D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). Tables 7B–1 through 7B–11, except 7B–7, copyright ASTM Int'l. Reprinted with permission.

Table 7B–1 Criteria for describing angularity of coarse-grained particles

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

Table 7B–2 Criteria for describing particle shape

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

Table 7B–3 Criteria for describing moisture condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible moisture
Wet	Visible free water, usually soil is below water table

Table 7B–4 Criteria for describing the reaction with HCL

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

Table 7B–5 Criteria for describing cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

Table 7B–6 Criteria for describing structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

Table 7B–7 Criteria for describing consistency

Description	Criteria for Fine-grained Saturated Soils	Penetrometer tons/ft^2 or kg/cm^2	Std. Penetration Test (ASTM D 1586) blows/ft
Very soft	Thumb will penetrate soil more than 1 in	< 0.1	< 2
Soft	Thumb will penetrate soil about 1 in	0.10–0.25	2–4
Firm	Thumb will indent soil about 1/4 in	0.25–1.00	4–15
Hard	Thumb will not indent soil, but readily indented with thumbnail	1.00–2.00	15–30
Very hard	Thumbnail will not indent soil	> 2.00	> 30

Table 7B–8 Criteria for describing dry strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen crumbles into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

Table 7B–9 Criteria for describing dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

Table 7B–10 Criteria for describing toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

Table 7B–11 Criteria for describing plasticity

Description	Criteria
Nonplastic	A 1/8-in (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

Checklist—Description of coarse-grained soils (ASTM D 2488)

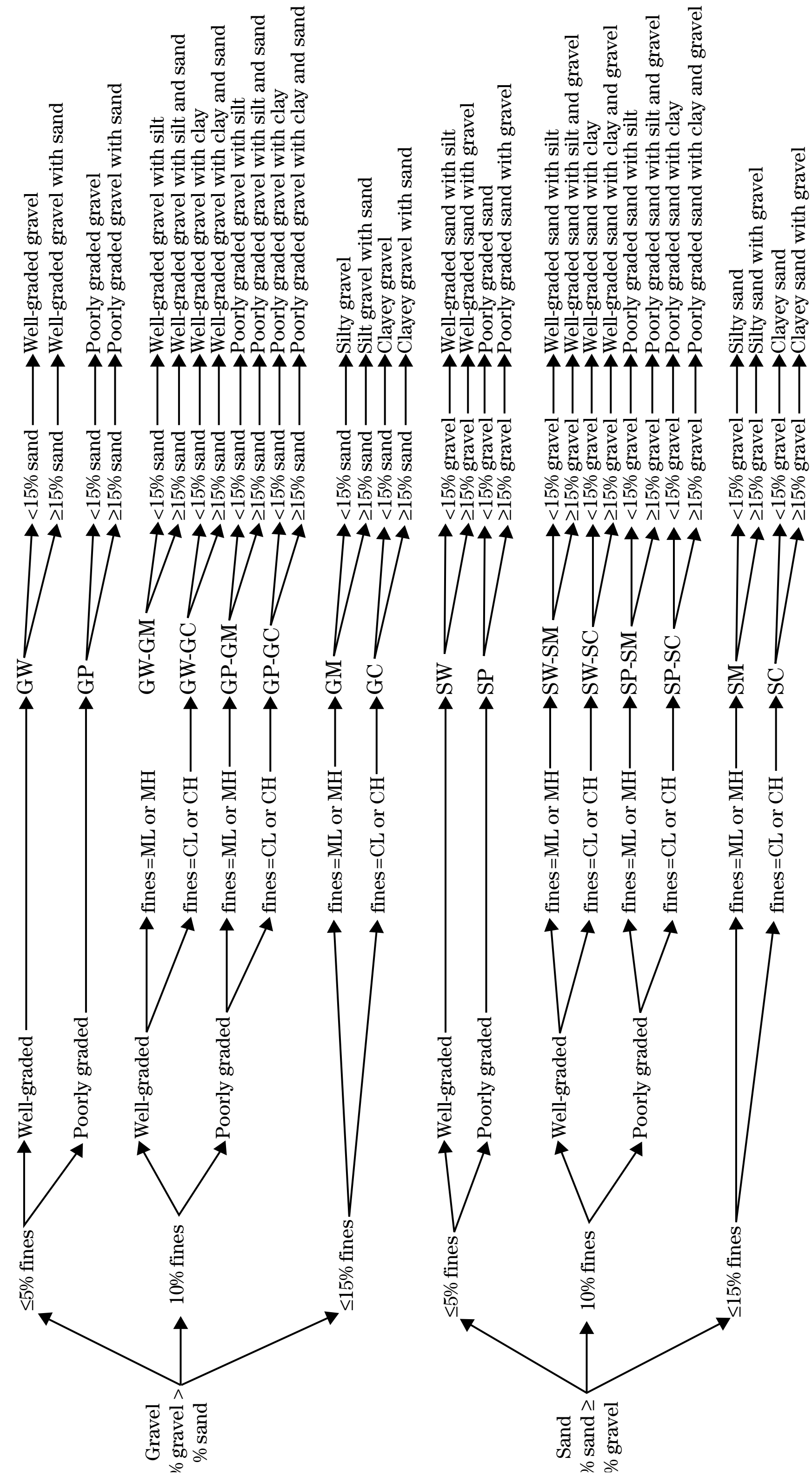
1. **Typical Name:** Boulders Cobbles Gravel Sand
   Add descriptive adjectives for minor constituents.
2. **Gradation:** Well-graded Poorly graded (uniformly graded or gap-graded)
3. **Size Distribution:** Percent gravel, sand, and fines in fraction finer than 3 inches (76 mm) to nearest 5 percent. If desired, the percentages may be stated in terms indicating a range of values, as follows:
   Trace: < 5%
   Few: 5–10%
   Little: 15–25% Or, with gravel
   Some: 30–45% Or, gravelly
   Mostly: 50–100%
4. **Percent Cobbles and Boulders:** By volume
5. **Particle Size Range:** Gravel—fine, coarse
   Sand—fine, medium, coarse
6. **Angularity of Coarse Material:** Angular Subangular Subrounded Rounded
7. **Particle Shape (if appropriate):** Flat Elongated Flat and elongated
8. **Plasticity of Fines:** Nonplastic Low Medium High
9. **Mineralogy:** Rocky type for gravel, predominant minerals in sand. Note presence of mica flakes, shaly particles, and organic materials.
10. **Color:** Use common terms or Munsell notation (in moist or wet condition).
11. **Odor (for dark-colored or unusual soils only):** None Earthy Organic
12. **Moisture Content:** Dry Moist Wet

—For intact samples—

13. **Natural Density:** Loose Dense
14. **Structure:** Stratified Lensed Nonstratified
15. **Cementation:** Weak Moderate Strong
16. **Reaction (dilute with HCL):** None Weak Strong (or pH)
17. **Geologic Origin:** Examples—Alluvium, Residuum, Colluvium, Glacial Till, Outwash, Dune Sand, Alluvial Fan, Talus
18. **Unified Soil Classification Symbol:** Estimate (see table 7B–12, Field identification of coarse-grained soils)

Note: See tables 7B–1 through 7B–11 for criteria for describing many of these factors.

Figure 7B–1 Flow chart for identifying coarse-grained soils (less than 50% fines) (Source: ASTM D 2488 (fig. 2). Copyright ASTM Int'l. Reprinted with permission.)



Note 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

Table 7B–12 Field identification—coarse-grained soils

Coarse Particle Grade Sizes

Grade name	Grade size	Sieve no	Comparative size
Boulders	12" +	–	Basketball or larger
Large cobbles	6" - 12"	–	Cantaloupe to basketball
Small cobbles	3" - 6"	–	Orange to cantaloupe
Coarse gravel	3/4" - 3"	-	Cherry to orange
Fine gravel	1/4" - 3/4"	4 - 3/4"	Pea to cherry
Coarse sand	2.0 - 4.76 mm	10 - 4	Wheat grain to pea
Medium sand	0.42 - 2.0 mm	40 - 10	Sugar to wheat grain
Fine sand	0.074 - 0.42 mm	200 - 40	Flour to sugar

Coarse-grained soils[1]	**Gravel and gravelly soils**[2]	More than half of coarse fraction (by weight) is larger than 1/4-inch.	**Clean gravels** Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate sizes.
				Mostly one size or a range of sizes with some intermediate sizes missing.
			Dirty gravels Will leave a dirt stain on a wet palm.	Low to nonplastic fines (for identifying fines see Field Identification of Fine-grained Soils for ML soils).
				Plastic fines (for identifying fines see Field Identification of Fine-grained Soils for CL soils).
	Sand and Sandy soils[2]	More than half of coarse fraction (by weight) is smaller than 1/4-inch.	**Clean sands** Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.
				Mostly one size or a range of sizes with some intermediate sizes missing.
			Dirty sands Will leave a dirt stain on a wet palm.	Low to nonplastic fines (for identifying fines see Field Identification of Fine-grained Soils for ML soils).
				Plastic fines (for identifying fines see Field Identification of Fine-grained Soils for CL soils).

1/ To classify as coarse-grained, more than half of the material (by weight) must consist of individual grains visible to the naked eye. Individual grains finer than no. 200 sieve cannot be seen with the naked eye nor felt by the fingers.
2/ For visual classification, 1/4-inch size may be used as equivalent to no. 4 sieve.

Checklist—Description of fine-grained soils (ASTM D 2488)

1. **Typical Name:** Silt Elastic silt Lean clay Fat clay
   Silty clay Organic silt or clay Peat
2. **Dry Strength:** None Low Medium High Very high
3. **Size Distribution:** Percent gravel, sand, and fines in fraction finer than 3 inches (76 mm) to nearest 5 percent. If desired, the percentages may be stated in terms indicating a range of values, as follows:
   Trace: < 5%
   Few: 5–10%
   Little: 15–25% Or, with sand
   Some: 30–45% Or, sandy
   Mostly: 50–100%
4. **Percent Cobbles and Boulders:** By volume
5. **Dilatancy:** None Slow Rapid
6. **Toughness of Plastic Thread:** Low Medium High
7. **Plasticity of Fines:** Nonplastic Low Medium High
8. **Color:** Use common terms or Munsell notation (in moist or wet condition).
9. **Odor (for dark-colored or unusual soils only):** None Earthy Organic
10. **Moisture content:** Dry Moist Wet

—For intact samples—

11. **Consistency:** Very soft Soft Firm Hard Very hard
12. **Structure:** Stratified Laminated (varved) Fissured Slickensided Blocky Lensed Homogeneous
13. **Cementation:** Weak Moderate Strong
14. **Reaction (dilute with HCL):** None Weak Strong (or pH)
15. **Geologic Origin:** Examples—Alluvium, Residuum, Colluvium, Loess, Glacial till, Lacustrine
16. **Unified Soil Classification Symbol:** Estimate (see table 7B–13, Field identification of fine-grained soils)

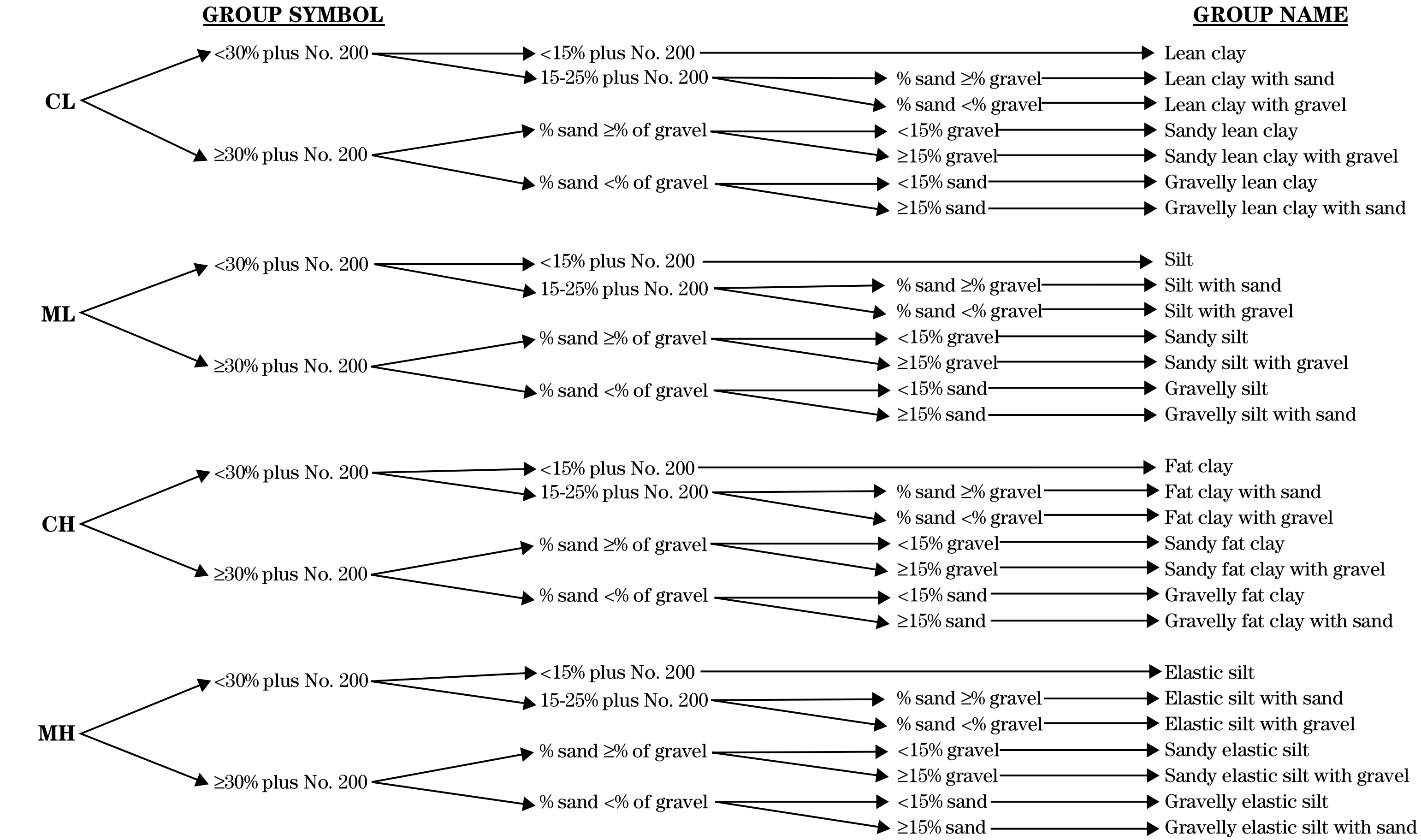
Note: See tables 7B–1 through 7B–11 for criteria for describing many of these factors.

Table 7B–13 Field identification—fine-grained soils

Dry Strength	Dilatancy	Toughness	Plasticity	Symbol
None to low	Slow to rapid	Low or no thread	Nonplastic to low	ML
Medium to high	Slow	Medium	Low to medium	CL
Low to medium	None to slow	Low (spongy)	None to low	OL
Medium	None to slow	Low to medium	Low to medium	MH
Very high	None	High	Medium to high	CH
Medium to high	None	Low to medium (spongy)	Medium to high	OH
Highly organic soils	Primarily organic matter, dark in color, spongy feel, organic odor, and often fibrous texture			PT

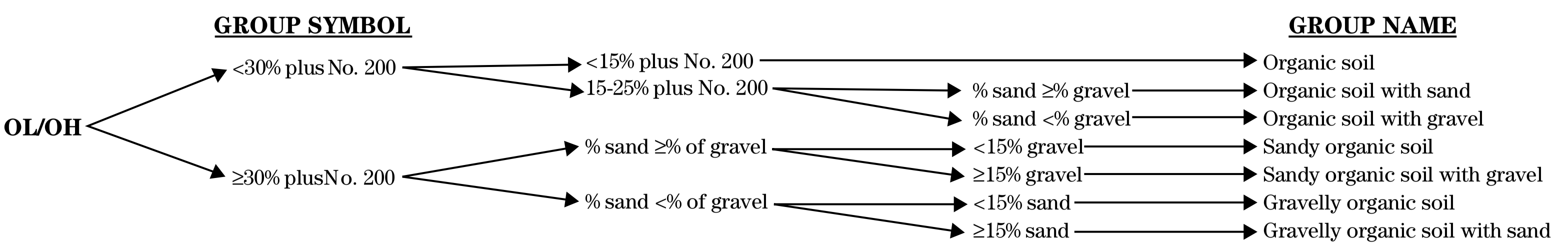
Note—To classify as fine-grained, more than half the material (by weight) must consist of fines (material finer than the no. 200 sieve).

Figure 7B–2 Flow chart for identifying fine-grained soils (50% or more fines) (Source: ASTM D 2488 (figs. 1 a and 1 b). Copyright ASTM Int'l. Reprinted with permission.)



Note 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1 a Flow Chart for Identifying Inorganic Fine-Grained Soil (50% or more fines)



Note 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

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Agricultural Waste Management
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Chapter 8 Siting Agricultural Waste Management Systems

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Chapter 8 Siting Agricultural Waste Management Systems

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Chapter 8 Siting Agricultural Waste Management Systems

651.0800 Introduction

Chapter 8 focuses on arranging and integrating components of agricultural waste management systems (AWMS) into an existing or proposed farmstead. Properly siting AWMS components can improve efficiency, minimize adverse affects, and improve aesthetics. The specific components of an AWMS will vary depending on the type of waste and local ordinances. Specific component design is addressed in Agricultural Waste Management Field Handbook (AWMFH), Chapter 10, Agricultural Waste Management System Component Design.

A supplemental checklist is included in appendix 8A to further aid in using the information provided.

651.0801 Process

Various physical components are needed to address the six basic functions of an AWMS: production, collection, transfer, storage, treatment, utilization. The nine-step conservation planning process described in AWMFH, Chapter 2, Planning Considerations, is the basis for determining which components are needed.

During the planning process, it is critical to arrange and locate the various AWMS components so they are functional and compatible with the surrounding landscape. It is also important to properly locate components so they meet local ordinances, such as locating lagoons at the proper setback distance from streams and placing components to minimize impacts to adjacent land uses.

(a) Siting the system components

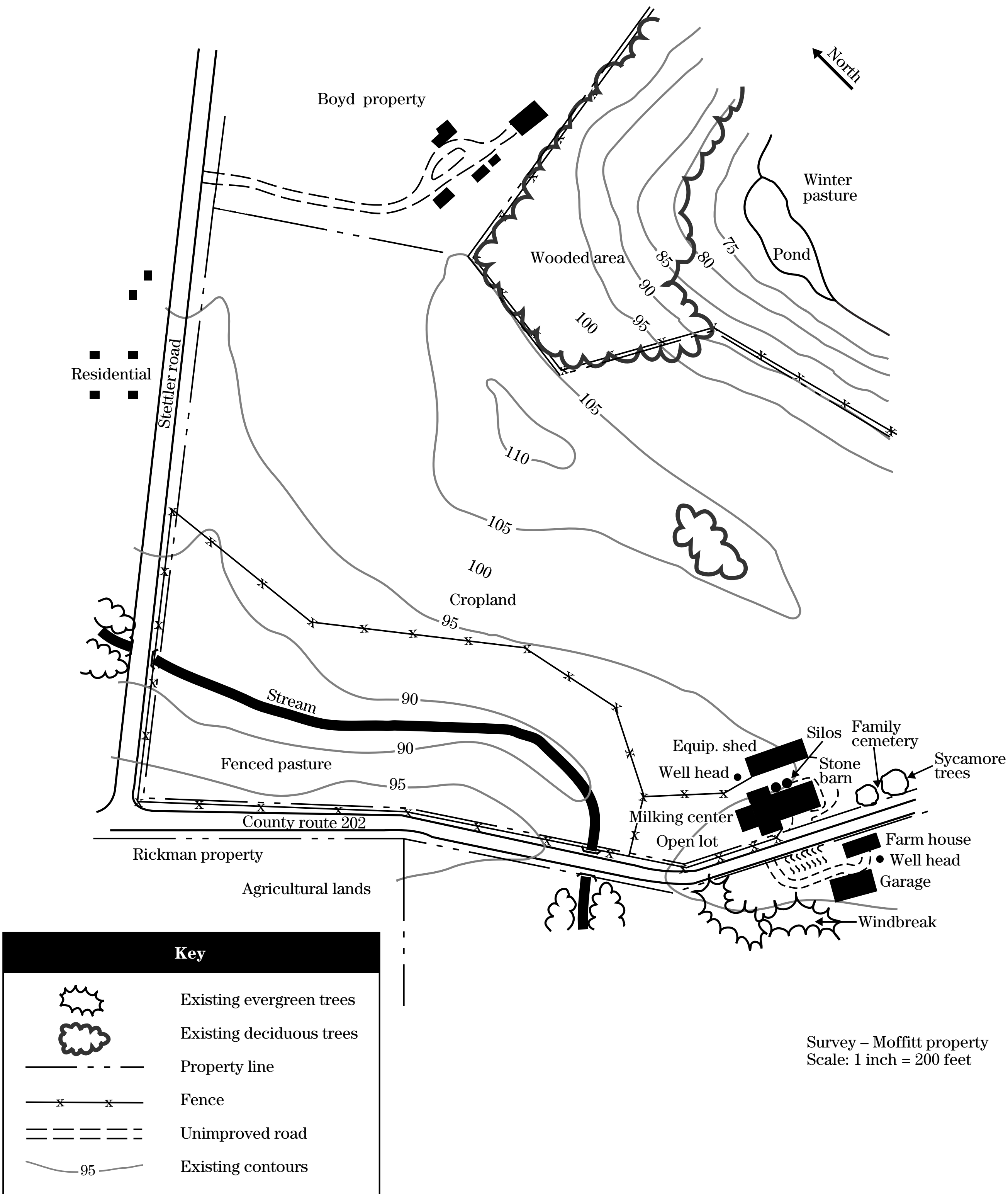
The process of placing AWMS components on the land is similar to that for integrating other conservation practices. The following process will help site the system, as well as provide a means to document planning decisions.

(1) Base map

During the planning process, a topographic survey or aerial photograph is prepared (fig. 8–1). (A conservation plan map may be sufficient for this purpose.) Although the decisionmaker's objectives will influence the scope and detail of the survey, the data to be obtained should include:

- property lines, easements, rights-of-way
- names of adjacent parcel owners
- positions of buildings, wells, culverts, walls, fences, roads, gutters, and other paved areas
- location, type, and size of existing utilities
- septic systems
- location of wet areas, streams, and bodies of water
- rock outcrops and other geological features
- geologic and soils data
- existing vegetation

Figure 8–1 Base map



- elevations at contour intervals of 1 foot around anticipated storage/treatment areas and 2 to 5 feet around anticipated utilization areas
- zoning ordinances and deed restrictions
- land uses—onsite and adjacent
- climatic information, including prevailing wind directions

(2) Site analysis

One method of understanding site conditions and implementing step 4 in the planning process (analyze the resource data) is to prepare a site analysis diagram (fig. 8–2). This step of the process is the identification of problems and opportunities associated with installation of the AWMS. A topographic map, aerial photograph, or conservation plan map should be taken into the field where site conditions and observations can be noted.

The site analysis should note such things as:

- land use patterns and their relationships
- potential impacts to or from the proposed AWMS
- existing or potential odor problems
- existing or potential circulation (animals, equipment, and people) problems or opportunities
- soil types and areas of erosion
- water quality of streams and water bodies
- drainage patterns
- vegetation to be preserved and/or removed
- logical building locations, points of access, and areas for waste utilization
- good and poor views
- sun diagram documenting location of sunrise and sunset in winter and summer to determine sunny or shaded areas
- slope aspect
- prevailing summer and winter wind directions
- frost pockets and heat sinks
- areas where snow collects and other important microclimatic conditions
- farmstead features that have special cultural value or meaning to the decisionmaker
- options for removal or relocation of existing buildings to allow for more siting alternative for AWMS components

Figure 8–2 illustrates a site analysis for a 100 cow dairy on which the decisionmaker wishes to install an AWMS. The decisionmaker has requested an open view of the dairy operation and adjoining cropland from the residence and does not want views of the barn blocked. During summer, several neighbors downwind of the operation have complained of unpleasant odors. The site includes a family cemetery and some large sycamore trees that have special meaning. The existing stone barn structure is unique to the area and is in good condition.

(3) Concept plan

As a part of steps 5 and 6 of the conservation planning process (formulate and evaluate alternatives), conceptual plans are developed to evaluate alternatives (fig. 8–3). The area required for collection, transfer, storage, treatment, and utilization of waste is determined and first displayed at this step of the process. This and related information, such as associated use areas, access ways, water management measures, vegetated buffer areas, and ancillary structures, should be drawn to approximate scale and configuration directly on the site analysis plan or an overlay.

In instances where several sites may satisfy the decisionmaker's objectives, propose the site that best considers cost differences, environmental impacts, legal ramifications, and operational capabilities. Continued analysis can further refine the location, size, shape, and arrangement of waste facilities. If the best area for a component will require a buffer, provide adequate space. If no site seems viable, reassessment of the objectives in cooperation with the decisionmaker is appropriate. Generally, a minor adjustment in goals and objectives offers viable alternatives. Where a potential for major adverse effects exists, however, it may be necessary to make significant adjustments in operations requiring a large economic commitment and attention to management.

(4) Site plan

Completion of subsequent steps of the planning process results in the final site plan (fig. 8–4) as preface to

Figure 8–2 Site analysis diagram

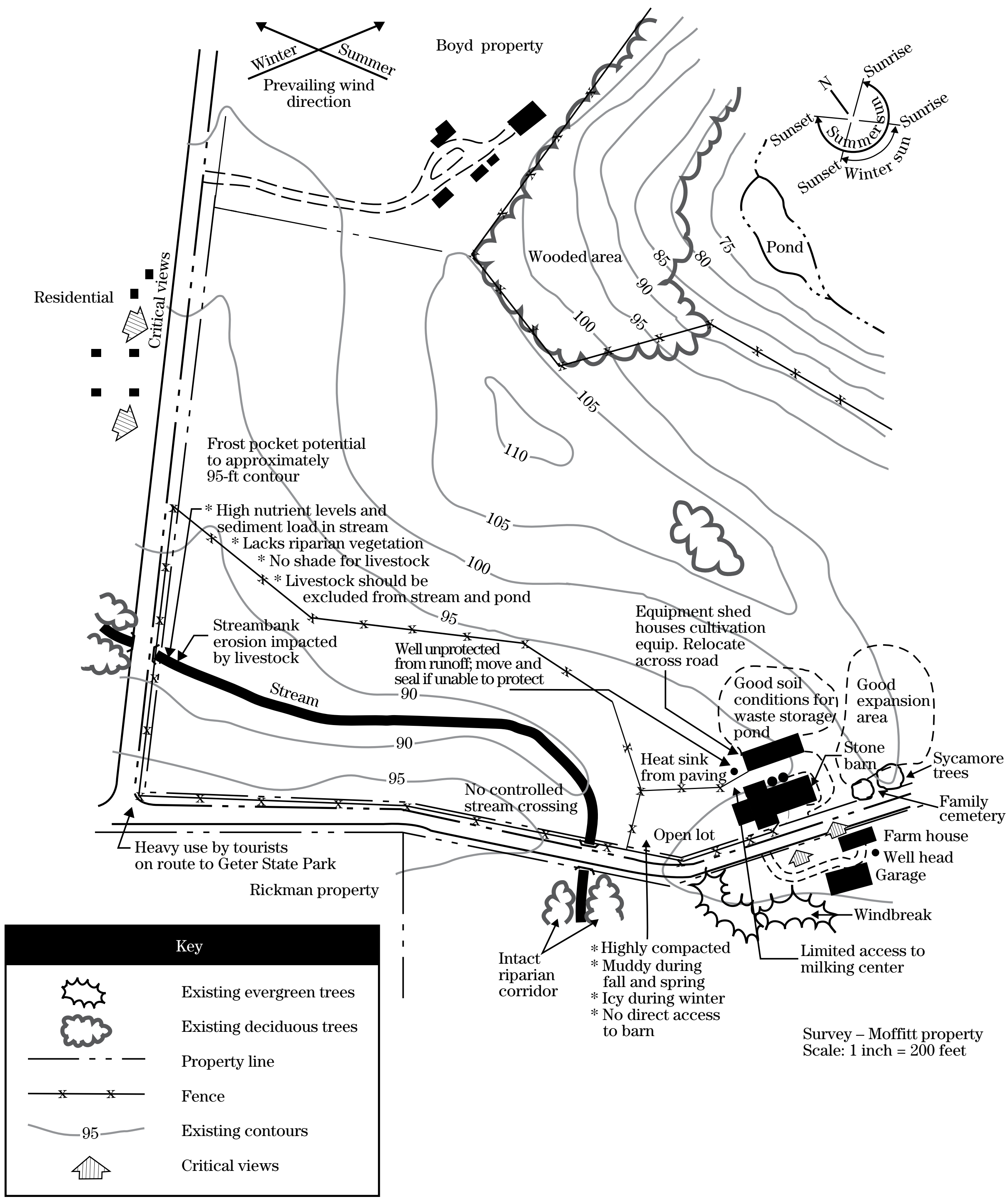
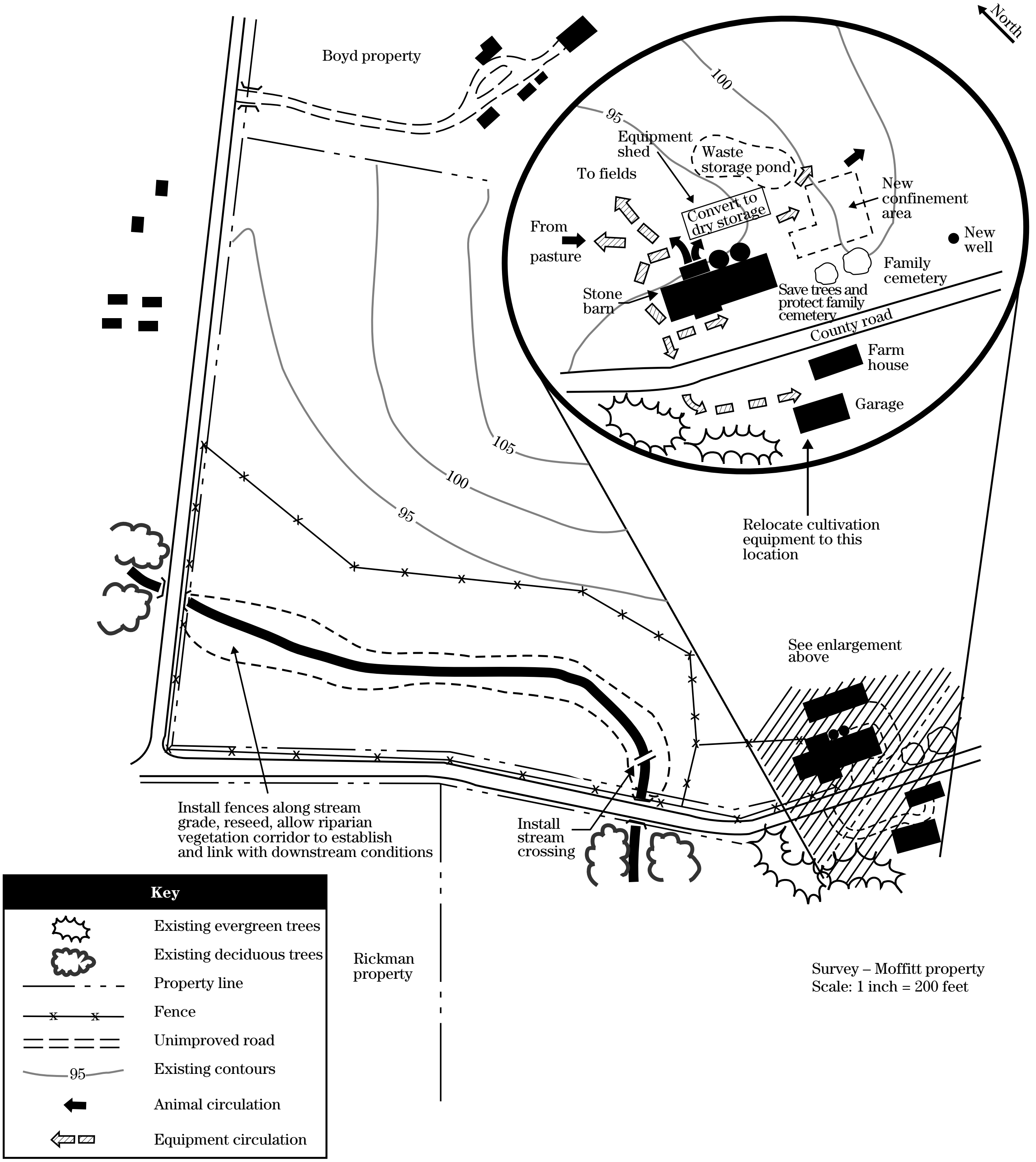
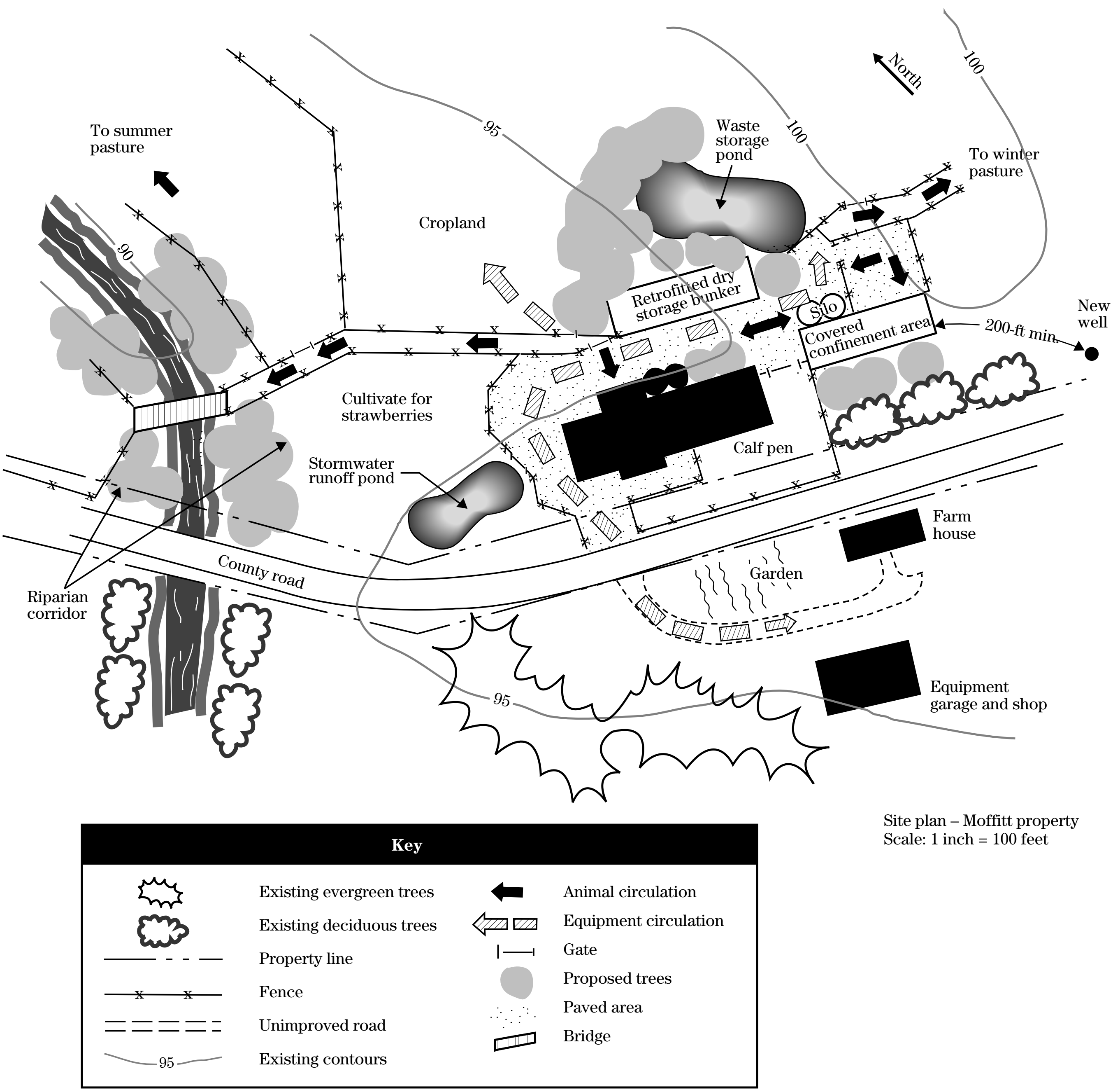


Figure 8–3 Concept plan



construction drawings and specifications. Final locations and configurations of proposed components and ancillary structures, finished elevations, construction materials and exterior finishes, suitable plant species and planting areas, circulation routes, utility corridors, and utilization areas are examples of information to be included. This plan is submitted to the decisionmaker for approval.

Figure 8–4 Site plan



651.0802 Design considerations

The AWMS should be designed to blend into the site and its surroundings with no adverse environmental effects. The following design considerations will aid the planner in achieving this objective.

(a) Landscape resources

Consider landscape resources in the design: visual quality—the appearance of the landscape, visibility—who views the landscape, and landscape use—how people use the landscape. All three factors need to be considered when siting AWMS components.

Visual quality and landscape character
Visual quality is acknowledged as an integral part of daily life and underlies economic and other decisions about the land (fig. 8–5). Many land management decisions, including those related to planning and design of an AWMS, are made because of a decisionmaker's perception of what will enhance visual quality and reflect a stewardship ethic to neighbors.

Highly visible AWMS components, such as storage tanks that are easily identified by their color, and associated conservation practices may be installed because they are attractive and show that the decisionmaker cares about stewardship. Conversely, decisionmakers may be reluctant to install an AWMS that contradicts aesthetic norms for attractive or well-cared-for farmsteads and land.

Figure 8–5 The visual quality shown on this farm is often important to the farm family.

The farm's layout and structures also should be discussed with the decisionmaker to identify special features. Long-established and enjoyed views from the farmhouse, large trees or windbreaks planted by ancestors, and an old springhouse or stonebase banked barn are just a few of the many possibilities that often provide a sense of place and have special meaning to the farm family or community.

The composition or structure of the site's surroundings must be understood so that waste management systems are designed to fit onto the landscape. To accomplish this objective, the patterns and linkages formed by farmsteads, riparian corridors, and similar features on the landscape should be examined.

Patterns of land use and management, siting and design of structures, and field size and shape reflect cultural values that have long guided farmstead planning and determined variations in landscape character. Landscapes are organized in response to surrounding environmental and cultural conditions and the decisionmaker's objectives.

(b) Landscape elements

Landscape elements of landform, structures, vegetation, and water can be used to describe the landscape character of the site. Manipulation of landscape elements can improve the operation of an existing AWMS or help to integrate a new AWMS into the farmstead.

Each farm can be viewed as a series of spaces used for different operations linked together by roads or paths. The arrangement of structures, landform, water, and vegetation within this system affects the aesthetic quality, operational efficiency, energy consumption, runoff, and specific functions on the site. Manipulation of these elements can establish desirable views, buffer noise, determine circulation of animals and equipment, manage odor, modify air temperature, affect snow or windblown soil deposition, and optimize use of available space. In addition, proper placement can help reduce health and safety hazards and enhance quality of life values.

Depending upon objectives, components of the AWMS can be subdued or made prominent on the landscape. Generally, the components should blend with the surrounding landscape or be screened from view. The relationship of existing farmstead features to each other in terms of spacing, height, width, and orientation provides a clue to alternative siting locations. On a landscape divided into fields, hedgerows, and farmsteads, the AWMS components should be located where they will not disrupt existing relationship patterns.

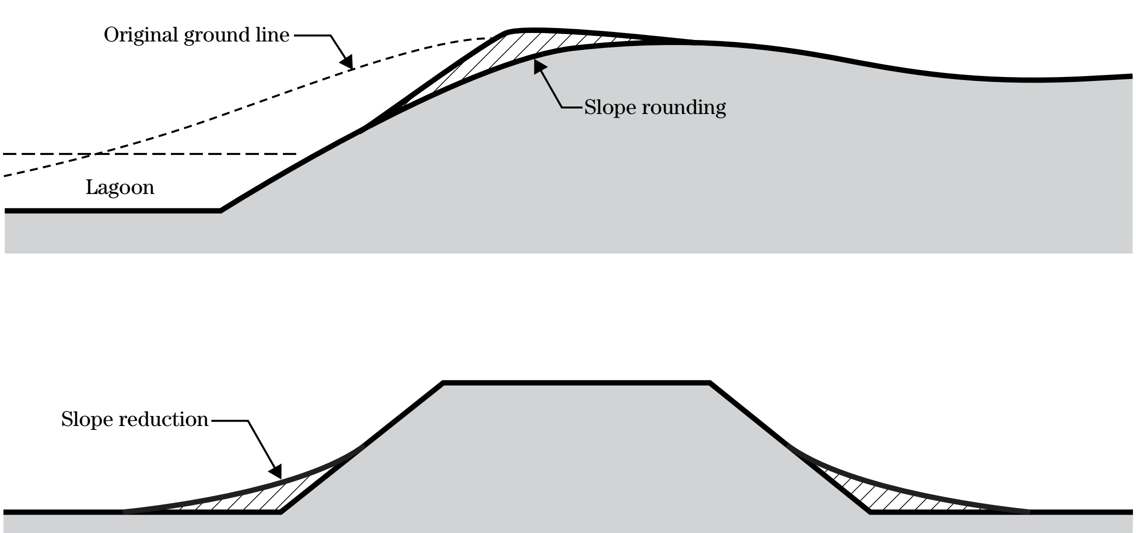
(1) Landform

Landform can be used as it occurs on the site, or it can be modified to improve farm operations, direct or screen views, buffer incompatible uses, reduce massiveness of aboveground structures, control access, improve drainage, and influence microclimates. Landforms often provide a backdrop for an AWMS (fig. 8–6) and serve as a model for designing new landforms, such as embankments, berms, and spoil disposal mounds. An existing landform can serve as a model for the design of new earth mounds.

Slope rounding and slope reduction (fig. 8–7) are two of many earth grading and shaping techniques that can reduce erosion and help to blend landforms into the landscape.

Figure 8–6 The landforms screen the view of the AWMS.

Figure 8–7 Slope rounding and reduction help to blend landforms onto the landscape.



Integrating aboveground AWMS components into flat landscapes (fig. 8–8) is more difficult because structures often project above the horizon as prominent features. Many landform modifications can be employed to address this and other site conditions or land user objectives. Excavated soil, for example, can be used to build small landforms to reduce the prominence of new components. This effect is further enhanced through the addition of vegetation.

In excavating for a pond or lagoon, the shoreline can be irregularly shaped with smooth, curved edges to make the pond or lagoon appear natural (fig. 8–9). Operation and maintenance requirements of the structure need to be considered. Embankments may also be shaped to match the surrounding landform.

Landform mounds constructed from excess excavated material can be used to convey runoff and save the cost of hauling excess material to a disposal site. Either excess or imported soil can be used to fill depressions and improve drainage.

(2) Structures

Structures provide space for ongoing farm activities by creating enclosure. Existing barns, sheds, houses, fences, storage tanks, ponds, and silos are structural elements to be considered when siting components of an AWMS.

Planning for new AWMS components may give the decisionmaker an opportunity to update and reorganize farm structures and land uses between them. Existing operations and equipment may have indoor and outdoor spaces very different in size and shape than those currently needed. Structures also provide options for collecting runoff, channeling or dispersing air flows and wind, controlling circulation of animals and equipment, and separating use areas.

Coordinating colors of a new AWMS with colors and materials of the existing farm buildings will reduce their visibility and preserve existing landscape character. The newly installed aboveground storage tank shown in figure 8–10 is sited to be an inconspicuous part of the overall farmstead. Its color is also compatible with those of the surrounding landscape.

Large concrete surfaces of aboveground waste storage tanks or paved travel ways around below grade ponds can be textured or color tinted (earth-tone colors

Figure 8–8 Structures projecting above the horizon are prominent features on this flat landscape.

Figure 8–9 The shoreline and reflective surface of this waste storage pond make it appear to be a traditional farm pond.

Figure 8–10 An aboveground storage tank is inconspicuous on this highly scenic landscape due to careful design, siting, and color.

based on surrounding soil conditions) to reduce contrast and reflectivity. Reflective metal can be painted or otherwise treated to harmonize with surroundings. Existing and planned facilities should be unified in style and materials.

Architectural style is an indication of an area's cultural values. Unique structures, materials, or construction methods should be considered to avoid possible conflicts from proposed improvements. A historic barn, for example, can be diminished by locating an above ground waste storage tank adjacent to it, whereas a properly designed waste storage pond may serve the need and be less disruptive.

Existing structures can often retain their original exterior appearance while their interiors are altered. The added expense may well be justified by the value of preserving an important cultural resource.

The architectural style (shape, height, and materials) of farmstead buildings should be analyzed to blend new structures into those existing. Modern, prefabricated buildings differ from traditional structures, which tend to be large, multistory, and have a dramatic roof line. The large floor space of traditional structures is balanced by height. Modern, prefabricated buildings generally have a lower profile, creating a greater horizontal appearance. Where possible, emulate the architectural style of existing farm buildings in the design of new structures.

(3) Water

Clean water has magnetic appeal. It can add to aesthetic quality, modify temperature, serve as a buffer between use areas, or divert attention from undesirable views. Water features created by an AWMS may not be a visual asset. If scum or other material can be seen floating on the surface, the water feature will be perceived as a negative quality (fig. 8–11). When siting water features, determine their potential for affecting visual quality and locate them accordingly.

(4) Vegetation

Vegetation can be used to organize space and circulation; establish desirable views; buffer noise, wind, or incompatible uses; promote or impede airflows; reduce massiveness of aboveground structures; absorb particulates and/or gaseous compounds to mitigate odor; cool air temperature; and reduce soil erosion and runoff. As with other elements, vegetation can be used to divert attention to other features.

Existing vegetative patterns, such as hedgerows, stream corridors, and even aged stands of trees or shrubs, can be expanded or duplicated with plantings to integrate a new AWMS into an existing landscape.

When siting components, avoid creating gaps in existing vegetative corridors. If corridors are affected, try to restore the connectivity by adding vegetation.

The waste storage pond in figure 8–12 was designed to take advantage of an existing screen of shrubs and trees. Views of the pond from outside of the farmstead are blocked.

Figure 8–11 The solids on the surface of this liquid manure storage pit would be perceived as having a negative visual quality.

Figure 8–12 Vegetation near this recently constructed waste storage pond provides a screen.

Caution must be used when working near existing vegetation. The heavy equipment used during construction or operation and maintenance compacts the soil. Soil compaction reduces the amount of air available to the roots of plants, which can kill them. Therefore, these activities should be avoided in the root zones where the vegetation is to be saved.

New plantings can be used to help integrate AWMS components into a farmstead. The storage tank in figure 8–13(a) is located close to the farmhouse. Notice how the addition of vegetation (fig. 8–13(b)) helps to soften the impact.

Figure 8–13 Newly planted trees and shrubs can help blend farmhouse and nearby waste storage tank into the landscape (as shown in simuation).

(a) Waste tank installation adjacent to farmhouse

(b) Simulation of newly planted trees and shrubs soften the visual impact of the tank on the farmhouse. Earth-toned concrete helps the tank blend into landscape.

An important design consideration is restoring the site to a vegetated condition after construction is completed. In figure 8–14, the decisionmaker backfilled, graded, and reseeded the area to reduce erosion and blend the structure into the landscape. Once established, the newly planted trees will further enhance this effect.

New plantings used to minimize the scale or geometric appearance of components should not attract attention by their color, texture, or form. Planting techniques include grouping plants in random arrangements to simulate natural patterns and using several sizes and species to duplicate the natural vegetation. Figure 8–15 illustrates common vegetative patterns that can be used as models. The best guide, however, is to duplicate the vegetation patterns of the locality or region. Naturally occurring vegetation is more likely to be in irregular configurations rather than straight, geometric arrangements.

In selecting new vegetation, avoid plants that may later cause problems. This includes plants that are wrong for the available space, require frequent pruning, are poisonous to livestock, will not survive the ordinary growing conditions on the farm, or require more than normal maintenance.

Surface runoff patterns need to be evaluated when planting new vegetation or utilizing existing vegetation near an AWMS. If plantings are not designed as water

Figure 8–14 Vegetation can quickly restore a construction site.

quality buffers, runoff that contains high concentrations of nutrients and other contaminants may overwhelm the vegetation. Water management practices may be needed to protect adjacent vegetation from harmful runoff.

(5) Visibility

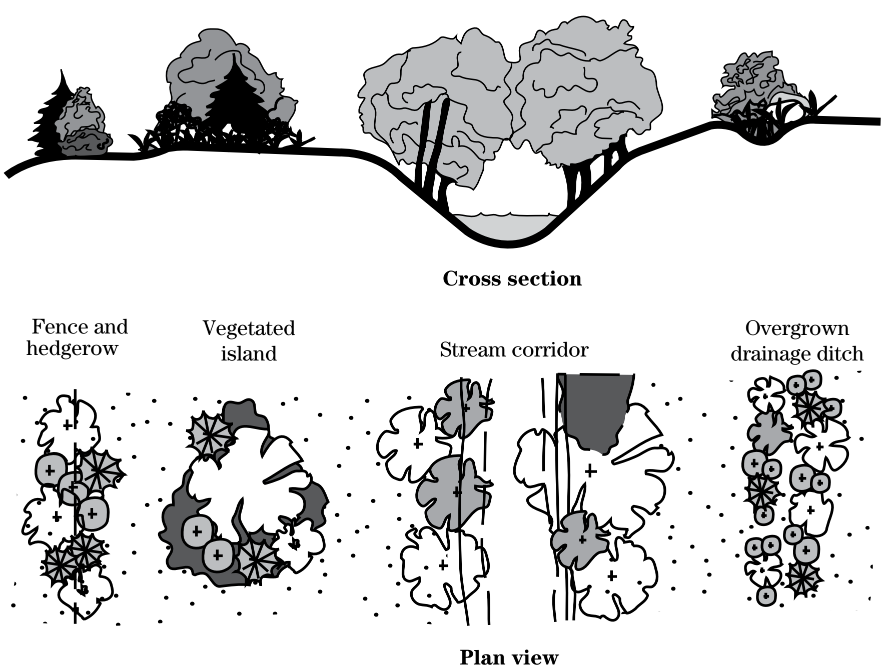
Visibility involves both views from within the site and views of the site. Important views to mountains and valleys, water bodies, or areas of special meaning to the decisionmaker should not be blocked when siting components unless other alternatives are not available. Views from adjacent landowners and roads also need to be evaluated to determine potential visual impacts.

Blending proposed facilities with the surrounding landscape while satisfying the decisionmaker's objectives should be a primary consideration in designing an AWMS. If blending is not possible, screening the facilities from view becomes an option.

The waste storage pond shown in figure 8–16 is visible from an adjacent road. The concrete liner, made necessary by existing soil conditions, contrasts dramatically with the dark manure and surrounding soil and vegetation. Using color stains or additives in the concrete to make its color more compatible with that of the soil would be one way to reduce its visibility. If this is not possible, landform and vegetation can be used to

Figure 8–16 A nearby road and contrasting concrete liner make this waste storage pond highly visable.

Figure 8–15 Common vegetative patterns



screen the component from view and transition it into the site. Vegetation can also be used to direct attention away from the pond. The landform or vegetative patterns common to the existing landscape should be reproduced to screen an AWMS component.

Reducing the visibility of an obtrusive facility is not accomplished simply by covering it with vegetation. To be effective, vegetation should be placed as an intervening feature between the viewer and the object being viewed. Generally, the closer the vegetation is to the viewer, the more effective it becomes in reducing visibility of the obtrusive facility.

Where vegetation is used to reduce visibility, the resulting effects upon available sunlight, air movement, snow drift, freezing and thawing, and pest control should be considered.

Structures can screen views of agricultural waste facilities. In figure 8–17, existing barns and other farmstead structures effectively screen a storage pond as viewed from the farm residence and the highway. Roads and other landscape elements can also direct a viewer's attention away from AWMS components.

(6) Landscape use

People value landscapes based on how they are used. Landscapes can be used directly by physical interaction, such as farming or recreating, or indirectly by gaining benefits, such as wind protection or screening an undesirable view from a shelterbelt. Evaluating both the direct and indirect uses on the site and adjacent areas is important when locating AWMS components.

Figure 8–17 Farmstead buildings effectively block views to a waste storage pond.

Existing activities on the site need to be identified during the site analysis. AWMS components should be located so they do not eliminate or hinder critical activities. Circulation patterns also need to be evaluated when siting components.

Analyzing the compatibility of the proposed design alternatives with adjacent land uses helps to prevent potential conflicts. In poultry areas, for example, where most residents are involved in poultry production, associated activities and impacts are expected and more likely to be accepted. The potential for incompatible land use is less likely in these situations than in those where isolated poultry operations are mixed with other uses.

(c) Circulation

The circulation patterns of animals and equipment can be easily affected by installation of an AWMS. New roads and pathways are often required to ensure an efficient new system. Roads, pathways, and other forms of circulation should lead to their destination in an orderly and efficient manner. They ought to optimize the use of available area by providing adequate width, gradient, and turning space. In some cases, existing shortcuts must be abandoned and new circulation barriers must be used to accomplish this.

For example, an existing manure storage pond (fig. 8–18(a)) may take cropland out of production and require additional maneuvering by cultivation equipment. The visual simulation (fig. 8–18(b)) places the pond on an unused, marginal cropland site adjacent to the brooder house, leaving more land available for production.

Alignment of roads and pathways should attempt to follow the existing contour of the land to prevent steep gradients and excessive cuts and fills. Sufficient drainage (0.5 to 0.75 in/ft of slope for gravel surfaces and 0.25 to 0.5 in/ft of slope for paved surfaces) should be provided. A minimum of 14 feet of vertical clearance should be allowed to accommodate equipment. Where feasible, existing roads, pathways, or parking areas can be eliminated or relocated to increase operational efficiency (fig. 8–19).

Figure 8–18 Alternative location for waste storage pond improves circulation and enhances cropland production (as shown in simulation)

(a) Existing photo

(b) Simulation

Figure 8–19 Farmstead roads consolidated to improve operations (as shown in simulation)

(a) Existing photo

(b) Simulation illustrates road consolidation for improved operations

(d) Odor mitigation

The odor associated with the six functions of agricultural waste management often generates the most immediate response from the decisionmaker and adjacent residents. The amount of odor depends on animal species, housing types, manure storage and handling methods, size of the odor sources, and implementation of odor control technologies. The impact of odor on adjacent land uses is dependent on the amount of odor produced, weather conditions, and topographical and structural features.

By anticipating the intensity, duration, and frequency of odors, AWMS components can be planned to mitigate odors and the associated complaints. Odor problems can be prevented or reduced through adequate drainage, runoff management, keeping animals and facilities clean and dry, and appropriate waste removal, handling, and transport.

Odor-mitigating techniques include using manure storage covers, manure amendments, organic mats, and biofilters on building exhaust fans. Odors can also be dispersed or masked using stacks, chimneys, vegetated and structural windbreaks, air flow alteration, windbreak walls, site selection, setback distances, and deodorant or masking agents.

Locate waste management facilities and utilization areas as far as practical from neighboring residences, recreational areas, or other conflicting land uses. Avoid sites where there are radical shifts in air movement between day and night, such as those near large bodies of water or steep topography. A component's location in relation to surrounding topography may also strongly influence the transfer of odor because of daily changes in temperature and resulting air flow. To provide optimum conditions, prevailing winds should carry odors away from those who might object.

Odor can be further mitigated by providing conditions or design features that alter the microclimate around specific AWMS components. An abundance of sunlight and good ventilation, for example, helps keep livestock and poultry areas dry and relatively odor free. A southern exposure with adequate slope to provide positive drainage for runoff is a preferred condition.

Keeping waste aerated and at appropriate moisture and temperature levels slows the development of anaerobic conditions and reduces odor.

Odor-causing substances from waste material are frequently attracted to dust particles in the air. Collecting or limiting the transport of dust aids in reducing odor. Vegetation is very effective in trapping dust particles as is demonstrated by observing dust-covered trees and shrubs on the edges of unpaved roads and quarry sites. Surface features on leaves or needles, such as spines, hairs, and waxy or moist films, help trap particulates (fig. 8–20). These complex surface features can also help to enable odorous gases to adsorb to the vegetation and remove them from the atmosphere or a concentrated air flow. In figure 8–21, black pines were planted to create both a visual barrier and particulate trap between the swine operation and nearby residence.

Figure 8–20 Dust particles trapped on leaves next to building exhaust fan

Figure 8–21 A vegetative screen between house (behind vegetative screen) and swine operation traps dust particles.

In addition to trapping dust particles, vegetation, landform, and structures can channel wind to carry odors away from sources of potential conflict (fig. 8–22).

(e) Temperature and moisture control

Vegetation can alter microclimates and lower temperatures. By shading the areas beneath the vegetation and through the process of evapotranspiration, trees and shrubs produce a cooling effect. They can also regulate temperature by reducing or increasing wind velocity. The placement of vegetation can help cool buildings in summer and allow heat generating sunlight to penetrate in winter (fig. 8–23).

Dairy animals and other livestock seek streams or ponds and the shade of trees for their cooling effects. Where access to these features is removed, the animal should be provided other means of cooling. The benefits and liabilities of sunlight, shade, and wind must be weighed in each geographic region. Bacterial activity in waste treatment lagoons is slowed by cooler temperatures, which reduces the potential for odor generation and thus, necessary treatment of odor. Too much shade in a feedlot can allow an increase in snow or ice buildup and the amount of runoff during periods of thaw. It can also promote an increase in algae growth on paved surfaces, creating unsafe footing for animals and operators. Too little ventilation can cause the temperature and humidity to soar, while too much ventilation, especially in the form of winter winds, can create life-threatening conditions for animals.

Structures can be located to influence internal temperatures (fig. 8–24). The central or long axis of new buildings can be oriented to regulate the angle and duration that sunlight strikes the roof and sides. In cool or temperate regions, for example, heat can be generated in buildings where drying of waste is needed by:

Figure 8–22 Topography, structures, and vegetation can uplift winds to disperse odor.

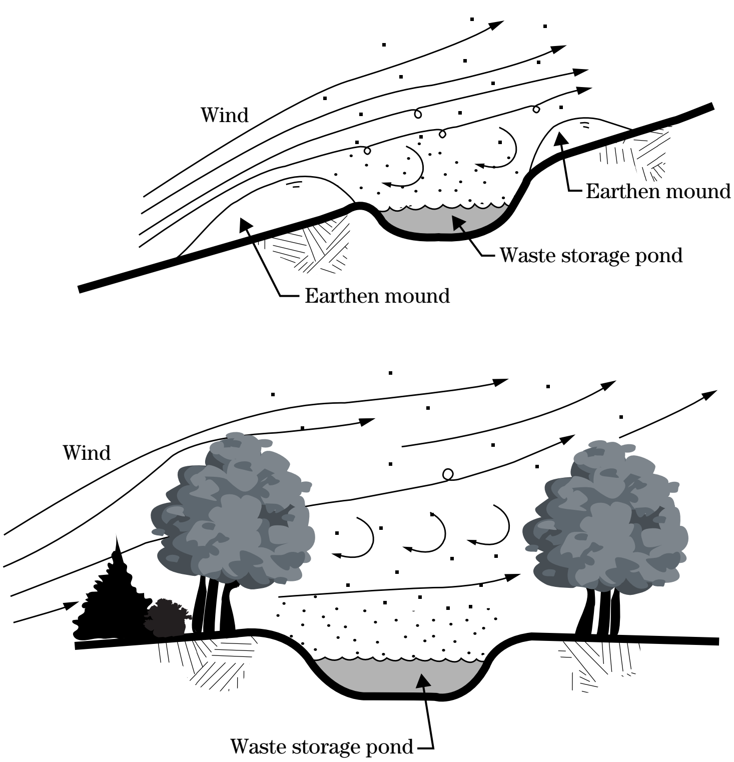


Figure 8–23 Vegetation modifies temperature in various ways.

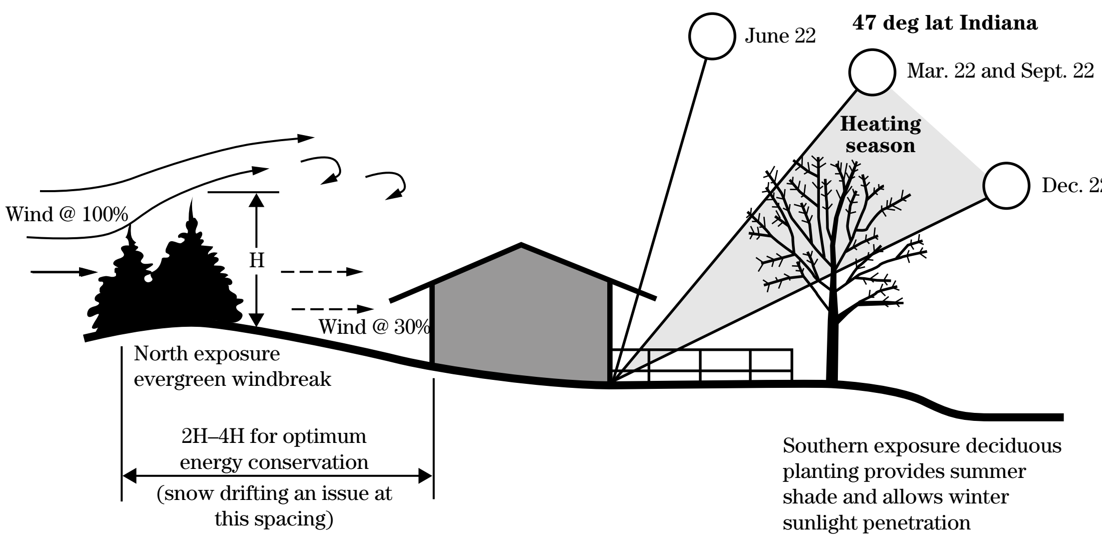
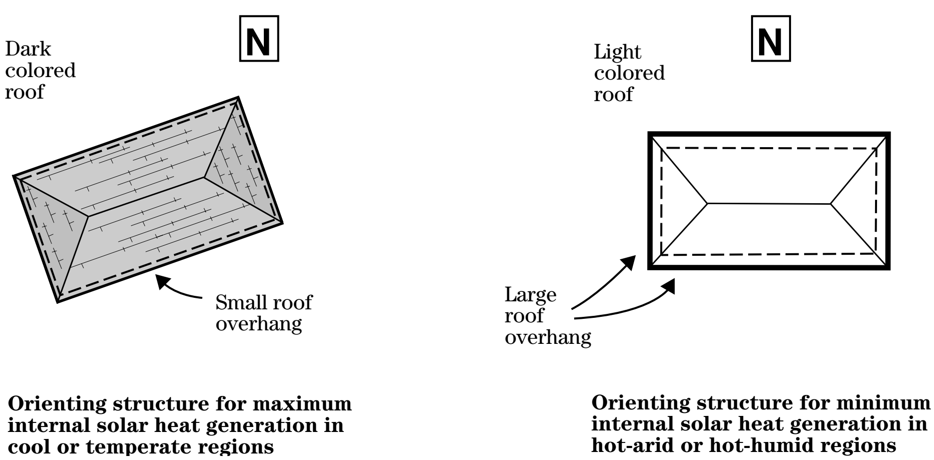


Figure 8–24 Orientation can influence the amount of internal sun-generated heat within buildings.



- orienting the long axis of the building in a northeast-southwest direction
- constructing the roof with a small overhang to allow maximum sunlight to strike the sides of the building
- locating the windows along the south and west walls
- using dark roofing materials to enhance radiation adsorption

If livestock buildings are naturally ventilated, shelterbelts should be setback 150 feet in order not to interfere with ventilation.

Where minimal internal heat is desired, such as in the hot, arid Southwest or the hot, humid Southeast, different building orientation and architecture are recommended. In these regions, it is best to minimize the amount of sunlight on the sides of the building. Because the arc of the sun is higher in the sky, a minimum amount of sunlight can be expected to strike the south side of the building during midday. Therefore, the long axis of the building should be oriented in an east-west direction. The amount of wall and window area along the east and west walls should be minimized to reduce early morning and late afternoon exposure. The windows should be along the north and south walls. The roof should have wide overhangs and be finished in a light color.

If increased humidity is desirable, consider locating storage ponds or treatment lagoons upwind of livestock or poultry confinement facilities. The air flowing over the pond or lagoon will pick up moisture and carry it through the confinement facilities. Care must be exercised, however, to avoid directing undesirable odor-bearing winds through the facilities. Ventilation can also be enhanced by orienting buildings to optimize prevailing winds. Care should be exercised where prevailing winds will have an adverse effect upon the temperature or humidity within confinement facilities.

Temperature and moisture conditions greatly affect the presence of insects, rodents, and other pests, often a major concern of the decisionmaker and source of complaints from neighbors. Each type of livestock or poultry operation attracts specific species of insects that can affect not only the health and productivity of the animals, but also the quality of the food product and the cost of production.

Several species of flies commonly breed in moist animal manure. House flies, which can impact areas up to 4 miles from their breeding location, are a major carrier of more than 100 human and animal pathogenic organisms. Other species of insects can range equal or further distances.

Because sanitation, including proper and timely manure handling procedures, has been reported to be the most important factor in reducing fly populations, the AWMS must be designed with this factor in mind. Avoid areas that have odd shapes or corners, which prevent thorough scraping or other means of removing manure. Provide adequate drainage to aid in moisture control.

Many practices used for insect control also apply to rodents. Reducing nesting sites by careful selection and placement of vegetation around buildings and waste facilities helps to lower populations of insects and rodents. Many insect traps work best in full sunlight; one of many reasons to plot the course of sunlight through the farmstead.

(f) Climatic conditions

Snow and ice often hamper farm operations and cause critical runoff conditions during periods of melt. Where appropriate, the depth and location of snowdrift as well as ice and other winter conditions should be considered when siting an AWMS. Accumulation of snow on a waste storage pond or lagoon may not be desirable in areas where precipitation is abundant, especially as a waste storage pond nears capacity late in winter. Conversely, in more arid regions or areas where most of the precipitation is received as snow, accumulation within the waste storage facility may be desirable. In both cases, vegetation and fences are effective in trapping snow.

The distance to which a fence or vegetative windbreak will affect snow accumulation is dependent on its height and porosity and on the wind speed. A solid fence (0% porosity) causes most snow deposition to occur on the upwind (windward) side. However, its effective distance downwind (leeward) is so limited it is not recommended for use with an AWMS. Fences that have 15 to 25 percent porosity trap snow on the downwind side in an area that is as long as the fence and as wide as four or five times the fence's height. The standard snow fence is 4 feet high and 50 percent porous. Deposition occurs from the base of the fence to about 40 feet downwind. Figure 8–25 illustrates how fence porosity affects snow deposition patterns. As shown, a 50 percent porous barrier captures about four times as much snow as a 15 percent porous barrier. The same conditions are true for windblown soil in the more arid regions of the country.

Because of the additional height, vegetative windbreaks influence snow and windblown soil deposition over a greater distance than fences. Depending upon location, they may provide additional benefits including odor and particulate filtration and mitigation, screening, temperature control, and wildlife habitat. Available planting space and the amount of snow or soil deposition anticipated will influence the location, width, and alignment of windbreaks.

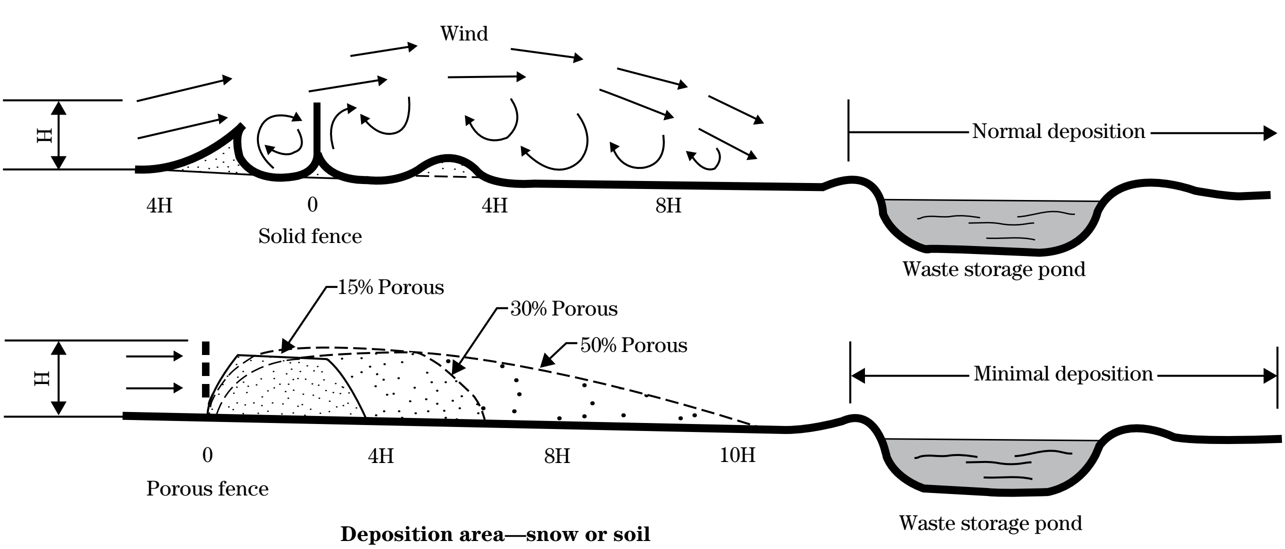
When managing snow or soil deposition, the use of fences and vegetation should be combined whenever feasible. The fence will provide immediate results, while vegetation, which may require several years growing time, often provides additional multiple benefits. A second fence may be required near windbreaks to prevent livestock from damaging the vegetation. Figure 8–26 illustrates how a fence and multiple rows of vegetation with 50 percent porosity influence deposition.

Agricultural waste facilities that have the back wall protected from the wind, such as an open-front dry manure storage building, tend to have some snow accumulation just inside the front door. To prevent this, a 6- to 8-inch slot can be cut in the rear wall near the eaves to provide some wind penetration.

Ice buildup can be reduced by considering shade patterns of buildings and vegetation. Because deciduous trees shade only in summer and allow heat-generating sunlight in the winter, they are more effective than evergreens in regulating a microclimate affecting ice and snow accumulations. A mixture of deciduous trees and evergreen understory can often provide a desired screen during winter while serving the need to minimize buildup.

Fences used for wind control should not connect directly to the corner of buildings, otherwise wind

Figure 8–25 Fence porosity affects snow deposition



and snow can be directed inside the building. Fences should be placed at least 16 feet out from the building and 16 feet from the corner as illustrated in figure 8–27. Any gates should be of the same height and porosity as the rest of the windbreak fence.

The prevailing wind direction for a site can be determined by looking at wind rose diagrams (fig. 8–28). Search the Internet for the NRCS Water Climate Center; navigate to Climate → Climate Data → Wind Data for U.S. → Wind Rose Data Sets, then select the nearest weather station to the site. Use the wind rose diagrams to determine the frequency of prevailing winds.

Figure 8–26 The combination of fence and windbreak plantings greatly enhances the pattern of snow and soil deposition.

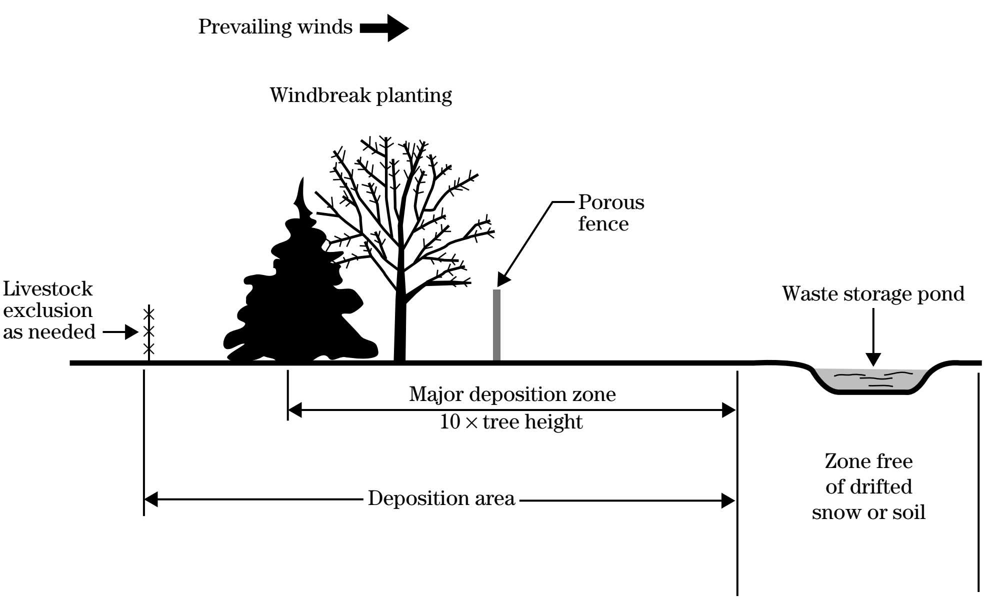


Figure 8–27 Fences affect snow and soil deposition around buildings.

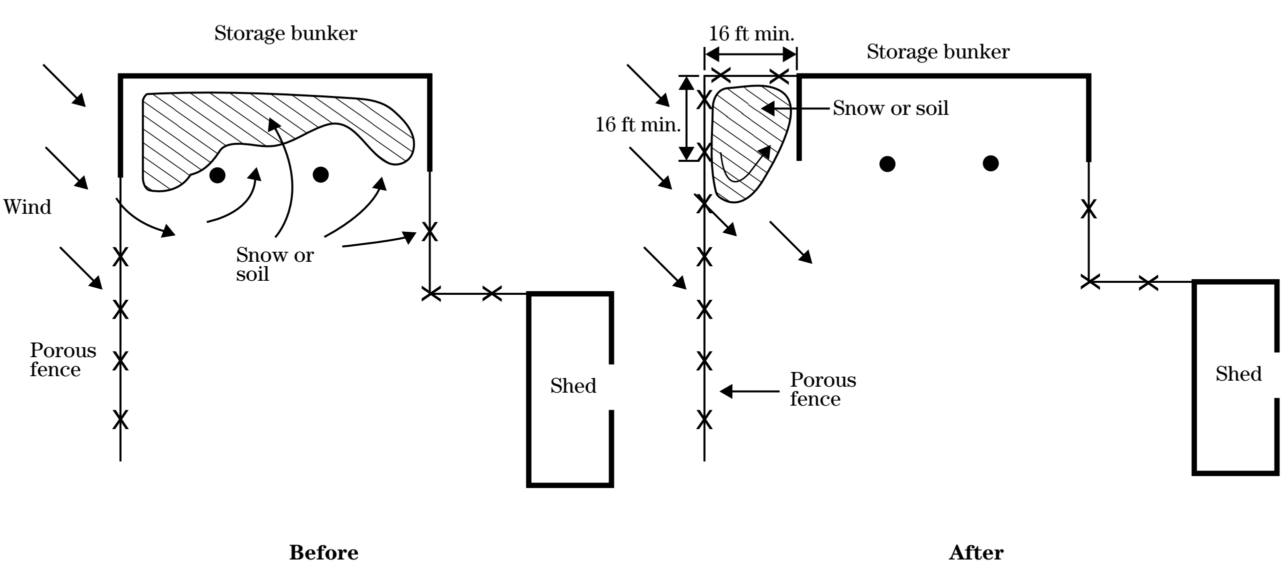
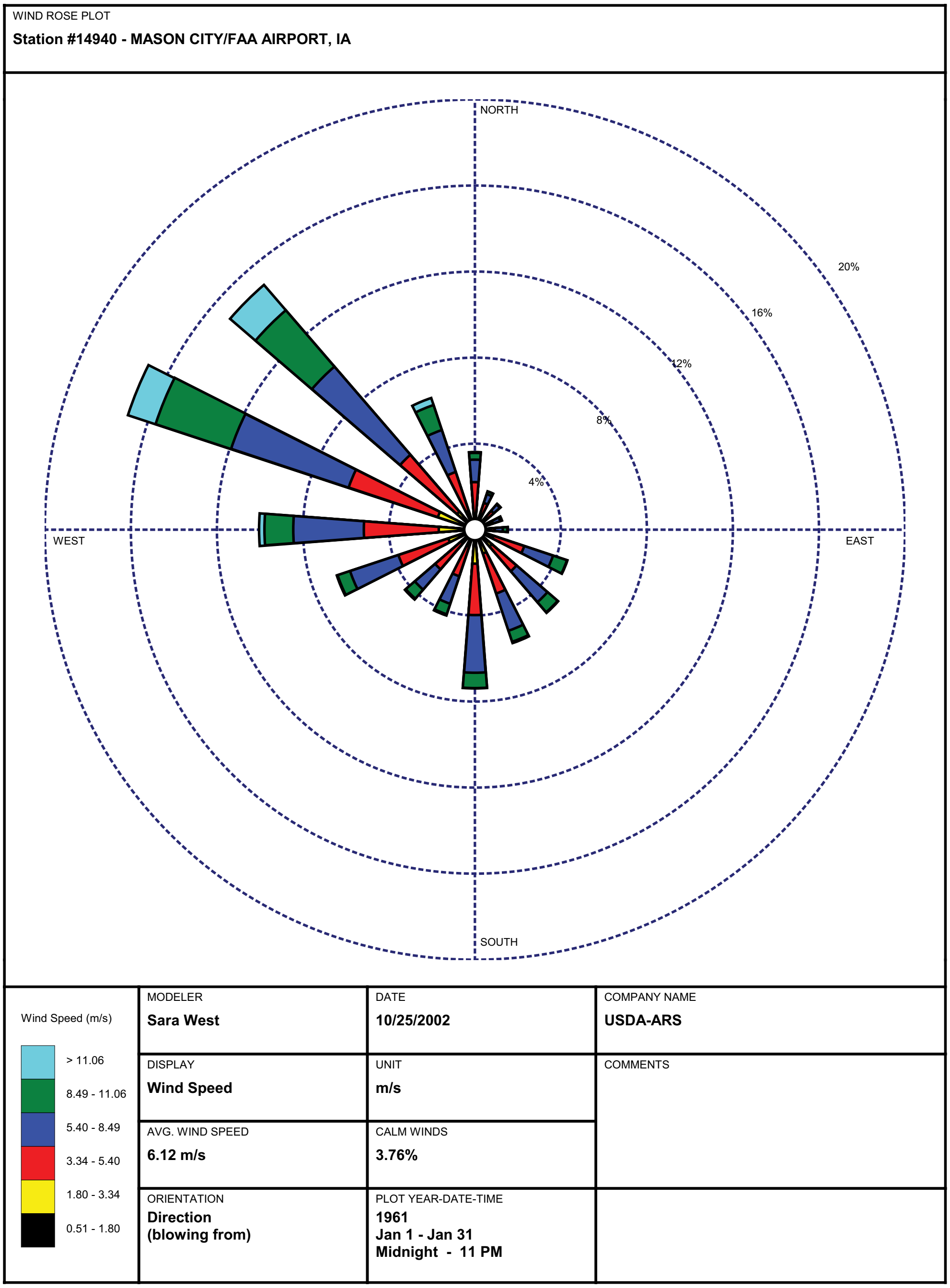


Figure 8–28 Wind rose diagrams can be used to determine prevailing wind directions. This wind rose diagram is for January from Mason City, IA.



Note: Wind speeds shown are in meters per second (m/s). To convert into miles per hour (mi/h), multiply by 2.237. Thus, the 6.12 m/s wind is a 13.7 mi/h wind.

(g) Water quality

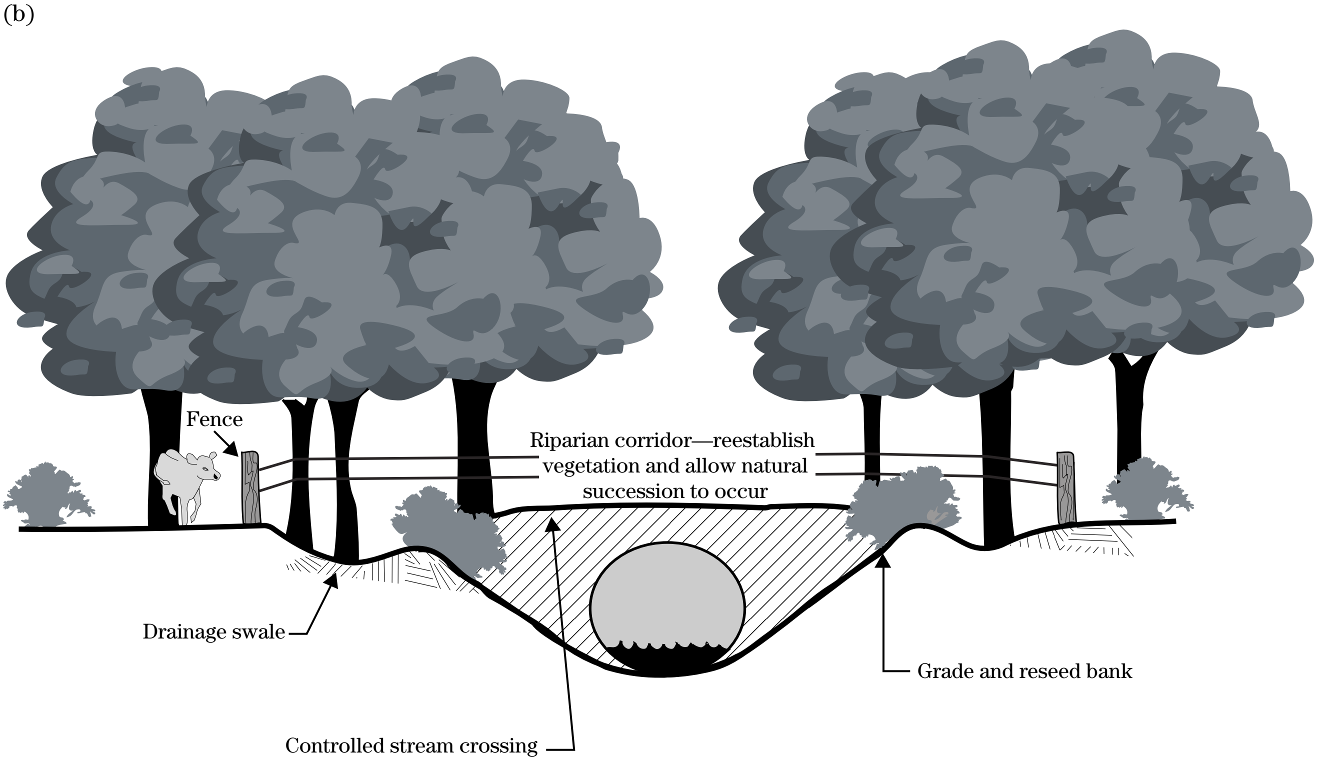
The design of an AWMS must consider measures to improve and protect water quality. Water bodies in close proximity to the waste source are more susceptible to contamination. Many states have ordinances that define setbacks and buffer requirements when siting AWMS near water courses.

Relocating a pasture to an area further from a stream is often the best solution in preventing degraded streambanks and animal waste from entering the stream (fig. 8–29(a)). Because this is not always possible, such measures as fencing, controlled stream crossings, and regraded and revegetated streambanks can aid in minimizing transport of contaminants in runoff from directly entering the stream (fig. 8–29(b)).

Figure 8–29 Streamside measures improve water quality

(a)

(b)



Developing a new AWMS or adding to an existing system often presents an opportunity to improve runoff management. The following can be used to minimize muddy areas and contaminated runoff: adding diversions; using roof gutters to separate precipitation from waste sources; paving feedlots or loafing areas, drainage swales; and filter strips.

(h) Noise

Noise is defined as unwanted sound, such as diesel engines, pumps, and electrical equipment. Some AWMS components can generate undesirable levels of noise. These components should be sited to minimize potential conflicts or abatement measures may be needed. Noise levels are reduced by increasing the distance from a noise source, terrain, vegetation, and natural and human-constructed obstacles.

Noise sources are defined as either point source (stationary) or line source (moving). A roadway would be an example of a line source, and an irrigation pump would be an example of a point source. Sound levels are measured in decibels (dBA) and an increase or decrease of 10 dBA in the sound pressure level will be perceived by an observer to be a doubling or halving of the sound. For example, a sound at 70 dBA will sound twice as loud as a sound at 60 dBA.

Noise levels decrease with distance. Point source noise will decrease by 6 dBA for each doubling of distance. Line source noise varies differently with distance, because sound pressure waves are propagated all along the line and overlap at the point of measurement. It drops off less, about 4.5 dBA for each doubling of distance (if the ground is predominately in pavement 3 dBA is used).

Noise impacts from AWMS can occur when sound levels are unacceptably high (absolute level) or when a proposed component will substantially increase the existing noise environment (substantial increase).

Acceptable absolute levels for various human use areas can be placed into four broad classes of noise abatement criteria (NAC):

- Class A—lands on which serenity and quiet are of extraordinary significance (60 dBA NAC).
- Class B—picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals (70 dBA NAC)
- Class C—developed lands, properties, or activities not included in classes A or B above (75 dBA NAC)
- Class D—undeveloped (no NAC)

Each class has been assigned a NAC dBA level. The Federal Highway Administration developed the NAC for determining when to use noise barriers next to highways. It is based upon noise levels associated with interference of speech communication. The NAC are a compromise between noise levels that are desirable and those that are achievable.

A substantial increase in noise levels can be described as:

0–5 dBA—no increase

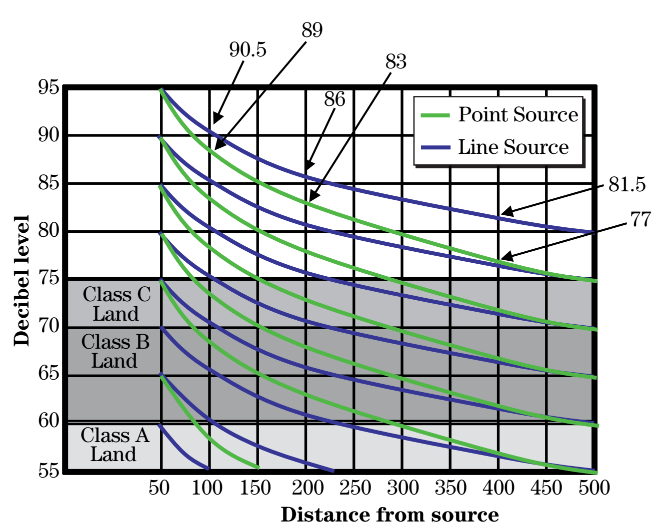
5–10 dBA—minor increase

10–15 dBA—major increase

>15 dBA—substantial increase

Figure 8–30 can be used to determine how much noise levels will decrease with distance. The figure can also be used to determine if noise from AWMS will be a problem to adjacent land uses. For example, if a 85

Figure 8–30 Noise reduction by distance from source



dBA pump (point source) is located within 100 feet of a residential area (class B land), the noise level would be 78 dBA, which is above the 70 dBA noise abatement criteria for that class. The 8 dBA would be considered a minor increase. If the pump could be relocated to be at least 300 feet from the use area, the dBA would be within the class B 70 dBA criteria. If the pump cannot be relocated, noise abatement measures may be needed.

Solid walls or earthen mounds are effective noise barriers and can reduce noise levels by 10 to 15 dBA, cutting the loudness of noise in half. Vegetative barriers are less effective; wide barriers are needed and only reduce noise levels from 5 to 8 dBA. For a noise barrier to work, it must be high enough and long enough to block the view of the source.

651.0803 References

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Appendix 8A Checklist of Siting Factors for AWMS Components

Structures

_____ 1. Will the roof line, shape, materials, and color of proposed structures be designed to blend with existing structures?

_____ 2. Will proposed structures be located where their size and shape contribute to snow and ice management; wind or air flow reduction, promotion, or dispersion; cooling from shade; or windblown soil deposition?

_____ 3. Will outdoor lighting be installed at strategic spots, such as near steps or equipment areas, for safety and security?

_____ 4. Will signs be easily recognizable, legible, and uniform in appearance?

_____ 5. Will visual clutter be reduced by attaching signs to walls or other available structures? Can any signs be combined?

_____ 6. Can fences and walls be combined with plantings?

_____ 7. Will fences be uniform throughout the site to visually link discontinuous parts?

_____ 8. Will fences and walls be properly sited to prevent cold air pockets or snow, ice, and soil accumulation, or to capture sun for maximum comfort levels, or to promote, disperse, or reduce wind or air flow?

_____ 9. Will fences and other linear components be located at existing landscape edges to enhance compatibility?

_____ 10. Will fencing be installed along ridges or the top of landforms where it is emphasized on the landscape? Could it be relocated at the bottom of the slope or below the horizon and still maintain its intended function?

Landforms

_____ 1. Will the plan consider highly erodible or ecologically important areas (steep slopes, areas with highly erodible soil, streambanks, natural areas, wetlands)?

_____ 2. Will disturbed areas be as small as possible?

_____ 3. Will established slopes be left undisturbed where possible?

_____ 4. Will grade changes be natural appearing slopes that avoid abrupt transitions?

_____ 5. Will new construction fit elevations of existing landforms rather than requiring grading of the land to a continuous level, which may destroy its character?

_____ 6. Will grading and any new landforms allow successful runoff while assuring that the site is suitable for the agricultural waste management system?

_____ 7. Will excess excavated soil be used to create landforms to act as screens to buffer noise or to promote, disperse, or reduce wind or air flow?

Vegetation

_____ 1. Will existing vegetation be retained to serve its important mitigation functions, such as screening, shading, wind or air flow reduction, promotion, or dispersion; erosion control; odor or particulate; and separation of incompatible uses?

_____ 2. Are roads of AWMS components designed to minimize disruption of vegetation?

_____ 3. Will roads, pathways, turnarounds, or other system components permit safe retention or introduction of vegetation?

_____ 4. Will required vegetative removal be staged to decrease the area and duration of exposure thus reducing erosion/sedimentation potential?

_____ 5. Will removal of vegetation impact adjacent properties?

_____ 6. Will vegetation provide a buffer, visual barrier, wind or air flow reduction, promotion, or dispersion, and/or odor or dust mitigation, for adjacent properties?

_____ 7. Will new vegetative species and patterns be based on those occurring naturally or appear compatible with those onsite and in the region?

_____ 8. Will measures be used during construction to protect trees or other vegetation and if so, how successful will they be?

_____ 9. Will the survival rate of installed vegetation be acceptable? If not, what corrective measures can be used to guarantee establishment?

_____10. Will vegetation be protected from livestock?

Water quality

_____ 1. Will existing waterways be used and maintained for full value (open space, landscape character, and wildlife habitat)?

_____ 2. Will the design include measures to prevent runoff from draining across disturbed areas during construction?

_____ 3. Will the design preserve, restore, or enhance streambank vegetation?

_____ 4. Are slope changes designed for minimum slope length and gradient?

_____ 5. Where steeper slopes are unavoidable, will diversions be installed to intercept runoff before it reaches slopes?

_____ 6. Will components be located at sufficient distances from streams and wells to meet local and state ordinances?

_____ 7. Will vegetative filter strips be retained or installed to slow down runoff, trap sediment, and reduce runoff volumes on slopes?

_____ 8. Will clean water be diverted from the waste storage facility?

_____ 9. Will animals be provided with alternative water sources so they can be kept out of streams and ponds?

_____ 10. Can clean water be diverted to storage for such future uses as irrigation and stock watering?

_____ 11. If aquifer recharge is desired, will clean water runoff be directed to retention and infiltration facilities?

_____ 12. Where concentrated runoff leaves paved areas, will provisions be made for stabilized outlet points?

_____ 13. Will runoff be directed away from adjacent properties?

_____ 14. Will the design use paved watercourses where grassed swales would suffice?

_____ 15. Will roadways contribute to effective stormwater runoff management?

Visual quality

_____ 1. Will the AWMS components retain or improve the visual quality of the farmstead and surrounding landscape?

_____ 2. Will the AWMS take full advantage of the natural features of the site?

_____ 3. Will the building materials and finishes be compatible with those existing?

_____ 4. Will color be used either to visually organize features on the site or to direct the eye away from undesirable views?

_____ 5. Will concrete and other building materials be textured or tinted to blend it into the landscape or reduce reflective surfaces?

_____ 6. Will the design allow for retention of landscape features with special meaning, such as specimen trees, exceptional views, or historic structures?

Compatibility

_____ 1. Will the measure adversely impact adjacent properties?

_____ 2. Will the reaction of community and nearby residents to the completed AWMS be positive or negative? What changes might obtain a more favorable response?

_____ 3. Will the measure be compatible with adjacent developments in terms of land use, density, scale, identity and overall design?

_____ 4. Will structures, landform, water, and vegetation be used fully to buffer incompatible land uses?

Visibility

_____1. Will views from adjacent landowners and roads be considered in locating AWMS components?

_____2. Will views from farmstead be considered in locating AWMS components?

_____3. Will visual screens be tall enough to block views?

Odor reduction

_____ 1. Will the design utilize fencing, structures, and/or vegetation for wind or air flow reduction, promotion, or dispersion, and/or odor or dust mitigation?

_____ 2. Is the animal waste facility sited downwind as far as practical from the farmhouse and neighbors?

_____ 3. Will the design provide maximum sunlight for biological decomposition?

_____ 4. Will the site of waste generation be designed to be as well drained as possible?

_____ 5. Will vegetation and water bodies be used to keep waste materials at optimum temperatures to prevent odor generation?

_____ 6. Will the design use landforms, vegetation, and structures to direct wind over or away from sources of odor?

_____ 7. Can equipment, work areas, storage areas, and livestock be kept as clean as practical?

Temperature and moisture control

_____ 1. Will the species of pests on site be identified in order to control them at all stages of their development?

_____ 2. Has an Integrated Pest Management plan been considered?

_____ 3. Will breeding sites be reduced by improving drainage, increasing sunlight and ventilation to manure generating sites?

_____ 4. Will vegetation placed around buildings and other AWMS components reduce pest breeding and nesting sites?

_____ 5. Will measures be installed for energy conservation (exposure to wind and sun, vegetation for shading)?

_____ 6. Will new structures be oriented and architecturally designed to benefit from or modify solar generated heat and prevailing winds?

Circulation

_____ 1. Will adequate pathways be provided for animals and humans?

_____ 2. Will paved walkways function to direct surface runoff?

_____ 3. Will drainage improvements interfere with vehicular, pedestrian, or animal circulation?

_____ 4. Will pedestrian, animal, and vehicular traffic be adequately separated?

_____ 5. Will maintenance access routes serve as pedestrian/animal walkways?

_____ 6. Will roads, pathways, and parking areas be designed to follow the shape of the land, thereby reducing costly grading and land disturbance?

_____ 7. Will roads, pathways, and parking areas be designed to allow for future expansion or change in size of equipment?

_____ 8. Will roads, pathways, and parking areas be designed to minimize disruption of vegetation and cropping practices?

_____ 9. Will roadways interrupt pedestrian and animal pathways?

_____ 10. Will sight distances be adequate for safe turning maneuvers?

_____ 11. Will access points onto highways be located at safe distances from intersections? Will warning signs reflectors, or lane striping be installed as appropriate?

_____ 12. Will roads avoid wetlands, meadows, creeks, and other ecologically critical areas?

_____ 13. Will circulation routes be wide enough to accommodate anticipated traffic?

Noise

_______ 1. Will adequate sound barriers be provided for noise abatement?

_______ 2. Will the sound levels be in accordance with Noise Abatement Criteria, (NAC)?

Chapter 9 Agricultural Waste Management Systems

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Chapter 9 — Agricultural Waste Management Systems

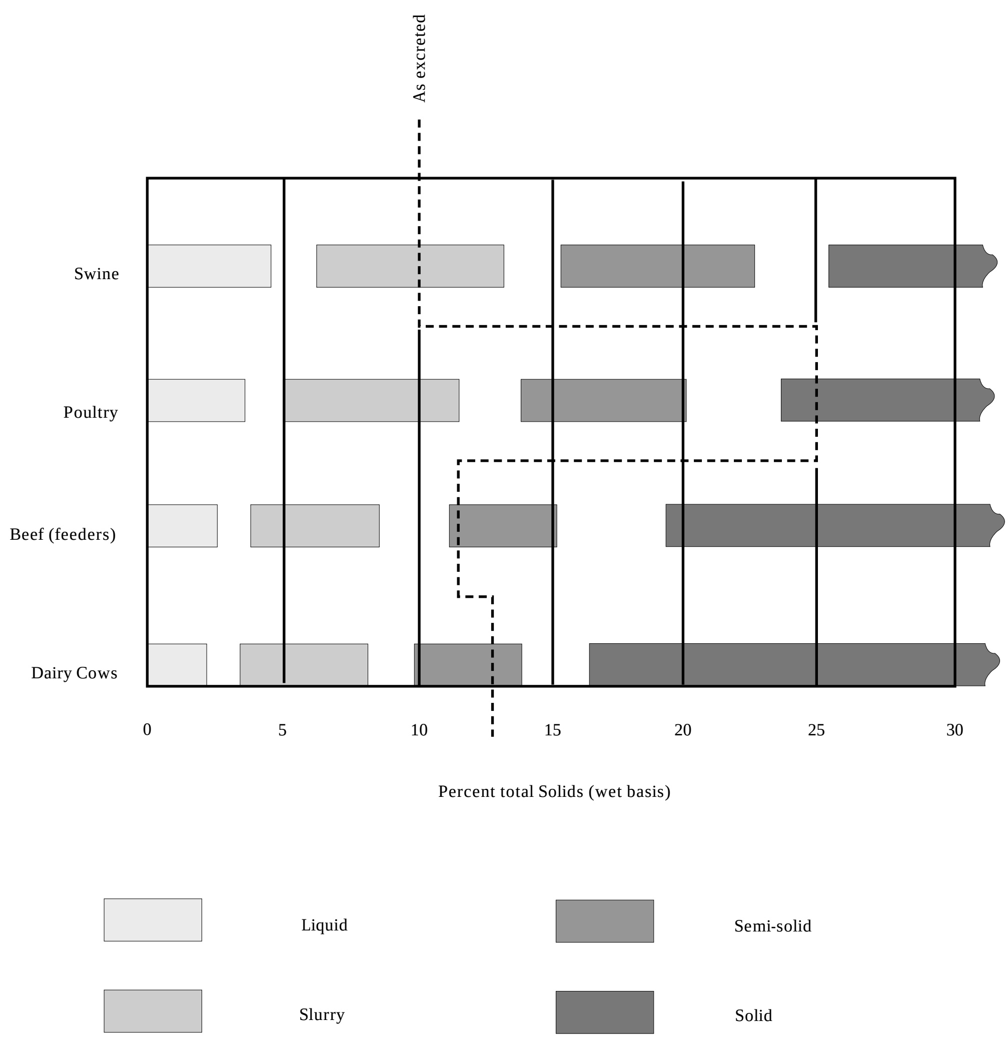
651.0900 Introduction

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

651.0901 Total systems

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

Figure 9–1 Relative handling characteristics of different kinds of manure and percent total solids



651.0902 Interface with other systems

The primary objective of most agricultural enterprises is the production of marketable goods. To be successful the farm manager must balance the demand on limited resources among many complicated and interdependent systems, often including, but not limited to:

- cropping system
- livestock management system
- irrigation and drainage system
- nutrient management system
- pest control system
- resource conservation system
- equipment maintenance and replacement system
- produce storage, transport, and marketing system
- financial management system

For an AWMS to be practical, it must interface with these other systems. Chapter 2 of this handbook gives detailed descriptions of the factors to consider when planning an agricultural waste management system.

651.0903 Waste consistency

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

Factors that influence the TS concentration of excreted manure include the climate, type of animal, amount of water consumed by the animal, and the feed type. In most systems the consistency of the waste can be anticipated or determined. The TS concentration of the waste can be increased by adding bedding to the waste, decreased by adding water, and stabilized by protecting it from additional water. Figure 9–1 illustrates how varying the TS concentration for different animal manures affects consistency. Additional information is in chapter 4.

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

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

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

651.0904 Waste management functions

An agricultural waste management system consists of six basic functions (fig. 9–2):

Production
Collection
Storage
Treatment
Transfer
Utilization

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

(a) Production

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

The waste management system may need to accommodate seasonal variations in the rate of production.

The production of unnecessary waste should be kept to a minimum. For example, a large part of the waste associated with many livestock operations includes contaminated runoff from open holding areas. The runoff can be reduced by restricting the size of open holding areas, roofing part of the holding area, and installing gutters and diversions to direct uncontaminated water away from the waste. A proverb to remember is, “Keep the clean water clean.”

Leaking watering facilities and spilled feed contribute to the production of waste. These problems can be reduced by careful management and maintenance of feeders, watering facilities, and associated equipment.

A record should be kept of the data, assumptions, and calculations used to determine the kind, consistency, volume, location, and timing of the waste produced. The production estimates should include future expansion.

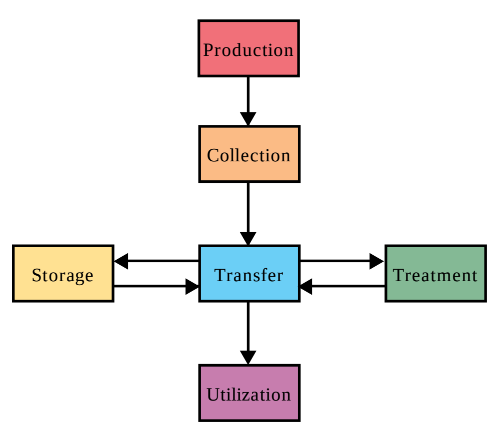
(b) Collection

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

(c) Storage

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

Figure 9–2 Waste management functions



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

(d) Treatment

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

(e) Transfer

This refers to the movement and transportation of the waste throughout the system. It includes the transfer of the waste from the collection point to the storage facility, to the treatment facility, and to the utilization site. The waste may require transfer as a solid, liquid, or slurry, depending on the total solids concentration.

The system plan should include an analysis of the consistency of the waste to be moved, method of transportation, distance between points, frequency and scheduling, necessary equipment, and the installation and management costs of the transfer system.

(f) Utilization

Utilization includes recycling reusable waste products and reintroducing nonreusable waste products into the environment. Agricultural wastes may be used as a source of energy, bedding, animal feed, mulch, organic matter, or plant nutrients. Properly treated, they can be marketable.

A common practice is to recycle the nutrients in the waste through land application. A complete analysis of utilization through land application includes selecting the fields; scheduling applications; designing the distribution system; selecting necessary equipment; and determining application rates and volumes, value of the recycled products, and installation and management costs associated with the utilization process.

Refer to chapter 10 for detailed discussion of the collection, storage, treatment, and transfer functions, and refer to chapter 11 for information on utilization through land application.

651.0905 Waste management systems design

An agricultural waste management system design will:

- Describe the management, operation, and maintenance of the waste from production to utilization
- List the practices to be installed
- Locate the major components on a plan map
- Include an installation schedule

Agricultural waste management systems are highly varied, and many alternatives are available. The various processes mentioned above are usually interdependent. For example, if a landowner wants to store waste as a dry material, the waste cannot be collected using a flush system. If limited land is available for utilization, the landowner may need to select a treatment process that reduces the nitrogen content of the waste.

Because of the variety of situations into which an AWMS must be incorporated, no one procedure can be followed to arrive at a system design; however, the following guidelines may be helpful.

Determine decisionmaker's concerns and needs. Landowner objectives along with social concerns must guide the planning of the AWMS.

Determine the characteristics and annual production of the waste requiring management. The waste characteristics and amount could limit alternatives and influence management decisions. Future changes in operation size and management must also be considered.

The nitrogen and phosphorus content of the waste, including heavy metals, toxins, pathogens, oxygen demanding material, or total solids, must be known. Knowing what is produced, how much is produced, when it is produced, and where it is produced helps the planner understand the existing agricultural enterprise into which the waste management system must be integrated.

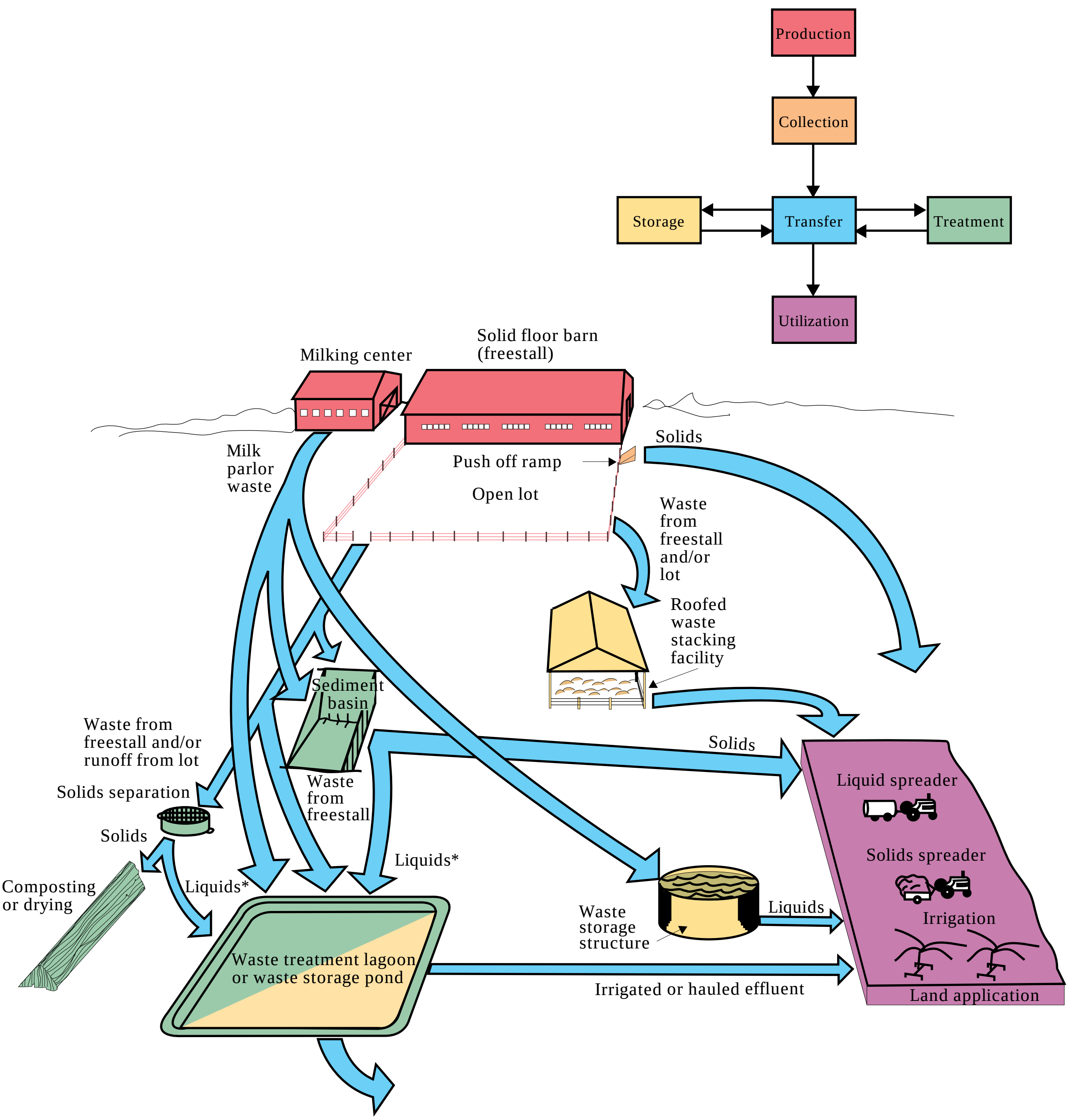
Determine the alternatives the decisionmaker is willing to consider for utilization. This helps the planner know what to work toward. Some alternatives may have specific limitations or requirements for the characteristics of the waste, and the system must be designed to deliver waste with those characteristics. If the utilization alternative involved land application, a quick check needs to be made to determine if sufficient land is available and when the spreading operations can take place. This helps determine whether treatment will be necessary and what the storage period should be.

Determine the landowners preferences for equipment and location of facilities. The landowner may desire specific features in the system or may have specific equipment available. These features and site characteristics detailed in chapter 2 should be identified and discussed with the landowner so that their impact on the total agricultural enterprise and their effect on onsite and offsite natural resources are fully understood. Existing equipment and the opinions of the decisionmaker should not limit the discussion and consideration of other alternatives.

Design the system beginning with production and ending with utilization. At this point the entire system begins to take shape. The management requirements and safety concerns should be fully addressed and understood. The previous decisions may need to be adjusted or refined.

A good way to document the decisions of the landowner is to list the major processes in the order in which they occur in the system and then record under each heading the pertinent information associated with that process.

Figure 9–3 Waste handling options—dairy



* Liquids from lot runoff discharged to waste storage pond only

651.96 Typical agricultural waste management systems

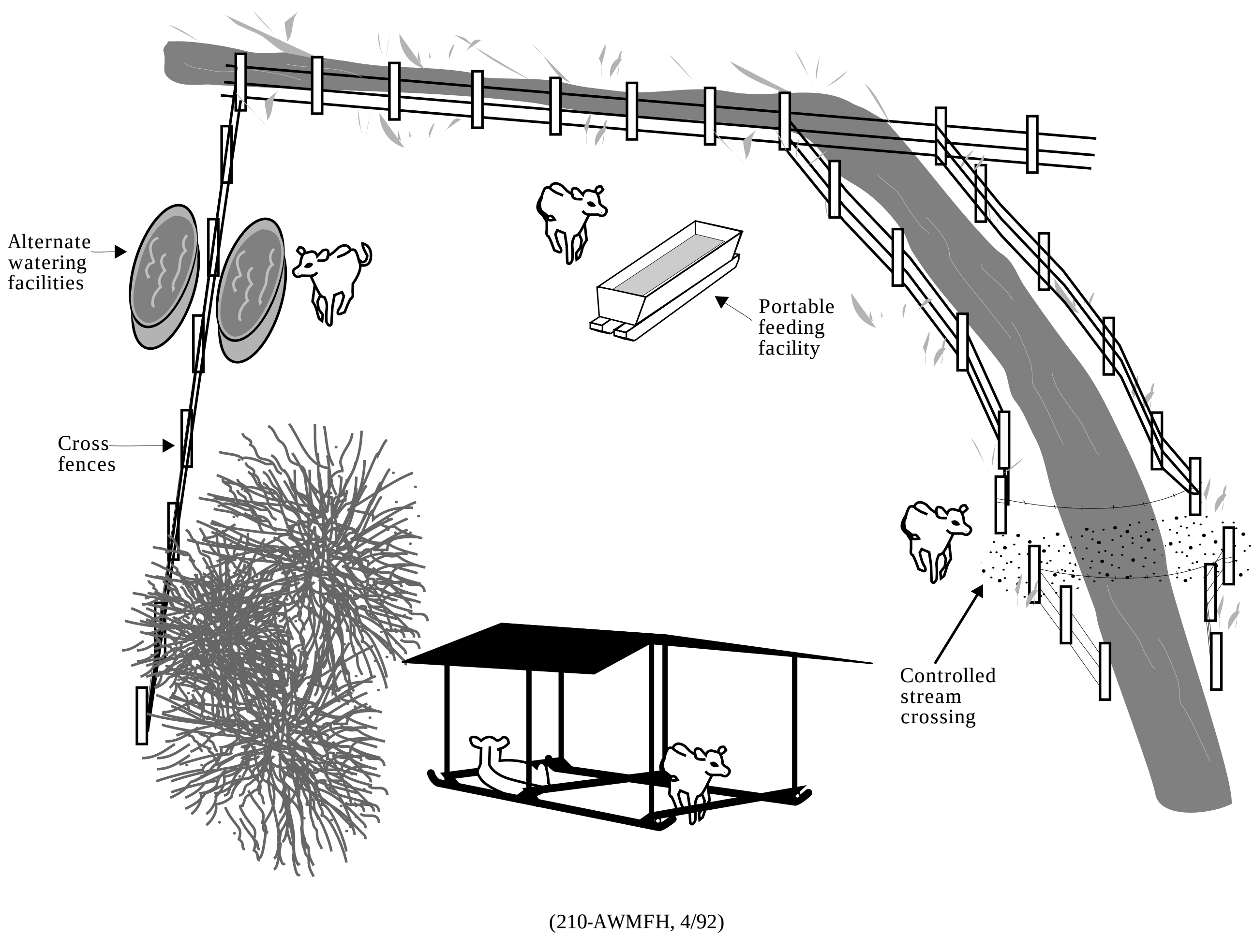
(a) Dairy waste management systems

Dairy operations vary, and each operation presents its own unique problems (fig. 9–3). Many older dairy operations were not designed with sufficient consideration given to waste management. As a result, the design of a waste management system may require major modifications or alterations of existing facilities.

The dairy industry generally is concerned with the overall appearance of the dairy farms. Dairy operations require high standards of sanitation and must prevent problems associated with flies. Operations near urban areas must manage the waste in a manner that minimizes odors.

Dairy animals are typically managed on pastures in partial confinement. While animals are on pasture, their waste should not be a resource concern if stocking rates are not excessive, grazing is evenly distributed, manure from other sources is not applied, and grazing is not allowed during rainy periods when the soils are saturated. To prevent waste from accumulating in feeding, watering, and shade areas, the feeding facilities can be moved, the number of watering facilities can be increased, and the livestock can be rotated between pastures. To reduce deposition of waste in streambeds, access to the stream may be restricted to stable stream crossings and access points (fig. 9–4).

Figure 9–4 Livestock waste management on pasture includes cross fences for rotation, portable feeding facilities, shade areas away from streams, alternate water facilities, and controlled stream crossing



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

(1) Production

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

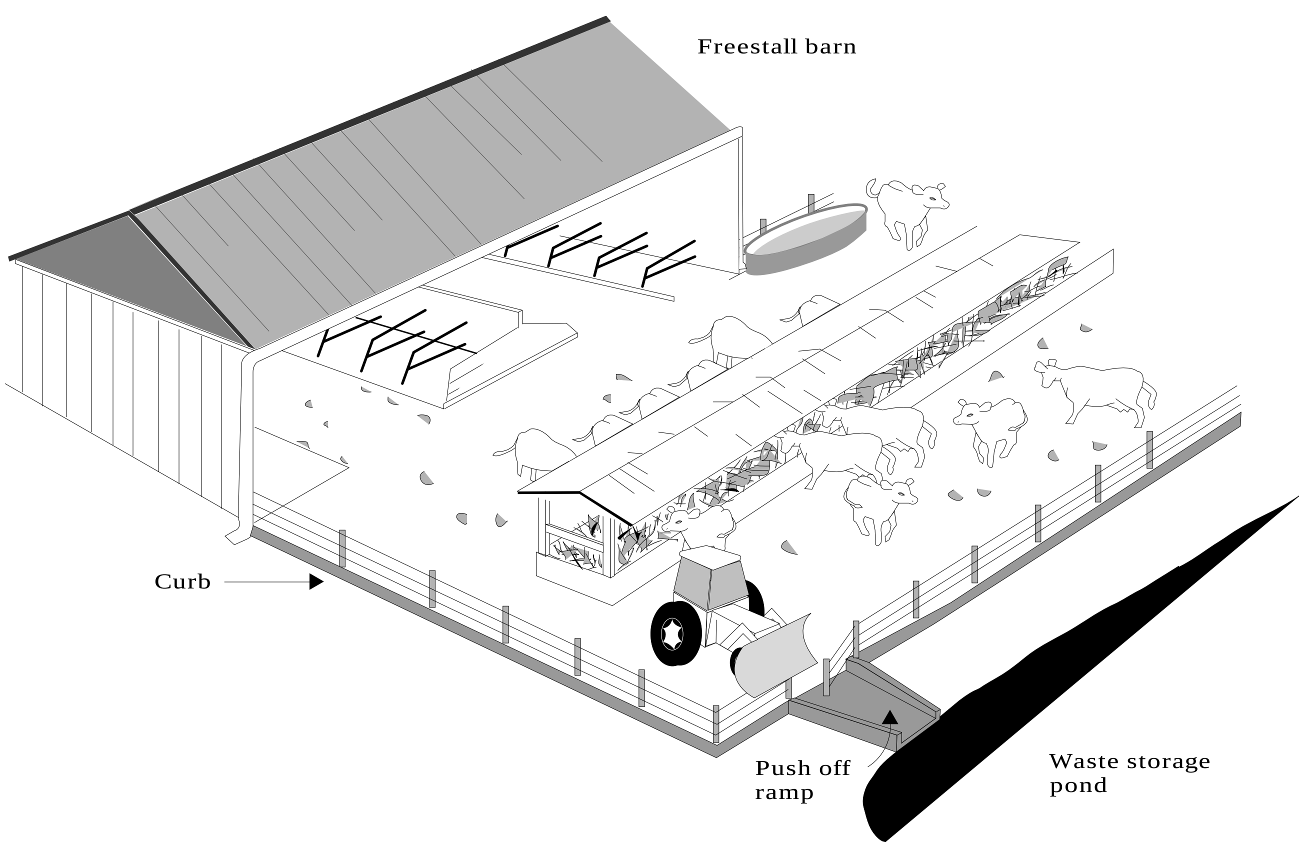
(2) Collection

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

Unroofed confinement areas must have a system for collecting and confining contaminated runoff. This can be accomplished by using curbs at the edge of the paved lots (fig. 9–5) and reception pits where the runoff exits the lots. Paved lots generally produce more runoff than unpaved lots. On unpaved lots, the runoff may be controlled by diversions, sediment basins, and underground outlets. The volume of runoff can be reduced by limiting the size of the confinement area, and uncontaminated runoff can be diverted if a roof runoff management system and diversions are used.

The manure and associated bedding accumulated in roofed confinement areas can be collected and stored as a solid. The manure can also be collected as a solid in unroofed lots in humid climates where the manure is removed daily and in unroofed lots in dry climates. Manure can be removed from paved areas by a flushing system. The volume of contaminated water produced by the system can be greatly reduced if provisions are made to recycle the flush water.

Figure 9–5 Confinement area with curbing



(3) Storage

Milking house waste and contaminated runoff must be stored as a liquid in a waste storage pond or structure. Manure may be stored as a slurry or liquid in a waste storage pond designed for that purpose or in a structural tank (figs. 9–6 & 9–7). It can be stored as a semi-solid in an unroofed structure that allows for the drainage of excess water and runoff or as a solid in a dry stacking facility. In humid areas the stacking facility should have a roof.

(4) Treatment

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

(5) Transfer

The method used to transfer the waste depends largely on the consistency of the waste. Liquid and slurry wastes can be transferred through open channels, pipes, or in a portable liquid tank (fig. 9–8). Pumps can be used to transfer liquid waste as needed. Solid and semi-solid waste can be transferred by mechanical conveyance equipment, in solid manure spreaders, and by pushing them down curbed concrete alleys. Semi-solid waste has been transferred in large pipes through the use of gravity, piston pumps, or air pressure.

(6) Utilization

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

Figure 9–6 Aboveground waste storage structure

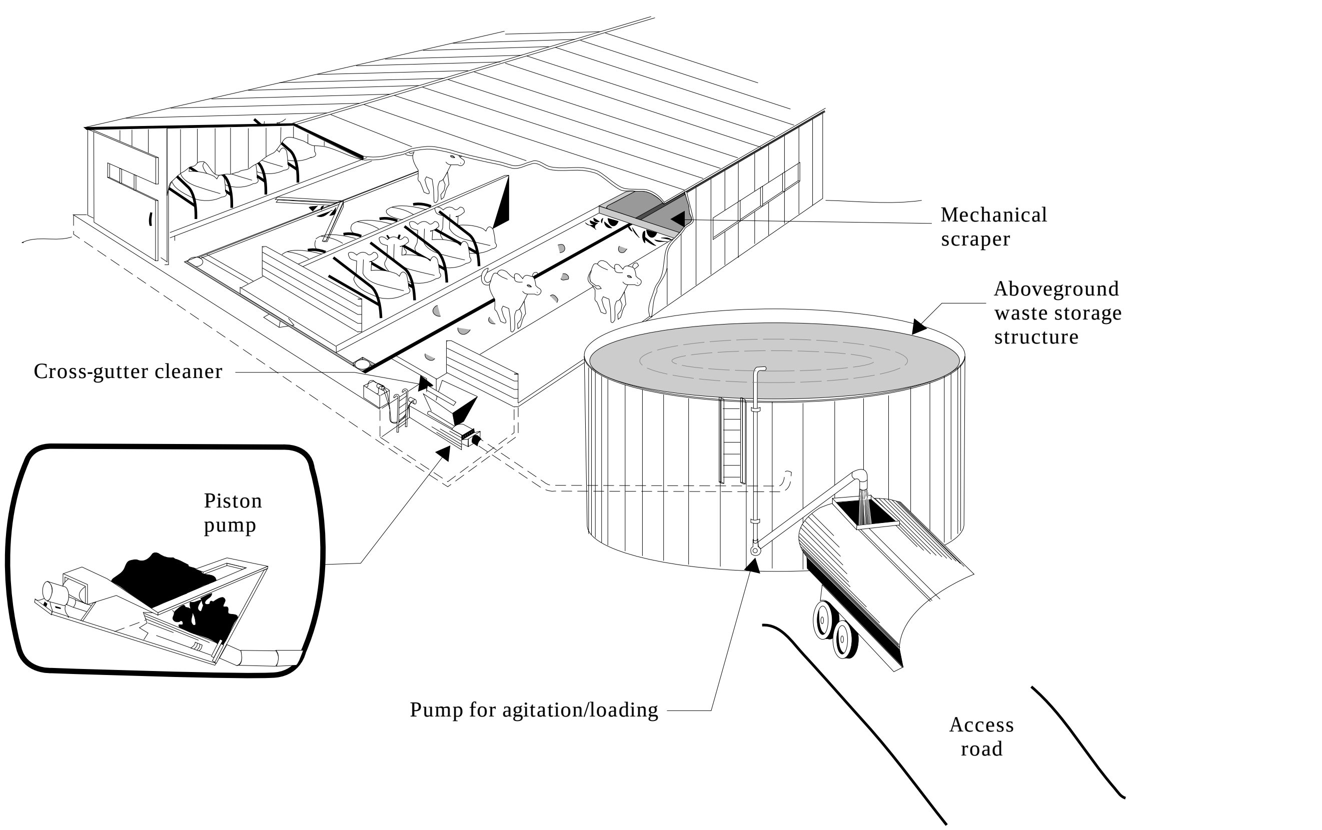


Figure 9–7 Storage facilities

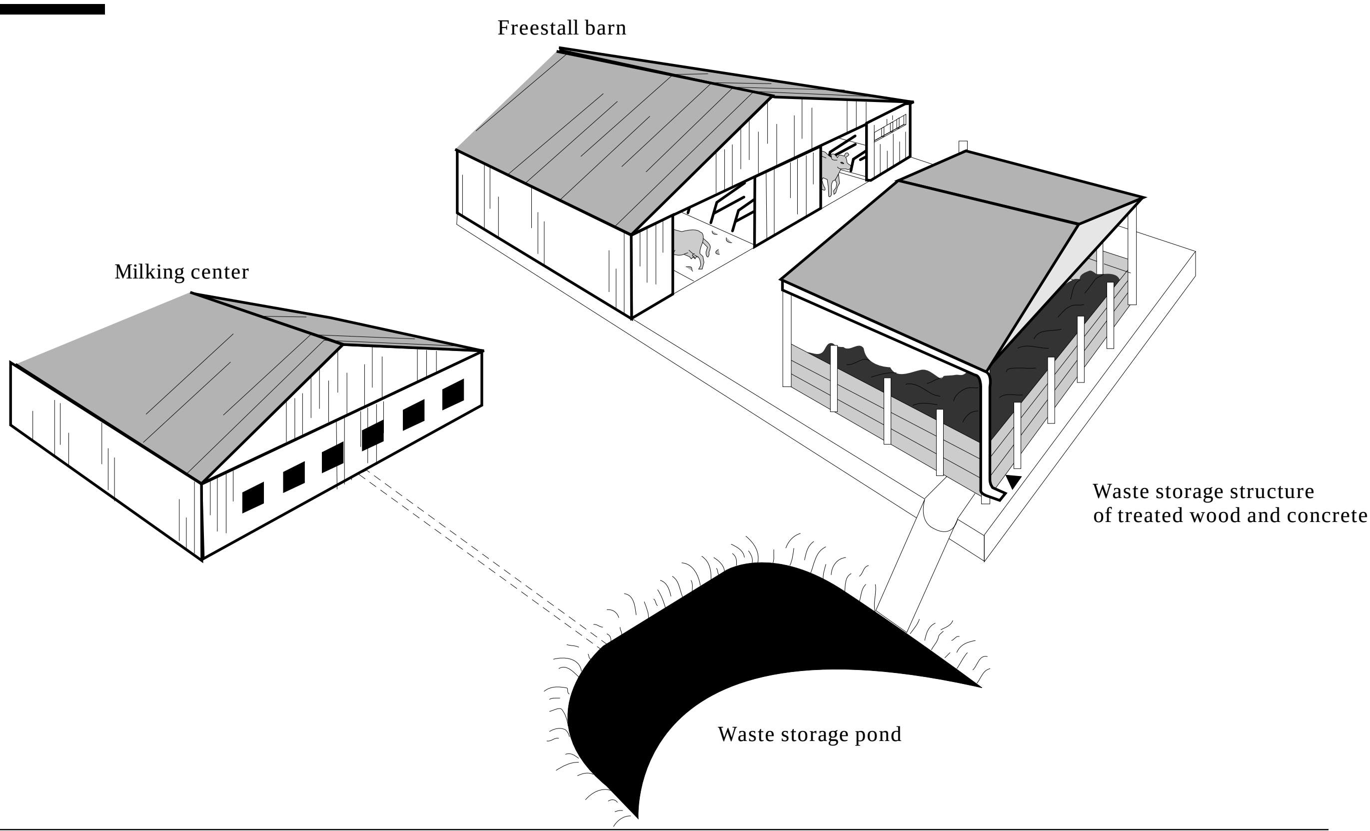


Figure 9–8 Tank wagon used to spread liquid wastes from below ground storage structure

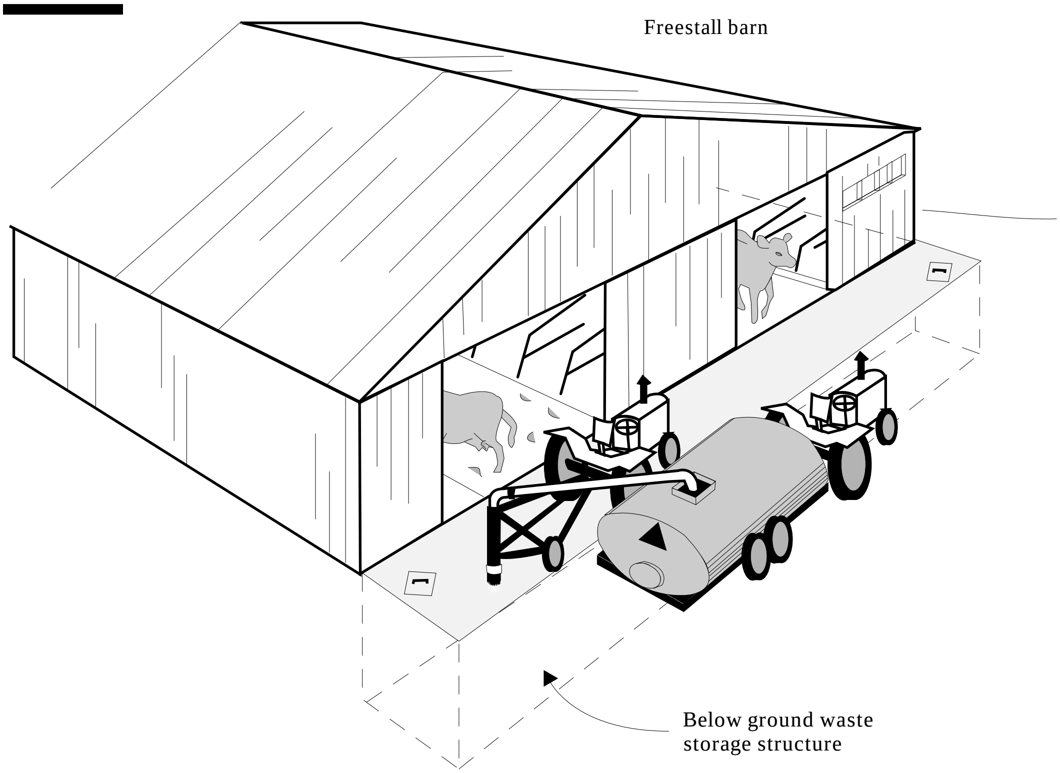


Figure 9–9 Freestall barn with flushing alleyway and irrigation system

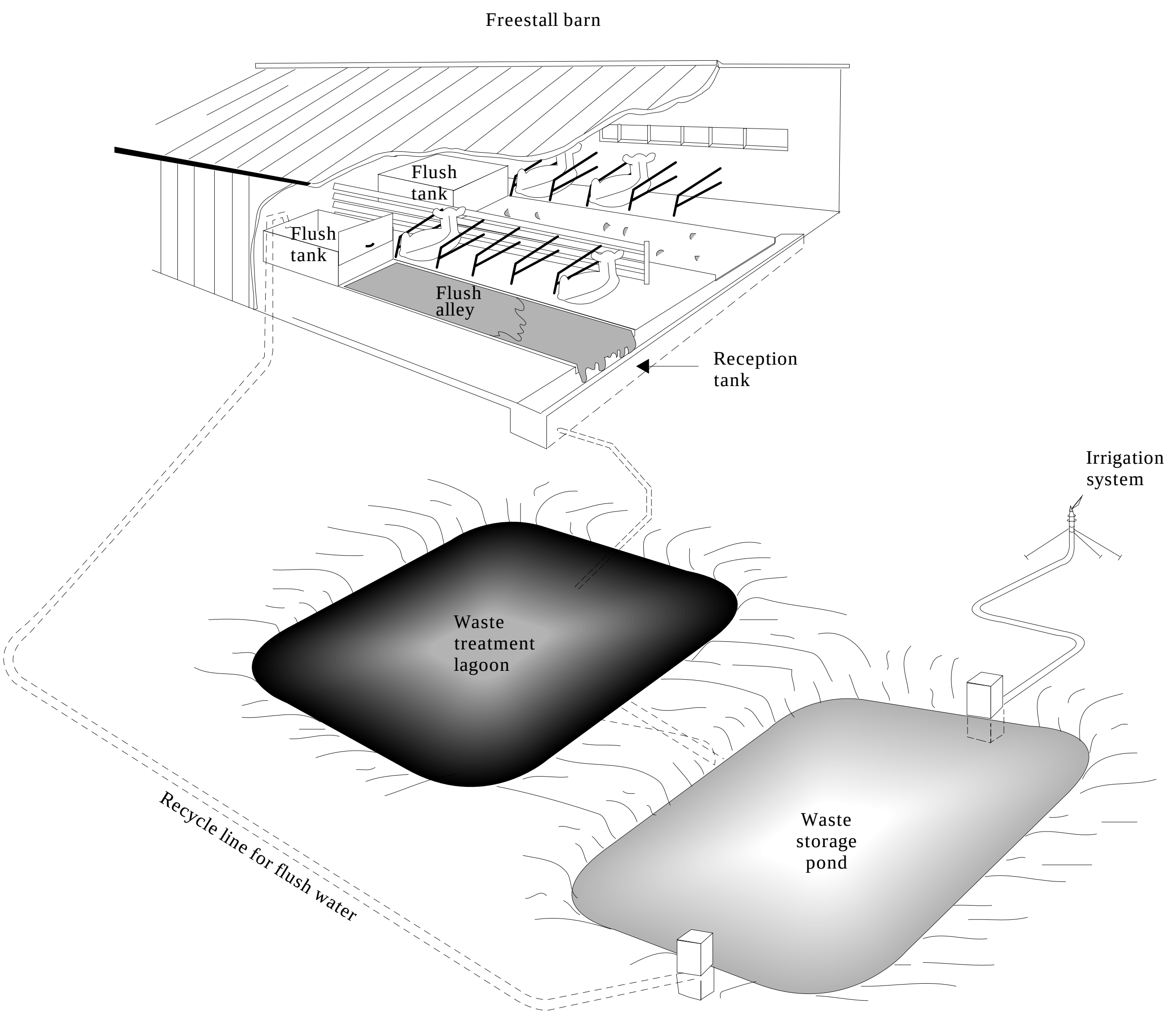
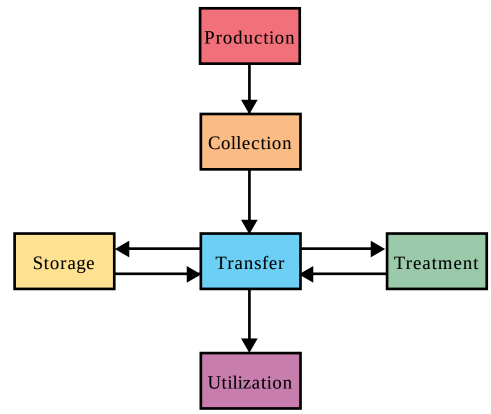
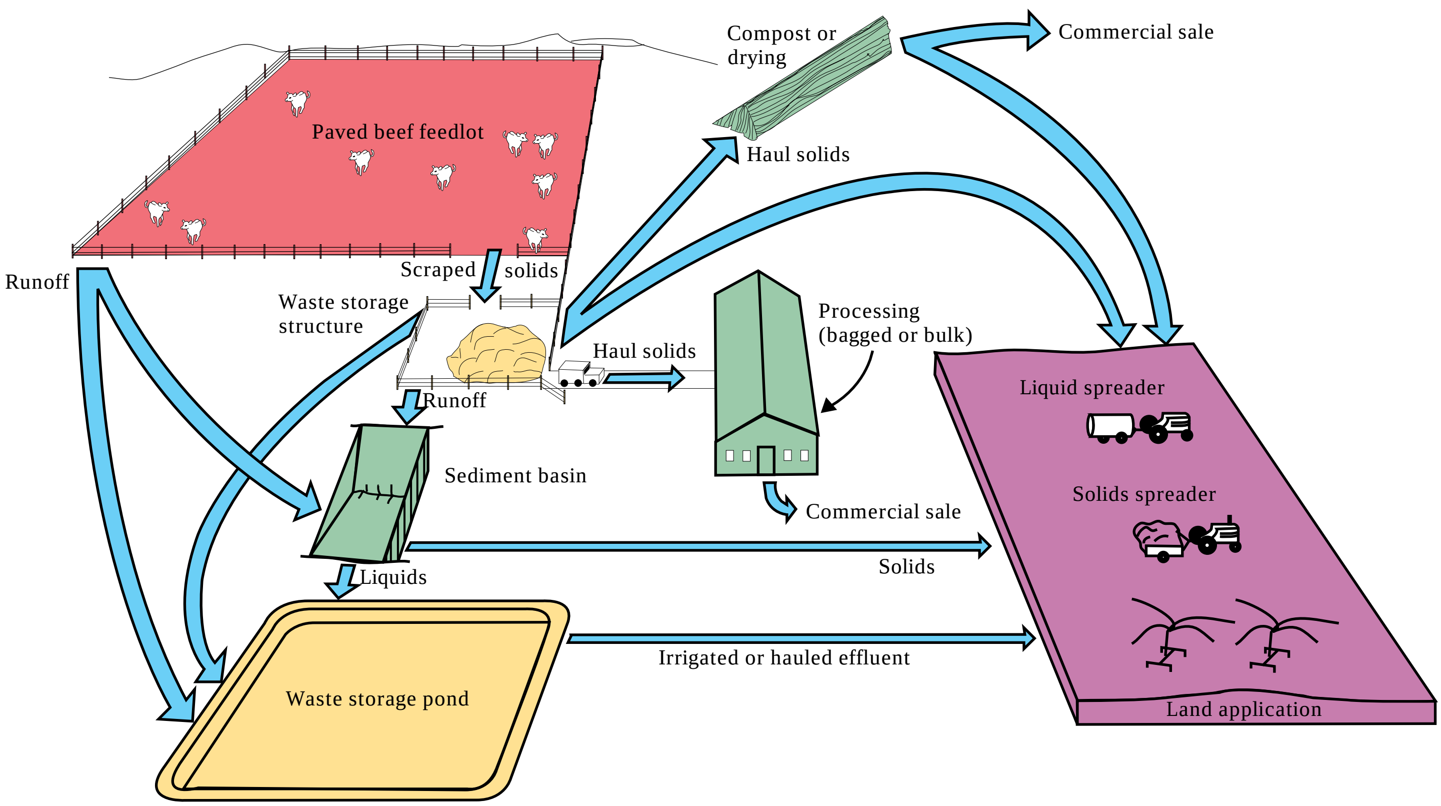


Figure 9–10 Waste handling options—beef





(b) Beef waste management systems

Beef brood cows and the calves less than a year old are usually held on pastures or range. The calves are then finished in confined feeding facilities. While the animals are on pastures, their waste should not become a resource concern if the stocking rates are not excessive and the grazing is evenly distributed. To prevent waste from accumulating in feeding, watering, and shade areas, the feeding facilities can be moved, the number of watering facilities can be increased, and the livestock can be rotated between pastures. To reduce deposition of waste in streambeds, access to the stream may be restricted to stable stream crossings and access points. Figure 9–10 shows a paved beef feedlot operation.

(1) Production

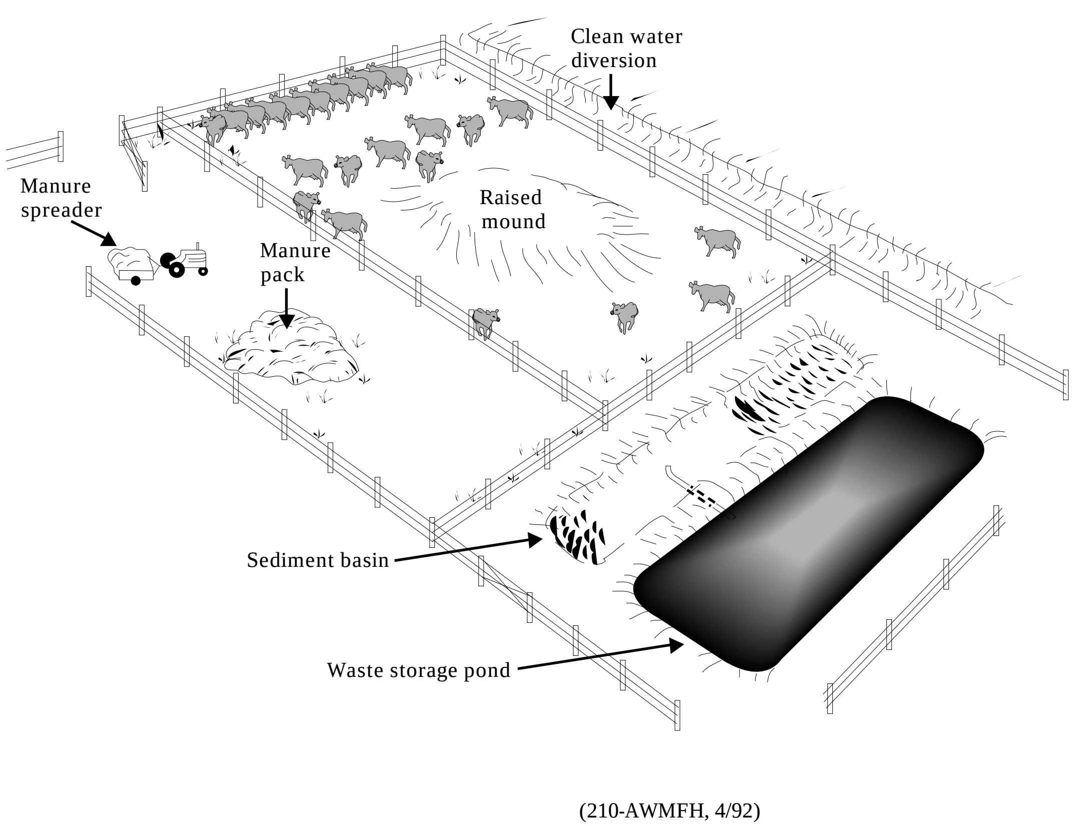
Waste associated with confined beef operations include manure, bedding, and contaminated runoff.

(2) Collection

Beef cattle can be confined on unpaved (fig. 9–11), partly paved, or totally paved lots. If the cattle are concentrated near wells, adequate protection must be provided to prevent well contamination. Because much of the waste is deposited around watering and feeding facilities, paving these areas, which allows frequent scraping, may be desirable.

On unpaved lots, the traffic of the livestock tends to form a seal on the soil that prevents the downward movement of contaminated water. Care must be taken when removing manure from these lots so that damage to this seal is minimized. The seal tends to break down after livestock are removed from the lot. To prevent possible contamination of ground water resources, all the manure should be removed from an abandoned lot.

Figure 9–11 Waste collection from an unpaved beef feedlot



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

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

(3) Storage

Manure can be stored as a bedded pack in the confinement area if bedding is added in sufficient quantities. Manure removed from the confinement area can be stored as a liquid or slurry in an earthen pond or a structural tank, as a semi-solid in an unroofed structure that allows drainage of excess water and runoff to a waste storage pond, or as a solid in a dry stacking facility designed for storage. In areas of high precipitation, dry stacking facilities should be roofed (fig. 9–12). Contaminated runoff must be stored as a liquid in a waste storage pond or structure.

(4) Treatment

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

(5) Transfer

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

(6) Utilization

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

Figure 9–12 Storage facilities for wastes from paved feedlot in high precipitation area

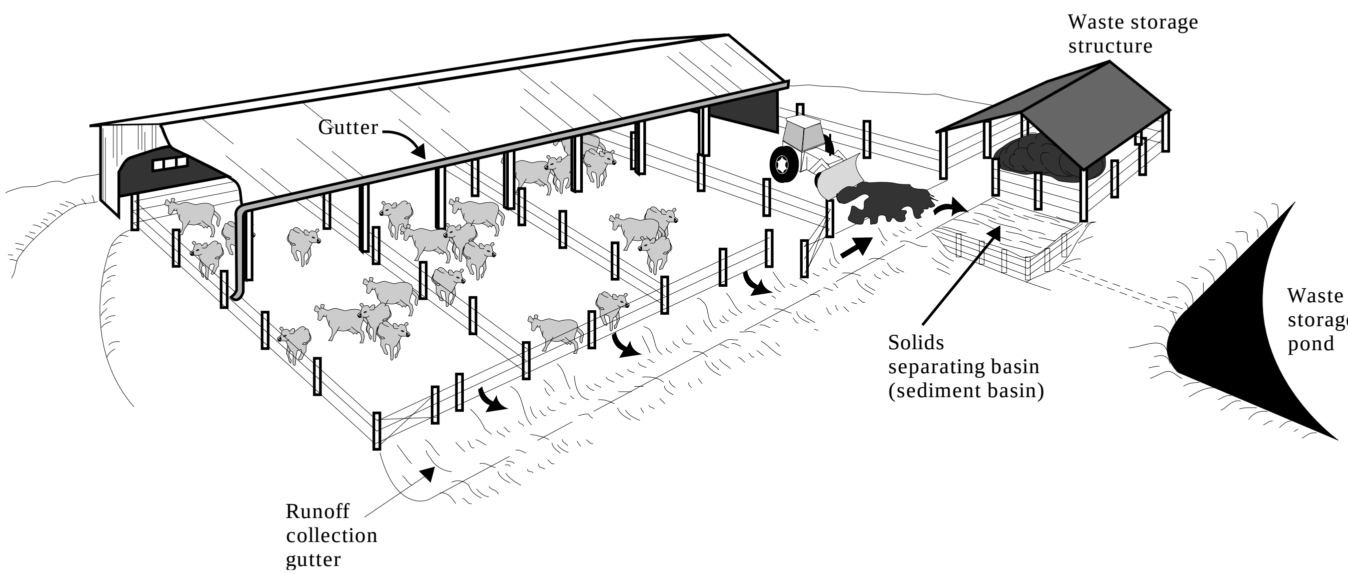
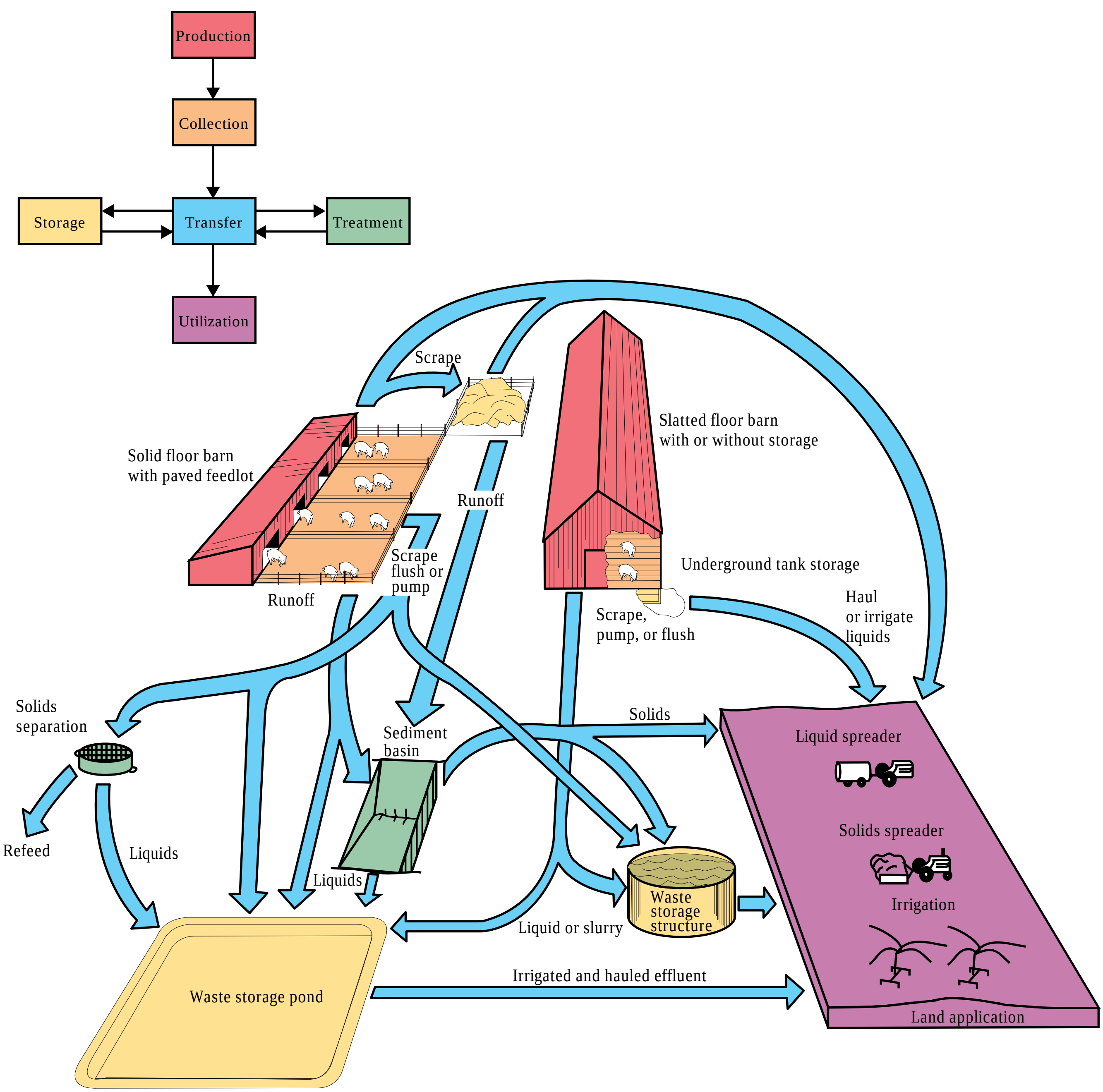


Figure 9–13 Waste handling options—swine



(c) Swine waste management systems

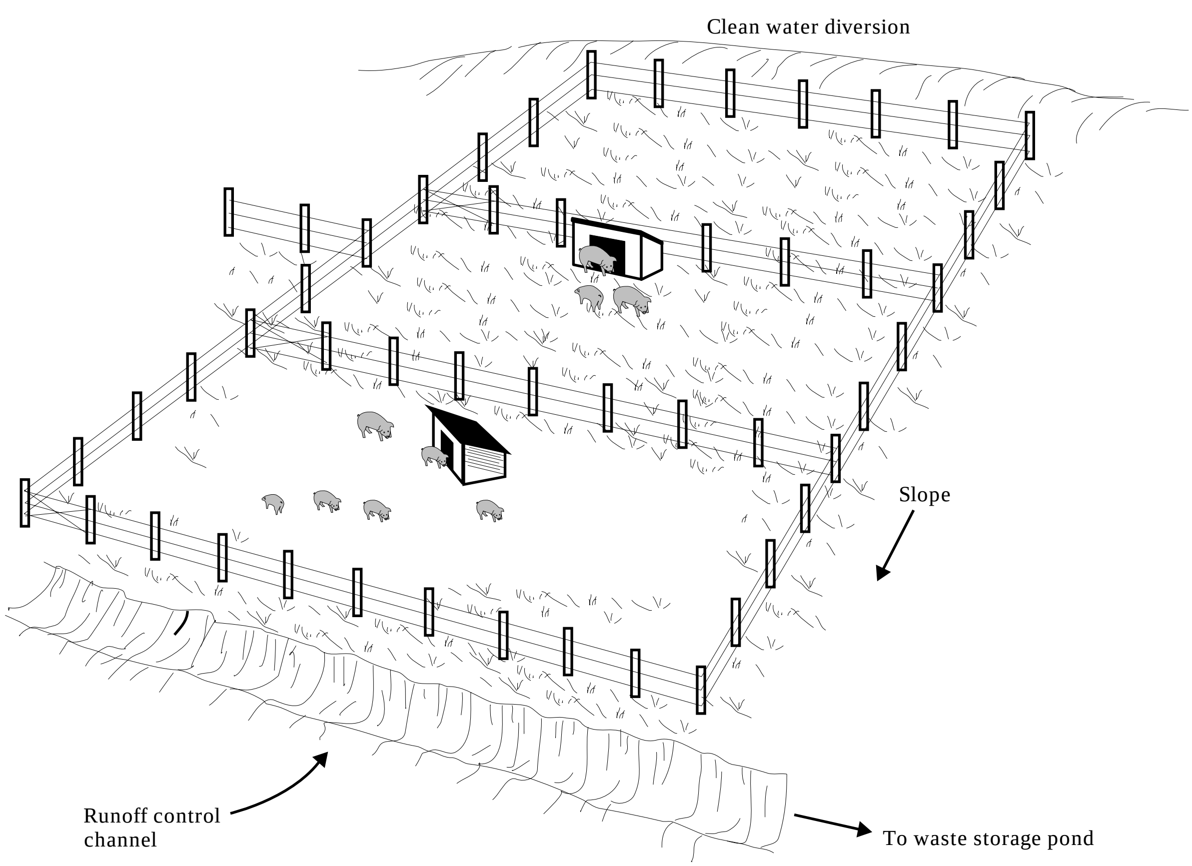
Open systems (pastures, woodlots, and wetlands), feedlot systems, confinement systems, or a combination of these, are used for raising swine (fig. 9–13).

Raising hogs in an open system may appear to have a low initial investment, but often results in animal health and pollution control problems. Even if sufficient land is available, hogs tend to congregate and concentrate their waste. This can be prevented by moving the feeding, watering, and housing facilities and by rotating the hogs through a series of open lots. Hogs raised in an open system should not have unrestricted access to streams. Runoff is difficult to manage in an open system because of the large area and topographic limitations. Rather than invest the capital and time necessary to install and manage an extensive runoff management system, it may be more efficient to convert to a more concentrated operation.

Manure in feedlot systems can be handled as a solid if the feedlots are cleaned regularly, sufficient bedding is added to the manure, and the collected manure is protected from excessive precipitation. It can also be handled as a slurry or liquid, but measures must be taken to manage contaminated runoff (fig. 9–14). Total confinement systems eliminate the need to manage contaminated runoff and may allow for more automation in waste management.

Undesirable odors are often associated with swine operations. A swine waste management system should incorporate odor control measures where possible. A clean, neat appearance; efficient management system (fig. 9–15); and positive public relations with those affected by the odors eliminates many complaints.

Figure 9–14 Runoff control



(1) Production

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

(2) Collection

Swine manure can be collected by scraping or flushing. Scraped manure is collected as a solid or slurry, and flushed manure must be handled as a liquid. The flush water should be recycled if possible so that the volume of contaminated water is kept to a minimum. The collection process can use automated equipment, or it can be as simple as raising swine on slatted floors over waste storage pits (fig. 9–16).

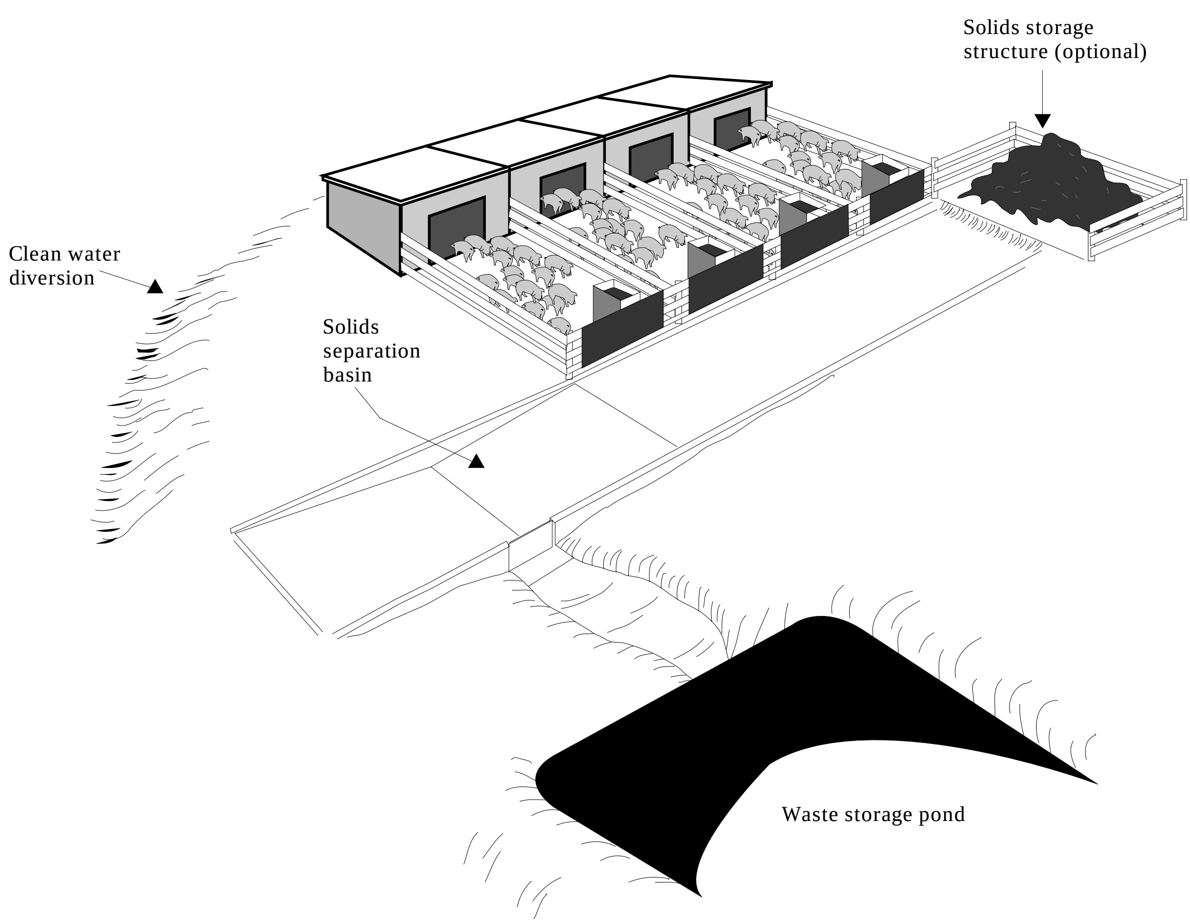
(3) Storage

Swine manure can be stored as a solid, slurry, or liquid. If stored as a solid, it should be protected from precipitation. Above or below ground tanks (fig. 9–17) or an earthen waste storage pond can be used to store slurries or liquid waste.

(4) Treatment

Liquid waste from a swine operation is commonly treated in an anaerobic lagoon, but it can also be treated in an aerobic lagoon (fig. 9–18) or oxidation ditch. Solid waste and dead pigs can be composted.

Figure 9–15 Manure scraped and handled as a solid on paved lot operation



(5) Transfer

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

(6) Utilization

Swine waste is used as a feed supplement and an energy source through methane production. With proper ventilation and sufficient bedding, the solid manure can be composted in confinement facilities, and the heat generated from the composting process can be used to supplement heat in the buildings.

The most common use of the nutrients in swine waste is through land application. The waste can be hauled and distributed over the land by spreading devices. If odors are a problem, liquid waste can be injected below the soil surface. It can also be distributed through an irrigation system. Slurries can be distributed through an irrigation system equipped with nozzles that have a large opening.

Figure 9–16 Confined housing with farrowing crates, partly slatted floor, pit storage, and liquid manure handling

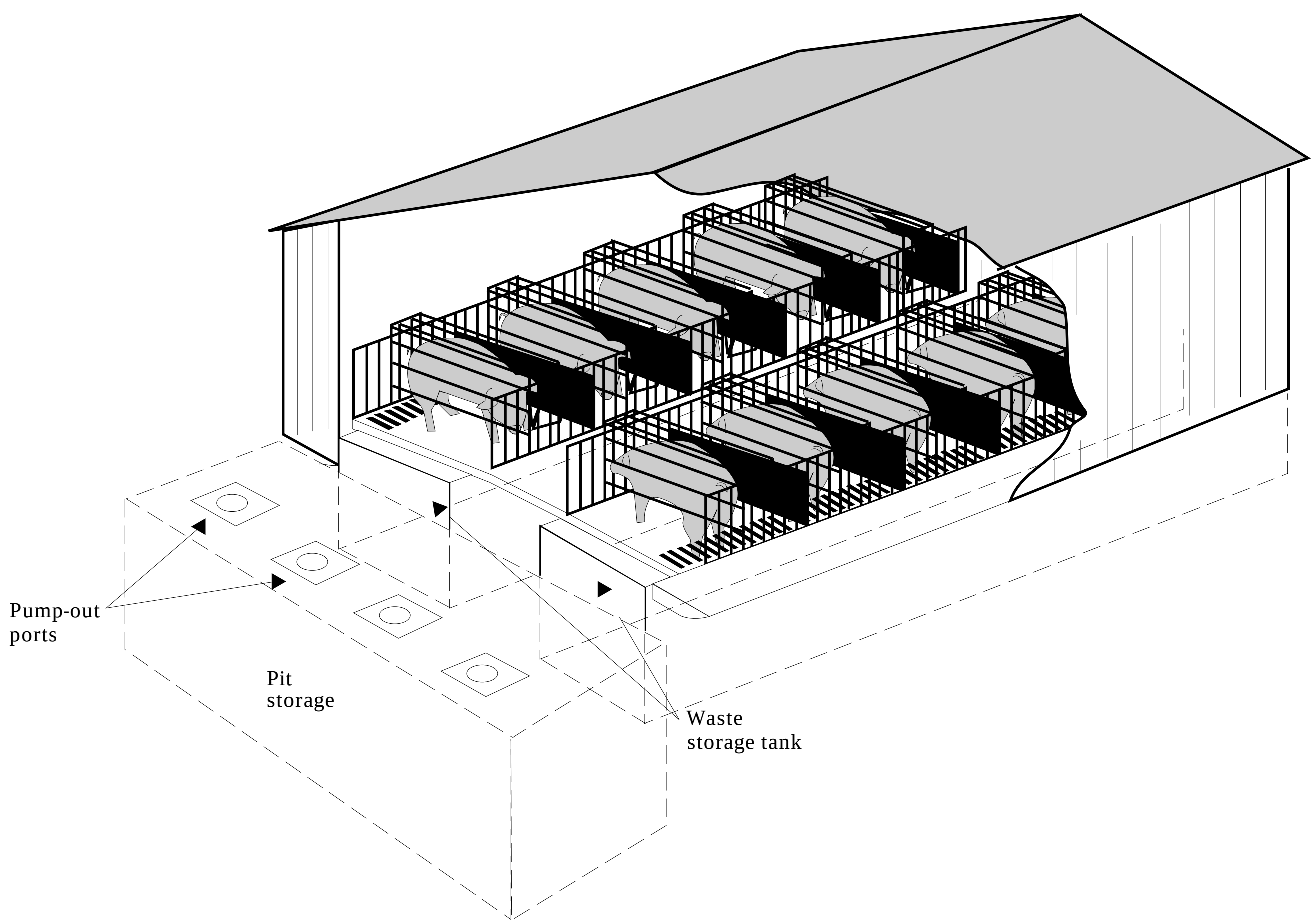


Figure 9–17 Fed hogs in confined area with concrete floor and tank storage liquid manure handling

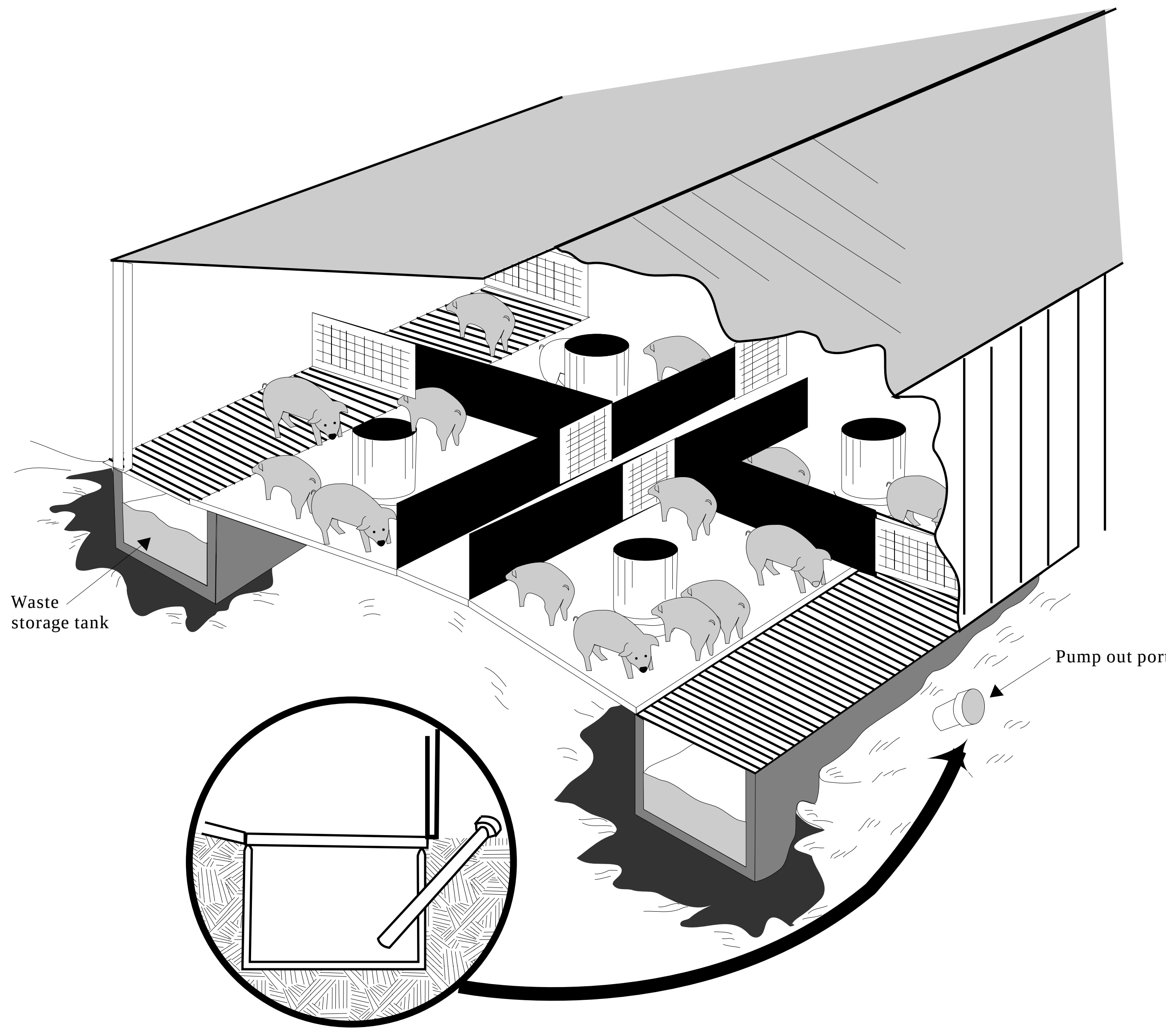


Figure 9–18 Two stage aerobic lagoon system for treatment of waste flushed from swine building

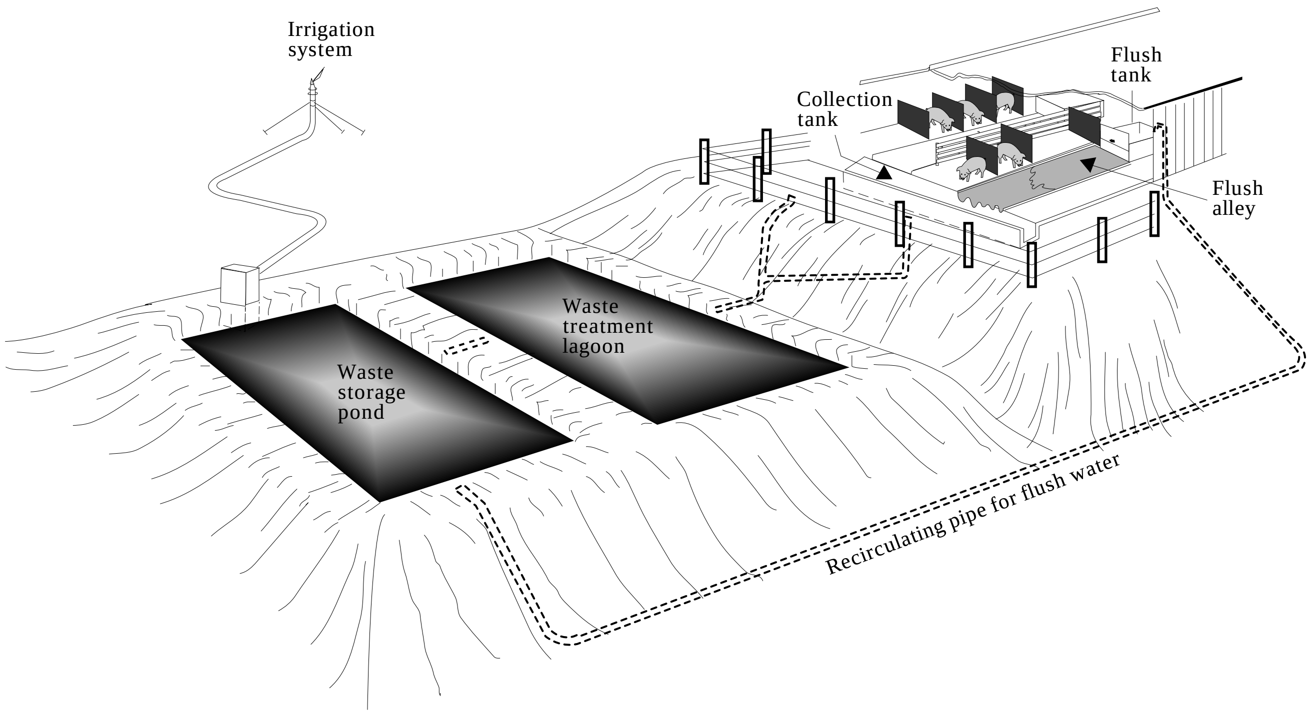
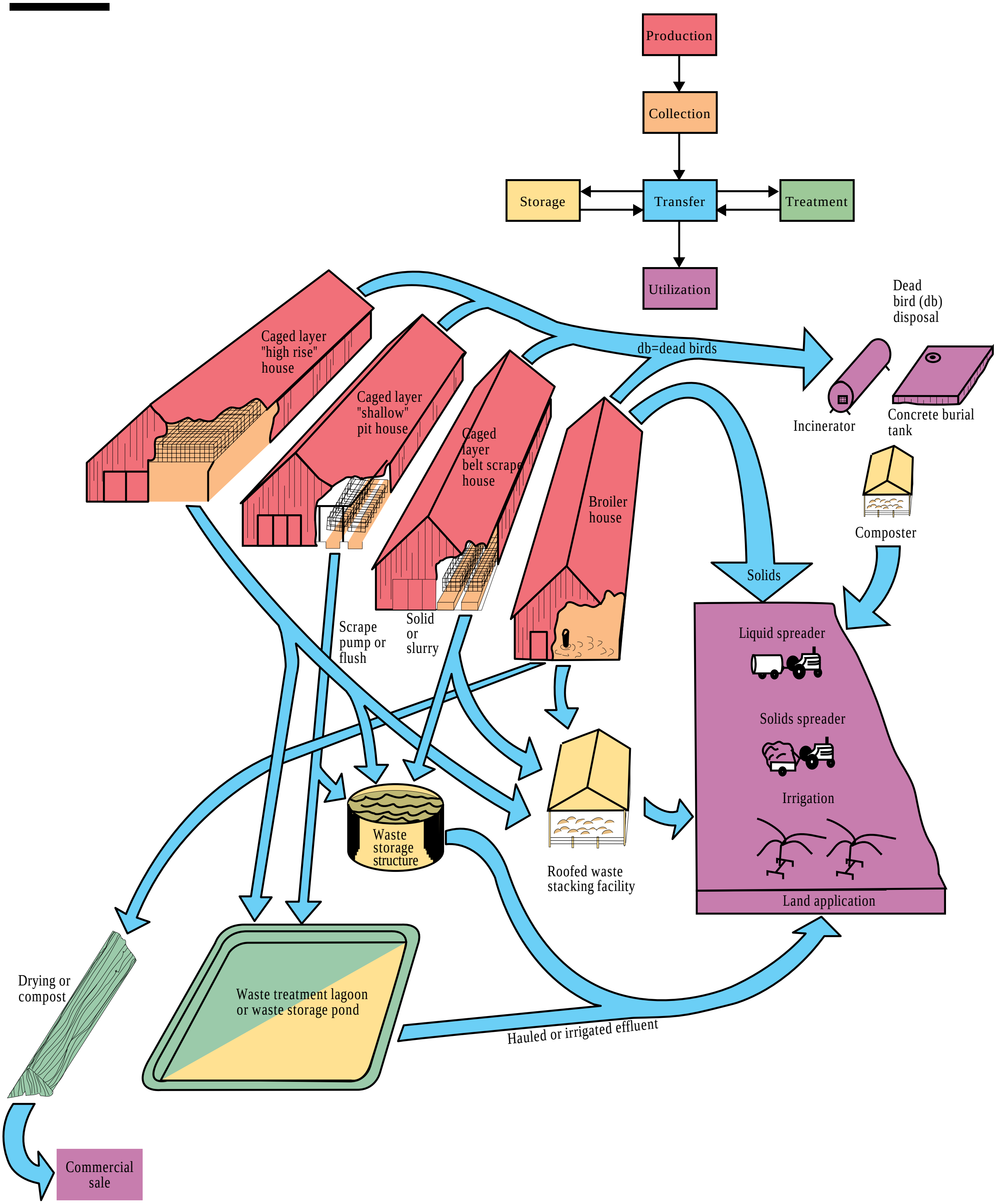


Figure 9–19 Waste handling options—poultry



(d) Poultry waste management systems

The two basic poultry confinement facilities include those to raise turkeys and broilers used for meat (fig. 9–19) and those to house layers. Broilers and young turkeys are grown on floors on beds of litter shavings (fig. 9–20), sawdust, or peanut hulls. Layers are confined to cages. Fly control around layers is important to prevent spotting of the eggs. Disease control is important in both systems.

