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Department of
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**Soil
Conservation
Service**

Agricultural
Waste Management
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

Many environmental laws enacted by Congress are enforced by the United States Environmental Protection Agency (EPA). 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 Soil Conservation Service (SCS), that provide technical assistance to producers. State public health and environmental control agencies generally are responsible for implementing Federal as well as State control programs.

Federal legislation aimed at control of water pollution over the past two decades illustrates the national commitment to develop and implement a strategy that leads to cleaner air and water.

(b) Air

The Air Pollution Act of 1955 authorized federally funded air pollution research. Later legislation included the Motor Vehicle Pollution Control Act of 1965, the Air Quality Act of 1967, and the Clean Air Act of 1970. The Clean Air Act provides for uniform air quality standards and control of emissions from existing facilities. It also prohibits construction of new facilities that violate or interfere with Federal or State regulations for air quality standards. Many of the State air quality requirements have been established as a direct result of Federal legislation. Most private citizen complaints and civil suits brought against livestock operators have been because of odor problems.

The Clean Air Act Amendment of 1990 (Public Law 101-549) has provisions of importance to producers of agricultural products. Goals of the law having an agricultural orientation are those for reduction of emissions that cause acid rain and those that target protection of stratospheric ozone. Ammonia volatilization from animal and other agricultural operations will most likely come under increased scrutiny and possible control as a source of soil and water acidification. Some states are starting to request atmospheric ammonia test results on air samples taken at the property lines of the animal operations.

Methane emissions from "rice and livestock production" and from "all forms of waste management . . . including storage, treatment, and disposal" are mentioned in the 1990 law as being of concern with regard to ozone depletion. These sources and others, both nationally and internationally, are to be evaluated by EPA jointly with the Secretaries of Agriculture and Energy, and control options will be developed that can be used to stop or reduce growth of methane concentrations in the atmosphere.

(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, the Clear Water Restoration Act of 1966, and the 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 Code of Federal Regulations (CFR) 40, part 122, to include wetlands and intermittent streams as well as conventional lakes, ponds, rivers, streams, and the territorial seas.

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).

Other Federal actions of interest to agriculture:

The National Environmental Policy Act (NEPA) is the basic national charter for protection of the environment. 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. SCS 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 EPA will protect, restore, and maintain the Nation's coastal and marine water 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 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 (in Public Law 101-508, Budget Reconciliation Act) amended the Coastal Zone Act of 1972 (16 USC 1455) by including requirements for 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

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 parts 122, 123, 124, and 125 of Title 40, Code of Federal Regulations. Except for concentrated animal feeding operations, agricultural activities are not point sources of pollution subject to NPDES permits.

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

(1) Concentrated animal feeding operations

Only an animal feeding operation defined as a “concentrated animal feeding operation” is subject to NPDES permit requirements. An animal feeding operation is a lot or facility without vegetation where animals are confined for 45 days or more a year. A concentrated animal feeding operation occurs where:

- More that 1,000 animal units are confined and the site has discharge of pollutants from storms smaller than the 25-year, 24-hour storm event.
- More than 300 animal units are confined and the site has discharge of pollutants from storms smaller than the 25-year, 24-hour storm event through a manmade device or directly into navigable waters flowing through a feedlot. The regional administrator of 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.
- 300 animal units or less are confined and the regional administrator of EPA or the director of the State program, after onsite inspection, determines that pollutants are discharged into the water of the United States through a manmade device or directly into such water flowing through a feedlot.

Animal units are computed as the number of:

- Slaughter and feeder cattle multiplied by 1.0
- Mature dairy cattle multiplied by 1.4
- Swine weighing over 55 pounds multiplied by 0.4
- Sheep or lambs multiplied by 0.1
- Horses multiplied by 2.0
- Laying hens or broilers, with continuous overflow watering, multiplied by 0.01
- Laying hens or broilers, with liquid manure handling systems, multiplied by 0.0333
- Turkeys multiplied by 0.0182
- Ducks multiplied by 0.02

The number of animal units for an operation that has various kinds of animals is computed by adding the computed animal units for each kind.

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

(2) Concentrated aquatic animal production facilities

Concentrated aquatic animal production facilities designated as point sources subject to NPDES permit requirements are hatcheries, fish farms, or other facilities that grow or hold aquatic animals of the following categories:

- Cold water fish species or other cold water aquatic animals in ponds, raceways, or similar structures that discharge at least 30 days per year, produce more than 20,000 pounds of aquatic animals per year, and receive more than 5,000 pounds of food during the month of maximum feeding.
- Warm water fish species or other warm water aquatic animals in ponds, raceways, or similar structures that discharge at least 30 days per year. Closed ponds that discharge only during periods of excess runoff or facilities that produce less than 100,000 pounds of aquatic animals per year are not point sources under this category.
- Facilities determined on a case-by-case basis by the permitting authority to be significant contributors of pollution to waters of the United States.

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 concentrated animal feeding operations, concentrated aquatic animal production facilities, and certain silvicultural activities.

Part 122, Title 40, Code of Federal Regulations 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.

Note: A permit is not required of any operation (concentrated animal feeding operation or otherwise) where runoff, wastewater, or polluted water of any kind is prevented from leaving the land owned or under the control of the producer, except during storms equaling or exceeding the 25-year, 24-hour storm event, and is used on that land for crop production, soil amendment, or any other beneficial purpose in a nonpolluting manner.

(4) Nonpoint source pollution

While concentrated animal facilities 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 1–1.

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.

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, and land application. Many of the State laws, rules, and regulations are more stringent than those promulgated by the Federal Government. In the absence of State requirements, EPA assumes enforcement.

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).

Table 1–1 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

651.0104 Owner/producer responsibilities

All work in which SCS assists 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). SCS 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 SCS contracting (Federal Acquisition Regulations, Clause 52.236-13, and Code of Federal Regulations, 29 CFR 1910 & 1926).
- Safety requirements for construction contracts under locally awarded contracts (120-V-CGCAM (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 SCS assistance if unsafe construction conditions are not corrected (110-GM, part 402.13).

651.0106 Policies — USDA and SCS

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 USDA.
- Encourage the use of best management practices 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) SCS water quality policy

General Manual (GM), title 460, part 401, subpart A, establishes responsibilities in support of implementing water quality activities from the SCS Chief through the various national office levels to the SCS 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 Best Management Practices (BMP’s) as part of Resource Management Systems (RMS’s), 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's to minimize pollution problems from animal wastes, nutrients, pesticides, salts, sediments, and related pollutants; and
- Maintain adequately trained personnel in surface water and ground water quality concepts and management techniques.

(d) SCS planning policy on control of pollutants

The National Conservation Planning Manual, part 506, establishes the level of SCS involvement in pollution abatement activities. Subpart C Appendix, Section 507.31, "Guide to SCS Technical Assistance in Control of Pollutants," gives the appropriate levels of assistance that can be provided for managing such activities as livestock waste, food processing waste, pesticides, and municipal wastewater and sludge. Technical assistance should always be provided within the limits of knowledge and ability of the available personnel.

Livestock waste—Inventory (I), planning (P), and application (A) 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. P and A do not apply to systems used strictly for disposal.

Food processing waste—I, P, and A may be provided to farmers, ranchers, and food processors for waste management systems that include beneficial use of water, nutrients, and organic material. SCS doesn't often provide P and A to large corporate food processors. Traditionally, I, P, and A have been provided to smaller, family owned and operated food processing companies that grow the products that they process.

Pesticides—I and P 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 SCS policy establishes I, P, and A for farmers and ranchers who accept sludge, septage, and wastewater for beneficial agricultural purposes. P and A are not to be provided 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. (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) 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). SCS 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 sludges for food chain crop production. It states that through use of high quality sludges coupled with proper management procedures, the consumer should be protected from contaminated crops, and potential adverse environmental effects will be minimized.

(f) 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 Field Office Technical Guide (FOTG) "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).

Resource Management Systems and Best Management Practices are similar, but they have some fundamental differences. Their differences are indicated by the following definitions:

Resource management systems 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.

Best management practices, 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. BMP's address one or more resource concerns.

(g) SCS flood plain and wetland policy

SCS environmental policy in 190-GM, 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 SCS 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 SCS 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 SCS policy to aid in protecting, maintaining, managing, and restoring wetlands.

(h) Agricultural waste management 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 establish the minimum level of quality with which these practices are planned, designed, installed, operated, and maintained. SCS conservation practice standards can be used to address specific waste management needs of producers. Some examples are:

Waste Management System (Code 312)—The purpose of this system practice is to use the necessary practices in a systems approach such that wastes are properly managed and the degradation of air, animal, water, plant, or soil resources is prevented.

Waste Storage Structure (Code 313)—A fabricated facility for the temporary storage of animal or other agricultural wastes. The purpose of the practice is to store waste until it can be safely and effectively used.

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 strength of the waste.

Waste Storage Pond (Code 425)—An impoundment made by excavation or earthfill for temporary storage of animal or other agricultural wastes. The purpose of the practice is to store waste until it can be safely and effectively used.

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.

Filter Strips (Code 393)—A designed area or strip of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater. The primary purpose of this practice is to improve or maintain offsite water quality. To meet conservation objectives and offsite water quality goals for lands adjacent to cultivated agricultural land or other land that is periodically disturbed, other practices generally must be installed in the areas contributing runoff to the filter strip. Consequently, a filter strip will not often be a stand-alone practice.

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.

Pest Management (Code 595)—Managing agricultural pest infestations (including weeds, insects, and diseases) to reduce adverse effects on plant growth, crop production, and environmental resources. The purpose of this practice in the context of this handbook is to properly manage waste chemicals for environmental protection.

Many other practice standards are used to support those listed, such as those for irrigation and tillage and cropping systems. Others will be developed for constructed wetlands for wastewater treatment, pesticide containment facility, and riparian zone buffer strips. Until a conservation practice and other technical support documents are available, the technical requirements for constructed wetlands for wastewater treatment issued by SCS should be used.

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 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 criteria 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 EPA are more appropriate for local conditions.

Water quality criteria are continually changing, so the summary of EPA criteria given in table 1–2 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.

Table 1–2 Water quality criteria (EPA 1986)

Color:	1) For aesthetic purposes, water shall be virtually free from substances producing objectionable color; 2) The source of the color should not exceed 75 color units in the standard platinum-cobalt scale for domestic water supply; and 3) 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:	1) 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; and 2) A minimum concentration of dissolved oxygen to maintain good fish populations is 5 mg/L.
Fecal coliform bacteria:	1) 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 2) 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 is 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.

(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 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 of 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 1–3 gives an example of a designated area classification system. Classification systems vary from State to State.

Table 1–3 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 nonbody contact recreation. Any other usage requiring water of lower quality.
V	Sources used only for agriculture or industrial supplies, fish survival, or navigation.

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.

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 (a) nutrients, (b) oxygen-demanding materials, (c) bacteria that indicate potential presence of pathogens, (d) sediment, suspended or dissolved materials, and (e) 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 (1) domestic, industrial, and agricultural water supplies; (2) swimming, fishing, boating, and other forms of recreational use; and (3) 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 manmade and natural substances. Under the 1986 amendments to the Safe Drinking Water Act, EPA set primary standards for 83 contaminants. Some of the substances that are associated with agriculture include nitrate, bacteria, selenium, lindane, toxaphene, 2-4,D, 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 1–4.

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 micro-organisms, 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

Table 1–4 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% 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.

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 (1) separation processes, (2) transport of materials, (3) cooling, (4) chemical reactions, and (5) 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 1–5 lists the maximum allowable concentrations of constituents in raw water supplies for several industrial operations as determined by the National Academy of Sciences (1974).

(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.

Table 1–5 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	—	—

Nitrate-nitrogen standard for human consumption is 10 mg/L. No standards for livestock are established, but it is generally accepted that nitrate-nitrogen levels of over 100 mg/L 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 mg/L. 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 ml 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 1–6, 1–7, and 1–8 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 substances that would harm crop growth unless

Table 1–6 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) USEPA*	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

* U.S. Environmental Protection Agency (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 1–7 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.

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 1-2 for criteria for fecal coliform bacteria.

Table 1–8 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.

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 ml, or 33 per 100 ml for enterococci. For marine water bathing, the geometric mean of enterococci bacteria densities should not exceed 35 per 100 ml. 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
Department of
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**Soil
Conservation
Service**

Agricultural
Waste Management
Field Handbook

Chapter 2 Planning Considerations

(210-AWMFH, 4/92)

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.

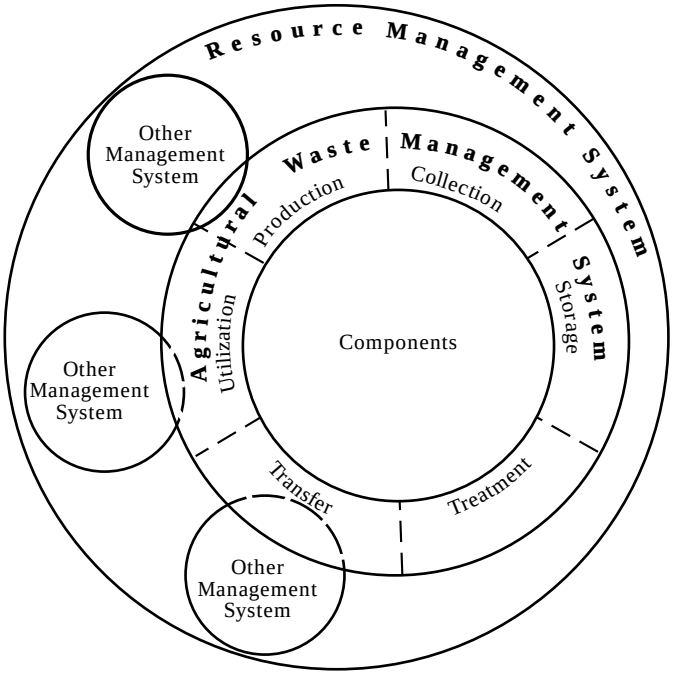
The planning process is often complex because of the number of alternatives to be considered; however, the AWMS selected should be as simple and easily managed as possible.

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.

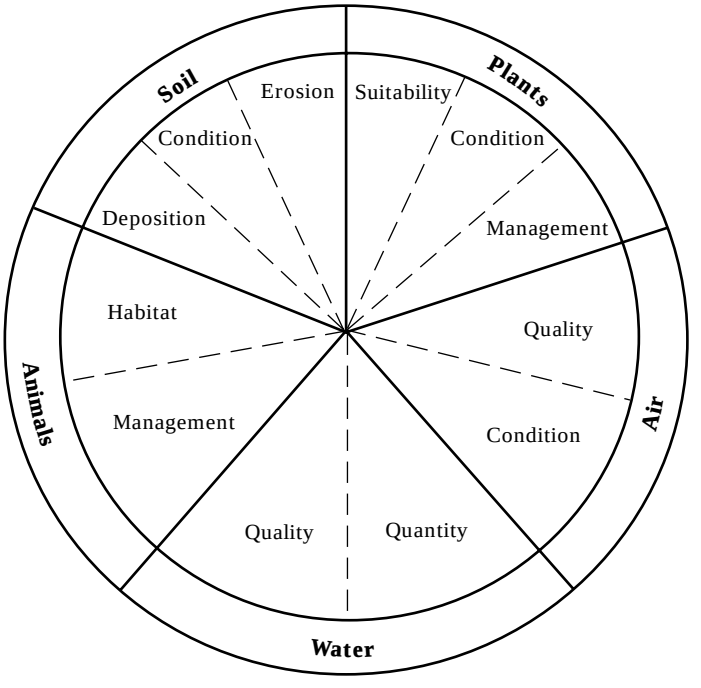
The usual objective in planning an AWMS is to exclude unneeded clean water and capture polluted water for storage or treatment for subsequent use when conditions are appropriate.

(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

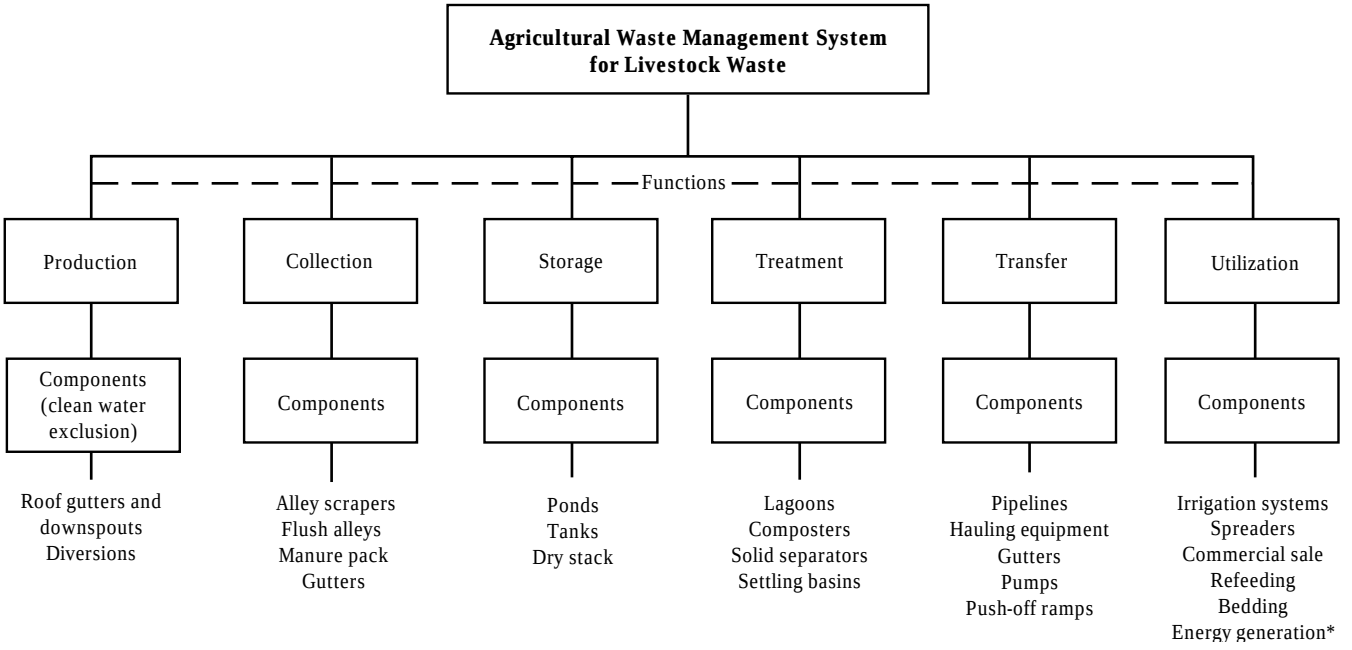
Alternative solutions need to be evaluated to determine if they meet the objectives, solve the problem, and are socially, culturally, and economically acceptable.

(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

United States
Department of
Agriculture

**Soil
Conservation
Service**

Agricultural
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

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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.

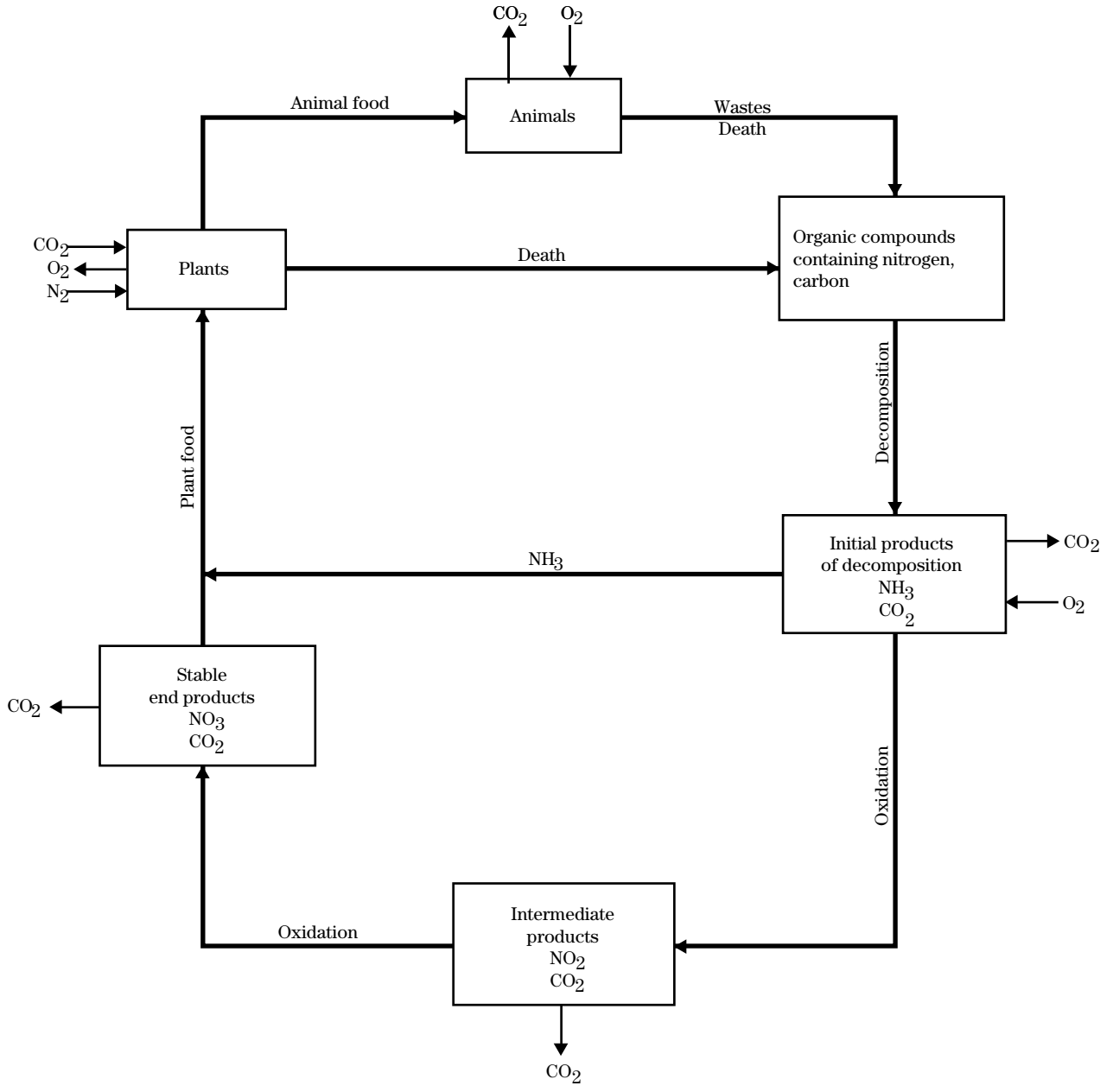
The amount of organic matter in water can be determined with laboratory tests, including those for 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and volatile solids (VS). Table 3–1 illustrates BOD_5 values for a sampling of lagoon influents and effluents for various livestock 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.

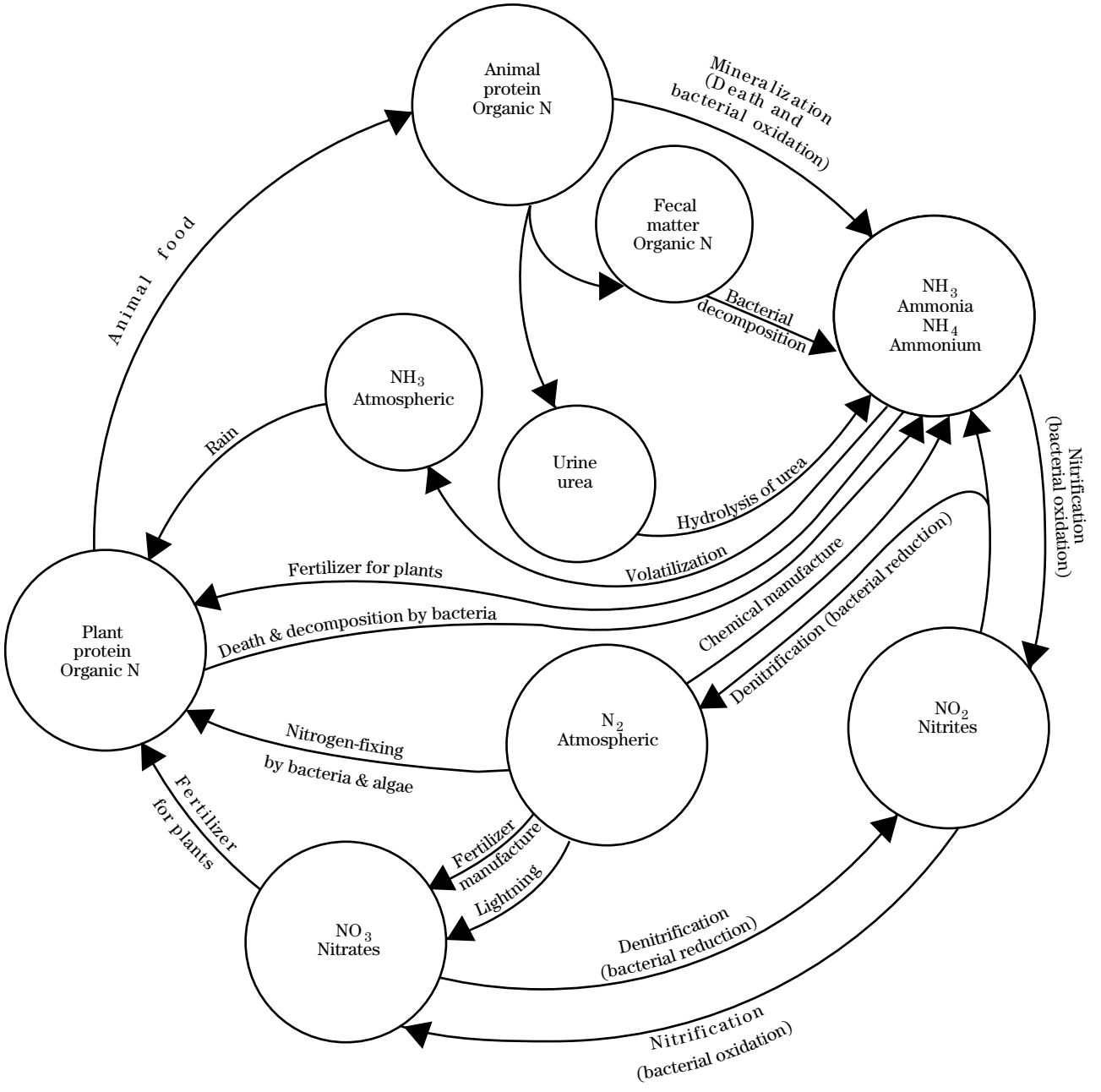
Un-ionized ammonia is toxic to fish and other aquatic life in very small concentrations. In one study, the concentration required to kill 50 percent of a salmonid (for example, trout) population after 96 hours of exposure (the 96-hour LC_{50}) ranged from 0.083 to 1.09 mg/L; for nonsalmonids the range 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	pH values						
(°C)	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.

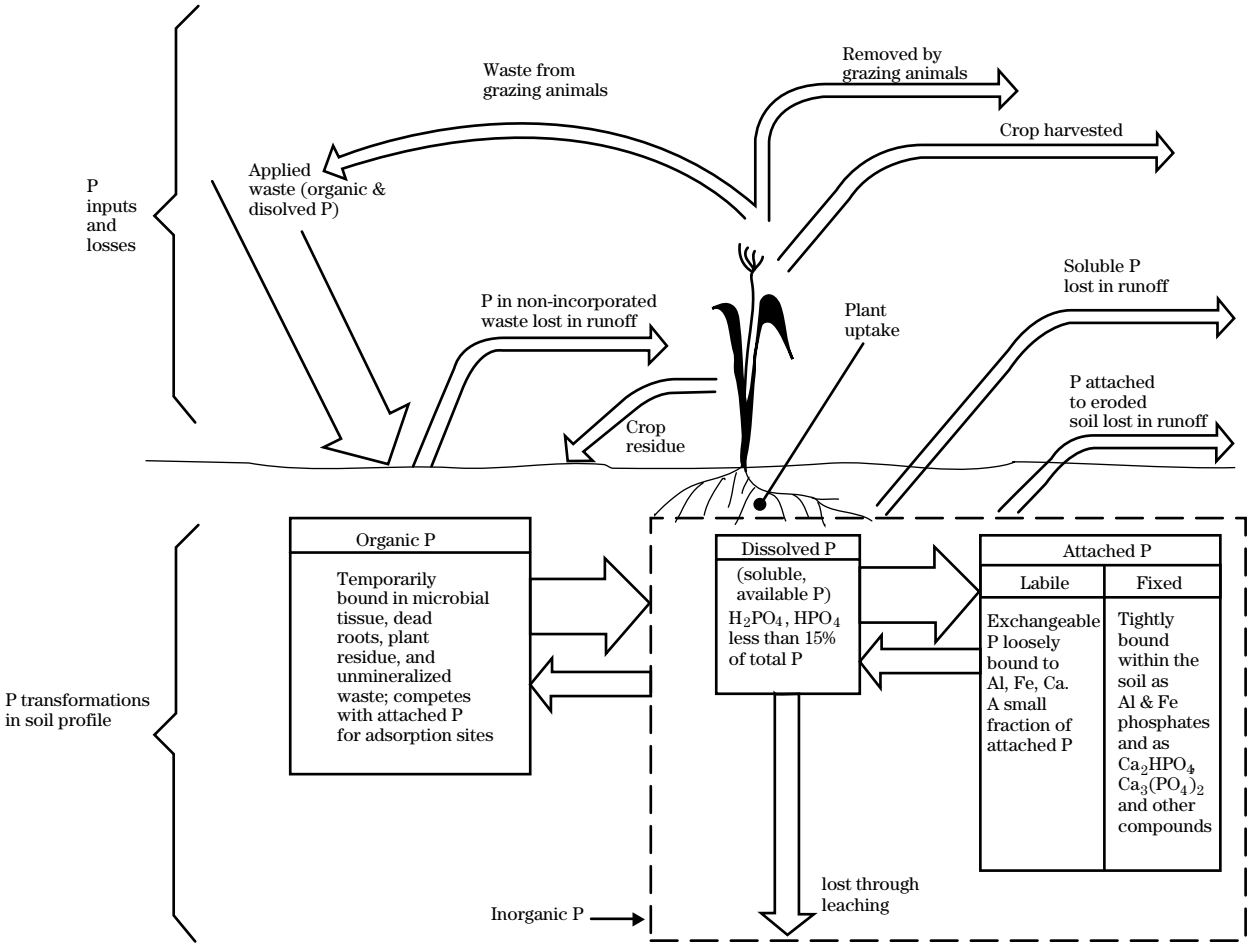
Attached phosphorus includes those compounds that are formed when the anionic (negatively charged) forms of dissolved P become attached to cations, such as iron, aluminum, and calcium. Attached phosphorus includes labile, or loosely bound, forms and those that are "fixed," or tightly adsorbed, on or 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.

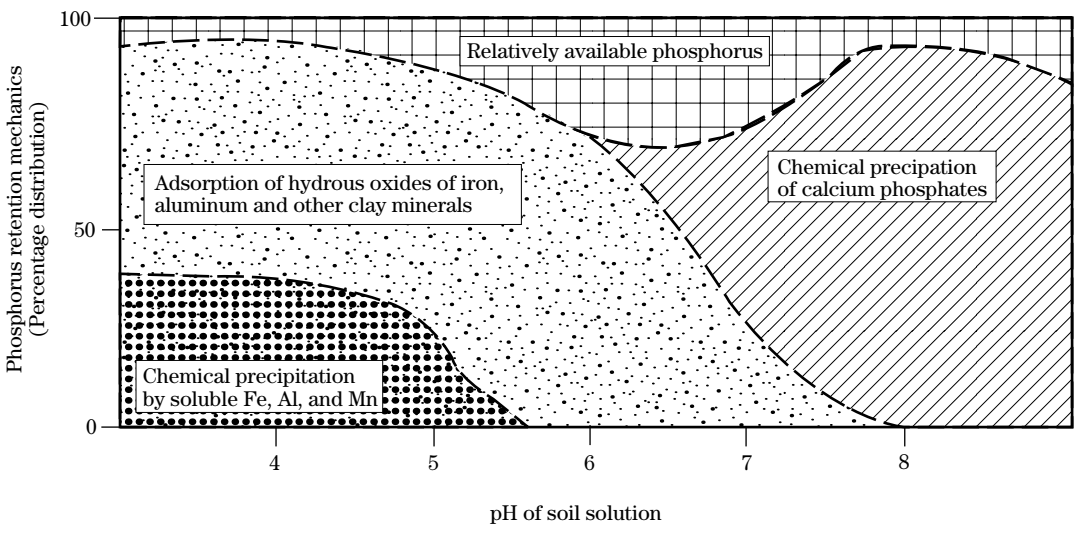
Research has shown that soils with even a modest clay fraction have the potential to adsorb large amounts of P. For example, one study revealed that a Norfolk sandy loam soil receiving swine lagoon effluent at phosphorus application rates of 72, 144, and 288 pounds per year would require 125, 53, and 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

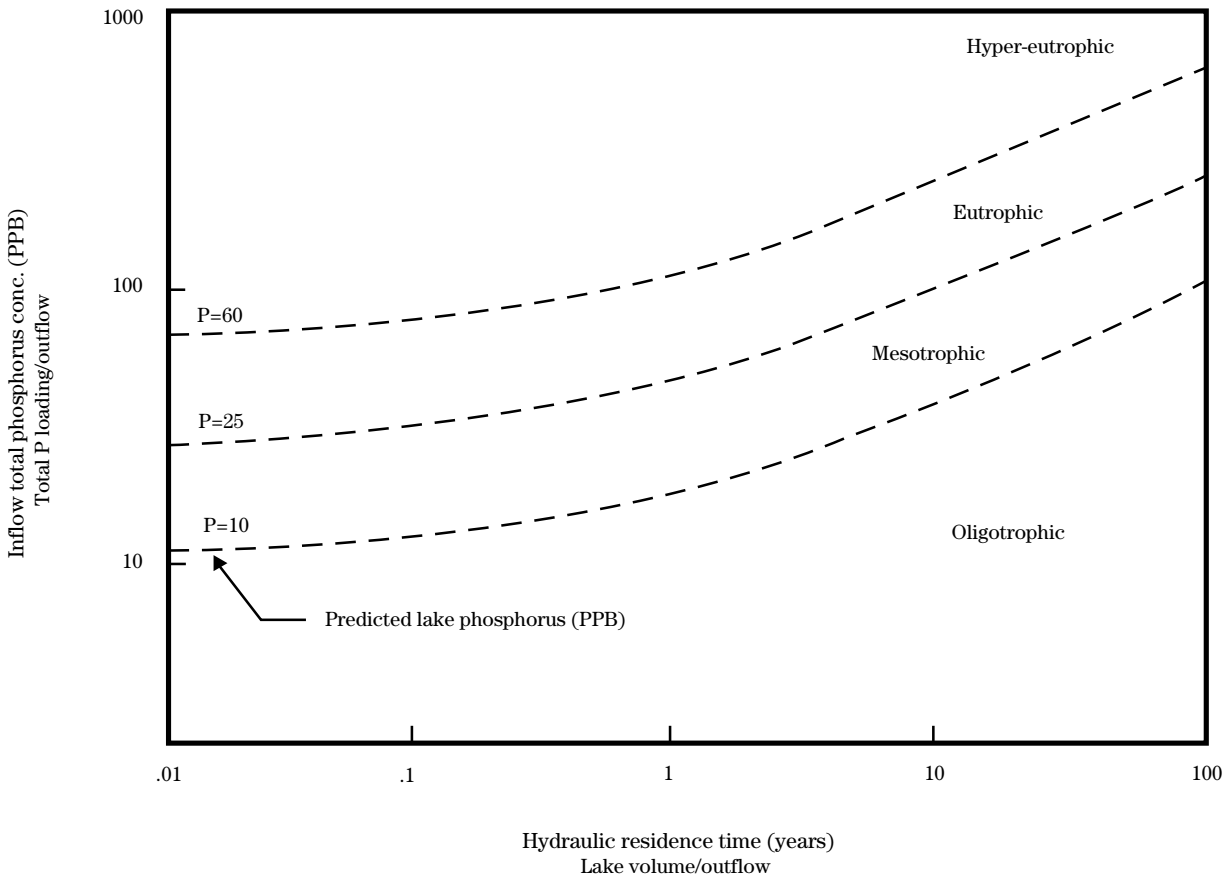
The excreta from warmblooded animals have countless micro-organisms, including bacteria, viruses, parasites, and fungi. Some of the organisms are pathogenic (disease causing), and many of the diseases carried by animals are transmittable to humans, and vice versa. Table 3–5 lists some of the diseases 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
Bacterial	
Salmonella	Salmonella sp.
Leptospirosis	Leptospiral pomona
Anthrax	Bacillus anthracis
Tuberculosis	Mycobacterium tuberculosis Mycobacterium avium
Johnes disease	Mycobacterium paratuberculosis
Brucellosis	Brucella abortus Brucella melitensis Brucella suis
Listerosis	Listeria monocytogenes
Tetanus	Clostridium tetani
Tularemia	Pasturella tularensis
Erysipelas	Erysipelothrix rhusiopathiae
Colibacilosis	E. coli (some serotypes)
Coliform mastitis-metritis	E. coli (some serotypes)
Rickettsial	
Q fever	Coxiella burneti
Viral	
New Castle	Virus
Hog Cholera	Virus
Foot and Mouth	Virus
Psittacosis	Virus
Fungal	
Coccidioidomycosis	Coccidoides immitus
Histoplasmosis	Histoplasma capsulatum
Ringworm	Various microsporum and trichophyton
Protozoal	
Coccidiosis	Eimeria sp.
Balantidiasis	Balatidium coli.
Toxoplasmosis	Toxoplasma sp.
Parasitic	
Ascariasis	Ascaris lumbricoides
Sarcocystiasis	Sarcocystis sp.

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	Bacterial density and dimensions
Organic matter type & content	Nature of organic matter in waste effluent solution (concentration & size)
Pore size distribution	pH
Temperature	
Moisture content	
Fragipan (hardpan)	
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.

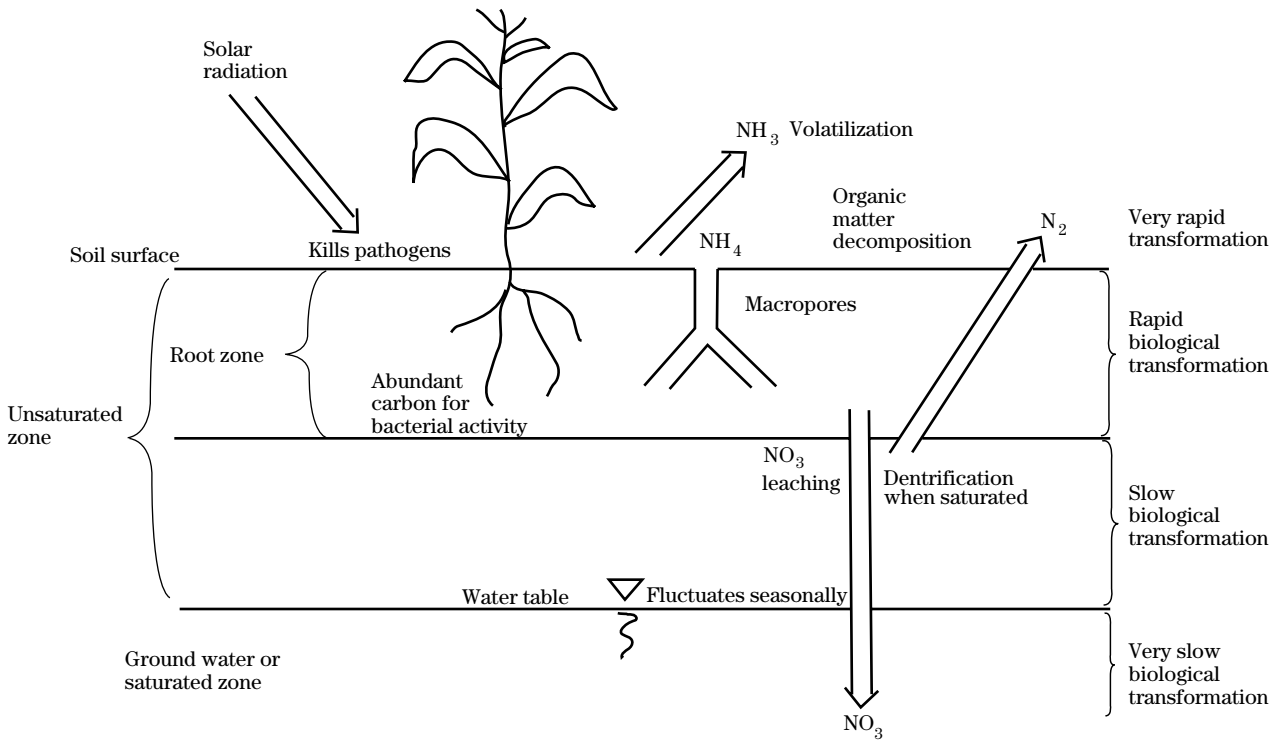
The unsaturated zone includes the root zone and an unsaturated area below the root zone. The root zone is characterized by an abundance of macropores, created in part by decaying roots and wormholes. The macropores allow rapid downward movement of substances carried by percolating water.