(1) Production

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

(2) Collection

The manure from broiler and turkey operations is allowed to accumulate on the floor where it is mixed with the litter. Near watering facilities the manure-litter pack forms a “cake” that generally is removed between flocks. The rest of the litter pack generally has low moisture content and is removed once a year in the spring. The litter pack can be removed more frequently to prevent disease transfer between flocks.

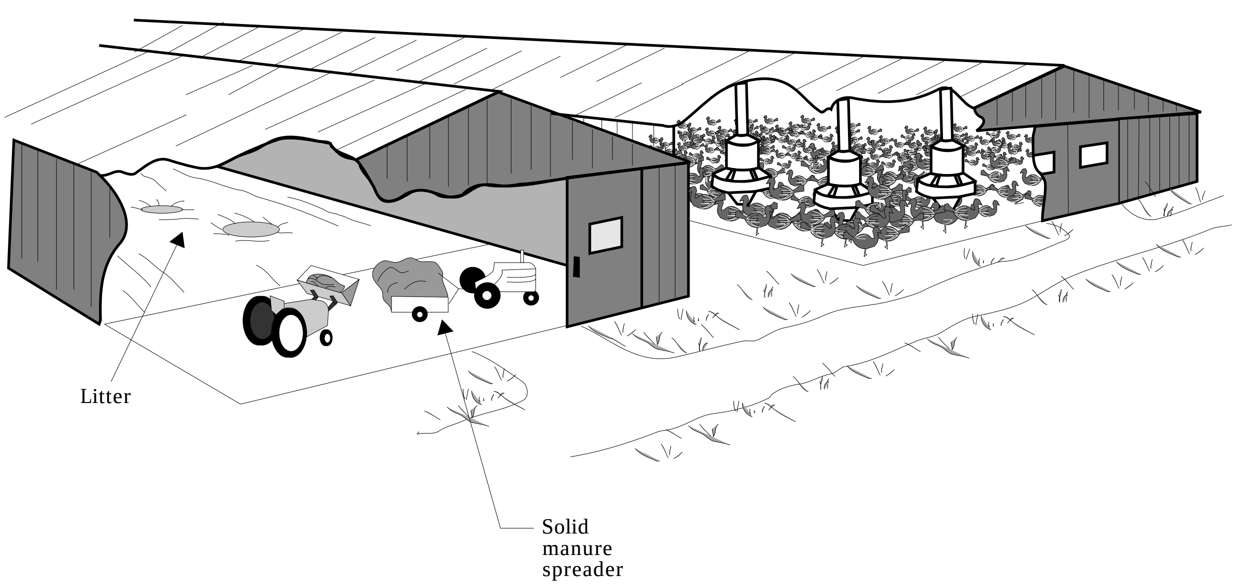
In layer houses, the manure that drops below the cage collects in deep stacks (fig. 9–21) or is removed frequently using either a shallow pit located beneath the cages for flushing or scraping or belt scrapers positioned directly beneath the cages.

(3) Storage

Litter from broiler and turkey operations is stored on the floor of the housing facility (fig. 9–22). When it is removed, it can be transported directly to the field for land application. If field conditions are not suitable or spreading is delayed for other reasons, the litter must be stored outside the housing facility. In some areas the litter may be compacted in a pile and stored in the open for a limited time; however, it generally is better to cover the manure with a plastic or other waterproof cover until the litter can be used. If the spreading is to be delayed for an extended period of time, the litter should be stored in a roofed facility.

If the manure from layer operations is kept reasonably dry, it can be stored in a roofed facility. If it is wet, it should be stored in a structural tank or an earthen storage pond.

Figure 9–20 Litter system for broilers and turkeys



(4) Treatment

Broiler and turkey litter can be composted. This stabilizes the litter into a relatively odorless mass that is easier to market and also helps to kill disease organisms so that the litter can be reused as bedding or supplemental feed to livestock. The litter can also be dried and burned directly as a fuel.

Liquid manure may be placed into an aerobic digester to produce methane gas or it can be treated in a lagoon. The high volatile solid content of the layer manure may require an aenaerobic lagoon of considerable size. If odors are a problem, the lagoon can be aerated.

(5) Transfer

The method used to transfer the waste depends on the TS content of the waste. Liquid waste can be transferred in pipes, gutters, or tank wagons, and dried litter can be scraped (fig. 9–23), loaded, and hauled as a solid. If the distances between the poultry houses and the fields for application are great, the litter may need to be transported in a truck.

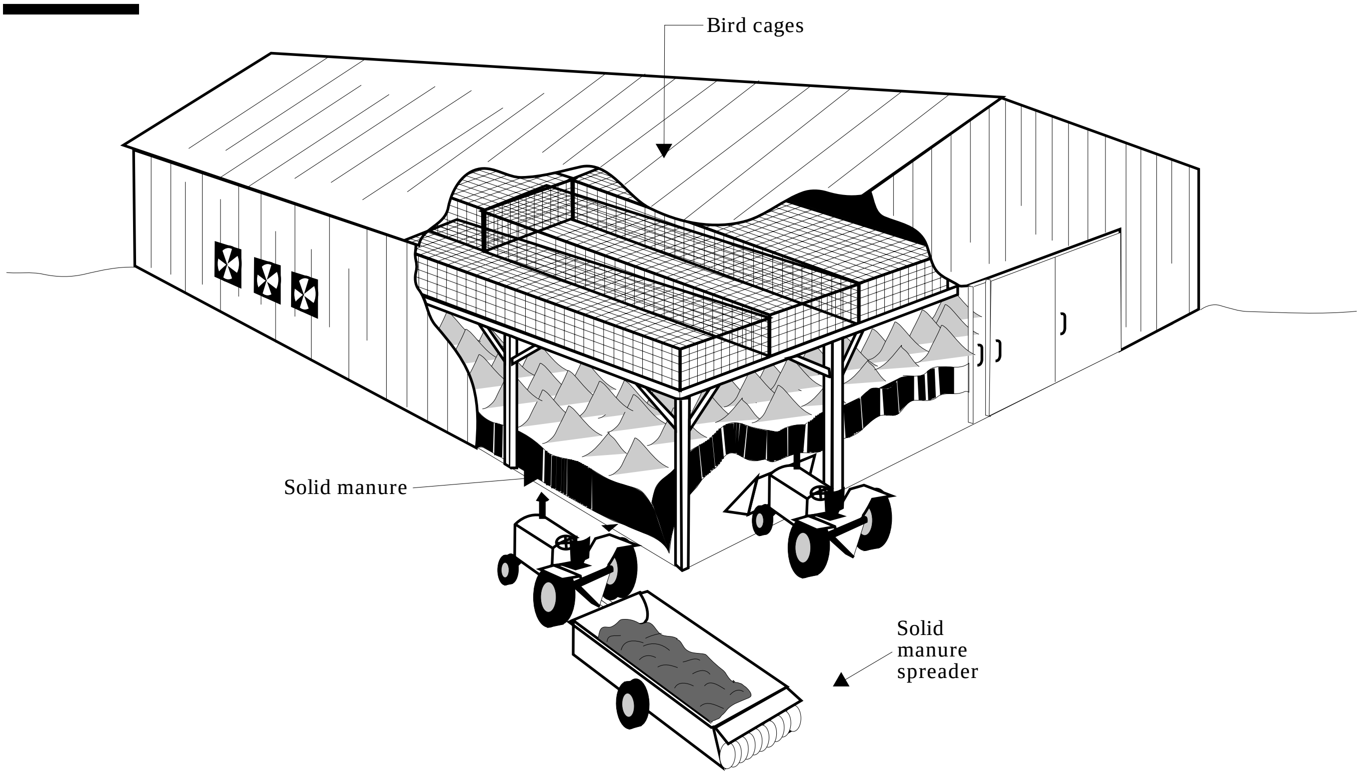
(6) Utilization

The waste from poultry facilities can be applied to the land. If the owners of the poultry houses do not have enough land suitable for application, they should arrange to apply the waste to their neighbors' land. Because of the high nutrient value of the litter, many landowners are willing to pay for the litter to be spread on their land. Whether on the owner's land or the neighbor's land, the waste must be spread according to an appropriate waste utilization plan. Poultry waste can also be used for the production of methane gas, buried directly as a fuel, reused as bedding, or used as a feed supplement to livestock.

(7) Dead poultry disposal

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

Figure 9–21 Manure accumulates under cages in "high-rise" house for layers



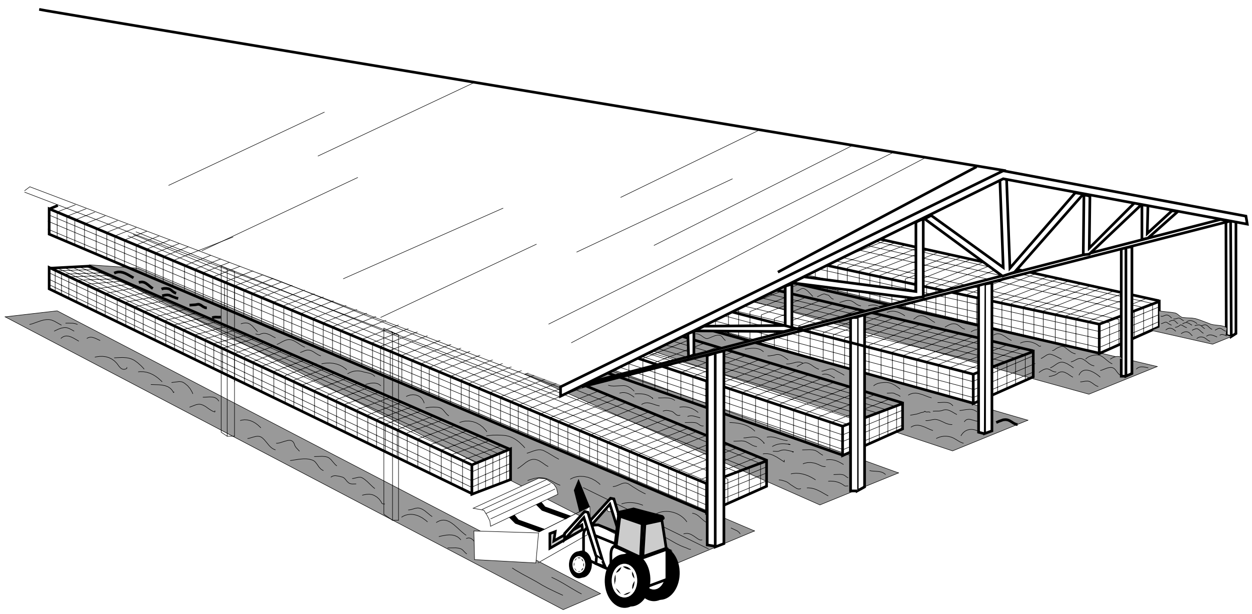


Figure 9–22 Litter from poultry operations may be stored on the floor of the facility until scraped after several cycles of birds

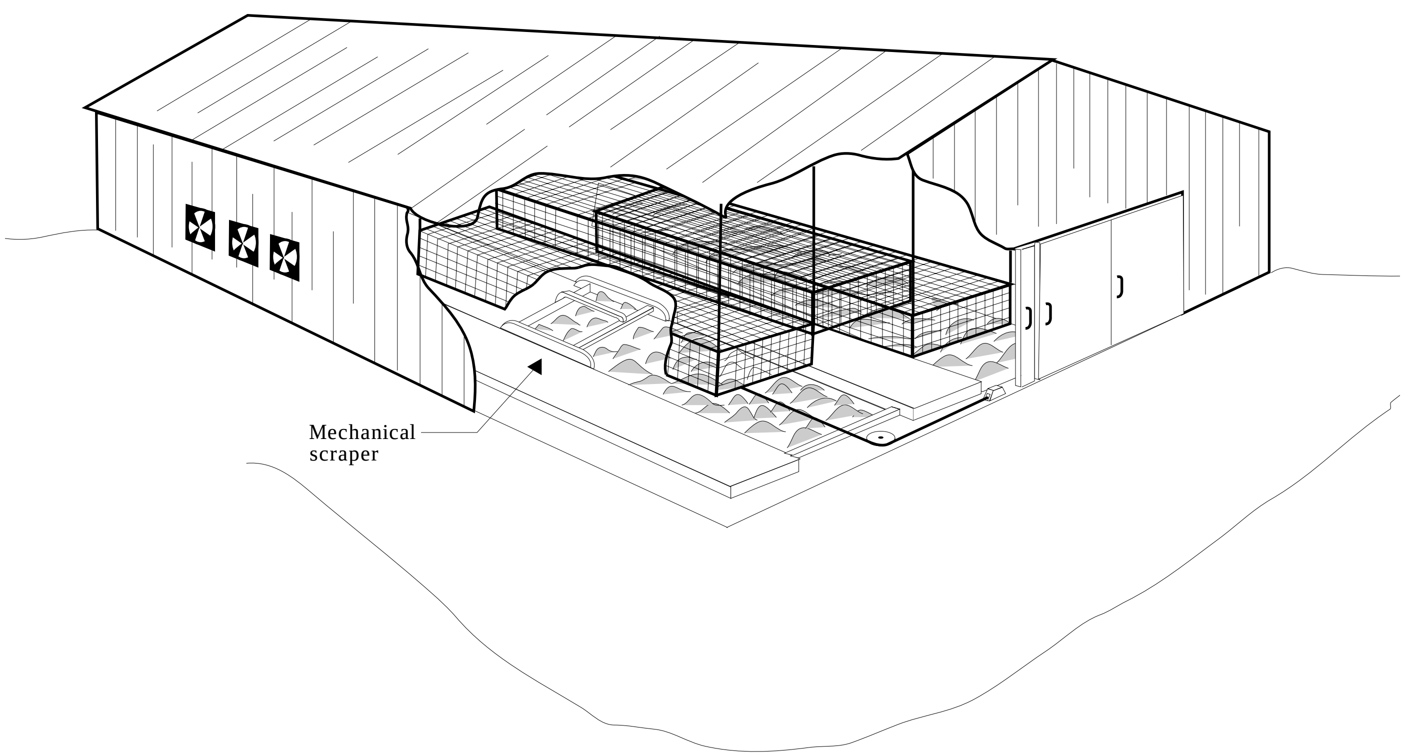
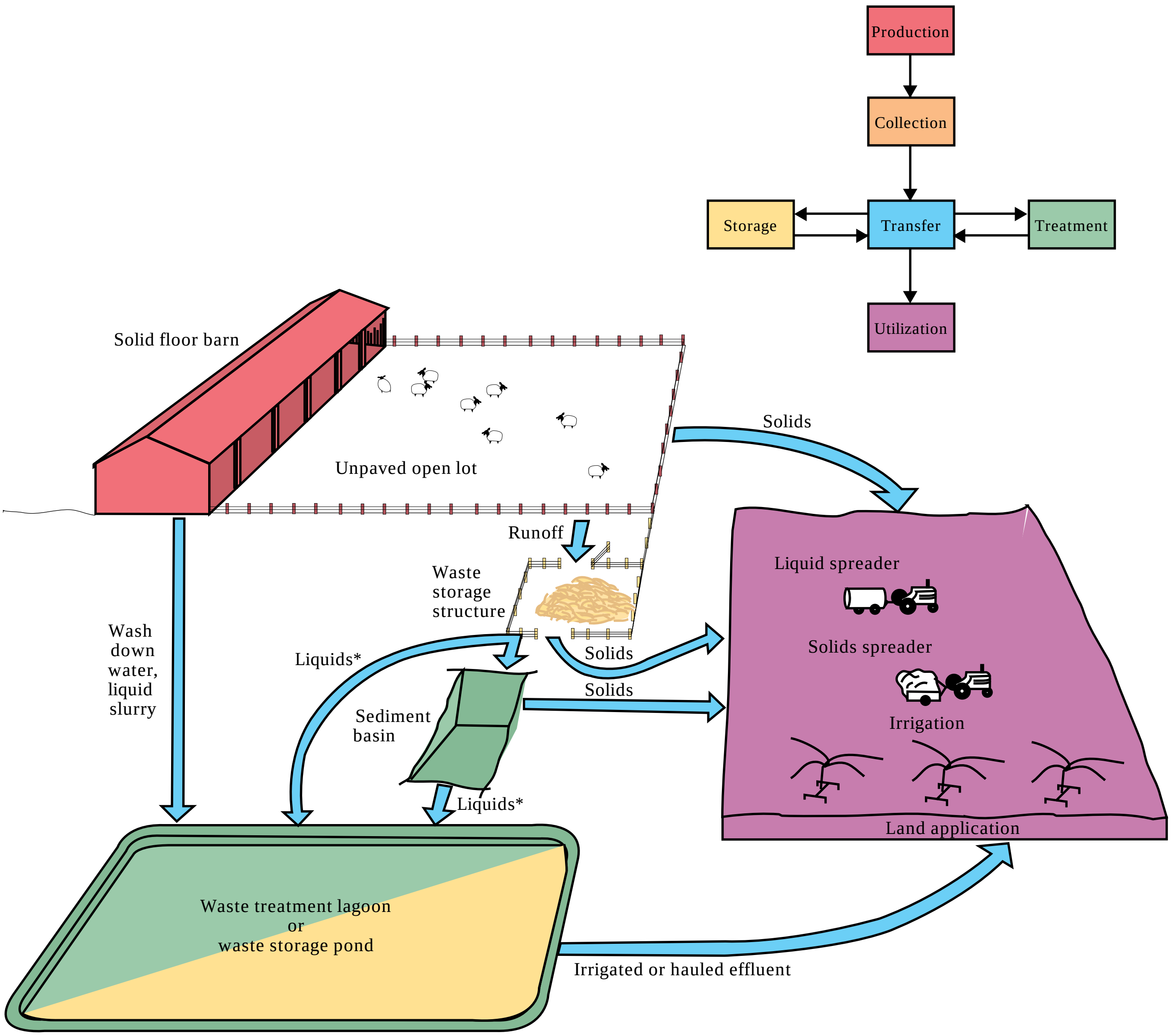


Figure 9–23 Solid waste may be scraped regularly (possibly by mechanical scraper) from facility for transport to the field

Figure 9–24 Waste handling options—sheep



•Discharge of liquids to a waste storage pond only

(e) Other animals

(1) Sheep and goat waste management systems

Sheep or goats produced in confinement are grown either on paved lots or pasture (fig. 9–24). Their manure can be managed as a solid material. Where the animals are on pasture, waste management includes controlling stocking rates and periodic pasture renovation. On paved lots, the manure is periodically removed by scraping for immediate land application, storage in a solid manure storage facility, or treatment in a lagoon.

(2) Horse waste management systems

Management of a horse operation near urban areas must include methods to keep flies and odors to a minimum. Horses are housed in confinement in paddocks or they are on pasture. Horse paddocks or stalls receive liberal amounts of bedding; therefore, most horse manure is handled as a solid. It should be removed from stalls daily if possible and can be land applied, stored in solid manure storage structures, or processed by composting. Some precautions should be taken if the manure is land applied to pastures because this can result in internal parasites spreading to other horses. The manure can be used in gardens, greenhouses, nurseries, and by mushroom growers.

(3) Veal waste management systems

Veal calves are produced using a liquid diet; therefore, their manure is highly liquid. It is typically removed from housing facilities by scraping or flushing from collection channels. The manure is then flushed or pumped into either liquid waste storage structures or ponds or into lagoons.

(4) Small animals

Small animals include dogs, cats, rabbits, commercial furbearing animals, and laboratory animals. Keeping waste material dry and regular clean-out and disposal of waste help to prevent odor and pest problems. The system should not allow the accumulation of waste materials that can become breeding, feeding, or nesting sites for rodents or insects. Waste from small animals may contain disease organisms that can be transmitted to humans.

(f) Municipal and industrial sludge and wastewater application systems

The application of sludge is regulated by State, Federal, and, in some cases, local laws. Only sludge that meets certain criteria regarding degree of treatment can be applied. Sludge must be treated to kill pathogens before it is land applied. The sludge and wastewater should not be stored on the farm, but should be applied immediately to the land.

Municipal sludge (and wastewater to a much smaller degree) contains heavy metals that can be detrimental to crops and human and livestock health. (See table 6–2 in chapter 6). The sludge needs to be analyzed for certain metals, such as mercury, lead, zinc, cadmium, and nickel. The annual application rate for cadmium is regulated. Specific cumulative applications for the life of the site have been established by the U.S. Environmental Protection Agency for all of these metals. The application rates are dependent on the soil characteristics. State regulations should be consulted for specific metal loadings.

The production of certain crops, such as root crops, is prohibited on land receiving sludge. Because sludge and wastewater can have objectionable odors, caution should be exercised during application to minimize offensiveness.

(g) Food processing waste

Food processing facilities produce large amounts of waste, some of which are suitable for land application. Food processing waste can be either solid, slurry, or liquid. The chemical properties of the waste must be determined before a waste handling system can be designed. If the waste is biological in nature, it can be treated and handled much the same as livestock waste.

Waste treatment lagoons can be used for some food processing waste. The material must be analyzed for its volatile solids content or its BOD concentration so that volumetric or areal loading rates can be determined. Because some canneries are seasonal, lagoons may need to be oversized to accept anticipated periodic heavy organic loading.

State and local regulatory personnel must be contacted and necessary permits obtained before land application. Many permits require ongoing monitoring of ground water and possibly soil and plant matter. Hydraulic loading is often ignored. If the site has a high water table or low permeability, the amount of water that can be applied generally is reduced. In some food processing waste, the level of salt is too high or the pH is too high or too low for land application. Most food processing waste land application sites should be designed by a professional who has experience in these type systems.

(h) Agricultural chemical waste management

Many agricultural enterprises use large amounts of agricultural chemicals. The use of these chemicals seems to increase as the cost of labor increases. With this increased usage comes the potential for surface and ground water contamination as a result of improper storage of chemical residue, rinse water, and unused chemicals and the improper disposal of empty containers. Considerable research is being conducted in this area; however, to date few easily managed, cost-effective alternatives have been identified. State and local regulations should be considered before planning any chemical handling system.

The chemicals and solids in rinse water should be concentrated. This can be done by collecting the material in an evaporative pond. Once the sludge has dehydrated, it should be placed in a leakproof container. If possible the container should be disposed of by local or state officials or by private businesses that specialize in this activity. Proper clothing and breathing equipment should be used when handling spent chemicals and sludge from settling/drying basins. Precaution should be taken to prevent animals and children from gaining access to such facilities.

Rinse water may be collected in below ground pits. This liquid can then be used as a part of the make-up water when the chemical is needed again. Separate pits are needed for different chemicals.

Purchase and use only the amount of material actually needed. This requires accurate determination of the amount of pesticide solution needed and careful calibration and operation of application equipment. Once a chemical solution is prepared, all of the material needs to be used for the purpose intended. This reduces the amount of waste material to be processed.

Chemical containers can be disposed of properly in one of two ways. They can be turned over to authorities or businesses that have the responsibility of handling them, or they can be buried. Before the containers are buried, they must first be triple rinsed, opened, and the liquid allowed to evaporate. Burial is practical only in locations where the burial site will always be above the ground water level.

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Chapter 10

Agricultural Waste Management System Component Design

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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 decisionmaker 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.

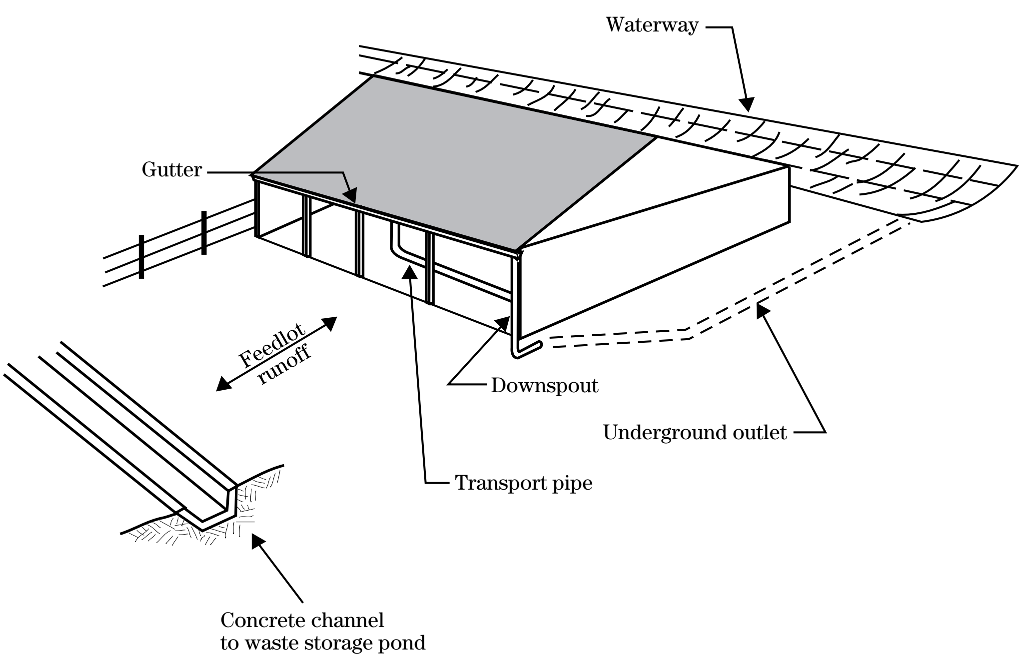
(a) Roof runoff management

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.

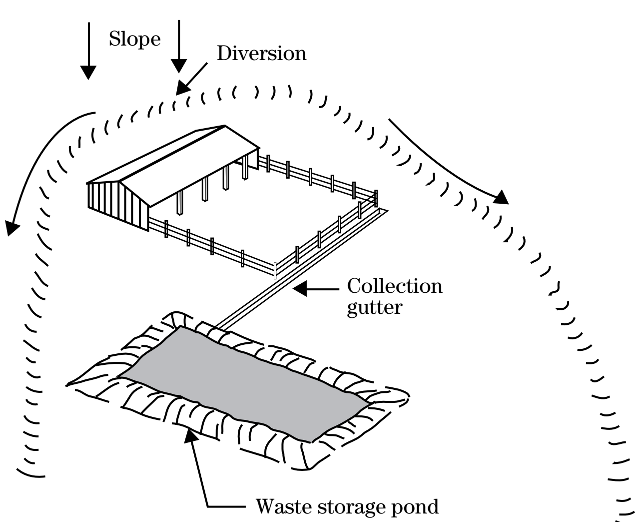
(b) Runoff control

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.

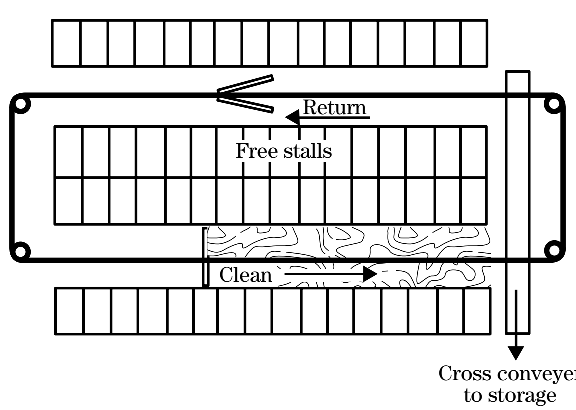
A tractor scraper can be used in irregularly shaped alleys and open areas where mechanical scrapers cannot function properly. It can be a blade attached to either the front or rear of a tractor or a skid-steer tractor that has a front-mounted bucket.

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

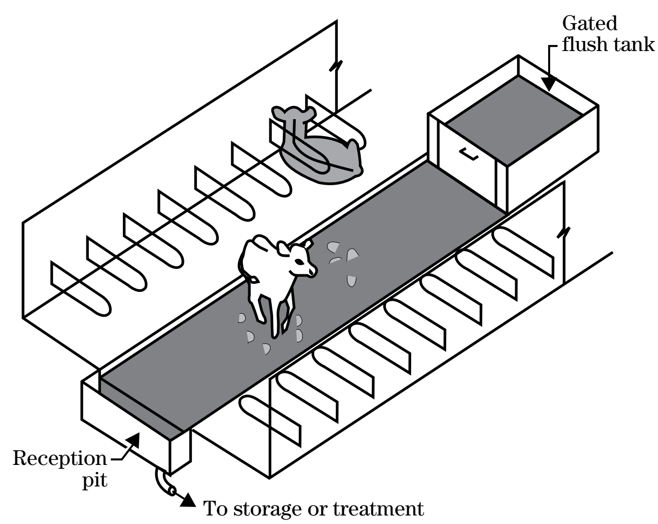
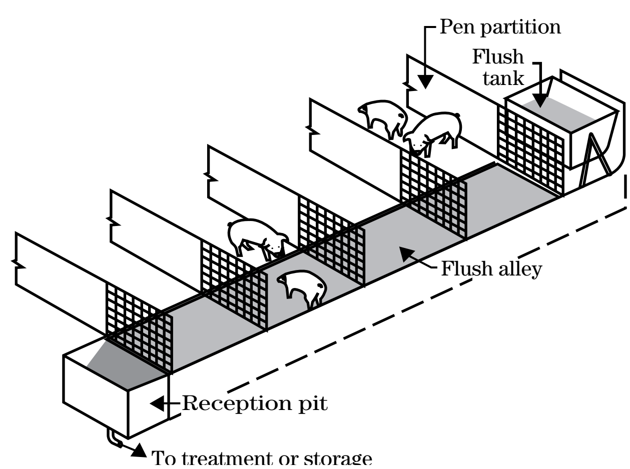


Figure 10–5 Swine flush alley



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.

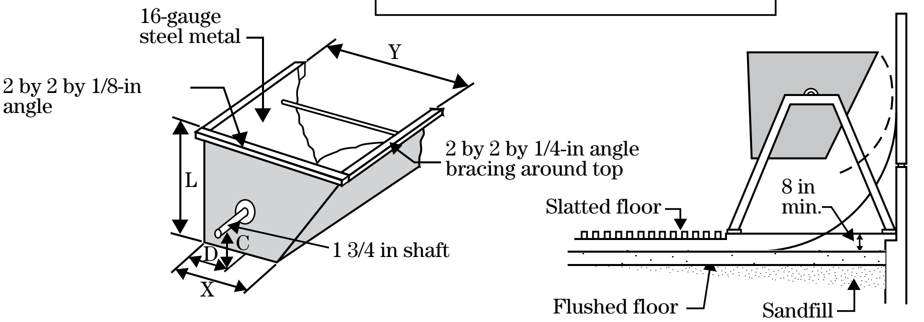
Some flush tanks have manually opened gates. These tanks are emptied by opening a valve, standpipe, pipe plug, or flush gate. Float switches can be used to control flushing devices.

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.

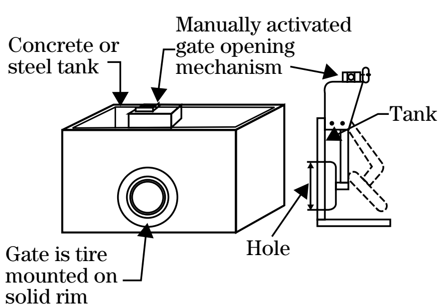
Most flush systems use pumps to recharge the flush tanks or to supply the necessary flow if the pump flush technique is used. Centrifugal pumps typically are used. The pumps should be designed for the work that they will be doing. Low volume pumps (10–150 gal/min) may be used for flush tanks, but high 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

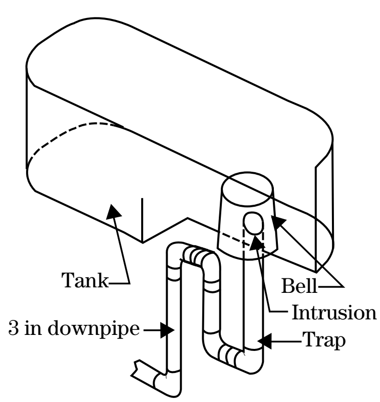
Gal/ft of	Tank dimensions in				
tank length	X	Y	L	C	D
40	18	36	30	15 1/2	14 1/2
30	18	33	24	12 1/2	13
24	18	30	20	10 1/2	12



Tipping tank



Tank with circular flush gate



Automatic siphon tank

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.

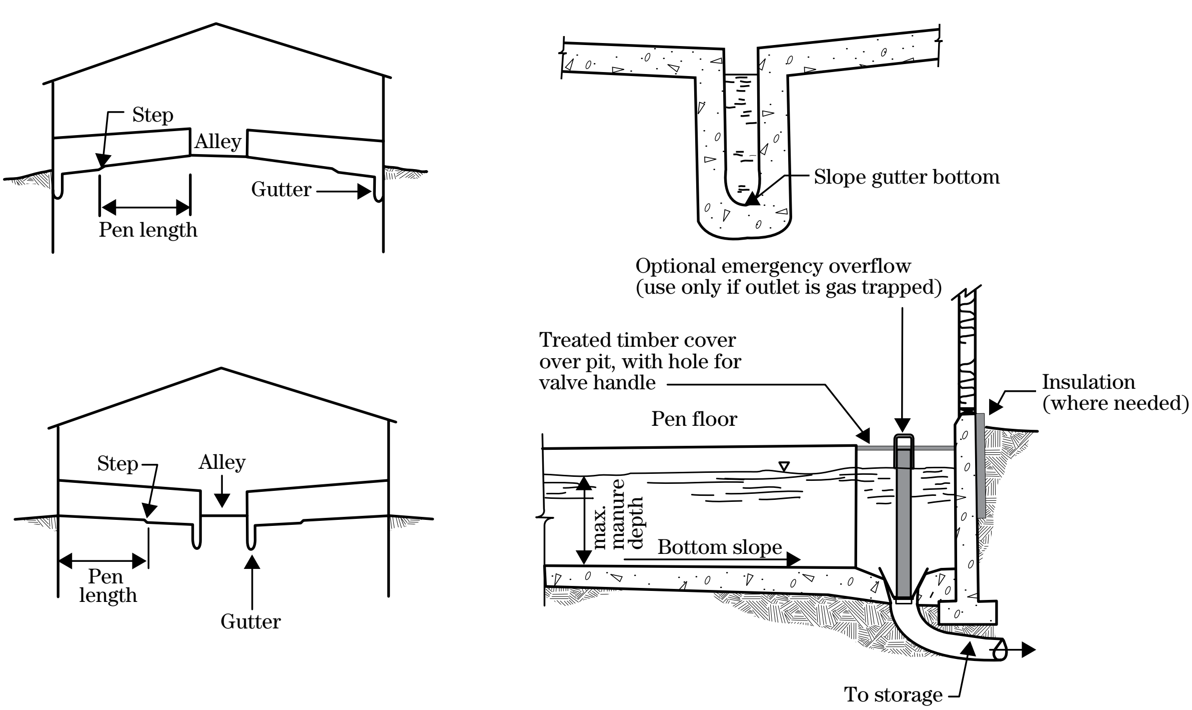
(2) Step-dam gutters

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

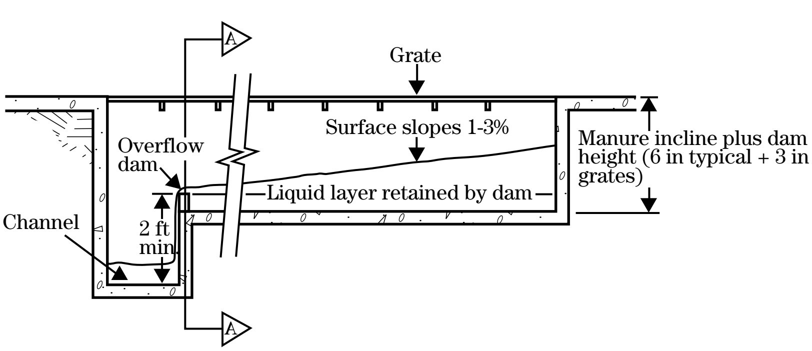
Narrow gutters can also be cleaned by flushing. Flush gutters are usually a minimum of 2 feet deep on the shallow end. The depth may be constant or increase as the length of the gutter increases. The bottom grade can vary from 0 to 5 percent depending on storage requirements and clean out technique. 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

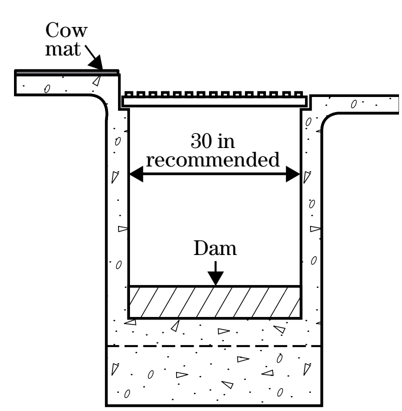
Manure and bedding are worked through the slats by the animal traffic into a storage tank or alley below. Most slats are constructed of reinforced concrete (fig. 10–11); however, some are made of wood, plastic, or aluminum. They are manufactured either as individual units or as gangs of several slats. 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

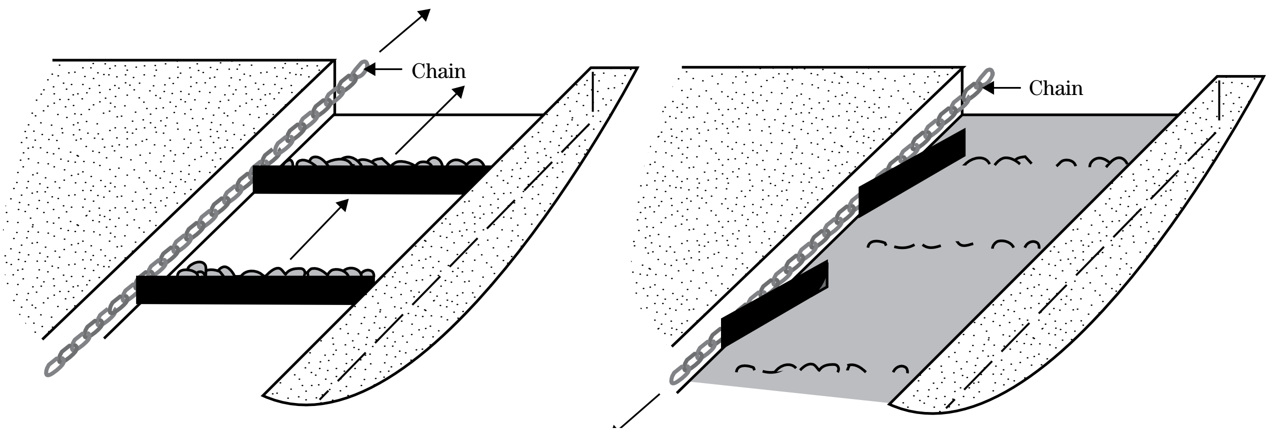


Figure 10–10 Chain and flight gutter cleaner

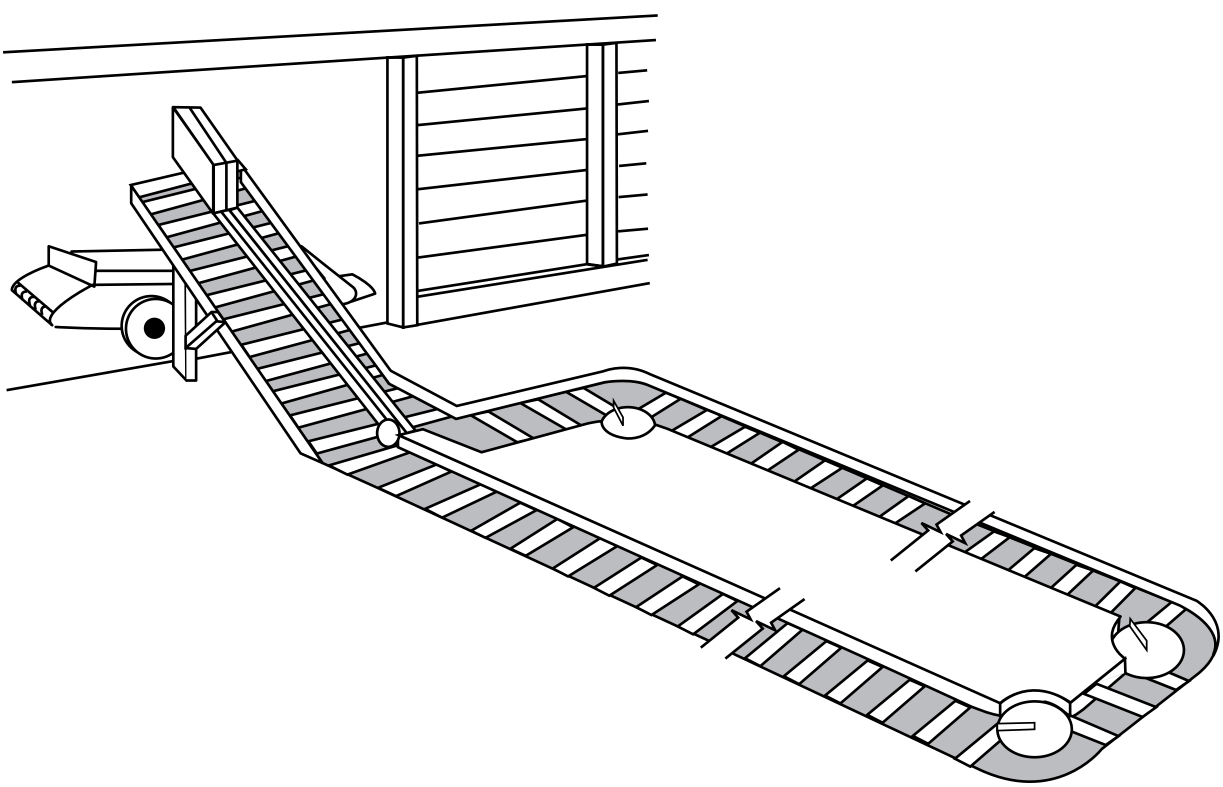
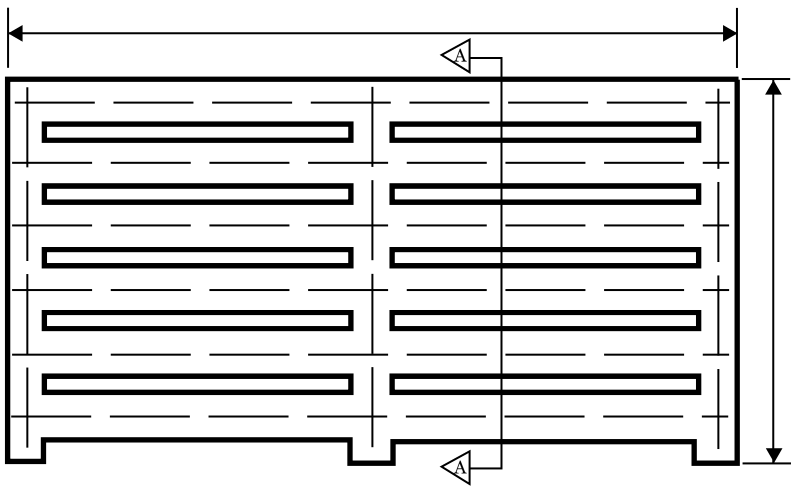
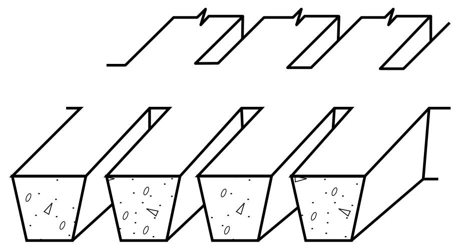


Figure 10–11 Concrete gang slats





Isometric section A-A

651.1003 Transfer

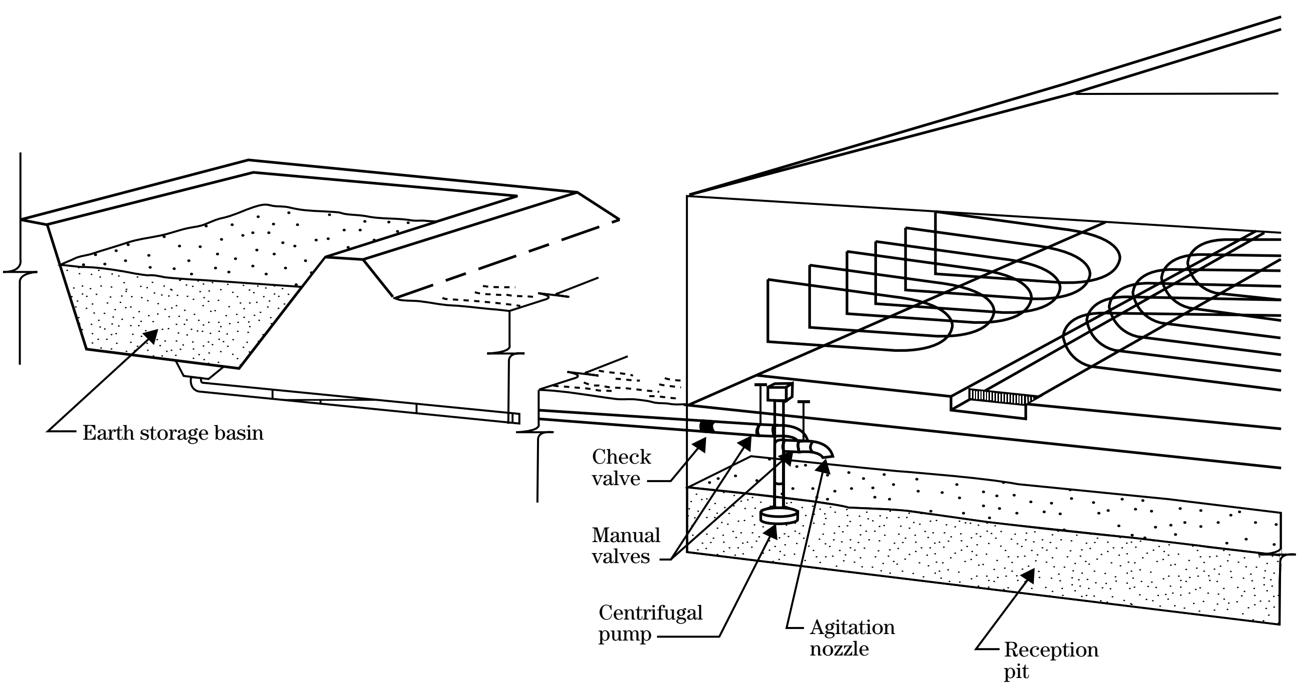
Manure collected from within a barn or confinement area must be transferred to the storage or treatment facility. In the simplest system, the transfer component is an extension of the collection method. More typically, transfer methods must be designed to overcome distance and elevation changes between 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.

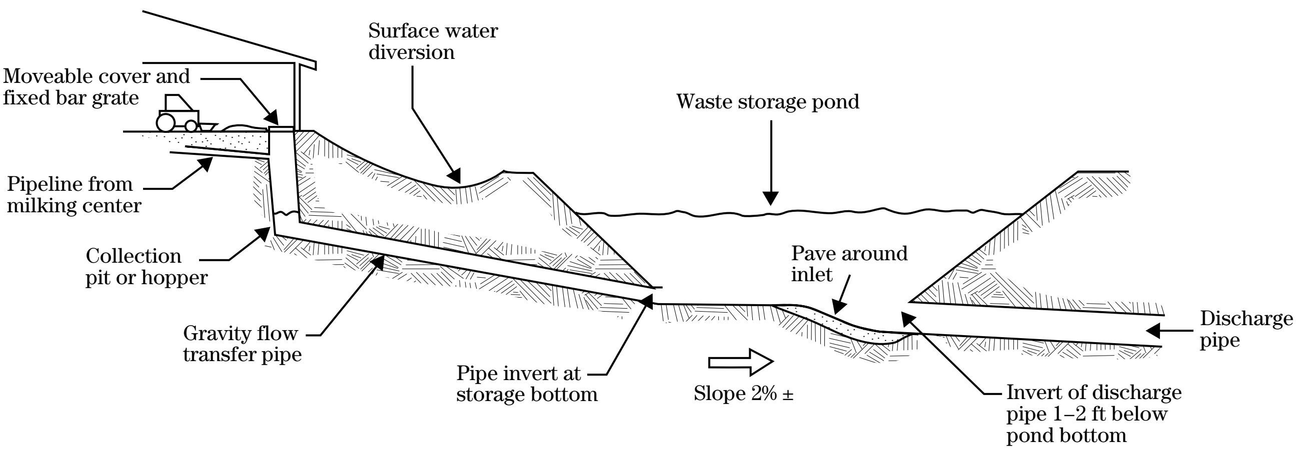
(c) Push-off ramps

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.

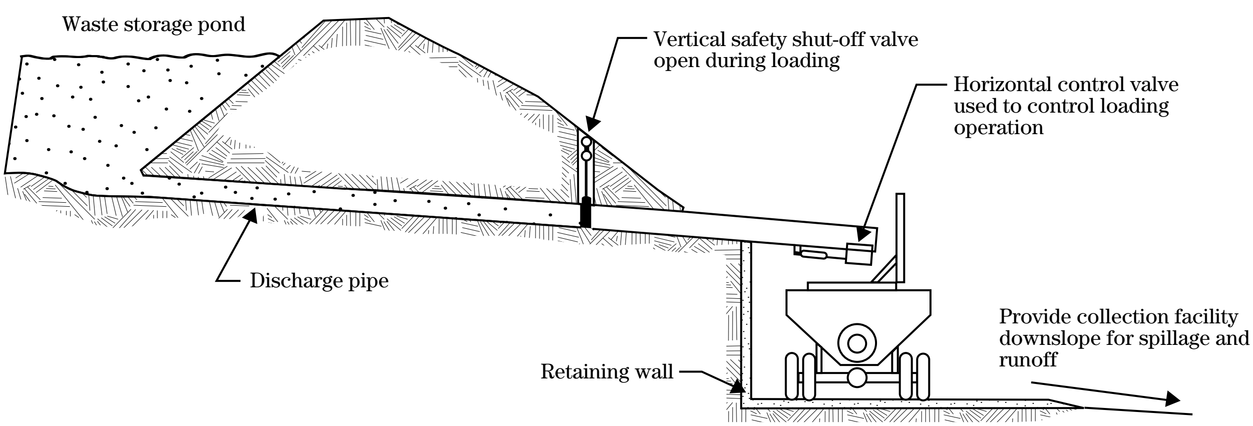
(d) Pumps

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

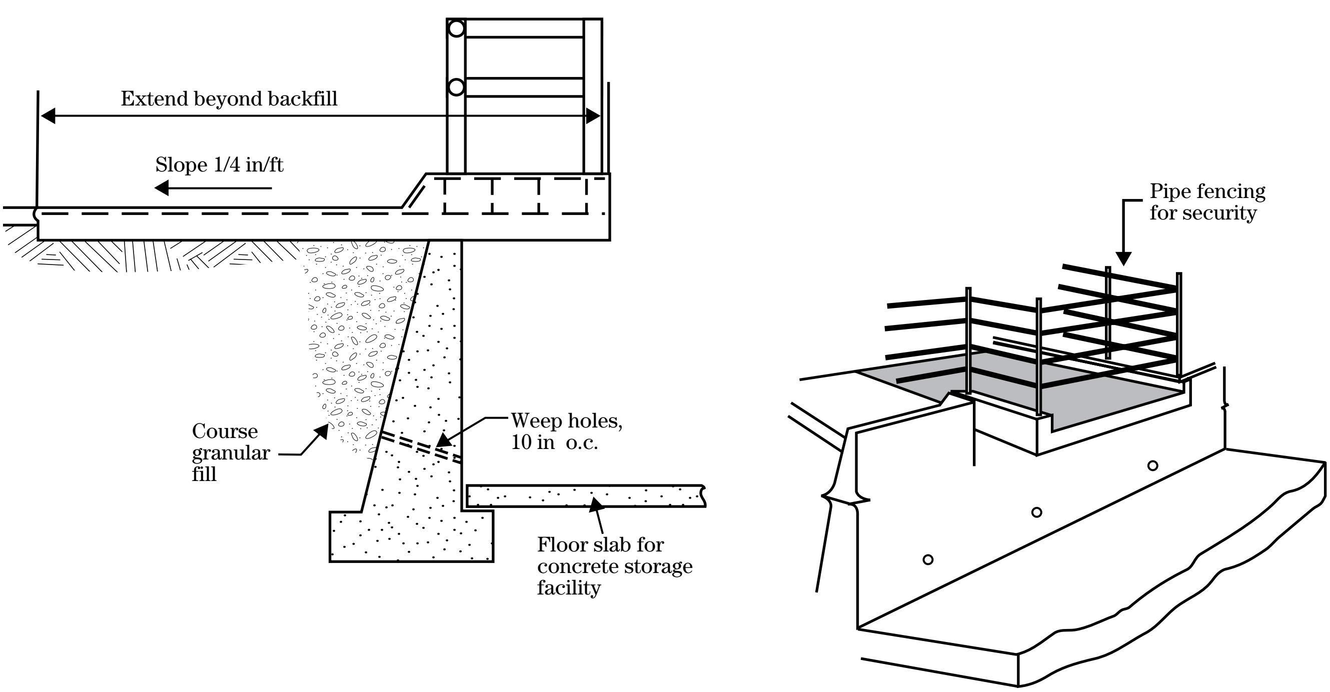
The centrifugal group includes vertical shaft, horizontal shaft, and submersible pumps. They can be used for agitation and transfer of liquid manure; however, only vertical and horizontal shaft pumps are used for irrigation because of the head that they can develop.

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:

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

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:

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

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

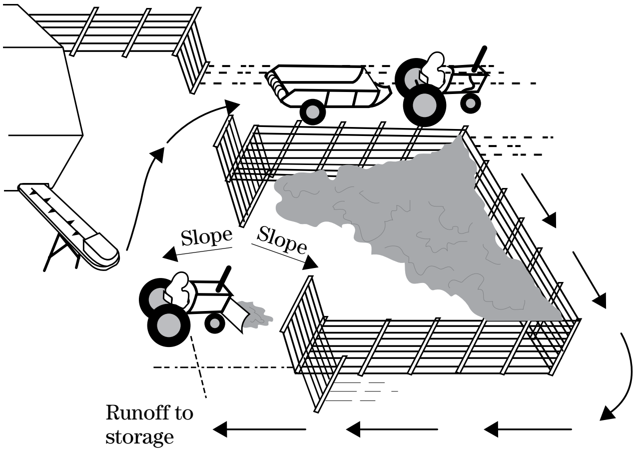
Using the recommended volumetric void ratio of 0.5, the equation becomes:

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

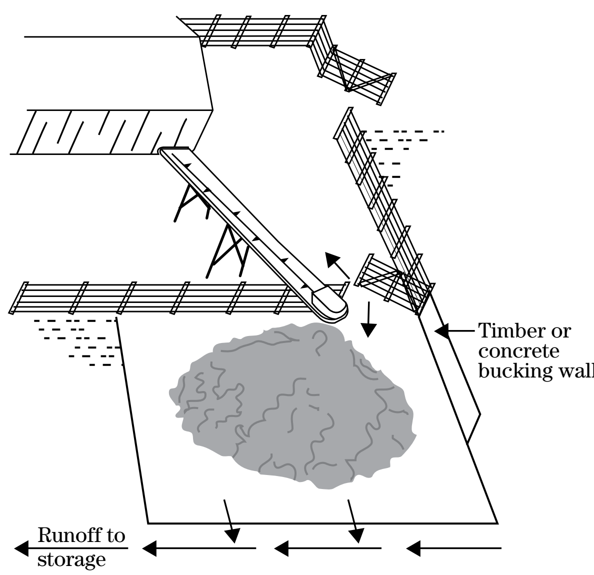
Characteristics of manure and bedding are described in AWMFH, chapter 4. Other values may be available locally or from the farmer or rancher.

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

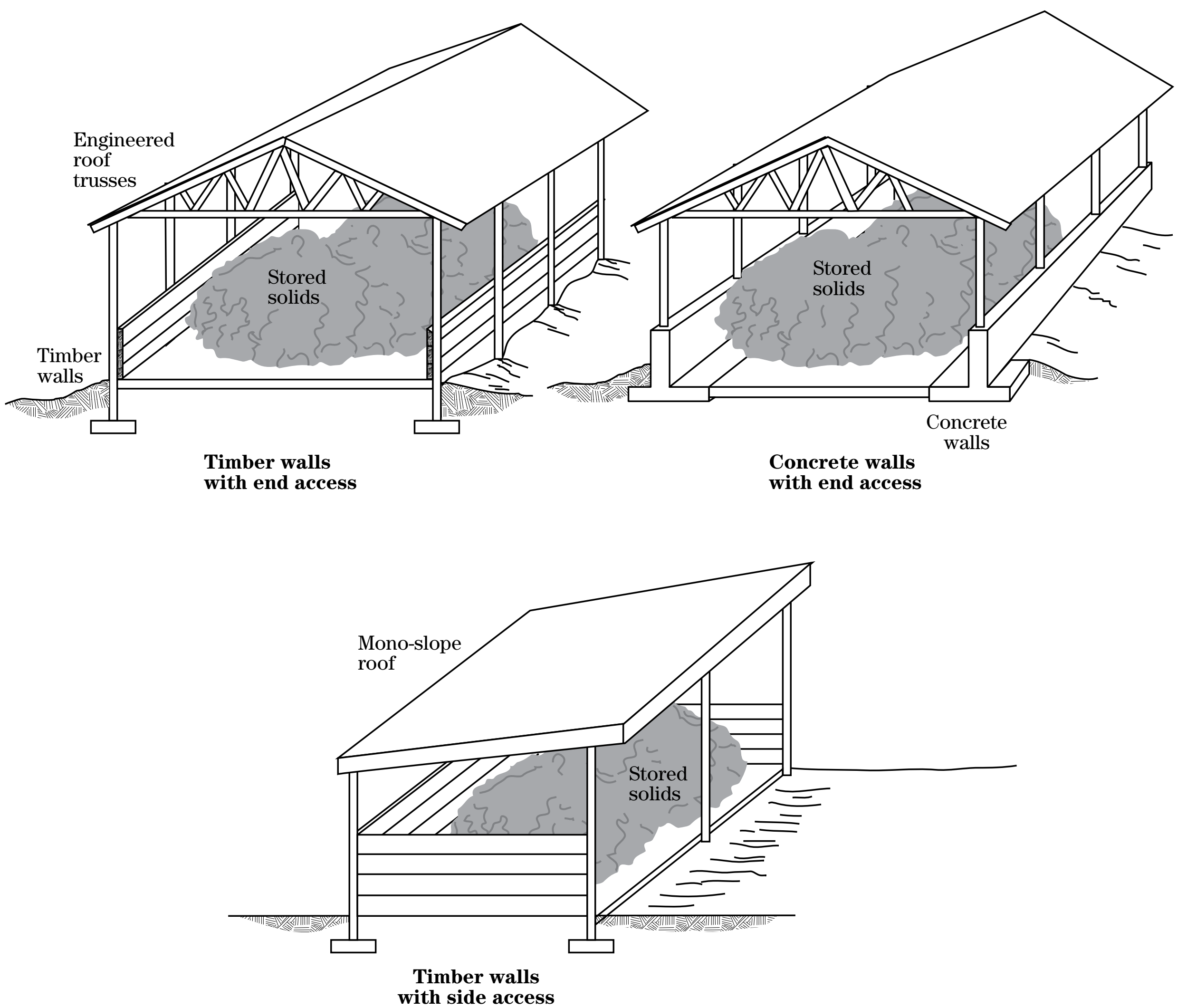


Barn cleaner to spreader or tractor stacking



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.

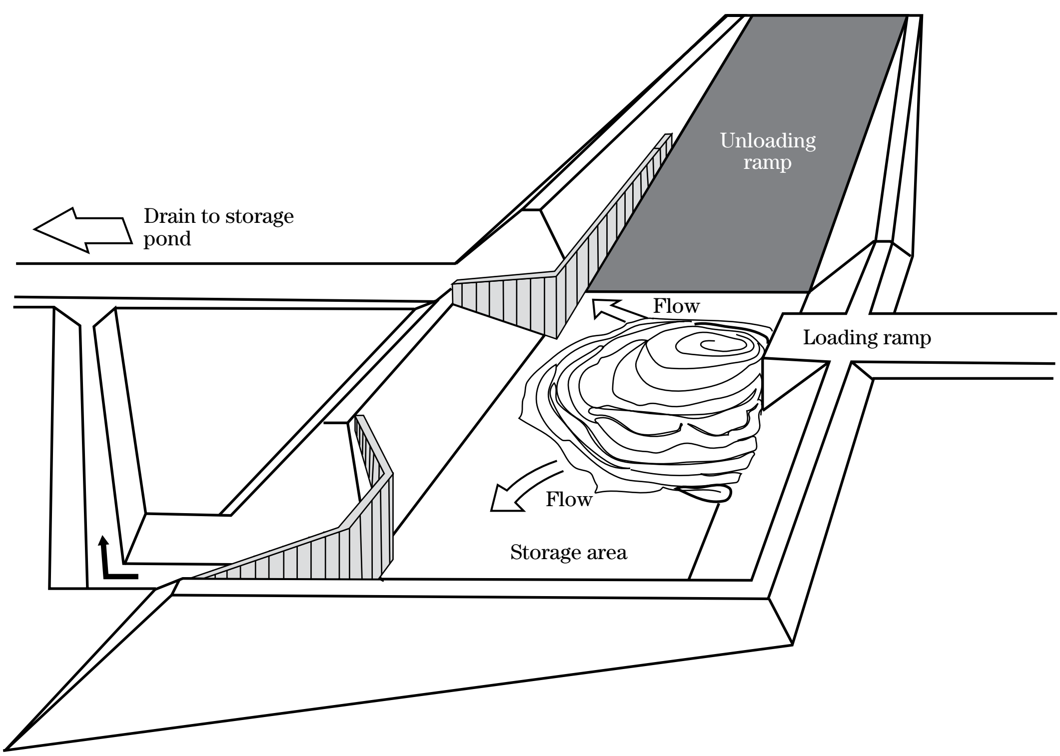
The picket dam should be near the unloading ramp to collect runoff and keep the access as dry as possible. It should also be on the side of the storage area opposite the loading ramp. Water should always have a clear drainage path from the face (leading edge) of the manure pile to the picket dam.

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

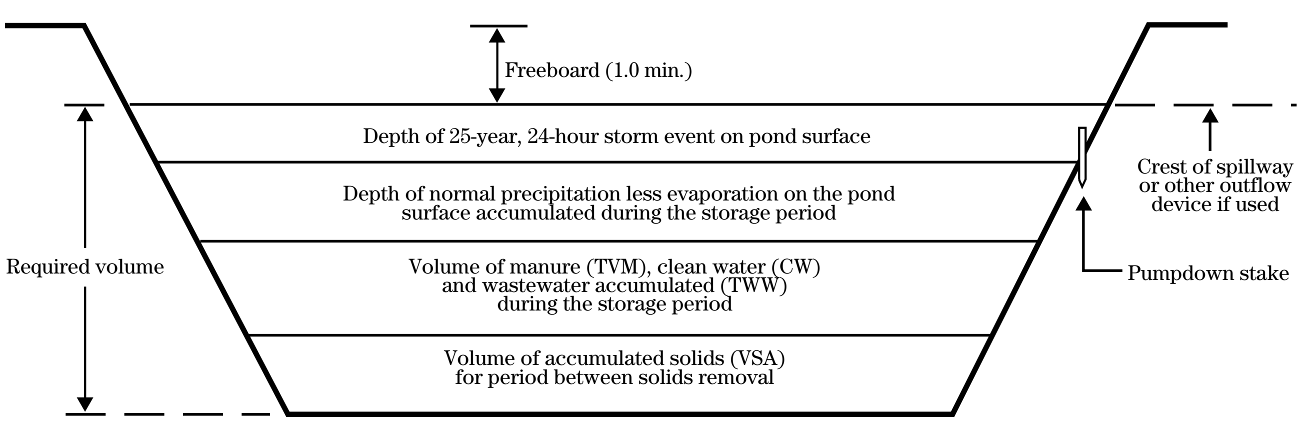
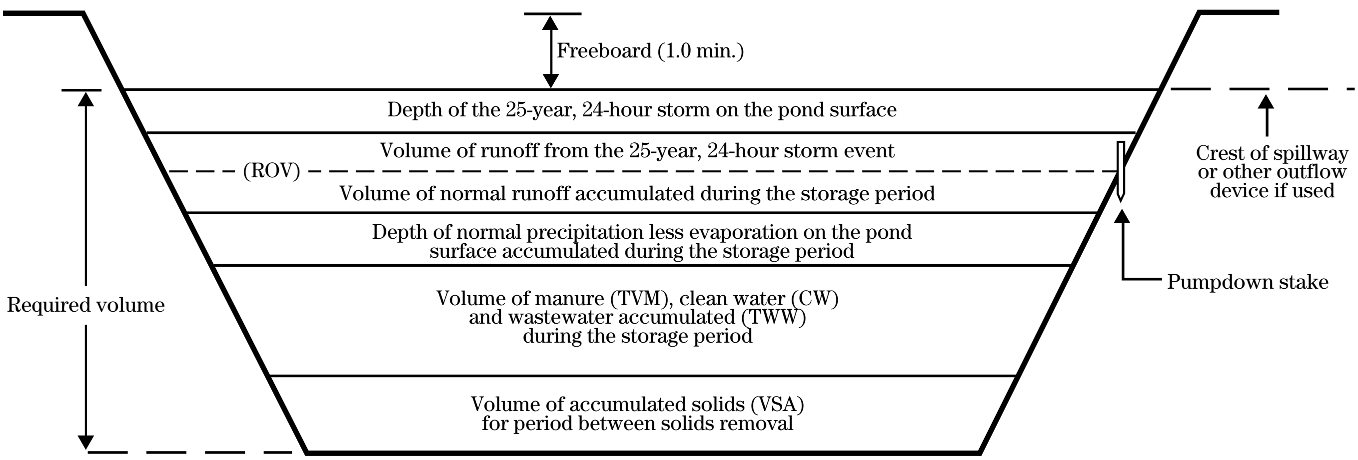
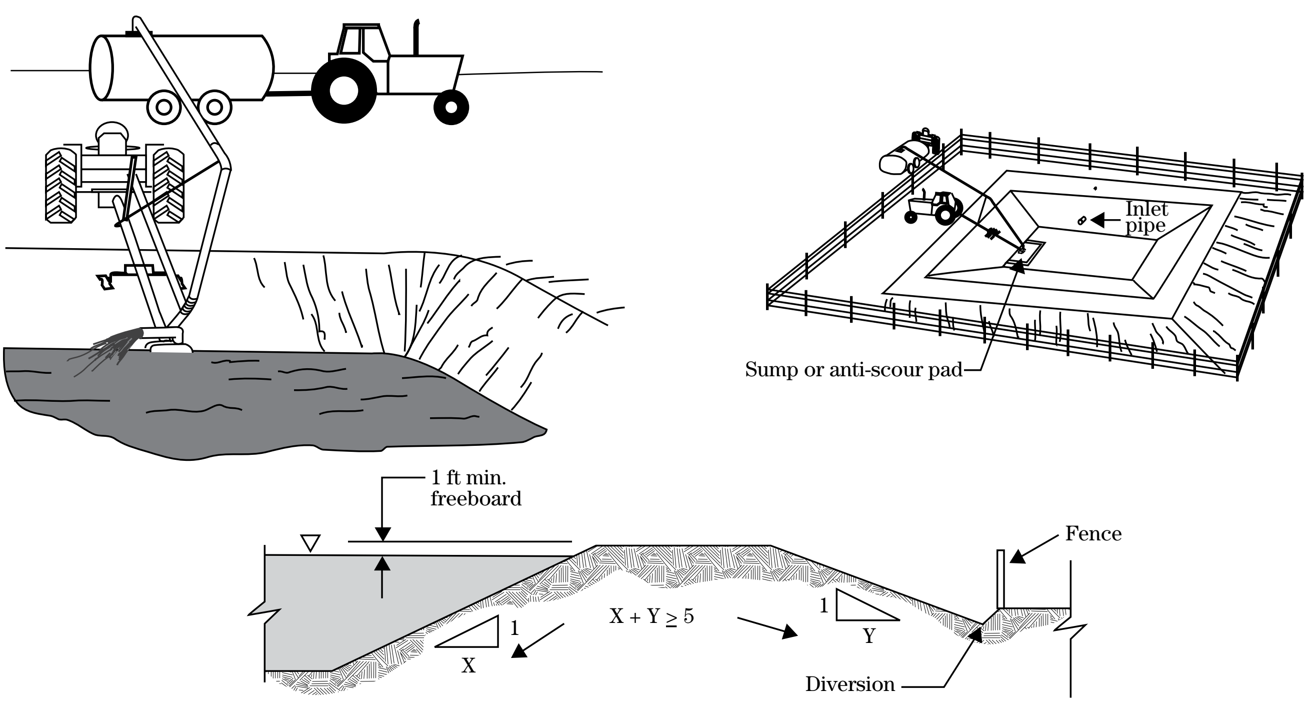


Figure 10–19 Cross section of waste storage pond with watershed



*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 ≤ 1 x 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

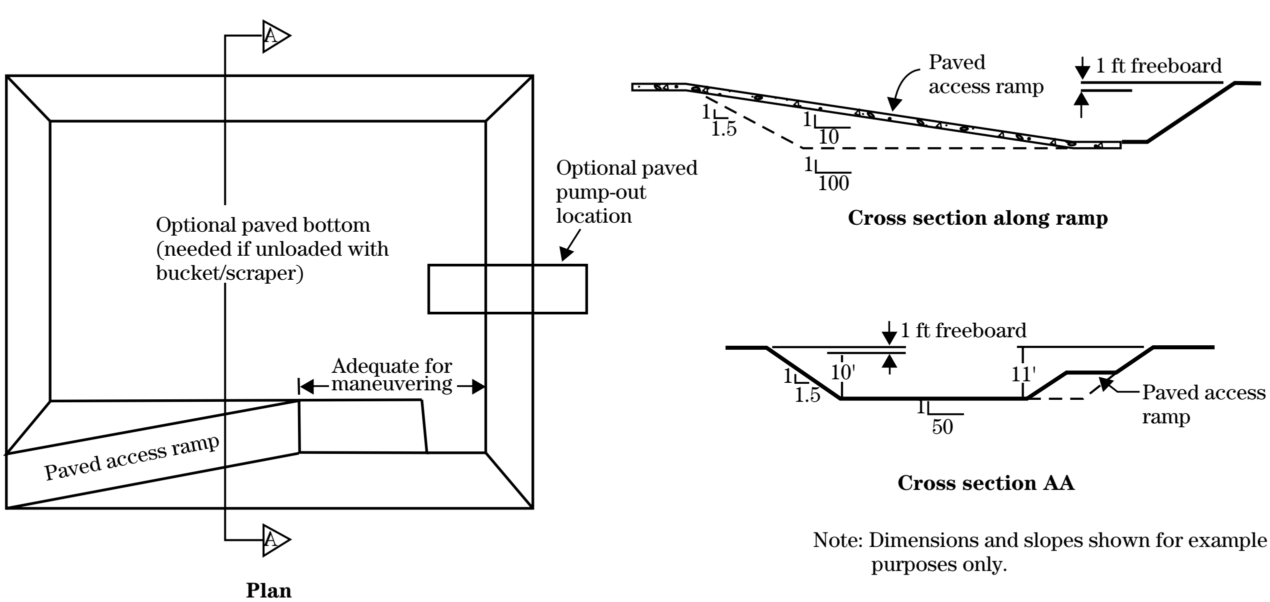


Figure 10–22 Aboveground waste storage tank

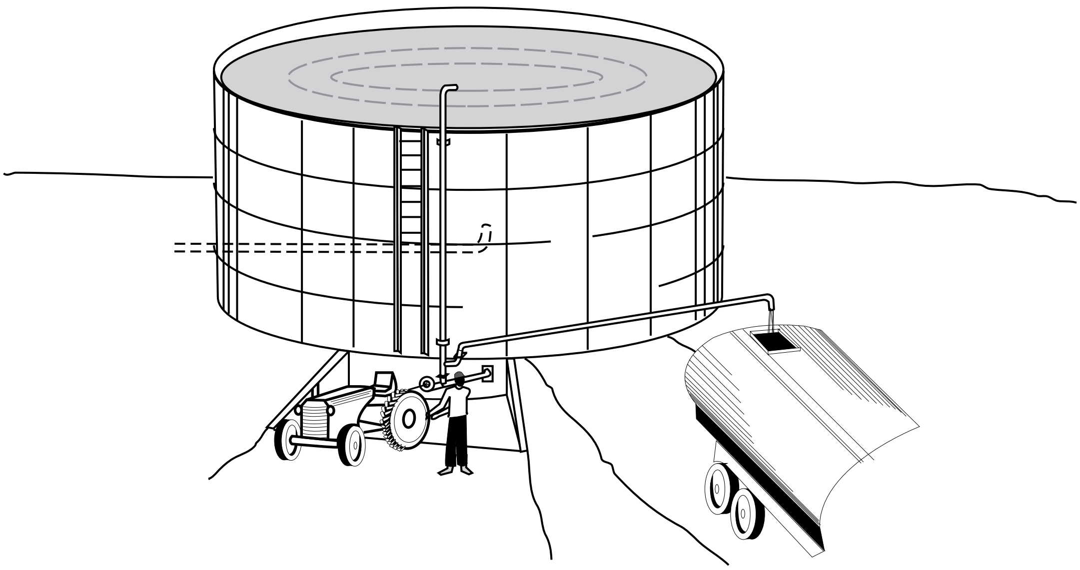
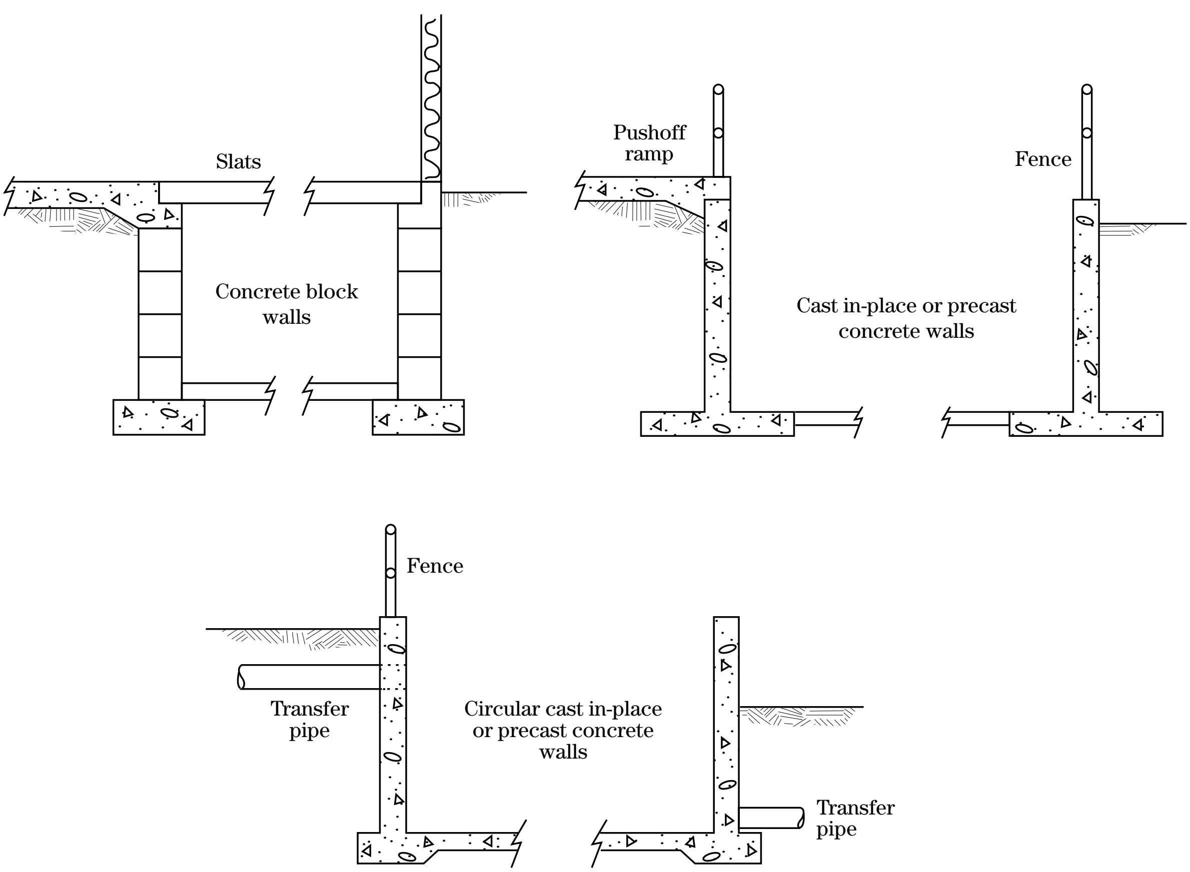


Figure 10–23 Belowground waste storage structure



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.

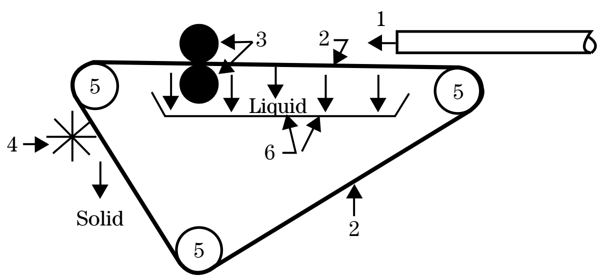
Mechanical separation—Several kinds of mechanical separators can be used to remove by-products from manure (fig. 10–24). One kind commonly used is a screen. Screens are statically inclined or in continuous motion to aid in separation. The most common type of continuous motion screen is a vibrating screen. 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.

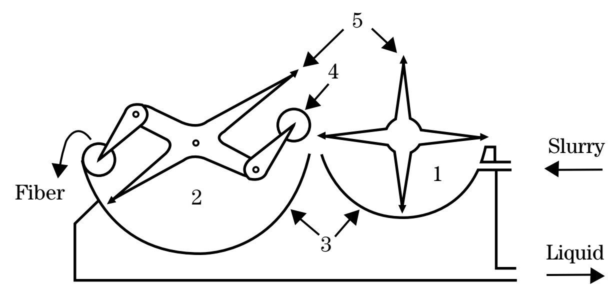
Figure 10–24 Schematic of mechanical solid-liquid separators

Flat belt separator



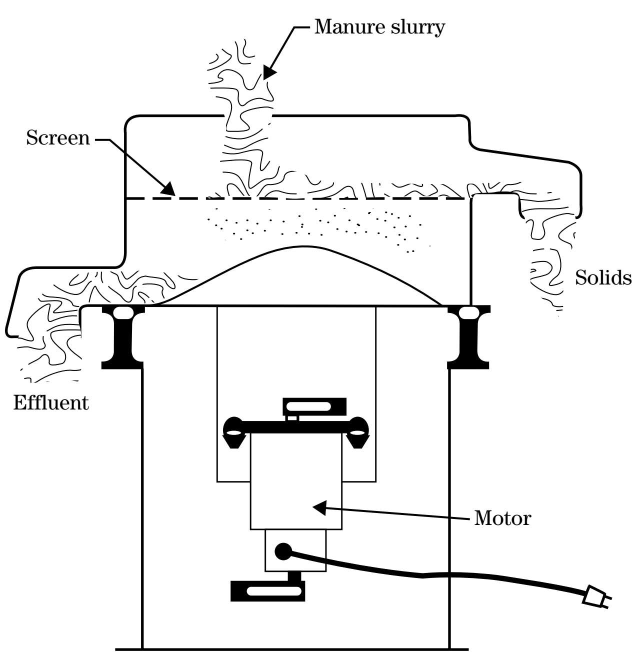
1 Slurry input
2 Polyester mesh belt
3 Press rollers
4 Rotary brush
5 Belt guide rollers
6 Liquid collection trough

Roller-press separator

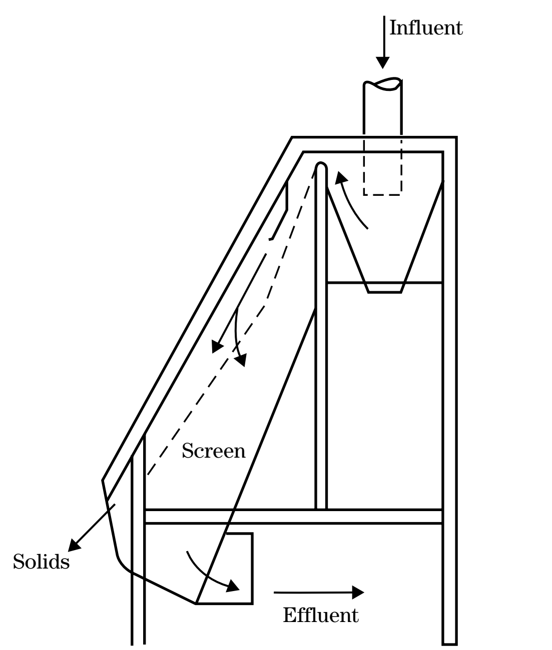


1 Screening stage
2 Roller pressing stage
3 Screens
4 Spring loaded press roller
5 Brushes

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.

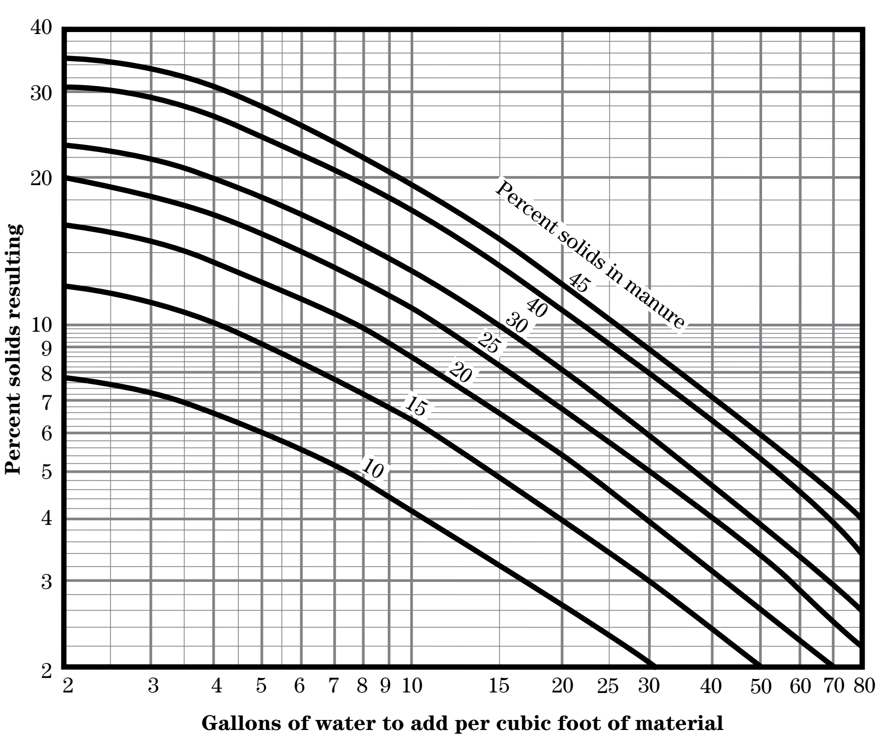
(2) Anaerobic lagoons

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.

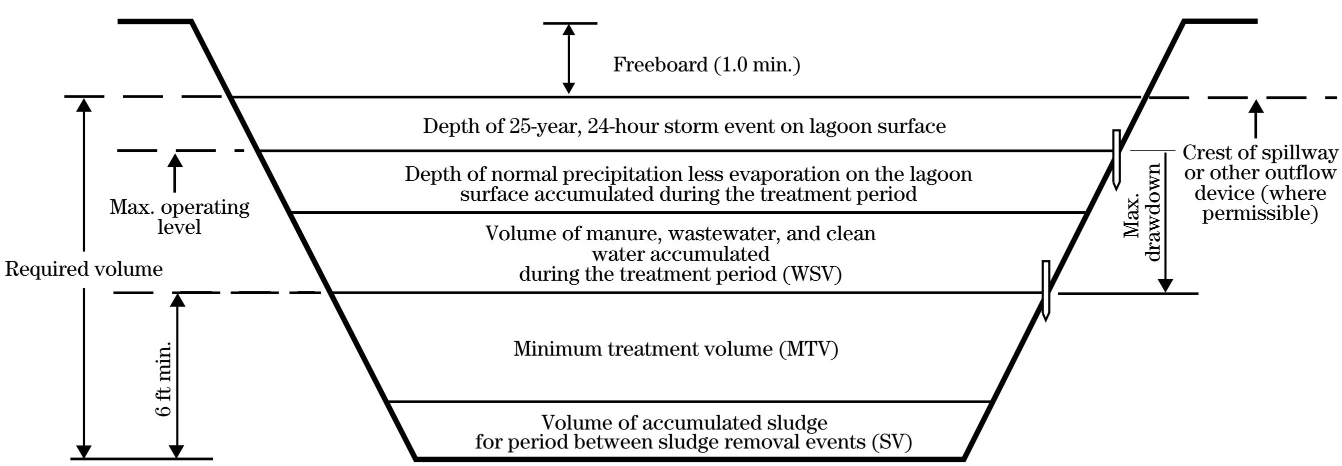
The MTV represents the volume needed to maintain sustainable biological activity. The MTV for volatile solids (VS) can be determined using equation 10–4.

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

where:

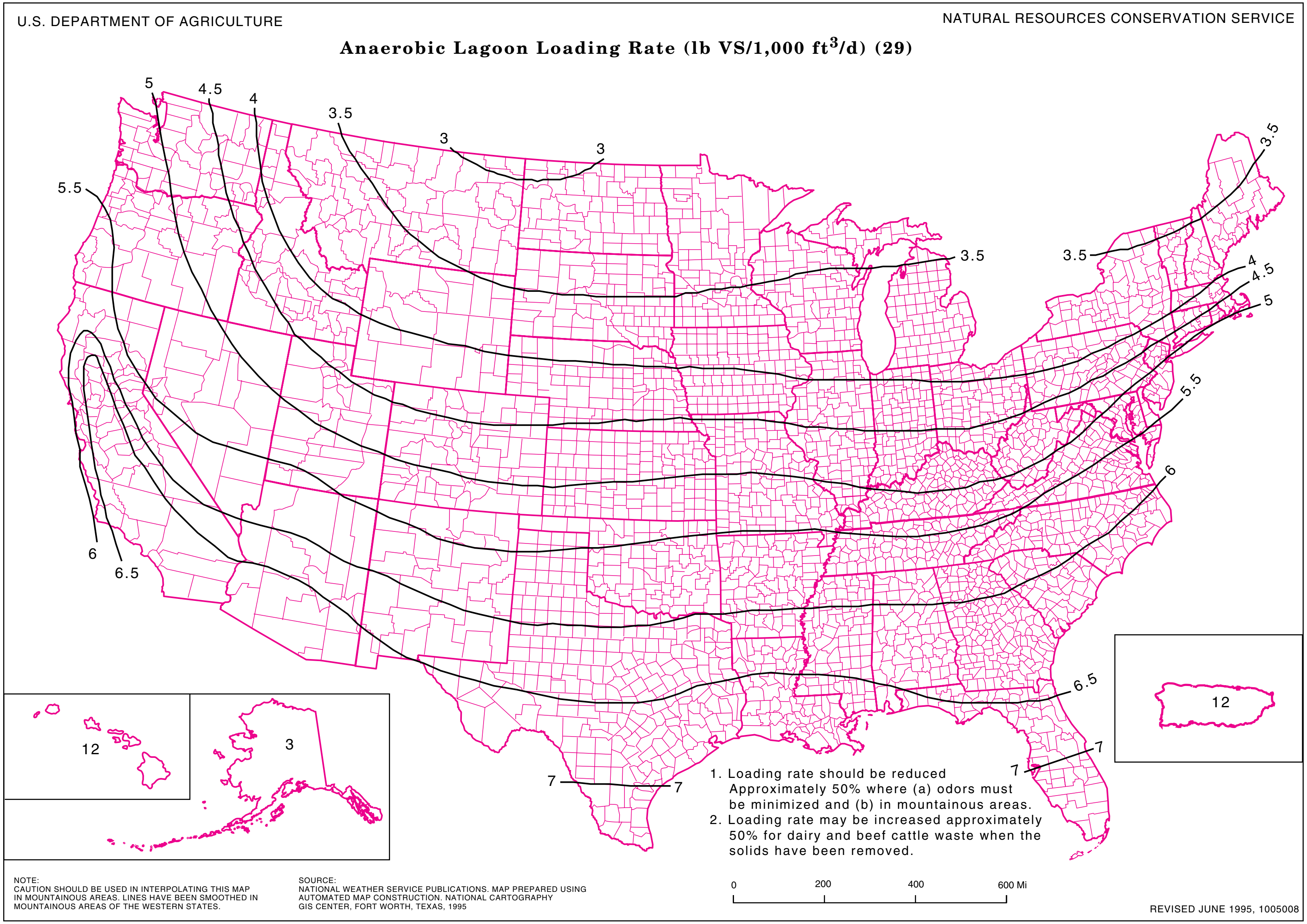
MTV = minimum treatment volume, ft^3
TVS = total daily volatile solids loading (from all sources), lb/d
VSLR = volatile solids loading rate, lb/1,000 ft^3/d (from fig. 10–27)

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)



Daily VS production for various wastes can be determined using tables in AWMFH, chapter 4. If feed spillage exceeds 5 percent, VSP should be increased by 4 percent for each additional 1 percent spillage.

Waste volume (WV) should reflect the actual volume of manure, wastewater, flushwater that will not be recycled, and clean dilution water added to the lagoon during the treatment period. The treatment period is either the detention time required to obtain the desired reduction of pollution potential of the waste or the time between land application events, whichever is longer. State regulations may govern the minimum detention time. Generally, the maximum time between land application events determines the treatment period because this time generally exceeds the detention time required.

$$WV = TVM + TWW + CW \qquad \text{(eq. 10–5)}$$

where:
WV = waste volume for treatment period, ft^3
TVM = total volume of manure for treatment period, ft^3
TWW = total volume of wastewater for treatment period, ft^3
CW = clean water added during treatment period, ft^3

In the absence of site-specific data, values in AWMFH, chapter 4, may be used to make estimates of the volumes.

As the manure is decomposed in the anaerobic lagoon only part of the TS is reduced. Some of the TS is mineral material that will not decompose, and some of the VS require a long time to decompose. These materials, referred to as sludge, gradually accumulate in the lagoon. To maintain the MTV, the volume of sludge accumulation over the period of time between sludge removal must be considered. Lagoons are commonly designed for a 15- to 20-year sludge accumulation period. The sludge volume (SV) can be determined using equation 10–6.

$$SV = 365 \times AU \times TS \times SAR \times T \qquad \text{(eq. 10–6)}$$

where:
SV = sludge volume (ft^3)
AU = equivalent 1,000-pound animal (live weight)
T = sludge accumulation time (yr)
TS = total solids production per AU per day (lb/AU/d)
SAR = sludge accumulation ratio (ft^3/lb TS)

TS values can be obtained from the tables in AWMFH, chapter 4. Sludge accumulation ratios (SAR) should be taken from table 10–7. An SAR is not available for beef, but it can be assumed to be similar to that for dairy cattle.

The lagoon volume requirements are for accommodation of the MTV, the SV, and the waste volume for the treatment period. This is expressed in equation 10–7.

$$LV = MTV + SV + WV \qquad \text{(eq. 10–7)}$$

where:
LV = lagoon volume requirement, ft^3
MTV = minimum treatment volume, ft^3 (see eq. 10–4)
SV = sludge volume accumulation for period between sludge removal events, ft^3 (see eq. 10–6)
WV = waste volume for treatment period, ft^3 (see eq. 10–5)

In addition to the lagoon volume requirement (LV), a provision must be made for depth to accommodate the normal precipitation less evaporation on the lagoon surface; the 25-year, 24-hour storm precipitation; the depth required to operate the emergency outflow; and freeboard. Normal precipitation on the lagoon surface is based on the critical treatment period that produces the maximum depth. This depth can be offset to some degree by evaporation losses on the lagoon surface. This offset varies, according to the climate of the region, from a partial amount of the precipitation to an amount in excess of the precipitation. Precipitation and evaporation can be determined from local climate data.

Table 10–7 Sludge accumulation ratios (Barth 1985)

Animal type	SAR
Poultry	
Layers	0.0295
Pullets	0.0455
Swine	0.0485
Dairy cattle	0.0729

The minimum acceptable depth for anaerobic lagoons is 6 feet, but in colder climates at least 10 feet is recommended to assure proper operation and odor control.

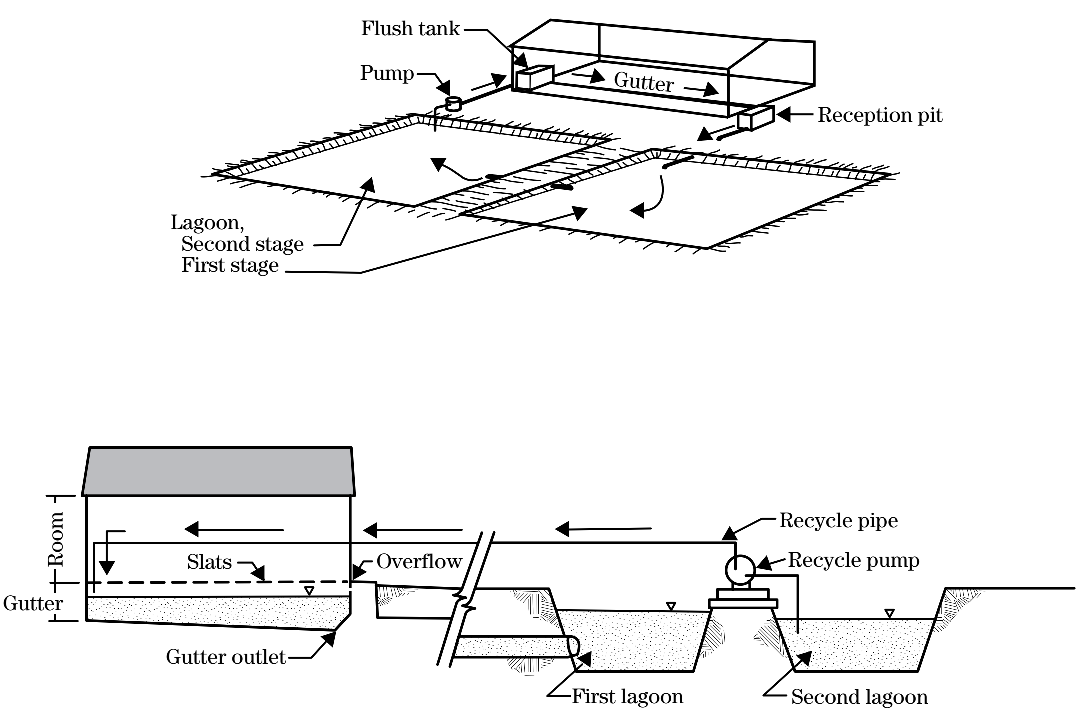
The design height of an embankment for a lagoon should be increased by the amount needed to ensure that the design elevation is maintained after settlement. This increase should not be less than 5 percent of the design fill height. The minimum top width of the lagoon should be in accordance with NRCS Conservation Practice Standard 359, Waste Treatment Lagoon.

The combined side slopes of the settled embankment should not be less than 5 to 1 (horizontal to vertical). The inside slopes can vary from 1 to 1 for excavated slopes to 3 to 1 or flatter where embankments are used. Construction technique and soil type must also be considered. In some situations, a steep slope may be used below the design liquid level, while a flatter slope is used above the liquid level to facilitate maintenance and bank stabilization. The minimum elevation of the top of the settled embankment should be 1 foot above the maximum design water surface in the lagoon.

A lagoon should be constructed to avoid leakage and potential ground water pollution. Care in site selection, soils investigation, and design can minimize the potential for these problems. In cases where the lagoon needs to be sealed, the techniques discussed in AWMFH, chapter 7 can be used. Figure 10–28 shows two lagoon systems.

If overtopping can cause embankment failure, an emergency spillway or overflow pipe should be provided. A lagoon can have an overflow to maintain a constant liquid level if the overflow liquid is stored in a waste storage pond or otherwise properly managed. The inlet to a lagoon should be protected from freezing. This can be accomplished by using an open channel that can be cleaned out or by locating the inlet pipe below the freezing level in the lagoon. Because of possible blockages, access to the inlet pipe is needed.

Figure 10–28 Anaerobic lagoon recycle systems



Venting inlet pipes prevents backflow of lagoon gases into the animal production facilities.

Sludge removal is an important consideration in the design. This can be accomplished by agitating the lagoon and pumping out the mixed sludge or by using a drag-line for removing floating or settled sludge. Some pumps can remove sludge, but not deposited rocks, sand, or grit. The sludge removal technique should be considered when determining lagoon surface dimensions. Many agitation pumps have an effective radius of 75 to 100 feet. Draglines may only reach 30 to 50 feet into the lagoon.

Management—Anaerobic lagoons must be managed properly if they are to function as designed. Specific instructions about lagoon operation and maintenance must be included in the overall waste management plan that is supplied to the decisionmaker. Normally, an anaerobic lagoon is managed so that the liquid level is maintained at or below the maximum operating level as shown in figure 10–26. The liquid level is lowered to the minimum treatment level at the end of the treatment period. It is good practice to install markers at the minimum treatment and maximum operating levels.

The minimum liquid level in an anaerobic lagoon before wastes are added should coincide with the MTV. If possible a lagoon should be put into service during the summer to allow adequate development of bacterial populations. A lagoon operates more effectively and has fewer problems if loading is by small, frequent (daily) inflow, rather than large, infrequent slug loads.

The pH should be measured frequently. Many problems associated with lagoons are related to pH in some manner. The optimum pH is about 6.5. When pH falls below this level, methane-producing bacteria are inhibited by the free hydrogen ion concentration. The most frequent cause of low pH in anaerobic digestion is the shock loading of organic material that stimulates the facultative acid-producing bacteria. Add hydrated lime or lye if pH is below 6.5. Add 1 pound per 1,000 square feet daily until pH reaches 7.

Lagoons are designed based on a given loading rate. If an increase in the number of animals is anticipated, sufficient capacity to handle the entire expected wasteload should be available. The most common problem in using lagoons is overloading, which can lead to odors, malfunctioning, and complaints. When liquid removal is needed, the liquid level should not be dropped below the MTV plus SV levels. If evaporation exceeds rainfall in a series of dry years, the lagoon should be partly drawn down and refilled to dilute excess concentrations of nutrients, minerals, and toxics. Lagoons are typically designed for 15 to 20 years of sludge accumulation. After this time the sludge must be cleaned out before adding additional waste.

Sometimes operators want to use lagoon effluent as flushwater. To polish and store water for this purpose, waste storage ponds can be constructed in series with the anaerobic lagoon. The capacity of the waste storage pond should be sized for the desired storage volume. A minimum capacity of the waste storage pond is the volume for rainfall (RFV), runoff (ROV), and emergency storm storage (ESV). By limiting the depth to less than 6 feet, the pond will function more nearly like an aerobic lagoon. Odors and the level of ammonia, ammonium, and nitrate will be more effectively reduced.

Design example 10–5 Anaerobic lagoon

Mr. Oscar Smith of Rocky Mount, North Carolina, has requested assistance in developing an agricultural waste management system for his 6,000 pig finishing facility. The alternative selected includes an anaerobic lagoon. The animals average 150 pounds. The 25-year, 24-hour storm for the area is 6 inches (appendix 10B). Mr. Smith needs 180-day intervals between lagoon pumping. During this time, the net precipitation should be 2 inches, based on data from appendices 10B and 10C. He wants to use the lagoon for at least 5 years before removing the sludge. Worksheet 10A–3 is used to determine the necessary volume for this lagoon.

Completed worksheet for Design example 10–5

Worksheet 10A-3—Anaerobic lagoon design

Decisionmaker: Oscar Smith   Date: 6/13/90

Site: Rocky Mount, NC

Animal units

1. Animal type: Growers
2. Animal weight, lbs (W): 150
3. Number of animals (N): 6000
4. Animal units, $AU = \frac{W \times N}{1000}$ = 900

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM)= 1.1
6. Treatment period, days (D) = 180
7. Total volume of manure production for animal type for treatment period, ft^3 VMD = AU x DVM x D = 178,200
8. Total manure production for treatment period, ft^3 (TVM) 178,200

Wastewater volume

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

Clean water volume

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

Waste volume

13. Waste volume for treatment period, ft^3 WV = TVM + TWW + CW = 178,200 + 0 + 0 = 178,200

Manure total solids

14. Daily manure total solids production, lbs/AU/day (MTS) = 6.5
15. Daily manure total solids production for animal type, lbs/day MTSD = MTS x AU = 5,850
16. Total manure total solids production, lbs/day (TMTS) = 5,850

Manure volatile solids

17. Daily manure volatile solids production per AU, lbs/AU/day (MVS) = 5.4
18. Daily manure volatile solids production for animal type per day, lbs/day MVSD = AU x MVS = 4860
19. Total manure volatile solids production, lbs/day (TMVS) 4860

Wastewater volatile solids

20. Daily wastewater volatile solids production, lbs/1000 gal (DWVS) =
21. Total wastewater volatile solids production for animal type, lbs/day

$$WVSD = \frac{DWVS \times DWW \times 7.48}{D \times 1{,}000} =$$

22. Total wastewater volatile solids production, lbs/day (TWVS) = 0

Total volatile solids (manure and wastewater)

23. Total daily volatile solids production, lbs/day TVS = TMVS + TWVS = 4860 + 0 = 4860

Minimum treatment volume

24. Selected lagoon VS loading rate, lbs VS/1,000 ft^3 (VSLR) = 6
25. Minimum treatment volume, ft^3

$$MTV = \frac{TVS \times 1000}{VSLR} = \frac{(4860) \times 1000}{(6)} = 810{,}000$$

Sludge volume requirement

26. Sludge accumulation ratio, ft^3/lb TS (SAR) = 0.0485
27 Sludge accumulation period, years (T) = 5
28. Sludge volume requirement, ft^3 SV = 365 x TMTS x T x SAR = 365 x (5,850)(5)(0.0485) = 517,798

Minimum lagoon volume requirement

29. Minimum lagoon volume requirements, ft^3 (MLVR) = MTV + SV + WV = 810,000 + 517,798 + 178,200 = 1,505,998

Completed worksheet for Design example 10–5—Continued

Worksheet 10A-3—Anaerobic lagoon design—Continued

Lagoon sizing

30. Sizing by trial and error

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

Side slope ratio, (Z) = 2

V must be equal to or greater than MLVR = 1,505,998 ft³

Trial no.	Bottom width ft (BW)	Bottom length ft (BL)	Depth* ft (d)	Volume ft³ (V)
1	150	1000	8	1,349,931
2	150	1100	8	1,482,731
3	150	1125	8	1,515,931 ~ MLVR

* Depth must be adjusted in Step 31.

Depth adjustment

31. Depth adjustment

Depth, ft (d) 8

Add depth of precipitation less evaporation on lagoon surface (for the treatment period) .... + 0.6

Add depth of 25-year, 24-hour storm .... + 0.5

Add for freeboard (1.0 foot minimum) .... + 1.0

Final depth 10.1

32. Compute total volume using final depth, ft³ (use equation in step 30) 1,969,995

(3) Aerobic lagoons

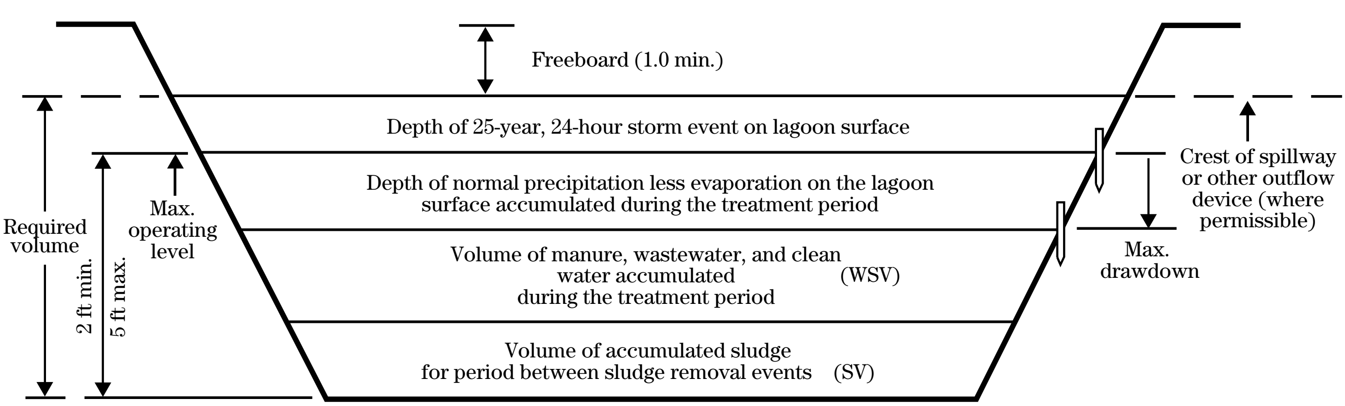
Aerobic lagoons can be used if minimizing odors is critical (fig. 10–29). These lagoons operate within a depth range of 2 to 5 feet to allow for the oxygen entrainment that is necessary for the aerobic bacteria.

The design of aerobic lagoons is based on the amount of biochemical oxygen demand (BOD_5) added per day. If local data are not available, use the BOD_5 values from the tables in AWMFH, chapter 4. Figure 10–30 shows the acceptable aerobic loading rates for the United States in pounds BOD_5 per acre per day. The lagoon surface area at the average operating depth is sized so that the acceptable loading rate is not exceeded.

Even though an aerobic lagoon is designed on the basis of surface area, it must have enough capacity to accommodate the waste volume (WV) and sludge volume (SV). In addition, depth must be provided to accommodate the normal precipitation less evaporation on the lagoon surface, the 25-year, 24-hour storm precipitation on the lagoon surface, and freeboard. Should State regulations not permit an emergency outflow or for some other reason one is not used, the minimum freeboard is 1 foot above the top of the required volume. Figure 10–29 demonstrates these volume depth requirements.

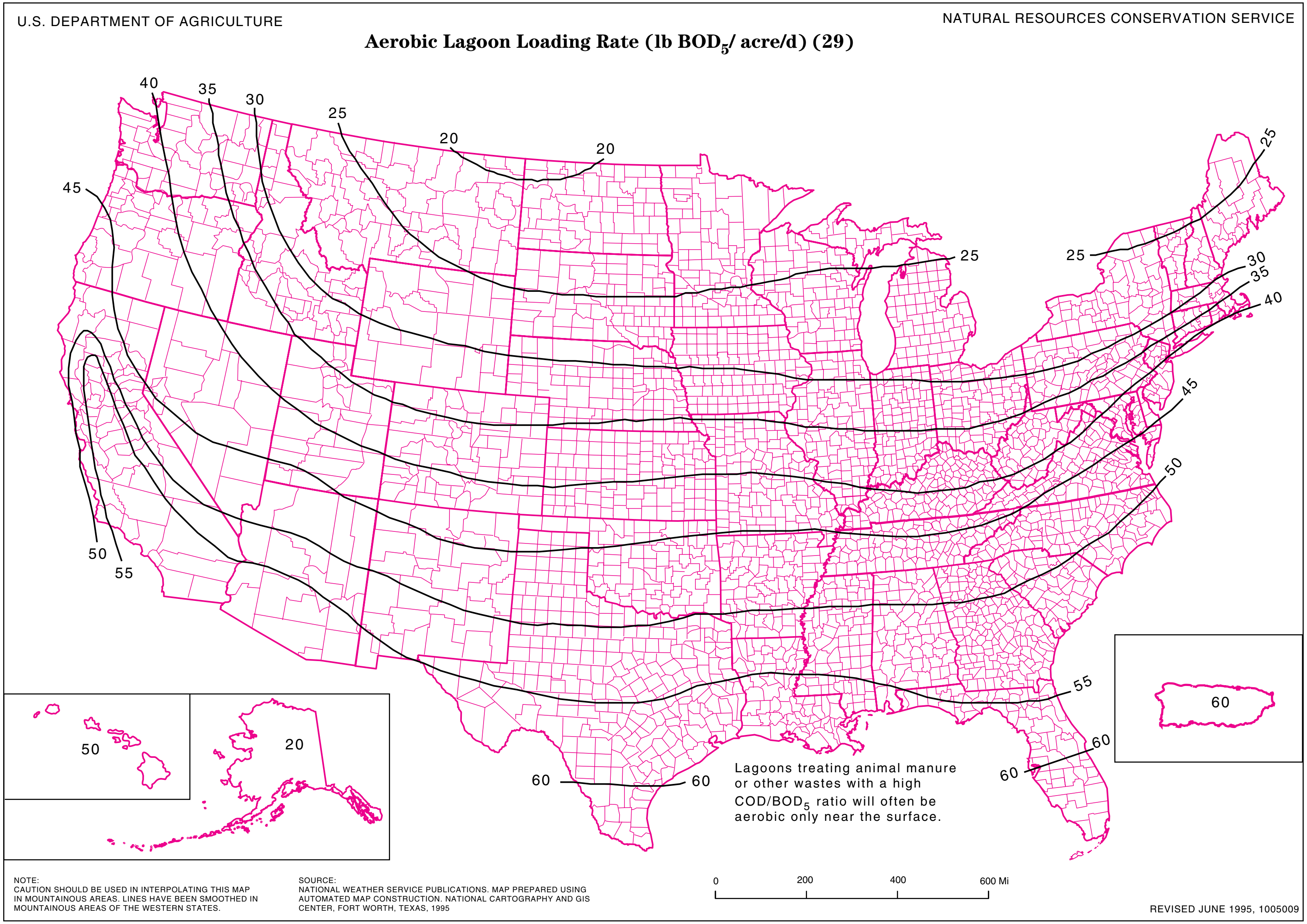
Aerobic lagoons need to be managed similarly to anaerobic lagoons in that they should never be overloaded with oxygen demanding material. The lagoon should be filled to the minimum operating level, generally 2 feet, before being loaded with waste. The maximum liquid level should not exceed 5 feet. The water level must be maintained within the designed operating range. Sludge should be removed when it exceeds the designed sludge storage capacity. Aerobic lagoons should also be enclosed in fences and marked with warning signs.

Figure 10–29 Aerobic lagoon cross section



Note: An aerobic waste treatment lagoon has a required minimum surface area based on BOD_5

Figure 10–30 Aerobic lagoon loading rate (lb BOD_5/acre/d)



Design example 10–6 Aerobic lagoon

Mr. John Sims of Greenville, Mississippi, has requested assistance on the development of an agricultural waste management system. He has requested that an alternative be developed that includes an aerobic lagoon to treat the waste from his 50,000 caged layers, which have an average weight of 4 pounds. Completed worksheet 10A–4 shows the calculations to size the lagoon for this design example.

Worksheet 10A-4—Aerobic lagoon design

Decisionmaker: John Sims | Date: 11/16/90

Site: Greenville, MS

Animal units

1. Animal type: Caged Layers
2. Animal weight, lbs (W): 4
3. Number of animals (N): 50,000
4. Animal units, AU = $\frac{W \times N}{1000}$ = 200

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM) = 0.93
6. Treatment period, days (D) = 180
7. Total volume of manure production for animal type for treatment period, ft^3 VMD = AU x DVM x D = 33,480
8. Total manure production for treatment period, ft^3 (TVM) 33,480

Wastewater volume

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

Clean water volume

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

Waste volume

13. Waste volume for treatment period, ft^3 WV = TVM + TWW + CW = 33,480 + 0 + 0 = 33,480

Manure total solids

14. Daily manure total solids production, lbs/AU/day (MTS) = 15
15. Daily manure total solids production for animal type, lb/day MTSD = MTS x AU = 3000
16. Total manure total solids production, lbs/day (TMTS) = 3000

Manure 5-day biochemical oxygen demand

17. Daily manure BOD_5 production per AU, lbs/AU/day (MBOD) = 3.3
18. Daily manure BOD_5 production for animal type per day, lbs/day MBOD = AU x BOD = 660
19. Total manure production, lbs/day (TMBOD) 660

Wastewater 5-day biochemical oxygen demand

20. Daily wastewater BOD_5 production, lbs/1000 gal (DWBOD) =
21. Total wastewater BOD_5 production for animal type, lbs/day WBOD = $\frac{(DWBOD \times TWW \times 7.48)}{D \times 1,000}$ =
22. Total wastewater BOD_5 production, lbs/day (TWBOD) = 0

TOTAL BOD_5 (manure and wastewater)

23. Total daily production, lbs/day TBOD = TMBOD + TWBOD = 660 + 0 = 660

Minimum treatment surface area

24. Selected lagoon BOD_5 loading rate, lbs BOD_5/acre (BODLR) = 50
25. Minimum treatment surface area, acres MTA = $\frac{TBOD}{BODLR} = \frac{(660)}{(50)}$ = 13.2

Sludge volume requirement

26. Sludge accumulation ratio, ft^3/lb TS (SAR) = 0.0295
27. Sludge accumulation period, years (T) = 5
28. Sludge volume requirement, ft^3 SV = 365 x TMTS x T x SAR = 365 (3000)(5)(0.0295) = 161,513

Minimum lagoon volume requirement

29. Minimum lagoon volume requirements, ft^3 MLVR = SV + WV = 161,513 + 33,480 = 194,993

Worksheet 10A-4—Aerobic Lagoon Design—Continued

Lagoon sizing

30. Sizing by trial and error:

Side slope ratio, (Z) = 4

V must be equal to or greater than MLVR = 194,993 ft^3

SA must be equal to or greater than MTA = 13.2 acres

Rectangular lagoon:

d must be less than 5 feet

$$SA = \frac{(BL + 2Zd)(BW + 2Zd)}{43{,}560}$$

Trial no.	Bottom width ft (BW)	Bottom length ft (BL)	Depth* ft (d)	Volume ft^3 (V)	Surface area acres (SA)
1	500	1000	0.5	251,503	11.6
2	600	1000	0.5	301,603	13.9
3	570	1000	0.5	286.573	13.2 OK

* Depth must be adjusted in Step 31

Depth adjustment

31. Depth adjustment

Depth , ft (d) ------------------------------------ 0.5

Add depth of precipitation less evaporation on lagoon surface + 0.5
(for the treatment period)

Add depth of 25-year, 24-hour storm------------------- + 0.6

Add for freeboard (1.0 foot minimum)--------------- + 1.0

Final depth ------------------------------------ 2.6

32. Compute total volume using final depth, ft^3
(use equation in step 30)---------------------------- 1,524,828

(4) Mechanically aerated lagoons

Much of this material was taken directly from technical notes on the design of mechanically aerated lagoons for odor control (USDA SCS 1980).

Aerated lagoons operate aerobically and are dependent on mechanical aeration to supply the oxygen needed to treat waste and minimize odors. This type of design is used to convert an anaerobic lagoon to an aerobic condition, or as an alternative, to a naturally aerated lagoon that would otherwise need to be much larger. Mechanically aerated lagoons combine the small surface area feature of anaerobic lagoons with relative odor-free operation of an aerobic lagoon. The main disadvantages of this type of lagoon are the energy requirements to operate the mechanical aerators and the high level of management required.

The typical design includes 1 pound of oxygen transferred to the lagoon liquid for each pound of BOD_5 added. The TS content in aerated lagoons should be maintained between 1 and 3 percent with dilution water. The depth of aerated lagoons depends on the type of aerator used. Agitation of settled sludge needs to be avoided. As with naturally aerobic lagoons, consideration is required for storage of manure and rainfall.

Two kinds of mechanical aerator are used: the surface pump and the diffused air system. The surface pump floats on the surface of the lagoon, lifting water into the air, thus assuring an air-water mixture. The diffused air system pumps air through water, but is generally less economical to operate than the surface pump.

(i) Lagoon loading

Lagoon loading should be based on 5-day BOD_5 or carbonaceous oxygen demand (COD). NRCS designs on the basis of BOD_5. The tables in AWMFH, chapter 4 show recommended BOD_5 production rates, but local data should be used where available.

(ii) Aerator design

Aerators are designed primarily on their ability to transfer oxygen (O_2) to the lagoon liquid. Of secondary importance is the ability of the aerator to mix or disperse the O_2 throughout the lagoon. Where the aerator is intended for minimizing odors, complete mixing is not a consideration except as it relates to the surface area.

For the purpose of minimizing odors, aerators should transfer from 1 to 2 pounds of oxygen per pound of BOD_5. Even a limited amount of oxygen transfer (as little as 1/3 lb O_2/lb BOD_5) reduces the release of volatile acids and accompanying gases. For design purposes, use 1 pound of oxygen per pound of BOD_5 unless local research indicates a higher value is needed.

Aerators are tested and rated according to their clean water transfer rate (CWTR) or laboratory transfer rate (LTR), whichever term is preferred. The resulting value is given for transfer at standard atmospheric pressure (14.7 lb/in^2), dissolved oxygen equal to 0 percent, and water at 20 degrees Celsius. The actual transfer rate expected in field operation can be determined by using equation 10–8.

$$\mathrm{FTR} = \mathrm{CWTR} \times \frac{\left(\mathrm{B} \times \mathrm{C_{dc}}\right) - \mathrm{DO}}{\mathrm{C_{sc}}} \times \mathrm{O}^{t-20} \times \mathrm{a} \qquad \text{(eq. 10–8)}$$

where:

FTR = lb O_2 per horsepower-hour transferred under field conditions

CWTR = clean water transfer rate in lb per horsepower-hour transferred under standard laboratory conditions

B = salinity-surface tension factor. It is the ration of the saturated concentration in the wastewater to that of clean water. Values range from 0.95 to 1.0.

C_{dc} = O_2 saturation concentration at design conditions of altitude and temperature (mg/L) from figures 10–31 and 10–32

DO = average operating O_2 concentration (mg/L). The recommended value of DO can vary from 1 to 3 depending on the reference material. A value of 1.5 should be considered a minimum. For areas where minimizing odors is particularly critical, a DO of 2 or more should be used.

t = design temperature (°C)

O = temperature correction factor; values range from 1.024 to 1.035

a = ratio of the rate of O_2 transfer in the wastewater to that of clean water. Generally taken as 0.75 for animal waste

C_{sc} = saturation concentration of O_2 in clean water, 20 °C and sea level (9.17 mg/L)

Unless local information supports using other values, the following values for calculating field transfer rates should be used: B=1.0, DO=1.5, O=1.024, a=0.75, and C_{sc} = 9.17.

Figure 10–31 Relation of dissolved oxygen saturation to water temperature (clean water at 20 °C and sea level)

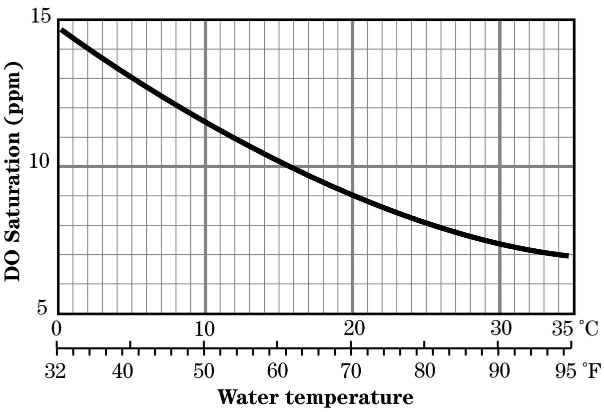


Figure 10–32 Relation of dissolved oxygen saturation to elevation above mean sea level

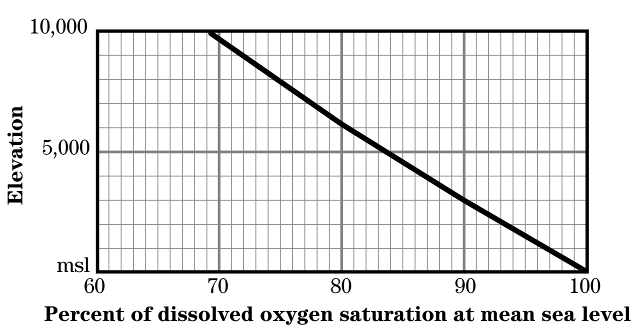
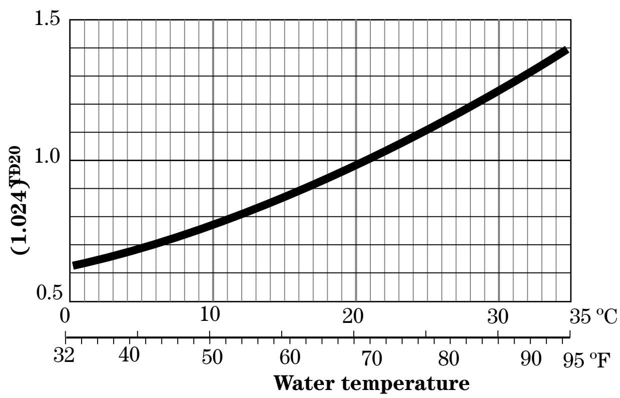


Figure 10–33 provides a quick solution to the term O^{t-20}, where O is equal to 1.024. Designs for both summer and winter temperatures are often necessary to determine the controlling (least) transfer rate.

Figure 10–33 Numeral values for O^{t-20} at different temperatures where O=1.024



Having calculated FTR, the next step is to determine horsepower requirements of aeration based on loading rates and FTR as calculated above. Horsepower requirements can be estimated using equation 10–9.

$$HP = \frac{BOD_5}{FTR \times HO} \qquad \text{(eq. 10–9)}$$

where:
HP = horsepower
BOD_5 = 5-day BOD_5 loading of waste, lb/d
HO = hours of operation per day

Most lagoon systems should be designed on the basis of continual aerator operations.

The actual selection of aerator(s) is a subjective process and often depends on the availability of models in the particular area. In general, multiple small units are preferred to one large unit. The multiple units provide better coverage of the surface area, as well as permit flexibility for the real possibility of equipment failure and reduced aeration.

(5) Oxidation ditches

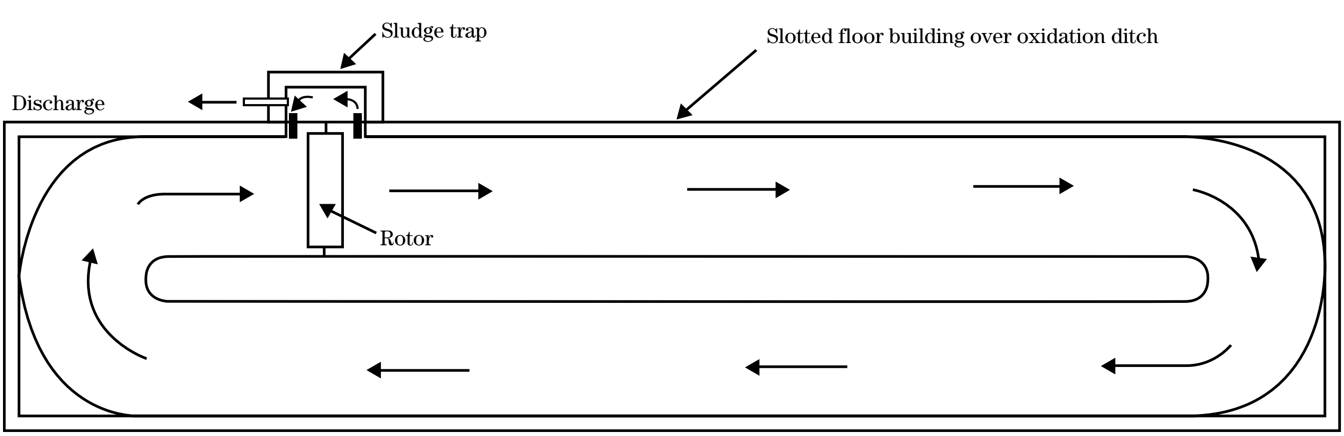
In some situations, sufficient space is not available for a lagoon for treating animal waste, and odor control is critical. One option for treating animal waste under these circumstances is an oxidation ditch (fig. 10–34).

The shallow, continuous ditch generally is in an oval layout. It has a special aerator spanning the channel. The action of the aerator moves the liquid waste around the channel and keeps the solids in suspension. Because of the need for continuous aeration, this process can be expensive to operate. Oxidation ditches should only be designed by a professional engineer familiar with the process.

The range of loading for an oxidation ditch is 1 pound of BOD_5 per 30 to 100 cubic feet of volume. This provides for a retention time of 30 to 70 days. Solids accumulate over time and must be removed by settling. The TS concentration is maintained in the 2 to 6 percent range, and dilution water must be added periodically.

If oxidation ditches are not overloaded, they work well for minimizing odors. The degree of management required, however, may be more than desired by some operators. Daily attention is often necessary, and equipment failure can lead to toxic gas generation soon after the aerators are stopped. If the ditches are properly managed, they can be effective in reducing nitrogen to N_2 through cyclic aerobic/anaerobic periods, which allows nitrification and then denitrification.

Figure 10–34 Schematic of an oxidation ditch



(6) Composting

Composting is the aerobic biological decomposition of organic matter. It is a natural process that is enhanced and accelerated by the mixing of organic waste with other ingredients in a prescribed manner for optimum microbial growth.

Composting converts an organic waste material into a stable organic product by converting nitrogen from the unstable ammonia form to a more stable organic form. The end result is a product that is safer to use than raw organic material and one that improves soil fertility, tilth, and water holding capacity. In addition, composting reduces the bulk of organic material to be spread; improves its handling properties; reduces odor, fly, and other vector problems; and can destroy weed seeds and pathogens. Composters should be planned and designed in accordance with NRCS Conservation Practice Standard 317, Composting Facility.

Composting methods—Descriptions of three basic methods of composting—windrow, static pile, and in-vessel—follow.

Windrow method—the windrow method involves the arrangement of compost mix in long, narrow piles or windrows (fig. 10–35). To maintain an aerobic condition, the compost mixture must be periodically turned. This exposes the decomposing material to the air and keeps temperatures from getting too high (>170 °F). The minimum turning frequency varies from 2 to 10 days, depending on the type of mix, volume, and ambient air temperature. As the compost ages, the frequency of turning can be reduced.

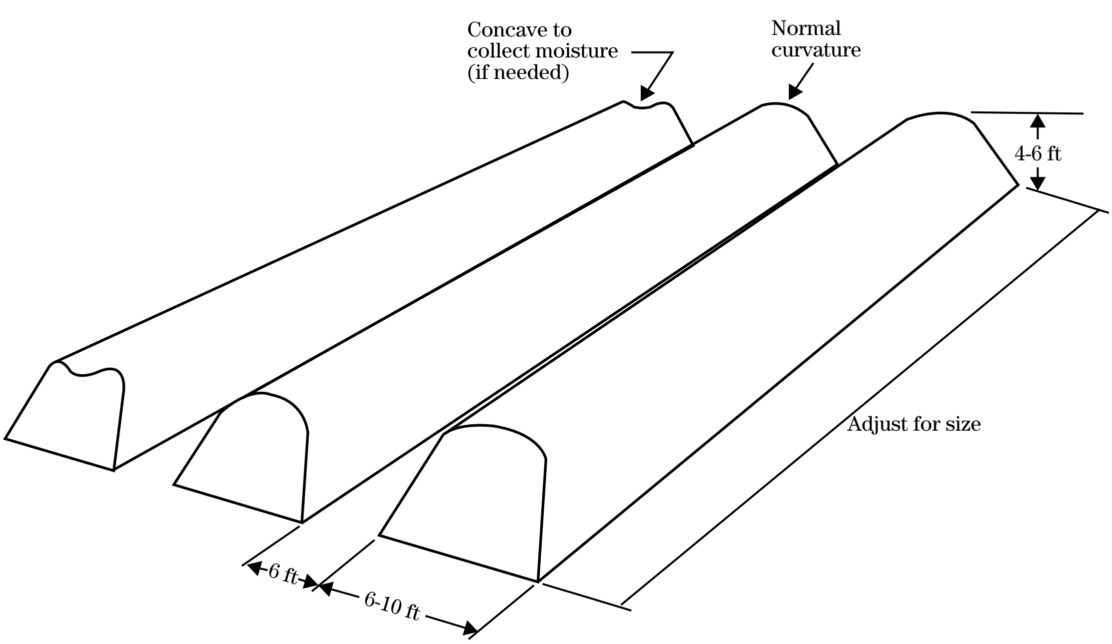
The width and depth of the windrows are limited only by the type of turning equipment used. Turning equipment can range from a front-end loader to an automatic mechanical turner. Windrows generally are 4 to 6 feet deep and 6 to 10 feet wide.

Some advantages and disadvantages of the windrow method include:

Advantages:

- rapid drying with elevated temperatures
- drier product, resulting in easier product handling

Figure 10–35 Windrow schematic



- ability to handle high volumes of material
- good product stabilization
- low capital investment

Disadvantages:

- not space efficient
- high operational costs
- piles should be turned to maintain aerobic conditions
- turning equipment may be required
- vulnerable to climate changes
- odors released on turning of compost
- large volume of bulking agent might be required

Static pile method—the static pile method consists of mixing the compost material and then stacking the mix on perforated plastic pipe or tubing through which air is drawn or forced. Forcing air through the compost pile may not be necessary with small compost piles that are highly porous or with a mix that is stacked in layers with highly porous material. The exterior of the pile generally is insulated with finished compost or other material. In nonlayered operations, the materials to be composted must be thoroughly blended before pile placement.

The dimensions of the static pile are limited by the amount of aeration that can be supplied by the blowers and the stacking characteristics of the waste. The compost mixture height generally ranges from 8 to 15 feet, and the width is usually twice the depth. Individual piles generally are spaced about a half the distance of the height.

With forced air systems, air movement through the pile occurs by suction (vacuum) or by positive pressure (forced) through perforated pipes or tubing. A filter pile or material is normally used to absorb odor if air is sucked through the pile (fig. 10–36).

Some advantages and disadvantages of the static pile method include:

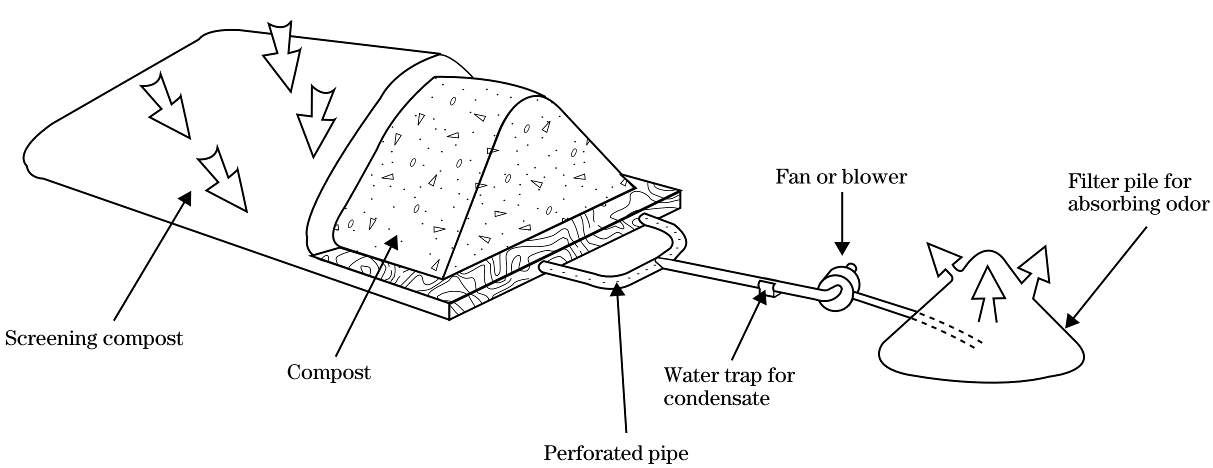
Advantages:

- low capital cost
- high degree of pathogen destruction
- good odor control
- good product stabilization

Disadvantages:

- not space efficient
- vulnerable to climate impacts
- difficult to work around perforated pipe unless recessed
- operating cost and maintenance on blowers

Figure 10–36 Static pile composting schematic



In-vessel method—the in-vessel method involves the mixing of manure or other organic waste with a bulking agent in a reactor, building, container, or vessel (fig. 10–37) and may involve the addition of a controlled amount of air over a specific detention time. This method has the potential to provide a high level of process control because moisture, aeration, and temperature can be maintained with some of the more sophisticated units.

Some of the advantages and disadvantages of the in-vessel method include:

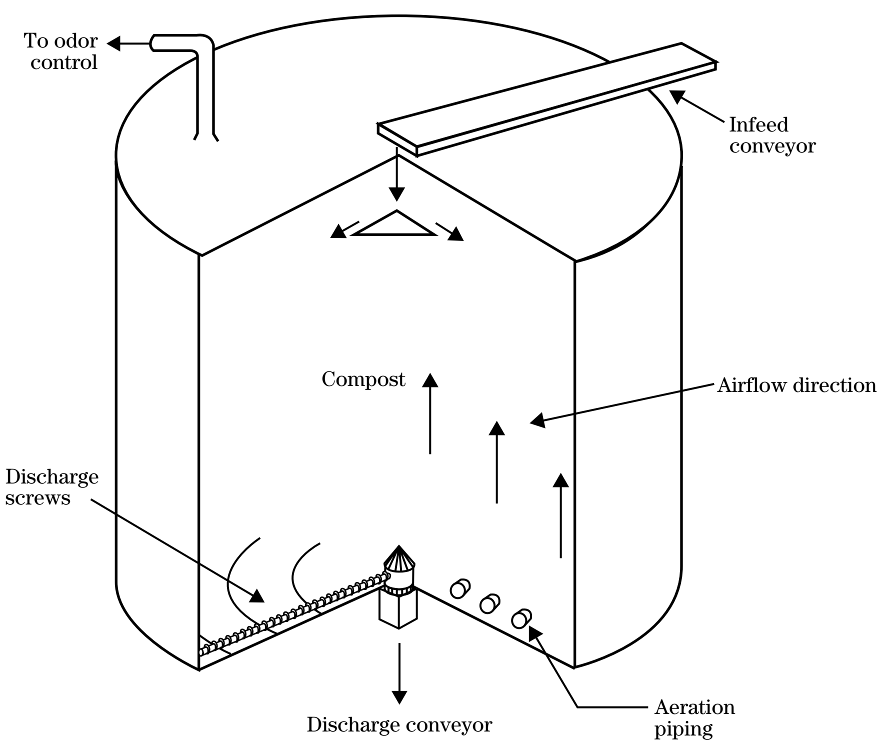
Advantages:

- space efficient
- good process control because of self-containment
- Protection from adverse climate conditions
- good odor control because of self-containment and process control
- potential for heat recovery dependent on system design
- can be designed as a continuous process rather than a batch process

Disadvantages:

- high capital cost for sophisticated units
- lack of operating data, particularly for large systems
- careful management required
- dependent on specialized mechanical and electrical equipment
- potential for incomplete stabilization
- mechanical mixing needs to be provided
- less flexibility in operation mode than with other methods

Figure 10–37 In-vessel composting schematic



Method selection—The composting method must fit the individual farm operation. Highly sophisticated and expensive composting operations are not likely to be a viable option for small farming operations. Some factors to consider when selecting the particular method of composting include:

Operator management capability—the management capability of the operator is an important consideration when selecting the right composting method. Even simple composting methods require that the operator spend additional time in monitoring and material handling. The operator should fully understand the level of management that is required. The windrow method generally is the simplest method to manage, but requires additional labor for periodically turning the compost mix. The static pile is generally next in complexity because of having to maintain blowers and work around perforated pipe. In-vessel composting can be the simplest or the most difficult to manage, depending on the sophistication of the system.

Equipment and labor availability—consider what equipment is available for loading, unloading, turning, mixing, and hauling. The windrow method requires extra equipment and labor to periodically turn the rows. All methods require some type of loading and unloading equipment.

Site features—if a limited amount of space is available, the static pile or in-vessel method may be the only viable composting alternatives. Proximity to neighbors and the appearance of the compost operation may make the windrow and static pile methods unattractive alternatives. If the only composting site has limited accessibility, the static pile or in-vessel method should be considered because of less mixing requirements. Siting considerations are discussed more fully in the siting and area considerations section that follows.

Compost utilization—if the compost is to be marketed commercially, a composting method that produces a predictable, uniform product should be considered. Because of varying climatic conditions, the windrow method may not produce a predictable end product. Sophisticated in-vessel methods provide the most process control; therefore, they produce the most uniform and predictable product.

Climate—in extremely wet climates, the static pile and aerated composting methods may become too wet to compost properly unless measures are taken to protect the compost from the weather. In very cold climates, the composting process may slow in the winter. Sheltering the compost pile from the wind helps to prevent a slowdown in the composting process. The windrow and static pile methods are the most vulnerable to freezing temperatures because they are exposed to the elements. All methods may perform unsatisfactorily if the organic waste and amendments are initially mixed in a frozen state.

Cost—composting capital and operating costs vary considerably depending on the degree of sophistication. The windrow method generally has the least capital cost, but also has the most operational costs. The in-vessel method usually has the highest initial capital cost, but the lowest operational cost.

Siting and area considerations—The location of the composting facility is a very important factor in a successful compost operation. To minimize material handling, the composting facility should be located as close as possible to the source of organic waste. If land application is the preferred method of utilization, the facility should also be located with convenient access to the land application sites. Several other important considerations when locating a compost facility follow.

Wind direction—improperly managed compost facilities may generate offensive odors until corrective actions are taken. Wind direction and proximity to neighbors should be considered when locating a composting facility.

Topography—avoid locating composting facilities on steep slopes where runoff may be a problem and in areas where the composting facility will be subject to inundation.

Ground water protection—the composting facility should be located downgradient and at a safe distance from any wellhead. A roofed compost facility that is properly managed should not generate leachate that could contaminate ground water. If a compost facility is not protected from the weather, it should be sited to minimize the risk to ground water.

Area requirements—the area requirements for each composting method vary. The windrow method requires the most land area. The static pile method requires less land area than the windrow method, but more than the in-vessel method. The pile dimensions also affect the amount of land area necessary for composting. A large pile that has a low surface area to total volume ratio requires less composting area for a given volume of manure, but it is also harder to manage. The size and type equipment used to mix, load, and turn the compost should also be considered when sizing a compost area. Enough room must be provided in and around the composting facility to operate equipment. In addition, a buffer area around the compost site should be considered if a visual barrier is needed or desired. In general, given the pile dimensions, a compost bulk density of 35 to 45 pounds per cubic feet can be used to estimate the surface area necessary for stacking the initial compost mix. To this area, add the amount of area necessary for equipment operation, pile turning, and buffer.

Existing areas—to reduce the initial capital cost, existing roofed, concrete, paved, or gravel areas should be used if possible as a composting site.

***Compost utilization*—**Finished compost is used in a variety of ways, but is primarily used as a fertilizer supplement and soil conditioner. Compost improves soil structure and soil fertility, but it generally contains too low a quantity of nitrogen to be considered the only source of crop nitrogen. Nutrients in finished compost will be slowly released over a period of years, thus minimizing the risk of nitrate leaching and high nutrient concentrations in surface runoff. For more information on land application of organic material, see AWMFH, chapter 11.

A good quality compost can result in a product that can be marketed to home gardeners, landscapers, vegetable farmers, garden centers, nursery/greenhouses, turf growers, golf courses, and ornamental crop producers. Generally, the marketing of compost from agricultural operations has not provided enough income to completely cover the cost of composting. If agricultural operations do not have sufficient land to spread the waste, marketing may still be an attractive alternative compared to hauling the waste to another location for land spreading. Often, compost operators generate additional income by charging municipalities and other local governments for composting urban yard waste with the waste products of the agricultural operations.

Finished compost has also been successfully used as a bedding material for livestock. Because composting generates high temperatures that dry out and sterilize the compost, the finished product is generally acceptable as a clean, dry, bedding material.

***Compost mix design*—**Composting of organic waste requires the mixing of an organic waste with amendment(s) or bulking agent(s) in the proper proportions to promote aerobic microbial activity and growth and to achieve optimum temperatures. The following must be provided in the initial compost mix and maintained during the composting process:

- a source of energy (carbon) and nutrients (primarily nitrogen)
- sufficient moisture
- sufficient oxygen for an aerobic environment
- a pH in the range of 6 to 8

The proper proportion of waste, amendments, and bulking agents is commonly called the recipe.

A composting amendment is any item added to the compost mixture that alters the moisture content, C:N ratio, or pH. Many materials are suitable for use as a composting amendment. Crop residue, leaves, grass, straw, hay, and peanut hulls are just some of the examples that may be available on the farm. Others, such as sawdust, wood chips, or shredded paper and cardboard, may be available inexpensively from outside sources. Table 10–8 shows typical C:N ratios of common composting amendments. The C:N ratio is highly variable, and local information or laboratory values should be used whenever possible.

A bulking agent is used primarily to improve the ability of the compost to be self-supporting (structure) and to increase porosity to allow internal air movement. Wood chips and shredded tires are examples of a bulking agent. Some bulking agents, such as large wood chips, may also alter the moisture content and C:N ratio, in which case they would be both a bulking agent and a compost amendment.

Compost design parameters—to determine the recipe, the characteristics of the waste and the amendments

Table 10–8 Typical carbon to nitrogen ratios of common composting amendments

Material	C:N ratios
Alfalfa (broom stage)	20
Alfalfa hay	12–18
Asparagus	70
Austrian pea straw	59
Austrian peas (green manure)	18
Bark	100–130
Bell pepper	30
Breading crumbs	28
Cantaloupe	20
Cardboard	200–500
Cattle manure (with straw)	25–30
Cattle manure (liquid)	8–13
Clover	12–23
Clover (sweet and young)	12
Corn and sorghum stover	60–100
Cucumber	20
Dairy manure	10–18
Garden wastes	20–60
Grain rice	36
Grass clippings	12–25
Green leaves	30–60
Green rye	36
Horse manure (peat litter)	30–60
Leaves (freshly fallen)	40–80
Newspaper	400–500
Oat straw	48–83
Paper	173
Pea vines (native)	29
Peat (brown or light)	30–50
Pig manure	5–8
Pine needles	225–1000
Potato tops	25
Poultry manure (fresh)	6–10
Poultry manure (henhouse litter)	12–18
Reeds	20–50
Residue of mushroom culture	40
Rice straw	48–115
Rotted manure	20
Rye straw	60–350
Saw dust	300–723
Sawdust (beech)	100
Sawdust (fir)	230
Sawdust (old)	500
Seaweed	19
Shredded tires	95
Soil organic matter	10–24
Soybean residues	20–40
Straw	40–80
Sugar cane (trash)	50
Timothy	80
Tomato leaves	13
Tomatoes	25–30
Watermelon	20
Water hyacinth	20-30
Weeds	19
Wheat straw	60-373
Wood (pine)	723
Wood chips	100–441

*For further information on C:N ratios, see AWMFH, chapter 4.

and bulking agents must be known. The characteristics that are the most important in determining the recipe are moisture content (wet basis), carbon content, nitrogen content, and the C:N ratio. If any two of the last three components are known, the remaining one can be calculated.

Carbon to nitrogen (C:N) ratio—the balance between carbon and nitrogen in the compost mixture is a critical factor for optimum microbial activity. After the organic waste and the compost ingredients are mixed together, microorganisms multiply rapidly and consume carbon as a food source and nutrients to metabolize and build proteins. The C:N ratio of the compost mix should be maintained for most compost operations between 25 and 40 to 1. If the C:N ratio is low, a loss of nitrogen generally occurs through rapid decomposition and volatilization of ammonia. If it is high, the composting time increases because the nitrogen becomes the limiting nutrient for growth.

Moisture—microorganisms need moisture to convert the carbon source to energy. Bacteria generally can tolerate a moisture content as low as 12 to 15 percent; however, with less than 40 percent moisture, the rate of decomposition is slow. At greater than 60 percent moisture, the process turns from one that is aerobic to one that is anaerobic. Anaerobic composting is less desirable because it decomposes more slowly and produces putrid odors. The finished product should result in a material that has a low moisture content.

pH—generally, pH is self-regulating and is not a concern when composting agricultural waste. Bacterial growth generally occurs within the range of pH 6.0 to 7.5, and fungi growth usually occurs within the range of 5.5 to 8.5. The pH varies throughout the compost mixture and during the various phases of the composting process. The pH in the compost mixture is difficult to regulate once decomposition is started. Optimum pH control can be accomplished by adding alkaline or acidic materials to the initial mixture.

Compost mix design process—the determination of the compost mix design (recipe) is normally an iterative process of adjusting the C:N ratio and moisture content by the addition of amendments. If the C:N ratio is out of the acceptable range, then amendments are added to adjust it. If this results in a high or low moisture content, amendments are added to adjust the moisture content. The C:N ratio is again checked, and the process may be repeated. After a couple of iterations, the mixture is normally acceptable. Figure 10–38 is a mixture design process flow chart that outlines the iterative procedure necessary in determining the compost recipe.

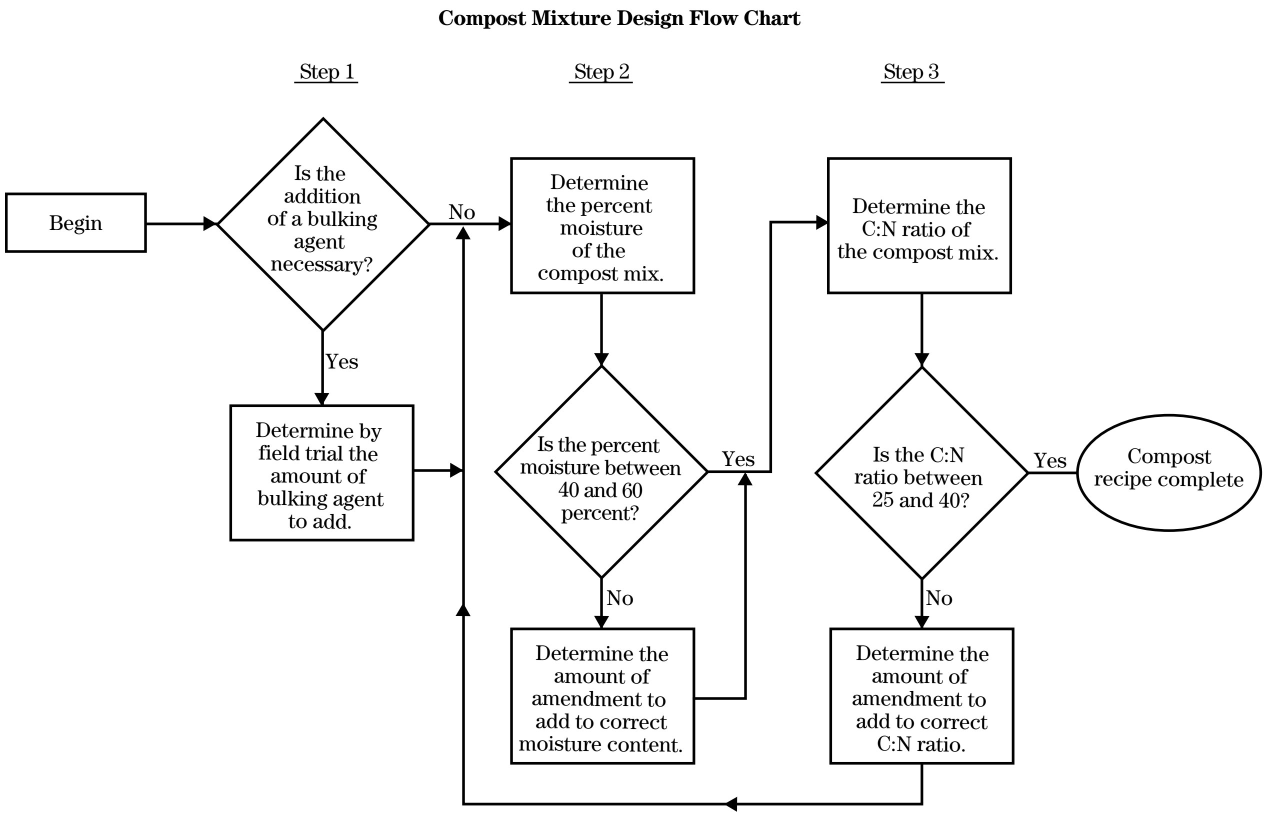
The iterative process of the compost mix design can be summarized to a series of steps to determine the compost mix design. These steps follow the mixture design process flowchart shown in figure 10-38.

Step 1 Determine the amount of bulking agent to add. The process normally begins with determining whether or not a bulking agent is needed. The addition of a bulking agent is necessary if the raw waste cannot support itself or if it does not have sufficient porosity to allow internal air movement. A small field trial is the best method to determine the amount of bulking agent required. To do this, a small amount of raw waste would be weighed and incremental quantities of bulking would be added and mixed until the mix has the structure and porosity desired. The wood chips, bark, and shredded tires are examples of bulking agents commonly used.

Step 2 Calculate the moisture content of the compost mix. After the need for and quantity of bulking agent have been determined, the moisture content of the mixture or raw waste should be calculated. AWMFH, chapter 4 gives typical values for moisture content (wet basis) of excreted manure for various animals. Because water is often added as a result of spillage from waterers and in the cleaning processes, raw waste that is to be composted may have significantly higher moisture content than that of “as excreted” manure. If the amount of water added to the manure can be determined, the moisture content of the mix can be calculated using equation 10–11, ignoring the inappropriate terms.

In addition to extra water, feed spillage and bedding material can constitute a major part of the raw waste to be composted. The moisture content for each additive can be determined individually and used to determine the moisture content of the entire mix (equation 10–11). A sample of the raw waste (including the bedding, wasted feed, and water) can also be taken, weighed, dried, and weighed again to determine the

Figure 10–38 Compost mixture design flowchart



moisture content of the mix. Using this procedure the moisture content can be calculated as follows:

$$M_i = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \times 100$$

(eq. 10–10)

where:

M_i = percent moisture content (wet basis)

Note: To avoid confusion and repetition, the combination of "as excreted" manure, bedding, water, and bulking agent will be referred to as the "compost mix."

The general equation for the moisture content of the compost mix is as follows. (The equation may contain variables that are not needed in every calculation.)

$$M_M = \frac{\frac{(W_w \times M_w) + (W_b \times M_b) + (W_a \times M_a)}{100} + H_2O}{W_m}$$

(eq. 10–11)

where:

M_m = percent moisture of the compost mixture (wet basis), eq. 10–10
W_w = wet weight of waste (lb)
M_w = percent moisture content of waste (wet basis), eq. 10–10
W_b = wet weight of bulking agent (lb)
M_b = percent moisture content of bulking agent wet basis), eq. 10–10
W_a = wet weight of amendment (lb)
M_a = moisture content of amendment (wet basis)
H_2O = weight of water added (lb) = G × 8.36, where G = gallons of water
W_m = weight of the compost mix (lb) including wet weight of waste, bulking agent, amendments, and added water

Step 2 (continued) Determine the amount of amendment to add, if any, to the compost mix that will result in final moisture content that is between 40 and 60 percent. If the moisture content of the compost mix is less than 40 percent, adding an amendment is necessary to raise the moisture content to an acceptable level. Water is the amendment that is generally added to raise the moisture content, but an amendment that has higher moisture content than the desired moisture content of the compost mix is acceptable. It is generally best to begin the composting process when the moisture content is closer to 60 percent because the process of composting elevates the temperature and reduces moisture.

If the moisture content of the compost mix is above 60 percent, the addition of an amendment is necessary to lower the moisture content at or below 60 percent. Straw, sawdust, wood chips, and leaves are commonly used.

Equation 10–12 can be used to determine the amount of amendment to add to lower or raise the moisture content of the compost mix.

$$W_{aa} = \frac{W_{mb} \times (M_{mb} - M_d)}{(M_d - M_{aa})}$$

(eq. 10–12)

where:

W_{aa} = wet weight of amendment to be added
W_{mb} = wet weight of mix before adding in amendment
M_{mb} = percent moisture of mix before adding amendment
M_d = desired percent moisture content of mix (wet bases)
M_{aa} = moisture content of amendment added

Note: Equation 10–12 can be used for the addition of water by using:

$$M_{aa} = 100\% \text{ for water}$$

Step 3 Calculate the C:N ratio. The C:N ratio for the compost mix is calculated from the C:N ratios of the waste, bulking agents, and amendments. Typical values for various selected agricultural wastes are shown in AWMFH, chapter 4. The C:N ratios for various waste products and amendments are also shown in table 10–9. The C:N ratios not reported in the literature can be estimated from the amount of fixed solids (amount of ash left after organic matter is burned off) or the volatile solids and the nitrogen content. Equations 10–13 and 10–14 are used to estimate the C:N ratio from the fixed or volatile solids.

$$\%C = \frac{100 - \%FS}{1.8} \quad \text{(eq. 10–13a)}$$

$$W_c = \frac{VS}{1.8} \quad \text{(eq. 10–13b)}$$

$$C:N = \frac{\%C}{\%N} = \frac{W_c}{W_n} \quad \text{(eq. 10–14)}$$

where:
%C = percent carbon (dry basis)
%FS = percent fixed solids (dry basis)
W_c = dry weight of carbon
VS = weight of volatile solids
C:N = carbon to nitrogen ratio
%N = percent total nitrogen (dry basis)
W_n = dry weight of nitrogen

Typical values for nitrogen content of manure are reported in AWMFH, chapter 4, and typical values for percent nitrogen (dry basis) for many agricultural crops are reported in AWMFH chapter 6. The C:N ratio and nitrogen content of manure and of other amendments are highly variable. Using local values for C:N ratios and nitrogen or testing of the compost constituents is highly recommended. The general equation for estimating the C:N ratio of the compost mix is given by equation 10–15.

$$R_m = \frac{W_{cw} + W_{cb} + W_{ca}}{W_{nw} + W_{nb} + W_{na}} \quad \text{(eq. 10–15)}$$

where:
R_m = C:N ratio of compost mix
W_{cw} = weight of carbon in waste (lb)
W_{cb} = weight of carbon in bulking agent (lb)
W_{ca} = weight of carbon in amendment (lb)
W_{nw} = weight of nitrogen in waste (lb)
W_{nb} = weight of nitrogen in bulking agent (lb)
W_{na} = weight of nitrogen in amendment (lb)

The weight of carbon and nitrogen in each ingredient can be estimated using the following equations:

$$W_n = \%N \times W_{dry} \quad \text{(eq. 10–16a)}$$

$$W_n = \frac{W_c}{C:N} \quad \text{(eq. 10–16b)}$$

$$W_c = \%C \times W_{dry} \quad \text{(eq. 10–17a)}$$

$$W_c = C:N \times W_n \quad \text{(eq. 10–17b)}$$

where:
W_{dry} = dry weight of material in question

The dry weight of material can be calculated using equation 10–18.

$$W_{dry} = W_{wet} \times \frac{100 - M_{wet}}{100} \quad \text{eq. (10–18)}$$

where:
W_{wet} = wet weight of material in question
M_{wet} = percent moisture content of material (wet basis)

Step 3 (continued): Determine the amount of amendment, if any, to add to the compost mix that will result in an initial C:N ratio that is between 25 and 40. If the C:N ratio calculated in step 3 is less than 25 or more than 40, the type and amount of amendment to add to the compost mix must be determined. For a compost mix that has a C:N ratio below 25, an amendment should be added that has a C:N ratio higher than the desired C:N ratio. For a compost mix that has a C:N ratio of more than 40, an amendment must be added that has a C:N ratio that is less than the desired C:N ratio.

Equation 10–19 or 10–20 can be used to calculate the weight of amendment to add to achieve a desired C:N ratio.

$$W_{aa} = \frac{W_{nm} \times (R_d - R_{mb}) \times 10{,}000}{N_{aa} \times (100 - M_{aa}) \times (R_{aa} - R_d)} \quad \text{(eq. 10–19)}$$

$$W_{aa} = \frac{N_m W_{mb} \times (100 - M_{mb}) \times (R_d - R_{mb})}{N_{aa} \times (100 - M_{aa}) \times (R_{aa} - R_d)} \quad \text{(eq. 10–20)}$$

where:
W_{nm} = weight of nitrogen in compost mix (lb)
R_d = desired C:N ratio
R_{mb} = C:N ratio of the compost mix before adding amendment
N_{aa} = percent nitrogen in amendment to be added (dry basis)
R_{aa} = C:N ratio of compost amendment to be added

N_m = percent nitrogen in compost mix (dry basis)
M_{mb} = percent moisture of compost mix before adding amendment (wet basis), equation 10–10

For a compost mix that has a C:N ratio of more than 40, a carbonless amendment, such as fertilizer, can be added to lower the C:N ratio to within the acceptable range. In this special case, the following equation can be used to estimate the dry weight of nitrogen to add to the mix:

$$W_{nd} = \frac{W_{cw} + W_{cb} + W_{ca}}{R_d} - \left(W_{nw} + W_{nb} + W_{na}\right) \quad \text{(eq. 10–21)}$$

where:
W_{nd} = dry weight of nitrogen to add to mix

After the amount of an amendment to add has been determined to correct the C:N ratio, the design process then returns to step 2. If no change is necessary in steps 2 and 3, the compost mix design process is complete.

Design example 10–7 Compost mix—bedding

A dairy farmer wishes to compost the waste generated from the herd in the barn. The waste is scraped daily from the barn and contains straw as a bedding material, but no extra water is added. Straw is the cheapest and most abundant source of a high C:N ratio amendment on the farm. The 100-cow Holstein herd is in the barn for an average of 6 hours. The average weight of a cow is 1,200 pounds with an average milk production of 75 pounds per day. Ten 60-pound bales of straw (chopped) are added daily for bedding. No bulking agent is necessary to improve the compost porosity or structure. Determine the design mix for the compost operation on a daily basis.

Given:

Wheat straw:

Moisture content = 15% (estimated)
C:N ratio = 80 (from table 10–9)
Percent N = 0.67% (from AWMFH, chapter 6)

Manure:

Number of cows = 100
Size of cows = 1,200 lb
Number of AU = 100 × 1,200/1,000 = 120
Moisture content = 87% (from AWMFH, chapter 4, table 4–5(b))
Manure production = 108 lb/d/1,000 lb (from AWMFH, chapter 4, table 4–5(b))
Fraction in barn = 6 h/24 h = 0.25
Nitrogen production = 0.71 lb/1,000 lb/d (from AWMFH, chapter 4, table 4–5(b))
Volatile solids = 11 lb/1,000 lb/d (from AWMFH, chapter 4, table 4–5(b))

Step 1 Bulking agent. A sample of the manure was stacked, and the manure appeared to have sufficient porosity to allow air movement and had the ability to support itself. Therefore, the addition of a bulking agent is not necessary.

Step 2 Determine the moisture content of the waste. To determine the quantity of waste:

Manure in barn:

$$120\,\text{AU} \times 108\ \text{lb/d} \times 0.25 = 3{,}240\ \text{lb}$$

Weight of straw added daily:

$$10\ \text{bales} \times 60\ \text{lb} = 600\ \text{lb}$$

Weight of manure and straw (W_m):

$$10\ \text{bales} \times 60\ \text{lb} = 600\ \text{lb}$$

Using equation 10–11, determine the moisture content of manure plus straw.

$$M_m = \frac{\frac{(3{,}240 \times 87) + (600 \times 15)}{100}}{(3{,}240 + 600)} \times 100 = 76\%$$

Design example 10–7 Compost mix—bedding—Continued

Step 2 (continued) Using equation 10–12, determine the amount of straw to add to bring the moisture content of the compost mix to 60 percent.

$$W_{aa} = \frac{3,840 \text{ lb} \times (76\% - 60\%)}{60\% - 15\%} = 1,365 \text{ lb}$$

New weight of compost mix:

$$W_m = 3,840 \text{ lb} + 1,365 = 5,205 \text{ lb}$$

Step 3 Determine the C:N ratio of the compost mix. Determine the carbon and nitrogen content of the straw.

Total weight of straw:

$$600 + 1,365 = 1,965 \text{ lb}$$

Straw dry weight (equation 10–18):

$$1,965 \times \frac{(100 - 15)}{100} = 1,670 \text{ lb}$$

Weight of nitrogen in straw:

$$W_{na} = \frac{(0.67 \times 1,670 \text{ lb})}{100} = 11.2 \text{ lb}$$

Weight of carbon in straw (equation 10–17b) :

$$W_{ca} = 11.2 \times 80 = 896 \text{ lb}$$

Determine the carbon and nitrogen content in manure.

Weight of volatile solids in barn:

$$120 \text{AU} \times 11 \text{ lb/d/AU} \times 0.25 = 330 \text{ lb}$$

Weight of carbon in manure (using equation 10–13b):

$$W_{cw} = \frac{330 \text{ lb}}{1.8} = 183.3 \text{ lb}$$

Weight of nitrogen in manure:

$$W_{nw} = 120 \text{ AU} \times 0.71 \times 0.25 = 21.3 \text{ lb}$$

C:N ratio of manure:

$$\frac{183.3}{21.3} = 8.6$$

Determine C:N ratio of mixture (equation 10–15).

$$C:N = \frac{183.3 + 896}{21.3 + 11.2} = 33.2$$

A compost mix that has a C:N ratio of 33 is in the acceptable range, but for purposes of this example, continue step 3.

Step 3 (continued) Determine the type and amount of amendment to add to bring the C:N ratio of the mix to 30:1. To lower the C:N ratio, an amendment with a C:N ratio that is less than the desired final C:N ratio is necessary. Fresh manure that has a C:N ratio of 10.5 could be collected outside the barn, or fertilizer could be added to the mix. The farmer would like to see both alternatives.

Weight of nitrogen in current compost mix:

$$21.3 + 11.2 = 32.5 \text{ lb}$$

Dry weight of manure (equation 10-18):

$$3,240 \times \frac{(100 - 87)}{100} = 421 \text{ lb}$$

Percent nitrogen in manure:

$$\frac{21.3}{421} \times 100 = 5.1\%$$

Pounds of manure to add to bring mix to 30:1 (using equation 10–19):

$$W_{aa} = \frac{32.5 \times (30 - 33) \times 10,000}{5.1 \times (100 - 87) \times (8.6 - 30)}$$
$$= 687 \text{ lb}$$

Pounds of nitrogen to add to bring compost mix to 30:1 (using equation 10–21)

$$W_{nd} = \frac{183.3 + 896}{30} - (21.3 + 11.2)$$
$$= 3.5 \text{ lb}$$

Design example 10–7 Compost mix—bedding—Continued

Adding 3.5 pound of nitrogen is easier than adding 687 pounds of manure, so the obvious choice is to add nitrogen. If the farmer chooses to add nitrogen, no further calculations are necessary, because the moisture content of the mix is not changed with the addition of nitrogen. The design process would continue with step 2 if another type of amendment was added that resulted in a change in the moisture content of the manure.

The final compost mix consists of the following:

- Manure and bedding scraped from the barn: 3,840 lb
- Additional straw to correct moisture: 1,365 lb
- Nitrogen added to lower C:N ratio: 3.5 lb

Design example 10–8 Compost mix—grass straw

A grass seed farmer wishes to compost straw from rye grass seed harvest. A nearby dairy operation has agreed to furnish fresh manure for 2 weeks. Determine the compost mixture design.

Given:

Rye grass straw:

Amount	= 600 tons
Moisture content	= 7%
N per ton	= 6 lb
C:N ratio	= 100:1

Manure:

Number of cows	= 400
Size of cows	= 1,400 lb
Number of AU	= 400 × 1,400/1,000=560
Manure production	= 108 lb/d/1,000 lb
Nitrogen production	= 0.71 lb/d/1,000 lb
Volatile solids	= 11 lb/d/1,000 lb
Percent moisture	= 87%

Step 1 No bulking agent is needed to improve structure or porosity.

Step 2 Determine moisture content of rye grass straw and manure mixture.

Straw weight:

$$600 \text{ tons} \times 2{,}000 \text{ lb/ton} = 1{,}200{,}000 \text{ lb}$$

Manure weight:

$$560 \text{ AU} \times 108 \text{ lb/d/AU} \times 14 \text{ d} = 846{,}720 \text{ lb}$$

Moisture content (M_m) of straw and manure (eq. 10–11):

$$\frac{\dfrac{(1{,}200{,}000 \times 7) + (846{,}720 \times 87)}{100}}{1{,}200{,}000 + 846{,}720} \times 100 = 40\%$$

The 40 percent moisture content of the mix is between 40 and 60 percent; for purposes of this exercise, add water to bring the moisture content to 50 percent.

Step 2 (continued) Using equation 10–12, determine the amount of water to add to bring the moisture content to 50 percent (W_{aa}).

$$\frac{(1{,}200{,}000 + 846{,}720) \times (40 - 50)}{50 - 100} = 409{,}344 \text{ lb}$$

$$\frac{409{,}344}{8.33} = 49{,}141 \text{ gal}$$

Step 3 Determine C:N ratio of the straw and manure mix. Determine the amount of carbon and nitrogen in the rye straw:

Nitrogen in straw:

$$W_{na} = 600 \text{ ton} \times 6 \text{ lb/ton} = 3{,}600 \text{ lb}$$

Design example 10–8 Compost mix—grass straw—Continued

Carbon in straw (eq. 10–17b):

$$W_{ca} = 100 \times 3{,}600 \text{ lb} = 360{,}000 \text{ lb}$$

Determine the amount of carbon and nitrogen in the manure.

Nitrogen in manure (use AWMFH, chapter 4 values for N):

$$560 \text{AU} \times 0.71 \times 14 \text{ d} = 5{,}566 \text{ lb}$$

Assume a 20 percent loss of nitrogen in handling manure. Nitrogen left in manure:

$$W_{nw} = 5{,}566 \times \frac{100 - 20}{100} = 4{,}453 \text{ lb}$$

Weight of volatile solids in manure (use AWMFH, chapter 4 values):

$$560 \text{ AU} \times 11 \times 14 \text{ d} = 86{,}240 \text{ lb}$$

Carbon in manure (using eq. 10–13b):

$$W_{cw} = \frac{86{,}240 \text{ lb}}{1.8} = 47{,}911 \text{ lb}$$

C:N ratio of straw and manure mix (eq. 10–15):

$$\frac{360{,}000 + 47{,}911}{3{,}600 + 4{,}453} = 51:1$$

A C:N ratio of 51:1 is more than the maximum recommended of 40:1. The compost mix needs more nitrogen.

Step 3 (continued) Determine the amount of commercial nitrogen to add to the mix to bring the C:N ratio to 40:1.

Amount of nitrogen to add (eq. 10–21):

$$N_a = \frac{360{,}000 + 47{,}911}{40} - (3{,}600 + 4{,}453)$$
$$= 2{,}145 \text{ lb}$$

The final design mix is:

Rye grass straw	= 600 tons
Manure (14 days)	= 423.4 tons
Commercial nitrogen	= 2,145 lb

***Composting operational considerations*—**The landowner/operator should be provided a written set of instructions as a part of the waste management plan. These instructions should detail the operation and maintenance requirements necessary for successful composting operation. They should include the compost mix design (recipe), method or schedule of turning or aerating, and instructions on monitoring the compost process and on long-term storage compost. The final use of the compost should be detailed in the Waste Utilization Plan.

Composting time—one of the primary composting considerations is the amount of time it takes to perform the composting operation. Composting time varies with C:N ratio, moisture content, climate, type of operation, management, and the types of wastes and amendments being composted. For a well managed windrow or static pile composting operation, the composting time during the summer months ranges from 14 days to a month. Sophisticated in-vessel methods may take as little as 7 days to complete the composting operation. In addition to the actual composting time, the amount of time necessary for compost curing and storage should be considered.

Temperature—consideration should be given to how the compost temperature is going to be monitored. The temperature probe should be long enough to penetrate a third of the distance from the outside of the pile to the center of mass. The compost temperature should be monitored on a daily basis if possible. The temperature is an indicator of the level of microbial activity within the compost. Failure to achieve the desired temperatures may result in the incomplete destruction of pathogens and weed seeds and can cause fly and odor problems.

Initially, the compost mass is at ambient temperature; however, as the microorganisms multiply, the temperature rises rapidly.

The composting process is commonly grouped into three phases based on the prominent type of bacteria present in the compost mix. Figure 10-39 illustrates the relationship between time, temperature, and compost phase. If the temperature is less than 50 degrees Fahrenheit, the compost is said to be in the psychrophillic stage. If it is in the range of 50 to 105 degrees Fahrenheit, the compost is in the mesophillic stage. If the compost temperature exceeds 105 degrees Fahrenheit, the compost is in the thermophillic stage. For complete pathogen destruction, the compost temperature must exceed 135 degrees Fahrenheit.

The compost temperature will decline if moisture or oxygen is insufficient or if the food source is exhausted. In compost methods where turning is the method of aerating, a temperature rhythm often develops with the turning of the compost pile (fig. 10–40).

Moisture—the moisture content of the compost mixture should be monitored periodically during the process. Low or high moisture content can slow or stop the compost process. High moisture content generally results in the process turning anaerobic and foul odors developing. High temperature drives off significant amounts of moisture, and the compost mix may become too dry, resulting in a need to add water.

Odor—the odor given off by the composting operation is a good indicator of how the compost operation is proceeding. Foul odors may mean that the process has turned from aerobic to anaerobic. Anaerobic conditions are the result of insufficient oxygen in the compost. This may be caused by excessive moisture in the compost or the need for turning or aerating of the compost.

***Compost process steps*—**The composting operation generally follows these steps (fig. 10–41):

Step 1 Preconditioning of materials (as needed). Grinding or shredding of the raw material may be necessary to increase the exposed surface area of the compost mixture to enhance decomposition by microorganisms.

Step 2 Mixing of the waste with a bulking agent or amendment. A typical agricultural composting operation involves mixing the raw waste with a bulking agent or amendment, or both, according to a prescribed mix or design. The prescribed mix should detail the quantities of raw waste, amendments, and bulking agents to be mixed. The mixing operation is generally done with a front-end loader on a tractor, but other more sophisticated methods can be used.

Step 3 Aeration by forced air or mechanical turning. Once the materials are mixed, the composting process begins. Bacteria begin to multiply and consume carbon and free oxygen. To sustain

Figure 10–39 Composting temperature

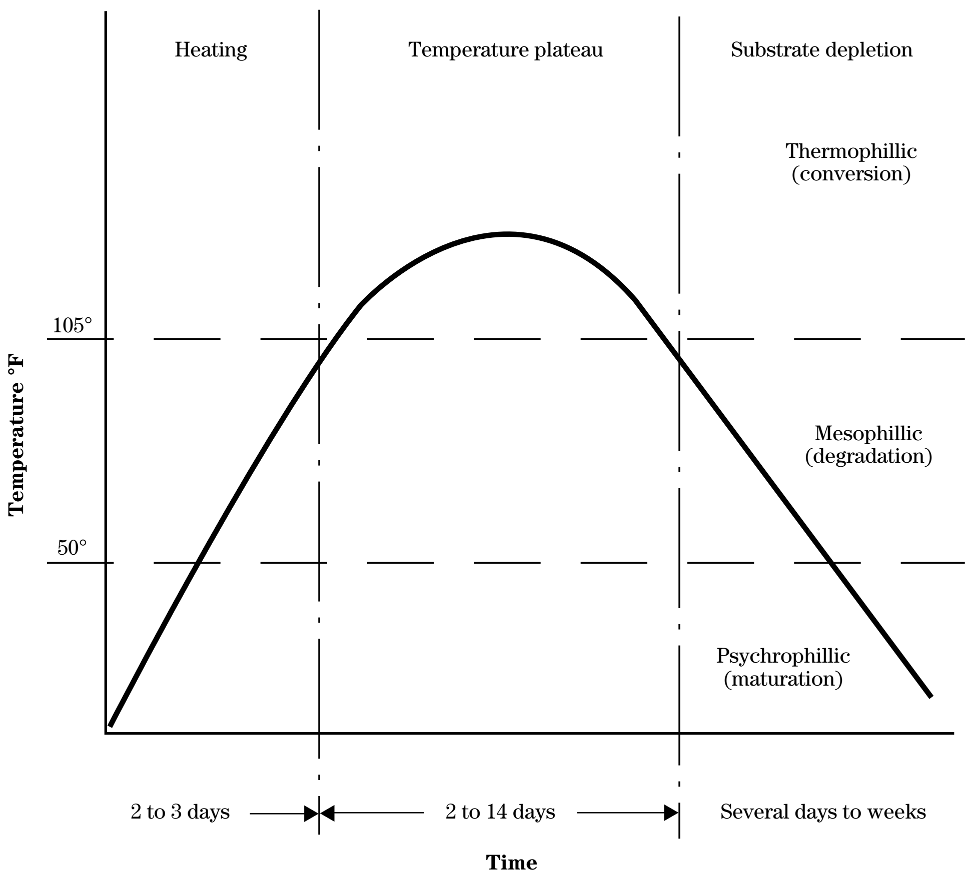


Figure 10–40 Typical temperature rhythm of windrow method

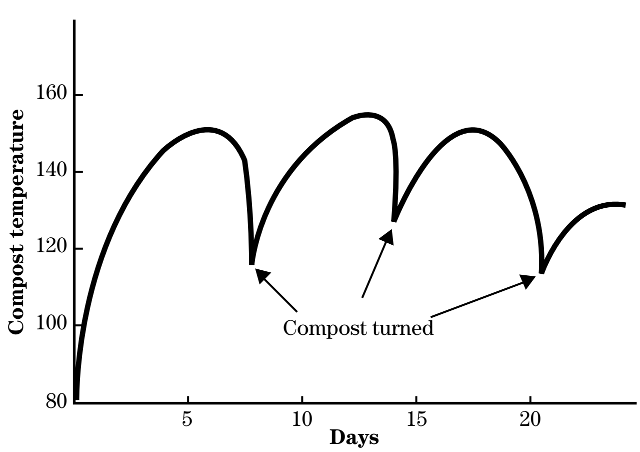
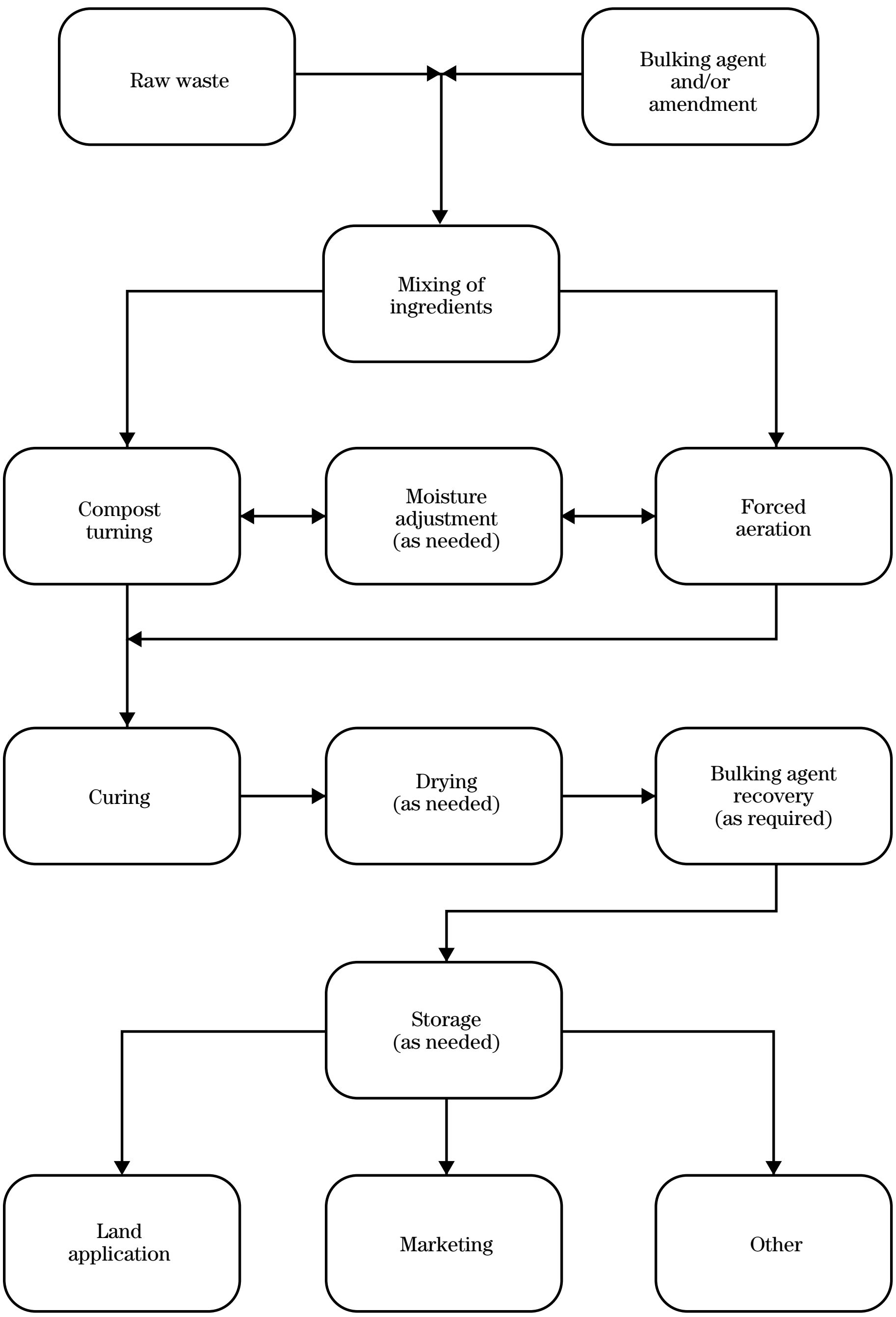


Figure 10–41 Agricultural composting process flow



microbial activity, air must be added to the mix to re-supply the oxygen to the compost pile. Air can be added by simply remixing or turning the compost pile. With more sophisticated methods, such as an aerated static pile, air is forced or sucked through the compost mix using a blower. The pounds of air per pound of volatile matter per day generally range from 5 to 9. Given in percentage, the optimum oxygen concentration of the compost mixture ranges from 5 to 15 percent, by volume. An increase of oxygen beyond 15 percent generally results in a decrease in temperature because of greater air flow. Low oxygen concentrations generally result in anaerobic conditions and slow processing times. Inadequate aeration results in anaerobic conditions and increased odors. Odor is an excellent indicator of when to turn and aerate a compost pile.

Step 4. Moisture adjustment (as needed). Water should be added with caution because too much moisture can easily be added. A compost mix that has excessive moisture problems does not compost properly, appears soggy and compacted, and is not loose and friable. Leachate from the compost mixture is another sign of excessive moisture conditions.

Step 5. Curing (optional). Once the compost operation is completed, it can be applied directly to the field or stored and allowed to cure for a period of months. During the curing process, the compost temperature returns to ambient conditions and the biological activity slows down. During the curing phase, the compost nutrients are further stabilized. The typical curing time ranges from 30 to 90 days, depending on the type of raw material and end use.

Step 6. Drying (optional). Further drying of the compost to reduce weight may be necessary if the finished compost is to be marketed, hauled long distances, or used as bedding. Drying can be accomplished by spreading the compost out in warm, dry weather or under a roofed structure until a sufficient quantity of moisture evaporates.

Step 7. Bulking agent recovery (as needed or required). If such bulking agents as shredded tires or large wood chips are used in the compost mixture, they can be recovered from the finished compost by screening. The recovered bulking agents are then reused in the next compost mix.

Step 8. Storage (as needed). Finished compost may need to be stored for a period of time during frozen or snow-covered conditions or until the compost product can be marketed. If possible, finished compost should be covered to prevent leaching or runoff.

(7) Vegetated treatment areas

A vegetated treatment area is a wide, flat area of vegetation used for removing suspended solids and nutrients from concentrated livestock area runoff and other liquid by-products of agricultural operations. The vegetated areas are designed with adequate length and limited flow velocities to promote filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilization of contaminants. Consideration must be given to hydraulic as well as contaminant loading.

Vegetated treatment areas rely on nutrient uptake to remove nitrates and other nutrients that are in solution, since these constituents are very mobile in water. Soils are used to infiltrate the liquid faction. Provision for rest periods between loadings is recommended. In cases where a large volume of runoff is expected, settling basins are needed above the treatment area. Clean water must be diverted from the treatment area. Installation and maintenance are critical.

The total treatment area should be designed to match crop nutrient uptake from the runoff or volume of water runoff with soil infiltration capacity. Typically, the nutrient balance approach is the limiting design sizing method. Uniform flow across the vegetated slope is required, possibly requiring shaping and other methods for distributing flow, in addition to field maintenance to limit erosion and channeling.

NRCS Conservation Practice Standard 635, Vegetated Treatment Area, gives more detailed planning considerations and design criteria. Also, see AWMFH, 651.0605(c) for additional information. If State or local government has restrictions on the use of vegetated treatment areas, the requirements must be met before design and construction. This is especially true if the outflow from the treatment area will flow into a stream or waterway. Unless permitted by State regulations, agricultural runoff treatment by a vegetated treatment area is not sufficient to allow discharge to surface water.

(8) Constructed wetlands

A constructed wetland is a shallow treatment system that uses aquatic vegetation and microorganisms to reduce nutrients, organic matter, and suspended solids in runoff from agricultural operations. Constructed wetlands treatment systems can utilize subsurface flow, surface flow, or a combination of these two processes. A natural or constructed subsurface barrier is used to control seepage. The design and operating parameters include hydraulic retention, cell depth and size, substrate composition, and recycling requirements.

Subsurface flow systems utilize submerged flow through a permeable medium, reducing odor problems. Examples are root-zone systems, rock-reed-filters, and vegetated submerged bed systems. Typical media includes soil, sand, and gravel or crushed rock.

Surface flow systems are similar to natural wetlands, utilizing shallow water flowing over a soil surface. Vegetation and aerobic bacteria provide nutrient reduction. Surface flow systems should be planned and designed according to NRCS Conservation Practice Standard 656, Constructed Wetland, which gives more detailed planning considerations and design criteria. Also, see NEH 637, Environmental Engineering, Chapter 3, Constructed Wetland (NEH637.0305) for additional information.

Reciprocating flow systems (RECIP) are designed to create alternating surface and subsurface flow between paired wetland cells. By using fill and drain, the environment alternates between aerobic and anaerobic conditions, allowing oxidation and reduction to occur. Organic decomposition occurs through nitrification/denitrification, phosphorus removal, sulfate reduction, and limited methanogenesis.

If State or local government has restrictions on the use of constructed wetlands, the requirements must be met before design and construction. This is especially true if the outflow from the wetland will flow into a stream or waterway. Unless permitted by State regulations, agricultural runoff treatment by a constructed wetland is not sufficient to allow discharge to surface water.

(9) Human waste management

If at all possible, human waste should be treated in municipal facilities designed to provide proper treatment. However, in many rural areas, this is not possible.

Septic tank systems designed for specific soil conditions are typically used for treating human waste in areas not served by municipal treatment facilities.

Most home sewage systems rely on anaerobic decomposition in septic tanks with the resulting effluent being discharged into a leaching field. Some conditions, such as a high water table, require that the septic system be constructed above ground in mounds. Human waste is not to be stored or processed in animal waste management facilities because of the potential for disease transmission.

Landowners should contact local health authorities for design requirements and permit information before installing treatment systems for human waste. NRCS does not design human waste management systems, but some States have extension specialists or environmental engineers that can assist in designing suitable systems.

651.1006 Utilization

Utilization is a function in a manure management system employed for a beneficial purpose. The typical method is to apply the manure to the land as a source of nutrients for plant growth and of organic matter to improve soil tilth and water holding capacity and to help control erosion. The vast majority of manure produced in the United States is applied to cropland, pasture, and hayland. Manure properly managed and applied at the appropriate rates and times can significantly reduce the amount of commercial fertilizer needed for crop production.

Manure and other by-products of agricultural operations can also be used directly as fuels for energy production or converted to generate biogas. In addition, by drying or composting, the material can be used for bedding or potting material. Solid and liquid separation increase available alternatives for utilization.

(a) Nutrient management

Manure should be applied at rates where the nutrient requirements of the crop to be grown are met. Concentration of nutrients in the manure should be known, and records on manure application rates should be maintained.

Between the time of manure production and the time of application, nutrient concentrations can vary widely because of storage, dilution, volatilization, settling, drying, or treatment. To accurately use manure, representative samples of the material to be land applied should be analyzed for nutrient content. Before application rates can be computed, the soil in the fields where manure will be applied should be analyzed and nutrient recommendations obtained. This information should indicate the amount of nutrients to be applied for a given crop yield.

Scheduling land application of wastes is critical. Several factors must be considered:

- amount of available manure storage
- major agronomic activities such as planting and harvesting
- weather and soil conditions
- availability of land and equipment
- stage of crop growth

A schedule of manure application should be prepared in advance. It should consider the most likely periods when application is not possible. This can help in determining the amount of storage, equipment, and labor needed to make application at desired times. NRCS Conservation Practice Standard 590, Nutrient Management, gives more detailed planning considerations and design criteria.

(b) Land application equipment

Manure is land applied using a variety of equipment. The kind of equipment used depends on the TS concentration of the material. If the manure handles as a solid, a box spreader or flail spreader is used. Solids spreaders are used for manure from solid manure structures and for the settled solids in sediment basins.

Slurry manures are applied using tank wagons or flail spreaders. Some tank wagons can be used to inject the material directly into the soil. Slurry spreaders are typically used for manure that is stored in above or belowground storage structures, earthen storage structures, and sometimes lagoons.

Manure that has a TS concentration of less than 5 percent can be applied using tank wagons, or it can be irrigated using large diameter nozzles. Irrigation is used primarily for land application of liquids from lagoons, storage ponds, and tanks. Irrigation systems must be designed on a hydraulic loading rate, as well as on nutrient utilization.

Custom hauling and application of manure are becoming popular in some locations. This method of utilization reduces the amount of specialized equipment needed by the owner/operator. NRCS Conservation Practice Standard 634, Waste Transfer, gives more detailed planning considerations and design criteria.

(c) Land application of municipal sludge

Municipalities in the United States treat wastewater biologically using anaerobic or aerobic processes. These processes generate sludge that has agronomic value as a nutrient source and soil amendment. Land application of sludge is currently recognized as acceptable technology; however, strict regulations and practices must be followed.

(d) Bioenergy production

Bioenergy can be produced from commonly used materials on the farm such as crops, animal excretions, and by-products from food processing. The conversion process into solid, liquid, or gaseous fuels can be separated into three broad categories: thermochemical, biochemical, and agrochemical processes. Thermochemical processes include direct combustion, liquefaction, gasification, and pyrolysis. Biochemical processes include hydrolysis-fermentation and anaerobic digestion. Agrochemical processes include the crushing of seed crops and the extraction of the oil for fuel, such as biodiesel and heating oil. The products from these processes include such items as biogas, methanol, ethanol and biodiesel oils.

(1) Anaerobic digestion

An anaerobic digester used for biogas production is considered a utilization function component because the manure is being managed for use even though further management of the digester effluent is required. Anaerobic digestion is the process of storing liquid manure in an air-tight vessel to be decomposed by microbes into methane, carbon dioxide, hydrogen sulfide, and water vapor as gaseous by-products. This biological conversion process has a number of advantages. Fresh manure has high moisture content (about 80%), making it unsuitable for most thermochemical processes; the high content of lignin makes it unattractive for fermentation to ethanol or other products. Additionally, the process offers the potential for onsite energy production and odor reduction.

Biogas, the product of anaerobic digestion, is typically made up of 55 to 65 percent methane (CH_4), 35 to 45 percent carbon dioxide (CO_2), and traces of ammonia (NH_3) and hydrogen sulfide (H_2S). Although biogas can range from approximately 55 to 80 percent CH_4, biogas generated from animal manures is typically around 65 percent CH_4. The amount of CH_4 generated depends on the livestock type, frequency of waste collection, waste handling method, and climate. Pure methane is a highly combustible gas that has an approximate heating value of 994 British thermal units (BTU) per cubic foot. Biogas can be burned in boilers to produce hot water, in engines to power electrical generators, and in absorption coolers to produce refrigeration.

The most frequent problem with anaerobic digestion systems is related to the economical use of the biogas. The biogas production rate from a biologically stable anaerobic digester is reasonably constant; however, most on-farm energy use rates vary substantially. Because compression and storage of biogas is expensive, economical use of biogas as an on-farm energy source requires that farm use must closely match the energy production from the anaerobic digester. Additionally, environmental conditions can directly affect biogas production efficiency.

Because of the presence of hydrogen sulfide, biogas may have an odor similar to that of rotten eggs. Hydrogen sulfide mixed with water vapor can form sulfuric acid, which is highly corrosive. It can be removed from biogas by passing the gas through a column of iron-impregnated wood chips or adding air to the digester headspace area. Water vapor can be removed by condensers or condensate traps. Carbon dioxide can be removed by passing biogas through lime water under high pressure.

Biogas can be used to heat the slurry manure in the digester. From 25 to 50 percent of the biogas is required to maintain a working digester temperature of 95 degrees Fahrenheit, depending on the climate and the amount of insulation used. Belowground digesters require less insulation than those aboveground. Engines can burn biogas directly from digesters; however, removal of hydrogen sulfide and water vapor is recommended.

If digested solids are separated from digester effluent and dried, they make an excellent bedding material. A brief period of composting may be necessary before it is used.

Anaerobic digestion in itself is not a pollution control practice. Digester effluent must be managed similarly to undigested manure by storing in storage ponds or treating in lagoons. Initial start-up of a digester is critical. The digester should be partly filled with water (50–75% full) and brought to temperature using an auxiliary heater. Feeding of the digester with manure should increase over a period of 3 to 6 weeks starting with a feeding rate of about 25 percent of full feed (normal operation).

Biogas production rates can be measured using specially designed corrosion resistant gas meters. These rates and carbon dioxide levels are good indicators of digester health during start-up. Several simple tests can be used in the field to determine carbon dioxide.

The potential amount of biogas produced from animal manure can be theoretically or empirically estimated. At a minimum, laboratory testing of animal manure to determine the chemical oxygen demand (COD) and TS contents should be conducted when considering anaerobic digestion as a treatment alternative. This information can be used to estimate potential biogas production and to evaluate applicable anaerobic digester configurations. The volume of biogas generated from the anaerobic digestion of manure can be theoretically predicted based on the COD of the manure and the COD to CH_4 conversion efficiency. If the COD is not available, VS content can be used to estimate potential methane production. NRCS Conservation Practice Standard 366, Anaerobic Digester, gives more detailed planning considerations and design criteria.

Design procedure—Because of the safety issues and economic and operational complexities involved, NRCS assistance on biogas production is generally limited to planning and feasibility. The information presented here is intended for that type of assistance. Interested farmers and ranchers should be advised to obtain other assistance in the detailed design of the facility.

The guidelines presented here are based on digestion of manure in the mesophillic temperature range (about 95 °F) and may be subject to change as a result of additional research and experience. They provide a basis for considering biogas production facilities based on current knowledge as part of a waste management system.

Several digester types are used (figs. 10–42, 10–43, 10–44). The mixed tank is a concrete or metal cylindrical vessel constructed aboveground. If the manure is highly liquid (low TS), the digester must be periodically mixed to get complete digestion. This can be done mechanically using a mechanical mixer, recirculating digestion liquid, or pumping biogas into the bottom sludge to remix the contents of the digester.

Another digester, known as the plug flow, is used for relatively thick manure (12–14% TS), such as dairy manure. The manure is introduced at one end and theo-

Figure 10–42 Two-stage, mixed tank anaerobic digester

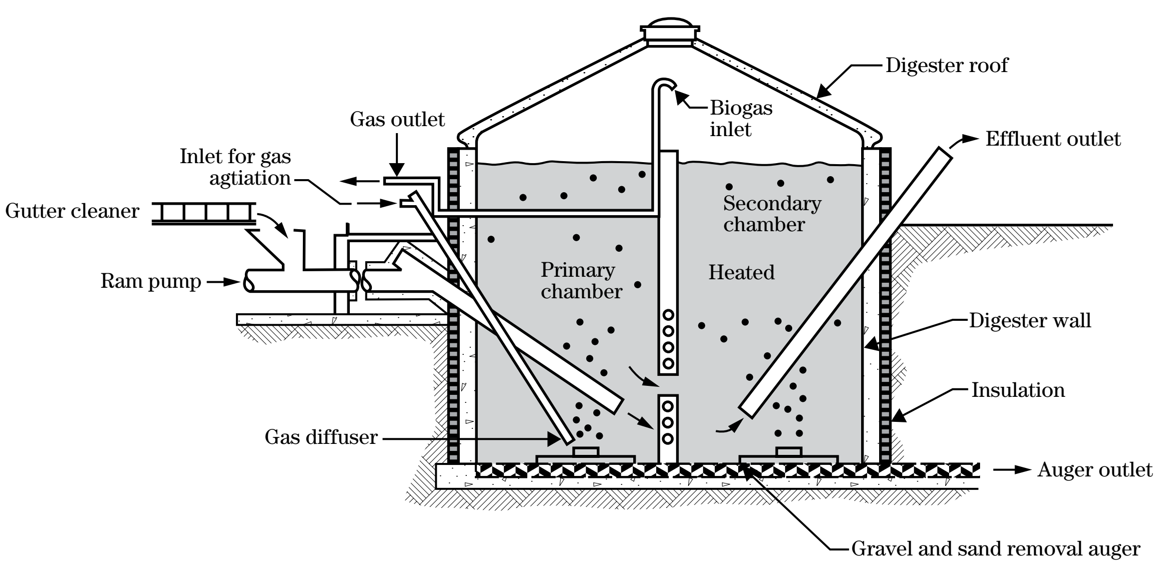


Figure 10–43 Typical anaerobic digester types

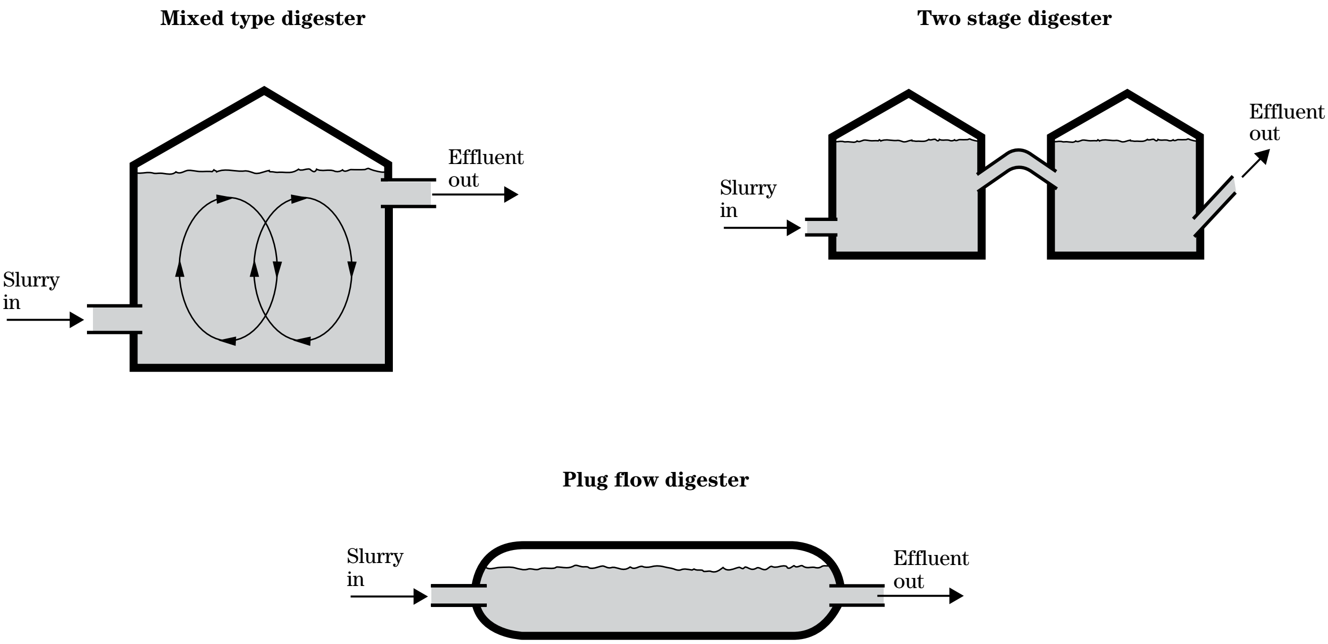
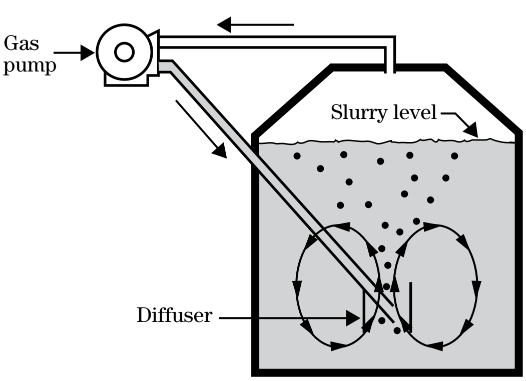


Figure 10–44 Gas agitation in an anaerobic digester



retically moves as a plug to the other end. However, if the TS content of the influent manure is too low, the manure will channel, the actual retention time will be reduced, and the biogas yield will diminish.

Biogas production is dependent upon the animal species, type of digester used, storage and handling losses, collection methods, and feed management. For any digester, the influent must be managed for consistency in frequency of feeding. For this to happen, the rations fed and manure management must be consistent. Some manure requires preprocessing before it enters the digester. For example, poultry manure must be diluted to about 6 percent TS to allow grit to settle before the manure is pumped into the digester. Grit material is very difficult to remove from digesters. All digesters must be periodically cleaned. The frequency of cleaning can vary from 1 to 4 years.

Step 1 Determine manure production. Manure production can be based on the tables in AWMFH, chapter 4 or on reliable local data. The following data will be needed:

Volume of manure produced	= —ft^3/d
Wet weight of manure produce	= —lb/d
Total solids (TS)	= —lb/d
Volatile solids (VS)	= —lb/d
Percent solids (TS/wet weight)	= —%

Fresh manure is desirable for digestion. Characteristics of beef feedlot manure must be determined for each operation.

Step 2 Establish TS concentration for digester feed. TS concentrations considered desirable as input to the digester can range from about 6 to 12 percent. The following are guidelines:

Dairy manure	10 to 12%
Confined beef manure	10 to 12%
Beef feedlot manure (after settling grit)	8 to 10%
Swine manure	8 to 10%
Chicken manure	7 to 9%

These percentages may need to be adjusted to eliminate scum formation and promote natural mixing by the gas produced within the mass. If scum forms, a small increase in percent solids may be desirable. This increase may be limited by pumping characteristics and should seldom go above 12 percent solids.

Step 3 Determine effective digester volume. A hydraulic detention time of 20 days is suggested. This time appears to be about optimum for efficient biogas production. The daily digester inflow in cubic feet per day can be determined using equation 10–24.

$$DMI = \frac{TMTS \times 100}{DDSFC \times 62.4} \qquad \text{(eq. 10–24)}$$

where:
DMI = daily manure inflow, ft^3
TMTS = total manure total solids production, ft^3/d
DDSFC = desired digester input total solids concentration, %

The necessary digester volume in cubic feet can be determined using equation 10–25.

$$DEV = DMI \times 20 \qquad \text{(eq. 10–25)}$$

where:
DEV = digester effective volume, ft^3
20 = recommended detention time, d

Step 4 Select digester dimensions. Optimum dimensions of the liquid part of the digester volume have not been established. The digester should be longer than it is wide to allow raw manure to enter one end and digested slurry to be withdrawn at the other. An effectively operating digester has much mixing by heat convection and gas bubbles.

Sufficient depth should be provided to preclude excessive delay at start-up because of the oxygen interchange at the surface. A combination of width equal to about two times the depth and length equal to about four times the depth is a realistic approach. Other proportions of width and length should work equally well. For the purpose of discussion assume:

$$H = \left(\frac{DEV}{8}\right)^{0.33}$$
$$WI = 2 \times H$$
$$L = 4 \times H$$

where:
H = height, ft
WI = width, ft
L = length, ft

Dimensions should be adjusted to round numbers to fit the site and provide economical construction.

Step 5 Estimate potential biogas production. Biogas production is dependent on manure decomposition within the digester. Biogas production from manure may vary significantly from the estimates that follow. Animals fed a high roughage ration produce less biogas than those fed a high concentrate ration. Also, solids separation can significantly affect biogas production. Finally, volatile solids reduction may vary from 30 to 60 percent, depending upon management and animal characteristics.

Estimated VS reductions are:

Dairy	35%
Beef	40%
Swine	50%
Poultry	55%

Estimated daily biogas production rates are:

Dairy	10 ft^3/lb VS destroyed
Beef	10 ft^3/lb VS destroyed
Swine	12 ft^3/lb VS destroyed
Poultry	11 ft^3/lb VS destroyed

Biogas production per day is estimated by multiplying the percent volatile solids reduction times the estimated daily biogas production rate times the daily volatile solids input. Biogas production in cubic feet per day would be:

Dairy	3.5 × daily VS input
Beef	4 × daily VS input
Swine	6 × daily VS input
Poultry	6 × daily VS input

Initial start-up of a digester requires a period of time for anaerobic bacteria to become acclimated and multiply to the level required for optimum methane production. If available, sludge from a municipal anaerobic digester or another anaerobic manure digester can be introduced to speedup the start-up process. The digester contents must be maintained at about 95 degrees Fahrenheit for continuous and uniform biogas production. Hot water tubes within the digester can serve this purpose.

Other considerations—Biogas is difficult to store because it cannot be compressed at normal pressures and temperatures. Storage pressures above 250 pounds per square inch are rarely used. Because of these reasons, biogas usage is generally planned to match production and, thus, eliminate the need for storage.

The most common use of biogas is the production of electricity using an engine-generator set. The thermal conversion efficiency is about 25 percent for this type of equipment. The remainder of the energy is lost as heat. Heat exchangers can be used to capture as much as 50 percent of the initial thermal energy of the biogas from the engine exhaust gases and the engine cooling water. This captured heat can sometimes be used onsite for heating. Some of it must be used to maintain the digester temperature.

Effluent from anaerobic digesters has essentially the same amount of nutrients as the influent. Some of the organic nitrogen will be converted to ammonia, making it more plant available, but more susceptible to volatilization unless the liquid is injected. Only a little volume is lost by processing the manure through an anaerobic digester. For manure requiring dilution before digestion, the amount of liquid to be stored and handled actually increases as compared to the original amount of manure.

Design example 10–9 Biogas digester

Mr. Joe Sims of Hamburg, Pennsylvania, has requested assistance on development of a manure management system for his 100 Guernsey milk cows that weigh an average of 1,200 pounds. He has requested that an alternative be developed that includes an anaerobic digester to produce methane gas. Determine the approximate size of the digester using worksheet 10A–5.

Worksheet 10A-5—Anaerobic digester design

Decisionmaker: Joe Sims

Date: 6/13/89

Site: Hamburg, PA

Animal units

1. Animal type: Milkers
2. Animal weight, lbs (W): 1200
3. Number of animals (N): 100
4. Animal units, $AU = \frac{W \times N}{1000}$ = 120

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM)= 1.7
6. Total volume of daily manure production for animal type, ft^3/day
   MPD = AU x DVM 204
7. Total daily manure production volume, ft^3/day (TMP) 204

Manure total solids

8. Daily manure total solids production, lbs/AU/day (MTS) = 14
9. Daily manure total solids production for animal type, lb/day
   MTSD = MTS x AU = 1680
10. Total manure total solids production, lbs/day (TMTS) = 1680

Manure volatile solids

11. Daily manure volatile solids production per AU, lbs/AU/day (MVS) = 11
12. Daily manure volatile solids production for animal type per day, lbs/day MVSD = AU x MVS = 1320
13. Total manure volatile solids production, lbs/day (TMVS) 1320

Percent solids

14. Percent solids, % (PS)

$$PS = \frac{TMTS \times 100}{TMP \times 62.4} = \frac{(1680) \times 100}{(204) \times 62.4} = 13.2$$

Digester feed solid concentration

15. Desired digester feed solids concentration, % (DDFSC) = 12.0

Daily manure inflow

16. Daily manure inflow, ft^3

$$DMI = \frac{TMTS \times 100}{DDFSC \times 62.4} = \frac{(1680) \times 100}{(12) \times 62.4} = 224.4$$

Digester effective volume

17. Digester effective volume, ft^3
    DEV = DMI x 20 = (224.4) x 20 = 4,488

Digester dimensions

18. Digester depth, ft

$$H = \left(\frac{DEV}{8}\right)^{0.33} = \left(\frac{4{,}488}{8}\right)^{0.33} = 8.08$$

19. Digest width, ft WI = 2 x H = 2 x (8.08) = 16.2
20. Digest length, ft L = 4 x H = 4 x (8.08) = 32.3

Estimated energy production

21. Biogas per unit (VS), ft^3/lb (BUVS) = 3.5
22. Estimated biogas production ft^3/day
    EBP = BUVS x TMVS = (3.5) x (1320) = 4,620
23. Estimated energy production BTU/day
    EEP = EBP x 600 = (4620) x (600) = 2,772,000

(2) Thermochemical conversion

Anaerobic digestion may have a thermal efficiency as low as 30 percent, since only the methane portion of biogas is available for energy conversion. Thermochemical energy conversion efficiency may be double that of anaerobic digestion, since all hydrocarbon compounds are converted to fuel. Thermochemical conversion uses pressure or heat to decompress biomass to produce energy. Examples include incineration (burning with excess air to produce heat), pyrolysis (thermal treatment in little to no air, producing pyrolysis oil and biogas), gasification (thermal treatment using high temperatures in little to no air to produce biogas), and liquefaction (thermal conversion of a slurry to produce oils and char). Some processes may require air emission permits, depending upon local regulations.

(i) Incineration

Incineration is the direct combustion of dry manure (15–20% moisture) to produce heat without generating intermediate fuel gases, liquids, or solids. Temperatures range between 1500–3000 degrees Fahrenheit. Combustion requires the simultaneous processes of heat and mass transport, pyrolysis, gasification, ignition, and burning, with fluid flow. Usually excess air is supplied to ensure maximum fuel conversion. Combustion produces heat, carbon dioxide, water vapor, and ash, with the heat typically used for steam production. However, incomplete combustion can produce pollutants like carbon monoxide, particulate matter, and volatile organic compounds (VOCs). Additionally, nitrogen and sulfur compounds in the dry manure and other reactions caused by the high combustion temperatures can lead to emissions of oxides of nitrogen and sulfur (NO_x and SO_x).

(ii) Pyrolysis

Pyrolysis is a low oxygen process that operates at temperatures between 390 and 1100 degrees Fahrenheit to produce liquids, gases, and solids from manure. Pyrolysis oils can be used as boiler fuel or refined similar to crude oil. Solids can be used similar to charcoal. Combustion of pyrolysis liquids and gases result in the same end products as produced by direct combustion of solids, but with improved pollution control, conversion efficiencies, and easier fuel storage and handling. Minimal oxygen requirements reduce the formation of pollutants. The process can also be optimized for the production of liquids or gases, depending upon job requirements. Part of the energy budget must be used to dry the manure to 15 to 20 percent moisture.

(iii) Gasification

Gasification is a form of pyrolysis to optimize gas production at temperatures between 1100 and 1800 degrees Fahrenheit. The gas (syngas) is primarily carbon monoxide, hydrogen, methane, and some light weight hydrocarbons. By-products of gasification include liquids (tars, oils, and other condensates) and solids (char and ash). Syngas can be used in internal combustion engines or used to produce methanol. Combustion of syngas result in the same end products as produced by direct combustion of solids, but with improved pollution control, conversion efficiencies, and easier fuel storage and handling. Internal combustion engines can use their own pollution control systems to minimize by-products.

(iv) Liquefaction

Liquefaction is the conversion of manure slurry to hydrocarbon oils and tars using pressures up to 200 atmospheres and temperatures between 390 and 900 degrees Fahrenheit. Typical processing time is measured in minutes. Products of liquefaction can be converted to hydrocarbon fuels and chemicals similar to those produced from petroleum. Pyrolysis and direct liquefaction differ in the operating conditions and end products. Additionally, drying of manure is not a limiting factor in liquefaction.

651.1007 Mortality management

Every livestock and poultry facility experiences loss of animals by death. Mortality management involves hygienic, environmental, and aesthetical considerations to deal with carcasses in a timely, safe, and nonoffensive manner. Although many methods of mortality management are available, local and State regulations will often restrict the locally available options. Mortality management facilities should be planned and designed in accordance with NRCS Practice Standard 316, Animal Mortality Facility.

Utilization of the nutrients and energy contained in the dead animals should be given first consideration. Rendering and composting of dead animals both result in by-products that can recycled. Gasification can provide energy to reduce the energy requirements of combustion. If utilization is not viable, consideration can be given to disposal by incineration or burial.

(a) Rendering and freezing

Rendering provides a method to recycle the nutrients in the carcass, usually as an ingredient in pet food. Because of the need to minimize decomposition, the carcass needs to be transported to a rendering facility within 24 hours. Decomposition can be minimized by preservation using freezing or fermentation. Freezing requires large custom-built or commercial freezer boxes to preserve dead animals until they can be picked up for delivery to the rendering plant. Although expensive, freezing minimizes pathogen transfer between farms. Fermentation requires grinding the carcass and adding carbohydrates for preservation by fermentation.

(b) Incineration

Burning carcasses at elevated temperatures provides an effective method of waste disposal. Ashes generated from a properly operating incinerator do not pose a pollution problem or an insect vector. However, costs of equipment and fuel in addition to potential odor and air pollution, are significant design challenges.

(c) Gasification

Using carcasses to generate energy and mineral ash are an attractive alternative. A burner heats a combustion chamber at temperatures between 1100 and 1800 degrees Fahrenheit. Carcasses are placed in the combustion chamber with low to no oxygen. The generated gases go from the combustion chamber to the gasification chamber as fuel to the gasification unit. The resulting ash is sterile, with bio-available minerals such as phosphorous, calcium, and magnesium. Also, the system may have sufficient capacity for multiple units to be used for catastrophic losses. However, air emission permits may be required, depending upon local regulations.

(d) Sanitary landfill

Sanitary landfills are disposal sites for solid waste. They are designed, constructed, and operated to be environmentally safe. Although one of the simplest methods of disposal, landfill sites often restrict the items can be placed in the landfill.

(e) Burial

A common method for onsite dead animal disposal is burial for anaerobic decomposition. The burial sites need to be at least 150 feet downgradient from any ground water supply source. Sites that have highly permeable soils, fractured or cavernous bedrock, and a seasonal high water table are not suitable and should be avoided. In no case should the bottom of the burial pit be closer than 5 feet from the ground water table. Surface water should be diverted from the pit.

(f) Composting

The disposal of dead animals is a major environmental concern. Composting can be an economical and environmentally acceptable method of handling dead animals. This process produces little odor and destroys harmful pathogens. Composting of dead poultry is the most common process. The process does apply equally well to other animals. Several universities have developed criteria for successfully composting whole large animals. For more information on composting animal mortality, refer to the NRCS National Engineering Handbook, Part 637, Environmental Engineering, Chapter 2, Composting.

Composting of dead animals should be considered when:

- a preferred use, such as rendering, is not available
- the mortality rate as a result of normal animal production is predictable
- sufficient land is available for nutrient utilization
- State or local regulations permit dead animal composting
- other disposal methods are not permitted or desired
- marketing of finished compost is feasible

(1) Special planning considerations

Because composting of dead animals is similar in many ways to other methods of composting, the same siting and planning considerations apply. These considerations will not be repeated here. Composting of dead animals does, however, have unique problems that require special attention.

Many States and localities regulate the disposal of dead animals. A construction permit may be required before installation of the facility begins, and an operating permit may be necessary to operate the facility. The animal producer is responsible for procuring all necessary permits to install and operate the facility.

The size of the animals to be composted should be considered when planning a compost facility. Larger animals require additional equipment, labor, and handling to cut the animals into smaller pieces to facilitate rapid composting. In lieu of dissecting carcasses, longer composting times can be used.

Dead animal composting facilities should be roofed to prevent rainfall from interfering with the compost operation. Dead animal composting must reach a temperature in excess of 130 degrees Fahrenheit for a minimum of 5 days to destroy pathogens. The addition of rainfall can elevate the moisture content and result in a compost mix that is anaerobic. Anaerobic composting takes much longer and creates odor problems.

(2) Sizing mortality composting facilities

A typical mortality composting facility consists of two stages. The first stage, also called the primary composter, is made up of equally sized bins in which the dead animals and amendments are initially added and allowed to compost. The mixture is moved from the first stage to the second stage, or secondary digester, when the compost temperature begins to decline. The second stage can also consist of a number of bins, but it is most often one bin or concrete area or alley that allows compost to be stacked with a volume equal to or greater than the sum of the first stage bins.

The design volume for each stage should be based on peak disposal requirements for the animal operation. The peak disposal period normally occurs when the animals are close to their market weight. The volume for each stage is calculated by multiplying the weight of dead animals at maturity times a volume factor. The volume factor (VF) can vary depending upon typical animal weight, type of composter, local conditions, and expeiences. Table 10–9 can be used to estimate VF.

Equation 10–22 can be used to calculate the volume for each stage in the compost facility.

$$\mathrm{Vol} = B \times \frac{M}{T} \times W \times \frac{VF}{100} \qquad \text{(eq. 10–22)}$$

where:
Vol = volume required for each stage (ft^3)
B = number of animals
M = percent normal mortality of animals for the entire life cycle expressed as percent
T = number of days for animal to reach market weight (d)
W = market weight of animals (lb)
VF = volume factor

Table 10–9 Volume factor if nitrogen source, such as poultry litter or manure, is used

Carcass size (lb)	Volume factor
0–4	1.0–2.5
4–10	3.0
10–25	5.0
25–300	10.0
300–750	14.0
750–1,400	20.0

Note: M/T is used to estimate the percentage of dead animals to be composted at maturity. Other estimators or field experience may be more accurate.

The number of bins required for the first and second stages can be estimated to the nearest whole number by dividing the total volume required by the volume of each bin (eq. 10–23).

$$\# \text{ Bins} = \frac{\text{Total 1st stage volume } \left(\text{ft}^3\right)}{\text{Volume of single bin } \left(\text{ft}^3\right)} \qquad \text{eq. (10–23)}$$

Bins are typically 5 feet high, 5 feet deep, and 8 feet across the front. The width across the front should be sized to accommodate the equipment used to load and unload the facility. To prevent spontaneous combustion and to allow for ease of monitoring, a bin height of no more than 6 feet is recommended. The depth should also be sized to accommodate the equipment used.

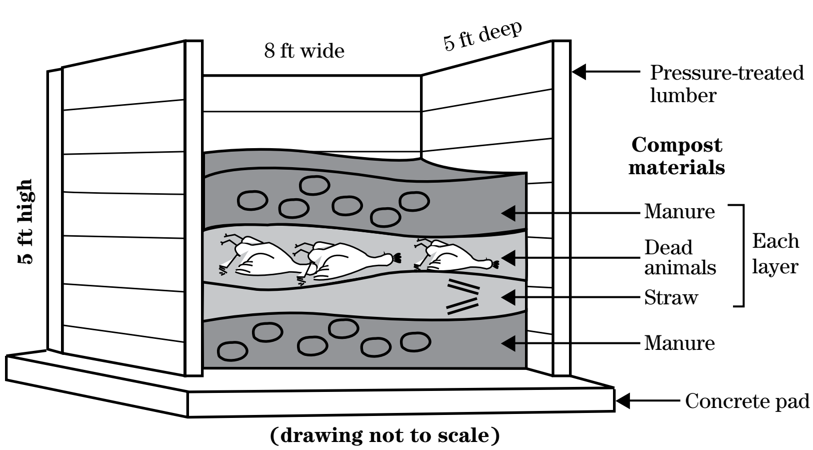
A high volume to surface area ratio is important to insulate the compost and allow the internal temperature to rise. The bin height and depth should be no less than half the width. Shallow bins are easier to unload and load; therefore, the bin depth should be no more than the width. Figure 10–45 is an example of a dead animal composting bin.

Mortality rates vary considerably because of climate and among varieties, species, and types of operation. Information provided by the animal producer/operator should be used whenever possible. Table 10–10 gives typical mortality rates, growth cycle, and market weights for animals and poultry.

Mix requirements—rapid composting of dead animals occurs when the C:N ratio of the compost mix is maintained between 10 and 20. This is considerably lower than what is normally recommended for other types of composting. Much of the nitrogen in the dead animal mass is not exposed on the surface; therefore, a lower C:N ratio is necessary to ensure rapid composting with elevated temperatures. If the dead animals are shredded or ground up, a higher C:N ratio of 25:1 would be more appropriate. The initial compost mix should have a C:N ratio that is between 13 and 15. As composting proceeds, nitrogen, carbon, and moisture are lost. Once composting is complete, the C:N ratio should be between 20 and 25. A C:N ratio of more than 30 in the initial compost mixture is not recommended because excessive composting time and failure to achieve the temperature necessary to destroy pathogens may result.

The moisture content of the initial compost mixture should be between 45 and 55 percent, by weight, to facilitate rapid decomposition. An initial moisture content of more than 60 percent would be excessively moist and would retard the compost process. The most common problem in dead animal composting is the addition of too much water. Depending on the mass of dead animals and the moisture content of the

Figure 10–45 Dead animal composting bin



amendments, water may not need to be added to the initial mix. Because water is relatively dense compared to the compost mix, the addition of a little water can raise the moisture content of the mix considerably. Even though water may not need to be added to the initial mix, it is advisable to have a source of water available at the compost site for temperature control.

Composting of dead animals should remain aerobic at all times throughout the process. Anaerobic conditions result in putrid odors and may not achieve temperatures necessary to destroy pathogens. Foul odor during the compost process indicates that the compost process has turned anaerobic and that corrective action is needed. These actions will be addressed later. To prevent the compost process from going anaerobic, the initial mix should have enough porosity to allow air movement into and out of the compost mix. This can be accomplished by layering dead animals and amendments in the mix. For example, a dead poultry compost mix would be layered with straw, dead birds, and manure or waste cake from the poultry houses. Layers of such high porosity material as straw, wood chips, peanut hulls, and bark allow lateral movement of air in the compost mix. Figure 10–46 is an example of commonly recommended layering of manure, straw, and dead poultry.

Table 10–11 is a typical recipe for composting dead birds. The ingredients are presented by volume as well as weight.

Table 10–10 Animal mortality rates

Animal type Poultry type	Mortality rate (%)	Growth cycle (d)	Cycles (per year)	Market weight (lb)
Broiler	4.5–5.0	42–49	5.5–6.0	4.2
Roaster				
female	3	42	4	4.0
male	8	70	4	7.5
Laying hen	14	440	0.9	4.5
Breeding hen	10–12	440	0.9	7–8
Breeder male	20–25	300	1.1	10–12
Turkey female	5–6	95	3	14
Turkey male	9	112	3	24
Swine, farrow—prewean	11	20		10
Swine, farrow—nursery to 60 lb	2.6	47		35
Swine, grower/finisher	6	119	2.5	210
Swine, sow and gilt <250 lb	2.5			
Swine, sow and gilt 250–500 lb	3			
Swine, sow and gilt >500 lb	3.7			
Beef cattle (>500 lb)	1.2			
Beef calf	3.3			
Dairy cattle (>500 lb)	2.8			
Dairy calf	6.4			
Horse <20 years old	1.2			
Horse >20 years old	10.2			
Horse, foal (less than 30 days)	4.9			
Sheep, all causes	6.2			
Sheep, nonpredator	3.9			
Lamb, all causes	10.1			
Lamb, nonpredator	5.5			

Figure 10–46 Recommended layering for dead bird composting

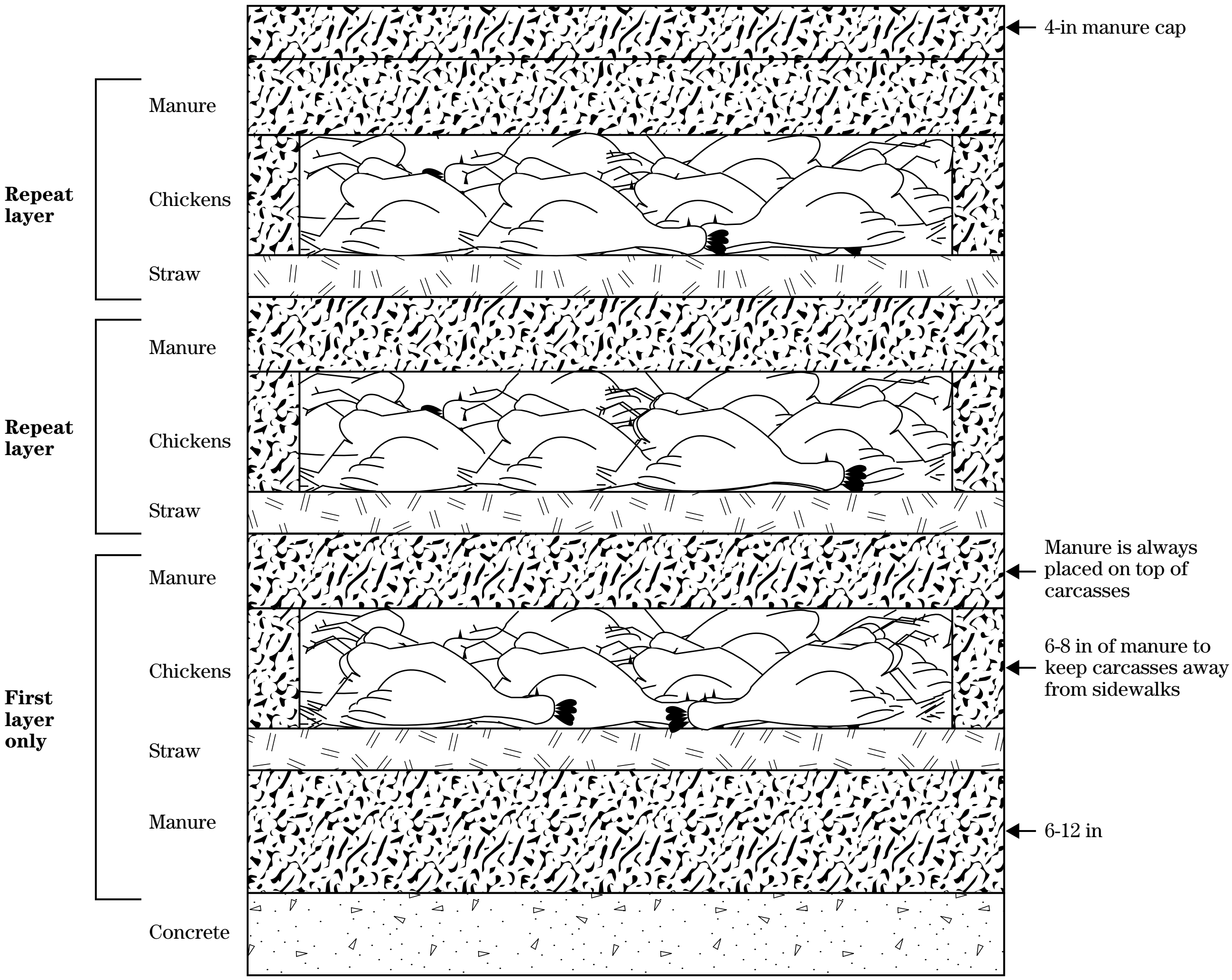


Table 10–11 Broiler compost mix

Ingredient	Volume (parts)	Weight (parts)
Straw	1.0	0.1
Broiler	2.0	1.0
Manure	2.0	1.5
Water*	0.5	0.75

* More or less water may be necessary depending on the moisture content of the straw and manure.

Research and evaluation on composting dead animals other than poultry is limited. The differences between livestock and poultry as related to composting are insignificant except for the size of the animal to be composted and the density of skeletal material. Large birds, such as turkeys, have been successfully composted. If large animals are to be composted, they should be cut into no larger than 15-pound pieces and be cut in a manner to maximize surface exposure. Large animal composting is a promising technology, but it is not well documented. Caution is advised.

Operational considerations—efficient and rapid composting requires careful control of the C:N ratio, percent moisture and aerobic conditions, and the internal temperature of the compost mix. A deficiency in any of these three areas retards and possibly inhibits the composting process achieving temperatures too low for pathogen destruction. Careful planning and monitoring is required to ensure that the process is proceeding as expected.

The landowner/operator should be provided a written set of instructions as a part of the waste management plan that detail the operation and maintenance requirements necessary for successful dead animal composting. The instructions should include compost mix design (recipe), method or schedule of when to unload the primary digester (first stage) and load the secondary digester (second stage), methods to monitor the compost process, and information on long-term compost storage. The final utilization of the compost should be detailed in the waste utilization plan.

Temperature is an important gauge of the progress of the composting operation. After initial loading into the first stage, the compost temperature should peak between 130 and 140 degrees Fahrenheit in 5 to 7 days. The same is true for when the compost is moved and stacked in the second stage. Elevated temperatures are necessary to destroy the fly larvae, pathogenic bacteria, and viruses. The two-stage process maximizes the destruction of these elements.

When the compost is initially loaded into the compost bin, the internal temperature begins to rise as a result of bacterial activity. Maximum internal temperatures within the first stage should exceed 130 degrees Fahrenheit within a few days. Although internal compost temperatures rise to a level necessary for the destruction of pathogenic organisms and fly larvae, the temperatures near the edge of the compost pile will not be sufficient to destroy these elements. The edge of the compost stack in the first stage may remain an incubation area for fly larvae and allow the survival of the more heat-resistant pathogens.

Removing the compost from the first stage and restacking in the second stage mixes and aerates the compost. The compost that was on the edge of the compost pile is mixed with the internal compost material, and subsequently is exposed to temperatures in excess of 130 degrees Fahrenheit in the second stage stack.

The internal temperature of the compost in the first and second stages should be monitored on a daily basis. The compost should be moved from the first stage to the second stage when the internal temperature of the first stage compost begins to decline. This generally occurs after 5 to 7 days.

If internal temperatures fail to exceed 130 degrees Fahrenheit in the first or second stages of the composter, the compost material should immediately be incorporated if land applied or remixed and composted a second time.

Excessively high temperatures are also a danger in dead animal composting because spontaneous combustion of the compost material can occur when the compost temperature exceeds 170 degrees Fahrenheit. If the temperature exceeds 170 degrees Fahrenheit, the compost should be removed from the bin and spread out in a uniform layer no more than 6 inches deep. Water should be used, if necessary, to further cool the compost. Once the temperature has fallen to a safe level, the compost can be restacked. Adding moisture to the compost should retard the biological growth and reduce the temperature. Excessive applications of water stop the process and can cause anaerobic conditions to develop. The compost mix should be rehydrated to a moisture content of 55 to 65 percent, by weight, to reduce excessive temperatures.

Anaerobic conditions may develop if the initial porosity of the compost mix is too low, excessive amounts of water are added to the mix, or the C:N ratio is excessively low. Odor generally is a good indicator of anaerobic conditions. If foul odors develop, the reason for the odor problem must be identified before corrective action can be taken. Anaerobic conditions may be the result of any one or a combination of excessive moisture, low porosity, or low C:N ratio.

(h) Emergency mortality management

Catastrophic mortality can occur for many reasons like fire, heat stress, inadequate ventilation, poisoning, diseases, and bioterrorism. An effective disease control and carcass disposal strategy is critical. Any animal feeding operation should have an emergency action plan for catastrophic mortality. Planning for a catastrophic event should include a study of local regulations specifying acceptable methods for disposal. Planning and preparation should also include identification of sites for disposal and obtaining insurance to cover the resultant costs.

(1) Biosecurity concerns

Carcass disposal is a major concern for biosecurity. Both disease control and environmental impacts are major considerations. Should a major disease outbreak occur, disposal of slaughtered animals requires large investments of time and space in an isolated environment. Transportation options are usually very limited. Current disease control policies usually require isolation and immediate mass slaughter to control a disease outbreak. Vaccination in conjunction with later slaughter can provide additional time and reduce immediate disposal requirements, but create tradeoffs between carcass disposal and disease control.

(2) Available options

Alternatives for carcass disposal for catastrophic mortality traditionally use normal mortality management facilities. However, these facilities may have limited availability and limited capacity.

Burial of catastrophic mortality shall be timed to minimize the effects of bloating during early stages of the decay process. When permitted by State law, mortality shall remain uncovered or lightly covered until bloating has subsided. Some topsoil should be stockpiled to re-grade the disposal site after the ground has settled and the decay process is largely completed.

Where composting is used for catastrophic mortality disposal, the operation and maintenance plan should identify the most likely compost medium, possible compost recipes, operational information, and readily available equipment.

Incineration and gasification will combust the carcass, kill pathogens, and produce ash high in phosphorus and magnesium. However, fuel costs and availability of facilities are limiting factors.

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.

- Provide the necessary distance between the fence and surface water to be protected for the interception of lot runoff in a channel, basin, or other collection or storage facility located above the lot.
- Reduce the lot area and thus reduce the volume of lot runoff to be collected or stored.
- Exclude livestock from hazardous areas such as waste storage ponds.
- Allow management of livestock for waste utilization purposes.
- Protect vegetative filters from degradation by livestock.

651.1009 References

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651.1050 Appendix 10A—Blank worksheets

Worksheet 10A-1—Waste storage structure capacity design

Decisionmaker: ______ Date: ______

Site: ______

Animal units

1. Animal type ______ ______ ______
2. Animal weight, lbs (W) ______ ______ ______
3. Number of animals (N) ------------ ______ ______ ______
4. Animal units, $AU = \frac{W \times N}{1000}$ = ----- ______ ______ ______

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM)= ______ ______ ______
6. Storage period, days (D) = ----------------- ______
7. Total volume of manure production for animal type for storage period, ft^3
   VMD = AU x DVM x D = ______ ______ ______
8. Total manure production for storage period, ft^3 (TVM) -------- ______

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) ------------------------------ ______

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 BV = ______ ______ ______

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

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

Minimum waste storage volume requirement

16. Waste storage volume, ft^3 (WV) = TVM + TWW + TBV = ______ + ______ + ______ = ______

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 (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.

Worksheet 10A-2—Waste storage pond design

Decisionmaker: Date:

Site:

Animal units

1. Animal type ______ ________ ________ ________
2. Animal weight, lbs (W) ________ ________ ________
3. Number of animals (N) ____________ ________ ________ ________
4. Animal units, $AU = \frac{W \times N}{1000}$ = _____ ________ ________ ________

Manure volume

5. Daily volume of manure production per AU, ft^3/AU/day (DVM)= ________ ________ ________
6. Storage period, days (D) = ________________ ________
7. Total volume of manure production for animal type for storage period, ft^3 ________ ________ ________
   VMD = AU x DVM x D =
8. Total manure production for storage period, ft^3 (TVM) ________ ________

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) ______________________________ ________

Clean water volume

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

Runoff volume

13. Runoff volume, ft^3 (ROV) (attach documentation) __________ ________
    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) __________ ________

Minimum waste storage volume requirement

15. Waste storage volume, ft^3 (WSV) = TVM + TWW + CW + ROV + VSA

= ________ + ________ + ________ + ________ + ________ = ____________

Pond sizing

16. Sizing by trial and error

Side slope ratio, (Z) = ____________ V must be equal to or greater than WSV = ____________ 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)

* *Depth must be adjusted in Step 17.*

Depth adjustment

17. Depth adjustment

Depth, ft (d) __________________________ ________

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

Add depth of 25-year, 24-hour storm ______+ ________

Add for freeboard (1.0 foot minimum) + ______________________ ________

Final depth ____ ________

Worksheet 10A-3—Anaerobic lagoon design

Decisionmaker: ____ Date: ____

Site: ____

Animal units

1. Animal type ____ ____ ____
2. Animal weight, lbs (W) ____ ____ ____
3. Number of animals (N) ____ ____ ____
4. Animal units, AU = $\frac{W \times N}{1000}$ = ____ ____ ____

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM)= ____ ____ ____
6. Treatment period, days (D) = ---------------- ____
7. Total volume of manure production for animal type for treatment period, ft^3 VMD = AU x DVM x D = ____ ____ ____
8. Total manure production for treatment period, ft^3 (TVM)- ____

Wastewater volume

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

Clean water volume

12. Clean water added during treatment period, ft^3 (CW) ---------------- ____

Waste volume

13. Waste volume for treatment period, ft^3 WV = TVM + TWW + CW = ____ + ____ + ____ = ____

Manure total solids

14. Daily manure total solids production, lbs/AU/day (MTS) = ____ ____ ____
15. Daily manure total solids production for animal type, lbs/day MTSD = MTS x AU = ____ ____ ____
16. Total manure total solids production, lbs/day (TMTS) = ____

Manure volatile solids

17. Daily manure volatile solids production per AU, lbs/AU/day (MVS) = ---------------- ____ ____ ____
18. Daily manure volatile solids production for animal type per day, lbs/day MVSD = AU x MVS = ____ ____ ____
19. Total manure volatile solids production, lbs/day (TMVS) ---------------- ____

Wastewater volatile solids

20. Daily wastewater volatile solids production, lbs/1000 gal (DWVS) ---------------- = ____ ____ ____
21. Total wastewater volatile solids production for animal type, lbs/day

$$WVSD = \frac{DWVS \times DWW \times 7.48}{D \times 1{,}000}$$ ---------------- = ____ ____ ____

22. Total wastewater volatile solids production, lbs/day (TWVS) ---------------- = ____

Total volatile solids (manure and wastewater)

23. Total daily volatile solids production, lbs/day TVS = TMVS + TWVS = ---------- ____ + ____ = ____

Minimum treatment volume

24. Selected lagoon VS loading rate, lbs VS/1,000 ft^3 (VSLR) = ____
25. Minimum treatment volume, ft^3

$$MTV = \frac{TVS \times 1000}{VSLR} = \frac{(\quad) \times 1000}{(\quad)} = \_\_\_\_$$

Sludge volume requirement

26. Sludge accumulation ratio, ft^3/lb TS (SAR) = ____
27 Sludge accumulation period, years (T) = ____
28. Sludge volume requirement, ft^3 SV = 365 x TMTS x T x SAR = 365 x ( )( )( ) = ____

Minimum lagoon volume requirement

29. Minimum lagoon volume requirements, ft^3 (MLVR) = MTV + SV + WV = ---------- ____ + ____ + ____ = ____

Lagoon sizing

30. Sizing by trial and error $$V = \frac{(4 \times Z^2 \times d^3)}{3} + (Z \times BL \times d^2) + (Z \times BW \times d^2) + (BW \times BL \times d)$$

Side slope ratio, (Z) = ____________   V must be equal to or greater than MLVR = ____________ ft^3

Trial no.	Bottom width ft (BW)	Bottom length ft (BL)	Depth* ft (d)	Volume ft^3 (V)

* *Depth must be adjusted in Step 31.*

Depth adjustment

31. Depth adjustment

Depth, ft (d) -- ____________

Add depth of precipitation less evaporation on lagoon surface ---------+ ____________
(for the treatment period)

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

Add for freeboard (1.0 foot minimum) ---------------------------+ ____________

Final depth -- ____________

32. Compute total volume using final depth, ft^3 (use equation in step 30) -- ____________

Worksheet 10A-4—Aerobic lagoon design

Decisionmaker:	Date:
Site:	

Animal units

1. Animal type ---------- ________ ________ ________

2. Animal weight, lbs (W) ________ ________ ________

3. Number of animals (N) ---------- ________ ________ ________

4. Animal units, AU = $\frac{W \times N}{1000}$ = ----- ________ ________ ________

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM) = ________ ________ ________

6. Treatment period, days (D) = ---------- ________

7. Total volume of manure production for animal type for treatment period, ft^3
VMD = AU x DVM x D = ________ ________ ________

8. Total manure production for treatment period, ft^3 (TVM) ---------- ________

Wastewater volume

9. Daily wastewater volume per AU, ft^3/AU/day (DWW) = ________ ________ ________

10. Total wastewater volume for animal description for treatment period, ft^3
WWD = DWW x AU x D = ________ ________ ________

11. Total wastewater volume for treatment period, ft^3 (TWW) ---------- ________

Clean water volume

12. Clean water added during treatment period, ft^3 (CW) ---------- ________

Waste volume

13. Waste volume for treatment period, ft^3 WV = TVM + TWW + CW = ________ + ________ + ________ = ________

Manure total solids

14. Daily manure total solids production, lbs/AU/day (MTS) = ________ ________ ________

15. Daily manure total solids production for animal type, lb/day
MTSD = MTS x AU = ________ ________ ________

16. Total manure total solids production, lbs/day (TMTS) = ________

Manure 5-day biochemical oxygen demand

17. Daily manure BOD_5 production per AU, lbs/AU/day (MBOD) = ---------- ________ ________ ________

18. Daily manure BOD_5 production for animal type per day, lbs/day MBOD = AU x BOD = ________ ________ ________

19. Total manure production, lbs/day (TMBOD) ---------- ________

Wastewater 5-day biochemical oxygen demand

20. Daily wastewater BOD_5 production, lbs/1000 gal (DWBOD) ---------- = ________ ________ ________

21. Total wastewater BOD_5 production for animal type, lbs/day

$$WBOD = \frac{(DWBOD \times TWW \times 7.48)}{D \times 1{,}000}$$ ---------- = ________ ________ ________

22. Total wastewater BOD_5 production, lbs/day (TWBOD) ---------- = ________

TOTAL BOD_5 (manure and wastewater)

23. Total daily production, lbs/day TBOD = TMBOD + TWBOD = ---------- ________ + ________ = ________

Minimum treatment surface area

24. Selected lagoon BOD_5 loading rate, lbs BOD_5/acre (BODLR) = ________

25. Minimum treatment surface area, acres

$$MTA = \frac{TBOD}{BODLR} = \frac{(\qquad)}{(\qquad)} =$$ ________

Sludge volume requirement

26. Sludge accumulation ratio, ft^3/lb TS (SAR) = ________

27 Sludge accumulation period, years (T) = ________

28. Sludge volume requirement, ft^3
SV = 365 x TMTS x T x SAR
= 365 (   )(   )(   ) = ________

Minimum lagoon volume requirement

29. Minimum lagoon volume requirements, ft^3
MLVR = SV + WV = ---------- ________ + ________ = ________

Lagoon sizing

30. Sizing by trial and error:

Side slope ratio, (Z) = ________________

V must be equal to or greater than MLVR = _______________ ft^3

SA must be equal to or greater than MTA = _______________ acres

Rectangular lagoon:

d must be less than 5 feet

$$SA = \frac{(BL + 2Zd)(BW + 2Zd)}{43{,}560}$$

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

Trial no.	Bottom width ft (BW)	Bottom length ft (BL)	Depth* ft (d)	Volume ft^3 (V)	Surface area acres (SA)

** Depth must be adjusted in Step 31*

Depth adjustment

31. Depth adjustment

Depth , ft (d) ------------------------------------ ___________

Add depth of precipitation less evaporation on lagoon surface + ___________
(for the treatment period)

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

Add for freeboard (1.0 foot minimum) ---------------- + ___________

Final depth -- ___________

32. Compute total volume using final depth, ft^3
(use equation in step 30) ------------------------------ ___________

Worksheet 10A-5—Anaerobic digester design

Decisionmaker: Date:

Site:

Animal units

1. Animal type ___ ___ ___

2. Animal weight, lbs (W) ___ ___ ___

3. Number of animals (N) - - - - - ___ ___ ___

4. Animal units, $AU = \frac{W \times N}{1000}$ = - - - - ___ ___ ___

Manure volume

5. Daily volume of daily manure production per AU, ft^3/AU/day (DVM)= ___ ___ ___

6. Total volume of daily manure production for animal type, ft^3/day

$MPD = AU \times DVM$ ___ ___ ___

7. Total daily manure production volume, ft^3/day (TMP) - - - - ___

Manure total solids

8. Daily manure total solids production, lbs/AU/day (MTS) = ___ ___ ___

9. Daily manure total solids production for animal type, lb/day

$MTSD = MTS \times AU$ = ___ ___ ___

10. Total manure total solids production, lbs/day (TMTS) = ___

Manure volatile solids

11. Daily manure volatile solids production per AU, lbs/AU/day (MVS) = - - - - - - - - ___ ___ ___

12. Daily manure volatile solids production for animal type per day, lbs/day $MVSD = AU \times MVS$ = ___ ___ ___

13. Total manure volatile solids production, lbs/day (TMVS) - - - - - - - - - - - - - - - - ___

Percent solids

14. Percent solids, % (PS)

$$PS = \frac{TMTS \times 100}{TMP \times 62.4} = \frac{(\quad\quad) \times 100}{(\quad\quad) \times 62.4} = \_\_\_$$

Digester feed solid concentration

15. Desired digester feed solids concentration, % (DDFSC) = ___

Daily manure inflow

16. Daily manure inflow, ft^3

$$DMI = \frac{TMTS \times 100}{DDFSC \times 62.4} = \frac{(\quad\quad) \times 100}{(\quad\quad) \times 62.4} = \_\_\_$$

Digester effective volume

17. Digester effective volume, ft^3

$DEV = DMI \times 20 = (\quad\quad) \times 20$ = ___

Digester dimensions

18. Digester depth, ft

$$H = \left(\frac{DEV}{8}\right)^{0.33} = \left[\frac{(\quad\quad)}{8}\right]^{0.33} = \_\_\_$$

19. Digest width, ft $WI = 2 \times H = 2 \times (\quad\quad)$ = ___

20. Digest length, ft $L = 4 \times H = 4 \times (\quad\quad)$ = ___

Estimated energy production

21. Biogas per unit (*VS*), ft^3/lb *(BUVS)* = ___

22. Estimated biogas production ft^3/day

EBP = $BUVS \times TMVS = (\quad\quad) \times (\quad\quad)$ = ___

23. Estimated energy production BTU/day

$EEP = EBP \times 600 = (\quad\quad) \times (600)$ = ___

Worksheet 10A-6—Monthly precipitation minus evaporation

Decisionmaker:	Date:
Site:	

Annual FWS Evaporation (*FWS*) = ____________ inches

Month	Monthly precipitation MP (inches)	Monthly portion of annual evaporation MPAE (percent)	Monthly evaporation ME (inches)*	Monthly precipitation less evaporation MPLE (inches)
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

**ME = FWS* x *MPAE*

Storage or treatment period, days (D) = ____________

months = ____________

Critical successive months

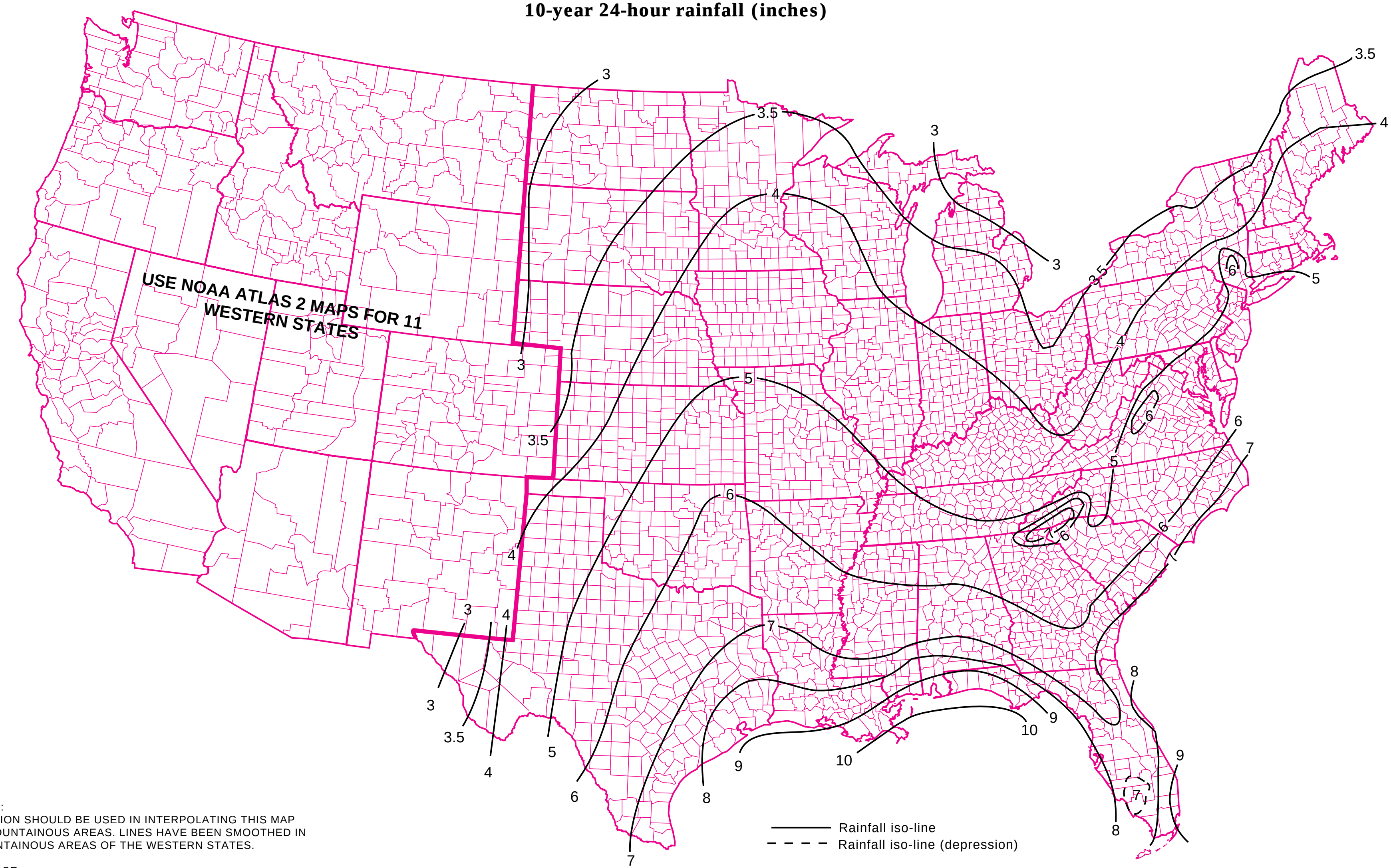
Month	Monthly precipitation less evaporation MPLE (inches)	Month	Monthly precipitation less evaporation MPLE (inches)
Total			

651.1060 Appendix 10B—Rainfall Intensity Maps

U.S. DEPARTMENT OF AGRICULTURE

NATURAL RESOURCES CONSERVATION SERVICE

Figure 10B-1
10-year 24-hour rainfall (inches)



NOTE:
CAUTION SHOULD BE USED IN INTERPOLATING THIS MAP IN MOUNTAINOUS AREAS. LINES HAVE BEEN SMOOTHED IN MOUNTAINOUS AREAS OF THE WESTERN STATES.

SOURCE:
NATIONAL WEATHER SERVICE PUBLICATIONS. MAP PREPARED USING AUTOMATED MAP CONSTRUCTION. NATIONAL CARTOGRAPHY AND GIS CENTER, FORT WORTH, TEXAS, 1995

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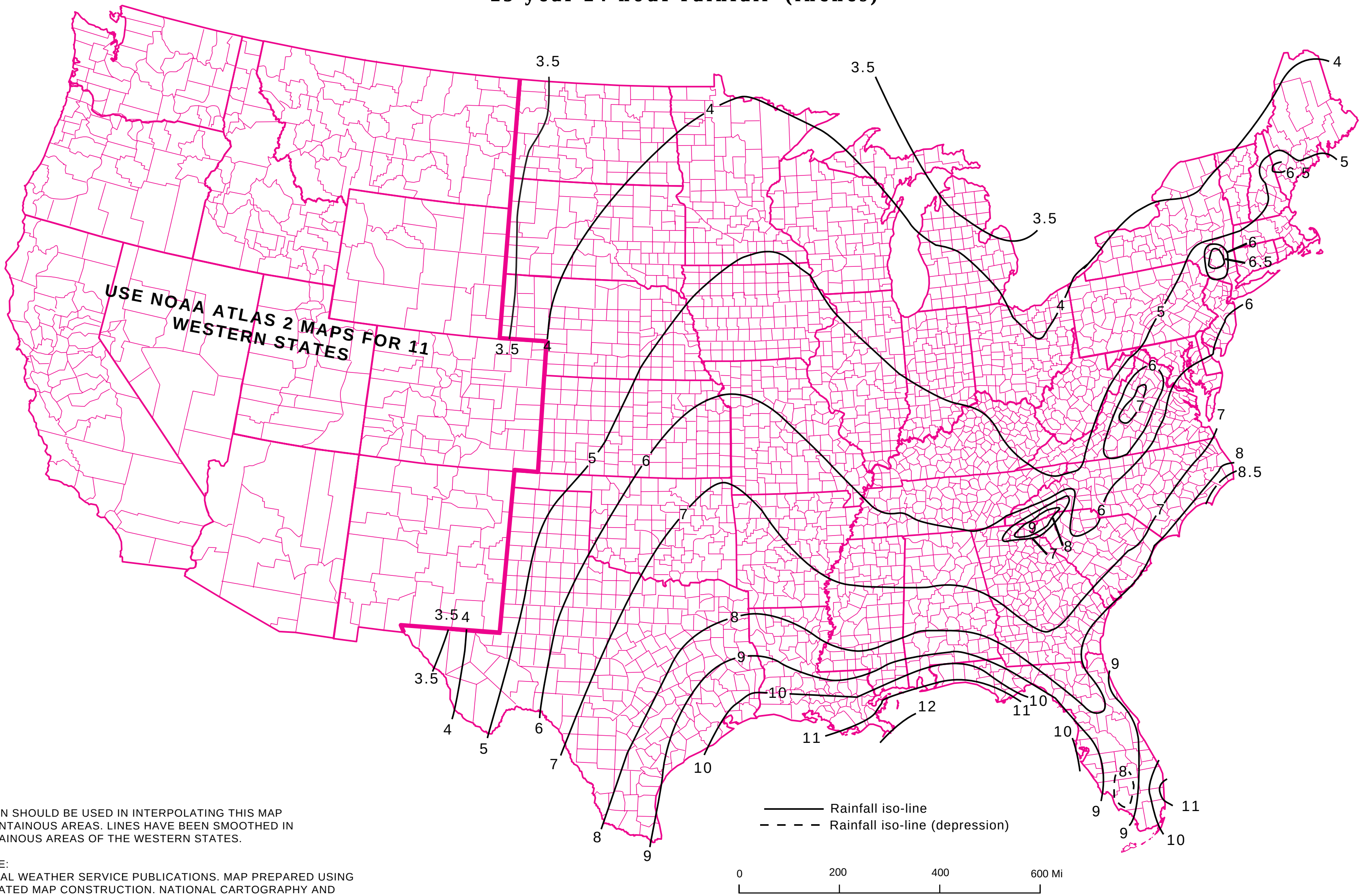
U.S. DEPARTMENT OF AGRICULTURE

NATURAL RESOURCES CONSERVATION SERVICE

Figure 10B-2
25-year 24-hour rainfall (inches)



NOTE:
CAUTION SHOULD BE USED IN INTERPOLATING THIS MAP IN MOUNTAINOUS AREAS. LINES HAVE BEEN SMOOTHED IN MOUNTAINOUS AREAS OF THE WESTERN STATES.

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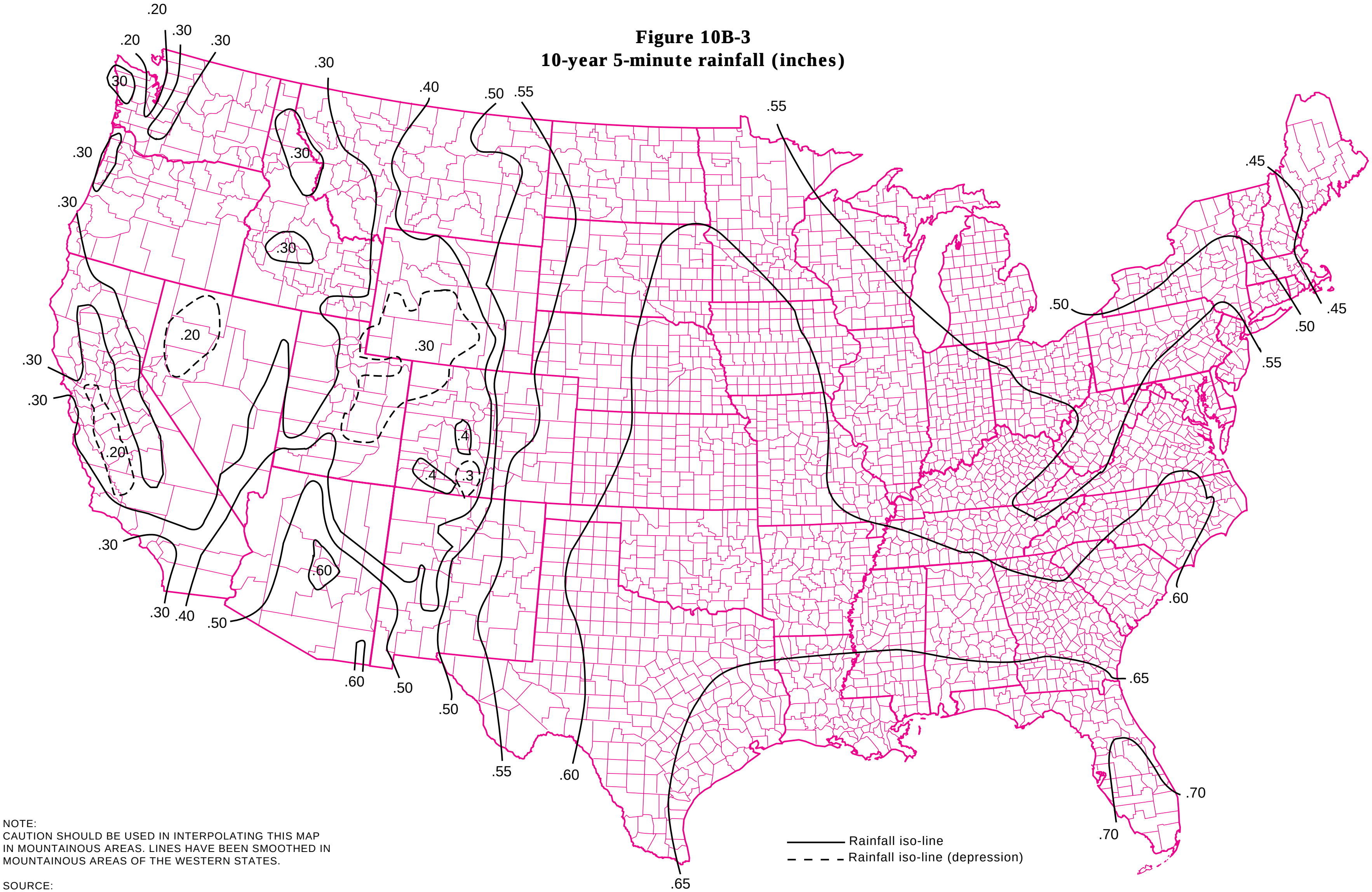
Figure 10B-3
10-year 5-minute rainfall (inches)



NOTE:
CAUTION SHOULD BE USED IN INTERPOLATING THIS MAP IN MOUNTAINOUS AREAS. LINES HAVE BEEN SMOOTHED IN MOUNTAINOUS AREAS OF THE WESTERN STATES.

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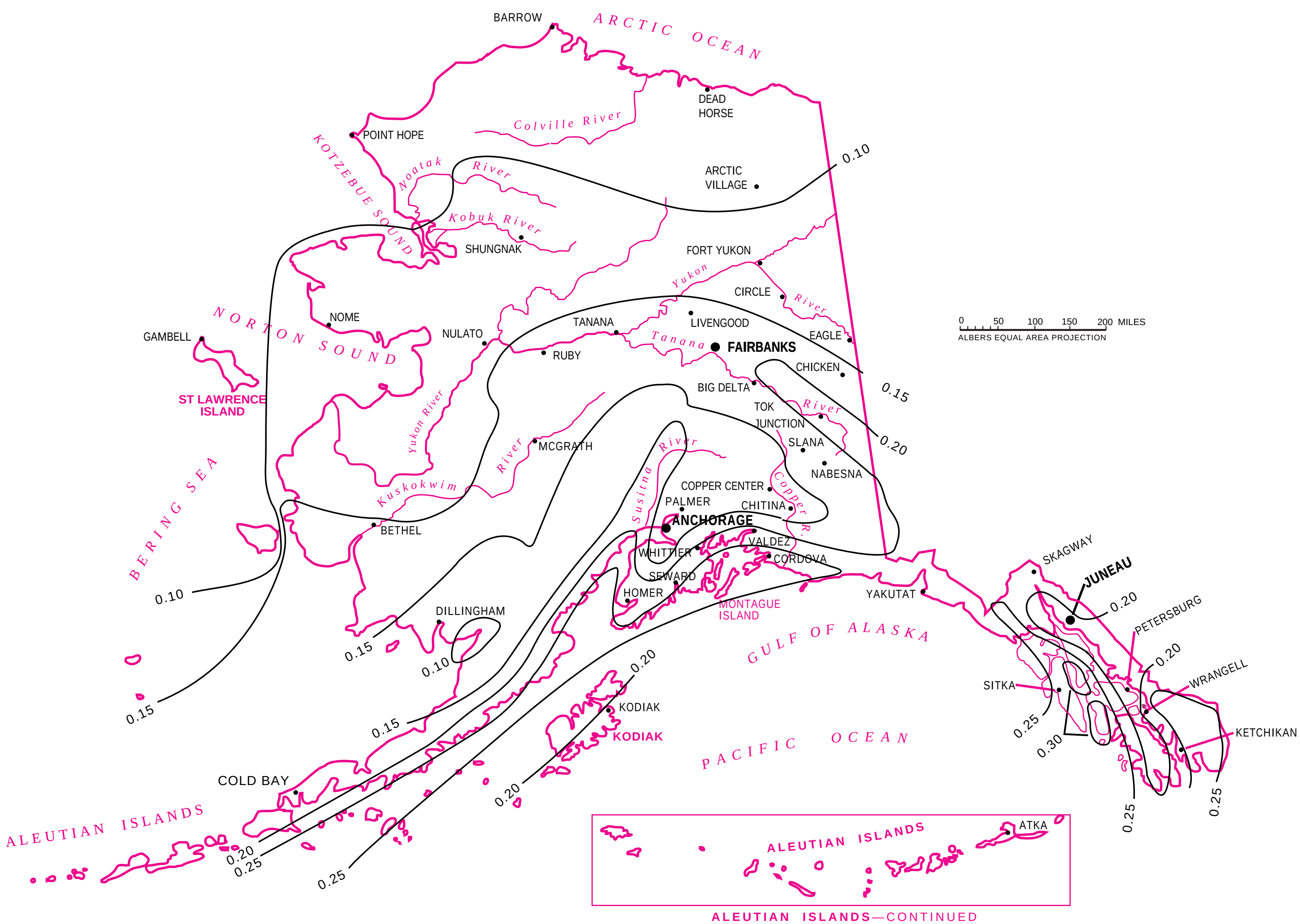
FIGURE 10B-3a
10-YEAR 5-MINUTE RAINFALL (INCHES)
ALASKA



SOURCE:
DATA PROVIDED BY SCS FIELD PERSONNEL
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FORT WORTH, TEXAS

FEBRUARY 1994 1007912

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SOIL CONSERVATION SERVICE

FIGURE 10B-3b
10-YEAR 5-MINUTE RAINFALL (INCHES)

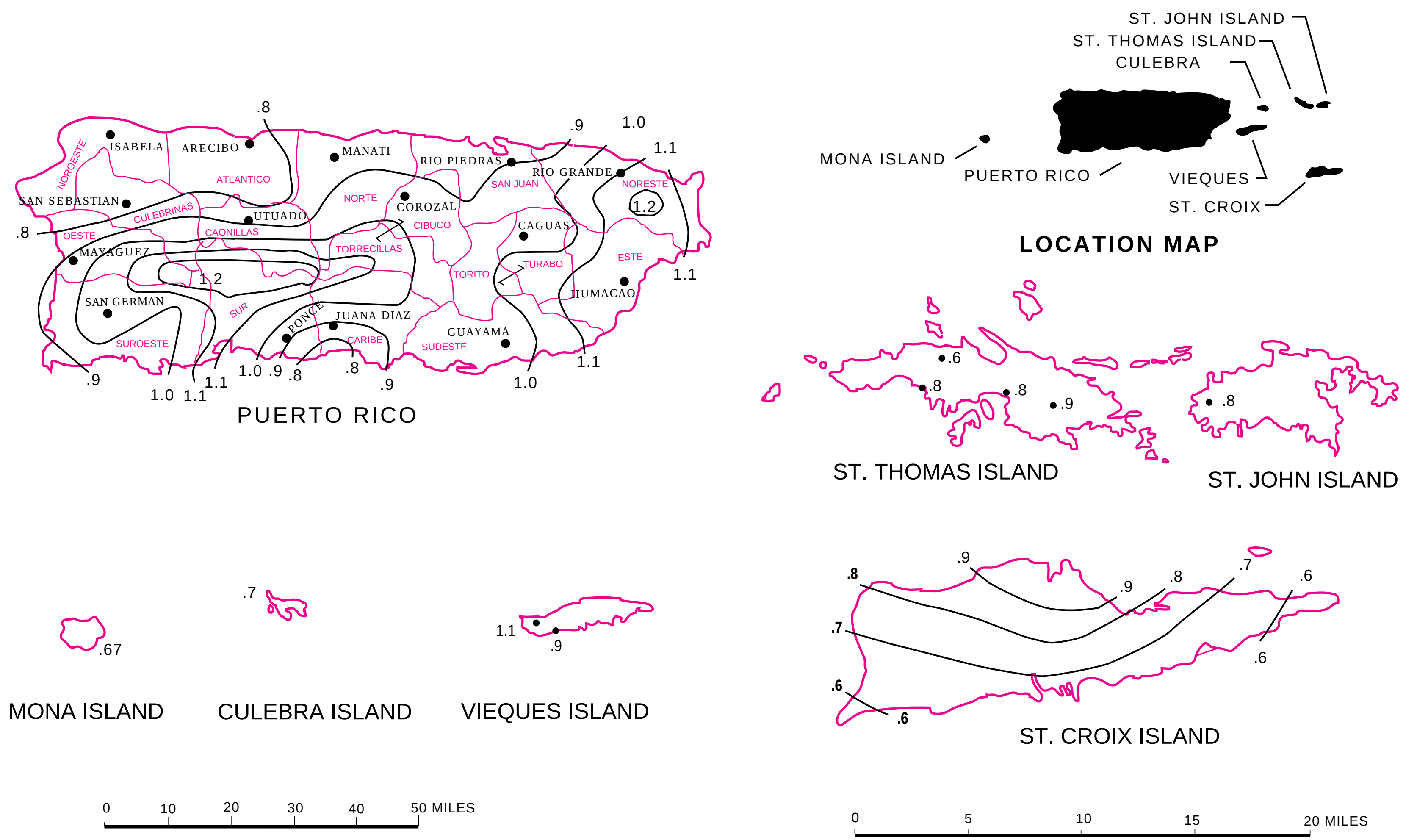

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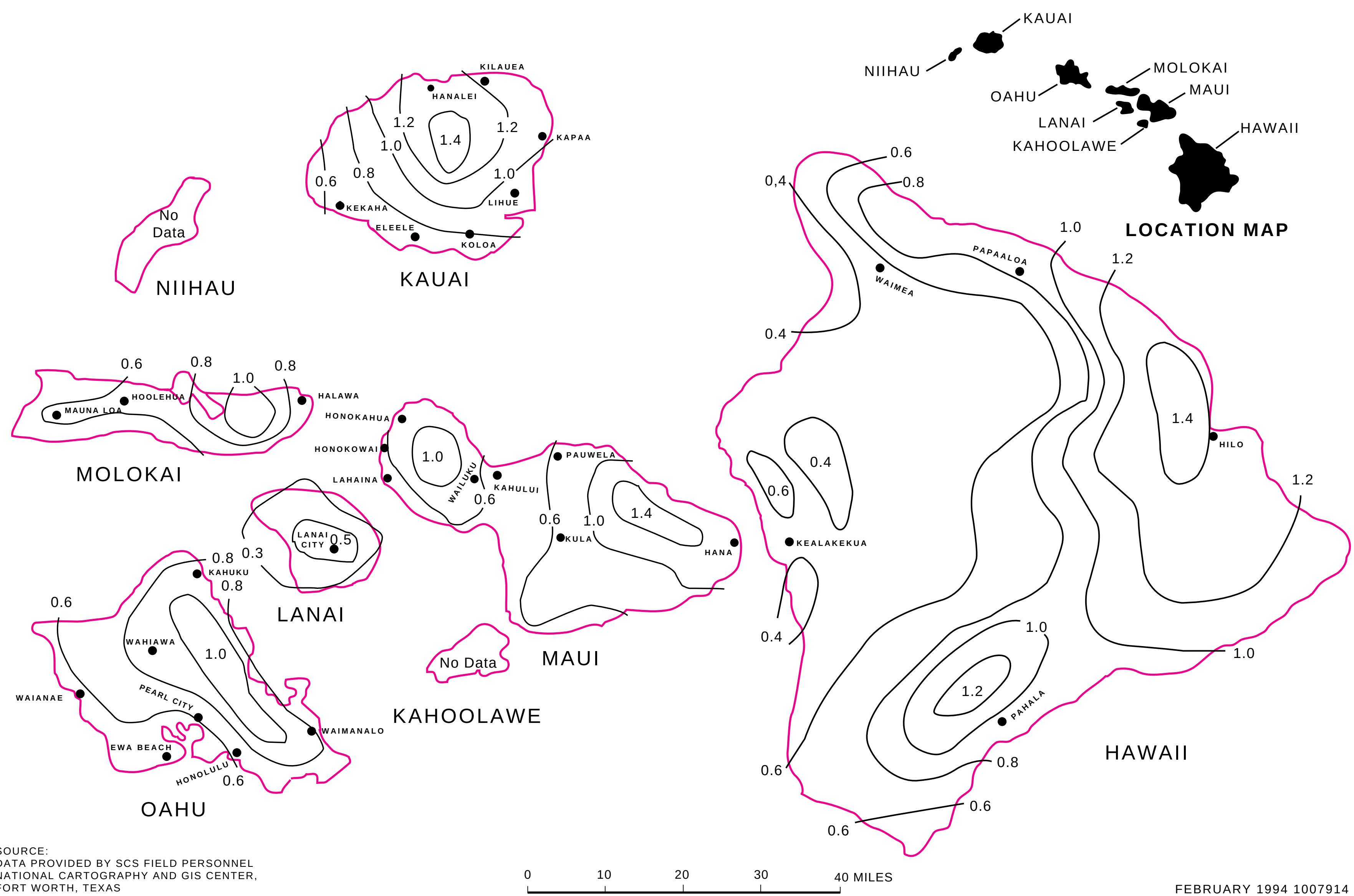
FIGURE 10B-3c
10-YEAR 5-MINUTE RAINFALL (INCHES)



SOURCE:
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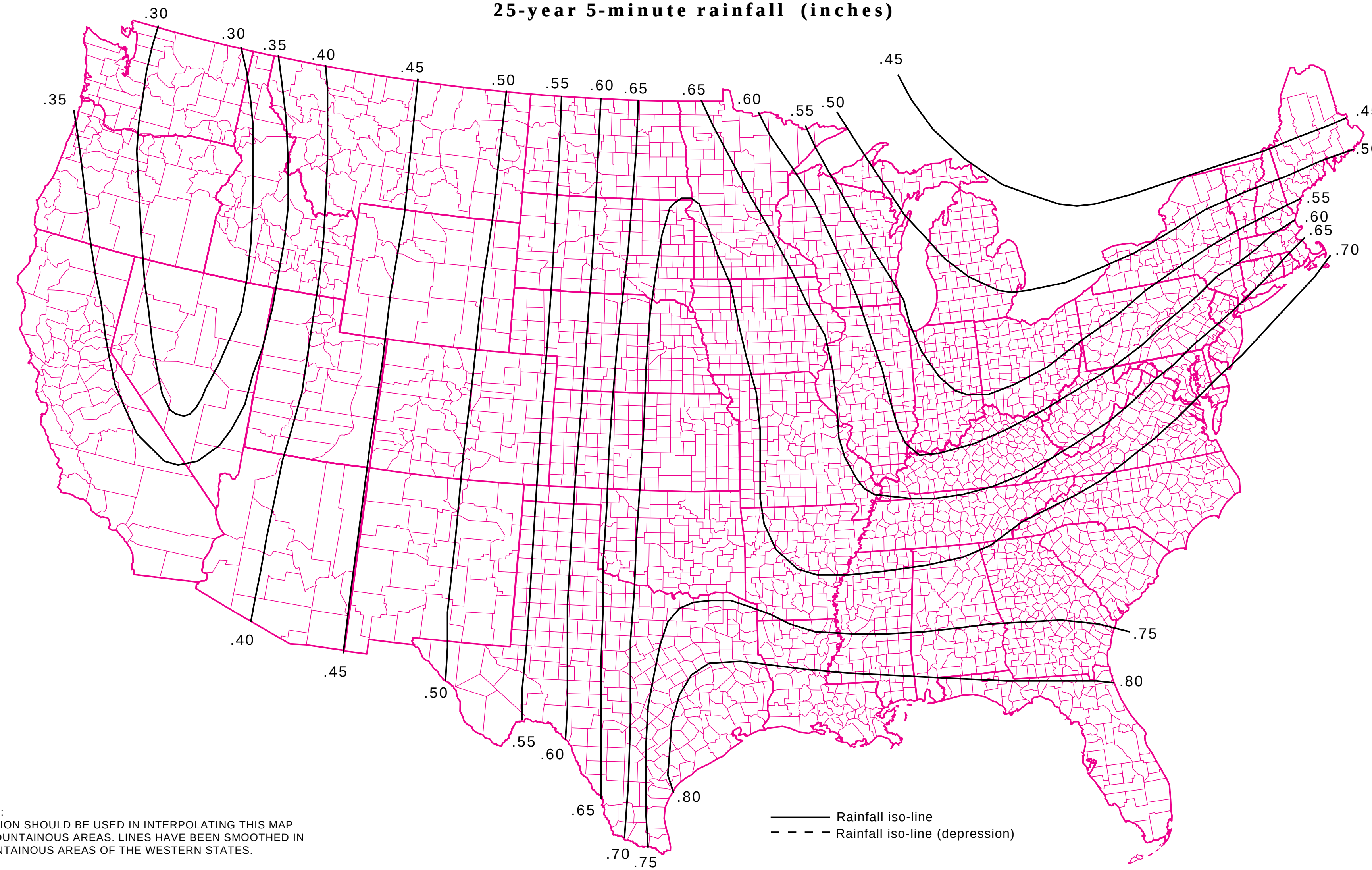
FORT WORTH, TEXAS

FEBRUARY 1994 1007914

Figure 10B-4
25-year 5-minute rainfall (inches)



NOTE:
CAUTION SHOULD BE USED IN INTERPOLATING THIS MAP IN MOUNTAINOUS AREAS. LINES HAVE BEEN SMOOTHED IN MOUNTAINOUS AREAS OF THE WESTERN STATES.

SOURCE:
NATIONAL WEATHER SERVICE PUBLICATIONS. MAP PREPARED USING AUTOMATED MAP CONSTRUCTION. NATIONAL CARTOGRAPHY AND GIS CENTER, FORT WORTH, TEXAS, 1995

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651.1070 Appendix 10C—Runoff From Feedlots and Evaporation

(a) Runoff

Runoff must be handled if feedlots or other components of the livestock production unit are exposed to the weather. Contaminated runoff should be collected in settling basins and storage ponds.

A paved or surfaced feedlot typically has a runoff curve number (RCN) of about 97; an RCN of 90 is representative of an unpaved or unsurfaced feedlot. Based on these RCN's, the amount of runoff from feedlots can be estimated as a percentage of the precipitation that is expected over a period of time.

Figures 10C–1 and 10C–2 describe for the continental United States the percentage of annual precipitation that will occur as runoff from unsurfaced and surfaced feedlots, respectively. Figures 10C–3 through 10C–14 describe the percentage of monthly precipitation that will occur as runoff from unsurfaced feedlots. Figures 10C–15 through 10C–26 describe the percentage of monthly precipitation that will occur as runoff from surfaced feedlots.

Other available sources give the annual or monthly precipitation data to which the runoff percentages are applied. One such source is "Climatography of the United States No. 81 (by state) Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1941–70," prepared by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Another source available in many counties is the local soil survey, which contains a section on climatic data.

The runoff percentage from figures 10C–1 through 10C–26 is multiplied by the precipitation from the corresponding time period to determine the amount of runoff. This is the runoff volume (ROV) value used in several of the worksheets in chapter 10.

Design example 10C-1—Runoff from a concrete feedlot

Determine the annual runoff from a concrete feedlot near Portland, Oregon. From the reference cited, the mean annual precipitation is 37.6 inches. From figure 10C–2, the annual runoff is 49 percent of the precipitation. Therefore, the annual ROV = (37.6 in. x 0.49) = 18.4 inches.

Design example 10C-2—Runoff from an earth feedlot

Determine the runoff to be expected from an earth feedlot near Dallas, Texas, for the period October to March.

Month	Precip. (inches)	—— Runoff —— %	(inches)
Oct.	3.18	36	1.14
Nov.	2.60	27	0.70
Dec.	2.34	24	0.56
Jan.	1.96	20	0.39
Feb.	2.57	20	0.51
Mar.	3.04	22	0.67
Total			3.97

(b) Evaporation

Storage and treatment facilities require an allowance for precipitation less evaporation for the most critical design period. For example, for a 90-day storage period, an allowance for storage is planned using the three successive months that result in the greatest sum of precipitation less evaporation that is critical.

Some ponds or structures, especially those containing dairy manure and straw bedding, develop a crust on the surface, and evaporation may be limited. This will vary among areas and individual farms. For a conservative design when crusting is anticipated, the allowance evaporation in the pond sizing can be omitted.

Local records are almost always available for the average monthly precipitation for each month of the year. Local records may also be available for average monthly evaporation. If evaporation data are not readily available, however, the annual free water surface evaporation (shallow lake evaporation) may be determined using figure 10C–27. Monthly free water surface evaporation may be determined using table 10C–1, which gives the approximate mean monthly percent of the annual evaporation for selected stations in the continental United States.

Table 10C–1 was developed for use in obtaining monthly evaporation for selected stations from annual Class A pan evaporation maps. This table is to be used on free water surface maps. Although the information in this table is not completely correct, the monthly percentages are adequate for estimating free water surface evaporation. Several other factors prevent an exact correlation between evaporation from waste storage ponds and lagoon surfaces and Class A pan evaporation. Factors causing differences include effects of salinity, coloration, and floating surface material, such as bedding, on evaporation rates.

Worksheet 10A–6 can be used to determine the monthly precipitation less evaporation value for each month.

Design example 10C-3

Mr. Austin Peabody of Rocky Mount, North Carolina, has selected an alternative for an agricultural waste management system that includes a waste storage pond. Designing the depth of the pond requires that an allowance for containing the precipitation evaporation minus evaporation for the storage period be determined. Using worksheet 10A–6, determine the precipitation less evaporation value to use for a 180-day storage period.

- The annual FWS evaporation (FWS) is selected from figure 10C–27.

- The monthly precipitation (MP) values are selected from local data.

- The monthly portion of annual evaporation (MPAE) is determined using the appropriate station in table 10C–1.

- The monthly evaporation (ME) is computed by the equation:

$$ME = FWS \times MPAE$$

- The monthly precipitation less evaporation (MPLE) is determined by the equation:

$$MPLE = MP - ME$$

- The 180-day storage period is about 6 months; therefore, the successive 6 months that are critical are determined by inspection. For this example, the storage period is September through February.

- The total precipitation less evaporation depth that must be accommodated in the waste storage pond is the sum of monthly values for September through February.

Completed worksheet for design example 10C–3

Worksheet 10A-6 – Monthly precipitation minus evaporation

Decisionmaker: Austin Peabody

Date:

Site:

Annual FWS Evaporation (FWS)= 39 inches

Month	Monthly precipitation MP (inches)	Monthly portion of annual evaporation MPAE (percent)	Monthly evaporation ME (inches)*	Monthly precipitation less evaporation MPLE (inches)
January	3.53	3	1.17	2.36
February	3.71	5	1.95	1.76
March	3.49	8	3.12	0.37
April	3.50	10	3.90	-0.40
May	3.61	12	4.68	-1.07
June	4.47	13	5.07	-0.60
July	5.58	13	5.07	0.51
August	4.45	12	4.68	-0.23
September	3.95	9	3.15	0.44
October	2.79	7	2.73	0.06
November	2.24	5	1.95	0.29
December	3.49	3	1.17	2.32

ME = FWS x MPAE

Storage or treatment period, days (D) = 180

months = 6

Critical successive months

Month	Monthly precipitation less evaporation MPLE (inches)	Month	Monthly precipitation less evaporation MPLE (inches)
SEPT	0.44		
Oct	0.06		
NOV	0.29		
DEC	2.32		
JAN	2.36		
FEB	1.76		
Total			7.2 inches

Table 10C–1 Adjusted approximate mean monthly free water surface evaporation for selected stations

Station name	Lat.	Long.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May thru Oct	Nov thru Apr
			Percent of annual													
Fairhope, AL	30°32'	87°55'	4	5	7	10	12	13	12	11	9	8	5	4	65	35
Bartlett Darn, AZ	33°49'	111°381	3	4	6	9	12	14	14	11	10	8	5	4	69	31
Bacus Ranch, CA	34°57'	118°11'	3	3	7	9	11	14	15	15	10	7	3	3	72	28
Sacramento, CA			2	3	6	8	12	15	16	15	11	7	3	2	76	24
Wagon Wheel Gap, CO	37°48'	106°58'					14	16	14	12	11	7			74	26
Hartford, CT			3	3	6	10	13	14	15	14	9	6	4	3	71	29
Tantiami Trail, FL	25°45'	80°50'	5	6	9	10	11	10	11	10	9	8	6	5	59	41
Experiment, GA	33°16'	84°17'	4	5	7	10	12	13	13	11	9	7	5	4	65	35
Moscow, U of 1, ID	46°44'	116°58'				7	12	14	19	18	12	6			81	19
Pocatello, ID			2	2	6	8	12	15	19	14	11	6	3	2	77	23
Ames, IA	42°00'	98°39'				10	15	16	15	13	9	8	3		76	24
Toronto Darn, KS	37°45'	95°56'	2	3	7	10	13	13	15	14	9	8	4	2	72	28
Tribune, KS	38°28'	101°46'				9	12	14	16	14	10	7			73	27
Madisonville, KY	37°19'	87°29'				11	13	14	14	13	10	8			72	28
Urbana, IL	40°06'	88°14'				9	13	15	15	14	10	7	4		75	25
Woodworth S. F., LA	31°08'	92°28'	3	4	7	9	12	13	13	13	9	8	5	4	68	32
Caribou, ME	46°52'	68°01'	2	3	5	8	15	16	16	14	9	7	3	2	77	23
Rochester, MA	41°47'	70°55'				8	13	15	15	13	9	5			70	30
E.Lansing Hort Fin, MI	42°43'	84°28'				9	14	15	16	14	10	6	2		75	25
Scott, MS	33°36'	91°05'	3	4	7	10	13	14	13	12	9	7	5	3	68	32
Weldon Spr. Fin, MO	38°42'	90°44'				10	12	14	14	13	11	8	4		72	28
Bozeman Agr. C., MT	45°40'	111°09'				8	12	14	19	17	10	6			78	22
Medicine Ck Darn, NE	40°23'	100°13'				10	12	14	15	14	11	8			74	26
Boulder City, NV	35°59’	114°51'	3	4	6	9	12	14	15	13	10	7	4	3	71	29
Topaz Lake, NV	38°41'	119°02'				8	12	14	16	14	11	7	3		74	26
Elephant Bte Dam, NM	33°09'	107°11'	3	4	8	11	14	15	12	11	8	7	4	3	67	33
El Vado Dam, NM	36°36'	106°44'			10	10	15	14	15	12	9	6			71	29
Aurora Res Fin, NY	42°44'	76°39'					13	15	17	14	10	7			76	24
Chapel Hill, NC	25°55'	79°06'	3	5	8	10	12	13	13	12	9	7	5	3	66	34
Wooster Exp Sta, OH	40°47'	81°36'				9	13	15	15	14	10	7			74	26
Canton Dam, OK	36°05'	98°36'	3	4	7	10	11	13	14	14	9	7	5	3	68	32
Detroit Pwr. Hse, OR	44°43'	122°15'	1	2	4	7	12	15	22	18	11	5	2	1	83	17
Redfield, SD	44°53'	98°23'				10	13	15	17	16	11	7			79	21
Neptune, TN	36°19'	87°11'	2	4	7	11	12	14	14	13	9	7	4	3	69	31
Grapevine, TX	32°58'	97°03'	3	4	7	9	10	12	15	14	10	7	5	4	68	32
Welasco, TX	26°09'	97°48'	4	5	7	9	11	11	13	13	10	7	6	4	65	35
Utah Lake, UT	40°22’	111°54'			6	9	13	15	18	15	11	7			79	21
Templeau Darn, Wl	44°00'	91°26'					14	16	16	14	10	8			78	22
Heart Mountain, WY	44°41'	108°57'				7	13	14	16	15	10	6			74	26

Source: Adapted from Evaporation Atlas for the Contiguous 48 United States, NOAA Technical Report NWS 33, Table 3-Adjusted mean monthly Class A pan evaporation for selected stations, 1956-70.

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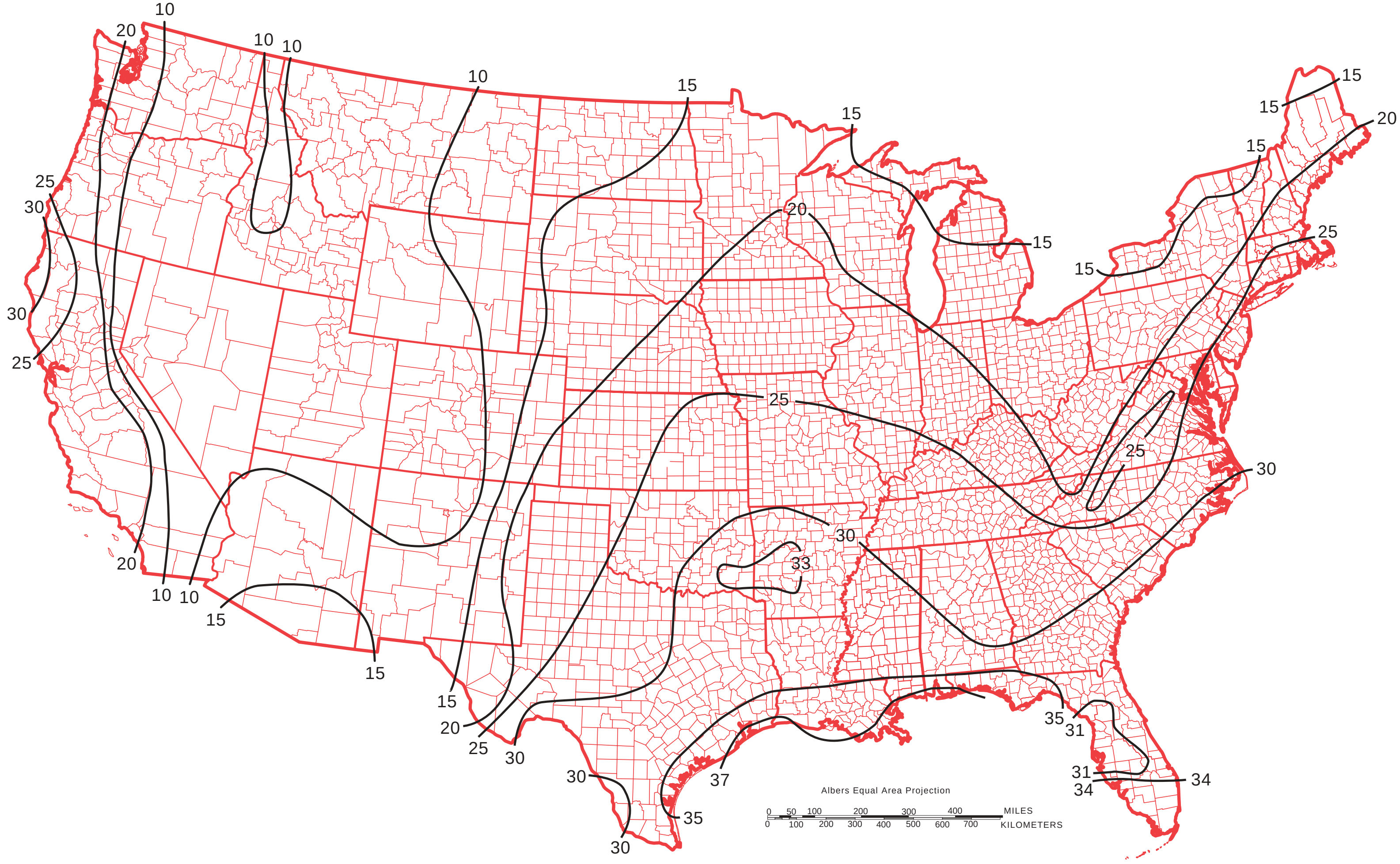
ANNUAL RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90)
AS PERCENT OF MEAN ANNUAL PRECIPITATION

FIGURE 10C-1



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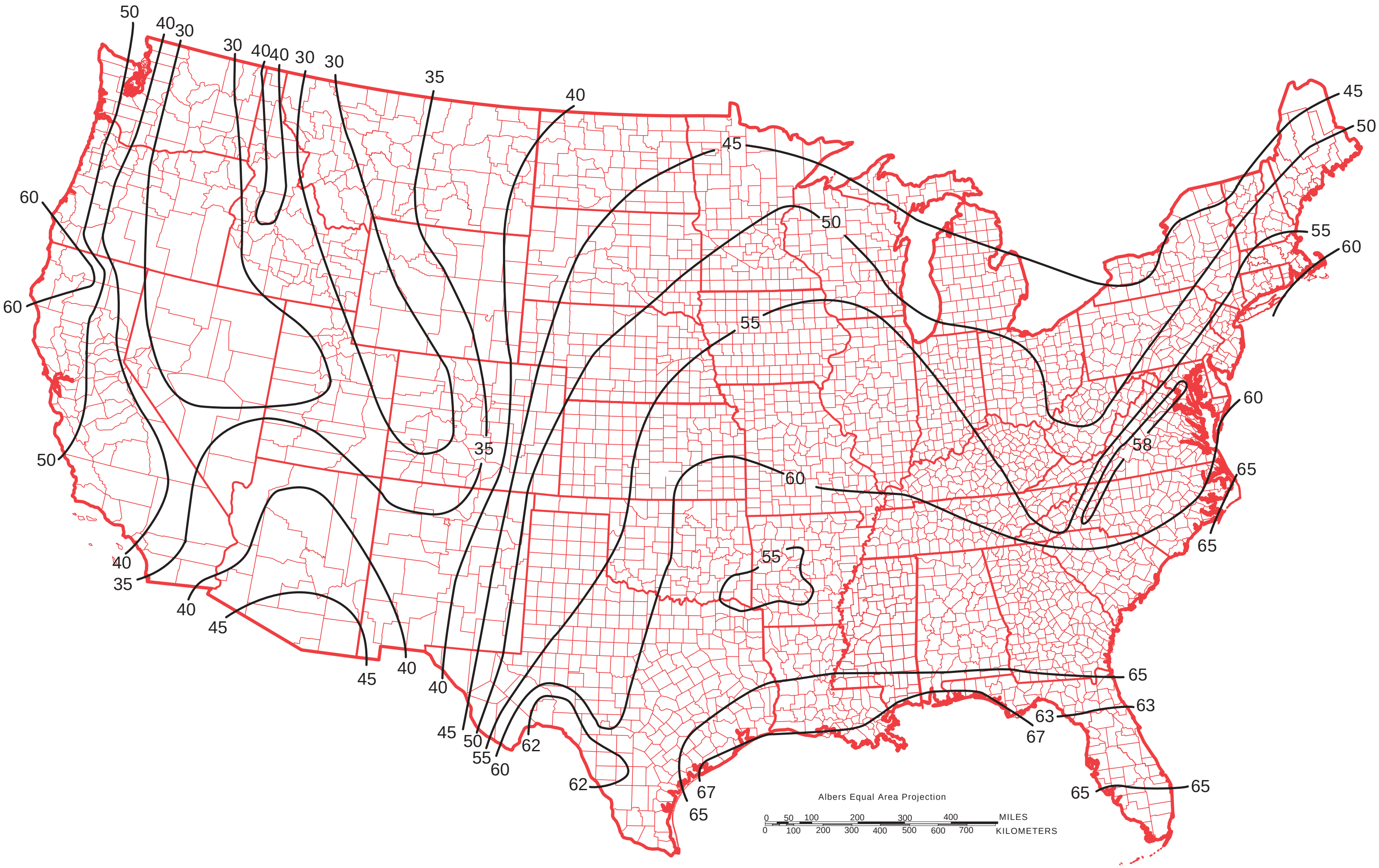
ANNUAL RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-2



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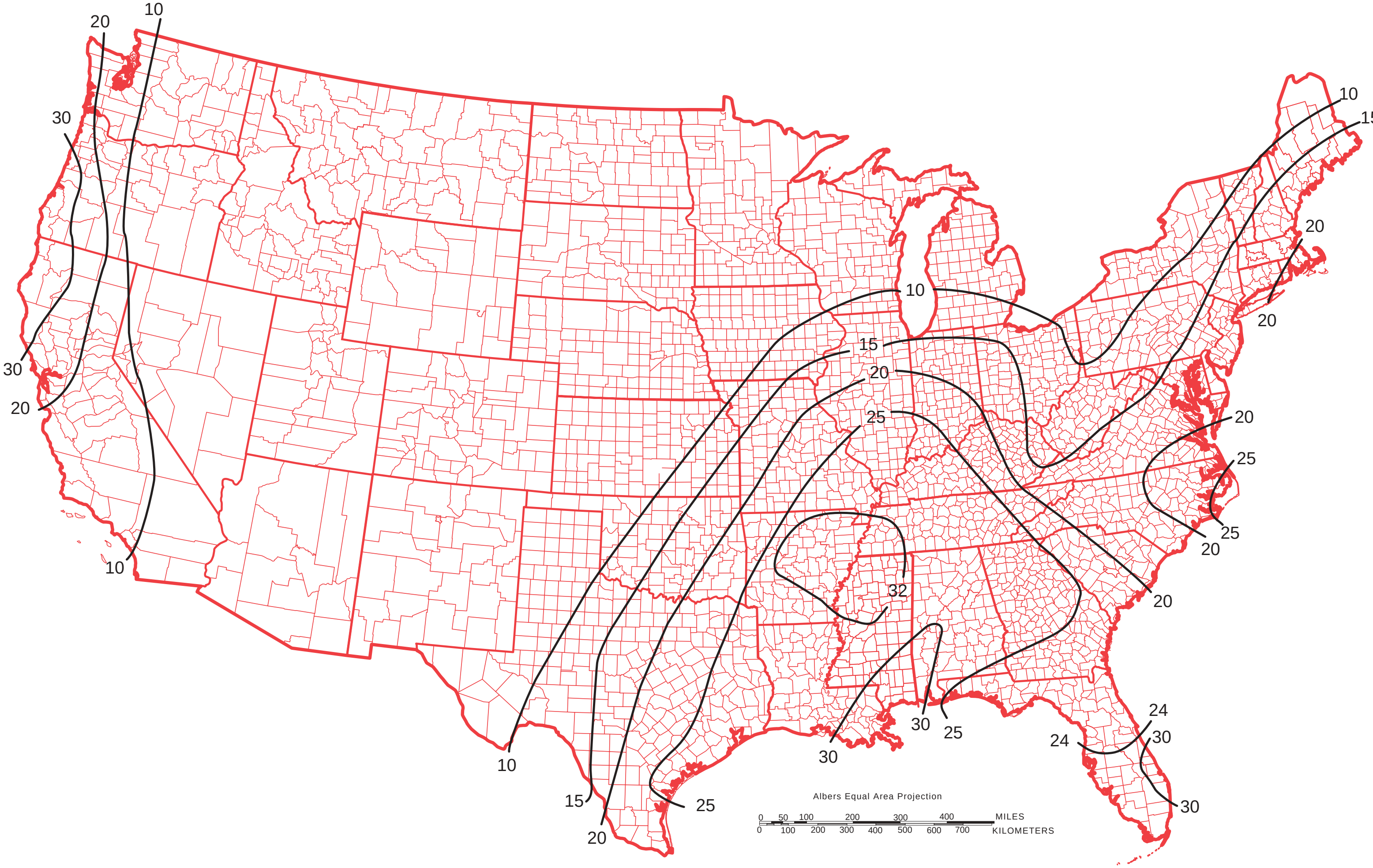
JANUARY RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-3



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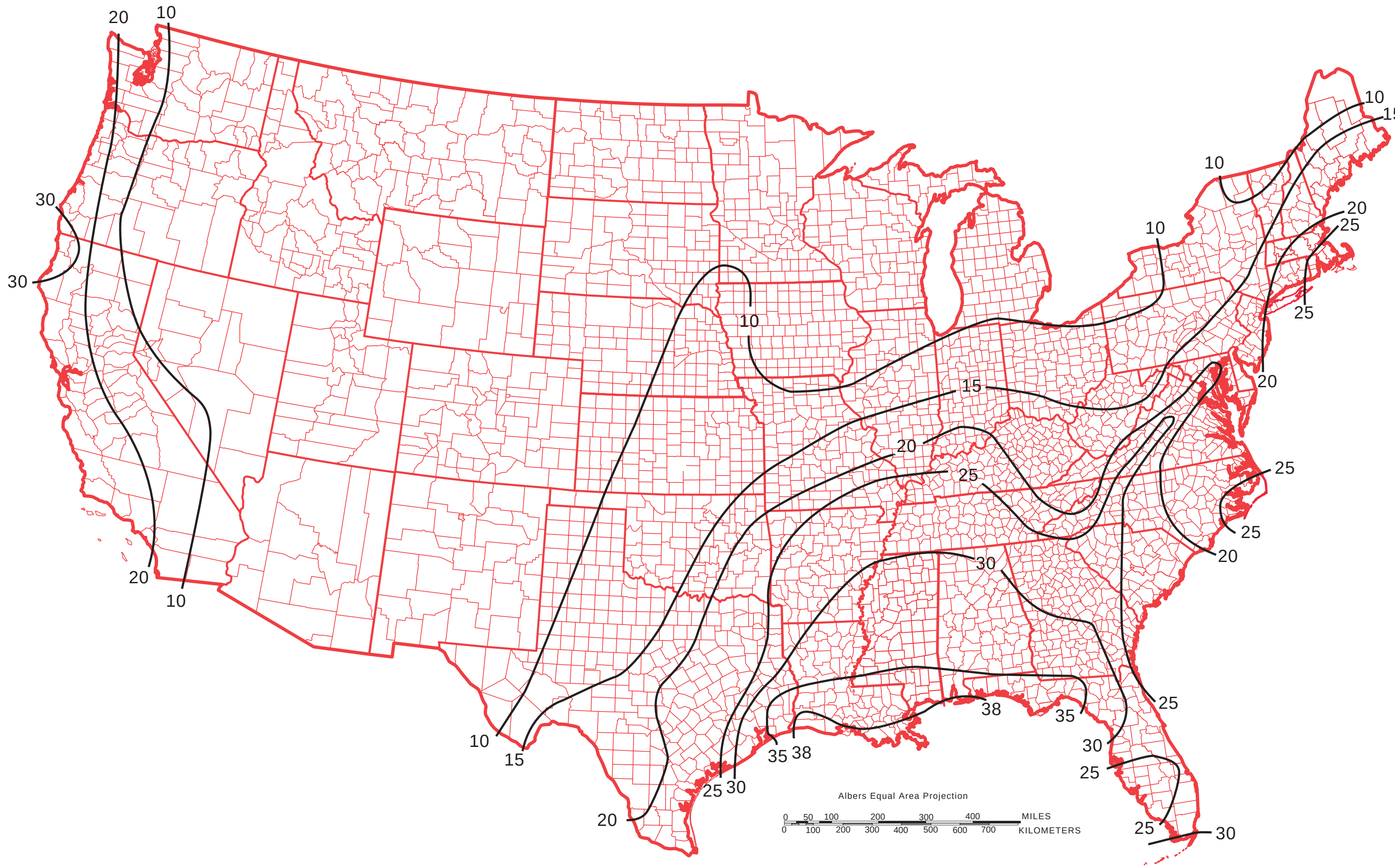
SOIL CONSERVATION SERVICE

FEBRUARY RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-4



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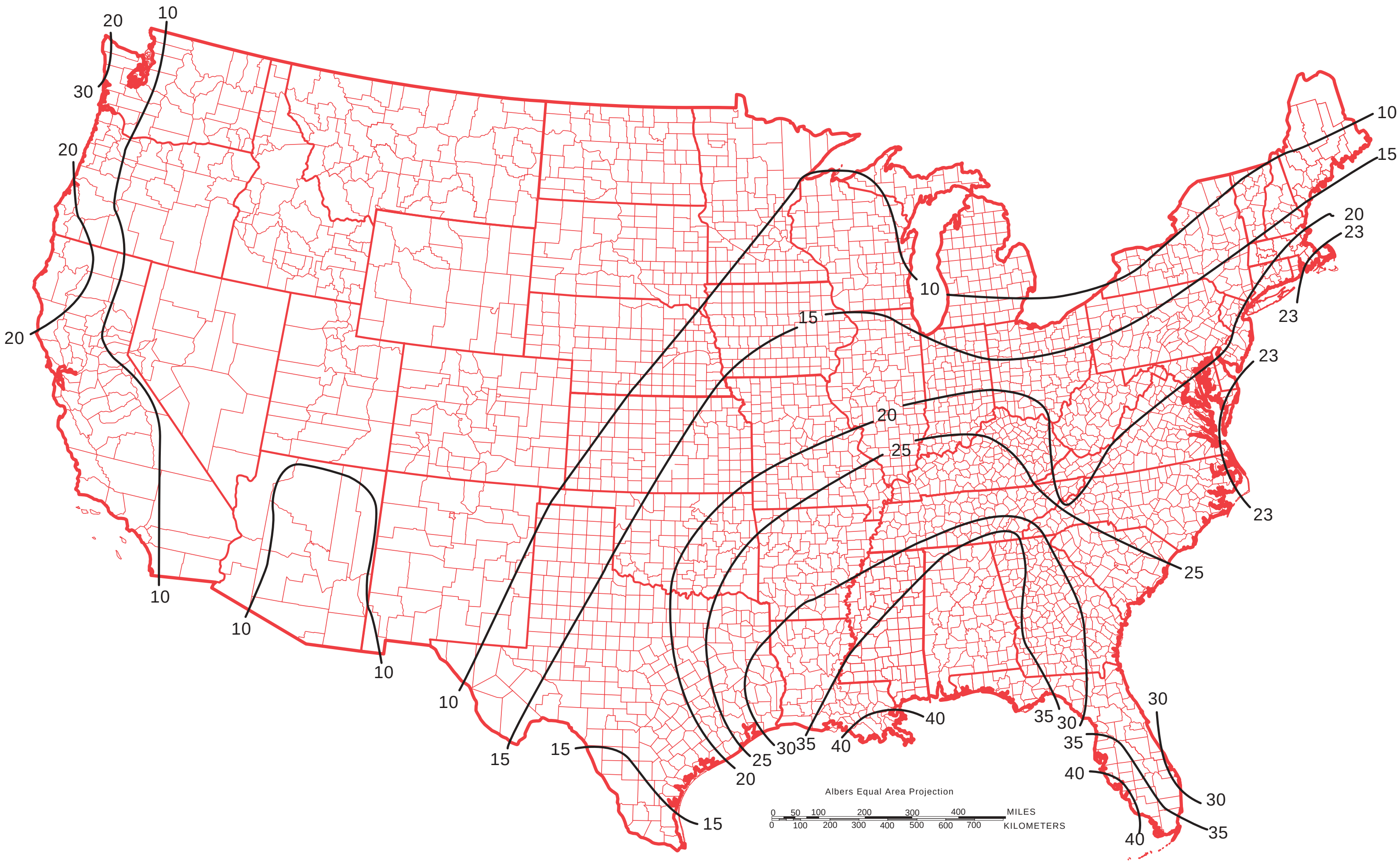
MARCH RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-5



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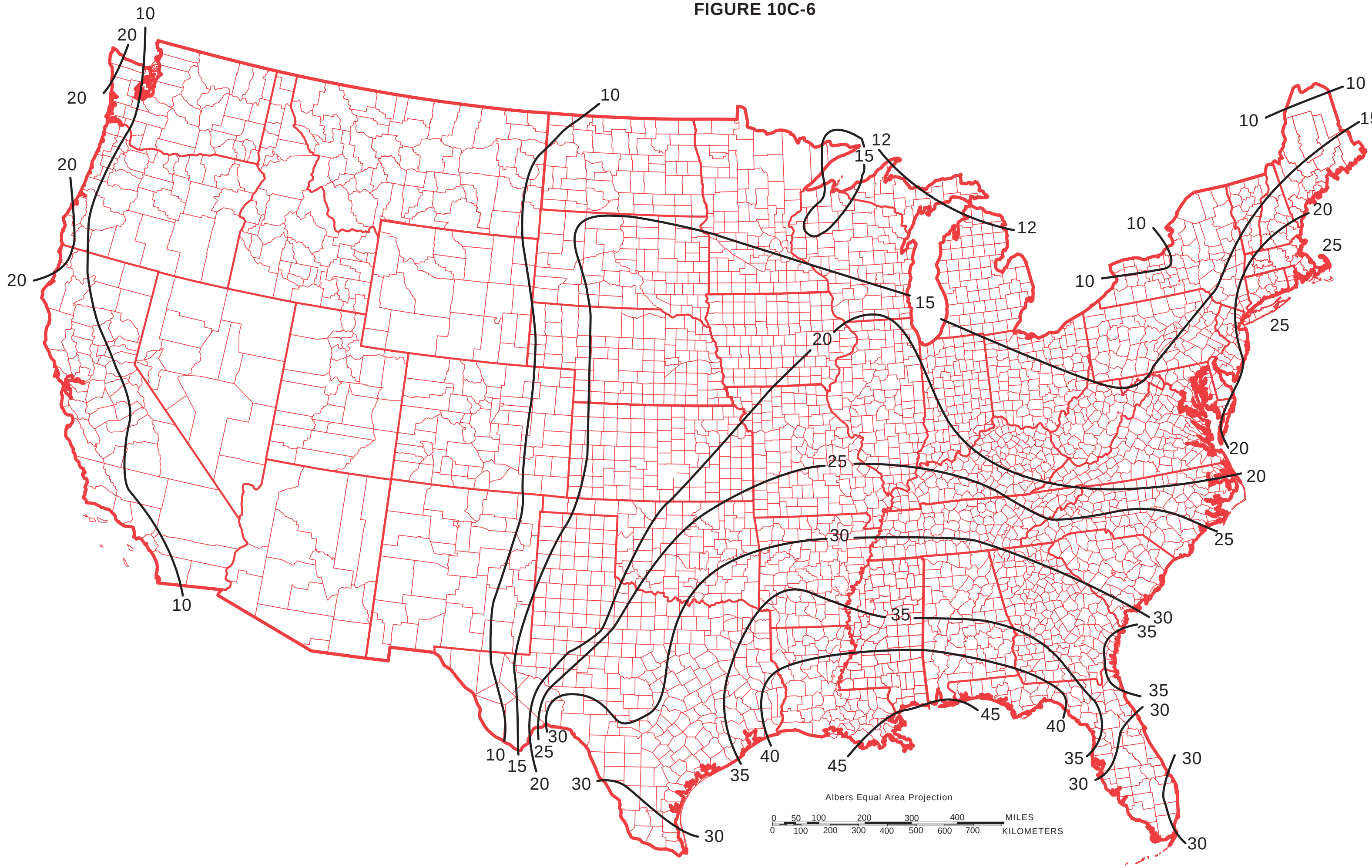
APRIL RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-6



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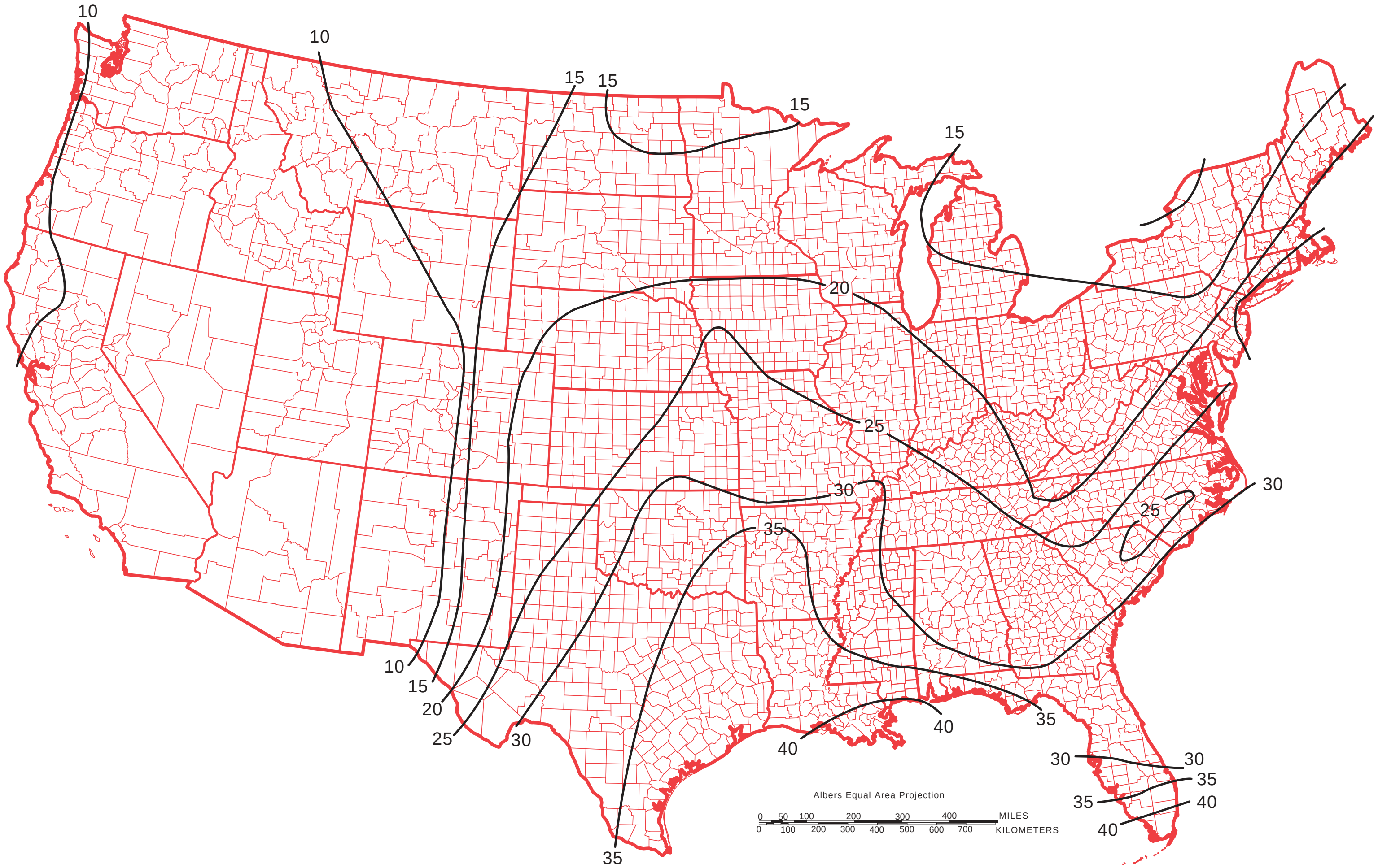
APRIL RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-7



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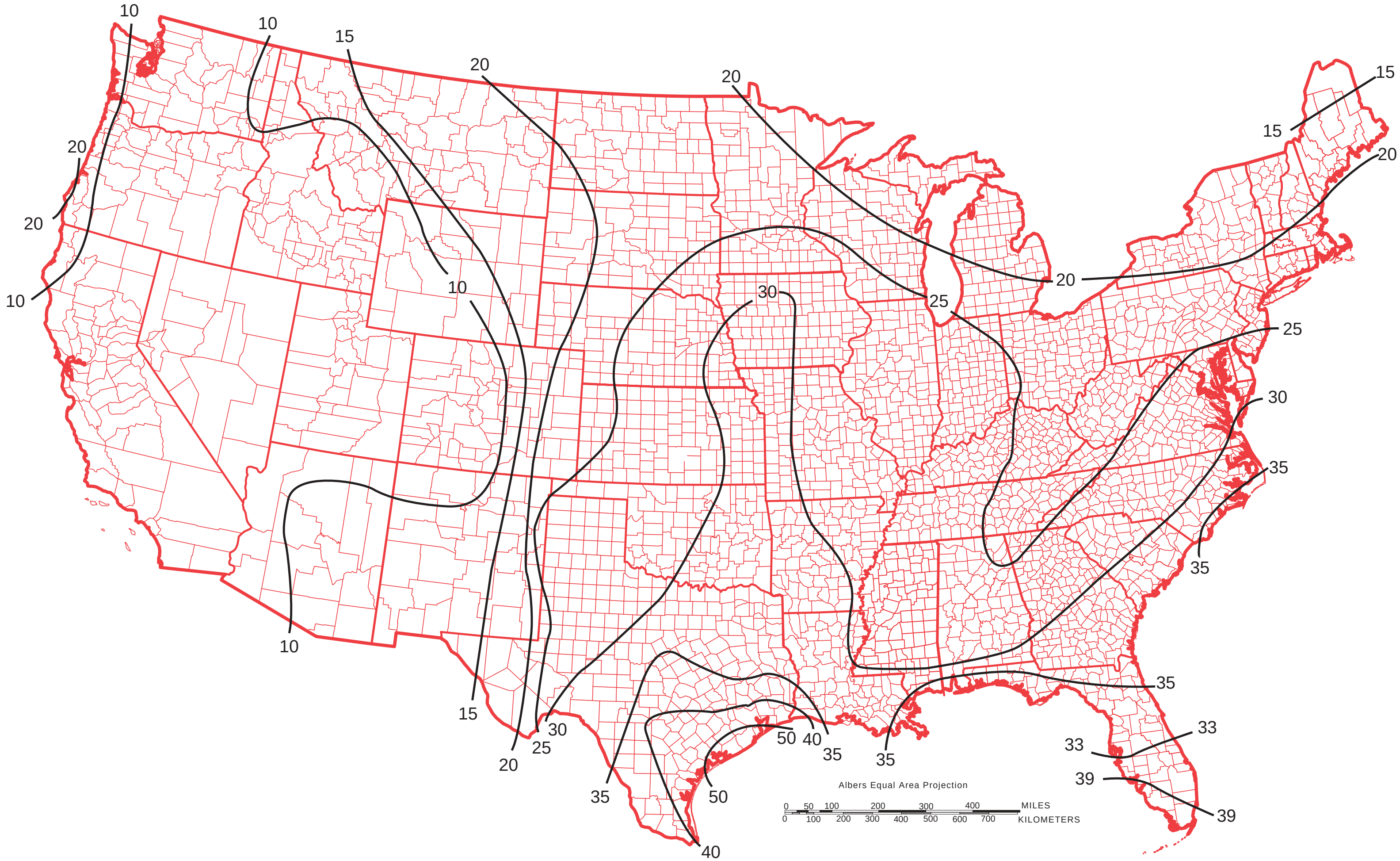
JUNE RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-8



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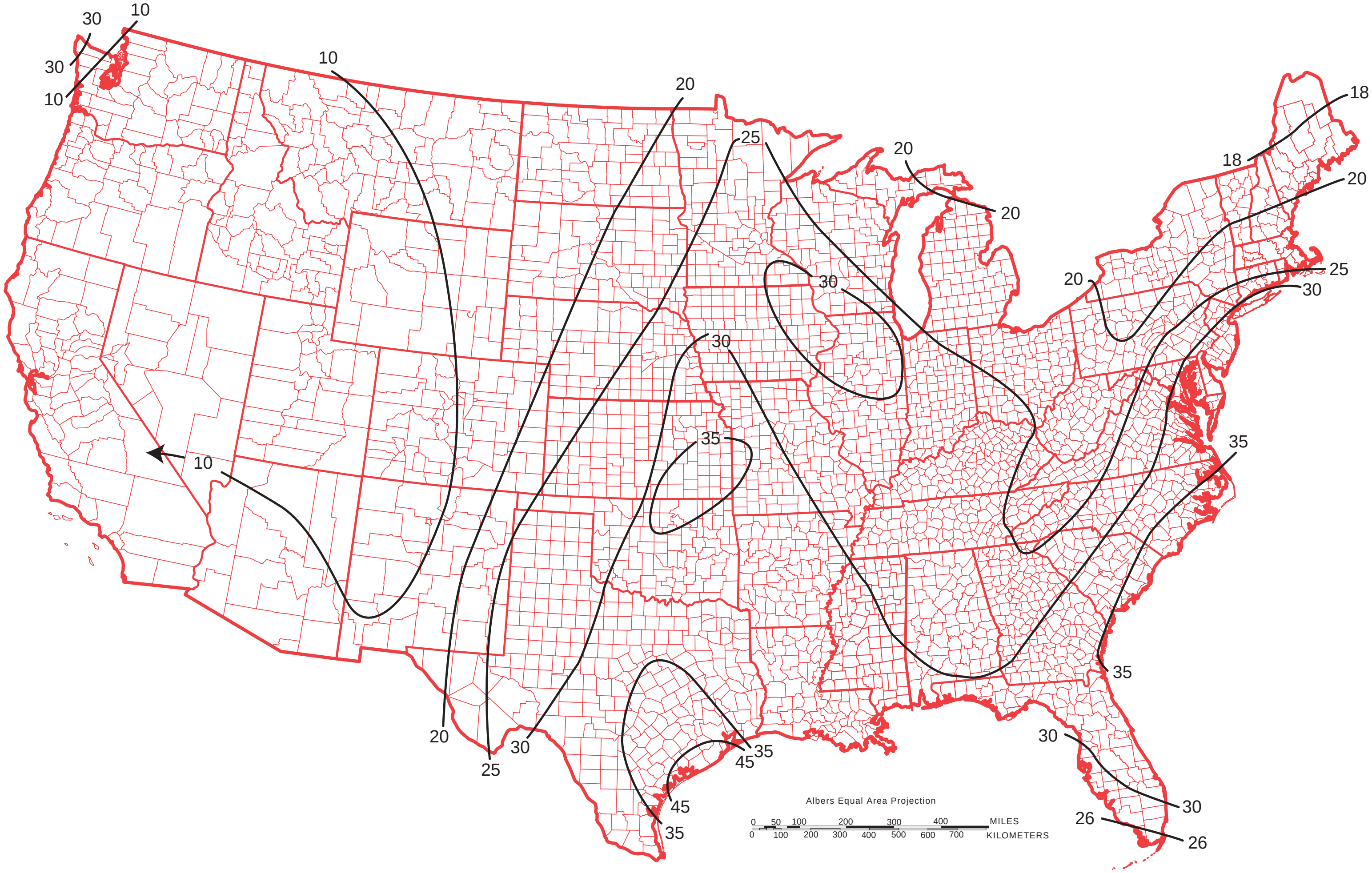
JULY RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-9



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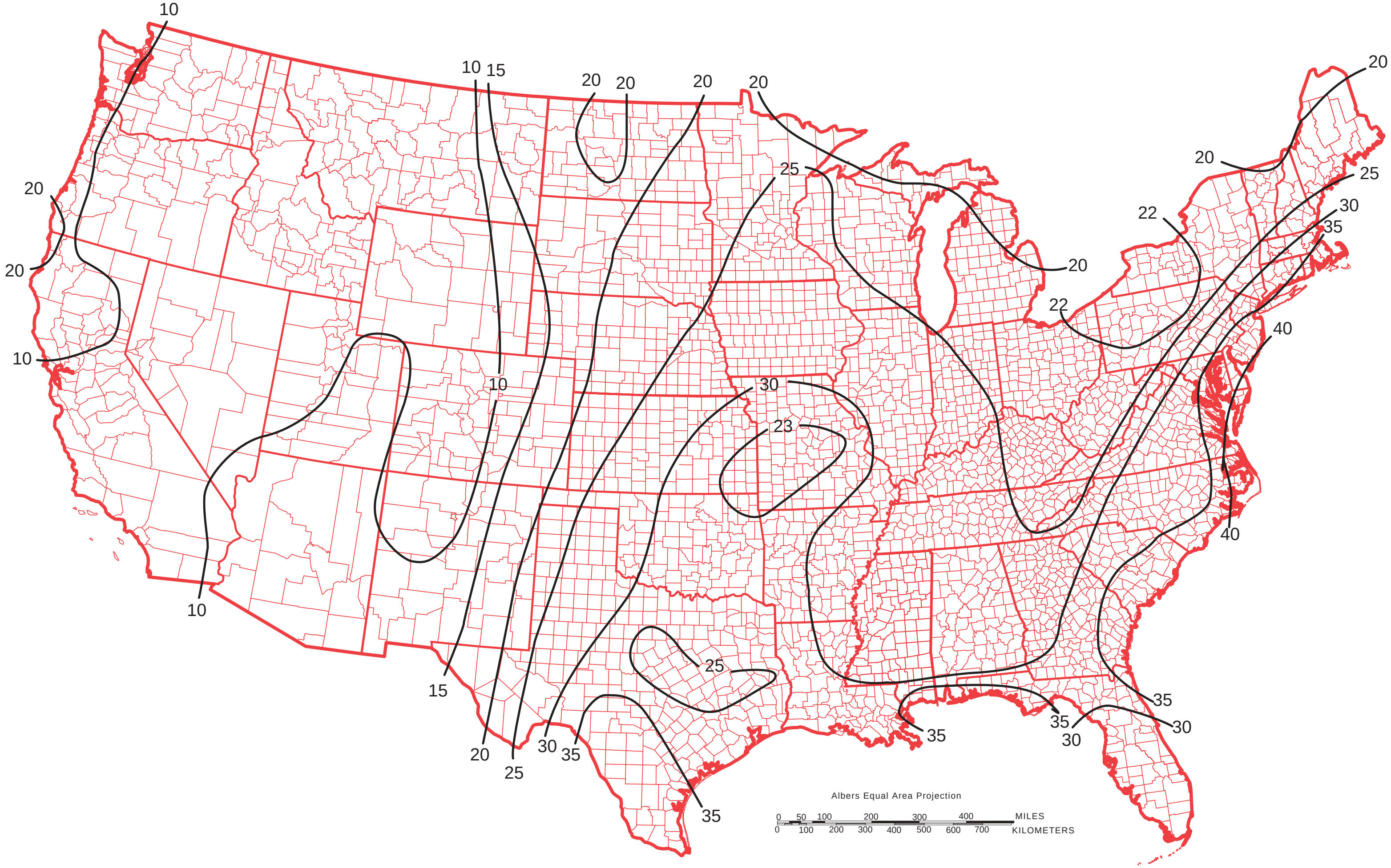
AUGUST RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-10



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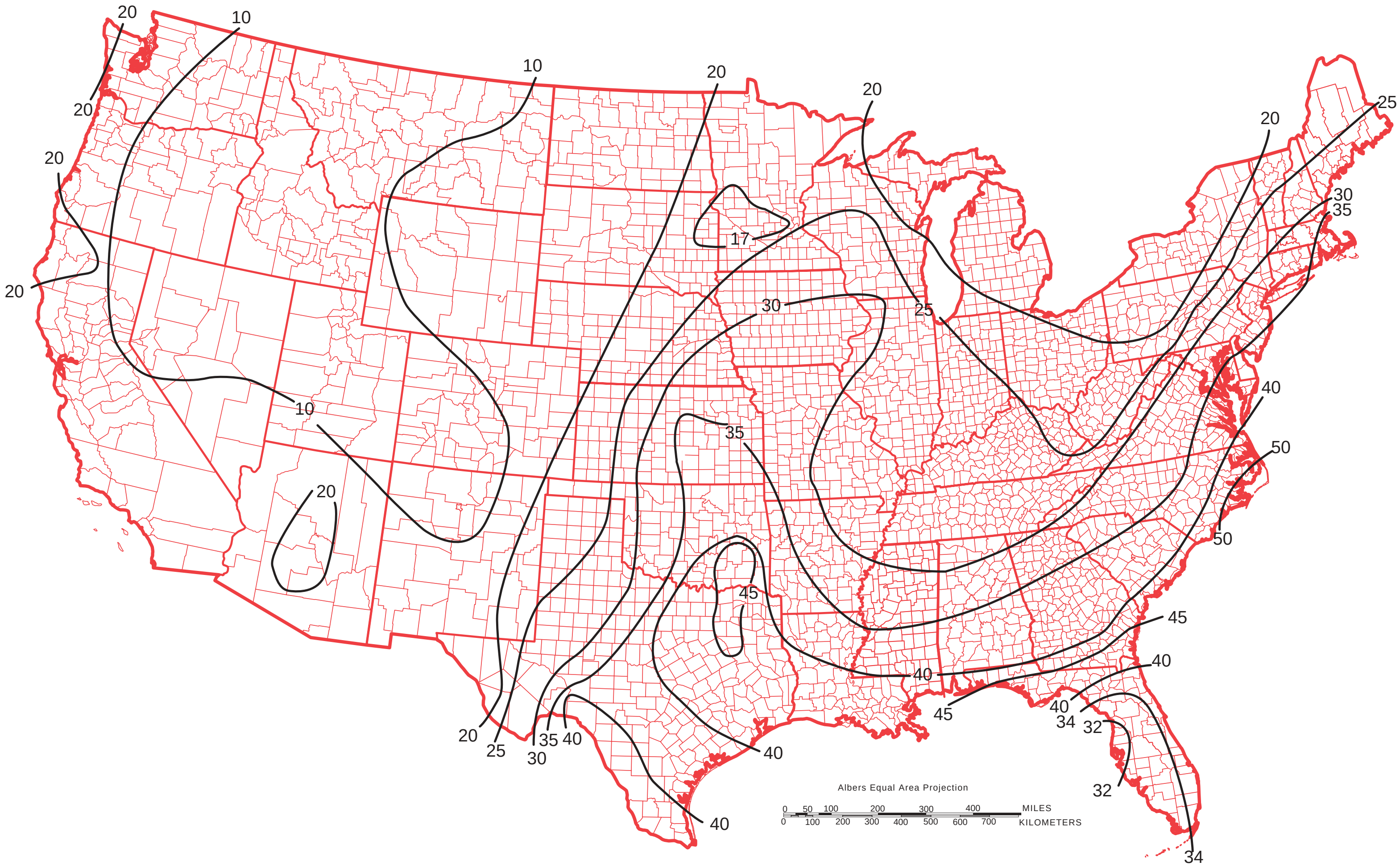
SEPTEMBER RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-11



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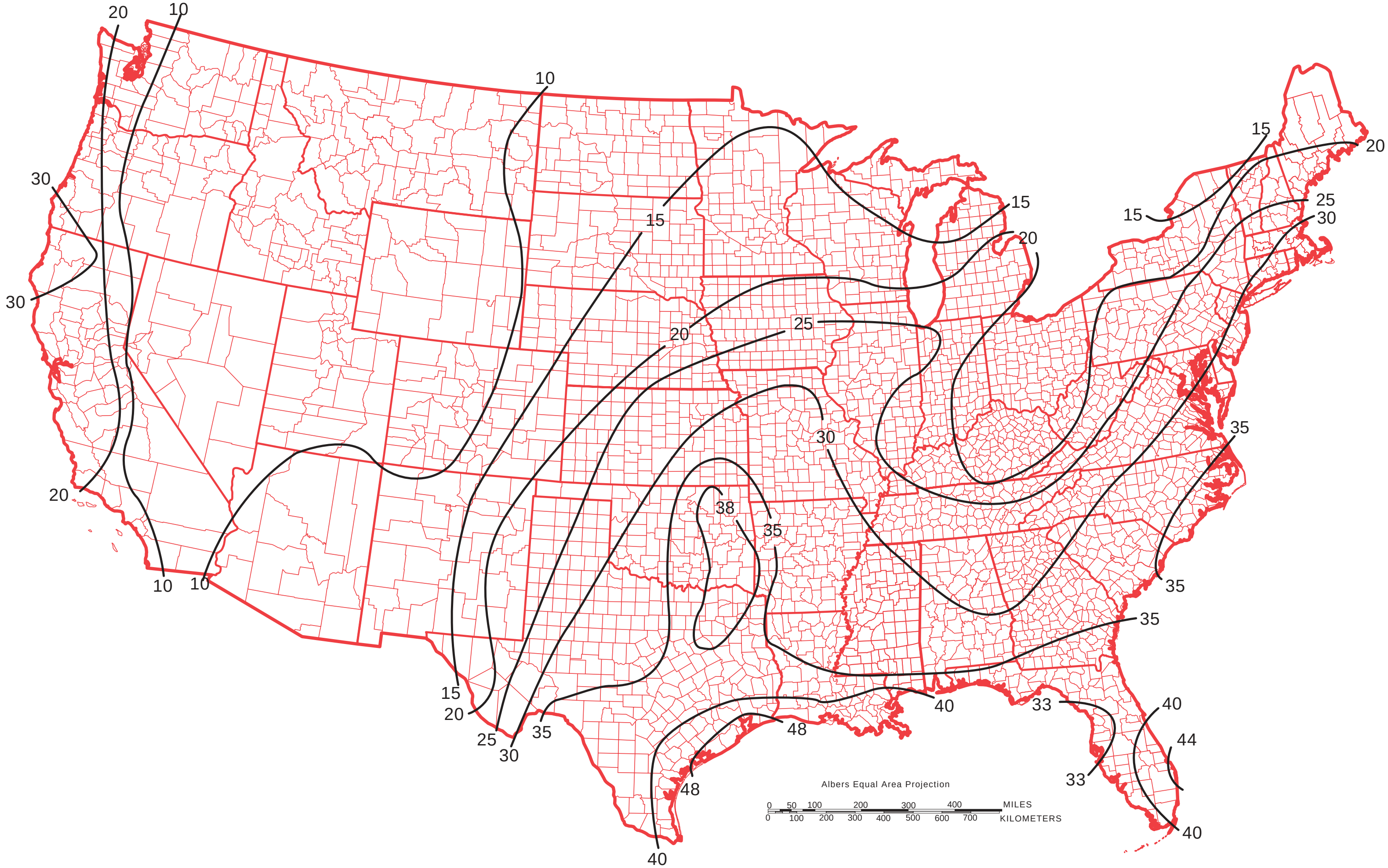
OCTOBER RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION
FIGURE 10C-12