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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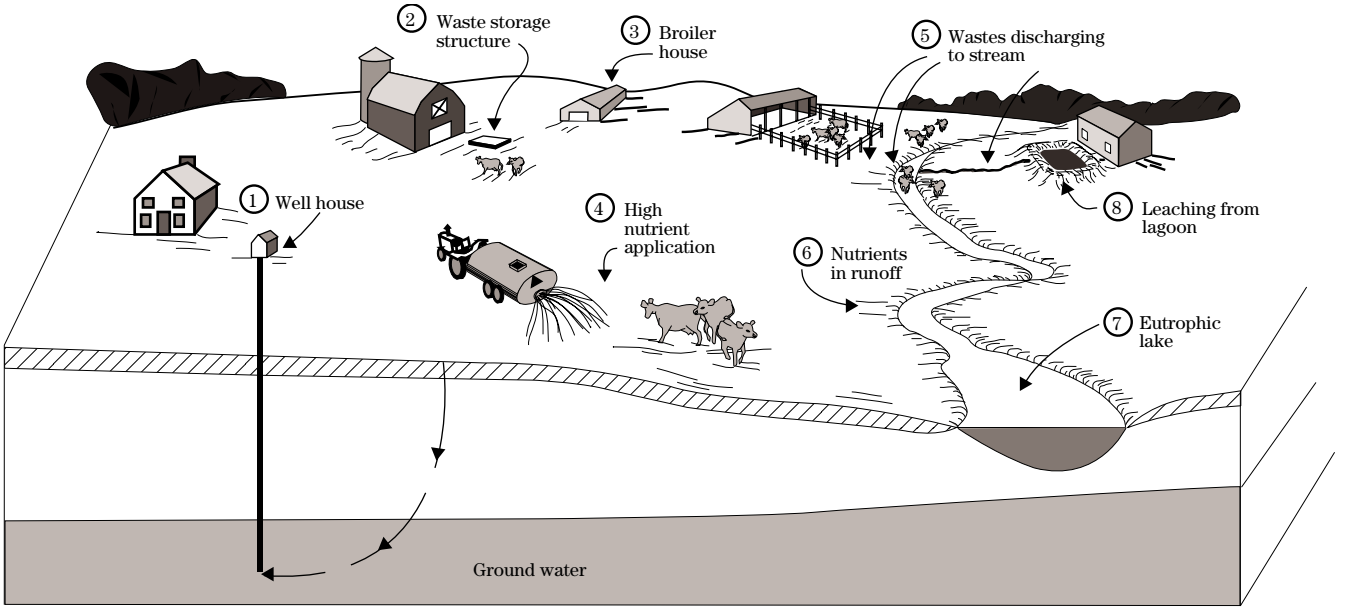
United States Environmental Protection Agency. 1990. The lake and reservoir restoration guidance manual. EPA-440/4-90-006, Wash., DC.

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.

United States
Department of
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**Soil
Conservation
Service**

Agricultural
Waste Management
Field Handbook

Chapter 4 Agricultural Waste Characteristics

(210-AWMFH, 4/92)

Chapter 4 Agricultural Waste Characteristics

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Chapter 4 Agricultural Waste Characteristics

651.0400 Introduction

(a) Purpose and scope

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

(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.

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

651.0401 Definitions of waste characterization terms

Table 4–1 gives definitions and descriptions of waste characterization terms. It includes abbreviations, definitions, units of measurement, methods of measurement, and other considerations for the physical and chemical properties of manure, waste, and residue.

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

Total solids and the fractions of the total solids that are volatile solids (VS) and fixed solids (FS) are presented. Volatile solids and fixed solids are sometimes referred to, respectively, as total volatile solids (TVS) and total fixed solids (TFS). Characterization of these solids gives evidence of the origin of the waste, its age and previous treatment, its compatibility with certain biological treatment procedures, and its possible adaptation to mechanical handling alternatives.

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

Table 4–1 Definitions and descriptions of waste characterization terms (% w.b. is percent measured on a wet basis, and % d.b. is percent measured on a dry basis)

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

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

Term	Abbreviation	Units of measure	Definition	Method of measurement	Remarks
Chemical Properties					
Ammoniacal nitrogen (total ammonia)		mg/L µg/L	Both NH_3 and NH_4 nitrogen compounds.	Common laboratory procedure uses digestion, oxidation, and reduction to convert all or selected nitrogen forms to ammonium that is released and measured as ammonia.	Volatile and mobile nutrients; may be a limiting nutrient in land spreading of wastes and in eutrophication.
Ammonia nitrogen	NH_3–N	mg/L µg/L	A gaseous form of ammoniacal nitrogen.		
Ammonium nitrogen	NH_4–N	mg/L µg/L	The positively ionized (cation) form of ammoniacal nitrogen.		Can become attached to the soil or used by plants or microbes.
Total kjeldahl nitrogen	TKN	mg/L µg/L	The sum of organic nitrogen and ammoniacal nitrogen.		
Nitrate nitrogen	NO_3–N	mg/L µg/L	The negatively ionized (anion) form of nitrogen that is highly mobile.		Nitrogen in this form can be lost by denitrification, percolation, runoff, and plant microbial utilization.
Total nitrogen	TN N	%; lb	The summation of nitrogen from all the various nitrogen compounds listed above.		Macro-nutrient for plants.
Phosphorus	P	%; lb	Acid-forming element that combines readily with oxygen to form the oxide P_2O_5. As a plant nutrient, it promotes rapid growth, hastens maturity, and stimulates flower, seed, and fruit production.	Laboratory procedure uses digestion and/or reduction to convert phosphorus to a colored complex; result measured by spectrophotometer.	Critical in water pollution control; may be a limiting nutrient in eutrophication and in spreading of wastes.

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

Term	Abbre-viation	Units of measure	Definition	Method of measurement	Remarks
Chemical Properties					
Potassium	K	%; lb	As a plant nutrient, available potassium stimulates the growth of strong stems, imparts resistance to disease, increases the yield of tubers and seed, and is necessary to form starch, sugar, and oil and transfer them through plants.	Laboratory digestion procedure followed by flame photometric analysis to determine elemental concentration.	
5-day Bio-chemical Oxygen Demand	BOD_5	lb of O_2	That quantity of oxygen needed to satisfy biochemical oxidation of organic matter in waste sample in 5 days at 68 °F (20 °C).	Extensive laboratory procedure of incubating waste sample in oxygenated water for 5 days and measuring amount of dissolved oxygen consumed.	Standard test for measuring pollution potential of waste materials that could be discharged to surface water.
Chemical Oxygen Demand	COD	lb of O_2	Measure of oxygen consuming capacity of organic and some inorganic components of waste materials.	Relatively rapid laboratory procedure using chemical oxidants and heat to fully oxidize organic components of waste.	Estimate of total oxygen that could be consumed in oxidation of waste material.

Wastes are often given descriptive names that reflect their moisture content, such as liquid, slurry, semi-solid and solid. Wastes that have a moisture content of 95 percent or more exhibit qualities very much like water and are called liquid waste or liquid manure. Wastes that have moisture content of about 75 percent or less exhibit the properties of a solid and can be stacked and hold a definite angle of repose. They are called solid manure or solid waste. Wastes that have between about 75 and 95 percent moisture content—25 and 5 percent solids—are semi-liquid (slurry) or semi-solid. See chapter 9, section 651.0903. Because wastes are heterogeneous and inconsistent in their physical properties, the moisture content and range indicated above must be considered generalizations subject to variation and interpretation.

Table 4–1 also lists physical and chemical properties of livestock and other organic agricultural wastes. Data on biological properties, such as numbers of specific micro-organisms, are not presented in this chapter. Micro-organisms are of concern as possible pollutants of ground and surface water, but they are not commonly used as a design factor for no-discharge waste management systems that use wastes on agricultural land.

The terms manure, waste, and residue are sometimes used synonymously. In this chapter **manure** refers to combinations of feces and urine only, and **waste** includes manure plus other material, such as bedding, soil, wasted feed, and water that is wasted or used for sanitary and flushing purposes. Small amounts of wasted feed, water, dust, hair, and feathers are unavoidably added to manure and are undetectable in

the production facility. These small additions must be considered to be a part of manure and a part of the "as excreted" characteristics presented. **Litter** is a specific form of poultry waste that results from "floor" production of birds after an initial layer of a bedding material, such as wood shavings, is placed on the floor at the beginning of and perhaps during the production cycle.

Because of the high moisture content of "as excreted" manure and treated waste, their specific weight is very similar to that of water—62.4 pounds per cubic foot. Some manure and waste that have considerable solids content can have a specific weight of as much as 105 percent that of water. Some dry wastes, such as litter, that have significant void space can have specific weight of much less than that of water. Assuming that wet and moist wastes weigh 60 to 65 pounds per cubic foot is a convenient and useful estimate for planning waste management systems.

Odors are associated with all livestock production facilities. Animal manure is a common source of significant odors, but other sources, such as poor quality or spoiled feed and dead animals, can also be at fault. Freshly voided manure is seldom a cause of objectionable odor, but manure that accumulates or is stored under anaerobic conditions does develop unpleasant odors. Such wastes can cause complaints at the production facility when the waste is removed from storage or when it is spread on the fields. Manure-covered animals and ventilation air exhausted from production facilities can also be significant sources of odor. The best insurance against undesirable odor emissions is waste management practices that quickly and thoroughly remove wastes from production facilities and place them in treatment or storage facilities or apply them directly to the soil.

651.0402 Units of measure

Waste production from livestock is expressed in pounds per day per 1,000 pounds of livestock live weight (lb/d/1000#). Volume of waste materials is expressed in cubic feet per day per 1,000 pounds of live weight (ft^3/d/1000#). Food processing waste is recorded in cubic feet per day (ft^3/d), or the source is included as in cubic feet per 1,000 pounds of apples processed. In this chapter English units are used exclusively for weight, volume, and concentration data for manure, waste, and residue.

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

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

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

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

Amounts of the major nutrients, nitrogen (N), phosphorus (P), and potassium (K), are always presented in terms of the nutrient itself. Only the nitrogen quantity in the ammonium compound (NH_4) is considered when expressed as ammonium nitrogen (NH_4-N).

Commercial fertilizer formulations for nitrogen, phosphorus, and potassium and recommendations are expressed in terms of N, P_2O_5, and K_2O. 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.

Table 4–2 Factors for determining nutrient equivalency

Multiply	By	To get
NH_3	0.824	N
NH_4	0.778	N
NO_3	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
ppm	0.0083	lb/1000 gal

651.0403 Animal waste characteristics

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

Carbon:nitrogen ratios were established using the ash content in percent (dry weight basis) to determine the carbon. The formula used, which estimates carbon in percent (dry weight basis), was:

$$C = \frac{100 - \%\ \text{ash}}{1.8}$$

Total dissolved salts values were derived from a paper by R.M. Arrington and C.E. Pachek.

(a) "As excreted" manure

Daily "as excreted" manure production data are presented where possible in pounds per day per 1,000 pounds livestock live weight (lb/d/1000#) for typical commercial animals and birds. Units of cubic feet per day per 1,000 pounds live weight (ft^3/d/1000#) allow waste production to be calculated on a volumetric basis. Moisture content and total solids are given as a percentage of the total wet weight (% w.b.) of the manure. Total solids are also given in units of lb/d/1000#. Other solids data and the nutrient content of the manure are presented in units of lb/d/1000# on a wet weight basis.

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

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

(b) Foreign material in manure

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

(1) 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 manure volume plus a half of the bedding volume. Only half of the bedding volume is used to compensate for the void space in bedding materials.

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.

(2) Wasted feed and water

Wasted feed has a great influence on the organic content of manure. Feed consumed by animals is 50 to 90 percent digested, but spilled feed is undigested. A pound of spilled feed results in as much waste as 2 to 10 pounds of feed consumed. Small quantities, about 3 percent, of wasted feed are common and very difficult to see. Wastage of 5 percent is common and can be observed. Obvious feed wastage is indicative of 10 percent or more waste. Anticipated feed waste of more than 5 percent should be compensated for as noted on the “as excreted” manure data summaries (tables 4–5, 4–8, 4–11, 4–14, 4–17, 4–18, 4–19, 4–20).

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

Table 4–3 Unit weights of common bedding materials

Material	Loose	Chopped
	lb/ft^3	
Legume hay	4.25	6.5
Nonlegume hay	4.00	6.0
Straw	2.50	7.0
Wood shavings	9.00	
Sawdust	12.00	
Soil	75.00	
Sand	105.00	
Ground limestone	95.00	

Table 4–4 Daily bedding requirements for dairy cattle

Material	Barn type: Stanchion stall	Free-stall	Loose housing
	lb/d/1000#		
Loose hay or straw	5.4		9.3
Chopped hay or straw	5.7	2.7	11.0
Shavings or sawdust		3.1	
Sand, soil, or limestone		1.5	

limitations and problems in the manure management system. Excess water from foggers and misters used for cooling stock in hot weather may be of concern in some instances.

(3) Soil

Soil is another natural adulterant of livestock manure. Its presence is most common on dairies on which the cows have access to paddocks and pastures. Dry soil adheres to the cows' 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.

(c) Dairy

Manure characteristics for lactating and dry cows and for heifers are listed in table 4–5. These data are appropriate for herds of moderate to high milk production. Quantities of dairy manure vary widely from small cows to large cows and between cows at low production and high production levels. Figure 4–1 more accurately reflects these quantities of "as excreted" manure total solids and volatile solids where more precise data are desired. Dairy feeding systems and equipment often allow considerable feed waste, which in most cases is added to the manure. Feed waste of 10 percent can result in an additional 40 percent of total solids in a dairy waste. Dairy cow stalls are often covered with bedding materials that improve animal comfort and cleanliness. Virtually all of the organic and inorganic bedding materials used for this purpose will eventually be pushed, kicked, and carried from the stalls and added to the manure. The characteristics of these bedding materials will be imparted to the manure. Quantities of bedding materials added to cow stalls and resting areas are shown in table 4–4. See 651.0403(b), "Foreign material in manure," for additional information.

Milking centers—the milk house, milking parlor, and holding area—can produce about 50 percent of the waste volume, but only about 15 percent of the total solids in a dairy enterprise (table 4–6). Because this very dilute wastewater has different characteristics than the waste from the cow yard, it is sometimes managed by a different procedure. Values used to compute characteristics from milkhouses came from research by Cornell University completed in 1979 in New York.

About 5 to 10 gallons of fresh water per day for each cow milked are used in a milking center where flushing of wastes is not practiced. However, where manure flush cleaning and automatic cow washing are used, water use can be 150 gal/d/cow or more. Dairies employing flush cleaning systems use water in approximately the following percentages for various cleaning operations.

Parlor—cleanup and sanitation	10%
Cow washing	30%
Manure flushing	50%
Miscellaneous	10%

Lagoons that receive a significant loading of manure, such as from the holding area or the cow feed yard, generally operate in an anaerobic mode (table 4–7). Supernatant (upper liquid layer of the lagoon) concentration in an anaerobic lagoon is much greater than that in an aerobic lagoon. Anaerobic dairy lagoon

Table 4–5 Dairy waste characterization — as excreted*

Component	Units	Cow Lactating	Cow Dry	Heifer
Weight	lb/d/1000#	80.00	82.00	85.00
Volume	ft^3/d/1000#	1.30	1.30	1.30
Moisture	%	87.50	88.40	89.30
TS	% w.b.	12.50	11.60	10.70
	lb/d/1000#	10.00	9.50	9.14
VS	"	8.50	8.10	7.77
FS	"	1.50	1.40	1.37
COD	"	8.90	8.50	8.30
BOD_5	"	1.60	1.20	1.30
N	"	0.45	0.36	0.31
P	"	0.07	0.05	0.04
K	"	0.26	0.23	0.24
TDS		0.85		
C:N ratio		10	13	14

* Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

sludge accumulates at a rate of about 0.073 cubic foot per pound of total solids added to the lagoon. This is equivalent to about 266 cubic feet per year for each 1,000 pound lactating cow equivalent (100% of waste placed in lagoon).

If a dairy waste lagoon receives wastewater only from the milk house or the milking parlor, the lagoon generally exhibits a very dilute supernatant and operates in an aerobic mode (table 4–7). The rate of sludge accumulation in such lagoons is slow.

Figure 4–1 allows a more specific estimation of dairy manure solids production based on lactating cow size and the level of milk production. The following examples show how this graph can be used.

Example 4–1: Estimate the daily production of total volatile and fixed solids in the manure of a 1,000 pound cow that is producing milk at the rate of 11,000 pounds per year.

Entering figure 4–1 on the horizontal scale at the annual milk production level of 11,000 pounds and projecting vertically to the TS and VS curves for the 1,000 pound cow and then horizontally to the vertical scale, the values of 8.9 lb/d and 7.6 lb/d are found for TS and VS, respectively. Fixed solids, which are determined by taking the difference between TS and VS, equal 1.3 lb/d (8.9 – 7.6).

Example 4–2: Estimate the daily production of total volatile and fixed solids in the manure of a herd of 125 cows of 1,400 pound average weight producing 19,200 pounds of milk per cow per year.

Entering figure 4–1 on the horizontal scale at the annual milk production level of 19,200 pounds and projecting vertically to the TS and VS curves for the 1,400 pound cow and then horizontally to the vertical scale, the values of 14.2 lb/d and 12.1 lb/d are found for TS and VS, respectively. Multiplying each of these values by 125, the number of cows in the herd, and determining FS from the difference of TS and VS, the daily manure solids produced by the herd are:

$$TS = (125 \times 14.2) = 1{,}775 \text{ lb / d}$$
$$VS = (125 \times 12.1) = 1{,}513 \text{ lb / d}$$
$$FS = (1{,}775 - 1{,}513) = 262 \text{ lb / d}$$

Table 4–6 Dairy waste characterization — milking center

Component	Units	Milking center* MH	MH+MP	MH+MP+HA **	MH+MP+HA ***
Volume	ft³/d/1000#	0.22	0.60	1.40	1.60
Moisture	%	99.72	99.40	99.70	98.50
TS	% w.b.	0.28	0.60	0.30	1.50
VS	lb/1000 gal	12.90	35.00	18.30	99.96
FS	"	10.60	15.00	6.70	24.99
COD	"	25.30	41.70		
BOD	"		8.37		
N	"	0.72	1.67	1.00	7.50
P	"	0.58	0.83	0.23	0.83
K	"	1.50	2.50	0.57	3.33
C:N ratio		10	12	10	7

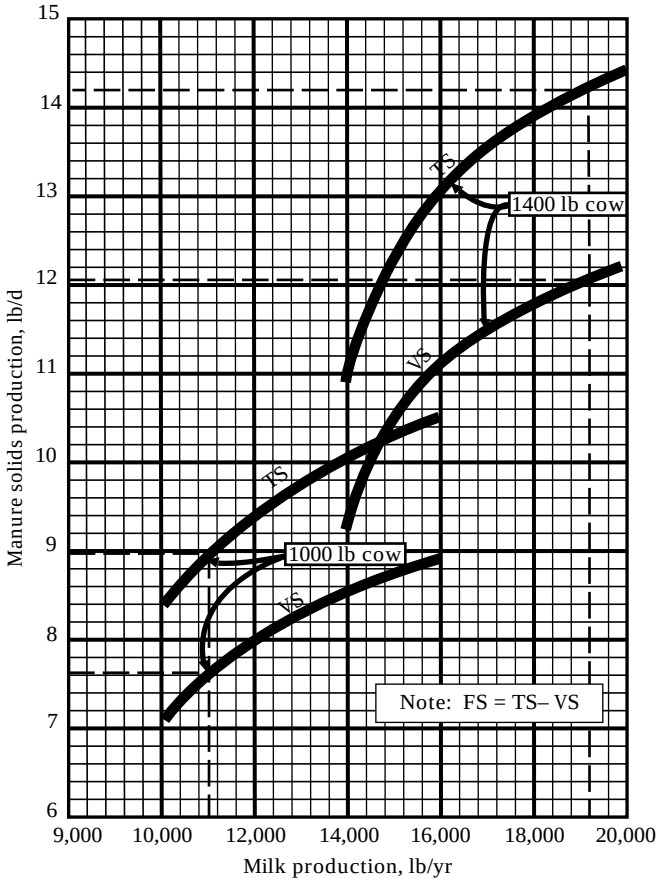
* MH – Milk house; MP – Milking parlor; HA – Holding area.
** Holding area scraped and flushed—manure excluded.
*** Holding area scraped and flushed—manure included.

Table 4–7 Dairy waste characterization — lagoon

Component	Units	Lagoon Anaerobic Super-natant	Anaerobic Sludge	Aerobic* Super-natant
Moisture	%	99.75	90.00	99.95
TS	% w.b.	0.25	10.00	0.05
VS	lb/1000 gal	9.16	383.18	1.67
FS	"	11.66	449.82	2.50
COD	"	12.50	433.16	1.25
BOD_5	"	2.92`		0.29
N	"	1.67	20.83	0.17
NH_4-N	"	1.00	4.17	0.10
P	"	0.48	9.16	0.08
K	"	4.17	12.50	
C:N ratio		3	10	

* Milk house and milking parlor wastes only.

Figure 4–1 Dairy manure solids production



(d) Beef

Table 4–8 lists characteristics of "as excreted" beef manure. Beef waste of primary concern are those from the feedlots (table 4–9). The characteristics of these solid wastes vary widely because of such factors as climate, diet, feedlot surface, animal density, and cleaning frequency. The soil in unsurfaced beef feedlots is readily incorporated with the manure because of the animal movement and cleaning operations. Wasted feed is an important factor in the characterization of beef wastes.

Beef feedlot runoff water also exhibits wide variations in character (tables 4–10 & 4–10a). The influencing factors that are responsible for feedlot waste variations are similar to those listed for solid wastes. Surfaced feedlots produce more runoff than unsurfaced lots.

Table 4–8 Beef waste characterization — as excreted*

Component	Units	Feeder, yearling - 750 to 1,100 lb - High forage diet	High energy diet	450 to 750 lb	Cow
Weight	lb/d/1000#	59.10	51.20	58.20	63.00
Volume	ft^3/d/1000#	0.95	0.82	0.93	1.00
Moisture	%	88.40	88.40	87.00	88.40
TS	% w.b.	11.60	11.60	13.00	11.60
	lb/d/1000#	6.78	5.91	7.54	7.30
VS	"	6.04	5.44	6.41	6.20
FS	"	0.74	0.47	1.13	1.10
COD	"	6.11	5.61	6.00	6.00
BOD_5	"	1.36	1.36	1.30	1.20
N	"	0.31	0.30	0.30	0.33
P	"	0.11	0.094	0.10	0.12
K	"	0.24	0.21	0.20	0.26
C:N ratio	"	11	10	12	10

* Average daily production for weight range noted. Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

Table 4–9 Beef waste characterization — feedlot manure

Component	Units	Unsurfaced lot*	- - Surfaced lot** - - High forage diet	High energy diet
Weight	lb/d/1000#	17.50	11.70	5.30
Moisture	%	45.00	53.30	52.10
TS	% w.b.	55.00	46.70	47.90
	lb/d/1000#	9.60	5.50	2.50
VS	"	4.80	3.85	1.75
FS	"	4.80	1.65	0.75
N	"	0.21		
P	"	0.14		
K	"	0.03		
C:N ratio		13		

* Dry climate (annual rainfall less than 15 inches); annual manure removal.
** Dry climate; semiannual manure removal.

Table 4–10 Beef waste characterization — feedlot runoff pond

Component	Units	- - - Runoff pond - - - Super-natant	Sludge
Moisture	%	99.70	82.80
TS	% w.b.	0.30	17.20
VS	lb/1000 gal	7.50	644.83
FS	"	17.50	788.12
COD	"	11.67	644.83
N	"	1.67	51.66
NH_4-N	"	1.50	
P	"		17.50
K	"	7.50	14.17

Table 4–10a Nitrogen content of cattle feedlot runoff (Alexander and Margheim 1974)[1]

Annual rainfall	Below-average conditions[2]	Average conditions[3]	Above-average conditions[4]
	- lb N/acre-inch -		
<25 inches	360	110	60
25 to 35 inches	60	30	15
>35 inches	15	10	5

[1] 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.

[2] 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.

[3] 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.

[4] 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 4–11 lists characteristics of "as excreted" swine manure from feeding and breeding stock. More specific data on manure solids produced by growing swine ranging from 10 to 220 pounds are in figure 4–2. Breeding stock manure characteristics, also shown in table 4-11, are subject to less variation than those for growing animals. Wasted feed also significantly changes manure characteristics. A 10 percent feed waste increases manure total solids by 40 percent.

Ration components can make a significant difference in manure characteristics. Corn, the principal grain in swine rations, has a high digestibility (90%). Table 4–11 and figure 4–2 were developed for corn-based rations. If a grain of lower digestibility, such as barley (79%), is substituted for 50 percent of the corn in the ration, the total solids of the manure increase 41 percent and the volatile solids increase 43 percent above that of a ration based on corn. Wasted feed further increases the necessary size of storage units and lagoon facilities needed for manure from rations of lower digestibility.

A common procedure for collecting and storing swine waste under slatted floors is in deep or shallow tanks that may be allowed to overflow to lagoons or longer-term storage units. Daily accumulation of such waste cannot be accurately predicted. Table 4–12 presents concentration data on solids and nutrients in swine waste in tanks. Using these concentrations and the volume of waste on hand, plans for use of the waste can be made.

Swine waste storage structures and facilities must make allowances for wasted water. Small pigs, especially, play with automatic waterers and can waste up to 3 gallons of water per day per head. See section 651.0403(b)(2) for additional information. Table 4-13 gives data on the nature of rainfall runoff and settling basin sludge from surfaced swine feedlots exposed to precipitation.

Anaerobic lagoons have been used extensively for swine waste in the United States. Supernatant, the upper liquid layer, of properly operating swine lagoons is often brownish, chocolate, or purple. It's characteristics are listed in table 4–13. Light yellowish-green lagoon supernatant is generally less concentrated, and black generally is more concentrated than indicated in the table.

Sludge accumulates in a good anaerobic swine lagoon at a rate of 0.0485 cubic foot per pound of total solids placed in the lagoon. This is about 12 cubic feet per grower/finisher equivalent annually.

Table 4–11 Swine waste characterization — as excreted*

Component	Units	Grower 40 – 220 lb	Replacement gilt	------ Sow ------ Gestation	Lactation	Boar	Nursing/ nursery pig 0 – 40 lb
Weight	lb/d/1000#	63.40	32.80	27.20	60.00	20.50	106.00
Volume	ft^3/d/1000#	1.00	0.53	0.44	0.96	0.33	1.70
Moisture	%	90.00	90.00	90.80	90. 00	90.70	90.00
TS	% w.b.	10.00	10.00	9.20	10. 00	9.30	10.00
	lb/d/1000#	6.34	3.28	2.50	6.00	1.90	10.60
VS	"	5.40	2.92	2.13	5.40	1.70	8.80
FS	"	0.94	0.36	0.37	0.60	0.30	1.80
COD	"	6.06	3.12	2.37	5.73	1.37	9.80
BOD_5	"	2.08	1.08	0.83	2.00	0.65	3.40
N	"	0.42	0.24	0.19	0.47	0.15	0.60
P	"	0.16	0.08	0.06	0.15	0.05	0.25
K	"	0.22	0.13	0.12	0.30	0.10	0.35
TDS		1.29					
C:N ratio		7	7	6	6	6	8

* Average daily production for weight range noted. Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

Figure 4–2 permits planners, designers, and others to estimate the manure solids production of growing swine in the weight range of 10 to 220 pounds.

Example 4–3: Estimate the total volatile and fixed solids produced daily in the manure of a 140-pound grower swine.

Entering figure 4–2 on the horizontal scale at an animal weight of 140 pounds, project vertically to the TS and VS curves and then horizontally to the vertical scale to read the values of 0.77 lb/d and 0.69 lb/d for the TS and VS, respectively. Fixed solids production is the difference between TS and VS values, or FS = 0.08 lb/d (0.77–0.69).

Example 4–4: Estimate the daily total volatile and fixed solids production in the manure of 450 grower/finisher swine with an average weight of 100 pounds. Enter figure 4–2 on the horizontal scale at weight of 100 pounds and project vertically to the TS and VS curves. Project horizontally to the vertical scale and read values of 0.63 lb/d and 0.57 lb/d for TS and VS, respectively. Multiplying by 450, the total number of animals, and determining fixed solids by the difference between TS and VS, the following amounts are determined:

$$TS = (125 \times 14.2) = 1,775 \text{ lb / d}$$

$$VS = (125 \times 12.1) = 1,513 \text{ lb / d}$$

$$FS = (1,775 - 1,513) = 262 \text{ lb / d}$$

Table 4–12 Swine waste characterization — storage tanks under slats

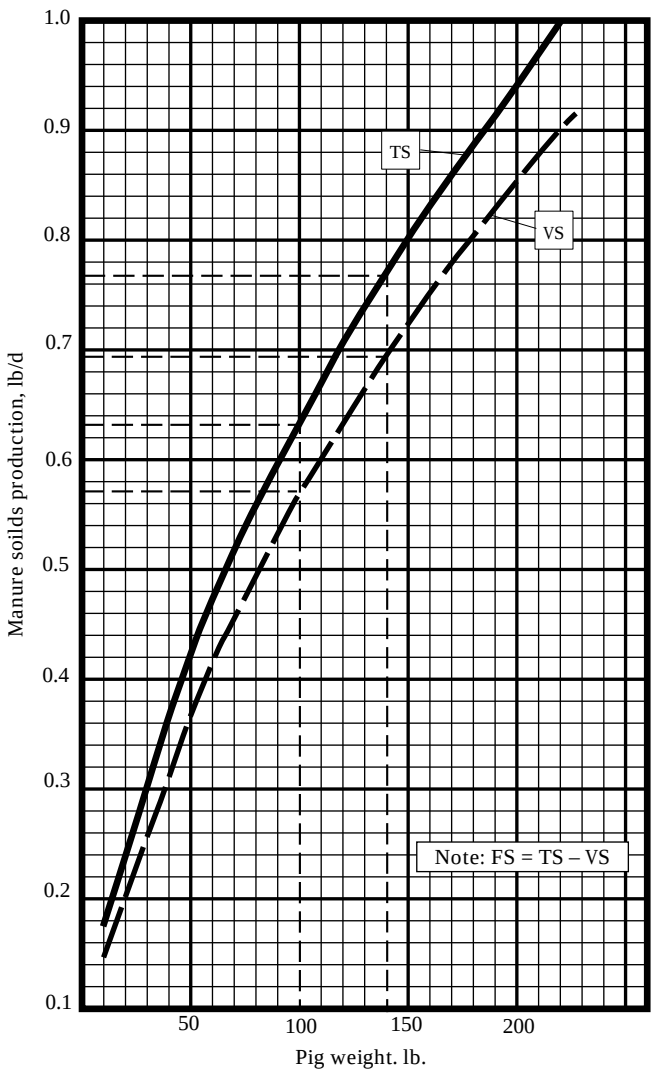
Component	Units	Farrow	Nursery	Grow/ finish	Breeding/ gestation
Moisture	%	96.50	96.00	91.00	97.00
TS	% w.b.	3.50	4.00	9.00	3.00
VS	lb/1000 gal	189.85	233.27	562.35	149.96
FS	"	101.64	99.97	187.45	99.97
N	"	29.16	40.00	52.48	25.00
NH_4-N	"	23.32	33.32		
P	"	15.00	13.32	22.50	10.00
K	"	23.32	13.32	18.33	17.50
C:N ratio		4	3	6	3

Table 4–13 Swine waste characterization — anaerobic lagoon; feedlot runoff

Component	Units	- Anaerobic lagoon - Super-natant	Sludge	- - Feedlot runoff* - - Runoff water	Settling basin sludge
Moisture	%	99.75	92.40	98.50	88.8
TS	% w.b.	0.25	7.60	1.50	11.2
VS	lb/1000 gal	10.00	379.89		90.7**
FS	"	10.83	253.27		21.3**
COD	"	10.00	538.18		
BOD_5	"	3.33			
N	"	2.91	25.00	2.00**	5.6**
NH_4-N	"	1.83	6.33	1.20**	4.5**
P	"	0.63	22.50	0.38**	2.2**
K	"	3.16	63.31	1.10**	10.0**
C:N ratio		2	8		

* Semi-humid climate (approx. 30" annual rainfall); annual sludge removal.
** lb/yr/1000#.

Figure 4–2 Manure solids production vs. pig weight for growing swine



(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 4–14 presents waste characteristics for “as excreted” poultry manure.

Table 4–14 Poultry waste characterization — as excreted*

Component	Units	Layer	Pullet	Broiler	Turkey	Duck
Weight	lb/d/1000#	60.50	45.60	80.00	43.60	
Volume	ft^3/d/1000#	0.93	0.73	1.26	0.69	
Moisture	%	75.00	75.00	75.00	75.00	
TS	% w.b.	25.00	25.00	25.00	25.00	
	lb/d/1000#	15.10	11.40	20.00	10.90	12.0
VS	"	10.80	9.70	15.00	9.70	7.0
FS	"	4.30	1.70	5.00	1.25	5.0
COD	"	13.70	12.20	19.00	12.30	9.5
BOD_5	"	3.70	3.30	5.10	3.30	2.5
N	"	0.83	0.62	1.10	0.74	0.7
P	"	0.31	0.24	0.34	0.28	0.3
K	"	0.34	0.26	0.46	0.28	0.5
TDS				2.89		
C:N ratio		7	9	8	7	6

* Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

Table 4–15 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 levels of nitrogen.

Most broiler houses are now cleaned out one or two times a year. Growers generally have five or six flocks of broilers each year, and it is fairly common to take the "cake" out after each flock. The cake is generally 1 to 2 inches of material. About 2 or 3 inches of new litter is placed on the floor before the next flock. Much of the waste characterization data for broiler litter are based on five or six cycles per year.

When a grower manages for a more frequent, complete cleanout, the data in table 4–15 need 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 and the nutrients are less concentrated. The amount of nutrients is less compared to the litter volume because less time is allowed for the nutrients to accumulate. A further complication is that nitrogen is lost to the atmosphere during storage while fresh manure is being continually deposited.

Table 4–15 Poultry waste characterization — litter

Component	Units	Layer high-rise*	Broiler	Turkey	Broiler breeder**	Duck**
Weight	lb/d/1000#	24.00	35.00	24.30		
Moisture	%	50.00	24.00	34.00	34.00	11.20
TS	% w.b.	50.00	76.00	66.00	66.00	88.80
	lb/d/1000#	12.00	26.50	16.10		
VS	"		21.40			58.60
FS	"		5.10			30.20
N	"	0.425	0.68	0.88	1.06	2.31
NH_4-N	"			0.01		
P	"	0.275	0.34	0.40	1.32	
K	"	0.30	0.40	0.45	1.19	
C:N ratio	"		9			14

* No bedding or litter material added to waste.
** All values % w.b.

Figure 4–3 shows the field determined relationship between the number of brood cycles between cleanouts and the nitrogen concentration in the litter after five cycles. The adjustment factor for five cycles is 1.0, thus no change. For example, a broiler producer generally has about 60 pounds of nitrogen per ton of broiler litter when a complete cleanout is done annually. The producer decides to do a complete cleanout after only one cycle. The nitrogen concentration would be about half that expected with an annual cleanout. Thus, only about 30 pounds of nitrogen would be in a ton of litter, so the producer would need to make twice as many trips to apply the same amount of nitrogen to the field. Figure 4–3 was developed using information from A.H. Stephenson, T.A. McCaskey, and B.G. Ruffin (Stephenson et al. 1989).

High-rise layer houses use no bedding and store manure for up to a year. Bird densities in high-rise houses have increased greatly in recent years, and the manure characteristics have been subject to great change. Use of current data for high-rise manure characterization is important.

As in other livestock operations, feed waste greatly increases the volume and organic content of the waste. A 10 percent wastage of feed, when added to the manure, increases total solids by 42 percent.

Poultry lagoon supernatant and sludge characteristics are in table 4–16. Anaerobic lagoon supernatant from good layer and pullet lagoons is brown, rosy, or burgundy. Yellowish-green supernatant is less concentrated. Blackish supernatant is more concentrated and generally has a higher value than those shown.

Layer lagoon sludge is much more dense 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 waste 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.

Figure 4–3 Curve to adjust broiler waste nitrogen concen-tration based on frequency of cleanout of litter

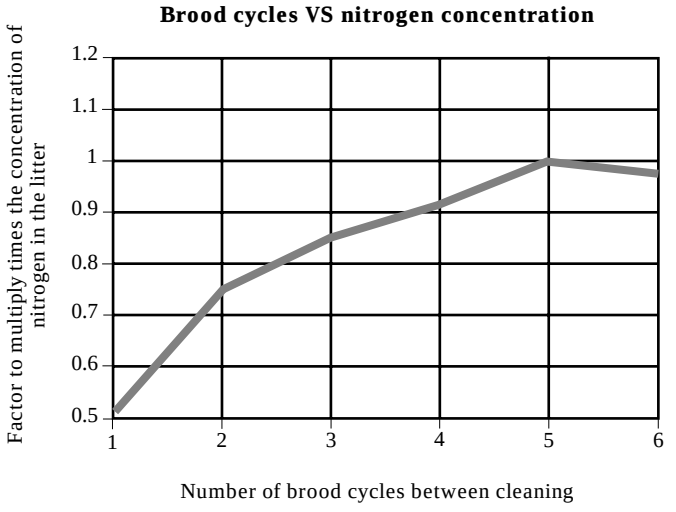


Table 4–16 Poultry waste characterization — anaerobic lagoon

Component	Units	Layer Super-natant	Layer Sludge	Pullet Super-natant	Pullet Sludge
Moisture	%	99.50	86.90	99.70	92.60
TS	% w.b.	0.50	13.10	0.30	7.40
VS	lb/1000 gal	18.33	404.06	10.83	314.09
FS	"	23.32	687.32	14.17	302.42
N	"	6.25	32.50	3.00	24.17
NH_4-N	"	4.58	7.66	2.24	4.91
P	"	0.83	45.82	0.75	27.49
K	"	8.33	6.00	7.00	6.17
C:N ratio		2	7	2	7

(g) Veal

Data on manure characteristics from veal production are shown in table 4–17. 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.

Table 4–17 Veal waste characterization — as excreted

Component	Units	Veal feeder
Weight	lb/d/1000#	60.00
Volume	ft^3/d/1000#	0.96
Moisture	%	97.50
TS	% w.b.	2.50
	lb/d/1000#	1.50
VS	"	0.85
FS	"	0.65
COD	"	1.50
BOD_5	"	0.37
N	"	0.20
P	"	0.03
K	"	0.25
C:N ratio		2

(h) Sheep

"As excreted" manure characteristics for sheep are limited to those for the feeder lamb (table 4–18). In some cases bedding may be a significant component of sheep waste.

Table 4–18 Lamb waste characterization — as excreted*

Component	Units	Lamb
Weight	lb/d/1000#	40.00
Volume	ft^3/d/1000#	0.63
Moisture	%	75.00
TS	% w.b.	25.00
	lb/d/1000#	10.00
VS	"	8.30
FS	"	1.76
COD	"	11.00
BOD_5	"	1.00
N	"	0.45
P	"	0.07
K	"	0.30
C:N ratio		10

* Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

(i) Horse

Table 4–19 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 4–19 Horse waste characterization — as excreted*

Component	Units	Horse
Weight	lb/d/1000#	50.00
Volume	ft^3/d/1000#	0.80
Moisture	%	78.00
TS	% w.b.	22.00
	lb/d/1000#	11.00
VS	"	9.35
FS	"	1.65
N	"	0.28
P	"	0.05
K	"	0.19
C:N ratio		19

* Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

(j) Rabbit

Some properties of rabbit manure are listed in table 4–20. 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 4–20 Rabbit waste characterization — as excreted*

Component	Units	Rabbit
VS	% d.b.	0.86
FS	"	0.14
COD	"	1.00
N	"	0.03
P	"	0.02
K	"	0.03
C:N ratio		16

* Increase solids and nutrients by 4% for each 1% feed waste more than 5%.