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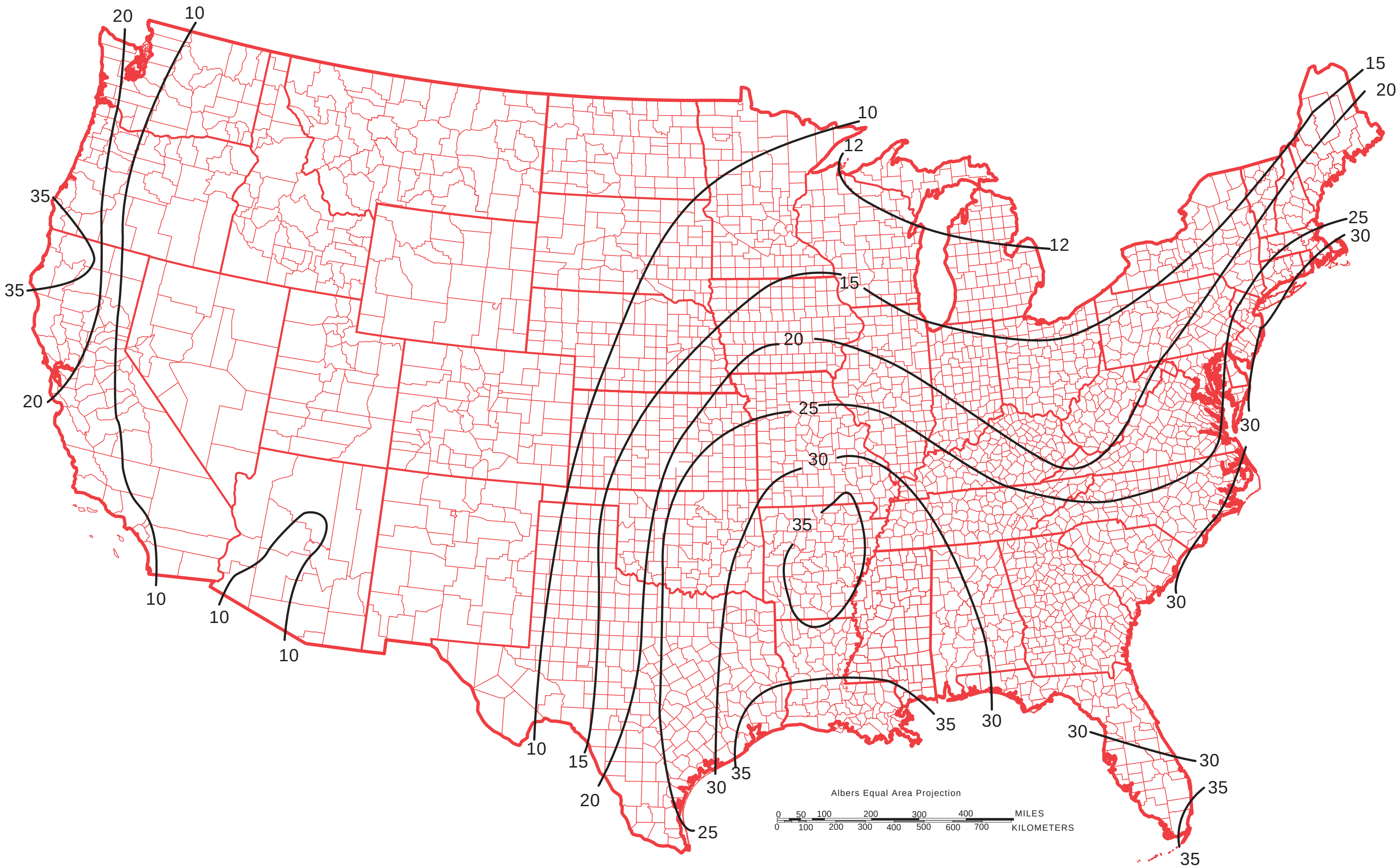
NOVEMER RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION
FIGURE 10C-13



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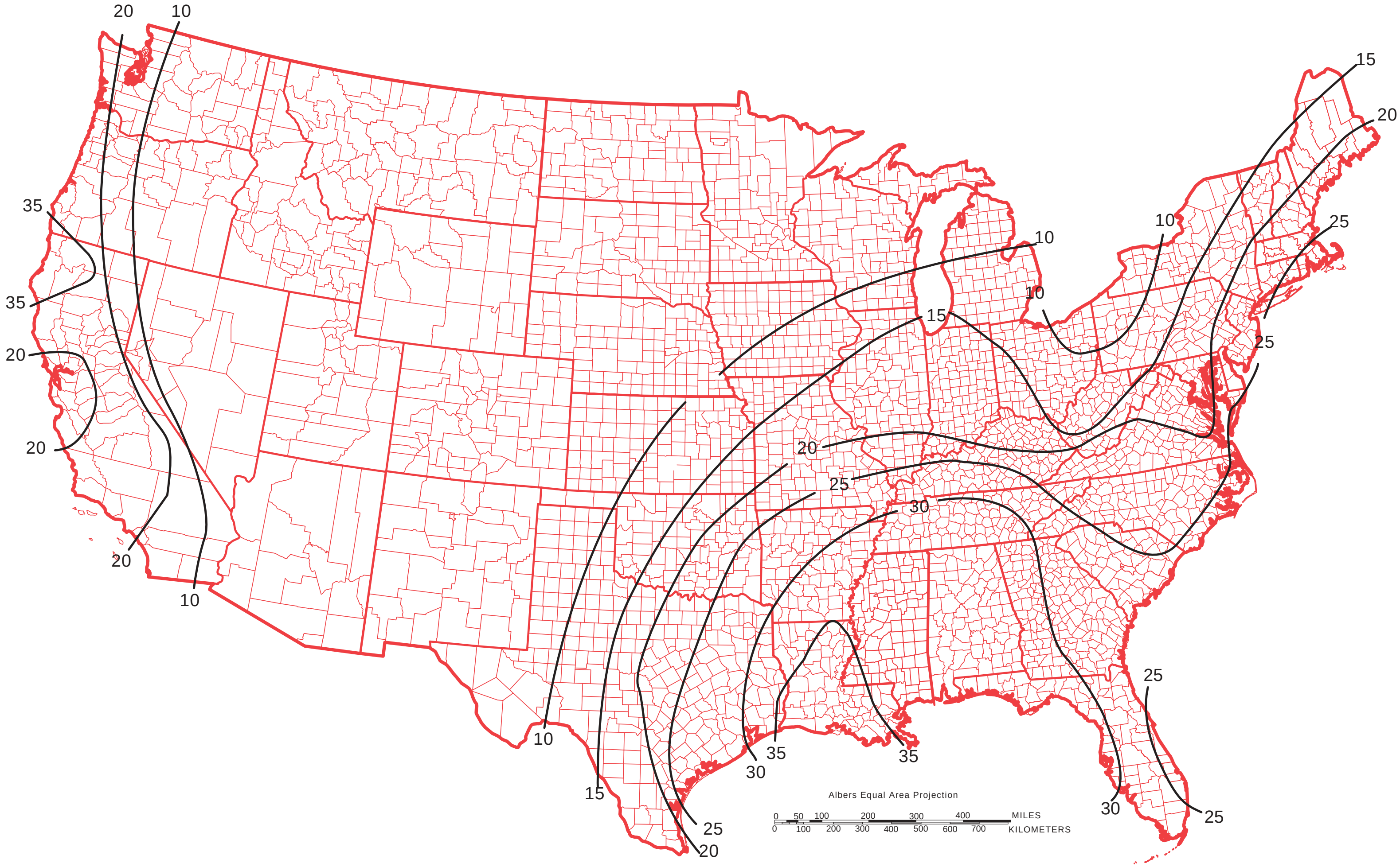
DECEMBER RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-14



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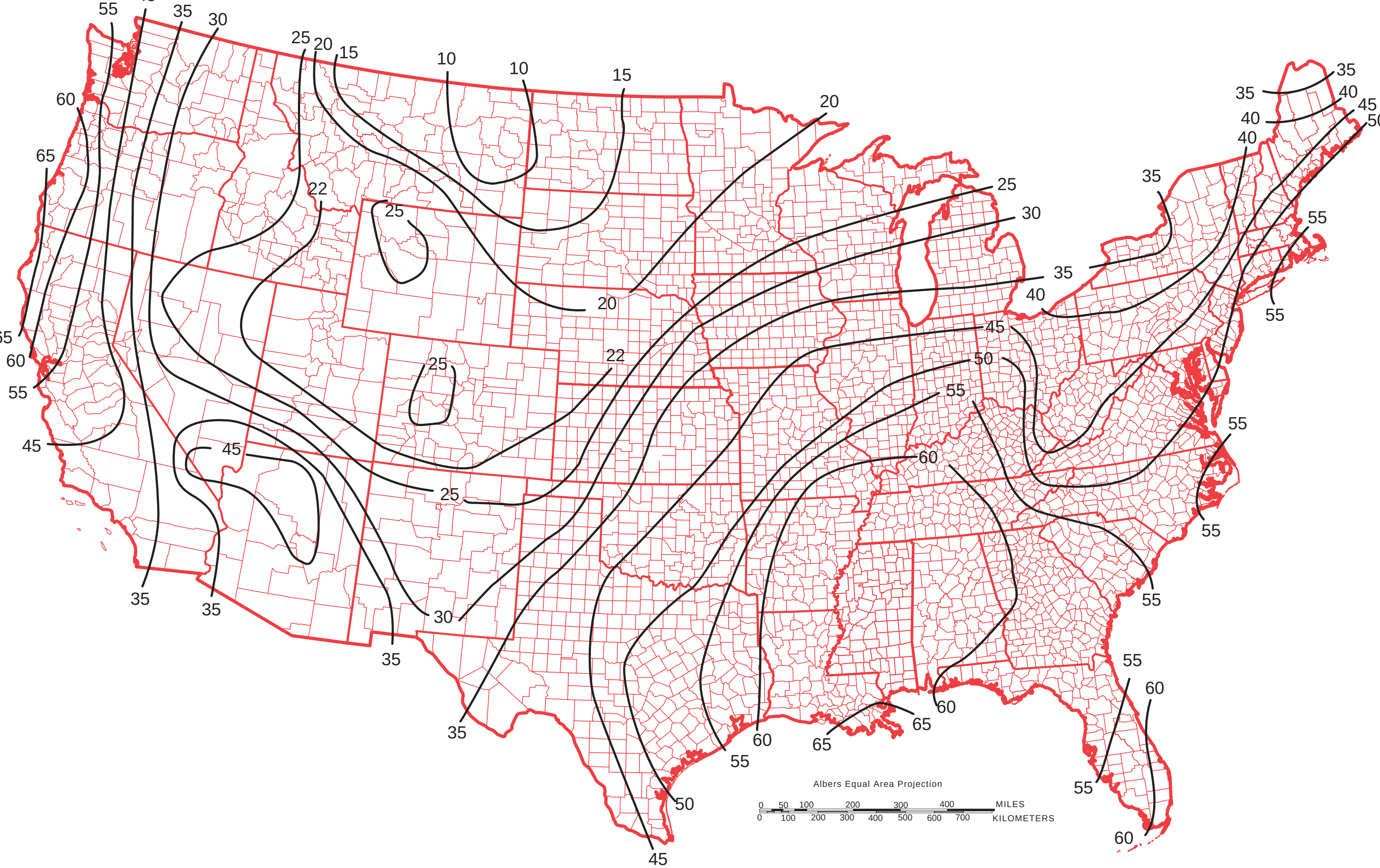
SOIL CONSERVATION SERVICE

JANUARY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-15



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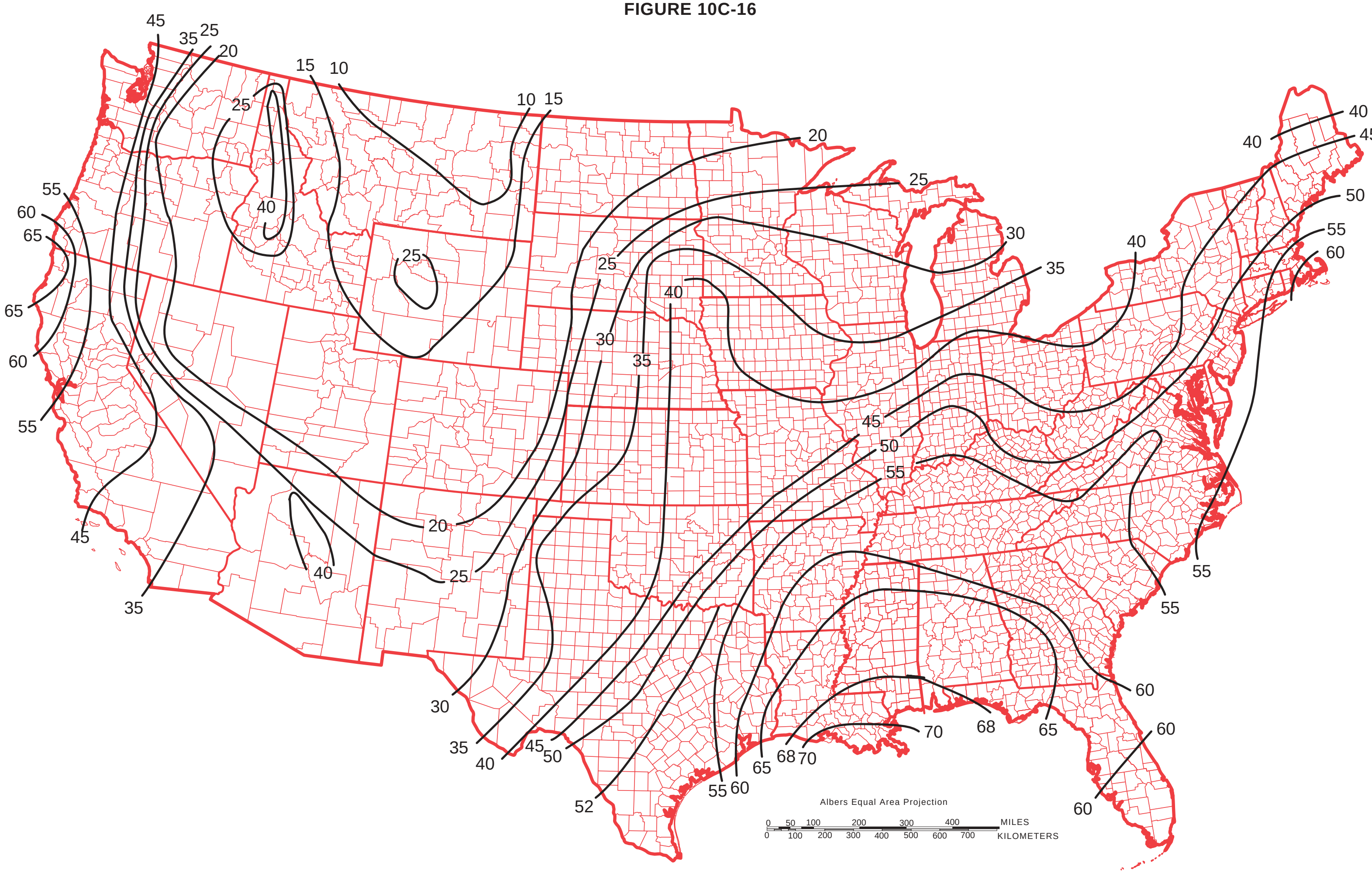
FEBRUARY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-16



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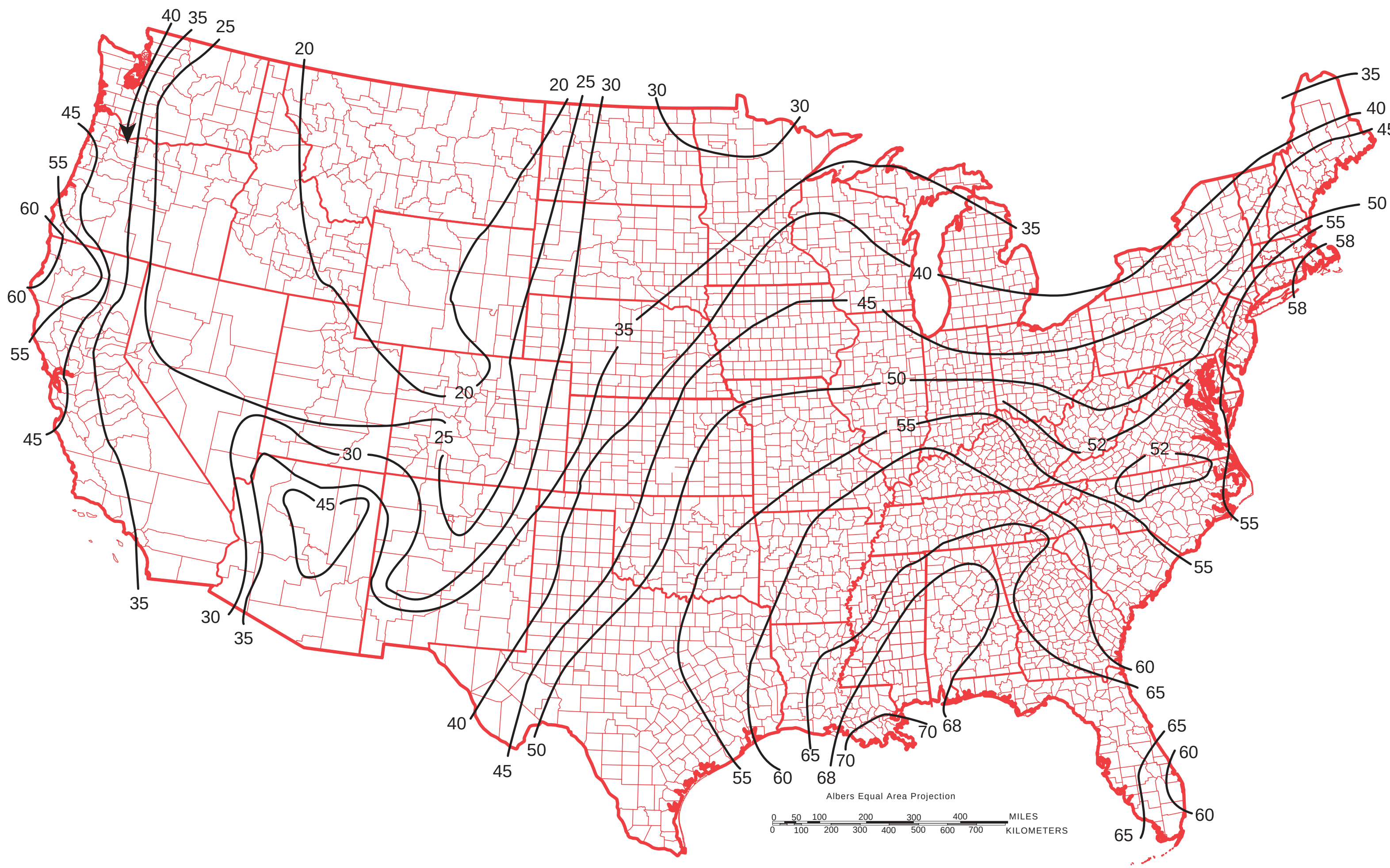
SOIL CONSERVATION SERVICE

MARCH RUNOFF
FROM CONCRETE FEEDLOTS (CN-97) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-17



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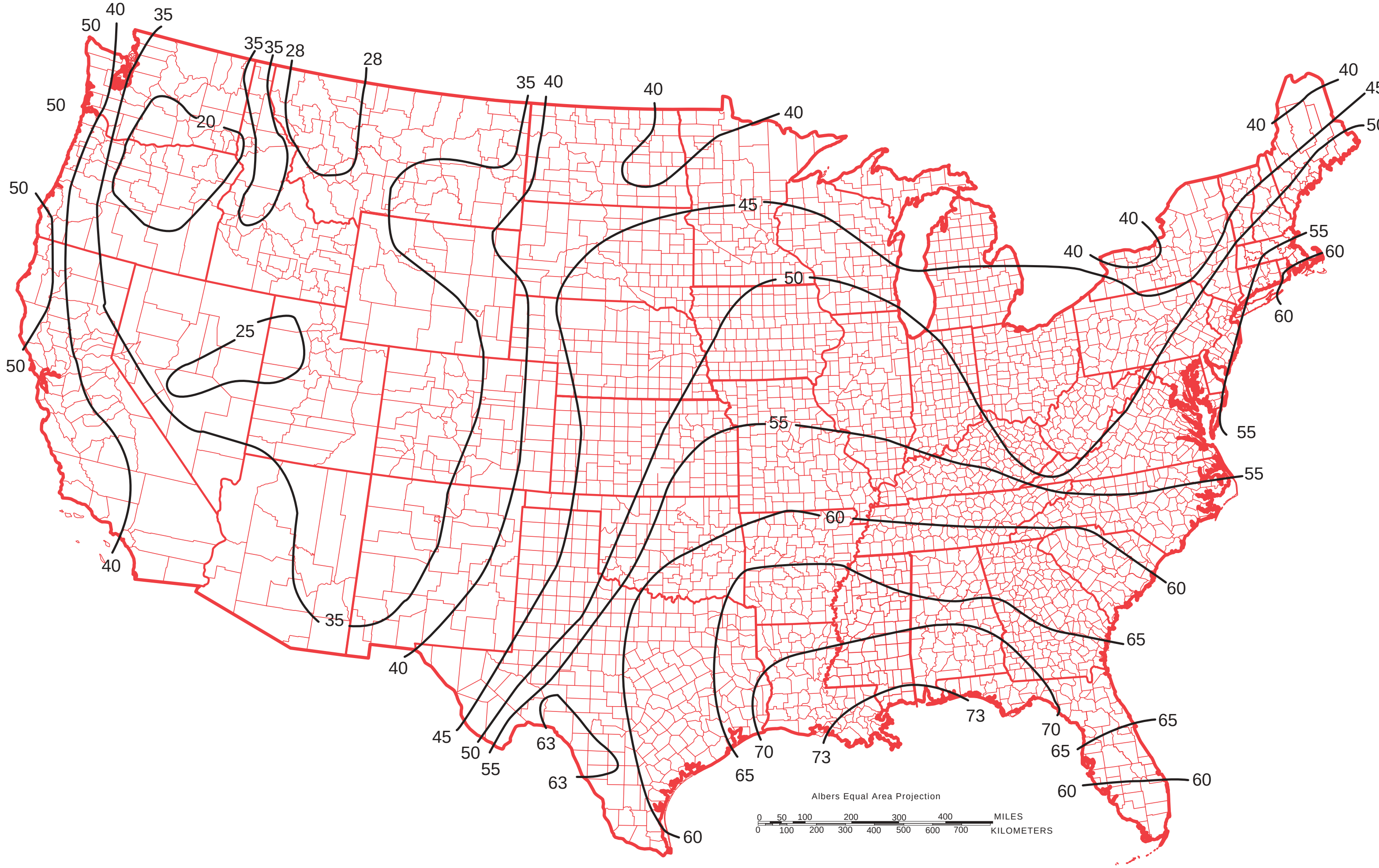
APRIL RUNOFF
FROM CONCRETE FEEDLOTS (CN-97) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-18



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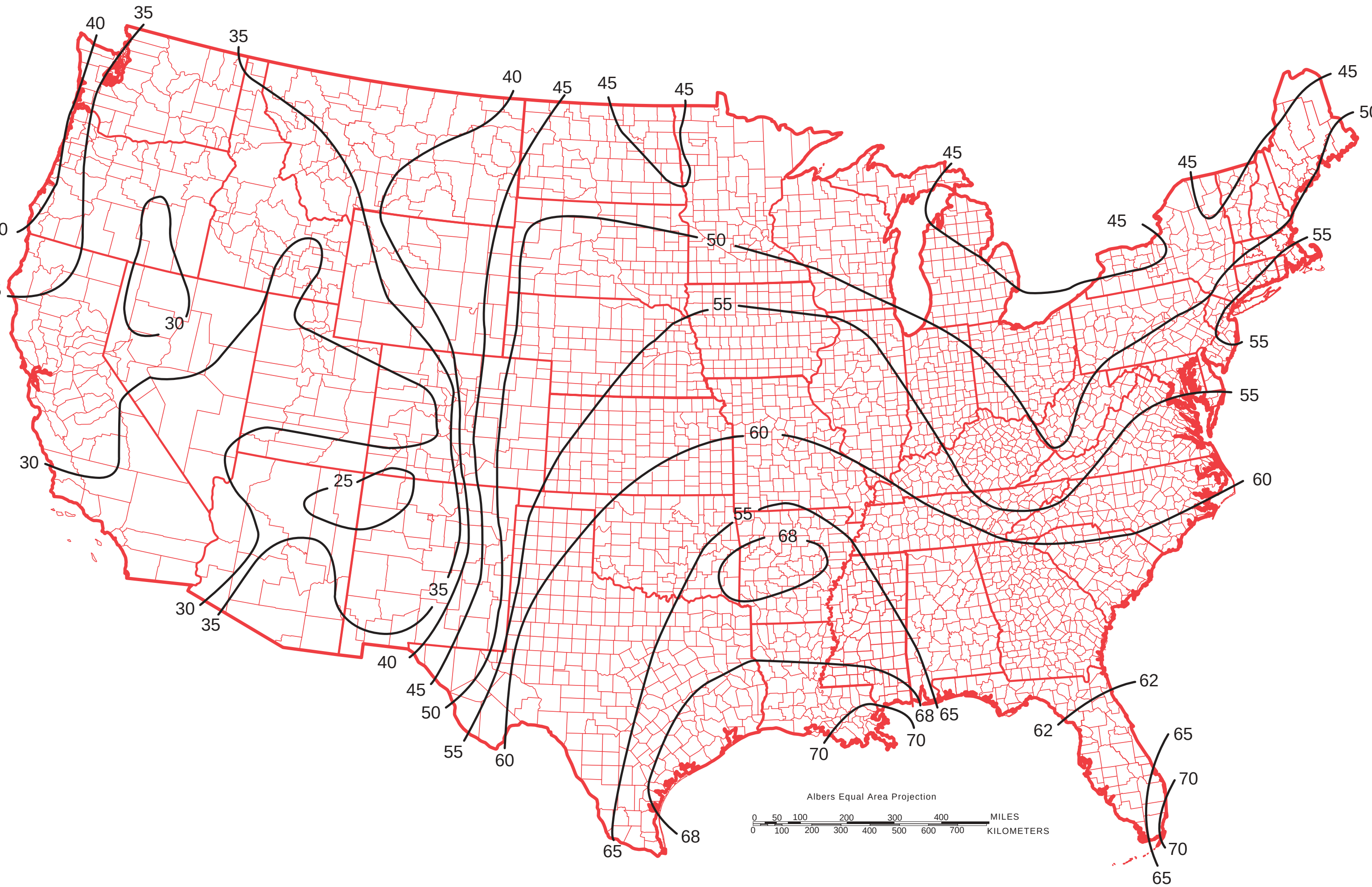
MAY RUNOFF
FROM CONCRETE FEEDLOTS (CN-97) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-19



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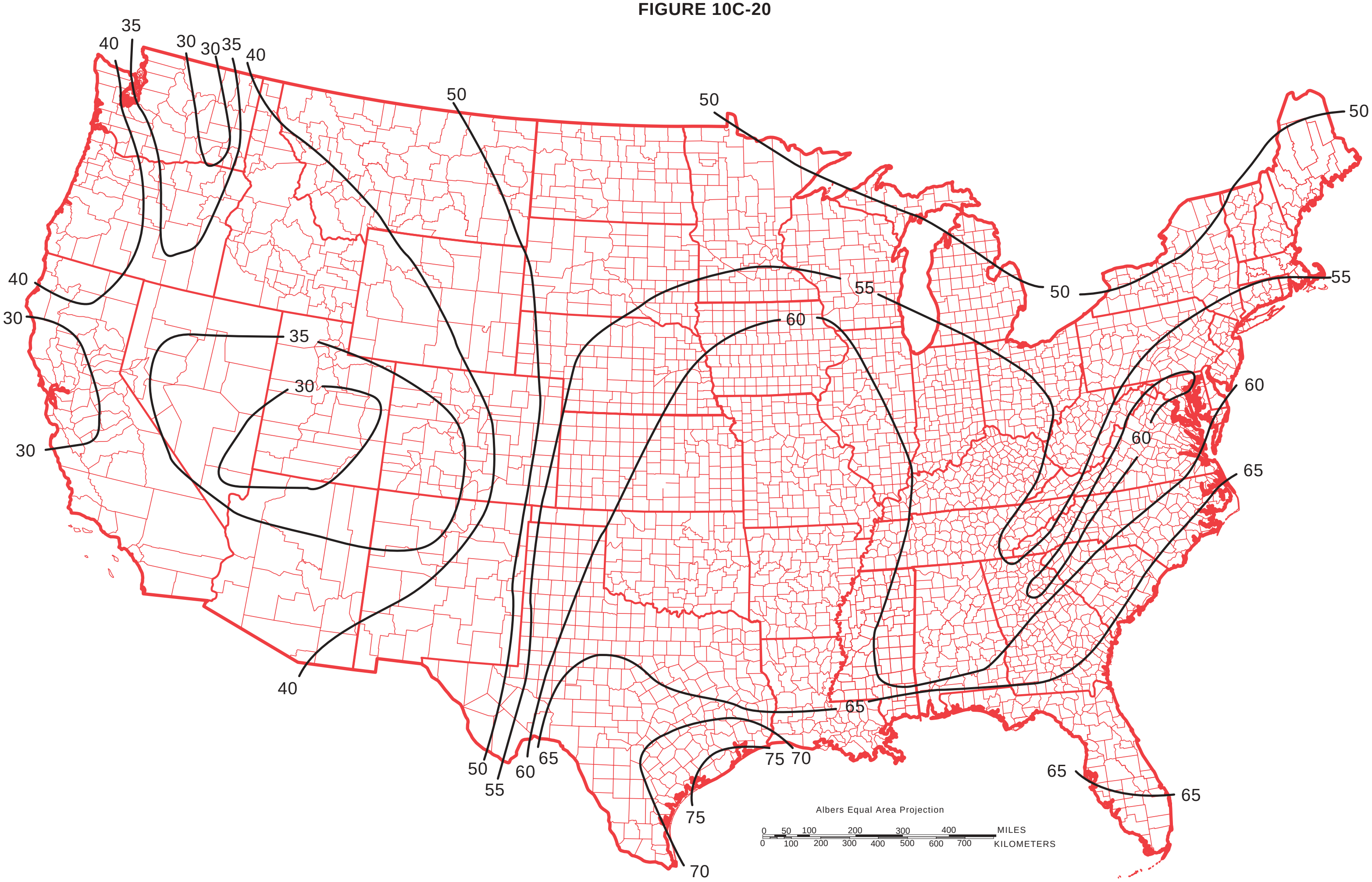
JUNE RUNOFF
FROM CONCRETE FEEDLOTS (CN-97) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-20



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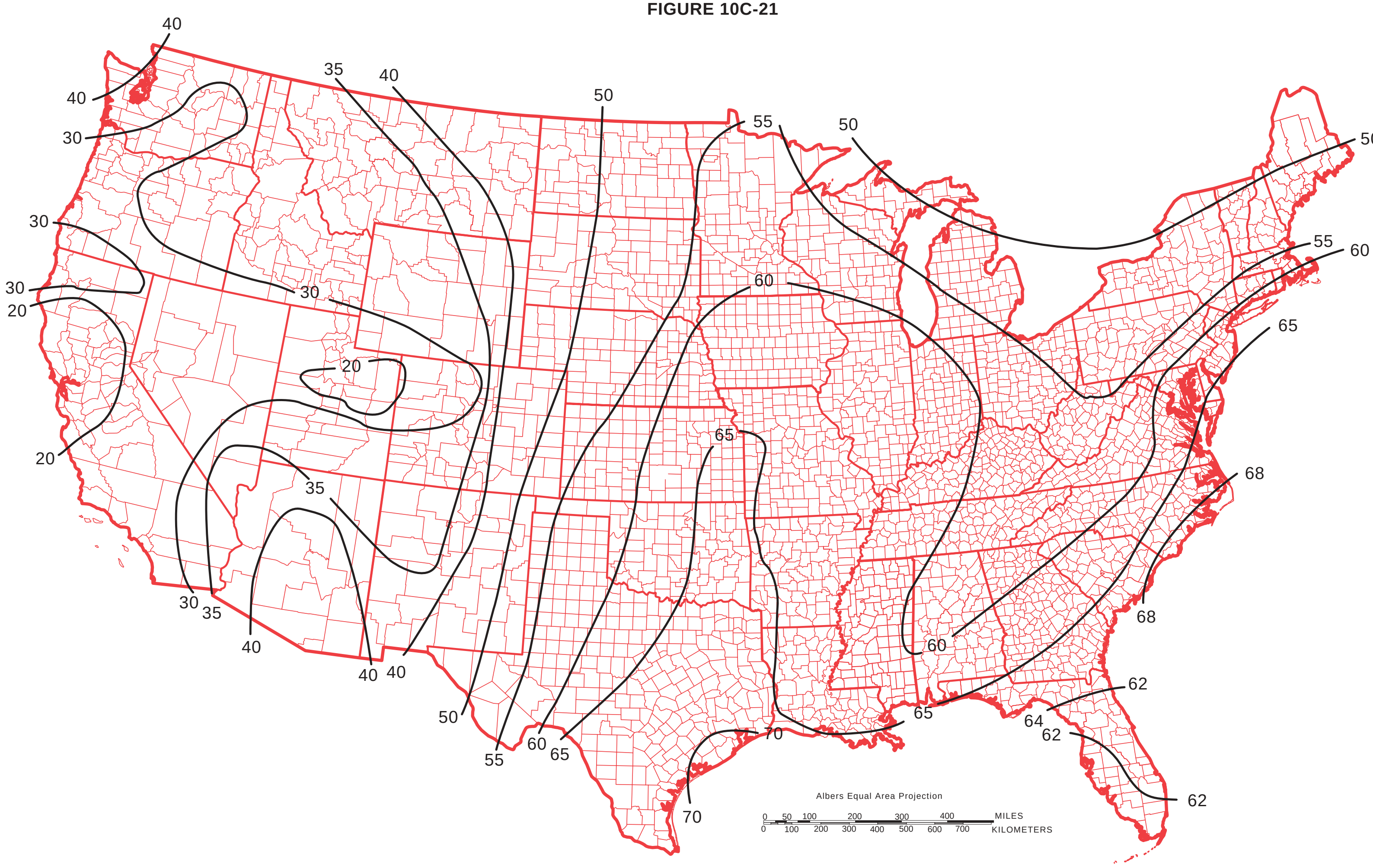
JULY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-21



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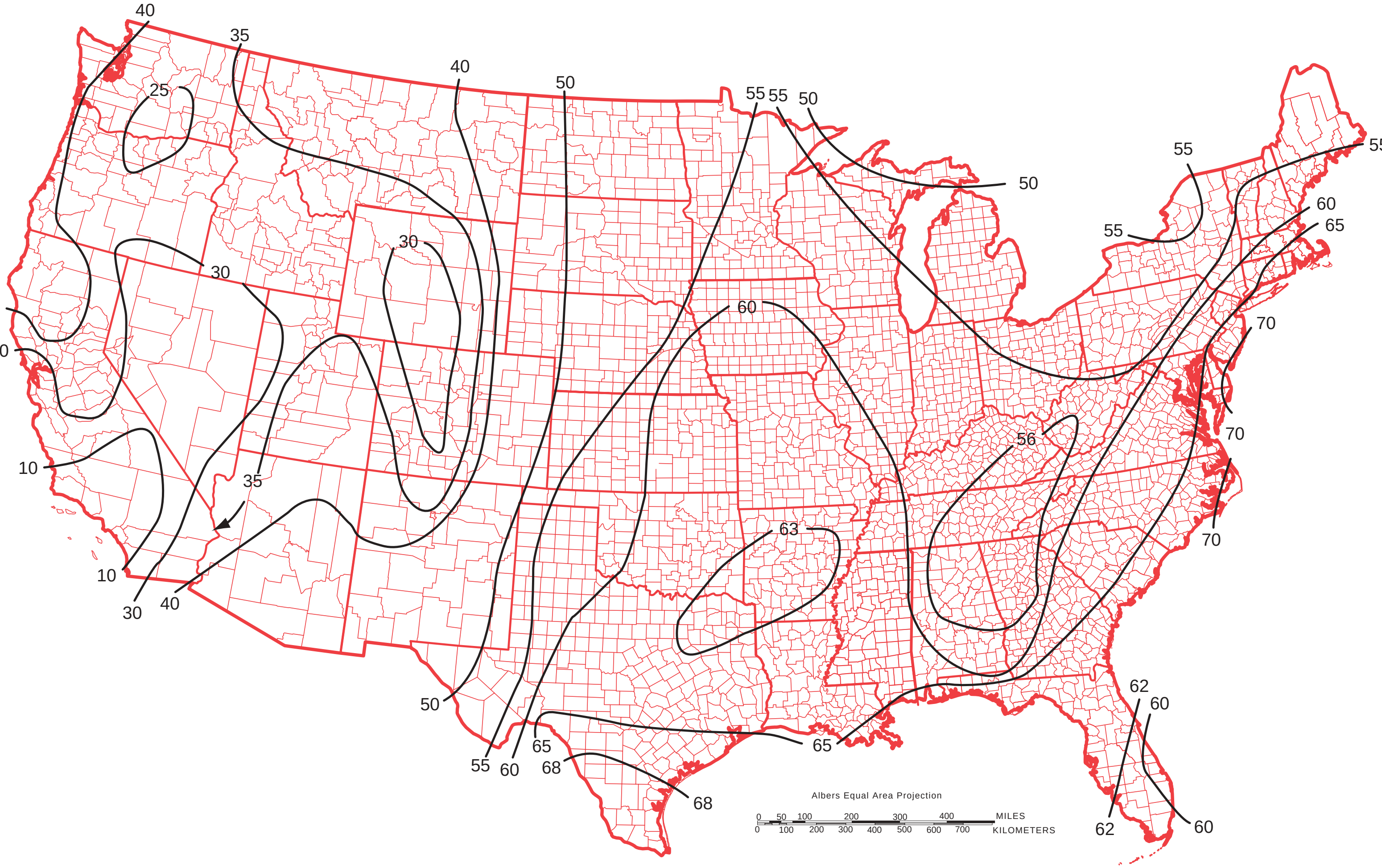
AUGUST RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-22



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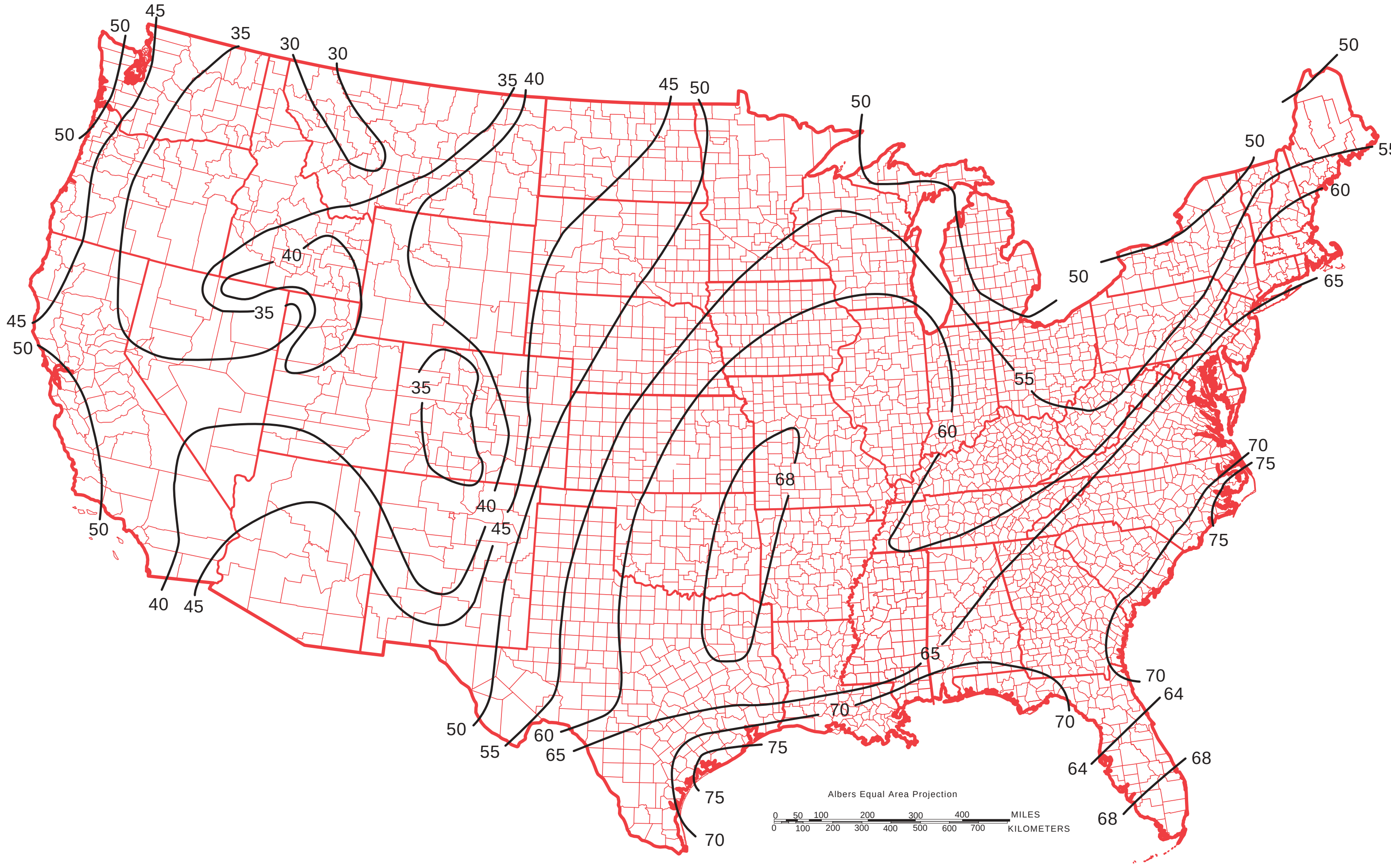
SEPTEMBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-23



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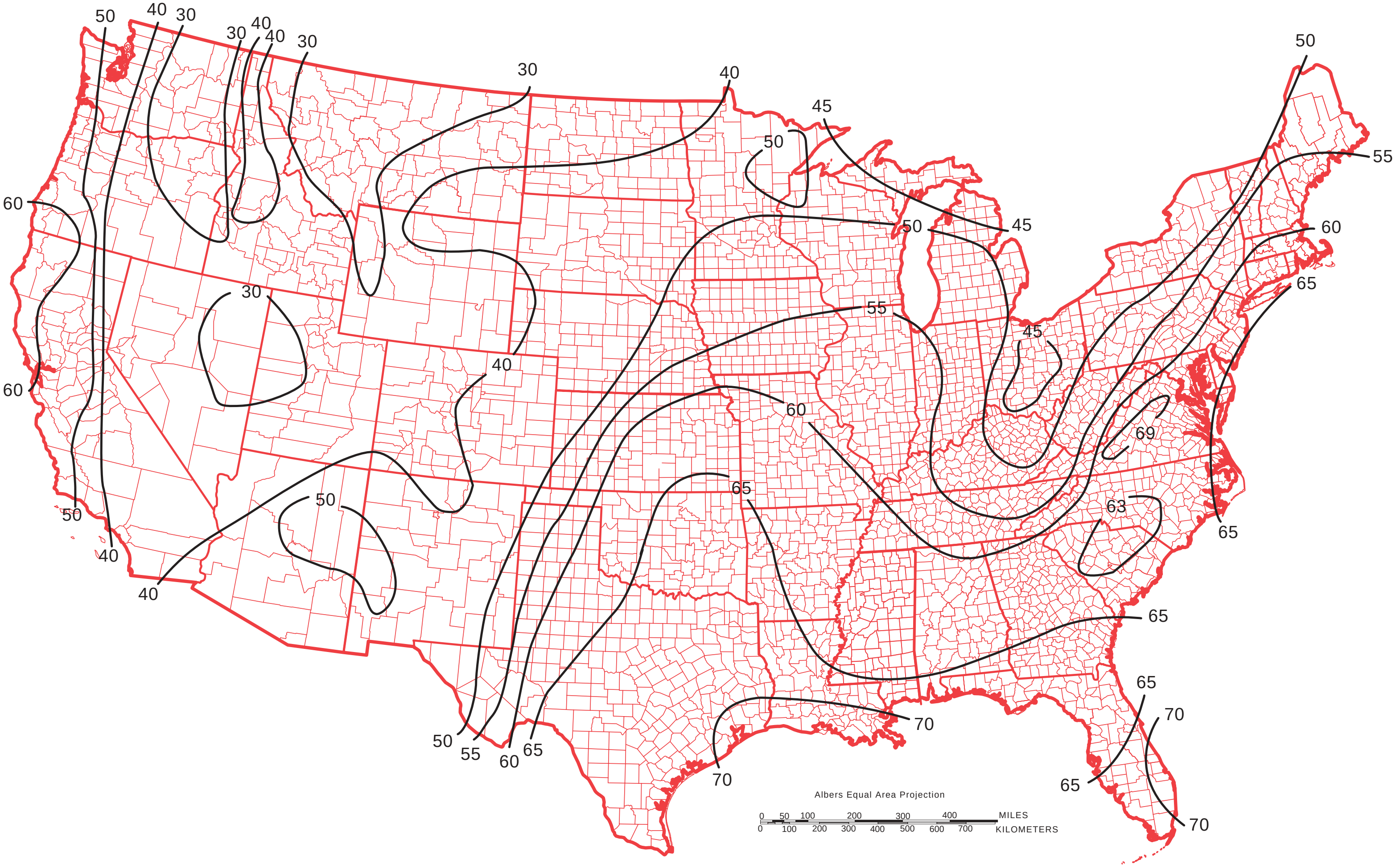
OCTOBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-24



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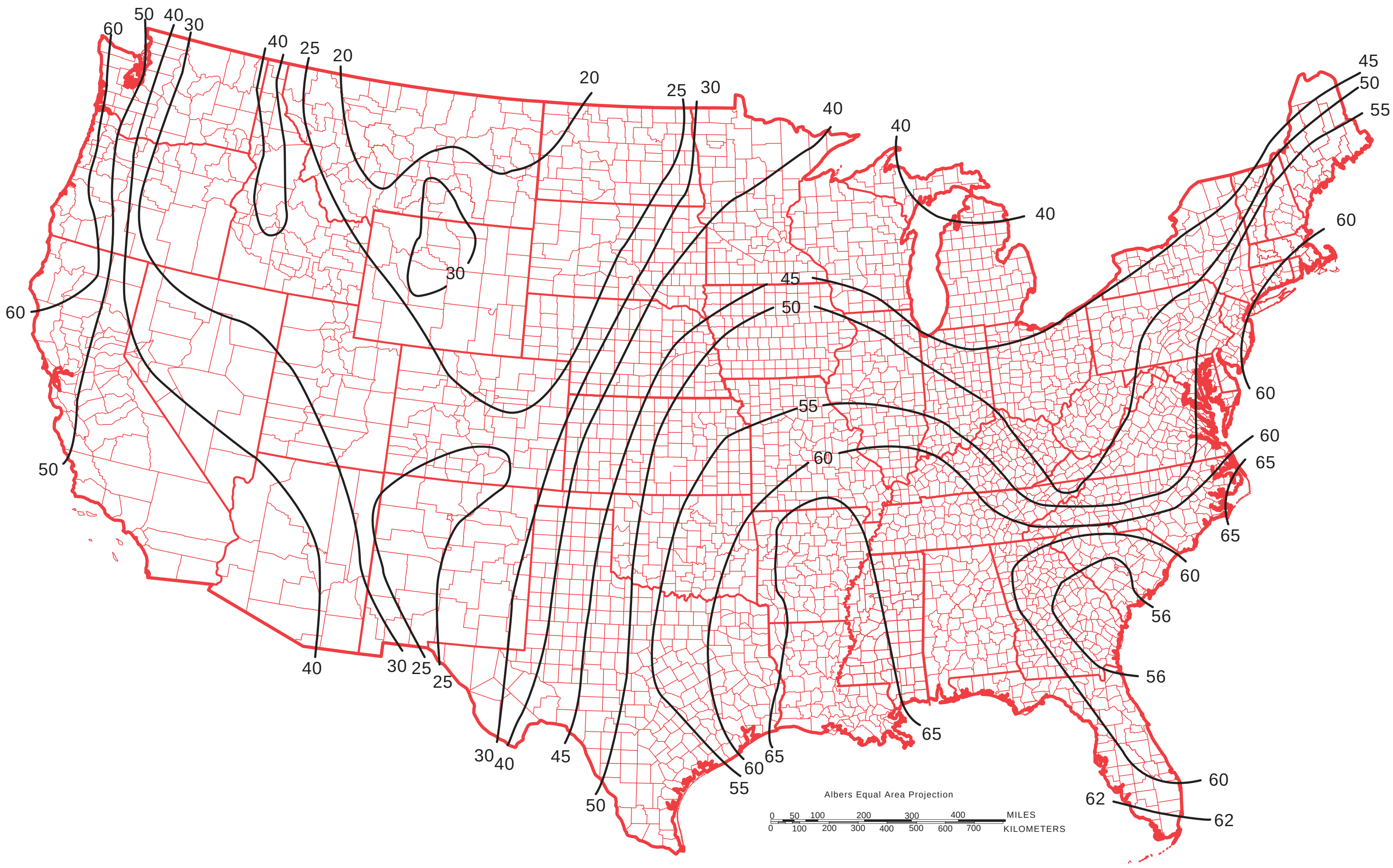
NOVEMBER RUNOFF
FROM CONCRETE FEEDLOTS (CN-97) AS
PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-25



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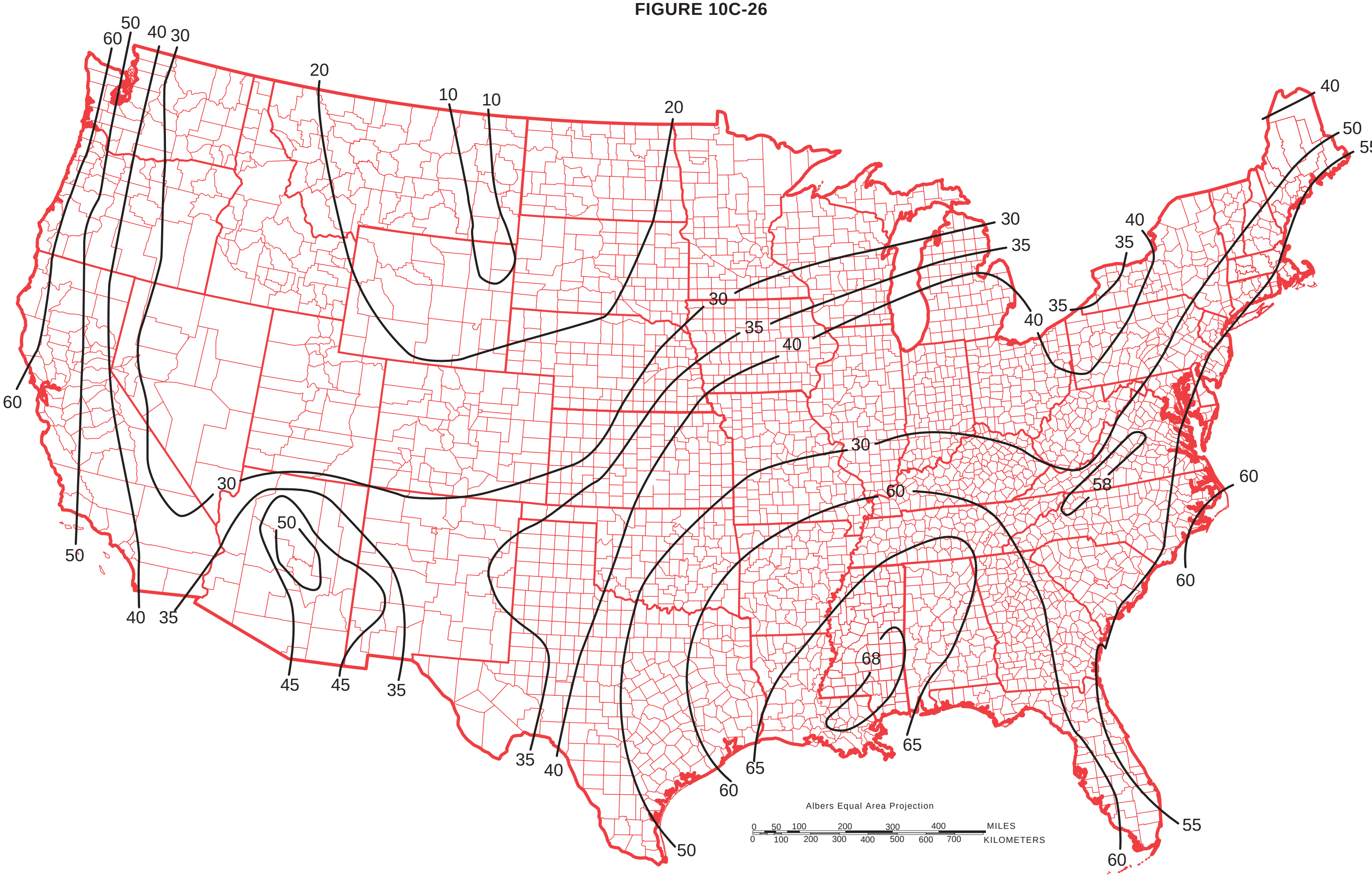
DECEMBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-26



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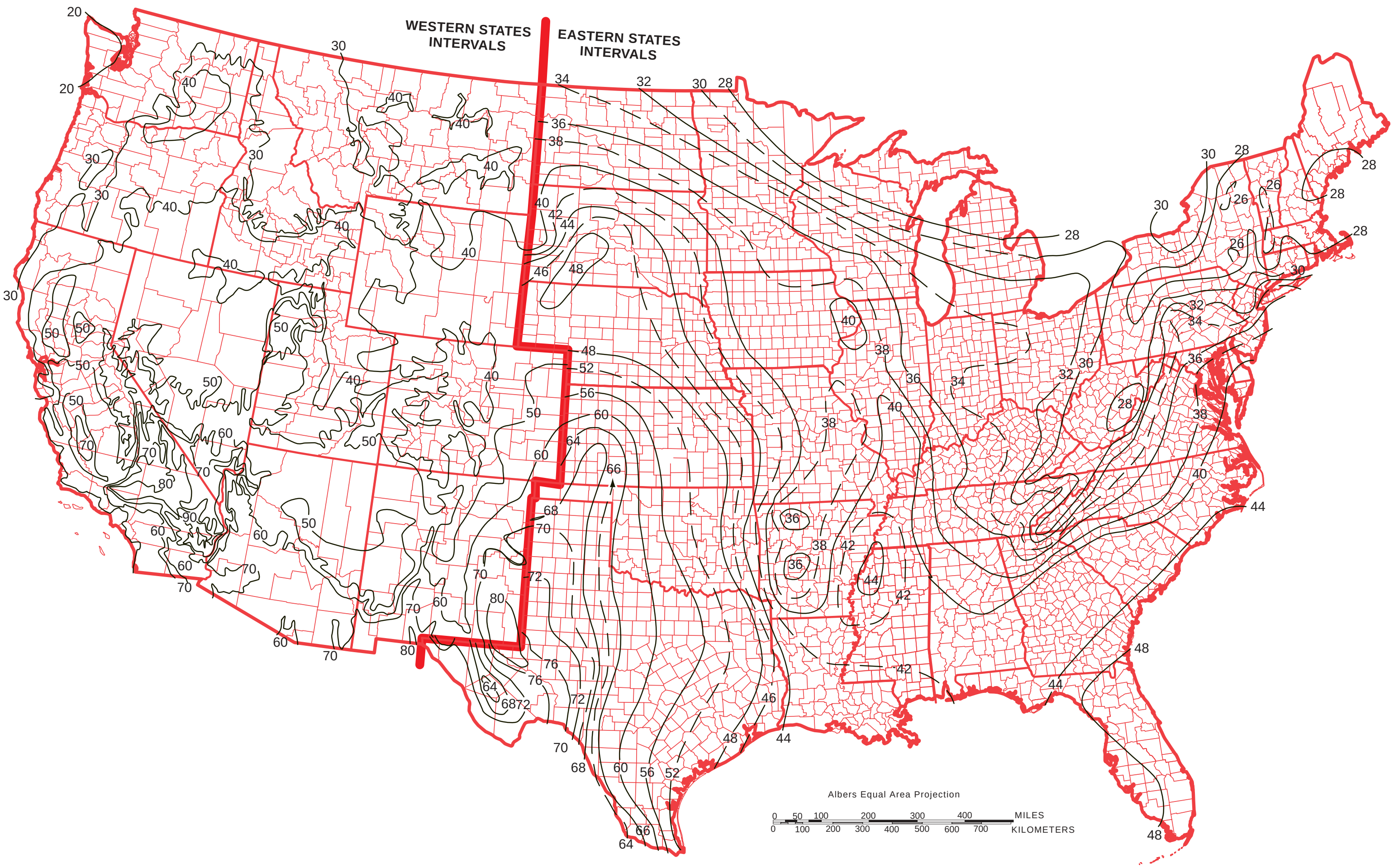
ANNUAL
FREE WATER SURFACE EVAPORATION

FIGURE 10C-27



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Appendix 10D Design and Construction Guidelines for Waste Impoundments Lined with Clay or Amendment-treated Soil

Appendix 10D Design and Construction Guidelines for Impoundments Lined with Clay or Amendment-treated Soil

Introduction

Waste storage ponds and treatment lagoons are used in agricultural waste management systems to protect surface and ground water and as a component in a system for properly utilizing wastes. Seepage from these structures has the potential to pollute surface water and underground aquifers. The principal factors determining the potential for downward and/or lateral seepage of the stored wastes are the:

- permeability of the soil and bedrock horizons near the excavated limits of a constructed waste treatment lagoon or waste storage pond
- depth of liquid in the pond that furnishes a driving hydraulic force to cause seepage
- thickness and permeability of horizons between the boundary of the lagoon bottom and sides to the aquifer or water table

In some circumstances, where permitted by local and/or State regulations, designers may consider whether seepage may be reduced from the introduction of manure solids into the reservoir. Physical, chemical, and biological processes can occur that reduce the permeability of the soil-liquid interface. Suspended solids settle out and physically clog the pores of the soil mass. Anaerobic bacteria produce by-products that accumulate at the soil-liquid interface and reinforce the seal. The soil structure can also be altered in the process of metabolizing organic material.

Chemicals in waste, such as salts, can disperse soil, which may also be beneficial in reducing seepage. Researchers have reported that, under some conditions, the seepage rates from ponds can be decreased by up to an order of magnitude (reduced 1/10th) within a year following filling of the waste storage pond or treatment lagoon with manure. Manure with higher solids content is more effective in reducing seepage than manure with fewer solids content. Research has shown that manure sealing only occurs when soils have a minimal clay content or greater. A rule of thumb supported by research is that manure sealing is not effective unless soils have at least 15 percent clay content for monogastric animal generated waste and 5 percent clay content for ruminant animal generated waste (Barrington, Jutras, and Broughton 1987a, 1987b). Manure sealing is not considered effective on relatively clean sands and gravels, and these soils always require a liner as described in the following sections.

Animal waste storage ponds designed prior to about 1990 assumed that seepage from the pond would be minimized by the accumulation of manure solids and a biological seal at the foundation surface. Figure 10D–1 shows one of these early sites, where the soils at grade were somewhat permeable sands. Monitoring wells installed at some sites with very sandy soils showed that seepage containing constituents from the pond was still occurring even after enough time had passed that manure sealing should have occurred.

This evidence caused U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) engineers to reconsider guidance on suitable soils for siting an animal waste storage pond. In the late 1980s guidance was developed that designs should not rely solely on the seepage reduction that might occur from the accumulation of manure solids in the bottom and on the sides of the finished structure. That initial design document was entitled “South National Technical Center (SNTC) Technical Guide 716.” It suggested that if any of four site conditions were present at a proposed structure location, a clay liner or other method of reducing seepage would be used in NRCS designs. A few revisions were made, and the document was re-issued in September 1993.

Figure 10D–1 Animal waste storage pond constructed before the implementation of modern design guidelines

NRCS was reorganized in 1994, and guidance in old SNTC documents was not part of the revised document system of the Agency. Consequently, the 716 document was revised considerably, and the revised material was incorporated into appendix 10D of the Agricultural Waste Field Management Handbook (AWMFH) in October 1998. This 2008 version of appendix 10D continues to update and clarify the process of designing an animal waste storage pond that will meet NRCS-specified engineering design criteria and stated specified permeability requirements.

General design considerations

Limiting seepage from an agricultural waste storage pond has two primary goals. The first is to prevent any virus or bacteria from migrating out of the storage facility to an aquifer or water source. The second is to prevent the conversion of ammonia to nitrate in the vadose zone. Nitrates are very mobile once they are formed by the nitrification process. They can then accumulate significantly in ground water. The National drinking water standard for nitrate is 10 parts per million, and excessive seepage from animal waste storage ponds could increase the level of nitrates in ground water above this threshold. Other constituents in the liquid manure stored in ponds may also be potential contaminants if the seepage from the pond is unacceptably high.

Defining an acceptable seepage rate is not a simple task. Appendix 10D recommends an allowable seepage quantity that is based on a historically accepted tenet of clay liner design, which is that a coefficient of permeability of 1×10^{-7} centimeters per second is reasonable and prudent for clay liners. This value, rightly or wrongly, has a long history of acceptability in design of impoundments of various types, including sanitary landfills.

Assuming that a typical NRCS waste impoundment has a maximum liquid depth of 9 feet, a compacted clay liner thickness of 1 foot, and a one order of magnitude reduction in seepage due to manure sealing effects, the resulting seepage associated with this historically accepted permeability rate is about 1×10^{-6} centimeters per second, or about 9,240 gallons per acre per day. However, the NRCS no longer recommends basing design decisions on the assumption that a full one order of magnitude reduction will be achieved. The following criteria should be used in assessing the adequacy of a compacted clay liner system:

- When credit for a reduction of seepage from manure sealing (described later in the document) is allowed, NRCS guidance considers an acceptable initial seepage rate to be 5,000 gallons per acre per day. This higher value used for design assumes that manure sealing will result in at least a half order of magnitude reduction in the initial seepage. If State or local regulations are more restrictive, those requirements should be followed.
- If State or local regulations prohibit designs from taking credit for future reductions in seepage from manure sealing, then NRCS recommends the initial design for the site be based on a seepage rate of 1,000 gallons per acre per day. Applying an additional safety factor to this value is not recommended because it conservatively ignores the potential benefits of manure sealing.

One problem with basing designs on a unit seepage value is that the approach considers only unit area seepage. The same criterion applies for small and large facilities. More involved three-dimensional type analyses would be required to evaluate the potential impact of seepage on ground water regimes on a whole-site basis. In addition to unit seepage, studies for large storage facilities should consider regional ground water flow, depth to the aquifer likely to be affected, and other factors.

The procedures in appendix 10D to the AWMFH provide a rational approach to selecting an optimal combination of liner thickness and permeability to achieve a relatively economical, but effective, liner design. It recognizes that manipulating the permeability of the soil liner is usually the most cost-effective approach to reduce seepage quantity. While clay liners obviously allow some seepage, the limited seepage from a properly designed site should have minimal impact on ground water quality. Numerous studies, such as those done by Kansas State University (2000), have shown that waste storage ponds located in low permeability soils of sufficient thickness have a limited impact on the quality of ground water.

If regulations or other considerations require that unit seepage be less than 500 gallons per acre per day (1/56 inch per day), synthetic liners such as high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), ethylene propylene diene monomer (EPDM), or geosynthetic clay liners (GCL), concrete liners, or aboveground storage tanks may be more feasible and economical and should be considered. Figure 10D–2 shows a pond lined with a synthetic liner, figure 10D–3 shows a concrete-lined excavated pond, and figure 10D–4 shows an aboveground concrete tank. Above-ground tanks may be also constructed of fiberglass-lined steel. NRCS has significant expertise in the selection, specification, and construction of sites using these products in addition to clay liners. Guidance on these other technologies is contained in other chapters of the AWMFH.

Figure 10D–2 Pond with synthetic liner *(Photo credit NRCS)*

Figure 10D–3 Excavated animal waste storage pond with concrete liner *(Photo credit NRCS)*

Figure 10D–4 Aboveground storage tank for animal waste *(Photo credit Mitch Cummings, Oregon NRCS)*

Progressive design

Waste storage ponds and waste treatment lagoons are usually designed with specific objectives that include cost, allowable seepage, aesthetics, and other considerations. Designs are usually evaluated in a progressive manner, with less costly and simple methods considered first, and more costly and complex methods considered next. These design concepts should generally be considered in the order listed to provide the most economical, yet effective, design of these structures. The following descriptions cover details on design and installation of these individual design measures.

- The least expensive and least complex design is to locate a waste impoundment in soils that have a naturally low permeability and where horizons are thick enough to reduce seepage to acceptable levels. The site should also be located where the distance to the water table conforms to requirements of any applicable regulations.
- Soils underlying the excavated boundaries of the pond may not be thick enough or slowly permeable enough to limit seepage to acceptably low values. In this case, the next type of design often considered is a liner constructed of compacted clay or other soils with appropriate amendments. This type of liner may be constructed with soils from the excavation itself or soil may be imported from nearby borrow sources. If the soils require amendments such as bentonite or soil dispersants, the unit cost of the compacted liner will be significantly higher than for a liner that only requires compaction to achieve a satisfactorily low permeability.
- A synthetic liner may be used to line the impoundment to reduce seepage to acceptable levels. Various types of synthetic materials are available.
- A liner may be constructed of concrete, or a concrete or fiberglass-lined steel tank can be constructed above ground to store the wastes.

A useful tool in comparing design alternatives is to evaluate unit costs. Benefits of alternatives may then be compared against unit costs to aid in selecting a design alternative. Benefits may include reduced seepage, aesthetics, or other considerations. Many geomembrane suppliers may be able to provide rough cost estimates based on the size and locale of the site. In estimating the cost of a compacted clay liner, one should evaluate the volume of compacted fill involved in a liner of given thickness. Table 10D–1 illustrates a cost comparison for different thicknesses of compacted clay liners. If methods other than compacted clay liners are used, higher unit costs may apply (table 10D–2).

Table 10D–1 Cost comparisons of design options for compacted clay liner

Thickness of compacted liner (ft)	Number of cubic yards of fill per square foot (yd^3)	Assumed cost of compacted fill, per cubic yard ($)	Unit cost of stated thickness liner ($\$/ft^2$)
1.0	0.037037	3.00–5.00	0.11–0.19
1.5	0.055555	3.00–5.00	0.17–0.28
2.0	0.074074	3.00–5.00	0.22–0.37
3.0	0.111111	3.00–5.00	0.33–0.56

Table 10D–2 Cost comparison for other design options

Liner type	Unit costs ($\$/ft^2$)
Geosynthethic	0.50–1.25
Concrete, reinforced 5 inches thick	7.50–8.00

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}

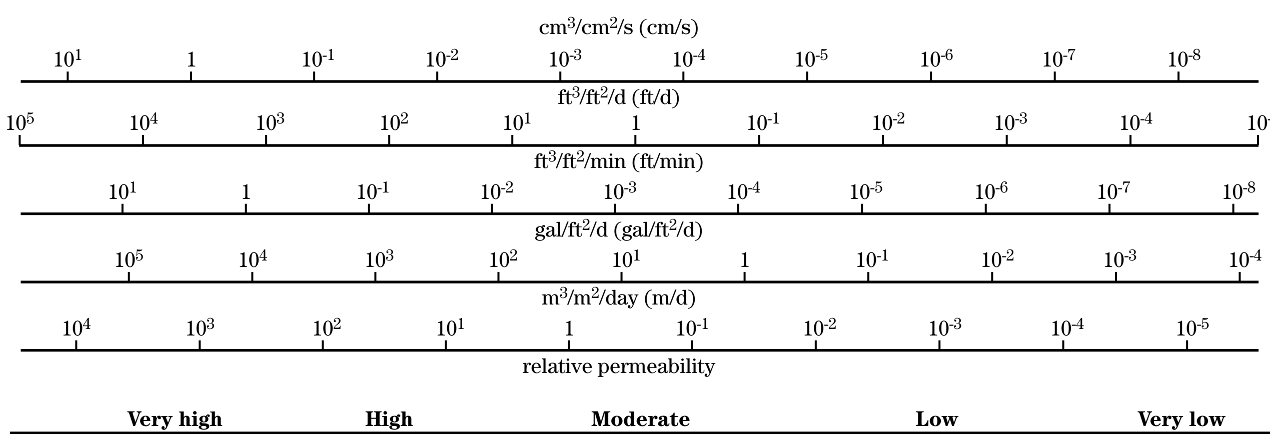
of high calcium parent rock, such as limestone. Soil scientists and published soil surveys are helpful in identifying these soil types.

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.

Many rural domestic and stock water wells are developed in fractured rock at a depth of less than 300 feet. Some rock types, such as limestone and gypsum, may have wide, open solution channels caused by chemical action of the ground water. Soil liners may not be adequate to protect against excessive leakage in these bedrock types. Concrete or geomembrane liners may be appropriate for these sites. However, even hairline openings in rock can provide avenues for seepage to move downward and contaminate subsurface water supplies. Thus, a site that is shallow to bedrock can pose a potential problem and merits the consideration of a liner. Bedrock at a shallow depth may not pose a hazard if it has a very low permeability and has no unfavorable structural features. An example is massive siltstone.

Excavation boundary of an impoundment is underlain by soils in group I—Coarse grained soils with less than 20 percent low plasticity fines generally have higher permeability and have the potential to allow rapid movement of polluted water. The soils are also deficient in adsorptive properties because of their lack of clay. Relying solely on the sealing resulting from manure solids when group I soils are encountered is not advisable. While the reduction in permeability from manure sealing may be one order of magnitude, the final resultant seepage losses are still likely to be excessive, and a liner should be used if the boundaries of the excavated pond are in this soil group.

Excavation boundary of an impoundment is underlain by some soils in group II or problem soils in group III (flocculated clays) and group IV (highly plastic clays that have a blocky structure)—Soils in group II may or may not require a liner. Documentation through laboratory or field permeability testing and computations of specific discharge (unit seepage quantities) is advised. Higher than normal permeability can occur when soils in group III or IV are flocculated or have a blocky structure. These are special cases, and most soils in groups III and IV will not need a liner provided the natural formation is thick enough to result in acceptable predicted seepage quantities.

These conditions do not always dictate a need for a liner. Specific site conditions can reduce the potential risks otherwise indicated by the presence of one of these conditions. For example, a thin layer of soil over high quality rock, such as an intact shale, is less risky than if the thin layer occurs over fractured or fissured rock. If the site is underlain by many feet of intermediate permeability soil, that site could have equivalent seepage losses as one underlain by only 2 feet of low permeability soil.

Some bedrock may contain large openings caused by solutioning and dissolving of the bedrock by ground water. Common types of solutionized bedrock are limestone and gypsum. When sinks or openings are known or identified during the site investigation, these areas should be avoided and the proposed facility located elsewhere. However, when these conditions are discovered during construction or alternate sites are not available, concrete or geosynthetic liners may be required, but only after the openings have been properly cleaned out and backfilled with concrete.

Specific discharge

Introduction

One way to require a minimal design at a site is to require a minimum thickness of a given permeability soil for a natural or constructed liner. An example of this would be to require that a clay liner constructed at a waste storage pond should be at least 1 foot thick, and the soil should have a coefficient of permeability of 1×10^{-7} centimeters per second or less.

However, using only permeability and thickness of a boundary horizon as a criterion ignores the effect of the depth of liquid on the predicted quantity of seepage from an impoundment. Using this approach would mean that the same design would be used for a site with 30 feet of water as one with 8 feet of water, for instance. A more rational method for stating a limiting design requirement is to compute seepage using Darcy's law for a unit area of the pond bottom.

A rational method of comparing design alternatives at a given site is needed. Such a method allows designers to evaluate the effect of changing one or more of the design elements in a site on the predicted seepage quantities. This document presents methods for computing the term "specific discharge" to use in comparing alternatives and to document a given design goal for a site. Specific discharge is defined as unit seepage.

It does not reflect the total seepage from a site, but rather provides a value of seepage per square unit area of pond bottom.

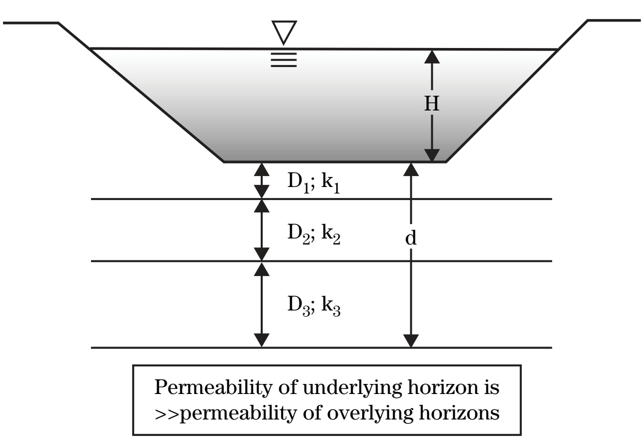
This document uses calculations of specific discharge to compare design alternatives and to determine if a given design meets regulatory requirements and guidelines. In some cases, the total seepage from a pond may be of interest, particularly for larger ponds in highly environmentally sensitive environments.

In those cases, more elaborate three-dimensional seepage computations using sophisticated finite-element computer programs may be warranted. It is outside the scope of this document to describe these types of analyses. Specialists who are experienced in using the complex software used for these computations should be consulted.

The parameters that affect the seepage from a pond with a natural or constructed clay liner are:

- The size of the pond—The total bottom area and area of the exposed sides of the pond holding the stored waste solids and liquids.
- The thickness of low permeability soil at the excavation limits of the pond—For design, the thickness of the soil at the bottom of the pond is often used because that is where seepage is likely to be highest. In some cases, however, seepage from the sides of the pond may also be an important factor. Seepage from the sides of ponds is best analyzed using finite element flow net programs. In some cases, rather than a single horizon, multiple horizons may be present.
- The depth of liquid in the pond—The depth of liquid at the top of the reservoir when pumping should commence is normally used.
- The coefficient of permeability of the soil forming the bottom and sides of the pond—In layered systems, an average or weighted permeability may be determined as shown in figure 10D–7.

Figure 10D–7 Conversion of permeability in layered profile to single value



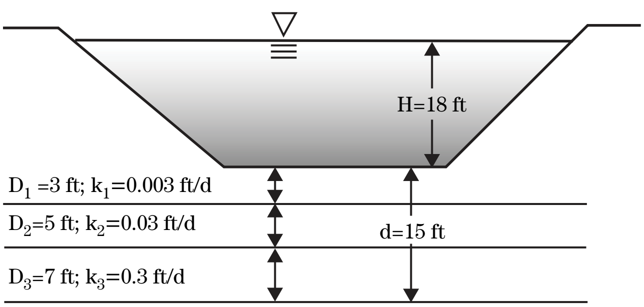
$$k_{average} = \frac{d}{\frac{D_1}{k_1} + \frac{D_2}{k_2} + \frac{D_3}{k_3}}$$

Example 10D–1 shows how to convert a multiple layer system into a single equivalent permeability. Using this method allows a designer to compute specific discharge when several horizons of constructed or natural soils occur below a site.

Example 10D–1

The excavated pond is underlain by 15 feet of soil consisting of three different horizons (fig. 10D–8). The thickness and permeability of each horizon is shown in the sketch. Compute the average vertical permeability of the 15 feet of soil.

Figure 10D–8 Idealized soil profile for example 10D–1



Solution

$$k_{average} = \frac{d}{\frac{D_1}{k_1} + \frac{D_2}{k_2} + \frac{D_3}{k_3}}$$

$$k_{average} = \frac{15}{\frac{3}{0.003} + \frac{5}{0.03} + \frac{7}{0.3}} = 0.0126 \text{ ft/d}$$

Definition of specific discharge

The term “specific discharge” has been coined to denote the unit seepage that will occur through the bottom of a pond with a finite layer of impervious soil. Specific discharge is the seepage rate for a unit cross-sectional area of a pond. It is derived from Darcy’s law as follows. First, consider Darcy’s law.

$$Q = k \times i \times A$$

For a pond with either a natural or constructed liner, the hydraulic gradient is the term i in the equation, and it is defined in figure 10D–9 as equal to (H+d)/d.

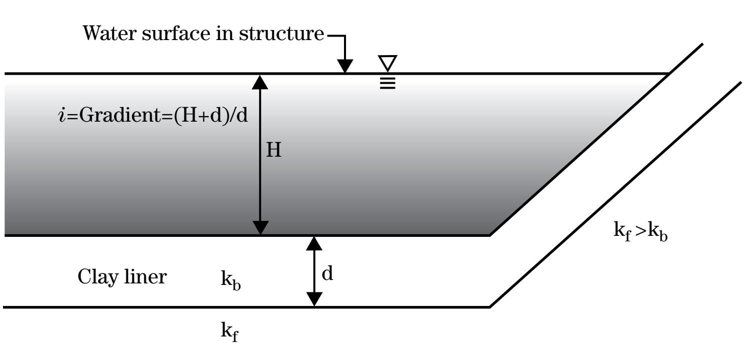
Given:
The Darcy’s law for this situation becomes:

$$Q = k \times \frac{H+d}{d} \times A$$

where:

Q	=	total seepage through area A	(L^3/T)
k	=	coefficient of permeability (hydraulic conductivity)	($L^3/L^2/T$)
i	=	hydraulic gradient	(L/L)
H	=	vertical distance measured between the top of the liner and top of the liquid storage of the waste impoundment (fig. 10D–9)	(L)
d	=	thickness of the soil liner (fig. 10D–9)	(L)
A	=	cross-sectional area perpendicular to flow	(L^2)
L	=	length	
T	=	time	

Figure 10D–9 Definition of terms for clay liner and seepage calculations



Rearrange terms:

$$\frac{Q}{A} = \frac{k(H+d)}{d} \qquad (L/T)$$

By definition, unit seepage or specific discharge, is Q÷A. The symbol ν is used for specific discharge:

$$\nu = \frac{k(H+d)}{d} \qquad (L^3/L^2/T)$$

Specific discharge may be confused with permeability because the units are the same. In the metric system, specific discharge and permeability are often expressed in units of centimeters per second. The actual units are cubic centimeters of flow per square centimeter of cross section per second, but this reduces to centimeters per second. Specific discharge is different than permeability because specific discharge is an actual flow rate of liquid through a cross section of a soil mass, whereas permeability is a property of the soil mass itself. Permeability is independent of the hydraulic gradient in a particular site, whereas specific discharge accounts for both permeability of the soil and the gradient causing the flow, as illustrated in figure 10D–9. Because hydraulic gradient is dimensionless, the units of specific discharge and permeability are then the same.

Because specific discharge expressed as L/T has the same units as velocity, specific discharge is often misunderstood as representing the average rate or velocity of water moving through a soil body rather than a quantity rate flowing through the soil. Because the water flows only through the soil pores, the actual cross-sectional area of flow is computed by multiplying the soil cross section (A) by the porosity (n). The seepage velocity is then equal to the unit seepage or specific discharge, ν, divided by the porosity of the soil, n. Seepage velocity = (ν/n). In compacted liners, the porosity usually ranges from 0.3 to 0.5. The result is that the average linear velocity of seepage flow is two to three times the specific discharge value. The units of seepage velocity are L/T.

To avoid confusion between specific discharge and permeability, one possibility is to use different units for specific discharge than for the coefficient of permeability. Common units for permeability are recommended to be in feet per day or centimeters per second. Units for specific discharge should be in gallons per acre per day, acre-feet per acre per day, or acre-inches per acre per day.

To illustrate a typical computation for specific discharge, assume the following:

- A site has a liquid depth of 12 feet.
- The site is underlain by 2 feet of soil that has a coefficient of permeability of 1×10^{-6} centimeters per second (assume that a sample was obtained at the grade of the pond and sent to a laboratory where a flexible wall permeability test was performed on it).
- Compute the specific discharge, ν. First, the coefficient of permeability may be converted to units of feet per day by multiplying the given units of centimeters per second by 2,835.

  $$k = \left(1\times10^{-6}\ \text{cm/s}\right)\times 2,835 = 0.002835\ \text{ft/d}$$

  Then, the specific discharge ν is computed as follows:

  $$\begin{aligned}\nu &= k\times\frac{H+d}{d}\\ &= 0.002835\times\frac{12+2}{2}\\ &\cong 0.02\ \text{ft}^3/\text{ft}^2/\text{d}\\ &\cong 0.02\ \text{ft/d}\end{aligned}$$

Conversion factors for specific discharge are given in table 10D–6.

Table 10D–6 Conversion factors for specific discharge

To convert from	To units of	Multiply by
$ft^3/ft^2/d$	$in^3/in^2/d$	12
$ft^3/ft^2/d$	gal/acre/d	325,829
$in^3/in^2/d$	gal/acre/d	27,152.4
$in^3/in^2/d$	$cm^3/cm^2/s$	2.94×10^{-5}
$cm^3/cm^2/s$	gal/acre/d	9.24×10^{8}
$cm^3/cm^2/s$	$in^3/in^2/d$	34,015
$cm^3/cm^2/s$	$ft^3/ft^2/d$	2,835

To convert the computed specific discharge in the example into units of gallons per acre per day and cubic inches per square inch per day (in/d), use conversion factors given in table 10D–6.

- 0.02 foot per day×325,829 ≅ 6,500 gallons per acre per day
- 0.02 foot per day×12 = 0.24 cubic inch per square inch per day

A variety of guidelines have been used and regulatory requirements stated for specific discharge. Usually, guidelines require the specific discharge for a given waste storage structure to be no higher than a stated value. The following example demonstrates the unit seepage that will result from a typical size animal waste storage lagoon or storage pond with 2 feet of either very good natural soil or a very well constructed, 2-foot-thick clay liner in the bottom of the lagoon. A practical lower limit for the assumed permeability of a compacted clay or a very good natural liner is a coefficient of permeability equal to 5×10^{-8} centimeters per second. This is based on considerable literature on field and laboratory tests for compacted clay liners used in sanitary landfills.

The specific discharge for this ideal condition follows, assuming:

- The pond has a liquid depth of 15 feet.
- The site is underlain by 2 feet of soil (either a natural layer or a constructed clay liner) that has a coefficient of permeability of 5×10^{-8} centimeters per second
- Compute the specific discharge, ν. First, the coefficient of permeability is converted to units of feet per day by multiplying the given units of centimeters per second by 2,835. Then,

$$k = \left(1\times10^{-6}\ \text{cm/s}\right)\times 2,835 = 0.002835\ \text{ft/d}$$

Then, the specific discharge ν is computed as follows:

$$\begin{aligned} \nu &= k\times\frac{H+d}{d} \\ &= 1.42\times10^{-4}\ \text{ft/d}\times\frac{15\ \text{ft}+2\ \text{ft}}{2\ \text{ft}} \\ &\cong 0.0012\ \text{ft}^3/\text{ft}^2/\text{d} \\ &\cong 0.0012\ \text{ft/d} \end{aligned}$$

Converting this into units of gallons per acre per day:

$$0.0012\ \text{ft/d}\times 325,829 \cong 393\ \text{gal/acre/d}$$

Table 10D–7 lists typical specific discharge values used by State regulatory agencies. Requirements vary from State to State. Individual designers may regard minimum requirements as too permissive. Some States permit a designer to assume that the initial computed seepage rate will be reduced in the future by an order of magnitude by taking credit for a reduction in permeability resulting from manure sealing. Although the State or local regulations should be used in design for a specific site, the NRCS no longer recommends assuming that manure sealing will result in one order of magnitude reduction. A more conservative assumption described previously allows an initial seepage rate of 5,000 gallons per acre per day, which for the assumed typical site dimensions of 9 feet of liquid and 1 foot thickness of liner, assumes a one half order of magnitude reduction.

Table 10D–7 Typical requirement for specific discharge used by State regulatory agencies

Example specific discharge value	Equivalent value in gallons per acre per day
1/56 $in^3/in^2/d$	485
1/8 $in^3/in^2/d$	3,394
1/4 $in^3/in^2/d$	6,788
$1\times10^{-6}\ cm^3/cm^2/s$	924

Design of compacted clay liners

If a site does not have a sufficient thickness of *in situ* low permeability soil horizons to limit seepage to an acceptably low value, a clay liner may be required. Some State regulations may also require a constructed clay liner regardless of the nature of the *in situ* soils at a site. Regulations sometimes require a specific thickness of a compacted soil with a documented permeability of a given value. An example of this is a State requirement that a waste storage pond must have in the bottom and sides of the pond at least 2 feet of compacted clay with a documented coefficient of permeability of 1×10^{-7} centimeters per second.

Clay liners may also be designed based on a stated allowable specific discharge value. Computations may be performed as detailed in following sections to determine a design that will meet a design specific discharge goal.

Detailed design steps for clay liners

The suggested steps for design of a compacted clay or amendment-treated liner are:

Step 1—Size the impoundment to achieve the desired storage requirements within the available construction limits and determine this depth or the height, H, of storage needed.

Step 2—Determine (from a geologic investigation) the thickness and permeability of horizons of natural clay underlying the bottom of the planned excavated pond. Investigate to a minimum of 2 feet below the planned grade of the pond or to depths required by State regulations, if greater. If natural low permeability horizons at least 2 feet thick or an equivalent thickness of soil with different permeability do not underlie the site, assume that a compacted clay liner (with or without amendments) will be constructed. The liner may be constructed of soils from the excavation if they are suitable for use, or soil may be imported from a nearby borrow source.

Step 3—Measure or estimate the permeability of the natural horizons or the compacted liner planned at the site. Use procedures shown in example 10D–1 to obtain a weighted permeability for the natural horizons.

Step 4—Compute the specific discharge using the values of head in the pond and thickness of natural horizons and their equivalent permeability in the specific discharge equation. If State or local regulations provide a required value for allowable specific discharge, design on the basis of those regulations. Currently, State regulations for specific discharge range from a low of about 500 gallons per acre per day (1/56 inch per day) to a high of about 6,800 gallons per acre per day (1/4 inch per day). If no regulations exist, a value of 5,000 gallons per acre per day may be used. If a designer feels that more conservative limiting seepage is advisable, that rate should be used in computations. It is seldom technically or economically feasible to meet a design specific discharge value of less than 500 gallons per acre per day using compacted clay liners or amendment-treated soil liners. To achieve lower values of unit seepage usually requires synthetic liners, concrete liners, or aboveground storage tanks.

Step 5—If the computed specific discharge meets design objectives, the site is satisfactory without additional design and may be designed and constructed.

Step 6—If the computed specific discharge at the site does not meet design objectives, use either method A or method B shown in following sections to design a compacted clay liner or a liner with soil amendment.

Notes to design steps:

- The calculated thickness of the soil liner required is sensitive to the relative values of soil permeability and the assumed allowable specific discharge value.
- The best and most economical way to reduce the required liner thickness is by reducing the soil's permeability. Liner permeability may be reduced by compacting soils to a higher degree, compacting them at a higher water content, and by using an appropriate additive such as bentonite or soil dispersants.
- By using higher compaction water contents and compacting soils to a high degree of saturation, permeability often can be reduced by a factor of 1/100.
- The liner soil must be filter compatible with the natural foundation upon which it is compacted. Filter compatibility is determined by criteria in NEH 633, chapter 26. As long as the liner soil will not pipe into the foundation, the magnitude of hydraulic gradient across the liner need not be limited.
- Filter compatibility is most likely to be a significant problem when a liner is constructed directly on top of very coarse soil, such as poorly graded gravels and gravelly sands.
- The minimum recommended thickness of a compacted clay liner is given in CPS 521D. The

minimum thickness varies with the depth of liquid in the pond.

- Clay liners constructed by mixing bentonite with the natural soils at a site should have a minimum thickness shown in CPS 521C. These minimum thicknesses are based on construction considerations rather than calculated values for liner thickness requirement from the specific discharge equations. In other words, if the specific discharge equations indicate a 7-inch thickness of compacted bentonite-treated liner is needed to meet suggested seepage criteria, the CPS 521C could dictate a thicker liner. That guidance should be considered in addition to the specific discharge computations.
- Natural and constructed liners must be protected against damage by mechanical agitators or other equipment used for cleaning accumulated solids from the bottom of the structure. Liners should also be protected from the erosive forces of waste liquid flowing from pipes during filling operations. CPSs provide guidance for protection.
- Soil liners may not provide adequate confidence against ground water contamination if foundation bedrock beneath the pond contains large, connected openings. Collapse of overlying soils into the openings could occur. Structural liners of reinforced concrete or geomembranes should be considered because the potential hazard of direct contamination of ground water is significant.
- Liners should be protected against puncture from animal traffic and roots from trees and large shrubs. The subgrade must be cleared of stumps and large angular rocks before construction of the liner.
- If a clay liner (or a bentonite-treated liner) is allowed to dry, it may develop drying cracks or a blocky structure. Desiccation can occur during the initial filling of the waste impoundment and later when the impoundment is emptied for cleaning or routine pumping. Disking, adding water, and compaction are required to destroy this structure created by desiccation. A protective insulating blanket of less plastic soil may be effective in protecting underlying more plastic soil from desiccation during these times the liner is exposed. CPSs address this important consideration.
- Federal and State regulations may be more stringent than the design guidelines given, and they must be considered in the design. Examples later in this section address consideration of alternative guidelines.

Two methods for designing constructed clay liner

Two methods for designing a clay liner are available. In method A, designers begin with an assumed or required value for allowable specific discharge. Using the depth of liquid storage in the pond and known or estimated values of the liner's coefficient of permeability, a required thickness of liner is computed. If the value obtained is unrealistic, different values for the liner permeability are evaluated to determine what values produce a desirable thickness of liner. CPSs also determine minimum liner thicknesses.

In method B, designers begin with a desired thickness of liner and an assumed or required value for specific discharge. Using the depth of liquid storage in the pond and the desired thickness of liner, a required coefficient of permeability for the liner is computed. If the value obtained is unrealistic, different values for the liner thickness are evaluated to determine what values produce an achievable permeability. Coordinating with soil testing laboratories is helpful in evaluating alternatives that can provide the required permeability for the liner.

Each of these methods is illustrated with detailed design examples as follows:

Method A—Using assumed values for the coefficient of permeability of a compacted clay based on laboratory tests of the proposed liner soil, compute the required thickness of a liner to meet the given specific discharge design goal. In the absence of more restrictive State regulations, assume an acceptable specific discharge of 5,000 gallons per acre per day.

The required thickness of a compacted liner can be determined by algebraically rearranging the specific discharge equation, as follows. Terms have been previously defined.

$$d = \frac{k \times H}{\nu - k}$$

Note: If the k value assumed for the liner is equal to or greater than the assumed allowable specific discharge, meaningless results are attained for d, the calculated thickness of the liner in the last equation. The reason is that the denominator would be zero, or a negative number. Another way of stating this is that the allowable specific discharge goal cannot be met if the liner soils have k values equal to or larger than the assumed allowable specific discharge, in consistent units. Note also that CPS 521D has requirements for minimum thickness of compacted clay liners. If the computed value for the required thickness is less than that given in CPS 521D, then the values in the CPS must be used.

Example 10D–2—Design a clay liner using method A

Given:
Site design has a required depth of waste liquid, H, in the constructed waste impoundment of 12 feet. A soil sample was obtained and submitted to a soil mechanics laboratory for testing. A permeability test on a sample of proposed clay liner soil resulted in a permeability value of 6.5×10^{-7} centimeters per second (0.00184 ft/d) for soils compacted to 95 percent of maximum Standard Proctor dry density at a water content 2 percent wet of optimum. The State requirement for the site requires a specific discharge no greater than an eighth of an inch per day. Compute the required thickness of liner to be constructed of soil having the stated permeability that will achieve this specific discharge.

Solution:
First, convert the required specific discharge into the same units as will be used for the coefficient of permeability. Using values for permeability of feet per day, convert the stated eighth of an inch per day specific discharge requirement into feet per day. To convert, divide an eighth by 12 to obtain a specific discharge requirement of 0.010417 foot per day. It is given that the k value at the design density and water content is 0.00184 foot per day. Calculate the required minimum thickness of compacted liner as follows:

The equation for required d is:

$$d = \frac{k \times H}{\nu - k}$$

Using English system units, substituting the given values for H and k, assuming an allowable specific discharge, ν, of 0.010417 foot per day, then

$$d = \frac{0.00184 \text{ ft/d} \times 12 \text{ ft}}{0.010417 \text{ ft/d} - .00184 \text{ ft/d}} = 2.6 \text{ ft}$$

CPS 521D requires a pond with a depth of water of 12 feet to have a minimum thickness liner of 1 foot, so the 2.6 foot requirement governs.

Method B—Using a given value for depth of liquid in the pond, assumed values for the thickness of a compacted clay based on construction considerations, CPS 521D requirements, State regulations, or the preference of the designer, compute the required permeability of a liner to meet the given specific discharge design goal. In the absence of more restrictive State regulations, assume an acceptable specific discharge of 5,000 gallons per acre per day. The required permeability of a compacted liner can be determined by algebraically rearranging the specific discharge equation as follows. Terms have been previously defined.

$$k = \frac{\nu \times d}{H + d}$$

If the computed value for the required permeability is less than 5×10^{-8} centimeters per second (1.4×10^{-4} ft/d), NRCS engineers' experience is that lower values are not practically obtainable and a thicker liner or synthetic liners should be used to achieve design goals.

Example 10D–3—Design a clay liner using method B

Given:
Site design has a required depth of waste liquid, H, in the constructed waste impoundment of 19 feet. CPS 521D requires a liner that is at least 18 inches (1.5 feet) thick. The site is in a State that allows NRCS design guidance of 5,000 gallons per acre per day to be used in the design. The NRCS guidance assumes that manure sealing will reduce this seepage value further and no additional credit should be taken.

Solution:
Step 1 First, convert the required specific discharge into the same units as will be used for the coefficient of permeability. Using values for permeability of feet per day, convert the stated 5,000

gallons per acre per day specific discharge requirement into feet per day. To convert using conversions shown in table 10D–6, divide 5,000 by 325,829 to obtain a specific discharge requirement of 0.0154 foot per day. The thickness of liner is given to be 1.5 feet. Calculate the required coefficient of permeability of the compacted liner as follows:

$$k = \frac{\nu \times d}{H + d}$$

Using English system units, substituting the given values for H of 19 feet and for d of 1.5 feet, assuming an allowable specific discharge, ν, of 0.0154 foot per day, then:

$$k = \frac{.0154 \text{ ft/d} \times 1.5 \text{ ft}}{19 \text{ ft} + 1.5 \text{ ft}}$$
$$= 1.1 \times 10^{-3} \text{ ft/d}$$

Convert to centimeters per second by dividing by 2,835.

$$k = \frac{1.1 \times 10^{-3} \text{ ft/d}}{2,835}$$
$$k = 4.0 \times 10^{-7} \text{ cm/s}$$

Step 2—The designer should coordinate testing with a laboratory to determine what combinations of degree of compaction and placement water content will result in this value of permeability or less. Design of the 1.5-foot-thick liner may proceed with those recommendations.

Construction considerations for compacted clay liners

Thickness of loose lifts

The permissible loose lift thickness of clay liners depends on the type of compaction roller used. If a tamping or sheepsfoot roller is used, the roller teeth should fully penetrate through the loose lift being compacted into the previously compacted lift to achieve bonding of the lifts. A loose lift thickness of 9 inches is commonly used by NRCS specifications. If the feet on rollers cannot penetrate the entire lift during compaction, longer feet or a thinner lift should be specified. A loose layer thickness of 6 inches may be needed for some tamping rollers that have larger pad type feet that do not penetrate as well.

Method of construction

Several methods are available for constructing a clay liner in an animal waste impoundment. Each has its advantages and disadvantages as described in following sections. A designer should consider the experience of local contractors and the relative costs of the methods in selecting the most appropriate design for a given site. The thickness of the planned soil liner, haul distance, planned side slopes for the pond, and other factors also guide a designer's decision on the best method to use.

Bathtub construction

This method of construction consists of a continuous thickness of soil compacted up and down or across the slopes. Figure 10D–10 shows the orientation of the lifts of a compacted liner constructed using this method, as contrasted to the stair step method, which is covered next. Figure 10D–11 shows two sites where the bathtub method of construction is being used.

This construction method has the following advantages over the stair-step method:

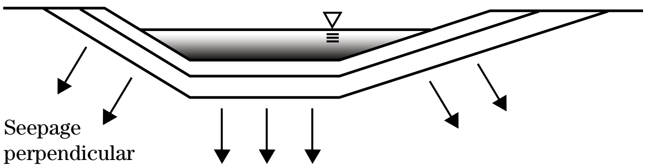
- The layers of compacted clay are oriented perpendicular to flow through the liner in this method. If the lifts making up the liner are not bonded well, the effect on seepage is minor, compared to the stair-step method.
- This method lends itself to constructing thinner lifts, which is more economical.

The bathtub construction method has the following disadvantages compared to the stair-step method:

- Side slopes must be considerably flatter than for the stair-step method, creating a pond with a larger surface area. A pond with a larger surface area has to store more precipitation falling on it, which could be considered an extra cost of the method.
- To permit equipment traversing up and down the slopes, slopes must be an absolute minimum of 3H:1V. Shearing of the soil by the equipment on steeper slopes is a concern. To prevent shearing of the compacted soil, the slopes of

Figure 10D–10 Methods of liner construction (after Boutwell 1990)

Bathtub construction



Stair-step construction

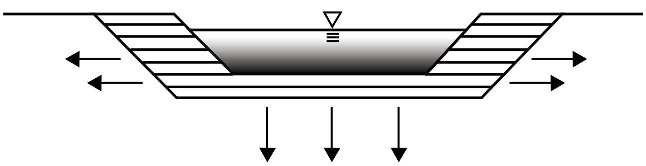


Figure 10D–11 Bathtub construction of clay liner *(photo courtesy of NRCS Virginia (top) and NRCS Nebraska (bottom))*

many compacted liners in ponds constructed using this method use 4H:1V slopes so that equipment will exert more normal pressure on the slope than downslope pressure.

Stair-step construction

The stair-step method of construction is illustrated in figure 10D–10. Construction of the liner consists of compacting lifts of soil around the perimeter of the liner in a stair-step fashion, finishing the job by shaving off some of the side liner and placing it in the bottom of the pond. This method of construction is required if the side slopes of the pond are any steeper than about 3H:1V. Advantages of this method of construction are:

- A thicker blanket, measured normal to the slope, will result compared to the bathtub method of construction (fig. 10D–10). This is a positive factor in seepage reduction.
- It allows steeper side slopes, and thus the surface area of the pond exposed to rainwater accumulation is smaller than a bathtub construction would permit.
- The thicker blanket reduces the impact of shrinkage cracks, erosive forces, and potential mechanical damage to the liner.
- Ponds constructed with this method are deeper for a given volume of waste than ponds constructed with the bathtub method, which favors anaerobic processes in the pond.

Disadvantages of the method are:

- This method may be more expensive than the bathtub method because the liner on the sides of the pond are thicker.
- Flow is parallel to the orientation of the layers forming the compacted liner on the pond sides. If care is not taken to obtain good bonding between lifts, seepage through the interface between lifts could be higher than expected.
- Contractors may be less familiar with this method of operation of equipment.

In the stair-step method of construction, the pond is first excavated. Borrow soil is then imported with a truck or scraper and spread in thin lifts (8 to 9 in thick) prior to compaction. Figure 10D–12a shows the first layer being constructed on the sides of the pond. This pond used a bentonite application. Each lift of soil is compacted with a sheepsfoot roller to obtain the desired dry density at the specified water content (fig. 10D–12b). The interior liner is constructed by bringing up lifts the full depth of the pond. Photo 10D–12c provides an overview of the stair-step process of constructing a clay liner in an animal waste storage pond. After the sides are constructed, some of the liner is shaved off and used to construct a liner in the bottom of the pond (fig. 10D–12c).

Soil type

Soils in groups III and IV are the most desirable for constructing a clay liner (table 10D–3). Some soils in group II may also be good materials for a clay liner, but definitely require laboratory testing to document their permeability characteristics. Soils in group I always require bentonite to form a liner with acceptably low permeability. Some soils in group II may also require bentonite to be an acceptable material for a liner. Some soils in groups III and IV require a soil dispersant to create an acceptably low permeability.

Classification

The most ideal soils for compacted liners are those in group III. The soils have adequate plasticity to provide a low permeability, but the permeability is not excessively high to cause poor workability. Group IV soils can be useful for a clay liner, but their higher plasticity index (PI greater than 30) means they are more susceptible to desiccation. If clay liners are exposed to hot dry periods before the pond can be filled, desiccation and cracking of the liner can result in an increase in permeability of the liner. A protective layer of lower PI soils is often specified for protection of higher PI clay liners to prevent this problem from developing.

Highly plastic clays like those in group IV are also difficult to compact properly. Special effort should be directed to processing the fill and degrading any clods in high plasticity clays to prevent this problem.

Size of clods

The size and dry strength of clay clods in soil prior to compaction have a significant effect on the final quality of a clay liner. Soil containing hard clayey clods is difficult to break down and moisten thoroughly. Adding water to the soil is difficult because water penetrates the clods slowly. High speed rotary pulverizers are sometimes needed if conditions are especially unfavorable. If soils containing large clay clods are

Figure 10D–12 Stair-step method *(Photo credit John Zaginaylo, PA, NRCS)*

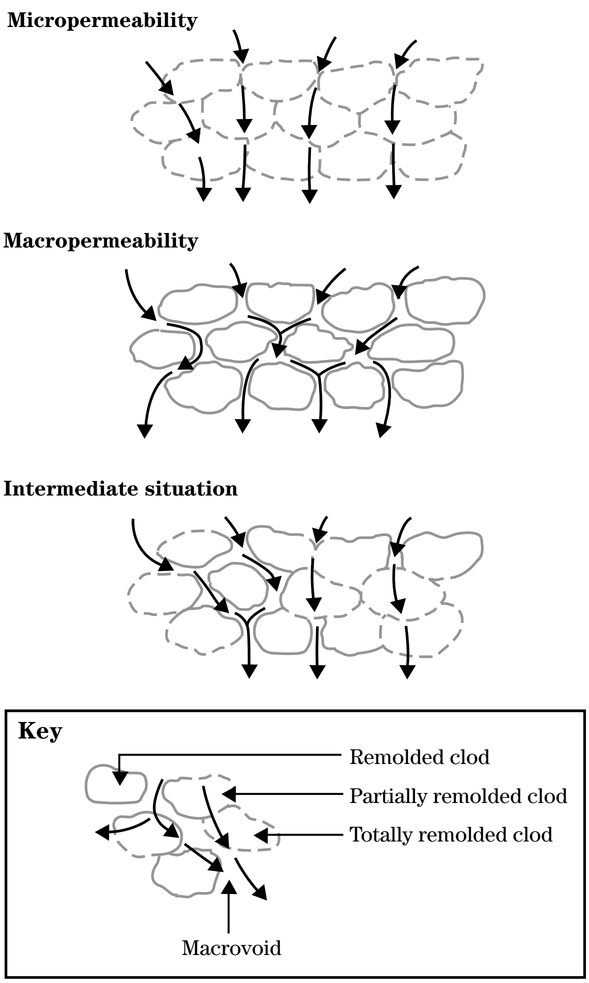
(a)

(b)

(c)

not treated properly, the resultant permeability will be much higher than might otherwise be true. Figure 10D–13 shows the structure that results from compacting soils containing clods that are not adequately broken down.

Figure 10D–13 Macrostructure in highly plastic clays with poor construction techniques (from Hermann and Elsbury 1987)



Natural water content of borrow

The water content of soils used to construct a clay liner is the most important factor in obtaining a low permeability liner for a given soil. If soils are too dry, they cannot effectively be compacted to a condition where their structure is acceptable and their permeability may be higher than desirable. Compacting a soil at the proper water content creates a structure that is most favorable to a low permeability. Adding water to compacted clay liners is an additional expense that must be considered. A good rule of thumb is that it requires about 3.2 gallons of water to increase the water content of a cubic yard of compacted soil by 1 percent.

Dry conditions in the borrow

If soils in the borrow area are dry, several problems may need to be addressed. If the soils are clays with relatively high plasticity (PI values greater than about 20), they are likely to be very cloddy when excavated. Water is slow to penetrate the clods and compaction is less likely to degrade clods if enough time has not elapsed between adding the water and compaction. More descriptions follow in subsequent sections, and figure 10D–13 illustrates how clods left in the compacted fill will likely cause the soil to have a higher than expected permeability.

If the water content of borrow soils is more than 3 or 4 percent drier than required for specified compaction conditions, consideration should be given to wetting the soils in the borrow prior to construction. Adding large amounts of water during processing on the fill is difficult and inefficient. Sprinklers can be set up in the borrow some time before construction is planned and then time will allow water to soak into the soils more thoroughly.

Wet conditions in the borrow

If the natural water content of the borrow soil is significantly higher than optimum water content, achieving the required degree of compaction may be difficult. A good rule of thumb is that a soil will be difficult to compact if its natural water content exceeds about 90 percent of the theoretical saturated water content at the dry density to be attained. The following procedure can help to determine if the soils in the borrow are too wet for effectively compacting them.

Step 1 Measure the natural water content of the soil to be used as a borrow source for the clay liner being compacted.

Step 2 Compute the highest dry density to which the soil can be compacted at this water content using the following equation, which assumes that the highest degree of saturation achievable is 90 percent:

$$\text{Achievable } \gamma_{dry} \text{ lb/ft}^3 = \frac{62.4}{\frac{w_n\,\%}{90} + \frac{1}{G_s}}$$

where:

$w_n(\%)$ = natural water content of borrow soils, %

G_s = specific gravity of the soil solids (dimensionless)

Specific gravity values are obtained by ASTM Standard Test Method D854. An average value for specific gravity is often assumed to be 2.68. However, soils with unusual mineralogy may have values significantly different. Soils with volcanic ash may have specific gravity values as low as 2.3, and soils with hematite in them may have values as high as 3.3, based on NRCS laboratory results.

Step 3 Perform a Standard Proctor (ASTM D698) compaction test on the same soil and determine the maximum dry density value. Compute the achievable degree of compaction by dividing the computed value of achievable dry density by the maximum Standard Proctor dry density.

Step 4 If the computed achievable degree of compaction is less than 95 percent, then drying of the sample will probably be required. In rare cases, compaction to a lower degree, such as 90 percent of Standard Proctor, at higher water contents will achieve an acceptably low permeability. Laboratory tests should be performed to evaluate whether a lower degree of compaction will result in an acceptable permeability value.

Note: The experience of NRCS engineers is that when the natural water content of a soil is more than 4 percent above optimum water content, it is not possible to achieve 95 percent compaction. Computations should always be performed, as this rule of thumb sometimes has exceptions. In most cases, drying clay soils by only disking is somewhat ineffective, and it is difficult to reduce their water content by more than 2 or 3 percent with normal effort. It may be more practical to delay construction to a drier part of the year when the borrow source is at a lower water content. In some cases, the borrow area can be drained several months before construction. This would allow gravity drainage to decrease the water content to an acceptable level.

Step 5 Another way of examining this problem is to assume that soils must be compacted to 95 percent of their Standard Proctor (ASTM D698) dry density and then compute the highest water content at which this density is achievable. Commonly, soils are difficult to compact to a point where they are more than 90 percent saturated. The following equation is used to determine the highest feasible placement water content at which the dry density goal is achievable:

$$\text{Highest placement } w(\%) = \frac{90(\%)}{100} \times \left[\frac{62.4}{\gamma_{dry} \text{ lb/ft}^3} - \frac{1}{G_s} \right]$$

Example 10D–4—Compute the achievable dry density of a potential borrow source

Given:

A borrow source is located and found to be in a desirable group III type soil. The soil has 65 percent finer than the No. 200 sieve and a PI of 18. The soil was sampled and placed in a water tight container and shipped to a soils laboratory. The natural water content of the soil was measured to be 21.8 percent. The lab also performed a specific gravity (G_s) test on the soil, and measured a value of 2.72. A Standard Proctor Test was performed on the sample and values for maximum dry density of 108.5 pounds per cubic foot and an optimum water content of 17.0 percent were measured.

Solution:

The maximum degree of compaction of this soil at the measured water content. If the soil is too wet to be compacted to 95 percent of maximum standard Proctor dry density, how much will it have to be dried to achieve compaction to 95 percent of maximum density?

$$\text{Achievable } \gamma_{dry} \text{ lb/ft}^3 = \frac{62.4}{\frac{w_n\%}{90} + \frac{1}{G_s}}$$

$$\text{Achievable } \gamma_{dry} \text{ lb/ft}^3 = \frac{62.4}{\frac{21.8\%}{90} + \frac{1}{2.72}} = 102.3 \text{ lb/ft}^3$$

Next, compute the achievable degree of compaction by dividing the achievable dry density by the maximum Standard Proctor dry density, expressed as a percentage. The achievable degree of compaction is then equal to 102.3 divided by 108.5×100=94.3 percent.

Now, determine how wet the sample could be and still achieve 95 percent compaction. Ninety-five percent of the maximum Standard Proctor dry density is 0.95×108.5=103.1 pounds per cubic foot. Substitute this value into the equation given:

$$\text{Highest placement w\%} = \frac{90}{100} \times \left[\frac{62.4}{\gamma_{dry} \text{ lb/ft}^3} - \frac{1}{G_S}\right]$$

$$\text{Highest placement w\%} = \frac{90}{100} \times \left[\frac{62.4}{103.1 \text{ lb/ft}^3} - \frac{1}{2.72}\right] = 21.4\%$$

This computation confirms the rule of thumb given that it is difficult to achieve 95 percent degree of compaction if the natural water content is greater than 4 percent above optimum. The stated value for optimum water content is 17.0 percent, so the rule of thumb says that if the natural water content exceeds 21.0 percent, achieving 95 percent degree of compaction will be difficult.

Methods of excavating and processing clay for liners

Clods in borrow soil

If borrow soils are plastic clays at a low water content, the soil will probably have large, durable clods. Disking may be effective for some soils at the proper water content, but pulverizer machines may also be required. To attain the highest quality liner, the transported fill should be processed by adding water and then turned with either a disk or a high-speed rotary mixer before using a tamping roller. Equipment requirements depend on the strength and size of clods and the water content of the soil.

Placement of lifts

Individual lifts of soil usually consist of an equipment width (often about 8 to 10 feet wide) layer of soil about 6 inches thick, after compaction. These lifts should be staggered to prevent preferential flow along the inter-lift boundaries. Figure 10D–14(a) shows the preferred way of offsetting the lifts. Figure 10D–14(b) shows a method that should be avoided. Bonding between the 6-inch lifts is also important so that if water does find its way down the boundary between two lanes of compacted soil that it cannot flow laterally and find the offset boundary.

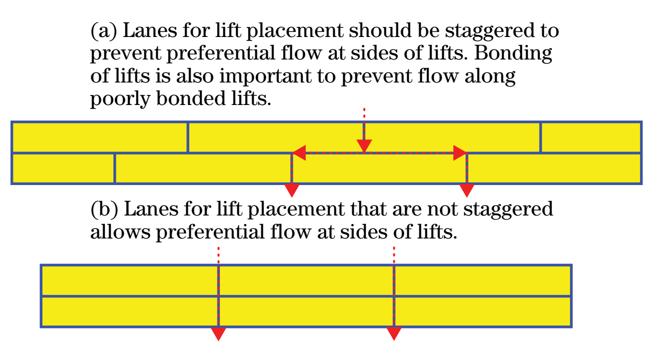
Macrostructure in plastic clay soils

Clods can create a macrostructure in a soil that results in higher than expected permeability because of preferential flow along the interfaces between clods. Figure 10D–13 illustrates the structure that can result from inadequate wetting and processing of plastic clay. The permeability of intact clay particles may be quite low, but the overall permeability of the mass is high because of flow between the intact particles.

Dry density and optimum water content

Compaction specifications for most earthfill projects normally require a minimum dry density (usually referenced to a specified compaction test procedure) and an accompanying range of acceptable water contents (referenced to the same compaction test procedure). This method of fill specification is usually based on en-

Figure 10D–14 Construction methods to limit interlift preferential flow paths



gineering property tests such as shear strength, bearing capacity, and permeability. When permeability is the primary engineering property of interest, as would be the case for a compacted clay liner, an alternative type of compaction specification should be considered. The reason for this is a given permeability value can be attained for many combinations of compacted density and water contents (Daniels and Benson 1990). Figure 10D–15 illustrates a window of compacted dry density and water content in which a given permeability could be obtained for an example soil. The principles involved can be illustrated as follows.

Assume that a given soil is being used to construct a clay liner for an animal waste impoundment. A moderately plastic silty clay classifying as CL in the USCS is used. In case 1, the soil being obtained from a nearby borrow area has a relatively high natural water content. The contractor elects to use lighter construction equipment that applies a relatively low energy in compacting the soil. The result is the soil is compacted to a condition where the compacted density is relatively low and the placement water content is relatively high. This is labeled as point 1 in the figure 10D–15. In case 2, the same soil is being used, but the site is being constructed in a drier time of year. The contractor elects to use a larger sheepsfoot roller and apply more passes of the equipment to achieve the desired product. This time the same soil is compacted to a significantly higher density at a significantly lower water content. This is labeled point 2 in the figure 10D–15.

Laboratory tests can be used to establish the boundary conditions and arrive at a window of acceptable densities and water contents for a clay liner. Figure 10D–16 shows how a different structure results between soils compacted wet of optimum and those compacted dry of optimum water content. It also illustrates that soils compacted with a higher compactive effort or energy have a different structure than those compacted with low energy.

Mitchell (1965) was instrumental in explaining how the permeability of clay soils is affected by the conditions under which they were compacted. Figure 10D–17 illustrates results of one series of experiments summarized in the study. Two samples of a soil were compacted using different energy at different water contents and their permeability was measured. Soil C was compacted using higher energy, like that used when a heavy sheepsfoot roller passed over each compacted lift multiple times. Soil B was compacted using a lower energy, equating to a smaller roller with a smaller number of passes used in the compaction process.

Figure 10D–15 Range at acceptable moisture/density for a typical clay liner

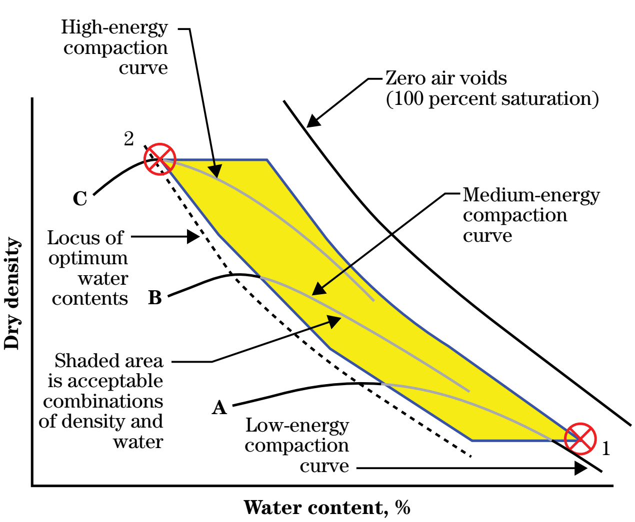
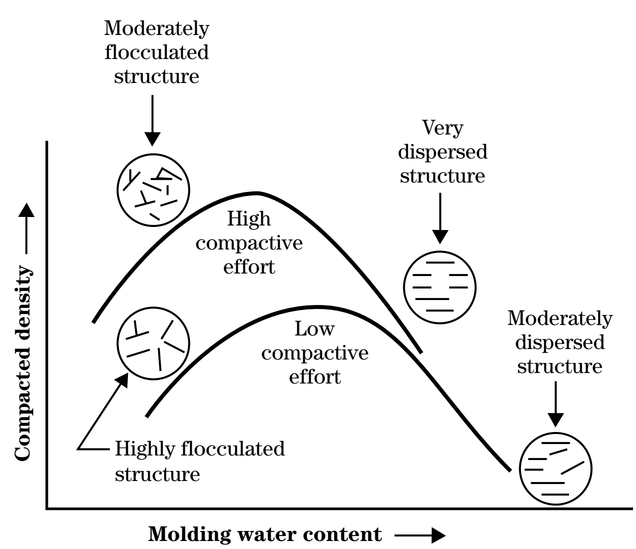


Figure 10D–16 Effect of water content and compactive effort on remolding of soil structure in clays (from Lambe 1958)

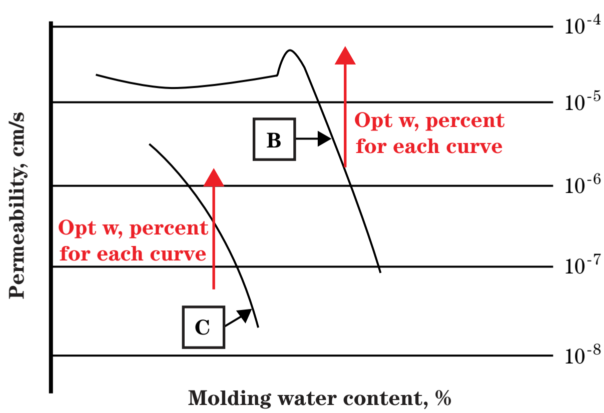


The curves show the relationship between the permeability of the compacted soil and the compaction water content, for the two energies used. The following general principles are seen:

- The permeability of the low energy soil (curve B) is high unless the compaction water content is significantly wet of optimum. Very high permeability results for compaction dry of optimum.
- The permeability of the higher energy soil (curve C) is relatively high for water contents less than optimum.

Lambe (1958) explains how the energy used and the water content of the soil at the time of compaction affect the permeability of the soil by creating structure in the soil. Figure 10D–16 summarizes his explanation of how different soil structures results from these two factors. Soils compacted with higher energy (heavier equipment and numerous passes of the equipment) at a higher water content have a dispersed structure. This structure creates very small plate-shaped voids that are resistant to water flow. Soils that are compacted with lower energy and/or lower water contents have a flocculated structure. This structure involves larger voids that are more conducive to water flow.

Figure 10D–17 Plot showing effect of molding water content on permeability (Mitchell 1965)



Percent saturation importance

Benson and Boutwell (2000) studied the correlation between field measured permeability values on compacted liners with laboratory measured values. The study found that when soils were compacted at drier water contents, even if a high density were obtained, that correlation between field and lab permeability test values was poor. The study found good correlation when soils were compacted at relatively higher water contents. Clods in clay soils are probably not broken down as well at lower compaction water contents which explains the higher permeability in the field. In lab tests, breaking down clods and obtaining test specimens without a structure is easier than done with field compaction procedures.

The conclusions of Benson and Boutwell's research were that if a designer is going to rely on laboratory permeability tests to predict the permeability of a compacted clay liner, the following rules of thumb apply.

- Soils should generally be compacted wet of the line of optimums. The line of optimums is illustrated in figure 10D–15. It is the locus of optimum water content values for a given soil for a range of compactive energy. A soil compacted with a low energy (like that resulting from a small sheepsfoot roller), curve A in figure 10D–15, will have a relatively low maximum density and high optimum water content. A soil compacted with a high energy (like that resulting from using a large heavy tamping roller), curve C in figure 10D–15, will have a high value for maximum density and a low value of optimum water content. The line of optimums is the locus of points connecting the values of optimum water content. Remember that optimum water content depends on the energy used and that Standard Proctor (ASTM D698) is only one standard type of compaction test. ASTM D1557, the modified energy test is also used for design of some clay liners.
- Eighty percent of field tests of dry density and water content should plot to the right of the line of optimums if the field permeability is expected to reflect the same values obtained in laboratory testing.
- The average water content of all quality control tests should be from 2 to 4 percent wetter than the line of optimums as defined.

Energy level of compaction

The relationship of maximum dry density and optimum water content varies with the compactive energy used to compact a soil. Higher compactive energy results in higher values of maximum dry unit weight and lower values of optimum water content. Lower compactive energy results in lower values of maximum dry unit weight and higher values of optimum water content. Because optimum water content varies with the energy used in compaction, its nomenclature can be misleading. The optimum water content of a soil varies with the particular energy used in the test to measure it.

Compactive energy is a function of the weight of the roller used, thickness of the lift, and number of passes of the roller over each lift. Rollers should be heavy enough to cause the projections (teeth or pads) on the roller to penetrate or almost penetrate the compacted lift. Enough passes must be used to attain coverage and break up any clods. Additional passes do not compensate for rollers that are too light.

Roller size is often specified in terms of contact pressure exerted by the feet on sheepsfoot or tamping rollers. Light rollers have contact pressures less than 200 pounds per square inch, while heavy rollers have contact pressures greater than 400 pounds per square inch.

Limited data are available for various sizes of equipment to correlate the number of passes required to attain different degrees of compaction. Typically, from 4 to 8 passes of a tamping roller with feet contact pressures of 200 to 400 pounds per square inch are required to attain degrees of compaction of from 90 to 100 percent of maximum Standard Proctor dry density. However, this may vary widely with the soil type and weight of roller used. Specific site testing should be used when possible.

Equipment considerations

Size and shape of teeth on roller

Older style sheepsfoot-type projections on rollers are best suited for compacting clay soils to achieve the lowest possible permeability. They are better suited than the modern style rollers called tamping rollers that have more square, larger area projections. The longer teeth on the older style sheepsfoot rollers are better at remolding plastic clay soils that are wet of optimum water content, and they are better at degrading clods in the soils (fig. 10D–18). The modern tamping-type rollers are effective in compacting soils at a drier water content when high bearing capacity is needed, like soils being compacted for highway subgrades (fig. 10D–19). The older style of sheepsfoot roller compactors are better suited for compaction to achieve low permeability.

Total weight of roller

To attain penetration of the specified loose lift, the roller weight must be appropriate to the specified thickness and the shape of the roller projections. Many modern rollers are too heavy to compact soils that are more than 1 or 2 percent wet of optimum water content. When the specified compaction water content is 2 percent or more wet of optimum water content, lighter rollers are essential. Permeability of clays is minimized by compaction at water contents wet of optimum.

Speed of operation

Heavy rollers operated at excessive speed can shear the soil lifts being compacted, which may result in higher permeability. Close inspection of construction operations should indicate if this problem is occurring, and adjustments to equipment or the mode of operation should then be made.

Vibratory versus nonvibratory sheepsfoot and tamping rollers

Some sheepsfoot and tamping rollers have an added feature, a vibratory action. This feature can usually be activated or deactivated while soils are being compacted. Vibratory energy adds little to the effectiveness of these rollers when the soils being compacted are clays. At the same time, the vibration of the equipment is not usually detrimental. One condition in which the vibratory energy of this type of equipment might be detrimental is when a clay liner is being constructed on a subgrade of low plasticity silts or sands that are saturated. The vibration of the equipment often causes these types of foundation soils to become dilatant as they densify, and the water expelled in this process can create a trafficability problem. For this reason, when subgrade soils are saturated low plasticity silts and sands, the vibratory action of the compaction equipment should be disabled.

Vibratory smooth-wheeled rollers

Vibratory smooth-wheeled rollers are well suited to compacting bentonite-treated liners. They should not be used for compacting clay liners, however. The smooth surface of the roller results in poor bonding between lifts and can cause problems like those shown in figure 10D–14. The load distribution of the rollers also causes the top of a lift to be compacted well but the bottom of the lift not as well, when fine-grained soils are being compacted. A vibratory smooth wheeled roller is shown in figure 10D–20.

Figure 10D–18 Longer style of teeth preferable for compacting soils for clay liner

Figure 10D–19 Modern type of tamping roller less well suited for compacting soils for clay liner

Freeze-thaw and desiccation

Freeze-thaw

Compacted clay liners may become damaged when the liner is exposed during freezing weather. Articles by Kim and Daniel (1992) and Benson and Othman (1993) describe the effects of freezing on clay liners and how the damage resulting from freezing may be permanent. Laboratory tests show that permeability rates may increase by 2 to 3 orders of magnitude (100–1,000 times). Freeze-thaw damage is more likely to affect the side slopes of a clay-lined pond than it will the bottom of the pond after it is filled. If freeze-thaw damage is regarded as likely to increase the permeability of the

Figure 10D–20 Smooth-wheeled steel roller compactor

soils on the side slopes of the pond, a thicker liner or protective cap of cover soil should be considered. The extra cost of freeze-thaw protection may cause a designer to consider a synthetic liner alternative for reasons of economy and confidence in the low permeability of the synthetic liner. For instance, Minnesota designs often include the use of GCL liners for this reason.

Desiccation

Compacted clay liners may also be damaged when the liner is exposed during hot, dry weather after construction and before the pond is filled. Desiccation may also occur during periods the pond is emptied. Articles by Daniel and Wu (1993) and Kleppe and Olson (1985) describe factors that affect desiccation. Using the sandiest soil available that will be adequately impermeable is helpful. Compacting the soil as dense and dry as practical while still achieving the design permeability goal is also helpful. Protective layers must be at least 12 inches thick to be effective, and even thicker layers may be needed for more plastic clay liners, those with PI values of 30 or higher.

Design and construction of bentonite amended liners

When soils at grade of an excavated pond are low plasticity sands and silts in groups I or II of table 10D–3, an unlined pond will result in unacceptably high seepage losses. Several design options are normally considered for this situation. The options are listed as follows in order of increasing cost:

- Clay soils suitable for a clay liner are located in a nearby borrow area and imported to the site to construct a compacted clay liner. CPS 521D applies to this practice.
- Soils from the excavation and at the excavated subgrade are treated with bentonite to create a compacted liner with the required permeability and thickness. CPS 521C applies to this practice.
- The pond may be lined with geosynthetic, a GCL, or lined with concrete. An aboveground storage tank is also an option.

Bentonite type and quality

Several types of bentonite are mined and marketed for use in treating soils to produce a low permeability liner. The most effective type of bentonite (less volume required per cubic foot of treated soil) is finely ground sodium bentonite that is mined in the area of northeast Wyoming, southeast Montana, and western South Dakota. This sodium bentonite is derived from weathered volcanic ash. Sodium bentonite is a smectite clay composed primarily of the mineral montmorillonite (Bentofix 2007). It has the ability to swell up to 10 to 15 times its dry natural volume when exposed to water. Other types of bentonite, usually calcium bentonite are also mined and marketed for treating soils. These types of bentonites are less active (less free swell potential) and more volume of bentonite per treated cubic yard of soil will be required to produce a target permeability than would be required if sodium bentonite were used.

Two methods of evaluating a bentonite source being considered for use as an additive for a liner has high swell properties exist. They are:

- Determine the level of activity based on its Atterberg limit values as determined in a soil testing laboratory. High-quality sodium bentonite has LL values greater than 600 and PI values greater than 550.
- High-quality sodium bentonite has a free swell value of 22 milliliter or higher, based on experience of NRCS engineers and generally accepted guidance. An ASTM Standard test method to evaluate the free swell potential of bentonite is used to verify the quality of bentonite used in GCL liners and is also suitable for evaluating bentonite proposed for a liner being constructed using CPS 521C. The ASTM method is D5890. A summary of the method follows.
  - — Prepare a sample for testing that consists of material from the total sample that is smaller than a No. 100 sieve.
  - — Partially fill a 100-milliliter graduated cylinder with 90 milliliters of distilled water.
  - — Add 2 grams of bentonite in small increments to the cylinder. The bentonite will sink to the bottom of the cylinder and

swell as it hydrates. Wash the sides of the cylinder and fill to the 100-milliliter level.

— After 2 hours, inspect the hydrating bentonite column for trapped air or water separation in the column. If present, gently tip the cylinder at a 45-degree angle and roll slowly to homogenize the settled bentonite mass.

— After 16 hours from the time the last of sample was added to the cylinder, record the volume level in milliliters at the top of the settled bentonite. Record the volume of free swell, for example, 22 milliliters free swell in 24 hours.

Figure 10D–21 shows an excellent quality bentonite reaction to the test. It has a free swell of about 27 milliliters.

Bentonite is furnished in a range of particle sizes for different uses. Fineness provided by the bentonite industry ranges from very finely ground, with most particles finer than a No. 200 sieve, to a granular form, with particles about the size of a No. 40 sieve. Laboratory permeability tests have shown that even though the same bentonite is applied at the same volumetric rate to a sample, a dramatic difference in the resulting permeability can occur between a fine and a coarse bentonite. It is important to use in construction the same quality and fineness as was used by the soils laboratory for the permeability tests to arrive at recommendations. Fineness for use in treating liners for waste impoundment can also be specified by an acceptable bentonite by supplier and designation, or equivalent. An example specification is Wyo Ben type Envirogel 200, CETCO type BS–1, or equivalent.

Figure 10D–21 Free swell test for bentonite ASTM D5890

Design details for bentonite liner

The criteria given in CPS 521C, Pond Sealing or Lining, Bentonite Treatment, provide minimum required liner thicknesses for various depth of liquids.

CPS 521C provides guidance on rates of application of bentonite for preliminary planning purposes or where the size and scope of the project does not warrant obtaining samples and having laboratory tests performed. These preliminary recommended rates of application are based on using high-quality sodium bentonite that is finely ground. The CPS 521C includes a table that shows a range of recommended application rates which vary with the type of soil being treated. Higher rates of application are needed for coarse, clean sands and lower rates for silts. The table shows a recommended application rate expressed in pounds of bentonite per square foot per inch of liner to be built. For example, a typical rate of application for a relatively clean sand would be about 0.625 pounds per square foot per inch of compacted bentonite-treated liner. The most up-to-date CPS 521C should always be consulted for recommended rates, in case they have changed since this document was written.

For planning purposes, using these recommended rates, the amount of bentonite needed for a job can be estimated. For example, assume that a pond is to be constructed with an area of the sides and bottom totaling one acre. Assume that considering the planned depth of water in the pond, a design has been formulated that calls for a 1-foot-thick bentonite-treated liner and that an application rate of 0.625 pounds per square foot per inch is needed. The total amount of bentonite required per square foot will be

$$0.625 \text{ lb/ft}^2 \times 12 \text{ in/ft} = 7.5 \text{ lb}$$

of bentonite per square foot. For an acre of pond area, the total amount needed will be

$$\begin{aligned} 7.5 \text{ lb/ft}^2 \times 43{,}560 \text{ ft}^2\text{/acre} &= 326{,}700 \text{ lb} \\ &= 163 \text{ tons} \end{aligned}$$

The cost of bentonite is affected strongly by freight, and the further a site is from the area of the United States where bentonite is produced, the more costly it will be. Better unit prices are available for larger quantities.

Remember that the preliminary rates of application provided in CPS 521C assume that finely ground high-swell sodium bentonite is used. If plans anticipate that a lower quality bentonite with a free swell less than about 22 milliliters or a coarsely ground bentonite may be used, laboratory testing is required to establish a rate of application that will create a suitably low permeability. Design using the specific discharge approach will establish what the target permeability value should be.

The recommended procedure to arrive at a design for a bentonite-treated liner then is as follows:

Step 1 Obtain a sample of the soil to which the bentonite is to be added. Have the sample tested in a soils laboratory to determine its basic index properties, including percent fines and plasticity.

Step 2 Have a standard Proctor (ASTM D698) test performed to determine the maximum dry density and optimum water content.

Step 3 From the preliminary design of the site, determine the depth of water in the structure. Use CPS 521C to determine the minimum thickness of liner required.

Step 4 Using given or assumed values for allowable specific discharge, compute the required permeability of the bentonite-treated liner.

Step 5 Coordinate with a soils laboratory on testing to determine what degree of compaction, water content, and rate of application of the proposed additive is required to obtain this permeability. Consider whether high quality (free swell > 22 mL) is being used and whether finely ground or coarsely ground bentonite is proposed.

Step 6 Design the final liner based on the results of step 5.

Example 10D–5—Design of a bentonite-treated liner

Given:

A waste storage pond is planned with a depth of liquid of 21 feet. The State requirement for the location is a specific discharge no greater than one-fifty-sixth of an inch per day of seepage. Assume the soils at grade have been tested and found to be suitable for bentonite treatment. Find the minimum thickness liner required according to CPS 521C, and determine the required permeability to meet this specific discharge requirement.

First, consult CPS 521C to determine the minimum required thickness. Assume the current CPS requires a liner that is 18 inches thick (1.5 ft).

Convert the specified unit seepage rate (specific discharge) of one-fifty-sixth of an inch per day into the same units as will be used for permeability (centimeters per second). To convert, use conversion values shown in table 10D–6, multiply:

$$\nu = \frac{1}{56}\ \text{in/d} \times 2.94 \times 10^{-5} = 5.25 \times 10^{-7}\ \text{cm/s}$$

The thickness of the liner and depth of liquid in the pond must also be converted to metric units. To convert the liner thickness of 18 inches to centimeters, multiply by 2.54, which equals a liner thickness, d, of 45.72 centimeters. The liquid depth, H, of 21 feet is equal to

$$H = 21\ \text{ft} \times 12\ \text{in/ft} \times 2.54\ \text{cm/in} = 640.1\ \text{cm}$$

Using the equation described previously, solve for the required permeability:

$$k = \frac{\nu \times d}{H + d}$$

$$k = \frac{5.25 \times 10^{-7}\ \text{cm/s} \times 45.72\ \text{cm}}{640.1\ \text{cm} + 45.72\ \text{cm}} = 3.5 \times 10^{-8}\ \text{cm/s}$$

The designer should coordinate with a soils laboratory to determine how much bentonite of given quality is required to obtain this low a permeability. In the experience of NRCS engineers, relying on this low a permeability means that construction quality control must be excellent and all the procedures and materials used are of highest quality. Seldom should designs for clay liners rely on a design permeability much lower than 5×10^{-8} centimeters per second. A designer might want to proceed with this design but require a slightly thicker liner (24 in) to provide additional assurance of obtaining the design specific discharge.

Considerations for protective cover

CPS 521C recommends considering the addition of a protective soil cover over the bentonite-treated compacted liner in waste impoundments. There are several reasons why a soil cover should be provided:

- Desiccation cracking of the liner after construction and prior to filling is a significant problem because the bentonite used in treatment is highly plastic.
- Desiccation cracking of the liner on the side slopes may occur during periods when the impoundment is drawn down for waste utilization or sludge removal. Desiccation cracking would significantly change the permeability of the liner. Rewetting generally does not completely heal the cracks.
- Bentonite-treated liners are generally thinner than compacted clay liners. Because the liner is thin, it can be more easily damaged by erosion from rainfall and runoff while the pond is empty. Rills in a thin liner provide a direct pathway for seepage.
- Over excavation by mechanical equipment during sludge removal can damage the liner. A minimum thickness of 12 inches measured normal to the slope and bottom is recommended for a protective cover. The protective cover should be compacted to reduce its erodibility.

Construction specifications for bentonite liner

The best equipment for compacting bentonite-treated liners is smooth-wheeled steel rollers, as shown in figure 10D–20. Crawler tractor treads are also effective. Sheepsfoot rollers that are often used in constructing clay liners are not as effective. CPS 521C specifies that for mixed layers, the material shall be thoroughly mixed to the specified depth with disk, rototiller, or similar equipment. In addition, intimate mixing of the bentonite is essential to constructing an effective liner. If a standard disk is used, several passes should be specified. A high-speed rotary mixer is the best method of obtaining the desired mix (fig. 10D–22). A minimum of two passes of the equipment is recommended to assure good mixing. When multiple passes of equipment are used for applying and mixing the bentonite, the passes should be in directions perpendicular to each other. This encourages a more homogeneous mixture.

Another construction consideration is the moisture condition of the soil into which the bentonite is to be mixed. Unless the soil is somewhat dry, the bentonite will most likely ball up and be difficult to thoroughly mix. Ideally, bentonite should be spread on a relatively dry soil, mixed thoroughly, then watered and compacted.

Depending on the type of equipment used, tearing of the liner during compaction can occur on slopes of 3H:1V or steeper. Compacting along, rather than up and down slopes, could be unsafe on 3H:1V or steeper side slopes. For most sites, slopes of 3.5H:1V or 4H:1V should be considered.

Bentonite-treated liners are often constructed in lifts that are 4-inch compacted thickness. Liners should be designed in multiples of 4 inches for this reason. Often, the first layer of bentonite-treated soil is the soil exposed in the bottom of the excavation. By applying bentonite to the exposed grade, disking it in to a depth of about 6 inches, and compacting it, the first layer is formed. Subsequent lifts are formed by importing loose fill adequate to form additional 4-inch-thick lifts.

Figure 10D–22 Pulvermixer (high-speed rotary mixer) (*Photo credit Stacy Modelski, NRCS*)

Design and construction of clay liners treated with soil dispersants

Previous sections of this appendix caution that soils in groups III and IV containing high amounts of calcium may be more permeable than indicated by the percent fines and PI values. Groups III and IV soils predominated by calcium usually require some type of treatment to serve as an acceptable liner. The most common method of treatment to reduce the permeability of these soils is use of a soil dispersant additive containing sodium.

Types of dispersants

The dispersants most commonly used to treat high calcium clays are soda ash (Na_2CO_3) and polyphosphates. The two most common polyphosphates are tetrasodium pyrophosphate (TSPP), and sodium tripolyphosphate (STPP). Common salt (NaCl) has been used in the past, but it is considered less permanent than other chemicals and is not permitted in the current CPS 521B. NRCS experience has shown that usually about twice as much soda ash is required to effectively treat a given clay when compared to the other two dispersants. However, because soda ash is often less expensive, it may be the most economical choice in many applications.

Design details for dispersant-treated clay liner

CPS 521B, Pond Sealing or Lining, Soil Dispersant, provides minimum thicknesses of liners using the dispersant-treated layer method, based on the depth of liquid in the pond. CPS 521B provides guidance on approximate rates of application of soil dispersants based on testing performed by the NRCS laboratories. Rates provided in the CPS are in terms of pounds of dispersant required per 100 square feet for each 6-inch layer of liner. The total amount of dispersant per 100 square feet is then equal to the number of 6 inch lifts in the completed liner multiplied by the rate per lift.

Example 10D–6—Steps in design of a dispersant-treated liner

Assume for the purposes of this example that a soil has been tested at a site and found to be a flocculated clay with an unacceptably high permeability. The designer chooses to evaluate a soda ash-treated liner. Consult the current CPS 521B for guidance on application rates for soda ash. Assume that the current CPS suggests an application rate of 15 pounds of soda ash per 100 square feet of liner for each 6-inch-thick lift of finished liner. Next, assume that based on the depth of water in the pond that the CPS 521B requires a total liner thickness of 12 inches. Then, because each 6-inch-thick lift requires 15 pounds of soda ash per 100 square feet, the total amount of soda ash required for this example would be 30 pounds of soda ash per 100 square feet. The most up-to-date CPS 521B should always be consulted for recommended rates, in case they have changed since this document was written.

The recommended rates of application of dispersants in CPS 521B are based on the most up-to-date information from the NRCS soils testing laboratories. The rates are in general conservative, and if a designer wanted to evaluate lower rates of application, samples should be obtained and sent to a laboratory for documenting the efficacy of lower rates. If this procedure is followed, the following steps are usually implemented.

Step 1 Obtain a sample of the soil to which the dispersant is to be added. Have the sample tested in a soils laboratory to determine its basic index properties, including percent fines and plasticity.

Step 2 A standard Proctor (ASTM D698) test is performed to determine the maximum dry density and optimum water content.

Step 3 From the preliminary design of the site, determine the depth of water in the structure and use CPS 521B to determine the minimum thickness of liner required.

Step 4 Using given or assumed values for allowable specific discharge, compute the required permeability of the dispersant-treated liner.

Step 5 Coordinate with a soils laboratory on testing to determine what degree of compaction, water content, and rate of application of the proposed additive is required to obtain this permeability. Consider local practice and consult suppliers to determine the relative costs of soda ash versus polyphosphates.

Step 6 Design the final liner based on the results from previous steps.

Example 10D–7—Comprehensive example for a dispersant-treated liner

Given:

A waste storage pond is planned with a depth of liquid of 18 feet. The State requirement for the location is a specific discharge no greater than 2,000 gallons per acre per day of seepage. Assume the soils at grade have been tested and found to require dispersant treatment. Assume that the current CPS 521B requires a minimum liner thickness of 1.5 feet. The example problem is to determine what permeability is required to meet the stated specific discharge requirement.

Solution:

First, the required specific discharge value, which is given in units of gallons per acre per day has to be converted the same units that will be used for required permeability. Assume that permeability will be expressed in centimeters per second, so use table 10D–6 to convert the value of 2,000 gallons per acre per day to centimeters per second as follows:

$$\nu = \frac{2{,}000 \text{ gal/acre/d}}{9.24 \times 10^{8}} = 2.2 \times 10^{-6} \text{ cm/s}$$

Next, convert the liner thickness and depth of liquid from units of feet to centimeters:

$$d = 18 \text{ in} \times 2.54 \text{ cm/in} = 45.72 \text{ cm}$$

$$H = 18 \text{ ft} \times 12 \times 2.54 \text{ cm/ft} = 548.64 \text{ cm}$$

Using the equation described previously, solve for the required permeability:

$$\begin{aligned} k &= \frac{\nu \times d}{H + d} \\ &= \frac{2.2 \times 10^{-6} \text{ cm/s} \times 45.72 \text{ cm}}{548.64 \text{ cm} + 45.72 \text{ cm}} \\ &= 1.7 \times 10^{-7} \text{ cm/s} \end{aligned}$$

The designer should coordinate with a soils laboratory to determine how much soil dispersant of the desired type is required to obtain this low a permeability. In the experience of NRCS engineers, obtaining this value of permeability using a soil dispersant should not require special effort or unusual amounts of additive. At the same time, seldom should designs for dispersant-treated clay liners rely on a design permeability much lower than 5×10^{-8} centimeters per second. A designer should proceed with this design specifying the application rate recommended by the soils lab and a 1.5-foot-thick liner to obtain the design specific discharge.

Construction specifications for a dispersant-treated clay liner

The best equipment for compacting clays treated with dispersants is a sheepsfoot or tamping type of roller. CPS 521B specifies that the material shall be thoroughly mixed to the specified depth with a disk, high speed rotary mixer, or similar equipment. Because small quantities of soil dispersants are commonly used, uniform mixing of the dispersants is essential to constructing an effective liner. If a standard disk plow is used, several passes should be specified. A high-speed rotary mixer is also essential to obtain a thorough mixture of the dispersant with the clay being amended. Figure 10D–23 shows this type of equipment. At least two passes of the equipment is recommended to assure good mixing.

Other construction considerations are also important. Using the bathtub method of construction on slopes of 3H:1V or steeper can cause tearing of the liner during compaction and reduce the effectiveness of compac-

Figure 10D–23 High-speed rotary mixer used to mix dispersants into clays (*Photo credit Jody Kraenzel, NRCS*)

tion equipment. Slopes as flat as 3.5H:1V or 4H:1V should be considered for this factor alone, for bathtub type construction.

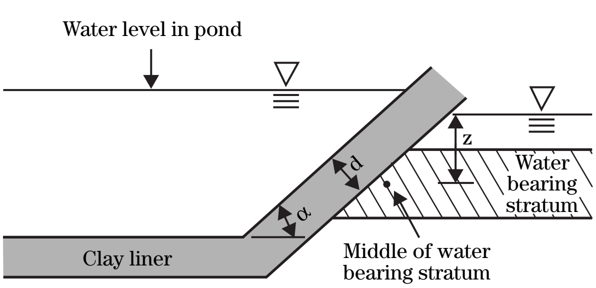
Current CPSs usually require a liner thicker than 6 inches. A liner generally can be satisfactorily constructed in a series of lifts by mixing in the required amount of soil dispersant to a 9-inch-thick loose depth and then compacting it to the 6 inches. Thicker liners should be constructed in multiple lifts, with the final compacted thickness of each lift being no greater than 6 inches.

Uplift pressures beneath clay blankets

A clay blanket may be subject to uplift pressure from a seasonal high water table in the foundation soil underneath the clay liner. The uplift pressure in these cases can exceed the weight of the clay liner, and failure in the clay blanket can occur (fig. 10D–24). This problem is most likely to occur during the period before the waste impoundment is filled and during periods when the impoundment may be emptied for maintenance and cleaning. Figure 10D–25 illustrates the parameters involved in calculating uplift pressures for a clay blanket. The most critical condition for analysis typically occurs when the pond is emptied. Thicker blankets to attain a satisfactory safety factor should be used if they are required.

Figure 10D–24 Failure of compacted liner from uplift forces below clay blanket *(Photo credits NRCS, TX)*

Figure 10D–25 Uplift calculations for high water table and clay blanket (from Oakley 1987)



The factor of safety against uplift is the ratio of the pressure exerted by a column of soil to the pressure of the ground water under the liner. It is given by the equation:

$$FS = \frac{\gamma_{sat} \times d \times \cos(\alpha)}{z \times \gamma_{water}}$$

where:

d	=	thickness of liner, measured normal to the slope
α	=	slope angle
γ_{water}	=	unit weight or density of water
γ_{sat}	=	saturated unit weight of clay liner
z	=	vertical distance from middle of clay liner to the seasonal high water table

A factor of safety of at least 1.1 should be attained. The safety factor can be increased by using a thicker blanket or providing some means of intercepting the ground water gradient and lowering the potential head behind the blanket. Often, sites where seasonal high water tables are anticipated designs include a perimeter drain to collect the water and prevent this type of damage. Another option is a concrete structure above ground.

Another situation where a clay liner may be damaged from hydrostatic pressure is one where a site is located in a flood plain of a stream or river. The site may have to be built above ground level in this location to avoid a seasonal high water table. Figure 10D–26 illustrates the problem that may occur that must be considered by designers. A temporary flood condition in the flood plain can subject the agricultural waste impoundment to a differential head when the pond is empty. The pond could be empty shortly following construction or it could be empty to apply waste to crops. Uplift pressure may cause piping of sandy horizons underlying the site and boils, and sloughing of side slopes can occur as shown in figure 10D–26. The photo shows a clay-lined animal waste impoundment where the clay liner was damaged from excessive hydrostatic uplift forces caused by temporary storage of flood waters outside the embankment. The liner must be thick enough to resist predicted buoyant forces if it is possible for the pond to be empty or near empty during a flood. Drains will be ineffective because in a flood, outlets will be submerged.

Figure 10D–26 Uplift conditions caused by temporary flood stage outside lagoon (*Photo credit NRCS, WA*)

Perimeter drains for animal waste storage ponds

When a high water table is anticipated and uplift pressures are anticipated, one approach to solving the problem is to install a drain around the pond. The drain may completely encircle the pond if a designer anticipates a general elevated water table in the site vicinity. At other sites with a more sloping ground surface, the perimeter drain may only be installed on the side(s) of the impoundment where the elevated water table is anticipated. Drains may be used both for clay liners and geosynthetic liners.

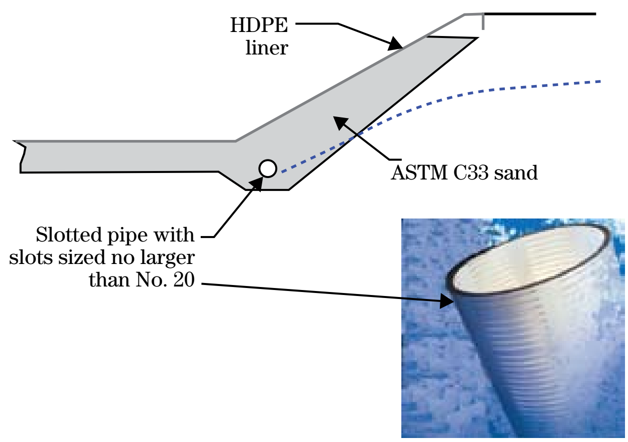
Drains usually are constructed by
- digging a trench to the depth needed to draw down the water table
- placing a perforated or slotted drainage pipe
- surrounding the drain with granular material that is compatible with both the slot size in the pipe and the gradation of the surrounding foundation soils

Pipes with small slots that are compatible with a filter sand like ASTM C–33 are preferred to avoid having to use two filter gradations. If pipes with larger perforations are used, they should be surrounded with gravel to prevent particles from moving into the pipe. Figure 10D–27 (a, b, and c) show typical installations where a single filter and perforated pipe is used. Another approach to installing a drain is to dig a trench, line it with geotextile, and after putting a slotted collector pipe in the trench, filling it with gravel. Figure 10D–28 shows this type of installation.

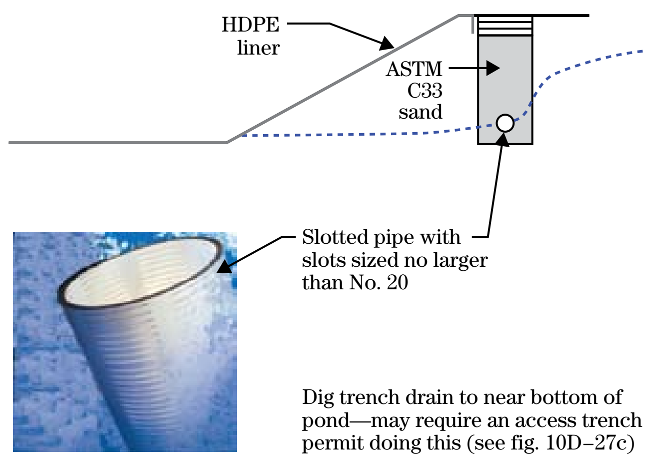
Several types of drain pipe may be used. One type is a low strength corrugated pipe with slots or perforations surrounded by a filter envelope of granular material. Figure 10D–29 is an example of this type of collector pipe. If a higher strength pipe is required, figure 10D–30 shows another type of pipe that is sometimes used for these types of installations.

Figure 10D–27 Typical drain installations using single filter with well-screened collector pipe

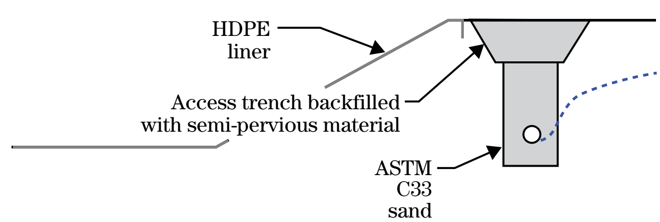
(a)



(b)



(c)



Illustrated access trench construction to permit installing deeper trench drain. Access trench filled with semi-pervious soil to limit infiltration of surface runoff.

Figure 10D–28 Perforated collector pipe installed the gravel envelope with trench lined with geotextile

Figure 10D–29 Low-strength perforated drainage tubes

Figure 10D–30 Corrugated drainage pipe with slots, doubled walled pipes may be specified if higher strengths are needed

Soil mechanics testing for documentation

Laboratory soil testing may be required by regulations for design, or a designer may not choose to rely on correlated permeability test values. The NRCS National Soil Mechanics Center Laboratories have the capability to perform the necessary tests. Similar testing is also available at many commercial labs. The accepted method of permeability testing is by ASTM Standard Test Method D5084, Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. Figure 10D–31 shows the equipment used for performing the test.

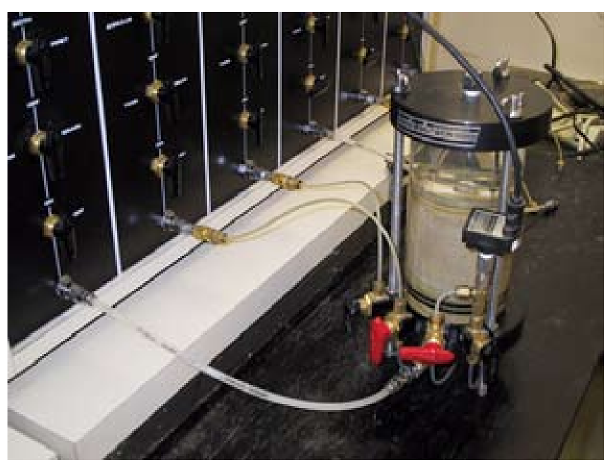
Contact the labs for more detailed information on documentation needed and for procedures for submitting samples.

Figure 10D–31 Equipment used for performing ASTM D5084

Molding a sample for a flexible wall permeability test

Disassembled mold with compacted specimen

Preparing sample in cell for flexible wall permeability test



Molded sample after dissembling mold

If the only tests requested are gradation and Atterberg limit tests, smaller samples are needed. The size of sample that should be submitted depends on the gravel content. The following recommendations should be adhered to:

Estimated gravel content of the sample 1/ (%)	Sample moist weight (lb)
0–10	5
10–50	20
>50	40

1/ The sample includes the gravel plus the soil material that passes the No. 4 sieve (approx. 1/4-inch mesh).

If gradation analysis, Atterberg limits, compaction, and permeability testing are requested, considerably larger samples are required. When all these tests are needed, the sample size should be as follows:

Estimated gravel content of the sample 1/ (%)	Sample moist weight (lb)
0–10	50
10–50	75
>50	100

1/ The sample includes the gravel plus the soil material that passes the No. 4 sieve (approx. 1/4-inch mesh).

Submitting samples at their natural water content is important so designers can compare the natural water content to reference compaction test values. Samples should always be shipped in moisture proof containers for this reason. The best container for this purpose is a 5-gallon plastic pail commonly obtained in hardware stores. These pails have tight fitting lids with a rubber gasket that ensures maintenance of the water content in the samples during shipping. These 5-gallon pail containers are much more robust and less likely to be damaged during shipment than cardboard containers.

If designs rely on a minimum degree of compaction and water content to achieve stated permeability goals in a clay liner, testing of the clay liner during construction may be advisable to verify that design goals have been achieved. Field density and water content measurements are routinely made using procedures shown in NEH, Section 19, Construction Inspection.

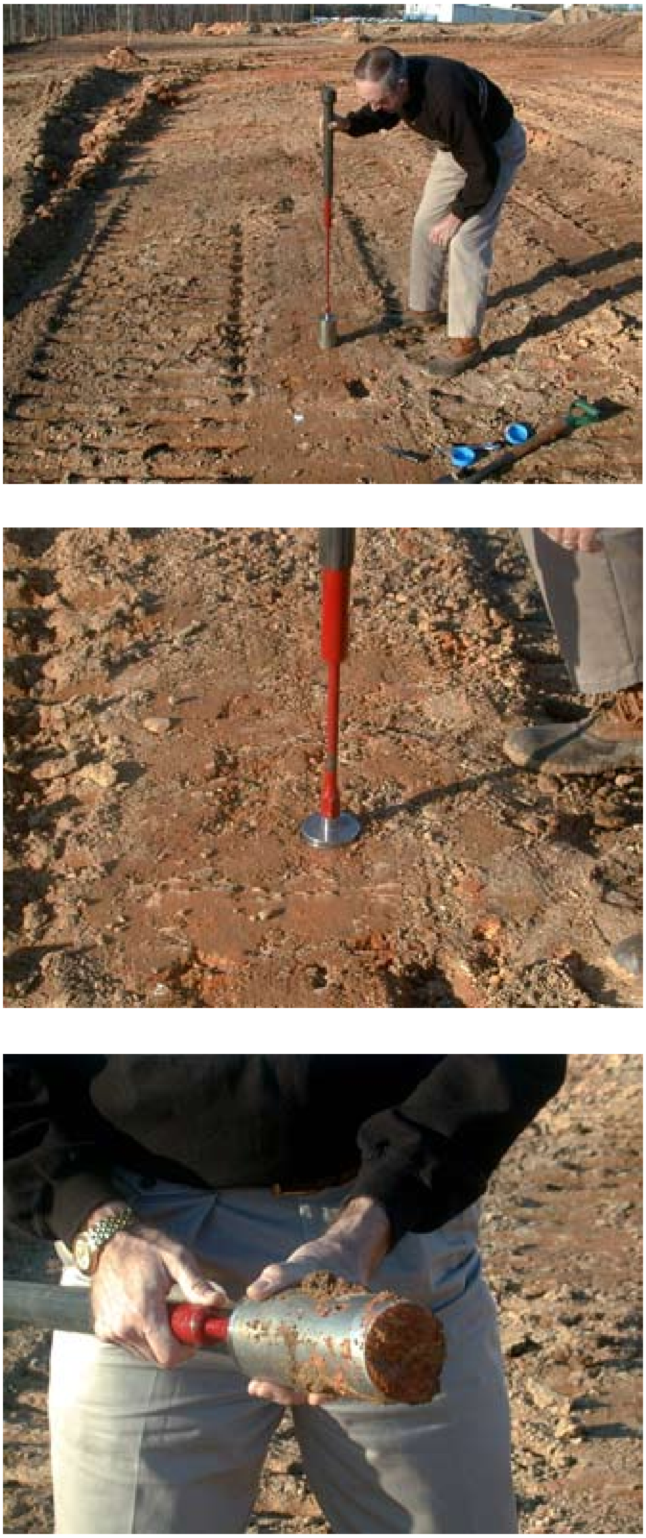
Other methods for documenting liner seepage

Performing density/water content tests during construction is a generally accepted method of documenting that a clay liner has been constructed according to specifications. If the liner is found to meet the requirements of the compaction specifications, the assumption is that the permeability values documented from laboratory testing on samples that were compacted at the specified density and water content will be achieved. In some cases, no additional documentation is required. In other cases, regulations require obtaining samples of the completed liner and performing permeability tests on them. Figure 10D–32 shows one way that a Shelby tube type of sample may be obtained without mobilizing a drilling rig. The Shelby tube used is typically a standard tube with a 3-inch outside diameter and 2 7/8-inch inside diameter. This size sample can be placed directly in a flexible wall permeameter for testing, after extrusion in the laboratory.

Another method for obtaining a sample of a compacted clay liner is with a drive sampler like that shown in figure 10D–33.

Figure 10D–32 Shelby tube sample being obtained with backhoe bucket used to force tube into clay liner *(Photo credit Jody Kraenzel, NRCS, NE)*

Figure 10D–33 Obtaining undisturbed sample of compacted clay liner using thin-walled drive cylinder



In the situation where a storage pond was constructed several years before documentation on quality of construction and permeability was required, studies are sometimes made in an attempt to measure seepage losses directly. One approach that has been used was developed by researchers at Kansas State University. This approach involves installing precise water level monitoring devices and evaporation stations. Seepage losses can be estimated by carefully monitoring the levels in the pond during periods when no waste is introduced into the pond and no rainfall occurs. After estimating the amount of evaporation, and subtracting that from the total decline in the level of the pond during that period, seepage loss can be estimated. Figure 10D–34 shows equipment for measuring evaporation in a pond.

Figure 10D–34 Equipment used to monitor evaporation at an agriculture waste storage lagoon. Measurements are used in total lagoon seepage evaluations.

Summary

- The reduction in the quantity of seepage that occurs as manure solids accumulate in the bottom and on the sides of storage ponds and treatment lagoons is well documented. However, manure sealing is not effective for soils with a low clay content. Its effectiveness is not accepted by all designers and cannot be used in the designs of storage ponds by some State and local regulations.
- Soils can be divided into four permeability groups based on their percent fines (percent finer than the No. 200 sieve) and plasticity index (PI). Soils in groups III and IV may be assumed to have a coefficient of permeability of 1×10^{-6} centimeters per second or lower unless they have an unusual clay chemistry (high calcium), or they have a very blocky structure.
- Group I soils will generally require a liner. Soils in group II will need permeability tests or other documentation to determine whether a desirable permeability rate can be achieved for a particular soil.
- If natural clay blankets are present at a site below planned grade of an excavated pond, the seepage rate should be estimated based on measured or estimated permeability values of the low permeability horizons beneath the liner and above an aquifer. If the estimated seepage rate is less than that given in NRCS guidance or State regulations, no special compacted liner may be required. If the soils at grade are not of sufficient thickness and permeability to produce a desirably low seepage rate, a liner should be designed to achieve the seepage rate that is the design goal.
- Guidance is given on factors to consider whether a constructed liner may be required. Four conditions are listed in which a liner should definitely be considered.
- Allowable specific discharge values are discussed and guidance is provided on reasonable values to use for design when other regulatory requirements are not specified.
- Flexibility is built into the design process. The depth of the liquid, the permeability, and thickness of the soil liner can be varied to provide an acceptable specific discharge.
- The guidelines provided for design of clay liners in this appendix provide designers with the tools to evaluate the probable unit seepage or specific discharge through a clay liner. The methods presented allow a designer to determine what treatment is required to achieve specific discharge or permeability goals.
- Methods provide designers with the ability to evaluate the effect of changes in a proposed design on the estimated unit seepage rate.
- As additional research becomes available, practice standards and guidance in this document may warrant revision.

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Appendix 10E
Synthetic Liner Guidelines

Appendix 10E Synthetic Liners Guidelines

Synthetic liners

Although compacted clay liners are the most common type of liners for manure impoundment structures, a storage pond or lagoon may require a synthetic liner for the following reasons:

- locating an acceptable clay material is not possible
- transporting an acceptable clay is too expensive
- using soil additives such as bentonite for sandy soils or a dispersant for higher permeability clays is too expensive
- using a reasonably thick compacted clay liner will not provide required seepage control
- using a synthetic liner is required by local regulations

Synthetic liner materials

NRCS Conservation Practice Standard 521A, Pond Sealing or Lining—Flexible Membrane, provides the minimum criteria for pond liners constructed of synthetic materials. The standard describes the acceptable liner types and the minimum recommended thickness of each type of material. The standard covers two types of liners: geomembranes and geosynthetic clay liners (GCL). A GCL consist of bentonite embedded between two geosynthetic materials. Geomembranes are plastic or rubber liners. These NRCS criteria are shown in table 10E–1.

Material selection

Selection of a geosynthetic liner material should consider several factors. In most cases, any of the liner materials included in the NRCS practice standard could perform adequately, but some may be preferred over others or be more economical. Factors to consider, although not comprehensive, are:

- pond size
- material flexibility
- ease of installation and quality control
- site geology
- site ground water conditions
- use of cover soil
- availability of experienced installers
- temperature during construction
- regulations
- costs

Material flexibility and ease of installation and quality control are independent of the site characteristics and location. Availability of experienced installers and regulations are independent of the specific site characteristics, but are location dependent.

Materials such as PVC, EPDM, PP, and RPP can be delivered to the site in panels of a fourth acre to greater in size. Pond liners of less than a half acre can often be installed with one field seam.

The flexibility of the material allows larger panels to be delivered to the site. Flexible materials such as PVC, EPDM, PP, RPP, and GCL are much easier to work with and install in an anchor trench and around corners. The more flexible materials may also conform to small undulations in the subgrade and reduce stress concentration in these areas.

Table 10E–1 NRCS minimum criteria for liners

Type	Thickness	Type
HDPE	40 mil	Geomembrane
LLDPE	40 mil	Geomembrane
PVC	30 mil	Geomembrane
GCL	0.75 lb/ft (bentonite)	Geosynthetic clay liner
EPDM	45 mil	Geomembrane
PP	40 mil	Geomembrane
RPP	36 mil	Geomembrane

1 mil =1/1000 of an inch
HDPE =High density polyethylene
LLDPE =Linear low density polyethylene
PVC =Polyvinyl chloride
GCL =Geosynthetic clay liner
EPDM =Synthetic rubber
PP =Polypropylene
RPP =Reinforced polypropylene

Due to the relatively small size of most NRCS waste pond applications, large installers may not be interested in NRCS projects. The ease of installation, seaming, and quality control of a material may allow installation by a less experienced installer or even farm labor under the direction of one experienced installer. Patching and repair of some liners, such as EPDM and GCL, are often completed by the land owner.

Locating an animal waste pond in areas of known sinkholes is not recommended. Consider having the site checked by using ground penetrating radar to identify any potential sinkhole areas. If sinkholes or karst terrain exist in an area, a geomembrane liner with sufficient strength and elongation properties is recommended to withstand some foundation movement. Reinforced geomembranes provide significantly more strength than unreinforced geomembranes. The use of heated seams rather than chemical or adhesive seams is also recommended.

The presence of ground water near the base of the liner can uplift the liner and cause significant damage. The use of cover soil provides some resistance to uplift from a high ground water table. A collection and drainage system may also be considered to dewater the foundation and soils surrounding the liner.