(k) Flush water

Hydraulic manure transport, or flush cleaning, is an effective method of manure collection and handling, but relatively large quantities of water are used. Small quantities of manure can be diluted 5 to 10 times in the cleaning process; therefore, waste handling problems are multiplied.

Because the resulting quantity of waste or wastewater is large, lagoons and irrigation equipment are usually parts of waste management systems using flush cleaning. While fresh water is required for cleaning in many instances, recycled lagoon liquid (supernatant) can be used and can greatly reduce the volume of fresh water needed for waste management. Where necessary, the approval of appropriate State and local authorities should be requested before lagoon supernatant recycling is implemented.

Because quantities of flush water vary widely between operations, it is recommended that estimated values be based on local calculations or measurement. Estimates of flush water requirements for various mechanisms and for various species may be made from the following equations and test results.

Swine — (siphon, gated tank, or tipping tank)

$$Q = 0.5\ L \times W \qquad [4–1]$$

where:
Q = Flush water vol, gal/flush
L = Gutter length, ft
W = Gutter width, ft

Dairy

	Gated tank	Pump flush
Gal/d/ft^2 alley surface	2.5	15.0
Gal/d/cow	80.0	550.0

Dairies that have gated tank flush cleaning and automatic cow washing commonly use 100 to 150 gal/d/cow, but multiple flushing and alternative equipment may double this amount.

Poultry — (pump flush) 1.0 to 1.5 gal/bird/flush.

For more information on flush systems, refer to chapter 10.

651.0404 Other wastes

(a) Residential waste

Rural residential waste components are identified in tables 4–21 and 4–22. Table 4–21 lists the characteristics of human excrement. Household wastewater (table 4–22) 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.

Residential wastewater of municipal origin is usually categorized into raw (untreated) and treated types (table 4–23). 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 (table 4–23).

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.

Table 4–21 Human waste characterization — as excreted

Component	Units	Adult
Weight	lb/d/1000#	30.00
Volume	ft^3/d/1000#	0.55
Moisture	%	89.10
TS	% w.b.	10.90
	lb/d/1000#	3.30
VS	"	1.93
FS	"	1.40
COD	"	3.00
BOD_5	"	1.30
N	"	0.20
P	"	0.02
K	"	0.07

Table 4–22 Residential waste characterization — household wastewater

Component	Units	Graywater	Composite*	Septage
Volume	ft^3/d/1000# of people	27.00	38.00	35.00
Moisture	%	99.92	99.65	99.75
TS	% w.b.	0.08	0.35	0.25
	lb/d/1000# of people	1.33	7.75	5.50
VS	% w.b.	0.024	0.20	0.14
FS	"	0.056	0.15	0.11
N	"	0.0012	0.007	0.0075
NH_4-N	"			0.0018
P	"	0.0004	0.003	0.0019
K	"		0.003	0.0025

* Graywater plus blackwater.

Table 4–23 Municipal waste characterization — residential

Component	Units	- - - - - Wastewater - - - -		- - - - - - Sludge - - - - - -		Compost*
		Raw	Secondary	Raw	Digested	
Volume	ft^3/d/1000# of people	90.00	85.00			
Moisture	%	99.95	99.95			40.00
TS	% w.b.	0.05**	0.05***	4.00	4.00	60.00
VS	"	0.035		3.00	2.10	
FS	"	0.015		1.00	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

* Origin is household refuse.
** Suspended solids 0.03%; dissolved solids 0.02%.
*** Suspended solids 0.0025%; dissolved solids 0.0475%.

(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 use or 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 4–24 and 4–25 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 4–26 and 4–27.

Table 4–26 presents data on raw wastewater discharges from red meat and poultry processing plants.

Table 4–27 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 4–28 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 4–29.

Table 4–24 Dairy food processing waste characterization

Product/Operation	Wastewater: Weight lb/lb milk processed	Wastewater: BOD_5 lb/1000 lb milk received
Bulk milk handling	6.1	1.0
Milk processing	4.9	5.2
Butter	4.85	1.46
Cheese	2.06	1.8
Condensed milk	1.85	4.5
Milk powder	2.8	3.9
Milk, ice cream, & cottage cheese	2.52	6.37
Cottage cheese	6.0	34.0
Ice cream	2.8	5.76
Milk & cottage cheese	1.84	3.47
Mixed products	1.8	2.5

Table 4–25 Dairy food waste characterization — processing wastewater

Component	Units	Industry-wide	Whey: Sweet cheese	Whey: Acid cheese	Cheese wastewater sludge
Moisture	%	97.60	93.10	93.40	97.50
TS	% w.b.	2.40	6.90	6.60	2.50
VS	"	1.49	6.35	6.00	
FS	"	0.91	0.55	0.60	
COD	"		1.30		
BOD_5	"	2.00			
N	"	0.077	7.48		0.18
P	"	0.050			0.12
K	"	0.067			0.05

Table 4–26 Meat processing waste characterization — wastewater

Component	Units	Red meat: Slaughter [1]	Red meat: Packing [2]	Red meat: Processing [3]	Poultry [4]	Broiler [5]
Volume	gal/1000# [6]	696.0	1,046.0	1,265.0	2,500.0	
Moisture	%					95.05
TS	% w.b.					4.95
	lb/1000# [6]	4.7	8.7	2.7	6.0	
VS	"					4.30
FS	"					0.65
BOD_5	"	5.8	12.1	5.7	8.5	
N	"					0.30
P	"					0.084
K	"					0.012

1 Slaughter—Killing and preparing the carcass for processing.
2 Packing—Killing, preparing the carcass for processing, and processing.
3 Processing—Butchering, grinding, packaging.
4 Quantities per 1,000 lb product.
5 All values % w.b.
6 Per 1,000 lb live weight killed.

Table 4–27 Meat processing waste characterization — wastewater sludge

Component	Units	Dissolved air flotation sludge: Poultry	Dissolved air flotation sludge: Swine	Dissolved air flotation sludge: Cattle	Wastewater sludge
Moisture	%	94.20	92.50	94.50	96.00
TS	% w.b.	5.80	7.50	5.50	4.00
VS	% w.b.	4.80	5.90	4.40	3.40
FS	"	1.00	1.60	1.10	0.60
COD	"	7.80			
N	"	0.41	0.53	0.40	0.20
NH_4-N	"	0.17			
P	"	0.12			0.04

Table 4–28 Vegetable processing waste characterization — wastewater

Component	Units	Cut bean	French style bean	Pea	Potato	Tomato
Volume	ft^3/1000 lb				270*	
TS	lb/1000 lb†	15	43	39	53**	134
VS	"	9	29	20	50**	
FS	"	6	14	19	3**	
COD	"	14	35	37	71***	96
BOD_5	"	7	17	21	32	55

† Lb/1000 lb raw product. * Ft^3 per lb processed. ** Total suspended solids. *** Percent of TSS.

Table 4–29 Fruit and vegetable waste characterization — solid waste

Fruit/vegetable	Moisture content	Total solids	Volatile solids	Fixed solids	N	P	K
	Percent wet weight basis						
Banana, fresh	84.0	16.0	13.9	2.1	0.53		
Broccoli, leaf	86.5	13.5			0.30		
Cabbage, leaf	90.4	9.6	8.6	1.0	0.14	0.034	
" core	89.7	10.3			0.38		
Carrot, top	84.0	16.0	13.6	2.4	0.42	0.03	
" root	87.4	12.6	11.3	1.3	0.25	0.04	
Cassava, root	67.6	32.4	31.1	1.3	1.68	0.039	
Corn, sweet, top	79.8	20.2	19.0	1.2	0.67		
Kale, top	88.4	11.6	9.7	1.9	0.22	0.06	
Lettuce, top	94.6	5.4	4.5	0.9	0.05	0.027	
Onion, top, mature	8.6	91.4	84.7	6.7	1.37	0.02	
Orange, flesh	87.2	12.8	12.2	0.6	0.26		
" pulp	84.0	16.0	15.0	1.0	0.24		
Parsnip, root	76.3	23.7			0.47		
Potato, top, mature	12.8	87.2	71.5	15.7	1.22		
" tuber					1.60	0.25	1.9
Pumpkin, flesh	91.3	8.7	7.9	0.8	0.12	0.037	
Rhubarb, leaf	88.6	11.4			0.20		
Rutabaga, top	90.0	10.0			0.35		
" root	89.5	10.5			0.20		
Spinach, stems	93.5	6.5			0.065		
Tomato, fresh	94.2	5.8	5.2	0.6	0.15	0.03	0.30
" solid waste	88.9	11.1	10.2	0.9	0.22	0.044	0.089
Turnip, top	92.2	7.8				0.20	
" root	91.1					0.34	

(c) Silage leachate

Leachate, a liquid by-product in which the potential for pollution is severe, results from the storage of forage materials for the production of silage. In general, 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. As a rule of thumb, it is suggested that storage facilities for silage leachate provide 1 cubic foot (7.5 gallons) capacity for each ton of forage placed in storage. If materials that have a moisture content of 80 percent or more are to be ensiled, even greater leachate quantities can be expected.

651.0405 References

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**Soil
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Agricultural
Waste Management
Field Handbook

Chapter 5 Role of Soils in Waste Management

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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

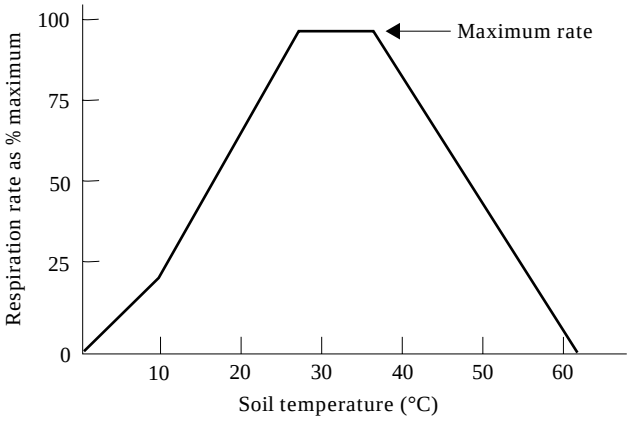
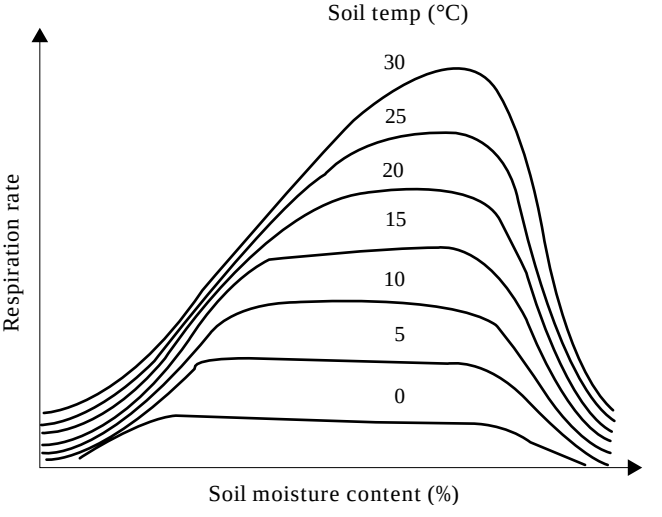


Figure 5–2 Relationship of microbial respiration rate to temperature and moisture



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 hydro-

logic 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 (Available water capacity)	(inches) > 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) Soil texture:	(grams/cc)			
Medium & fine Coarse	<1.7 All	Slight	Apply when soil moisture content is such that the field is in tillable condition.	Reduces bulk density and minimizes compaction.
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 agricultural 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 infiltration and permeability.
Liquid waste	0.6 – 2.0	Slight	Apply waste.	Improves soil surface infiltration and permeability.
Liquid waste	0.2 – 0.6	Moderate	(Slow permeability and potential 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 contamination 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. Reduced permeability from organic matter accumulation 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.

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**Soil
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Agricultural
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Field Handbook

Chapter 6 Role of Plants in Waste Management

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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.

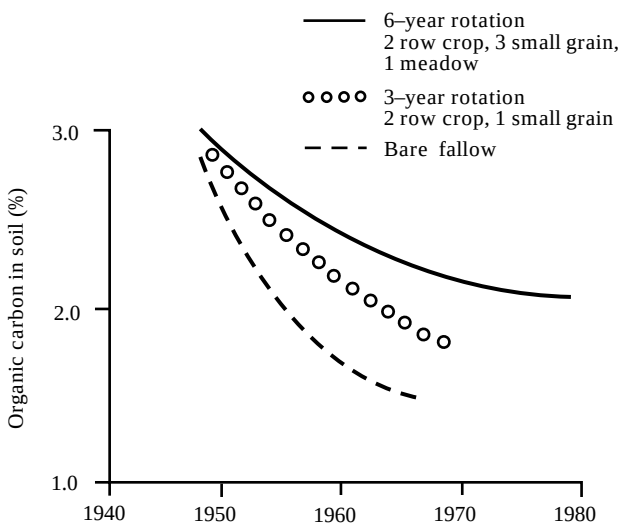
(b) Soil supports plant growth

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

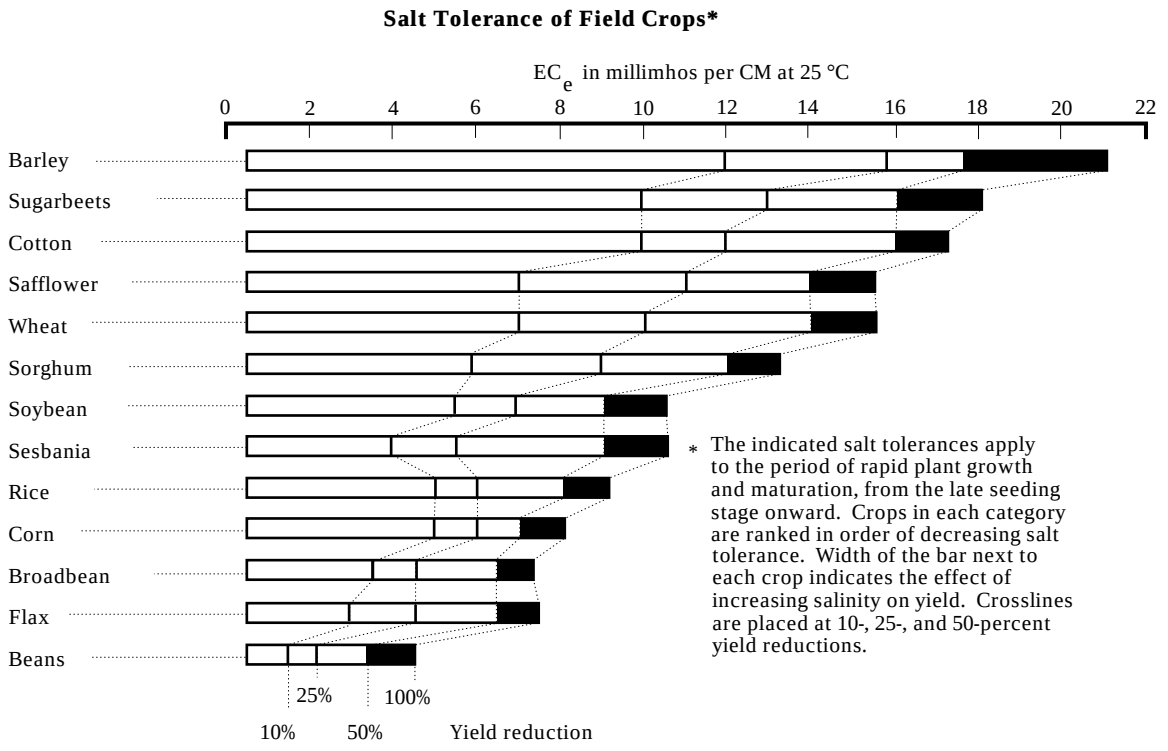


Figure 6–3 Effect of soil salinity on growth of forage crops

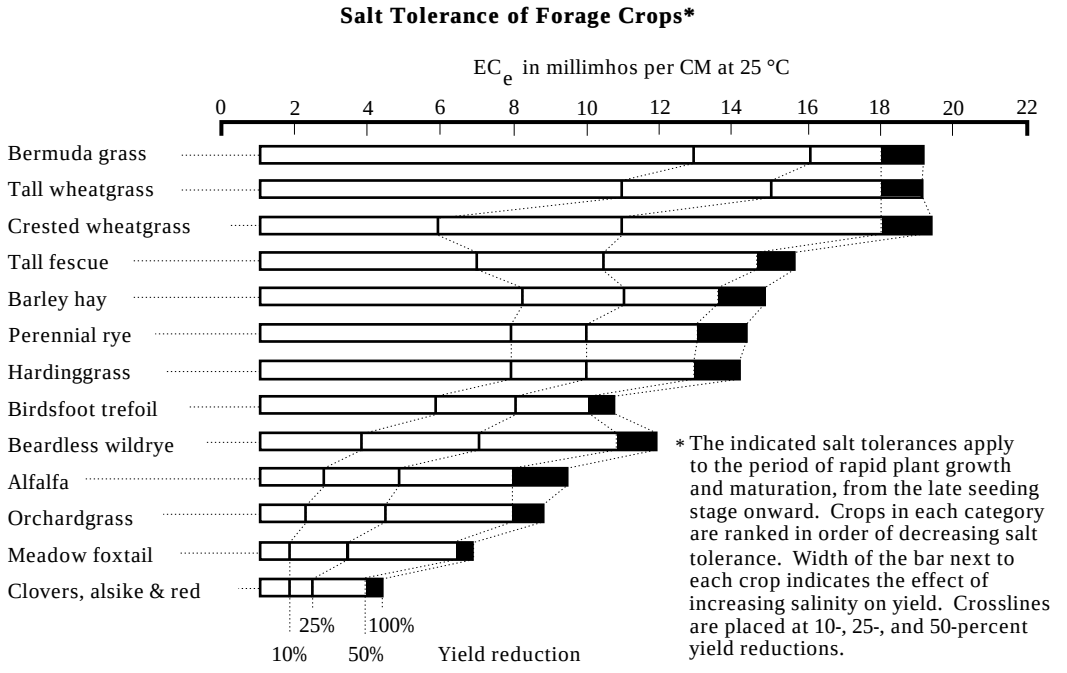
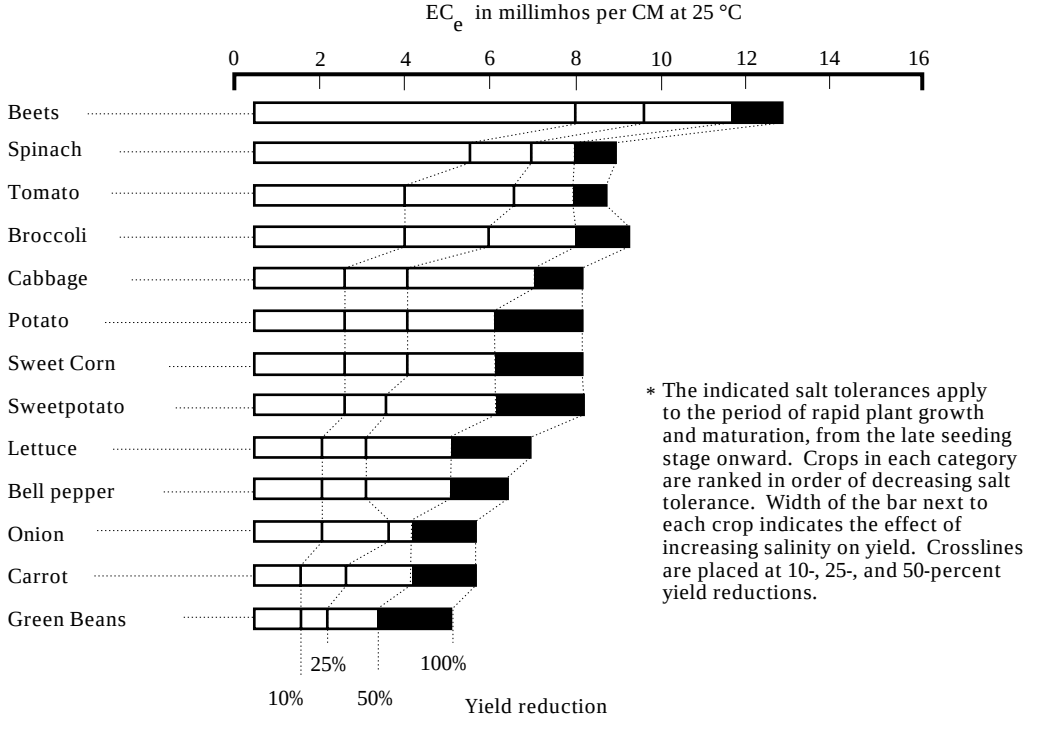


Figure 6–4 Effect of soil salinity on growth of vegetable crops



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).

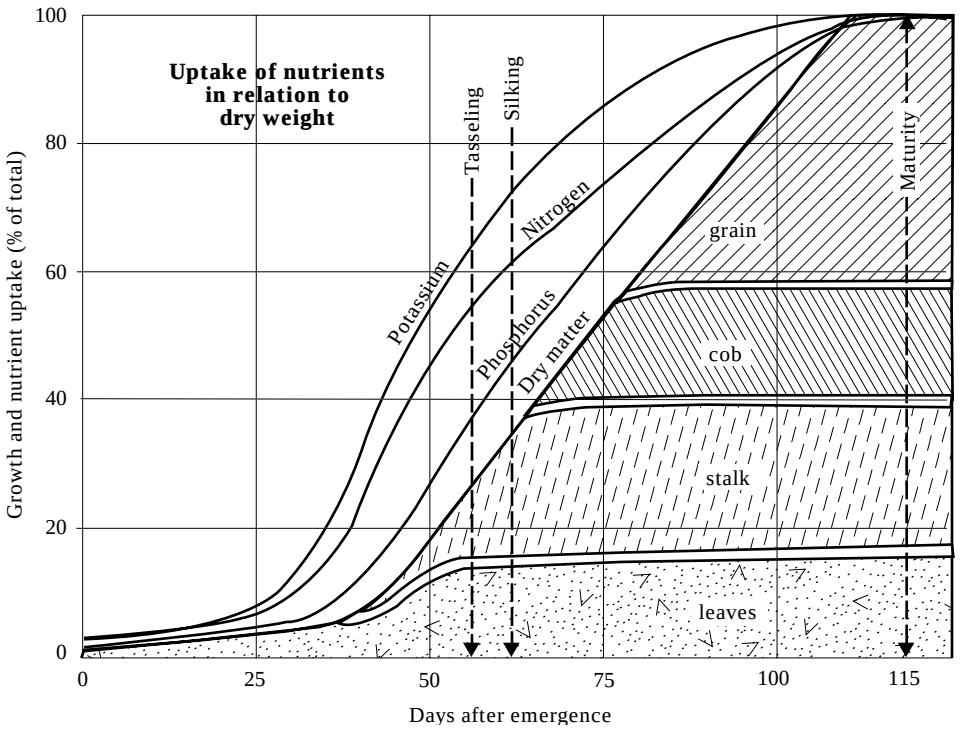
The total uptake of nutrients by crops from agricultural waste applications increases as the crop yields increase, and crop yields for the most part increase with increasing soil nutrients, provided toxic levels are not reached or nutrient imbalances do not occur. The total nutrient uptake continues 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:

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

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	Average concentration of nutrients (%) N	P	K	Ca	Mg	S	Cu	Mn	Zn
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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**Natural
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Agricultural Waste
Management
Field Handbook

Chapter 7 Geologic and Ground Water Considerations

June 1999

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Chapter 7 Geologic and Ground Water Considerations

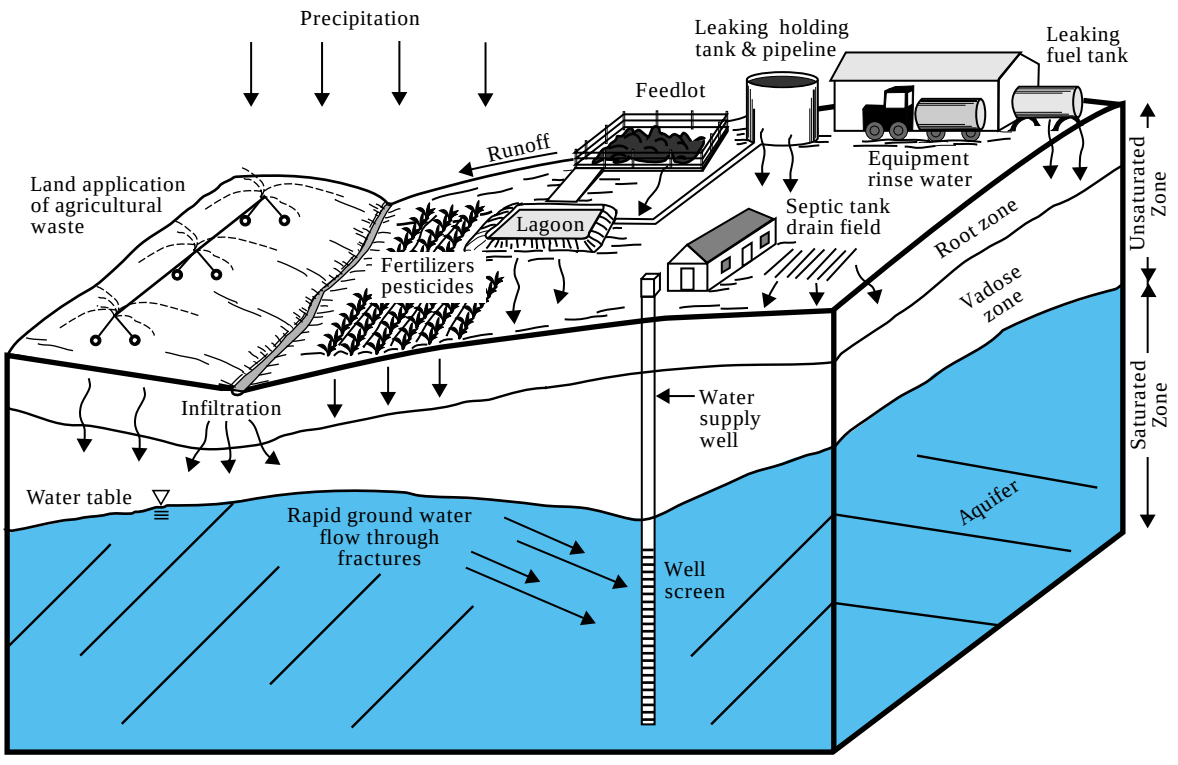
651.0700 Introduction

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

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

Storing, treating, or utilizing agricultural wastes and nutrients at or below the ground surface has the potential to contaminate ground water (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 encountered in investigation and planning.

Figure 7–1 Agricultural sources of potential ground water contamination



651.0701 Overview of geologic material and ground water

(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 inplace 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 solutionally widened joints, sinkholes, and caves. 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 NRCS 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.

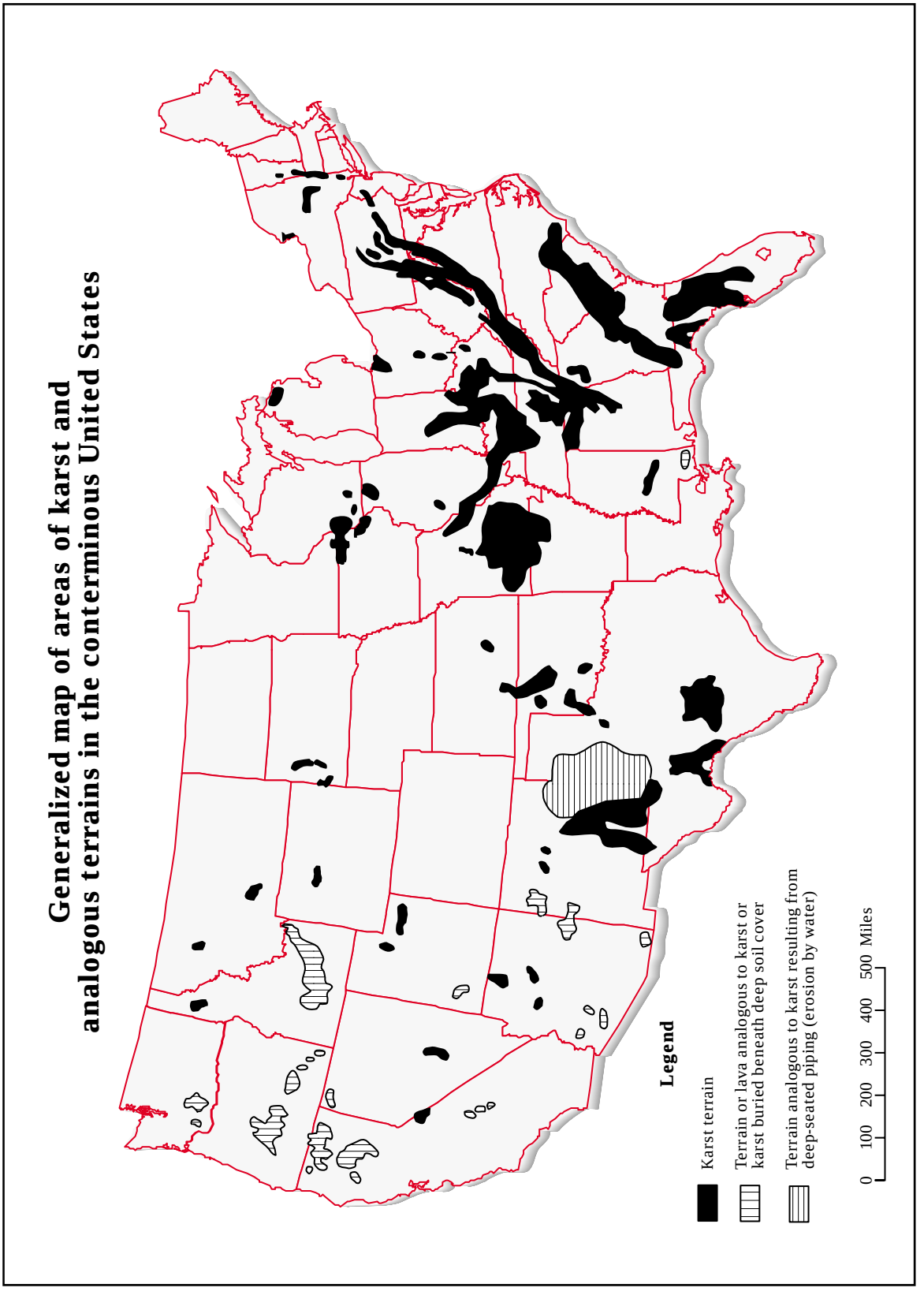
Structural discontinuities are extremely common in almost any geologic material. They include fractures of all types that develop sometime after a soil or rock mass has formed. Almost all types of bedrock are fractured near the Earth's surface. Forces acting on the mass that cause deformation include 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 rock. These wells are at risk of contamination from waste impoundment facilities if rock 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. Discontinuities can, therefore, 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) Ground water

Many Natural Resources Conservation Service (NRCS) programs deal with the development, control, and protection of ground water resources. The planners of agricultural waste management practices should be familiar with the principles of ground water. NRCS references that include information on ground water include National Engineering Handbook (NEH) Section 16, Drainage of Agricultural Lands; NEH Section 18, Ground Water; Engineering Field Handbook (EFH) Chapter 12, Springs and Wells; and EFH Chapter 14, Drainage.

Figure 7–2 Karst areas in the United States

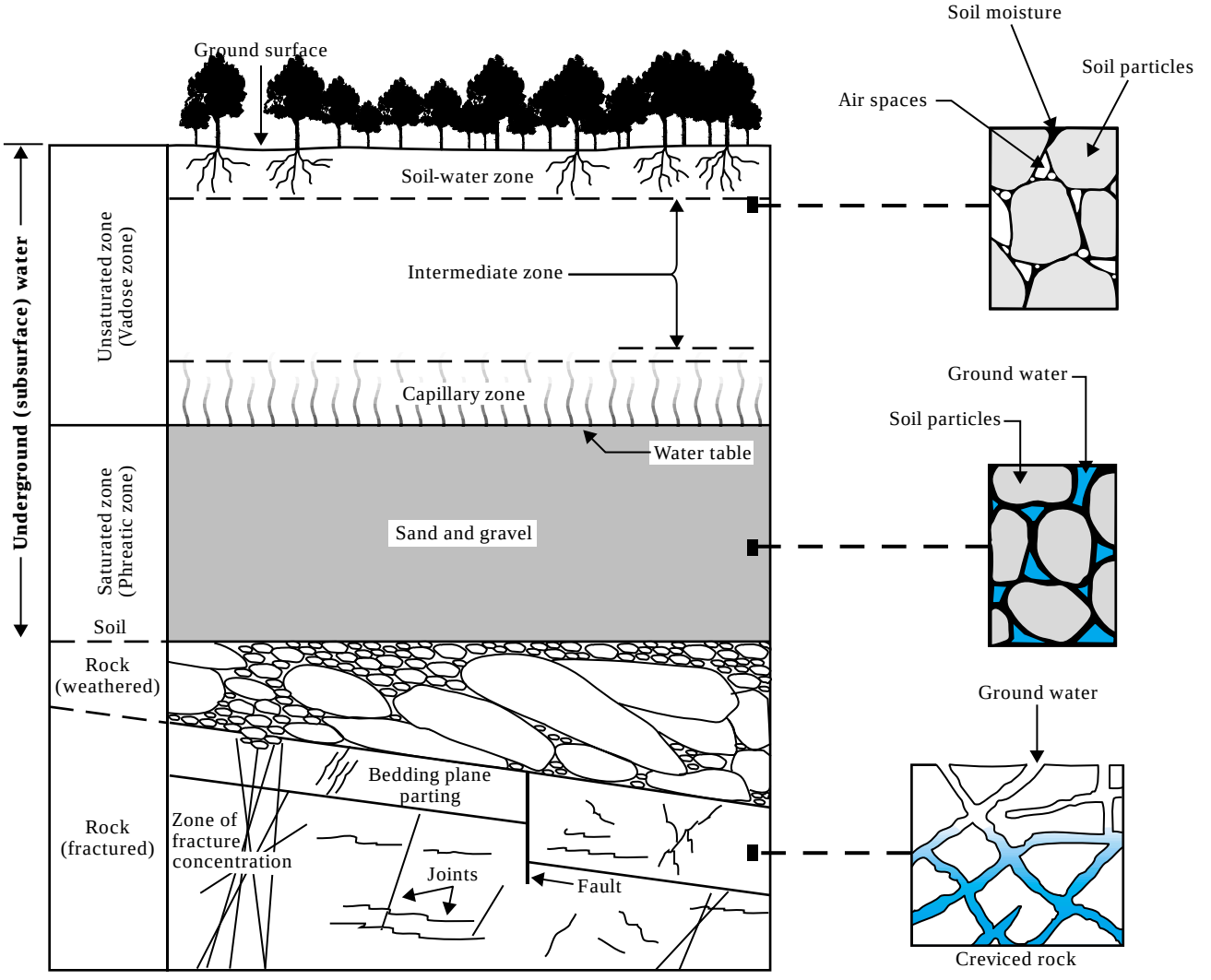


(1) Zones of underground water

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 ground water applies to the saturated zone. Ground water is the only underground water available for wells and springs.

The vadose zone includes the soil-water zone, the intermediate zone, and the capillary fringe. 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 by plants or direct evaporation. This zone is usually at less than saturation except during rainfall or irrigation. Water held by surface tension moves by capillary action. Excess water percolates through the soil-water zone by gravity. An intermediate zone may separate the soil zone from the capillary fringe. An intermediate zone does not exist where the water table (described later)

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



approaches the ground surface. Regions in the intermediate zone may be hundreds of feet thick. Water in the intermediate zone cannot move back up to the soil-water zone by capillary action. Intermediate zone water moves either downward under gravity or is held in place by surface tension.

Directly above the water table is a saturated zone, the capillary fringe. This zone occurs in fine to medium grained soils and in rocks with fractures less than 1/8 inch wide. Water in the capillary fringe is under less than atmospheric pressure. It rises a few inches to more than 10 feet above the water table, depending on the earth materials (sand, low; clay, high). Surface tension and capillary action cause water in this zone to rise. Capillary rise increases as the pore spaces decrease.

In the saturated zone, water is under hydrostatic pressure and occupies all pore spaces. The upper surface of the saturated zone is called the water table. The elevation of the water table is at atmospheric pressure. The saturated zone extends from the plane of the water table down to impermeable geologic material.

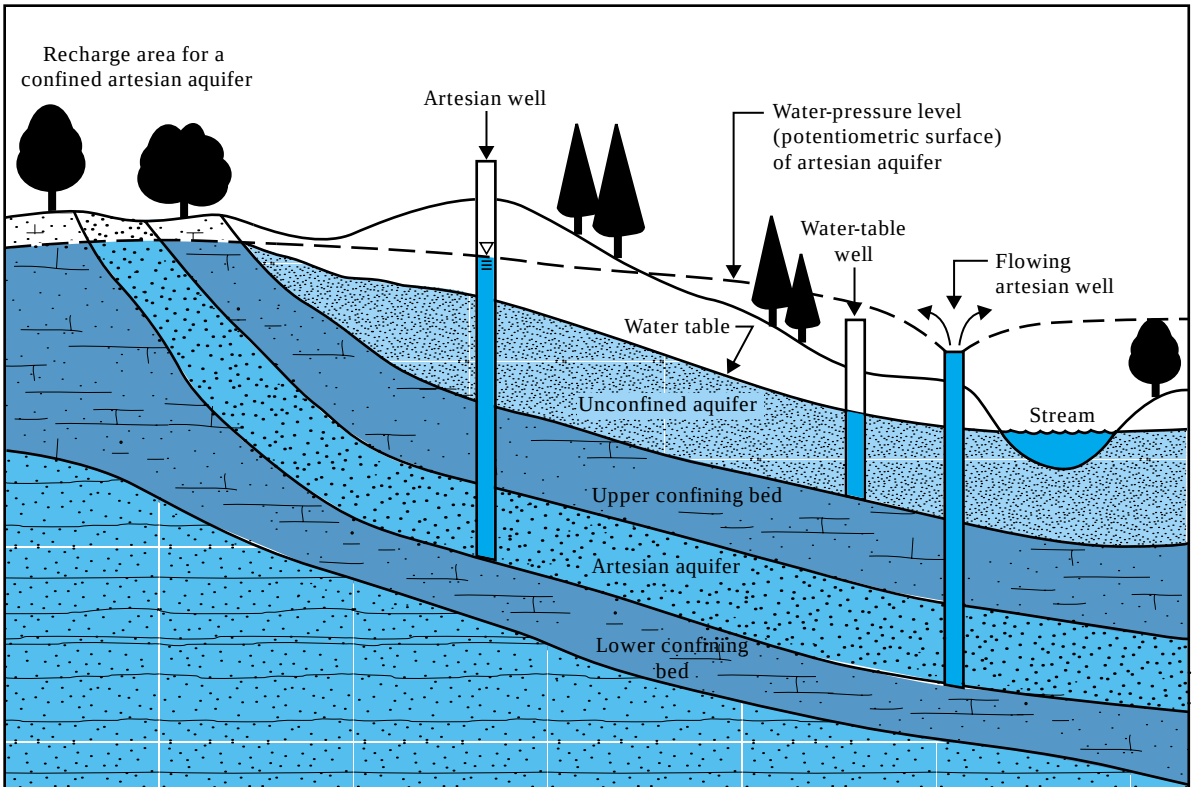
(2) Aquifers

An aquifer is a geologic unit capable of storing and conveying usable amounts of ground water to wells or springs (fig. 7–4). When siting any agricultural waste management component, it is important to know:

- What type(s) of aquifers may be present and at what depths.
- What the aquifer use classification is, if any.

Aquifers occur in many types of soil or rock material. Productive aquifers include sand and gravel alluvial deposits on flood plains of perennial streams; glacial outwash; coarse-grained, highly porous, or weakly cemented sedimentary rocks (some sandstones and conglomerates); and karst topography. An aquifer need not be highly productive to be an important resource. For example, there are millions of low-

Figure 7–4 Aquifers (from AIPG 1984)



yielding (less than 10 gpm) private domestic wells throughout the country. In upland areas, often the only aquifer available for a ground water source is fractured rock occurring near the surface (up to 300 feet deep).

An aquifer may be unconfined, confined, or perched. An unconfined aquifer, or water table aquifer, has no upper confining layer (fig. 7–5). Hence, the upper surface of the saturated zone is under only atmospheric pressure. It is, therefore, free to rise and fall with recharge or pumping. Recharge generally occurs locally. The static water level in a well in an unconfined aquifer is the elevation at which water stabilizes after pumping ceases. Unconfined aquifers are the type most commonly experienced in NRCS work.