Cover soil is required to be placed on PVC liners and GCLs. Current PVC liners are susceptible to UV degradation and must be covered, while GCLs require a normal load on the liner to develop its low permeability once it is hydrated. Cover soil must be free of sharp or large particles, 3/8-inch for geomembranes and a half inch for GCLs. When cover soil is placed on the side slopes of ponds, a slope of 3H to 1V or flatter is typically recommended to maintain the soil on the slope without sliding down the slope on top of the liner. The friction between the cover soil and the liner may also be tested and evaluated to determine a stable side slope.

Installers in a geographic area may be more experienced with one material than another. In the recent years, experienced installers have traveled to rural and remote areas to install liners. The installation often takes 1 to 2 days once the subgrade is prepared.

Most geomembrane materials are stiffer in cooler temperatures. Less flexible materials, such as HDPE, are very difficult to handle in cold temperatures. Seaming of all geomembranes is restricted during extremely high temperatures.

State regulations may require a particular type of liner material. If such State regulations exist, the required liner material should be used or equivalent substitute proposed to the regulatory agency.

Cost of the materials is always a consideration. All factors being equal, the liner materials have relatively similar total cost, including materials and installation. Liners that are covered will have the added cost of placing the cover material.

Synthetic liner installation

Installation of the liner is often the most critical point in the life of the liner. Installation involves subgrade preparation, proper handling and storage, placement, seaming, completion of the anchor trench, and placement of cover soil, if required.

Subgrade preparation should include excavation or earthfill to the proper grade, removing any large and sharp objects, removing particles greater than 3/8-inch for geomembranes and a half inch for GCLs, removing soft material to provide a uniformly compacted base, and smoothing the surface with a rubber tired or steel wheel roller, if necessary. Geotextile padding, as shown in figure 10E–1, or soil padding and drains, if required, should be placed before the liner.

Figure 10E–1 Geotextile padding

Prior to placement of the liner, the proposed material should be compared to the specifications. A certificate from the liner manufacturer is typically provided which details the properties of the proposed liner. Labels should be on each roll or panel identifying the manufacturer and material product name.

The liner material should be shipped, handled, and stored in a manner to prevent damage. The liner material should be protected from puncture, dirt, grease, excessive heat, or other damage. GCLs should be protected from moisture to prevent premature hydration. Rolls should be stored on a smooth surface (not wooden pallets) and stacked no more than two to three rolls high, as shown in figure 10E–2. Panels of material should be shipped and stored on a pallet, as shown in figure 10E–3, and should not be stacked unless contained within a crate.

Rolls of material should be unloaded with a spreader bar or other method that provides support to the full length of the roll. Figures 10E–4 and 10E–5 show simple methods of providing this support. A spreader bar with lift cables is often used in place of the equipment bucket.

Figure 10E–2 Stacked rolls

Figure 10E–3 PVC Panel prepared for shipment

Figure 10E–4 Unloading a roll

Figure 10E–5 Unloading a roll with steel pipe through core

The liner should be placed to minimize slack and folds, but loose enough to allow thermal contraction. It should then be positioned to achieve the proper overlap for seaming. The liner should be positioned with the seams up and down the slope, as shown in figure 10E–6, rather than across the slope. Rolls are positioned using the "stationary pull," as shown in figure 10E–7 or the "moving roll pull," as shown in figure 10E–8. Liners delivered in large panels must be unfolded as shown in figure 10E–9 and "floated" into place by one person every 10 to 15 feet along the perimeter of the liner. The liner is floated into place on a pillow of air as shown in figure 10E–10. The liner should extend beyond the top of the slope to provide enough material for a proper anchor trench as shown in figure 10E–11. Following proper positioning of the liner, sand bags are recommended to ballast the liner against movement and uplift due to wind.

Proper seaming includes cleaning the area to be seamed, conducting the seaming with the proper method and according to the manufacturer's recommendations, inspection, and testing of all the seams. Seaming methods and seam testing are described in more detail in the following sections.

An anchor trench is constructed around the perimeter of the pond to prevent the liner from sliding down the slope, prevent surface runoff from getting beneath the

Figure 10E–7 Stationary pull

Figure 10E–6 Seams up and down the slope

Figure 10E–8 Moving roll pull

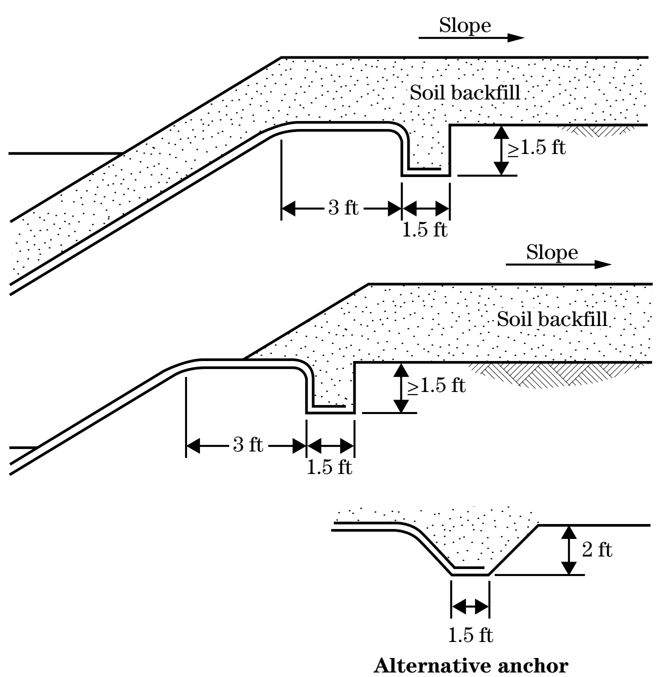
liner, and reduce uplift and wind damage. The trench is typically 18 to 24 inches deep, 12 to 24 inches in width, and located 3 feet from the top of the slope, as shown in figure 10E–12. The anchor trench backfill must not damage the liner. The backfill for the anchor trench must have the same particle size limit as the subgrade. To reduce stress on the liner, the trench should be backfilled during the cooler part of the day. The liner should extend down the side and across the bottom of the anchor trench. The corners of the anchor trench should be rounded, rather than squared, to reduce concentration of stresses at the corner.

Figure 10E–9 Unfolding large panels

Figure 10E–10 Floating liner into place

Figure 10E–11 Liner extending into anchor trench

Figure 10E–12 Anchor trench details (Source: Poly-Flex, Inc., 1995)



Seaming methods

Geomembranes are seamed using several methods. Table 10E–2 identifies the available seaming methods for the various liner materials.

The primary method of seaming HDPE, LLDPE, RPP, and PP liners should be dual track hot wedge welds. Extrusion welds are recommended for repairs, T-seams, appurtenances and other details. Hot air fusion or solvent (also known as chemical fusion) welds may also be used on RPP or PP liners. A contact adhesive is not recommended for HDPE, LLDPE, RPP, or PP liners.

PVC liners may be seamed by hot air fusion, solvent (chemical), or by an adhesive. Dual track hot air fusion welds are recommended when possible for PVC liners.

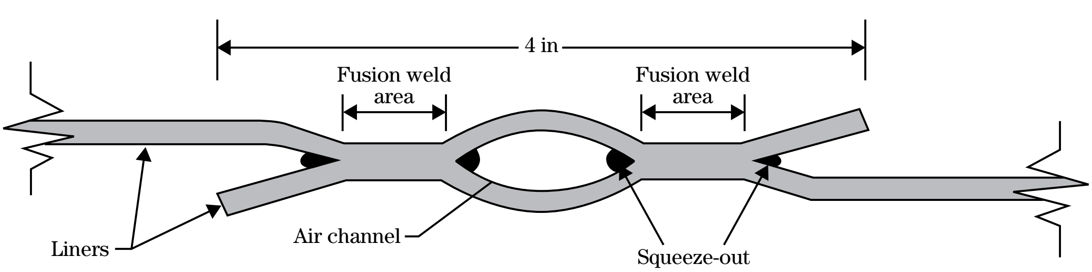
EPDM seams are considered adhesive seams and may consist of a 3-inch inseam tape or a 5- to 6-inch cover strip. The materials for the cover strip are more expensive than the inseam tape but provide a better seam with less time, skill, and effort. The cover strip is often preferred by liner installers.

A dual track hot wedge weld creates two seams with an air channel in between them, as shown in figures 10E–13 and 10E–14. The seaming process melts the surface of the adjoining areas of the liner and fuses them together with dual rollers. The air channel can be pressurized to allow seam integrity tests. Calibrated equipment and an experienced welder are required to weld a good seam. The temperature and speed of seaming must be balanced to create a good weld. This is the most common seaming method for HDPE, LLDPE, and PP.

Table 10E–2 Geombrane seaming methods

Material	Extrusion	Hot air	Hot wedge	Solvent	Contact adhesive
PVC		X		X	X
PP or RPP	X	X	X		X (not recommended)
HDPE	X	X	X		X (not recommended)
LLDPE	X	X	X		X (not recommended)
EPDM					X

Figure 10E–13 Dual track hot wedge or air weld



Extrusion welding is similar to welding steel. The liner is heated by hot air and a ribbon of molten polymer (same polymer as the liner) is extruded to the edges of the adjacent panels, patches, or seams as shown in figure 10E–15. Extrusion welding is essentially the only method to seam HDPE and LLDPE patches for repairs, pipe boots, and other details. The surface of the area to be welded should be ground, as shown in figure 10E–16, no more than 15 minutes prior to welding and no more than 10 percent of the thickness of the liner shall be ground.

Hot air welding may be a single or dual track hot air weld. The dual track hot air weld creates two seams with an air channel in between them just as the dual track hot wedge weld. Calibrated equipment and an experienced welder are required to weld a good seam. The temperature and speed of seaming must be balanced to create a good weld. Hot air welders are available in hand held or automated models. Since it is very difficult to control the temperature of the liner with the hand held models, automated welders are recommended. The dual track hot air weld is becoming the most common seaming method for PVC and is often used to weld PP and RPP.

Solvents (chemically welded seams) are created by use of a liquid solvent which “melts” the surface of the geomembrane material followed by applying pressure with a roller. Once the solvent dissipates, the weld is fused.

Figure 10E–14 Dual track hot wedge welder (Source: Poly-Flex, Inc., 1995)

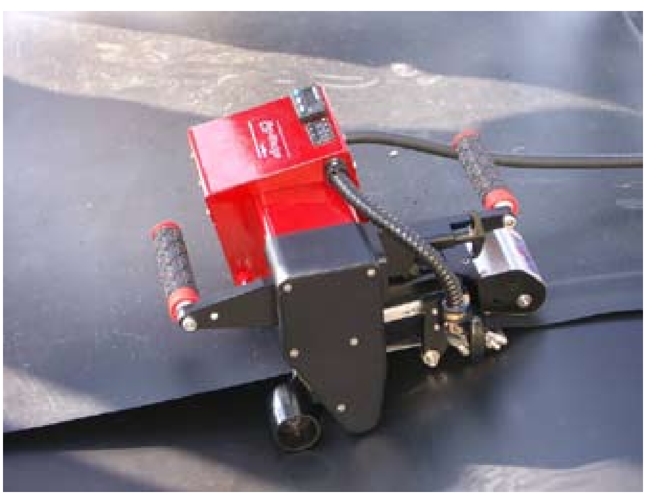
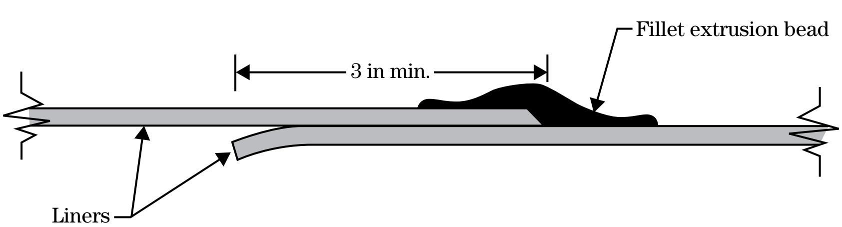


Figure 10E–16 Grinding for an extrusion weld

Figure 10E–15 Extrusion weld



Adhesive seams are created by applying the adhesive between the overlap of adjacent panels with a brush or other approved method. Pressure is then applied to the seam to provide adequate contact between the panels. This type of seam is used primarily on EPDM liners with some use on PVC and PP.

The rate at which geomembrane seaming may be accomplished is presented in table 10E–3. PVC, PP, and EDPM liners require one to two seams on a typical animal waste pond. HDPE/LLDPE requires a seam every 20 to 25 feet. Fortunately, the seaming rate for hot wedge and extrusion welds is relatively fast.

Table 10E–3 Geomembrane seaming rates

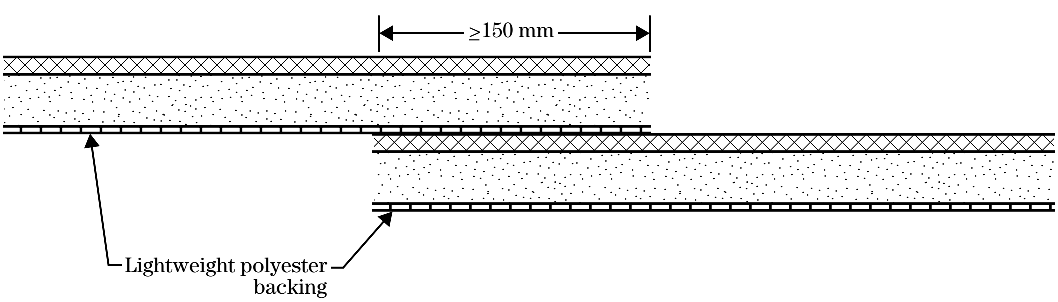
Method	Typical rate
Extrusion	100 ft/h
Hot air	50 ft/h
Hot wedge	300 ft/h
Solvent (chemical)	300+ ft/h
Adhesive	400+ ft/h

GCL seams are constructed with a 6-inch overlap, as shown in figure 10E–17. Seams typically require a quarter pound of powder bentonite per foot of seam. Some manufacturers have developed products that have the bentonite exposed near the edge. Additional bentonite at the seam is not required on these products. The critical aspect of GCL seaming is to have sufficient cover soil over the seam prior to hydration of the bentonite. If the bentonite at the seam hydrates without a load, it will not develop the low permeability required for an adequate seam.

Seam testing

Seams may be nondestructively field tested by various methods. Standard methods are available for air channel test (ASTM D 5820), air lance test (ASTM D 4437), or a vacuum box test (ASTM D 5641). Double-track hot wedge and hot air seams are typically tested by an air channel test. Vacuum box tests are performed on all extrusion welds and may be used on PP chemical fusion welds. Due to the flexibility of PVC, vacuum box tests often give false indications of a good seam. Air lance tests are performed on single-track fusion welds, chemical fusion welds, and adhesive PVC seams and EPDM seams. Air lance tests may also be used on PP chemical fusion seams.

Figure 10E–17 Typical GCL seam



The air channel test is conducted in accordance with ASTM D 5820 and illustrated in figure 10E–18. The test pressure varies based on the material type and thickness. The typical test pressures for 40 mil HDPE, LLDPE, and PP; 30 mil PVC; and 40 mil PVC are 25 to 30 pounds per square inch, 15 to 25 pounds per square inch, and 20 to 30 pounds per square inch, respectively. The associated allowable pressure drops over a 5-minute period are 4 pounds per square inch, 5 pounds per square inch, and 4 pounds per square inch, respectively.

An air lance test is conducted in accordance with ASTM D 4437 and illustrated in figure 10E–19. The test includes applying air pressure of 50 pounds per square inch through a 3/16-inch nozzle along the entire length of the seam. The nozzle is maintained no more than 2 inches from the seam. Defects in the seam will flutter under pressure, and small defects will whistle as the pressurized air passes through the defect.

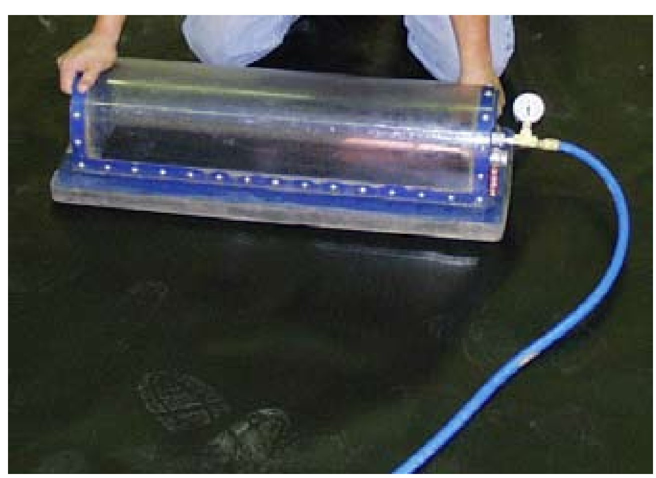
A vacuum box test is used to test extrusion welded seams and is conducted in accordance with ASTM D 5641 and illustrated in figure 10E–20. The seam to be tested is covered with soap and water and the vacuum box is placed over the area to be tested. A vacuum of 4 to 8 pounds per square inch is applied to the box and the area being tested in observed for bubbles which will appear to unbonded areas.

Destructive seam testing is often not required on the seams of animal waste storage pond liners. Destructive seam testing is recommended on trial seams to be conducted once or twice daily. A trial seam and test involves welding a seam that is not part of the actual

Figure 10E–19 Air lance test

Figure 10E–18 Air channel test

Figure 10E–20 Vacuum box test



pond liner, cutting specimens with a device similar to that shown in figure 10E–21, and testing the specimen in both peel and shear using a field tensiometer, as shown in figure 10E–22.

Appurtenances

Appurtenances for animal waste pond synthetic liners include pipe penetrations, attachment to structures, vents, and liner protection. Appurtenances should always be designed to prevent damage to the liner during installation or operation.

Pipe penetrations may be a pipe boot, concrete collar/pad, or bentonite (for GCLs). A pipe boot should be fabricated from the same material as the liner and fastened to the pipe and liner in a manner to prevent leakage, such as shown in figure 10E–23. Fastening to the pipe includes a neoprene gasket and metal bands or clamps to secure the boot to the pipe. Use of stainless steel bands/clamps is recommended. A sealant applied at the downstream edge of the boot to pipe connection is also recommended.

Concrete collars are often used for large pipe penetrations where a pipe boot is not practical. Use of a sealant between the pipe and concrete collar is recommended.

A pipe penetration through a GCL included excavation of a 3- to 4-inch-deep notch around the penetration, which is filled with powder or granular bentonite. This is overlain by a GCL with a hole for the pipe with a quarter pound of bentonite per square foot of area between the GCL liner and GCL collar, as shown in figure 10E–24.

The common methods of attachment to structures include mechanical attachments, embed channel, or adhesives.

Mechanical attachments to concrete structures should consist of concrete anchor bolts, neoprene gaskets, flat metal bar (batten strip), washers, and nuts. All metal components should be stainless steel or aluminum. A typical detail is shown in figure 10E–25.

An embed channel is a channel-shaped section of the same material as the liner that is embedded in the concrete while the concrete is still wet. Adjacent channels should be extrusion welded to prevent gaps between the channel sections. The geomemebrane is welded to the embed channel with a continuous extrusion weld as shown in figure 10E–26. Embed channels are available for HDPE, LLDPE, and PP.

Figure 10E–21 Test specimen cutter

Figure 10E–22 Field tensiometer (Source: Poly-Flex, Inc., 1995)

Figure 10E–23 Pipe boot (Source: CETCO)

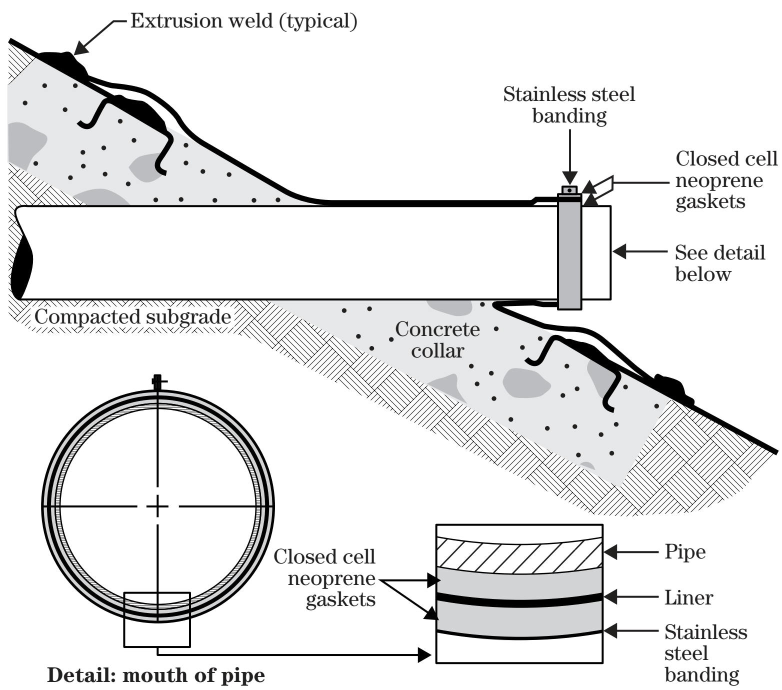


Figure 10E–24 GCL pipe penetration (Source: Poly-Flex, Inc.)

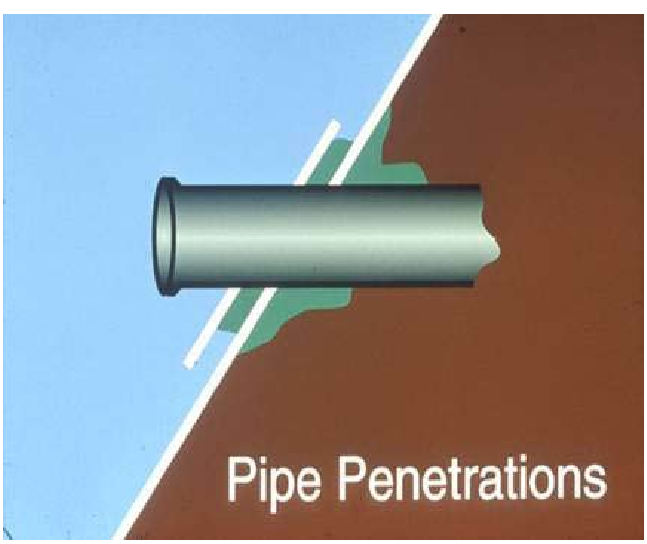


Figure 10E–25 Typical mechanical attachment (Source: Poly-flex, Inc.)

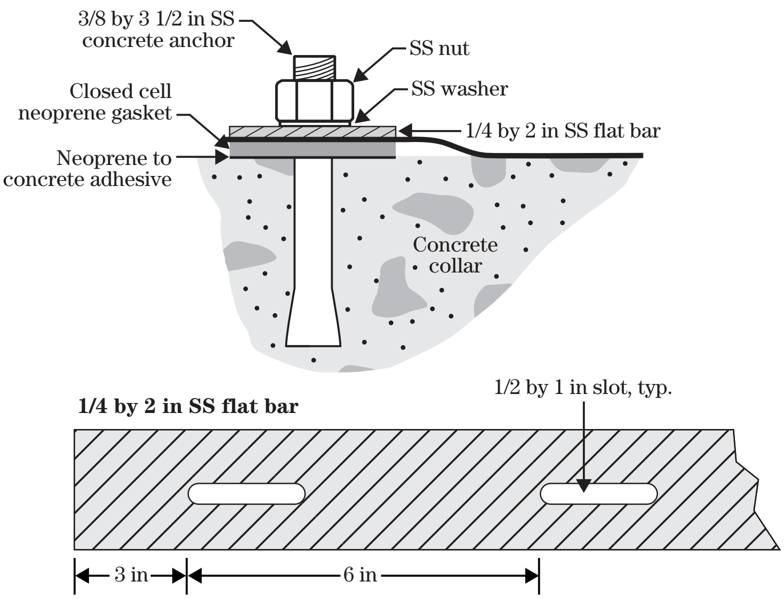
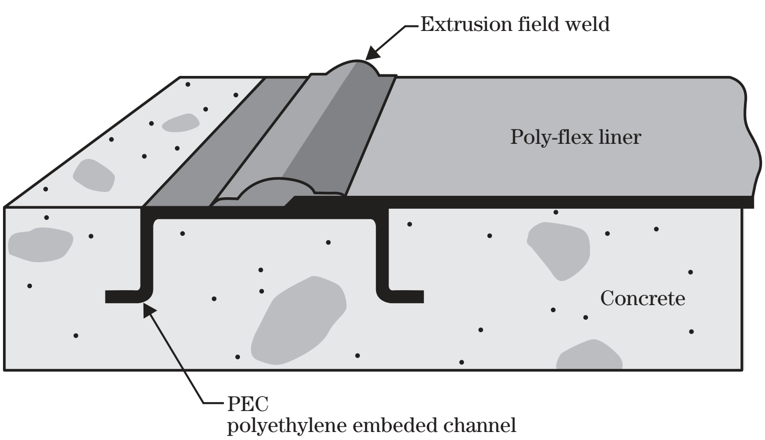


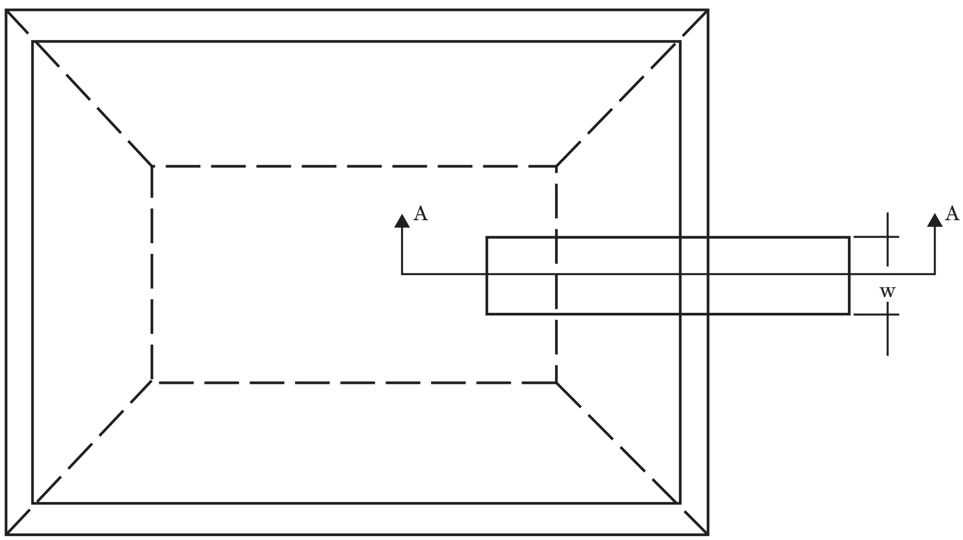
Figure 10E–26 Embed channel



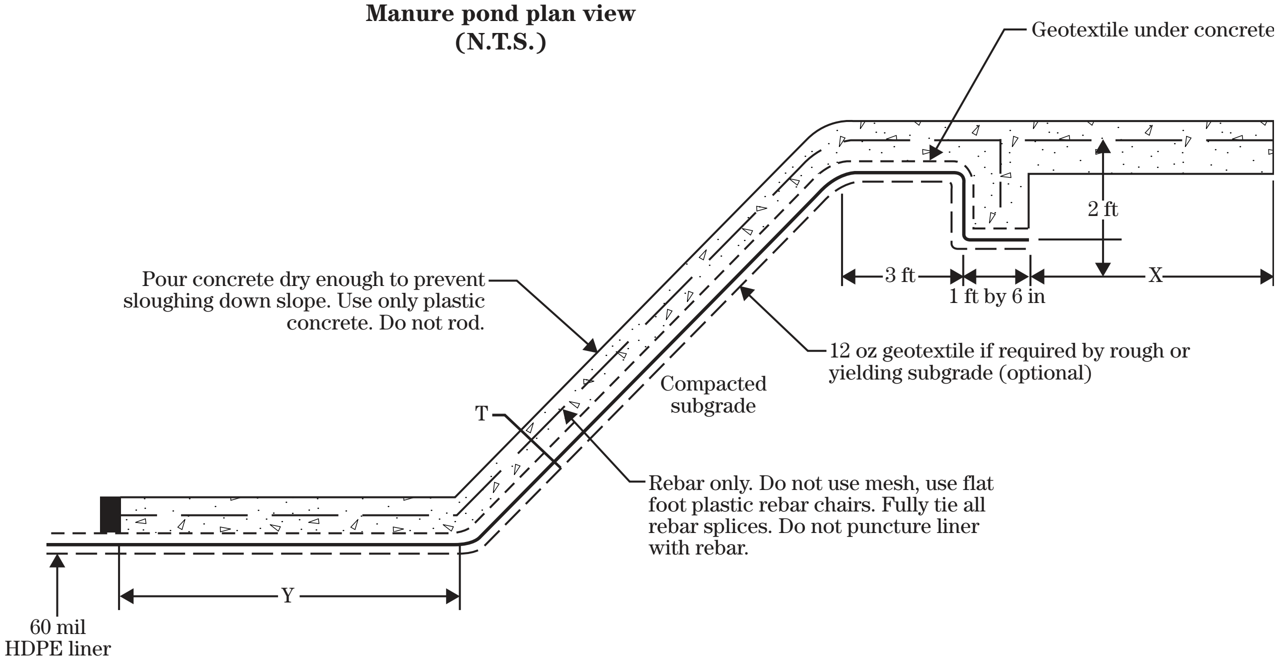
Liner protection from maintenance equipment such as agitators and pumps is often provided by concrete ramps, a geotextile pad, or an additional liner. A detail of a concrete ramp is shown in figure 10E–27.

Gas may build up beneath a liner due to a rising water table, organic soil or waste beneath the liner, or leaks within the liner. Where this is a concern, liner vents should be considered. Vents should be installed above the normal water line to prevent waste from entering the vent. Vents are typically spaced 30 to 50 feet around the entire perimeter of the liner. Covered and uncovered vents are shown in figures 10E–28 and 10E–29.

Figure 10E–27 Concrete ramp



Manure pond plan view
(N.T.S.)



Section A–A

Figure 10E–28 Uncovered liner vent

Figure 10E–29 Covered liner vent

Maintenance and repairs

Successful performance of animal waste pond liners requires some maintenance and often requires repair. The visible portions of the liner should be inspected for tears, punctures, or other damage. The interface of the liner with inlets, outlets, ramps, or other appurtenances should also be inspected. The level of the pond should be monitored to prevent overflow. Each time the pond is pumped down, a visual inspection of the entire liner is recommended. If the pond is agitated, special precautions should be taken in the area of the agitator. Ballooning of the liners indicates the presence of gas beneath the liner which is often the result of leaks.

Any observed damage should be repaired immediately. Burrowing rodents that could damage the liner should be removed from the area.

Any vents should be clear and the flaps free to release any gases beneath the liner. Vent covers that are missing or damaged should be replaced. Operation of the pond should insure that the waste level never rises to an elevation that would allow waste to enter the vents.

All failed seams should be repaired by installing a cap strip over the entire length of the failed seam. Cap strip should consist of the same material as the liner and extend beyond the failed seam a minimum of 6 inches. A repaired seam is shown in figure 10E–30. A failed seam on HDPE, LLDPE, or PP may be repaired by extrusion welding along the entire length of the seam. Small defects in EPDM liners may be repaired with a cover strip that extends a minimum of 4 inches beyond the damaged area. The cut edges of reinforced patches must be sealed with an extrudant to prevent wicking of waste through the reinforcement.

If a GCL is damaged, the area should be completely exposed and all soil removed from the top of the GCL. A GCL patch should extend a minimum of 12 inches beyond the damaged area. Granular bentonite should be placed between the patch and liner at a rate of 1 pound per 2 square feet of area covered to minimum width of 6 inches.

Figure 10E–30 Liner repair

Example

A half acre (total bottom and sides area) AWSP is to be constructed at a site where the soils are classified as SP and SM with some gravel in accordance with the Unified Soil Classification System. The excavated soils will not be used as cover soil. The depth of the pond is 10 feet. The depth to the seasonal high ground water is 10 feet. The site is located in a rural area several hours from experienced installers and geomembrane welders. The landowner does not efficiently separate solids from the waste and applies the waste to adjacent fields twice a year.

Since the site soils consist of sandy materials, construction of a compacted clay liner would require importing clay materials. Geosynthetic liners that require cover soil such as PVC and GCL should not be considered first. Materials such as HDPE, LLDPE, and PP that require special welding procedures for seams should not be considered first.

Materials such as EPDM, PVC, and GCL are best suited for installation by less experienced installers. Due to the flexibility of EPDM, PP, RPP and PVC, the materials could be delivered in large panels requiring only one field seam. Since the excavated soils will not be used for cover soils, obtaining cover soil from another source would be an additional expense for PVC and a GCL. The EPDM and PP liners do not have to be covered and should be the first considered.

The NRCS Conservation Practice Standard 521A, Pond Sealing or Lining—Flexible Membrane, lists the minimum thickness of the acceptable geosynthetic liner materials. The NRCS practice standard minimum thickness for EPDM is 45 mil and for PP is 40 mil. A GCL is also allowed.

The site soils contain some gravel. Removal of particles over 3/8 inch and sharp particles is required to prevent damage of the liner. An altenative to removing all the gravel is to include a nonwoven geotextile or sand padding beneath the liner.

The seasonal water table is near the bottom of the pond. Design should consider constructing approximately 2 feet of the pond above the ground to raise the bottom of the pond above the water table. This will affect the design of the site considerably because a wider berm will be needed for equipment access and the anchor trench. A perimeter trench may also be an alternative to keep the water table from impacting the liner.

The rising water table may induce gas pressure beneath the liner. Since the site soils consist of sand, the addition of a geotextile to allow migration of gas to the sides is not necessary. Vents above the high water line along the perimeter of the pond should be installed.

The landowner does not separate solids and will pump liquid from the pond. Equipment access ramps and pads should be installed to allow access of an agitator and pumps. A fence around the pond is required by the practice standard. A safety ladder should be considered to allow escape upon accidental entry. A staff gage should be used to indicate when the pond should be emptied. Diversions should be designed to keep all possible surface water runoff out of the pond.

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United States
Department of
Agriculture

**Soil
Conservation
Service**

Agricultural
Waste Management
Field Handbook

Chapter 11 Waste Utilization

Chapter 11 Waste Utilization

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Chapter 11 Waste Utilization

651.1100 Introduction

Water and air quality protection requires proper management of organic waste from agricultural operations. Recycling of agricultural waste materials by land application for plant uptake and crop production is a traditional and proven waste utilization technique. Properly done, recycling by land application and crop uptake is an environmentally sound method of waste management.

The primary purpose of this chapter is to give information on utilization of livestock and poultry manure. It describes methods for applying animal waste to land and lists cautions and restrictions for specific methods. Other methods are discussed, but not presented.

Other waste utilization methods include handling products of solids separation and composting, biogas generation, and wetlands creation. Solids from solids separation operations can be used for bedding for livestock; they can be mixed with grains and other materials and re-fed to cattle; and they can be dried, bagged, and sold on the retail market. Liquids from the solids separation operation must be accounted for in waste management operations.

Waste materials can be used for biogas generation. The gas can be used for powering electricity generating equipment, the electricity from which can be either used onfarm or sold to a local utility. The gas can also be used directly to run heating equipment for some livestock, such as farrowing houses or pig nurseries, and for poultry operations, such as egg laying operations. The volume of waste material and the content of elements do not diminish significantly through the biogas generation process.

Composting of organic materials to reduce their reactivity or to stabilize the material is a viable waste management component. The agricultural producer must have the necessary skills and equipment to manage composting operations, and there must be a need for or use of the composted material. Waste that needs to be managed using composting techniques include dead bird carcasses (poultry) because an environmentally safe utilization alternative is not available and such highly unstable nitrogenous material as livestock manure because adequate land is not available or the crop nutrient needs are insufficient. Sale of composted materials as nursery rooting materials or on the retail market makes composting a viable waste utilization component.

Use of constructed wetlands falls peripherally under the utilization topic in terms of providing a nutrient source for aquatic vegetation associated with the wetlands. The primary function of wetlands used in waste management systems is treatment. Effluent from wetlands should be monitored to assure that state water quality standards are being met. Influent quality of wastewater being supplied to the wetlands should be checked to assure that nutrient strength is not excessive for the aquatic vegetation involved.

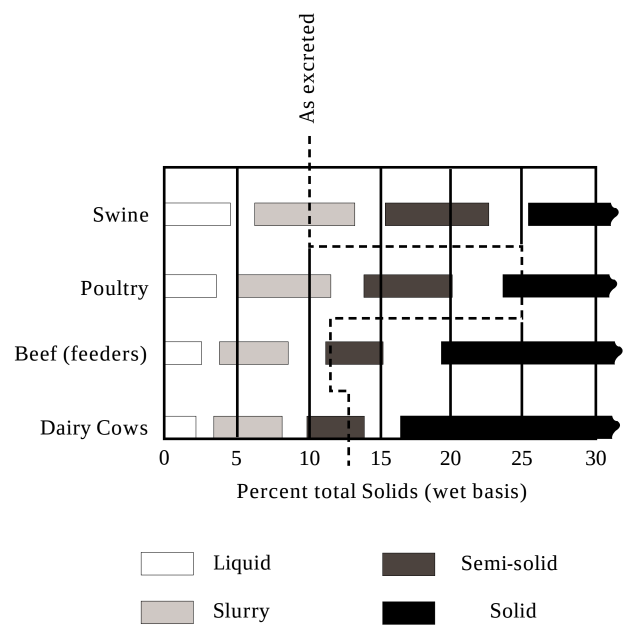
Agricultural land is also the recipient of many other wastes, such as municipal wastewater and sludge, food processing waste, and waste classified as hazardous under the Resource Construction and Recovery Act. These other wastes have widely varying characteristics requiring special design considerations that are not treated in this handbook.

Utilization of waste agrichemicals is not in the scope of this chapter. The chapter on pesticide management describes how to properly manage and dispose of waste agrichemicals (to be added).

Other than those where the waste products are used by offsite sources, waste treatment options described above have a resultant waste material that must be used on the farm. The option available to the farm owner/operator ultimately comes down to land application for recycling purposes. Consequently, this chapter's primary function is to provide information on utilization of animal manure and wastewater applied on agricultural land for crop production and environmental protection.

As a review of information presented in chapter 9, consistency of the waste controls how the waste is handled. Total solids (TS) content in the waste controls consistency. Wastes are classified in four categories according to their consistency—solid, semi-solid, slurry, and liquid. As the moisture content varies, the handling characteristics vary. Chapter 4 gives the moisture content of manure (feces and urine) as excreted; however, changes in consistency as moisture is added or removed must be taken into account in planning a waste management system. The consistency of manure when it is applied to the land affects the type of equipment used and the amount applied.

Figure 11–1 Relative handling characteristics of different types of manure and percent total solids (ASAE 1990)



651.1101 Waste consistency

Ruminants tend to produce a manure that is in the semi-solid range when excreted; swine excrete a slurry manure; and poultry excrete a manure that is classified as a solid. This clearly points out the need to be knowledgeable of waste consistency in terms of total solids to properly select waste management system components.

(a) Solid

Waste with a high percent total solids—called solid waste—is produced by a wide variety of agricultural, municipal, and industrial operations. Animal-feeding operations, particularly feedlots, yield large quantities of solid organic wastes that can be applied to land. Manure that is more than about 20 percent solids (fig. 11–1) can be handled as a solid. A mixture of manure, bedding (straw or wood chips), and feed waste is generally a solid. It is transported by box/open spreaders or dump trucks to the land for application.

(b) Semi-solid

Semi-solid waste has a somewhat firm consistency. With reference to figure 11-1, total solids content of semi-solid animal manure can range from 10 to about 22 percent, depending on the animal species. Semi-solid manure generally can be transported and spread using the same box/open spreaders and dump trucks used for solid manure.

(c) Slurry

Slurry generally is associated with confined feeding operations for cattle and swine. The feces and urine as excreted behave as a slurry rather than as a solid or a liquid. The solids content of slurry ranges from about 5 to 15 percent except as noted below. In this range, manure has fluid handling characteristics, but requires special pumping equipment. It can be transported by either tank wagon or pump and pipeline. Pump and pipeline are more economical for transporting large volumes of slurry because of the time and labor requirements for tank wagons. Slurry can be applied to the land by sprinklers that have a large nozzle, by broadcasting from slurry tanks, or by injection under the ground surface. Because of its propensity to cause odors and pollute water, slurry should be incorporated immediately into the soil profile.

If slurry material from confined livestock facilities is properly agitated, it generally flows readily to a pump inlet. It may have a solids content of as much as 10 or 15 percent for swine and cattle manure and 20 percent for some poultry manure. The more viscous materials are pumped into tank wagons by high-capacity, low-head pumps or are drawn in by vacuum pumps. On occasion, additional water is required for easier agitation and pumping.

Swine and poultry manure with about 12 percent solids and cattle manure with about 7 percent solids can be handled by certain types of large bore irrigation equipment. Large gun-type sprinklers must be powered by relatively low-capacity, high-head pumps that have chopping blades.

Swine or poultry manure diluted to less than 7 percent solids and cattle manure diluted to less than 4 percent solids can be applied by most irrigation equipment if the manure is free of fibrous material. Standard centrifugal pumps, regular sprinkler nozzles, or gated pipes can be used. If the material is distributed in graded furrows, the tail water should be recovered to prevent the runoff from polluting the surface water.

Figure 11–2 can be used to determine the amount of water needed to dilute manure for a specific pumping consistency. For example, assume that cattle manure that is 20 percent solids must be diluted for use with a standard irrigation sprinkler. The desired solids content is 4 percent. According to information in figure 11–2, roughly 30 gallons of water are needed per cubic foot of manure.

Figure 11–2 Gallons of water required per cubic foot of material for dilution to pumping consistency

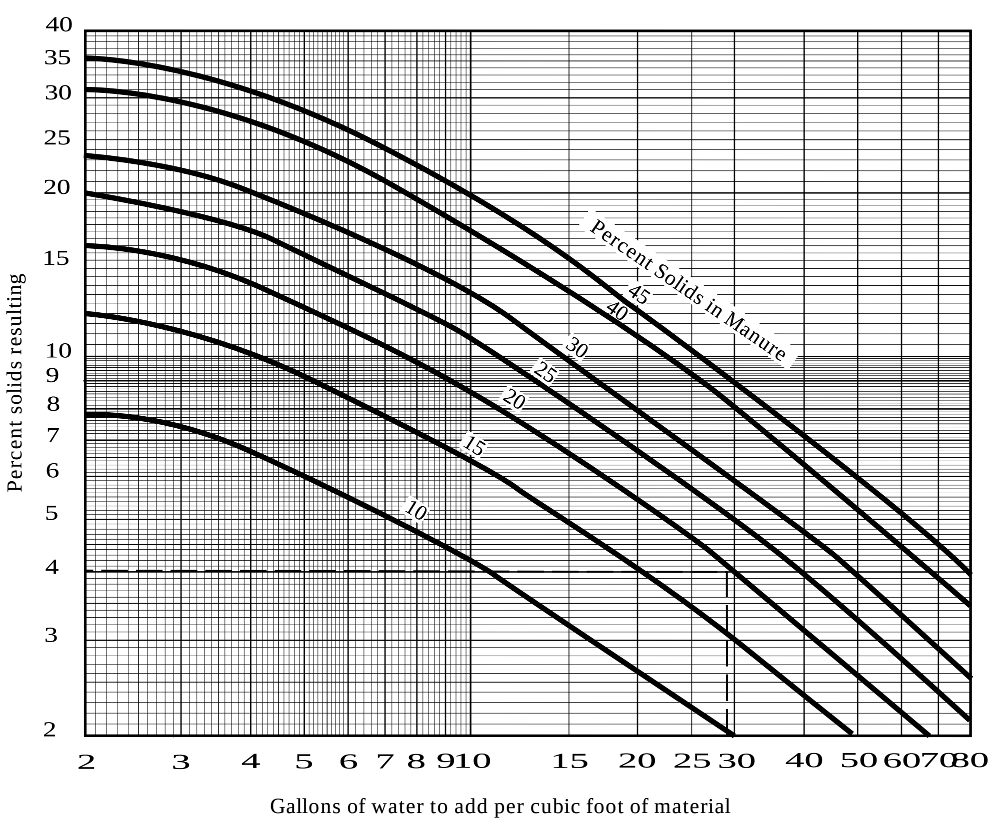


Figure 11–2 is based on the equation:

$$G = \frac{7.48\left(P_o - P_d\right)}{P_d}$$

where:

G = Gallons of water required to be added to mixture per cubic foot of manure
P_o = Original percent of solids in the mixture
P_d = Desired percent of solids in the mixture

Important characteristics of different manure during storage in slurry form include:

- Poultry manure is heavy and dense and generally stratifies with a liquid layer forming on top.
- Swine manure tends to remain in suspension. Solids separation using short-term settling is difficult.
- The solids in cattle manure generally rise to the top and form a crust. This is particularly true if long hay or silage is fed to the cattle or if bedding is collected with the manure.

(d) Liquid

Liquid waste has solids content of 5 percent or less. This consistency generally is produced where manure is diluted by wash water, flushing water, rainfall or runoff, or snowmelt. A common example is the liquid in a waste storage pond used to store runoff from a feedlot or outside dairy housing. Liquids also result from food processing operations and from municipal wastewater treatment.

Liquid waste can be handled by any type of sprinkler system or by such flood irrigation methods as furrows or borders. Waste application systems can often be combined with surface irrigation. Manure solids distribution, hence nutrients, may be uneven if flood irrigation methods are used because solids tend to settle out near the turnout.

If adequate water is available for irrigation, the system can be designed for maximum use of the manure for crop fertilization while meeting the consumptive use requirements; for example, the water needs of the crop. A screen must be installed in the system for removal of long fibers, hair, and other debris before irrigation begins.

651.1102 Land application

This section describes how manure can be applied to land to furnish nutrients for crops without degrading the environment.

(a) The conservation plan

Land application of agricultural waste for crop production requires careful planning. Conservation plans developed for animal-feeding operations should include a plan for agricultural waste management needs and must address the overall nutrient management requirements for the farm or ranch operation. Chapter 2 gives details of the planning considerations. The goal should be to recycle nutrients in the waste material as fertilizer in amounts that can be used by the crop and will not degrade the environment.

The nutrients in the animal waste to be land applied must be accounted for in the nutrient management plan for the farming operation. Realistic crop yield goals must be established that recognize soil limitations and provide a fertility program that balances the nutrient application among all sources—manure, organic residue, soil minerals, commercial fertilizer, irrigation water, and nitrogen fixing plants.

(b) Benefits of recycling

The most obvious benefit of recycling manure to the land is the fertilizer value. The return of the nutrients saves:

- Money otherwise spent for commercial fertilizer
- Natural resources
- Energy required to produce chemical fertilizers

The supply of easily mined phosphate for fertilizer is declining and needs to be conserved. More than 500 billion cubic feet of natural gas are used annually to produce ammonia nitrogen for fertilizer (Nelson 1975).

Other onfarm benefits result from land application of manure. Manure adds organic matter to the soil, which improves soil structure, infiltration, and tilth. Soil erosion is controlled, and the moisture holding capacity is increased. Many farmers report that the fields on which manure has been applied always seem more loose and moist. Another benefit is that phosphorus and the organic part of the nitrogen are released slowly from the manure by the action of micro-organisms. This conserves these elements and makes them available to crops throughout the growing season. A disadvantage is that the nutrient release rate generally cannot be controlled.

Off-farm benefits also accrue. Properly applying manure reduces the potential of overenrichment of lakes and streams and also decreases the possibility of ground water contamination.

(c) Application methods

The land application method should be based on the type and consistency of waste available, management of the confined animal operation (including waste management system), physical features of the farm, operator preferences, and availability of labor. No one correct method of waste application is always the right one to use. Generally, several alternatives are available. For the purpose of this discussion, waste application methods are categorized into two groups—pumped and hauled. The travel distances and application rates achievable with the application equipment must be addressed in preparing nutrient management plans and planning waste management systems.

Whether hauled or pumped, applied waste should be incorporated into the soil as soon as possible to preserve nutrient value and reduce the opportunity for runoff or odor complaints. Sections 651.0304 and 651.0802(b) provide guidance on management to minimize problems where wastes are applied on pasture.

(1) Pumped application methods

Pumped application methods require either a liquid or slurry waste material, a delivery system of pump and conveyance, and suitable application equipment, such as large gun-type sprinklers, manure guns, or gated pipe. Gravity-fed conveyance systems can be substituted for pumps where the specific operation provides the elevation differential required for operation.

Because pumped irrigation application applies waste at a much faster rate than hauling, special consideration must be given to soil characteristics as follows (Horsfield 1973):

- Soils that have very low internal drainage and a very slow intake rate result in runoff and ponding, which means a greater chance for unequal infiltration and potential stream pollution.
- A sloping terrain at the application site makes it increasingly important that waste application rates are less than soil intake rates to ensure no runoff to watercourses.
- A high water table means that nutrients produced from waste decay have to move only short distances to contaminate the ground water. Shallow or sandy soils that have little filtering capacity increase the potential for a problem.
- Excessively drained, low yield-potential soils are a problem because crops remove less of the applied nutrients and irrigation water moves through the soil too rapidly for adequate assimilation.

The design of a pumped application system is site specific. The local irrigation specialist and irrigation guides should be consulted where available. If the pumped system is to be used for both application and the irrigation water supply, special care should be taken to size the system to meet the water consumption requirements of the crop.

(i) Sprinkler systems—Sprinkler systems are widely used to apply liquid manure and agricultural wastewater. The type of irrigation system depends upon the consistency of the manure and wastewater. Particle size of the solids contained in the manure and wastewater also affects the applicability of the particular type of irrigation system.

Liquid consistency of the waste can be assured by the addition of dilution water (fig. 11–2), removal of solids, or both. With proper screening, waste materials that meet the liquid consistency test can be applied with any type sprinkler system. Pump intake screens should be sized with openings no larger than the smallest sprinkler orifice.

Slurry can be applied using special pumping equipment and sprinklers that have a large nozzle or manure guns that have a flexible nozzle. Wastes containing trash, abrasives, bedding, or stringy material are not suitable for most sprinklers unless preconditioned by chopping or grinding.

(ii) Pipelines—Pipe friction losses for water that has solids are higher than those for clean water. The velocity in pipes should be less than 5 feet per second (fps), with a minimum of 2 fps to prevent sedimentation. Table 11–1 gives the relative increase in friction loss for slurries as compared to clean water for asphalt-dipped cast-iron pipe that is 6 to 10 inches in diameter. Although friction ratios will be slightly higher for smoother pipe materials at high velocities, the ratios below are satisfactory for most design conditions using PVC. Head losses in valves and fittings because of the turbulence should be approximately equal to those for clean water.

Example 11–1:

An 8-inch pipeline (PVC, IPS, SDR = 32.5, C = 150) is to deliver 550 gpm of slurry containing 10 percent solids. The friction loss for clean water is 0.19 psi/100 ft., and the velocity is 3.42 fps. From table 11–1, the factor (ratio) for slurry vs. clean water is 2.5 at 3.5 fps with 10 percent solids. The friction loss for the slurry would be calculated as:

$$\frac{0.19 \text{ psi}}{100 \text{ ft}} \times 2.5 = \frac{0.48 \text{ psi}}{100 \text{ ft}}$$

Although pipe friction losses might be higher for wastewater than for clean water, friction losses generally are a small percentage of the total power requirement in a sprinkler system. When the same pump is used for pumping both slurries and clean water, the pump might operate at different points on the pump curve for the two liquids. The effects when pumping slurries are a marked increase in brake horsepower requirements, a reduction in head produced, and some reduction in capacity. The increased horsepower requirement is caused by the higher fluid viscosity and is necessary to overcome the velocity head loss and the pipe friction losses. To account for the differences associated with presence of solids and higher viscosity, it is satisfactory to increase the power unit rating by 10 percent as a rule of thumb for situations where friction loss ratio exceeds 1.0.

Table 11–1 Friction loss ratio, slurries vs. clean water (pipe, 6" to 10" diameter)

Velocity	- - - Percent solids - - -					
fps	4	5	6	7	8	10
1.0	1.1	1.5	2.1	2.9	4.0	5.3
1.5	1.0	1.2	1.5	2.1	2.5	4.0
2.0	1.0	1.0	1.0	1.6	1.9	3.3
2.5	1.0	1.0	1.0	1.3	1.6	2.9
3.0	1.0	1.0	1.0	1.2	1.5	2.7
3.5	1.0	1.0	1.0	1.1	1.3	2.5
4.0	1.0	1.0	1.0	1.0	1.0	2.4
4.5	1.0	1.0	1.0	1.0	1.0	2.3
5.0	1.0	1.0	1.0	1.0	1.0	2.2
5.5	1.0	1.0	1.0	1.0	1.0	2.1
6.0	1.0	1.0	1.0	1.0	1.0	2.0
6.5	1.0	1.0	1.0	1.0	1.0	2.0
7.0	1.0	1.0	1.0	1.0	1.0	2.0

Source: Adapted from Colt Industries Hydraulic Handbook, figure 44, Fairbanks Morse Pump Div., 11th Ed.

Table 11–2 Maximum application rate (in/hr)

Soil texture	- - - Application amount in inches - - -						
	0.25	0.5	0.75	1.0	1.25	1.5	2.0
Sand	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Loamy sand	6.00	6.00	4.83	4.22	3.86	3.62	3.32
Sandy loam	4.91	2.97	2.32	1.99	1.80	1.67	1.51
Loam	3.11	1.69	1.21	0.98	0.84	0.74	0.62
Silt loam	2.70	1.45	1.03	0.82	0.70	0.61	0.51
Sandy clay loam	1.74	0.96	0.69	0.56	0.48	0.43	0.37
Clay loam	1.27	0.68	0.48	0.39	0.33	0.29	0.24
Silty clay loam	1.09	0.57	0.40	0.32	0.26	0.23	0.19
Sandy clay	0.61	0.33	0.23	0.19	0.16	0.14	0.12
Silty clay	0.84	0.44	0.30	0.24	0.20	0.17	0.14
Clay	0.39	0.21	0.14	0.11	0.09	0.08	0.07

Note: This table is for infiltration rate for full cover conditions and initial moisture content at 50 percent of the available water capacity. Field capacity of sand through sandy loam is assumed to be at 1/10 bar.

***(iii) Application rates and amounts*—**For total solids content of 0.5 percent or less, sprinkler application rates should be consistent with the local irrigation guide recommendations, with no adjustment. If no local irrigation guide data are available, application rates in table 11–2 (based on soil texture) can be used for irrigation system design and management to help avoid ponding and runoff.

For total solids content in the wastewater of 0.5 percent or greater, application rates from the irrigation guide or table 11–2 should be reduced according to the information in table 11–3. The reduction coefficients in table 11–3 are based solely on decreases in hydraulic conductivity because of a layer of manure that forms on the soil surface during irrigation and has a lower hydraulic conductivity than the soil. Further reductions may be necessary in some situations, such as applications of wastewater with salt concentrations sufficient to disperse clay aggregates. Salt content of the wastewater should be determined to assess its effect of the intake rates of the soil where it will be applied.

Example 11–2:
The land user wants to apply 1 inch of wastewater with a 5 percent solids content on a loam soil. What is the allowable application rate in inches per hour?

Table 11–3 Reduction coefficients by percent solids

Soil texture	Percent solids (by wt) 0.5	1.0	2.0	3.0	5.0	7.0	10.0
Sand	0.88	0.55	0.31	0.22	0.13	0.10	0.07
Loamy sand	0.70	0.54	0.37	0.28	0.19	0.14	0.10
Sandy loam	0.87	0.77	0.63	0.53	0.40	0.32	0.25
Loam	0.97	0.93	0.88	0.83	0.74	0.67	0.59
Silt loam	0.98	0.95	0.91	0.87	0.81	0.75	0.68
Sandy clay loam	0.99	0.97	0.95	0.92	0.87	0.83	0.78
Clay loam	0.99	0.99	0.98	0.97	0.94	0.92	0.89
Silty clay loam	1.00	1.00	0.99	0.99	0.98	0.97	0.96
Sandy clay	1.00	1.00	1.00	1.00	0.99	0.99	0.99
Silty clay	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Clay	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Maximum application rate from table 11–2 is 0.98 inch per hour. The reduction coefficient from table 11–3 is 0.74. The allowable application rate is:

$$0.98 \times 0.74 = 0.73 \text{ in/hr}$$

Example 11–3:
A land user wants to apply wastewater with a 5 percent solids content on a silt loam soil that has dense vegetation. The estimated surface storage is 0.2 inches, before any runoff would occur. The land user would like to apply 1.2 inches at a set. What is the allowable application rate?

Because 0.2 inches can be applied before surface runoff starts, the minimum amount that must infiltrate into the soil is 1.2 less 0.2, or 1.0 inch. From table 11–2, the maximum application rate is 0.82 inches per hour. To determine the application rate for 5 percent solids, the maximum application rate for clean water is multiplied by the reduction coefficient for 5 percent solids. The factor is 0.81 from table 11–3. Therefore, the application rate for 5 percent solids is:

$$0.82 \text{ in/hr} \times 0.81 = 0.66 \text{ in/hr}$$

The amount of application must be based upon either the nutrient requirements of the crop or consumptive use requirements of the crop, whichever factor is limiting. For example, to achieve a desired nutrient loading, the irrigation requirement might be exceeded. In this case, irrigation requirements would govern because meeting the nutrient requirement requires an excess water application, leading to excessive deep percolation and leaching of nutrients below the root zone. If meeting the irrigation requirement is not a management objective, water requirements must still be considered so that excess leaching or runoff can be avoided.

***(iv) Management considerations*—**Waste must be applied in a manner that

- Prevents runoff or excessive deep percolation of the wastewater,
- Applies nutrients in amounts that do not exceed the needs of the crop, and
- Minimizes odors from the waste being applied.

Other management considerations include flushing systems with clean water to clear manure solids from pipelines and to wash waste materials from leaves of the crop, and maintenance of equipment.

(2) Hauled

Hauling waste requires a means of transferring the waste from a collection or storage area to a container, transporting the container and waste to the application area, and spreading the waste material on the land. All consistencies of waste are suitable for hauling.

Hauling equipment provides a mechanism for evenly applying or spreading the waste to the application area. Manure spreaders or box spreaders are used primarily for solid and semi-solid manure, and tank wagons (commonly called honey wagons) and tank trucks are used for slurry and liquid manure. Injection equipment can be added to liquid and slurry spreaders for subsurface injection where odors are a problem or where maximum nutrient conservation is desired. Large volume tanker type equipment can transport the waste to the general area of application, where the waste is transferred to the application equipment. The separation of hauling equipment from the application equipment allows the economical transport of waste over considerable distances.

When transporting wastes to a field, special consideration should be given to soil and climate characteristics that limit the opportunity for waste application. As discussed in a later section, soil texture and drainage characteristics can limit trafficability at application sites. Excess traffic on the sites during certain periods of the year can lead to soil compaction and eventually to excessive surface runoff.

(i) Pumping vs. hauling—Pumping of animal waste generally is more economical than hauling. The most important factors in making the economical determination are the volume of waste to be applied, time requirements, capital investment, and labor and fuel costs. Figures 11–3 and 11–4 provide a method of comparing time needed to empty a waste storage facility by pumping or by hauling with a tank wagon. The availability of existing equipment must also be considered.

Example 11-4:
A dairy operation has a 34,000 cubic foot aboveground storage structure that needs to be emptied and a pump and pipe system that can deliver 275 gallons per minute to the field. A 1,000 gallon tank wagon is available to haul manure. It takes 17 minutes to fill the tank and make a round trip to the field. The operator estimates 1 hour of labor for pipe moving for each acre inch of waste applied, at a cost of $7 per hour.

Questions:

1. How much actual pumping time is required to empty the storage structure using the pump-pipeline system? Using the tank wagon?
2. What is the labor cost for pumping the waste to the field as compared to that for using a tank wagon and hauling?

Pump-pipeline—

$$\begin{aligned}\text{Storage} &= \frac{34{,}000 \text{ ft}^3 \times 12 \text{ in}}{43{,}560 \text{ ft}^2/\text{ac} \times 1 \text{ ft}} \\ &= \frac{34{,}000 \times 12 \text{ in}}{43{,}500} \\ &= 9.4 \text{ ac-in}\end{aligned}$$

Enter figure 11–3 at 9.4 acre-inches pumped and proceed vertically to the curves for 250 gpm and 300 gpm; 275 gpm will be halfway between the curves. Go horizontally and read 15.5 hours pumped.

Tank wagon—Enter figure 11–4 at 34,000 cubic feet storage. Move up vertically to the curve for a 1,000 gallon tank wagon. Move horizontally through the number of loads line (255 trips) to the cycle time (17 minutes), which is between the 15 and 20 minutes per cycle lines. Then move down vertically to the removal time in hours (about 70 hours).

Actual time to remove 34,000 cubic feet is 72.3 hours:

$$\frac{34{,}000 \text{ ft}^3 \times 7.5 \text{ gal/ft}^3}{1{,}000 \text{ gal tank/cycle}} \times \left(17 \text{ min/cycle} \times \frac{1 \text{ hr}}{60 \text{ min}}\right)$$

Pumping would require about 15 hours as compared to 70 hours to haul the waste to the field.

Labor requirement—From given information, 1 hour of labor is required for each acre-inch of waste applied; therefore, for 9.4 acre-inches, 9.4 hours of labor are required.

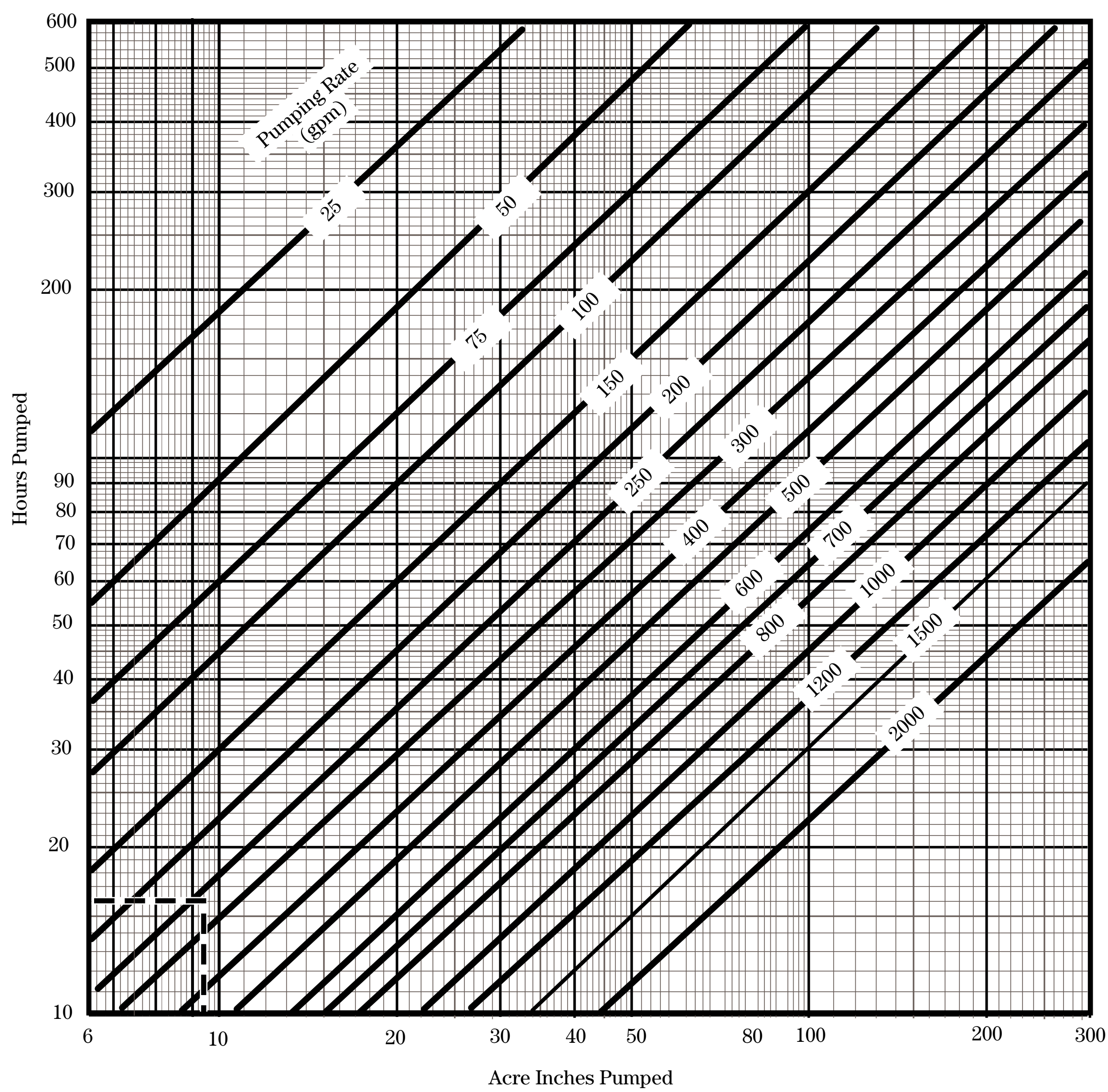
$$\text{Labor cost} = 9.4 \text{ hr} \times \$7/\text{hr}$$
$$= \$65.80$$

Tank wagon—Labor costs for hauling can be calculated by multiplying the emptying time by the hourly labor rate.

$$\text{Labor cost} = 72 \text{ hr} \times \$7/\text{hr}$$
$$= \$504.00$$

Labor costs for hauling wastes to the field are seven times the labor costs for pumping.

Figure 11–3 Acre inches pumped in given time at various pumping rates



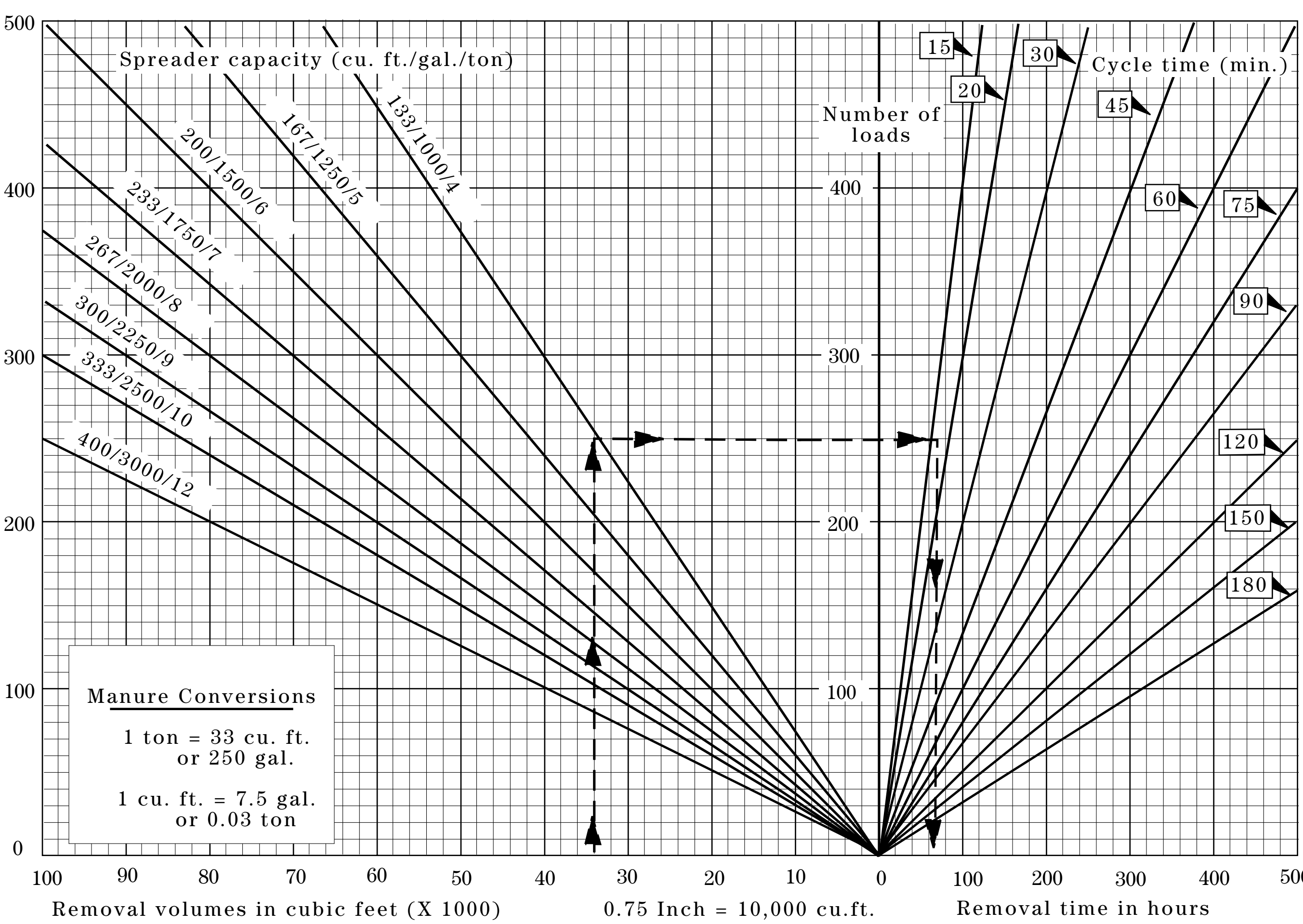
The actual cost of pumping as compared to hauling involves much more than just an analysis of labor cost, even though labor may be the largest component in many cases. Other factors include fuel costs, capital investment, maintenance, and availability of power. Even though a worker may not be physically observing a pump system during the entire pumping period, some attention is required. Therefore, the total labor cost for pumping could be underestimated. Dilution of the waste in the storage structure to make it pumpable and agitation requirements for both the pumping and hauling processes also need to be evaluated.

(d) Application management

Successful land application of organic waste programs start with good planning. Success is measured in terms of sound economics and environmental protection. Consequently, plans must be in concert with the physical, managerial, and economic limitations of the farming operation. See chapter 2 for guidance.

The key features of a waste utilization plan include details about objectives, rates, quantities, and timing.

Figure 11–4 Removal time for various cycle times and spreader capacities



(1) Objectives

The primary objective of a utilization program is to use the nutrients for crop production while minimizing negative water quality impacts. A secondary objective is improvement of the soil profile through increased organic matter amendment. Where application is on pasture, the final objective is to use nutrients to grow forage while timing the application to avoid rejection of the forage by livestock.

(2) Rates and quantities

Liquid waste materials must be applied at a rate that is compatible with the infiltration characteristics of the soil. For example, if a soil has a slow rate of intake, apply waste materials at a slow rate. Total quantities must not exceed the amount that can be used by the crop being grown or that can be safely stored in the root zone for carryover to the next crop. Rates and quantities must be carefully controlled on sites that have a high water table.

(3) Timing

Organic waste should be applied:

- With mineralization rates considered and as close to the time of crop nutrient needs as possible. Crop growth stage curves should be consulted.
- On days when winds are relatively calm so that aerosols and odors are prevented from drifting onto neighboring areas, thus reducing odor complaints.
- When the ground is not frozen or snow covered.
- During periods that will result in minimizing leaching and runoff of the waste components.
- When the soil moisture content is such that excessive soil compaction from equipment traffic is not promoted.
- Early in the day when the ground and air are warming, as opposed to late in the day when the temperature is dropping and the air is settling.

651.1103 Salinity

Salinity (saline or sodic soils) is not a problem in areas that receive high rainfall amounts and have soils that are naturally leached. Excess soluble salt, however, can cause problems on some land in low rainfall areas, and the application of any material containing salt must be limited. Germination suffers and yields are reduced if the soils in these areas are not managed to minimize salt accumulation.

Poor seed germination and seedling growth have been experienced in humid areas where large amounts of broiler litter or manure have been applied just before planting time. This situation lasts only until rainfall can dilute the salts accumulated in the seed germination zone. A more probable cause of poor germination and seedling growth is the high levels of ammonia associated with the poultry manure rather than excess soluble salts. Excess soluble salts reduce the amount of soil water available to plants and can cause nutrient imbalance or deficiencies that restrict plant growth (see section 651.0604(b) in chapter 6).

Many saline or sodic soils can be farmed successfully if an abundance of irrigation water is available to leach excess salts below the root zone. Because all irrigation water contains some level of soluble salts, the application of manure to irrigated land adds an additional source of salt.

Guidelines have been developed for using waste storage pond water on cropland to minimize the risk of reducing crop yields (Sweeten 1976). The guidelines were developed primarily for data collected in the Midwest and should be used where local information is not available and when natural leaching cannot be assured.

The soluble salt content of liquid and slurry wastes in storage vary from one storage to another. It also varies during the year in any one storage. The soluble salt content can be estimated by measuring the electrical conductivity of the pond water. Electrical conductivity is reported in units of millimhos per centimeter (mmhos/cm) or micromhos per centimeter (µmhos/cm). One millimho per centimeter is equal to 1,000 micromhos per centimeter. The relationship between salt content and electrical conductivity varies from one storage facility to another, but is generally consistent in the same facility. Sweeten found that 1 mmhos/cm in a pond was equivalent to 1,900 pounds of soluble salt per acre-foot of water; others have referenced as much as 4,200 pounds of salt per acre-foot as equivalent to 1 mmhos/cm. Table 11–4 presents typical total salts and electrical conductivity for wastes that may be applied to agricultural land.

Where natural leaching does not occur, the salt content of waste storage ponds must be considered. If sufficient salts are present in the pond to cause problems, the pond contents should be diluted with good quality water or application volumes should be limited.

Figures 11–5 through 11–7 can be used to determine appropriate dilution factors and application rates. The dilution factors are based on an annual application rate of waste plus clear water of 24 inches. If application rates are less, annual soils tests are recommended. Where no opportunity for dilution exists and undiluted wastewater is applied as recommended in figure 11–8, annual soils tests are a must. Dilution needs related to soil texture generally can be ignored where adequate leaching water can be applied by irrigation.

Table 11–4 Total salts and electrical conductivity for various waste material (Stewart 1975)

Source of waste	Total salts	Electrical conductivity
	(mg/L)	(mmhos/cm)
Beef cattle waste	44 – 544	0.3 – 3.9
Feedlot runoff	1,810	13.0
Food process waste	44 – 653	0.3 – 4.7
Municipal wastewater	165 – 436	1.2 – 3.1
Municipal sludge	544 – 871	3.9 – 6.1

Figure 11–5 Waste storage pond dilution factors for resulting low salinity on coarse textured soils

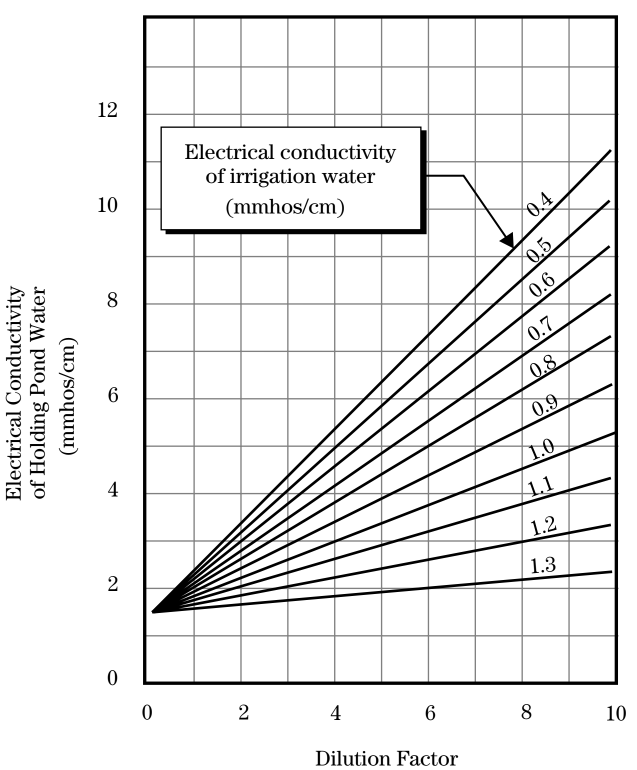
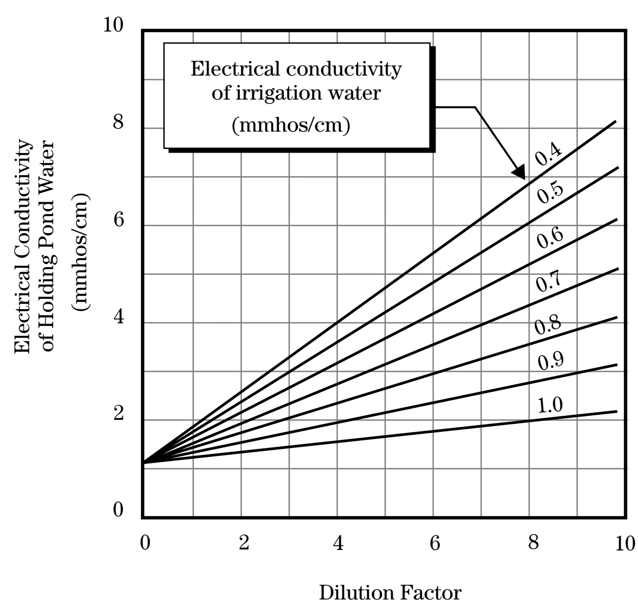


Figure 11–6 Waste storage pond dilution factors for resulting low salinity on medium textured soils



Example 11–5:
Liquid waste from a 5 acre-feet dairy waste storage pond is to be applied to irrigated cropland. The annual irrigation application will be 28 inches per acre, and natural leaching is limited. The wastewater has an electrical conductivity of 2,700 µmhos/cm. The irrigation supply has an electrical conductivity of 400 µmhos/cm. The soil is clay.

Questions:

1. What dilution factor should be used to maintain a low salinity hazard in the irrigated cropland? What is the maximum waste application rate in inches per acre, considering salts?
2. If no dilution water is available, what is the maximum annual application of undiluted storage pond waste? How many acres would be required to apply the entire contents of the pond, again only accounting for salts?

Enter figure 11–7 with an electrical conductivity of holding pond water of 2.7 mmhos/cm (2,700 µmhos/cm). Proceed horizontally to the line for an electrical conductivity of irrigation water of 0.4 mmhos/cm (400 umhos/cm). Read down vertically to a dilution factor of 3.8 (answer to first part of question 1). For every inch of wastewater applied, 3.8 inches of irrigation water is needed.

Total wastewater application:

$$\frac{\text{Annual application (in/ac)}}{\text{Diluted waste (in/in of wastewater)}}$$

$$\begin{aligned}\text{Diluted waste} &= 1 + \text{dilution factor} \\ &= 1 + 3.8 \\ &= 4.8 \text{ in}\end{aligned}$$

Therefore, the wastewater application in inches per acre is:

$$\frac{28 \text{ in/ac}}{4.8 \text{ in/in}} = 5.8 \text{ in/ac}$$

This is the answer to the second part of question 1.

To address the situation where no dilution water is available, enter figure 11–8 at an electrical conductivity of storage pond water of 2.7 mmhos/cm. Proceed horizontally to the curve for fine textured soils. Read down to a maximum annual irrigation of 2 inches (answer to the first part of question 2).

Figure 11–7 Waste storage pond dilution factors for resulting low salinity on fine textured soils

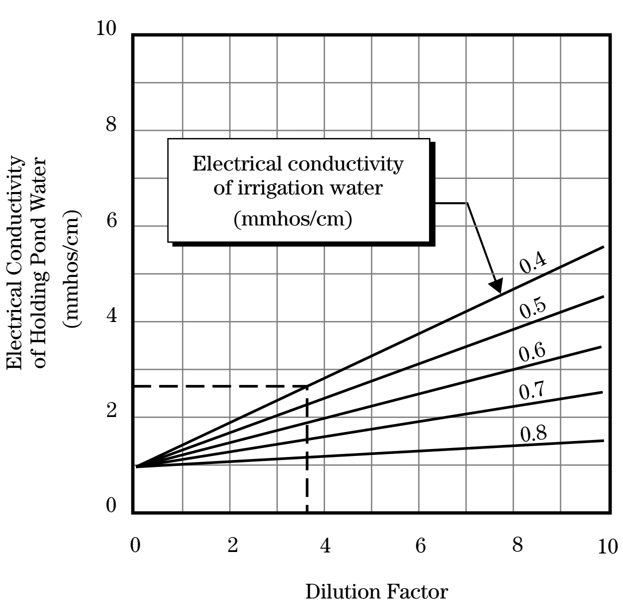
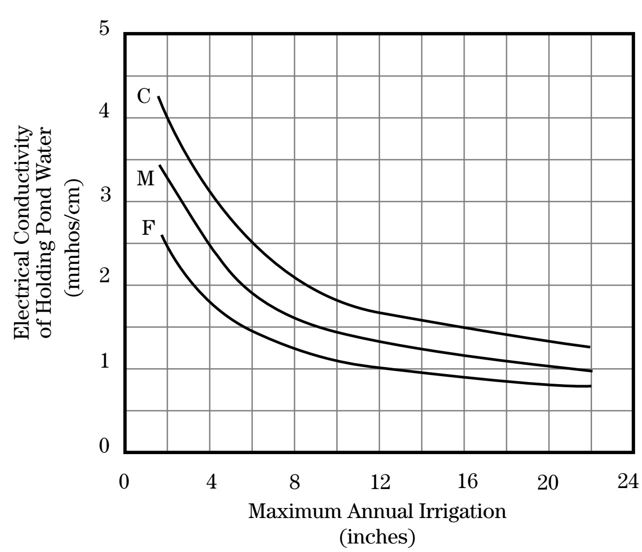


Figure 11–8 Maximum annual amount of undiluted waste storage pond water that can be added to a coarse (C), medium (M), or fine textured (F) soil



Each acre of land should receive no more than 2 inches of waste per year. To empty the 5 acre-foot storage would require:

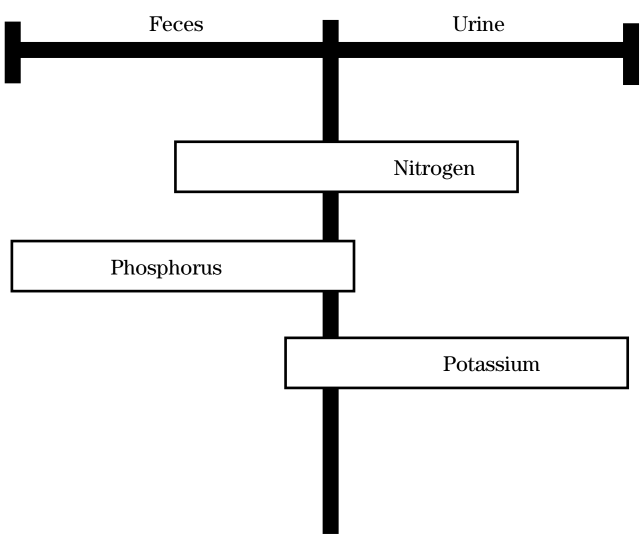
Application area:

$$= \frac{\text{pond vol. (ac-ft)} \times 12 \text{ in/ft}}{\text{annual irrigation (in.)}}$$
$$= \frac{5 \text{ ac-ft} \times 12 \text{ in/ft}}{2 \text{ in}}$$
$$= \frac{60 \text{ ac-in}}{2 \text{ in}}$$
$$= 30 \text{ acres}$$

This is the answer to the second part of question 2.

As will be discussed in the next section, nutrients are another factor to be considered when calculating application rates.

Figure 11–9 Distribution of nutrients between feces and urine



651.1104 Plant nutrients

Nitrogen, phosphorus, and potassium are the major nutrients in manure that are normally managed. With reference to figure 11–9, about half of the nitrogen and over three-fourths of the potassium in as-excreted animal manure are in the liquid part, but the preponderance of phosphorus is in the solids part. Consequently, the importance of managing nutrients according to their availability and potential for transport with runoff is evident.

(a) Nitrogen

Nitrogen (N) is one of the most important major plant nutrients in animal manure and other organic wastes. Phosphorus is challenging to manage; however, nitrogen is the most difficult to manage because of the many pathways it can follow.

Nitrogen is a key element in plant growth and crop production and is a major pollutant if excess amounts are present. Because of the complexities of the element, the nitrogen cycle and what drives it need to be understood. To understand the cycle, N needs to be traced throughout its life cycle. Figure 3–2 in chapter 3 shows a nitrogen cycle.

Nitrogen exists in one of three states in the environment—gas, liquid, or solid. It occurs in organic and inorganic forms. Although nitrogen can occur as an element, N, nitrogenous compounds (nitrogen in association with another element, such as hydrogen, H) are more important to agriculture. Ammonium (NH_4) and nitrate (NO_3) are primary plant nutrient forms.

Microbial decomposition of soil organic matter converts organic N into NH_4, a plant available form of nitrogen. The positively charged cation is held in the soil, and it does not leach. Negatively charged soil clay minerals and soil organic matter hold the positively charged ion. This greatly restricts its movement by percolating water (Bundy 1985). In addition to being attached to soil particles, ammonium nitrogen can be taken up by plants, consumed by micro-organisms, or transformed to ammonia gas and nitrates.

Nitrification is the conversion of NH_4 to nitrate NO_3 by soil bacteria and is a key reaction in the N cycle. NO_3 is readily available to plants and is an important form of N to most crops; however, negatively charged nitrate remains in the soil solution and readily moves with water.

Nitrates can also be reduced by bacteria, with nitrogen lost to the atmosphere in gaseous form. This process is called denitrification. In the nitrate form, nitrogen can leach through soil because it is an anion that has low sorptive capacity and does not form insoluble precipitates. Generally, nitrate has the greatest pollution potential of the three elements and limits the amount of organic waste that can be safely applied on the land.

(b) Phosphorus

The phosphorus cycle (see fig. 3–3 in chapter 3) shows that phosphorus can have some of the same pathways as nitrogen. Low solubilities of the mineral forms of phosphorus, when combined with calcium, iron, or aluminum, and its high potential for adsorption to clay particles result in a low tendency of leaching in most soils. The exception is in sandy soils that are low in clay content and organic material (carbon). Although the conversion rate of phosphorus in the soil to insoluble forms varies among soils, availability for plant uptake of phosphorus in the soil does decrease rapidly with time. Chemical reactions in the soil immobilize about half of the added soluble phosphate within the first day, with additional retention over the first month (Ghoshal 1974 and Larsen 1965). Soil phosphorus can be a potential source of contamination to surface water for both sediment-attached and soluble phosphorus in runoff.

(c) Potassium

Potassium is an important macronutrient for plant growth (see chapter 6). Native grasses that have an abundance of nitrogen available for uptake have been reported to show essentially no production when little to no potassium is available (Wagner 1968).

Potassium is moderately soluble in water and is known to be available for transport in surface runoff or by leaching through the soil. It is also fixed in most soils, exchanging with such soil elements as calcium, sodium, magnesium, and ammonium.

Water quality problems are not associated with potassium if it is applied at agronomic rates. These problems can occur only where manure or other organic materials are applied on the land in amounts in excess of 100 tons per acre for disposal purposes. In those cases, other more serious problems associated with organic material, nitrogen, phosphorus, and bacteria would most likely overshadow the problems associated with potassium. At any rate, agricultural wastes applied on land for disposal purposes only are outside the scope of this handbook.

Summary: Nitrogen or phosphorus, or both, will in all cases be the nutrient that controls planning and implementation of programs for land application of agricultural waste materials for crop production and environmental protection. Other constituents, such as organic matter and bacteria, also need to be addressed in the management program.

651.1105 Nutrient management

A variety of factors must be considered in designing nutrient management programs. Production and environmental goals need to be balanced, and these goals might not always be compatible. Crop nutrient requirements should be met, and soil limiting features must be considered.

Waste utilization programs must be designed for a limiting nutrient, either nitrogen or phosphorus. Application of organic material that contains a predominance of nitrogen generally must be designed with the nitrogen as the limiting nutrient. The deficiencies of other nutrients are supplied by commercial fertilizer. Organic materials high in phosphorus should have land application areas sized with phosphorus as the limiting nutrient.

In most cases, environmental and water resource considerations relate to nitrogen being the constituent of concern for ground water, and phosphorus is of concern in surface water, although both can be limiting in either surface or ground water. Phosphorus movement can be a problem, for example, in erodible soils that are on a sloping landscape and have a water supply reservoir in close proximity. Nitrogen leaching presents problems in areas having shallow aquifers used for drinking water.

A nutrient management program must be planned to account for all the pathways of nutrient transformation and movement as it is produced and released from agricultural wastes. The conservation practice standard Nutrient Management (590) must be followed in developing a nutrient balance for the cropping rotation. Nutrient management is an essential component of an agricultural waste management system. Plans should be based on soil tests, crop yields, manure nutrient analyses, and environmental concerns of the farm enterprise. The plan must account for the nutrients available in the waste, the crop's requirement for the nutrients, and timing and method of application. It should be formulated to minimize the potential offsite losses of nutrients by runoff, leaching, and volatilization.

Both the pathways and transformation of the two major crop nutrients in waste are complex. While nitrogen generally is in higher concentrations and quantities than phosphorus, its availability and predictability of form is less certain. Though phosphorus is not considered a health risk when found in high quantities in surface or ground water, it is considered an environmental threat to fresh water because of the potential enrichment of water bodies that can lead to eutrophic conditions. Nitrogen nutrients are fleeting in the soil and plant environment and only accumulate in some organic forms. Phosphorus does accumulate in the soil and can build to levels that become enriched as sediment and runoff.

Soil fertility in connection with phosphorus management should focus on soil tests, tillage practices, and application methods. Soils that show adequate phosphorus levels may not require addition of fertilizer. A soil test level does exist that makes additional nutrient applications an environmental risk. These excessive soil constituent levels should be considered in each State, and guidance should be given for prolonged application of nutrients.

Water budgets are essential evaluation tools needed for establishing nutrient budgets. In areas that have ground water concerns, figure 11–10 shows that nutrient application plans need to be structured to account for periods of excess movement of water into and over the soil.

Using figure 11–10, for example, the period of maximum deep percolation is August through November, with the deepest percolation occurring in September. Smaller quantities of deep percolation occur October through March and again in June.

Generally, if nutrients in organic form are applied in the fall, especially early fall, and mineralize, the soluble fraction tends to move with deep percolating water. If they are not incorporated, they move with surface runoff. Nutrients applied and incorporated late in spring or early in summer may not be available for percolation or runoff, but also may not be available when needed by the plants (as indicated by the shape of the evapotranspiration curve, which somewhat matches the nutrient uptake curve).

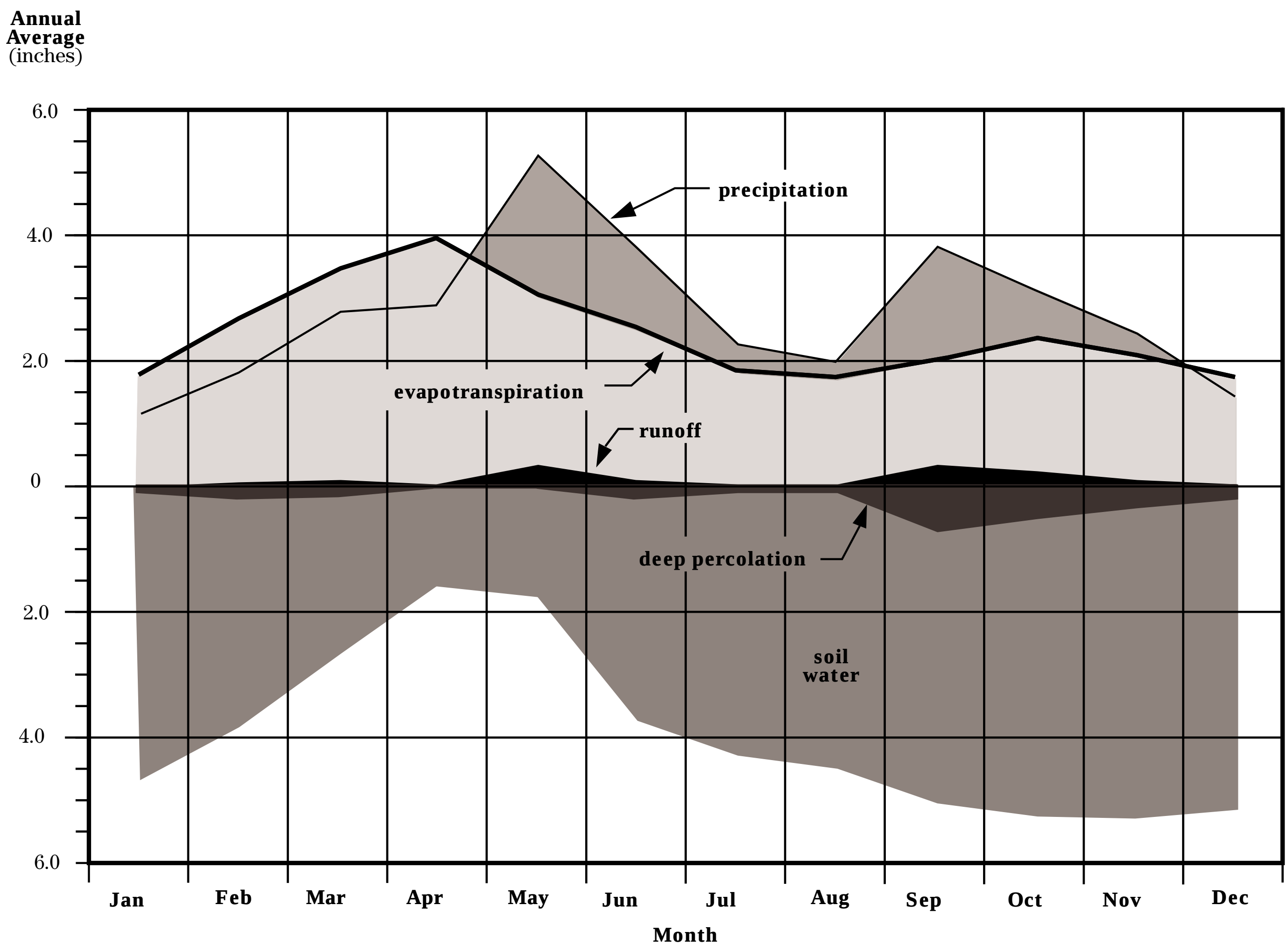
The optimum time for nutrient application based on figure 11–10 would be late in winter or early in spring so the nutrients will be readily available to plants. If the nutrients in a waste material are less available, such as with manure solids mixed with bedding giving a higher C:N ratio, incorporating the waste late in fall or early in winter allows additional time for the waste to mineralize, releasing nutrients as the plants begin growing in the spring. The objective is to match the timing of the crop's nutrient uptake requirement with the release of nutrients from the manure.

(a) Nutrient losses

Nutrient losses can be grouped into two general categories—those from the manure before it is incorporated into the soil and those within the soil after incorporation.

To accurately determine the amount of nutrients reaching the ground, samples collected at the soil surface must be analyzed. Because this procedure generally is not done, the nutrient losses can be estimated using procedures that follow. Tabular values and calculations are included to demonstrate accounting for the major nutrients in manure.

Figure 11–10 Example of a water budget for winter wheat



(1) Before incorporation

Nutrient losses from manure before incorporation into the soil vary widely, depending on the method of collection, storage, treatment, and application. These losses must be considered when calculating the amount of nutrients available for plant uptake. Climate and management have the greatest effect on the losses. Volatilization losses are more rapid during warm weather and as the wind increases. They also increase with the length of storage or treatment. Microbial activity almost ceases when the temperature falls below 41 °F (5 °C). Thus most volatilization losses cease in the fall and do not resume again until spring. This is a natural conservation phenomenon.

Local information should be used if available. In the absence of local data, tables 11–5 and 11–6 give estimates that may be used.

Table 11–5 Percent of original nutrient content of manure retained by various management systems

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

Table 11–5 shows nutrients remaining for manure that has been stored or treated. It includes the consideration of losses during the collection process.

Losses in the application process can be estimated using the information in table 11–6. These losses are in addition to those considered in forming table 11–5.

Timing of waste incorporation is critical to conserving the nitrogen in the manure. Volatilization loses increase with time, higher temperature, wind, and low humidity. To minimize volatilization losses, manure should be incorporated before it dries. The allowable time before a significant loss occurs varies with the climate. Manure applied to cool, wet soils does not dry readily and thus does not volatilize for several days. Manure applied to hot, dry soil dries quickly and loses most of the ammonia fraction within 24 hours, particularly if there is a hot, dry wind.

If the manure has been stored under anaerobic conditions, more than 50 percent of the total nitrogen is in the ammonium form, which readily volatilizes on drying and is lost. Dried manure, such as that from a feedlot in an arid or semi-arid climate, has already lost much of its ammonium nitrogen through formation of ammonia gas. There is little additional loss with time.

(2) After incorporation

Some nitrogen losses occur within the soil after manure has been incorporated. Nitrogen is lost from the soil primarily by leaching and denitrification; however, organic nitrogen must be transformed or mineralized for this to happen. Losses of phosphorus and potassium are minimal after incorporation, but the mineralization process does take place. Mineralization is discussed in this chapter.

***(i) Leaching*—**As discussed earlier, nitrogen in the nitrate form is soluble and can pass through the root zone with percolating water. Water moving into the soil profile from rainfall, snow melt, and irrigation drive soluble nutrients through the profile. Losses are to be minimized by applying organic materials in amounts that the plants can use. The applications should be before or at the time of plant uptake and in harmony with the water budget.

In irrigated areas, good water management is needed to prevent excessive leaching of soluble nutrients. Some leaching will occur, however, if excess irrigation water is used to flush salts below the root zone.

The nutrient management plan must be developed with considerations to minimize leaching losses. In addition to the water budget, the rate of manure application, its timing, and the crop uptake requirement must be considered. The Soil Leaching Index referred from section II of the Field Office Technical Guide (FOTG) is to be used in developing the manure utilization program to estimate nitrate leaching. Table 11–7 should only be used to provide general guidance in planning, as shown in example 11–6.

The Leaching Index (LI) is a seasonably weighted estimate of nitrogen leaching potential. The probability of nutrients leaching below the root zone is dependent on the LI. An LI of less than 2 inches is unlikely to contribute to a problem, 2 to 10 inches is a possible contributor, and more than 10 inches is a likely contributor (Williams & Kissel 1991).

Table 11–6 Percentage of nitrogen of that in the applied manure still potentially available to the soil (Ammonia volatilization causes the predicted losses) (Willrich, et.al. 1974)

Application method	Percentage remaining/delivered		
Injection	95		
Sprinkling	75		
Broadcast (fresh solids)			
Days between application and incorporation	Soil conditions		
	warm dry	warm wet	cool wet
1	70	90	100
4	60	80	95
7 or more	50	70	90

Nutrient management practices and techniques must be applied on soils that have a high leaching index. See the FOTG for guidance.

***(ii) Denitrification*—**Nitrogen can also be lost from the root zone through denitrification. This occurs when nitrogen in the nitrate form is subject to anaerobic activity. If an energy source is available in the form of carbon (and it generally is within the root zone) and if other conditions favor the growth of anaerobic bacteria, the bacteria will convert the nitrates to the gaseous form as nitrous oxide or nitrogen gas, which then escapes into the atmosphere. Because manure is more carbonaceous than commercial fertilizer and carbon is a common energy source, some denitrification will most likely occur.

Anaerobic conditions in the soil generally are controlled by soil water content (reflected in soil drainage classes) and available soil carbon (reflected in soil organic matter levels). Table 11–8 gives a gross estimate of the percent denitrification from all inorganic nitrogen in soils related to various drainage classes and organic matter content. This table assumes that nitrate concentrations are not limited, denitrifying microbes are present, and temperature is suitable for denitrification.

(b) Nutrient mineralization

Once manure is in the soil, the nutrients available to a plant depend on the rate of mineralization (converted to the inorganic form) and from the amount remaining after losses through leaching and denitrification. Organic and inorganic manure nutrients are in the soil. The amount of inorganic nutrients available from manure depends on the rate of biological conversion from the organic state. The inorganic forms are soluble and available for plant uptake. The rate of conversion is called the mineralization or decay rate and is generally expressed as a decay series in terms of percent change of the original amount.

Table 11–7 An estimate of inorganic nitrogen losses to leaching related to the soil Leaching Index*

Leaching index	Inorganic N losses by leaching (%)
<2	5
2 – 10	10
>10	15

* This table should be used to provide general guidance in planning.

The rate for nitrogen mineralization depends on the

- concentration of total nitrogen in the manure,
- amount in the urea or uric acid form (organic nitrogen in the urine fraction),
- temperature and moisture conditions,
- amount of organic N (or mineralizable N) already in the soil, and
- C:N ratio.

Nitrogen is excreted in various forms, depending on the animal (Conn & Stumpf 1972). Fish excrete substantial amounts of nitrogen as ammonia (NH_3). Birds, including poultry, excrete a high percentage as uric acid. Mammals excrete about half of their nitrogen in urine as urea and the rest in the feces as undigested organic matter and synthesized microbial cells (Azevedo & Stout 1974). Uric acid and urea are unstable and are rapidly metabolized by micro-organisms and converted to the inorganic form, ammonium. The feces, however, is mineralized much more slowly.

Poultry manure has a faster mineralization rate than cattle or swine manure because it has a higher concentration of nitrogen, mostly in the form of uric acid. Fresh manure has a faster mineralization rate than that of old manure because it contains a higher percentage of the nitrogen in the urea form. Urea is easily transformed to ammonia. Generally manure that has a higher concentration of nitrogen mineralizes faster than that with a low concentration.

The mineralization rate can also be affected by the C:N ratio. See chapter 4 for some selected C:N values of manure. The common C:N ratio of excreted manure is below 20:1. If straw, sawdust, or other high carbon to nitrogen materials are used for bedding, the C:N ratio of the resulting material becomes higher and more of the nitrogen becomes immobilized by the micro-organism into the organic component. This nitrogen tied up by the microbes becomes less available for plant uptake during this interval. Consideration should be given to compensate for this temporary lag in nitrogen mineralization from the manure when developing the nutrient management plan.

A higher percentage of the total nitrogen in manure incorporated into the soil is converted to inorganic nitrogen in the first year than in the second. More is converted in the second year than in the third year. This occurs because the easily biodegradable part is mineralized quickly and the residue is mineralized slowly. Soil micro-organisms use the part of the waste that gives them the most energy first and the part that yields the least energy last. Again, the urine fraction is used first and the feces part last.

Research data on mineralization are limited. Pratt (1976) found the decay series for fresh bovine manure incorporated daily to be 0.75; 0.15; 0.10; 0.05. This means that 75 percent of the incorporated nitrogen becomes available the first year, 15 percent of the remaining nitrogen becomes available in the second year, 10 percent of the remainder in the third year, and so on. Theoretically, with enough time almost 100 percent of the incorporated nitrogen will be converted to the inorganic form.

For example, if fresh cattle manure is applied every year at the rate of 100 pounds of total nitrogen per acre, 75 pounds (75 percent) will be available the first year. In year 2, 15 percent of the remaining 25 pounds becomes available, or 4 pounds (rounded from 3.75).

In the second year, however, 75 pounds will also be available from the second manure application. Thus, 79 pounds are available in year 2. The nitrogen available in the third year would be the sum of that available from year 3, year 2, and year 1.

Although not as well documented as the nitrogen cycle, similar cyclic relationships exist for phosphorus and, to some extent, for potassium. The mineralization rate for phosphorus and potassium are generally more rapid than that for nitrogen, reflecting a larger proportion of the nutrients in available form as excreted.

Table 11–9 displays the rate of mineralization of nitrogen, phosphorus, and potassium for some typical manures and management conditions. As has been previously discussed, the rate of mineralization for nitrogen is proportional to the amount of the nutrient conserved in waste collection, storage, treatment, and application.

Microbial activity necessary for nitrogen mineralization is dependent on soil moisture. The mineralization is accelerated in moist soils as compared to the same soil where the profile is dry. Table 11–9 values for nitrogen should be reduced 5 to 10 percent in arid and semi-arid areas where irrigation is not used. Local mineralization rates should be used if data are available.

(c) Nutrient requirements

Manure can provide part, all, or even excessive amounts of the nutrients required for plant production. The amount of nutrients required by plants must be determined as part of the nutrient management program.

Table 11–8 Approximate N denitrification estimates for various soils — See footnote for adjustments because of tillage, manure N, irrigation, drainage, and special soil conditions (Meisinger & Randall 1991)

Soil organic matter content	Soil drainage classification: Excessively well drained	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained
%	% of inorganic N (fert., precip.) denitrified*				
<2	2–4	3–9	4–14	6–20	10–30
2–5	3–9	4–16	6–20	10–25	15–45
>5	4–12	6–20	10–25	15–35	25–55

* Adjust for tillage, manure, irrigation, and special soils as follows: For no-tillage, use one class wetter drainage; **for manure N, double all values**; for tile drained soils, use one class better drainage; for paddy culture, use values under poorly drained; for irrigation or humid climates, use value at upper end of range; for arid or semi-arid nonirrigated sites, use values at lower end of range; for soils with compacted, very slowly permeable layer below plow depth, but above 4 feet deep, use one class wetter drainage.

The most effective way to determine the crops' needs is to develop a nutrient management plan based on the Nutrient Management conservation practice standard (590). The standard uses the components of a nutrient balance program starting with setting yield goals, soil and manure analysis, and plant nutrient availability for the growing season. A nutrient budget worksheet can be used to collect and calculate the information needed for a nutrient management plan. The local State Cooperative Extension Service values for crop recommendations, yield productions, manure nutrient mineralization rates, and soil test results can be used on the worksheet.

Two strategies can be used for manure utilization: 1) management for maximum nutrient efficiency, and 2) management for maximum application rate of manure.

Srategy 1—Management for maximum nutrient efficiency. The rate of application is based on the nutrient available at the highest level to meet the crop's needs. For most animal waste, this element is phosphorus. The manure rate is calculated to meet the requirement of phosphorus, and additional amounts of nitrogen and potassium are added from other sources (generally commercial fertilizers). This rate is most conservative and requires the greater supplement of fertilizer, but applies nutrients in the quantities that do not exceed the recommended rates for the crop.

Strategy 2—Management for maximum application rate of manure. The most abundant element in the manure, generally nitrogen, is used to the greatest extent possible. The manure rate is calculated to meet the nitrogen need of the crop. This maximizes the

Table 11–9 General mineralization rates for nitrogen, phosphorus, and potassium*

Waste and management	Nitrogen 1	Nitrogen 2	Nitrogen 3	Phosphorus 1	Phosphorus 2	Phosphorus 3	Potassium 1	Potassium 2	Potassium 3
	Years after initial application								
	Percent available (accumulative)								
Fresh poultry manure	90	92	93	80	88	93	85	93	98
Fresh swine or cattle manure	75	79	81	80	88	93	85	93	98
Layer manure from pit storage	80	82	83	80	88	93	85	93	98
Swine or cattle manure stored in covered storage	65	70	73	75	85	90	80	88	93
Swine or cattle manure stored in open structure or pond (undiluted)	60	66	68	75	85	90	80	88	93
Cattle manure with bedding stored in roofed area	60	66	68	75	85	90	80	88	93
Effluent from lagoon or diluted waste storage pond	40	46	49	75	85	90	80	88	93
Manure stored on open lot, cool-humid	50	55	57	80	88	93	85	93	98
Manure stored on open lot, hot-arid	45	50	53	75	85	90	80	88	93

* Table assumes annual applications on the same site. If a one time application, the decay series can be estimated by subtracting year 1 from year 2 and year 2 from year 3. For example, the decay series for nitrogen from fresh poultry manure would be 0.90, 0.02, 0.01; the decay series for phosphorus from manure stored in open lot, cool-humid, would be 0.80, 0.08 and 0.05. The decay rate becomes essentially constant after 3 years.

application rate of manure, but will over apply phosphorus and potassium for the crop's requirement. Over the long term this will lead to an undesirable accumulation of plant nutrients in the soil.

(d) Nutrient accounting

The nutrients available for plant growth can be determined by an accounting procedure. A procedure for determining manure application in wet tons (actual weight) per acre for solids and slurries and in acre-inches per acre for liquids is included. The procedure is reasonable for estimating the available nutrients, acres needed for application, and application rates.

Variability of manure, differences in site and climate conditions, and the lack of localized research data are factors that influence accuracy of estimates. However, sampling of manure throughout the process will help minimize influences of variations and provide confidence in the accounting method.

The mineralization series and the accounting for previous applications of manure may be of no value unless the farm owner/operator keeps adequate records over the years so the history of each field is known. If the owner/operator does not have records, the soil should be tested or the application should be adjusted on the basis of experience or crop yields.

(e) Accounting procedure

Figure 11-11 displays the following steps for nitrogen.

Step 1. Estimate nutrients in the excreted manure.

The starting point for all calculations is to estimate the total nutrient content of the manure as excreted. Use State Cooperative Extension Service research or local information to derive the nutrient concentration (N, P_2O_5, K_2O) in the manure. If manure tests or local information is not available, use tables in chapter 4 that show the average nutrient production for various animals. Use the worksheets in chapter 10 to compute manure production.

Step 2. Add nutrients in wastewater, dropped feed, and added bedding.

Wastewater, such as feedlot runoff, milking center waste, and other process water, may also be applied to the soil for recycling of the contained nutrients (see the worksheets in chapter 10). Also see appropriate tables in chapter 4 for the nutrient content of wastewater. Because of the variability caused by dilution, feeding, and climate, wastewater samples should be analyzed to determine the nutrient content. Convert the elemental nutrients given in the tables in chapter 4 to fertilizer equivalents (N, P_2O_5, K_2O).

Step 3. Subtract nutrients lost during storage.

Account for all losses of nutrients in the manure from the time it is excreted until it is ready to be applied to the field. Table 11–5 gives a range of nutrients retained in the manure that has been stored or treated by various methods. Multiply the percent retained (table 11–5) by the total nutrients from step 2 to obtain the nutrient value after storage and at the time of field application.

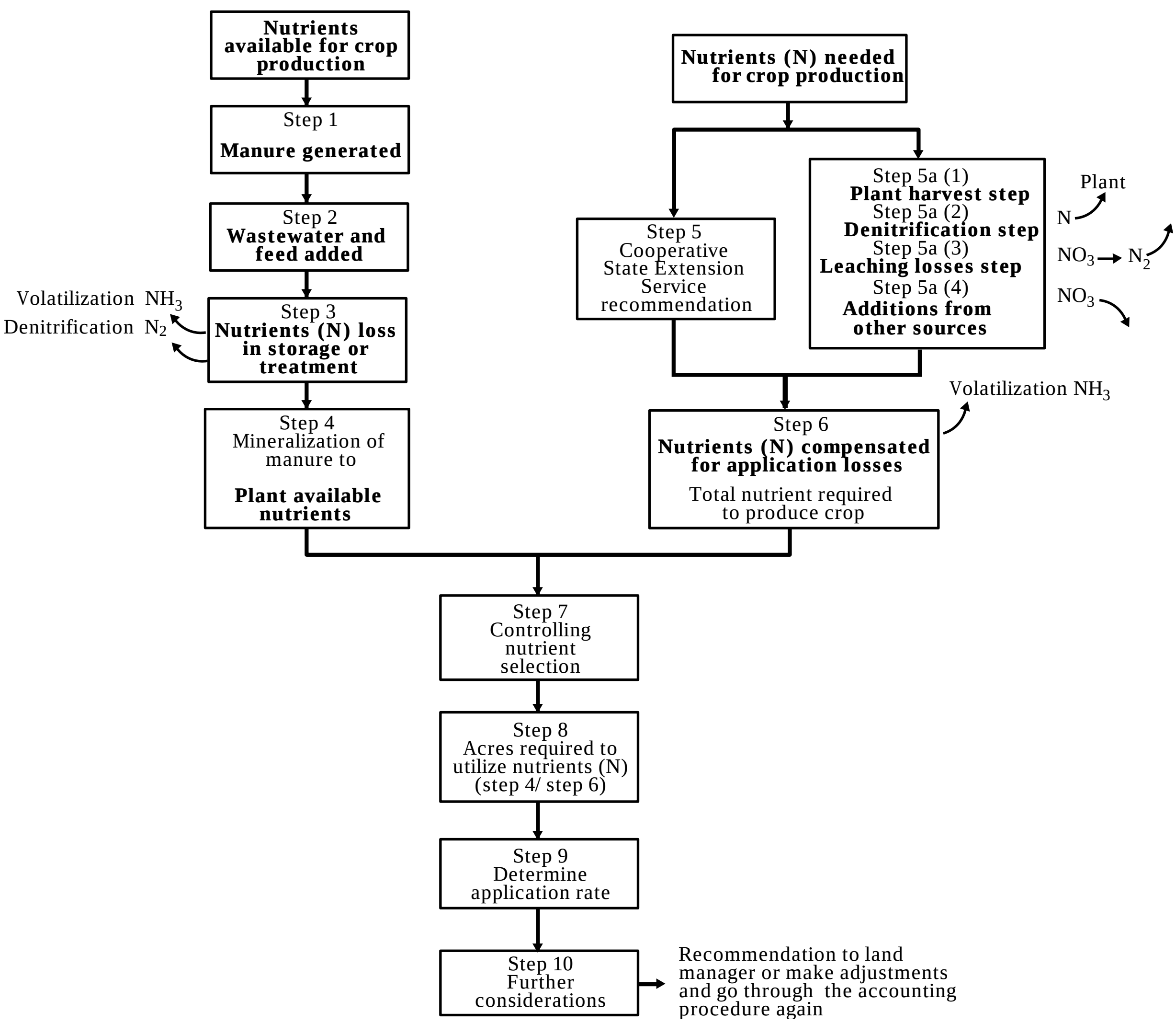
Step 4. Determine the plant available nutrients contained in the manure.

Use State Cooperative Extension Service information, if available, to determine the fraction of the plant available nutrients that will be released by the manure over the first crop growing season. A manure analysis that gives results as plant-available nutrients is preferred. A large fraction of the inorganic nitrogen (the ammonium and nitrate), phosphorus, and potassium are plant-available the first year. Only a part of the organic nitrogen (the total nitrogen minus the inorganic nitrogen) is broken down by micro-organisms each year and made available to the plants. If localized data are not available, use table 11–9. It gives values for mineralization rates of nitrogen, phosphorus, and potassium following land applications for several wastes and management options. The values in the columns represent the mineralization rate (plant availability) of one year's manure application over a three consecutive year period of cropping with additional manure application occurring each year. The values in table 11–9 are accumulative, thus give the total available nutrients for a year from applications made in previous years. Use the value of year 3 for each subsequent year past year 3 that manure is applied. Multiply the mineralization factor for each of the nutrients by the total nutrients ready for land application (from step 3).

Step 5. Determine the nutrients required by the crop and soil to produce the yield goal.

Step 5 should be used when waste analysis, soil tests, and State Cooperative Extension Service recommendations are available. This is the best basis for managing nutrients. Proceed to step 5a if needed data are not available. The use of step 5a is not recommended for calculating a nutrient budget for a nutrient management plan, but may be used for general planning and estimating land application area requirements. The variation in nitrogen availability would cause discrepancies (either deficits or excess) in nitrogen recommendations.

Figure 11–11 Nitrogen transformation in the accounting procedure



variation in nitrogen availability would cause discrepancies (either deficits or excess) in nitrogen recommendations.

State Cooperative Extension Service guidelines for nutrient requirements are based on soil tests, crop yields, and local field trials. Soil fertility recommendations are given in Extension bulletins and on soil test reports.

Step 5a. In lieu of a soil test or local State Cooperative Extension Service crop nutrient recommendation, an estimate can be made of the nutrient requirements to produce the crop at the yield goal set. The estimate accounts for the removal of the nutrients in the harvested crop and the anticipated loss because of denitrification and leaching in the soil, but nutrient additions can also occur. No attempt is made to account for losses caused by erosion, volatilization, or immobilization.

1. Estimate the amount of nutrient removed by the harvested plant materials. Table 6–6 in chapter 6 provides an estimate of the nutrients concentration in the harvested part of the crop. Multiply the yield goal by the volume weight (in pounds per unit measure) and the fraction of the nutrient concentration. The values for phosphorus and potassium are expressed in the elemental form and must be converted to P_2O_5 and K_2O.

2. Add to the plant material requirement the soil potential for denitrification. Table 11–8 provides a rough estimate of potential denitrification losses that can be expected for a specific field condition. This estimate is for the inorganic fraction of the nitrogen available from the manure during the growing season and dependent on the soil drainage class and soil organic matter content. It is also dependent on the conditions in the soil being present for denitrification to take place. Only nitrogen will undergo this process.

3. Add to the plant material requirement and denitrification potential loss the potential loss that could occur when nitrate nitrogen leaches below the root zone. Table 11–7 provides estimates of the percent of the inorganic nitrogen applied that can be lost by leaching based on the Leaching Index. Adding steps 5a 1, 2, and 3 gives an estimate of the nitrogen balance in the system. Again, phosphorus and potassium are not considered.

   Leaching losses are difficult to estimate on a site specific basis because it is dependent on local information, such as rainfall and nutrient additions. Local data may be available from field trial and nitrogen prediction models, such as NLEAP (Nitrate Leaching and Economic Analysis Package) (Shaffer et al. 1991). Leaching losses may range from 5 to 40 percent of the inorganic nitrogen available in the soil profile.

4. Because additions to the nitrogen pool occur, they must be considered so that nutrients are not over applied. The sources of additional nitrogen are:
   - Mineralization of soil organic matter
   - Atmospheric deposition
   - Residue mineralization
   - Irrigation water
   - Credits from legumes

   No adjustment for any of these additions are in the example, but they can be substantial. These additions need to be subtracted from the estimated nitrogen needed. General values for nitrogen mineralized per acre from soil organic matter (SOM) are 40 pounds per year for each 1 percent of SOM. Nitrogen from atmospheric deposition ranges up to 26 pounds per acre per year. (Local data must be available before adding this value). Legumes can result in another 30 to 150 pounds of nitrogen per acre per year. Irrigation additions can be estimated by multiplying the nitrogen concentration in parts per million by the quantity of water applied in acre-inches by 0.227. Additions of nutrients form crop residue may be calculated using information in table 6–6, and manure residual release of nutrients is given in table 11–9.

Step 6. Compute increased nitrogen to compensate for application losses.

Table 11-6 is used to estimate the volatilization of ammonium nitrogen that can occur when manure is applied to the soil.

Step 7. Select nutrient for calculation of manure application rates.

Consider the soil test levels, crop requirements, and environmental vulnerability in selecting the critical nutrient for calculating application rates of manure. The ratio of the nutrients (N, P_2O_5, K_2O) in the manure can be compared with the ratio of plant nutrients required. If ratio imbalance is present, every effort should be made to minimize applications that exceed soil test limits or crop requirements.

Step 8. Compute the acres on which manure can be applied to use the nutrients available.

Using the critical nutrient selected (step 7), divide the amount of plant available nutrients in the manure (step 4) by the amount of nutrients required per acre for production of the crop (step 6). This is the number of acres that will be supplied by the selected nutrients for crop production. Supplemental nutrients may have to be supplied from other sources (for example, commercial fertilizer) to complete the total crop and soil requirements for the selected yield goal.

Step 9. Determine application rate of manure.

Solid, semi-solid, and slurry manure—Determine the application rate. Divide the weight of manure to be applied in tons by the acres required (step 8) to give tons per acre.

Liquid manure**—**These computations assume that the manure has been diluted enough to act as a liquid. Field application is normally by pipelines and sprinklers, but the manure can be hauled and applied. To determine the application rate, divide the volume of manure and liquids to be applied in acre-inches by the acres required (step 8) to give acre-inches per acre.

Step 10. Further considerations.

Where the application rates solely based on one nutrient result in excessive amounts of other nutrients, the long-term impact must be considered. Continual overapplication of phosphorus or potassium may not be detrimental in soils that have a high affinity to adsorb and hold these nutrients from erosion and leaching. Yet in soils that do not have these holding characteristics, the contamination of water bodies is a potential hazard.

Nitrogen applications in excess of plant requirements should not be practiced because of the environmental and health problems that can occur. In some situations the amount of land available is not adequate to use the total quantities of nutrients in the waste. Alternatives should be explored to use the excess manure produced. Some possibilities are additional land acquisition, agreement to apply on neighboring farms, decrease in animal numbers, composting and off-farm sales, refeeding of waste, mechanical separation and reuse of solids as bedding, and treatment to increase the nutrient losses in environmentally safe ways. It also may be possible to change the cropping rotation for greater utilization of the nutrients.

If no solution is apparent, a more detailed planning effort should be considered to formulate another alternative for the agricultural waste management system. (See chapter 2.) State and local laws, rules, and regulations regarding land application of organic materials must be met.

Example 11–6:
Given: 200 lactating dairy cows in central Wisconsin, average weight 1,200 pounds, are confined all year. All manure and milking parlor/milkhouse wastewater are pumped into an uncovered waste storage pond (SCS Practice Code 425). The bottom of the pond is 60 by 200 feet, and the maximum operating depth is 12 feet. Side slopes are 2:1. Milking parlor plus milk-house wastewater amount equals 5 gal/cow/day. Manure is applied every spring and plowed down within 1 day. No runoff from holding areas or adjoining fields is allowed to flow into the pond. Land is used for grain corn and has received manure for a number of years. Mean annual precipitation is 32 inches, evaporation from the pond surface is 12 inches, and the 25-year, 24-hour storm is 6 inches.

Soils on the sites for waste application are moderately well drained silt loam and have a leaching index of 6 (6 inches percolates below the root zone) and an organic matter content of 3 percent. The yield goal for grain corn is 130 bushels per acre. The soils are subject to frequent flooding and have 10 percent, by volume, rock fractions that are greater than 3 inches in diameter. Slopes range up to 10 percent. A 3,000 gallon tank wagon is available for spreading the liquid manure.

Questions:

1. What is the amount of nutrients available after mineralization (assume 3 consecutive years of application)?
2. What are the net available nutrients after leaching, denitrification, and other losses?
3. Estimate the area required, based on nitrogen being the critical nutrient.
4. What area would be required to use the maximum amount of nutrients?
5. What is the application rate in tons per acre for the area that would provide maximum nutrient utilization?
6. What number of passes per day with the tank wagon would be required to apply the manure?
7. For an irrigation system design, determine the total depth of wastewater application for nutrients that have nitrogen control, and assess adjustments needed for phosphorus control.

Solution:

Step 1. Estimate the total nutrients (NPK) in the excreted manure.

Nutrients per storage period = Number of animals x weight (lb) x daily nutrient production (lb/day/1,000 lb) x storage period (days).

Nutrient values for as excreted dairy cow manure are obtained from table 4–5, chapter 4.

$$N = \frac{200 \times 1,200 \times 0.45 \times 365}{1,000} = 39,420 \text{ lb}$$

$$P = \frac{200 \times 1,200 \times 0.07 \times 365}{1,000} = 6,130 \text{ lb}$$

$$K = \frac{200 \times 1,200 \times 0.26 \times 365}{1,000} = 22,780 \text{ lb}$$

Step 2. Add nutrients contained in wastewater.

No field runoff enters the waste storage pond. Nutrients in the parlor/milkhouse wastewater are calculated as follows:

Based on observations and using table 4–6 as a guide, 5 gal/cow/day was estimated to be representative.

Estimate the nitrogen, phosphorus, and potassium involved to be equal to the values provided in table 4–6 of 1.67, 0.83, and 2.50 lb/1,000 gal. of wastewater. This results in a small amount of double accounting because some manure affected the values in table 4–6; however, the answer will still be reasonable and slightly conservative.

Nutrients in the wastewater = Number of animals x daily wastewater production (gal./day/cow) x daily nutrient production (lb. of nutrient/1,000 gal.) x no. of days.

$$N = \frac{200 \times 5 \times 1.67 \times 365}{1,000 \text{ gal}} = 610 \text{ lb}$$

$$P = \frac{200 \times 5 \times 0.83 \times 365}{1,000 \text{ gal}} = 300 \text{ lb}$$

$$K = \frac{200 \times 5 \times 2.50 \times 365}{1,000 \text{ gal}} = 910 \text{ lb}$$

Total nutrients produced:

$$\text{Total N} = 39,420 + 610 = 40,030 \text{ lb}$$
$$\text{Total P} = 6,130 + 300 = 6,430 \text{ lb}$$
$$\text{Total K} = 22,780 + 910 = 23,690 \text{ lb}$$

Converting to fertilizer form:

$$\text{Total N} = 40,030 \text{ lb}$$
$$\text{Total } P_2O_5 = 6,430 \times 2.29 = 14,725$$
$$\text{Total } K_2O = 23,640 \times 1.21 = 28,604$$

Step 3. Subtract nutrients lost during storage.

From table 11–5, estimate values using entry for "manure liquids and solids held in waste storage pond (diluted less than 50 percent)." The lower values should be used because dilution is about equal to 50 percent. Multiply the percent retained (from table 11–5) by the total nutrients from step 2 to compute the amount of nutrients remaining after the storage losses.

Nutrients after storage losses = Total nutrients produced x fraction retained = Amount available for land application.

$$N = 40,030 \times 0.65 = 26,020 \text{ lb}$$
$$P_2O_5 = 14,725 \times 0.80 = 11,780$$
$$K_2O = 28,604 \times 0.80 = 22,883$$

Step 4. Determine the plant available nutrients.

Using table 11–9, estimate the amount of nutrients that will be available each year after the third consecutive year of application.

Plant available nutrients = Amount applied x fraction available

$$N = 26,020 \text{ lb} \times 0.55 \left(\text{est}\right) = 14,311 \text{ lb}$$
$$P_2O_5 = 11,780 \times 0.90 = 10,602$$
$$K_2O = 22,883 \times 0.93 = 21,281$$

This is the answer to question 1.

Note: 0.55 was used for nitrogen because in table 11–9 it fell between 0.68 for an open pond condition and 0.49 for a diluted waste storage pond.

Step 5. Determine the nutrients required by the crop and soil to produce the yield goal.

Generally, a soil analysis would be taken and the State Cooperative Extension Service recommendation would be used, but for illustrative purposes the method to estimate nutrient requirements given in chapter 6 will be used. An example in chapter 6 provides the nutrients removed by the harvest of 130 bushels of corn.

Step 5a (1). Estimate the amount of nutrients removed by the crop using table 6–6.

(See section 651.0606(b), Nutrient uptake example.)

$$N = 117 \text{ lb/ac}$$
$$P = 20$$
$$K = 29$$

Converting to fertilizer form:

$$N = 117 \text{ lb/ac}$$
$$P_2O_5 = 20 \times 2.29 = 46$$
$$K_2O = 29 \times 1.21 = 35$$

Step 5a (2). Add to the plant requirements additional nitrogen to replace anticipated denitrification losses.

From table 11–8 for a moderately well drained soil that has an organic matter content of 3 percent, the table gives a value of 26 percent denitrified. (Estimating 13 percent and doubling for manure gives 26 percent.)

Nitrogen needed considering denitrification = Plant requirements from Step 5a (1) divided by the percent retained as a decimal after denitrification, which is 100 percent less the percent lost (from table 11–7).

$$N = \frac{117}{0.74} = 158 \text{ lb}$$

An additional 41 pounds of nitrogen is needed to compensate for the anticipated denitrification losses.

Step 5a (3). Add to the plant requirements additional nitrogen to replace anticipated leaching losses.

From table 11–7, for a leaching index of 6 (6 inches of annual percolation below the root zone), the estimated loss is 10 percent. This means 90 percent of the nitrogen would be retained. Divide the amount of nitrogen required from step 5a (2) by the percent retained (0.90) to increase the nitrogen to provide adequate nitrogen for the plant after losses anticipated from leaching.

Nitrogen = Nitrogen required anticipating denitrification losses divided by the percent retained (as a decimal) after leaching losses.

$$N = \frac{158}{0.9} = 176 \text{ lb}$$

An additional 18 pounds of nitrogen is needed to compensate for the anticipated leaching losses.

Step 6. Add additional nitrogen to compensate for application losses.

From table 11-6 determine the nitrogen anticipated to be retained after application losses in the form of ammonia by volatilization. For broadcast manure, plowed down within one day, use a delivered percentage of 95 (estimate for a wet soil in spring, between warm and cool temperatures).

Nitrogen to apply = Nitrogen anticipated from Step 5a (3) divided by the percent delivered in decimal form (from table 11-6):

$$N = \frac{176}{0.95} = 185 \text{ lb}$$

An additional 9 pounds of nitrogen is needed to compensate for application losses (volatilization).

The answer to question 2 would be:

$$\begin{aligned} N &= 185 \text{ lb/ac} \\ P_2O_5 &= 46 \\ K_2O &= 35 \end{aligned}$$

Note: Estimates for nitrogen additions to the field from soil organic matter, crop residue, atmospheric deposition, or legumes were not made.)

Step 7. Select nutrient for calculation of manure application rates.

To answer question 3, “How many acres are required to recycle nitrogen?” in this example, nitrogen is selected as the controlling nutrient.

Step 8. Compute the acres on which manure can be applied to use the nutrients available.

Required acres = Amount of PAN (from step 4) divided by the amount of selected nutrient for crop production (step 6)

Required acres:

$$\frac{14,311 \text{ lb N}}{185 \text{ lb N/ac}} = 77 \text{ ac}$$

This is the answer to question 3.

To answer question 4, “What area would be required to use the maximum nutrient utilization?” we must return to step 7.

Step 7. Select nutrient for calculation of manure application rates.

In this example potassium is both the nutrient that is used least by the crop and also produced in most abundance, so it will control if maximum utilization of nutrients is desired. In less obvious cases it may be necessary to go through step 8 to see which nutrient requires the most acres.

Step 8. Compute the acres on which manure can be applied to use the nutrients available.

Required acres = Amount of PAN (step 4) divided by the amount of selected nutrient for crop production.

$$\begin{aligned} K_2O &= 21,281 \text{ lb } (\text{PAN}) \\ K_2O &= 35 \text{ lb/ac} \end{aligned}$$

Required acres:

$$\frac{21,281 \text{ lb}}{35 \text{ lb/ac}} = 608 \text{ ac}$$

This is the answer to question 4.

Only 77 acres are needed to fully utilize the nitrogen, but 608 acres are required so that the potassium is not over applied.

Step 9. Estimate application rate.

The waste storage pond contains the manure produced by the 200 cows plus the milk parlor wastewater. Precipitation and evaporation must be considered to obtain the total volume of stored material. Chapter 10 discusses procedures to account for climatic conditions.

Manure excreted per day = 1.30 ft^3/da/1,000 lb cow (table 4–5).

Total manure volume per year:

$$\frac{200 \times 1,200 \times 1.3 \times 365}{1,000} = 113,880 \text{ ft}^3$$

Total wastewater volume per year:

$$\frac{200 \times 5 \times 365}{7.5} = 48,670 \text{ ft}^3$$

Volume of precipitation = Average annual rainfall – Average annual evaporation:

$$32 - 12 = 20 \text{ in. precipitation storage}$$

The 20 inches of precipitation translates to about 44,640 cubic feet. A waste storage pond with bottom dimensions of 60 by 200 feet, 2:1 side slopes, and 12 feet deep would have a maximum surface area of 26,784 square feet. The annual precipitation storage is:

$$20 \text{ in} \times 26,784 \text{ ft}^2 = 44,640 \text{ ft}^3$$

Total volume stored is:

$$113,880 + 48,670 + 44,640 = 207,190 \text{ ft}^3$$

Volume in acre-inches:

$$207,190 \text{ ft}^3 \times 12 \text{ in/ft} \times \frac{1 \text{ ac}}{43,560 \text{ ft}^2} = 57 \text{ ac} - \text{in}$$

Volume of water that has been added per cubic foot of manure is:

$$\frac{\left(48,670 \text{ ft}^3 + 44,640 \text{ ft}^3\right) \times 7.5}{113,880} = 6 \text{ gal/ft}^3$$

Total solids (TS) of manure as produced equals 12.5 percent (table 4–5). Resultant TS with wastewater and precipitation added equals 7 percent (fig. 11–2).

Calculate weight of stored material:

$$\frac{207,190 \text{ ft}^3 \times 60 \text{ lb/ft}^3}{2,000} = 6,216 \text{ tons}$$

From step 8, use application area of 77 acres for N utilization and 608 acres for maximum waste utilization. Application rate is calculated by dividing tons applied by the acres covered.

$$\frac{\text{Tons applied}}{\text{Application area}} = \text{Application rate (tons/acre)}$$

N accounting:

$$\frac{6,216 \text{ tons}}{77 \text{ ac}} = 81 \text{ tons/ac}$$

Maximum utilization:

$$\frac{6,216 \text{ tons}}{608 \text{ ac}} = 10 \text{ tons/ac}$$

This is the answer to question 5.

These application rates are almost equal to seven 3,000-gallon tank wagon loads (81 tons/acre) or less than one 3,000-gallon tank wagon loads (10 tons/acre) per acre. The application rate of 81 tons per acre is higher than normally encountered, but the waste is fairly dilute. Salinity and ground water effects should be monitored.

The following calculations demonstrate a method for adjusting waste applications to consider site characteristics.

Application by tank wagon:
Calculate the number of passes over the same ground by the 3,000-gallon tank wagon to distribute the waste material.

Travel distance of one pass is determined by field observation and verified by the producer to be 3,500 feet. Average width of application is determined to be 15 feet (outflow from tank is by gravity and varies with head in tank). Area of application in acres:

$$3,500 \times 15 = \frac{52,500 \text{ ft}^2}{43,560 \text{ ft}^2/\text{ac}} = 1.21 \text{ ac}$$

Application rate in one pass:

$$\frac{3,000 \text{ gal} \times 8.34 \text{ lb/gal}}{2,000 \text{ lb/ton} \times 1.21 \text{ ac}} = 10.3 \text{ tons/ac}$$

$$\begin{aligned}
\# \text{ passes} &= \frac{\text{application rate (total)}}{1 \text{ pass}} \\
&= 10.3 \text{ tons/ac} \\
&= \frac{81}{10.3} \\
&= 7.9 \text{ passes (8 tank loads/3,500 ft run)}
\end{aligned}$$

The answer to question 6 is 8 passes per acre.

Application by sprinkler:
Starting at step 3, recompute the additional nitrogen required for sprinkler application losses. Nitrogen to apply = Nitrogen anticipated from Step 5a(3) divided by the percent delivered (from table 11–6):

$$\begin{aligned}
N &= \frac{176 \text{ lb/ac}}{0.75} = 235 \text{ lbs/ac} \\
P_2O_5 &= 46 \text{ (no change)} \\
K_2O &= 35 \text{ (no change)}
\end{aligned}$$

Note: Increased soil moisture from irrigation may increase soil losses by leaching and denitrification of nitrogen.

Returning to step 8, compute the acres required: Required acres = Amount of PAN (from step 4) divided by the Amount of nutrient per acre (step 6). Required acres:

$$\frac{14,311 \text{ lb}}{235 \text{ lb/ac}} = 61 \text{ ac}$$

Using the 61 acres of corn that has been established for application of waste materials, determine the application quantities for nitrogen control and assess adjustments needed for a phosphorus control design.

At design depth, a waste storage pond contains 57 acre-inches of waste material at about 7 percent of total solids (TS) (previously determined). To successfully irrigate material of this consistency through "ordinary" irrigation equipment, the TS should be no higher than 5 percent, preferably 4 percent (use 4%). To lower TS from 7 percent to 4 percent, water must be added at the rate given in figure 11–2. Compute mathematically as follows:

$$\frac{7.48 \times (7-4)}{4} = 5.6 \text{ gal/ft}^3 \text{ of waste}$$

Note: The quantity of water added to the manure causes the waste material to act essentially like water. It has in fact become wastewater.

Determine the total depth of application for nitrogen:

$$\begin{aligned}
\text{Volume} &= 57 \text{ ac-in} + \frac{5.6 \text{ gal/ft}^3 \times 207,190 \text{ ft}^3}{27,154 \text{ gal/ac-in}} \\
&= 57 + 43 \\
&= 100 \text{ ac-in} \\
\text{Depth} &= \frac{100 \text{ ac-in}}{61 \text{ ac}} \\
&= 1.64 \text{ in}
\end{aligned}$$

This is the answer to the first part of question 7.

For ground water protection in sensitive aquifer areas, the 1.64 inches of wastewater application should be stored in the upper half of the root zone where most of the plant uptake occurs. Known from the example problem statement, the soils used to grow corn have an available water capacity of 5 inches in the top 60 inches of soil.

Normal irrigation design/operation techniques set 50 percent soil moisture depletion as the point at which irrigation operations are initiated.

$$5.0 \text{ in} \times 0.50 = 2.5 \text{ in}$$

Sprinkler irrigation efficiencies can be as low as 65 percent; therefore, the gross irrigation application would need to be increased to result in the soil receiving 1.64 inches of wastewater.

To assure that the leaching potential is minimized, the quantity (1.64 inches) can be split between two or three separate applications. Application rates in inches per hour must be set according to the intake rates established in local irrigation guides and adjusted for the soil texture and TS of the wastewater (tables 11–2 & 11–3).

Phosphorus application:
For crop growth, 46 pounds per acre P_2O_5 are needed, but 193 pounds per acre will be applied, which is about 4 times the amount needed. A continual application of phosphorus at this excessive rate may result in very high soil phosphorus availability. Phosphorus losses by runoff, erosion, and, in certain soil conditions, leaching can present a serious water quality concern. To limit irrigation application to the phosphorous requirement, the application quantity would need to be reduced to a fourth of 1.64 inches, or about 0.41 inches.

The answer to the second part of question 7 is 0.41 inches.

(f) Adjustments for site characteristics

Land slope, soil surface texture, flooding potential, permeability, salinity, and soil depth all play a role in assessing pollution potential. This is particularly true where the preceding procedures are used to calculate the minimum area required to recycle nutrients based on nitrogen.

A procedure was developed in Oklahoma to consider site characteristics in assigning a pollution potential to any given field (Heidlage 1984). The procedure was used in one watershed, and after 4 years monitoring, no pollution from any of the farms studied was indicated (Watters 1984 and 1985).

The following soil properties and features were considered in selecting suitable sites for land application of wastes:

Flooding was considered the most important feature in Oklahoma because waste applied to flood prone soils can be readily transported into a watercourse.

Rock fragments greater than 3 inches affect the ease of tillage potential for waste incorporation and trafficability.

Texture primarily affects the trafficability of the soil and plant growth potential.

Slope affects the potential for runoff from the site.

Depth affects the thickness of the root zone, plant growth potential, and nutrient storage.

Drainage affects plant growth potential, the ease of travel or trafficability, tillage, nutrient conversion, and runoff potential.

Yield potential was an expression of the soil's ability to produce forage and, consequently, nutrient uptake.

In the Oklahoma procedure, a predominant or limiting soil is selected as being representative of the waste application site. Soil properties and site conditions are given a numerical rating, and these ratings are summed for the site. Heidlage weighted the numerical rating system so that those items, in his judgment, that could most contribute to potential surface water pollution were given more prominence.

The rating values were scaled so that the least degree of limitation imposed by the property or characteristic provides the highest value. The Oklahoma researchers recommended reducing or eliminating waste application on sites where the sum of the ratings fell below established levels. Where management or structural solutions are implemented to overcome the limiting factor(s), the limitation of the site is eliminated.

Similar reasoning to that done by Heidlage in Oklahoma can be used to factor soil and other site limitations into waste application strategies. Table 5–3 in chapter 5 lists several soil characteristics, degrees of limitation, and recommendations for overcoming limitations. This understanding of soil limitations at application sites and methodology for overcoming the limitations provide a tool for identifying components of a waste application plan and, in some cases, further planning needs.

For example, if the field(s) to receive manure is subject to frequent flooding, table 5–3 shows a severe site limitation and recommends wastes be applied during periods when flooding is unlikely. A waste application strategy would need to include a recognition of the periods when waste can be applied, and the waste storage component of the system would have to be adequately sized to provide storage between application opportunities. Other potential remedial actions might include waste injection to reduce opportunity for runoff of the manure during flood event and some form of structural measure to reduce flooding.

(g) Rule-of-thumb estimates

Tables 11–10, 11–11, 11–12, and 11–13 can be used for rule-of-thumb estimates of available nutrients in different manure for the common methods of manure management. Field offices can develop additional tables for other livestock handling methods that are customary in their areas. Tables 11–10, 11–11, 11–12, and 11–13 are limited to:

- Solid and slurry manure applied in tons
- Available nutrients, first year only
- Situations where there is little carryover of nutrients from previous manure applications
- Common methods of manure management

Manure liquids are not included because manure of this type will be diluted 4 to 10 times so that it can be flushed into storage or treatment facilities. With this method of waste management, a large loss of nitrogen can occur during storage, and tests should be made to determine the nitrogen concentration.

The amounts shown in the tables are in pounds of available nutrients per ton. The estimated nutrients vary considerably according to the climate and waste management system. (Refer to table 11-9 for nutrient mineralization rates.) The tables also show the estimated moisture content, which can be used as a guide. The tons are the actual weight of the manure as it is applied, which includes moisture and bedding. Use reliable local data if they are available. In most cases, manure changes weight during storage and treatment because it almost always gains or loses moisture.

The manure from beef cattle on the Texas High Plains provides an example of moisture loss. Mathers (1972) found that the manure on 23 feedlots ranged from 20 to 54 percent moisture content, averaging 34 percent. This compares to fresh manure that has 86 percent moisture content and 14 percent TS. The lot manure has an average TS content of 66 percent. The manure had to dry considerably for the TS content to increase from 14 percent to 66 percent. If no loss of volatile solids occurred, the manure would have shrunk about five times. Because some loss of solids always occurs, the shrinkage is even greater. Stated another way—of 5 tons of manure excreted, only 1 ton remains on the lot, although most of the constituents, such as salt, are retained.

Table 11–10 Rule-of-thumb estimate of available nutrients in manure from dairy cows by management system

Management system	Final moisture	Nutrients available first year N	P_2O_5	K_2O
	%	----- lb/ton -----		
1. Fresh manure, collected and applied daily, incorporated before drying	89	7	3	5
2. Manure collected daily, 50% processing water added, stored in covered tank, applied semi-annually, incorporated before drying	92	3	3	5
3. Manure placed daily in open storage pond; 30% processing water added; liquids retained; spread annually in fall; incorporated before drying; cool, humid climate; evap. = precip	92	3	3	4
4. Bedded manure, unroofed stacking facility (bedding is 10% by weight); spread in spring before drying; cool, humid climate; evap. = precip	82	3	2	4
5. Manure, no bedding, stored outside; leachate lost; spread in spring before drying; cool, humid climate	87	3	2.5	4
6. Open lot storage—see beef cattle				

An example of moisture gain is seen in waste management for dairy cows in the northern part of the country. Typically, the manure is placed in storage daily in either a covered tank or an open storage pond. The milking center wastewater is added, which amounts to about 5 or 6 gal/cow/day (Zall 1972). If 5 gallons of washwater are added daily to the manure from a 1,400-pound cow, the volume is increased by about 35 percent. Similarly, if the original moisture content is 89 percent, it is increased to almost 92 percent. Consequently, it is then necessary to haul more than 13 tons of manure to the field for every 10 tons excreted if there is no drying or further dilution.

Table 11–11 Rule-of-thumb estimate of available nutrients in manure from feeder swine by management system

Management system	Final moisture	Nutrients available first year N	P_2O_5	K_2O
	%	----- lb/ton -----		
1. Fresh manure, collected and applied daily, no dilution or drying, incorporated before drying	90	9	7	10
2. Covered storage tank, applied and incorporated before drying, diluted with 50 percent additional water	93	4	6	6
3. Ventilated storage pit beneath slotted floors, diluted 1:1, emptied every 3 months, incorporated before drying	95	2.5	3	5
4. Open lot storage, removed in spring; incorporated before drying; warm, humid climate	80	6	10	12
5. Open lot storage, cleaned yearly and incorporated; hot, arid climate	40	9	28	52

Table 11–12 Rule-of-thumb estimate of available nutrients in manure from broilers and layers by management system

Management system	Final moisture	Nutrients available first year N	P_2O_5	K_2O
	%	----- lb/ton -----		
1. Fresh manure, collected and applied daily, incorporated before drying	75	27	21	15
2. Layer manure stored in shallow pit, cleaned every 3 months, incorporated before drying*	65	25	27	23
3. Layer manure stored in fan ventilated deep pit; cleaned yearly and incorporated; cool, humid climate**	50	23	45	42
4. Broiler manure on sawdust or shavings cleaned every 4 months and incorporated; warm humid climate*	25	36	35	40

* Wilkinson 1974.
** Sobel 1976.

Example 11–7:

Given: Manure from a 50,000 layer operation in Georgia is stored in a shallow pit. The manure is spread every 6 months and plowed down. The land is used for silage corn. The recommended nutrient application rate is 150 pounds nitrogen per acre per year.

Questions:

1. What is the application rate using the rule-of-thumb tables?
2. What is needed to recycle the manure at this rate?

Solution, question 1:

From table 11–12, management system 2, about 25 pounds of nitrogen per ton of manure are available the first year per ton of manure applied.

$$\text{Rate} = \frac{150 \text{ lb N } \left(\text{State nutrient guide rate}\right)}{25 \text{ lb N/ton}}$$
$$= 6 \text{ tons/ac}$$

Solution, question 2:

1. Calculate weight of manure produced (see table 4–14). Weight of layers = 50,000 birds x 4 pounds average weight = 200,000 pounds, or 200 1,000-pound units.

$$\text{Manure} = \frac{60.5 \text{ lb/da}}{1{,}000 \text{ lb}}$$
$$\text{Weight} = \frac{200 \times 60.5 \times 365 \text{ da/yr}}{2{,}000 \text{ lb/ton}}$$
$$= 2{,}210 \text{ ton/yr}$$

2. Calculate weight of manure applied since manure can change weight while in storage. From table 11–12, management systems 1 and 2, moisture content can be estimated as 75 percent (fresh) and 65 percent (applied). Thus, total solids content is 25 percent (fresh) and 35 percent (applied).

$$\text{Applied wt} = \frac{25\%}{35\%} = 0.71 \text{ of wt produced}$$
$$= 0.71 \times 2{,}210 \text{ ton}$$
$$= 1{,}570 \text{ ton/yr}$$

3. Calculate area required:

$$\text{Area} = \frac{1{,}570 \text{ ton/yr}}{6 \text{ ton/ac } \left(\text{from question 1}\right)}$$
$$= 262 \text{ acres required}$$

Table 11–13 Rule-of-thumb estimate of available nutrients in manure from feeder beef by management system

Management system	Final moisture	Nutrients available first year N	P_2O_5	K_2O
	%	----- lb/ton -----		
1. Fresh manure, collected and applied daily, incorporated before drying	86	9	5	8
2. Manure collected daily, stored in covered tank, no dilution or drying, applied semi-annually, incorporated before drying	86	7	6	8
3. Bedded manure pack under roof, cleaned in spring, incorporated before drying (bedding = 7.5% by wt)	80	5	5	7
4. Open lot storage, cleaned in spring, incorporated before drying, cold humid climate	70	7	9	14
5. Open lot storage, cleaned semi-annually and incorporated; warm semi-arid climate	30	11	16	3
6. Open lot storage, cleaned bi-annually and incorporated; hot arid climate	20	6	15	36

651.1106 References

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Chapter 12 Waste Management Equipment

651.1200 Introduction and scope

The objective of chapter 12 is to explain the equipment used with agricultural waste handling. Machine, implement, device, tool, item, and component are often used instead of the word *equipment*. In this chapter, *equipment* refers to a specialty item specifically designed to push, lift, convey, agitate, or otherwise handle or process agricultural wastes. The term equipment does not include structural measures, such as flush gutters, tanks, stack pads, waste storage ponds, or waste treatment lagoons.

Detailed considerations for planning an Agricultural Waste Management System (AWMS) are in chapter 2 of the Agricultural Waste Management Field Handbook. The major equipment used in a waste management system is listed in figure 12–1.

651.1201 Selecting waste handling equipment

Wastes and equipment relationships are characterized in chapters 4, 9, 10, and 11. The flowcharts in figures 12–2 to 12–5 can be used in equipment selection and handling system planning. The collection flowchart (fig. 12–3) requires that the decisionmaker know if storage is needed. This depends on climate conditions, environmental regulations, and land application space. The storage selection flowchart (fig 12–4) is based on the assumption that an earthen waste storage pond is more practical unless prevented by available space or site conditions.

In any individual situation, major considerations of equipment selection and use must meet local conditions. These considerations include climate, management, waste characteristics, available equipment sales and service, and the experience and desires of the decisionmaker. Small to medium family operations, for example, tend to use more daily labor and invest in equipment that can be multipurpose (e.g., tractor loader, elevator-conveyor, box spreader). Large operations require more, but less versatile equipment (e.g., separator, high-capacity pump, long pipeline) for separate AWMS function needs. They typically assign tasks to hired laborers to accomplish in a specified time (e.g., scraping, agitation, hauling).

Safety must be considered in addition to the cost, correct type, size, and practicality of the selected equipment. In an AWMS, relatively complex, pressurized equipment is often used by one person alone. It may be used in a noisy, remote location that is in semi-darkness and a long way from help or medical service. Suppliers, owners, and others involved must correctly instruct family and hired help about safe operation of the equipment, the hazards involved, and emergency procedures. Also, uninterrupted electric power is essential for operating some equipment (e.g., compost aerator, flushing pump, biogas production), so a system failure alarm and emergency power system may need to be a part of the AWMS.

Figure 12–1 Major equipment used in an agricultural waste management system [1/]

Agricultural Waste Management System

Functions

Production
- Roof gutters and downspouts (12-10 ff[2])
- Culvert (12-10)
- Pipe (12-10)

Collection
- Hand tools (12-13)
- Scrapers (12-1 ff)
- Loaders (12-15 ff)
- Gutter and Alley Scrapers (12-21)
- Conveyors and stackers (12-24)
- Flush gutters and alleys (12-24 ff)
- Air pressure and vacuum pumps (12-25)
- Piston-plunger pumps (12-30)

Storage
- Access ramps (12-31)
- Access ladders (12-31)
- Depth markers (12-31)
- Warnings signs (12-31)
- Valves (12-28)
- Fences (12-35)
- Covers (12-31 ff)
- See detection devices (12-38)
- Liners (12-38 ff)

Treatment
- Cutters, shredders, crushers, and grinders (12-40 ff)
- Agitators, stirrers, and mixers (12-43 ff)
- Aerators (12-48 ff)
- Separators (12-54 ff)
- Dehydrators, incinerators, and renderers (12-64 ff)

Transfer
- Augers and conveyors (12-43 ff)
- Pumps (12-35 ff)
- Picket dams (12-36 ff)

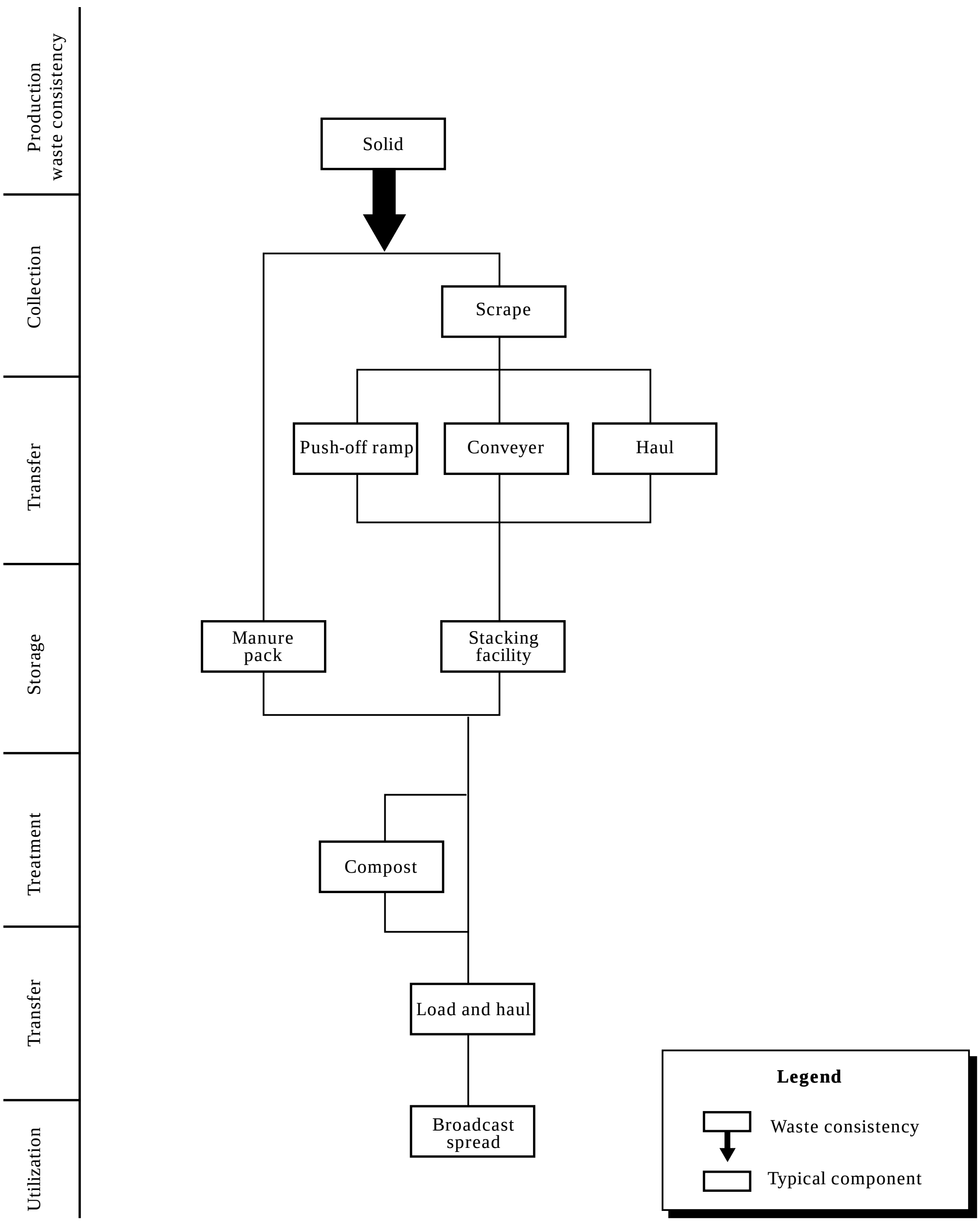
Utilization
- Box spreaders (12-73 ff)
- V-box bottom spreader (12-76 ff)
- Vacuum load tanker spreader (12-79)
- Pipe and pipelines (12-83)
- Gated pipe (12-85 ff)
- Handmove sprinkler (12-88)
- Towline sprinkler (12-89)
- Side-roll sprinkler (12-89)
- Big gun sprinkler (12-90)
- Traveling gun sprinkler (12-90 ff)
- Soil injector spreaders (12-92 ff)
- Biogas production equipment (12-94 ff)

[1] Numbers in parenthesis are the page where the equipment is described.
[2] ff—and following pages

Different models of similar equipment are available. The design and durability needed for an AWMS depends on the consistency and amount of waste and the type and length of storage. (See section 651.1000.) Some examples are:

- A tractor loader used to dig out and load packed solids should be heavier than one used for alley scraping and loadout.

Figure 12–2 Waste management typical component alternatives matrix (solid)



- A 1-horsepower pump used intermittently for liquid milkhouse waste should be designed and constructed differently than a pump that must agitate and lift swine waste that has been stored (and settled) for several months.
- A spreader for a large feedlot is designed and constructed differently than one for a 50-sow, farrow-to-finish swine operation.

Figure 12–2 Waste management typical component alternatives matrix (semi-solid/slurry)—continued

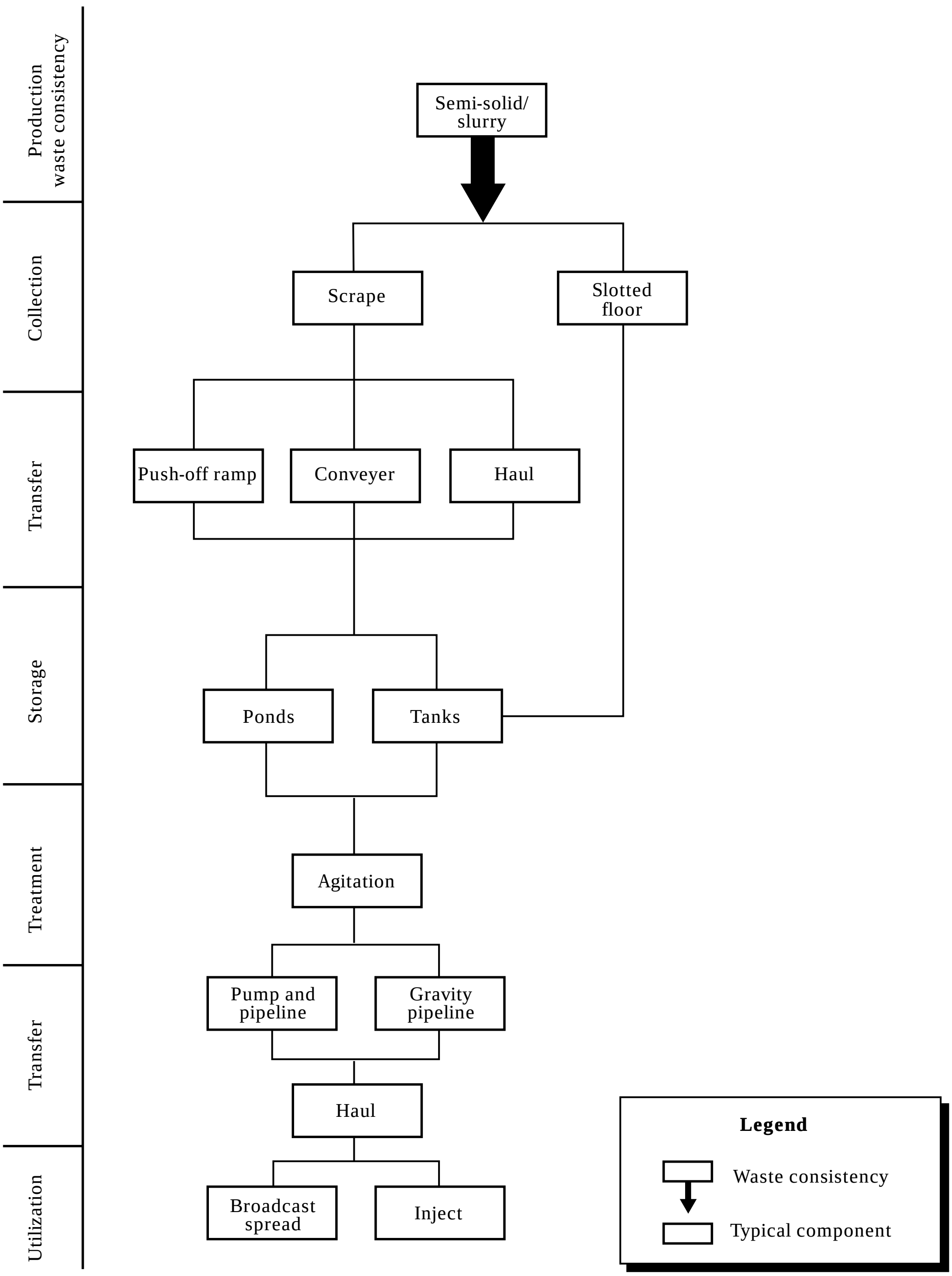


Figure 12–2 Waste management typical component alternatives matrix (liquid)—continued

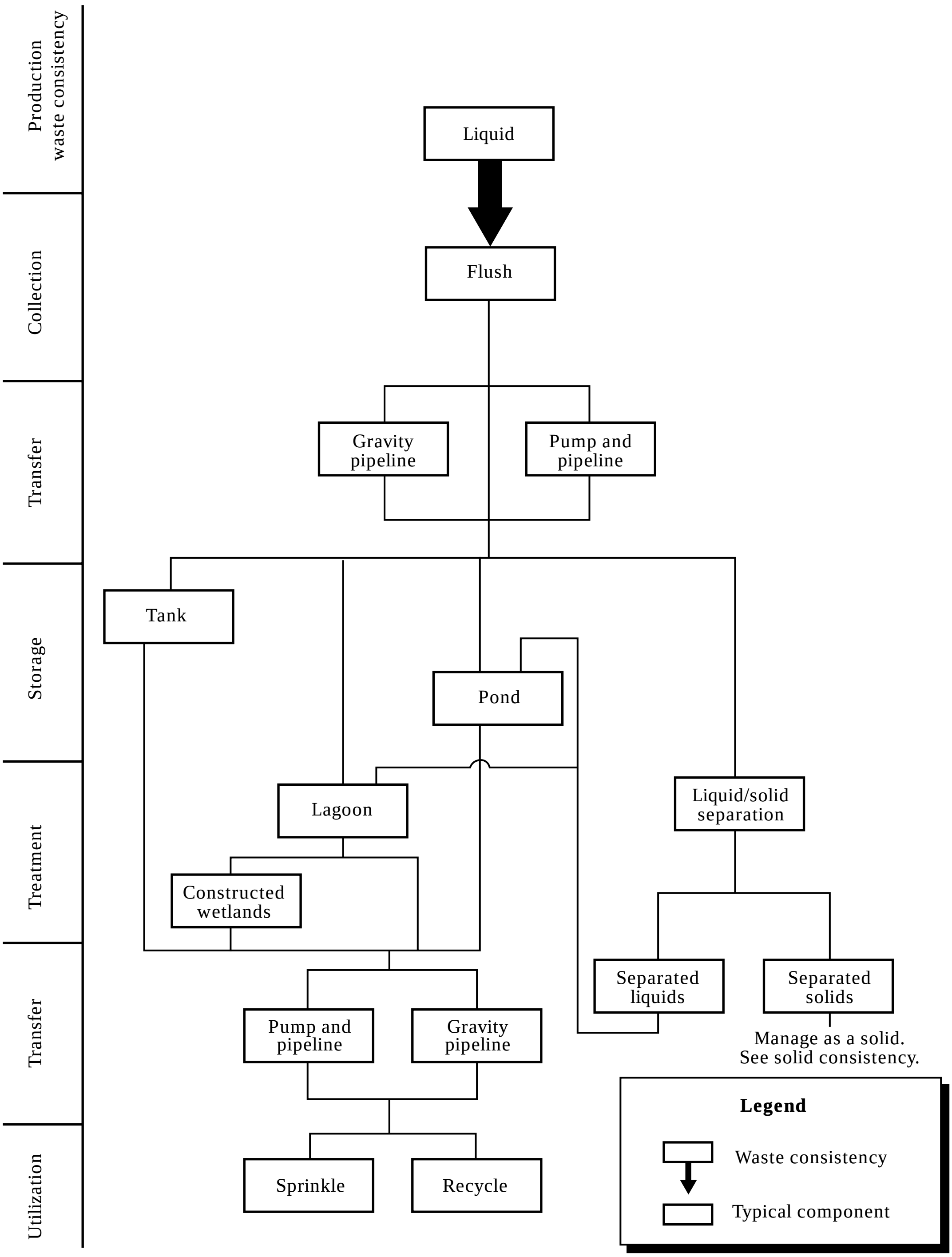


Figure 12–3 Waste management system typical collection and transfer component selection matrix

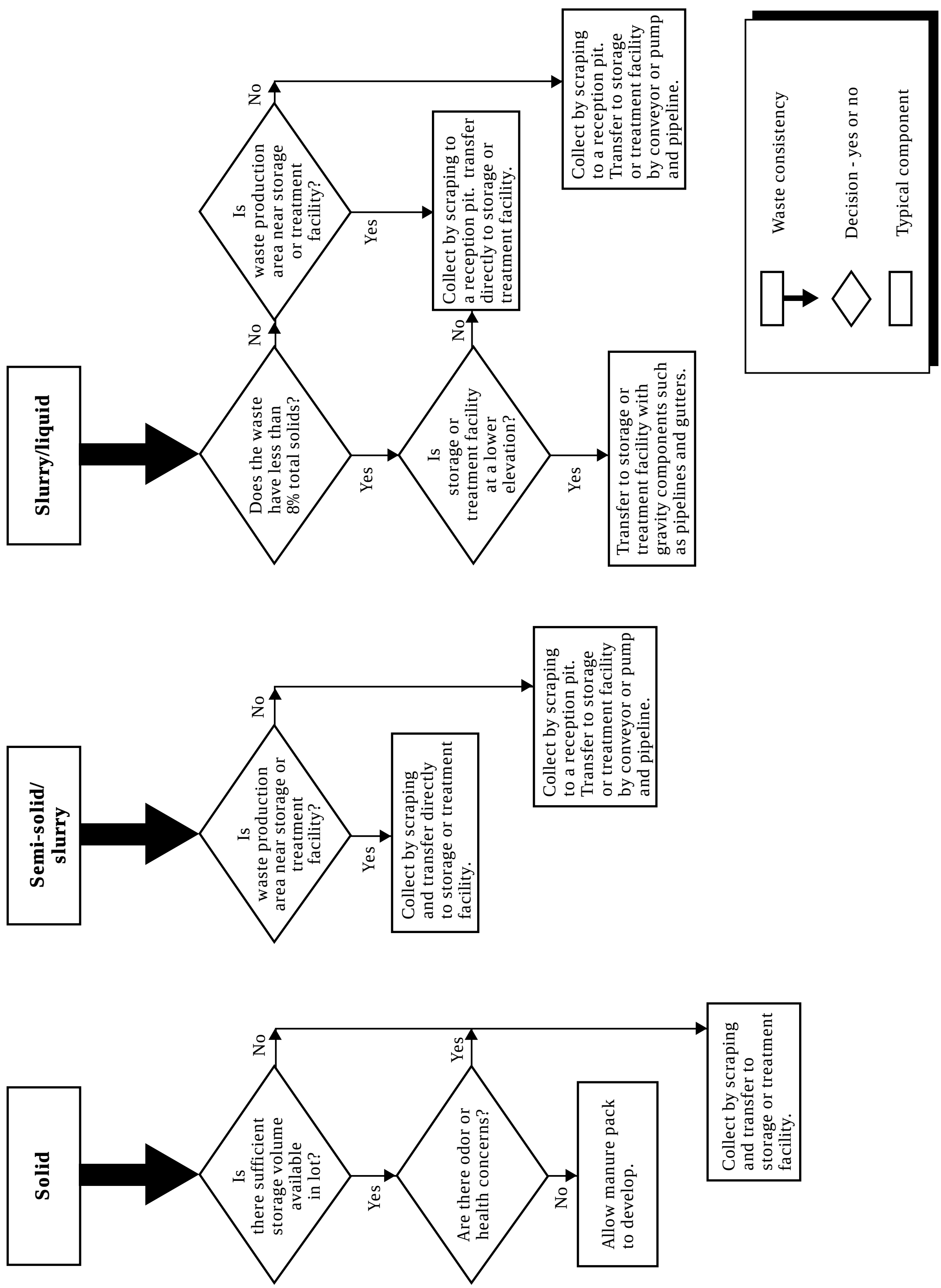


Figure 12–4 Waste management system typical storage component selection matrix

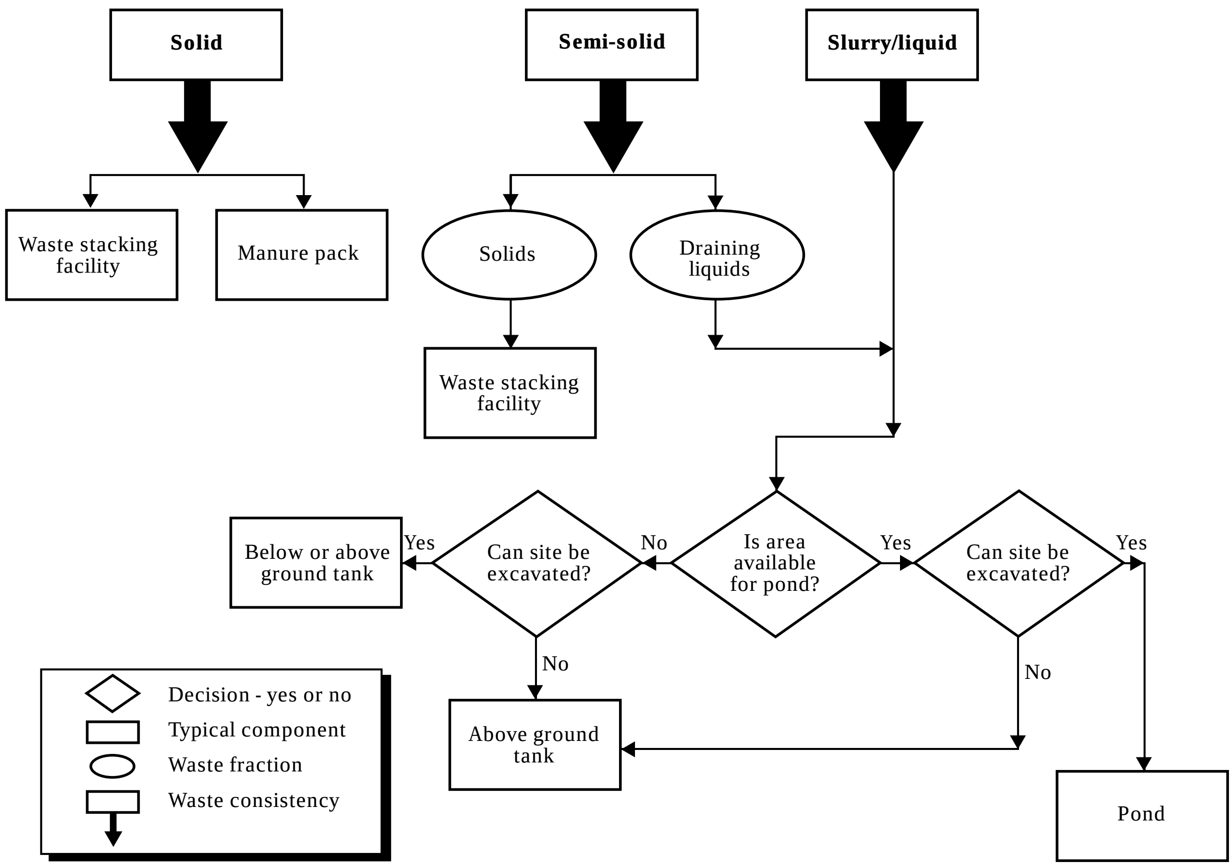
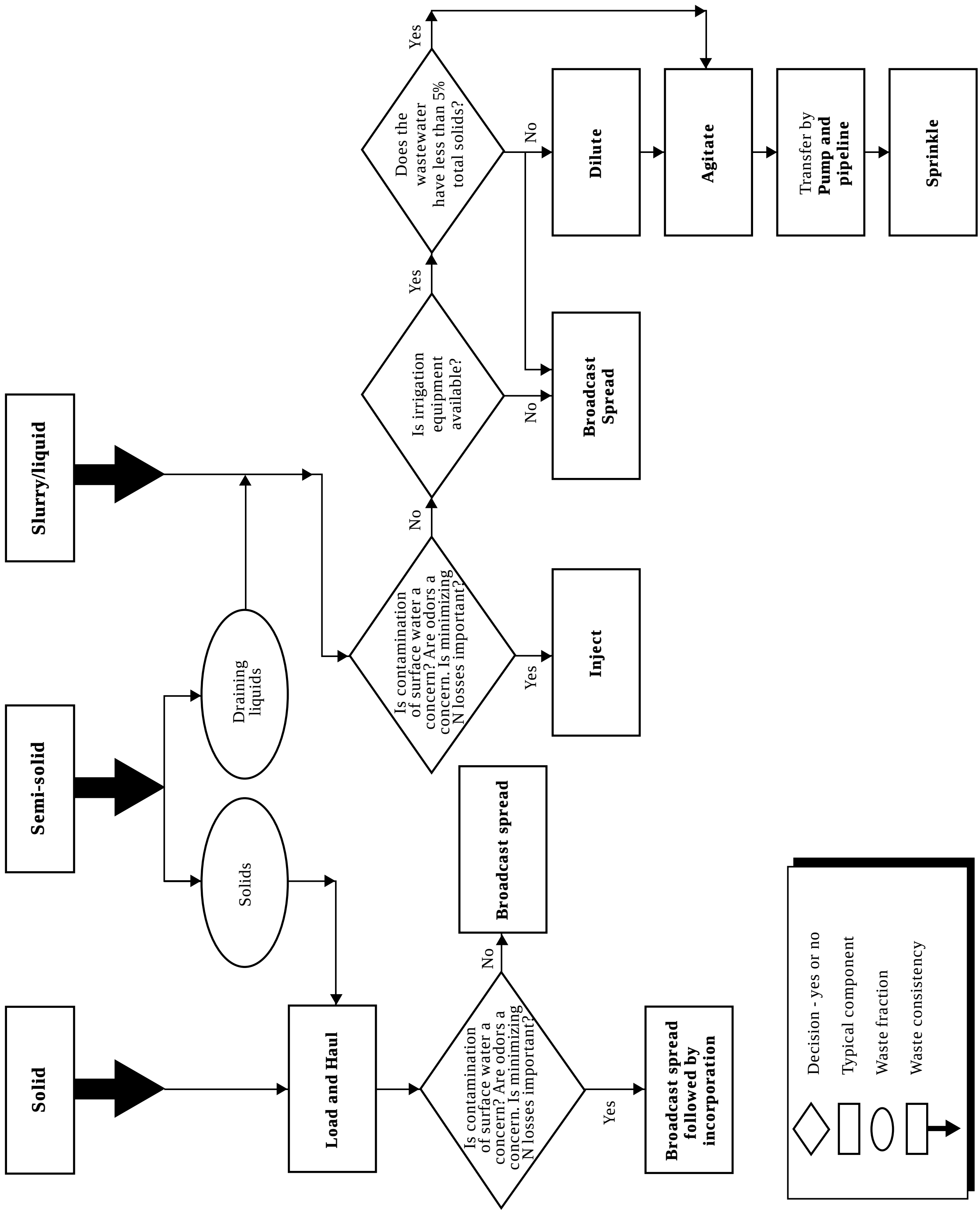


Figure 12–5 Land application typical component selection matrix



651.1202 Waste production equipment

In an agricultural waste management system, excluding clean water is considered a component of waste production (see section 651.1001). Typically this involves roof gutters, downspouts (fig. 12–6), lined or unlined ongrade waterways or open-channels (see fig. 10-1), and belowground pipes and culverts.

(a) Roof gutters (eave troughs) and downspouts

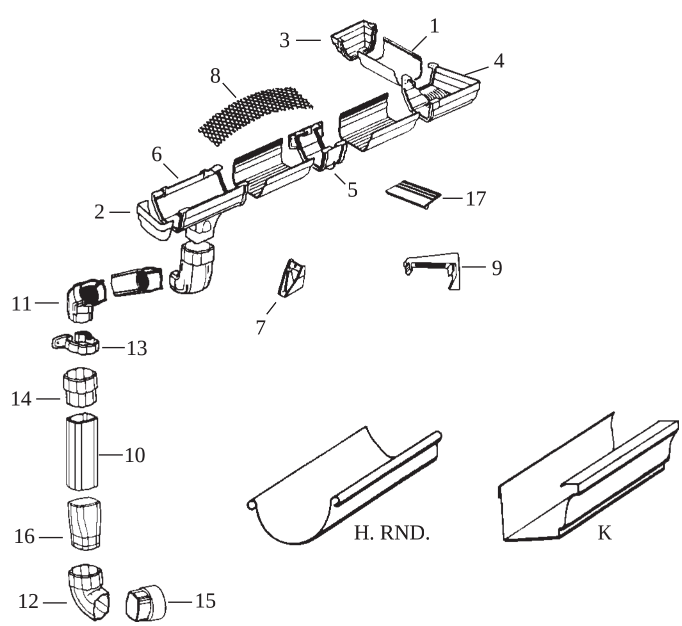
Although roof gutters require investment and maintenance, they can reduce the total quantity of waste to be handled and result in overall dollar savings for the system. NRCS Conservation Practice Standard, Roof Runoff Management, Code 558 and section 651.1001 of this handbook explain sizing of gutters and downspouts. Plastic, aluminum, and galvanized or painted steel are common gutter and downspout materials. For a given thickness, galvanized steel is the strongest and most durable. Plastic can flex with freeze-up and settling. Cast iron, steel, copper, or plastic are used for downspouts inside buildings.

Roof drainage equipment generally is supplied through building suppliers. Special fastenings may be needed to attach the equipment to a prefabricated steel building. Local independent fabricators can custom rollform light-gage metal gutter systems onsite for different buildings and do installation.

Gutter size is indicated by the top width opening. Style K box gutter is usually made in 4-, 5- and 6-inch widths; halfround gutter is made in 4-, 5-, 6-, and 7-inch diameters (fig. 12-6). A gutter is installed to slope slightly toward a downspout and is secured to the building eaves with cast iron, steel, or plastic hangars or with long spikes according to the manufacturer's specifications. Hangars need to be compatible material with the gutters and spaced accordingly. Installing the front, top edge of the gutter about 2 inches below the roof edge reduces melt water from backing up under the roofing when the gutter is frozen shut or flooded.

Figure 12–6 Roof gutter and downspout equipment (drawing courtesy of Genova Products, Inc.)

1 Gutter (10' lengths)
2 Inside end cap
3 Outside end cap
4 Gutter corner
5 Gutter slip joint
6 Highflo® drop outlet
7 Gutter bracket spacers (wedgies)
8 Debri-shield™
9 Top-notch™ gutter bracket
10 Downspout (10' lengths)
11 Front elbow - A-style
12 Side elbow - B-style
13 Downspout bracket
14 Downspout coupler
15 Downspout adapter
16 A/B downspout transition
17 Drip edge (5' lengths)
Drip edge (10' lengths)



Correct design, installation, and maintenance aid the proper operation of roof gutter and downspout drainage, especially during extreme weather. Regular cleanout of debris and dirt on screens and in gutters and downspouts is essential to prevent their plugging. Expansion and contraction from ice and temperature extremes loosen gutter and downspout supports. Snow and ice slides or buildup damage gutters and downspouts, especially lightweight types. Exterior downspouts are vulnerable to machinery and livestock damage, and some protection may be needed.

Downspouts generally are located at both ends of small buildings (<1000 ft^2 roof drainage). For large buildings, intermediate downspouts on about 30- to 50-foot spacings are installed to drain to a drainpipe or waterway sloping away from the building (see fig. 10–1 in this handbook). A float-controlled drainage sump storage and pump system is a consideration where there is insufficient slope for gravity flow.

Dripline drains are a viable option to roof gutters, especially where the designer must address freezing, snow damage, or uneven roof lines. As with downspouts, dripline drains must be protected from livestock and vehicle traffic.

Figure 12–7 Corrugated plastic drainpipe (courtesy Advanced Drainage Systems)

(b) Roof drainage outlets

Use of a waterway or open channel as an outlet for roof gutter and downspouts permits ready maintenance and simple changing when needed. A grassed waterway is sometimes practical. A hard-surfaced drive, lined waterway, or grated opentop concrete gutter (see figs. 10–1, 10–2) withstands year-round foot and wheeled traffic. Grated, modular, preformed, drain-trench sections comparable to the U-gutter (see fig. 10–7) are available that have built-in slope and different strengths and styles of cover grates. Such opentop gutters need periodic cleanout (see NRCS Conservation Practice Standard, Underground Outlet, Code 620).

Underground drainpipe is generally made of corrugated or ribbed polyethylene plastic pipe that has a 4- to 36-inch inside diameter (fig. 12–7). This drainpipe is economical, lightweight, and durable. A smooth inside surface improves flow characteristics and reduces plugging. Plastic drainpipe is available in over 1,000-foot long, flexible coils that are up to 6 inches in diameter and in various other coil lengths for other diameters. The smooth lined pipe and corrugated pipe that is more than 6 inches in diameter are available in 20-foot lengths. Extra installation care is needed for lightweight pipe to reduce crushing from trench protrusions and backfilling. Consult manufacturer's recommendations and Natural Resources Conservation Service (NRCS) construction engineers for proper installation technique.

Heavy, but strong and durable, concrete drainpipe that is 0.5 foot to 6 feet in diameter is available in up to 10-foot sections. Concrete pipe resists soil movement, heavy crushing loads, and corrosion. Hoist equipment is needed for installing the larger concrete pipe.

Corrugated steel or aluminum culvert is made in 1- to 12-foot diameters and up to 8-gage thickness, depending on size. A 16-gage (0.0598 inch) steel is common. (Corrugated and sheet metal thickness is often stated in gage thickness. As the gage number gets larger, the metal is thinner.) The size of the culvert depends on available soil cover or height clearance (see fig. 8-8), flow rate required, and if the outlet can free flow or is submerged.

Various inlet and outlet pieces, corners, and other fittings are available to aid drainpipe performance, safety, and maintenance. A removable, screened outlet, for example, reduces pest entry and plugging. Pipe drains installed belowground need clear identity aboveground to prevent their being misaligned or crushed by heavy loads or accidentally damaged in future excavation. Cleanouts need to be marked so they are noticeable above snowdrifts and weed growth (see NRCS Conservation Practice Standard, Underground Outlet, Code 620).

More information about specific needs and design of culvert systems is in the Handbook of Steel Drainage and Highway Construction Products (Amer. Iron & Steel Ins. 1993).

651.1203 Waste collection equipment

Waste collection systems are described in chapter 9 of this handbook, and components for waste collection at the farmstead in section 651.1002. Collection of vegetative wastes involves equipment types such as rakes, stackers, bale bunchers and haulers, brushcutters, and choppers, and a description is not included here.

(a) Hand scrapers, shovels, brooms, washers

Common waste collection chores include washing, disinfecting, and cleaning in corners, surfaces beneath fences, along partitions, in alleys, and in stalls or pens. Regularly cleaned, neat-appearing facilities reduce complaints about odors, insects, and other pests (see appendix 8A, section 651.0850). Warm, moist, manures are ideal for pests and need to be frequently and thoroughly removed. Flies, for example, are a noticeable nuisance, especially during warm weather when the egg-to-adult fly cycle is completed within 10 to 14 days.

Shovels, forks, scrapers, brooms, brushes, pressure-washers, and related hand tools (fig. 12–8) are needed for small area cleanup. A variety of hand tool heads and handles are available with handle angle (lie) and length variations for individual needs. A straight-grained ash wood or fiberglass handle provides strength, grip, protection from electric shock, and handling comfort. A short handle with an end D-grip permits heavier lifts and working in close quarters. A long handle provides better leverage for digging and throwing.

Aluminum and plastic shovels are lightweight, rust-proof, and nonsparking. The extra investment required and the relatively faster wear compared to steel should be considered in choosing these shovels.

Forks are available with forged flat, oval, or round tempered steel tines in 3-, 4-, 5-, and up to 12-tine (18-inch) widths. These forks handle loose or heavy, wet wastes. The flat tines assist in getting under and holding coarse, chunky waste. The oval tine is stiff, and the round tine forks do not clog as easily as the flat or oval ones.

A long-handled, relatively heavy, floor scraper minimizes the labor of loosening stuck-on materials. Lightweight squeegees and scrapers are designed for cleaning and drying wet, smooth surfaces. A scraper blade that can be reversed when worn doubles the blade life.

Long, upright-handle brooms are used to sweep corners and small spaces, even wet areas. Push brooms that are up to 2.5 feet wide assist fast cleanup of large areas. A broom that has short, flexible bristles is designed for sweeping lightweight dirt and dust from smooth surfaces. The long, stiff bristles are for rough, tough sweeping. Plastic bristles resist moisture and bacteria, but not heat. A secure head for the bristles and handle attachment assists broom durability. The chemical, solvent, fat, and oil resistance of the bristles should also be considered in choosing a broom. A flow-through handle assists in washdown cleaning.

Pressure washers (fig. 12–8) can provide up to 4,000 pounds per square inch of water pressure to loosen and wash away hard, dried, stuck-on waste. Washers that have an optional electric, gas, or oil heater can heat the water or produce steam to help speed waste removal (table 12–1). A fuel per hour rating is the measure of their efficiency.

Table 12–1 Typical pressure washer manufacturer's data

horsepower	volts	amp	psi	gpm	hot water
1.5	115	13	1,000	2.2	no
2	115	18	1,500	2.1	yes
3	230	—	1,500	3.0	yes
3.5	gas	—	1,500	2.2	no
5	230	—	2,000	4.0	yes
5.5	gas	—	2,000	3.0	yes
6	240	—	2,500	—	yes
7.5	230	—	3,000	4.0	yes
7.5	230	—	2,500	5.0	yes
9.0	gas	—	2,400	3.7	no
11.0	gas	—	3,000	4.2	no
13.0	gas	—	3,000	4.0	no
18.0	gas	—	4,000	4.0	no

Pressure washer selection considerations include:
- cost,
- kind of cleaning desired (grease soil),
- pressure durability of the surface to be cleaned,
- water supply quality and quantity needs,
- cleaner-aid injection,
- portability,
- hose insulation and length,
- heater fuel type,
- washer corrosion protection, and
- available power source.

Electric power is convenient, quiet, and generally available, but circuit capacity might be limited. Internal combustion engine-powered washers are useful in a wide range of locations; however, they need adequate exhaust gas ventilation to prevent carbon monoxide (CO) accumulation when used indoors. A freeze protected, inplace pressure washer pipeline, strategically placed in quick-connect plug-in locations for an easily moved pressure washer head, helps in areas that need frequent cleaning.

Figure 12–8 Hand tools used for waste collection

(b) Tractor scraper blades

Scraping and collecting wastes with a tractor rear- or front-mounted blade is relatively fast over large, flat areas. Tractor scraping requires operator time, however, and takes a tractor away from other uses.

A rear-mounted tractor scraper blade, 12 to 18 inches in height, permits corner cleanout and smooth, fast, straightaway operation (fig. 12–9). Available in 4- to more than 10-foot widths, the size selected needs to match the tractor weight, hitch design, hydraulic system, and alley space. The replaceable, high-carbon steel blade used on many tractor rear scrapers is needed to clean off dried, packed-down or frozen waste. Frequent scraping is needed in subzero weather to reduce frozen waste buildup. A rubber-edged blade can be used to clean off wet, roughened concrete surfaces, but it slides over stuck-on waste. A diagonal or diamond-shape groove pattern on concrete surfaces reduces slippage and minimizes scraper bounce and metal blade wear (see fig. 12–22).

Most rear scraper blade models can be rotated horizontally right or left, as needed, to direct the waste flow into a row for temporary storage or to simplify loadout. A hydraulic powered, 3-point hitch is common with rear mounted scraper blades. Other models can also be tilted and adjusted side-to-side and rotated 180 degrees for reverse pushing (figs. 12–9, 12–10). Blade curvature and tilt adjustments aid waste flow while scraping.

A 1- to 2-inch depth of semi-solid or slurry waste on a paved alley fills a scraper blade and spills out the ends after scraping about a 10-foot length. A box type scraper (fig. 12–10) can increase scraper travel distance three to five times before end spillage begins. Box type scraper models have end pieces and up to 32-inch-high blades to hold in waste. Beside mechanical or hydraulic control options, different blade tilting and reversing options are available.

Large (up to 8-ft. diameter) discarded earthmover equipment tires can be used to scrape slurry and semi-solid waste from long, wet alleys (fig. 12–11). The tires are cut in half with the tire sides removed, and are then mounted on the towing frame. They are available as tractor front-end loader push, as push-only, and as 3-point hitch tow models. An inside scraper height of 16 inches maximizes the slurry holding capacity without end spillage. A smooth, straight-cut edge on the tire side is essential to avoid scraper blade bounce and leakage.

Figure 12–9 Tractor rear scraper blade with vertical tilt (courtesy Worksaver, Inc.)

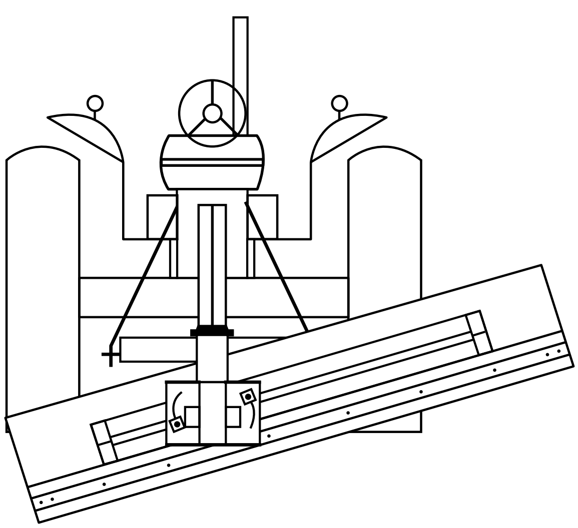
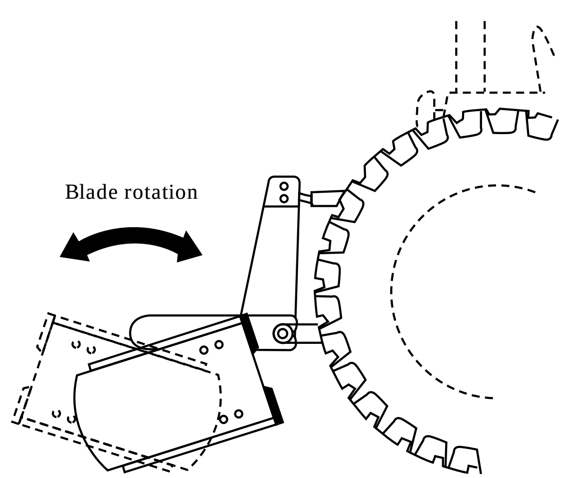


Figure 12–10 Box type slurry blade scraper; rear-mounted model (courtesy Degelman Industries, Ltd.)



(c) Lawn and garden size tractor scraping

A lawn and garden or compact tractor scraper has advantages for access, visibility, and agility over the larger tractors, but the capacity is less (fig. 12–12). The small tractors have a wide selection of other useful attachments for sweeping, mowing, and dust and dirt collection. Electric, gasoline, and diesel-powered units are available in sizes of up to 25 horsepower.

(d) Tractor front-end loaders

A tractor front-end loader (fig. 12–13, also see fig. 9–20) is perhaps the single most used multipurpose equipment item for waste handling. Useful for scraping, collecting, and agitating most types of wastes, it is indispensable for loading solid and semi-solid wastes for hauling. Various attachments are available for all sizes of tractor power. Typical 30- to over 100-horsepower agricultural tractors and low clearance, compact tractor loaders are more widely used for waste handling in and around facilities. Live, high-capacity, hydraulic power on tractors is basic to loader development and use. Buckets, forks, blades, and other implements (fig. 12–14) are readily attached to and detached from the loader frame.

In addition to the available attachments, the following characteristics should be considered in selecting a tractor front-end loader:

- Lift capacity
- Breakout force
- Lift height
- Clearance when dumped
- Dump angle and the time needed to raise and lower

The measurements designated in figure 12–13 are standard operational specifications used by manufacturers based on the ASAE Standard S301.2, Front-end Agricultural Loader Ratings (ASAE [c] 1991). These measurements provide a comparison standard for loader selection. For example, a comparison of over 200 typical tractor loader models indicates maximum lift height (A) ranges from about 6 to 21 feet clearance with attachment dumped (B) ranges from 52 to 183 inches, and maximum dump angle (D) varies from 6 to 98 degrees (Hudson 1993).

A loader is often described by the manufacturer in terms of its horsepower and recommended usage. The loader frame design and construction are for light or heavy duty. While many models are rated at about a 2,000-pound capacity, full height lift capacities are available to nearly 5,000 pounds. However, at this

Figure 12–11 Tractor scraper blade using earthmover tire (courtesy Tillamook Concrete Groving)

Figure 12–12 Lawn and garden tractor scraping equipment (courtesy Kubota Tractor Corporation)

capacity, the tractor framework, traction, and overturning are limitations. Elements to consider in selecting a loader are the operator's view, quick attachment, clearances, operating speed, and joystick type hydraulic control.

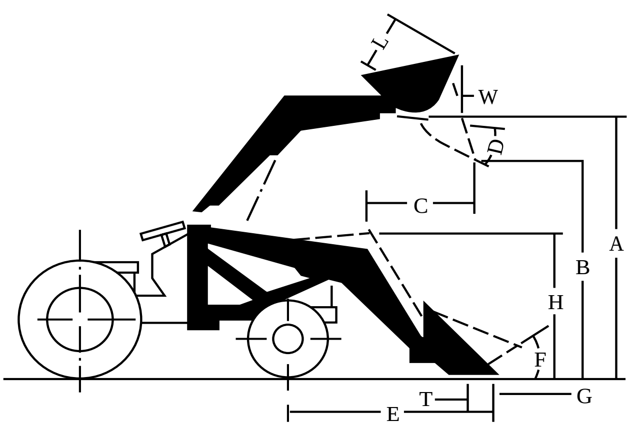
The ASAE Standard 355.1, Safety for Agricultural Loaders, relates basic rules for safe tractor front-end loader operation (ASAE [j] 1991). Some of the rules include:

- Four-wheel drive and wide-spaced front tractor wheels are more stable than tricycle-type tractors.
- A loaded bucket reduces rear wheel traction and limits efficient use to areas with slopes of 10 horizontal to 1 vertical or less.
- Usefulness is hindered with building and yard layouts that require backing down long alleys or that have difficult turns.

The following operation and maintenance items are important for efficient front-end tractor loader use:

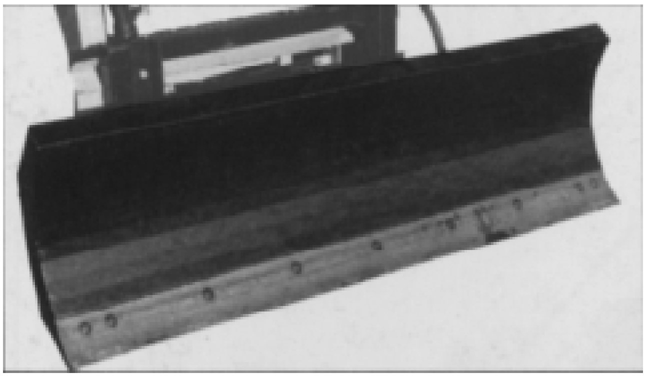
- Tires are properly inflated.
- Tractor steering and hydraulic systems are maintained.
- Extra front-end tractor weight are not used.
- Rear wheel weighting and wide tire setting are in place.
- Hydraulic pressure relief valve operation should be avoided (hastening fluid breakdown).
- All moving joints are regularly lubricated.

Figure 12–13 Tractor front-end loader measurements

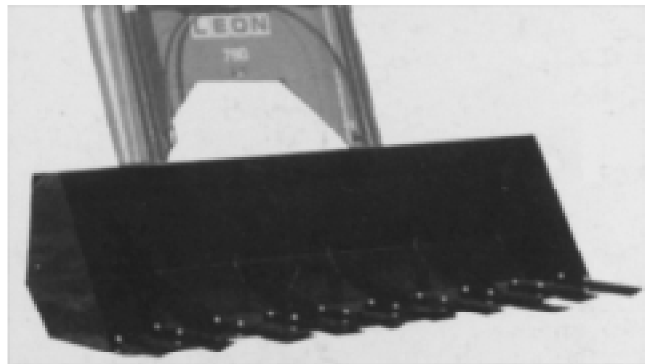


A – Maximum lift height
B – Clearance with bucket dumped
C – Reach at maximum height
D – Maximum dump angle
E – Reach with bucket on ground
F – Bucket rollback angle
G – Digging depth
H – Overall height in carry position
L – Length of bucket
W – Lift capacity to full height

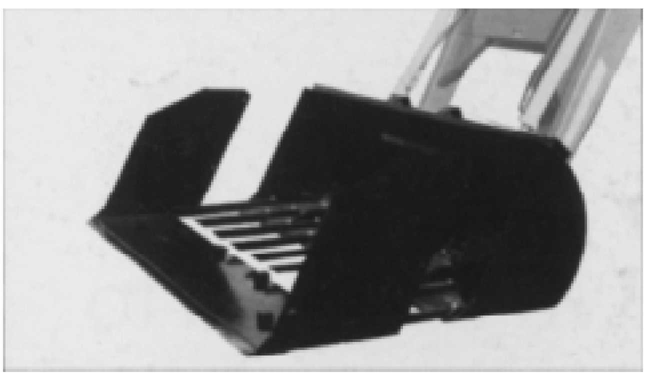
Figure 12–14 Tractor front-end loader attachments (courtesy Leon Mfg. Co.)



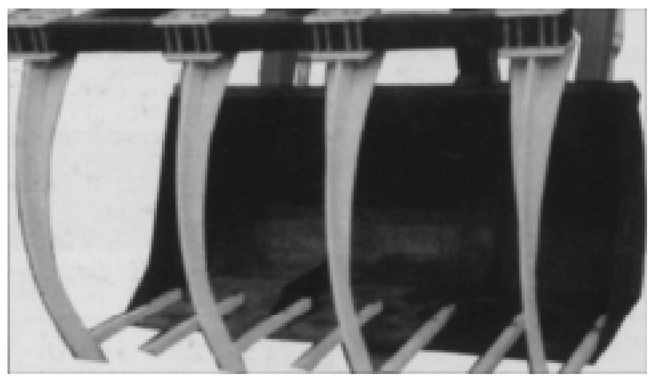
Blade



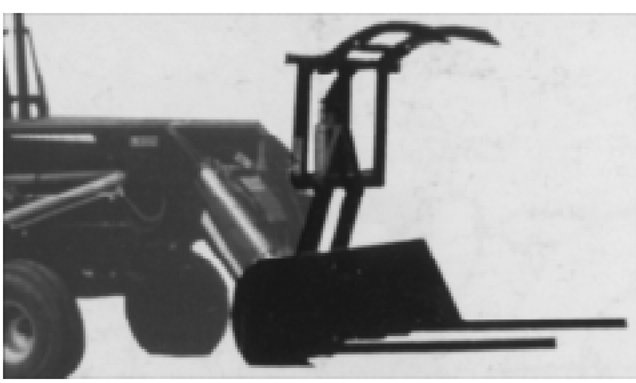
Scoop



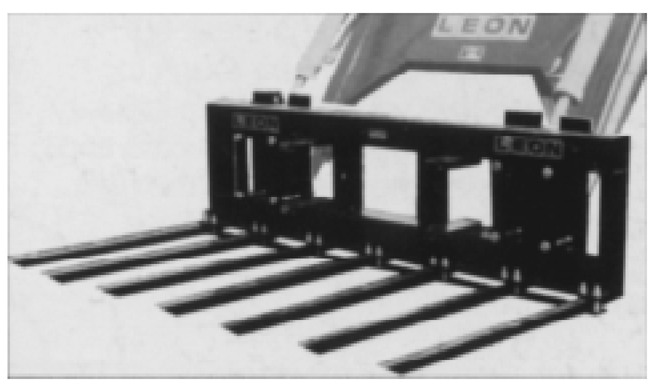
Bucket



Claw



Handler



Fork

(e) Skidsteer and articulated loaders

Compact skidsteer and articulated-steer loader tractors are especially designed for scraping and loading semi-solid and solid wastes in small spaces (fig. 12-15, see fig. 10-42). The front-end lifting arms, with a selected attachment, are integral with the tractor. Most skidsteer tractors can turn 360 degrees in their own tracks. The longer wheelbase, medium compact, articulated-steer tractor loader needs more turn space, but it gives a smoother ride (less spillage) and has a higher reach.

Skidsteer loader sizes vary according to horsepower and rated operating load. The Society of Automotive Engineers (SAE) J818 Standard sets their rated operating load at half the tipping load. The tipping load is the most weight the loader can lift without tipping forward. The rated operating load is well within limits of safe operation. The loader can lift more if carefully handled, however, the rated value is a basis for size comparison. The 1,000- to 1,500-pound capacity range is relatively popular, but loaders that have more than a 4,000-pound lifting capacity are available.

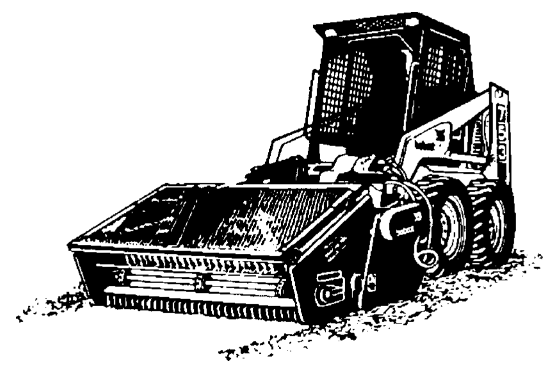
Beside the investment, major considerations in selecting a loader are:

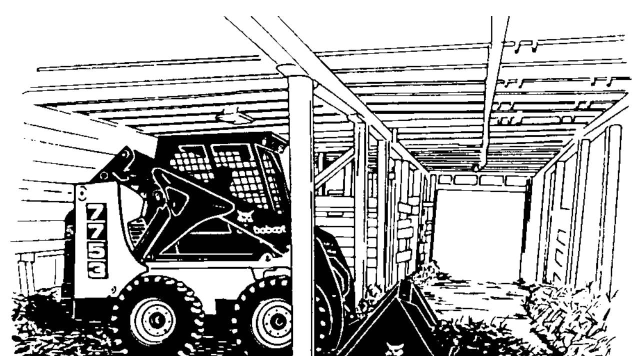
- load rating (capacity and tipping),
- turning radius,
- length/width sizes,
- power,
- noise, and
- available attachments.

Figure 12–15 Skidsteer and articulated-steer type loaders (courtesy Melroe Company and Northwestern Motor Company)

Model Dimensions

	T15	T25	T50	T75
A	82" (2082 mm)	83 1/2" (2121 mm)	93" (2362 mm)	111" (2819 mm)
B	61" (1549 mm)	63" (1600 mm)	70" (1778 mm)	86" (2191 mm)
C	48" (1219 mm)	52" (1321 mm)	58" (1473 mm)	72" (1829 mm)
D	137" (3479 mm)	162" (4115 mm)	176" (4770 mm)	208" (5283 mm)
E	83" (2108 mm)	88" (2235 mm)	96" (2438 mm)	102" (2590 mm)
F	104 " (2642 mm)	110" (2794 mm)	120" (3048 mm)	138" (3504 mm)





Overall height and width clearances are important for maneuverability. A loader bucket width, the same or wider than the tractor width, aids steering when scraping; and reduces tracking spilled waste. Buckets range from 3 to 6 feet wide.

Rubber, steel with rubber pads, and steel grouser tracks are available to fit over the tractor tires. These tracks improve traction and flotation and provide a smoother ride, depending on the working surface.

(f) All-wheel drive front-end loader

The investment involved in purchasing a large, high-capacity, all-wheel drive bucket loader (payloader) is justifiable for a year-round, near daily operation (figs. 12–11, 12–16, and 12–17). This type loader is best adapted to open yard cleaning and to handling heavy and bulky materials around big work areas with high headspace. Durability, high lift, and relatively fast high-capacity operation are major features. Four-wheel drive is basic, with articulated-steer or crabsteer as options. Available models range from 60 to more 275 horsepower and have a 1- to 8-cubic-yard load carrying capacity. A 5-cubic-yard bucket capacity is common. Loaders with interchangeable buckets and forks generally have less loading capacity than that of the fixed bucket models. Most are diesel powered.

A telescoping-frame type boom or bucket loader reduces transmission shifting and much of the wheel movement and speeds up loading and piling (fig. 12–17). The reach is a major feature.

Cattle feedlot cleanout and waste loading are often done using the telescopic, all-wheel drive loader. The operator must be skillful in the use of this loader to efficiently collect waste on an unpaved lot (usually with some wet and some dry areas) and yet leave the compacted waste and soil layer. Shifting gears four times per bucket load while travelling in a forward-reverse, forward-reverse motion and simultaneously steering the loader, plus guiding the vertical movement of the bucket, can be tiring.

The most efficient method for annual waste collection in open, large Texas feedlots was determined to be chisel-plowing the feedlot to reduce chunk sizes, stacking the waste in the pen with a wheel-type loader, and then loading and hauling the waste on trucks. However, this chisel-plow, all-wheel drive loader method can disturb the compacted waste and the soil interface seal needed to protect against nutrient leaching (Sweeten 1984).

Figure 12–16 All-wheel drive (agricultural bucket loader)

(g) Motor grader

A common road grader and maintainer can be practical for frequent scraping of solid waste buildup on long paved aprons and open yard surfaces. Although a large turn space is needed, this equipment is designed for scraping and has the adjustments, visibility, capacity and other features needed to scrape big areas. In dry climates the smooth surface left by the grader blade facilitates frequent waste collection. Like the self-propelled, elevator scraper (see fig. 12–18), the accurate control of the scraper blade minimizes disturbance of the sealed soil surface layer.

(h) Elevating type box scrapers

A self-loading elevator type scraper-hauler (fig. 12–18) that both loads and hauls is more efficient than an all-wheel drive loader for cleanout of soid waste from large open feedlots with few corners. The ability of the elevating scraper to make a precise cut permits slicing through built-up solid waste while leaving the desired undisturbed waste and soil sealing surface layer. The operator can travel continuously forward in an oval-shaped pattern, rather than the forward and reverse cycles needed with the all-wheel drive loader (Sweeten 1991).

A self-propelled elevating scraper has an 11- to 25-cubic-yard loading capacity and 100- to 250-horsepower moving capacity. Similar size towed models have less capacity and power need. Models are available with varied wheel arrangements, height and width clearances, hitching and loading transfer features, dumping or push-off unloading features, cutting depth control, and hydraulics options. A compact adaptation of the elevating scraper for poultry litter agitation and hauling is called a cruster (see fig. 12–50).

The wheeled, tractor-towed, conventional box-scraper is useful for collecting loose solid waste in open yards, constructing mounds, and performing drainageway maintenance (Livestock 1979). The operating capacity generally is lower than that for a comparable sized, self-loading elevating scraper. The scraper's capacity ranges from 1- to about 8-cubic-yards, and the power needs are about 25 to 450 horsepower, depending on operating speed and hydraulic capacity. A useful model for working around the typical facility is about 5-cubic-yards and 100-horsepower capacity.

Figure 12–17 Telescopic, all-wheel drive bucket loader (courtesy Gehl Company)

(i) Mechanical scrapers for gutters and alleys

Open scrape alley design for semi-solid and slurry waste is explained in section 651.1002(a). The relatively light duty cable-drive scraper (fig. 12–19) can use manual or automatic control of a 0.75- to 1.5-horsepower electric motor. Automatic control is generally set to reverse or shut-off the power when the scrapers reaches the end of the set travel distance or overloads from an obstruction. Alley scraping arrangements can be designed so one drive can power several scrapers at once (fig. 10–3). Operation is quiet, and alley corner turns can be made right or left.

To reduce corrosion and weight, a high-strength stainless steel cable, 3/16 to 5/16 inch in diameter, is used for pulling the scraper. The size used depends on the scraper width and length. Small diameter cable, with adequate strength, is more flexible around corners than larger steel cable, and the investment is less. Cable stretching requires periodic adjustment.

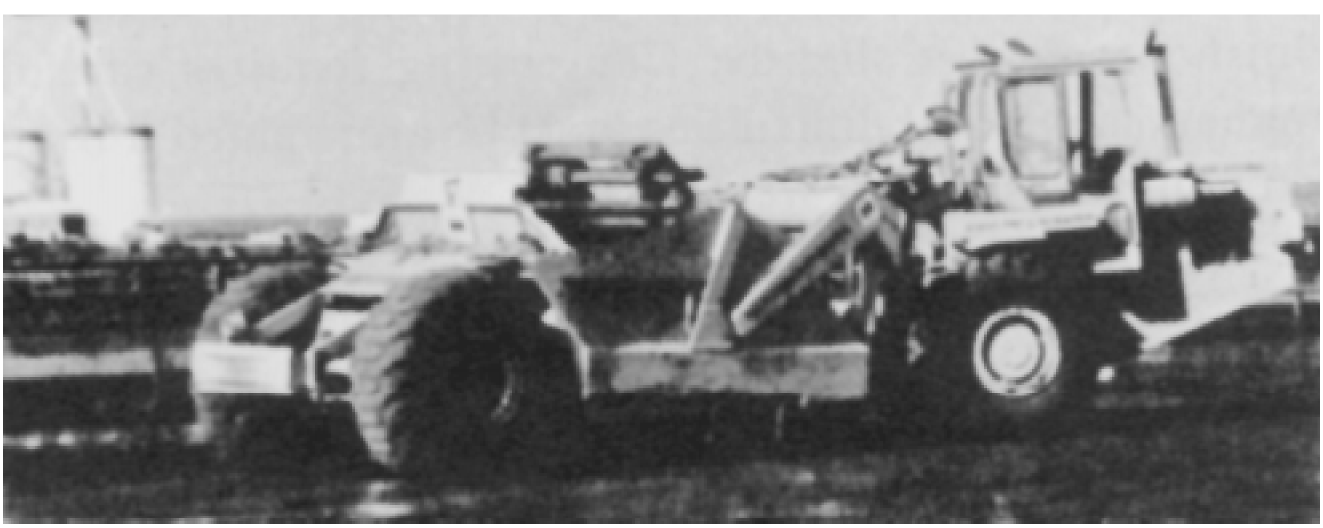
Cable-drive power units are available for alleys that are up to 1,000 feet long. Scraper blades up to 12 feet wide and 8 inches high are available. Most are made from corrosion-resistant steel. Some models have a flexible material on the scraper edge for cleaner scraping of a rough surface.

Scraper speeds of 4 to 8 feet per minute are practical for open alley scraper travel. Speeds to 50 feet per minute are used with slurry waste below a slat floor where there is no foot traffic interference.

Most models scrape one way, then tip or fold up and return empty. Rigid blade models push the waste each way and require a collection gutter at each end of travel. Minimum clearance at blade ends and construction of a uniform alley floor minimize leakage or spillage of scraped waste. A scraper blade pushes only so much semi-solids, and then it overflows. Because of this, frequent operation is needed; however, the frequent use increases drive, cable, and scraper wear and hastens floor wear and slipperiness.

A wide and long alley scraper for semi-solid waste needs a heavy-duty link chain. The chain generally is set in a preformed groove in the alley floor to pull a 7- to 10-inch high scraper blade (fig. 12–20, see fig. 9–6). The chain drive is similar to that used with a gutter cleaner (fig. 12–21). Heavy-duty chain links are forged and heat-treated from high carbon steel. Hook-type chain links can flex in all directions. Alloy steel pintle connected chain is used for corrosion resistance and mostly horizontal movement.

Figure 12–18 Self-propelled elevator type scraper-hauler



A chain drive intermittently operated in wet waste corrodes, wears, and stretches over a few years of use, especially where the alley is long and wide or the waste is dense. This wear demands periodic maintenance of the chain and replacement about every 8 to 12 years.

The concrete of open, scraped concrete alleys is grooved when the alley is constructed or later using a concrete saw. The grooved concrete helps to reduce slipperiness. The grooves are about 0.375 inch wide and deep. They are spaced 4 to 8 inches apart and are diagonal to the scraper travel, which helps to make the scraping smoother and cleaner (fig. 12–22). Too deep or wide grooves interfere with cleaning and disinfecting, which can affect foot health.

In some cases loose aluminum oxide grit (as on sandpaper) is worked into the surface of the fresh concrete instead of grooving the concrete. The grit is applied at 0.25 to 5 pounds per square foot. Coarse grit of 4 to 6 meshes is recommended. Such grit surfaces increase scraper wear (Barquest et al. 1974).

The widely used gutter, or barn cleaner, designed for collecting semi-solid and solid waste, generally uses a continuous, one-way heavy chain drive (fig. 12-21, see fig. 10-10). The less-used back and forth shuttle-stroke cable or rod pull type (fig 10-9) costs less than other cleaners and only needs 1 to 2 horsepower and manual control. Its practical use is with a relatively short gutter and slurry waste where up to 140 feet per minute speeds are used.

The heavy-duty one-way driven cleaner requires 2 to 10 horsepower, depending on gutter width, length, and the cleaner speed. The gutter generally is 16 to 18 inches wide. It is usually 12 to 18 inches deep. The gutter chain can be up to 700 feet long. The typical speed for this cleaner is about 20 feet per minute.

Scraper paddles that are 2 to 4 inches high and spaced 1.5 to 4 feet apart are available. Higher paddles and closer spacing are required for slurry and liquid waste. Corner-wheel construction, installation, and maintenance are critical because the system experiences major wear in these areas. Reverse turns are located where the unloaded chain runs empty on its return.

Figure 12–19 Cable-drive scraper for open alley or under slat floor (courtesy of Acorn Equipment Company)

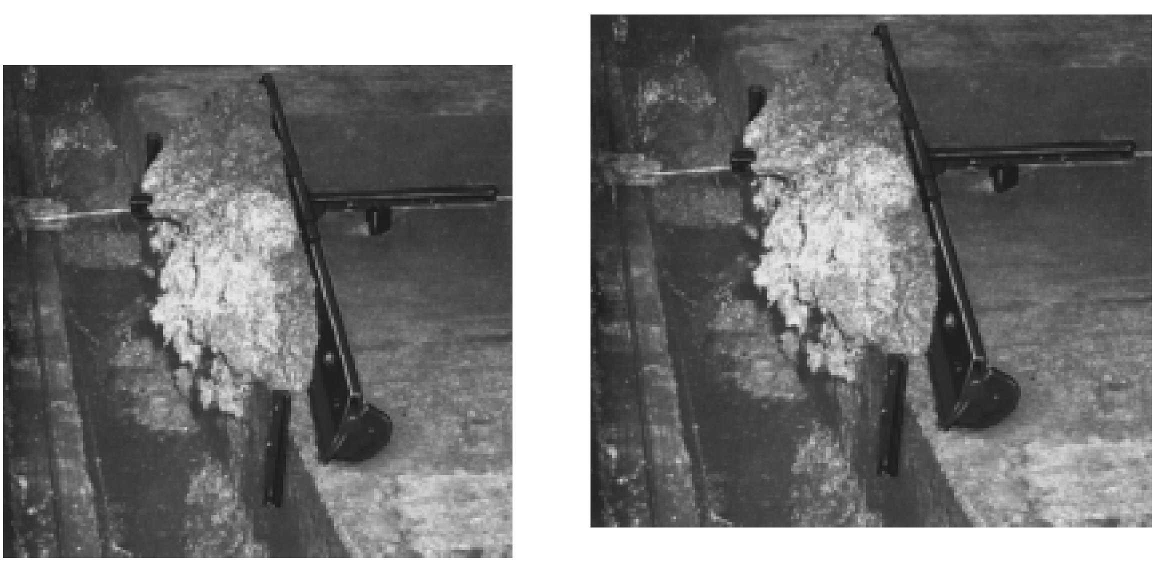
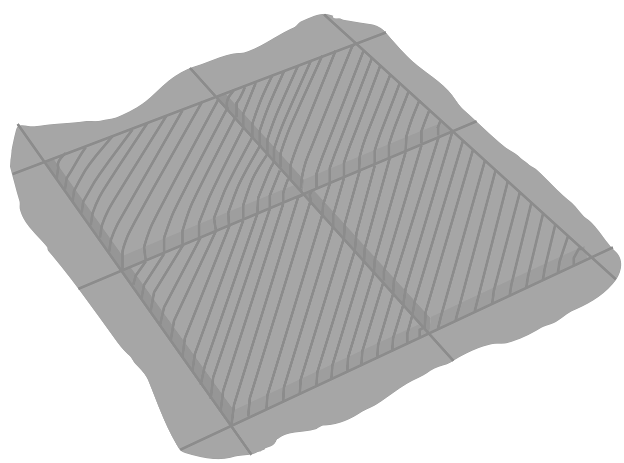


Figure 12–20 Heavy-duty alley scraper, chain drive (courtesy of Alfa Laval Agri, Inc.)

Figure 12–21 Heavy-duty alley gutter cleaner with chain drive (courtesy Patz Sales, Inc. and Husky Farm Equipment, Ltc.)

Figure 12–22 Diamond-shaped concrete floor grooves



(j) Conveyors and stackers

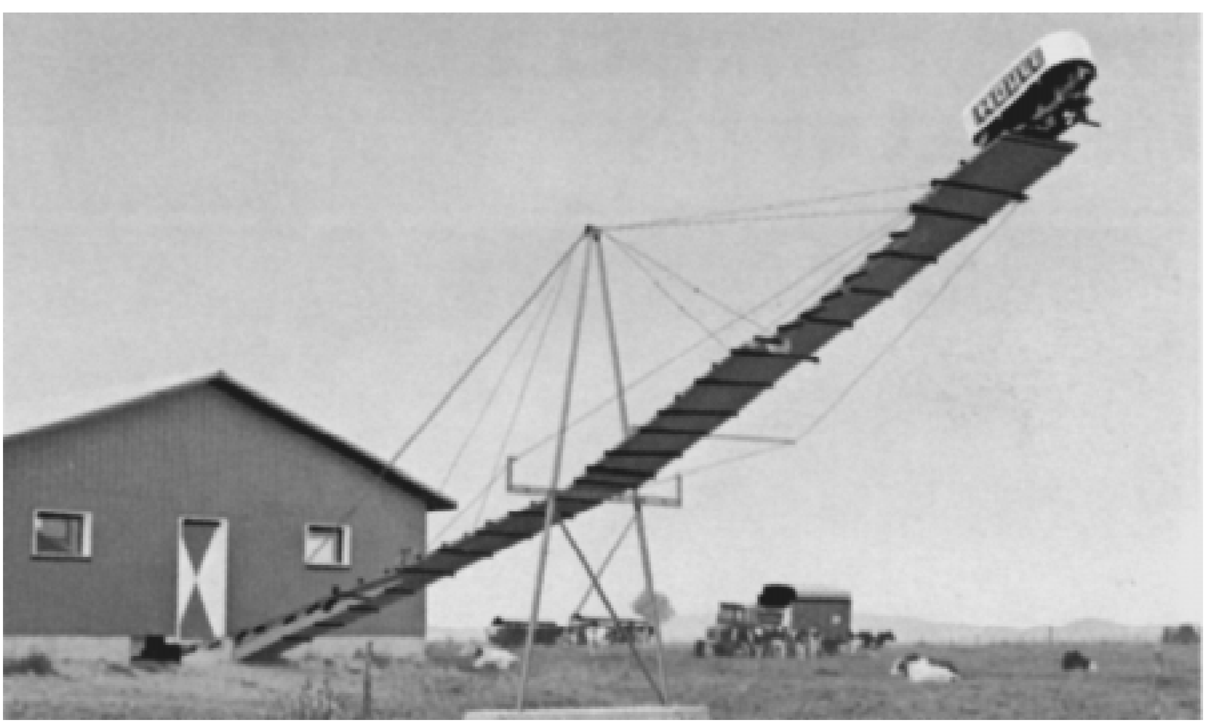
Most gutter cleaner equipment has unloading elevator ramp options for piling or stacking solid and semi-solid waste onto outside storage piles and aboveground storage tanks (see figs. 8–22, 10–12, 12–21). A wheeled undercarriage or overhead cable suspension support of the ramp permits semi-circle movement of the elevator for more storage space (fig. 12–23). A picket dam (see fig. 12–36) or other method (see fig. 9–7) may be needed for drainage to storage. See section 651.1005(d) of this handbook for additional information.

Clean-off options for semi-solid waste that sticks on paddles is part of gutter cleaner equipment. Melting snow or rainwater drains down an unprotected, inclined conveyor and into the gutter. Stacking fresh waste on old increases the rate of decomposition and nutrient loss and increases odor, pest, and frozen waste buildup problems; however, the temperature of the resulting stack must be carefully monitored to prevent spontaneous combustion. Temperatures near 160 degrees Fahrenheit are indicative of problems.

An endless chain-slat type conveyor adapts to inclined elevating of scraped or separated solid waste to aboveground storage. It is used as part of the inclined screen solids/liquid separator (see fig.12-62). Semi-solid waste leaks liquid, sticks and dries on the chain and slat surfaces, and dribbles off or freezes on the return. The 5- to 10-horsepower need for a 30-foot lift is less than that required for an auger; however, the capacity is also less because the waste tends to slide or roll back down the incline. Typically, a 5 horizontal to 3 vertical slope is about the maximum elevating angle for a chain-slat conveyor, depending on slat design. A chain-slat speed of 75 to 125 feet per minute is typical.

Slurry and liquid wastes are best directly pumped or conveyed up at a less than 30 degree angle to storage with an enclosed auger. The capacity of an open-top, U-trough auger is increased if the auger is operated at flatter inclines. Although augers are operated at steep slopes with liquid waste, auger power requirements for semi-solid waste are high, about 1 horsepower per 2 feet of auger length for a 13- to 16-inch diameter auger at 200 rotations per minute.

Figure 12–23 Gutter cleaner conveyor stacker that is cable supported (courtesy of J. Houle & Fils, Inc.)



Powered thrower, or slinger, waste stacking equipment was once made for piling semi-solid waste conveyed onto it via a gutter cleaner. The power requirements were relatively high, and winds affected pile placement and development. Appearance and frozen waste buildup with regularly top-piled waste were also problems.

(k) Flushed gutters and alleys

Flush gutter and flush alley waste collection uses a relatively large quantity of regularly added flushwater for more thorough cleaning. Gutter or alley design and flushwater quantity are explained in sections 651.0403(k) and 651.1002(a) and (b) and in table 12–2. Different applications are shown in figures 9–9, 9–18, 10–4, 10–5, 10–6, and 10–23. A flushwater recycle arrangement (see fig. 12–28) reduces the amount of added fresh water.

In lieu of scrapers with mechanical power and control, flushing equipment involves pumps [see section 651.1206(b)], pipes, tanks, drains, and liquid overflow control. Electric power that allows automatic control is often used. A stored flushwater release valve needs to deliver flushwater to a gutter at the correct flow rate for a necessary length of time [see section 651.1002(a)(2)]. Several types of gutter or alley flushwater storage and release equipment are used. Which to use depends on investment, facility design, flushwater demand, and waste quality. The equipment can include:

- tip or dump tanks,
- storage tank gate valves,
- siphon-release storage tank, and
- tower-type storage with pipeline or valve flow control.

An ordinary stock watering tank, portable plastic tank, or used metal tank is adaptable for flushwater storage or release. Aboveground flushwater storage tanks are often locally custom built using poured-in-place or precast reinforced concrete, concrete block, or fiber glass. In flush alley cattle barns, the alley flushwater storage tank can also be used as a cattle waterer where fresh water is used. A gate-type flush tank door on the side (fig. 12–24) or flop-up valve on the bottom of the storage can be hand operated or semiautomatic operated using float-controlled weight assist, vacuum pump assist, or air pressure assist. A watertight seal and smooth door or gate operation are elusive features requiring workmanship, durable materials, and maintenance.

Dump-type flush tanks (fig. 12–25, see fig. 10–6) are manufactured or can be custom built from a plan (appendix 12A). These tanks are relatively low cost and can be readily changed or replaced. Such tanks can automatically dump when steadily filled to an adjustable, overbalance pivot-point. Bearing wear, sticking, tank corrosion, noise, floor space need, and splashed water are considerations when choosing a dump-type flush tank.

Unlike a dump-type flush tank, an automatic siphon flush tank generally has no moving parts (see fig. 10-6). The operation of this type flush tank is explained in section 651.1002(a)(2). An interruption of flushwater flow (e.g., power or pump failure) stops the automatic siphon action. A burping using a compressed-air blast through the siphon may then be needed along with resumed waterflow to restart the automatic siphon action. The investment is relatively high for a siphon. Unlike a dump-type flush tank, the siphon can be located overhead with a drop pipe outlet, which eliminates the use of building floorspace.

Table 12–2 Flushwater flow and pipe size (MWPS 1985)—Maximum velocity = 2.5 ft/s

Pump capacity (gpm)	Minimum pipe diameter (in)
10	1.5
20	2.0
30	2.5
50	3.0
75	3.5
100	4.0
200	6.0
400	8.0
600	10.0
800	12.0
1,000	15.0

Figure 12–24 Hand operated storage gate flush control (courtesy of Agpro, Inc.)

Figure 12–25 Flushwater storage tank with dump-type release (courtesy Agpro, Inc.)

Air leakage and foreign material that restricts flushwater flow are siphon operation problems. Siphon flush tanks can be purchased, or they can be constructed from plans (MWPS 1976). Appendix 12A shows USDA Plan 6349 for a gutter flush system. Although vulnerable to puncture or cracking, molded glass fiber tanks are noncorrosive. Repair can be difficult. Stainless steel tanks are also noncorrosive, but generally more costly.

Note: Mention of plans is only for planning information. Natural Resources Conservation Service procedure requires design analysis for specific site conditions.

An overhead or tower type flushwater storage tank, or reservoir, saves floor space, adds to flushwater pressure, and permits large volume flushing by pipes of several gutters from one water source. A sturdy, post-beam or other type tank support system is essential to hold the 2,000 to 5,000 gallons (8 to 21 tons) of overhead flushwater storage.

A tall, narrow, aboveground flushwater storage tank arrangement (fig. 12-26) is advantageous for large facilities that have several gutters or for several adjoining barns that collectively use a large volume of flushwater. Flushing can then be done at different times in the different gutters via pipes and valves from one flushwater source. A relatively small capacity fill pump, automatically operated by float switch over several hours, can fill the flushwater storage tank. A bottom drainplug is used for periodic or operation shutdown cleanout. Also, an overflow pipe from the tank to a drain is needed as the automatic controlled filler pump shutoff can malfunction.

University of Missouri agricultural engineers have compared the equipment for five ways to release flushwater release. The study was conducted in their 98- by 202-foot, 160-cow dairy freestall barn (fig. 12-26). The flushwater effectiveness was measured from two dump-type flush tanks, two baffled air-controlled valves on pipes, and a partly-embedded 12-inch diameter pipe with seven 3- by 6-inch holes spaced across a 10-foot-wide alley (fig. 12-27). The

Figure 12–26 Tall flushwater storage for five flushed alleys (Rural Builder 1992, Patrico 1992)

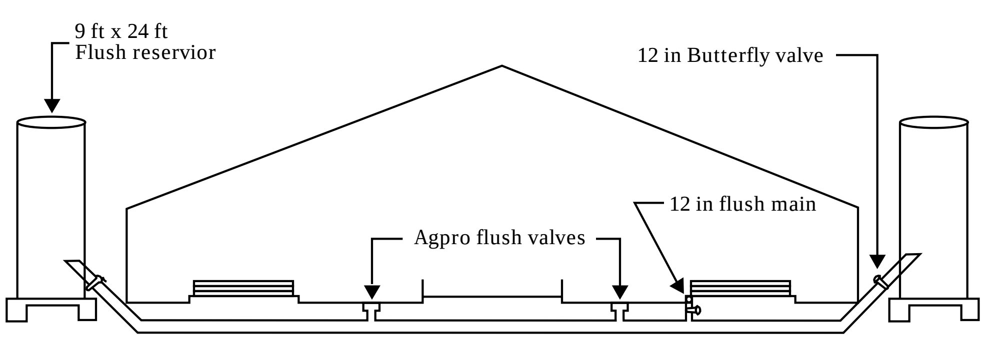
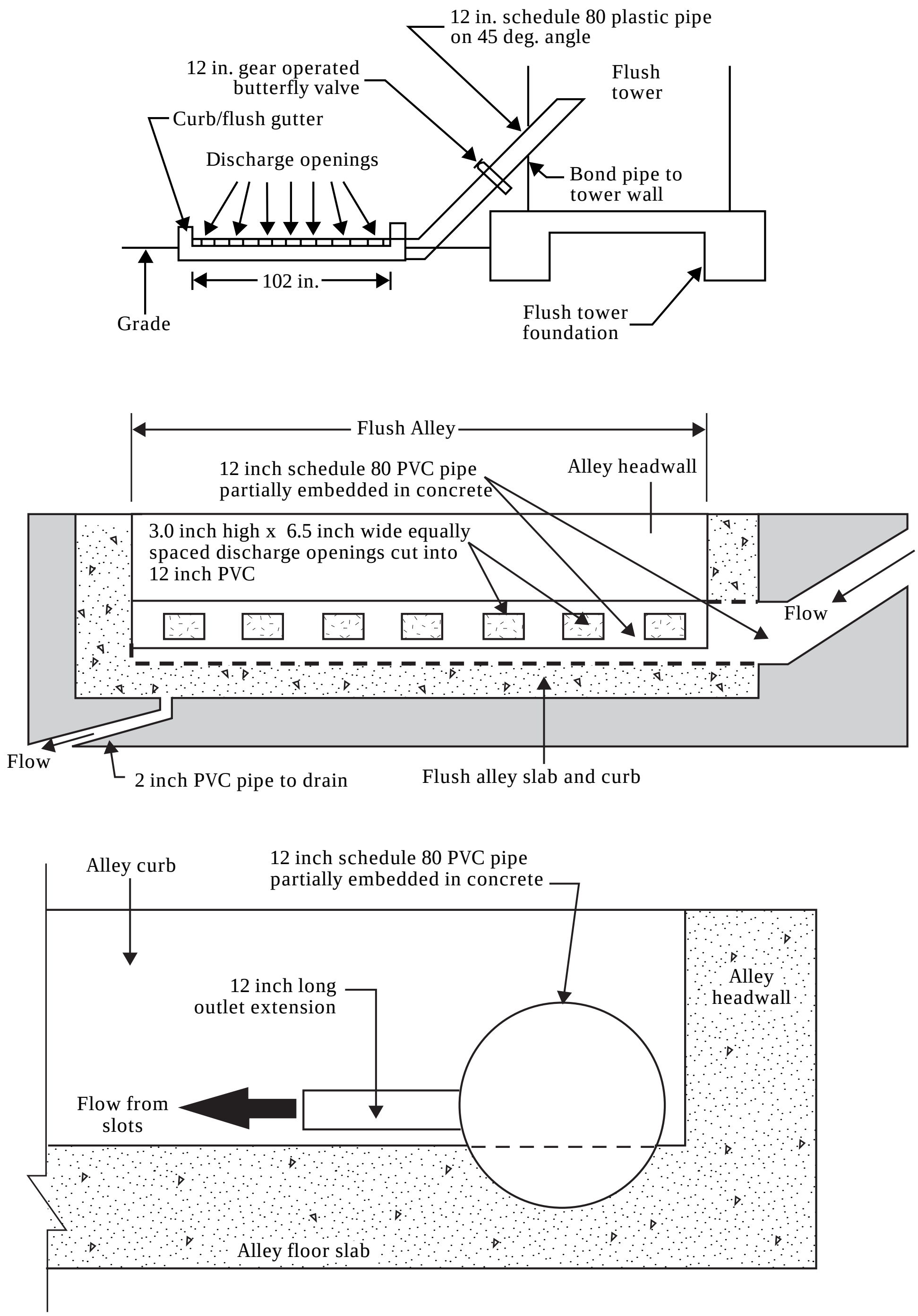


Figure 12–27 Flushwater alley entry from 3- by 6-inch holes (Rural Builder 1992, Patrico 1992)



holes had a 1-foot-long outlet extension and allowed flushwater volume to uniformly, but forcefully, exit into the alley as seven smaller streams rather than a large, concentrated stream. In daily flushing, the cleaning done by the spaced-hole flushwater discharge was preferable to the dump type flushtanks and the air-controlled pipe valve flushwater dischargers (Patrico 1992).

Direct pumping large volumes of alley flushwater from a second stage lagoon or an ample supply of freshwater is common in mild climates. Sections 651.0403(k) and 651.1002(a)(2) give more information. Table 12–2 shows the pumping capacity for various pipe sizes. Systems in use are similar to those shown in figure 12–28. (Also see figures 9–9, 9–18, 10–23.) Investment and daily operation of a large pump, such as that shown in figure 12–28, may be more practical than installing, operating, and maintaining several dump or siphon flushtanks or a large flushwater storage tank. Total water use with a pumped flush system generally is greater than that with dump-type or siphon flushtanks. A power failure or breakdown of the large capacity pump interrupts cleaning until repaired or replaced.

Figure 12–28 Large-volume, low-pressure flush pump used in a recycle system (courtesy of Gorman Rupp Company)

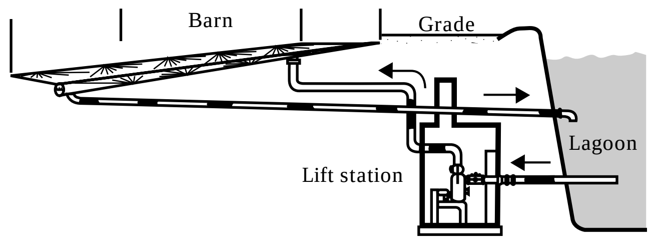


Figure 12–29 Cross gutter for alley flushwater collection

Difficulties with flushwater waste equipment include
- Pump, tank, and valve maintenance and repair
- Metal corrosion
- Struvite buildup
- Liquid freezing

In subzero climates, correct ventilation (airflow rate, direction, supplemental heating, and temperature operation) is critical to control building humidity and temper the cold drafts from freshly-pumped, cold flushwater. This is especially important for baby livestock operations.

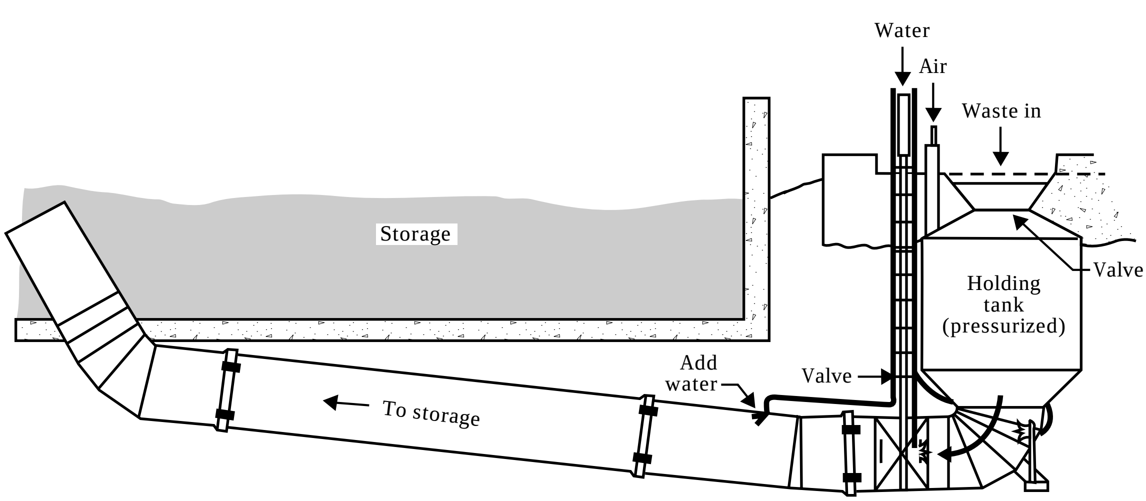
A cross gutter or drain that has adequate flow capacity is needed to smoothly carry away a large volume of flushwater from an alley or gutter (fig. 12–29, see fig. 9–9). The flow into the gutter or drain should be unrestricted. If flow is slowed, flushwater backs up and solids separate and block the subsequent flushwater.

(l) Air-pressure and vacuum waste pumping

An air-pressure (pneumatic) operated semi-solid and slurry waste pump uses a well-constructed below-ground collection or holding tank that can be closed and pressurized with compressed air (fig. 12–30). Most tanks are constructed of steel or poured-in-place reinforced concrete. Wastes are scraped into the 1,300- to 1,900-gallon tank through the top opening. When nearly filled, the top is covered and compressed air let into the tank to about 50-psi pressure. As pressure increases, the contained waste is forced out past a valve that prevents backflow from the storage. The waste moves under pressure through a 2- to 2.5-foot diameter steel pipe to storage. At least 3-horsepower of energy is needed to operate the air compressor—a larger compressor speeds airflow.

Figure 12–31 Vacuum solid waste collector and wood chipper (courtesy Crary Co.)

Figure 12–30 Air pressure chamber (pneumatic) waste pump (courtesy J. Houle & Fils, Inc.)



Although the investment for this type of equipment is relatively high, operating cost is low. Solid waste and freezing can restrict flow, and sand and excess soil in the waste can settle out and buildup in the pipe that leads to the storage tank.

Vacuum rather than air pressure is widely used for handling agricultural wastes. A PTO or hydraulic motor powered vacuum pump mounted on or inside a tanker spreader agitates and empties a slurry or liquid waste storage. The waste is agitated by simply emptying the loaded tanker back into the storage. The vacuum loaded waste is hauled and field spread with the one unit. Sections 651.1206(b) and 651.1207(a)(3) give further information.

Vacuum pumps are available in varied designs and capacities. Comparable to pumps used for liquids, vacuum pumps are rated in cubic feet per minute airflow at different negative pressure (vacuum) levels. The rotary vane type can quickly evacuate a large volume of air with reasonable power—about 10 horsepower per 100 cubic feet per minute down to about 15 inches mercury (or -7.5 psi) of vacuum.

Blower type vacuum is popular for collecting loose, dry solids where high flow vacuums of less than 10 inches are needed. Applications range from the household carpet vacuum to self-propelled street equipment. Household models simply filter out solids from the air flow. Larger capacity equipment can move the airflow through a cyclone separator where the air escapes out the top and solids drop out the bottom. Models used with agricultural waste collection include those made for a garden or lawn tractor (fig. 12-31) to high capacity, truck-mounted equipment. Their power needs range from 5 to 50 horsepower with capacity from 50 to 5,000 pounds per hour.

Although this type vacuum is noisy and relatively inefficient, the vacuum waste collection and handling is relatively clean. Screening and sorting of the accumulated waste may be needed depending on its ultimate use (see figs. 12-69, 12-70).

(m) Piston-plunger pumps

Piston pumps have been developed to convey slurry, semi-solid, and solid waste from a gutter cleaner or reception storage hopper to long-term storage (fig. 12-32, see fig. 9-6). The relatively large hopper inlet opening, piston size, and slow operation assist semisolid waste flow. An electric motor-powered mechanical pumpjack or 2-way reversing hydraulic cylinder is used to drive the piston plunger. The positive displacement piston develops high force and moves waste through an 8- to 16-inch diameter pipe up to 300 feet away. The pipe is generally buried below frostline. Cast iron, steel, or PVC pipe are used depending on pump type and distance. Pipe jointing technique and correct pipe installation are critical. Pump chamber pressures may exceed 100 pounds per square inch, and pipe anchorage must be secure, especially at sharp corners. A pressure relief valve can malfunction, so PVC pipe failure, puncture, collapse, or plugging can be troublesome. This is especially true with solid waste, too-dry waste that expands in the pipe between pumping times, or where the waste is pumped more than 150 feet. A central location permits one piston pump to receive waste from several gutters, alleys, or buildings. Provision is usually made to add water to the waste flowing into the piston chamber. This dilutes waste and aids pipe lubrication. One scheme is to collect gray or other washwater in a sump or tank, then pump or drain this into the waste hopper when the piston pump is operating.

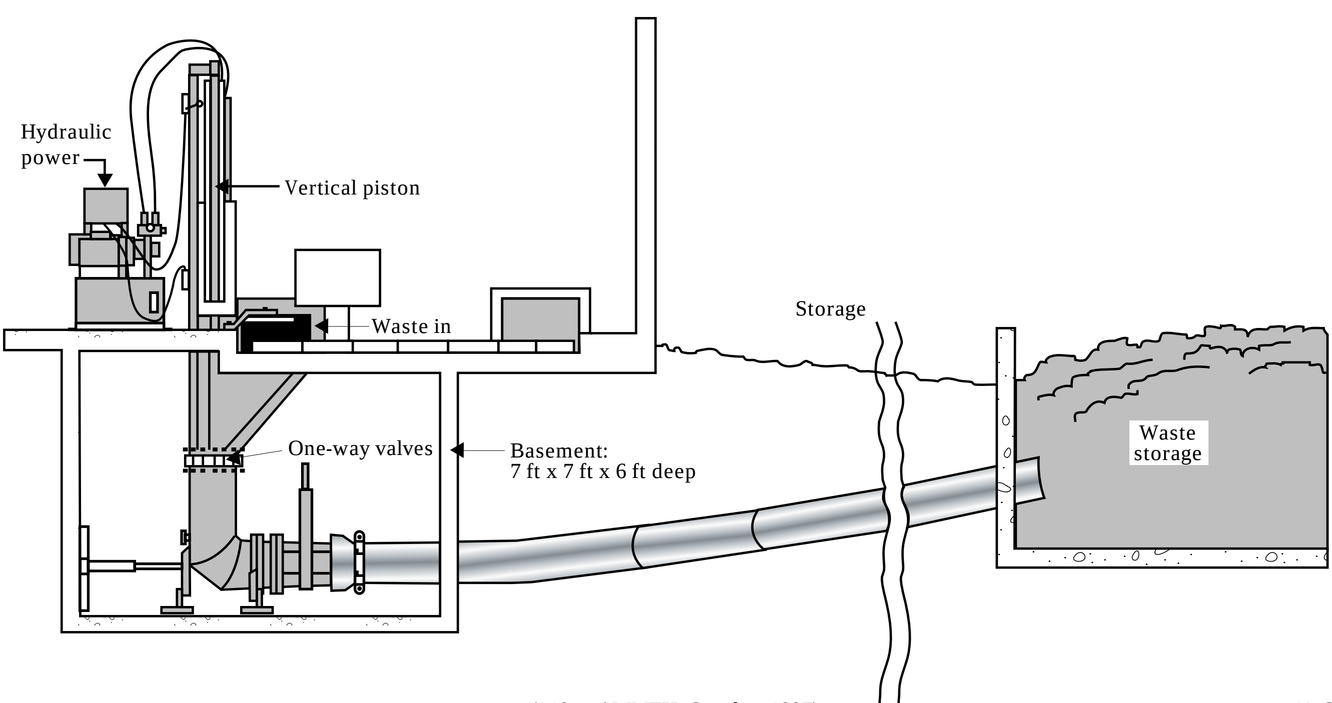
The vertical operated piston pump employs an automatic controlled hydraulic piston that moves up and down through a 3- to 4-foot stroke. It does 1.5-strokes per minute, which can move 60 to 70 gallons per minute of slurry waste (fig. 12-32). A tight-fitting, flexible, lubricated seal around the vertical piston causes it to draw semi-solid waste by suction from the fill hopper into the piston chamber. Waste that is solidified, such as frozen chunks or straw, will not flow into the piston chamber. A rounded, smooth hopper is helpful in these situations. A belowground basement, about 7 square feet, is used for the hydraulic pump and fill hopper. It also can be used for maintenance and repair. Although the basement is an extra investment, it frees up space on the main floor.

The slant operated piston pump (see fig. 9-6) uses a hollow piston that is about a 10- by 14-inch rectangle. Slurry waste that is scraped into a floor-level filling hopper flows through the flap valve face of the hollow piston on its return stroke. The flow is caused by gravity. Semi-solid waste flow to the piston is aided by gravity via the slanted piston chamber. The piston flap valve closes at the beginning of the next stroke. This forces the waste into and out the discharge pipe. Powered by up to a 15-horsepower electric motor, the mechanical drive pushes waste through the discharge pipe to storage up to 200 feet away. Stroke length is typically 11 to 18 inches. The piston operates at about 25 to 45 strokes per minute, so the potential capacity is about 375 gallons per minute.

This pump is simple to install and maintain; however, it tends to misalign from continuous, high-pressure operation unless correctly installed and anchored. Long straw may plug in the piston valve or the hollow piston.

The horizontal operated piston pump is installed at the bottom of a 6-foot by 12-foot by up to a 10-foot deep basement (see fig. 9–6). An automatically controlled, hydraulic powered solid-faced piston is located in a cylinder at the bottom of a floor level hopper. The piston is about 10 inches in diameter and has a 3-foot stroke. The cylinder fills with semi-solid waste that sinks down through the hopper and is drawn in front

Figure 12–32 Vertical piston plunger waste pump with a pipe anchor (courtesy of Berg Equipment Company)



of the solid piston with the return stroke. On the forward stroke, the waste is pushed out of the cylinder into the discharge pipe past a spring-loaded check valve. On the return stroke, the piston again is pulled completely through the cylinder and past the fill hopper. The spring-loaded check valve prevents waste from flowing back out of the discharge pipe, and the piston suction helps gravity fill the cylinder with waste from the hopper. Operating speed is about 2 to 4 strokes per minute, with a potential pumping capacity of 100 gallons per minute. The relatively slow operation assists the piston return suction (with gravity) to better fill the cylinder with waste.

651.1204 Waste storage equipment

The primary concerns about waste storage include pollution prevention, capacity, cost, durability, nutrient retention, safety, in-use appearance, odors, and expansion. Equipment used with stored waste can be an integral part of the storage (e.g., drive ramp access). The success of equipment use can directly affect how well the storage does its job. Also, some storage equipment use has related alternatives and additional considerations, such as a chopper-agitator pump. Associated equipment, such as loading and unloading access, personnel ladders, covers, and seepage control, is reviewed in this section. Chapters 10 (section 651.1008) and 13 of this handbook give further information on these concerns.

General selection and design information about waste storage is explained in section 651.1003. Additional information about location and management is in sections 651.0702(b), 651.0904(c), and 651.0906. Also see NRCS Conservation Practice Standards, Waste Storage Facility, Code 313, and Waste Treatment Lagoon, Code 359. The ASAE Engineering Practices 393.2, *Manure Storages,* and 403.2, *Design of Anaerobic Lagoons for Animal Waste Management,* include design aspects about storage and related waste equipment (ASAE [l] 1991, ASAE [n] 1993).

(a) Storage interior accessing

A paved ramp (see figs. 8–15, 10–17) is used for clean out and service access to waste storages. A paved ramp may also be appropriate for structural storage facilities. A corner location takes advantage of the existing minimum slope for installation. Ramp thawing or drying and operating visibility are aided if the ramp is located to receive the maximum exposure of the midday sun.

An access ladder is needed for storage structures that have vertical walls. It is used to observe filling, agitating, and pumping operations and to do periodic maintenance. Safety precautions for ladder construction, anchorage, and access by strangers or children are a must. ASAE Standard S412.1, Ladders, Cages, Walkways and Stairs, explains design and installation recommendations (ASAE [o] 1994). Briefly, the recommendations are:

- Space 16-inch wide rungs a maximum of 1 foot apart.
- Allow 7 inches of toe space in front of rungs.
- Use a 27- to 30-inch cage clearance about the ladder.
- Provide work landing platform access.

A waste storage ladder location in plain view by others is preferable. A portable ladder stored away from the waste storage can help deter unauthorized access (see figs. 9–6, 10–18). When in use, the portable ladder should be securely attached to the storage structure to prevent it from falling away and stranding the user. A ladder permanently attached to a storage structure needs to terminate beyond ordinary reach or an entry guard or gate must be used. The attached ladder should terminate at a height of more than 8 feet above the ground. A sunlit location for the ladder helps to quickly dry the ladder and is naturally well lighted.

A ladder permanently located inside a waste storage structure obstructs cleaning. It will also corrode and become unsafe as its deterioration is hidden by waste and poor light. A portable ladder, removed and stored when not in use, is a better alternative.

A stored waste depth marker helps to estimate remaining storage capacity, sludge buildup, and other such problems. The marker should be highly visible. It can be a treated 2 by 4 that is painted white and has footage numbers in red. The marker should be securely located in plain view at the edge of the storage and may need to be periodically cleaned to be visible.

Warning and safety signs and related safety equipment recommended for use with waste management equipment are reviewed in section 651.1208.

Warning: Various gases can be released in volume or otherwise be contained when agitating and pumping wastes in an enclosed space. The displacement of oxygen and/or accumulation of hydrogen sulfide or carbon monoxide is dangerous/fatal. Persons have died after entering an enclosed tanker, storage tank, or waste handling space.

(b) Storage exterior accessing

Waste storage agitation and emptying equipment needs overhead clearance and turning space access (see figs. 9–6, 9–8, 10–12, 10–16, 12–47 to 12–49). An example:

> A vertical wall, belowground, semi-solid/slurry storage structure that is up to about a 60-feet across and 12 feet deep can be agitated and pumped from one pump station using the same centrifugal-chopper pump used for filling the storage. A circular storage shape agitates in less time and encloses more storage capacity than does an equal perimeter length of a rectangle or other storage shape—everything else being equal.

Tables 12–3a and 12–3b can be used for estimating comparative sizes. For example, to store 21,600 cubic feet of waste would require a storage structure that is a 24- by 100- by 10-foot rectangle or a circular unit that is 55 feet across and 10 feet deep.

Additional access space or larger agitation equipment is needed for larger storages, especially for semi-solid waste. An impeller-type agitator (see figs. 10–16, 12–46), a centrifugal-chopper pump, and several agitation pump docks or ramps (see fig. 10–17) are usually needed with large (>100-foot-long) rectangular storage structures.

A straight-line operation for the tractor PTO pump powershaft reduces U-joint wear and fluctuation of speed (see figs. 12–34, 12–46). A level operating area may be needed for gravity lubrication of agitation and pumping equipment.

One of two arrangements is typically used for aboveground storage agitation. One uses a horizontal shaft, centrifugal, chopper-agitator pump mounted on the waste storage tank near the foundation (fig. 12–33, see fig. 9–6). A valve is opened in the storage drainpipe. The pump is then operated to draw waste from the bottom of the storage and pump it up and over the wall and around the top of the storage to agitate the storage contents. This is the only agitation access

Table 12–3a Approximate capacities in cubic feet of rectangular storage (10-foot-long tank)

Width (ft)	Depth (ft)* 4	6	8	10	12
4	120	200	280	360	440
6	180	300	420	540	660
8	240	400	560	720	880
10	300	500	700	900	1,100
12	360	600	840	1,080	1,320
16	480	800	1,120	1,440	1,760
20	600	1,000	1,400	1,800	2,200
24	720	1,200	1,680	2,160	2,640

* Allows 1 foot top freeboard

Table 12–3b Approximate capacities in cubic feet of circular storage (per 1-foot depth)

Diameter (ft)	Depth* (ft^3/ft)
20	314
30	707
40	1,257
50	1,963
60	2,827
70	3,848
80	5,026
90	6,358
100	7,850

* No freeboard

Figure 12–33 Horizontal shaft chopper-agitation pump (courtesy Wieser Concrete Products, Inc.)

unless one or more impeller-agitators are mounted on the inside wall of the storage (see fig. 12–47). In most cases provision is made for adding dilution water near agitators for mixing of semi-solid waste. After agitation the pumpout valve is switched from agitation, and the pump is used to fill a nearby tanker spreader or to supply an irrigator for more liquid slurry.

The second typical aboveground tank unloading arrangement uses a nearby belowground reception tank. In most cases this tank is the same one used for waste collection and for topfilling the storage (fig. 12–34). To agitate or pump, a valve is opened in the aboveground storage drainpipe so waste drains into the reception tank. A vertical shaft, chopper-agitation type pump, operated in the reception tank, pumps waste up over the wall and top of the tank for agitation, or the pump valve is switched to fill a tanker or supply an irrigator. This second arrangement demands closer attention than that required by the first arrangement during agitation or unloading to assure the reception tank does not overflow.

A second safety valve in the storage drain is used to ensure against unload valve failure with any storage that is above an open gravity drain. Such accidental draining protection is needed (see figs. 9–6, 12–34). Local regulations may require a secondary containment dike around an abovegound storage similar to those used for aboveground chemical or petroleum containment. Pumping access, sunlight drying and heating, snow accumulation, and prevailing winds should be considered in locating an agitation station.

Agitation and pumping openings for belowground storage need to be sized, spaced, and located to provide agitation access to tank contents, especially corners. A pump sump (see fig. 12–46) permits complete emptying of stored waste when desired.

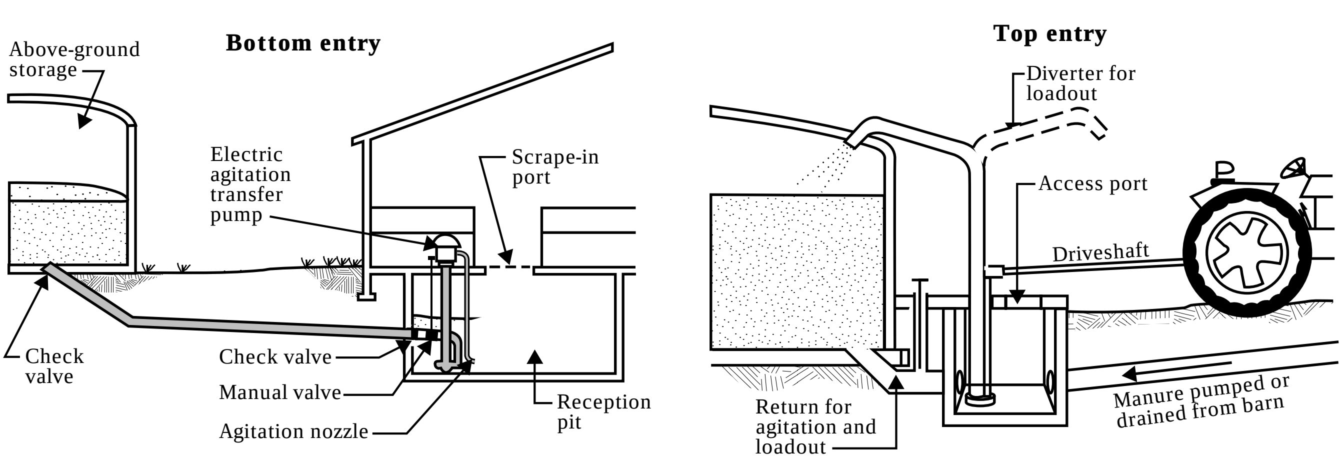
(c) Storage fencing with gates

A fence with locked gate entry is often used with an earthen basin and other open-top waste storage to control access by people and livestock. See NRCS Conservation Practice Standard, Fencing, Code 382, sections 651.1007(a) and 651.1008(c), and figures 8–15, 8–17, and 10–16 for more information. The type of fence should be commensurate with the hazard imposed by the facility.

(d) Covers, drainage, and runoff control

Although the extra cost is questionable in some climates, covering an open-top, aboveground storage reduces evaporation, nutrient loss, plant growth, and odor emission as well as excluding clean water. Study continues on cover equipment design (Huss 1994, Miner 1994, PAMI 1993). A relatively permanent clearspan truss rafter, arch rafter, or similar roof construction is used to support the cover (Switzky 1982). Interior deterioration of construction materials is a consideration. Pressure preservative treated wood,

Figure 12–34 Reception storage or pumping and abovegound storage (MWPS 1985)



exterior grade plywood, corrugated asphalt fiberboard, plastic, fiber glass, and stainless steel are construction alternatives.

Experience indicates that float-supported fabric sheeting, laid onto a holding pond surface and weighted in-place, can be used to collect gas and suppress odor (Melvin & Crammond 1980). Figure 12–35 shows a fabric membrane cover for open-top storage. Although fabric sheeting costs less, the wind can loosen, wear, and blow off a lightweight cover easier than heavier or more permanent covers. Also, accumulated rain and snow on the cover must be accommodated. A cover manufacturer should be consulted on floating plastic cover design and installation (Safley & Lusk 1991).

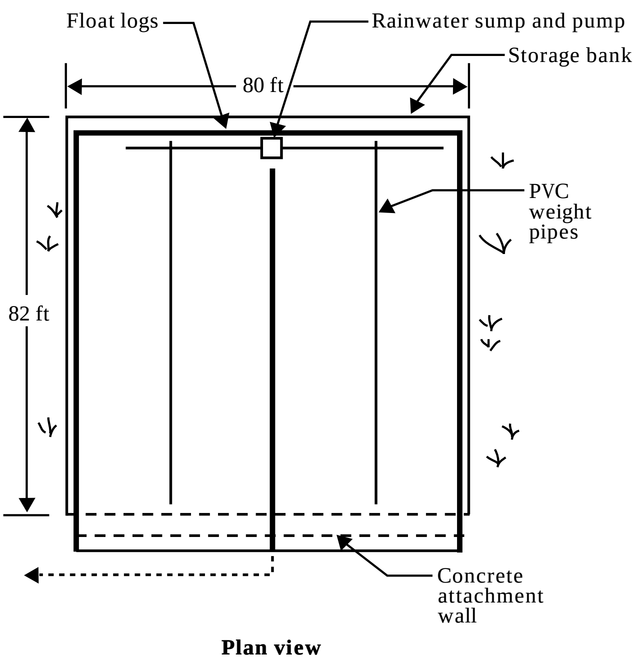
Barley, oats, durum wheat, and flax straws can be shredded and blown onto a storage's liquid surface using a straw spreader designed for spreading straw along new roadways. Straw is blown directly onto the liquid surface. A 6- to 10-inch-thick layer of good quality barley straw appears to be the most effective material for an unsupported cover. Under a relatively dry climate, one to two applications of this straw will effectively reduce odor for an entire season.

A 1-inch-thick polystyrene float supports a straw cover and keeps it dry for nearly the entire season with excellent odor reduction. The straw/float cover settles to the bottom as the liquid is pumped out. It can be mixed in with the stored slurry waste and field spread.

The Prairie Agricultural Machinery Institute developed a straw cannon that can blow straw out to 180 feet and discharge a 1,500-pound round bale in about 1.5 minutes (Grainews 1994). Straw mixed with polystyrene pellets enclosed in burlap has also been used as storage pond cover in the Pacific Northwest. Odors were greatly reduced, and the cover can be mixed with the pond contents.

The picket dam or vertical slot wall is used to retain solids while permitting water to run off the waste stacked in an uncovered, ground-level, solid or semi-solid waste storage structure (fig. 12–36). A picket dam is normally considered a component of the transfer function of a waste management system. It is described here, however, because it is an alternative to roofing a stacking facility.

Figure 12–35 Fabric membrane cover for open top storage (adapted from Safley & Lusk 1991)



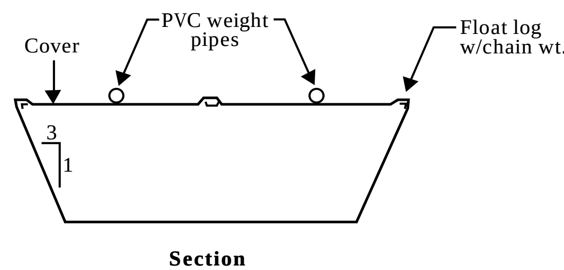


Figure 12–36 Picket dam for opentop storage drainage (MWPS 1985)

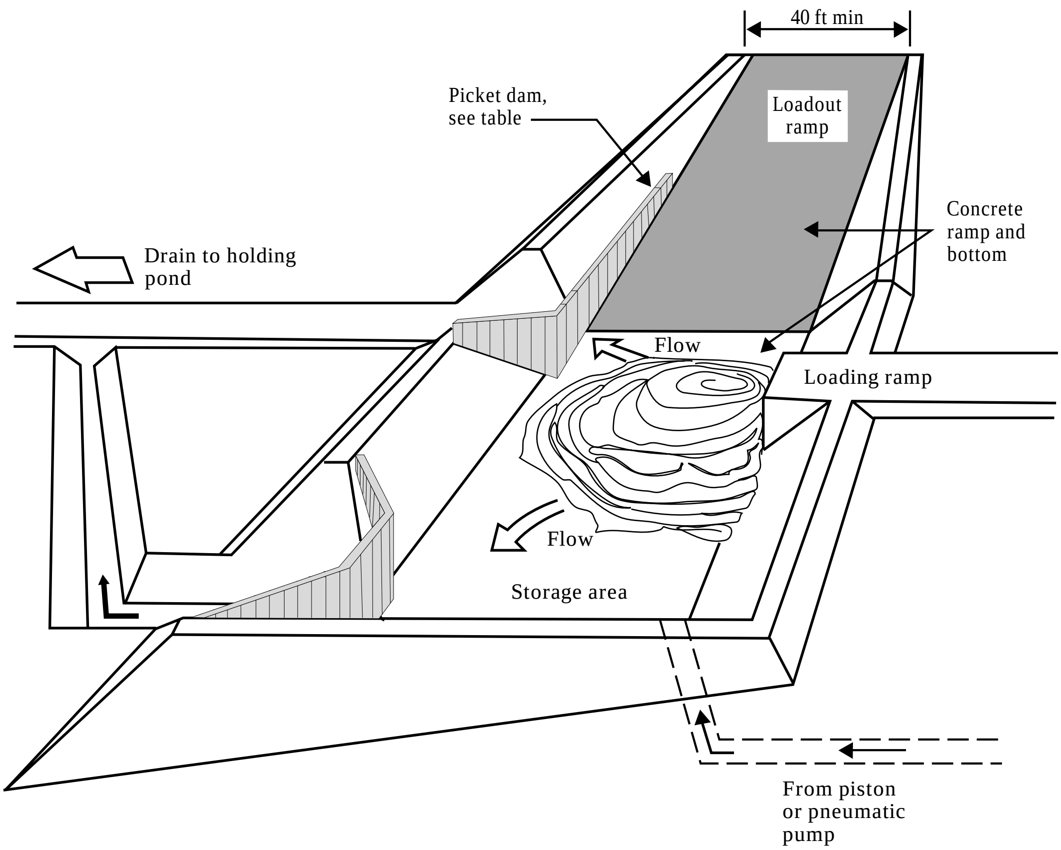
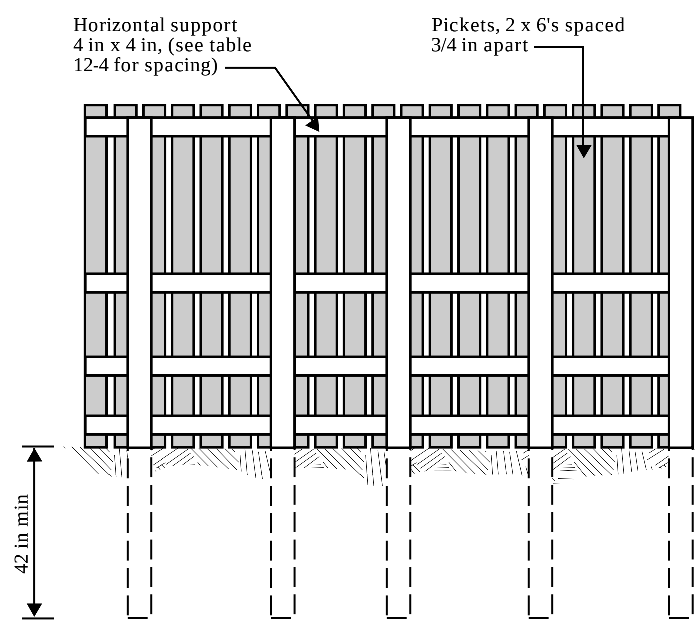


Table 12–4 Picket dam construction (MWPS 1985)*

Posts height (ft)	Posts size (in)	Posts spacing (ft)	Horizontal support distance from picket top (ft)	Horizontal support size (in)	Horizontal support spacing (ft)
0-4	4 x 6	5	0–4	4 x 4	3
5	6 x 6	4	4–6	4 x 4	2.5
6	6 x 8	4	6–8	4 x 4	2
7	8 x 8	3	—	—	—

* Pickets are pressure preservative treated 2 x 6's. Posts and horizontal supports are rough sawn timbers.

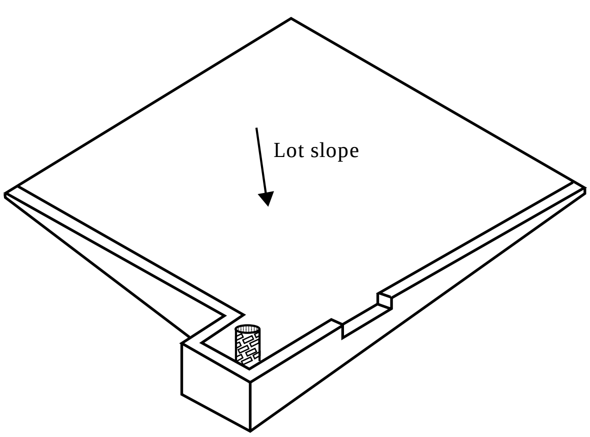


Picket dams are designed to allow runoff from the pile surface at any height within the range allowed by the stacking facility. The dam utilizes vertical slots because they drain and clean better than horizontal slots. The picket dam is located so that a clear drainage path is always away from the face (leading edge) of the pile. Drainage water that exits the dam is collected and transferred to a liquid waste storage facility. Table 12–4 gives construction information for picket dams.

A 6-inch-thick layer of corn cobs on the floor permits seepage from piled semi-solid dairy waste to flow to drains in the concrete floor of a rectangular wooden wall waste storage (Barquest, et. al 1974).

A perforated riser pipe and/or screened drain is used for runoff and piled waste seepage control (fig. 12–37). PVC plastic or steel culvert with 1- by 4-inch slots are typical. The riser pipe diameter and number of slots needs to match the expected flow rate and the required area of expanded metal screen or spaced-plank flow restrictor required. See NRCS Conservation Practice Standard, Structure for Water Control, Code 587, for more information.

Figure 12–37 Perforated pipe runoff seepage outlet (MWPS 1985)



(e) Storage seepage detection and control

Any earthen waste storage has some seepage or leakage (McElroy 1993). The quality of storage construction is a major factor affecting the quantity of seepage. Weak spots or holes in a soil liner, cracks in concrete, poor joints in wood planking or metal sheets, and soil or foundation shifting from frost or moisture changes cause leaks to develop. The small fines in waste seal soil passages around and below the storage; however, this may not suffice as the only sealing mechanism because of long-term unknowns, such as soil movement and repeated surface dryout after emptying. Compacted soil liners are practical unless haul distance is prohibitive. These liners and related expansive clay liners have long been used for pond water storage. However, pond water storage should not be aggressively agitated or regularly emptied to maintain the integrity of the liner. Reinforced concrete or plastic-net soil stabilizer systems used with crushed rock at agitation sites can protect against this problem. Section 651.0703 gives more information on clay liners and soil amendments.

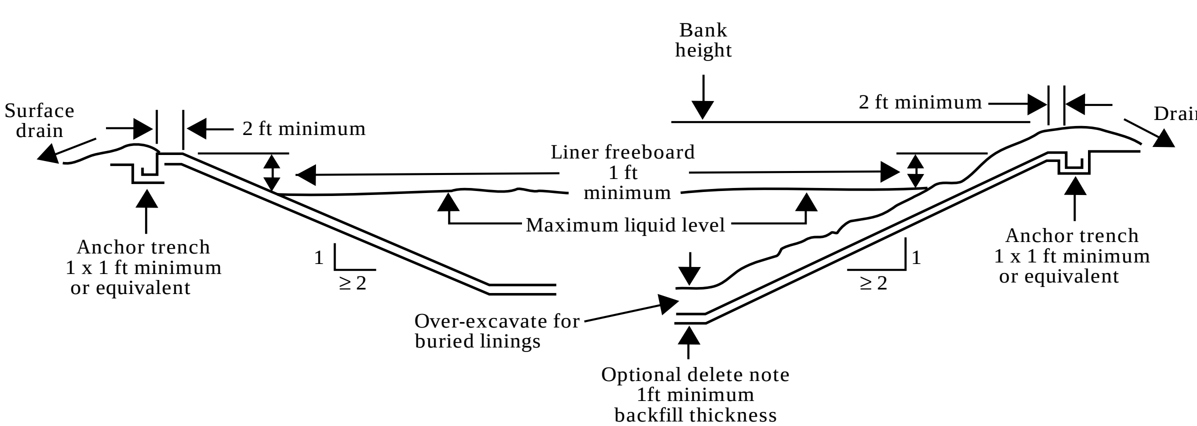
Chapter 7 of this handbook describes liquid movement through soil. Because of ground water quality concerns, a special lining may be required to assure leakage is held to acceptable limits. Different kinds and qualities of liners are used with earthen basin waste storage. NRCS Conservation Practice Standard, Pond Sealing or Lining, Code 521, and ASAE Engineering Practice 340.2, Installation of Flexible Membrane Linings (ASAE [i] 1992) explain criteria for different liners. The criteria include:
- availability
- size
- cost
- installation requirements
- durability for punctures, tears, ultraviolet light, and rodents and other pests

Safe access for agitation and pumping is needed to prevent fabric liner damage. Higher demands are being made on liners as water quality concerns increase and as liner materials are evaluated and developed for earth basin agricultural waste storage, chemical containment, landfill use, and other applications.

A source of current industry information is the Geotechnical Fabrics Report published by the Industrial Fabrics Association International. Each year, the December issue contains a Specifiers Guide that explains current information about products and services available. Figure 12–38 shows a membrane liner.

The Natural Resources Conservation Service has completed a study about seepage from earthen storage ponds and waste treatment lagoons (Moffitt 1993). A part of the study was to determine what are seepage conditions, and another part was to measure the extent of seepage. One promising technique is the electromagnetic terrain conductivity meter (EM-34) that senses the added electrical conductivity resulting from increase in ion concentrations that may be caused by waste impoundment seepage. The EM measurement information can be used along with that from monitoring wells and soil borings. The Geonics EM 39TM and companion tool, the natural gamma probe, measure the incremental conductivity in a borehole. They can indicate if the conductivity anomalies are in materials that are likely to transmit fluids.

Figure 12–38 Membrane liner installation for earthen basin (courtesy Hoechst Celanese Corp.)



651.1205 Waste treatment equipment

Treatment of waste is in sections 651.0904(d), 651.1004, and with the different waste management systems in section 651.0906. Treatment changes the makeup of waste into a more usable, stable product, or it mechanically enhances its natural biological breakdown. Treatment equipment includes that for grinding/shredding, agitation/mixing, aeration, separation, drying, dehydration, incineration, and rendering.

(a) Size reduction

Cutting, shredding, crushing, or grinding reduces the bulk and increases the flowability of relatively dry (>60% dry material) material, such as leaves, roughage, brush, paper, cardboard, cans, and bottles. Waste type, amount of use, power need, investment, noise, dust, and maintenance must be considered in selecting grinder and shredder equipment.

Cutting equipment pushes thin, sharp knives through a usually moist material to reduce its size into uniform pieces. Cutting, as such, results in minimum deformation and rupture of the reduced particles. Equipment with very sharp cutter blades and close tolerances is used with fruit and vegetable processing. Some chipper equipment uses heavy knives mounted on a high-speed cylinder that rotates inside a housing. The high-speed cutter/grinder for processing slurry waste also uses this type equipment (fig. 12–39). Unless the blades and cutter bar edges are intensively maintained, cutting equipment performance is more a shearing/tearing action. If this happens, a crushing as well as cutting action occurs, which increases power need, slows throughput, and produces a ragged product.

Shearing is generally used to reduce the size of loose, bulky, tough fibrous material. Brush and some straw chopper equipment usually employs more shearing than cutting to reduce material size (see fig. 12–31). A belt type shear shredder (fig. 12–40) uses a cleated belt operating in a hopper to force material against stationary knives. Material loaded into a receiver hopper feeds a conveyor that in turn drops it onto the cleated belt where it undergoes a continuous raking action to shred the load. Adjustable sweep fingers force oversized pieces back for further shredding while hard stones, metal, and glass are discharged through a trash chute. Engine-powered stationary or tow models are available. Power needs range from 7.5 to 500 horsepower with capacity from 5 to 50 tons per hour, depending on raw product moisture, density, and fineness.

Figure 12–39 Cutter-shredder for slurry waste (courtesy Hydro Engineering, Inc.)

The rotary shear shredder uses two counter-rotating shafts with overlapping hooked cutter discs (fig. 12–41). Cutters draw material down toward shafts at the base of a hopper. The cutters slice the chunks into small pieces until they pass through the spaces between the cutter discs. This process has been adapted to some wood chipper equipment. The piece size depends on cutter size and spacing.

As semi-solid waste is forced through relatively close tolerances, it is slurried by chopper-agitation pump impeller (propeller) action during agitation and pumping. See section 651.1206(b)(1)(ii). Stationary knives are included on some models to assist rotating exposed cutter blades to cut twine and other tough fibers (fig. 12–42). The rotating blades also crush or break apart semi-solid chunks as they are drawn into the pump impeller. Unless the impeller is plugged, the crushed material is then slurried. A common operator complaint is that twine and plastic wind onto the rotating cutter. Small stones, metal, or other foreign material quickly dulls cutting edges, so high maintenance is needed for satisfactory shearing performance.

The versatile hammermill grinder uses 20 to 50 short, free-swinging, hardened steel strap-irons mounted on a high-speed rotating shaft to hammer or crush solids through a surrounding, close-fitting perforated screen (fig. 12–43). Readily interchangeable screens, each with different-sized openings, are used to produce relatively uniform coarse to fine grinds. Fine grinding needs high power and a slow grinding rate as does higher moisture content (>15%) material. Different models of portable and stationary hammermills are available. These can require 5 to 550 horsepower and can coarse-grind up to 50 tons per hour of dry (≤15% moisture) waste.

Hammermill grinding increases the temperature of the material ground about 10 degrees Fahrenheit. It is increased more with fine grinding and higher moisture content materials. This increased temperature must be considered when the processed waste is stored. Compared to the cutter and shredder treatment, power and maintenance needs are higher for a hammermill grinder, especially if stones or metal pieces are in the waste.

Figure 12–40 Belt-type shear shredder (Rynk 1992)

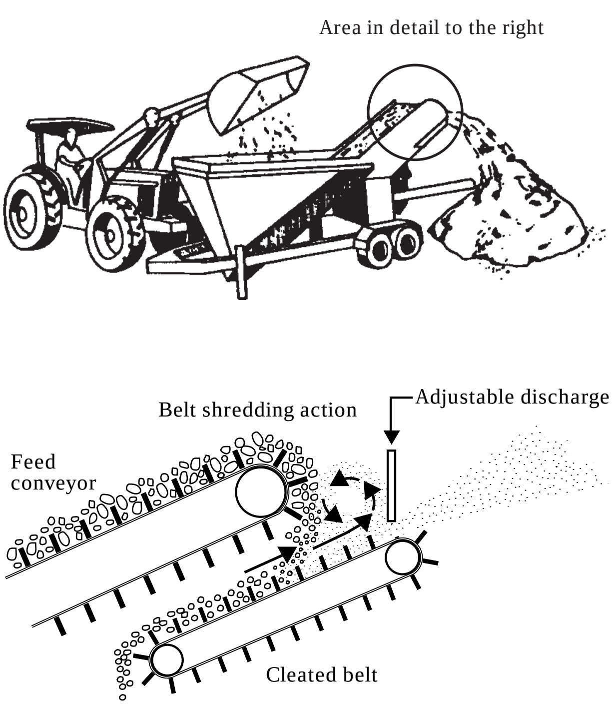
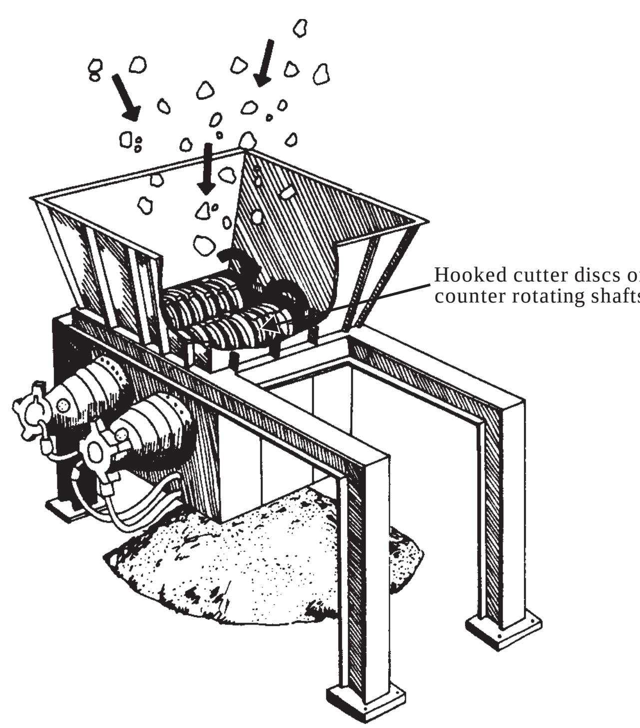


Figure 12–41 Rotary shear shredder (Rynk 1992)



Widely used on farms to grind livestock feed, the portable grinder-mixer usually employs a 50- to 100-horsepower PTO-powered hammermill in conjunction with a vertical auger type tank mixer. Larger, much heavier constructed models of this versatile equipment have been developed for high-rate processing of solid waste.

The tub-grinder (fig. 12–44) incorporates a hammermill type grinder in the floor of the slowly rotating hopper or tub. As the tub rotates, it carries around the material dropped into it. This material eventually feeds into the hammermill, is ground, and falls into a conveyor below. Tub grinder models are available that require about 70 to 525 horsepower. The smaller models can be PTO-driven, and larger units are industrial diesel-engine powered. Different models employ an intake screen, feeder/hopper, crusher, and various conveyors for separated materials. This equipment can all be on one moveable chassis.

Figure 12–42 Cutter blade on chopper-agitator pump (courtesy Clay Equipment Corp.)

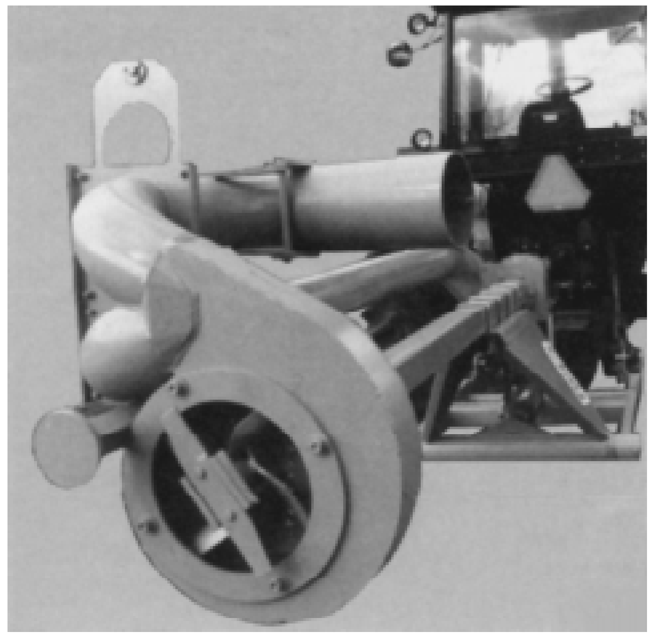


Figure 12–43 High capacity hammermill grinder (Rynk 1992)

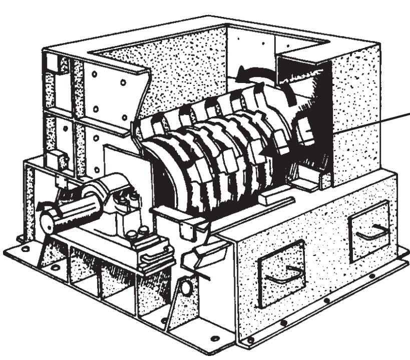
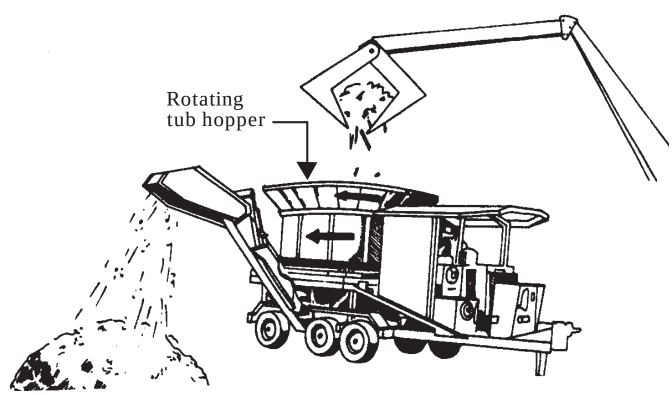


Figure 12–44 Large capacity engine powered tub grinder (Rynk 1992)



(b) Agitators, stirrers, mixers

Agricultural wastes usually contain materials of different densities. These tend to separate out during handling, storage, and use, especially with the more slurry waste. Soil and other dense materials settle over time while straw, feathers, and other bulky materials float. Agitation equipment is used to remix the separated materials together for complete product handling, improved aeration, and decomposition. Different agitation equipment is available. Selection depends on the waste moisture content, desired agitation capacity, investment, available power, and the waste use.

(1) Semi-solid and slurry waste agitators

Although useful with liquid waste, vacuum tanker agitation usually is insufficient with semi-solid waste, especially where there is a surface crust. See section 651.1207(a). Chopper-agitator PTO-driven pumps are designed to agitate as well as pump semi-solid waste (fig. 12–45, see figs. 9–8, 10–16). See section 651.1206(b)(ii). Such alternative equipment use helps reduce the total investment. This one-unit operation, however, may slow down loadout and spreading depending on how agitation progresses. During agitation a diverter valve on the pump outlet is manually set to return the pumped material back into stored waste via a hand operated nozzle that has vertical and horizontal adjustments. To agitate settled solids, a vertical shaft drive chopper-agitator pump (fig. 12–45) usually recirculates and discharges through a nozzle below the stored waste surface. Some models have a second, higher discharge nozzle to agitate a surface crust.

Agitation nozzle location and adjustments can be critical, especially for agitating into storage corners. Most 50- to 80-horsepower chopper-agitator pumps can agitate out about 40 feet depending on nozzle design, pump wear, waste consistency, and storage shape. Several moves generally are used to agitate a large rectangular storage. See section 651.1204(b). Agitation and pumping docks are needed with large earthen basin storage to be agitated with a vertical shaft drive chopper-agitator pump. Appendix 12B, USDA Plan 6381, explains concrete or wood dock construction. (**Note:** Mention of plans is only for planning information purposes. The Natural Resources Conservation Service approval procedures require that waste storage structures meet practice standards that include carefully engineered design analysis for specific site conditions.)

For faster, more effective agitation over a larger area, the open impeller (propeller) agitator has evolved from the vertical shaft drive chopper-agitator pump. Electric motor-powered models that are up to 12 feet long with 15 to 25 horsepower are made for use in vertical wall storages (fig. 12–46) or float-mounted for moving over and agitating earthen basin type storages (fig. 12–47). Models more than 40 feet long (fig. 12–48, see fig. 10–16) can be PTO- or hydraulic-motor powered and 3-point hitch, 2- or 4-wheel trailer mounted. All-purpose models of impeller type agitators have a chopper-agitation pump, separate agitation nozzle, and tanker fill pipe (see fig. 10–16).

A hydraulic shifted gearbox is used to select the desired agitation or pumping mode. Most impellers are 3 steel blades and are from 1 to 2 feet in diameter. Depending on speed, the power needs range from about 35 horsepower for the 1-foot model to about 150 horsepower for the 2-foot, 0.25-inch-thick steel, impeller agitators. Impeller size, pitch, and blade number are based on manufacturer experiences.

Agitator location and operation depend on the location and relative amounts of settled and floating materials in the waste. With earthen waste storage ponds, solids generally settle near the storage inlet. With vertical wall storage, they tend to build up in the corners.

Opinions vary on agitation techniques, and little research information is available for different storage shapes, sizes, and depths. The corners of rectangular earthen basin storage are often agitated first to break up the surface crust and get the storage contents moving. After the waste has been moved for several hours and given the available power, durable equipment, and added mix water, stored semi-solid waste becomes slurried.

Agitated semi-solid and slurry wastes, if allowed to resettle and separate after agitation, are more difficult to reagitate because of more fine material. In some cases where solids have settled in a semi-solid or slurry waste storage, the storage structure may require dredge agitation equipment or manual cleaning. A large dragline dredge is the most effective way to clean out a large open storage. Small (30 to over 100 horsepower) floater type agitation dredges are available (fig. 12–49).

Figure 12–45 Vertical shaft PTO-powered chopper-agitator pump (courtesy Whatcom Mfg.) Source: Canada Farm Building Plans Service (1993)

Figure 12–46 Chopper-agitator pump and open-impeller agitator (courtesy J. Houle & Fils, Inc.)

Figure 12–47 Float-mounted impeller agitator (courtesy US Farm Systems)

Figure 12–48 Open impeller with long shaft agitators (courtesy Whatcom Mfg.)

Skilled operation is needed to control the floating agitator location and to accomplish thorough agitation of stored material. Control of depth and forward movement is important to loosen and agitate settled solids without disturbing the storage liner.

Settled, packed solids in relatively small semi-solid storages can be loosened with correct use of chemical and biological additives and a high volume or pressure of water (>1,000 psi).

(2) Solid waste agitators

Stacked or piled waste settles and shrinks as it decomposes and dries. Compost methods use agitation equipment to mix dry and wet materials and provide airways (aeration) that aid decomposition. For more information on composting, see section 651.1004(f).

A tractor front-end loader or skidsteer loader is simplest to use for agitating (scoop-lift-move-dump) the piled compost. See section 651.1203(d). Depending on the site conditions and arrangement, operator expertise, and loader bucket size, the windrowed compost turning rates for this technique range from 20 to more than 70 cubic yards per hour.

Agitation quality is affected by the mix of added materials, unevenly wet compost, and strong wind gusts. To aid in uniform mixing, a box spreader, such as that described in section 651.1207(a); potato digger; rock picker; or related elevator laydown type of equipment can be adapted for agitating windrowed compost. Low profile cruster equipment has been developed to pick up and re-lay (or load) solid bedding litter in large poultry barns (fig. 12–50). This equipment needs 18 to 60 horsepower, depending on the loading rate and litter quality. Loaded litter can be stacked or field spread.

Figure 12–49 Floating dredge agitator (courtesy Crisafulli Pump Company)

Heavy duty agitation equipment has been developed for agitating windrowed compost to reduce labor, increase output, and provide a uniform mix (fig. 12–51). Tractor tow, PTO-powered, and self-propelled models are available. These windrow turners employ varied agitator designs. They include:

- A large diameter (about 3-ft) auger to move the windrow sideways.
- A rotating drum that has spike flails attached in a spiral. The spiral goes under the windrow, lifts it up, and re-lays it.
- A wide, high elevating belt that works the same as the rotating drum.

The auger type is simplest, but needs relatively high power. Rotary drum types are made in different models that require 65 to 440 horsepower and have a capacity rated from 800 to 4,000 tons per hour. The wide, high elevating belt agitators require from 65 to 125 horsepower and are rated from 2,000 to 3,000 tons per hour. The elevating belt models generally are towed by a tractor and turn or agitate half the windrow in a single pass. This requires tractor drive space between windrows that, in turn, need drainage and maintenance.

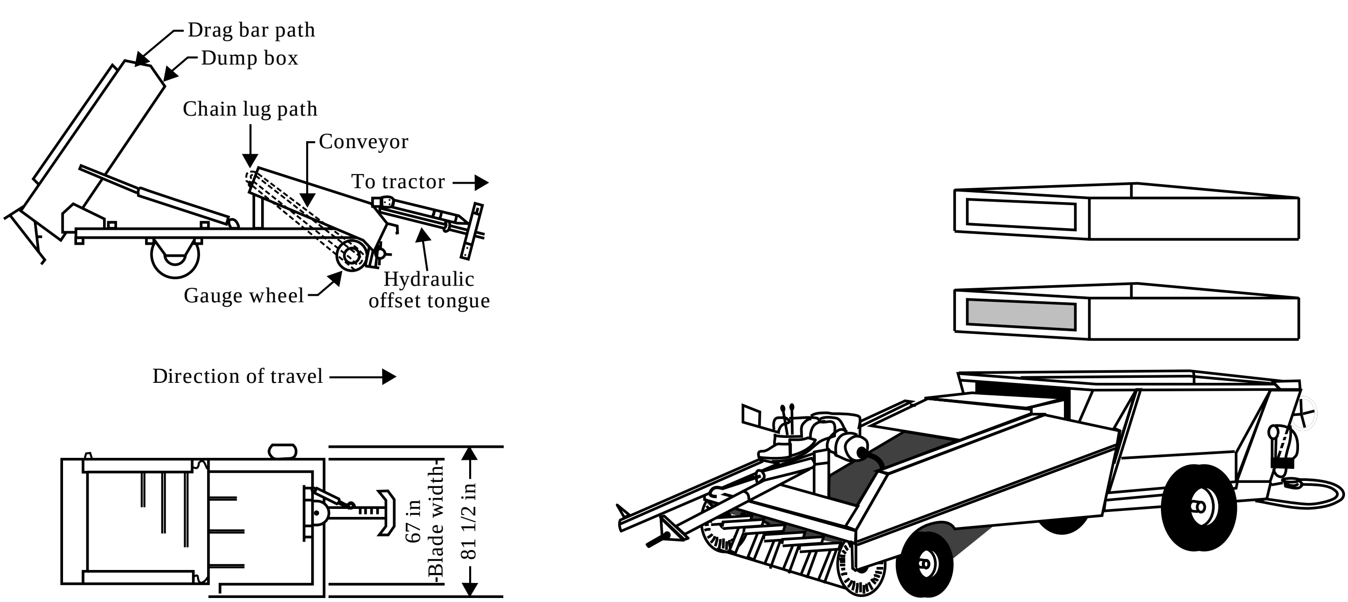
Mixing additional materials with wastes is another solid waste handling agitation procedure. Either continuous flow or batch mixing equipment is available. The following factors should be considered in selecting the equipment to use:

- Capacity
- Cost
- Material moisture content
- Mixing quality
- Power
- Dust
- Noise

An ordinary U-trough auger conveyor operated at an incline can be used as a continuous-flow solids mixer. The materials to be mixed are fed in at the low end of the auger. The conveyed material rolls and mixes when conveyed up an incline of 25 to 45 degrees. The length of conveyor required depends on the materials and mix quality.

The pug mill is a large capacity, continuous-flow heavy duty mixer used in sludge composting (fig. 12–52). The mill is generally operated at a stationary site, so materials to be mixed are conveyed over to and metered

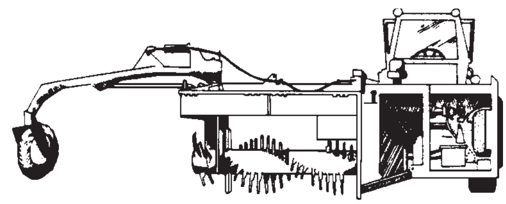
Figure 12–50 Elevator scraper for solid waste agitation and hauling (courtesy Gregory Mfg. Company)



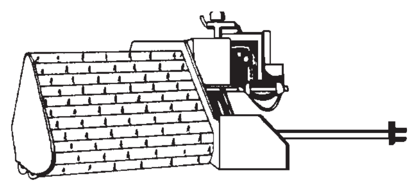
into the mill. Materials are mixed as they pass through the counter-rotating paddles. Different-sized pug mills are available. The throughput rates range from 10 to more than 500 tons per hour with power needs from 10 to more than 50 horsepower, depending on material quality.

Different batch mixer designs for mixing foodstuffs and fertilizers have been adapted to agitate solid waste, such as compost, sludge, straw, and paper. These mixers are mounted on a trailer or truck, and they use electric, PTO, or engine power. Batch mixers that use rotating horizontal-suspended augers that are 1 to 3 feet in diameter (fig. 12–53) may cost less than reel, paddle, or ribbon mixers, but they have higher power and operating time needs. Power needs range from 10 to more than 50 horsepower for reel mixers rated at 5 to 30 tons per hour. The rotating drum cement mixer has been adapted for solids mixing.

Figure 12–51 Windrowed compost agitators/turners (Rynk 1992)



Push-type, self-powered (diesel engine) rotary drum with flails



Tractor-towed, self-powered, elevating-face conveyor

Figure 12–52 Pug mill mixer for dense, solid waste (Rynk 1992)

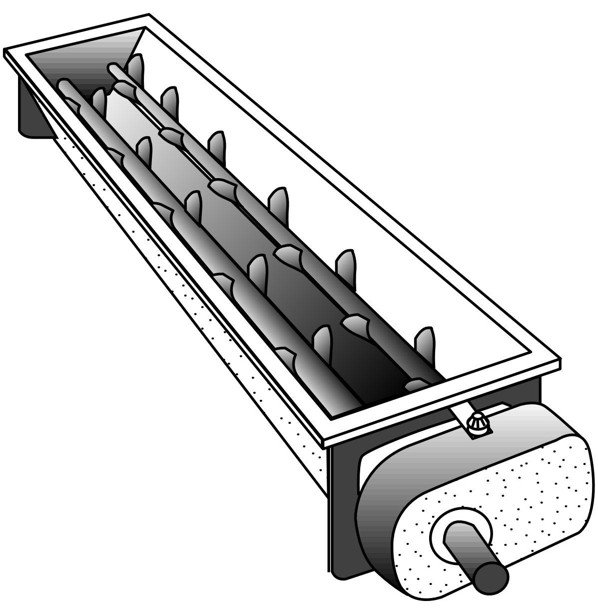
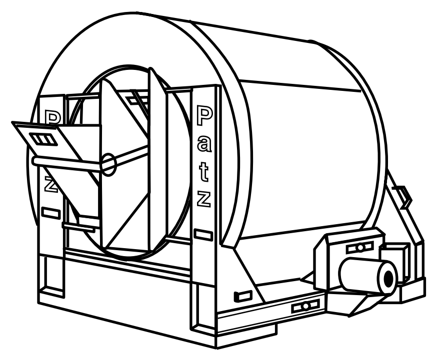
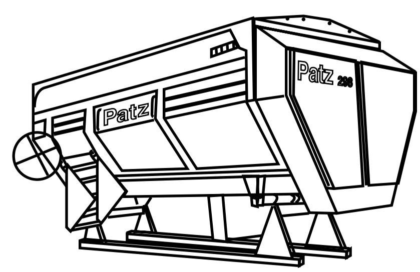


Figure 12–53 Batch mixers for solids mixing (courtesy Patz Sales, Inc.)



Tumble mixers



Stationary auger mixers

(c) Aerators

The continual forcing or mixing of air with stored waste affects its odor and temperature control as well as the decomposition rate. Equipment has been developed for aeration of solid, semi-solid, slurry, and liquid wastes. While the use of agitator equipment with stored waste also aerates, the aeration result is non-uniform and relatively temporary.

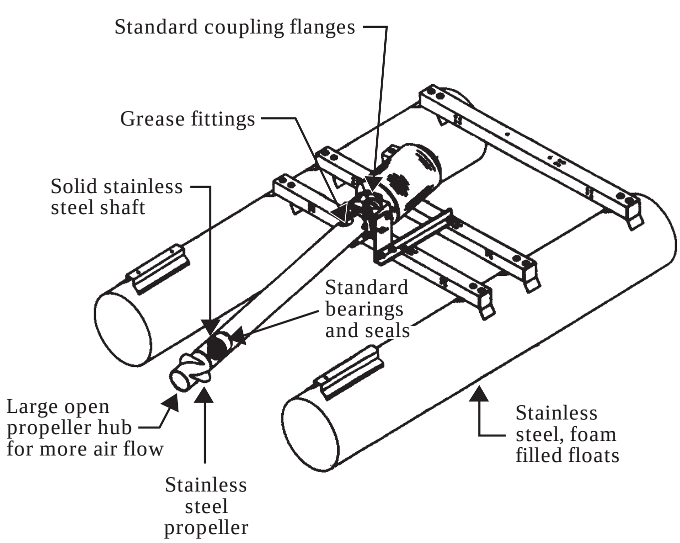
(1) Slurry and liquid waste aerators

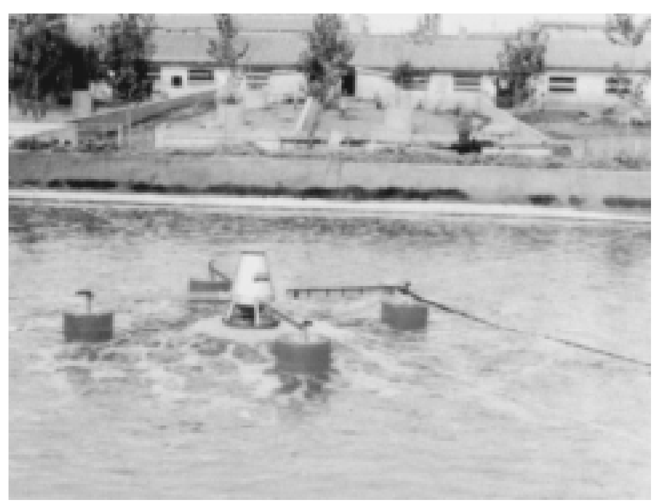
Mechanical aeration of liquid lagoon waste is explained in section 651.1004(c). Beside this kind of development for agricultural waste aeration, the aquaculture industry has varied equipment and experience with liquid aerators used with commercial fish farming as do wildlife agencies working with pond and lake aeration.

Mechanically aerated lagoons combine the odor control advantage of aerobic lagoons with the smaller size requirements of anaerobic lagoons. They are most often used to control odors in sensitive locations or for nitrogen removal where land disposal areas are severely limited. However, use of floating surface aerators to provide oxygen is much more expensive than anaerobic lagoon operation, both in initial cost and maintenance and operating expense. For floating aerators the minimum aeration requirement for odor control at the lagoon surface is about 1 horsepower per 750 to 1,000 square feet of surface area. Use of aeration equipment for complete mixing of the lagoon liquid is normally considered uneconomical and unnecessary except where a high level of odor control is required. An engineer needs to plan equipment needs based on the chemical oxygen demand and the fraction of total nitrogen that can be converted to nitrate by aeration for the design situation.

Floating liquid surface pump aerators use an impeller (propeller) directly connected to an electric motor. This impeller helps pump the liquid upward where it mixes with air and falls back down into storage (fig. 12–54). The pumping and aeration depth is generally less than 4 feet, and the affected area ranges to a 50-foot diameter, depending on the design and power available. Power needs, pump plugging, splash control, and freezing are problems. Liquid and air mixing is usually more effective with the pumped water than with the diffused-air type floating aerator that forces air into the liquid (fig. 12–55). Air is compressible, and liquid is not, so the lighter weight air has more tendency than pumped liquid to take a path of least resistance.

Figure 12–54 Floating aerators for liquid waste aeration (courtesy Aeromix Systems Inc. and AgriBusiness International, Inc.)





One or more floating aerators are typically strategically spaced over an open lagoon storage surface so that each unit aerates a certain area of designed capacity (fig. 12–54). These aerators are floated over to the desired location for operation and secured to the storage edge with anchor cables. The anchor cables can support 240-volt power wires; however, the support distance and wire size must be considered.

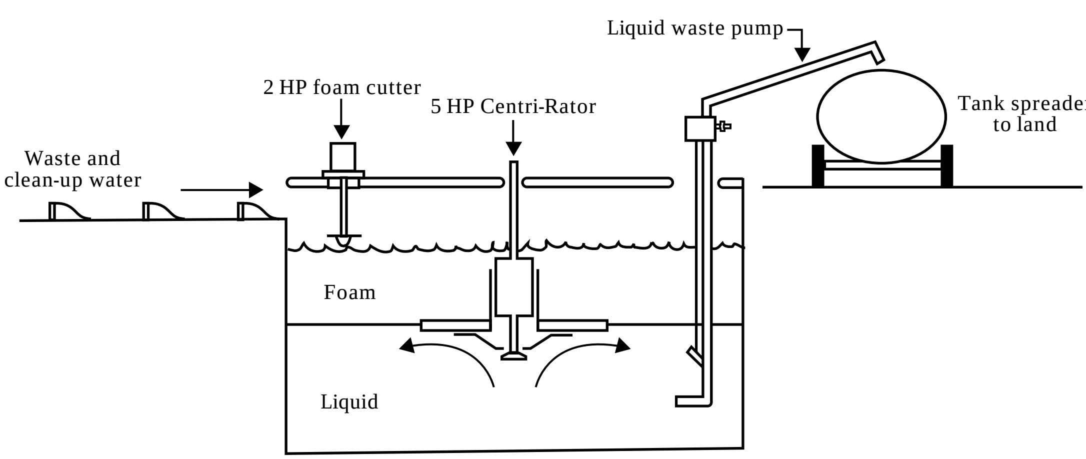
Diffused aerators that force air into liquid and slurry waste have varied designs (fig. 12–55). They include one that uses a submerged impeller that mixes air supplied to it via an intake tube with the surrounding stored waste. Another design uses an air blower located at the storage surface to force air down a duct or distributor arrangement into the stored liquid below. Most diffused aerators have relatively small capacity and horsepower; however, one manufacturer uses a supercharger blower to force air to the directed output of a submerged impeller. Several models are available with up to 10.5 horsepower; however, uniform mixing of air with the liquid and plugging of the diffuser hole are problems.

The Delaval Centri-Rator*tm (fig. 12–55) is a stationary diffused air type aerator used over the past 20 years for waste treatment. This design has the aerator mounted in the center of a circular waste holding tank. The regular inflow-outflow of waste is constantly agitated and aerated. A surface foam cutter or liquid spray is employed to break up surface foam that develops from intermittent waste loadings. After some 24 hours of aeration, the liquid waste flows on to another aerated tank or storage for continued decomposition (Rupp 1992). The flow deflector plate assists with more thorough mixing of air with liquid. Cost, continual power needs, regular maintenance, and freezing are considerations.

The rotating oxidation (aeration) wheel operating in a 3-foot deep oval racetrack-shaped concrete ditch was developed for liquid domestic waste treatment in the Netherlands (see fig. 10–29) (Martin et al. 1978). This oxidation wheel was adapted to livestock production systems around 1970 to provide a means of onsite waste treatment. Agricultural engineers at the University of Illinois studied its use with swine waste, and Purdue University studied its use for cattle waste treatment (Jones et al. 1972). University of Minnesota engineers researched oxidation wheel waste treatment for confined beef cattle over a slat floor in cold weather (Moore et al. 1969).

Varied designs have been used for oxidation wheels. A typical design is a series of many closely spaced paddles. The paddle lengths used vary from 0.5 to 1 foot long. They are securely fastened to a shaft about 4 feet long that is rotated at several hundred rotations

Figure 12–55 Diffused-air liquid and slurry aerator



per minute and requires about 20 horsepower (fig. 12–56). The vigorous action of the paddles moving through the liquid surface causes the air and liquid to mix. Correct design, installation, and operation are critical. Costs, uniform waste addition, continuous power need, bearing wear, foaming, solids build-up, and regular liquid overflow handling problems caused oxidation wheel use to disappear for agricultural waste treatment.

(2) Solid waste aerators

Unlike agitated pile solid waste composting, static pile composting employs natural or forced aeration to control pile temperature and aid aerobic decomposition. Figure 12–57 shows guidelines for perforated duct placement using passive or natural air movement.

For uniform airflow, the key is to establish good structure and pile porosity. Air naturally tends to flow into the open-ended pipes, that are 4 inches in diameter, and out through the 0.5-inch holes on 1-foot

Figure 12–57 Perforated duct placement for gravity aeration (Rynk 1992)

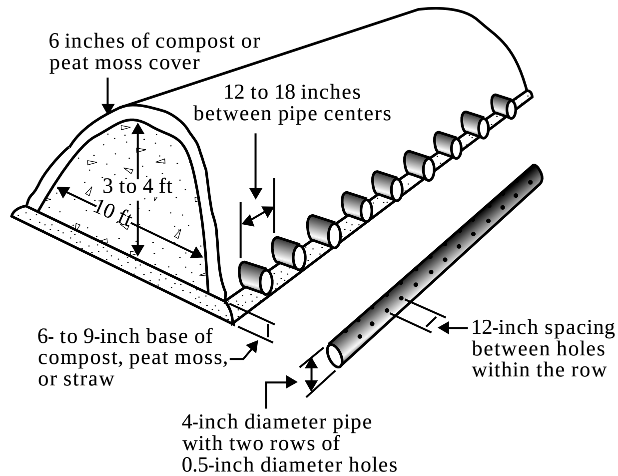
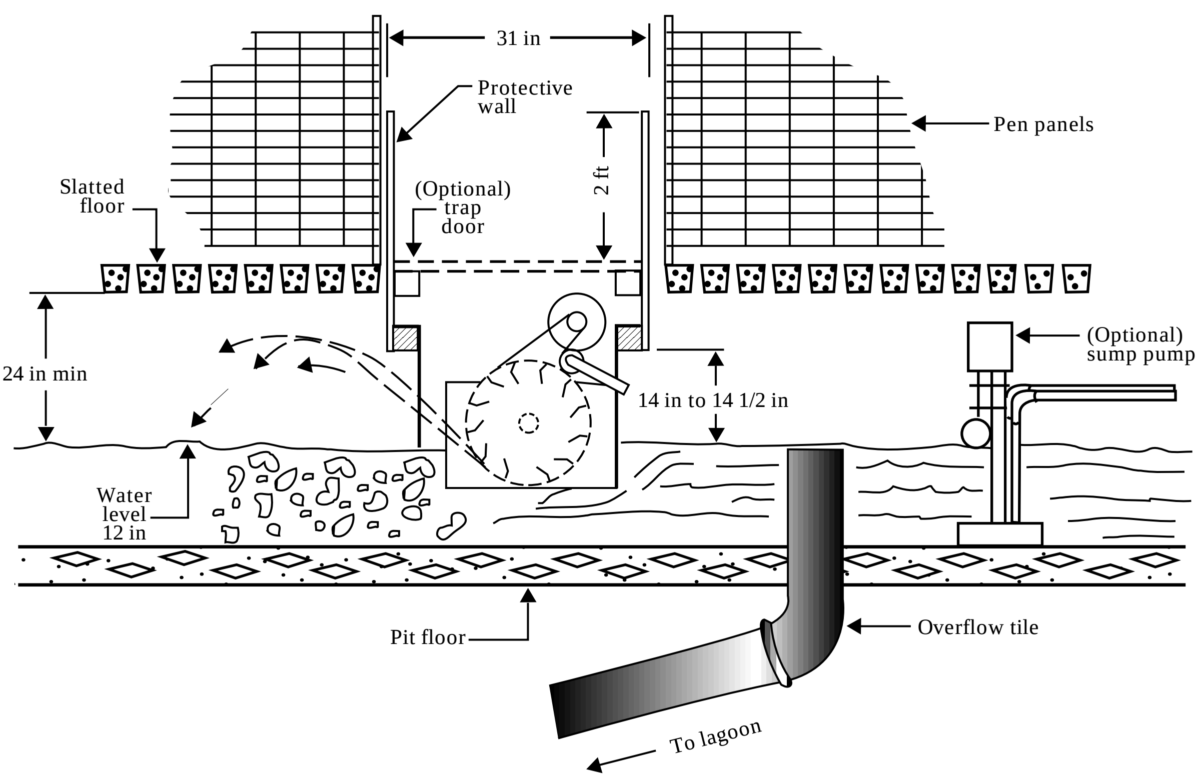


Figure 12–56 Oxidation wheel liquid waste aerator



centers and then through the pile. This movement is because of the chimney effect of warmed air moving upward out of the pile. A peat moss or similar covering insulates the pile, discourages flies, and aids moisture and odor retention. Ordinary septic or leaching field plastic pipe is used for the air ducts. The pipe holes are placed facing downward to avoid their plugging. The pipes are pulled out when composting is complete. Wind causes dust in an exposed area; however, it assists natural aeration.

Mechanical aeration of a static pile or in-vessel composting system employs an electric motor powered forced air blower that is temperature controlled. The system design depends on storage shape, airflow quantity, and distribution (see fig. 10–31). Approximate design requirements for temperate climate conditions are shown in table 12–5. Application of these specifications becomes complicated and is explained more in the On-Farm Composting Handbook (Rynk 1992).

Airflow static pressure for an approximately 6-foot-deep pile of roughage compost can range from 2 to more than 4 inches of water, depending on the compost mix, moisture content, and airflow (Keener et al. 1993). Fresh compost requires a controlled flow of air to maintain a pile temperature at about 140 degrees Fahrenheit. In practice the blower speed or cycle and the airflow through the duct system must be adjusted, or the pile size must vary to suit compost temperature conditions. Because pipe selection and airflow distribution arrangement affect operation performance and costs, especially for a large compost operation, these decisions are critical to the success of the operation, and special design planning is recommended.

Table 12–5 Blower and pipe sizing for pile aeration (Rynk 1992)

Component	Time-based control	Temperature-based control (130 to 140 °F)
Blower horsepower	0.33 to 0.5	3 to 5
Airflow ft^3/s per dry ton of waste	10 (continuous operation)	- - -
	25 (1/3 on 2/3 off)	100
Pipe diameter (in)	4	6 to 8
Maximum pipe length (ft)	75	50

Blower selection depends on the airflow rate at a needed static pressure, the tolerable noise level, and power availability. Airflow is measured in cubic feet per minute, and static pressure in inches of water column or inches of water. Blower static pressure is affected by:

- Depth of the compost—increases linearly for each added foot of depth.
- Quantity of the airflow (cubic feet per minute per cubic foot of compost)—the static pressure triples when airflow doubles.
- Quality of the compost—restricted by wet, heavy material, the air moves easily through fluffy, dry, uniform material.
- Airflow ducts—sharp corners and too small ducts restrict airflow, especially at high rates.

Correct blower selection provides the proper airflow amount for the quantity to be aerated. To determine the airflow rate, divide the cubic feet of material by the cubic feet to be aerated.

Electric motor power is nearly exclusively used for blower power with many types of control commonly available. The controls include: on-off, percentage timer, time-clock, thermostat, and variable speed. Motor horsepower is a poor way to compare blowers because the blower performance is determined by its design, and the blower horsepower is determined by airflow, static pressure, and blower efficiency. Horsepower needs vary at different combinations of airflow and static pressure, and a maximum horsepower input occurs at a specific combination thereof. The blower motor needs to operate continuously at this maximum requirement for horsepower. Manufacturers can supply this information for their different models.

The axial flow and centrifugal blowers are commonly used for forcing air through materials at relatively high static pressures (fig. 12–58). A wide selection of either blower type is available ranging from about 200 to over 5,000 cubic feet per minute capacity and at relatively high static pressures. An undersize blower will not control compost temperature. Too large a blower results in too much cooling and erratic compost decomposition. A high airflow rate at a higher static pressure generally is needed at the start of composting. Airflow needs reduce as decomposition and compost agitation occur, so a means of reducing airflow is needed. Total airflow can be reduced by careful use of intermittent blower operation, a slower speed, a smaller blower, or by diverting or blocking some airflow. The axial flow blower generally costs less than the centrifugal blower, is less noisy, and is better suited to static pressures below 3 inches.

Equipment for aerating the separated solids from dairy waste has been in use since 1990 at the USDA Dairy Forage Research Farm in Prairie du Sac, Wisconsin (fig. 12–59). Separated solids (about 20% dry matter) are conveyed from the solids/liquid separator and leveled to a depth of 6 feet in a 10- by 12-foot aeration bin. The plastic aeration tubes, which are 5 inches in diameter and have 0.5-inch holes about 1.5 feet apart, are laid on spacings in the concrete floor at 3-foot intervals. One bin is filled, during a 3-week period, while another bin is aerated. A third bin, previously aerated, supplies periodic bedding needs for stalls.

Recommended improvements for this equipment include (Straub 1993):

- Some means to prevent plugging of the air-outlet holes in the floor when driven over by a front-end loader to unload.
- A way to plug and unplug aeration holes during filling until they are covered with separated material.
- A way to assure that the first material in the bin is the first out.

Different models of relatively high investment in-vessel composters have equipment adapted to these problems (see fig. 10–32).

(d) Separators

Agricultural wastes include various materials mixed together. Even a rough separation (scalping) of these materials can aid handling, processing, and agricultural waste product end-use. Various screens are used for separating most types and sizes of relatively large solids. Filtering equipment is more useful for separating fines. Criteria to consider before adding separator equipment to a waste management system include:

- Waste moisture content—Some separators require a dilute slurry, so additional water may be needed, while the solids separated may need to be dried.
- Separator opening size—12- to 30-mesh screens are common for solids and liquid stationary screens. About half that size is needed for vibrated screens. Small openings remove solids, but they also slow the system throughput.
- Throughput rate or capacity—This determines the separator size needed for the system. Some plugging and slowdown are inevitable.
- Maintenance—The equipment must be maintained, and mechanical conveyors, pumps, and separators need power with belt or chain drives.
- Costs for peripheral equipment—Concrete pavement, separator support, pumps, conveyors, sumps, electric power, and building costs.
- Solids/liquid separator—Requires both solid and liquid waste handling equipment.

Figure 12–58 Vane axial and centrifugal aeration blowers

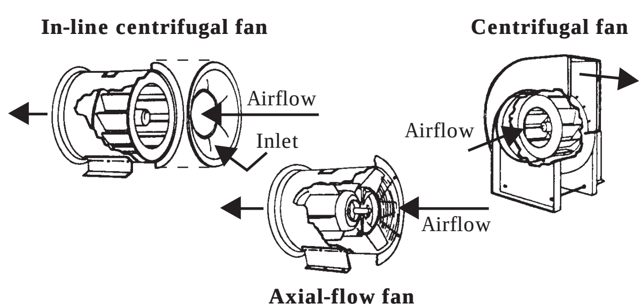
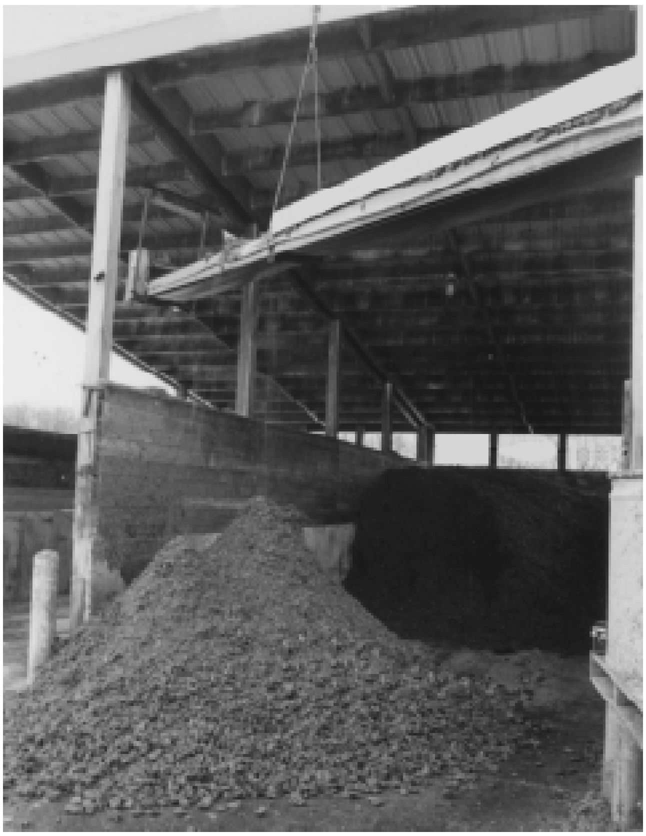
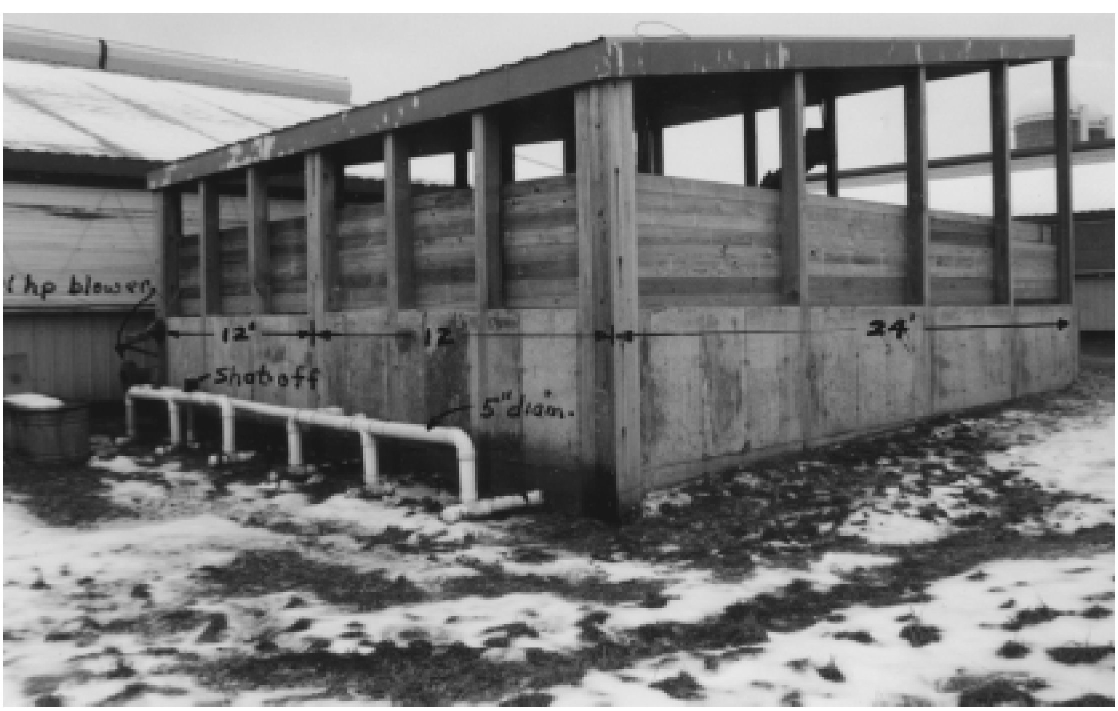


Figure 12–59 Aeration for separated dairy waste solids



Front view



Rear view

(1) Mechanical liquid, slurry, or semi-solid waste separators

The separation of liquid from solid waste requires some outside action or force to break down liquid tension. The force is generally gravity (settling) (fig. 12–60), but sometimes mechanical means, such as pressure, are used. Mechanical separators are described in chapter 10, section 651.1004(g). Tables 10–9 and 10–10 explain performance data for three different separators; however, such performance varies depending on waste quality and equipment management. Cattle slurry waste generally contains more large, readily-separated roughage pieces than does swine waste.

The capacity or throughput and the efficiency of separators are closely related. If a low efficiency (less separation) can be tolerated, the throughput capacity will be larger. In most cases high quality separation is desired. Separator equipment, however, is rated on how fast it operates (gpm).

If the waste is not already about 2 percent solids, it is generally diluted to about 2 percent solids for pumping to the separator. Mechanical separators, such as direct pressing, leave considerable volatile solids in the removed liquid. About a 60 percent efficiency is considered good (Moore et al. 1989; HHS 1990; Verdoes et al. 1992). In other words, about 40 percent of the solids remain with the liquid.

***(i) Sedimentation basin*—**Sedimentation basins (ASAE [t] 1994) are a group of structures alternately known as sedimentation tanks, settling basins, and settling tanks. Their purpose is to slow wastewater flow to allow solid material to settle by gravity. Sedimentation basins are formed from a variety of materials including earth, concrete, wood, and fiberglass.

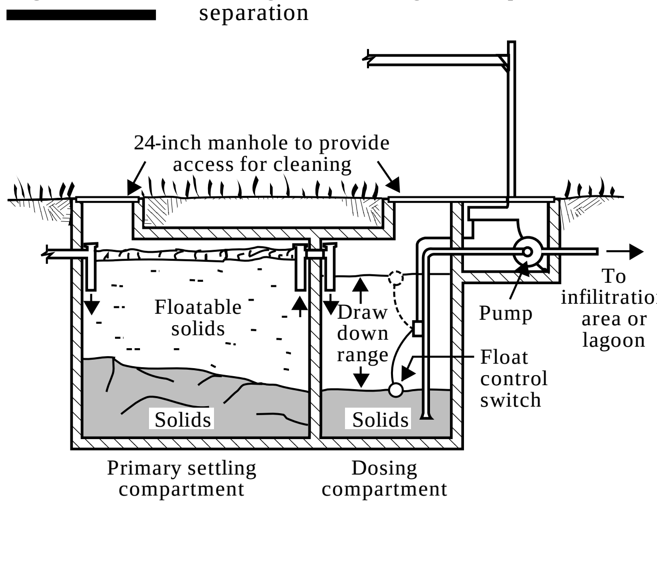
The Midwest Plan Service (MWPS 1985) distinguishes between settling basins and settling tanks. A settling basin is a structure designed to settle solids and drain the liquids, with the solids being periodically scraped and removed from the structure. A settling tank has a constant depth, and the contents of the tank are normally pumped on a regular basis. The MWPS terminology will be used here for descriptive purposes.

Figures 9–11, 9–12, and 9–15 in chapter 9 of this handbook show typical open gravity settling basin use. Their design is explained in chapter 10, section 651.1004(h). A diversion gate or valve in the flowstream can be used with two or more settling basins to permit one to dry and be cleaned while another is in use. Settling basins have particular application for intermittent large volume flows of wastewater.

In one study the settling efficiency was measured with time for different livestock specie waste slurries (Moore et al. 1989). This study reported that more than 60 percent of total solids from most dairy slurries can be removed in about 15 minutes of settling. The longer the slurry is held, the more solids that will settle or float. However, the increased settling time requires more volume.

A settling tank is used with a low-volume, relatively continuous flow of wastewater, such as recirculated lagoon flushwater, milkhouse washwater, or produce washwater (MWPS 1985). The design volume is based on a half hour flow detention time plus space for settled solids. Although earthen basin, metal, and other types of tanks are used, settling tanks are generally constructed of reinforced concrete or fiber glass. Surface baffles or a submerged inlet/outlet is used to hold back floating solids. Settled semi-solids need to be periodically removed by an in-place scraper or conveyor or agitated and pumped out.

Figure 12–60 Belowground settling tank, liquid/solid separation



(ii) Screens—The stationary inclined screen separator (fig. 12–61, see fig. 10–39) can produce a solids fraction of 12 to 23 percent dry material. This separator operates with liquid or slurry waste passing down and over the screen, permitting liquid waste to pass through the screen and semi-solids to pass over the end. In addition to wire mesh, round hole and slot types of separator screens are also common. Often these will have a sharp-edged hole or slot (when new) exposed to the slurry material to be separated. The hole diameter or slot width then increases slightly to assist liquid passage through the screen and to minimize plugging. The wedgewire screen, for example, permits smaller solids to readily pass on through once they get through the slot opening.

To reduce screen plugging and blinding, various sizes of screen openings and shapes and flushed, brushed, or scraped screen cleaning equipment are used. The extent of use depends largely on the waste quality. Some operators have found it necessary to periodically wash their screen separator with dilute boric or similar acid to remove solid chemical precipitate buildup (Buchanan et al. 1993).

Table 12–6 and tables 10–9 and 10–10 provide information about opening size for rectangular screen openings. Mesh number refers to the number of openings per inch. The larger the mesh number, the smaller the opening. In other words, a 10-mesh screen has 10 openings per inch, a 20-mesh has 20, and so on. The opening size dimension is the actual open distance of one side of the opening and does not include the wire that separates adjacent openings. The screen thickness limits the opening size, spacing, and support framework. A large opening allows more solids to pass through with the liquid, a small opening retains more liquid with solids. The size opening that screens out a major amount of solids is prone to plugging or blinding and needs frequent cleaning. This can affect separation quality.

In addition to collection and agitation pumps, the stationary inclined screen separator (as do most slurry separators) needs a 0.5- to 5-horsepower pump to raise 200 to over 1,000 gallons per minute of slurry above the screen. To help remove more liquid yet try to maintain throughput, press rollers are incorporated on a stationary inclined screen separator. They help produce a solids fraction of 15 to 25 percent dry material. More solids can pass through with the liquids, however, as the roll pressure is increased.

Figure 12–61 Wedgewire screen with sloped screen separator (MWPS 1975)

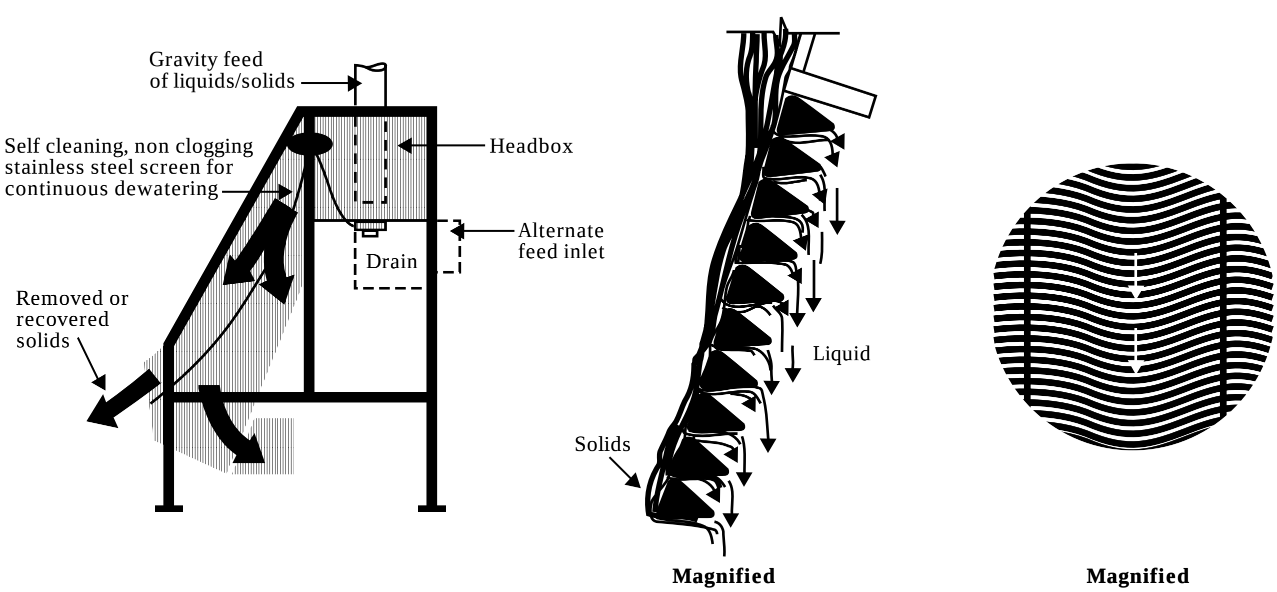
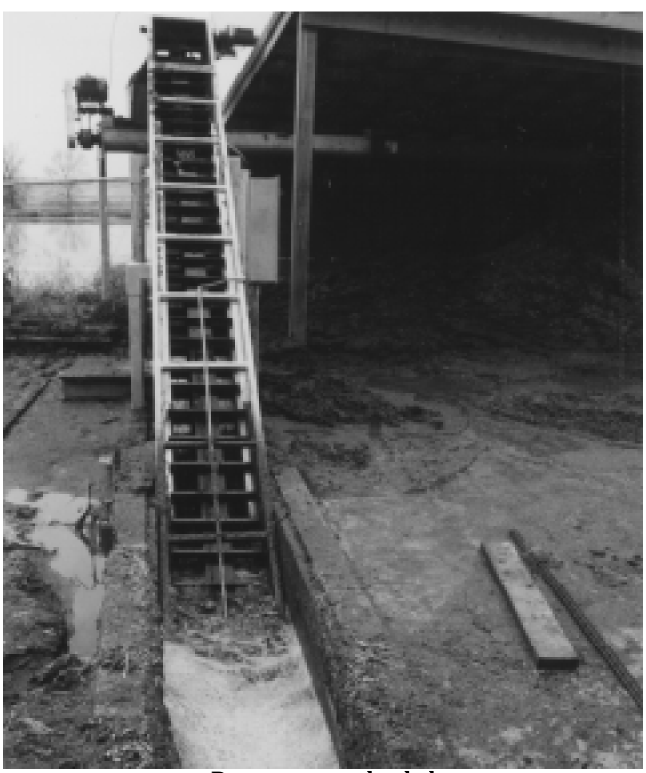


Table 12–6 Opening sizes for steel wire screens

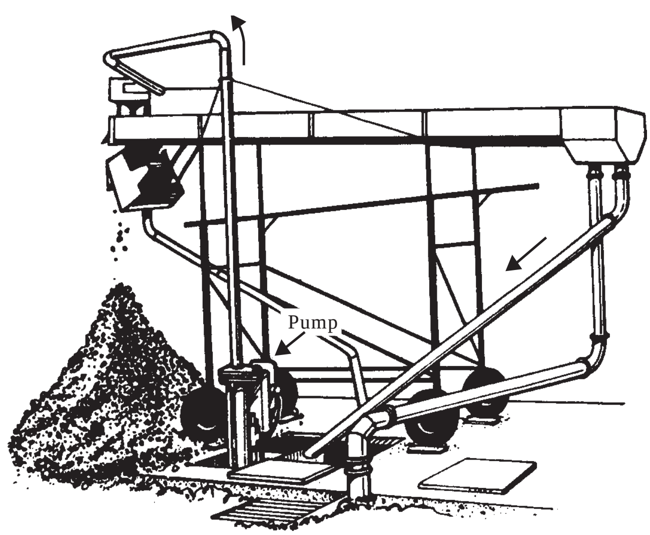
Mesh number (openings/inch)	Opening size (inches)
10	0.065
14	0.046
20	0.0328
28	0.0232
35	0.0164
48	0.0116
65	0.0082

(iii) Conveyor scraped screen**—**The conveyor scraped drag screen mechanical separator (fig. 12–62) includes features of the static inclined screen and vibrating screen type separators. Agitated slurry or liquid waste is conveyed directly out from reception storage or pumped up onto platform made of closely spaced (slotted) steel rods or perforated screen with openings about 0.12 to 0.2 inches wide. The platform is generally 1 to 2 feet wide and 10 to 30 feet long. It may be horizontal or on a less than 30-degree incline. The waste is conveyed or dragged along over the openings by gutter cleaner or chain slat conveyor paddles. The liquid waste drains through the openings to storage, and semi-solids are conveyed or dragged along, dropping off at the end of the conveyor. A roll-press separator may be used to further separate out liquid as the semi-solids leave the end of the conveyor. A 2- to 10-horsepower electric motor is needed to drive the conveyor or drag chain at about 15 to 25 feet per minute. Throughput capacity varies from about 75 to 150 gallons per minute.

Figure 12–62 Conveyor scraped screen mechanical separator (courtesy Clay Equipment Corp.)



Drag conveyor loaded



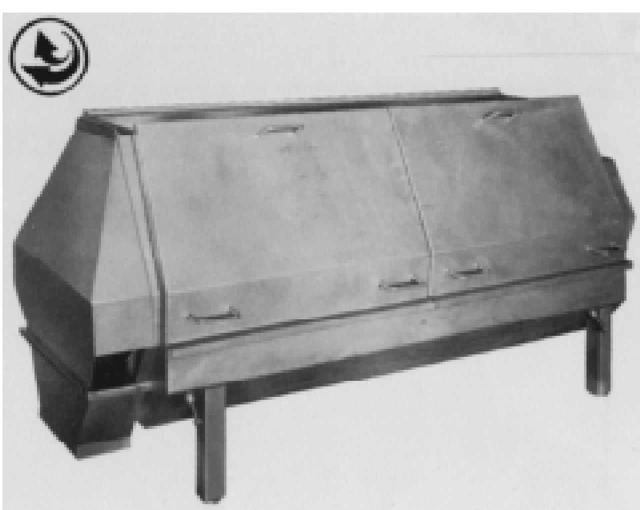
Pump and pipeline loaded

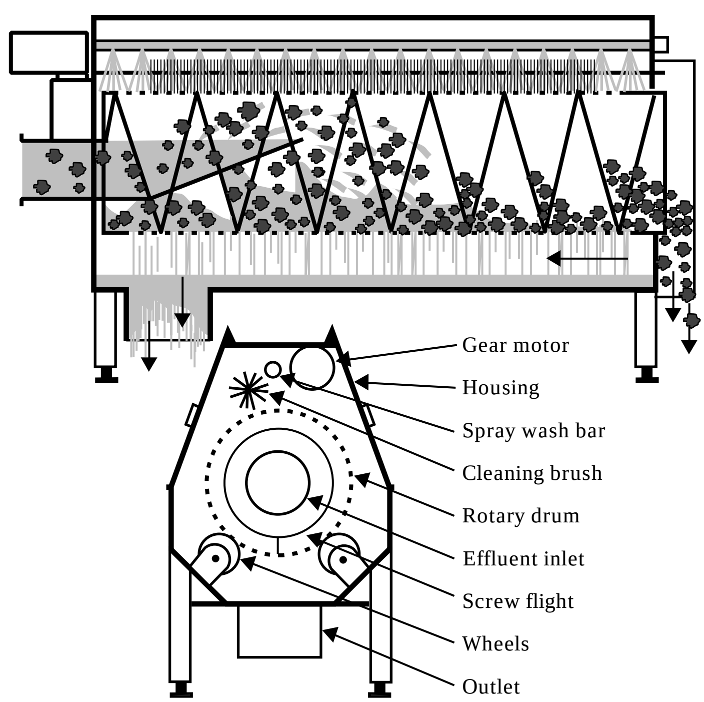
(iv) Rotating screen strainer—Perhaps more commonly used with vegetable processing, the rotating screen strainer (fig. 12–63) uses a perforated, horizontal cylinder that rotates at about 10 to 35 rotations per minute. The liquid waste to be separated gravity-flows into or onto (different models vary) the end of the rotating cylinder. Solids are pushed along by a rotating helix or scraped off the rotating screen and move out the opposite end. Liquid passes through the screen and drains to storage. Unless roller pressure is applied, the rotating strainer has relatively high volume and relatively low (15 to 25%) separating efficiency. Models are available with 500- to more than a 10,000 gallon per minute capacity, depending on screen size. The rotating screen strainer is comparable to the trommel screen separator (see fig. 12–69) that is used for solids sizing and separating operations.