Some unconfined aquifers result in flowing artesian wells. This occurs when the water table locally rises above the ground surface. Topography is the primary control on most flowing wells in major valley bottoms. The valleys serve as ground water discharge areas. Because hydraulic potential increases with depth in valley bottoms, deep wells frequently tap a hydraulic head contour with a head value greater than that of the land surface, and therefore, will flow (fig. 7–6).

A confined aquifer is overlain by a confining layer of lower permeability (fig. 7–7). The surface of ground water under confined conditions is often subject to higher than atmospheric pressure because it is confined by impermeable layers bounding the aquifer. A well in a confined aquifer that has higher than atmospheric pressure is called an artesian well. The potentiometric surface is the level to which ground water rises in a tightly cased well penetrating a confined aquifer. Recharge areas are typically remote from any given well location. The classic model of a flowing artesian well (see fig. 7–4) is the case where an aquifer crops out (that is, is exposed at the Earth's surface) and receives recharge in an upland area. Low permeability materials (aquicludes) lying above

Figure 7–6 Cross section through stream valley showing ground water flow lines and flowing (artesian) well from unconfined aquifer (from Fetter 1980)

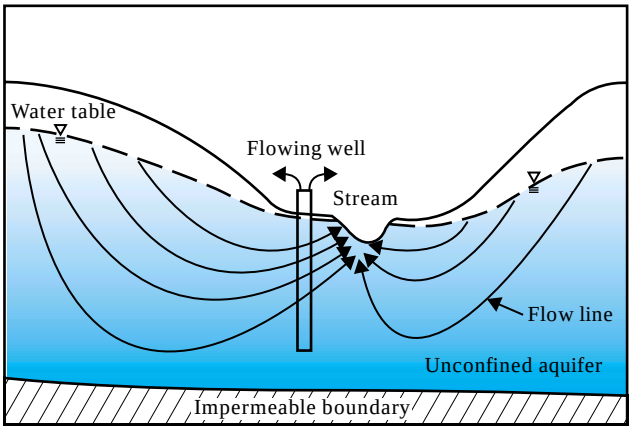
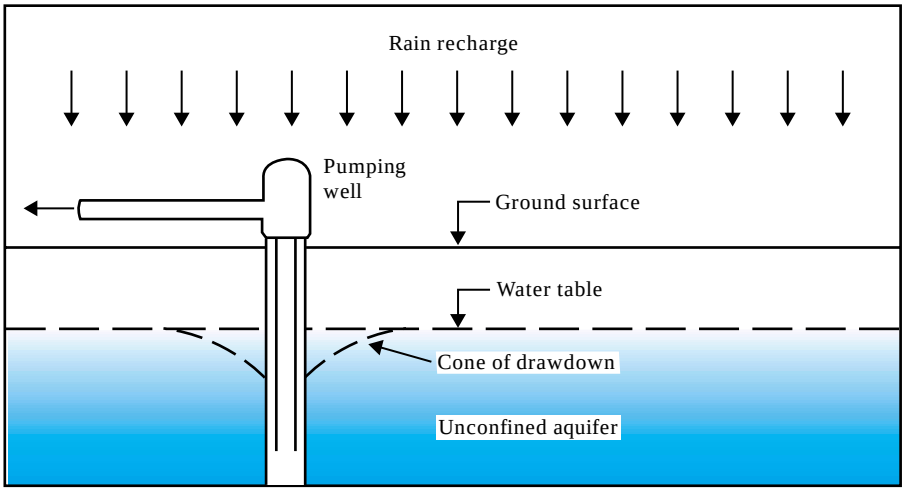


Figure 7–5 Unconfined aquifer (from AIPG 1984)



and confining the aquifer generate hydraulic heads greater than the surface elevation head. The confined aquifer, therefore, produces flowing artesian wells.

A perched aquifer is a local zone of unconfined ground water occurring at some level above the regional water table. An unsaturated zone separates the perched aquifer from the regional water table. A perched aquifer generally is of limited lateral extent. It forms in the unsaturated zone where a relatively impermeable layer, called a perching bed (for example, clay), intercepts downward-percolating water and causes it to accumulate above the bed (fig. 7–8). Perched aquifers can be permanent or temporary, depending on frequency and amount of recharge. Perched aquifers can present dewatering problems during construction if not discovered during investigation of the site.

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

A state may have designated use classifications just as surface water resources have. A state may have designated use classifications to protect aquifers for future use by a municipality, for example. Some aquifers may be regulated against overdraft or ground water mining.

(3) Porosity

Most earth 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.

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

Figure 7–8 Perched aquifer

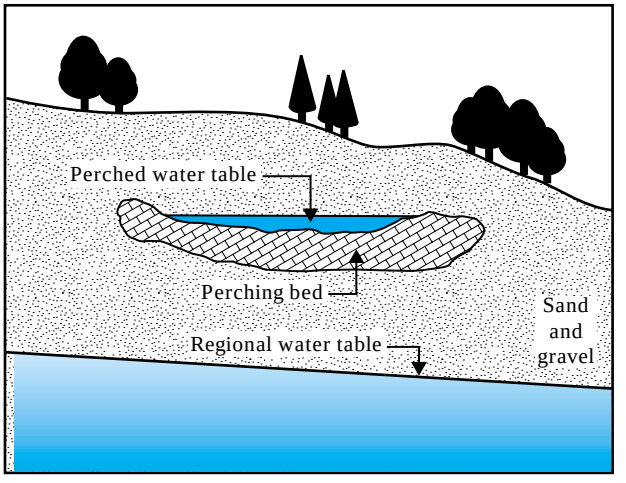
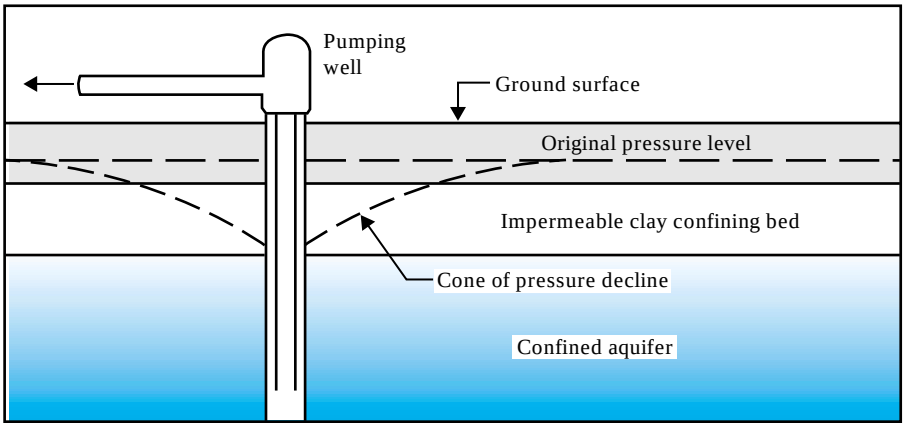


Figure 7–7 Confined (artesian) aquifer (from AIPG 1984)

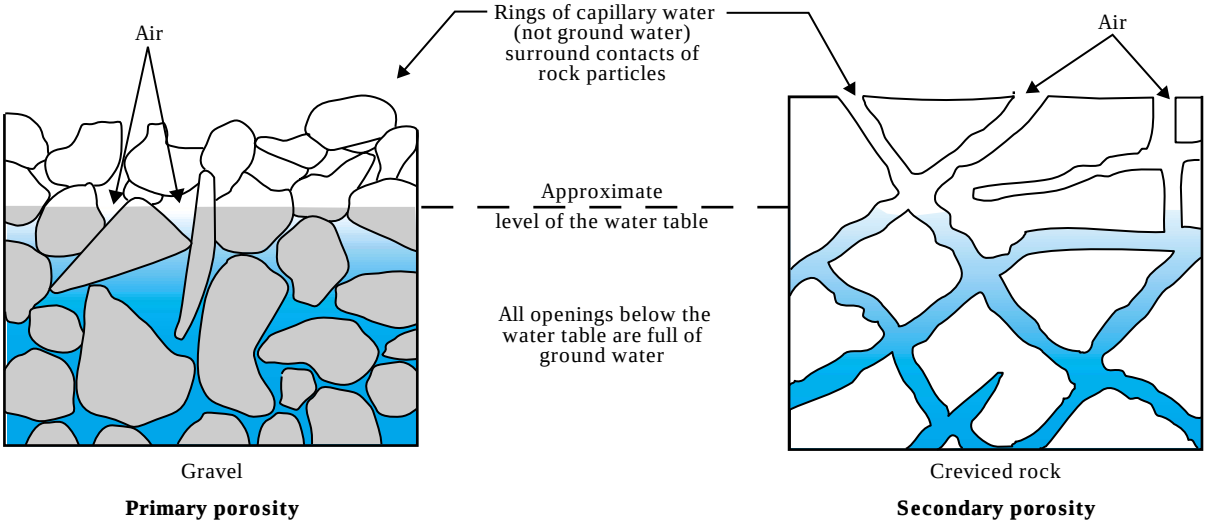


The two main types of porosity are primary and secondary (fig. 7–9).

Primary porosity refers to openings formed at the same 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. Porosity, however, is independent of particle size. Thus, a bathtub full of bowling balls has the same porosity as the same tub full of bb's. This assumes the arrangement (packing) is the same for balls and bb's. However, the tub full of a mixture of bowling balls and bb's will have a lower porosity than either the bb's or the bowling balls because bb's will occupy space between the bowling balls.

Secondary porosity refers to openings formed after initial deposition or formation of a material. Processes that create secondary porosity include physical weathering (freeze-thaw, 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.

Figure 7–9 Porosity—how ground water occurs in geologic materials



(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, 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.

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

Table 7–1 Porosity and specific yield for various geologic materials (from Driscoll 1986 and Johnson 1967)

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

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 encountered, justify requesting assistance of a geologist or other technical specialist.

(a) Corrosivity

Soil is corrosive to many materials used in AWMS components. Published soil surveys and the NRCS National Soil Characterization data base 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.

Obtain preliminary estimates of the depth to high water table from published soil surveys and the NRCS National Soil Characterization data base. Site-specific ground water 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 mottling is particularly important. Mottling indicates seasonal changes in soil moisture. Perennially saturated soil is typically gray. Perennially aerated soil is typically various shades of red, brown, or yellow.

Table 7–2 Engineering geology considerations 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	
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., buried pipelines)	X											X	

(c) Depth to rock

The selection of components that make up an agricultural waste management system 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 highly 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 rock may contaminate ground water 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. The physical hazard of ground collapse and the potential for ground water contamination through the large voids are severe limitations.

(d) Stability for embankment and excavated cut slopes

Embankments and excavated cut slopes must remain stable throughout their design life. Control of ground water 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 to prevent the increased loads caused by the static or dynamic weight of a component from causing downslope sliding or slumping, especially for a clay foundation having 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 lead to bank caving. Designers must consider this in determining the stable side slope of embankments and cutbanks, and in designing the liner thickness. Consideration should be given to addressing the maximum rate that wastewater should be withdrawn from waste impoundments to minimize this problem in operation and maintenance plans.

(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 available 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

Abrupt lateral or vertical changes in soil or rock materials may indicate faults (active or inactive) or bedrock structures, such as tight folds, shear zones, and vertical bedding. Seismic zones 3 and 4, as defined in TR-60, Earth Dams and Reservoirs, and locally delineated, typically require special considerations in

design of embankments including embankment slopes, cut slopes, zoned fill, or internal drainage. A foundation consisting of loose, saturated, fine-grained, relatively clean sand is most susceptible to seismic activity. Most well compacted embankments and those foundations and embankments consisting of fine-grained soil with plasticity are inherently resistant to seismic shocks.

Determine the seismic zone of a site using the map in TR-60. Identify other geologic hazards from information as may be listed in section I of the Field Office Technical Guide (FOTG) and in geology reports, geologic maps, or other local technical resources.

(g) Dispersion

Dispersed soils are those in which the clay fraction is or may become deflocculated or disaggregated. The clay particles in these soils have minimal electrochemical attraction and are not tightly bonded when saturated resulting in reduction of effective particle size and effective pore diameters. Dispersed soils are also characterized by high soluble sodium content. Whereas calcium ions promote flocculation, sodium ions enhance dispersion in clays. Dispersion tends to decrease permeability while flocculation tends to increase it. Dispersed soils occur in all regions of the United States. If dispersion is suspected, send representative soil samples to a laboratory for testing.

Table 7–3 Excavation characteristics of geologic materials (from Kirsten 1987)

Geologic material	Excavation characteristics	Equipment size flywheel horsepower
Very soft to very stiff cohesive soil or very loose to very dense granular soil	Hand pick and spade or light equipment (common excavation)	< 100
Very soft rock to moderately soft rock	Power tools or easy ripping (common excavation)	< 150
Moderately hard to hard rock	Hard to very hard ripping (rock excavation)	< 250
Very hard to extremely hard rock	Extremely hard ripping to blasting (rock excavation)	> 350 to blasting 1/

1/ Explosives may be an alternative to equipment.

Typical characteristics of dispersed soils are:

- Relatively high content of soluble sodium and varying amounts of exchangeable sodium.
- Highly erodible. Clay and colloidal fractions go readily into suspension and remain there. Surface exposures have appearance of melted sugar. Gullying or rilling is extensive.
- Shear strengths are lower than normal in CL, CH, and ML soils. Clay fraction goes into suspension within the pore fluid and reduces electrochemical attraction between particles.
- Generally have high shrink-swell potential and are thus subject to severe cracking when dried.
- Often occur in layers or lenses in a soil profile rather than as extensive masses of a mappable soil series.

Further information on dispersion is in Soil Mechanics Note 13, Dispersive Clays.

(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 planning consideration. 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 utilization of wastes. 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 discussion of permeability is given in 651.1080 Appendix 10D, Geotechnical, Design, and Construction Guideliens

(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 in contact with a tank may cause denting or puncturing. Angular particles greater than 0.5 inch can be a puncture hazard to 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. Examples include poured-in-place reinforced concrete tanks and steel tanks. These structures are particularly vulnerable to settlement. Differential settlement occurs when the settlement is not even over the entire foundation. The potential for differential settlement can be an important design consideration in certain earthfill and concrete waste impoundment structures. Segmentally designed structures are built of structurally independent units, such as, precast reinforced concrete retaining wall units. Although the potential of differential settlement may be less significant, some segmentally designed structures may be susceptible to settlement. The designer should be familiar with Engineering Field Handbook, Chapter 4, Elementary Soil Mechanics.

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—Layers or zones greater than 1 foot thick consisting of soft clays and silts, peat and organic-rich soil (OL and OH in the Unified System), and loose sands may settle excessively when loaded by an embankment or concrete structure.
- Weak foundations—Structures located in areas of active or abandoned underground mining or areas that have a high rate of ground water withdrawal can have problems resulting from settlement of the material.
- Steep abutments—Differential settlement of embankments may occur on abutment slopes steeper than 1 horizontal to 1 vertical. Adequate compaction is difficult to achieve on steep slopes. Settlement cracks may occur in the fill in the area where the base of a steep abutment joins the flood plain.
- Uneven rock surface—A foundation may settle if underlain by normally consolidated soil materials over a highly irregular, shallow bedrock surface or other uneven, unyielding material. As a rule, consider a foundation problematic if, in the foundation area, the difference between maximum and minimum thicknesses of the overlying compressible soil above an uneven rock surface divided by the maximum observed soil thickness is greater than 25 percent. This is expressed as "Problem foundation" when
  [100 (max. depth – min. depth/max.depth)]>25%
- Collapsible soil—This soil is common especially in the western continental States. It has low density and low water content and formed in windblown silts and fine sands and rapidly deposited alluvial fans. This soil may undergo large, sudden settlement when it becomes saturated after loading by a structure built on it.

(k) Shrink/swell

Soil containing montmorillonite clay may undergo substantial changes in volume when saturated or dried. Some types of 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 published soil surveys or the NRCS National Soil Characterization data base. Field investigations and previous experience in the area may often be the only ways to foresee this problem.

(l) Topography

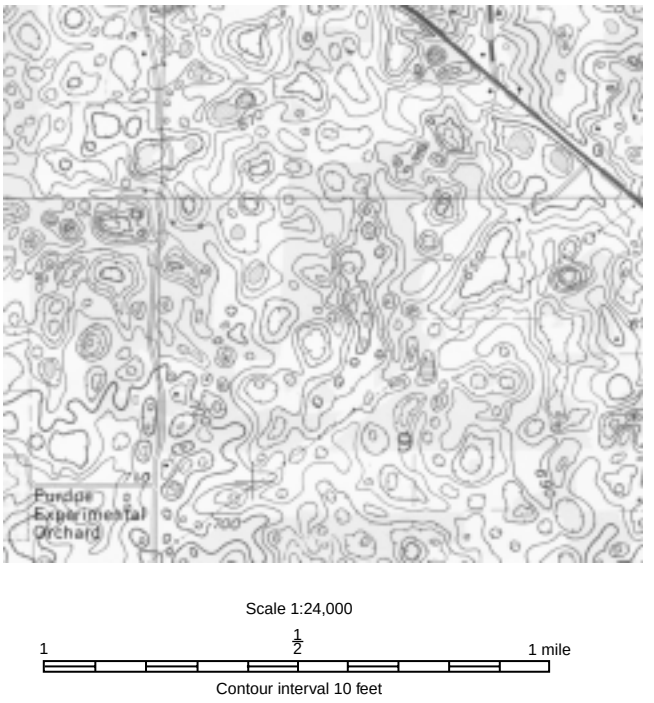
Recognition of land forms and their associated problems is a valuable asset when planning a component for an AWMS. For example, flood plain sites generally have a higher water table compared to that of adjacent uplands, are subject to surface flooding, and can indicate presence of permeable soils.

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

Steep slopes restrict use for some structural and vegetative measures. Hazards include instability (landslide potential) 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 ground water contamination, and collapsible ground. As such, its recognition is important in determining potential siting problems. Figure 7-10 is a topographic map that illustrates karst topography near Mitchell, Indiana. Note the lack of surface streams and numerous sinkholes and depressions.

Figure 7–10 Karst topography



(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 located within an economical hauling distance. Conditions of the borrow area itself may limit the usefulness of borrow materials. Limitations may include such things as moisture, thickness, location, access, land use, vegetation, or cultural resources.

(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 or AWMS component site relocation. If an abandoned well exists 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 651.0704 for guidance in planning investigations.

651.0703 Factors affecting ground water 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 root zone of surface soils. These processes, collectively called attenuation, retard the movement of contaminants into deeper subsurface zones. See section 651.0303 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 making up the material. Thus, attenuation potential increases as clay content increases, the soil deepens, and distance increases between the contaminant source and the well or spring.

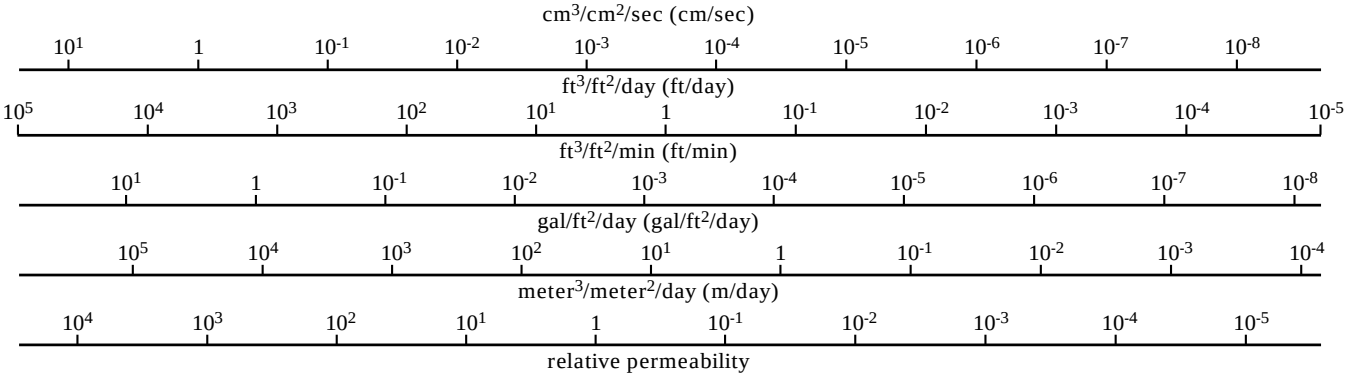
(1) Clay content

Increased clay content increases the opportunity for attenuation of contaminants because of its cation exchange capacity and its affect of reducing permeability. Clay particles hold a negative charge that gives them the capacity to interchange cations in solution. As such, clay can absorb contaminant ions and thus attenuate the movement of contaminants. Clay has a very low permeability (see fig. 7-11). Therefore, the greater the amount of clay, the slower contaminants move and the greater the contact time that allows more opportunity for attenuation.

(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

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



	Very high	High	Moderate	Low	Very low
			Representative materials		
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		

for attenuation. Very shallow (thin to absent) soil provides little to no protection against ground water contamination.

(3) Distance between contaminant source and ground water supply

Both the depth and the horizontal distance to a ground water supply affect the attenuation of contaminants. Depth refers to the vertical distance through which a contaminant must pass to reach the top of an aquifer. Assuming all other factors remain constant, the greater this depth, the greater the time of travel, and the greater the travel time, the more opportunity for a contaminant to be in contact with the surrounding material for attenuation processes. Horizontal distance also affects attenuation of contaminants. The greater the horizontal distance between the source of the contamination and a well, spring, or other ground water supply, the greater the time of travel will be. The greater the travel time, the greater opportunity for attenuation of contaminants.

(b) Ground water flow direction

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

The direction of flow in a water table aquifer generally can be ascertained from the topography. In most cases the slope of the land indicates the ground water flow direction. In most humid regions the shape of the water table is a subdued reflection of surface topography. Unconfined ground water moves primarily from topographically higher recharge areas down gradient to withdrawal areas at lower elevations. Lower areas serve as discharge points where ground water rises and merges with perennial streams and ponds, or flows as springs. However, 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 rock in upland areas where the direction of ground water 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 ground water flow is parallel to the ground slope can be significantly misleading in terrain where flow is controlled by bedrock fractures.

Appendix 7A gives a method of calculating ground water 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. See "Hydraulic conductivity".

The time available for attenuation in aquifer materials decreases as the permeability of the materials increases. Permeability may vary significantly among 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

Hydraulic conductivity is a mass property of an aquifer that is determined through field testing, such as pump tests or slug tests. It is commonly known as permeability and is the rate of flow (L/t) of water through an aquifer. Hydraulic conductivity reflects all of the aquifer's characteristics to transmit water. Note that in most aquifers the difference between vertical and horizontal conductivity rates is significant.

(e) Hydraulic head

Hydraulic head is the energy of a water mass produced mainly by difference in elevation, velocity, and pressure, expressed in units of length or pressure. Ground water moves in the direction of decreasing hydraulic head. Hydraulic head in an aquifer is measured using piezometers. See EFH Chapter 12, Springs and Wells, and Chapter 14, Drainage, for more information.

(f) Hydraulic gradient

Hydraulic gradient is the change in hydraulic head per unit distance of flow in a given direction and is expressed in units of length (elevation) per length (distance). Ground water velocity is a function of the hydraulic gradient. Most water in an unconfined aquifer moves slowly in undeveloped aquifers. However, an action such as pumping water from a well can steepen local hydraulic gradients. This results in acceleration of flow in toward the well, carrying any dissolved contaminants with it into the well. Appendix 7A gives a method calculating the hydraulic gradient in a water table aquifer.

(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 ground water use designations and impairments
- Geologic maps showing rock types, faults, and similar information
- Regional water table maps and, if available, tables of static water levels in wells
- Ground water vulnerability maps

(h) Land topography

Topographic features that pond contaminanted runoff water increase the potential for ground water contamination by infiltration. Example features include seasonal wetlands and level terraces. The hazard of surface water contamination from sediment 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 ground water areas:

- Sole source or other types of aquifers whose uses have been designated by the State
- Important recharge areas
- Well-head protection areas

(j) Type of aquifer

Refer to section 651.0701 for details on perched, confined, and unconfined 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 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:

- The 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 waste impoundment. The tank involves consideration of differential settlement of the foundation, while the earthen waste impoundment 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.

Make an initial evaluation of potential layout(s) of the component, access to the site, and location of active or abandoned wells, springs, and other such features. Farm*A*Syst worksheets and the Farm Bureau self-help water quality checklists are valuable tools in making initial site evaluations. These tools are not, however, suitable for making final design decisions.

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 need to be examined. Refer to the Field Office Technical Guide (FOTG) for the National Conservation Practice Standard, 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—These reports provide soil map units, photos of features near a site, information on seasonal flooding and the water table, and engineering interpretation 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, distances to identified resource features, such as wells, watercourses, houses, roads, and other cultural features.
- Aerial photos—These photos provide information on vegetation, surface runoff patterns, erosion conditions, proximity to cultural features, and other details.
- Local geologic maps and reports—These sources 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 ground water 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. The intensity of a detailed investigation is the joint responsibility of the designer and the person who has engineering job approval authority. 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 condi-

tions of materials encountered, 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, and power augers are used to allow direct observations for logging geologic materials, collection of samples, and access for field permeability testing. When logging soils with an auger, always consider that the augering process can obscure thin zones or mix soil layers. Test pits expose more of the foundation for detecting thin, but significant lenses of permeable soil.

Geophysical methods are indirect techniques that employ geophysical equipment, such as electromagnetic induction meters, resistivity meters, refraction seismographs, and ground penetrating radar units, to evaluate the suitability of sites and the performance of the component. These techniques require trained, experienced specialists to operate the equipment and interpret results. Geophysical methods require corrolation with test pits or borings for best results.

(2) Logging geologic materials

During an 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 TR-71, Rock Material Field Classification Procedure; TR-78, The Characterization of Rock for Hydraulic Erodibility; and NEH part 628, Dams, Chapter 52, Field Procedure Guide for the Headcut Erodibility Index. Soils are classified for engineering purposes according to the Unified Soil Classification System, ASTM D 2488, Standard Practice for the Description and Identification of Soils, Visual-Manual Procedure. This system is described in EFH Chapter 4, Elementary Soil Engineering; and NEH Section 8, Engineering Geology. Appendix 7B provides tables of criteria for identifying soils by the Unified System. 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 at the end of this chapter (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 (back hoe) including make and model. For each soil type encountered in a test pit or drill hole, record the following information, as appropriate. See EFH Chapter 4, Elementary Soil Engineering, for more details.

- Interval (depth range through which soil is consistent in observed parameters)
- Estimate particle size distribution (by weight, for fraction < 3 inches)
- Percent cobbles and boulders (by volume, for fraction > 3 inches)
- Angularity of coarse material
- Color of moist material, including presence of mottling. Mottling may be an indicator of the zone of water table fluctuation
- Relative moisture content
- Structure
- Consistency (saturated fine-grained materials) or relative density (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)
- Test hole or pit identification number
- Station and elevation of test hole or pit
- Depth (or elevation) of water table after stabilizing; give date measured and number of hours open
- Depth to rock, refusal (limiting layer), or total depth drilled or dug

(3) Samples

Samples of soil and rock materials collected for soil mechanics laboratory testing must meet minimum size requirements given in Geology Note 5. Sample size varies according to test 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 investigation

For foundations of earthfill structures, use at least four test borings or pits on the proposed enbankment 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. 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 (b)(2) of 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 for clay liners should be located, described, and mapped. Locate suitable borrow to at least 150 percent of the required fill volume. Soil samples for natural water content determinations should be obtained from proposed borrow and clay liner sources. Samples taken for testing should be maintained in moisture proof containers. The parameters listed in (b)(2) of this section should be logged.

If a system requires a soil liner, consult soil survey reports and local surficial geologic maps to help identify potential borrow areas for investigation. Nearby clay-rich deposits for potential borrow sources should be located, mapped, and logged. Some designs may require bentonite or a chemically treated soil to reduce permeability (see AWMFH Ch. 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 such small components 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 investigation pits or plugging test holes.

651.0705 References

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Appendix 7A Determining ground water 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 may be drawn. 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 ground water flow directions. Ground water 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 ground water flow direction and hydraulic gradient of the water table is 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. The 8-step procedure for this planning method follows, 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, whether developed or undeveloped, and 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 having the highest and lowest water level elevations, and record on the map.

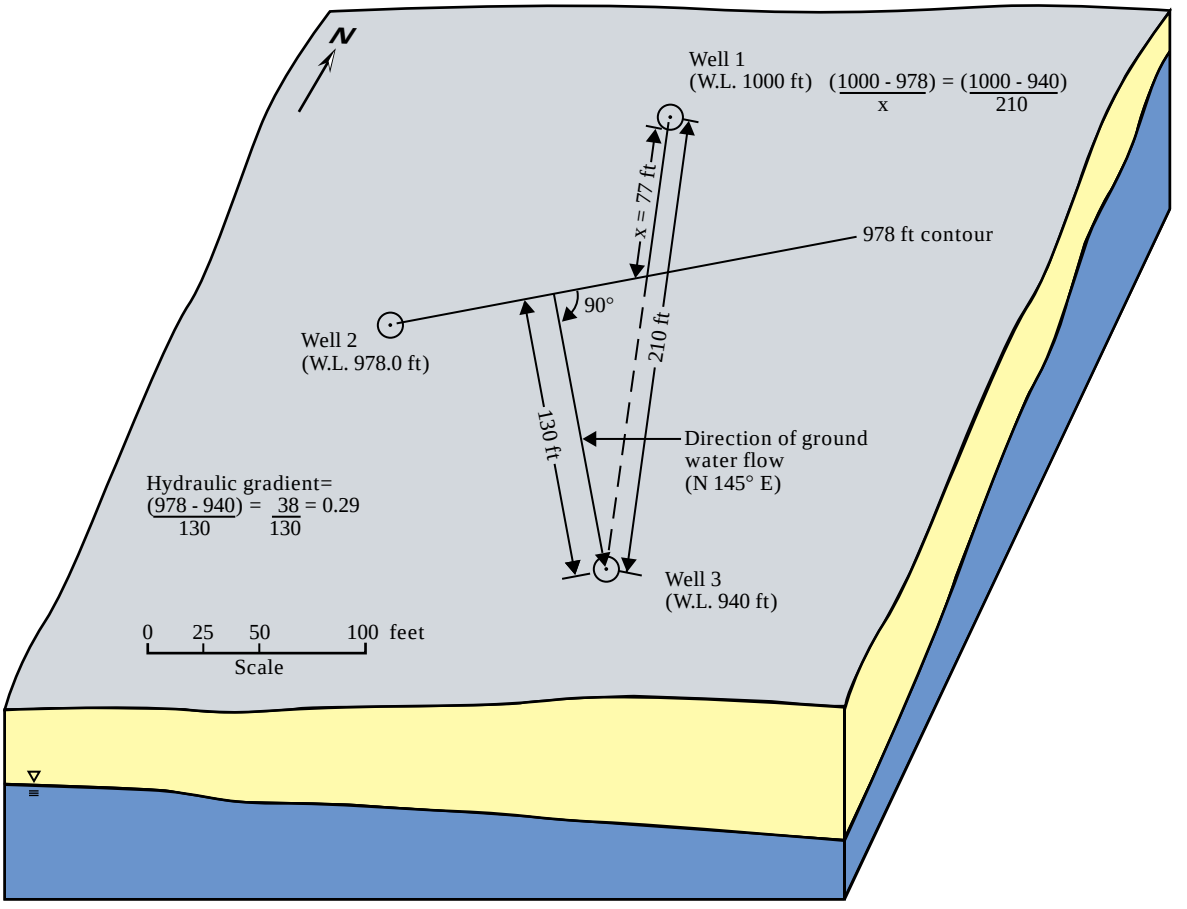
Step 5—Using the map, identify the well with the intermediate water table elevation (that is, neither the highest nor the lowest). Interpolate the position between the well with the highest head and the well with the lowest head where the head is equal to that in the intermediate well. Mark this point 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 (90°) from this contour to the lowest head well, and measure the distance. This line is parallel to the ground water 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 ground water 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 ground water 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			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_____

Table 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 2 Criteria for describing particle shape (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 & elongated	Particles meet criteria for both flat and elongated

Table 3 Criteria for describing moisture condition

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

Table 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 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 6 Criteria for describing structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 1/4 in (6 mm) thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 1/4 in (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

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Table7 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 inch	< 0.1	< 2
Soft	Thumb will penetrate soil about 1 inch	0.10 – 0.25	2 – 4
Firm	Thumb will indent soil about 1/4 inch	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 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 powder with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and hard surface
Very high	The dry specimen cannot be broken between thumb and hard surface

Table 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 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 near the plastic limit.
High	The thread and the lump have medium stiffness. Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

Table 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; thread cannot be rerolled after reaching the plastic limit; lump crumbles when drier than the plastic limit
High	Considerable time rolling and kneading to reach the plastic limit; thread can be rerolled several times after reaching the plastic limit; 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 Field Identification of Coarse-grained Soils below.)

Note: Refer to tables 1 through 11 for criteria for describing many of these factors.

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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.

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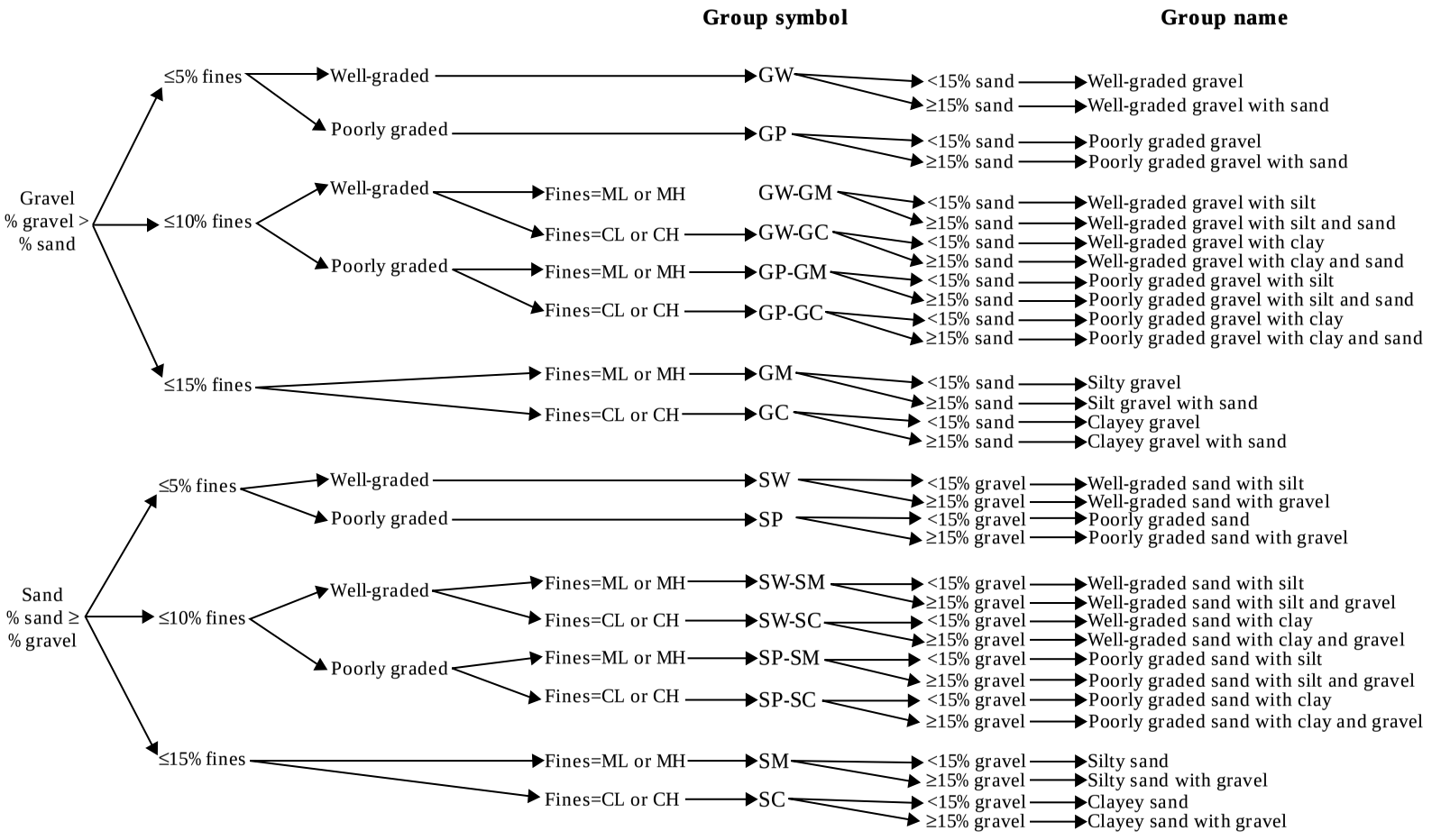
Identifying Coarse Grained Soils (less than 50% fines)



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

Source: ASTM D 2488 (fig. 2). Copyright ASTM. Reprinted with permission.

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 Field Identification of Fine-grained Soils below.)

Note: Refer to tables 1 through 11 for criteria for describing many of these factors.

Field Identification—Fine Grained Soils [1/]

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

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

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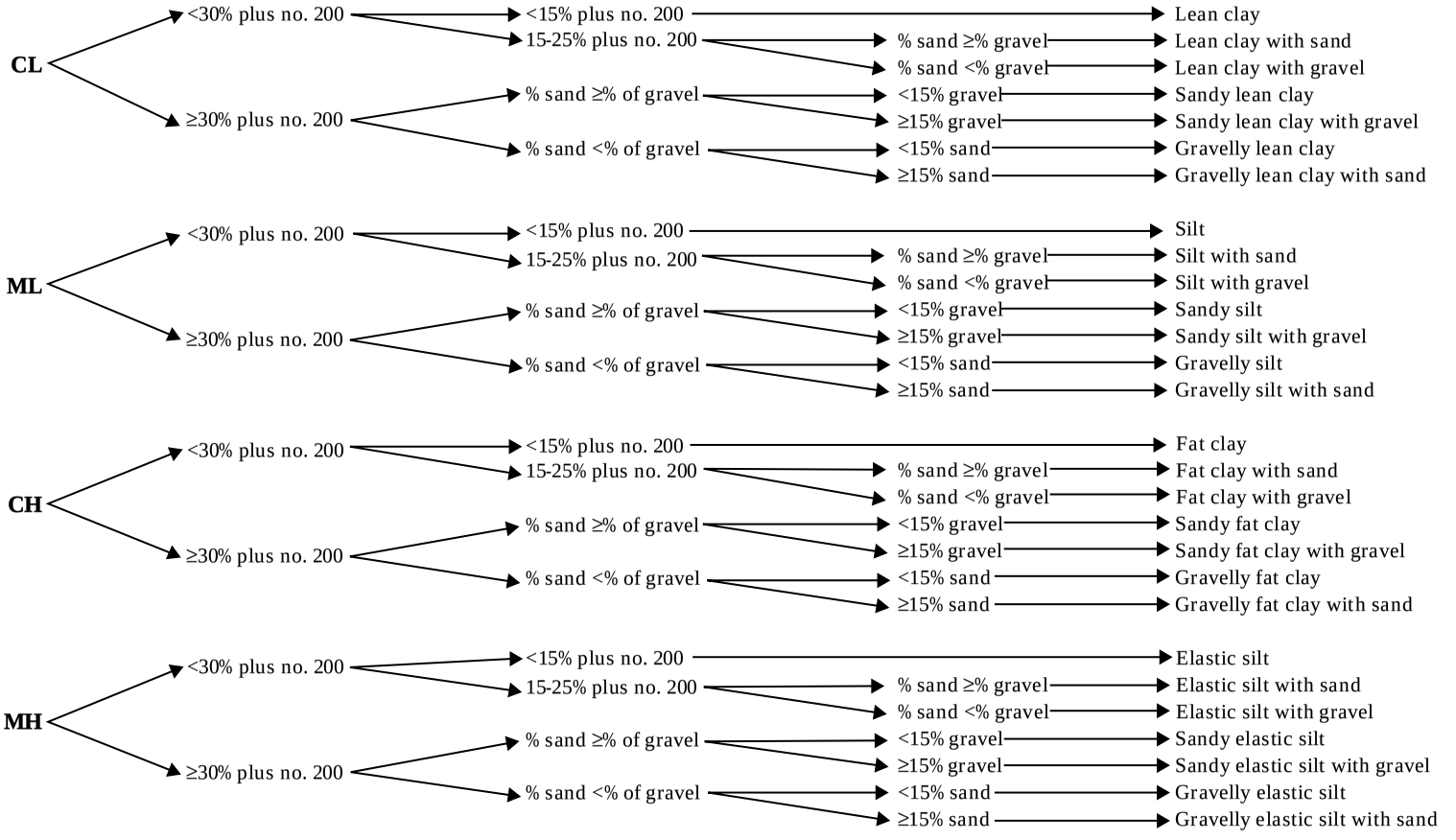
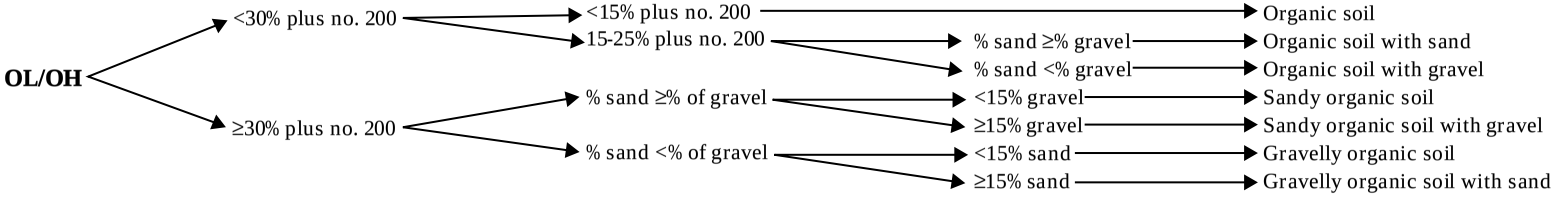
Identifying Fine Grained Soils



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



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

Source: ASTM D2488 (fig. 1a). Copyright ASTM. Reprinted with permission.

United States
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**Soil
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Agricultural
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Field Handbook

Chapter 8 Siting Agricultural Waste Management Systems

(210-AWMFH, 4/92)

Chapter 8 Siting Agricultural Waste Management Systems

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Chapter 8 Siting Agricultural Waste Management Systems

651.0800 Introduction

Planning and design options for arranging and integrating components of Agricultural Waste Management Systems (AWMS) into an existing or proposed farmstead are provided in this chapter. Application of waste products to the land will be addressed only in how adjoining land use and site conditions affect it. Although planning and design considerations vary depending on the type of waste and regional practices, the conservation planning process provides an essential framework for integrating the options presented in this chapter.

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

651.0801 Process and principles

(a) Landscape elements

Manipulation of landscape elements, such as structures, landform, water, and vegetation, 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 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.

(1) 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 wind, controlling circulation of animals and equipment, and separating use areas.

(2) Landform

Landform can be used as it occurs on the site or is modified to improve farm operations, direct or screen views, buffer incompatible uses, reduce massiveness of aboveground structures, control access, improve drainage, and influence microclimate. Existing landforms give each landscape its distinctive character. Landforms often provide a backdrop for an AWMS

(fig. 8–1) and serve as a model for designing new landforms, such as embankments, berms, and spoil disposal mounds.

Integrating aboveground AWMS components into flat landscapes (fig. 8–2) 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. 8–3). Operation and maintenance requirements of the structure need to be considered. Embankments may also be shaped to match the surrounding landform.

(3) Water

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.

(4) Vegetation

Vegetation can also be used to organize space and circulation; establish desirable views; buffer noise, wind, or incompatible uses; reduce massiveness of aboveground structures; absorb particulates to reduce odor; cool air temperature; and reduce soil erosion and runoff. As with other elements, vegetation can be used to divert attention to other features.

Figure 8–1 If structures are sited below the horizon line, the landforms provide a backdrop for the structure and serve as a model for new earth mounds

Figure 8–2 Structures projecting above the horizon are prominent features on this flat landscape

Figure 8–3 The shoreline and reflective surface of this waste storage pond makes it appear to be a traditional farm pond

Because native plants are often more hardy than introduced species of vegetation, they are recommended if compatible with the landscape setting. 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.

(b) Siting the system

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.

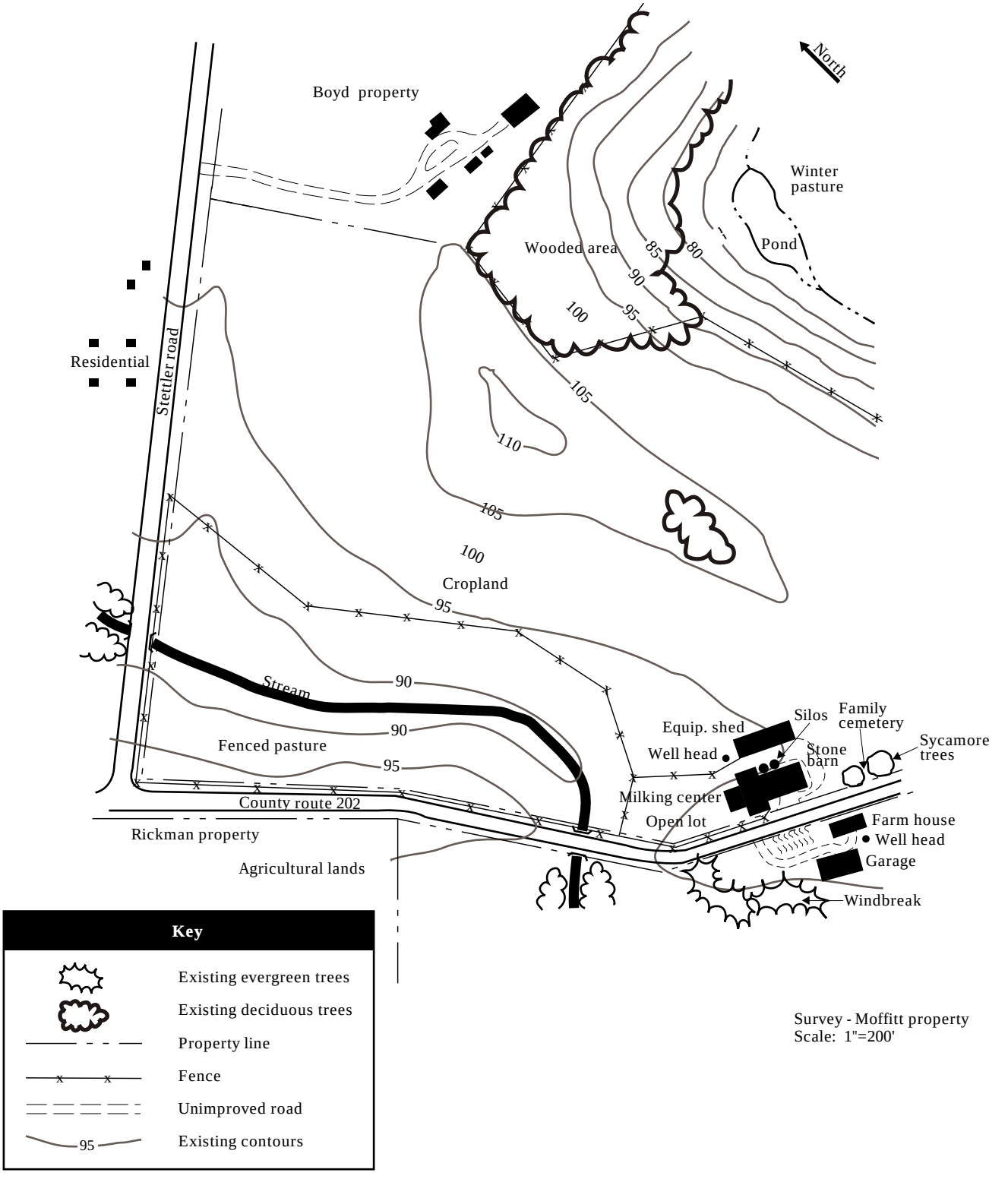
(1) Base map

During the planning process, a topographic survey or aerial photograph is prepared (fig. 8–4). (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
- Location of wet areas, streams, and bodies of water
- Rock outcrops and other geological features
- Edges of wooded areas
- 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
- Geologic and soils data
- Climatic information
- Septic systems
- Wells

Figure 8–4 Base map



(2) Site analysis

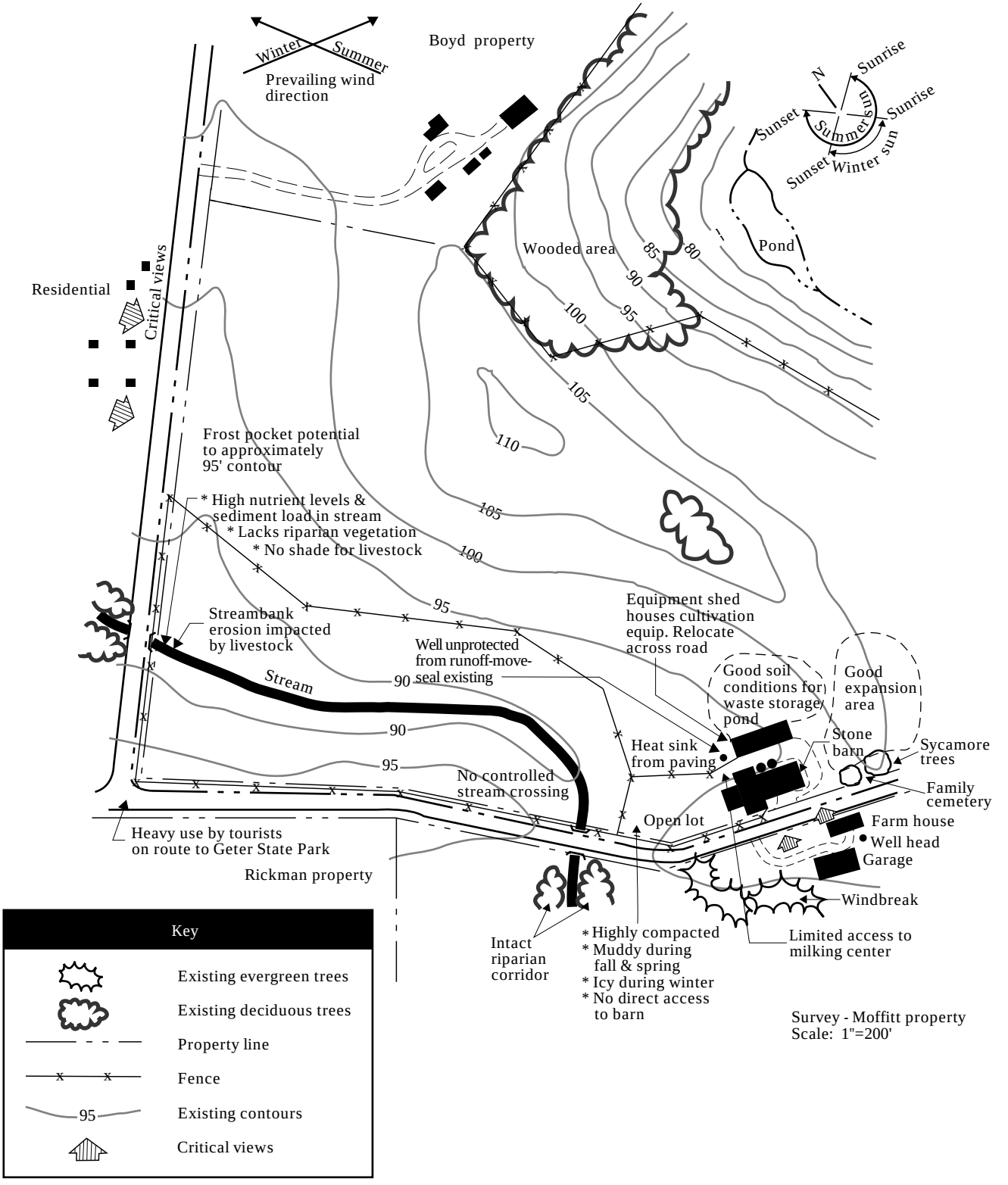
One method of understanding site conditions and implementing step 4 in the planning process (analyze the resource data) is to prepare a site analysis diagram. This step of the process is the identification of problems and opportunities associated with installation of the AWMS. A topographic map, aerial 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
- Vegetation to be preserved and what can be 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 alternatives for AWMS components

Figure 8–5 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.

Figure 8–5 Site analysis diagram

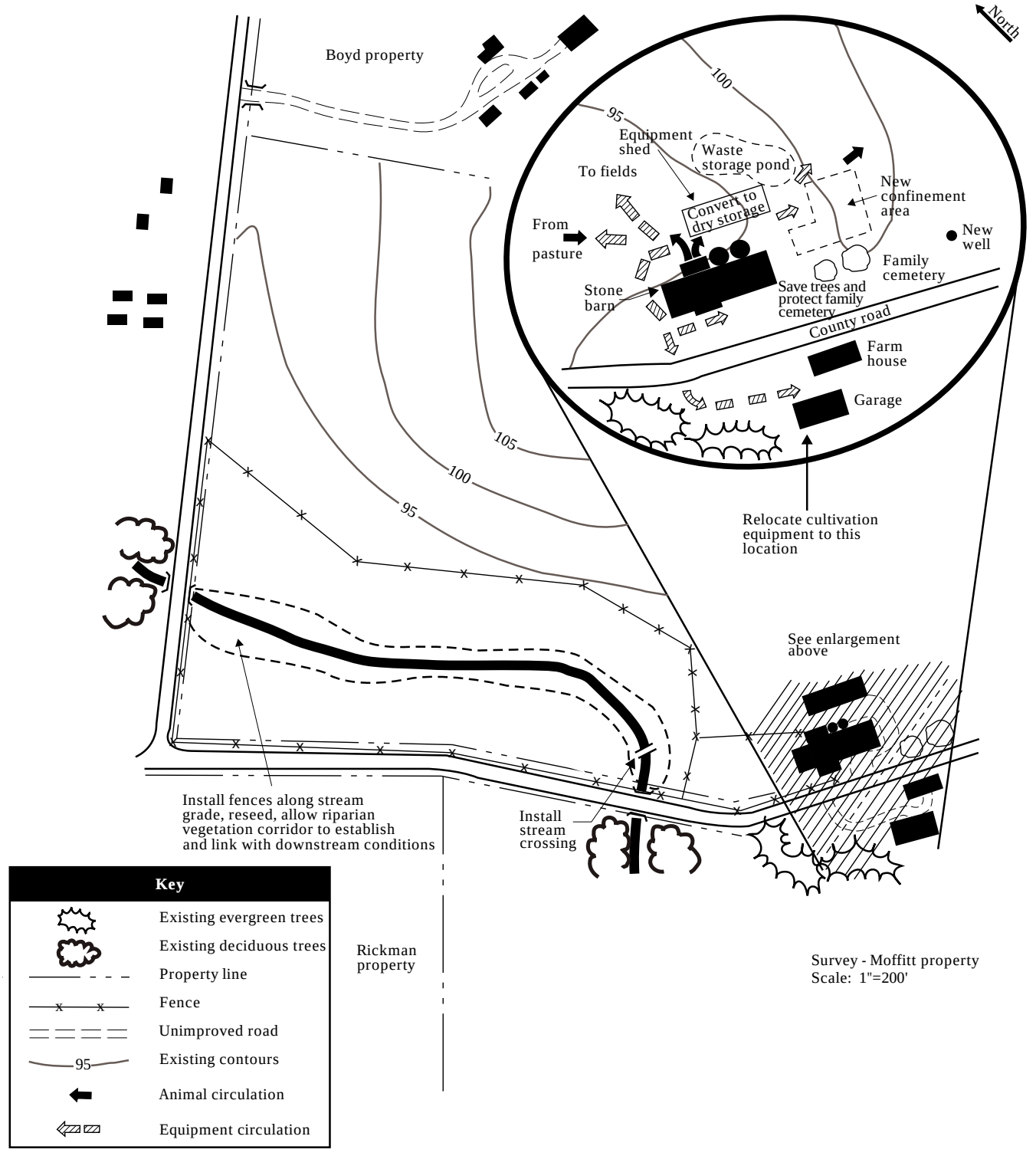


(3) Concept plan

As a part of steps 5 and 6 (formulate and evaluate alternative solutions), a concept plan or plans are developed to begin to evaluate alternative solutions (fig. 8–6). The area required for collection, storage, treatment, transfer, and utilization of waste is determined and first displayed at this step of the process. This and such related information as associated use areas, access ways, water management measures, vegetated buffer areas, and ancillary structures should be drawn freehand 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 will be necessary to make significant adjustments in operations requiring a large economic commitment and attention to management.

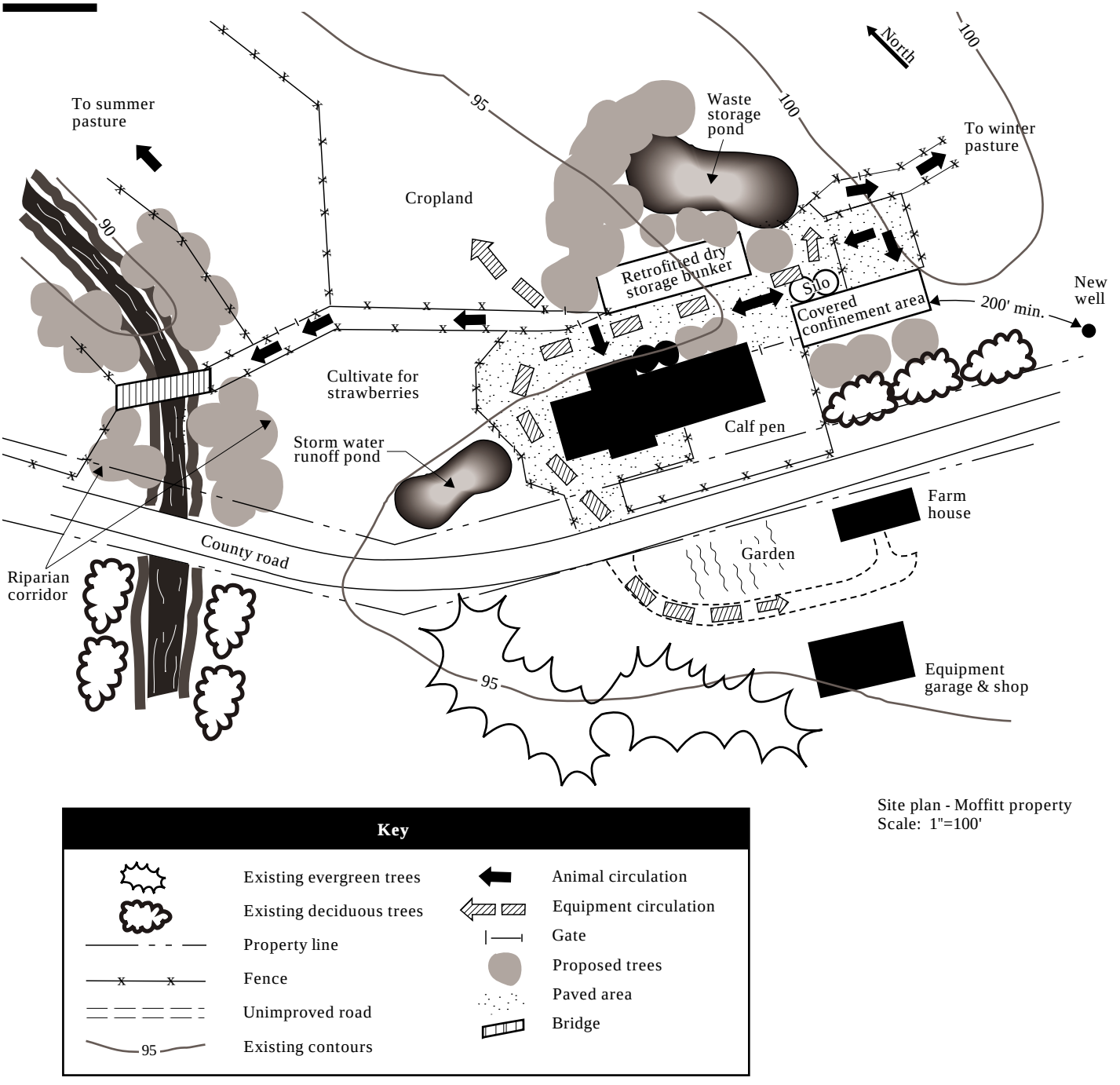
Figure 8–6 Concept plan



(4) Site plan

Completion of subsequent steps of the planning process results in the final site plan as preface to construction drawings and specifications (fig. 8–7). Final location and configuration 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 8–7 Site plan



651.0802 Design options

The AWMS should be designed to blend into the site and it's surroundings with no adverse environmental effects. The following design options will aid the planner in achieving this objective.

(a) 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. 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. 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. 8–8).

Developing a new AWMS or adding to an existing system often presents an opportunity to improve runoff management. The addition of diversions, roof gutters to separate precipitation from waste sources, paved feedlots or loafing areas, drainage swales, and filter strips helps to minimize muddy areas and contaminated runoff. 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. As addressed in chapter 6 of this handbook, vegetation can serve many functions including nutrient and sediment filtration, erosion control, moisture reduction, and temperature control.

(b) Odor reduction

The odor associated with the six functions of agricultural waste management often generates the most immediate response from the decisionmaker and adjacent residents. By anticipating the intensity, duration, and frequency of odors, AWMS components can be planned to reduce odors and for associated complaints. This includes areas of field application. Odor problems can be prevented or reduced through adequate drainage, runoff management, proper care to keep animals clean and dry, and appropriate waste removal, handling, and transport.

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. In figure 8–9 the black pines planted downwind trap odor-laden dust particles and provide a visual barrier between the swine operation and nearby residence.

In addition to trapping dust particles, vegetation, landform, and structures can channel wind to carry odors away from sources of potential conflict (fig. 8–10).

Figure 8–8 Streamside measures improve water quality

Before

After

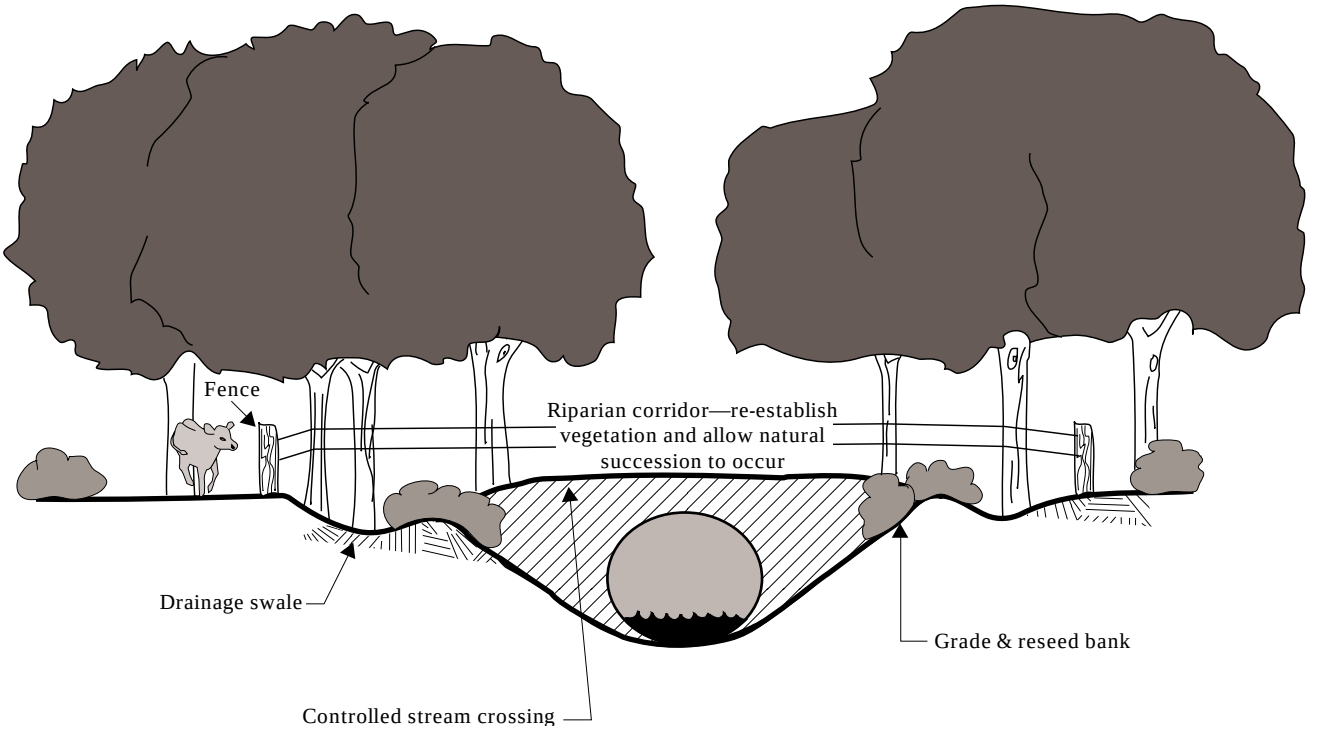
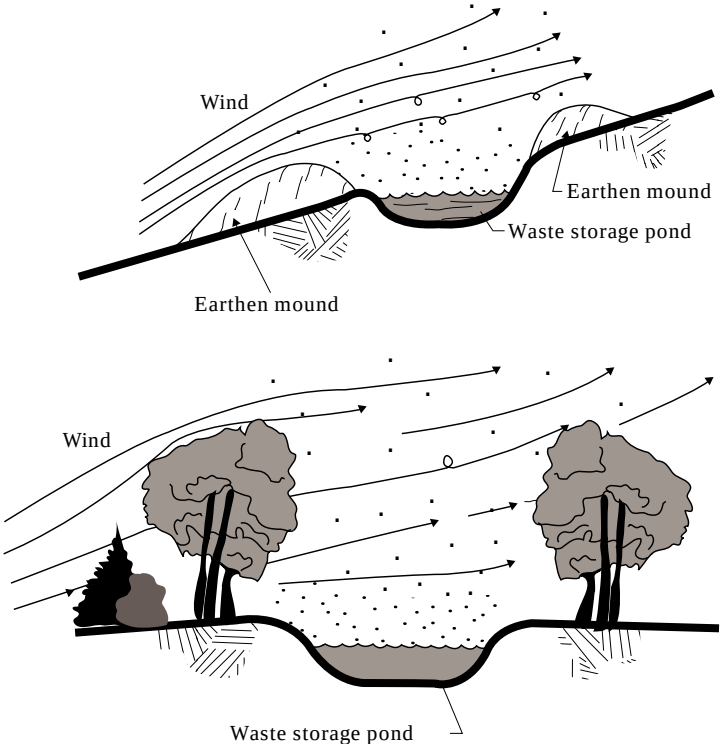


Figure 8–9 A vegetative screen between house (behind vegetative screen) and swine operation traps dust particles

Figure 8–10 Topography and vegetation can uplift winds to disperse odor



(c) Temperature and moisture control

Vegetation can alter microclimate and create lower temperatures. By shading the areas below them 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. 8–11).

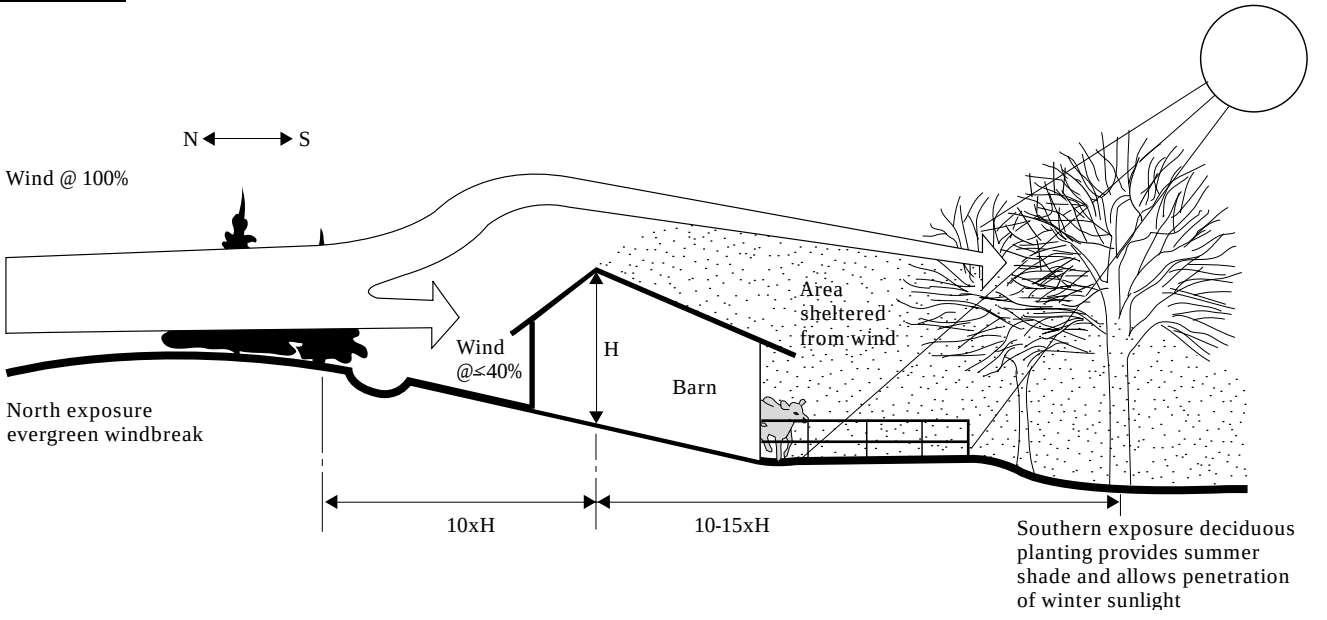
Dairy animals and other livestock seek streams or ponds and the shade of trees for their cooling effect. Where access to these features is removed, the animal should be provided other means of cooling.

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 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. 8–12). 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:

- 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 to enhance radiation adsorption

Figure 8–11 Vegetation modifies temperature in various ways



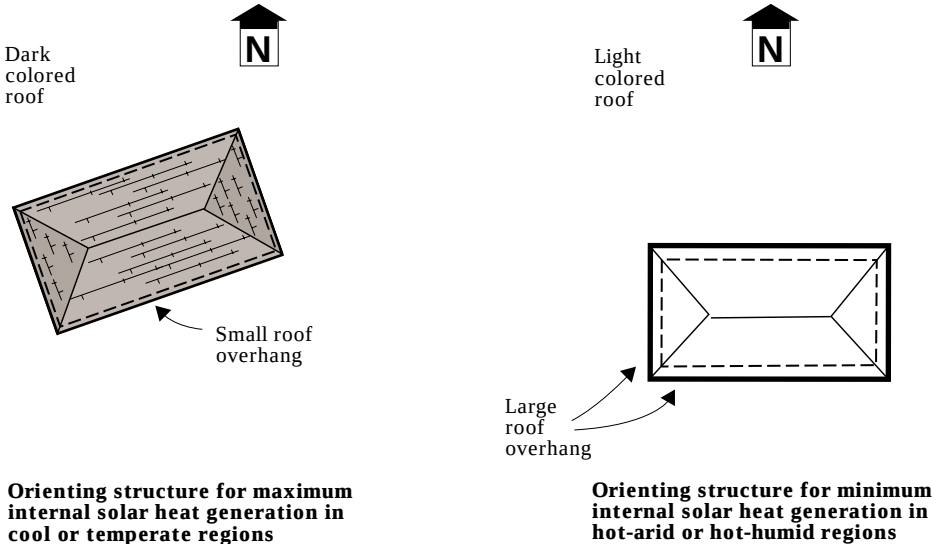
Where minimal internal heat is desired, such as in the hot, arid Southwest or the hot, humid Southeast, different building orientation and architecture are recommended. In these regions, it is best to minimize the amount of sunlight on the sides of the building. Because the arc of the sun is higher in 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.

Figure 8–12 Orientation can influence the amount of internal sun-generated heat within buildings



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, for example, 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.

(d) Aesthetic quality

Aesthetic quality is acknowledged as an integral part of daily life and underlies economic and other decisions about the land (fig. 8–13). 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 aesthetic 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 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 8–13 Aesthetic quality is often important to the farm family

(1) Landscape character

Patterns of land use and management, siting and design of structures, or 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.

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.

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 therefore 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.

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.

Architectural style is a reflection 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 aboveground 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 (fig. 8–14). 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 and 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.

Figure 8–14 Retrofitting to serve current needs can be a viable alternative

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.

(2) Visibility

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.

Blending proposed as well as existing 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 8–15 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 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 screen the component from view and transition it into the site. They 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.

Figure 8–15 A nearby road and contrasting concrete liner make this waste storage pond highly visible

In selecting new vegetation for screening, avoid plants that may later cause problems. 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 that require more than normal maintenance should be avoided.

Reducing the visibility of an obtrusive facility is not accomplished 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. New plantings should be provided the water and nutrients needed to become established.

Structures can screen views of agricultural waste facilities. In figure 8–16, existing barns and other farmstead structures effectively screen a storage pond as viewed from the farm residence and highway. Roads and other landscape elements can also direct a viewer's attention away from AWMS components.

(3) Compatibility

An important design consideration is restoring the site to a vegetated condition after construction is completed. In figure 8–17 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.

Figure 8–16 Farmstead buildings effectively block views to a waste storage pond

New plantings used to minimize scale or the 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 8–18 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.

Whenever possible, existing vegetation should be used in siting components of the system. The waste storage pond in figure 8–19 was designed to take advantage of an existing screen of shrubs and trees. Fill or compaction by heavy equipment during construction or operation and maintenance can seriously reduce the amount of air available to the roots. Therefore, these activities should be avoided where the vegetation is to be saved.

The AWMS component in figure 8–20 is located close to the farmhouse, but is integrated into the farmstead through the addition of vegetation.

Slope rounding and slope reduction (fig. 8–21) are two of many earth grading and shaping techniques that can reduce erosion and help to blend landforms into the landscape.

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 8–22 is sited to be an inconspicuous part of the overall farmstead. Its color is also compatible with those of the surrounding landscape.

Figure 8–17 Vegetation can quickly restore a construction site

Figure 8–18 Common vegetative patterns

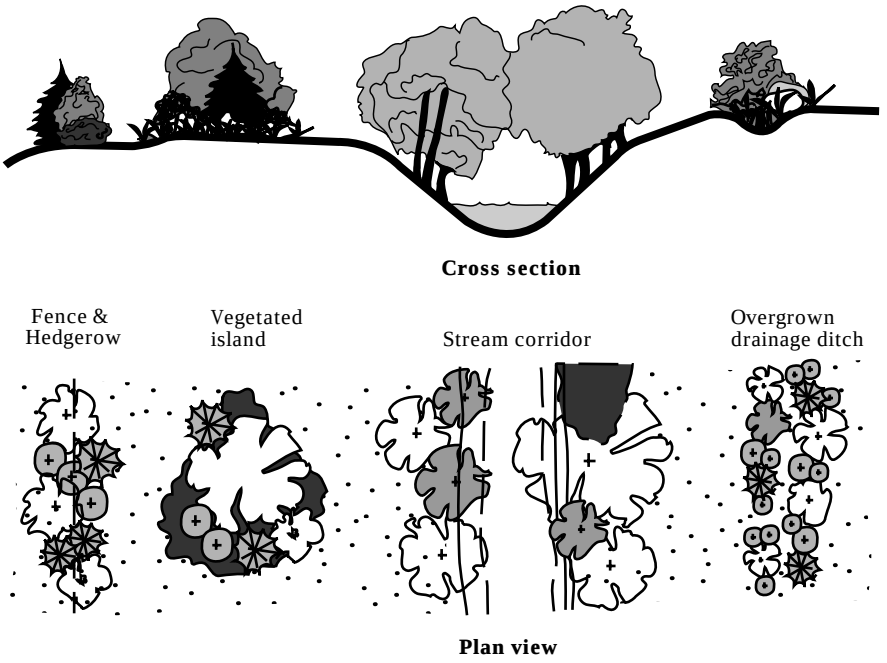


Figure 8–19 Vegetation near this recently constructed waste storage pond provides a screen

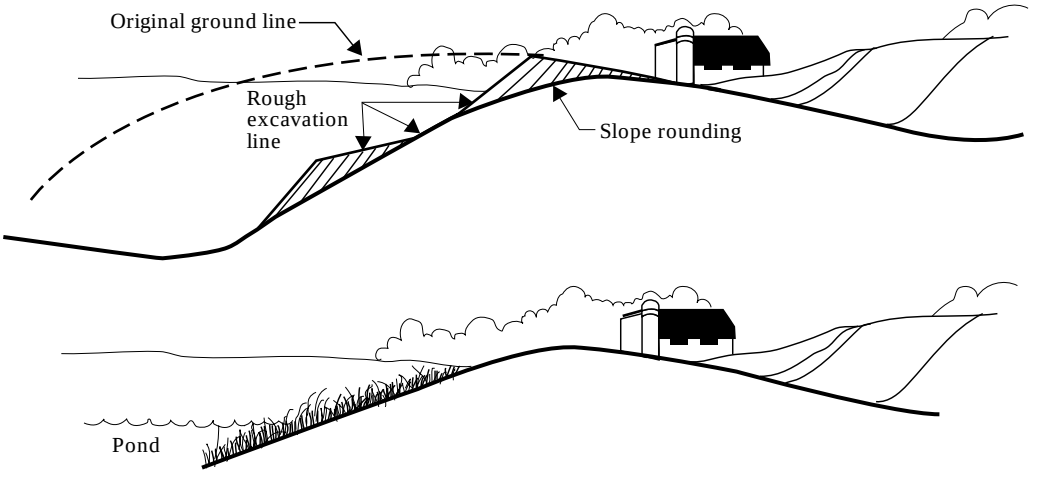
Figure 8–20 Newly planted trees and shrubs can blend farmhouse and nearby waste storage tank (as shown in simulation)

Before

After

Figure 8–21 Slope rounding and reduction help to blend landforms onto the landscape

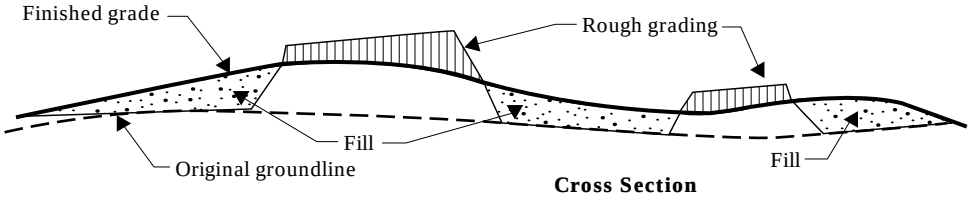
Slope rounding



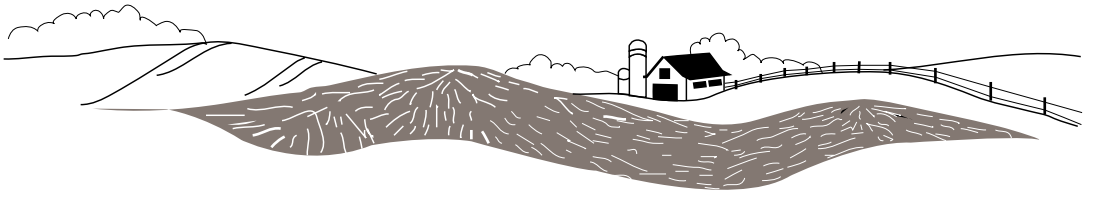
Before

After

Slope reduction



Cross Section



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 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.

(e) 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 windspeed. 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

Figure 8–22 An aboveground storage tank is inconspicuous on this highly scenic landscape

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 8–23 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 reduction, 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 8–24 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 can also be located to deposit snow or windblown soil away from building openings (fig. 8–25).