(v) Vibrating screen—A vibrating screen separator (see fig. 10–39) is perhaps used more with continuous-flow, large capacity separation needs, such as aggregate, vegetable, or wood processing systems. This type separator has relatively high investment and durable construction. Material to be separated is conveyed into a wide, shallow container that has a replaceable bottom screen. The container vibrates both vertically and horizontally to move the material over the screen and minimize screen plugging. As the material flows into the vibrating container, the liquid or smaller materials pass through the screen and the large solids work toward the container's edge, fall off, and are removed. Some solids are broken up in vibration and pass through with liquids, lowering the separation efficiency with some materials.

(vi) Screw and piston press—A screw press separator (fig. 12–64) uses a straight or tapered screw (auger) of fixed or varying pitch contained in a perforated or slotted cylinder. Liquid or slurried waste gravity flows or is force-fed to enter at one end of the rotating screw. As it is forced along by the rotating screw, liquid waste drains through the cylinder enclosure and goes to storage. The semi-solids are pushed out the end. Adjusting the end retainer restricts throughput, which forces out more or less of the liquid through the cylinder enclosure. Power need is increased as the quality of separation is increased and the throughput is slowed. A 4- to 40-horsepower

Figure 12–63 Internal drum rotating solid and liquid strainer (courtesy of Schlueter Company)





electric motor is used for throughput of 10 to more than 5,000 gallons per minute, depending on the waste type. A separated solids portion to about 30 percent dry material is possible.

Agricultural engineers at the University of Wisconsin, Madison, developed a hydraulic powered piston press to separate solids out of slurry waste (fig. 12–65). Slurried waste is pumped up from a holding tank and drops into an internal-external slotted cylinder that surrounds a hydraulic-driven, donut-shaped piston. As the piston moves horizontally back and forth, liquid waste is squeezed out through the surrounding interior and exterior slotted cylinders that have 0.157-inch slot widths. The semi-solids are forced out the ends past an adjustable restrictor (Keener et al. 1993, Straub 1993).

A cylinder that has an 8-inch outside diameter processes about 60 to 80 gallons per minute of slurried dairy waste at 30 strokes per minute. The the dewatered fibrous material retained has about 25 percent of the total solids in the influent. A cylinder that has a 10-inch diameter processes about 100 to 120 gallons per minute. (This is being tested at the time this chapter was written.) Waste with long fibers, such as straw, is more easily processed than that with short fibers, such as ground newspaper. This separator has been in use at the 250-cow operation at the USDA Dairy Forage Research Farm, Prairie du Sac, Wisconsin, since 1990. Commercially available piston press separator equipment uses a horizontally operated solid piston arrangement used mostly for high solids filtering applications.

Figure 12–65 Piston type (double-acting) annular separator

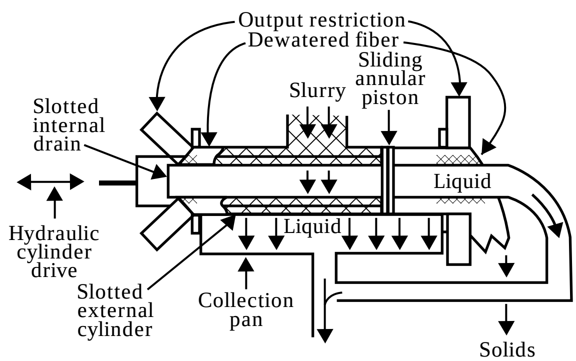
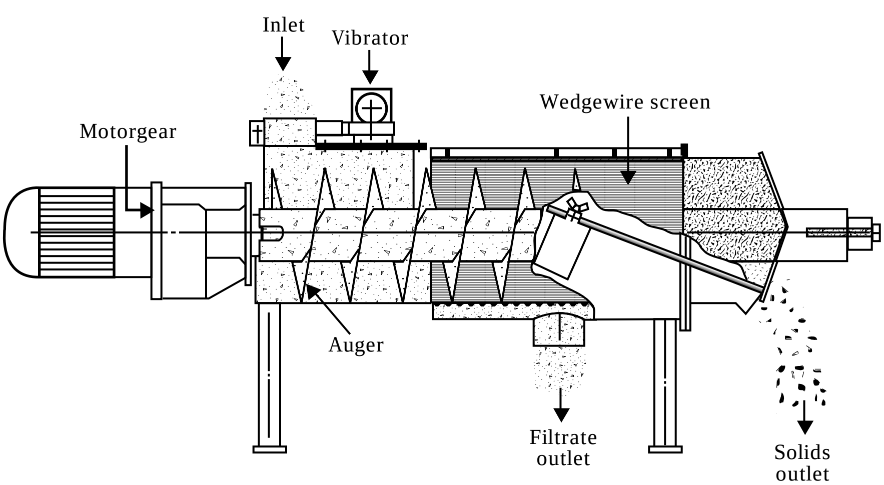


Figure 12–64 Screw-press type, cylinder separator (courtesy of Fan Engineering USA, Inc.)

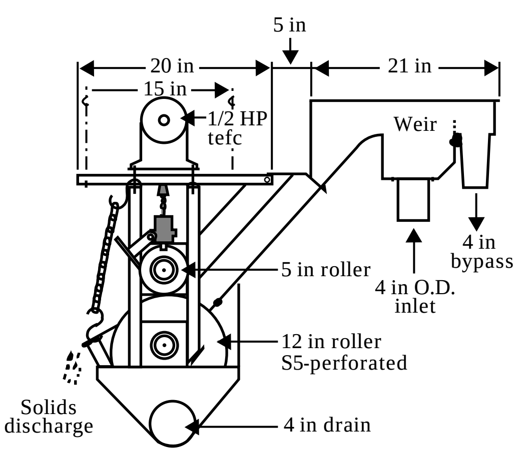


(vii) Roll press—A perforated pressure roller or roll press separator (fig. 12–66) uses sets of rollers through which liquid waste passes. It is similar to a clothes wringer-washer. The upper, solid roller may be compressible while openings in the bottom roller permit liquid to drain through and away. The pressure-roller separator is often incorporated and used in combination with the stationary inclined screen and drag conveyor scraped screen separators to help improve their separation efficiency (see figs. 12–61, 12–62). In such applications about a 0.5- to 1-horsepower electric motor can power the rollers alone, while throughput depends on how tight the rollers are set together.

(viii) Brushed screen—A brushed screen, roller press separator (see fig. 10–39) has screens lying side-by-side that provide two stages of separation. A multiple brush and roller assembly rotates over each screen, sweeping waste across the screen. Liquid waste is pumped into one side of the separator. The brush and roller movement forces liquid out through the screen. Larger solids on the screen get pushed off the separator at the opposite end. Small solids can be forced out with liquids depending on screen size and brush action.

(ix) Belt pressure roller—The belt pressure-roller separator is similar to the roller press separator. The belt pressure roller separator (see fig. 10–39) uses two concentrically rotating belts to squeeze out liquid from liquid waste deposited between the moving belts. More adapted to filtering out fines from liquid waste, the liquid is squeezed through or out of the sides as the belts pass over adjustable spring-loaded rollers. The remaining solids are scraped off the belt to a conveyer.

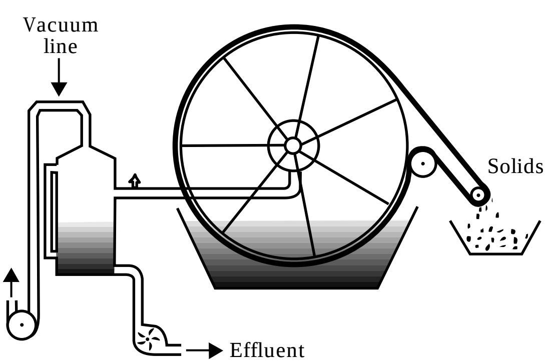
Figure 12–66 Perforated pressure-roller solid/liquid separator (courtesy Baler Equipment Co.)



Optional weir infeed

(x) Vacuum filter—A vacuum filter, horizontally mounted separator (fig. 12–67) has a cloth fiber cover over a belt or rotating perforated cylinder. An interior vacuum draws liquids out of waste that flows onto the cloth. The liquid passes through and drains away. The solids are scraped off the cloth cover at separation points and are conveyed to storage. Used with municipal and industrial processing, the vacuum filter is relatively efficient. However, throughput is low and filter plugging is a problem with certain solids sizes.

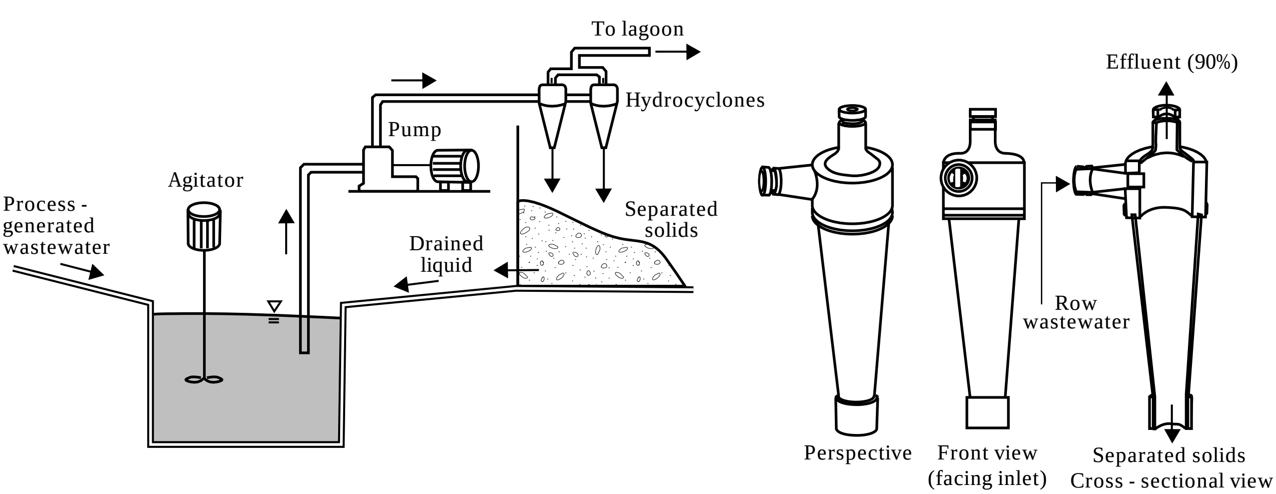
Figure 12–67 Vacuum filter separator



(xi) Centrifugal—A centrifugal separator uses centrifugal (outward velocity) force on liquid waste to separate denser solid material from the liquid. One type employs a relatively slow-speed, rotating cylindrical or conical screen. The waste is fed into one end where the solids are contained on the screen, scraped off, and discharged from the opposite end while the liquid passes through. This is comparable to the spin-dry cycle of an automatic clothes washer. Either a horizontal or vertical screen installation can be used.

A second type centrifugal separator uses centrifugal and centripetal (inward) forces on liquid waste forced horizontally into a conical-shaped bowl. Similar to the action of a feedmill dust collector, the liquid waste enters tangentially at the larger diameter of the cone at about 50 pounds per square inch (fig. 12–68). This causes a high velocity swirl or vortex. Semi-solid waste particles are propelled to the outside of the vortex and move downward toward the zero pressure outlet at the bottom. Liquid collects at the center and discharges out the top, along with the air. As forces on particles passing through the separator depend on the flow velocity, the operating pressure on the incoming waste affects separation efficiency. This dictates that the nozzle inlet and the cyclone be small to achieve minimum inlet pressure (Auvermann and Sweeten 1992).

Figure 12–68 Centrifugal-centripetal solids/liquid separator (courtesy AgKone, Inc.)



(2) Solid waste separators

A mechanical dryer may be needed to provide uniform moisture material for solids separation. A magnet under a conveyor or gravity flow chute can be used to sort out ferrous metal, generally from solid waste.

Although solids can also be separated by shape, density, and surface characteristics, one of several kinds of screening equipment is usually simplest. The screen opening size, shape, susceptibility to plugging (blinding), capacity, and cost should be considered in selecting screening equipment. Screening equipment can use brushes, vibration, forced air, or bouncing balls (below the screen) to reduce blinding. Screen openings of 0.25 to 0.5 inch are suggested for separating compost, depending on the material to be separated out. Small openings improve separation quality, but decrease capacity. Dryness of the material affects separator performance (e.g., more than 55 percent dry material compost is recommended).

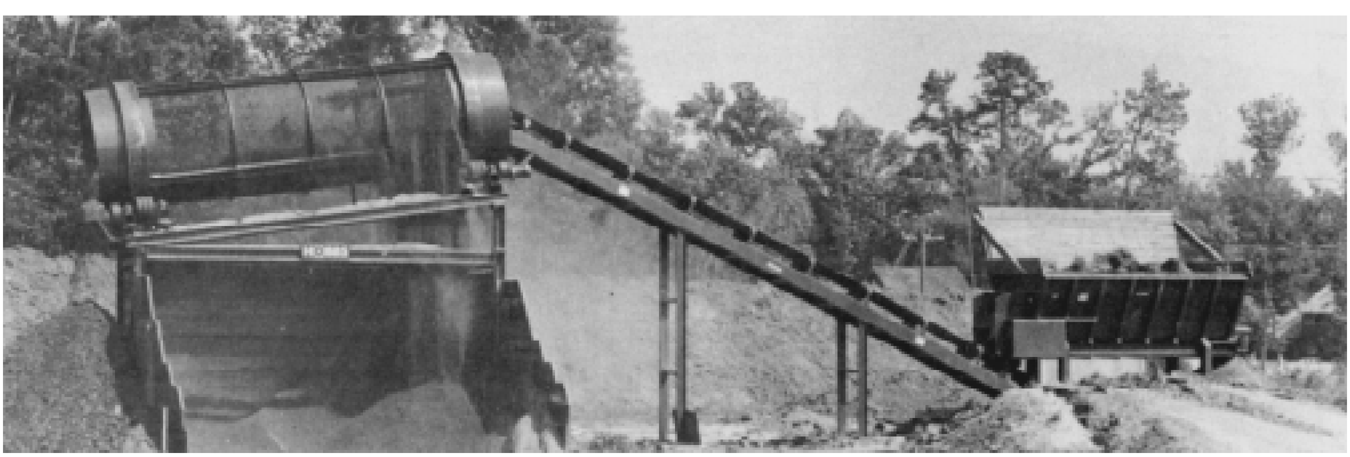
***(i) Trommel or rotating screen*—**The trommel screen separator is a long, rotating, inclined drum with openings (fig. 12–69). A gravity feed hopper, elevator auger, or chain-slat constant speed conveyor feeds a uniform material flow into the continually rotating drum. Screened material exits out the sides and is guided downward by a shield. Oversize material exits out the end.

Rotating drum equipment used with granular screening employs perforated metal, slotted metal, or wire mesh screen. Industrial trommel screens are available in different sizes, but generally are at least 3 feet in diameter and 10 feet long. They rotate at about 300 rotations per minute. Exterior rotating brushes can be used to clear screen openings. Depending on the capacity, power requirements vary from 5 to 50 horsepower. Screen sizes can be changed.

***(ii) Open screen conveyor*—**An auger rotating in an opentop, screened trough permits fine, dry, granular solids to drop through and separate from lighter, coarser solids while being conveyed. Coarse material is conveyed to the end. This separator can remove dry soil from wood chips, for example. Power need varies with speed, angle, and material conveyed, but would be about 2 to 4 horsepower per 10 feet of 0.5 to 1-foot diameter auger operated at a 25 degree angle at about 450 rotations per minute. The investment is relatively low as is the separation quality.

***(iii) Vibrating screen*—**A sloped shaker or vibrating screen separator uses a back-and-forth reciprocating motion to bounce material down along the length of a sloped screen (fig. 12–70). Material is fed onto the upper end of the screen and, depending on screen arrangement and hole size, either falls through the screen with the foreign material falling off the end, or

Figure 12–69 Trommel, rotating drum, solids separator (courtesy Amadas)



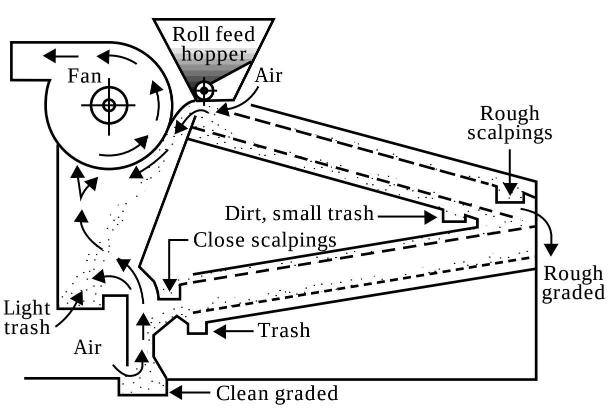
vice versa. Several screens can be used or changed, each with different sized and shaped openings, so most granular-shaped materials can be accurately sorted and sized. A controlled rate of forced air can be included with the shaker screen so lightweight material is blown out. Power need and throughput capacity are less than with comparable size trommel screen equipment, but the screened material quality is higher.

(iv) Slotted belt—A flexing belt screen separator uses a moving, wide slotted, flexible belt to carry along material that is metered onto it and is be separated. Sections of the belt are alternately flexed and snapped taut, throwing the material up and clearing the slots. The larger material is carried to the end, while the smaller material falls through the screen.

(v) Rotating screen or disc—A rotary screen or spinning disc separator has plates or discs with holes of selected sizes for material separation. Granular material metered onto the disc either falls through the disc openings or, if large, is spun off to the outside. The rotating screen solid separator is used in sawmills to separate sawdust from larger materials.

(vi) Fluidized bed—The fluidized bed separator was developed for more gentle separation of unwanted heavy solids from vegetables or other easily bruised solids. Fine sand moving over an adjustable air flow is blown upward to support the constant input of solids to be separated as they move through the separator. The selected solid is conveyed away while heavier solids fall and are separated from the recirculated sand. The fluidized bed separator has a high investment cost, relatively low power need, and high capacity, and is adaptable to special processing.

Figure 12–70 Sloped shaker screen solids separator



(e) Dehydrator, incinerator, renderors

Dehydrating, dewatering, or drying waste is explained in chapter 10, section 651.1004(e). Dried waste at about 85 to 90 percent dry material can be stored at normal conditions or packaged and distributed, depending on state laws about fertilizer quality, weed seeds, and disease. Dry, loose material is relatively easy to mix with other products for livestock feed, soil mulch, or fertilizer.

Shallow tray, batch or bin, continuous conveyor belt, rotary drum, and flash dryer equipment employ heated air blown over or through the waste.

The shallow tray dryer involves placing a 3- to 12-inch layer of material to be dried on a mesh screen or perforated metal floor. Hot air is blown through the material until it is dried to the desired level. It is then removed and another tray put on to dry. The continuous shallow bed dryer is similar except the material to be dried is conveyed through the heated airstream. The conveyor movement rate varies according to required drying time and operating temperature. One dryer arrangement is shown in figure 12–71. Available models are rated from 1 to 20 tons per hour capacity with a 3- to 25-horsepower blower motor and heater sizes to a million BTUs.

The rotating drum or inclined cylinder dryer is designed for use with high-capacity agricultural processing and waste drying (fig. 12–72). Wet incoming waste may need to be dewatered via short-term stacking, solid/liquid separator, or remixing with dried waste before entering the rotating drum dryer. This minimizes the formation of rolls or compacted balls as waste tumbles through the dryer. As wet waste moves through the drum, heat from a direct-flame burner is blown through the dryer in the opposite direction. This permits the hottest air to first evaporate water from the exiting drier material.

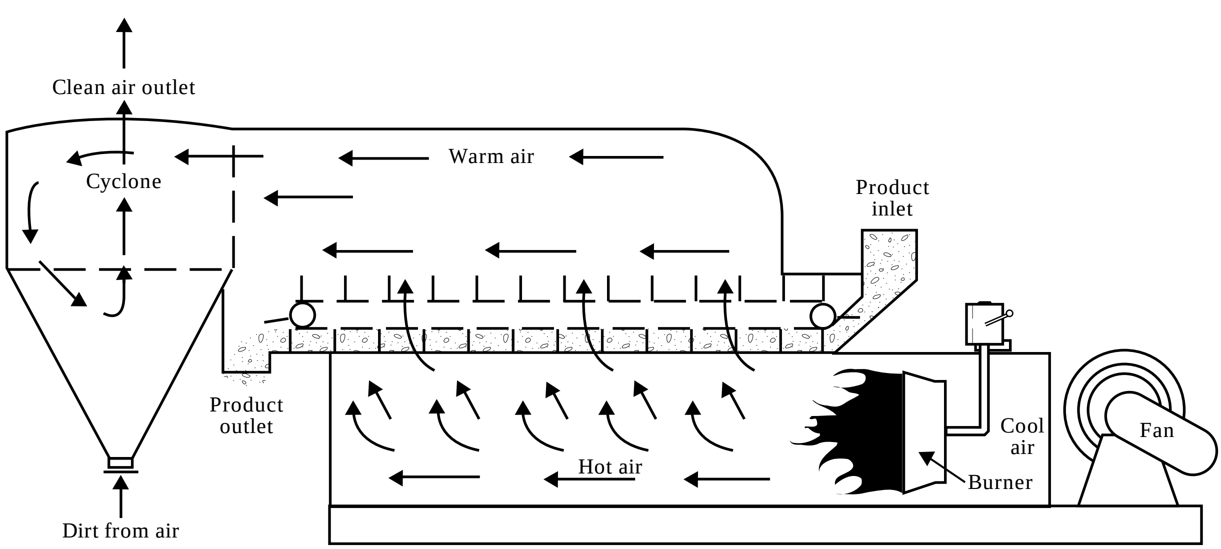
Dryer/dehydration equipment that has a relatively high capacity of 10 to 40 tons per hour of 50 percent dry material requires a high investment and has high operating cost. Odors from drying wastes can be a community problem. Operating power need from 10 to 125 horsepower and heat requirements to 30 million BTUs per hour may be required.

Mechanical drying of undiluted poultry waste has been extensively studied because of its high nutrients and total solids. The high investment and labor costs cause producers to not use mechanical drying of undiluted poultry waste inspite of the value of the final product. Heating air and forcing it through wastes to dry out moisture requires blower power and nearly 1,200 BTU of heat for each pound of water removed—if done at 100 percent efficiency. A ton of 40 percent dry material hay, for example (representative of some agricultural wastes), needs over 1,100 pounds, or 133 gallons, of water removed to make 90 percent dry material hay that is safe to store. Depending on weather conditions and efficiency, some 2- to 3-million BTU or 15 to 20 gallons of fuel oil equivalent would be needed. Research at Michigan State University indicated that 9.45 gallons of fuel oil were required to remove 1,000 pounds of water from poultry waste. Table 12–7 shows results from mechanically drying different kinds of animal excreta.

A pilot scale, odor-free waste drying system consisting of a continuous-flow crop dryer with an afterburner and heat exchanger was developed and its performance analyzed at the University of Guelph (Meiering et al. 1975). The exhaust air from the dryer entered the afterburner where odorous components and dust were oxidized by open-flame combustion at 1,200 degrees Fahrenheit. The burned air then flowed through the heat exchanger and heated the incoming air to the dryer. Complete odor elimination, except for traces of ammonia, was achieved in the drying of poultry and sheep wastes. Also safely dried was potato processing wastes that were generated in caustic soda and mechanical peeling processes. Nearly 60 percent of the heat generated in this process was recovered by the heat exchanger for the drying, which required about 2,165 BTU per pound of water removed. This is about 50 percent efficiency and would have been lower had the heat exchanger been excluded or poorly maintained.

Drying feedlot waste from the Fort Worth, Texas, Stockyards in 1964 involved wastes stockpiled outdoors in long rows and frequently turned to speed outdoor drying and decomposition, reduce odors, and kill vegetative growth. After several weeks the product was ground, shredded, moved through a gas heated dehydrator drum, screened, weighed, sacked, and conveyed to a truck for distribution (Compost Science 1964).

Figure 12–71 Continuous flow shallow tray dryer (courtesy Jet Pro, Inc.)



Incineration equipment is used for destroying dead animals and poultry. This equipment is useful for animal disposal and disease control with confined livestock production and animal health care operations. Oil-fired incinerators are available for a 100- to more than 500-pound animal load capacity (fig. 12–73). Suggested incinerator size is that needed to handle one day of animal loss. Burner capacity and door size affect actual use. An air-pollution approved incinerator has high investment and operation costs. These incinerators use 1.5 to 2.5 gallons of fuel per hour for about 2 hours per load. Regular maintenance, cleaning, and ash disposal are required.

Large scale incineration of waste has generally been limited to commercial situations that require specific planning and design. The kind of waste, its supply, hauling, odor from and appearance of stored unprocessed waste, and particulate emission must be considered. Equipment investment is high, and operation costly. Some 10 to 30 percent of the initial dry matter remains as ash that requires disposal (Agriculture Canada 1980). Fluidized-bed furnaces and incinerators use agricultural wastes as fuel (Annamali et al. 1985, Clanton 1993, Zygmunt 1992). Agricultural processing plants (e.g., seed processing) adapt this equipment for their in-plant energy supply and use their own dry processed waste. Some energy conservation grant support or other incentive can assist with costs. This nearly continuous-operating equipment can be effectively designed and used by regular skilled employees.

Rendering plants use dead animals for manufacturing useful products. Because it is a large capacity operation, a rendering plant requires installation approval and careful operation. An adequate supply of dead animals and a market for the products are essential. A regular pick-up service with enclosed trucks is needed. Because of the high investment and monitoring needs, the few installations that are currently in business are sparsely located to accommodate livestock production and supply.

Figure 12–72 Rotating drum type dryer/dehydrator (courtesy Vincent Corp.)

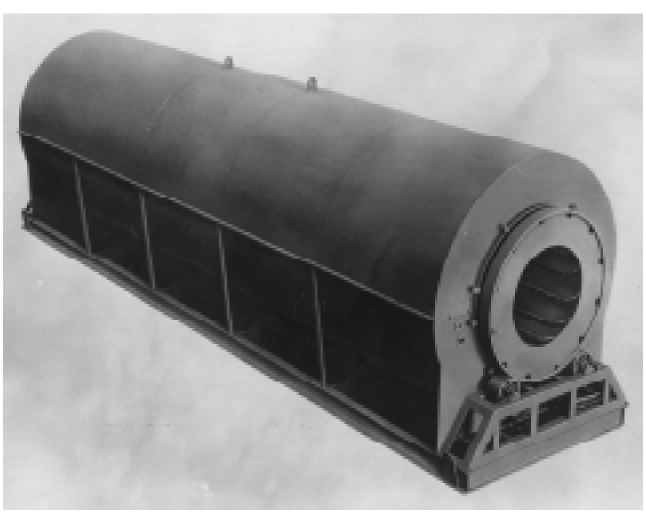
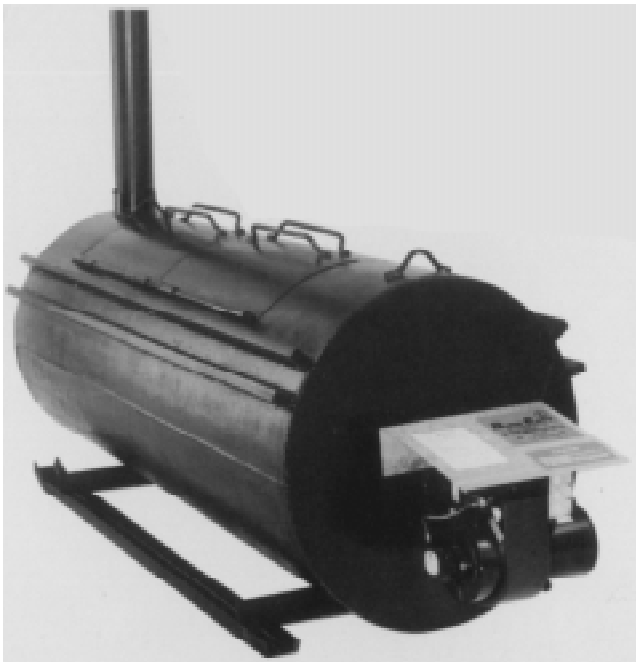


Table 12–7 Dryer performance with animal excreta (MWPS 1975)

Excreta source	Fresh excreta (lb/hr)	- - - Moisture - - - initial (%)	final (%)	Fuel use (gph)	Elec. use (kW)	Efficiency (%)
Poultry	340	76.3	11.1	2.4	4.2	72
Bovine + 2% straw	243	82.4	12.0	2.6	4.2	52
Swine	225	72.2	12.5	2.4	4.2	44

Figure 12–73 Incinerators for dead small animal disposal (courtesy R & K Incinerator Co. and Shenandoah Mfg.)



651.1206 Waste transfer equipment

The movement or transfer of agricultural wastes is described in chapter 9, sections 651.0904(e) and 651.0906. As further explained in chapter 10, section 651.1005, transfer equipment can be an extension of the waste collection equipment. The equipment that has common use either for collection or for transfer of waste is explained in section 651.1203. It includes:

- Tractor front-end loader
- Skidsteer and articulated-steer loaders
- All-wheel drive front-end loader
- Ramps and bumper walls
- Air-pressure/vacuum pumps
- Large piston pumps
- Earthmover scrapers

Solid waste is commonly transferred a batch or more at a time (i.e., scoopful, wagon load) and at a relatively low rate. It is relatively dense and not easily moved. While batch movement is intermittent, a relatively larger quantity of semi-solid, slurry, and liquid waste generally is transferred at one setting with continuous flow type equipment than with other equipment. Depending on what is calculated and how (e.g., labor, investment, odor, appearance, nutrient), the cost of actual dry matter transferred is probably similar. The liquid portion facilitates waste transfer, but, unless needed for irrigation itself, has little value and adds to transfer quantity.

(a) Augers and conveyors

A standard pitch auger that is 0.3- to 1.5-foot in diameter can be used to transfer solid, semi-solid, and liquid wastes. A clean auger intake and relatively tight auger fit within its housing assist throughput. A short pitch, sometimes called *double flight* auger (twice the flighting per foot) aids slurry or liquid waste transfer if operating at relatively steep inclines. Table 12–8 shows how water throughput changes with auger size, speed, power, and elevating angle. With slurry and semi-solid wastes, less throughput can be expected than that for liquid waste (MWPS 1975).

Although designed to transfer semi-solid waste, power requirements are relatively high for larger augers—about 1 horsepower per 2 feet for an auger that is 13 to 16 inches in diameter and operates at 200 rotations per minute. If stopped when full, auger startup is difficult. A 16-foot-long auger, that is 16 inches in diameter, operating at about a 30-degree incline should have about a 750 gallon per minute throughput when powered with a 7.5-horsepower motor at 200 rotations per minute. Most manufacturers use a plastic liner or pipe housing because it operates smoother and quieter and is resistant to wear and corrosion. Augers up to 40 feet long are available that are designed for slurry and semi-solid wastes (fig. 12–74). Some models that are more than 100 feet long and 0.33 to 1 foot in diameter are available for granular solids transfer.

(b) Pumps

Piston plunger and air pressure or vacuum pumps are explained in section 651.1203.

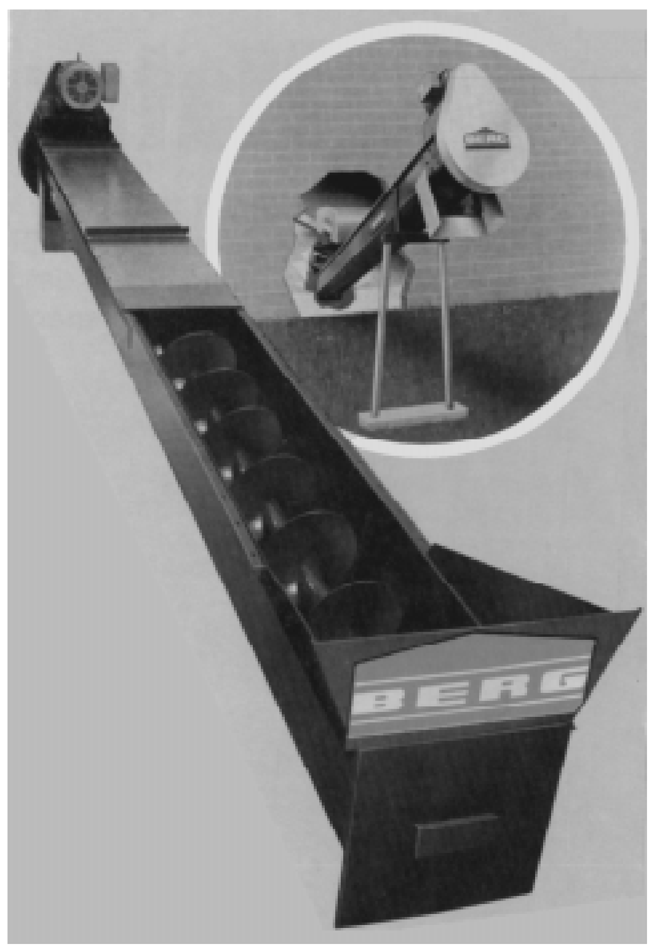
A variety of either variable or positive displacement pumps move liquid, slurry, and semi-solid waste to storage, tankers, or irrigators. Pump selection and rating depend on the amount and type of solids in the waste (see chapter 4 and sections 651.0905 and 651.1101), capacity desired, head or operating pressure needs, and available power. Table 12–9 compares the major characteristics of different pumps used for pumping waste. Because of the many model variations (inlet, outlet, impeller, speed, power), the manufacturers' literature on use and performance of a particular pump needs to be reviewed.

Measures are available to protect a pump and power supply against plugged pipes or nozzles, loss of prime, overheating, and lubricant loss. They include pressure and temperature gages, fuses, circuit breakers, and pressure switches. Lightning grounding is especially needed with exposed pipe irrigation pumping. Pressure surges in the discharge pipe (water hammer) are troublesome in starting high capacity pump systems. An open valve in the discharge pipeline can be slowly closed to reduce water hammer when pressurizing a system. A surge tank reduces water hammer as well.

Table 12–8 Auger (11 ft) speed, power, and capacity for water

- - - - - 4-inch diameter auger - - - -				- - - 6-inch diameter auger - - -			
rpm	hp	angle (%)	gpm	rpm	hp	angle (%)	gpm
1,500	0.8	45	32	950	2.0	45	80
		60	17			60	40
		90	10			90	—
1,700	1.6	45	48	1,150	2.8	45	180
		60	33			60	130
		90	19			90	85
1,900	2.6	45	66	1,350	4.0	45	330
		60	51			60	255
		90	30			90	200

Figure 12–74 Auger elevator slurry waste conveyor (courtesy Berg Equipment Company)



The wear on most pump bearings and seals is rapid when pumping waste. The severe pumping conditions also damage controls and valves. Regular lubrication and cleanup extend pump life and performance. A spare pump should be readily available to replace essential pumps in a waste system when they break down.

Pump inlet and outlet pipe configurations affect performance. An inlet or outlet pipe that has a smooth, funnel shaped transition or a gradual corner without a sharp edge or turn, or both, aids flow (see fig. 12–91). This is especially helpful where the flow rate is high. The diameter of the inlet and outlet pipes should match that of the pump openings. A minimum of bends, elbows, and other flow restrictions in the pipeline improves flow and reduces power and plugging.

Exclude foreign material, such as twine, hair, wood pieces, broken iron, afterbirth, stones, and plastic from waste to help prevent plugging and breakage. A screened pump inlet, if used, needs a large screen area with relatively large openings to reduce plugging. A screen is most efficient with liquid waste that has few large solids and at low pumping rates. Locating the pump inlet above the bottom of the waste impoundment and below the surface minimizes inlet plugging (see fig. 12–28). Adding dilution liquid to waste aids pumping, but adds to waste quantity, storage space, hauling, spreading, and possible water supply problems.

Pump use and waste handling system performance are assisted by waste storage construction design features. Access space, pumping sump, agitation mixing, proper pump location, and intake protection are needed in addition to the correct pump selection (see section 651.1204). The solids and liquids in liquid, slurry, and semi-solid wastes need to be thoroughly mixed so the solids are not left behind when these wastes enter the pump.

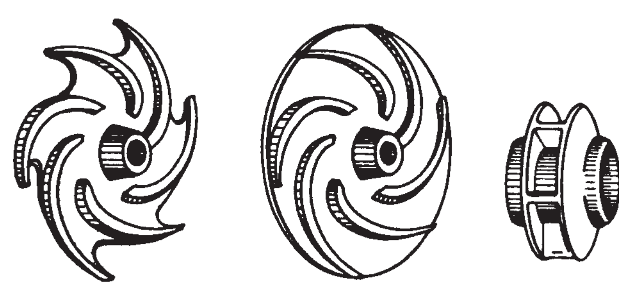
(1) Variable displacement centrifugal pumps

Centrifugal pumps are variable displacement. They are widely used for waste pumping because of their simplicity and range of capacities. These pumps have a power shaft with an attached impeller that rotates inside an enclosed housing. Gravity-flow liquid enters the housing near the center of the impeller and is forced outward by the rotation of the curved impeller blades (fig. 12–75). The higher velocity at the outer end of the blades and low pressure at the impeller center cause the liquid to flow.

Table 12–9 Waste pump characteristics summary (MWPS 1985, Patronsky 1978)

Pump type	Max. solids (%)	Agitate dis. (ft)	Pump rate (gpm)	Pump head (ft)	Power (hp)
Hi-pressure centrifugal	<10	40-60	1,000	200-300	80+
Chopper-agitator	10-12	50-75	<4,000	25-75	65+
Impeller agitator	10-12	75-100	<5,000	30-35	60+
Submersible	10-12	25-50	<1,000	10-30	<15
Helical screw	4-6	30-40	<300	200+	40+
Hollow piston	18-20	—	<150	30-40	<15
Solid piston	18-20	—	<150	30-50	<10
Pneumatic	12-15	—	<150	30-40	<10
Vacuum	8-10	20-25	<300	—	50+
Diaphragm	10-12	—	<300	100+	25+

Figure 12–75 Centrifugal pump impeller types (MWPS 1985)



Intake restrictions or plugging cause air-pockets (cavitation) by the impeller. This reduces flow and can hasten the impeller wear, especially where high-pressure pumps are used at a high speed. Because the pumped liquid can slip past the rotating impeller, the liquid displaced varies—hence the name *variable displacement*. As slippage increases and further lowers efficiency, the pump operating pressure is increased. Pumping capacity, pressure, and power needs depend on design and construction of the impeller, the impeller enclosure, and its inlet and outlet.

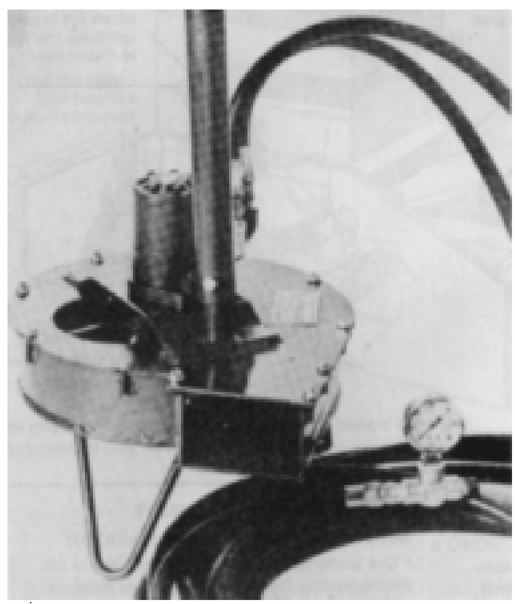
Established pump manufacturers design, develop, test, and manufacture a variety of centrifugal pumps for most uses. Models vary by size, impeller type and clearance, pump inlet and outlet, bearing seals, and drive arrangement. Selected models are often recommended by agricultural waste pumping equipment manufacturers that assemble pumping equipment for transfer, agitation, pumpout, and irrigating waste.

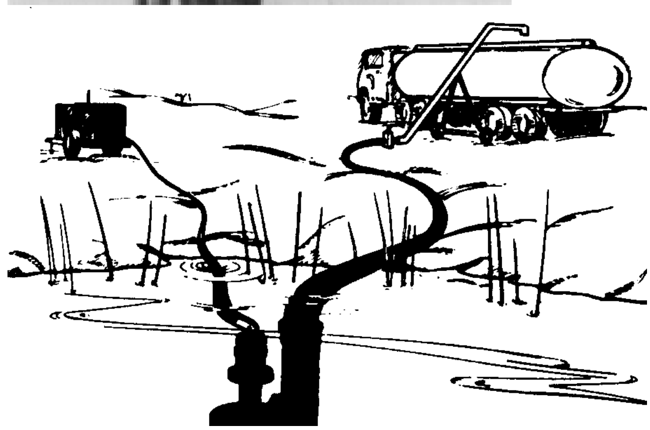
A closed impeller is efficient with liquid waste, but plugging with tough, stringy solids and chunks can be troublesome. A closed impeller pump is useful for high pressure irrigation or recirculating liquid for flushing. A semi-open or open impeller is less efficient, but is also less prone to plugging and is able to handle semi-solids. Although generally inefficient, a sloped and curved, semi-open impeller design minimizes flow cavitation and solids plugging. A sharp, hardened, chopper-blade attachment at the pump inlet (see fig. 12–42) can break up tough materials ahead of the impeller. The blade must be kept clean and sharp because a dull blade winds-up stringy materials, which restricts the flow.

Changes in the pressure at which a centrifugal pump operates efficiently can be made by changing the operating speed. However, when this is done the discharge and power required also change. Pump discharge generally increases directly as the speed increases; the pumping head increases as the square of the speed; and the power required increases as the cube of the speed. For example, a pump operating at 500 rpm could be expected to pump twice as much when operated at 1000 rpm. However, it would operate at half the operating pressure and use 8 times the power.

Liquid priming is necessary to start a centrifugal pump. Priming consists of filling the suction pipe and impeller enclosure housing with liquid to expel the air and cause suction as the impeller begins turning. A gate valve on the discharge side and a small hand pump attached to the volute are a usual priming pump arrangement. Holding liquid in the pump when stopped using one-way flow valves also is used, but plugging and leakage are problems. Priming becomes more difficult as a pump wears and air leaks develop around bearings. Some large capacity pumps have a separate small, powered priming pump. Locating (submerging) the pump in the liquid to be pumped eliminates hand priming (fig. 12–76).

Figure 12–76 Hydraulic motor powered centrifugal chopper pump (courtesy Liquid Waste Technology)





The practical limit of liquid suction for most centrifugal pumps is 22 feet at sea level, 17 feet at 5,000-foot elevation, and 14 feet at 10,000-foot elevation. Pumps will operate beyond these limits, but their performance is seriously reduced by cavitation or nonuniform liquid flow through the pump. Elevation can also affect vacuum pump suction and pumping performance (see fig. 12–88).

***(i) Transfer*—**Generally, two types of pumps, submersible and vertical shaft centrifugal, pump liquid and slurry waste from reception storage to long–term storage or separation. The relatively small, submersible, 0.5- to 15-horsepower centrifugal type (sump) pump (fig. 12–77) is designed to simply sit on the pump chamber floor. It has a flexible power cord and pump outlet pipe. This type pump is messy to use and difficult to service. Industrial and larger models use a raise and lower attachment and hose disconnect.

The submersible pump is designed and constructed, usually with an electric motor, as a complete waterproof unit to be immersed in the liquid to be pumped. This design makes it self-priming. An automatic on-off float-control switch can be an integral part of the pump unit.

Typically, a submersible centrifugal pump is used to transfer 50 to about 200 gallons per minute of liquid or slurry waste from a sump to a reception tank, solids separator, or lagoon, or to recirculate lagoon water (see fig. 9–9). Larger models are available. Those that are powered by a hydraulic motor can pump up to 3,000 gallons per minute (fig. 12–76) at high pressures if they are designed and constructed with an enclosed impeller. This equipment is higher cost than the smaller models, but is simpler to use, is portable, and the speed can be readily varied.

A second type transfer pump, used with reception storage, has a 4- to 8-foot-long vertical shaft to the impeller. The motor is above the waste level, and the centrifugal pump is immersed and self priming (see figs. 12–77, 10–41). Although this pump cost more than the submersible type, the power supply and service are simpler and less messy. Models are available that use 0.5 to 25 horsepower motors and have a capacity of up to 2,500 gallons per minute at zero discharge pressure.

***(ii) Chopper-agitator*—**The vertical shaft and inclined shaft chopper-agitator pump (see figs. 12–45, 12–48, 9–8, 10–16) typically employs a 10- to 20-inch diameter semi-enclosed impeller. This impeller has a relatively wide clearance, which helps to avoid plugging. See section 651.1205 (b) for more details.

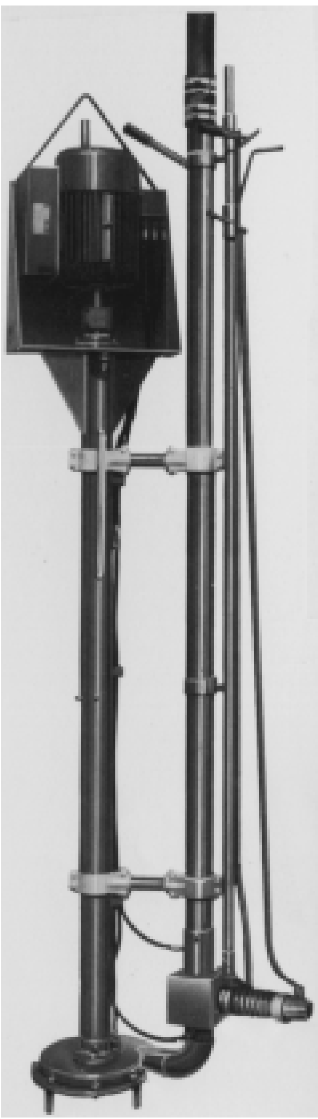
Generally a chopper-agitator pump impeller is individually welded and steel plated. Its bearings and seals are relatively rugged and simple in their design. The impeller runs at relatively low speeds at high volumes and low head.

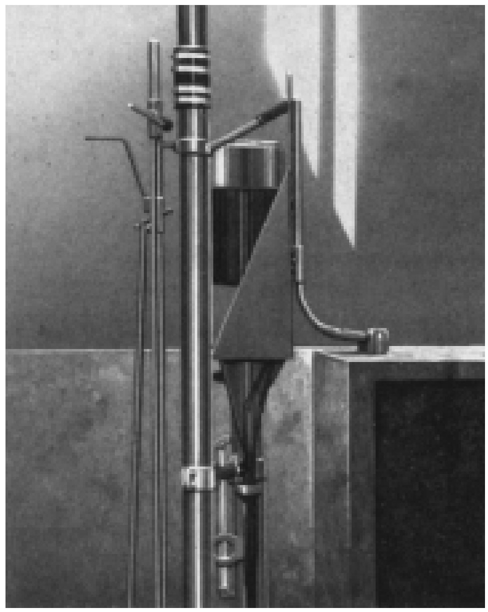
Although a hot-dipped galvanized coating is more durable, most chopper-agitator pumps are painted. Pumps in various sizes and capacities can pump up to 4,000 gallons per minute of waste when new. The pumps require 15- to 140-horsepower motors. Some models work to a depth of 12 feet. Most pumps are tractor PTO powered; some use electric or hydraulic motors. PTO power is less investment, but straight shaft alignment is important for smooth operation and minimum power train wear. Trailer tow models are simpler to hitch, move, and park in place. The 3-point hitch models use less space and cost less.

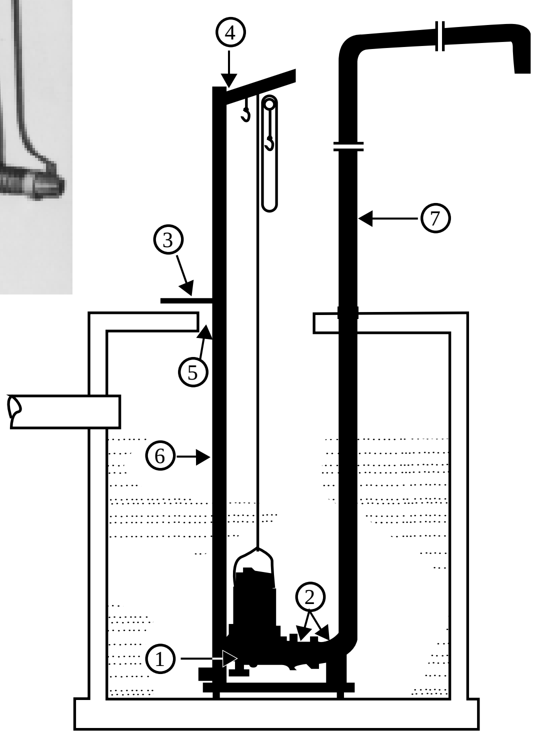
***(iii) High pressure and capacity*—**Centrifugal pumps with a horizontal power shaft and closed impeller are available. These pumps are engineered with close tolerances, securely sealed bearings, balanced power shafts, and other features for sustained operation at high rpm's, pressure, and throughput.

Impeller end thrust is high with all the severe operating conditions experienced by operations pumping several million gallons per year. The end thrust forces waste past the seals and into bearings. High capacity pumps are used for liquid and slurry waste agitation and pumped waste spreading (see figs. 9–18, 10–18). The 80 to 150 horsepower needed for more than 100 pounds per square inch pressure and 500 to 1,000 gallons per minute throughput is provided by a stationary engine, electric motor, or tractor PTO (see fig 12–92). A separate primer pump is needed on these models to execute pumping startup. Two such pumps may be used in tandem to overcome pressures in pumping waste several miles via pipeline to a towed injector field spreader or irrigator (see fig. 12–103).

Figure 12–77 Submersible and vertical shaft transfer pumps (courtesy J. Houle & Fils Company)







1. Submersible electric pump with chopper blades to cut hair, bedding and other manure solids
2. Discharge nozzle and outflow pipe can be uncoupled by rotating control handle 3 at safety platform
3. Control handle
4. Lifting davit with portable chain hoist
5. Guide bracket bolted to safety platform or tank top
6. Guide bar controls pump position when coupling at 2 or hoisting pump 1
7. Discharge pipe

ways and Stairs, explains design and installation recommendations (ASAE [o] 1994). Briefly, the recommendations are:

- Space 16-inch wide rungs a maximum of 1 foot apart.
- Allow 7 inches of toe space in front of rungs.
- Use a 27- to 30-inch cage clearance about the ladder.
- Provide work landing platform access.

A waste storage ladder location in plain view by others is preferable. A portable ladder stored away from the waste storage can help deter unauthorized access (see figs. 9–6, 10–18). When in use, the portable ladder should be securely attached to the storage structure to prevent it from falling away and stranding the user. A ladder permanently attached to a storage structure needs to terminate beyond ordinary reach or an entry guard or gate must be used. The attached ladder should terminate at a height of more than 8 feet above the ground. A sunlit location for the ladder helps to quickly dry the ladder and is naturally well lighted.

A ladder permanently located inside a waste storage structure obstructs cleaning. It will also corrode and become unsafe as its deterioration is hidden by waste and poor light. A portable ladder, removed and stored when not in use, is a better alternative.

(b) Storage exterior accessing

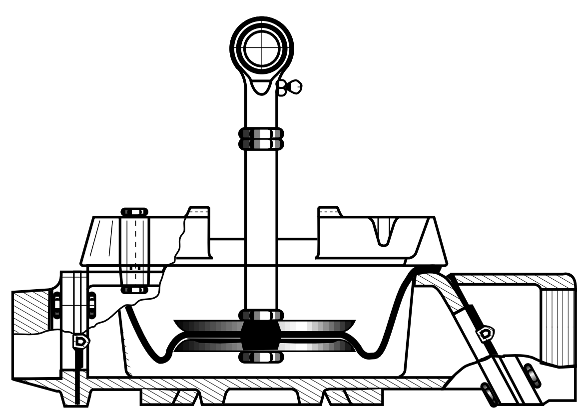
Waste storage agitation and emptying equipment needs overhead clearance and turning space access (see figs. 9–6, 9–8, 10–12, 10–16, 12–47 to 12–49). An example:

> A vertical wall, belowground, semi-solid/slurry storage structure that is up to about a 60-feet across and 12 feet deep can be agitated and pumped from one pump station using the same centrifugal-chopper pump used for filling the storage. A circular storage shape agitates in less time and encloses more storage capacity than does an equal perimeter length of a rectangle or other storage shape—everything else being equal.

Tables 12–3a and 12–3b can be used for estimating comparative sizes. For example, to store 21,600 cubic feet of waste would require a storage structure that is a 24- by 100- by 10-foot rectangle or a circular unit that is 55 feet across and 10 feet deep.

Additional access space or larger agitation equipment is needed for larger storages, especially for semi-solid waste. An impeller-type agitator (see figs. 10–16,

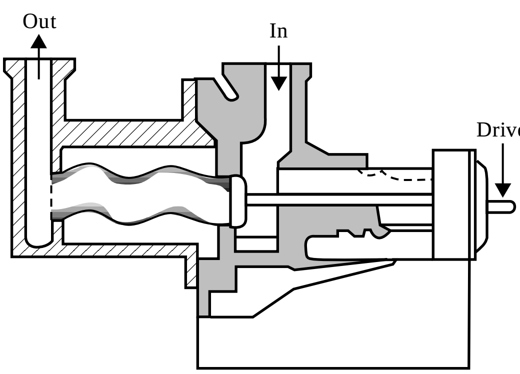
Figure 12–78 Diaphragm pump (courtesy Protek Specialty Company)



The diaphragm pump is commonly use by custom operators that pump or haul sewage sludge where performance is more important than high capacity. It is also used as a hand-operated primer pump with a high capacity centrifugal pump. Another common use for this type pump is for an automobile fuel pump. It can operate dry and be relatively trouble free with liquid and slurry wastes.

(iii) Helical rotor—A helical rotor, or rotary screw, pump (fig. 12–79) can pump liquid, slurry, and semi-solid wastes at pressures of up to 450 pounds per square inch. The pump is powered by a PTO or electric motor, so the operation is smooth and quiet. Sand, stones, and the metal hardware, however, prematurely wear out the composition material of the pump chamber. This chamber wear causes leakage that destroys the high positive displacement capability of the pump. Helical rotor pumps are used for slurry waste irrigation pumping. Some models can move up to 300 gallons of waste per minute at 150 pounds per square inch using a 50-horsepower motor.

Figure 12–79 Helical rotor pump (courtesy Continental Pump Company)



651.1207 Waste utilization equipment

The alternative end uses for agricultural wastes vary, and each use employs various equipment. Waste utilization is explained in sections 651.0605 and 651.0904(f). Land application is reviewed in sections 651.1006(a) and (b) and 651.1102(c), and biogas production in section 651.1006(d). Refeeding wastes to livestock, pyrolysis (a chemical change brought about by heat), and using waste as fuel are other alternatives, but they have limited applications to date (Annamali, et al. 1985, Landen 1992, MWPS 1985). Although a viable option, direct selling of raw waste is seldom done as timeliness, costs, weed seeds, and disease or organism spread are problems (Clanton 1993). NRCS considers solid/liquid separation, composting, and incineration of agricultural waste as treatment rather than utilization (section 651.1205).

Soil fertility levels and waste spreading use are monitored by soil sampling and land-grant university or commercial testing laboratory analysis. A direct reading nitrogen meter is available to directly measure waste nitrogen content (see fig. 12–122). The method for measuring the moisture content of waste is described in table 4–1.

(a) Hauled waste spreading equipment

The major use of agricultural waste is for crop fertilizer via field spreading. Equipment used to haul and field spread includes:

- Box spreader with floor conveyor/rear beater unload
- V-bottom box spreader with side or rear unload
- Flail spreader
- V-box rear unload broadcast spreader
- Tanker spreaders (two types)

Demand continues for larger capacity and faster equipment to haul and more uniformly spread solid, semi-solid, slurry, and liquid wastes at an optimum time of year. These demands and a growing need for field spreading at sites more distant from the waste production source add to hauling and spreading concerns and influence individual equipment selection.

Decisions about spreading equipment size or type depend on cost, amount and consistency of waste to be handled, haul distances, available spreading time, size of available tractor or truck power and braking, facility door or gate opening sizes, loading height limits, equipment warranty and service, and desired options (splash covers, type of power drive, wheel type, and tire size).

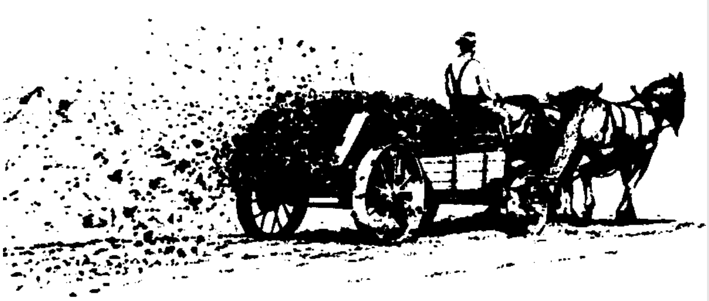
Renting or leasing of hauling, pumping, and spreading equipment can be advantageous for a few days use per year. This affords a way to try different equipment and to maximize the use of limited operating capital. Rental costs can be competitive to annual costs for private ownership of limited-use equipment when all aspects are considered. Another option is to share hauling and spreading equipment with a nearby operator. Compatibility and condition of shared equipment and competition for its use by others are considerations.

Hiring a contractor, commonly called a custom operator, to load, haul, pump, and spread waste is common. Although relatively high cost, the job gets done in a short time. Custom operators, however, generally seek payment based on the number of loads, the weight, or the gallons hauled and spread. The intensive skilled use of relatively high quality equipment by professionals can lead people to the false assumption that they can operate the equipment themselves to save time and money. This could lead to equipment, labor, and timeliness problems and poor use of waste.

(1) Box spreader

The traditional rear-unload box spreader remains popular for hauling and spreading semi-solid and solid waste (fig. 12–80). This equipment requires a relatively low investment and is simple to use. For frequent waste cleanup of small areas and small to average-size operations, hauling and spreading waste in a towed box spreader as a solid material is relatively more convenient and practical than pumping or irrigating the waste. Hitching and filling a box spreader involves less equipment and expertise to organize and operate than does agitation, connecting pipelines, pumping, and using an irrigator. This convenience can affect waste utilization as well as sanitation and appearance of facilities.

Figure 12–80 Box spreader (courtesy Gehl Company)



The load capacity of tractor-tow and truck-mounted box spreader models ranges from about 20 to more than 400 cubic feet. The ASAE Standard S324.1, Volumetric Capacity of Box Type Manure Spreaders (ASAE [f] 1990), is used by manufacturers to provide uniform load capacity ratings (in cubic feet) of different box spreader models. Some advertising materials, however, use bushels, gallons, or tons. See Conversion Factors and Tables of this handbook.

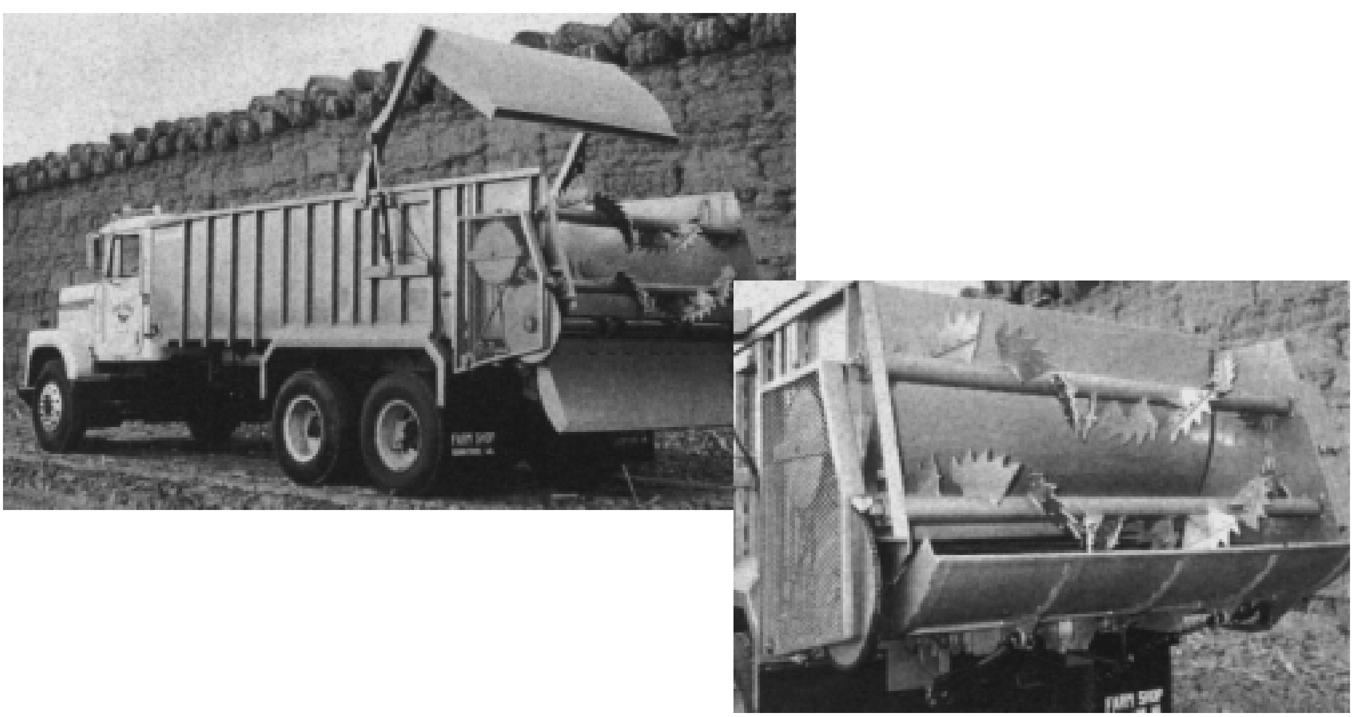
The box spreader's hydraulic-powered push-end gate unload, beater pan cover, and inward-curved front and side extensions aid cleaner hauling and more uniform spreading of slurry and semi-solid wastes.

Box spreaders are available in waterproof or pressure-preservative treated wood or in corrosion resistant or treated steel. A polyvinyl plastic plank or glass fiber-sheeted box interior liner aids unloading; however, plastic materials are not durable in some applications.

Tractor front-end loader damage to a spreader box is a problem in addition to rusting and rotting. Such deterioration and other repair are minimized by careful use, regular cleanup, lubrication, and shelter from weather.

While European studies continue (Malzeryd 1991, Wetterberg 1992), most of the development of spreader-beater design in the United States has come from field experience. The high/low rear beater configuration on box spreaders that is used to loosen solid waste and move it onto a rotating-spiral distributor beater has given way to a simpler rear shredder that is larger in diameter and has a widespread combination beater. The high/low beater configuration remains popular for large capacity, truck-mounted box spreaders, but the spreading uniformity is not always achieved (fig. 12–81).

Figure 12–81 Truck mounted box spreader (courtesy Farm Shop, Inc.)

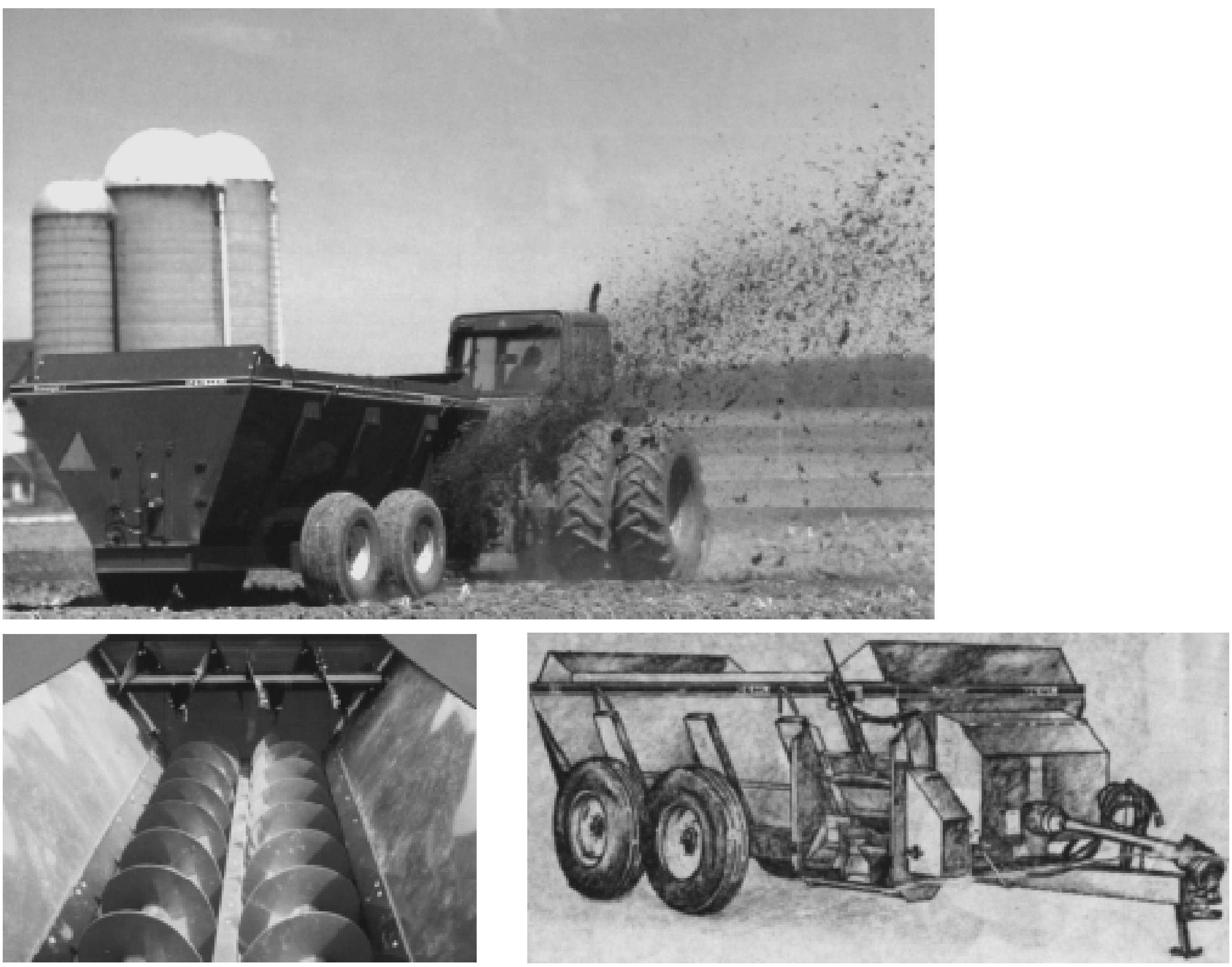


(2) V-box bottom spreader

The V-box bottom, rear unload spreader has been used for years to broadcast dry, bulk, granular fertilizer (see fig. 12–85). In recent years its designed has been combined with construction features of the flail and the box spreader so that it is now used to haul and spread solid, semi-solid, or slurry wastes. This relatively new spreader design is referred to as a side-delivery, slinger, or V-box spreader (fig. 12–82). Models that have a 200- to 500-cubic-foot heaped capacity require a tractor with at least a 60-horsepower motor to operate. Auger-out (rather than chain-apron) unload breaks up and mixes the waste that is then spread with a high speed side or rear mounted beater or slinger.

The tight, V-box bottom has minimum leakage, and the waste that is broken up and unloaded using an auger is more uniformly spread in a wide swath. Besides the spreader design, however, uniform spreading depends on the waste consistency, spreader operation, and spreading conditions. Investment for the V-box bottom spreader with auger unload design and its operating power needs is higher than that for the box spreader.

Figure 12–82 V-box bottom, side, or rear slinger spreader (courtesy of Gehl Company and H & S Manufacturing)

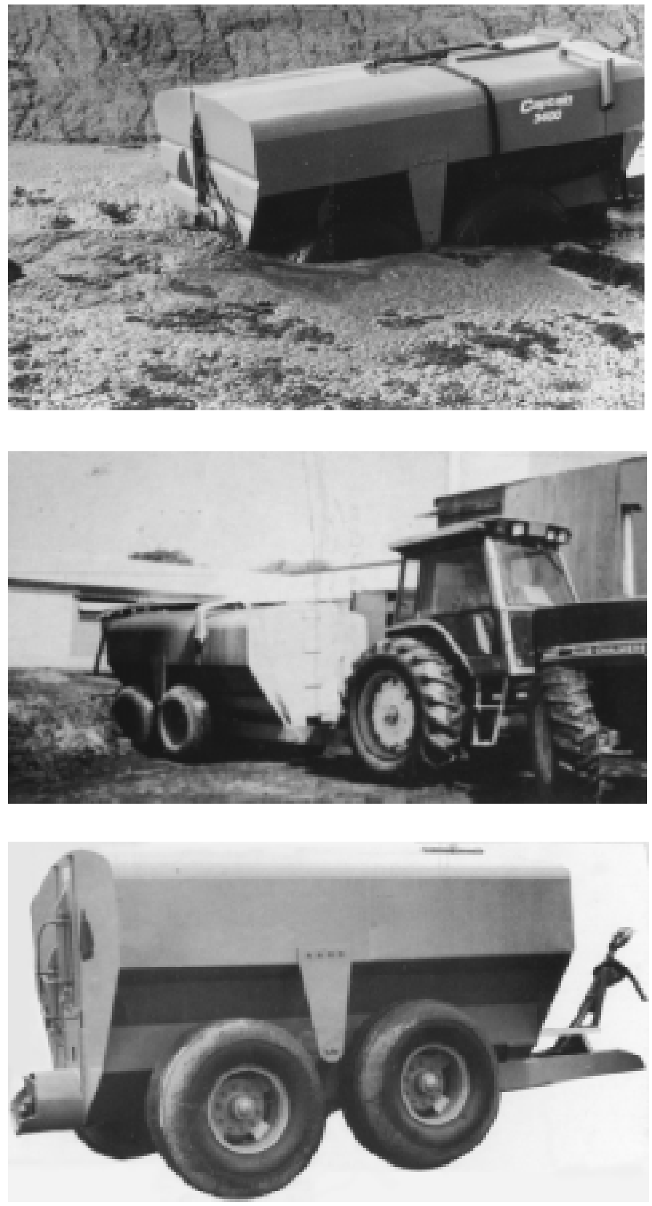


The flail spreader (fig. 12–83) is used for hauling and spreading slurry waste that is solid, frozen, chunky, or heavily bedded (Bartok 1994). This equipment is open top and unloads from the side. Its horizontal metal tank has an adjustable top and a tight bottom. The tank is generally 4 to 6 feet in diameter and varies in length. It is mounted on a sturdy running gear. A strong, PTO-powered shaft with 3-foot-long chains attached about every 6 inches is centrally mounted parallel to the tank length. When operated, the rotating shaft slings the waste out the top of the tank. The spreading rate is controlled by adjusting the top opening and the travel and PTO speeds. Available models have heaped capacity of 170 to 240 cubic feet and require a 60- to 90-horsepower motor to operate. The ASAE Standard S325.1, Volumetric Capacity of Open Tank Type Manure Spreaders, is used for uniform measurement and rating capacity in cubic feet (ASAE [g] 1990). Flail spreader use has slowed with the increased use of liquid and slurry waste handling. The limited load size, high power need, and wind problems when spreading are factors.

Different PTO-powered conveyor, self-loading wagon spreaders have been developed for solid, semi-solid, or slurry waste loading, hauling, and spreading (fig. 12–84). This equipment eliminates the investment and operation labor for a separate loader. The self-loading type spreader has specialized use, relatively high investment, and limited load-carrying capacity.

Figure 12–83 Flail type side unload spreader (Bartok 1994) (courtesy Ideal Industries Inc.)

Figure 12–84 Conveyor self-loading waste spreader (courtesy Jerry's Iron Works)



The V-bottom rear unload broadcast spreader remains popular for dry bulk commercial fertilizer application (fig. 12–85). The spreader is generally mounted on a truck. It is powered by a variable-speed hydraulic motor and uses a chain-apron unload and a high-speed horizontal rotating disc. The disc is designed for light, accurate spreading of dry granular material over a wide swath. An optional slinger/thrower attachment is available for some models. This attachment is used to spread solid fibrous material out about 100 feet (with the wind) onto steep side slopes, such as along roadways.

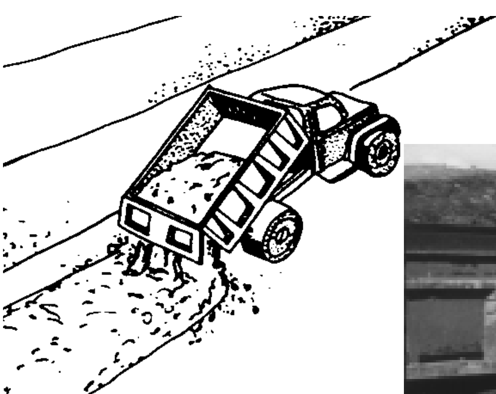
Figure 12–85 V-bottom rear-unload broadcast spreader (courtesy of Denair Trailer Company)

A hydraulic-lift dump box truck designed to haul gravel and grain is also useful to haul feedyard poultry litter and other solid waste (fig. 12–86). These alternative uses should be considered in selecting hauling and spreading equipment. The dump box capacity typically ranges from 4 to 12 cubic yards. Actual weight or volume of waste hauled depends on the waste characteristics and the dump box design. Spillage problems are minimized if the load is correctly trimmed, wetted down, or covered.

A dump box truck can safely transport large loads relatively quickly over several miles, night or day, and then dump the load. A prompt return for another load keeps the waste transfer equipment working efficiently with relatively few haulers. A tractor front-end loader can spread the dumped waste around the dump site, or used to reload a box spreader for spreading at the desired location.

Elevating-type earthmovers can scrape, load, haul, and spread solid waste from large open areas, such as cattle feedlots, in one operation. See section 651.1203(h) for more information. This equipment is efficient for relatively short hauls, and compaction of the field is minimized. Weather conditions, equipment availability, operator expertise, spillage, noise, safety, and travel routes and distances are considerations.

Figure 12–86 Dump box truck solid waste hauling



(3) Separate pump or vacuum load tanker spreaders

Two types of tanker spreaders are commonly used for hauling and field spreading semi-solid, slurry, and liquid wastes. These spreaders look alike, but operate differently.

The spreader tanker is an enclosed tank mounted on a wagon or a truck running gear. It requires a separate pump for loading the waste (fig. 12–87, see figs. 9–6 and 9–8). The separate pump load tankers are available in 1,000- to 9,500-gallon capacity models. The guide for uniform tanker capacity rating (in gallons) among manufacturers is the ASAE Standard S326.1, Volumetric Capacity of Closed Tank Type Manure Spreaders (ASAE [h] 1993).

Options, such as tanker agitation, inside tank access, wheel arrangement and size, injector spreader distributor, and other accessories, can increase the investment cost for this equipment. A sight-glass on the tanker, for example, permits ready observation of the tanker content during filling and emptying. A PTO or hydraulic motor powered recirculating pump or floor auger may be used to continually agitate the contents, which would aid in more uniform spreading, especially with injector spreading. Some models use a spreader discharge located at the top-rear of the tanker. This discharge is supplied by the tanker agitation pump to assist with a wider broadcast spread. This arrangement also minimizes dripping and accidental tank unload. Interior tank access for loading, cleaning, and repair through a top hatch door is simplest; however an end door has minimum hazard for inside air and gas ventilation and is more convenient for repairs.

Figure 12–87 Separate pump load tanker spreader (courtesy Badger Northland, Inc.)

The second type of tanker used to haul and spread slurry and liquid wastes includes an integral PTO or hydraulic motor powered air-vacuum pump for loading and unloading (fig. 12–88). For more information on this type pump, see sections 651.1203(l) and 651.1206(b)(1)(iv). The addition of this pump makes an “all-in-one” unit. To load the tanker, the vacuum pump empties air down to a pre-set level out of the airtight tank. A transfer hose is then inserted in the stored waste, the load valve is opened, and the waste is drawn up into the tank. The hose is 4 to 6 inches in diameter and 25 feet long. It is made of hard rubber and is relatively stiff. A loading rate at about 200 to 300 gallons per minute is limited to a vertical lift of no more than 12 feet.

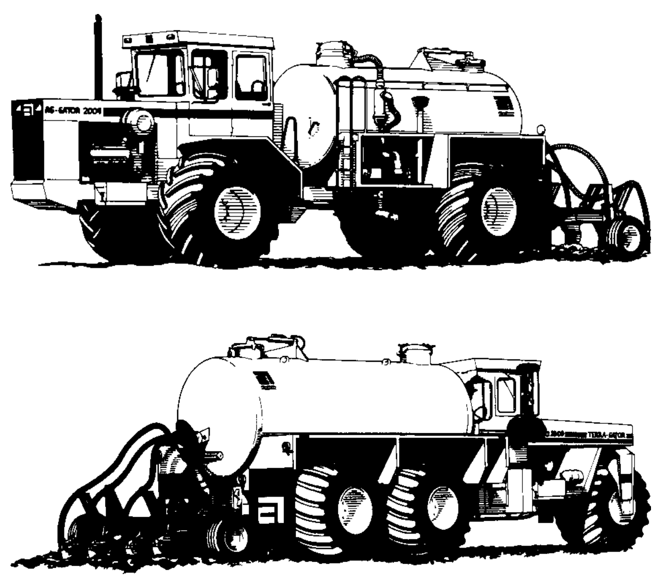
The vacuum tanker is used to agitate stored liquid waste by first loading the tanker, then switching the vacuum pump to pressure mode, pressurizing, and then unloading the full tanker load back into the storage. Tanker capacity and size, running gear options, and spreading aids are similar to those of the pump load spreader tanker.

Self-propelled tanker spreaders that have large floatation tires are designed to haul large loads for several miles or to use on soft soil (fig.12–89). Most of these tankers have self-contained, high-capacity vacuum pumps and extra options that are not available with towed tanker models. Sizes range from a 2,000- to more than a 4,000-gallon capacity with advertised spreading rates of about 15,000 gallons per hour with reasonable loading and haul conditions. Operator comfort, control, safety, and day or night operation are favorable features. Year-around use, such as that done by custom operators, can justify the needed investment.

Broadcast spreading waste from either tanker spreader can use a gravity baffle or splash plate or a powered rotating distributor (fig. 12–90). Models that use tanker pump agitation pump contents up and spread them from the top rear of the tanker, which allows more uniform spreading. The agitation pump is generally located under the tanker rear outlet. A hand or hydraulic-operated gate valve is adjusted open to empty the tank. Soil injection spreading is done with either tanker as explained in section 651.1207(b).

Figure 12–88 Tanker with PTO vacuum pump hose loading (courtesy Clay Equipment Corp.)

Figure 12–89 Self-propelled tanker spreader (courtesy Ag Chem Equipment)



Uniform spreading by gravity flow out of a tanker is difficult. The solids can partly block the tank discharge or less waste will flow as the waste depth in the tank decreases. Also, as the load lessens, travel-speed changes. European engineers have developed an electronic flow control interlocked with a ground-speed monitor (fig. 12–91) that automatically adjusts tanker unload flow according to a preset outlet valve pressure (Carlson 1991, Malzeryd 1991).

Additional safety precautions need to be taken in the operation of tractor towed tanker spreaders (fig. 12–92). Safety hazards are related to limited operator view, relatively slow speed, heavy braking needs, and potential for overturn and spillage. A super loaded towed tanker that hauls about 5,000 gallons, 667 cubic feet, or 20 tons of waste commands handling expertise and about 150 horsepower to safely operate. Table 12–l0 provides recommendations for spreader capacity and power need.

Table 12–10 Approximate waste spreader and tractor sizes (NE Dairy 1977)*

Box spreader heaped capacity (ft^3)	Min. tractor horsepower	Tanker capacity (gal)	Min. tractor horsepower
150	40	800	60
200	60	1,000	75
250	75	1,500	80
310	85	2,250	90
390	100	3,250	100
470	130	4,000	—

* Towed load should not exceed 1.5 times tractor weight.

Figure 12–90 Baffle plate distributor on tanker spreaders (courtesy J-Star Industries and Badger Northland, Inc.)

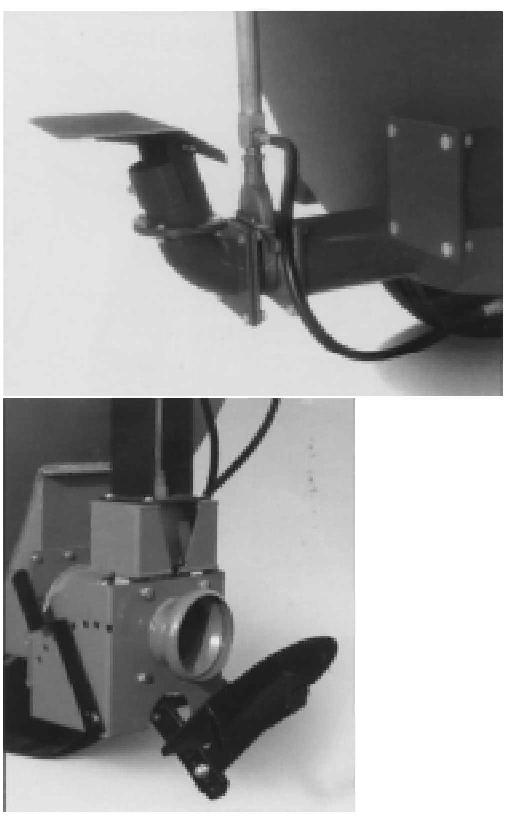
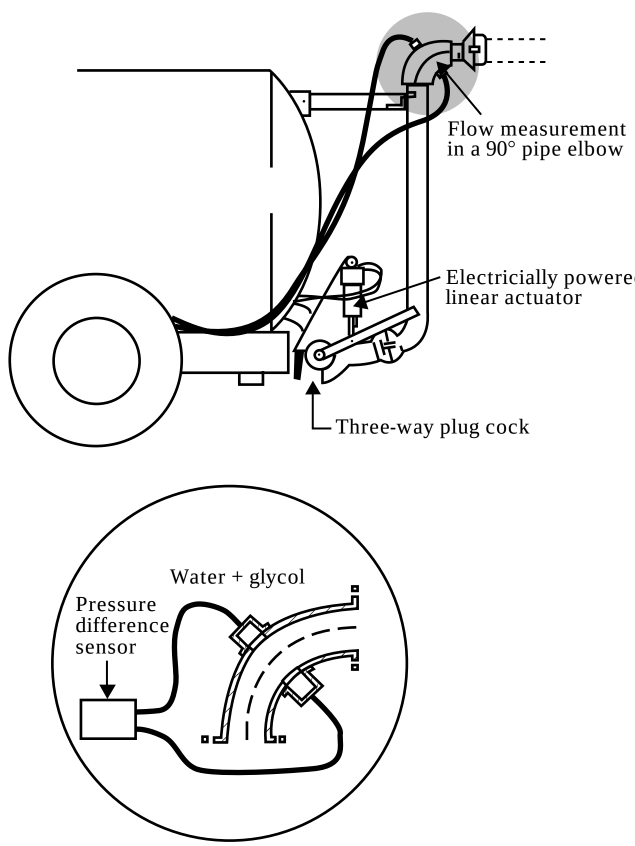


Figure 12–91 Tanker unload uniform discharge control (Carlson 1991)



Tractor power can fail going up a steep slope, or steering control can be lost going downhill. A general rule is that a towed load should not be more than 1.5 times the tractor weight. A 3,000-gallon loaded tanker can weigh more than twice a 100 deadweight brake horsepower tractor that has a ballasted weight of about 14,000 pounds. This is beyond the guideline of ASAE Standard S318.10 for equipment without brakes (ASAE [e] 1995). A surge trailer brake is designed for forward motion and may not function if the tractor power fails going uphill.

Although adequate tractor power is available, soil compaction is a major problem with large towed tanker spreaders. Depending on the design, up to 10 tons per axle is not uncommon. Large diameter wheels with wide tires improve tanker flotation. A single axle with large wheels is used on small models to minimize cost. Walking tandem axles are common with larger (>1,350 gallon) tankers. They aid load distribution and a smoother and faster ride; however, sharp turns cause extreme axle stress. Despite higher cost, triple axle (front axle only or front-and-rear steer) and flotation type tire or track support designs are being adapted on large tankers (see figs. 12–87, 12–89). Dual wheel use on towed tankers has waned because of the added equipment width, axle stress, and extra rolling resistance over rough fields and soft soils.

Routine cleanout and inside repair and maintenance access are necessary. Twine, stones, plastic, and wood pieces sometimes plug tanker pipes and openings. For safety reasons, a forced fresh air supply into the tank and a second person nearby are urged when working inside a tankwagon with only a top opening. See sections 651.1008 and 651.1208 for further information.

Figure 12–92 High pressure centrifugal pump (courtesy Cornell Pump Company)

Overall construction strength is critical for a tanker spreader, especially where it has attached soil injector spreading. Generally, 1/4-inch-thick corrosion resistant plate steel (painted) is used to construct the tank. As vacuum tanker spreaders age and corrode, too high of an evacuation of the tank can cause an end or side to collapse inward if the evacuation overload control device malfunctions. Regular maintenance, cleanup after use, and covered storage extends tanker life and increases trade-in value.

Vacuum pumps, moisture traps, pipe couplers, tires, and power shafts need regular attention. Shops that specialize in tanker repair report that a vacuum tanker regularly used for swine waste typically has about a 10-year life. The pump and running gear frequently outlast the tank, although adjustable wheel types (for different row crop spacings) and broken wheel spindles have been problems. Pump seals, vanes, and valves may need replacement depending on regular maintenance.

To hasten hauling and spreading liquid or slurry waste to distant fields, a semi-trailer nurse tanker is used to haul waste from storage to a smaller tanker or tractor towed field injector (see fig. 12–89) (Maschhoff 1985).

(b) Soil injection waste spreading equipment

Injecting (also called knifing or chiseling) liquid and slurry waste 3 inches or more into the soil minimizes odor and nutrient losses (Goodrich 1993). Nitrogen loss is significant within 4 to 6 hours after broadcast surface spreading. Section 651.1105(a) gives more detailed information on this loss. Injection is necessary, for example, when a nitrification inhibitor is added for N loss reduction of waste or when anhydrous ammonia is added to waste to enhance the N content and better suit crop needs (Sutton et al. 1983).

Traditional injector spreader equipment can be used on a tanker sprader or directly injected with tractor mounted toolbar equipment when waste is pumped to the field. A tanker needs the framework constructed for the twisting, bending loads from the attached injectors. Typically two to six injectors are mounted at the rear of a tanker about 2 feet apart. Mounting the injectors at the front of the tanker or on a toolbar attached on the tractor pulling the tanker aids depth control, traction, and the operator's view. However, this arrangement interferes with hitching and maneuvering. Also, the pressure of the tractor wheels on the injected soil forces out some of the injected waste, which defeats the purpose of injection. Staggered injector shanks reduce trash plugging, and injector shanks that swivel can make short turns. Some models use adjustable injector depth gage wheels. Most use hydraulic lift to raise or lower the injectors.

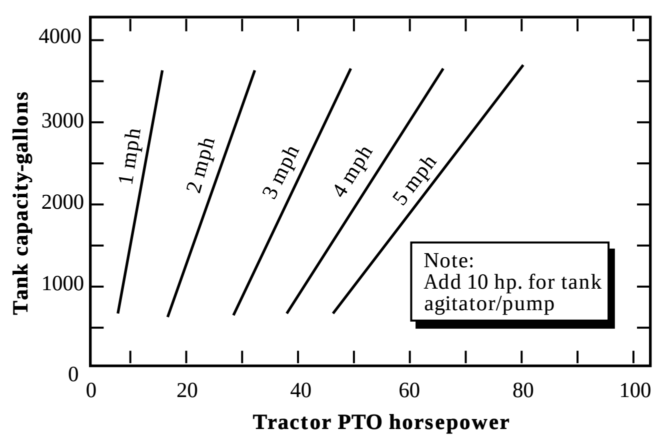
When directly injecting, a 5- to 6-inch diameter soft hose connected between the pipeline and the field spreading hose, which is 4 to 5 inches in diameter (fig. 12–94), aids flexing and reduces pumping friction. About 40 acres are covered at one hose setting. A strong, durable hose is needed to withstand the rubbing and turning friction. Attaching the field spreading hose to a distributor manifold that has a leakproof swivel head on the injector equipment assists turning at field ends, which is difficult with pressurized flowing pumped waste and injectors in the soil. An empty hose rolls and twists on turns. From 4 to 6 injector shanks generally are used for a 6- to 10-foot spreading width, but wider units are available that reduce the spreading rate and travel speed.

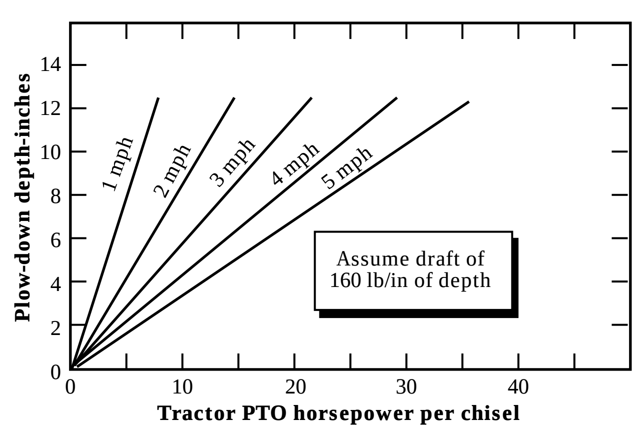
The soil surface moisture, field topography, and travel speed affect the power needed to pull a loaded tanker. Injector load is also a consideration and is affected by injector design and operating depth. Figure 12–93 can help to estimate power needs. For example, to pull a loaded 3,000-gallon tanker with four injectors running 4 inches deep in plowed soil at 3 miles per hour would require 80 horsepower [42 + 10 + (7 x 4)]. A Purdue University study determined an additional 18 horsepower per 8-inch deep chisel injector was needed at 4 miles per hour. The added power and injector ownership costs were more than offset by the reduced N volatilization loss (Dickey 1978).

The operation of a pumped waste, tractor towed, hose injector is comparable to that of the traveling gun irrigator. Stored waste agitation, pumping, pipeline, and field hose use are similar. The constant moving tractor with injector spreading, however, needs constant management. The 800 to 1,400 gallons per minute waste pumping rate to the injectors needs to be suited to the number of injectors, field travel speed, and soil nutrient needs. Another tractor and operator at the midpoint of the field is needed to regularly play out the 4- to 5-inch diameter by 660-foot-long hose full of moving, pressurized waste and keep it aligned with the injector spreader as it travels back and forth in the field. Equipment and labor organization, coordination, and operation are essential.

Over-application of waste, especially with vertical knife injectors running 8 to 14 inches deep, allows liquid to ooze out and up and then run downhill. Large rocks and hard soils hamper injector depth control, especially where wide blades are used. In loose soil with few stones, shallow-running 1- to 2-foot-wide sweep injector shovels distribute waste out more evenly and use less power.

Figure 12–93 Approximate power for tanker and per injector (FIS 1974)





Disc injector equipment (fig. 12–95) was developed to improve distribution and waste coverage and to reduce power. Rather than a sweep shovel or knife injector, one design uses a gang of convex, fluted-edge disc blades that rotate horizontally under the (soft) soil surface. The waste is injected under the blades as they are pulled along. The blades are 2 feet in diameter. Another design uses two convex disc blades mounted vertically and slightly angled to the travel direction. The waste is covered as it is injected into relatively soft soils.

The effect on crop residue and conservation tillage where wastes are injection spread should be considered. University of Minnesota engineers are studying injector equipment for more uniform waste application (Goodrich 1993). European research has found covering and soil mixing advantages where double press wheels are run behind injector spreaders used in moist sod. Some European countries require municipal sludge be injected when spread, so injecting in sod is common (Warner 1988). Additionally, some European countries require injection of manure to control ammonia emissions. Innovative injection techniques successfully inject slurry to a depth of 2 inches or less with minimum power requirements (Hujsmans 1994).

Figure 12–94 Tractor towed hose injector spreader (courtesy Hydro Engineering and Dr. P. Goodrich, Univ. of MN)

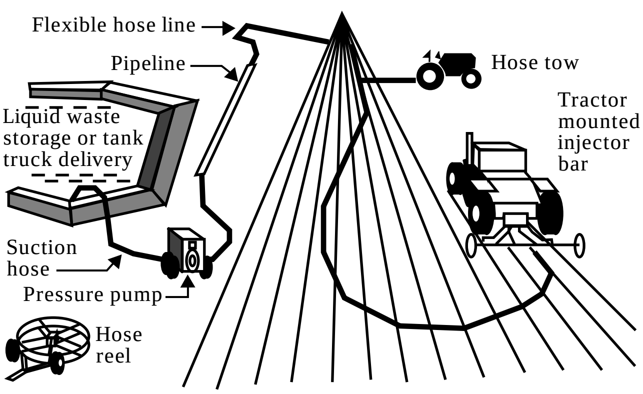
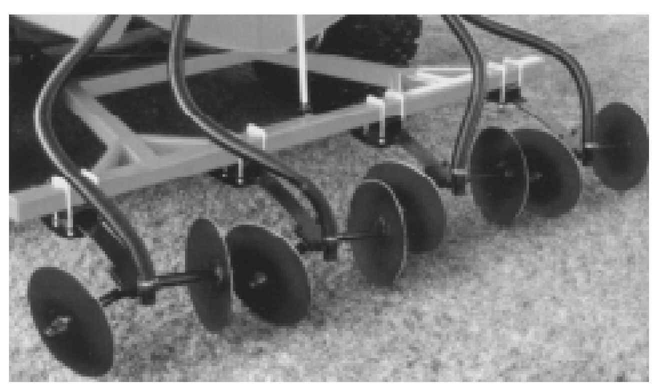


Figure 12–95 Vertical disc covers for injected waste (courtesy J. Houle & Fils Co.)



(c) Pumped waste spreading

Section 651.1206(b) explains characteristics of pumps and pipe used for waste transfer. Slurry waste with up to 10 percent solids can be pumped through a pipeline for several miles to storage or field spreading via gated pipe, irrigator, or towed injector. Less than 10 percent solids is preferred. Agitation before and during pumping is essential to break up and keep solids suspended. Solids sedimentation in low areas of the pipeline and irrigator nozzle clogging are problems. Chopper agitator pump action and a grinder attachment on the high capacity centrifugal pump can break apart and help suspend solids to move through the pipeline and irrigator. Dilution may be required. See sections 651.1102(c) and 651.1205(a) for more information.

Pumped waste spreading via irrigation is increasing in popularity, especially with operations that spread over a million gallons per year. Pumping minimizes soil compaction and labor and spreading equipment needs. Equipment adaptations continue. For example, gated polyethylene pipe is used to reduce labor, investment cost, and operating power. Also, irrigator low pressure drop nozzles are used to reduce waste spreading odor. More developments are expected as demand grows for pumping equipment to spread waste farther away from storage and to minimize odor complaints.

Wind affects uniform sprinkler spreading and may cause odor complaints from several miles away. With adequate storage, pumped slurry waste spreading (in quantity) is typically done in the spring or fall. Cropland is available during this time, and the seasonal competition for the labor needed for equipment setup, startup operation, and cleanup is less. The fate of the manure constituents must also be considered.

Different irrigation systems are used to spread agricultural wastes. Major selection factors are summarized in table 12–11.

Table 12–11 Irrigation system selection factors (Patronsky 1978, Shuyler 1973)

Factor	Type of system: Handmove sprinkler	Towline	Sideroll	Travel gun	Center pivot
Effluent solids	Up to 4% solids	Up to 4% solids	Up to 4% solids	Up to 10%	Up to 10%
Operation size	Small	Small to medium	Small to medium	All sizes	All sizes
Labor need	High	Medium	Medium	Medium to low	Low
Initial investment	Low	Low	Medium to high	Medium to high	High
Operation costs	Medium	Medium to high	Medium to high	Medium to high	Medium to high
Expansion	Purchase more pipe and equipment	Purchase more pipe and equipment	Purchase more pipe and equipment	Purchase more pipe and equipment	Purchase more pipe and equipment
Hourly attention	Medium	Medium	Medium	Medium	Low
Soil type	Suitable to wide range of intake rates	Suitable to wide range of intake rates	Suitable to wide range of intake rates	Suitable to wide range of intake rates	Suitable to wide range of intake rates
Surface topography	Wide	Wide	Limited	Wide	Wide
Crop height	Adaptable	Low	Low	Adaptable	Adaptable

Two or more power units and pumps can be employed during pumped waste spreading operations. This involves:

- One continuously operating chopper or impeller type agitator pump that is powered by an 80- to over 100-horsepower motor to keep stored solids mixed with liquids (see fig. 12–45).
- One similarly powered unit to operate a high pressure (at least 100 lb/in^2) centrifugal pump (sometimes 2 units) to move 200 to more 800 gallons per minute of slurry to the field (see fig. 12–92).
- One or two power units to operate the irrigation system.

Labor coordination and communication on starting, stopping, and operating the equipment are needed for uniform spreading. Pumps need to be primed, and mixed solids and liquids need to be kept moving to prevent settling and plugging. Pipes need to be rinsed and emptied when irrigation is completed. If this is not done, the retained waste dries or freezes, causing the equipment to plug the next time it is used.

(1) Pipe and pipeline equipment

Pipe size and friction is explained in section 651.1102(c). Small diameter pipe is made from steel, copper, aluminum, or various plastics. Steel, cast iron, plastic, or concrete pipe is used for culverts, drains, and some pipelines. See section 651.1202(b) for more information. Irrigation pipe greater than 2 inches in diameter is generally made from plastic or aluminum because they weigh less. Hard rubber, which resists vacuum pumping suction or load of towing the irrigation equipment, and flexible fabric pipe, which is pressurized, are used with tanker and irrigator connections.

In pumping applications, pipe from storage to field is coupled with ring lock or kamlock couplers and can be attached to a hose at the field using barb fittings and clamps. Most hoses are 4 to 8 inches in diameter. Pressure ratings on these hoses are 100 to 150 pounds per square inch. Drag hose for towed injector spreading is 4.5 to 5 inches in diameter and is rated at 150 pounds per square inch. This pressure rating is needed to withstand towing stresses.

The durability of the pipes varies:

- Aluminum is resistant to corrosion, but is easily dented and bent.
- Plastic pipe loses strength with temperature increase. Some plastics become brittle with exposure to sunlight, or they become stiff in cold weather and break.
- Flexible fabric pipes wear through and leak where excessively rubbed when pulled along the ground or where they are wound and unwound from a spool.

NRCS Conservation Practice Standard, Pipeline, Code 430, ASAE Standards (ASAE [m] 1991), and manufacturers' literature can be consulted for thickness, pressure rating, coupler assembly, and pipe installation requirements.

As liquid flows through a pipe, the liquid drag or friction against the pipewall restricts the flow. Larger diameter pipe with the same internal roughness has lower friction at a given flow rate and uses less pumping energy. However, the initial investment is higher than that required for a smaller pipe. The friction loss for steel and plastic pipe is shown in table 12–12. The loss is based on the diameter of the pipe and is for transport of water. Slurry waste may have as much as 10 percent more pipe friction losses. Section 651.1102(c) has more information on friction loss.

The required pressure to maintain flow is reported in feet (of water) or pounds per square inch. Feet equates to the pressure of a water column of that height (fig. 12–96). A vertical pipe that contains 2.31 feet of water has 1 pound per square inch of pressure at the bottom. Total head, in feet, is converted to pounds per square inch by dividing the feet of head by 2.31. Table 12–12 shows the friction loss in both feet and pounds per square inch. The total drag or friction loss in a pipeline includes pressure losses from pipe length, elbow/reducer fittings, and restrictions (e.g., nozzles). Note in the table the effect that increasing the flow rate has on pressure loss.

At about 2 feet per second velocity, solids settle in low spots along a pipeline. At a velocity more than 5 feet per second, friction loss and water hammer are problems. A velocity of 3 to 6 feet per second is used in pipe diameter selection designs. The velocity of liquid waste in pipes not buried or otherwise anchored in place should be limited to 5 feet per second. Flush pipelines with clean water and disassemble and drain them to remove contents after pumping waste. This helps to avoid problems with plugging.

(2) Surface irrigation equipment

Surface irrigation includes flooding, border, furrow, and gated pipe systems. A maximum land surface slope of 2 percent and a high level of management are required to control runoff and obtain uniform wastewater distribution. The low investment, power, and equipment needs of surface irrigation are the tradeoffs for the high labor. See NRCS Conservation Practice Standard, Irrigation System (Surface and Subsurface), Code 443-1, for more information.

Gated pipe wastewater distribution assists simpler, faster, more uniform wastewater application by gravity (Schnieder et al. 1993). Holes are spaced about 30 to 80 inches apart in 30- to 40-foot lengths of aluminum or plastic pipe that is at least 4 inches in diameter (fig. 12–97). The holes, which are about 2 by 6 inches each, have a sliding cover or gate that is opened or closed by hand. These covers are adjusted for uniform gravity discharge all along the gated pipe.

In operation, liquid waste is transferred from storage to the field and enters the gated pipe through a valve at one end. Lengths of gated pipe are connected together, and the gate openings (usually every second or third one) are adjusted for uniform outflow along the length of gated pipe (table 12–13). Non-uniform solids distribution in the liquid can be troublesome because dissolved nutrients are carried in the liquid. However, larger solids settle in the pipe, or the nutrients are filtered out by grass where wastewater leaves the gated pipe openings. The spreading arrangement and the size of the pipeline and pump should be considered in selecting a gated pipe system.

(3) Handmove sprinkler equipment

Although messy to handle, the handmove sprinkler is used with small wastewater capacity liquid waste spreading. Equipment needs and the initial investment are low, and the equipment is adjustable to fit various sized fields. See NRCS Conservation Practice Standard, Irrigation System (Sprinkler), Code 442-1, for more specific information.

Table 12–12 Friction loss in 100 feet for 3- and 4-inch diameter pipe used to transport water (MWPS 1985)

Gallons per minute	Steel I.D. 3.068" (ft)	Steel I.D. 3.068" (lb/in²)	Plastic I.D. 3.216" (ft)	Plastic I.D. 3.216" (lb/in²)	Steel I.D. 4.026" (ft)	Steel I.D. 4.026" (lb/in²)	Plastic I.D. 4.134" (ft)	Plastic I.D. 4.134" (lb/in²)
40	0.8	0.4	0.3	0.1	0.2	0.1	0.1	0.0
60	1.7	0.7	0.7	0.3	0.5	0.2	0.2	0.1
80	2.9	1.3	1.3	0.5	0.8	0.3	0.4	0.2
100	4.4	1.9	1.9	0.8	1.2	0.5	0.6	0.2
120	6.2	2.7	2.7	1.2	1.7	0.7	0.8	0.3
180	—	—	—	—	3.5	1.5	1.7	0.7
220	—	—	—	—	5.1	2.2	2.4	1.0

Figure 12–96 Total head (ft) equals elevation + pressure + friction

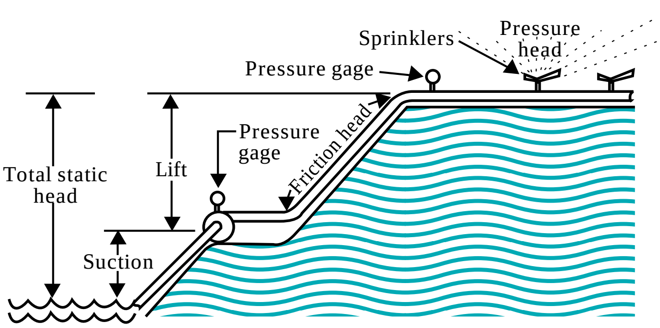


Table 12–13 Maximum recommended flow rate in openings in gated pipe with holes spaced 30 to 40 inches apart (MWPS 1985)

Gallons per minute	Land slope (%)
40	0.2
25	0.4
16	0.6
12	0.8
10	1
5	2

One or more laterals are hand-placed onto a mainline and operated as shown in figure 12–98. Each sprinkler has a capacity between 1 and 20 gallons per minute. The needed pump capacity is the sum of all the operating sprinklers. Lateral sets are assembled from hand-moved sections of pipe that has sprinkler nozzles 30 to 40 feet apart. Each sprinkler then theoretically covers a 60- to 80-foot circle When the laterals are set up and the centrifugal pump is operating, the lateral valve is opened and the system is operated for the required period. The system is then shut off, and the lateral is moved and reset at a new location. The operation is then repeated until completed. An example of this operation:

A 1,320-foot-long (0.25 mile) lateral covers about 1.8 acres. It has 22 sprinklers set 60 feet apart. Each sprinkler spreads about 10 gallons of liquid waste per minute (600 gallons per hour). This amounts to about 0.3 inches per hour on each 60-foot circle. Table 12–14 gives the discharge in gallons per minute for sprinkler nozzles.

Figure 12–97 Gated pipe gravity irrigation (courtesy Armin Plastics Corp.)

(4) Towline sprinkler equipment

The towline sprinkler is assembled and operated similar to the handmove sprinkler except that a tractor is used to move the lateral to the next setting (fig. 12–99). The investment is higher for the towline sprinkler, but labor is lower and the acres per hour covered are more than those with a handmove sprinkler. To avoid damage, a main line buried or placed in a shallow ditch is needed for tractor tow travel back and forth. To resist towing stresses, the lateral has strong couplers between sections. Laterals can be up to 1,320 feet long. The moveable equipment is adaptable to varied field sizes; however, the field shape should conform with the lateral length. The towline sprinkler is best used in rectangular fields and where hayland, pasture, or other low-growing crops are grown. Sod strips are best used for sets in tilled fields.

Table 12–14 Sprinkler nozzle discharge in gallons per minute (MWPS 1985)

Pressure (lb/in^2)	Nozzle diameter (inch) 3/16	1/4	5/16	3/8	1/2	3/4	1	1 1/4
50	7.1	12.9						
60	7.8	14.0	22.0					
70	8.5	15.4	23.9	33.2				
80	9.1	16.4	25.7	35.7	61.6	154	264	416
100	—	—	—	40.7	68.9	173	296	462
120	—	—	—	—	—	189	324	511

Figure 12–99 Towline sprinkler

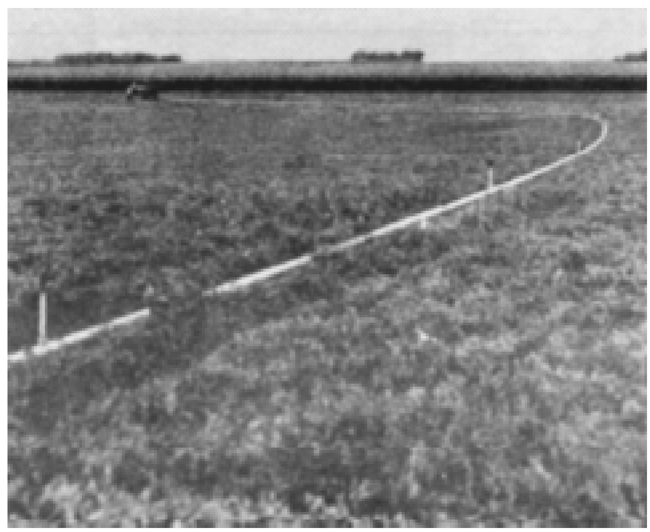
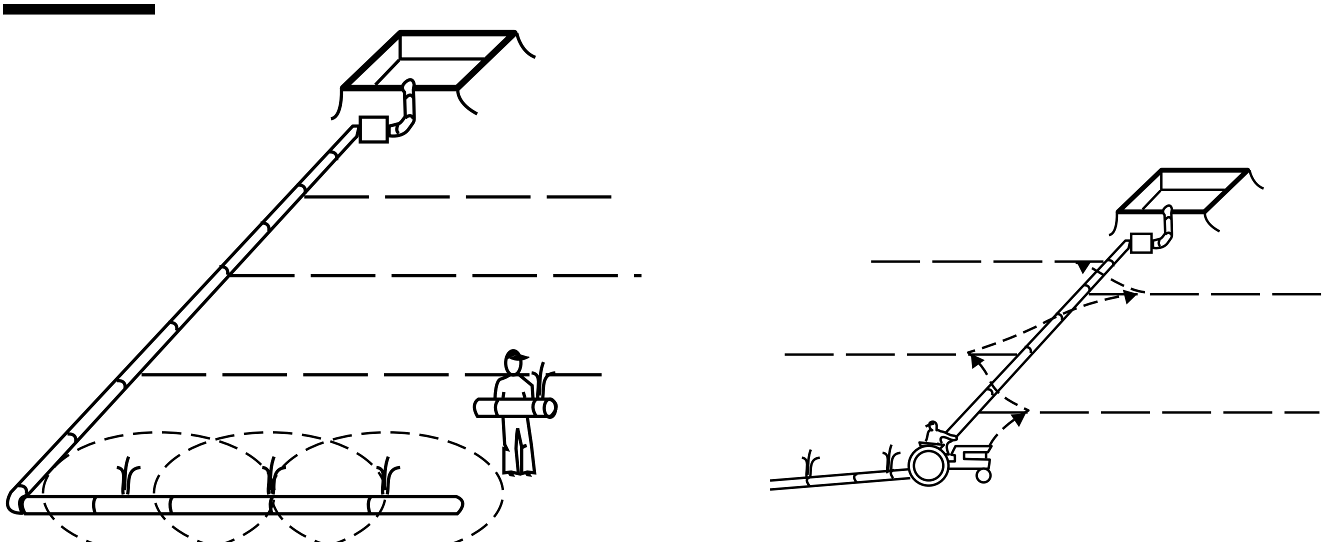


Figure 12–98 Handmove sprinkler



(5) Side-roll sprinkler

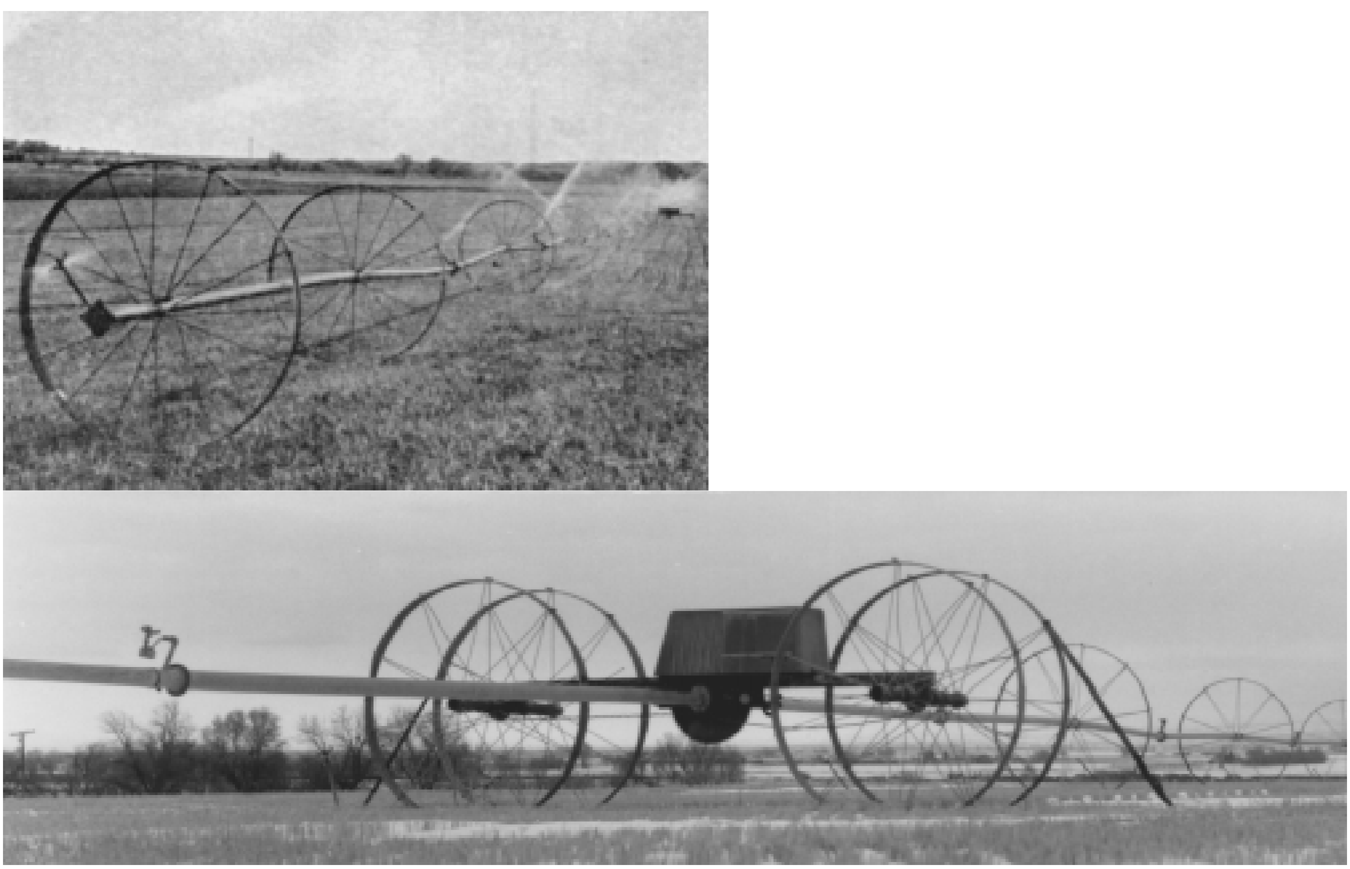
The side-roll sprinkler's operation and the area covered compare to that of the towed sprinkler. The side-roll is moved or rolled in uniform spaced sets along a main line (fig. 12–100). Rather than tractor towed, the side-roll sprinkler has wheels about 4 to 7 feet in diameter on about 30-foot spacings that use the lateral pipe as an axle. A 5- to 20-horsepower engine centrally mounted on the side-roll sprinkler is hand-started every few hours. This engine powers about a 660-foot length of the side-roll. It uses a chain drive to roll the section over to the next set.

The side-roll sprinkler is relatively messy, slow, and requires frequent attention. It is useful with small operations and for low-growing crops. Lateral alignment is a problem on uneven topography. Disassembly or special wheels are needed for moving the side-roll sprinkler to other locations.

(6) Stationary big-gun sprinkler

A stationary big-gun sprinkler is especially applicable with the frequent pumpout of a waste storage pond (<1 million gallons) to different locations (fig. 12–101). The 2- to 4-inch diameter, flexible high-pressure nozzle can pass solids and spread slurry waste over an area that is 100 to 300 feet in diameter (0.2 to 1.5 acres) per setting. The stationary big-gun sprinkler requires a moderate investment, is relatively simple to use, and completes the job quickly. However, it requires more labor than the traveling gun sprinkler and is messy to operate. The capacity and power need are comparable to that of the traveling gun. Some problems that have occurred in using this sprinkler are that it is messy to service, does not apply the waste uniformly, does not spread the waste efficiently in strong wind, and odor complaints are common.

Figure 12–100 Side-roll sprinkler



The big-gun sprinkler is generally mounted on a trailer or 3-point hitch and connected to a moveable hose or pipeline that has been laid down in sections from the waste storage. While agitating the stored waste with a chopper agitator or impeller agitator, a high capacity centrifugal pump (see fig. 12–92) pumps the agitated slurry to the big gun. After the desired amount of wastewater application at one set, the high capacity pump is stopped, the big-gun sprinkler is moved (usually with a tractor), and the pipeline is taken up. Then it is reset and the equipment operated at another setting. The uniformity of coverage of a circular or semi-circular area depends on management, the nozzle setting, and the wind.

(7) Traveling gun sprinkler

Traveling gun sprinkler are either cable-tow (soft hose) or hose tow (hard hose) type (fig. 12–102). The cable tow irrigator has a gun sprinkler mounted on a wheel cart or skids to which a soft, collapsible, 4- to 5-inch diameter hose is attached. Before operation, the gun cart, cable, and hose are unreeled across the area to be irrigated. The cable winch end is anchored at the end of the run or lane. Depending on stored waste quality and pumping distance from storage, one or two high capacity centrifugal pumps feed the irrigator from the agitated waste storage. During operation, the cable is slowly rewound by an auxiliary engine, water motor, water piston, or turbine driven winch that tows the irrigator. Most cable tow irrigators that have auxiliary power can be used to apply liquid and slurry wastes, which can plug a water drive sprinkler.

A hose tow traveling gun sprinkler includes a cart or skid mounted sprinkler gun towed along by a 2- to 4-inch diameter hard hose. The hose is attached to a powered, slowly rotating takeup and storage hose reel that is parked at the end of the irrigated lane. Before operation the hose reel is parked at the end of the irrigated lane or run and the hose is unreeled (with the sprinkler gun) to the opposite end. The flexible hard hose supplies the liquid to the sprinkler and also tows it slowly across the field when wound onto the take-up reel. The hose reel is powered by a turbine, bellows, liquid-piston, or auxiliary engine. Solids in the liquid affect liquid-drives as they do with the cable-tow traveling gun sprinkler.

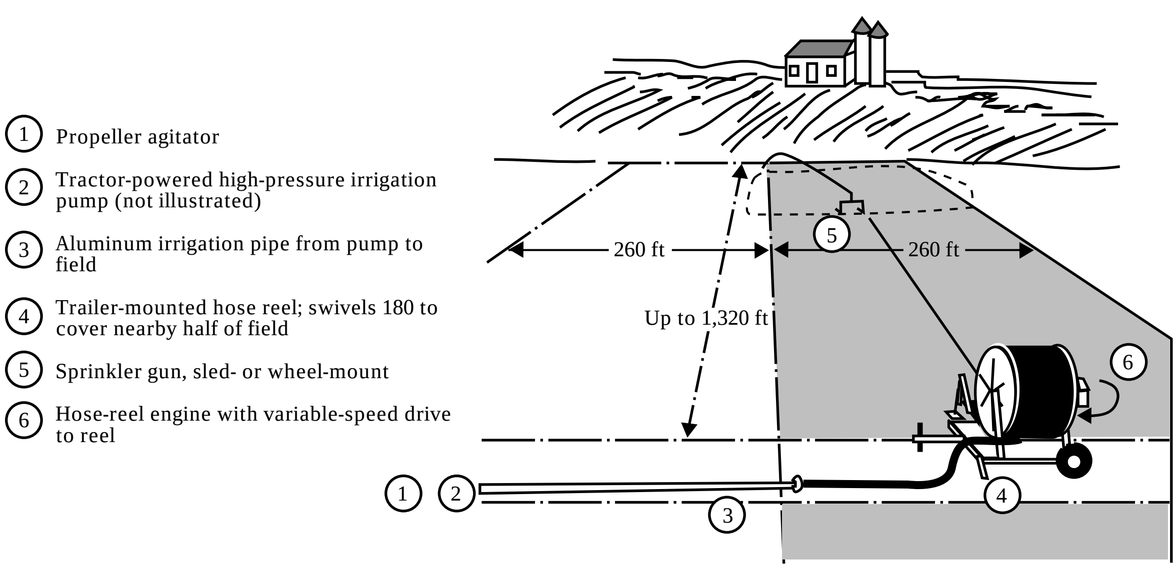
Figure 12–101 Stationary big-gun slurry sprinkler (courtesy Hydro Engineering and J. Houle & Fils, Inc.)

High, low, and multiple sprinkler gun cart designs are available for traveling gun sprinkler. The cart selected depends on crop height and the area to be irrigated. Nozzles are available for irrigating up to a 360-foot swath at more than 1,000 gallons per minute capacity. Table 12–15 gives the nozzle trajectory of a big gun stationary slurry sprinkler. Operating the nozzle in a part-circle pattern permits operating the gun on dry ground. In some models the size, length, and winch of the hose allow for irrigating up to 1,320 feet away from the mainline. The normal spacing between lanes is 60 to 70 percent of the sprinkler wetted diameter.

The hard hose maintains its shape and resists tow wear, but is bulky to handle, stiff to use (especially at freezing temperatures), and hard to store. The soft hose is more convenient to handle and expands slightly when pressurized, which increases the flow capacity. However, hose twisting and wear are problems when handling or moving the hose, which is necessary when resetting the sprinkler.

Depending on the nozzle, a traveling gun can irrigate up to 20 acres per setting. Adjusting the travel speed or nozzle affects the application rate. Different nozzle types, sizes, and capacities are shown in table 12–15. Either a taper bore or a ring bore nozzle is used for a traveling gun sprinkler. The taper bore nozzle is not adjustable, but spreads farther from the mainline than the ring bore nozzle, which can be adjusted. The 24

Figure 12–102 Traveling gun sprinkler with soft and hard hoses (courtesy Tuckasee Irrigation)



degree trajectory is lower than that of the 27 degree and has fewer problems caused by the wind, such as odors. The 27 degree trajectory can clear crops and spread farther out than the 24 degree trajectory.

Relatively popular for pumped waste spreading, the traveling gun irrigator needs minimal labor, has moderate power need, minimizes soil compaction, and can be moved to different fields and used for other irrigation. The relatively high investment, operator expertise, wind distortion, and odor source for a large surrounding area are major concerns. A traveling boom sprinkler that lays down an irrigated swath under low pressure is available and reduces some of these concerns (fig. 12–103). Low pressure traveling booms are subject to plugging.

Table 12–15 Irrigation gun pressure, size, and discharge (MWPS 1985)

	Nozzle trajectory													
	24°								27°					
Taper bore (in)	.6		.7		.9		1.1		1.3		1.5		1.75	
Ring nozzle (in)			.86		1.08		1.26		1.41		1.74		1.93	
(lb/in²)	gal/min	dia	gal/min	dia	gal/min	dia	gal/min	dia	gal/min	dia	gal/min	dia	gal/min	dia
50	74	225	100	250	165	290	255	330						
60	81	240	110	265	182	305	275	345	385	290	515	430	295	470
70	88	250	120	280	197	320	295	360	415	410	555	450	755	495
80	94	260	128	290	210	335	315	375	445	430	590	470	805	515
90	100	270	135	300	223	345	335	390	475	445	626	485	855	535
100	106	280	143	310	235	355	355	400	500	460	660	500	900	550
110	111	290	150	320	247	365	370	410	525	470	695	515	945	565
120		157	330	258	375	385	420	545	480	725	530	985	580	
130								565	485	755	540	1025	590	

Figure 12–103 Traveling boom sprinkler/spreader (courtesy Alfa Laval Agri, Inc.)

(8) Center pivot sprinkler equipment

A center pivot sprinkler propels itself in a full or part circle from a center anchor or pivot point (fig. 12–104). Different sizes spread liquid waste on a few acres to more than 600 acres per setting. Operable over uneven topography, the center pivot sprinkler uses 100 to more than 150 pounds of pressure per square inch to operate. This requires a 30- to 75-horsepower motor, depending on sprinkler size, construction, and nozzle. A pump is also needed for agitation and to transfer waste from storage to the sprinkler.

Drop tube nozzle distribution reduces the power need and odor problems of other nozzles used, but spreading may be uneven because of the variations in pressure. The driving power to slowly move the center pivot can be from the liquid pressure, an electric motor, or an oil or hydraulic drive wheel located at each of the irrigation pipe supports (towers). Variable speed and optional computer programmed control assist uniform application although wind is a problem. If the irrigator is constructed of aluminum, it requires less moving force, weighs less, and is resistant to corrosion. However, the investment is higher than that for a galvanized steel sprinkler.

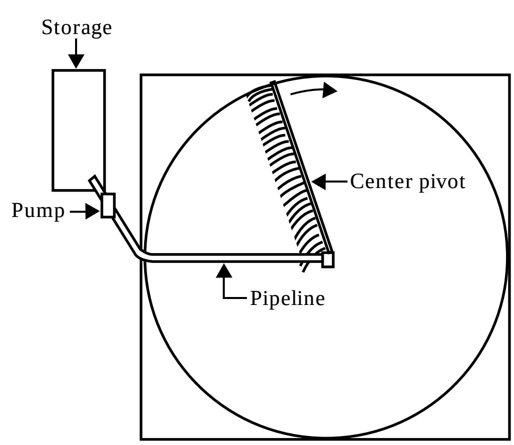
The relatively high investment for a center pivot sprinkler is tempered by its relatively low operating labor and speedy and uniform application. Most models are set up and used at only one location; some can be towed to different locations. Typically, one or more center pivot irrigators are regularly used each season to spread agricultural product processing plant liquid waste on growing crops. The sprinkler generally operates 6 to 10 feet above the ground surface for the most efficient spread and crop clearance, so it is vulnerable to high wind and lightning damage.

(d) Biogas production equipment

As explained in section 651.1006(d), biogas production is the anaerobic bacterial decomposition of organic matter into primarily methane (CH_4) and carbon dioxide (CO_2). Biogas production is well understood from a municipal sewage treatment standpoint and has been successfully done on a commercial basis for many years.

Biogas system management is demanding and critical as optimum temperature, pH, waste quality, loading rate, and related operating conditions are needed for desired bacteria performance. Because biogas is difficult to store, it needs to be used as it is produced. Although small installations are used for intermittent production of relatively small amounts of biogas, most installations focus on a moderate continuous production operation that can involve an array of different equipment. To date packaged biogas models have not been made available, so equipment from varied sources is used. The equipment shown in figure 12–105 is for one moderate-size, pilot model that may become commercially available (Vetter 1993).

Figure 12–104 Center pivot sprinkler (courtesy of Hydro Engineering, Inc.)



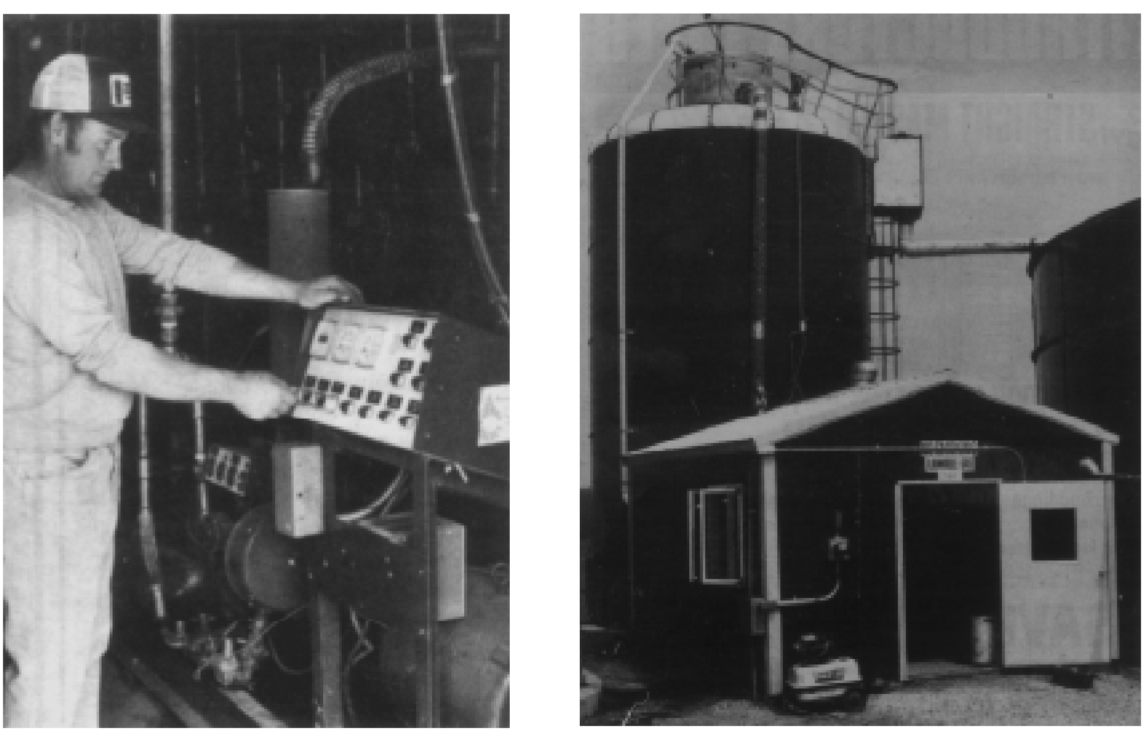
Typical biogas production equipment needs using agricultural waste are identified by Vetter (1990). Figure 12–106 is a schematic of an installation used since 1986 to generate biogas for heating a nursing home. This installation uses waste from a 300-cow dairy. As identified in this figure:

- The solids separator provides a more uniform liquid to aid bacterial action and digestion.
- The two mix pumps ensure that a well mixed supply is available if a pump fails.
- The feed pump intermittently, but regularly, feeds fresh waste into the digester.
- The digester mix pump continually circulates digester contents slowly around the heater to permit uniform heating of waste (also see fig. 10–45).
- The boiler provides the heated water supply to keep the digester contents at 95 °F.
- The scrubbers clean the sulfides from the raw biogas to minimize corrosion as the gas moves to storage and awaits burning for heating water that is circulated around the building.

While biogas is obtained from the digestion process, the liquid effluent and separated solids remain at about the same volume as dilution and cleanup water get added. These liquids and solids factions must be handled with pump, conveyor, and storage equipment similar to those of a waste handling system without a digester.

During the 1970’s, several non-commercial digesters of varying designs were constructed on American farms and at different research stations. The installation shown in figure 10–45 illustrates one constructed in 1974 at Pennsylvania Agricultural Experiment Station. It was designed to produce biogas using wastes from 50 to 100 dairy cows. It operated until 1978. The technical requirements and economics of such a system are explained in Agricultural Experiment Station Bulletin 827, Agricultural Anaerobic Digesters (Persson 1979).

Figure 12–105 Biogas production equipment



A comparable digester (fig. 12–107) was constructed in 1976 at the University of Missouri swine research farm. The investment at that time was estimated at $25,000, which did not include much skilled labor. This unit operated until 1986. Its condition at that time along with the design and construction information are in a report by D.M. Sievers (1990).

Rather than operate for a mesophilic bacteria temperature of about 95 degrees Fahrenheit, a simpler low temperature digester operates at 40 to 60 degrees Fahrenheit. While gas production from the microorganisms that thrive at these lower temperatures is slower and more variable than that for the mesophilic digester, the low temperature digester may have more applications for its use. See section 651.1006(d)(1)(v) for more information.

Figure 12–106 Biogas production equipment layout schematic (Vetter 1990)

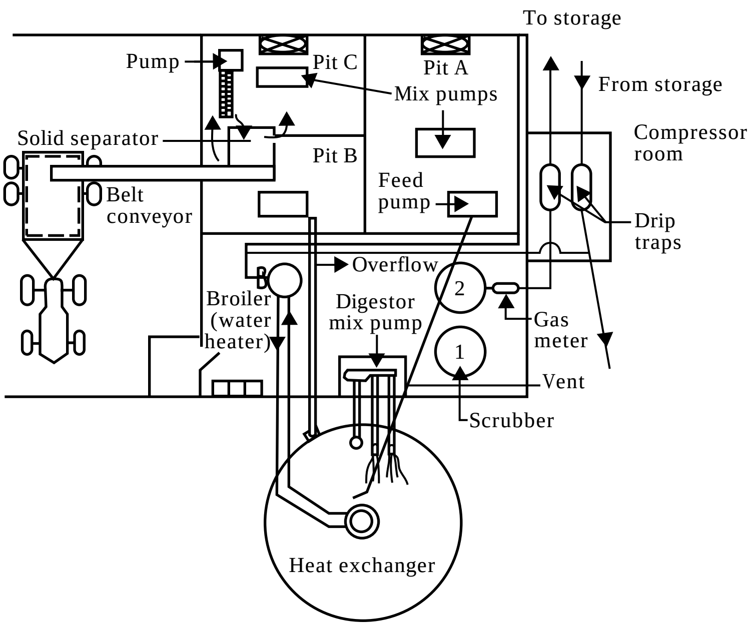
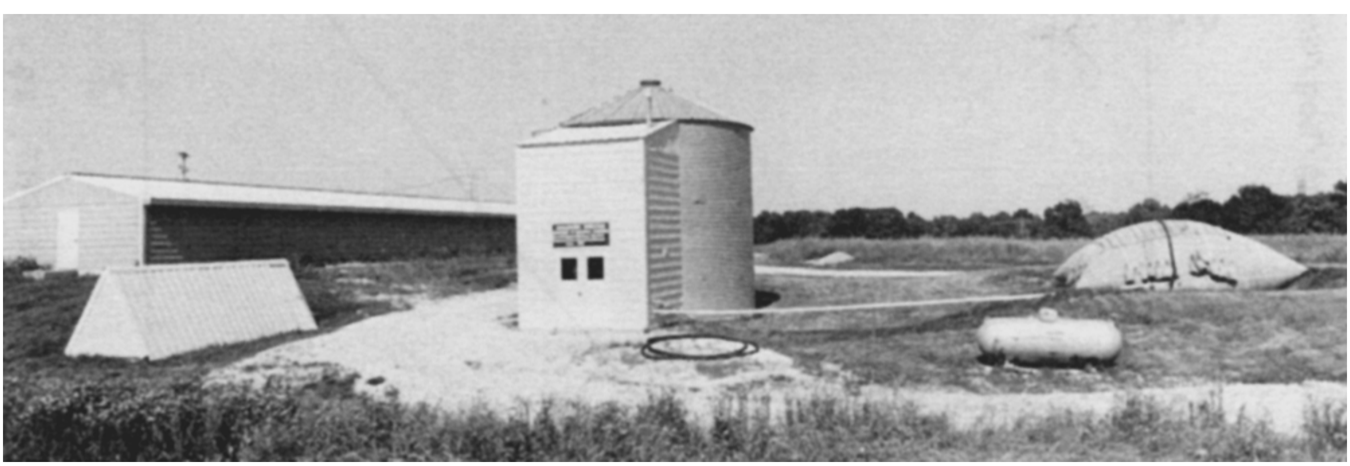


Figure 12–107 Biogas production equipment at the University of Missouri (Sievers 1990)

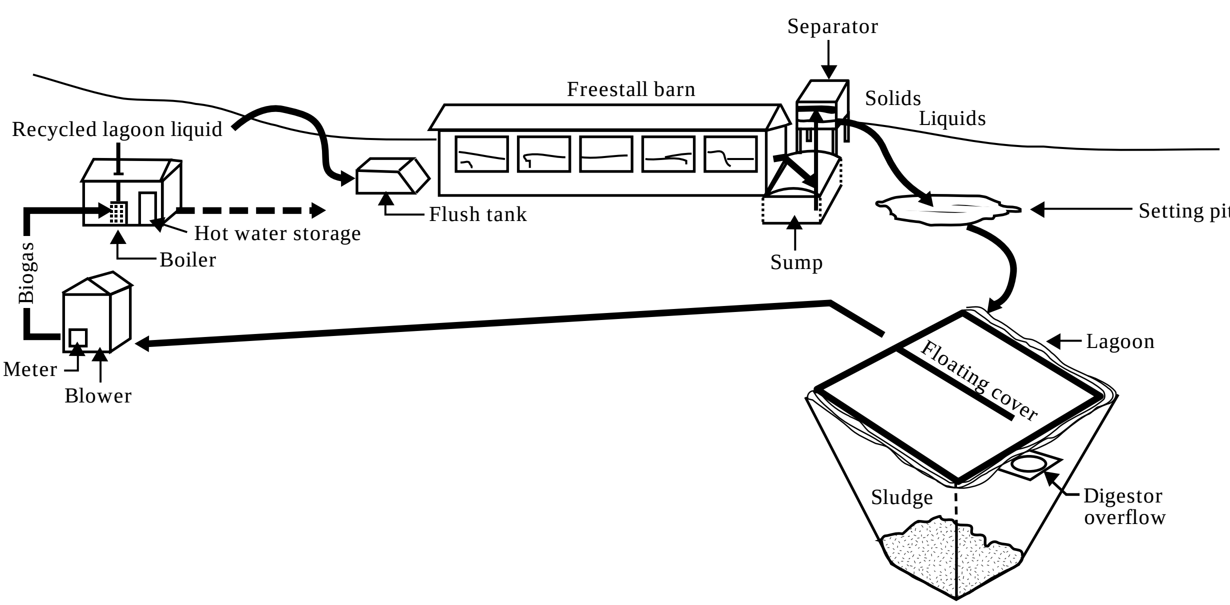


A design for a biogas production operation used for 4 years at North Carolina State University's Randleigh Dairy, in Raleigh, is shown in figure 12–108 (Williams 1994). The dairy was discontinued in June 1993. This design used an 80- by 100- by 25-foot deep anaerobic lagoon with a float supported weighted fabric cover to collect the gas and control odor. The floating cover is essential to this installation, and its design and installation by a reputable manufacturer is emphasized. The regenerative blower size and operation are critical to remove gas as it is produced and yet not collapse the airtight cover. To better predict an onsite feasibility, more data are needed on using this equipment at different locations, ambient temperatures, and production rates (Safley & Westerman 1992).

The following related equipment was included and used for the Randleigh Dairy biogas production system (Safley and Lusk 1991, Williams 1994):
- 72- x 80-foot floating fabric cover (HYPALON @DuPont) with 325 feet of Ethafoam@ float logs, 480 feet of 2-inch diameter PVC cover weight pipes, and 150 feet of 0.375-inch tiedown chain
- 80 feet of 4-inch diameter PVC perforated digester gas collection header pipe
- 650 feet of 2-inch diameter PVC gas pipe with a O.25-horsepower blower motor
- 1,500 ft^3 per hour gas meter (Dresser 1.5M175)
- 160,000 BTU boiler with 250-gallon hot water storage tank and 50 feet of 1-inch diameter hot water piping
- 2-horsepower lagoon effluent flushing pump
- 350 gallons per minute effluent pump to separator
- 4-foot diameter SWECO vibrator type solid/liquid separator
- 12- by 12- by 4-foot grit settling tank, reinforced concrete
- 0.5-horsepower effluent pump to digester
- 0.33-horsepower surface cover rainwater pump
- associated electric wiring and controls

Several, commercial-sized waste digesters for biogas were constructed in the 1970's at cattle feedyards in the South and Midwest to use feedyard wastes. In addition to the methane to be used for commercial electric generator power, utilization of the digester waste for feed or mulch was planned to help recover investment and reduce operating costs. Out of four installations, the digester in continued operation used waste from a covered confinement beef feeding barn (Eftink 1986).

Figure 12–108 Biogas equipment that has basin with fabric cover (Safley & Westerman 1992)



Gleaning from the results of these and other biogas production installations, J.M. Sweeten (1980) concluded the following keys to economical methane production from outdoor feedlot wastes:

- Collection of high quality manure from the feedlot surface.
- Efficient processing of feedstock, including ash removal.
- Low cost construction of digester.
- Efficient recovery and drying of high protein solids from digested slurry.
- Heat recovery from internal combustion engines used to convert methane into electricity.
- Large manure tonnage to achieve economics of scale.
- Efficient marketing of all by-products: methane, foodstuffs, fertilizer, and perhaps waste heat and carbon dioxide.

A 1992 survey of on-farm digester installations in the United States determined that out of 113 publicized installations, 93 had been constructed and 26 of those were operational at that time (Cantine 1992). The 93 included units at 10 different research stations. Constructed for research and demonstration purposes, most of the 93 units were closed because of the daily labor needed and the lack of continued funding for research.

Considering these experiences, detailed planning is essential about all the equipment required for a successful biogas production system from agricultural wastes. It is recommended to have the design made by an experienced, reputable consultant.

AgSTAR is a national cooperative effort of USDA, Department of Energy, and the Environmental Protection Agency to encourage the voluntary use of effective technologies to capture and utilize methane gas resulting from the anaerobic digestion of livestock waste. The effort also involves industry and agricultural partnerships to remove the barriers in use of the technology.

The goal of AgSTAR is to reduce methane emissions from livestock manure contributory to the greenhouse gases and global warming. Anthropogenic (human caused) methane emissions from coal mining, landfills, natural gas systems, domestic livestock, and livestock manure are significant. Of these emissions, it is estimated that 10 percent are from livestock manure storage and treatment facilities.

The focus of the AgSTAR program is in regions of the country where there are significant numbers of confined livestock and electric costs are high. In these regions, methane and recovery for energy generation can be economically feasible as well as a means of reducing odors. An important part of the AgSTAR program is charter farms that will be used to demonstrate methane recovery technology.

651.1208 Other associated equipment

In addition to the equipment for collection, storage, transfer, treatment, and utilization of wastes described thus far in chapter 12, varied other equipment is used with agricultural waste handling. The pertinent equipment for safety, odor evaluation, gas detection, and water quality is especially important. Equipment from alarms and backhoes to hoists to weigh scales (and more) get involved in typical operations, but they will not be included in chapter 12.

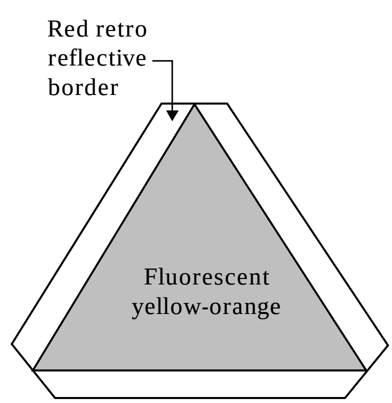
(a) Safety protection equipment

Agricultural waste handling involves hazards (651.1008). Waste handling equipment is often operated alone at all hours of the day and in a dirty, noisy, slippery, remote, semi-dark location, which is generally a long way from help and medical attention. Safety considerations made when planning facilities are essential and have been briefly included in this chapter. They are covered in depth in chapter 13. Workers should be knowledgeable about hazards, safe operation conditions, emergency procedures, phone numbers, and available medical facilities.

(1) Signs for safety, danger, and warning situations

Waste handling involves the use of slow moving equipment. The Slow Moving Vehicle (SMV) warning emblem (fig. 12–109) is mounted on the rear of equipment traveling less than 25 miles per hour on public roads. The emblem is mounted 2 to 6 feet above the ground, centered or to the left (whichever is most practical), and pointing upward. ASAE Standard S276.3 explains the specifications about SMV sign construction and use (ASAE [r] 1994). As with any equipment, the sign needs to be in good repair and regularly cleaned.

Figure 12–109 Slow moving vehicle emblem



Somewhat comparable to the SMV emblem is the Safety Alert Symbol for Agricultural Equipment (fig. 12–110). As explained by the ASAE Standard S350, the uniform symbol is to be used with warning statements, signs, manuals, and educational materials about agricultural equipment (ASAE [s] 1992). It is not to be used alone.

ASAE Standard S441, Safety Signs, is useful for signs needed with agricultural waste handling situations (fig. 12–111). This standard provides design guidelines for uniform safety signs, their situations, format, colors, size, and placement (ASAE [p] 1995). Uniformity in signs assists quick recognition and understanding. Work situation signal words include:

Danger High probability of death or irreparable injury.

Warning Hazard exists that could result in injury or death.

Caution Precaution needed against personal injury.

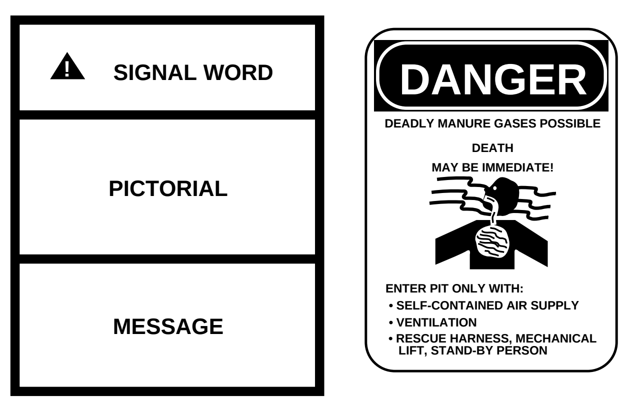
Warning sign situations would be where waste scraping, storage, agitation, or loading take place. ASAE Standard S441 explains that the warning sign needs a black background behind the signal word, which is to be in yellow letters. The message is black lettering on a yellow background. It is printed in 2-inch-high letters so it can be seen from about 80 feet away.

A **Danger** sign to be used near earthen basin waste storages was developed in Pennsylvania (Bowers 1992). This 10- by 14-inch aluminum sign generally follows the ASAE Standard 441 guidelines (see fig. 12–111). It is available through the D.W. Miller Industries, Inc., RD #1, Box 7B, Huntington, PA 16652.

Other pertinent ASAE standards for safe use of waste handling equipment include S344.3, Safety for Farmstead Equipment; S318.10, Safety for Agricultural Equipment; and S355.1, Safety for Agricultural Loaders. These respectively explain guarding, operation, safety needs, and references for their development (ASAE 1995).

Figure 12–110 Safety alert symbol for agricultural equipment

Figure 12–111 Safety signs format



(2) Fire extinguishers

Local fire departments, insurance agencies, and fire extinguisher sales and service shops are knowledgeable about fire extinguishers. Only a brief explanation is given here.

A full and operable 2A-10BC fire extinguisher (or larger) should be nearby where engines are operated. It will smother trash, paper, petroleum, and electrical fires (Fanning 1984).

Fires and extinguishers are classified as A, B, C, or D according to the material that is burning. Because of the characteristics of the different fires, the extinguisher that works on one type fire may be dangerous or ineffective on another. The classifications are:

Class A	Combustible solids, such as wood, straw, or rubbish.
Class B	Flammable liquids, such as gasoline, paint, or oil.
Class C	Energized electric equipment, such as motors or switches.
Class D	Combustible metals, such as magnesium and sodium.

Fire extinguishers need to be tested by an approved agency. The fire extinguishing potential for the fire classification is rated and put on the label. The rating is a number and letter combination. The letter indicates the fire type and the number indicates the size of fire the extinguisher will put out (fig. 12–112).

The ratings for Class A fire extinguishers show the relative extinguishing potential of one model compared to another. A 4A extinguisher should extinguish twice as much Class A fire as a 2A. The number on Class B fire extinguishers indicates relative size and the square foot area of deep layer flammable liquid that an average operator can extinguish. For example, a 6B unit should extinguish 6 square feet of deep layer flammable fire. A 6B unit will also extinguish twice as much Class B fire as a 3B.

Class C fires are either Class A or Class B fires with electrical equipment present. The C rating is the same as the Class A or the Class B rating depending on what is burning.

Dry chemical extinguishers are available from 2.5 to 20 pound sizes. The dry powder that smothers the fire is propelled by pressurized nitrogen or carbon dioxide gas. A dry chemical extinguisher is effective on Class B and C fires. It will knock down a Class A fire, which may then need water to completely smother smoldering materials. The remaining dry chemical residue is a disadvantage of using this type extinguisher on a Class A fire.

Figure 12–112 Fire extinguisher label

UL UNDERWRITERS LABORATORIES INC. ®
LISTED
DRY CHEMICAL FIRE EXTINGUISHER
CLASSIFICATION 2-A: 10-B:C

(b) Gases and confined space entry

Air quality in agricultural waste handling systems is explained in section 651.0305. Information about safety considerations are included in sections 651.1008 and 651.1204 and in chapter 13. Attention continues to focus on the air quality and safety aspects of handling agricultural wastes (Berg 1994). Protection and first aid is a concern for workers and for inspectors, visitors, and especially children.

Depending on employee numbers, family workers, corporate status, and perhaps State rules, the United States Department of Labor, Occupational Safety and Health Administration (OSHA) can become involved with agricultural production operations (U.S. HHS 1990). The OSHA promulgated a standard (Congressional Federal Register 1910.146) dealing with entry into confined spaces in April 1993 (Shutske et al. 1993). This action may have implications to confined spaces in agricultural related facilities. Included, for example, might be worker training, warning signs, and safety equipment and its approval and use.

In working with agricultural wastes, an operator at some time will need to enter and work in an enclosed storage or tanker space where there may be dangerous gases or absence of oxygen (Berg 1994). The confined space must be completely force-ventilated with a blower and flexible duct. If at all possible, employ an experienced person with proper equipment to do the work. Contacts about who can do this should be available through waste equipment suppliers, safety specialists, local emergency rescue concerns, fire departments, law enforcement persons, electric and gas power suppliers, military stations, underwater equipment suppliers, and related agencies. Suppliers and licensed operators should have current rescue procedure information and operable equipment.

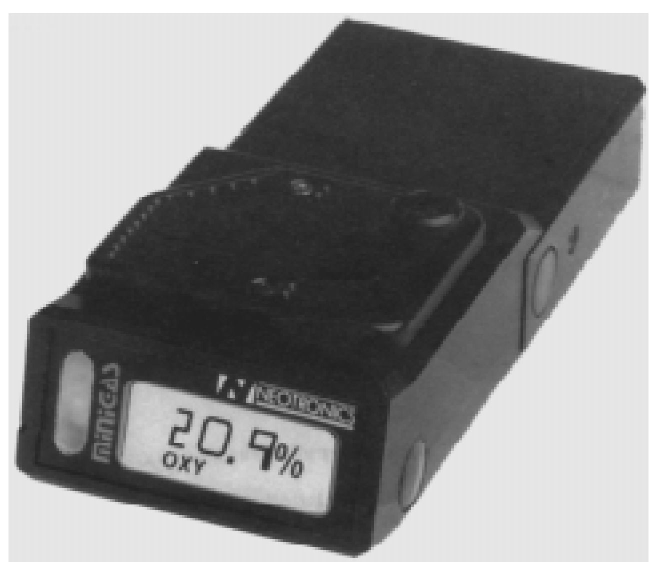
The minimum equipment used by a trained person when entering a confined space would be (Shutske et al. 1993):

- A monitor to test and provide continuous detection capabilities for presence of hydrogen sulfide (H_2S), methane (CH_4), and oxygen (O_2) before and during entry.
- A ventilation blower (1,000 cubic feet per minute) with about 15 feet of flexible ducting that can reach spaces requiring venting.
- A lifeline and harness system (tripod, cable, winch) to allow a helper to quickly remove an entrant in the event of a storage incident.

The same types of equipment are required by the confined space entry guidelines for manure pits (storages) issued in 1990 by the National Institute for Occupational Safety and Health (U.S. HHS 1990).

A portable, electronic gas monitor capable of detecting O_2 levels below 19.5 percent, H_2S levels above 15 ppm, CH_4 levels above 10 percent of the lower, explosive limit, and other combustible gases is advised. Most detectors have a calibration kit for that detector. An electronic detector measures the electrical variations of an exposed, special coating on a sensor. The sensor life would be dependent on use, gas concentration, and other environmental factors (fig. 12–113). Many different models are available. A single instrument could use several independent sensors to measure different, respective gases (e.g., H_2S, CO, O_2). In addition to a digital display of gas level, such detectors are available with alarm lights, audio alarm, and detachable sensors for remote monitoring.

Figure 12–113 Hand-held electronic multigas detector (courtesy Neotronics)



A hand-held air sampler with different indicator tubes (fig. 12–114) is moderate cost and remains reliable after repeated use. However, this detector is slower to operate than the electronic detector. The sealed sampler tubes are available for sensing different gases. To do a sample, a selected tube is broken open and inserted in the sampler. The plunger is extended to draw a specific quantity of air through the sample tube material, and the change of tube color is compared to a standard chart.

A wetted-paper gas level indicator costs less than any other indicator, but the indication response may be slower. Contamination of this indicator is possible, which then would not give a reliable indication. This indicator can be more cumbersome to use in typical situations involving agricultural wastes.

While self-contained breathing equipment (fig. 12–115) use is often suggested, many people are relatively unfamiliar with how to use it. The concerns with this equipment include high investment cost, need for knowledgeable operation, and correct maintenance, servicing, and replacement parts.

Self Contained Breathing Apparatus (SCBA) equipment is available in different configurations—closed or open circuit, pressure demand, or demand. A closed circuit apparatus removes CO_2 from exhaled breath and then restores O_2 content from a compressed O_2 or O_2 generating source. It generally has a longer service life than that of the open circuit apparatus. Open circuit equipment allows exhaled air to escape to the atmosphere and supplies breathing air from a compressed air source.

Pressure demand equipment maintains a slight positive pressure in the face piece, which eliminates inward leaking of atmospheric contaminants. This equipment is suitable for Immediately Dangerous to Life and Health (IDLH) environments, whereas the demand device is not suitable. Both types are suitable for O_2 deficient environments depending on the service life of the air source. Different kinds of face masks and user head protection can be used with the SCBA.

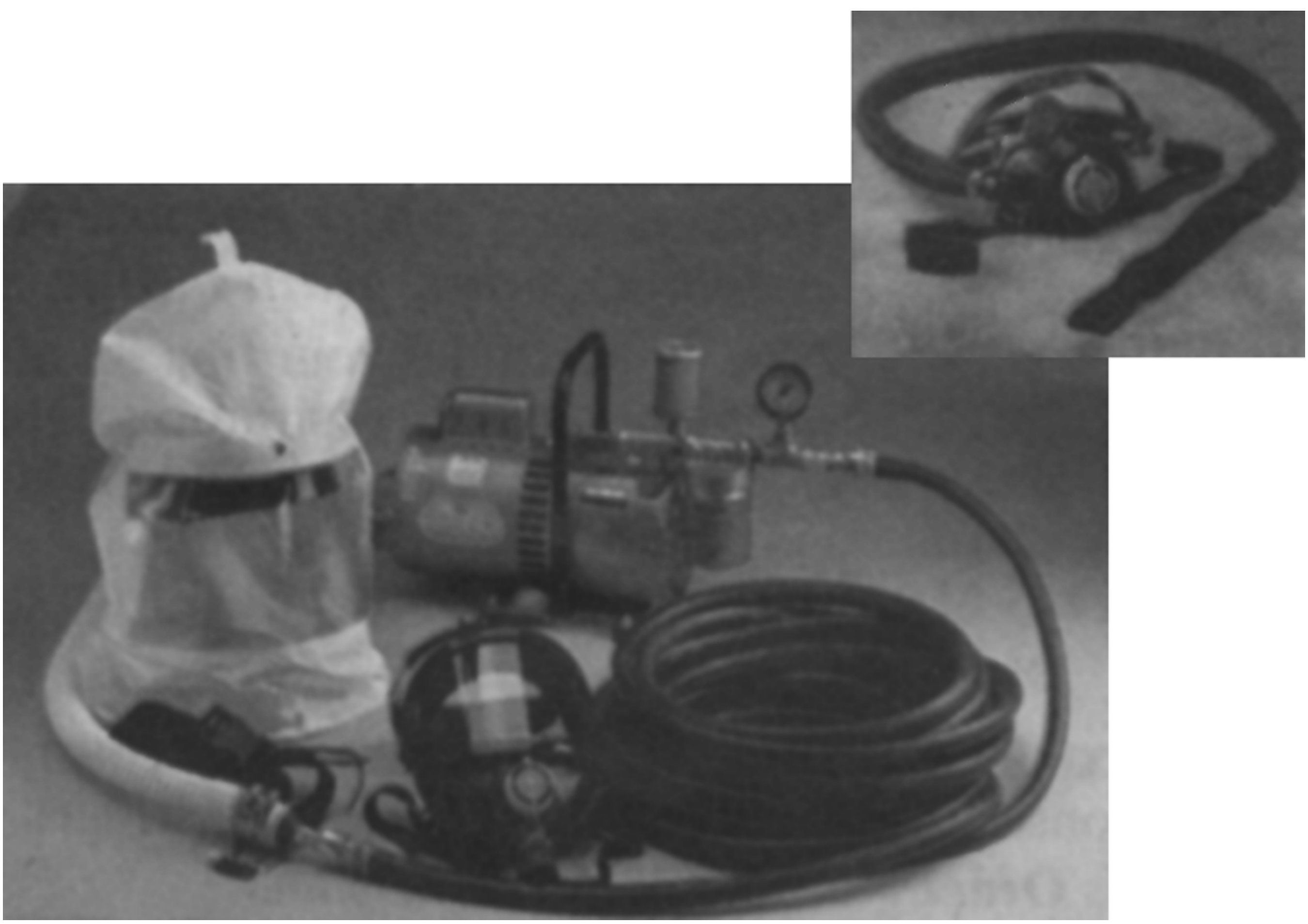
Figure 12–114 Air sampler with different gas detection tubes (courtesy Sensidyne, Inc.)

Figure 12–115 Self contained breathing equipment (courtesy Willson Safety)

The OSHA requires workspace respirator equipment to be tested and certified by the National Institute for Occupational Safety and Health (NIOSH). Respirator equipment is either the filtering and conditioning type that uses workspace air without adding anything to it or the air-supplied type that includes the Self Contained Breathing Apparatus (SCBA). The NIOSH approval is an assurance of quality. However, this approval is for new equipment, so wear, time, or abuse can negate this credibility. If the operator is not sure how to operate this equipment and the user manual is not available, the manufacturer of the equipment or the NIOSH should be consulted for items to check before use.

Relatively low cost outside atmosphere Supplied Air Respirator (SAR) equipment is generally available (fig. 12–116). An air-compressor, supply hose, and lightweight hood or face mask make up this equipment. SAR equipment is designed for use in dusty, humid, smelly, warm, or other such contaminated environments where an adequate supply of oxygen is present. It is not recommended for use in an atmosphere IDLH environment. Selection depends on the compressor capacity (rated in ft^3/m), filter quality, and hood supply hose type and length. Equipment is available that has a 5- to 10-minute emergency or exit air bottle attached. This air supply is the critical backup should something happen to the air supply hose.

Figure 12–116 Supplied air respirator equipment (courtesy Gempler's)



A tripod is used as the overhead anchorage for a winch hoist. The hoist is attached to a leather or web harness and used to raise and lower a person through a small opening, such as a manhole. A waist belt and shoulder straps have an attached ring at the back. Rescue harness and winch hoist equipment should be able to lift at least 500 pounds as it may need to support two persons (fig. 12–117). The winch needs a sturdy, smooth-operating, unwind latch to prevent unwanted release or jamming. The support frame needs workspace clearance for the harness and the person in it.

A rope located by a ramp or storage facility can provide a practical means of emergency escape. A nondegrading material, such as nylon, that is at least 0.75 inches in diameter is suggested. The rope should be knotted at 1-foot intervals (Bowers 1992). The rope can be used by anyone who accidentally falls into a storage to hold onto until help arrives or possibly to climb out.

Figure 12–117 Tripod, winch, and harness (courtesy D B Industries, Inc.)

(c) Odor detection/measurement equipment

Waste storage facilities and handling equipment produce offensive odors. Odor complaints about field spreading are increasing. Odor detection is relatively easy, but measurement is more difficult. Even though the human nose is an effective detector, it lacks constant sensitivity and varies among people.

Odorous gases are a combination of end and intermediate products of anaerobic decomposition that have enough volatility to escape from the liquid phase. More than 100 odor causing compounds are in agricultural wastes operations. Although research has been done on odors from waste, practical measurement of specific compounds at relatively low concentrations (<1 ppm) remains a problem (Bundy 1993, McFarland and Sweeten 1993). Gas-liquid chromatography equipment has been primarily used in odor identification. With highly sensitive detector equipment, frequently other compounds present in great concentration, but less odor significance, tend to interfere with analysis (MWPS 1983).

Reliable detector equipment is useful with odor reduction efforts where the general effectiveness of odor control treatment must be determined. An electronic indicator (fig. 12–118), for example, is useful to detect odor presence. Presently, this equipment is unable to detect specific odors; however, it can help quantify odors by using the relative response of the readout. Calibration to a specific compound is possible by exposing the meter to a known concentration and developing a graph.

Two aspects of odor are intensity and quality. The intensity of an odor is defined as the number of dilutions required to reduce the odor to the threshold level, which is the least distinguishable concentration of that odor. A scentometer (fig. 12–119) is useful for field measurement of odor intensity.

The scentometer is a 5- by 6- by 2.5-inch box with two ports through which air passes through activated charcoal beds. The four odorous air inlets are directly connected to a mixing chamber, which is connected to the nasal outlets. In use, several scentometers are taken to where an odor intensity measurement is desired. Each scentometer is used by a different observer. The observers place the nasal outlets to their nose and plug the odorous air ports to adjust their sense of smell to odor-free air. The person then opens successive ports until an odor is detected through the scentometer. Although subject to considerable variation, the results are useful to rank odor intensity (MWPS 1983). For relative comparison of more average conditions, odor measurement locations should be about 20 feet from lagoons and 50 feet from barns (Bundy 1993).

The butanol olfactometer (fig. 12–120) allows panelists to compare the intensity of odor in ambient air (without dilution) to the intensity of a dilute concentration of 1-butanol gas (C_4H_9OH). This approach is more useful with higher odor intensities. It is known as supra-threshold referencing, which is desirable to eliminate the odor threshold variability among panel observers. While portable, this equipment is heavy, relatively delicate and cumbersome, and requires expertise and time to operate. The data are generally more reliable than that of other odor measurement devices (Sweeten et al. 1984).

Figure 12–118 Odor measurement electronically (courtesy Sensidyne, Inc.)

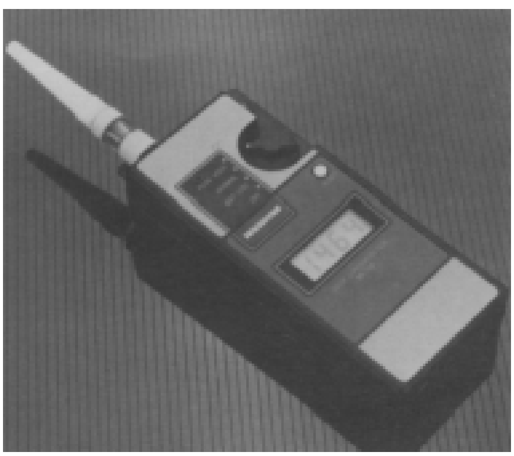


Figure 12–119 Scentometer for odor strength measurement (MWPS 1983)

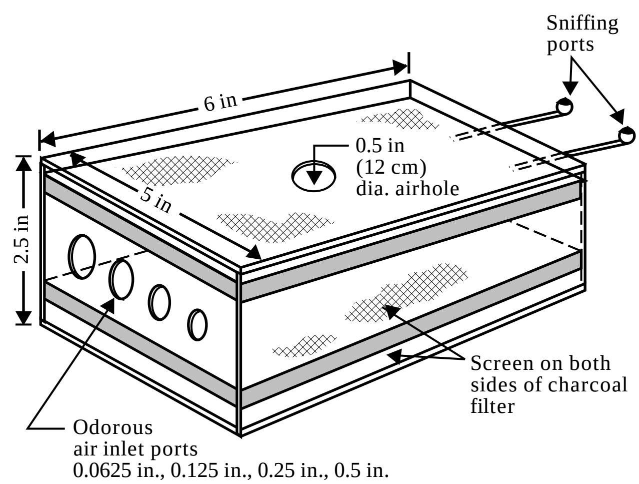
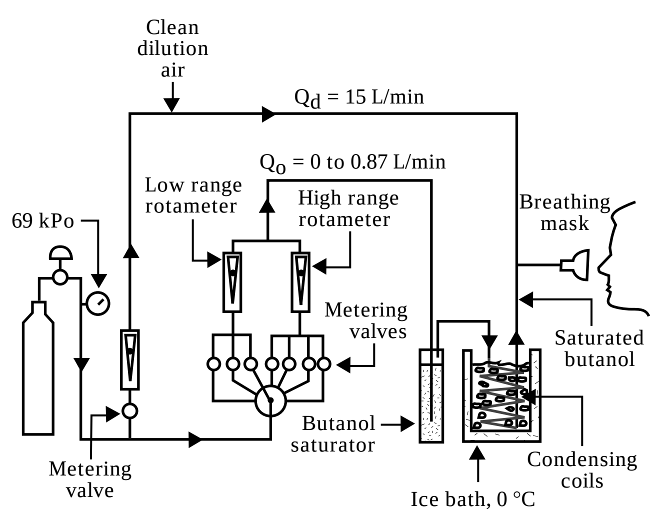


Figure 12–120 Butanol olfactometer for odor measurement (Sweeten et al. 1984)



Europeans have equipment for collecting an odor sample in a plastic or teflon bag. The sample is tested in a laboratory using an olfactometer (Bundy 1993).

In contrast to determining odor strength, odor quality is more difficult to define. One technique is comparing an odor to a familiar sensation categorized as foul, sweetish, acetate, nut-like, putrid, butter-like, and garlic. A less-specific alternative is to rank the offensiveness from 1 to 10 (Dickey 1978).

Physical means to manage odors include the use of covers, aeration, and such waste management practices as locating the waste treatment facilities away from people, cleaning and keeping the facilities dry, and using wind barriers. Management for odor reduction, odor sources, and the different odor reducing chemicals are reviewed in the ASAE Engineering Practice 379.1 (ASAE [k] 1991).