Figure 8–23 Fence porosity affects snow deposition

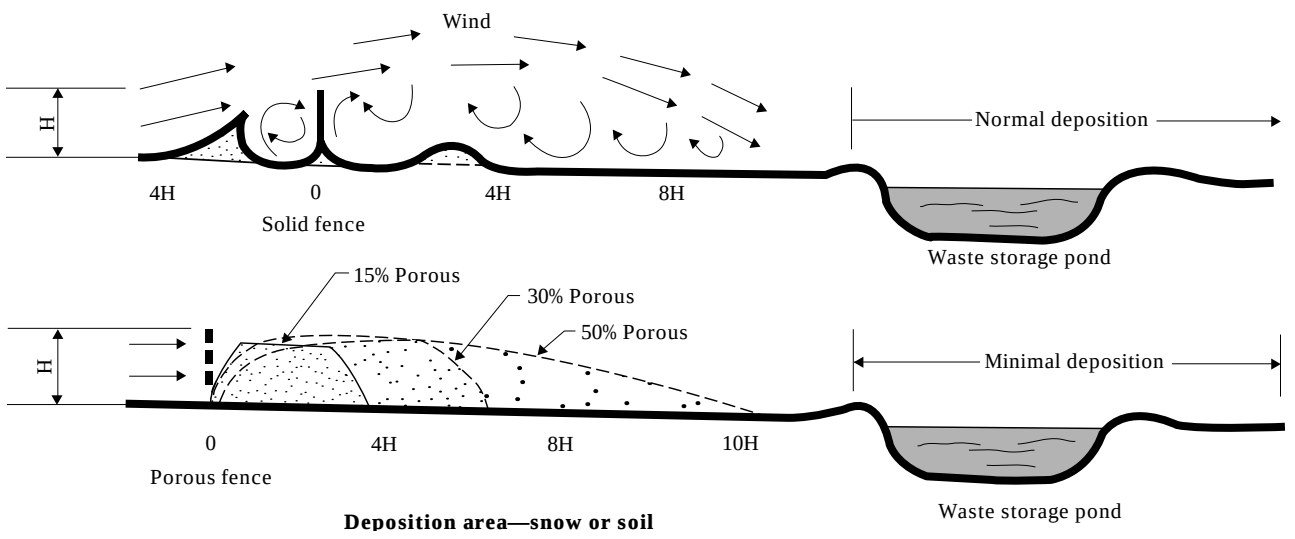


Figure 8–24 The combination of fence and windbreak plantings greatly enhances the pattern of snow and soil deposition

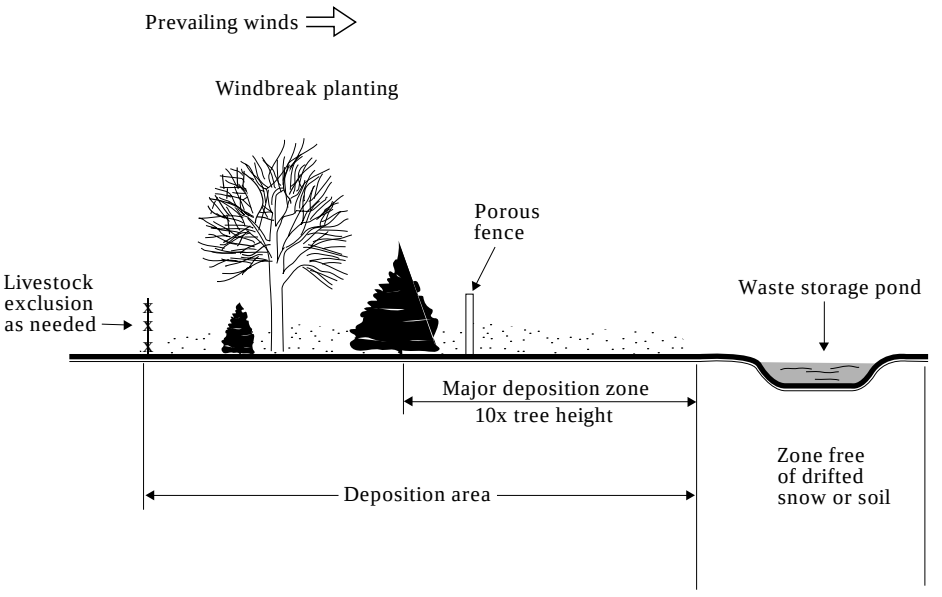
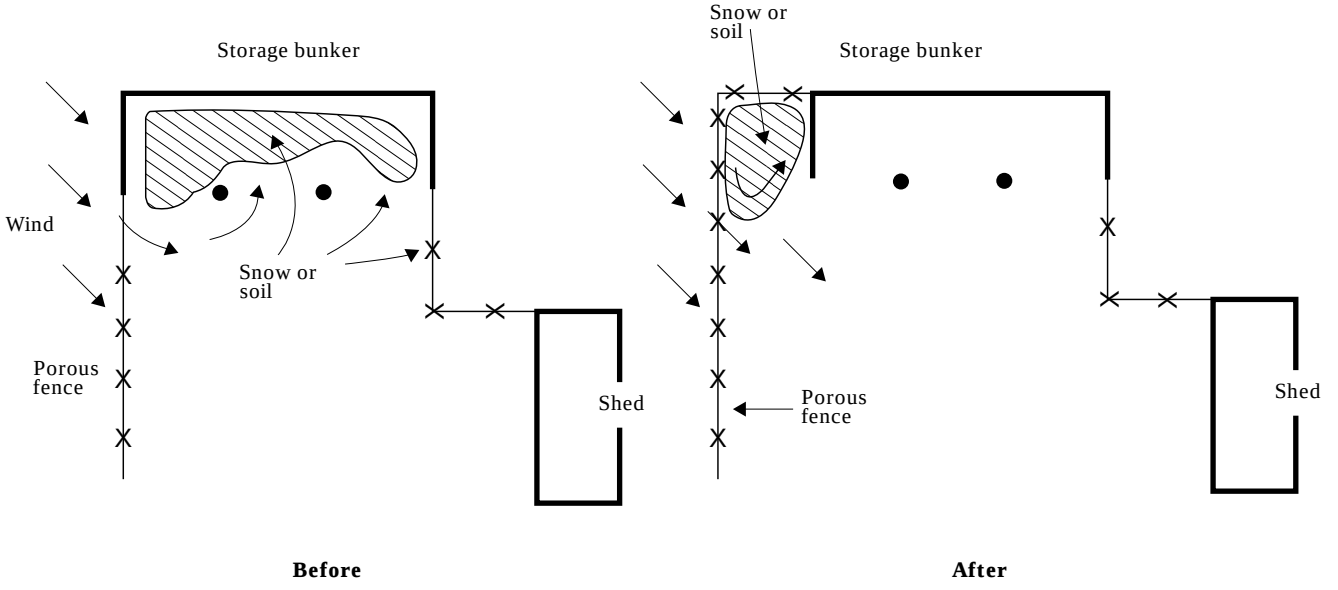


Figure 8–25 Fences affect snow and soil deposition around buildings



(f) 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 should 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.

An existing manure storage pond (fig. 8–26) has taken cropland out of production and requires additional maneuvering by cultivation equipment. An option, as simulated, 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 inch per foot of slope for gravel surfaces and 0.25 to 0.5 inch per foot 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. 8–27).

Figure 8–26 Alternative location for waste storage pond improves circulation and enhances cropland production (as shown in simulation)

Before

After

Figure 8–27 Farmstead roads consolidated to improve operations (as shown in simulation)

Before

After

651.0803 References

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651.0850 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 reduction, 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?

_____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, wind, or incompatible facilities?

Vegetation

_____1. Will existing vegetation be retained to serve its important functions, such as screening, shading, wind control, erosion control, particulate control, 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, and climatic and dust control 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?

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. Will the design filter and deposit sediment onsite?

_____6. Where steeper slopes are unavoidable, will diversions be installed to intercept runoff before it reaches slopes?

_____7. Will retaining walls be used successfully to reduce slope gradients and improve aesthetic quality?

_____8. Will vegetative filter strips be retained or installed to slow down runoff, trap sediment, and reduce runoff volumes on slopes?

_____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?

Odor reduction

_____1. Will the design utilize wind control, fencing, and/or vegetation to reduce dust generation?

_____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 control odor?

_____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?

Aesthetic quality

_____1. Will the AWMS components retain or improve aesthetic 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 roadways take advantage of desirable views?

_____7. Will the design allow for retention of landscape features with special meaning, such as specimen trees, exceptional views, or historic structures?

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.

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?

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?

United States
Department of
Agriculture

**Soil
Conservation
Service**

Agricultural
Waste Management
Field Handbook

Chapter 9 Agricultural Waste Management Systems

(210-AWMFH, 4/92)

Chapter 9 Agricultural Waste Management Systems

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Chapter 9 Agricultural Waste Management Systems

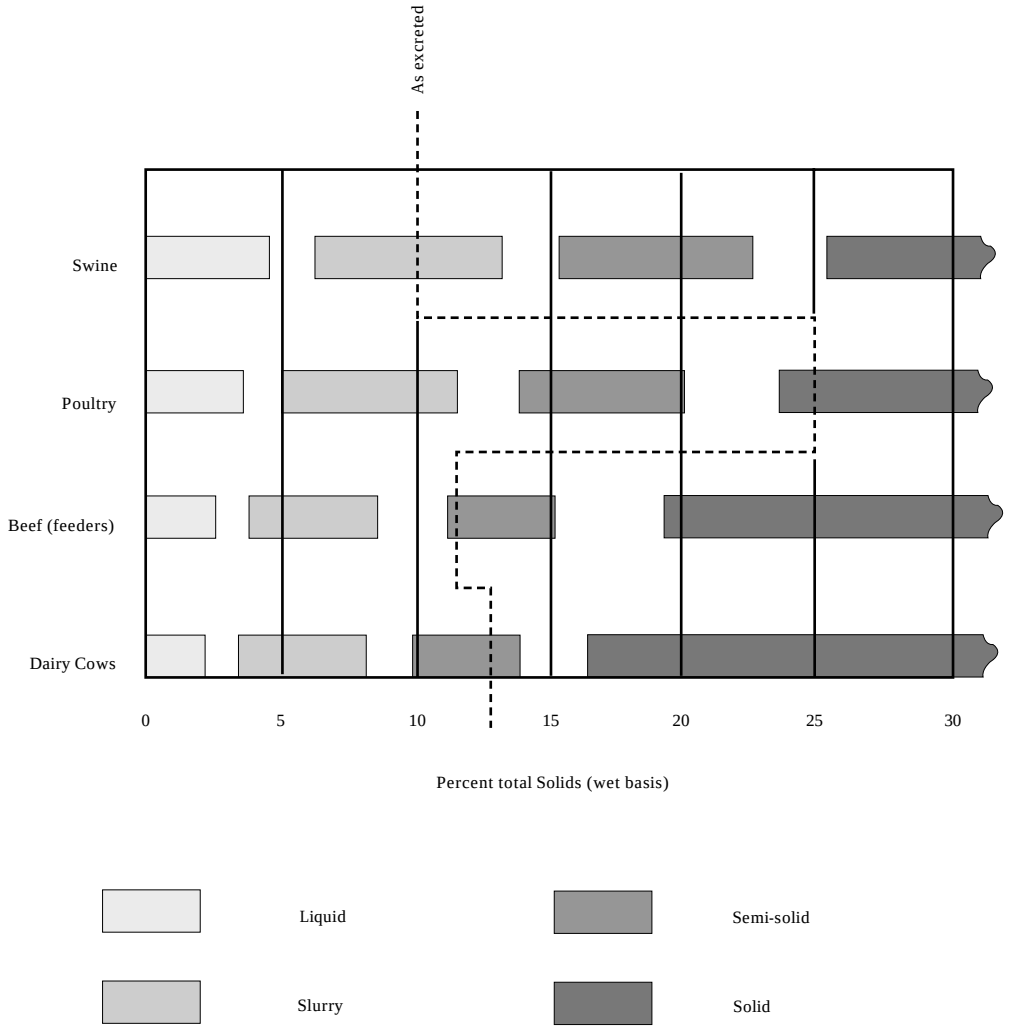
651.0900 Introduction

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.

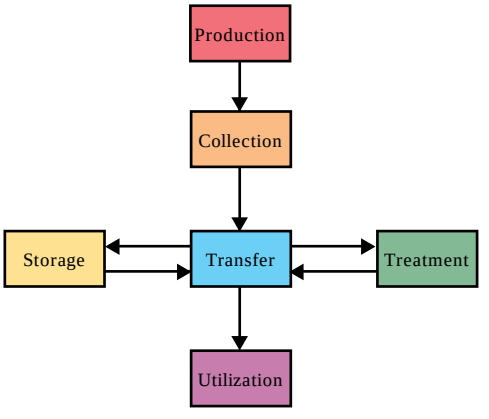
(b) Collection

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.

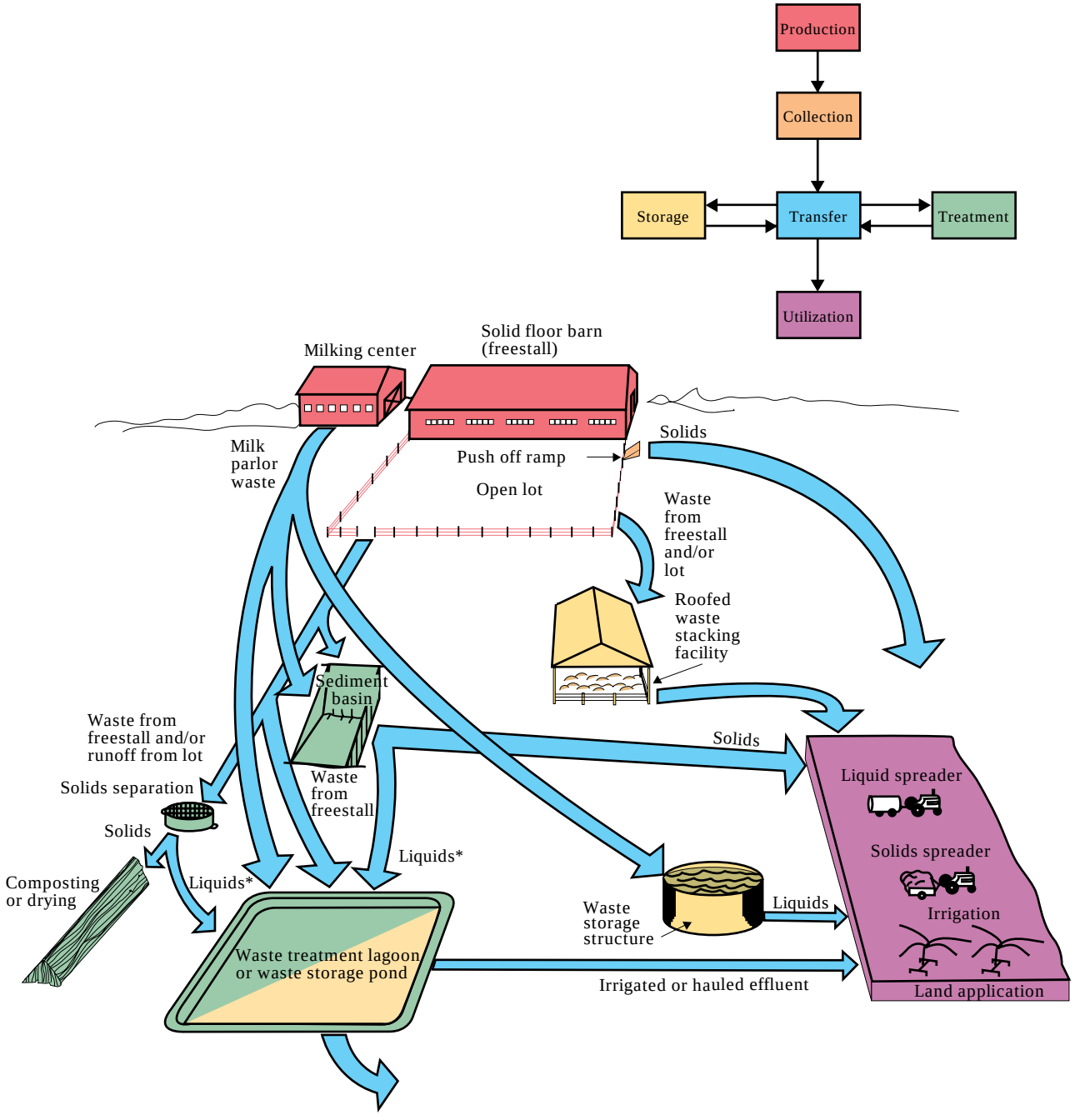
Determine the alternatives the decisionmaker is willing to consider for utilization. This helps the planner know what to work toward. Some alternatives may have specific limitations or requirements for the characteristics of the waste, and the system must be designed to deliver waste with those characteristics. 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

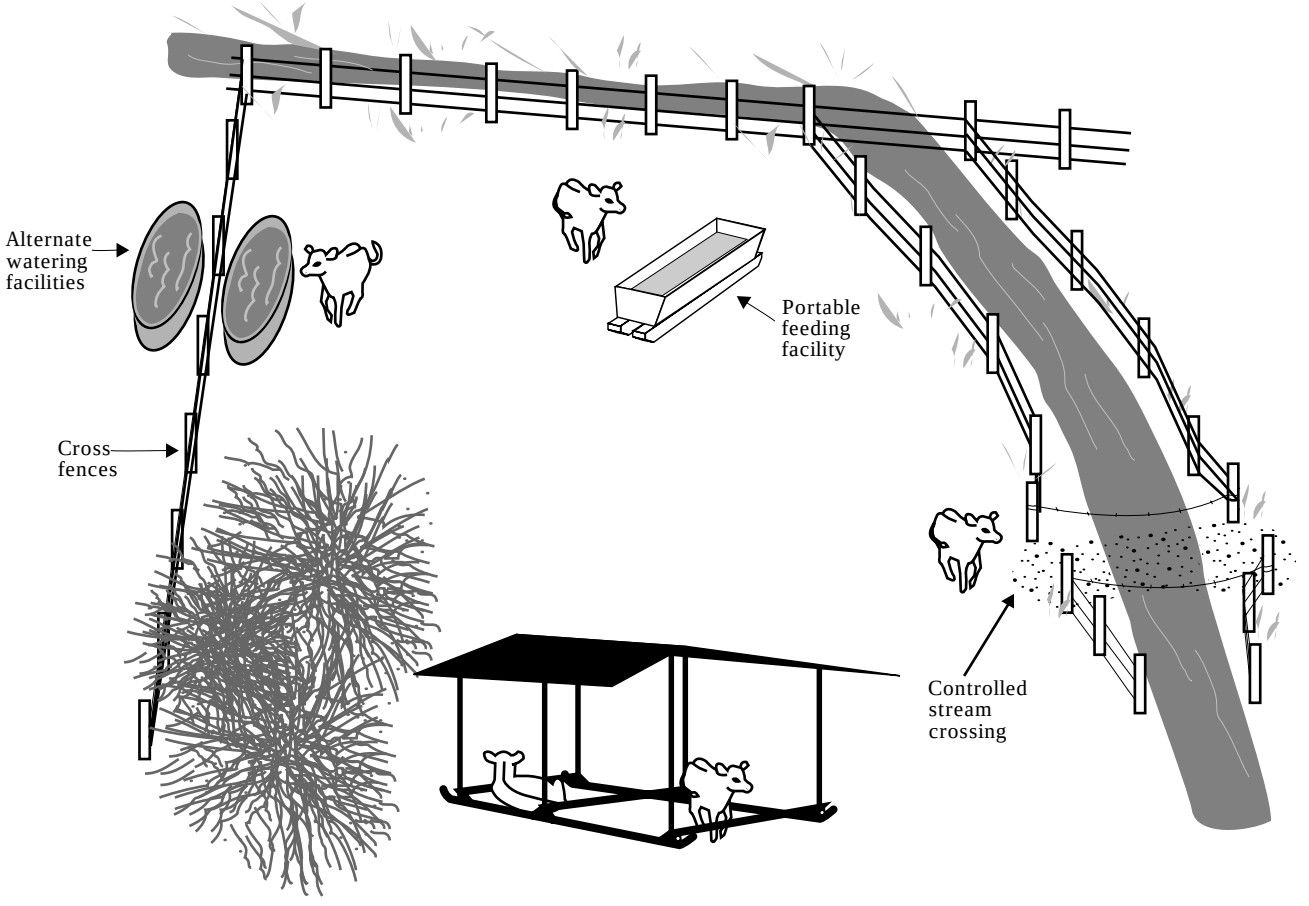
(a) Dairy waste management systems

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.

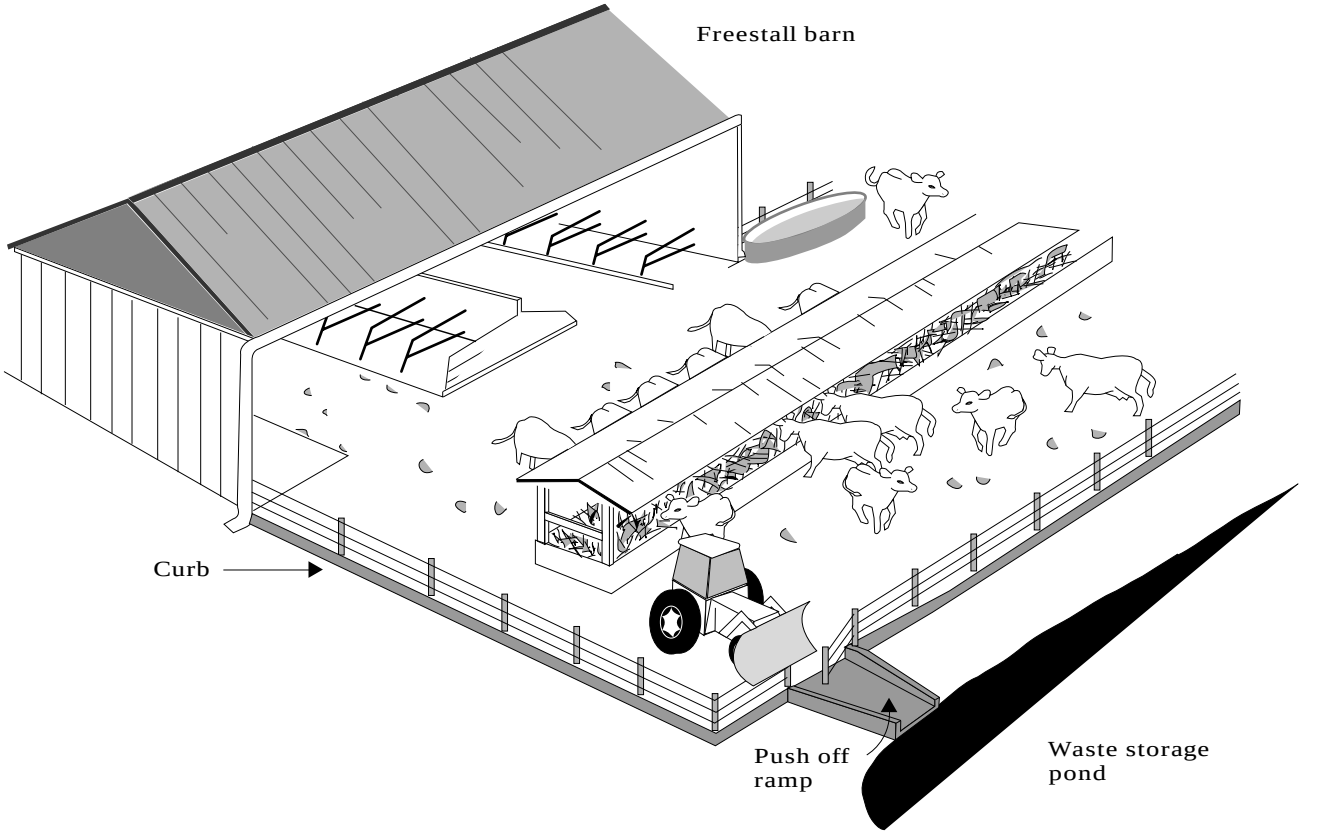
(2) Collection

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

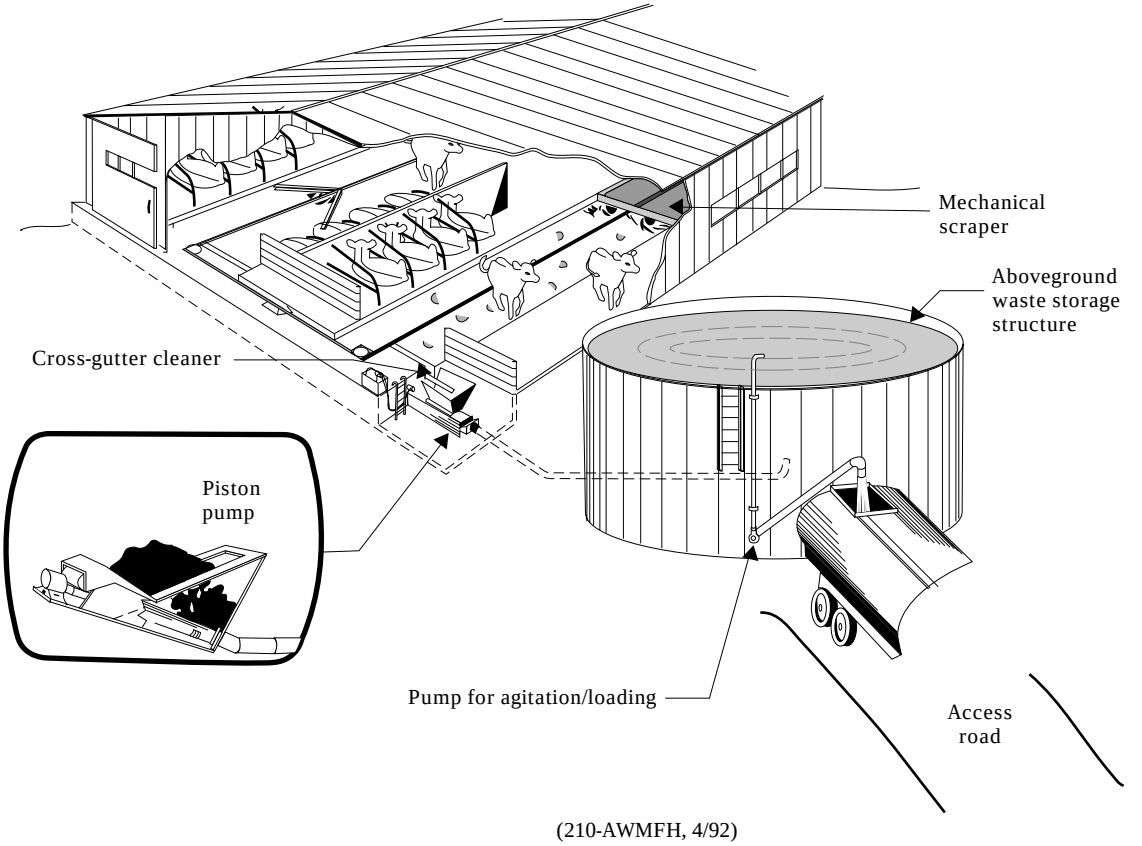


Figure 9–7 Storage facilities

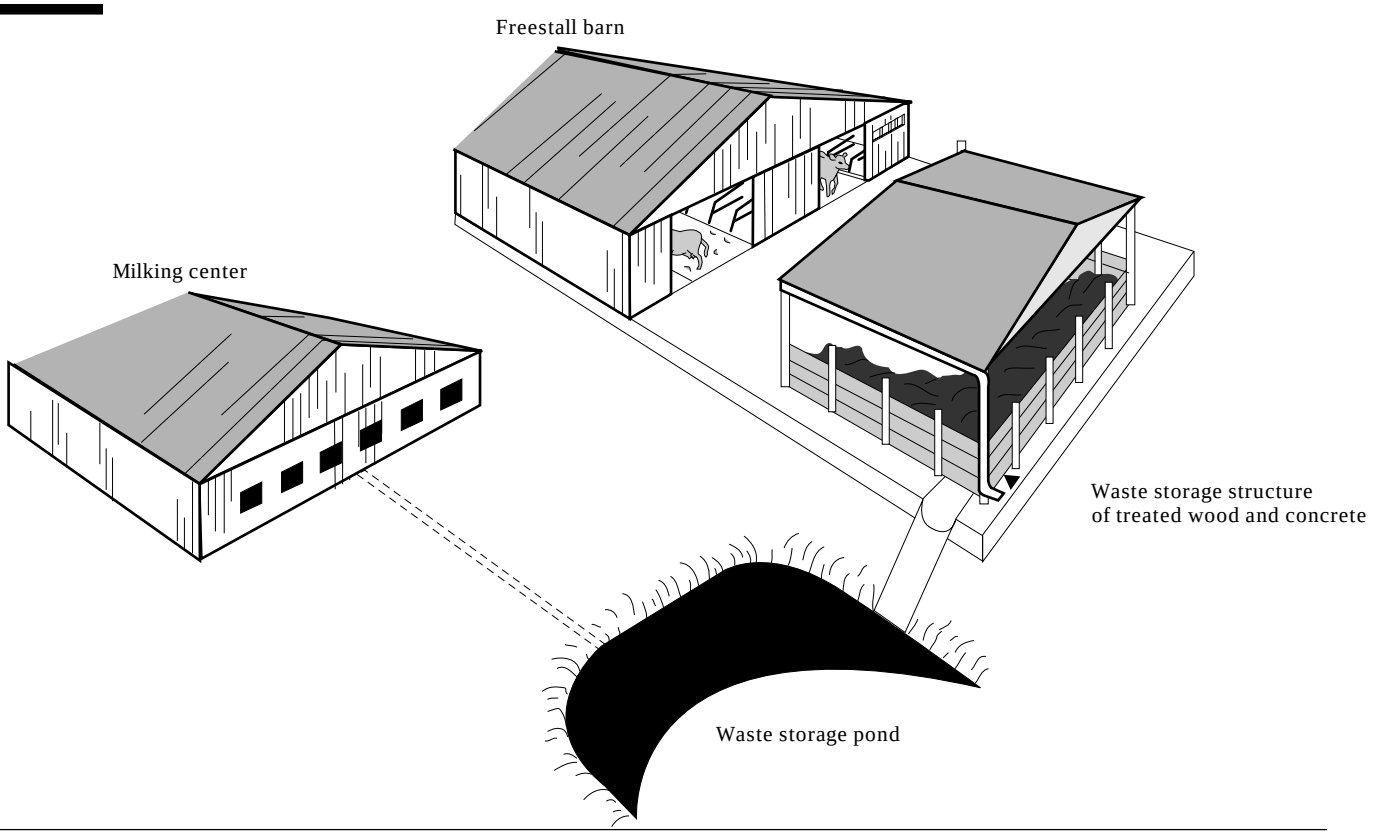


Figure 9–8 Tank wagon used to spread liquid wastes from below ground storage structure

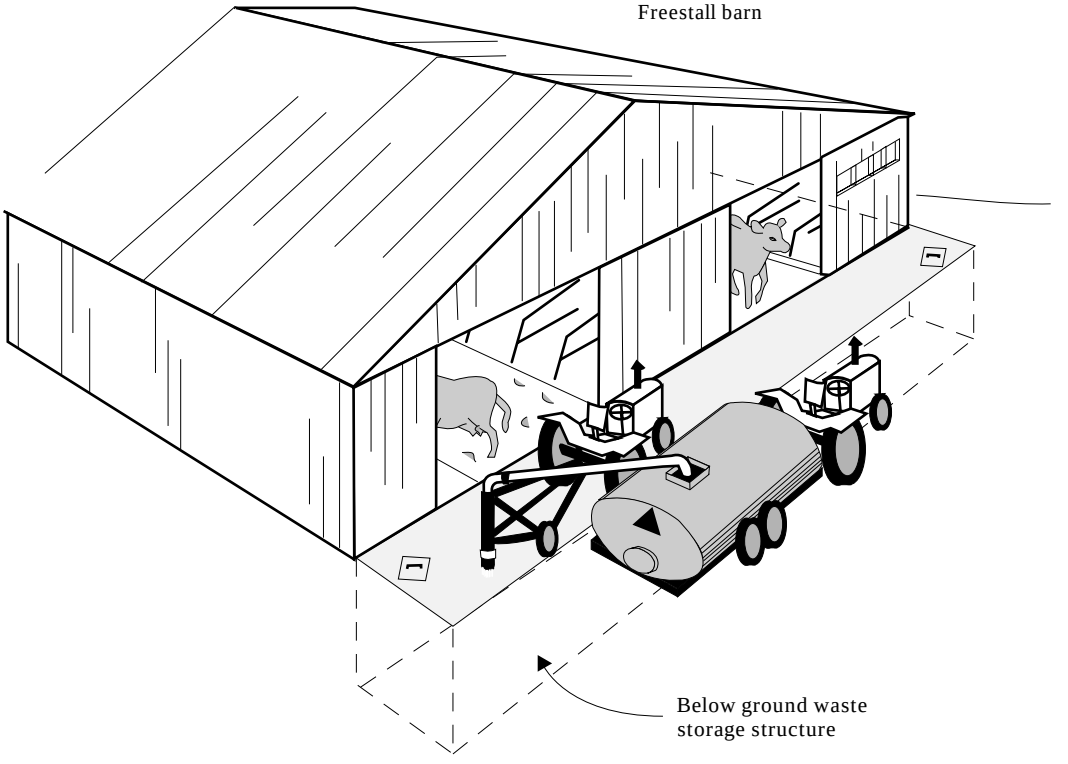


Figure 9–9 Freestall barn with flushing alleyway and irrigation system

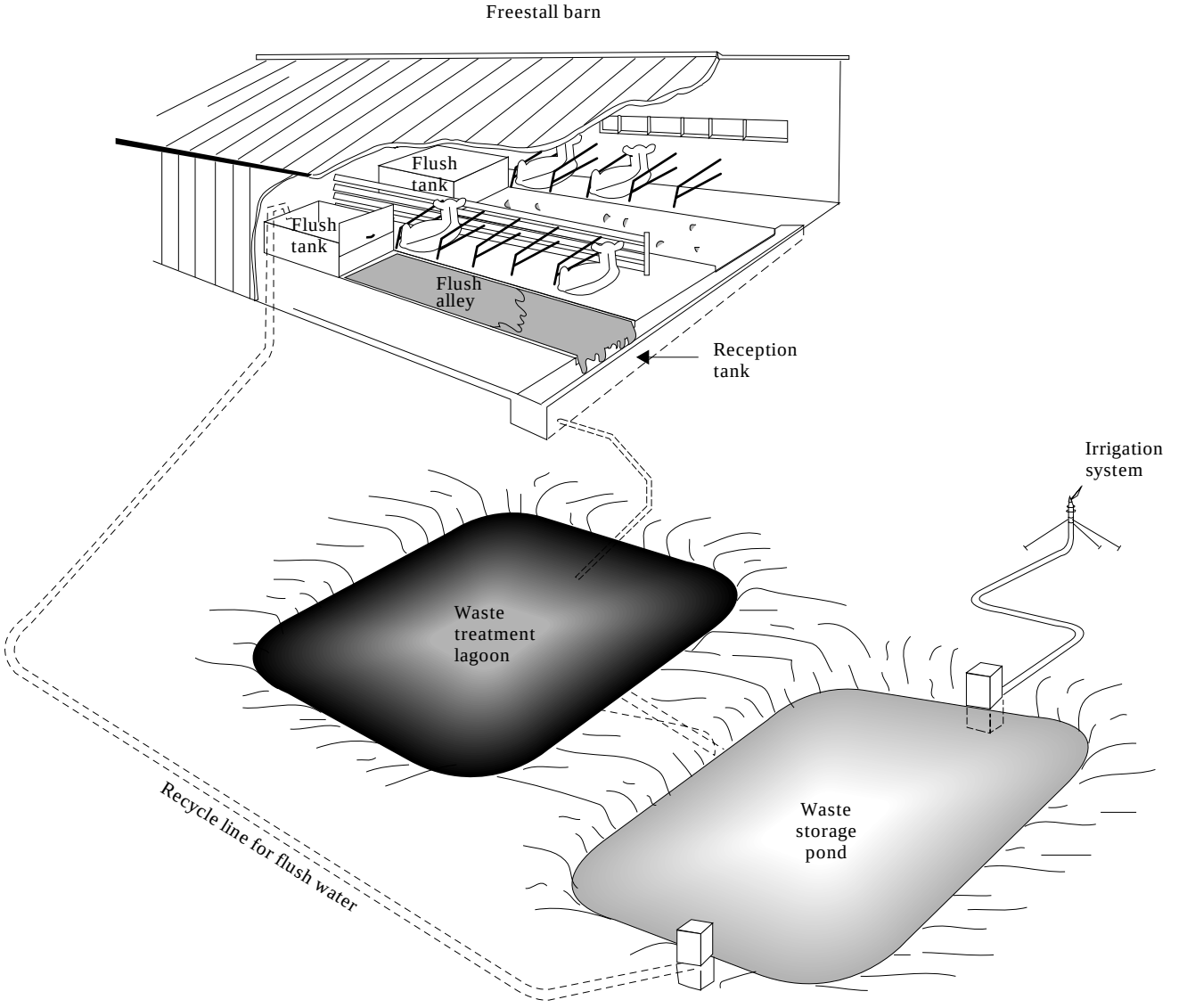
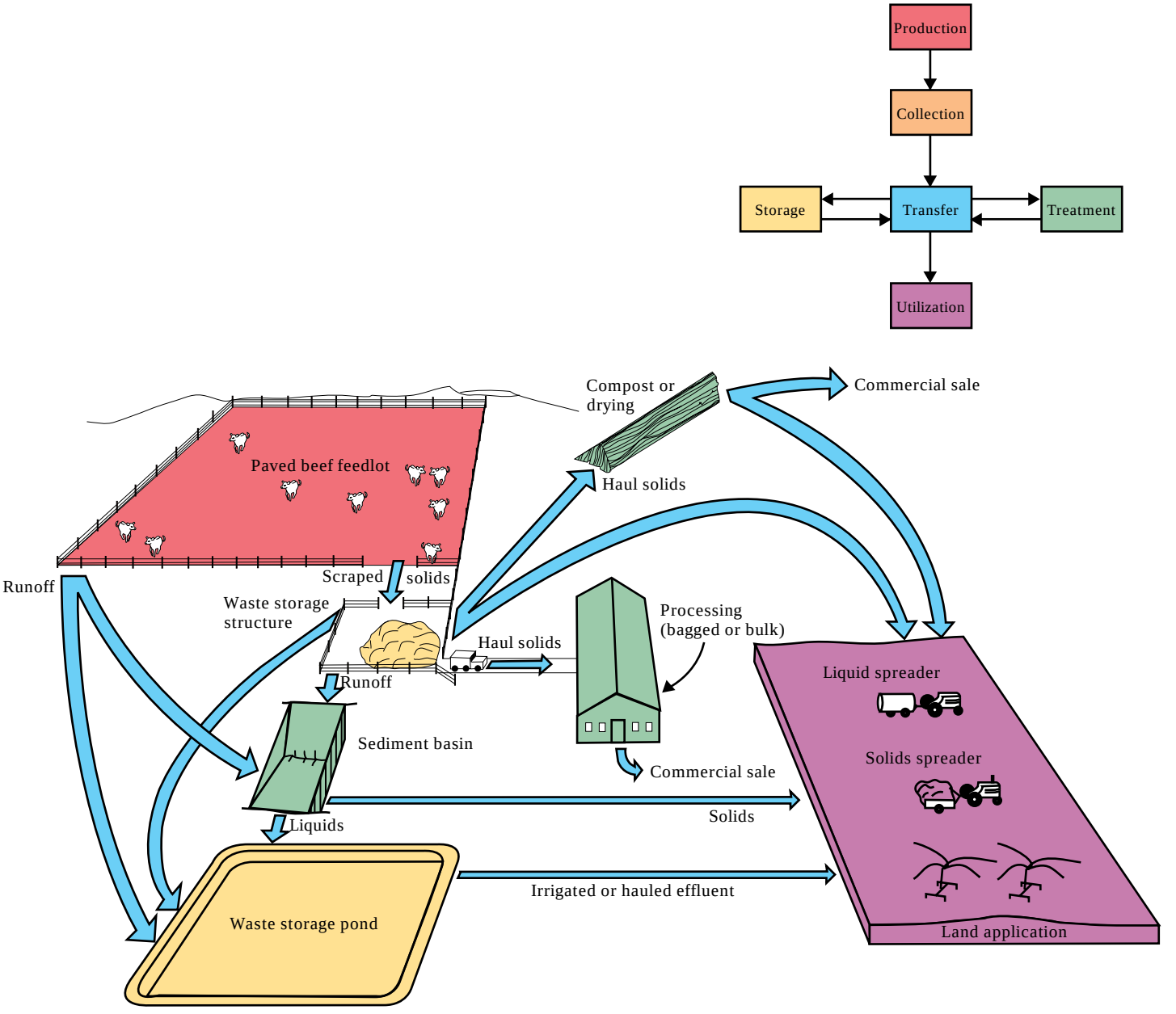


Figure 9–10 Waste handling options—beef



(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

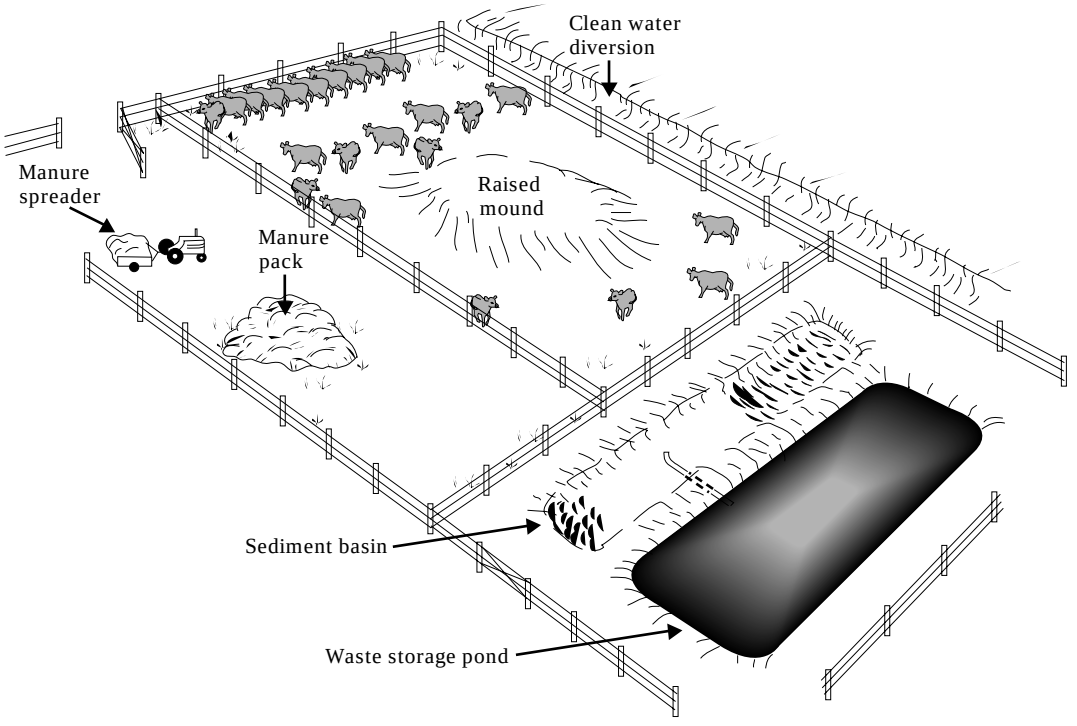
Waste associated with confined beef operations include manure, bedding, and contaminated runoff.

(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

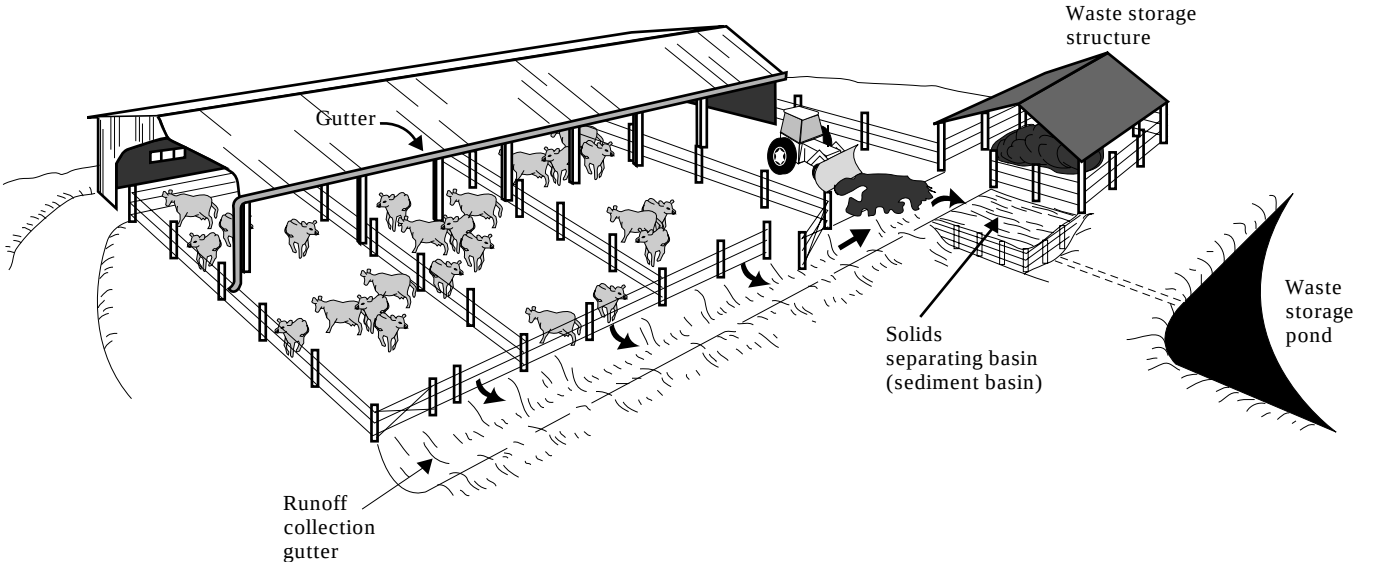
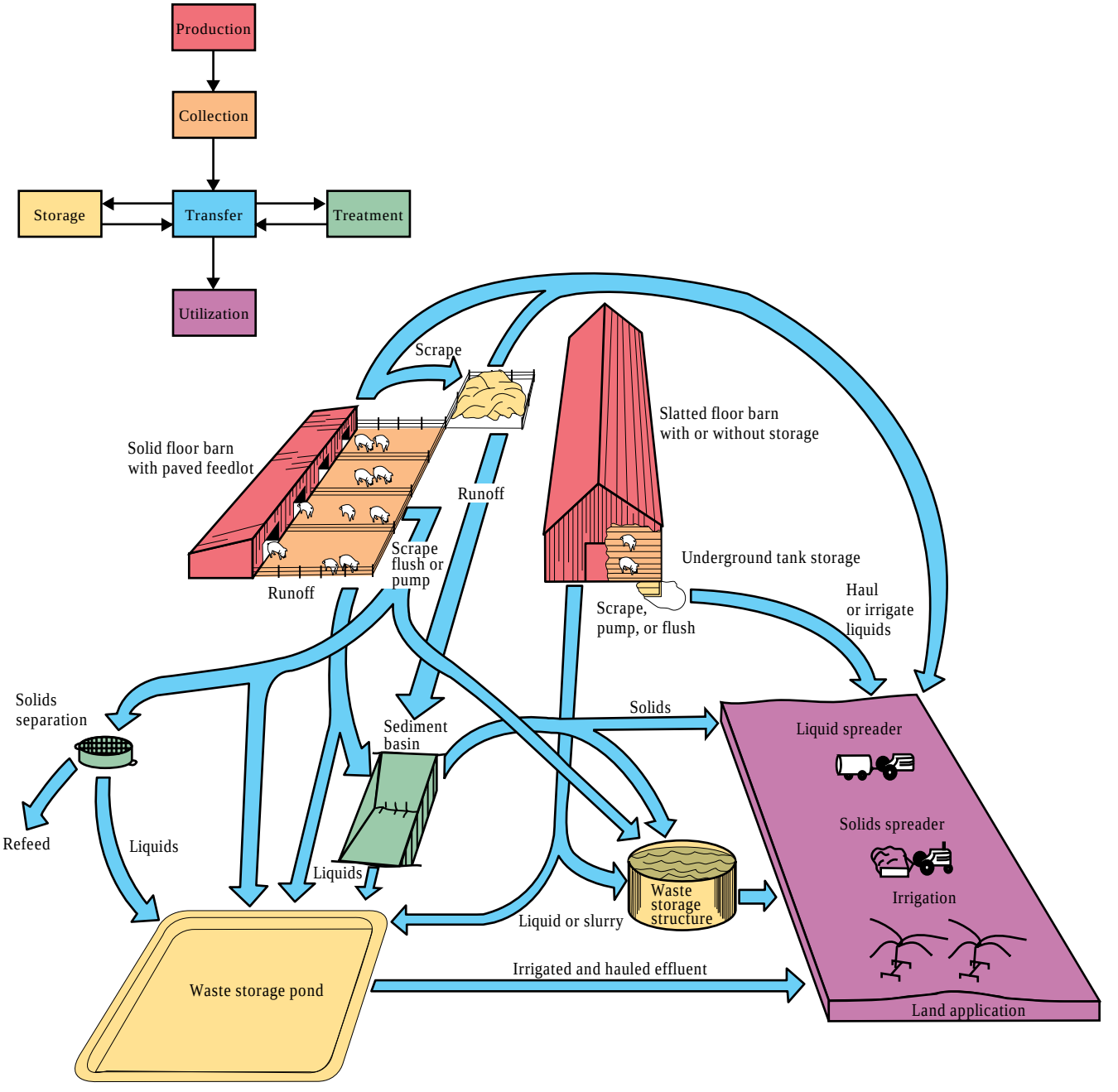


Figure 9–13 Waste handling options—swine



(c) Swine waste management systems

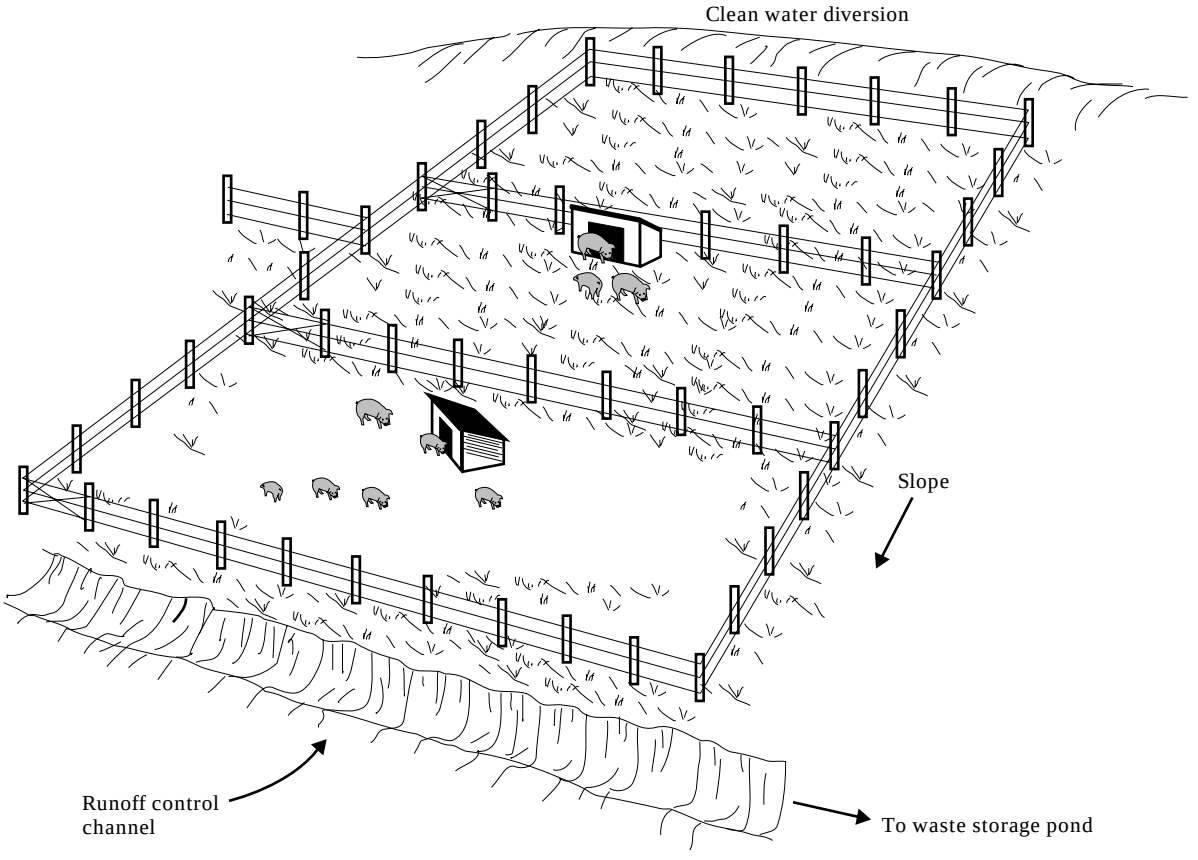
Open systems (pastures, woodlots, and wetlands), feedlot systems, confinement systems, or a combination of these, are used for raising swine (fig. 9–13).

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).

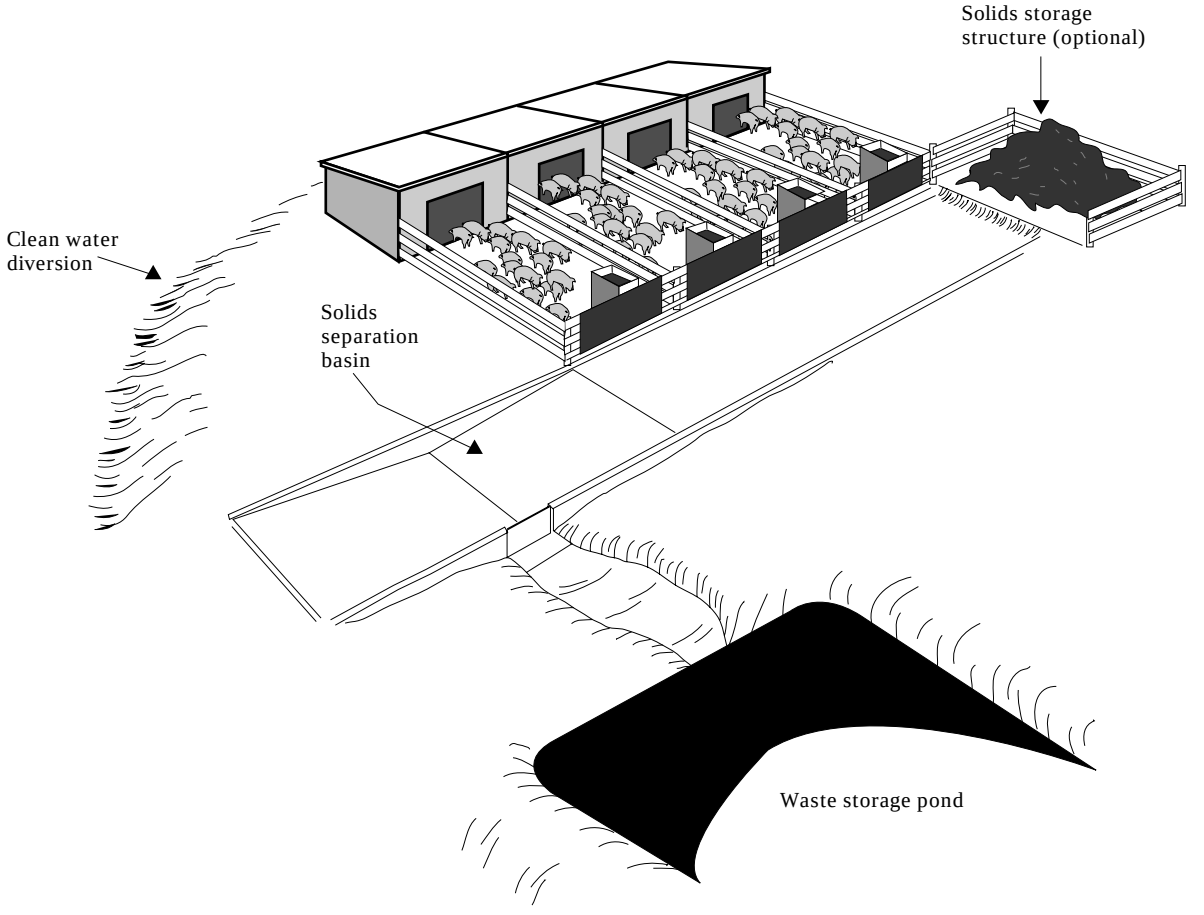
(3) Storage

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

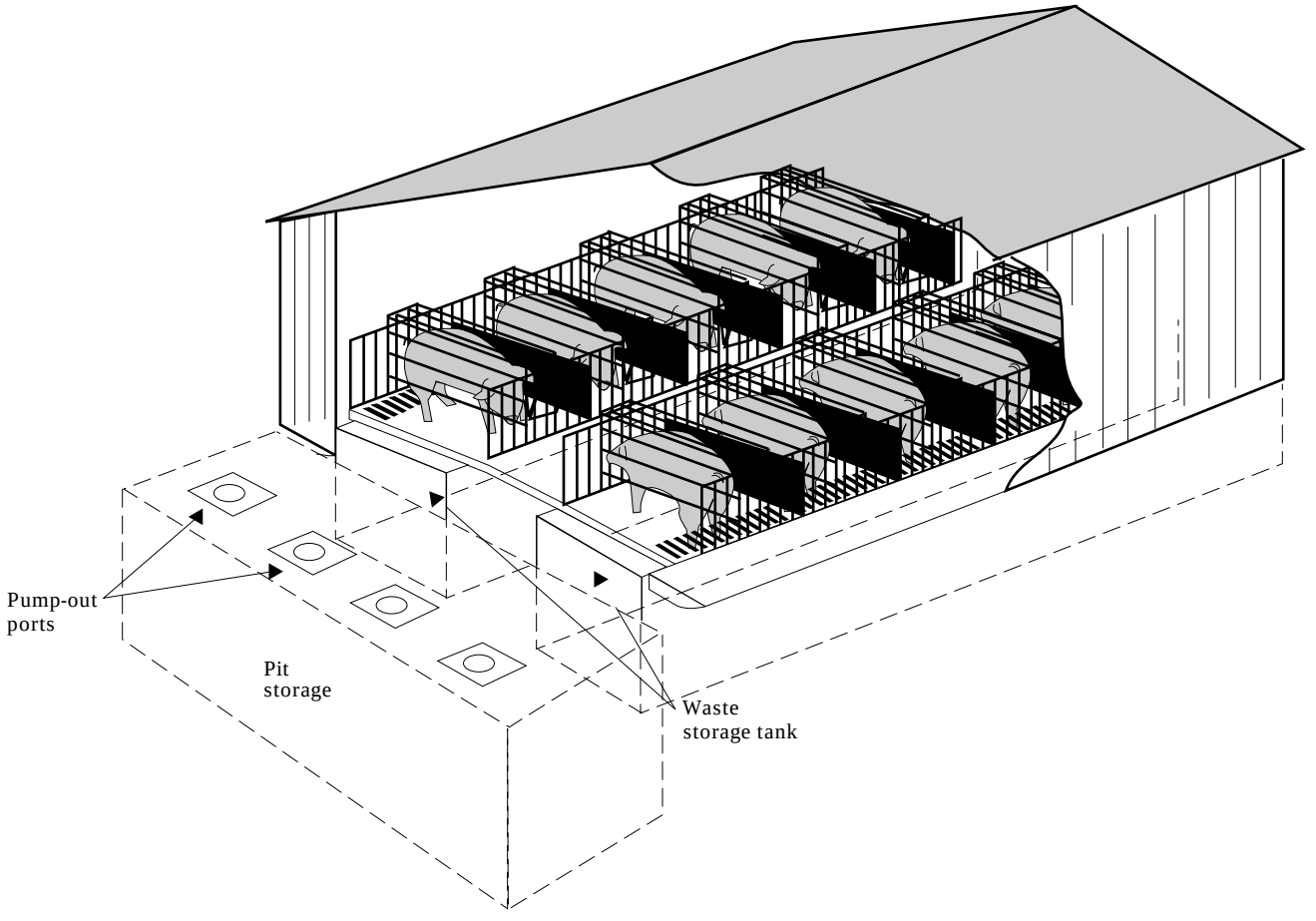


Figure 9–17 Fed hogs in confined area with concrete floor and tank storage liquid manure handling

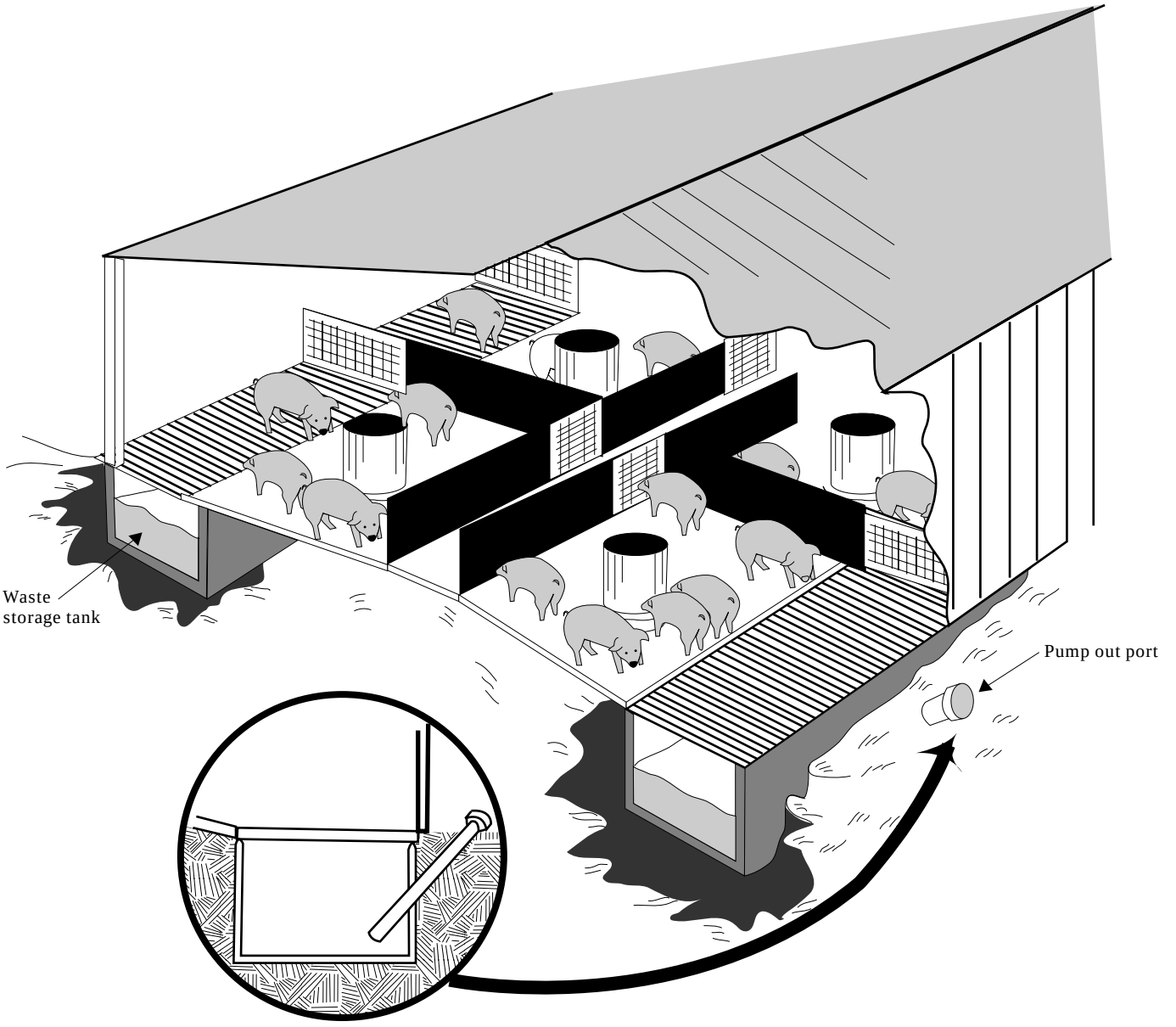


Figure 9–18 Two stage aerobic lagoon system for treatment of waste flushed from swine building

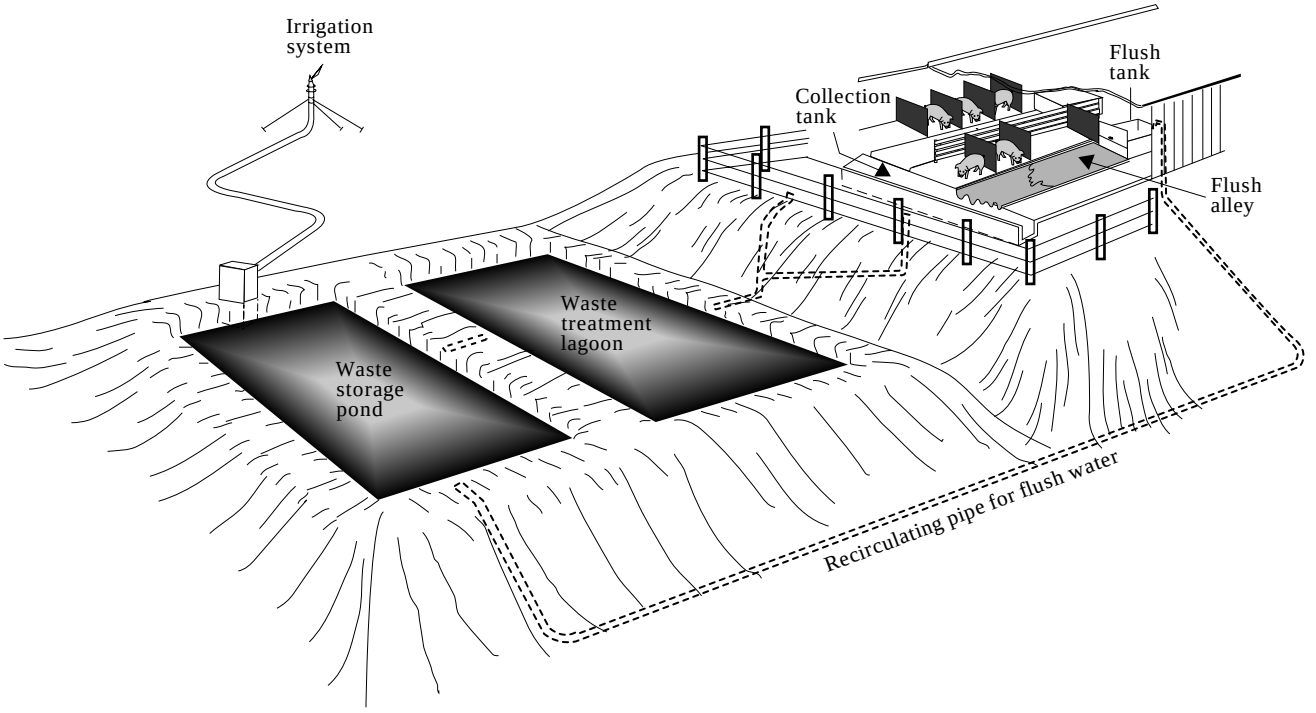
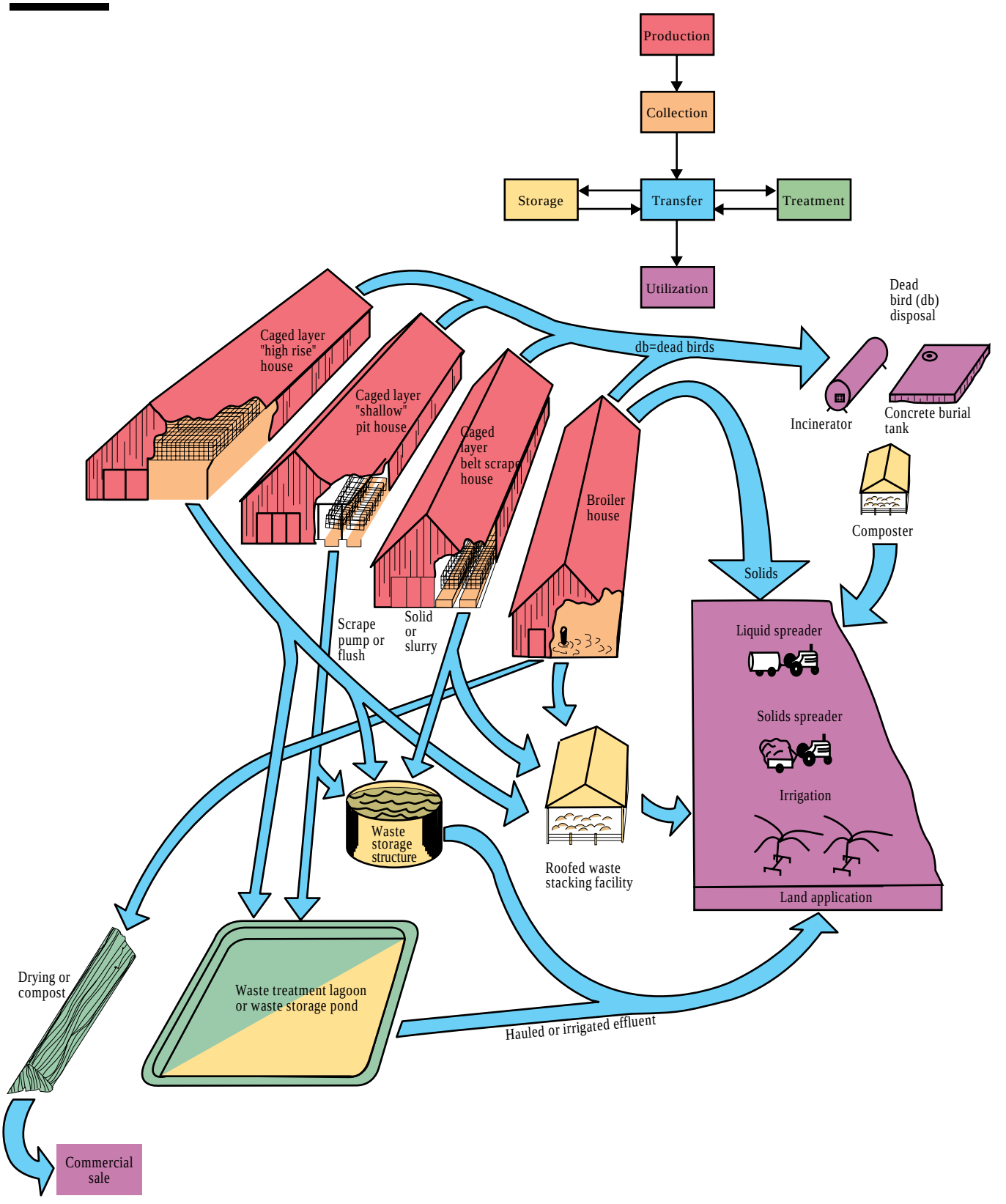


Figure 9–19 Waste handling options—poultry



(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.

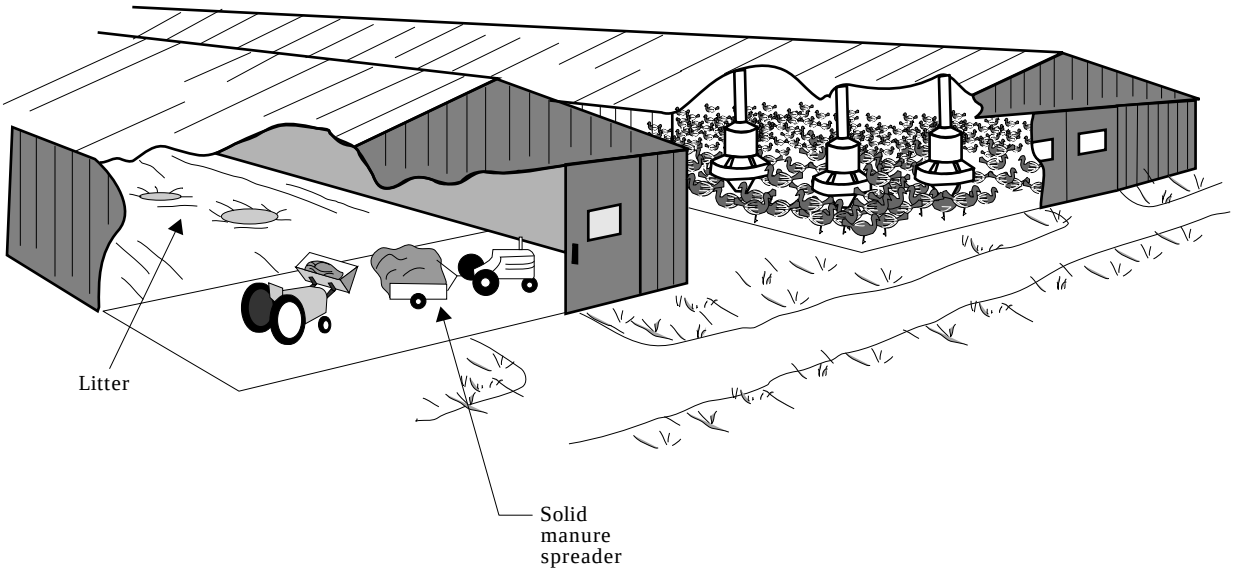
In layer houses, the manure that drops below the cage collects in deep stacks (fig. 9–21) or is removed frequently using either a shallow pit located beneath the cages for flushing or scraping or belt scrapers positioned directly beneath the cages.

(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

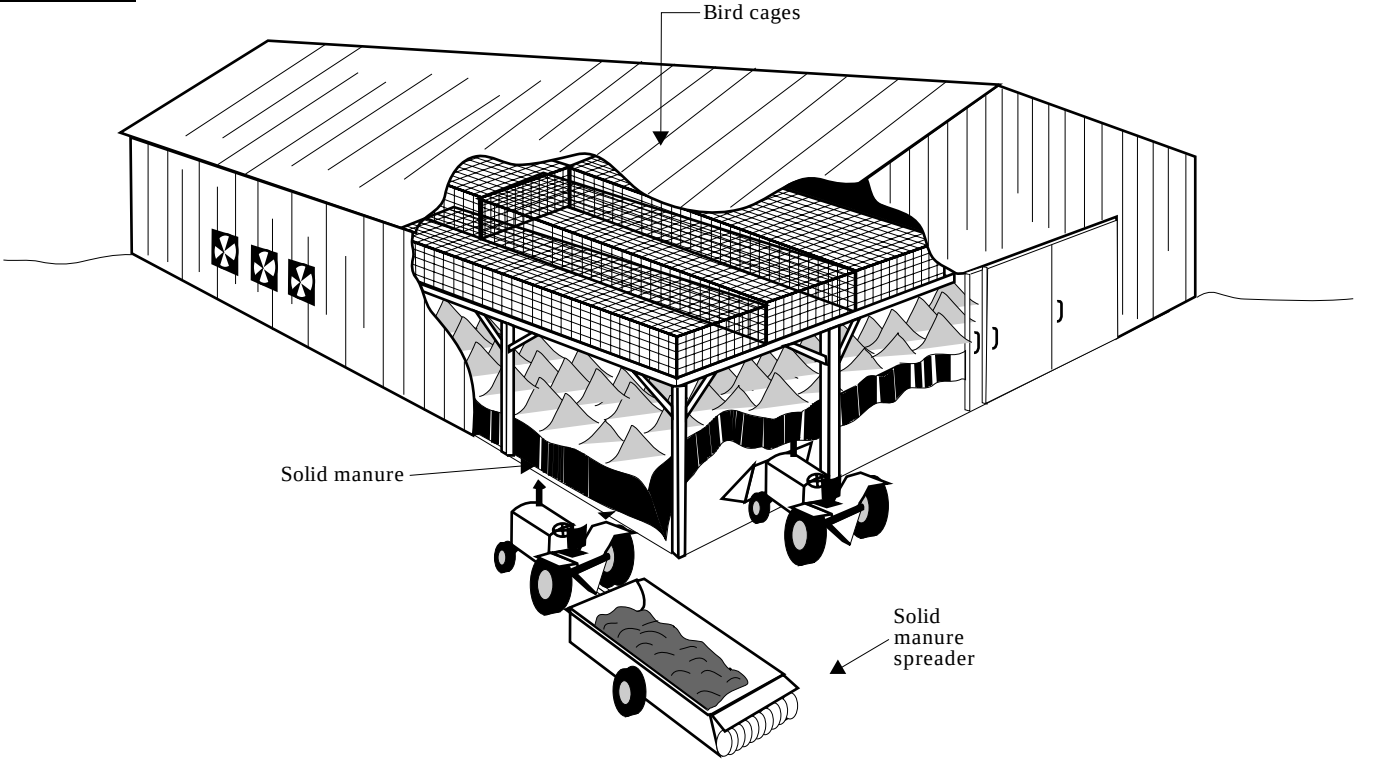


Figure 9–22 Litter from poultry operations may be stored on the floor of the facility until scraped after several cycles of birds

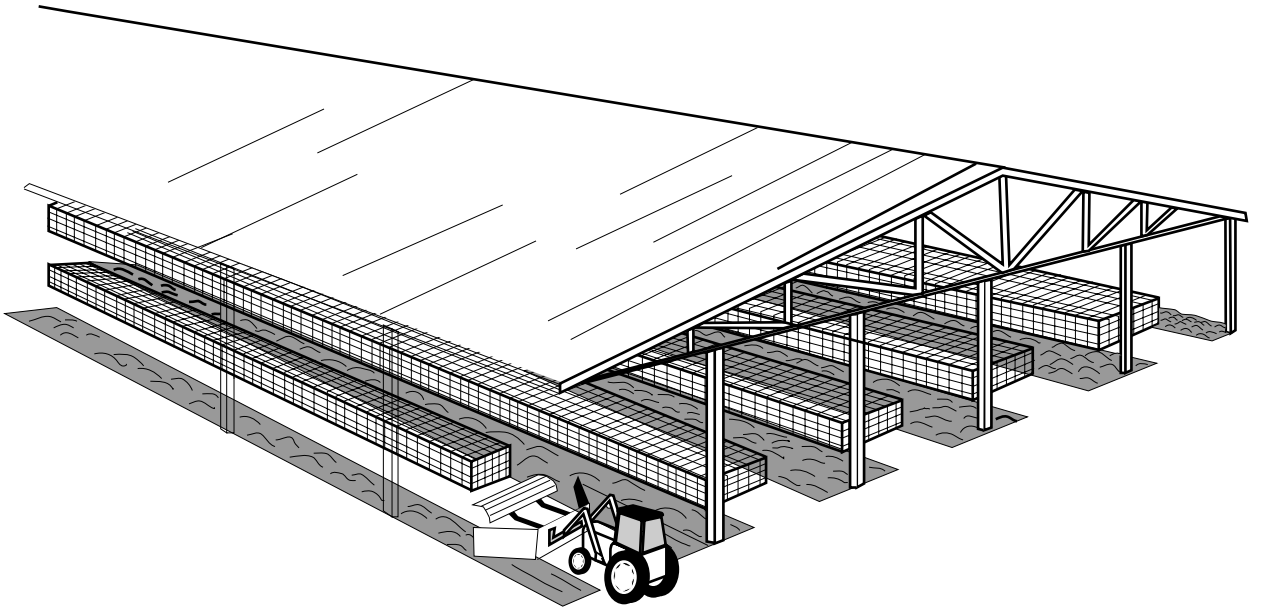


Figure 9–23 Solid waste may be scraped regularly (possibly by mechanical scraper) from facility for transport to the field

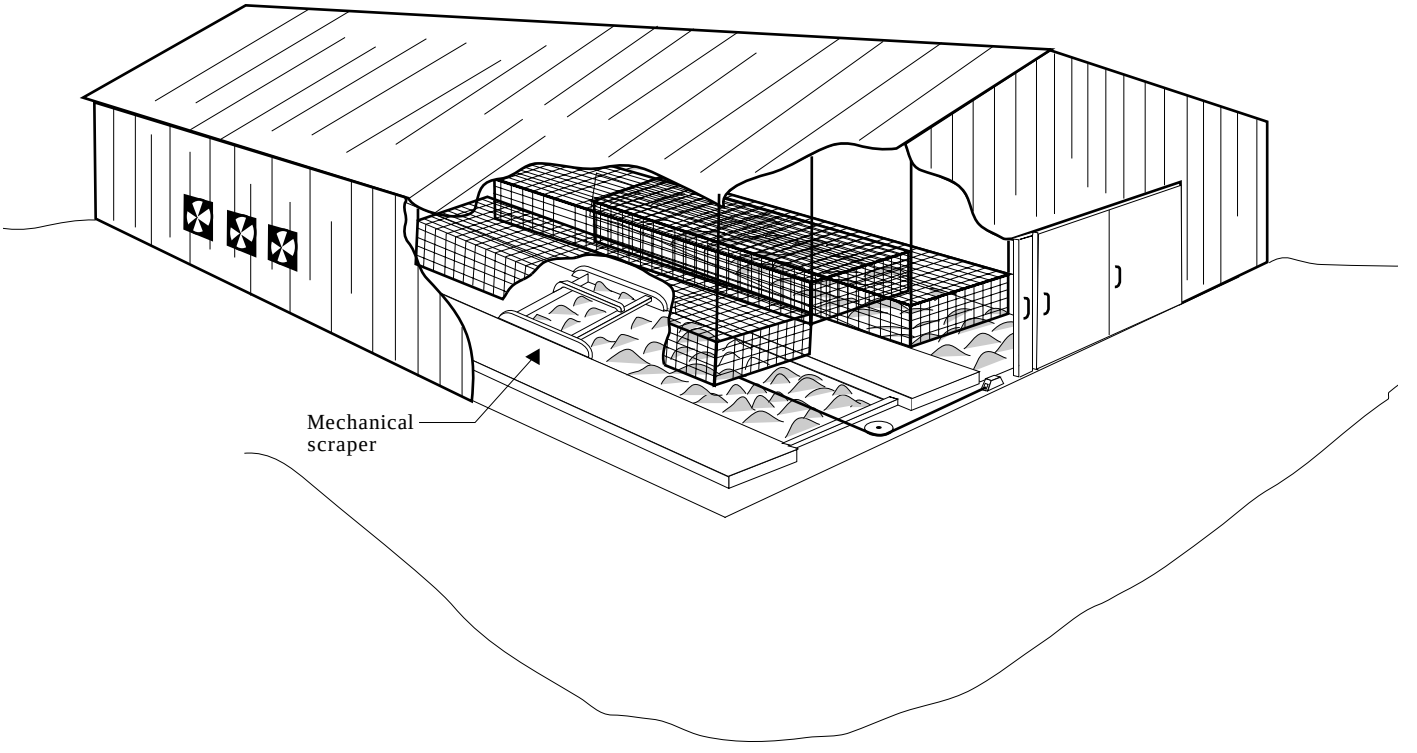
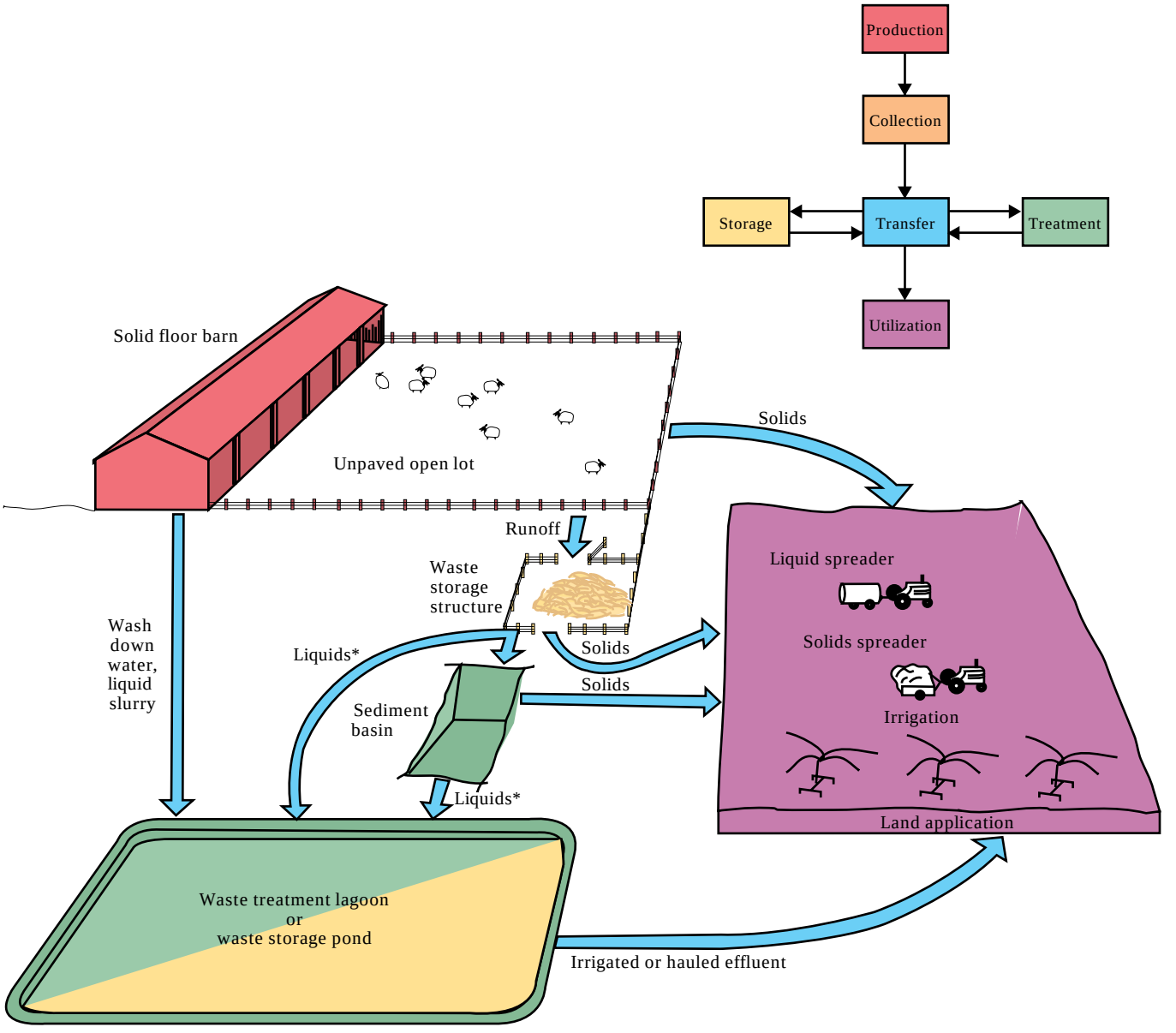


Figure 9–24 Waste handling options—sheep



•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

651.1000 Introduction

Alternatives for managing agricultural waste are available for any given agricultural operation. As described in chapters 2 and 9, an agricultural waste management system can 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 component can be a piece of equipment, such as a pump; a structure, such as a waste storage tank; or an operation, such as composting. The combination of the components should allow the flexibility needed to efficiently handle all forms of waste generated for a given enterprise. In addition, the components must be compatible and integrated with each other. 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.