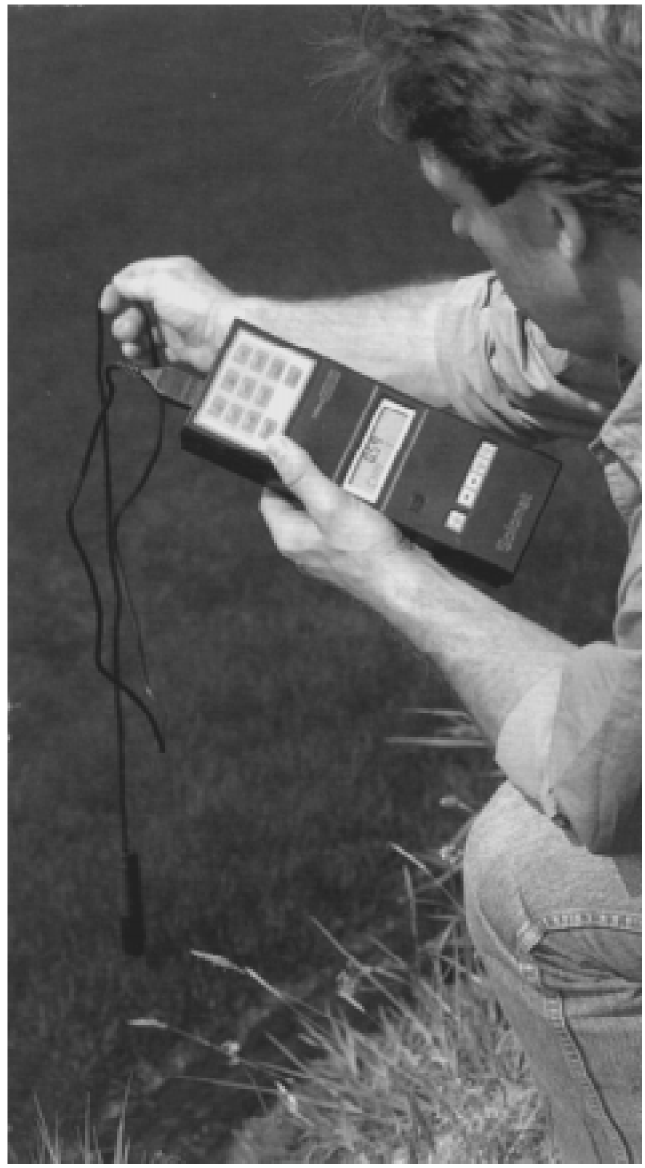
(d) Water quality testing equipment

The equipment described in the previous section is all an integral part of a waste management system planned and installed to protect water quality. Knowledge of equipment used to measure water quality is useful; however, the actual sampling and analysis normally require a skilled specialist.

State agencies are responsible for monitoring public water quality. Most public drinking water supplies are regularly checked for their quality. While there are Federal minimum quality standards, individual State standards may be stricter. Water quality is generally assessed by respective equipment or laboratory processes that measure coliform bacteria, pH, turbidity, hardness, dissolved solids, nitrates, phosphorus, and odor.

Except for the bacteria test, which requires a culture and microscope, quality tests on these items can be done manually using a color-comparison, visually judged result; with portable electronic equipment out in the field (fig. 12–121); or more reliably using electronic and oven equipment in controlled laboratory conditions. For analysis, selecting and getting an accurate water sample in an approved container is critical. Then correct handling and transporting the sample to the laboratory is another challenge.

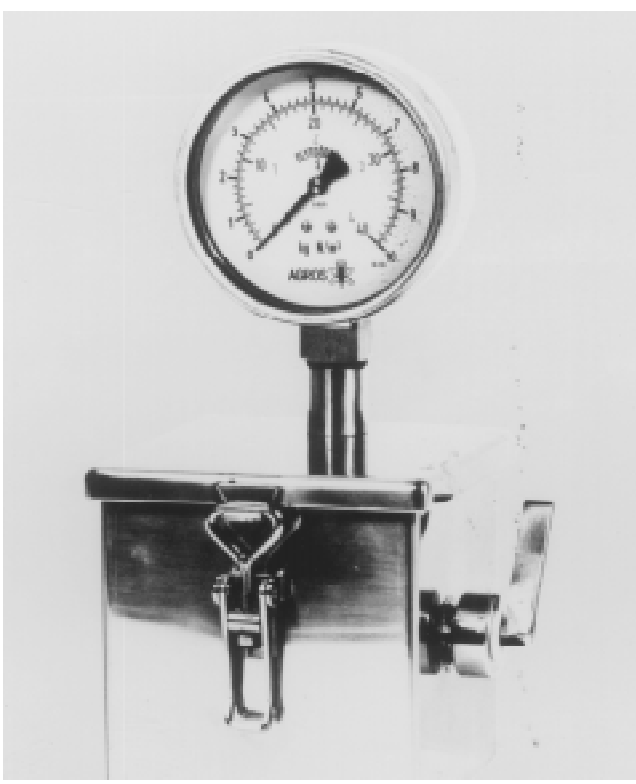
Figure 12–121 Water quality measurement electronically (courtesy Solomat Neotronics)



In addition to these more common water quality measurement items, chemical analysis in the laboratory can be made for arsenic, barium, boron, cadmium, chlorine, chromium, copper, fluorine, iron, lead, maganese, selenium, sulfate, zinc, and individual pesticides.

Although what develops from application of agricultural waste to soil is not directly related to water quality testing, it is closely related. Knowledge about how much waste to apply relates to the soil quality and the waste quality. Sections 651.0605, 651.0904(f), 651.1006, 651.1102, and 651.1207 give more details of application of wastes to soil. Also see NRCS Conservation Practice Standard, Nutrient Management, Code 590. Figure 12–122 shows a direct reading nitrogen meter that can assist with soil nitrogen management.

Figure 12–122 Direct-reading portable nitrogen meter (courtesy Agri-Waste Technology, Inc.)



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**Natural
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Service**

Agricultural Waste Management Field Handbook

Chapter 13 Operation, Maintenance, and Safety

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Chapter 13 Operation, Maintenance, and Safety

651.1300 Introduction

The purpose of an Agricultural Waste Management System (AWMS) is to control and use by-products of agricultural production in a manner that sustains or enhances the quality of air, water, soil, plant, and animal resources. Important to the success in achieving this purpose is adequate design and construction of the AWMS. At least as important to a system's success are its proper operation and maintenance (O&M). Safety is always coupled with proper O&M as an essential and integral part.

This chapter describes actions that would be taken by the operator of an AWMS or choices that would be made by the decisionmaker. It recognizes that the decisionmaker and the operator for an AWMS may not be the same person. For example, on an absentee owner's farm the decisionmaker and the operator are most likely different people. However, for the purpose of this chapter, reference to the decisionmaker implies the operator when appropriate to the context. The operation and maintenance described in this handbook is not all inclusive, but addresses the most common components.

Two prerequisites are necessary for proper O&M. First, the decisionmaker must have been involved throughout the decisionmaking process in planning the AWMS. This is essential if the decisionmaker is to accept full ownership of what is planned. Second, the decisionmaker must have a complete understanding of the system's O&M requirements. The AWMS plan is an essential tool for conveying these requirements to the decisionmaker. An AWMS plan is prepared as an integral part of and in concert with conservation plans. The purpose of this chapter is to discuss general operation, maintenance, and safety requirements for an AWMS.

651.1301 Operation

Operation of an AWMS includes the administration, management, and performance of nonmaintenance actions needed to keep the system safe and functioning as planned. The operation actions required depend on such factors as the type of enterprise, the components of the system, and the level of management. Because of this, the operational requirements for each AWMS must be system-specific. Following is a general description of the operational requirements for each function of an AWMS.

(a) Production function operation

The majority of the operational actions required for the production function are managerial. Examples of operation actions could include management of the amount of bedding and washwater used. The AWMS plan should document the production rate assumed in the design of the system and give a method for determining the actual rate. An important reason for doing this is to assure that the actual rate does not exceed that assumed in the design of the system. Repercussions can occur if the design rate is exceeded. For example, a storage facility of an AWMS could fill up more quickly than anticipated, requiring that the facility be emptied earlier than intended. A response is needed where a production rate exceeds design assumptions. For a dairy operation, the response might be reducing the amount of daily washwater used, excluding clean water entering the system, or enlarging the storage facility.

(b) Collection function operation

The collection function involves the initial capture and gathering of waste from the point of origin or deposition to a collection point. The managerial aspects of this function involve frequency and timing, which should be described in the AWMS plan. Frequency of collection is dependent on the type of operation. For a feedlot, the frequency of collection might be only once a year. On the other hand, a dairy with a flush system might collect waste several times a day.

Timing of collection can be an important consideration. For a feedlot without a storage facility, the timing should coincide with when the waste can be utilized. Timing for a poultry broiler operation may be most appropriate between production cycles when the facility is empty of birds.

(c) Storage function operation

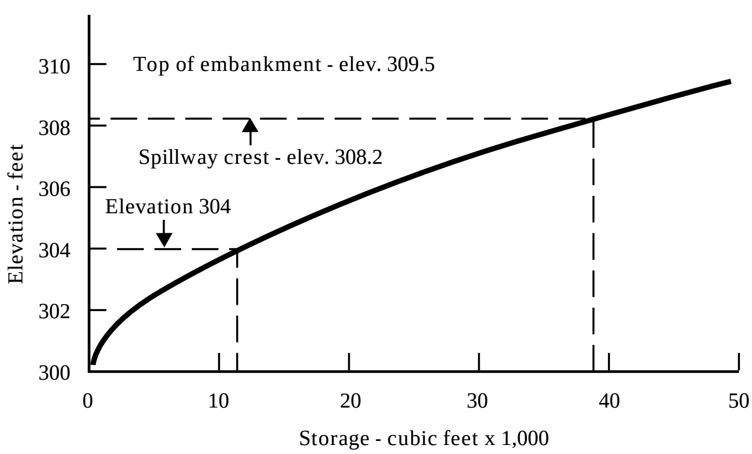
Storage function components include waste storage ponds and structures. Storage structures include tanks and stacking facilities. Monitoring storage levels in relationship to the storage period is of prime importance in the operation of storage components.

The AWMS plan should give target storage levels by date throughout the storage period. To assure that the facilities do not fill prematurely, these levels should not be exceeded. An excellent way to present this in the AWMS plan is to equip an impoundment type storage facility with a staff gauge so that target gauge readings versus dates are given. A stage-storage curve (fig. 13–1) can also assist the decisionmaker in monitoring the storage's filling. The stage-storage curve relates the pond's water surface at any elevation to the pond's storage at that elevation. For example, if the waste storage pond for figure 13–1 was measured as having a water surface elevation of 304 feet, it can be determined using the stage-storage curve that the pond contains 12,500 cubic feet of wastewater at that elevation. This storage can then be compared to anticipated storage if the pond had filled at the design filling rate.

To illustrate comparing actual versus design filling rate using the stage-storage curve, say the pond above is in its 50th day of the storage period, and the design filling rate is 200 cubic feet per day. Therefore, the target storage level for that day would be: 200 cubic feet per day times 50 days, or 10,000 cubic feet plus the depth of precipitation less evaporation assumed to occur during this 50-day period.

Using the stage-storage curve, it can be determined that at a storage of 10,000 cubic feet the water surface elevation in the pond would be 303.4. Add the assumed depth of precipitation less evaporation assumed for this 50-day period to this elevation.

Figure 13–1 Stage-storage curve



For this example, if the precipitation less evaporation was assumed in design to be 0.6 feet, the target filling elevation for the 50th day would be 303.4 + 0.6 = 304.0, which would indicate actual filling is at the assumed design rate. However, actual precipitation amounts may vary from that assumed in design. For this reason, actual precipitation less evaporation should also be evaluated. For example, if the actual precipitation is less than that assumed, it would mean the pond above is filling at a rate in excess of the 200 cubic feet per day. On the other hand, if the actual precipitation less evaporation is more, the pond is filling at a rate less than the 200 cubic feet per day.

Keeping a record of the waste accumulation throughout the storage period should be recommended. A record of precipitation and evaporation amounts may also be important in determining the source of filling.

Storage components are generally operated so they are empty at the beginning of the storage period and are filled to or below capacity at the end. The management of storage components may need to be coordinated with the management of the production function if the rate of filling exceeds that assumed in design. Uncovered impoundment storage components are subject to storm events that prematurely fill them. The AWMS plan should describe a procedure for emptying these facilities to the extent necessary in an environmentally safe manner to provide the capacity needed for future storms.

The design of liquid storage components may require a storage volume reserve for residual solids after the liquids have been removed. The amount reserved for this purpose depends on such things as the agitation before pumping and the care taken in pumping.

(d) Treatment function operation

Treatment components include waste treatment lagoons, composting, oxidation ditches, solid/liquid separation, and drying/dewatering. The treatment function reduces the polluting potential of the waste and facilitates further management of the waste. Proper operation of this function is essential if the desired treatment is to be achieved.

(1) Waste treatment lagoons

Proper operation of waste treatment lagoons includes maintaining proper liquid levels and assuring that the maximum loading rates are not exceeded. Lagoons are designed for an assumed loading rate. The AWMS plan should document the maximum loading rate and suggest that it be monitored to assure that it is not exceeded. This can be done by comparing the sources and amounts of waste entering the lagoon to what was considered in design, such as number of animals.

Laboratory testing may be required if loading becomes a serious question. If the design loading rate is exceeded, the lagoon may not treat the waste as needed and undesirable and offensive odors may result. The rate of filling is important as well. If the rate of filling exceeds the design rate, the storage period is reduced and the lagoon must be pumped more frequently. See section 651.1301(c). The AWMS plan should describe a procedure for emptying part of the lagoon contents following a storm event that fills the lagoon prematurely to near its capacity to provide storage for future storms.

The AWMS plan must emphasize the need to maintain the liquid level in anaerobic lagoons at or above the minimum design volume (fig. 13–2). The proper pH must also be maintained if the desired treatment is to be achieved. As such, the pH should be measured periodically. The minimum acceptable pH is about 6.5. If pH falls below 6.5, a pound of hydrated lime or lye should be added per 1,000 square feet of lagoon surface daily until the pH reaches 7.0.

Aerobic lagoons require a design surface area and a depth within the range of 2 to 5 feet to effectively treat waste. This information must be provided in the AWMS plan. Mechanically aerated lagoons require that a minimum design volume be maintained and the designed amount of aeration be provided for effective treatment and odor reduction. The plan should recommend that these operational aspects be carefully monitored.

(2) Composting facilities

Composting requires careful management to effectively treat waste. It relies on a proper blend of ingredients, called the recipe, to achieve the microbial activity necessary to stabilize reactive constituents and to attain the temperature necessary to destroy disease-causing organisms. For this reason, the AWMS plan should address careful monitoring of internal temperatures in the compost pile. The plan should give the recipe and recommendations for its adjustment if the temperature levels are either too low or too high. Caution should be given to the potential for spontaneous combustion. The plan must also address mixing requirements. See chapter 10 for a complete discussion of the management responses necessary for effective composting.

(3) Solid/liquid separation

Solid/liquid separation facilities include settling basins and a variety of stationary and mechanical screening devices. Maximum and minimum allowable flow rates are critical for these type facilities and need to be documented in the AWMS plan. If the flow rate exceeds the rate assumed in design, the residence time in settling basins may not be adequate for efficient settling. If it exceeds the design capacity of a screening device, its efficiency will diminish. Generally, the screen manufacturer's information provides data on minimum and maximum flow rates. However, the decisionmaker may need to fine tune the flow rate to fit the consistency of waste produced.

The frequency of cleaning out settling basins needs to be established by the design and documented in the AWMS plan. Solids sometimes adhere to screening devices and, if allowed to dry, can clog the screen. Rinsing the screen following use should be emphasized in the AWMS plan as a way to help avoid this problem.

(4) Oxidation ditches

Oxidation ditches require a high level of management to effectively treat the waste in a safe manner. Careful attention must be given to assure that pumps and other equipment are operating properly and that the ditch is not overloaded. Velocities must be maintained that do not permit solids to settle and accumulate. Input from the designer is essential in developing the operational requirements for oxidation ditches.

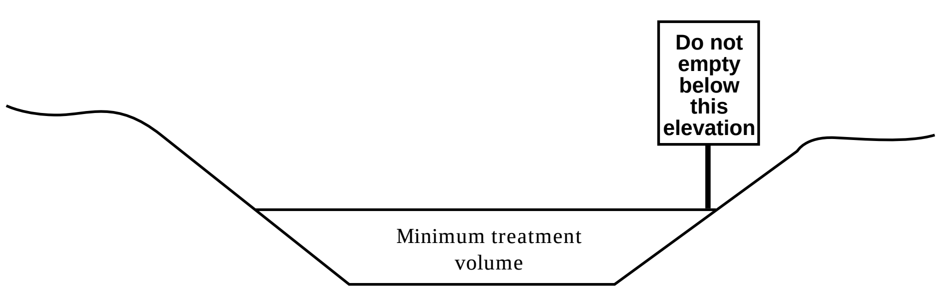
(e) Transfer function operation

Transfer function components include reception pits, pipelines, picket dams, pumps, and other equipment, such as tank wagons, agitators, chopper-agitation pumps, and elevators. A surveillance type inspection should be recommended to assure that the components are functioning properly.

A clean water flush following use of pipelines, tank wagons, and conveyors is helpful in minimizing the build up of sludge. Methods for unplugging pipelines should be described. Draining of pipelines or other protective freeze protection measures should be addressed.

Struvite, a phosphate mineral that can form a hard-scale deposit in pipelines and other similar waste transfer components, is a potential problem in an AWMS that utilizes recycled lagoon or waste storage pond effluent for flushing. Occasional clean water

Figure 13–2 Maintenance of minimum treatment volume



flushes of the transfer component or addition of struvite formation inhibitors to the wastewater may be effective in reducing struvite buildup. If a struvite buildup occurs, the system may need to be cleaned with an acid solution.

Proper agitation prior to transfer needs to be described in the AWMS plan. Agitation should be continued long enough so that the solids in the waste, including those in corners and recesses, are moved into suspension. The plan should address the spacing and duration of agitation. It should also give any precautions needed during agitation to prevent damage to pond liners. The consequences of inadequate agitation can be solids buildup, which can lead to difficult problems.

(f) Utilization function operation

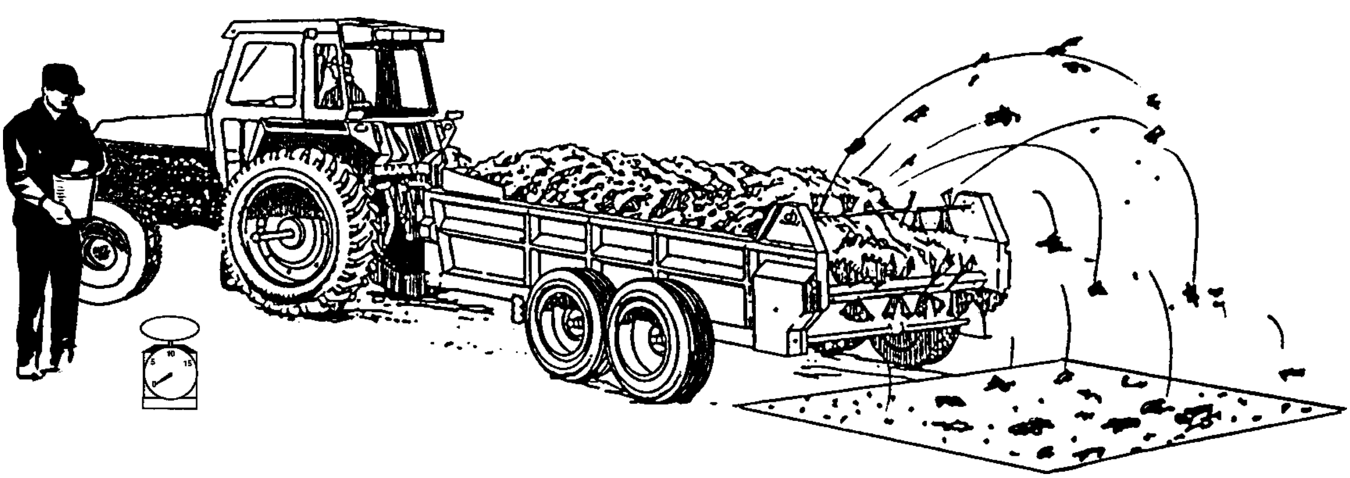
Utilization is a function in an AWMS for the purpose of taking advantage of the beneficial properties of agricultural wastes, such as its nutrient content. Components of utilization are land application of nutrients and biogas generation. Land application is the most prevalently used method.

The AWMS plan should establish the amount, method, placement, and timing of land application of agricultural wastes. The timing required should consider climate and stage of crop growth to maximize crop uptake and minimize environmental impact. Timing should also consider the potential for premature germination of planted crops if the waste is applied too early. Testing the waste and the soil for nutrient content must be recommended as good practice for use in determining the actual rates of application. See appendix 13A for more information on manure testing.

For liquid waste applied with an irrigation system, the plan should give sprinkler numbers, size and types of sprinklers, length of setting, and flow rates of waste and dilution water, if any. For slurry or solid wastes, the plan should indicate the necessity of calibrating spreading equipment to assure the desired rate of application is achieved (fig. 13–3). Appendix 13A also describes several methods of manure spreader calibration.

Utilization involving biogas/methane production and recovery requires a high level of management to be successful. Complicating the operation of a digester is coordinating use of gas once it is produced. Since compression and storage of biogas is not practical, its use must generally match the energy production. The designer of the biogas system must be involved in developing the specific operational requirements.

Figure 13–3 Manure spreader calibration



Methane production and recovery system options include the covered anaerobic lagoon, complete mix digester, and plug flow digester. Because each operates at a constant level and does not provide for waste storage, they must be operated in conjunction with a storage facility of some type. Operation of biogas components is dependent upon proper loading of waste in terms of volatile solids, total solids, and waste volume. As such, their loading must be carefully monitored. Some manure requires treatment, such as solid/liquid separation and dilution, before it enters a lagoon or digester. The amount of gas produced is a good indication of proper loading. If gas production falls off, the loading should be checked.

(1) Covered anaerobic lagoon

Operation of a covered lagoon for biogas production is much like that of a lagoon not associated with biogas production. The exceptions are that it is operated to have a constant liquid level, loaded at a higher rate, and has a minimum hydraulic retention time.

The inlet and outlet of the covered lagoon must remain free-flowing to maintain the required liquid level. The lagoon cover requires special attention to assure that methane produced is captured and directed to where it will be used. The cover should be periodically inspected for accumulation of excessive rainwater, tearing, wear holes, and proper tensioning. Excessive rainwater should be removed in the manner prescribed by the designer, usually by pumping or draining it into the lagoon or storage facility.

(2) Complete mix and plug flow digesters

These digesters require a constant temperature within a narrow range of variation to produce an optimum amount of biogas. Temperature is maintained by a heating system. The digester operating temperature must be monitored and kept within the temperature range specified by the designer. If the heating system is not functioning properly, waste should be routed around the digester to the storage facility. Both digesters have a cover of some kind. Like the lagoon cover, they must be periodically inspected to assure they are in good condition and are directing the gas to the exit point.

Effluent from anaerobic digesters has essentially the same amount of nutrients as the influent. As such, the O&M plan must address use of the effluent for land application.

651.1302 Maintenance

Maintenance of an AWMS includes actions that are taken to prevent deterioration of the system components, to repair damage, or to replace parts. Maintenance includes routine and recurring actions. The purpose of maintenance is to assure proper functioning and to extend the service life of AWMS components and equipment.

The two types of maintenance required by an AWMS are preventive and reactive. Preventive maintenance involves performing regularly scheduled procedures, such as lubricating equipment and mowing grass. Reactive maintenance involves performing repairs or rehabilitation of system components and equipment when they have deteriorated or cease to function properly. Examples of reactive maintenance include repair of a leak in a waste storage structure and replacement of a badly corroded piece of pipeline.

Essential to reactive maintenance is the discovery of items requiring attention before there is a serious consequence. Timely discovery can best be accomplished by regularly scheduled inspection of the AWMS components and equipment. The general maintenance and inspection requirements that should be considered for inclusion in the AWMS plan for each function of an AWMS are described in this section.

Proper maintenance of equipment used in an AWMS is essential for continuous operation. A thorough inventory of each function and its related equipment is recommended as a way to organize what must be maintained. The AWMS plan should recommend actions that will assist in the maintenance of equipment. An action to include would be collecting and filing information on equipment, such as name plate data, shop manuals, catalogs, drawings, and other manufacturer information. Other actions to recommend:

- Prepare checklists that give required maintenance and maintenance frequency.
- Keep a log book of the hours each piece of equipment is used to assist in determining when maintenance should be performed.
- Keep a replacement parts list indicating where the parts can be obtained.
- Keep frequently needed replacement parts on hand.

(a) Production function maintenance

(1) Roof gutters and downspouts

A good time to inspect roof gutters and downspouts is during storm events when leaks and plugged outlets can easily be discovered. Maintenance items would include cleaning debris from the gutters, unplugging outlets, repair of leaks, repair or replacement of damaged sections of gutters and downspouts, repair of gutter hangers and downspout straps, and repair of protective coatings.

(2) Diversions

Maintenance of diversions includes, as appropriate to the type of construction, mowing vegetation, eliminating weeds, repair of eroded sections, removal of debris and siltation deposits, and repair of concrete. Inspections should be made on a regularly scheduled basis and after major storm events.

(b) Collection function maintenance

Maintenance requirements for the collection function are primarily directed at mechanical equipment. Regularly scheduled lubrication and other preventive maintenance must be performed on electric motors, sprockets, and idle pulleys according to the manufacturer's recommendations.

Flush systems employ pumps, valves, and mechanical equipment involving gear boxes, stems, and guides. This type equipment also needs regularly scheduled preventive maintenance. Broken sprockets, idle pulleys, drive cables and rods, chains, and scraper blades must be repaired when they are seen to be damaged.

Tractors used in collection must be regularly maintained according to the manufacturer's recommendations. Equipment used in collection must be under constant surveillance to assure continuous and proper operation. Grates and covers on reception pits must be kept in place and in good condition.

(c) Storage function maintenance

(1) Waste storage ponds

Regularly scheduled inspections and timely maintenance are required for waste storage ponds because their failure can result in catastrophic consequences. The consequences of failure may affect public safety and environmental degradation. Inspections should focus on and result in the repair of leaks, slope failures, excessive embankment settlement, eroded banks, and burrowing animals.

Flow from toe and foundation drains should be inspected for quantity of flow changes and for discoloration. If flows from these drains suddenly increase, it could mean a leak has developed. If the flow is normally clear and suddenly becomes cloudy with silt, piping of the embankment could be suspected. Appurtenances, such as liners, concrete structures, pipelines, and spillways, need to be inspected and repaired if found to be deficient. Vegetative cover needs to be routinely maintained by mowing, and weeds and woody growth need to be eliminated. Safety features, such as fences, warning signs (fig. 13–4), tractor stop blocks, and rescue equipment, need careful maintenance.

Earthen waste storage ponds should be inspected carefully during and after they are emptied. Generally, these ponds are completely emptied over a short time. A consequence of this drawdown may be inside bank failures, especially where the pond is constructed in heavier soils or has an imported soil liner constructed

Figure 13–4 Waste storage pond warning sign

of heavier soils. Therefore, it should be recommended that the pond be carefully inspected during and immediately after emptying. Some pond features are best inspected when the pond is filling or is full. For example, inspection for toe drainage and foundation leaks is best done when the pond is filling or full.

(2) Waste storage structures—tanks

Inspection and maintenance of waste storage tanks depend on the type of tank and the material used in construction. However, regardless of the construction they should be inspected regularly for leaks and degradation. Concrete tanks should be inspected on a regularly scheduled basis for cracks and degradation of the concrete. Any sudden or unexpected drop or rise in the liquid level should be documented, the cause investigated, and the problem corrected.

Inspection or repair of waste storage tanks is a hazardous undertaking because it may involve entry into the tank where toxic, oxygen displacing, or explosive gases may be present. The safety section of this chapter gives a procedure for safe entry into confined spaces. Because of the caustic nature of wastes, a specialist in the repair of concrete should be consulted if cracks or degradation of concrete are observed.

An important consideration for below ground tanks is maintaining the water table below the elevations assumed in the design of the tank. Drains installed to control the water table must be inspected on a regular basis to assure that they are operating properly. If applicable, a caution should be included in the AWMS plan that liquid waste or water should not be allowed to pond on the ground surface surrounding the tank. This ponding can result in hydrostatic pressures that exceed the tank's design loadings, which can cause cracking or uplift.

A popular material for aboveground waste storage tanks is fused glass-coated steel. This material is virtually indestructible to the caustic action of the waste if the coating remains intact; however, deterioration of the steel may result if the coating is damaged. As such, it is important that the surface of these tanks be regularly inspected and repairs made. The area around bolts should be checked for loss of coating and rusting. Repairs should be made according to the manufacturer's recommendations.

Cathodic protection is required for some installations. When included, the cathodic protection system should be inspected to assure that it is functioning properly. The cathodic protection inspection requirements are dependent upon the type of system installed. The designer of the cathodic protection should be consulted on what to include in the O&M plan.

Steel tanks generally are not designed to withstand a load against the outside of the tank. Because of this, waste or other material should not be allowed to build up against the outside wall of the tank.

Careful attention needs to be given to the maintenance of safety features associated with waste storage tanks. These features include warning signs, grates and lids for openings, fences, barriers, and rescue equipment. Grates, lids, and gates should be secured in place when left unattended.

(3) Waste storage structures—Stacking facilities

Concrete and lumber are used in the construction of waste stacking facilities. Concrete should be inspected for cracks and premature degradation. If any problems are found with the concrete, appropriate repairs should be made.

Lumber should be inspected for damage either by natural deterioration or from man, animal, or weather event causes. Damaged lumber should be replaced. Roofs should be inspected regularly for leaks and damaged trusses, and repairs made promptly.

(d) Treatment function maintenance

(1) Waste treatment lagoons

The inspection and maintenance requirements for a waste treatment lagoon are about the same as those for a waste storage pond. One difference is that ponds generally are completely emptied, whereas lagoons retain a minimum storage pool. Maintenance of aerated lagoons would be complicated by the aeration equipment involved. The AWMS plan should indicate that the maintenance of the aeration equipment is to be according to the manufacturer's recommendations.

(2) Composting facilities

Composting facilities vary widely mainly because there are several methods of composting. However, many facilities use standard construction materials, such as concrete, concrete blocks, lumber, and steel.

Concrete should be inspected regularly for cracks and deterioration, and repaired as necessary. Lumber should be inspected for deterioration and physical damage, and replaced if found to be nonservicable. Protective coatings for steel structures should be inspected and repaired when damage is found. Manufactured composters should be maintained according to the manufacturer's instructions.

(3) Solid/liquid separation facilities

Settling basins are constructed of earth, concrete, or other material. Inspection and maintenance of these facilities are much the same as those for components constructed of similar material.

Screening devices are generally constructed using various kinds of steel. These devices should be inspected regularly for deterioration of protective coatings, and repaired as necessary. Many of these devices also involve the use of electric motors, pumps, and gears. These should be routinely maintained as recommended by the manufacturer.

(4) Oxidation ditches

The channel for oxidation ditches is generally constructed of concrete. The concrete should be inspected regularly for cracks and deterioration, and repairs made as needed. The rotor should be lubricated regularly and inspected for proper operation. Other equipment, such as pumps, agitators, and valves used in its operation, should be maintained as recommended by the manufacturer.

(e) Transfer function maintenance

Components and equipment for the transfer function of an AWMS vary widely. Manufactured transfer equipment, such as pumps, conveyors, and tank wagons, should be maintained according to the manufacturer's instructions. Pipelines should be inspected to assure that proper cover is maintained, vents are not plugged, valves are working properly, and inlet and outlet structures are in good condition.

(f) Utilization function maintenance

Waste utilization equipment includes solid manure spreaders, liquid manure spreaders, injection equipment, and irrigation equipment. The equipment should be maintained according to the manufacturer's recommendation.

If covered lagoons are used for biogas production, maintenance is similar to that needed for uncovered lagoons. The covered lagoons and other covered digesters need routine inspection of the covers or enclosures to check for tears or other opening that would allow gas to escape. Timely repairs must be made. The covered lagoon is generally designed for a constant level that is controlled by a pipe that discharges to either another lagoon or a waste storage pond. This pipe must be kept free of obstructions. Digestors accumulate sludge that must be periodically removed. Some digesters are heated, and use pumps to circulate heated water. These pumps must lubricated and impellers and seals repaired as necessary.

651.1303 Safety

Safety hazards are inherent to an agricultural waste management system. Some of these hazards lie hidden and await the unsuspecting. Others may be more obvious, but are just as formidable to the careless. For these reasons, attention to safety must always be given first consideration in the planning, design, construction, and operation of an AWMS.

Hazards associated with an AWMS can be minimized by incorporating safety features in the design and consequent construction of AWMS components. The AWMS plan needs to address operation and maintenance of these safety features. The safe operation requires that those involved in its operation be aware of the system's hazards, follow procedures of safe operation, and maintain its safety features. These procedures must be clearly defined in the AWMS plan.

Hazards associated with an AWMS are many and lurk in each of its functions. Because safety hazards of similar nature are not limited to one function, they will be described as those associated with gases, impoundments, and equipment operation.

Most states have rules and regulations for occupational safety and health in agricultural operations. The state occupational safety and health agency should be contacted to determine applicable regulations. The AWMS plan should be developed to be in accordance with these rules and regulations and the type of hazards that will be involved in the AWMS.

(a) Hazards from gases

A variety of gases can be generated in the operation of an AWMS. 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. What makes these gases especially insidious is that some are colorless and odorless, and defy detection except with specialized equipment. Colorless gases produced by an AWMS include carbon dioxide, ammonia, hydrogen sulfide, and methane. Numerous odorous gases are produced by an AWMS. These gases fall into the general classification of amines, amides, mercaptans, sulfides, and disulfides.

No direct tie between odors and safety problems has been found; however, odors can be a nuisance and cause complaints and even lawsuits. As such, they are an important consideration in the operation of an AWMS and need to be minimized. Chapter 8, Siting Agricultural Waste Management Systems, describes ways that odor problems can be minimized.

Gases can accumulate in any area of an AWMS where proper ventilation is not provided, such as animal housing and covered manure impoundments. Certain activities, such as agitation, can release gases that can cause problems if the facility is not properly ventilated. The major gases that may be produced by an AWMS and the consequences if these gases are encountered by humans and animals are described in the following paragraphs.

(1) Gases produced in an AWMS

Carbon dioxide (CO_2)—Carbon dioxide is a by-product of manure decomposition. Most of the gas bubbling up from storage and lagoons is CO_2. Carbon dioxide is not highly toxic in itself, but contributes to oxygen deficiency or asphyxiation. Concentrations above 10 percent (by volume) can cause a human to pant violently, and at increased levels are narcotic even if adequate oxygen is available. At 25 percent concentration, death occurs to humans after a few hours. Animals can tolerate up to a 7 to 9 percent CO_2 concentration, but with considerable discomfort. Concentrations above 10 percent may cause dizziness and even unconsciousness in animals.

Ammonia (NH_3)—Ammonia is released from fresh manure and anaerobic decomposition. Odors from as little as 0.0001 percent concentration can be detected and identified. Mixtures over 16 percent with air are explosive. Low concentrations, 0.0025 to 0.0030 percent, can irritate eyes and the respiratory tract of humans; higher levels can cause suffocation. Ammonia is an irritant to animals at concentrations up to 0.02 percent inducing sneezing, salivation, and appetite loss. Above 0.005 percent, eye inflammation develops in chickens. Prolonged exposure may increase respiratory diseases and pneumonia.

Hydrogen sulfide (H_2S)—Hydrogen sulfide is produced by anaerobic decomposition of organic wastes. It smells like rotten eggs at low concentrations, but cannot be detected at higher concentrations because it overpowers the sense of smell. High concentrations can be released by agitation and pumping. H_2S is the most toxic gas associated with manure storage, being both an irritant and asphyxiant. It is also flammable. Low concentrations severely irritate the eyes and respiratory tract of humans within an hour. Concentrations of 0.1 percent cause immediate unconsciousness and death through respiratory paralysis. Animals living continuously in facilities where the level of H_2S is 0.002 percent develop nervousness, appetite loss, and fear of light. Concentrations at 0.005 to 0.02 percent can cause vomiting, nausea, and diarrhea.

Methane (CH_4)—Methane is an odorless gas produced by anaerobic decomposition of organic wastes. It is not normally considered a toxic gas; however, it is highly explosive when mixed with air in concentrations as low as 5 percent. Lighter than air, methane tends to accumulate near the top of stagnant corners of buildings or covered manure impoundments. Accumulations of methane can be asphyxiating to both humans and animals; however, explosions are a more serious concern.

Carbon monoxide (CO)—Carbon monoxide gases in an AWMS result from operation of internal combustion engines and from gas, oil, and coal heaters rather than the decomposition of organic wastes. CO is mentioned because it is generated by equipment used in the operation of an AWMS. It is a colorless, odorless, toxic gas that can cause drowsiness at low concentrations and death at high concentrations.

(2) Gas hazard situation categories

Gases generated by an AWMS can be lethal if ventilation systems break down, during agitation of waste, and in poorly ventilated confined spaces, such as manure tanks including those that are uncovered. The hazards to both humans and animals include death, incapacitation, impairment of the ability to self rescue, or acute illness. A hazardous atmosphere occurs when flammable gases and vapors reach their flammable limit, when oxygen concentration is below 19.5 percent or above 23.5 percent, and when concentration of toxic gases exceeds permissible exposure limits. The AWMS plan should address these hazards and how to appropriately remediate or improve them. It is important that others, such as family members, who may frequent an AWMS be aware of the hazards of these situations as well.

Ventilation breakdowns—Ventilation depends on properly operating fans or vents. With no natural drafts to replenish the air in confined areas, death by asphyxiation from lack of oxygen and increased carbon dioxide, by poisoning from other gases, or by some combination of these can occur. Operators must be alert to failure of ventilation systems and take immediate action to either repair the system or activate a backup system until repairs can be made. Operators must also be aware of the dire consequences of purposely blocking ventilation systems, which may be considered during cold weather to reduce heat loss.

Agitation—Agitation of wastes to facilitate transfer and other waste management functions is a common practice in an AWMS. This activity may release large quantities of noxious gases and create dangerous and possible lethal conditions even with maximum ventilations. If agitation is done outdoors, it seldom is a problem; however, lethal conditions are a potential when it is done within buildings. To minimize the hazards, agitation should be done on mild days so the building can be ventilated to full capacity. For naturally ventilated buildings, it is best done on windy days. Animals should be removed from the building before the agitation is started, but if they are not removed, they should be observed for signs of ill effects.

Confined space—Death resulting from persons entering a covered waste storage tank or other confined space in an AWMS occurs all too often in the United States. Multiple deaths frequently occur when the first person to enter the confined space and the would-be rescuers all succumb to the atmosphere of the facility. These are tragic occurrences, and every safety precaution should be used to prevent them.

Often a person enters a tank as a spur-of-the-moment reaction to the desperate need for assistance to an animal or person who has accidentally fallen into the facility. Steps can be taken to avoid this type of accident. First, the AWMS design should include, and its plan should indicate, maintenance of such devices as grates and covers that prevent accidental entry from happening. Design consideration should also be given to:

- Features that minimize the need for confined space entry.
- Provisions that allow for maintenance of equipment outside the space or for equipment parts that can be easily retracted for maintenance.
- Corrosion resistant equipment that performs with minimum maintenance in caustic environments.
- Power ventilation systems that provide for both a supply of fresh air and exhaust of accumulated gases.

Secondly, the people who operate or frequent an AWMS must be made aware of the absolute rule that no one enters these facilities under any circumstance unless preparations have been made for their safe entry. Signs (fig. 13–5) should be prominently posted and maintained that warn of the hazard. Children and those that cannot read must be given special instruction to assure that they are aware of the hazard.

Entry into a confined space is sometimes necessary. Examples include:

- To inspect a tank for cracks and leaks.
- To rescue someone or something.

Confined spaces should, however, only be entered after preparations have been made for a safe entry. For this reason, the AWMS plan needs to address safe entry into confined spaces.

Some States may regulate entry into confined spaces for agricultural operations. The appropriate occupational and safety agency should be contacted to determine what the requirements are. The U.S. Department of Labor, Occupational Safety and Health Administration, has rules and regulations on entering confined spaces (Federal Register 1993). The regulatory aspects of these rules do not apply to agriculture. However, from a safety standpoint these rules should be followed to ensure the safety of persons required to enter hazardous confined spaces. Following is a summary of the practical aspects of these rules as they apply to entry of AWMS confined spaces:

- Any condition making it unsafe to remove an entrance cover to a confined space shall be eliminated before the cover is removed.
- When entrance covers are removed, the opening shall be promptly guarded by a railing, temporary cover, or other temporary barrier that will prevent an accidental fall through the opening and will protect persons working in the space from objects entering the space.
- Before a person enters the space, the internal atmosphere shall be tested with a calibrated direct-reading instrument for the following conditions in the order given:
  1. Oxygen content
  2. Flammable gases and vapors
  3. Potential toxic air contaminants

Figure 13–5 Confined space warning signs

- No hazardous atmosphere can be within the space whenever any person is inside the space.
- Continuous forced air ventilation shall be used as follows:
  - † A person may not enter the space until the forced air ventilation has eliminated any hazardous atmosphere.
  - † The forced air ventilation shall be so directed as to ventilate the immediate areas where a person is or will be present within the space and shall continue until all persons have left the space.
  - † The air supply for the forced air ventilation shall be from a clean source and may not increase the hazards in the space.
- No one should enter a confined space without a qualified safety watcher stationed outside the space. Persons entering confined space should know the hazards that may be faced during entry, be equipped with a full body harness with a retrieval line attached to a mechanical rescue device, and be able to communicate with a safety watcher. The safety watcher must be able to communicate with those inside the space and be able to perform the actions required to retrieve those inside the space.
- The atmosphere within the space shall be periodically tested as necessary to ensure that the continuous forced air ventilation is preventing accumulation of a hazardous atmosphere.
- If a hazardous atmosphere is detected during entry:
  - † Each person shall leave the space immediately.
  - † The space shall be evaluated to determine how the hazardous atmosphere developed.
  - † Measures shall be implemented to protect persons from the hazardous atmosphere before any subsequent entry takes place.

To fully implement the above procedure, the AWMS plan should recommend employing a safety professional who has the training and the testing equipment necessary to ensure a safe confined space entry. Local or State Government safety agencies may provide this service upon request. Some States require insurance companies that supply coverage for occupational accidents to provide their clients with consultation services on safety related problems.

A well thought-out plan of action for dealing with emergencies involving accidental entry into confined spaces needs to be included in the AWMS plan. The plan should recommend that the decisionmaker educate all who are involved in the operation of an AWMS in carrying out the plan. An AWMS plan should:

- Include a rescue service that could be called for assistance in an emergency.
- Suggest that equipment needed for emergency rescue, such as self contained breathing apparatus, life lines, and harnesses, be close at hand.
- Address the specific hazards from gases in each of the applicable functions of the AWMS.

Safety equipment used in confined space is described in chapter 12.

(b) Hazards with impoundments

Impoundment type components, such as waste storage ponds, waste treatment lagoons, and waste storage tanks, present a drowning hazard. The hazard for earthen waste impoundments is similar to that associated with any farm pond. However, crusts that may form on the water surface and slime formation make waste impoundments more hazardous.

Crusts have the appearance that they would support a person's weight; however, they often will not. The consequence of falling through the crust on a waste impoundment would be similar to falling through the ice on a pond—there is no escape. Slime that forms on the surface of impoundments makes them very slippery, and as such makes it easy for a person to loose their footing on inclines. In cold climates, ice formation can make any surface unsafe. Geotextile liners are generally smooth, and when wet they are so slippery a foothold cannot be achieved.

The best approach to minimizing the hazards of drowning in waste impoundments is to include features in the design to exclude both animals and people (fig. 13–6). This can be accomplished with fences and warning signs. Gates should be locked to limit access except to those who need to enter the impoundment area. Provision needs to be provided for emergency exit in case someone accidentally enters these areas. Prominent signs indicating the hazard should be displayed. The AWMS plan needs to emphasize the importance of maintaining these safety features.

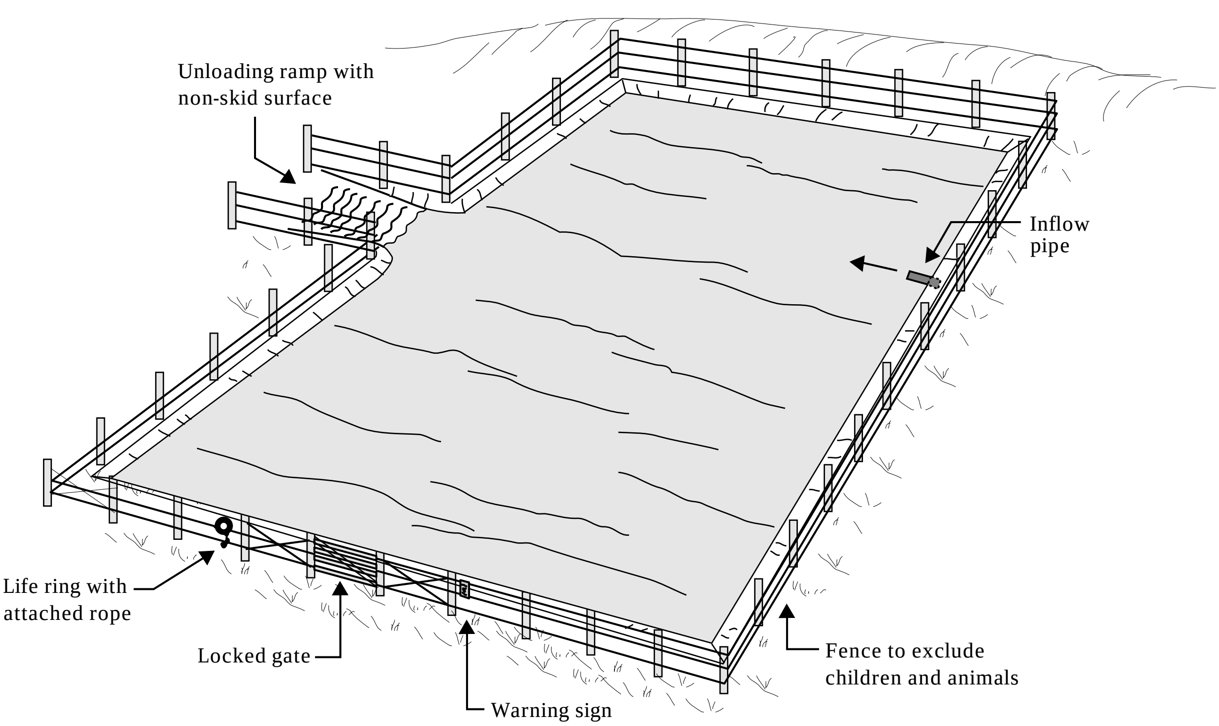
On some occasions, personnel must operate near these impoundments. The AWMS plan should recommend that life rings, life lines, poles, and boats be close at hand to assist in making a rescue.

Design of push-off ramps should include:

- Sturdy guard rails to prevent people and equipment from falling into waste impoundments.
- Loading ramps with a traction surface to minimize slipping.
- Walkways constructed of nonslip surfaces.

People can do little to escape if they fall into a storage tank with vertical walls. The side of the tank is slick and has nothing to hang onto unless it is provided. For this reason tank access should be limited to those who have need for entry. A ladder on the outside of the tank should terminate above the reach of people or should have locked entry guards.

Figure 13–6 Waste storage pond safety features



Some tanks have platforms for such equipment as solid/liquid separators and pumps. The platform should be equipped with guard rails to prevent accidental falls into the tank. A rope dangling from the platform would allow improved opportunity for survival from an accidental fall from the platform into the tank.

Providing a means of survival from accidental entry should also be considered for below-ground tanks; however, whatever is done should never invite entry. Examples of things to consider include:

- A ladder hinged to the tank cover that can be pulled down with a rope to allow escape.
- Perches installed on the tank floor or wall that a person can stand on to attain fresh air and call for help.

The AWMS plan should discuss the specific hazards of impoundments in each applicable function. Generally, this hazard would be discussed in an AWMS plan for systems that have waste storage ponds or tanks in the storage function and for systems that have waste treatment lagoons in the treatment function. See chapter 12, section 651.1204, for additional information on safety equipment for impoundments.

(c) Hazards in equipment operation

Equipment used in an AWMS is varied. Chapter 12, Waste Management Equipment, describes equipment used in an AWMS, as well as safety aspects of equipment operation. A few guiding principles in the safe operation of equipment should be included in the AWMS plan. Safety procedures should also be included. The procedures could include:

- Assuring that moving parts that would expose an operator to injury are properly guarded.
- Providing and using backup signals on equipment as appropriate.
- Maintaining electrical equipment and assuring that it is properly grounded.

Perhaps the most important safety precaution is assuring the equipment operators are trained in the safe use of the equipment before being allowed to operate it. This should be recommended in the AWMS plan. It is equally important that operators only be allowed to use equipment when they are well rested and not under the influence of a drug, prescribed or otherwise, which would impair their ability to operate the equipment safely.

The decisionmaker should be advised in the AWMS plan of the necessity of requiring workers to use personal protective equipment when appropriate (fig. 13–7). Rollover protective structures and seat belts should be on all equipment that is ridden. Safety belts should be used if there is a potential of falling.

Because many surfaces in an AWMS are slippery, shoes or boots with soles having good traction should be used. Hearing protection should be used if the noise level and duration would contribute to hearing loss. Operators should use eye and face protection if machines or operations present potential eye or face injury. Work areas should be well ventilated. If they are not, workers should use appropriate respiratory protection. Proper lighting is also important in providing a safe work environment.

The AWMS plan should discuss the specific hazards of the equipment used in each function of the AWMS.

Figure 13–7 Personal safety equipment

651.1304 Agricultural waste management system plans

The purpose of an AWMS plan is to convey to the decisionmaker details of the construction and O&M requirements of the system. It is important to remember this in its preparation. As such, the plan should have an easily followed format, use familiar terms, and be concise. It should be neat, invite reading, and be worthy of retention. Presenting the plan to the decisionmaker in a 3-ring binder encourages retention. An electronic copy could be provided those decisionmakers having computers. See Chapter 2, Planning Considerations, and Chapter 9, Agricultural Waste Management Systems, for more information on the AWMS plan.

The preparation of the AWMS plan requires input from all disciplines involved in the planning and design of the system. Information from the AWMS's planning documentation must be extracted for inclusion in the plan. This would include information extracted from inventories, investigation reports, alternatives considered, design reports, installation schedules, and other information that is necessary for explaining the system requirements. However, it is generally not appropriate to include the planning and design documents in their entirety.

An AWMS component design report should be reviewed to ascertain O&M activities that may have been identified as necessary for the component's performance. These O&M activities should be included in the O&M plan. The plan should include maps, charts, and other illustrative aids that enhance understanding of the system's O&M requirements. Appendix C is an example AWMS plan for a simple agricultural waste management system. A suggested format follows.

Name, address, and location of AWMS—This is self-explanatory.

General statement—Should indicate the purpose of the AWMS and the importance of O&M.

General description of AWMS—Should include the type and size of operation and the basic components of the AWMS. Including a plan view drawing of the component layout would be helpful for describing the AWMS.

Decisionmaker's responsibilities—It is suggested that this section clearly state that proper and safe system operation and maintenance within the laws and regulations are the responsibility of the decisionmaker.

Component installation schedule—Should consider proper sequence of installation so that each component will function as intended in the system.

Operation and Maintenance of production, collection, storage, treatment, transfer, and utilization functions— The specific O&M requirements for each function of the AWMS should follow the component installation schedule section. These requirements should expand on the general O&M considerations described in this chapter and include the appropriate safety requirements.

Decisionmaker's acknowledgment—This last section is intended to include a signature line allowing the decisionmaker to attest to having read and understood the plan.

651.1305 References

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651.1350 Appendix 13A—Calibrating Manure Spreaders

Appendix 13A Calibrating Manure Spreading

The use of animal manure as a cropland fertilizer is economically and environmentally important. However, farmers cannot simply spread manure. They must know the nutrient quality of the manure and control the quantity and uniformity of the manure spread to ensure that the entire crop receives the nutrients.

The nutrient content of the manure is estimated from laboratory tests, and the quantity to apply is determined through computations of crop need. Farmers can receive this information from their county Extension office or other nutrient management planners. In practice, farmers often do not know exactly how much or how uniformly manure has been applied. Manure spreader calibration provides this important information.

Manure spreaders can discharge manure at varying rates, depending on forward travel speed, PTO speed, gear box settings, discharge opening, width of spread, overlap patterns, and other parameters. Calibration defines the combination of settings and travel speed needed to apply manure at a desired rate. Following is a description of the measurement methods used to determine manure application rates and ensure uniform application.

Calibration techniques

Calibration requires the measurement of the quantity of manure applied to the soil under different conditions. There are two calibration techniques: the *load-area* method, which involves measuring the amount of manure in a loaded spreader and then calculating the number of spreader loads required to cover a known land area; and the *weight-area* method, which requires weighing manure spread over a small surface and computing the quantity of manure applied per acre.

The calibration method to use depends on the type of manure spreader. Soil-injection, liquid manure spreaders must be calibrated using the load-area method because soil-injected manure cannot be collected. Liquid manure surface applied through a tank spreader is also best measured by the load-area method because of the difficulty in collecting the liquid manure, but it can be measured with the weight-area method. Solid and semisolid manure also can be measured with either method.

Load-area calibration

Load-area calibration requires measuring the quantity of manure (tons or gallons) held in a spreader load; spreading a number of identical loads at a constant speed, spreader setting and overlap; measuring the total area of the spread; and computing the quantity of manure applied per acre. After completing the following steps, record the calculations on Worksheet 1, Manure Spreader Capacity and Worksheet 2, Load-Area Calibration.

Step 1. Determine the capacity of the manure spreader. The capacity of the manure spreader must be expressed in units compatible with the units used for the nutrient analysis and recommended application rate. In some cases, the manufacturer provides the appropriate information; in other instances. the manufacturer's information must be converted.

Liquid manure. Liquid manure analysis is expressed in pounds of nutrient per gallon and the application rate is provided in gallons per acre; therefore, use gallons to express the capacity of a liquid manure spreader. Manufacturers specify liquid manure spreaders by gallons of volumetric capacity. This information can be found in the owner's manual.

Solid and semisolid manure. Solid and semisolid manure analysis is expressed in pounds of nutrient per ton and the application rate is provided in tons per acre; therefore, solid and semisolid manure spreader capacity must be expressed in tons of manure.

Solid and semisolid manures of different moisture content have different weights; thus, the weight capacity of the spreader changes according to the kind of manure held. The most direct and accurate method of determining the weight of a load of manure is to actually weigh the spreader load on farm scales. If scales are not available, use the procedure in the next section to convert the volumetric capacity of the spreader to weight capacity for the particular manure held. Record your calculations on Worksheet 1, Manure Spreader Capacity.

Converting volumetric capacity to weight capacity. The volumetric capacity of box-type and open-tank or barrel spreaders for solid and semisolid manure is expressed in cubic feet. The manufacturer provides this information in the owner's manual. Two capacities are usually provided: heaped load (manure piled higher than the sides of the box) and struck load (the volume contained within the box). The capacity of older spreaders is sometimes designated in bushels; multiply the bushel capacity by 1.24 to determine capacity in cubic feet.

Multiply the volumetric capacity in cubic feet by the bulk density of the manure (in pounds per cubic foot) and convert it to tons. Bulk density depends on the amount of water, solids and air in the manure and can be measured by weighing a known standard volume of manure. A 5-gallon bucket has a volume of 2/3 cubic foot and can be used as a standard volume as follows:

1. Weigh the empty bucket and write the weight on the side of the bucket. This establishes the bucket's tare weight (the container weight subtracted from the gross weight to determine the weight of the manure).
2. Fill the bucket with manure from the loaded spreader. Use all the space in the bucket and pack the manure to the same density as in the spreader.
3. Weigh the full bucket and subtract the tare weight. The result is the manure weight in pounds.
4. Multiply the manure weight by 3 and then divide the product by 2. This gives the manure bulk density in pounds per cubic foot of volume.
5. Multiply the manure bulk density (in pounds per cubic foot) by the spreader capacity (in cubic feet) to get the weight of the spreader load in pounds. Divide by 2,000 to get tons.
6. Repeat this procedure at least three times. Sample the manure at different places and in different spreader loads. Average the values to obtain a representative composite of the manure.

Step 2. Spread manure on a selected field. Spread at least three full loads of manure on a field. Maintain the same speed and spreader setting for each load. Choose spreader path spacing to achieve what appears to be the most uniform coverage. Try to spread in a rectangle or square for easy calculation.

Step 3. Measure the area of the spread. Place flags at the corners of the spread area. Measure the width and length between the flags in feet using a measuring tape, measuring wheel, or consistent pace. Multiply the length by the width and divide that product by 43,560 to determine the area in acres.

Step 4. Compute the application rate. Multiply the number of loads spread by the number of tons or gallons per load to determine the total amount of manure applied to the area. Divide the total amount of manure by the area of the spread in acres to determine the application rate in tons per acre or gallons per acre.

The load-area method should be repeated at different speeds and spreader settings until the desired application rate is obtained. Maintain a record of the application rates at different settings to avoid recalibrating the spreader each season.

Weight-area calibration

Spreader calibration by weight-area requires laying out a ground sheet of known dimensions on the soil; spreading manure over it at a selected speed, spreader setting and overlap; retrieving the ground sheet and the manure deposited on it; weighing the manure retrieved; and computing the quantity of manure applied per acre. The weight-area method does not require measuring the amount of manure in the spreader. As you complete the following steps, record your calculations on Worksheet 3. Weight-Area Calibration.

Step 1. Select a manure collection surface. A ground sheet can be a cloth or plastic (6 mil) sheet of at least 100 square feet (10 feet by 10 feet) in area. Multiply the length of the sheet by the width to determine its area in square feet.

Liquid manure may run off a flat ground sheet; shallow plastic or metal pans are more useful. The pans should have a minimum area of 1 square foot each. Multiply the length of one pan by its width to determine the area of one pan. Multiply the area of one pan by the number of pans used to determine the total collection area in square feet. For handling and cleaning convenience, place the pan inside a plastic garbage bag for each field test so that the bag and manure can be discarded leaving the pan clean. Six or more pans are necessary for a test.

Weigh the ground sheet or pan and record the weights for use as a tare weight in calculations. Dirty sheets and pans can be used for multiple tests only after major manure deposits have been removed. Dirty sheets and pans must be weighed before each test so that any manure residue is included in the new tare weight.

Step 2. Secure the collection surface in the field. Lay the ground sheet out fully extended. Lay the sheet on the ground so that as the sheet is removed from the field the manure applied over the surface can be collected easily in its folds. If dirty sheets are being used for additional tests turn the dirty side up so that any manure residue included in the tare weight is not lost. Weights of stone metal or earth clods will be required to hold the ground sheet on the soil surface. A small breeze can easily fold the sheet or tractor wheels and forceful applications of manure can move it.

Pans are not as easily affected by wind, but may be moved by forceful streams from side outlet manure spreaders. Evenly space pans in a row perpendicular to the spreader's path. Pans are easily crushed by tires; allow for wheel tracks and adhere to the path provided. Placing flags at designated wheel tracks helps avoid pan damage.

Step 3. Spread manure over the collection area. Spread manure over and near the ground sheet or pans in a manner that best duplicates the spreading pattern you plan for the field. With rear outlet spreaders, make three passes: the first pass directly over the center of the collection area and the remaining two passes on the opposite sides of the first pass with an overlap. With side outlet spreaders, locate a first pass off of, but along one edge of, the collection area. Follow with subsequent passes farther away from the collection area and at the intended overlap until manure no longer reaches the surface.

In all cases. start spreading manure far enough before the collection area to ensure that the spreader is functioning. If a ground sheet is folded or a pan is moved during a spread pass, investigate its condition before continuing with the test. Folded edges can be straightened without major loss of accuracy. If more than one-fourth of the surface has moved and did not receive manure, the test should be conducted again with a newly weighed sheet. Pans that have been crushed but retain the applied manure can still be used. Return moved pans to their original position.

Step 4. Collect and weigh the manure. Remove weights used to hold the ground sheet in place. Fold the ground sheet and manure in short sections from all sides and corners inward to avoid losing any manure. A 10-foot by 10-foot sheet folded with wet manure may weigh as much as 150 pounds and tends to slip around when carried; place it in a feed tub or other container for easier handling.

Pans are easy to handle and will usually weigh less than 4 pounds each. Careful handling is required to avoid spilling liquid manure.

Select scales capable of accurately weighing the type and quantity of manure collected. A single pan may collect from 2 ounces to 4 pounds and can be weighed with a kitchen scale. A ground sheet may collect from 10 to 50 pounds with application rates of less than 10 tons per acre. A ground sheet can be weighed with spring-tension or milk scales. A ground sheet with application rates greater than 10 tons per acre will require a platform balance with a capacity of 50 to 150 pounds or greater.

The weight indicated on the scale will include the tare weight of the ground sheet or pan as well as that of any container used to hold the ground sheet or pan during weighing. Subtract the tare weights from the total weight to determine the net weight of the manure collected.

Step 5. Compute the application rate. The number of steps and the procedure used to compute the application rate depend on the method of collection and the units per acre.

Ground sheet to tons per acre. Divide the net pounds of manure collected by the area of the ground sheet to obtain the manure application rate in pounds of manure per square foot. Multiply the result by 43,560 and then divide by 2,000 to convert to tons per acre.

Pans to tons per acre. Add the net weights of manure collected in individual pans to determine the total weight of manure collected. Divide the total manure weight by the total collection area to obtain pounds of manure per square foot. Multiply the result by 43,560 and divide by 2000 to obtain tons per acre.

Pans to gallons per acre. If working with weight from pans to determine liquid applications in gallons per acre, make an additional measurement to calculate the weight per gallon of manure. Fill a 5-gallon bucket with liquid manure of the same consistency of that applied. Weigh the bucket of manure and subtract the tare weight of the bucket to determine the net weight of 5 gallons of manure. Divide the result by 5 to determine the weight in pounds per gallon. Follow the procedure for "Pans to tons per acre" through obtaining pounds of manure per square foot. Then multiply by 43,560 and divide by pounds per gallon to obtain gallons per acre.

Uniformity testing

The results of nonuniform manure spreading are often indicated by the lush, green growth within the spreader paths and the not-so-lush growth between spreader paths. This occurs because more manure was deposited in and near the spreader path than farther away from the path. Uniform application can be obtained by adjusting the application overlap. The amount of overlap necessary can be determined by a uniformity test. As you complete the steps in this uniformity test, record your calculations on Worksheet 4, Uniformity Testing.

The test procedure is identical to the weight-area calibration method, using pans or a series of 24-inch by 24-inch ground sheet sheets laid out with equal spacing across two spreader path widths. After the manure is applied, each pan or sheet is compared with the others. Uniformity can be recorded when manure is spread to determine the application rate.

If all containers collect about the same amount of manure during a test, the application is uniform; if some collect more than others, the overlap should be adjusted. High application in the center of paths and low application between paths indicate a need to increase the overlap by decreasing the path spacing. Higher application between paths than within paths indicates a need to decrease overlap by increasing path spacing.

Shortcuts

Developing a range of application rates for different manure spreader speeds can be simplified if the spreader is PTO-powered and the tractor or truck is equipped with a groundspeed indicator. Conduct one test at low groundspeed and one at high groundspeed, maintaining the same spreader setting and PTO speed for both tests. Plot these two application rates on a graph of groundspeed versus application and draw a straight line connecting the two points. The application rate available at intermediate groundspeeds can then be estimated from the graph. Conducting additional high-low tests at different settings or at different PTO speeds will define a full range of available application rates.

If solid or semisolid manure changes moisture content from season to season, the weight capacity in the spreader and the application rate by weight will change. Adjust previously calibrated spreader conditions for these changes by determining the bulk density of the new manure. To estimate the field application rate for the new manure for a particular speed and spreader setting, multiply the old application rate by the new bulk density and then divide by the old bulk density. This calculation eliminates the need to repeat the field test every time manure properties change.

Summary

By measuring the application rate and uniformity of manure spreading, a farmer can be sure of the amount of manure nutrients applied to a crop. This measurement, called calibration, can be accomplished with a little time and a few dollars. For further information, contact your county Extension office.

Source—Adapted from Calibrating Manure Spreaders, Fact Sheet 419, Cooperative Extension Service, University of Maryland System, H.L. Brodie, extension agricultural engineer, and G.L. Smith, extension agricultural engineer, Department of Agricultural Engineering, University of Maryland at College Park, Published 1985-86, revised 1990-91.

Worksheet 13A–1—Manure Spreader Capacity

A. Description of spreader.

Manufacturer ________________________________ Model ________________________________

Type: ❏ box ❏ open-tank ❏ liquid-tank

Capacity: This information is available from your dealer or owner's manual.

Older models: bushels x 1.24 = cubic feet

Box or open-tank: ________ ft^3 struck load ________ ft^3 heaped load

Liquid-tank: ________ gal

B. For open-tank and box spreaders, determine the pounds per cubic foot of manure and the weight capacity of the spreader.

Type of manure: ❏ solid ❏ semisolid

1. Determine manure density using a 5-gallon bucket.

	Trial 1	Trial 2	Trial 3	
a. Empty bucket weight or tare weight	______	______	______	lb
b. Bucket filled with manure	______	______	______	lb
c. Net weight of manure (b – a)	______	______	______	lb
d. Manure density [(c x 3) ÷ 2]	______	______	______	lb/ft^3
e. Average of three trials	______ lb/ft^3			

2. Weight capacity of the spreader.

	Struck load	Heaped load
Spreader capacity	______ ft^3	______ ft^3
x	x	x
Manure density	______ lb/ft^3	______ lb/ft^3
=	=	=
Load weight	______ lb	______ lb
÷	÷	÷
2,000	______ tons	______ tons

Worksheet 13A–2—Load-Area Calibration

Liquid-Tank Spreaders (Liquid Manure)

1. Determine the capacity of the manure spreader. ________ gal
2. Spread at least three full loads at the desired speed, spreader setting and overlap.
3. Measure the area of the spread.
   a. Spread manure area width ________ ft
   b. Spread manure area length ________ ft
   c. Spread area (a x b) ________ ft^2
   d. Spread area in acres (c ÷ 43,560) ________ acres
4. Compute the application rate.
   e. Number of loads spread
   f. Capacity per load ________ gal
   g. Total manure spread (e x f) ________ gal
   h. Application rate (g ÷ d) ________ gal/acre

Box and Open-Tank Spreaders (Solid and Semisolid Manure)

1. Determine the capacity of the manure spreader. ________ tons
2. Spread at least three full loads at the desired speed, spreader setting and overlap.
3. Measure the area of the spread.
   a. Spread manure area width ________ ft
   b. Spread manure area length ________ ft
   c. Spread area (a x b) ________ ft^2
   d. Spread area in acres (c ÷ 43,560) ________ acres
4. Compute the application rate.
   e. Number of loads spread ________
   f. Capacity per load ________ tons
   g. Total manure spread (e x f) ________ tons
   h. Application rate (g ÷ d) ________ tons/acre

Nutrient application = tons/acre x pounds of nutrient per ton
or gallons/acre x pounds of nutrient per gallon

Worksheet 13A–3—Weight-Area Calibration

1. Select a manure collection surface.
   a. Determine collection area
   Ground sheet:
   width ________ ft x length ________ ft = area ________ ft^2
   Pans:
   pan width ________ inch x pan length ________ inch ÷ 144 = pan area ________ ft^2
   pan area ________ x number of pans ________ = collection area ________ ft^2

2. Secure ground sheet or pans.

3. Spread manure over the collection area.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Forward speed, gear or throttle setting	________	________	________	________	________
PTO speed	________	________	________	________	________
Spreader setting	________	________	________	________	________

4. Collect and weigh the manure and compute the application rate.

a. Tare weight of sheet or pan andweighing container	________	________	________	________	________	lb
b. Gross weight of sheet or pan, collected manure and weighing container	________	________	________	________	________	lb
c. Net weight of manure (b – a)	________	________	________	________	________	lb
d. Area of sheet or pans	________	________	________	________	________	ft^2
e. Application rate (c ÷ d)	________	________	________	________	________	lb/ft^2

Ground sheet or pans to tons per acre.

f. Application rate [(e x 43,560) ÷ 2,000]	________	________	________	________	________	ton/ac

Pans to gallons per acre.

g. Tare weight of a 5-gallon bucket	________	________	________	________	________	lb
h. Weight of a 5-gallon bucket full of manure	________	________	________	________	________	lb
i. Net weight of 1 gallon of manure [(h - g) - 5]	________	________	________	________	________	lb/gal
j. Application rate [(e x 43,560) ÷ g]	________	________	________	________	________	gal/ac

Nutrient application = tons/acre x pounds of nutrient per ton
or gallons/acre x pounds of nutrient per gallon.

Worksheet 13A–4—Uniformity Testing

1. Layout a line of small ground sheet sheets or pans of equal size, equally spaced across two spreader path widths

   a. Determine the pan or sheet area.

      width ________ inch x length ________ inch ÷ 144 = area ________ ft^2

2. Spread manure over the collection area.

   Forward speed, gear or throttle setting ________

   PTO speed ________

   Spreader setting ________

	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	
a. Tare weight of sheet or pan and weighing container	______	______	______	______	______	______	______	lb
b. Gross weight of sheet or pan, collected manure and weighing container	______	______	______	______	______	______	______	lb
c. Net weight of manure (b – a)	______	______	______	______	______	______	______	lb
d. Area of sheet or pans	______	______	______	______	______	______	______	ft^2
e. Application rate (c ÷ d)	______	______	______	______	______	______	______	lb/ft^2

Uniformity is achieved when all pans or sheets collect the same amount of manure. To improve uniformity, adjust spreader paths to increase or decrease overlap.

Published 1985-86
Revised 1990-91

651.1360 Appendix 13B—Manure, Soil, and Plant Testing

Appendix 13B Manure, Soil, and Plant Testing

Manure testing

(Source—Adapted from Manure Testing, Fact Sheet 430, Cooperative Extension Service, University of Maryland System, H.L. Brodia, extension agricultural engineer, Department of Agricultural Engineering, and V. Allan Bandel, extension soil specialist, Department of Agronomy, University of Maryland at College Park, published 1986-87, revised 1986-87, reprinted 1990, 1991.)

Manure analysis is a vital part of nutrient management planning for farms, which can save producers money and protect water quality.

Benefits

Agricultural waste must not be viewed as merely a disposal problem, but as a valuable resource. Applied at proper rates to cropland, manure improves the physical condition of the soil and reduces the need for commercial fertilizers.

Agricultural wastes, such as manure, are rich in plant nutrients. A recent report by Cornell University showed that approximately 75 percent of the nitrogen, 60 percent of the phosphorus, and 80 percent of the potassium fed to dairy cattle is excreted in manure (poultry and swine have higher values for phosphorus and potassium). In addition, manure supplies calcium, manganese, magnesium, zinc, copper, sulfur and other micronutrients.

Manure produced

Livestock produce valuable amounts of fertilizer. Chapter 4, Waste Characteristics, shows just how much fertilizer beef and dairy cows and broilers produce daily. Actual nutrient content of manure varies with type of animal, feed, manure storage system, and method of manure application.

The bottom line

Assuming no nutrient loss during handling and a value of $0.22 per pound for nitrogen, $0.20 per pound for phosphoric acid (P_2O_5), and $0.10 per pound for potash (K_2O) (based on 1991 pricing data):

- A 100-head beef herd produces $4,410 worth of fertilizer per year.
- A 100-head dairy herd produces $4,810 worth of fertilizer per year.
- A 100,000-bird broiler operation produces $3,485 worth of fertilizer per year.

Costs of not testing

Without manure analysis, farmers may be buying more commercial fertilizer than is needed or spreading too much manure on their fields. Either practice can result in overfertilization, which, in turn, may depress crop yields and cut profits. Improper spreading of manure also can pollute surface and ground water. Additionally, contamination of wells by nitrates and bacteria may increase health risks.

Manure analysis

To get an analysis of manure, take the following steps:

1. Contact the county Extension agent or your local testing laboratory for a Nutrient Management Kit. The kit may contain a manure sampling jar, soil test bags, record sheets and instructions. A fee may be charged with each soil sample.
2. Collect a *representative* manure sample. For daily spreading, take many small samples over a representative period. In a manure pack, collect samples from a variety of locations in the pile. Be sure to collect both manure and bedding materials. Agitate liquid manure systems before you collect samples.
3. Follow the specific instructions included in the kit for collecting samples from your liquid, solid or semisolid system with a minimum of mess and effort. The small samples collected should be mixed together in a clean bucket. Place a portion of the mixture in the sample jar.
4. Keep samples cool and deliver them to the county Extension agent early in the week to avoid storage over weekends or holidays.

Collect samples well in advance of the date manure is plan to be spread so the test results can be used to calibrate the manure spreader. With liquid waste systems it may be easiest to collect samples when the manure is pumped into the spreader. Use these test results to calibrate the spreader for future applications of manure, or to determine if additional chemical fertilizer is needed.

The manure sample should be analyzed for nitrogen, phosphorus, potassium, moisture content, calcium, manganese, magnesium, sulfur, zinc and copper. A copy of the results will be sent directly to the applicant and the county Extension agent. The agent will be able to answer questions and help plan fertilization and nutrient management programs.

Soil testing

Soil testing is an important agronomic tool for determining crop nutrient needs. Soil testing evaluates the fertility of the soil to determine the basic amounts of fertilizer and lime to apply. The following sections describe how to use soil testing to evaluate crop nutrient needs.

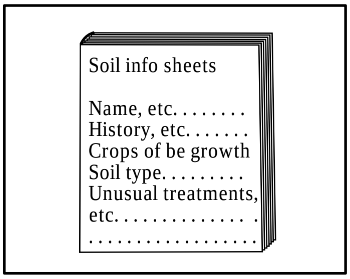
Sampling instructions

Collecting the sample is one of the most important steps in the soil testing program. When one considers that the 2-pound soil sample must adequately represent 10 million or more pounds of soil in the area being sampled, the importance of doing a good job of sampling becomes apparent. Instructions for collecting a good representative soil sample follow.

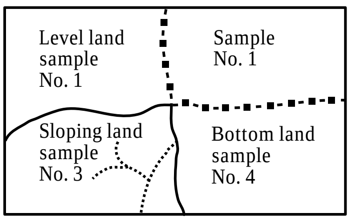
Using the soil test report

The soil test report generally contains the laboratory test results plus fertilizer and lime recommendations for the next two crops in the rotation. Additional information regarding time and method of fertilizer an slime application will also be provided in the form of a soil test note which will accompany the report. When several samples have been collected from the same field, the Soil Test Reports should be compared to determine the best rates of fertilizer and lime to use for the field. Large differences in the reports may call for fertilizer and/or lime at two or more different rates.

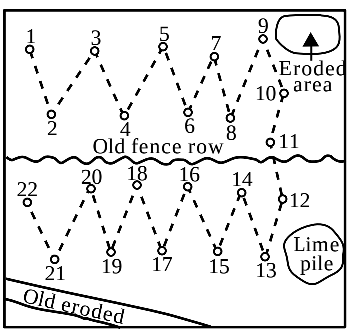
Sampling soil



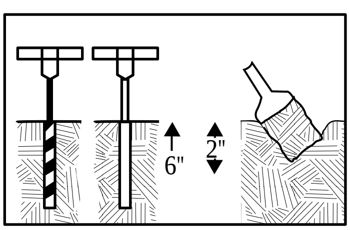
1. Obtain soil samples information sheet and soil boxes
A laboratory must be located that can provide appropriate soil testing. These laboratories can often be accessed through Extension Service agents and fertilizer dealers. The laboratory will provide directions to follow for soil sampling.



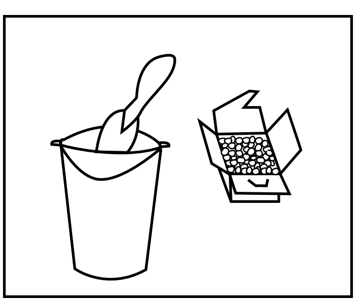
2. Divide farm into areas or fields
If the field is uniform, one sample will do. But most fields will have been treated differently, or the slope, drainage, or soil type will make it desirable to divide the field into small areas of 5 to 10 acres each.



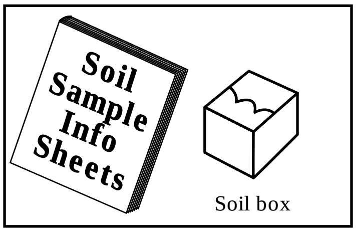
3. Obtain a good sample of soil
The soil test can be no better than the sample. Take the sample from 20 or more places in the field. Zig-zag across the field or area as shown in the diagram. When taking sample, avoid unusual places such as old fence row, old roadbeds, eroded spots, where lime or manure have been piled, or in the fertilizer band of row crops.



4. Use proper sampling tools
Sampling may be made with a soil auger, soil tube, or spade. The desired depth for cropland is plow depth (6 to 8 inches or more), and for pasture land, 2 to 4 inches. Place sample in clean container.



5. Mix well in clean plastic pail
From the 20 or more stops you have made, you now have 1/2 gallon or more of soil. Mix it thoroughly, then send about 1/2 pint of the mixed soil for analysis.



6. Fill out sample information sheet for each sample
It is essential that your name, address, and sample number be plainly written on the sheet you send with each sample. As a guide in making recommendations for each of your numbered areas, it is important that the history of treatments and any unusual treatments be stated.

7. Mail to soil testing and plant analysis laboratory
Place completed the Soil Sample Information Sheet inside the flap of the soil sample box and mail to the laboratory. Generally, the laboratory will make a routine test of seven analyses (soil pH, phosphorus, potassium, calcium, magnesium, zinc, and manganese) on all samples. Special tests on organic matter, nitrate-nitrogen, and soluble salts can be requested if needed.

Plant testing

Plant testing is also an important agronomic tool for determining crop nutrient needs. It is used as a monitoring tool to determine if the fertilization and liming program, as determined by the soil test, is providing the nutrients at the necessary levels for top yields. Plant analysis is the ultimate test; i.e., is the plant obtaining, from the soil, ample nutrients for good growth and development. If not, nutrients can be added during the existing growing season to improve yields, or the fertilization program can be modified for next year's crop.

Plant testing procedure

1. **Submit clean sample**
   Avoid submitting sample tissue that is contaminated with dust or soil. If tissue is dusty or dirty, remove as much of it as you can by shaking, brushing, or washing the tissue in gently-flowing water.
2. **Sample healthy plant**
   Do not sample disease, insect, or mechanically damaged plant tissue.
3. **Place in clean bag**
   Place the plant tissue in a clean paper bag. Do not use plastic bags. If the sample is wet or succulent, let it air-dry in the open for one day before sending it to the laboratory. Identify each sample by number and crop name.
4. **Take two samples**
   When using tissue analysis in the diagnosis of crop production problems, take one sample from the problem area in the field and one from an area where plants appear normal.
5. **Sample proper plant part at proper time**
   When sampling, both the time (growth stage) and plant part collected are important. Be sure to sample at the recommended time and collect the proper plant part.
6. **Follow sampling instructions**
   If there are no specific sampling instructions for the crop to be analyzed, a good rule of thumb is to sample mature leaves that are representative of the current season's growth during the mid period of the growth cycle or just prior to seed set.
7. **Fill out a Plant Analysis Information Sheet**
   The plant analysis laboratory will provide the information sheet. The completed sheet should indicate where the results should be mailed and record each sample number along with crop name. Send the sample and completed information sheet to the laboratory.
8. **Analyses performed**
   Sample should be analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu), iron (Fe), boron (B), and aluminum (Al). In addition, a sulfur (S) test can be run if needed.

(Source—A Handbook of Agronomy, Virginia Cooperative Extension Service, Publication 424-100, Revised December 1987.)

651.1370 Appendix 13C—Operation, Maintenance, and Safety Guidelines

Appendix 13C Operation, Maintenance, and Safety Inspection Guidelines

Production Function

Element to check	How to check	Recommended action
Nutrients produced	Compare feed ration, number of animals, and weights of animals assumed in design.	Make appropriate adjustments to the nutrient management plan if nutrients are significantly different from those assumed.
Volume produced	Compare actual number of animals, weights of animals, bedding used, areas producing polluted runoff, and other sources of wastewater to those assumed in design.	If actual volume produced is greater and will result in early filling of storage/ treatment facilities, see the Trouble-shooting Guide for recommended action.
Clean water exclusion	See that clean water exclusion practices, such as diversion channels, roof gutters and downspouts, and curbs, are functional and in good condition.	Maintenance should be performed to correct deficiencies found.

Collection Function

Element to check	How to check	Recommended action
Alley scrape	Observe that alleys are relatively clean after being scraped and that animals are not being interfered with during scraping. Note areas that are not being cleaned during scraping. Observe that mechanical scrapers are operating properly.	Evaluate consequences, such as odor, that may result because of lack of cleanliness. Make suggestion on how to achieve more cleanliness if consequence for not doing so would be significant. Tractor scrapers and other related equipment needed should be available, maintained, and equipped with adequate safety devices, such as roll over bars and shields. Equipment that is not properly equipped with safety devices should not be used until it has been so equipped.
Alley flush	See that alleys are relatively clean after being flushed, particularly along curbs and at the end of alleys.	Adjust flow rate and/or duration of flush as necessary to achieve necessary cleanliness. See that safety precautions are taken in use of flush tanks that tip or otherwise present a hazard.
Gutter scrap	Observe cleanliness after scraping.	Suggest adjusting travel speed of scraping mechanism if satisfactory cleanliness is not being achieved.
Reception hoppers	See that dry material is not being placed in hopper.	Blend wet material with dry material before placing in hopper.
	Observe whether ice is forming in hopper.	Hopper should be protected from freezing.
Slatted floors	See that ventilation is provided beneath slatted floors. Check structural integrity of slats.	Provide ventilation if not found.

Storage Function

Element to check	How to check	Recommended action
Waste storage pond		
Rate of filling	Observe availability and readability of staff gage in pond with marks or cross-bars at intervals that will permit calculation of volume of waste added per unit of time, i.e., month. Use gage readings in conjunction with pond's stage-storage relationships to determine rate of filling.	A staff gage should be installed if one is not present. If rate of filling will result in an early filling of storage facilities, see Troubleshooting Guide for recommended action.
	Determine waste and wastewater contribution.	Examine records kept of how often and what amounts of waste are added to the pond.
	Determine precipitation contribution to filling. Examine onsite or nearby weather station rain/snow gage readings. Compare with precipitation assumed in design.	If determined that precipitation has been excessive, reduce waste production to offset excess precipitation in storage or do emergency pumping to allow for future storm events.
	Determine amount of evaporation. Examine onsite or nearby weather station evaporation records. Compare actual evaporation with the amount assumed in design. Recognize that crusts formed on pond surfaces may reduce evaporation.	Reduce amount of waste produced or make adjustment in pumping schedule if evaporation is less than assumed in design.
Agitation	Observe that pond contents are agitated properly.	Assure that agitation is according to the agitation equipment manufacturer owner’s manual recommendation for time and spacing.
	Observe that bank protection at agitation points is adequate.	If erosion is present, install bank protection or make adjustment of agitation point so erosion will not occur.

Storage Function—Continued

Element to check	How to check	Recommended action
Waste storage pond (Continued)		
Pump intake	Observe that intake is located at a depth that will minimize intake of solids material that will clog land application equipment, such as nozzles and orifices.	Make appropriate revision to pump intake to minimize clogging of land application equipment. Check adequacy of agitation equipment.
	Observe that sides and bottom are protected or intake is far enough away to avoid erosion during pumping.	Install protection or move pump intake if erosion is occurring.
	Observe that intake screens with appropriate size opening are in place. Observe frequency of clogging of screens and method for cleaning screens.	Make adjustments to minimize clogging.
Safety measures	Observe that fences and gates are maintained and that warning signs are visible and in good condition.	
	Assure that access ramps have appropriate guard rails and safety curbs in place and cleaned so traction surfaces are exposed.	
	Ascertain that a life ring, life line, or pole is readily available in case of an emergency.	
Waste storage structure—tank		
Rate of filling	Use established method for determining depth of waste in the tank that will permit determination of volume of waste and allow calculation of volume per unit of time, e.g., cubic feet per month. This rate can be compared to rate of filling assumed in design. The rate can also be used as a basis for planning/design of subsequent AWMS's.	Make adjustment to reduce filling rate if it exceeds assumed rate.

Storage Function—Continued

Element to check	How to check	Recommended action
Waste storage structure—tank (Continued)		
Agitation	During agitation observe that dry crusts that may have formed on the surface and heavy solids that may have settled to the tank are put into suspension.	Improve methods used in agitation if it is inadequate.
Emptying	Confirm that tank is pumped out in accordance with established utilization plan and that records are kept of when and how much is removed from the tank.	
Structural integrity	For reinforced concrete structures, inspect for excessive cracking and concrete deterioration.	Consult with concrete repair specialist for recommended repairs.
	For steel tanks check for corrosion around bolts and deterioration of protective coatings.	Repair, if found.
	Observe differential or excessive settlement.	If found, consult an engineer for action needed.
Water table control drains	See that drains are properly functioning to maintain water table to level required for structure loadings assumed in design.	
Safety measure	Assure that warning signs are visible and in good condition, and that protective grates and covers are in place. Confirm that an emergency action plan is in place to deal with accidental tank entry or other crisis.	Assist in development of a plan if one has not been developed.

Storage Function—Continued

Element to check	How to check	Recommended action
Waste storage structure—Stacking facility		
Rate of filling	Make an estimate of volume based on measurement of stack. Divide the volume estimate by the number of days waste has been stored in the facility. Compare actual daily rate with that assumed in design.	If found to be excessive, make adjustments to reduce the daily volume of waste produced, such as using less bedding.
Structural integrity	For reinforced concrete structures, inspect for excessive cracking and concrete deterioration.	Consult with concrete repair specialist for recommended repairs.
	Check wood portions of structure for damage.	Replace as appropriate.
Roofing	Check trusses and rafters for damage.	Repair as necessary. Repair roofing if leaks are noted. See that fasteners are tight and in good repair.

Treatment Function

Element to check	How to check	Recommended action
Waste treatment lagoon		
Operating depth/treatment depth	Observe availability and readability of staff gage in lagoon marked to show minimum depth; maximum depth (depth above which insufficient storage remains for the 24-hour, 25-year storm event); and elevation of top of embankment or spillway.	Install staff gage if one is not present.
Loading rate	Compare wastewater sources being discharged in lagoon with those assumed in design.	If loading rates exceed those in design, suggest ways to reduce loading rates or changes in operation of the lagoon to accommodate the additional loading.
	Take wastewater samples, have them tested for VS or BOD_5 and compare results with the values assumed in design.	If loading rates exceed those in design, suggest ways to reduce loading rates or changes in operation of the lagoon to accommodate the additional loading.
Performance in reducing pollutants	Test lagoon contents periodically to determine changes in ammonia (NH_3), total phosphorus (TP), total nitrogen (TN), total dissolved solids (TDS), and bacteria.	Excessive ammonia and TDS (salts) can effect lagoon function. High TP and TN concentrations can create land application problems. If above parameters are suspected of being excessive, dilution, reduction in loading rates, increase in residence time, or some other appropriate measure should be considered to improve the lagoon's performance.
Agitation	Observe that lagoon contents are agitated properly.	Assure that agitation is according to agitation equipment manufacturer owner's manual recommendation for time and spacing.
	Observe that bank protection at agitation points is adequate.	If erosion is present, install bank protection or make adjustment of agitation point so erosion will not occur.

Treatment Function—Continued

Element to check	How to check	Recommended action
Waste treatment lagoon (Continued)		
Bottom sludge	Determine depth of the bottom sludge and compare the depth with that reserved for its acclamation in design.	If it exceeds the amount assumed in design, it will infringe on the minimum treatment volume and, as such, it should be removed from the lagoon. Consistency of the sludge determines how its thickness is measured and how it may be removed. If the bottom sludge has a solid consistency, determine top elevation of sludge and compare with "as built" lagoon bottom elevation to determine its thickness. Generally, some sort of excavating equipment must be used to remove solid sludge. If the bottom sludge has a liquid consistency, its thickness and total solids must also be determined. The depth is used to determine if the sludge volume infringes on the minimum design volume and total solids is used to decide if the sludge can be pumped. A light and light sensor apparatus can be used to determine the depth. A rigid translucent pipe driven into bottom of lagoon and retrieved with a soil plug can be used to obtain a sample for determining total solids. Generally, wastewater with less than 5% solids can be pumped. If the sludge has total solids of more than 5%, it may be necessary to agitate the bottom sludge before pumping.
Aeration	Assure that operation of aeration equipment is consistent with recommendations in manufacturer owner's manual(s) and conforms to design requirements.	If undesirable odor is present, take sample of lagoon contents from within the top 2 feet of lagoon water surface and test for dissolved oxygen at the detectable level, 0.1 mg/L. If aeration operation needs to be changed, a manufacture representative should be consulted.
	Observe that none to very few organic solids are present on the lagoon surface.	A few solids on the surface for a newly installed aeration system does not necessarily indicate a problem.

Treatment Function—Continued

Element to check	How to check	Recommended action
Waste treatment lagoon (Continued)		
Safety measures	Inspect fence and gates to see that they are in good repair. See that warning signs are visible and in good condition.	Correct deficiencies as appropriate.
Mechanical separation		
Volume of solids separated	Compare the volume of solids being separated with the volume assumed to be separated in planning/design.	If not to expectations, check that total solids of the wastewater is within the range recommended by the manufac- turer.
	Make sure wastewater is agitated so that all solids are in suspension prior to separation. Check flow rate to see that it does not exceed manufacturer's recommendation.	Reduce flow rate if found to be excessive.
Safety measures	Check to see that moving parts are guarded. See that warning signs, ladders, and handrails are in good condition. Also see that access to separation equipment towers and pits is denied to unauthorized people.	Safety deficiencies must be repaired or installed if hazards are found.
Settling basins		
Volume of solids settled out	Compare the volume of solids being settled out with the volume assumed to be settled in planning/design.	If found to be less, check detention time assumed in design. If found inadequate, increase detention time by reducing inflow and/or outflow from the settling basin or increasing volume of settling basin.

Treatment Function—Continued

Element to check	How to check	Recommended action
Dilution		
Adequacy of dilution	Test diluted wastewater for total solids. Compare with the desired total solids for the treated wastewater assumed in design.	If significantly different than assumed, evaluate the consequence of it being different on the basis of the purpose for dilution. Either reduce amount of dilution water added or add additional water with a lesser amount of total solids to achieve desired total solids.
Vegetative filters		
Performance of vegetative filter (infiltration area)	See that wastewater is not leaving filter area.	Lengthen filter if wastewater exits filter area.
	Assure that filter is given a minimum 2-day rest period each week.	
	Assure that wastewater is uniformly distributed over the width of the filter.	Regrade and revegetate filter as necessary.
Composting		
Pile temperature	Using thermometer probe, check internal temperature of compost pile. The pile temperature should be checked at a point one-third the distance from the outside of the pile to the center of the mass. Compost temperatures should peak between 130 and 140 degrees F in 5 to 7 days.	See the troubleshooting guide if piles fail to heat or exceed 150 degrees F.
Carbon:nitrogen ratio of compost mix	Take a representative sample of the raw compost mixture and have a laboratory determine the carbon and nitrogen content. The carbon to nitrogen ratio should range between 25 and 40 to 1.	Make adjustments to the ingredients of the recipe as necessary to achieve a carbon to nitrogen ratio within the range of 25 to 40 to 1.
Moisture of compost mix	Take sample and check moisture content. The moisture content should range between 40 and 60 percent.	Add water or drier material to adjust moisture content. If drier material is added, care must be taken to see that the carbon to nitrogen ratio of the mix is still in the 25 to 40 to 1 range.

Treatment Function—Continued

Element to check	How to check	Recommended action
Composting (Continued)		
pH of compost mix	Check pH of compost mix. The pH preferably should range between 6.5 and 8. Composting may be adequate between a pH of 5.5 and 9.0	
Finished compost	Observe that compost has little or no trace of the original raw material and has little odor. The material should be black to brown in color. Particle size should be consistent and soil-like in texture.	

Transfer Function

Element to check	How to check	Recommended action
Reception pits		
Structural integrity	For concrete and concrete block structures, inspect for excessive cracking and concrete deterioration.	Consult with concrete repair specialist for recommended repairs.
Foreign material	Check for excessive debris that will impair function of pit.	Remove debris remotely from outside the pit.
Safety	Assure that protective grates are installed in good condition.	
	Assure that pits enclosed in buildings are properly vented to prevent accumulation of gases.	
Gravity pipelines		
Outlet	See that outlet is free flowing and is not causing erosion.	
Safety	Note that pipeline inlets located within buildings are properly vented so gases do not accumulate.	
Pushoff ramps		
Safety	Assure that restraints to prevent equipment from accidentally going off the end are in place and in good repair.	
	Assure that traction surfaces are exposed.	

Transfer Function—Continued

Element to check	How to check	Recommended action
Picket fences		
Function	Assure that water has a clear drainage path from the face (leading edge) of the manure pile to the picket dam.	
Structural integrity	Inspect lumber and hardware elements for deterioration.	Replace as necessary.
Pumps		
Operation	Ascertain that pump and motor are receiving regularly scheduled lubrication.	
	Note that intake is properly protected to screen out oversized material and is not plugged.	
	Notice that wastewater to be pumped is adequately agitated prior to pumping to assure that all solids are in suspension.	
	During periods of non-use see that pump is drained or otherwise protected from freezing, if appropriate for climate.	
	Listen to operation of pump and motor for abnormal noise.	The pump and motor should be serviced by a qualified technician if abnormal noise is heard or excessive vibration is noted.
Suction and discharge	See that supports to bear weight of suction pipe and discharge pipes are in place and adequate.	
Pump and switch housing	Observe that housing for motor and switches is adequate for protection from sun and rain.	

Transfer Function—Continued

Element to check	How to check	Recommended action
Pumps (Continued)		
Safety	Determine that adequate safety devices, such as guards and shields, are in place.	
	Check that motors and switches are properly grounded and that exposed wiring is both insulated and protected against accidental contact.	
Equipment		
Proper operation and maintenance	Verify that equipment is operated and maintained in accordance with manufacturer's recommendations. Records of use should be kept.	Perform maintenance at recommended intervals.
Safety	Assure that safety devices and equipment is in good repair and being used as appropriate.	
	Assure that tractors are matched with hauling equipment being pulled.	
	Assure that public safety is protected when hauling equipment uses public roads.	Use proper signage and clean up spilled materials.

Utilization Function

Element to check	How to check	Recommended action
Land application		
Amount applied	Measure the amount of waste actually being applied. Estimate the amount of nutrients being applied by considering nutrient losses involved to the point of application. A laboratory analysis to determine nutrient content of the waste applied allows a more precise estimate. Compare actual amount of waste and nutrients being applied to the recommendations in the nutrient management plan. Observe the condition of the crop. For example, yellowing might indicate that not enough nutrients are being applied. On the other hand, burned leaves might indicate that too many nutirents are being applied.	If nutrients being applied are found excessive or crop condition indicates overapplication, reduce future application amounts. This may require that additional fields receive waste or that waste treatment be included in the AWMS to reduce nutrient content of the waste. If nutrients being applied are found insufficient for optimum production or the crop condition indicates under-application of nutrients, consider supplementing with commercial fertilizer. Recommend calibrating application equipment.
Method of application	Observe method being used to apply waste. Compare method being used with the method assumed in computing nutrient losses for the nutirent management plan.	If a different method is being used, it may be necessary to adjust to the amount of the waste applied. For example, if the nutrient management plan it was assumed a surface application method and an injection method is being used, nitrogen loss may be less than assumed, so more nutrient are actually being applied to the crop than planned. This may make the nutrient application excessive.
Placement of waste	Observe how the waste is being placed and its distribution on the farm. Check for field runoff during application.	Compare fields to which waste is being distributed to those planned to receive waste in the nutrient management plan. Recommend appropriate modification if they are found different. If waste application is not evenly distributed or is causing runoff, recommend adjustment to equipment itself or in the way equipment is being used.

Utilization Function—Continued

Element to check	How to check	Recommended action
Land application (Continued)		
Timing of application	Observe when waste is being applied.	Compare actual fiming with timing recommended in the nutrient management plan. Consider the environmental consequences if actual timing of application and recommended timing differ. Consequences, such as increased runoff and leaching losses, and inability of crop to use available nutrients should be considered. Recommend modification to timing of application if appropriate.
Safety	Observe unsafe actions or conditions, such as unshielded moving parts that could be injurious.	Recommend appropriate modification to unsafe activities or correct unsafe conditions (see 651.1303).
Biogas production		
Overall system	Evaluate daily operating temperatures and gas production records.	If gas production is not to the level anticipated, check volatile solid loading rates. Make appropriate adjustments.
Covered lagoon	Check cover visually for rainwater accumulation, tearing, wear holes, and proper tensioning.	Make appropriate repairs or adjustments to the cover.
Complete mix digester	Check operating temperature. Check cover visually for rainwater accumulation, tearing, wear holes, and proper tensioning. Evaluate mixer and heat exchanger maintenance records for proper lubrication.	Make appropriate repairs or adjustments to the operation of the digester system.
Plug flow digester	Check operating temperature. Check the effluent outlet and digester gas relief values for proper operation. Check cover visually for rainwater accumulation, tearing, wear holes, and proper tensioning. Evaluate heat exchanger pump maintenance record for proper lubrication.	Make appropriate repairs or adjustments to the digester system.

Utilization Function—Continued

Element to check	How to check	Recommended action
Biogas production (Continued)		
Safety	Visually check to see that safety fencing and warning signs are in good condition.	Correct unsafe conditions.

651.1380 Appendix 13D—Agricultural Waste Management System Troubleshooting Guidelines

Appendix 13D AWMS Troubleshooting Guide

Production function

Observed problem	Recommended actions
An unusually strong odor is present where animals are kept	Check for manure covered animals and excess manure. Animals should be cleaned and adjustments made to keep them separate from their manure. Look for evidence of poor drainage in lot areas. If noted, improve lot drainage and consider such things as installing concrete pavement around feeders and waterers to keep lot drier.

Collection Function

Observed problem	Recommended actions
An unusually strong odor is present in animal housing area	Check for spilled feed that is being allowed to ferment or areas where manure is not being routinely collected and removed. Remove these materials as a measure to reduce odors. Check the frequency of collection. Suggest consideration be given to more frequent collection to reduce odors. Check for manure covered animals. Check for soiled or wet bedding. If found in excessive amounts, a more frequent removal schedule should be considered. Consider providing additional ventilation.

Storage Function

Observed problem	Recommended actions
Waste storage pond	
Pond is filled at or near capacity too early	Activate the contingency plan for emptying a portion of pond's contents to allow for future waste storage and storm events.
Undesired material in pond	Initiate removal prior to pumping. Take remedial measures to exclude undesired material from pond.
Waste storage structure—Tank	
Undesired material in tank	Assure that measures, such as sand traps and settling tanks, are in place to prevent mineral material from entering the tank. Install measures to remove undesired material if not in place. If possible, exclude all foreign material, such as baling wire or twine, plastic bags, wood, and syringes, from the tank. Remove any materials that are found in the tank.
Waste storage structure—Stacking facility	
Waste will not stack	Suggest ways that the total solids of the waste can be increased, such as using less water or increasing the amount of bedding used.

Treatment Function

Observed problem	Recommended actions
Waste treatment lagoon	
An unusually strong odor is present	Check pH of lagoon water (should be between 5.5 and 8.0). The optimum pH is about 6.5. Testing for pH can be done in several ways. A meter with pH electrode provides a means of making a quick and accurate test. Tests should be taken at different locations and depths to assure a pH representative of the lagoon contents. If the pH falls below 6.5, add 1 pound of hydrated lime or lye per 1,000 square feet of lagoon surface daily until the pH reaches 7.0.
	Observe color of water. Very black water is indicative of low or no desired biological activity. Other colors, such as purple or various shades of brown, are indicative of water having high suspended solids content, and they normally represent proper operation. Dilution or aeration should be considered as possible ways of reducing odor.
	Test composition of water. Concentrations of ammonia should not exceed 600 mg/L, and TVS should not exceed recommended loading rates. Suggest reducing loading rates, dilution, or aeration as ways to reduce odor.
Undesired material in lagoon	Remove undesired material from lagoon if present.
Floating crust	Crust formation generally does not effect the treatment function of an anaerobic lagoon; however, it does reduce evaporation from the lagoon surface. If a crust forms and if design assumed a reduction in storage requirements because of normal evaporation, early filling may result. An adjustment, such as reducing the quantity of wastewater inflow, will be required to compensate for less evaporation losses.
Mechanical separation	
Plugs with solids	Completely wash out the separator. Washing remaining solids from the separator after each use so solids will not dry in place may also reduce potential of plugging.
Vegetative filters	
Excessive buildup of solids in vegetative filter	Consider solid separation prior to discharge into filter. Regrade and revegetate if buildup of solids is affecting performance of filter.
Vegetation is dying or has died	Revegetate as necessary. Consider dilution of the wastewater before discharge. An alternative treatment component to treat wastewater should also be considered.

Treatment Function—Continued

Observed problem	Recommended actions
Composting	
Pile temperature—Temperature too low	Check moisture content of pile. Remedy is adding water or wet ingredient if pile is too dry. Add dry material and remix if too wet (moisture content of more than 60%).
	Check C:N ratio of pile mix. Remedy is adding high nitrogen ingredient if the C:N ratio is greater than 50:1.
	Check pH of pile. Remedy is adding lime or wood ash and remixing if pH is less than 5.5.
	Observe pile structure evidenced by pile settling too quickly and few large particles. Remedy is adding bulking agent and remixing.
	If weather is cold, remedy is to enlarge or combine piles or to add highly degradable ingredients.
	Pile may fail to heat because of improper aeration. Aerate pile and check temperature frequently to see if it increases.
Pile temperature—Temperature prematurely falls consistently over several days	Indicates low oxygen. Remedy is to turn or aerate pile. Check moisture content. If low, the remedy is to add water.
Pile temperature—Temperature is uneven and has accompanying varying odor	Observe differences in pile's moisture content and materials. If observed the remedy is to turn or remix pile.
Pile temperature—Temperature gradually falls, and pile does not reheat after turning or aeration	Observe for completeness of composting as described in the O&M and Safety Inspection Guidelines, finished compost. If complete, no action is required. If composting is not complete, check for low moisture content. If low, add water.
Pile temperature—Pile overheating with temperatures greater than 165 °F and rising	Check the height of the composting material. It should never exceed the 5 to 7 feet range. Reducing the height will lessen the probability of spontaneous combustion.
	Check for low moisture and a pile interior that looks or smells charred or if temperatures are even exceeding 180 °F. If any of these conditions are apparent, then the material should be removed from the composting bin. Do not add water to the compost as this may promote additional combustion. Avoid putting materials with dissimilar moisture contents next to each other.

Treatment Function—Continued

Observed problem	Recommended actions
Composting (Continued)	
Pile temperature—Pile is extremely overheating with temperatures greater than 170 °F	Check for low moisture and a pile interior that looks or smells charred. If these conditions exist, break pile down and re-pile to a reduced size.
Strong ammonia odor is present	Check C:N ratio and add amendment if less than 20:1.
	Check pH. Add acidic ingredients and/or avoid alkaline ingredients if pH is greater than 8.0.
	If large woody particles are being used as a carbon source and C:N ration is less than 30:1, use another carbon amendment or increase the carbon proportion.
Rotten-egg or putrid odors comes from pile continuously	Check for low pile temperature and too high moisture content. Add dry amendment if these conditions exist.
	Check for low pile temperature and poor structure. Adding bulking agent is the remedy for this condition.
	Check for low pile temperature and high compaction. The remedy for this condition is to remix the pile and add bulking agent.
	Check for low pile temperature and insufficient aeration. Turning pile and increasing air flow are the options for improving this condition.
	Check for low pile temperature and too large a pile. The pile size should be decreased to correct this problem.
	Check for falling temperature and insufficient aeration. Turning the pile more frequently should improve this condition.
Flies or mosquitoes	Look for fresh manure or food material at pile surface and flies hovering around pile. Files or mosquito problems can be reduced by turning the pile every 4 to 7 days and by covering a static pile with a 6-inch layer of compost.
	Look for wet materials stored onsite for more than 4 days. Handling raw materials more promptly should reduce this problem.
	Look for nearby standing puddles or nutrient-rich pond. Grade site to drain puddles and maintain pond in an aerobic condition.

Treatment Function—Continued

Observed problem	Recommended actions
Composting (Continued)	
Compost contains clumps of materials and larger particles, and texture is not uniform	Check for discernible raw materials in compost. Screening compost and improving initial mixing achieve more complete composting.
	Check for wet clumps of compost. Remedy is to screen or shred compost and improve air distribution.
	Look for large, often woody particles in compost. Screening, grinding, and sorting of raw materials initially improve composting.
	If composted materials heat or develop odors, lengthen composting time or improve composting conditions.

Transfer Function

Observed problem	Recommended actions
Reception pits	
Foreign material in pit	Check for excessive debris, which will impair function of pit. Remove debris remotely from outside the pit.
Gravity pipelines	
Plugging	Longer agitation, dilution, liquid/solid separation prior to transfer, and clean water flushes after transfer help reduce the potential of plugging. Installing cleanouts at locations of frequent plugging can be considered for ease of unplugging.

Utilization Function

Observed problem	Recommended actions
Land application	
Crops are scum covered following application	Use a clean-water rinse following application to clean plants.
Soil is sealed following application	Reduce potential by lengthening drying cycle between applications, physically disturbing soil surface, or injecting waste.
Applied nutrients are excessive as determined by observed conditions, such as soil and leaf testing.	Change to a crop that uses a greater amount of nutrients. Use double cropping if appropriate.
	Increase crop yield with improved management by such things as pretreating with lime, practicing water management, managing pests, splitting waste applications, and making timely harvest.
	Take an action that would reduce the amount of nutrients produced.
	Treat the waste or a portion of the waste before land application to reduce its nutrient content and to prepare if for refeeding or for use as bedding.
	Locate an off-farm use for the waste.
	Enlarge area on which waste is applied.
Health hazards	Isolate and treat infected animals to reduce the potential for high levels of pathogenic bacteria in waste material.
	Apply waste on sunny days when temperatures are above 40 °F, ideally at higher temperatures, when bacterial and virus die-off is maximized.
	Apply wastes to crops that will not be eaten raw or directly grazed unless adequate time is allowed for bacterial and virus die-off on the produce.
	Apply wastes away from high density population area to reduce the possibility of disease transmittal by such factors as wind, insects, rodents, or flowing water.
	Limit amount of waste applied to a single site to reduce the possibility of pathogenic bacterial build-up.
	Apply waste when soil is not saturated and when rain is not forecast.
Runoff during or soon after application	Consider reducing rate at which waste is applied, applying waste only when rain is not forecast, not applying waste to snow or frozen ground, installing measures to capture runoff and return to AWMS for storage or treatment, and improving soil internal drainage by installing subsurface drainage.

651.1390 Appendix 13E—Example Agricultural Waste Management System Plan

Appendix 13E Example Agricultural Waste Management System Plan

Agricultural Waste Management System Plan for the Green Dairy

Decisionmaker: Joe Green

Address: P.O. Box 5000, Silverton, Oregon

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General

The agricultural waste management system for the Joe Green Dairy was planned and designed at the request and with the involvement of Mr. Joe Green. The plan is based on decisions and choices made by him. The system is planned to manage waste generated by the dairy in a manner that prevents or minimizes degradation of soil, water, air, plant, and animal resources and protects public health and safety. It is also planned to preclude discharge of pollutants to surface water from a 25-year, 24-hour storm event, to minimize ground water contamination, and to recycle the waste produced through soil and crops to the fullest extent possible.

The Natural Resources Conservation Service plans agricultural waste management systems viewed as having one or more of six functions. These functions are production, collection, transfer, storage, treatment, and utilization. Each of these functions is involved in the system planned for the Joe Green Dairy. The operation, maintenance, and safety requirements for the system presented in this plan are organized by these functions.

System description

The agricultural waste management system was planned to accommodate waste from a herd of 800 Holstein dairy livestock and wastewater from the milk parlor and milk house. The system is planned to divert clean water from the system with roof gutters and downspouts, to collect the manure from the freestall barn with flush alleys in a reception pit, to treat the wastewater with a solid/liquid separator, to store manure and wastewater in a waste storage pond, to transfer the wastewater in a pipeline from the waste storage pond to fields where it will be land applied, and to utilize the waste on 450 acres of pastures.

Decisionmaker's responsibilities

Mr. Green is responsible for the proper installation, operation, and maintenance of the waste management system. Although the system was designed by the Natural Resources Conservation Service using the best available technology, it needs to be inspected and properly operated and maintained in a safe manner if it is to operate as planned and designed.

Mr. Green is also responsible for obtaining a permit from the Oregon Department of Agriculture and all other necessary permits to operate the system. The system must be operated and maintained in accordance with these permits and other laws and regulations that pertain to its operation including the Oregon Occupational Safety and Health Code for Agricultural Operations and Farming. All personnel must be trained or informed of the safety and the operation and maintenance requirements for the system.

An inventory of equipment related to each function will be made and checklists developed, as necessary, for preventive maintenance and inspection. A supply of spare parts necessary to keep the system operating will be kept on hand. Nameplate data, reference manuals, catalogs, drawings, and other manufacturers' information necessary to operate and maintain the equipment used in the system will be kept. A record will be kept of hours of operation for system equipment that is routinely maintained on a time-used basis.

Component installation schedule

The system components will be installed according to the following schedule:

Component	Installation date
Reception pit	5/99
Roof gutters and downspouts	7/99
Solid/liquid separator (including storage pad)	10/99
Waste storage pond	6/00
Transfer pipeline	9/00

Production function requirements

The production function of an AWMS relates to the amount of waste produced within the system. The system design was based on waste production estimates for 800 Holstein dairy livestock, which includes 500 milk cows, 150 dry cows, and 150 heifers. Exceeding either the number or type of livestock may invalidate the design for the system. The system was designed based on a daily manure production of 1,336 cubic feet per day and milk house and milk parlor wastewater production of 420 cubic feet per day. The amount of manure and wastewater produced must be monitored to assure that it does not exceed these design volumes. These volumes can be estimated using the staff gauge readings and the stage storage curve for the waste storage pond. Production rates that exceed those estimated in design will result in premature filling of the waste storage pond.

The system was designed assuming that roof water would be excluded from the system. For this reason the roof gutter and downspout system on the barn must be maintained. The gutters and downspouts will be inspected during rainstorms to check for leaks and clogs. If found, the gutters and downspouts must be repaired. The gutters must be cleaned of debris annually. The protective coatings on the gutters should be inspected at this time and repaired if necessary.

Production function safety items include maintaining ventilation to prevent the buildup of gases within the freestall barn. Workers must be informed of the danger of gases and the necessity of keeping vents open at all times, even during cold weather.

Collection function requirements

The collection function pertains to the capture and gathering of manure and wastewater so it can be further managed. Manure is collected from a freestall barn with flush alleys. Temporary storage is provided by a below-ground, reinforced concrete reception pit. Flush water used in the system is recycled from the waste storage pond. Flush tanks are filled using a pump and pipeline. The pump enclosure will be maintained to prevent exposure to the elements. Pump maintenance will be according to the manufacturer's recommendations. Pump safety features will be maintained. The flushing operation will be monitored for effectiveness in moving the manure to the reception pit. The frequency and/or duration of flushing will be adjusted as necessary.

The grates and covers for the reception pit must remain secured in place except for maintenance purposes. During maintenance, temporary barriers must be positioned to prevent accidental entry. To prevent injury, caution shall be exercised when flush tanks are operated.

Treatment function requirements

The treatment function pertains to changing the characteristics of the waste by biological, chemical, or physical means. Manure and wastewater from the flush alleys, milk parlor, and milk house will be treated with a stationary, inclined-screen solid/liquid separator prior to discharge into the waste storage pond. Separated solids will be stored on an adjacent concrete pad. Manure and wastewater collected in the reception pit will be agitated and pumped to the separator once a day. Adequate ventilation must be provided before starting agitation. The rate of flow to the separator must be within the range recommended by the manufacturer. The flow must be adjusted for maximum solid separation efficiency. The screen will be given a clean-water rinse following each use to prevent solids from drying and adhering to the screen. The pump/agitator must be operated according to the manufacturer's recommendation.

The ladder attached to the tower for the solid/liquid separator shall be maintained. Workers using the ladder shall use the safety belt provided. Equipment used to move and stack the separated solids must be equipped with rollover protective structures, seat belts, and backup alarms. Equipment operators must be fully trained in safe use of the equipment.

Storage function requirements

The storage components for the system are a waste storage pond and a concrete slab for storage of separated solids. The 17 acre-foot waste storage pond was designed to provide 180 days of storage for manure and washwater. Also included in the design of the pond is a depth allowance of 2.6 feet. This allows for precipitation less evaporation anticipated for the storage period between October 15 and May 15 and for the 24-hour, 25-year storm event precipitation. The top of embankment elevation is 1.3 feet above the spillway crest, which is an allowance for the head to operate the spillway and freeboard.

The pond must be empty at the beginning of the rainy season, which is generally about October 15. The pond should fill to the elevation of the spillway crest (98.7) not sooner than April 15. To achieve this filling schedule, the approximate target elevations should be observed throughout the storage period according to the following schedule.

Filling Schedule

Date	Target elevation	Average precipitation less evaporation
October 15	90.0—Empty	5.0
November 15	91.6	6.0
December 15	93.2	6.5
January 15	94.7	5.9
February 15	96.2	4.0
March 15	97.7	2.0
April 15	98.7—Spillway crest	

Evaluation of the filling rate for the pond should consider actual precipitation less evaporation for the periods involved.

Removal of liquids before the end of the storage period may be necessary if above average precipitation has occurred and if future storms that may cause the spillway to operate are possible. Liquid must be removed to the extent necessary to allow for storage of these potential storm events. Applying liquids removed for this purpose to Pasture No. 2 during a period of good weather when soil conditions are not saturated or frozen is recommended.

The safety fence surrounding the pond shall be maintained. Entrance inside the fence must only be by those who are trained and have activities to perform. The hazard sign shall be kept in good condition. A boat will be moored and a life ring shall be placed near the pumping platform for emergency rescue.

The vegetative cover within the pond area shall be maintained by monthly mowing during the growing season. Weeds and woody vegetation will be controlled with herbicides, which must be applied according to label instructions.

The pond shall be inspected at least annually and after unusual storm events. The embankment will be inspected for leaks, slope failures, erosion, and excessive settlement. Excavated slopes will be inspected for slope failures and erosion. Repairs shall be made promptly. Assistance in planning the appropriate repairs may be requested from the Natural Resources Conservation Service.

The concrete slab for storage of separated solids will be inspected for cracking, and repairs will be made as necessary. Drains to the waste storage pond will be inspected regularly to see that they are operative.

Transfer function requirements

The transfer function applies to movement and transport of the waste throughout the system. Waste is pumped from the waste storage pond and transferred for land application using a 6-inch PVC pipeline that is buried. Valves, air vents, and other pipeline appurtenances will be inspected for proper operation prior to using the pipeline. The pipeline will be operated with a minimum pressure of 20 psi and a maximum pressure of 40 psi. To prevent solids accumulation, it will be flushed with clean water following each use. The pump must be operated and maintained according to the manufacturer's instructions. Heavy equipment will be allowed to cross the pipeline at established travelways where the pipeline has been designed for traffic loads. The pipeline will be drained at the end of each season to prevent cold weather damage.

Separated solids will be transferred using a solid manure spreader. The manure spreader must be maintained according to the manufacturer's recommendations. Equipment operated on the public road must have signs as required by local laws and regulations. Care shall be taken to minimize spillage on roadways.

Utilization function requirements

The utilization function is that part of the system that recycles reusable waste products. Wastewater from the waste storage pond and separated solids will be uniformly surface applied to 450 acres of pastures. The liquids will be applied using the sprinkler irrigation system. The separated solids will be applied using a manure spreader. Manure and wastewater will be applied only between May 15 and October 15 when the weather forecast is a high probability of 7 days without precipitation.

The nutrients available in the waste must not exceed the agronomic requirements for the yield goals of the pastures. The actual rates applied will be based on the nutrient content of the waste and soil fertility testing. See included job sheets for soil testing and manure testing.

Waste accumulated during the storage period will be applied to orchardgrass pastures beginning on or about May 15. Allowing for nitrogen losses in storage, application, and denitrification, and for the amount that will be mineralized, about 17,730 pounds of nitrogen, 7,750 pounds of phosphorus, and 31,495 pounds of potassium will be available for crop uptake from the waste storage pond. The separated solids during this same period will provide, after accounting for these same losses and for mineralization, about 6,000 pounds nitrogen, 1,940 pounds of phosphorus, and 7,870 pounds of potassium for crop uptake. The total nitrogen available for crop uptake from the waste storage pond and separated solids is 23,730 pounds or 52.7 pounds per acre for the 450 acres of pastures, 9,690 pounds or 21.5 pounds per acre of phosphorus, and 39,365 or 87.5 pounds per acre of potassium. Based on nitrogen, even application over the entire acreage will require that the wastewater from the waste storage pond be applied to 336 acres and the separated solids be applied to the remaining 114 acres.

The waste storage pond has a capacity of 17 acre-feet of wastewater. To apply this amount uniformly over 336 acres will require an application of about 0.6 inches of wastewater. The amount of solids accumulated over the storage period is estimated to weigh 2,840 tons. To apply this amount uniformly over 114 acres will require about 25 tons per acre. The attached worksheet will be used to calibrate the manure spreaders used.

Cattle will be grazed from about May 15 to October 15. It is estimated that the lactating cows will be on pasture about 50 percent of the time and the dry cows and heifers 100 percent of the time during this period. Allowing for application and denitrification losses and for the amount mineralized, it is estimated that about 21,810 pounds, or 48.5 pounds per acre of grazing applied nitrogen will be available for crop uptake. During this same period, wastewater and separated solids collected are estimated to provide, after losses and mineralization, another 8,192 pounds, or 18 pounds per acre of nitrogen uniformly applied on the 450 acres of pastures.

The total nutrients applied per acre available for plant uptake are estimated to be as follows:

	Nitrogen	Phosphorus	Potassium
Winter stored wastewater and separated solids	52.7	21.5	87.5
Grazing applied	48.5	14.1	60.4
Summer stored wastewater and separated solids	18.0	8.4	31.4
Total from waste	119.2	44.0	179.3

For a yield goal of 5 tons per acre, the orchardgrass pastures are estimated to uptake 147 pounds of nitrogen per acre, 20 pounds phosphorous per acre, and 216 pounds of potassium per acre. The waste will provide 119.2 pounds per acre of nitrogen. The deficit will require an additional 28 pounds per acre of commercial nitrogen be applied on or about July 1. No additional phosphorus is needed. An additional 37 pounds per acre of potassium will be applied with the nitrogen on or about July 1.

Guards and shields on moving parts of the pumps and manure spreader must be maintained at all times of operation. Other safety precautions must be as recommended by the equipment manufacturers.

Decisionmaker acknowledgment

I certify that this plan accurately represents my decisions for installation, operation, maintenance, and safety for my AWMS:

Joe Green, Decisionmaker Date

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

**Part 651
Agricultural Waste Management
Field Handbook**

Chapter 15 Computer Software and Models

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Chapter 15 Computer Software and Models

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Chapter 15 Computer Software and Models

651.1500 Introduction

The planning and design of an Agricultural Waste Management System (AWMS) requires an evaluation of alternative approaches in addressing an environmental concern. The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) uses computer software to speed and enhance this process. The software includes several nutrient assessment models and a component design program. This chapter of the Agricultural Waste Management Field Handbook (AWMFH) provides a brief description of available computer software and reference material.

651.1501 Planning software

Customer Service Toolkit (CST) is the primary conservation planning tool used by the NRCS, conservation districts, and technical service providers (TSP). CST is used for conservation planning and design, layout, and evaluation of approved conservation practices. With CST, the user can create and check in customer data to the National Conservation Planning Database (NCPDB) and also check out customer data from the NCPDB. In addition, the customer data is made available to the Performance Reporting System (PRS).

TSPs have an important role in the conservation planning process. With proper permissions, TSPs have access to the CST and NCPDB data via the Conservation Transaction Plug In Tool. Further information and guidance on the TSP certification process can be found at http://techreg.usda.gov.

Within the CST application resides a front-end ESRI® ArcGIS®[1] interface to geo-reference and digitize farming/ranching operations, fields, conservation practices, and other needed features. The ArcGIS application consists of a table of contents that contains the layers that may be displayed in the View. A menu bar and toolbars comprise the graphical user interface. Several pop-up menus are available using a right-mouse click to assist in planning.

1 ESRI and ArcGIS are trademarks, registered trademarks, or service marks of ESRI in the United States, the European Community, or certain other jurisdictions.

651.1502 Animal waste management design software

Animal Waste Management (AWM) software is a planning and design tool, providing assistance with the calculations associated with manure management systems. Using estimated daily production of manure, bedding, and process water, it supports the design of lagoons, storage ponds, storage tanks, and stacking facilities. The procedures and calculations used in AWM are based on information from the AWMFH and use average monthly precipitation and evaporation data. The program also supports the design of anaerobic and aerobic lagoons with multiple cells and operated either alone or in combination with other manure storage facilities. Options for anaerobic lagoon design include the AWMFH procedure and Clyde Barth's Rational Method (Barth 1985). The program also allows the user to print preconfigured design and/or operation and maintenance reports. Customized reports can be generated by using design variables imbedded in the report templates. Since the release of Version 2.4, AWM has the added capability of evaluating existing storage structures.

AWM also includes Manure Master, a simplified tool used to estimate the amount of cropland that will be needed for the nutrients produced by an animal feeding operation. Manure Master computes a gross nutrient balance between the nitrogen, phosphorus, and potassium content in the manure and the quantity of these nutrients used by crops. This balance can be calculated based upon recommended fertilizer application rates when known or upon estimated plant nutrient content when recommended fertilizer application rates are not known. For nitrogen, the balance is calculated taking into account expected losses from leaching, denitrification, and volatilization. Manure Master does not track mass or concentration of nutrients for determining land application rates or for other utilization components; therefore, Manure Master is not a sufficient nutrient management tool for producing a nutrient plan that will comply with the criteria in NRCS National Conservation Practice Standard (CPS) Code 590, Nutrient Management.

651.1503 Site modeling software

The Soil-Plant-Air-Water (SPAW) Field and Pond Hydrology Model is a software tool developed by the USDA Agricultural Research Service (ARS) to perform a one-dimensional water budget on agricultural fields using daily values. It can evaluate AWM designs by examining in detail how runoff and other inputs affect the resulting pond volumes. While this tool is fairly complex, it is ideally suited for special studies and evaluations where daily values are preferred over average monthly values. The performance of wastewater storage systems are modeled by SPAW using a water budget in the vertical dimension to simulate runoff, infiltration, evapotranspiration, percolation, and the water content of the soil profile. Including manure and process water inputs along with periodic pumping data allows the program to estimate the effects of management upon a given storage system.

651.1504 Nutrient management software

Manure Management Planner© [2] (MMP) is a Windows®[3]-based computer program, developed at Purdue University, used for development of nutrient management plans CPS Code 590 and Comprehensive Nutrient Management Plans (CNMPs) for crop and animal feeding operations. The user enters information about the operation's fields, crops, storage, animals, and application equipment. MMP streamlines the allocation process of both organic and inorganic nutrients (where, when, and how much) on a monthly basis for the length of the plan (1–10 years). This allocation process helps determine if the current operation has sufficient crop acreage, seasonal land availability, manure storage capacity, and application equipment to manage the manure produced in an environmentally responsible manner. MMP is also useful for identifying changes that may be needed for a nonsustainable operation to become sustainable and determining what changes may be needed to keep an operation sustainable if the operation expands.

Further information on MMP is available at http://www.purdue.edu/mmp. More information on the CNMP development process is available in the CNMP Field Handbook available at http://directives.sc.egov.usda.gov/viewerFS.aspx?hid=25650.

Base data for nutrient management planning is available from various locations and entities. To streamline this process and make it user friendly, the University of Missouri developed a data finder routine available to the public for download. Please note that the needed data can be pulled from other sources, as long as the data are authenticated.

- University of Missouri National Data Finder Web site located at http://www.nmplanner.missouri.edu/software/national_data.asp. The clipped download zip file contains the following base data:
  - Aerial photograph of the farm
  - Topographic map of the farm
  - Digitized soil survey layer for the farm
- Revised Universal Soil Loss Equation, Version 2 (RUSLE2) database that contains crop management zone, climate, and soils data required by RUSLE2 for the farm. The clipping feature automatically creates a RUSLE2 database for the farm's area that can be used with MMP.

2 MMP is copyrighted by the Purdue Research Foundation.
3 Microsoft, Encarta, MSN, and Windows are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

The Geospatial Nutrient Tool (GNT), developed by the NRCS in cooperation with the University of Missouri, is the spatial front end for NRCS conservation planners and used prior to streaming data to MMP. Its primary purpose is to enable NRCS planners to download previously accomplished work contained in the CST software. GNT operates as a toolbar within the CST application and runs in the ArcGIS 9.x environment. NRCS planners can access a customer's folder, produce or modify maps, and push the data to MMP to expedite development of an NRCS CNMP document. GNT includes the National Setbacks Database to provide access to manure setback requirements for the states currently supported by MMP. More States will be added as the MMP rollout to States continues. The tool is used primarily by nutrient management planners. Further information on GNT is available at http://www.wsi.nrcs.usda.gov/products/W2Q/nutr/nutrGNT.html.

Conservation planners can also digitize operations that have not been digitized yet and also refine field features for farming operations that have already been digitized. Larger fields that are adequate for conservation planning purposes generally need to be divided into subfields for nutrient management planning purposes. In addition, there is a field setbacks tab that steps the user through various voluntary and regulatory setbacks regarding nutrient (generally manure) applications. These setbacks are important when determining "spreadable acres" for manure applications, and developing a farm nutrient balance.

TSPs and other private industry individuals currently do not have access to the GNT. However, with the landowner's permission and NRCS authorization, TSPs can be granted access to NRCS client information using the Conservation Transaction Plug In Tool and use the client data in their own software to make nutrient management and CNMP changes. Changes made can also be uploaded back to the NRCS CST for NRCS usage.

The National Setbacks Database was developed by the University of Missouri in cooperation with the NRCS. The software is Windows®-driven, offered free of charge, and available at http://nmplanner.missouri.edu/software/setbacks.asp. The site currently provides access to manure setback requirements by categories established by each individual State, e.g., regulatory, NRCS, and other State-setback options. At present, setback requirements are furnished for the 34 States currently supported by MMP. More States will be added as the MMP rollout to States continues. The tool is used primarily by nutrient management planners.

AFOPro© [4] is a standalone nutrient management planning tool with optional connections to geographic information systems (GIS) such as ESRI ArcMap™ and ArcView®, and the NRCS's AWM (ver. 2.0.2 or higher) engineering software[5]. The application allows the user to plan manure and commercial fertilizer allocation decisions in compliance with CPS Code 590, which requires the documentation of form, source, timing, method, and placement of nutrients. The design of the application is open, transparent, and flexible, enabling it to be adapted to specific State crop removals, nutrient risk ratings, and nitrogen accounting requirements. Additionally, the application uses modular Phosphorus Indices (PI), State-specific fertility recommendations and State-specific CNMP templates.

The Idaho OnePlan Nutrient Management Planner© [6] provides data and software to help growers develop a single conservation farm plan that can be pre-endorsed by interested agencies, streamlining and simplifying the regulatory process for animal feeding operations. Several States use OnePlan for CNMP creation and offer training on its use.

4 AFOPro is intellectually copyrighted by the University of South Carolina Research Foundation (USCRF# 00354).

5 ESRI, ArcMap, and ArcView are trademarks, registered trademarks, or service marks of ESRI in the United States, the European Community, or certain other jurisdictions.

6 OnePlan is copyrighted by the University of Idaho.

651.1505 Site assessment software

The Nitrate Leaching and Economic Analysis Package (NLEAP) is a field-scale computer model developed to provide a rapid and efficient method of determining potential nitrate leaching associated with agricultural practices at a given location. It combines basic information concerning on-farm management practices, soils, and climate and then translates the results into projected nitrogen budgets and nitrate leaching below the root zone and to groundwater supplies and estimates the potential offsite effects of leaching.

The screening procedure uses a simplified annual water and nitrogen budget and is designed to give only a general estimate of potential leaching of nitrate. The monthly budget analysis calculates leaching with consideration for the seasonal and monthly effects of precipitation, temperature, evapotranspiration, and farm management. The event-by-event analysis provides the best estimate of nitrate leaching. Its water and nitrogen budgets track the impacts of each precipitation, irrigation, fertilization, and tillage event on potential nitrate leaching. The event-based procedure is recommended for analysis of potential nitrate leaching to domestic water supply. NLEAP can be operated alone or in conjunction with a GIS system.

The Agricultural Policy/Environmental eXtender[7] (APEX) model was developed by USDA Agricultural Research Service (ARS) and Texas A&M University for use in whole farm/small watershed management. The model was constructed to evaluate various land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather, and pests. Management capabilities include irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage. Besides the farm management functions, APEX can be used in evaluating the effects of global climate/CO^2 changes; designing environmentally safe, and economical landfill sites; designing biomass production systems for energy; and other spin-off applications. The model operates on a

7 Blackland Research and Extension Center, Texas A&M University (http://www.brc.tamus.edu).

daily time step and is capable of simulating hundreds of years if necessary. Farms may be subdivided into fields, soil types, landscape positions, or any other desirable configuration. Currently, APEX is not directly integrated with a GIS.

The individual field simulation component of APEX is taken from the Erosion/Productivity Impact Calculator (EPIC) model, developed by the USDA ARS. The drainage area considered by EPIC is generally a field-sized area, up to 247 acres (100 ha), where weather, soils, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control. Although EPIC operates on a daily time step, the optional Green and Ampt infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h). The model offers options for simulating several other processes including five potential evapo-transpiration (PET) equations, six erosion/sediment yield equations, and two peak runoff rate equations. EPIC can be used to compare management systems and their effects on nitrogen, phosphorus, pesticides and sediment. The management components that can be changed are crop rotations, tillage operations, irrigation scheduling, drainage, furrow diking, liming, grazing, tree pruning, thinning, and harvest, manure handling, and nutrient and pesticide application rates and timing.

The APEX model was developed to extend the EPIC model capabilities to whole farms and small watersheds. In addition to the EPIC functions, APEX has components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet. APEX also has groundwater and reservoir components. A watershed can be subdivided as much as necessary to assure that each subarea is relatively homogeneous in terms of soil, land use, management, etc. The routing mechanisms provide for evaluation of interactions between subareas involving surface runoff, return flow, sediment deposition and degradation, nutrient transport, and groundwater flow. Water quality in terms of nitrogen (ammonium, nitrate, and organic), phosphorus (soluble and adsorbed/mineral and organic), and pesticides concentrations may be estimated for each subarea and at the watershed outlet. Commercial fertilizer or manure may be applied at any rate and depth on specified dates or automatically. The GLEAMS pesticide model is used to estimate pesticide fate considering runoff, leaching, sediment transport and decay. Because of routing and subdividing there is no limit on watershed size. However, a practical limit may be about 965 square miles (2,500 km^2) because of the detailed crop/management system of APEX. APEX has its own data bases for weather simulation, soils, crops, tillage, fertilizer, and pesticides.

The PI is a site vulnerability assessment tool to help determine the relative risk for offsite transport of phosphorus and manure. The PI is a useful tool for prioritizing fields for the application of animal manure or other organic by-products that contains phosphorus. It may also be used to identify fields on which more careful management of phosphorus may be necessary by assessing the various landforms and management practices for potential risk of phosphorus movement to water bodies. The ranking of PI identifies sites where the risk of phosphorus movement may be relatively higher than that of other sites. Corrective soil and water conservation practices and management techniques can then be used to reduce the potential for movement of phosphorus and reduce the concern for excessive phosphorus enrichment. Each State may modify the PI, based on local criteria.

651.1506 References

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Conversion Factors and Tables

Length

Conversion table

Unit of measure	Symbol	mm	cm	m	km	in	ft	mi
millimeter	mm	1	0.1	0.001	—	0.0394	0.003	—
centimeter	cm	10	1	0.01	—	0.394	0.033	—
meter	m	1000	100	1	0.001	39.37	3.281	—
kilometer	km	—	—	1000	1	—	3,281	0.621
inch	in	25.4	2.54	0.0254	—	1	0.083	—
foot	ft	304.8	30.48	0.305	—	12	1	—
mile	mi	—	—	1609	1.609	—	5280	1

Area

Conversion table

Unit of measure	Symbol	m^2	ha	km^2	ft^2	acre	mi^2
square meter	m^2	1	—	—	10.76	—	—
hectare	ha	10,000	1	0.01	107,640	2.47	0.00386
square kilometer	km^2	lx10^6	100	1	—	247	0.386
square foot	ft^2	0.093	—	—	1	—	—
acre	acre	4,049	0.405	—	43,560	1	0.00156
square mile	mi^2	—	259	2.59	—	640	1

Volume

Conversion table

Unit of measure	Symbol	km^3	m^3	L	Mgal	acre-ft	ft^3	gal
cubic kilometer	km^3	1	lx10^9	—	—	811,000	—	—
cubic meter	m^3	—	1	1000	—	—	35.3	264
liter	L		0.001	1			0.0353	0.264
million U.S. gallons	Mgal	—	—	—	1	3.07	134,000	1x10^6
acre-foot	acre-ft	—	1,233	—	0.3259	1	43,560	325,848
cubic foot	ft^3	—	0.0283	28.3	—	—	1	7.48
gallon	gal	—	—	3.785	—	—	0.134	1

Flow Rate

Unit of measure	Symbol
cubic kilometers/year	km^3/yr
cubic meters/second	m^3/s (m^3/sec)
liters/second	L/s (L/sec)
million U.S. gallons/day	mgd (Mgal/d)
U.S. gallons/minute	gpm (gal/min)
cubic feet/second	cfs (ft^3/s)
acre-feet/day	acre-ft/day

Conversion table

km^3/yr	m^3/s	L/s	mgd	gpm	cfs	acre-ft/day
1	31.7	---	723	---	1,119	2,220
0.0316	1	1000	22.8	15,800	35.3	70.1
---	0.001	1	0.0228	15.8	0.0353	(0.070)
---	0.044	43.8	1	694	1.547	3.07
---	---	0.063	---	1	0.0022	0.0044
---	0.0283	28.3	0.647	449	1	1.985
---	---	14.26	0.326	226.3	0.504	1

Weights

Unit of measure	Symbol
ton (short)	T
pound	lb
kilogram	kg
gram	g
milligram	mg
microgram	μg

Conversion table

T	lb	kg	g	mg	μg
1	2000	907	---	---	---
	1	0.454	453.592	---	---
	2.205	1	1000	$lx10^6$	
		0.001	1	1000	$lx10^6$
			0.001	1	1000
				0.001	1

Note: 1 short ton = 2,000 lb
1 long ton = 2,240 lb
1 metric ton = 1,000,000 g = 1,000 kg = 2,205 lb

Miscellaneous

1 acre-inch	= 27,154 gallons
1 horsepower	= 0.746 kilowatts
1 horsepower	= 550 foot-pounds per second
degrees C	= 5/9 (F° – 32°)
degrees F	= 9/5 (C° + 32°)
1 gram	= 15.43 grains
1 ppm	= 8.345 pounds per million gallons of water = 0.2268 pounds per acre-inch
1 U.S. gallon	= 8.345 pounds

parts per million (ppm)—1 ppm is 1 part by weight in 1 million parts by weight.

milligrams per liter (mg/L)—1 mg/L is 1 milligram (weight) in 1 million parts (volume), i.e., 1 liter. Therefore, ppm = mg/L when a solution has the same specific gravity as water. Generally, substances in solution up to concentrations of about 7,000 mg/L do not materially change the specific gravity of water. To that limit ppm and mg/L are numerically interchangeable. A 1-percent solution has a concentration of 10,000 ppm, which equals 1 gm in 100 grams of water.

Electrical conductivity—Electrical conductance is expressed in mhos (reciprocal ohms); electrical conductivity (EC) is expressed in mhos/cm. 1 mhos/cm = 1,000 millimhos/cm (mmhos/cm) = 1,000,000 micromhos per centimeter (umhos/cm). 1.0 mmho/cm equals a concentration of approximately 640 ppm dissolved salts.

Glossary

Absorption The physical integration of a liquid into the pore spaces of a solid, such as water being absorbed into a sponge.

Adsorption The electro-chemical attraction of positively or negatively charged ions or molecules onto solids with an opposite charge.

Advection The process by which solutes are transported by the bulk motion of the flowing groundwater.

Aeration A process causing intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air, (b) bubbling air through the liquid, and (c) agitating the liquid to promote absorption of oxygen through the air liquid interface.

Aeration, soil The exchange of air in soil with air from the atmosphere. The air in a well aerated soil is similar to that in the atmosphere; the air in a poorly aerated soil is considerably higher in carbon dioxide and lower in oxygen.

Aerobic Having or occurring in the presence of free oxygen.

Aerobic bacteria Bacteria that require free elemental oxygen for their growth. Oxygen in chemical combination will not support aerobic organisms.

Agricultural waste management system A combination of conservation practices formulated to appropriately manage a waste product that, when implemented, will recycle waste constituents to the fullest extent possible and protect the resource base in a nonpolluting manner.

Agricultural wastes Wastes normally associated with the production and processing of food and fiber on farms, feedlots, ranches, ranges, and forests which may include animal manure, crop and food processing residues, agricultural chemicals, and animal carcasses.

Alluvial Pertaining to or composed of alluvium or deposited by a stream or running water.

Alluvium A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semi-sorted sediment in the bed of the stream or in its flood plain or delta, or as a cone or fan at the base of a mountain slope.

Amino acids Organic nitrogen compounds which are the building blocks of proteins.

Ammonia nitrogen The nitrogen component of the gas (NH_3) released by the microbiological decay of plant and animal proteins. (The term sometimes refers to the total of NH_3 and the ammonium ion, NH_4^+)

Ammonia volatilization The loss of ammonia gas to the atmosphere.

Ammonium An ion (NH_4^+) derived from ammonia (NH_3).

Anaerobic The absence of molecular oxygen, or growing in the absence of oxygen, such as anaerobic bacteria.

Anaerobic bacteria Bacteria not requiring the presence of free or dissolved oxygen.

Anaerobic digester A heated, air-tight apparatus that facilitates anaerobic digestion.

Anaerobic digestion Conversion of organic matter in the absence of oxygen under controlled conditions to such gases as methane and carbon dioxide.

Anaerobic lagoon A facility to treat animal waste by predominantly anaerobic biological action using anaerobic organisms, in the absence of oxygen, for the purpose of reducing the strength of the waste.

Ancillary practice A treatment or conservation practice used to meet a specific need in planning and carrying out soil and water conservation programs.

Anion exchange Ion exchange process in which anions in solution are exchanged for other anions from an ion exchanger.

Anion Negatively charged ion that can adsorb to negatively charged particles. Common soil anions are nitrates (NO_3^-) and orthophosphates ($H_2PO_4^-$).

Aquitard A geologic formation, group of formations, or part of a formation through which virtually no water moves.

Artesian well A well deriving its water from a confined aquifer in which the water level stands above the ground surface; synonymous with flowing well.

Available nitrogen Form of nitrogen that is immediately available for plant growth (NO_3^- or NH_4^+).

Available nutrient A nutrient molecule that can be adsorbed and assimilated by growing plants.

Available phosphorus Forms of phosphorus that can be immediately used for plant growth.

Available water capacity (available moisture capacity) The capacity of soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil. The capacity, in inches, in a 60-inch profile is expressed as:

Very low	0 to 3 inches
Low	3 to 6 inches
Moderate	6 to 9 inches
High	9 to 12 inches
Very high	> 12 inches

Bacteria A group of universally distributed, rigid, essentially unicellular procaryotic micro-organisms. Bacteria usually appear as spheroid, rod-like or curved entities, but occasionally appear as sheets, chains, or branched filaments.

Basalt A general term for dark-colored iron- and magnesium-rich igneous rocks, commonly extrusive, but locally intrusive. It is the principal rock type making up the ocean floor.

Baseflow Water that having infiltrated the soil surface, percolates to the ground water table and moves laterally to reappear as surface runoff.

Bedrock The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Best Management Practice (BMP) A practice or combination of practices found to be the most effective, practicable (including economic and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals.

Biochemical Oxygen Demand (BOD) An indirect measure of the concentration of biodegradable substances present in an aqueous solution. Determined by the amount of dissolved oxygen required for the aerobic degradation of the organic matter at 20 °C. BOD_5 refers to that oxygen demand for the initial five days of the degradation process.

Biological wastewater treatment Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize or oxidize the unstable organic matter present. Oxidation ditches, aerated lagoons, anaerobic lagoons and anaerobic digesters are examples.

Biomagnification The process by which toxic substances become concentrated in animal and plant tissues.

Biomass The total amount of living material, plants and animals, above and below ground in a particular area.

Boulders Rock fragments larger than 2 feet (60 cm) in diameter.

Candidate measure (CM) A practice that has the potential to reduce pollutant loading, and thereby, the potential to improve water quality.

Capillary fringe The zone at the bottom of the vadose zone where ground water is drawn upward by capillary force.

Carbonate A sediment formed by the organic or inorganic precipitation from aqueous solution of carbonates of calcium, magnesium, or iron.

Cation Positively charged ion; can adsorb to soil particle. Common soil cations are ammonium (NH_4^+), calcium (Ca^{+2}), and potassium (K^+).

Cation exchange Ion exchange process in which cations in solution are exchanged for other cations on the surface of a surface-active (ion exchanger) material, such as a clay colloid or organic colloid.

Cation-exchange capacity
The total amount of exchangeable cations that can be adsorbed by a soil, or a soil constituent expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value.

Chemical Oxygen Demand (COD)
An indirect measure of the biochemical load exerted on the oxygen content of a body of water when organic wastes are introduced into the water. If the wastes contain only readily available organic bacterial food and no toxic matter, the COD values can be correlated with BOD values obtained from the same wastes.

Chlorinated hydrocarbons
A class of synthetic organic compounds used by industry, farms, and households for a variety of purposes including pest control. These organic compounds can also be produced by chlorinating sewage effluent, which is done to aid oxidation and kill pathogens contained in the untreated effluent.

Clay
As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Coarse textured soil
Sand or loamy sand.

Coefficient of storage
The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Coliform bacteria
A group of bacteria predominantly found in the soil. The fecal coliform species inhabits the intestines of man or animal. Coliform bacteria includes all aerobic and facultative anaerobic, gram-negative, non-spore-forming bacilli that ferment lactose with production of gas. This group of "total" coliforms includes Escherichia coli (E-Coli), which is considered to be a typical coliform of fecal origin.

Complexation (chelation)
The reaction between a metallic ion and a complexing organic agent that form a complex chemical ring structure and the effective removal of the metallic ion from the system.

Composting
A process of aerobic biological decomposition of organic material characterized by elevated temperatures that, when complete, results in a relatively stable product suitable for a variety of agricultural and horticultural uses.

Conductivity
See electrical and hydraulic conductivity.

Cone of depression
A depression in the ground water table or potentiometric surface that has the shape of an inverted cone and develops around a well from which water is being withdrawn. It defines the area of influence of a well.

Confined aquifer
A formation in which the ground water is isolated from the atmosphere at the point of discharge by impermeable geologic formations. Confined ground water is generally subject to pressure greater than atmospheric.

Conservation cropping sequence — An adapted sequence of crops designed to provide adequate organic residue for maintenance or improvement of soil tilth and for other conservation purposes.

Conservative pollutants — Pollutants that are not altered as they are transported from their source to the receiving water.

Conservation practice — A specific structural, managerial, or cultural treatment of natural resources commonly used to meet a specific need in planning and carrying out soil and water conservation programs.

Contamination — The degradation of water quality as a result of natural processes and/or the activities of people. No specific limits are established because the degree of permissible contamination depends upon the intended end use or uses of the water.

Conventional tillage — Those primary and secondary tillage operations that are considered standard for the specific location and crop.

Cost-effectiveness — A term used to economically compare agricultural nonpoint source control alternatives. It is generally expressed as dollars per unit pollutant load reduction.

Cover crop — A close-growing crop, whose main purpose is to protect and improve the soil and use excess nutrients or soil moisture during the absence of the regular crop, or in the nonvegetated areas of orchards and vineyards.

Crop consumptive use — See Evapotranspiration.

Crop rotation — A planned sequence of crops.

Cultural eutrophication — The process of nutrient enrichment artificially accelerated by some action(s) of human society (see “Eutrophication”).

Darcy’s law — A derived equation for the flow of fluids on the assumption that the flow is laminar and that inertia can be neglected.

Decisionmaker — An individual or group of people with the responsibility for making decisions about land use and treatment.

Deep percolation — The downward movement of water through the soil and below the root zone.

Demineralization — The total removal of all ions.

Denitrification — The chemical or biological reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen (N_2) or as an oxide of nitrogen (N_2O).

Desorption — The release of sorbed ions or compounds from solid surfaces.

Detention pond — See Waste storage ponds.

Digestion The process of organic matter breaking down into simpler and/or more biologically stable products; e.g., ammonia to organic nitrogen.

Direct runoff Both surface flow and the interflow component of subsurface flow.

Dispersion The spreading and mixing of chemical constituents in ground water caused by diffusion and mixing because of microscopic variations in velocities within and between pores.

Dissolved oxygen (DO) The molecular oxygen dissolved in water, wastewater, or other liquid; generally expressed in milligrams per liter, parts per million, or percent of saturation.

Dry-weight percentage The ratio of the weight of any constituent to the oven-dry weight of the whole substance, such as plant or soil.

Earthen manure storage basin See Waste storage pond.

Effluent The liquid discharge from a waste treatment process.

Effluent standard Designated limit in the amount of any constituent within an effluent.

Electrical conductivity Conductivity of electricity through water or an extract of soil.

Enrichment ratio The ratio of pollutant concentration in the runoff or sediment to its concentration in the soil or soil water, respectively.

Equipotential line A contour line on the water table or potentiometric surface; a line along which the pressure head of ground water in an aquifer is the same. Fluid flow is normal to these lines in the direction of decreasing fluid potential.

Erosion The wearing away of the land surface by water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion (accelerated) Erosion much more rapid than geologic erosion, mainly as a result of the activities of man or other animals or of a catastrophe in nature, for example, fire, that exposes the surface.

Erosion (geologic) Erosion caused by geologic processes acting over long geologic periods.

Escherichia coli (E. Coli) One of the species of bacteria in the intestinal tract of warm-blooded animals. Its presence is considered indicative of fecal contamination.

Eutrophication A natural or artificial process of nutrient enrichment whereby a water body becomes abundant in plant nutrients and low in oxygen content.

Evapotranspiration The loss of water from an area by evaporation from the soil or snow cover and transpiration by plants.

Exchange capacity The abundance of sites (within the soil sample) which have the potential for being actively engaged in ion adsorption. See Cation-exchange capacity.

Fault A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

Fertilizer value An estimate of the value of commercial fertilizer elements (N, P, K) that can be replaced by manure or organic waste material. Usually expressed as dollars per ton of manure or quantity of nutrients per ton of manure.

Field (moisture) capacity The moisture content of a soil, expressed as a percentage of the ovendry weight, after the gravitational, or free, water has drained away.

Fine textured soil Sandy clay, silty clay, and clay.

Flow lines Lines indicating the direction followed by groundwater toward points of discharge. Flow lines are perpendicular to equipotential lines.

Flushing system A system that collects and transports or moves waste material with the use of water, such as in washing of pens and flushing confinement livestock facilities.

Grassed infiltration area An area with vegetative cover where runoff water infiltrates into the soil.

Ground water Water filling all the unblocked pores of underlying material below the water table.

Ground water table The surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

Half-life The time required for one half of a specified substance to be transformed to another substance.

Head loss That part of head energy which is lost because of friction as water flows.

Head Energy contained in a water mass; expressed in elevation (feet) or pressure (pounds per square feet).

Horizon, soil A layer of soil, approximately parallel to the surface, having distinct characteristics produced during soil-forming processes.

Hydraulic conductivity The rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature (gpd/ft^2). In the SI system, the units are m^3/day/m^2 or m/day.

Hydraulic gradient The rate of change in total head per unit of distance of flow in a given direction.

Hydrologic condition Description of the moisture present in a soil by amount, location, and configuration.

Hydrologic soil groups A classification system used by the Natural Resources Conservation Service to group soils according to their runoff-producing characteristics. The chief consideration is the inherent capacity of soil bare of vegetation to permit infiltration. The slope and the kind of plant cover are not considered, but are separate factors in predicting runoff. Soils are assigned to four groups. In group A are soils having a high infiltration rate when thoroughly wet and having a low runoff potential. They are mainly deep, well drained, and sandy or gravelly. In group D, at the other extreme, are soils having a very slow infiltration rate and thus a high runoff potential. They have a claypan or clay layer at or near the surface, have a permanent high water table, or are shallow over nearly impervious bedrock or other material.

Igneous rock Rocks that solidified from molten or partly molten material, that is, from a magma.

Infiltration The downward entry of water into the immediate surface of soil or other material.

Infiltration rate The rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. The rate can be limited by the infiltration capacity of the soil or the rate at which water is applied at the surface.

Interflow Water that enters the soil surface and moves laterally through the soil layers to reappear as surface flow. Flow takes place above ground water level.

Ion A charged element or compound that has gained or lost electrons so that it is no longer neutral electrically.

Karst topography A type of topography that is formed in limestone, gypsum, and other similar type rock by dissolution and is characterized by sinkholes, caves, and rapid underground water movement.

Labile Readily coming into equilibrium.

Lagoon See Waste treatment lagoon.

Land application Application of manure, sewage sludge, municipal wastewater, and industrial wastes to land for reuse of the nutrients and organic matter for their fertilizer and soil conditioning values.

Landscape The environment, both natural and built, that surrounds us.

Landscape character A measure of an apparent harmony or unity among all landscape elements, built and natural, that can be intensified or preserved to make a memorable scene.

Landscape quality A composite of those landscape conditions and perceived values that provide diverse and pleasant surroundings for human use and appreciation. Recognized components of landscape quality include visual resource, landscape use, viewscape, and visibility.

LC_{50}–lethal concentration The concentration at which 50 percent of the target organisms are killed in water. Generally expressed as milligrams of toxicant per liter of water (mg/L).

LD_{50}–lethal dose The dose at which 50 percent of the target organisms are killed. Toxicant is administered orally or subcutaneously. Generally expressed as milligrams of toxicant per kilogram of body weight (mg/kg).

Leaching (1) The removal of soluble constituents, such as nitrates or chlorides, from soils or other material by the movement of water. (2) The removal of salts and alkali from soils by irrigation combined with drainage. (3) The removal of a liquid through a non-watertight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surrounding permeable soil.

Limestone A sedimentary rock consisting chiefly of calcium carbonate.

Limiting nutrient Nutrient that restricts plant growth.

Linear programming (LP) Computational technique used to find solutions for multivariable problems.

Liquid manure A mixture of water and manure that behaves more like a liquid than a solid, generally less than 5 percent solids.

Livestock waste A term sometimes applied to manure that may also contain bedding, spilled feed, water, or soil. It also includes wastes not particularly associated with manure, such as milking center or washing wastes, and milk, hair, feathers, or other debris.

Load Quantity of substance entering the receiving body.

Macronutrient A chemical element required, in relatively large amounts, for proper plant growth.

Managerial controls Candidate treatments that involve changes in timing, chemical application rates, or tillage systems and generally do not involve separate field activities.

Manure The fecal and urinary excretions of livestock and poultry.

Mechanical solids separation The process of separating suspended solids from a liquid-carrying medium by trapping the particles on a mechanical screen or sieve or by centrifugation.

Microclimate Climate as experienced at the scale of a particular site. Includes such elements as solar orientation, wind direction, temperature, and precipitation.

Micronutrient A chemical element required, in relatively small amounts, for proper plant growth.

Mineralization The microbial conversion of an element from an organic to an inorganic state.

Molecular diffusion Dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Monitoring Systematic collection of data on a routine basis and the analysis of these data for an understanding of the changes that may occur in the sampled environment.

Morphology, soil The constitution of the soil including the texture, structure, consistence, color, and other physical, chemical, and biological properties of the various soil horizons that make up the soil profile.

Mulch Any substance that is spread on the soil surface to decrease the effects of raindrop impact, runoff, and other adverse conditions and to retard evaporation.

Municipal waste Solid and liquid fractions of wastes produced by a municipality. Municipal wastes may be treated or untreated and may be either used or disposed of.

Nitrification The biochemical transformation by oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) or nitrate (NO_3^-).

Nitrate nitrogen The nitrogen component of the final decomposition product (NO_3^-) of the organic nitrogen compounds; expressed in terms of the nitrogen part of the compound (NO_3^-–N).

Nitrogen A chemical element, commonly used in fertilizer as a nutrient, which is also a component of animal wastes. As one of the major nutrients required for plant growth, nitrogen can promote algal blooms that cause water body eutrophication if it runs off or leaches out of the surface soil. Nitrogen is immediately usable for plant growth in available forms (NO_3^- or NH_4^+).

Nitrogen cycle The succession of biochemical reactions that nitrogen undergoes as it is converted to organic or available nitrogen from the elemental form. Organic nitrogen in waste is oxidized by bacteria into ammonia (NH_3). If oxygen is present, ammonia is bacterially oxidized first into nitrite (NO_2^-) and then into nitrate (NO_3^-). If oxygen is not present, nitrite and nitrate are bacterially reduced to nitrogen gas, completing the cycle.

Nitrogen fixation The biological process by which elemental nitrogen is converted to organic or available nitrogen.

No-till A planting procedure that requires no tillage except that done by a coulter in the immediate area of the crop row.

Nonpoint source (NPS) Entry of effluent into a water body in a diffuse manner so there is no definite point of entry.

Nutrient absorption See Absorption.

Nutrient assimilation The conversion or incorporation of plant nutrients into plant cells and tissue.

Nutrient transformation The changing in the form of a plant element that may affect the stability, availability, or mobility of the compound. An example is the changing of ammonium nitrogen (NH_4^+) to nitrate nitrogen (NO_3^-).

Nutrient, plant See Nutrients.

Nutrients Elements required for plant or animal growth, including the macronutrients (nitrogen, phosphorus, and potassium), which are the major nutrients required and micronutrients, which include a number of other elements that are essential but needed in lesser amounts.

Organic matter The organic fraction of the soil exclusive of undecayed plant and animal residue.

Pathogens Disease causing micro-organisms; generally associated with viruses or bacteria.

Perched water Unconfined ground water separated from an underlying main body of ground water by an unsaturated zone (generally an aquaclude).

Percolation rate The rate of movement of water under hydrostatic pressure down through the interstices of rock, soil, or filtering media except movement through large openings, such as caves.

Percolation The downward movement of water through soil.

Permanent wilting point The moisture content of soil, on an ovendry basis, at which a plant (specifically a sunflower) wilts so much that it does not recover when placed in a humid, dark chamber.

Permeability The quality of the soil that enables water to move downward through the profile. Permeability is measured as the number of inches per hour that water moves downward through the saturated soil. Terms describing permeability are:

Very slow	less than 0.06 inches/hr
Slow	0.06 to 0.2 inches/hr
Moderately slow	0.2 to 0.6 inches/hr
Moderate	0.6 to 2.0 inches/hr
Moderately rapid	2.0 to 6.0 inches/hr
Rapid	6.0 to 20 inches/hr
Very rapid	more than 20 inches/hr

Persistence Relates to the time required for a chemical (usually a pesticide) to degrade into a harmless compound; expressed as half-life.

pH The negative logarithm of the hydrogen ion concentration. The pH scale ranges from zero to 14. Values below 7 are considered acidic and those above, alkaline.

Phosphate Phosphate ions exist in water as $H_2PO_4^-$ or HPO_4^{-2}. Otherwise phosphate is an ester or salt of phosphoric acid, such as calcium phosphate rock.

Phosphorus One of the primary nutrients required for the growth of plants. Phosphorus is often the limiting nutrient for the growth of aquatic plants and algae.

Point source The release of a contaminant or pollutant, often in concentrated form, from a conveyance system, such as a pipe, into a water body.

Pollutant Delivery Ratio (PDR) The fraction of a pollutant leaving an area that actually enters a body of water.

Pollution/polluted The presence in a body of water (or soil or air) of a substance (contaminant) in such quantities that it impairs the body's usefulness or renders it offensive to the senses of sight, taste, or smell. In general, a public health hazard may be created, but in some instances only economic or aesthetics are involved, such as when foul odors pollute the air.

Ponding Standing water on soils in closed depressions. Unless the soils are artificially drained, the water can be removed only by percolation or evapotranspiration.

Porous dam A runoff control structure that reduces the rate of runoff so that solids settle out in the settling terrace or basin. The structure may be constructed of rock, expanded metal, or timber arranged with narrow slots.

Potassium One of the primary nutrients required for the growth of plants.

Potentiometric surface An imaginary surface representing the total head of ground water in a confined aquifer that is defined by the level to which water could rise in a well.

Pumping test A test that is conducted to determine aquifer yield or well characteristics.

Reduced tillage A management practice whereby the use of secondary tillage operations is significantly reduced.

Resource base The combination of soil, air, water, plants, and animals that makes up the natural environment.

Resource Management System (RMS) A combination of conservation practices and management identified by the primary use of land or water that, when installed, will at a minimum protect the resource base.

Ridge planting The practice of growing a row crop on the ridges between the furrows.

Rock fragments Rock or mineral fragments having a diameter of 2 millimeters or more; for example, pebbles, cobbles, stones, and boulders.

Root zone The part of the soil that can be penetrated by plant roots.

Run-on The water moving by surface flow onto a designated area. Run-on occurs when surface water from an area at a higher elevation flows down onto an area of concern, such as a feedlot, vegetated filter strip, or riparian zone.

Runoff The part of precipitation or irrigation water that appears in surface streams or water bodies; expressed as volume (acre-inches) or rate of flow (gallons per minute, cubic feet per second).

Salt A compound made up of the positive ion of a base and the negative ion of an acid.

Sampling Collection of a small part of an entity and drawing conclusions about the whole. In water quality considerations, sampling consists of collecting a representative part of a water body for testing from which conclusions can be drawn about the water body as a whole.

Sandstone A sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Sediment Delivery Ratio (SDR) Fraction of eroded soil that actually reaches a water body.

Sediment delivery Sediment arriving at a specific location. See Sediment Delivery Ratio.

Sediment yield Quantity of sediment leaving a specified land area.

Sedimentary rocks Rocks resulting from the consolidation of loose sediment that has accumulated in layers.

Sedimentation tank A unit in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation basin, settling basin, settling tank, or settling terrace.

Septage Septic tank pumpings; the mixed liquid and solid contents pumped from septic tanks and dry wells used for receiving domestic type sewage.

Septic tank A settling tank in which settled solid matter is removed from the wastewater flowing through the tank and the organic solids are decomposed by anaerobic bacterial action.

Settleable solids (1) That matter in wastewater that will not stay in suspension during a preselected settling period, such as 1 hour. (2) In the Imhoff cone test, the volume of matter that settles to the bottom of the cone.

Sewage sludge Settled sewage solids combined with varying amounts of water and dissolved materials that are removed from sewage by screening, sedimentation, chemical precipitation, or bacterial digestion.

Shale A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. This rock is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Sheet erosion Soil erosion occurring from a thin, relatively uniform layer of soil particles on the soil surface. Also called interrill erosion.

Site design A careful search among physical elements to plan for human and animal occupation and utilization of a site so that comfort, profitability, and usefulness are maximized and harmful stress is reduced.

Slope The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.

Sodicity The degree to which a soil is affected by exchangeable sodium. Sodicity is expressed as a sodium adsorption ratio (SAR) of a saturation extract.

Soil A natural, three-dimensional body at the Earth's surface. It is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over time.

Soil amendment Any material, such as lime, gypsum, sawdust, or synthetic conditioner, that is worked into the soil to make it more amenable to plant growth. Amendments may contain important fertilizer elements, but the term commonly refers to added materials other than fertilizer.

Soil and Water Conservation Practices (SWCPs) The manipulation of such variables as crops, rotation, tillage, management, and structures to reduce the loss of soil and water.

Soil organic matter The organic fraction of the soil that includes plant and animal residue at various stages of decomposition, exclusive of undecayed plant and animal residue. Often used synonymously with humus.

Soil profile A section of the soil viewed on a vertical plane extending through all its horizons and into the parent material.

Soil solution The liquid phase of the soil including dissolved organic and inorganic materials.

Solid manure storage A storage unit in which accumulations of bedded manure or solid manure are stacked before subsequent handling and field spreading. The liquid part, including urine and precipitation, may or may not be drained from the unit.

Solids content (1) The sum of the dissolved and suspended constituents in water or wastewater. (2) The residue remaining when the water is evaporated away from a sample of sewage, other liquids, or semi-solid masses of material and the residue is then dried at a specified temperature (generally 103 °C for 24 hours); usually stated in milligrams per liter (mg/L) or percent solids.

Sorbed Adsorbed or absorbed.

Spatial The occupied space relationship between a soil or soil map unit to the landscape or geomorphic surface on which the soil or map unit is located.

Stones Rock fragments 10 to 24 inches (25 to 60 cm) in diameter.

Stream classification The identification of specific water uses for watercourses.

Struvite A colorless to yellow or pale-brown mineral, $(M_gNH_4PO_4)(6H_2O)$, that can build up as crystals on pump impellers and in pipes conveying wastewater.

Structural controls Candidate measures that require capital investment, construction activities, and, consequently, certain economic risks.

Structure, soil The arrangement of primary soil particles into compound particles or aggregates. The principal forms of soil structure are platy (laminated), prismatic (vertical axis of aggregates longer than horizontal), columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are either single grained (each grain by itself, as in dune sand) or massive (the particles adhering without any regular cleavage, as in many hardpans).

Subsoil Technically, the B horizon; roughly, the part of the solum below plow depth.

Subsurface runoff Water that infiltrates the soil and then moves laterally/vertically below the surface; includes baseflow and interflow.

Supernatant The liquid fraction in a lagoon.

Surface layer The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, ranging in depth from about 4 to 10 inches (10 to 25 centimeters). Frequently designated as the “plow layer,” or the “Ap horizon.” Some water quality models refer to surface layer as the first few centimeters of soil.

Surface soil The A, E, AB, and EB horizons. It includes all subdivisions of these horizons.

Suspended solids (1) Undissolved solids that are in water, wastewater, or other liquids, and are largely removable by filtering or centrifuging. (2) The quantity of material filtered from wastewater in a laboratory test, as prescribed in APHA Standard Methods for the Examination of Water and Wastewater or similar reference.

Symbiotic Two organism living together in close association in which nether are harmed and both benefit.

Synthetic organic compounds Organic compounds created by industry either inadvertently as a part of a chemical process or for use in a wide array of applications for modern day life. Some that have been created are persistent in the environment (slow to decompose) because oxidizers, such as soil microbes, may not be readily able to use them as an energy source.

Texture, soil The relative proportions of sand, silt, and clay particles in a mass of soil.

Tilth, soil The physical condition of the soil as related to tillage, seedbed preparation, seedling emergence, and root penetration.

Total solids The total amount of solids in a waste, both in solution and suspension.

Toxicity Degree of harmful effect an element or compound may have on a living organism, plant, or animal. Excessive amount of toxic substances, such as sodium or sulfur, that severely hinder establishment of vegetation or severely restrict plant growth.

Trace elements Chemical elements (for example, zinc, cobalt, manganese, copper, and iron) in soils in extremely small amounts that may be essential to plant growth.

Unconfined aquifer An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.

Universal Soil Loss Equation (USLE) An empirical equation estimating the amount of soil loss; used for the evaluation of a resource management system for water erosion control.

Vadose zone The zone containing water under less pressure than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below the surface of the zone of saturation, that is, the water table.

Vector A bearer or carrier; such as an organism (often an insect), that carries and transmits disease-causing micro-organisms.

Vegetative practices Candidate measures that include vegetation as the principal method of pollution control.

View A scene observed from a given vantage point; can be preserved, neutralized, modified, or accentuated.

Viewshed All the land and landscape elements that make up or affect a view from a given location or point; delineated by the horizon/silhouette line, enclosure by built or natural elements.

Vista A confined view, generally toward a terminal or dominant element or feature; may be natural or structural; may be created in its entirety and is therefore subject to close control.

Volatile solids Readily vaporizable solids. Those solids that are combustible at 600 °C.

Volatilization The loss of gaseous components, such as ammonium nitrogen, from animal manure.

Waste management system See Agricultural waste management system.

Waste storage pond An impoundment made by excavation or earthfill for temporary storage of animal or other agricultural waste.

Waste treatment lagoon An impoundment made by excavation or earthfill for biological treatment of animal or other agricultural wastes. Lagoons can be aerobic, anaerobic, or facultative, depending on their loading and design.

Water management system A planned system in which the available water supply is effectively used by managing and controlling the moisture environment of crops to promote the desired crop response, to minimize soil erosion and loss of plant nutrients, to control undesirable water loss, and to protect water quality.

Water quality The excellence of water in comparison with its intended use or uses.

Water table The surface between the vadose zone and the ground water; that surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere.

Wet-weight percentage The ratio of the weight of any constituent to the typical hydrated weight of the whole plant part as harvested.