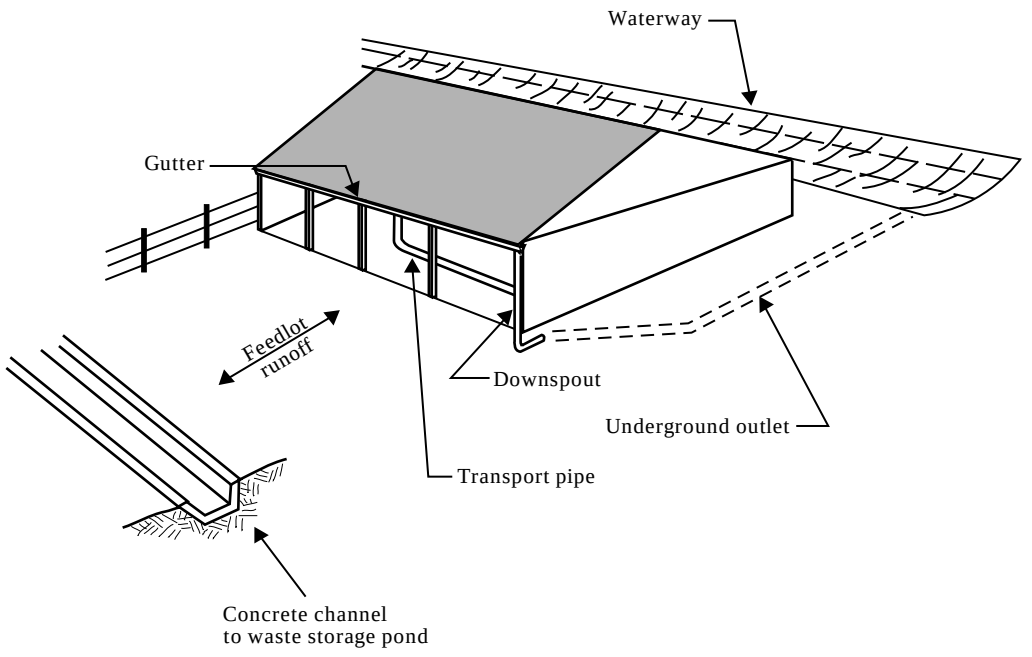
651.1001 Production

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 cattle, 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). Gutters and downspouts may not be needed if the roof drainage will not come into contact with areas accessible to livestock.

Figure 10–1 Roof gutter and downspout



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.

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 the 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, ft³/ sec
A_g = cross sectional area of gutter, in²
r = A_g / wp, inches
wp = wetted perimeter of gutter, inches

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, ft³/sec
A_d = cross sectional area of downspout, in²
h = head, inches (generally the depth of the gutter minus 0.5 inch)

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, ft²
q = capacity of system, either q_g or q_d, whichever is smallest, ft³/sec
P = 5-minute precipitation for appropriate storm event, inches

The above 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.

(1) 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 inches. 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.

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

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

$$H = \text{depth of gutter} - 0.5 \text{ in}^2$$
$$= 5.5 \text{ in}$$
$$A_d = 3.1416 \times \left(\frac{3}{2}\right)^2$$
$$= 7.06 \text{ in}^2$$
$$q_d = 0.010457 \times 7.06 \times 5.5^{0.5}$$
$$= 0.17 \text{ ft}^3 / sec$$

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 ft³/sec) exceeds the capacity of one downspout (0.17 ft³/sec) 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.

$$N_d = \frac{q_g}{q_d}$$
$$= \frac{0.46}{0.17}$$
$$= 2.7$$

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 ft³/sec. 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:

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

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

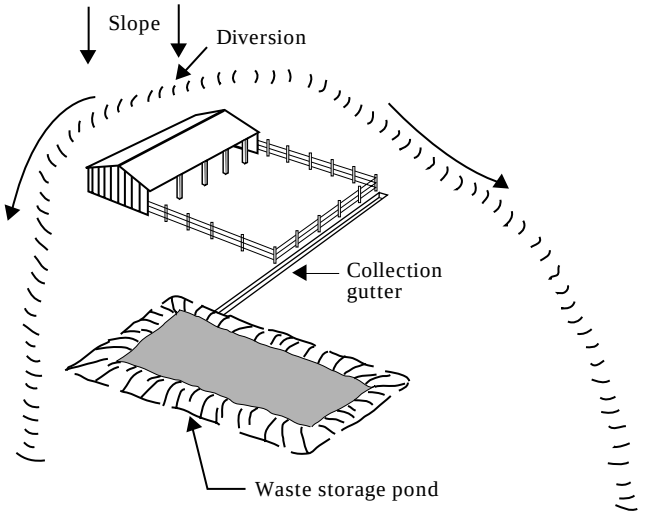
(b) Runoff control

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 waste storage or treatment facilities (fig. 10–2). Runoff from feedlots should be channeled into waste 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 Engineering Field Manual or by some other hydrologic method.

Diversions are to be designed according to NRCS Conservation Practice Standard, Diversion, Code 362 (USDA 1985). 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



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. Components that provide efficient collection of animal waste include paved alleys, gutters, and slatted floors with associated mechanical and hydraulic equipment as described below.

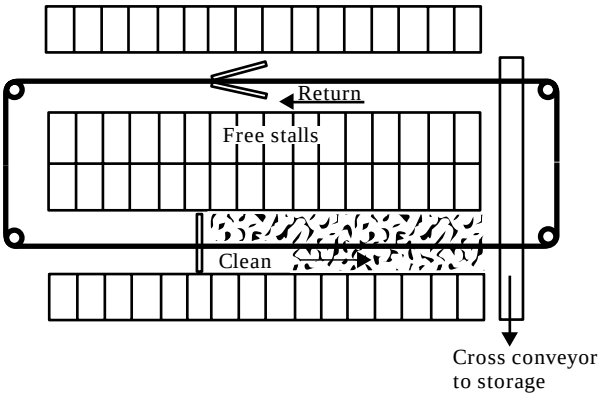
(a) Alleys

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

Figure 10–3 Scrape alley used in dairy barns



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.

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.

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

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

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.

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.

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.

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, gpm/ft of gutter width	Pump discharge, gpm/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 (MWPS1985)

	Underslat alley	Open Alley narrow width (<4')			Open Alley wide width (>4')		
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

Some flush tanks have manually opened gates. These tanks are emptied by opening either a valve, a standpipe, a pipe plug, or a 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 to 150 gpm) may be used for flush tanks, but high volume pumps (200 to 1,000 gpm) 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.

In some parts of the country where wastewater is recycled from lagoons for flush water, salt crystals (struvite) may form inside pipes and pumps and cause decreased flow. Use of plastic pipe and 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 animal waste. 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.

Figure 10–4 Dairy flush alley

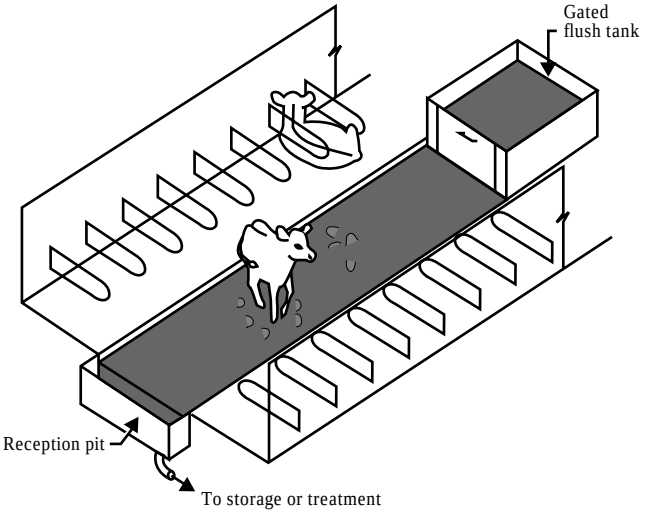
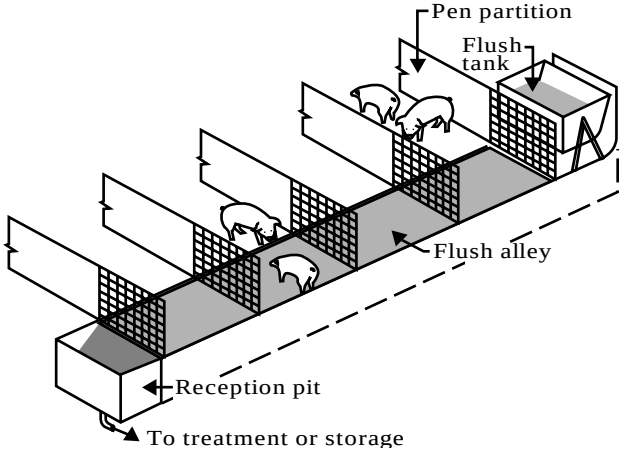


Figure 10–5 Swine flush alley



(2) Step-dam gutters

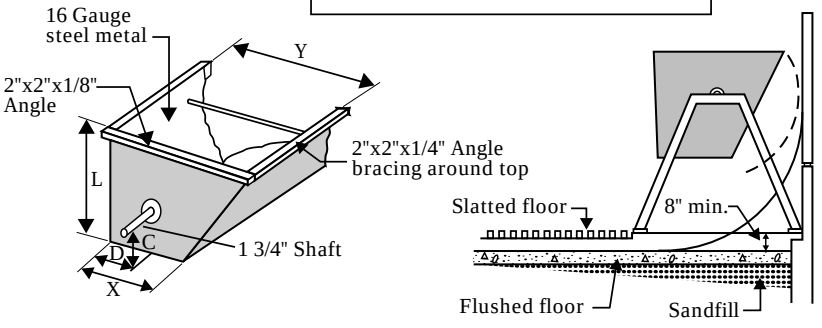
Step-dam gutters, which are also known as gravity gutters or gravity flow channels, provide a simple alternative for collecting dairy manure (fig. 10–8). A 6-inch high dam holds back a lubricating layer of manure in a level, flat-bottomed channel. Manure drops through a floor grate or slats and flows 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

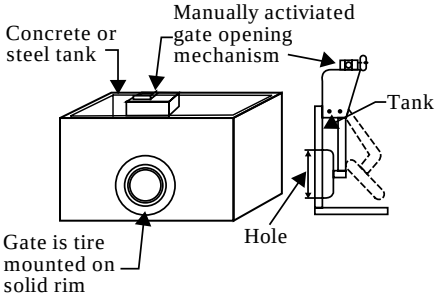
Scrape gutters are frequently used in confined stall dairy barns. The gutters are 16 to 24 inches wide, 12 to 16 inches deep, and generally do not have any bottom slope. They are cleaned using either shuttle-stroke or chain and flight gutter cleaners (figs. 10–9 & 10–10). Electric motor driven shuttle 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.

Figure 10–6 Flush tanks

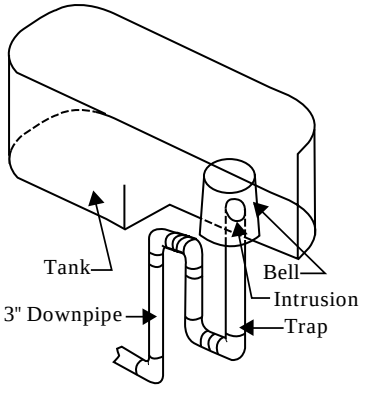
Gal/ft of tank length	Tank dimensions in. X	Y	L	C	D
40	18	36	30	15 1/2	14 1/2
30	18	33	24	12 1/2	13
24	18	30	20	10 1/2	12



Tipping tank



Tank with circular flush gate



Automatic siphon tank

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 or 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

Waste materials 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 inch 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 10–7 Flush and gravity flow gutters for swine manure

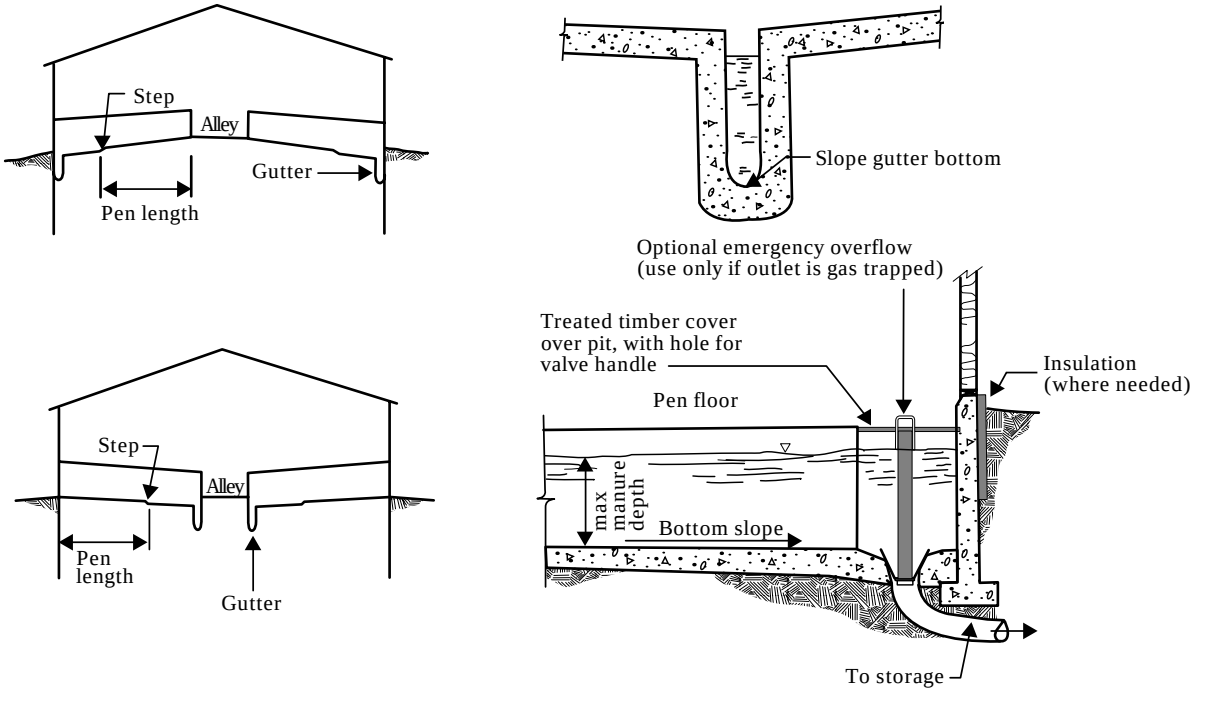
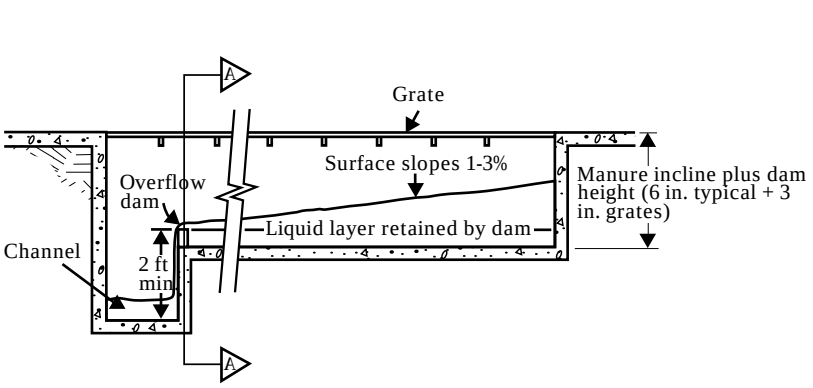
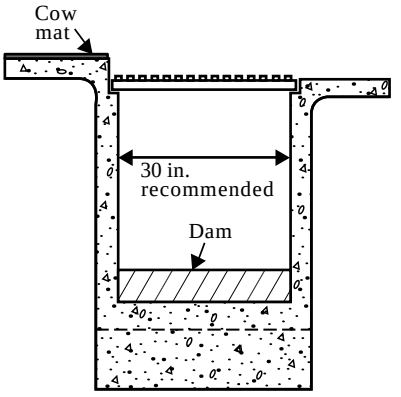


Figure 10–8 Gravity gutter for dairy manure



Cross section along stalls



Cross section AA

Figure 10–9 Shuttle-stroke gutter cleaner

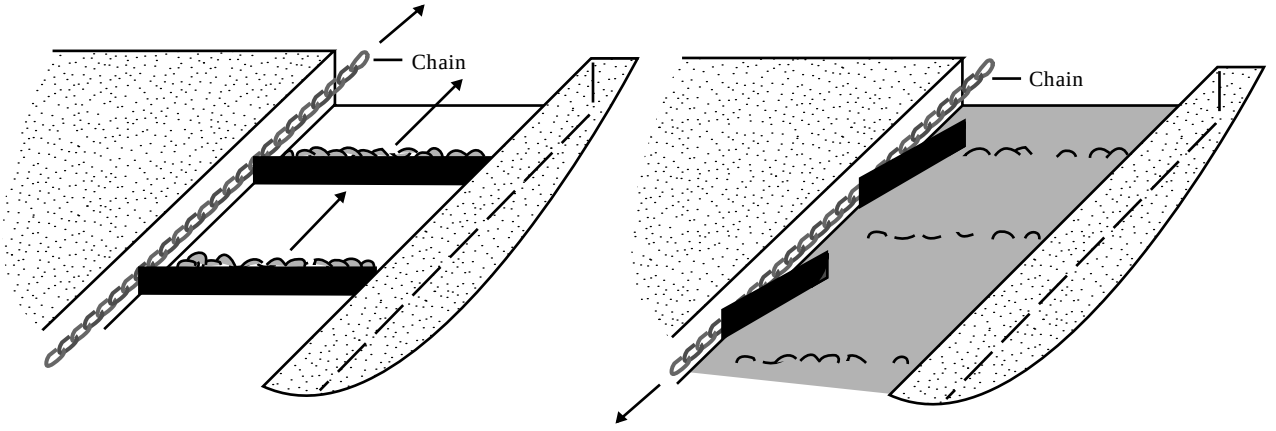


Figure 10–10 Chain and flight gutter cleaner

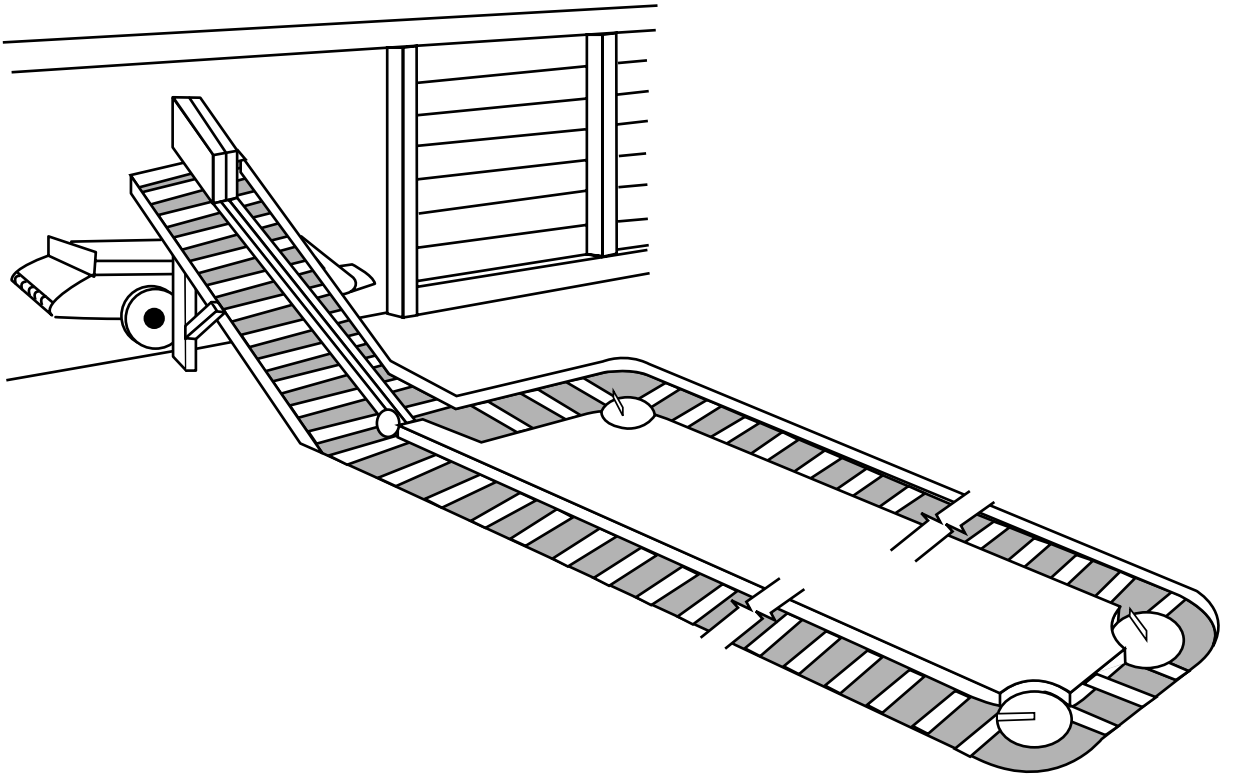
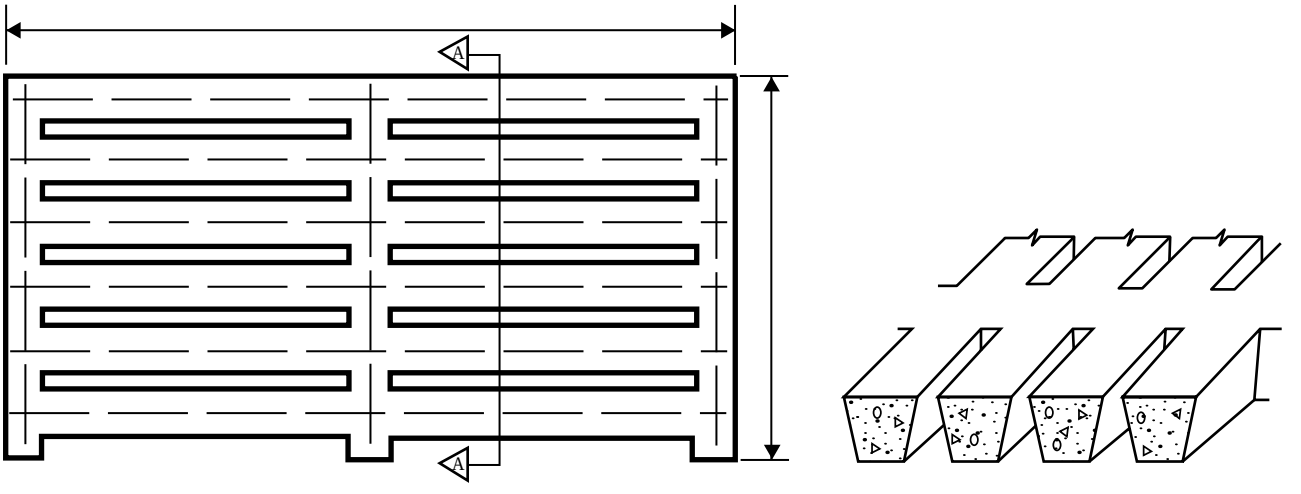


Figure 10–11 Concrete gang slats



Isometric section A A

651.1003 Storage

Waste generally must be stored so that it can be used when conditions are appropriate. Storage facilities for wastes 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 an agricultural waste management system. If too short a period is selected, the facility may fill before the waste can be used in an environmentally sound manner. Too long a period may result in an unjustified expenditure for the facility.

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 waste utilization is by land application, a storage facility must be sized so that it can store the waste during the nongrowing season. A storage facility that has a longer storage period generally will allow more flexibility in managing the wastes to accommodate weather variability, equipment availability, equipment breakdown, and overall operation management.

(a) Waste storage facilities for solids

Storage facilities for solid manure include waste storage ponds and waste storage structures. Waste storage ponds are earthen impoundments used to retain manure, bedding, and runoff liquid. Solid and semi-solid 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.

Waste 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 must be managed. Structures for open and covered stacks often have wooden, reinforced concrete, or concrete block sidewalls. The amount of bedding material often dictates whether or not the manure can be handled as a solid.

In some instances manure must be stored in open stacks in fields. Runoff and seepage from these stacks must be managed to prevent movement into streams or other surface or ground water. Figures 10–12 and 10–13 show various solid manure storage facilities.

(1) Design considerations

Solid waste storage ponds and structures 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 animal waste 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:

$$VMD = AU \times DVM \times D \qquad [10–1]$$

where:

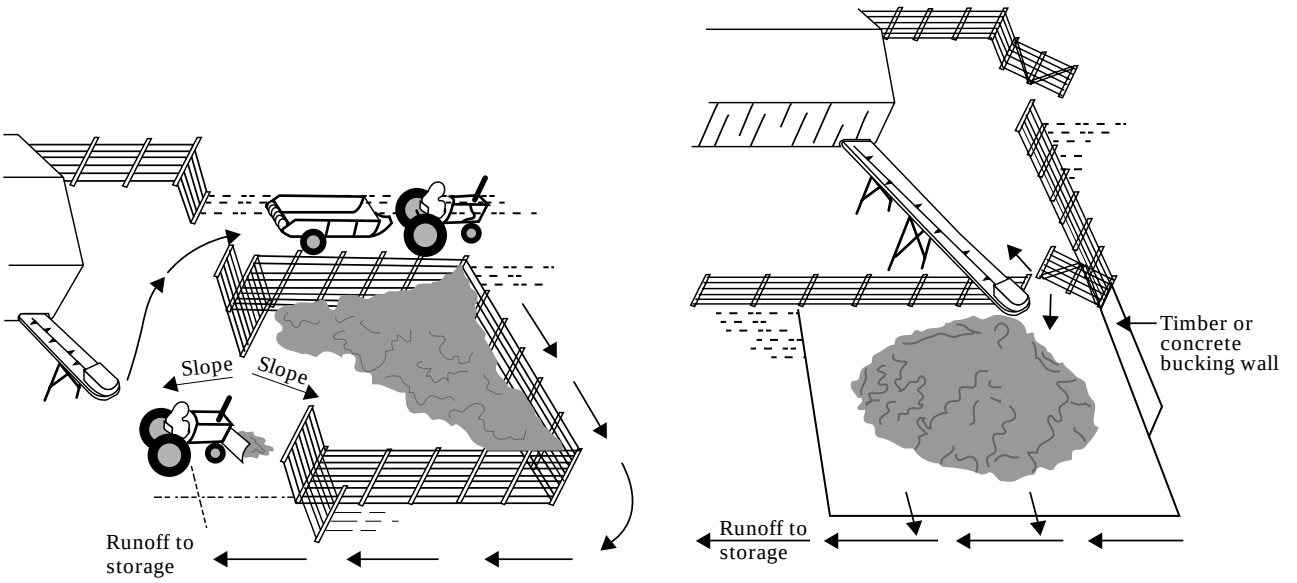
VMD = volume of manure production for animal type for storage period, ft^3

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

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

D = Number of days in storage period

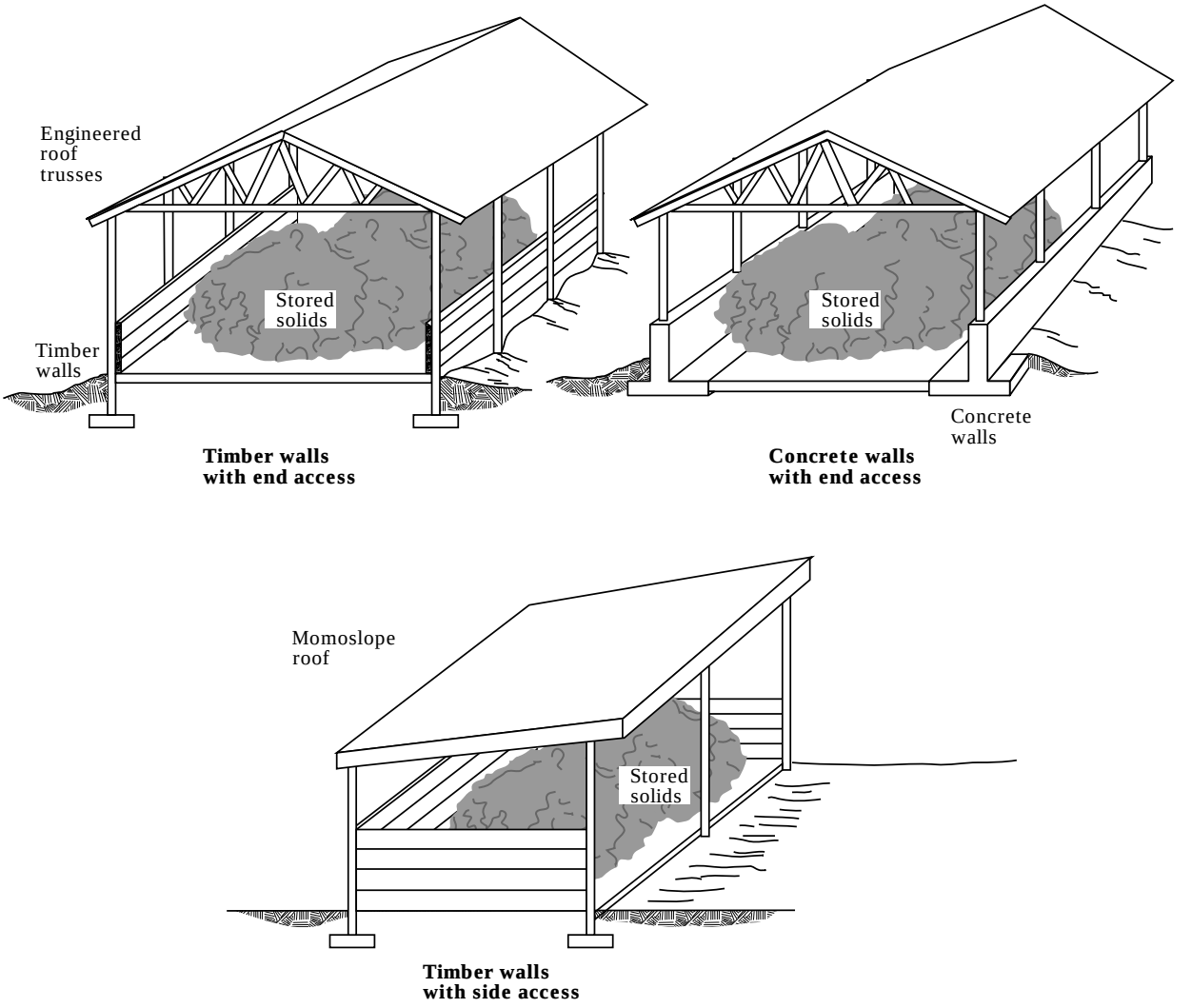
Figure 10–12 Solid manure stacking facilities



Barn cleaner to spreader or tractor stacking

To storage and/or spreader from elevator stacker

Figure 10–13 Roofed solid manure storage



The bedding volume to be stored can be computed using:

$$BV = \frac{FR \times WB \times AU \times D}{BUW} \qquad [10–2]$$

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/day
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 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.

(2) Design example 10–2—Waste stacking facility

Mr. Ralph Kilpatrick of Hoot Ridge, Kentucky, has requested assistance in developing a waste management system. He selected an alternative that includes solid manure storage for his 100 Holstein milking cows and 52 heifers. 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 no more than 7 feet deep. 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 units for each animal type is calculated and entered on **line 4**. Daily manure production **(line 4)** is in table 4–5 in chapter 4. The number of days in storage is entered on **line 5**. 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 is entered on **line 12.** The bedding unit weight, which may be taken from table 4–4, 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 and depth are known, so the length **(line 17)** is calculated 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, Waste Storage Facility, Code 313, are to be used (NRCS 1995).

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

Completed worksheet for Design example 10–2

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)= *1.30* *1.30* _____
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 = *16,380* *6,084* _____
8. Total manure production for storage period, ft^3 (TVM) *22,464*

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 = *22,464* + *0* + *2,232* = *24,696*

Waste stacking structure sizing

17. Structure length, ft $L = \frac{WV}{WI \times H}$ = *88.2 (USE 90)*
18. Structure width, ft $WI = \frac{WV}{L \times H}$ = *40*
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 $SA = \frac{WV}{E\,H}$ = _____

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.

(b) Liquid and slurry waste storage

Liquid and slurry manure can be stored in waste storage ponds or in aboveground or below-ground 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.

Storage ponds are earthen basins designed to store wastewater and manure (figs. 10–14, 10–15, 10–16). 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 should be 8 feet; 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 section 651.1005. Flow of wastes away from the inlet should be considered in selecting the location of the inlet.

Figure 10–14 Cross section of waste storage pond without a watershed

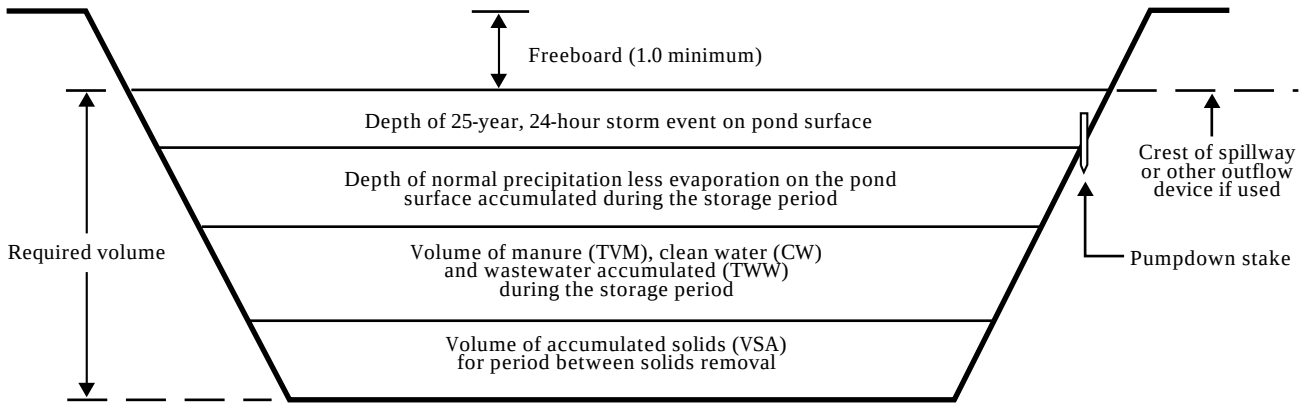
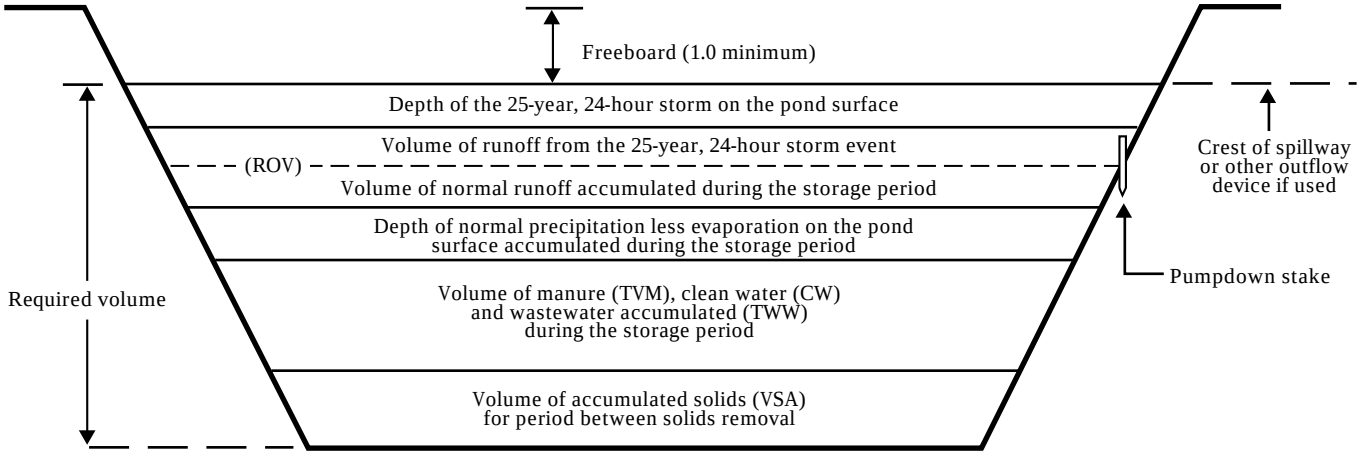
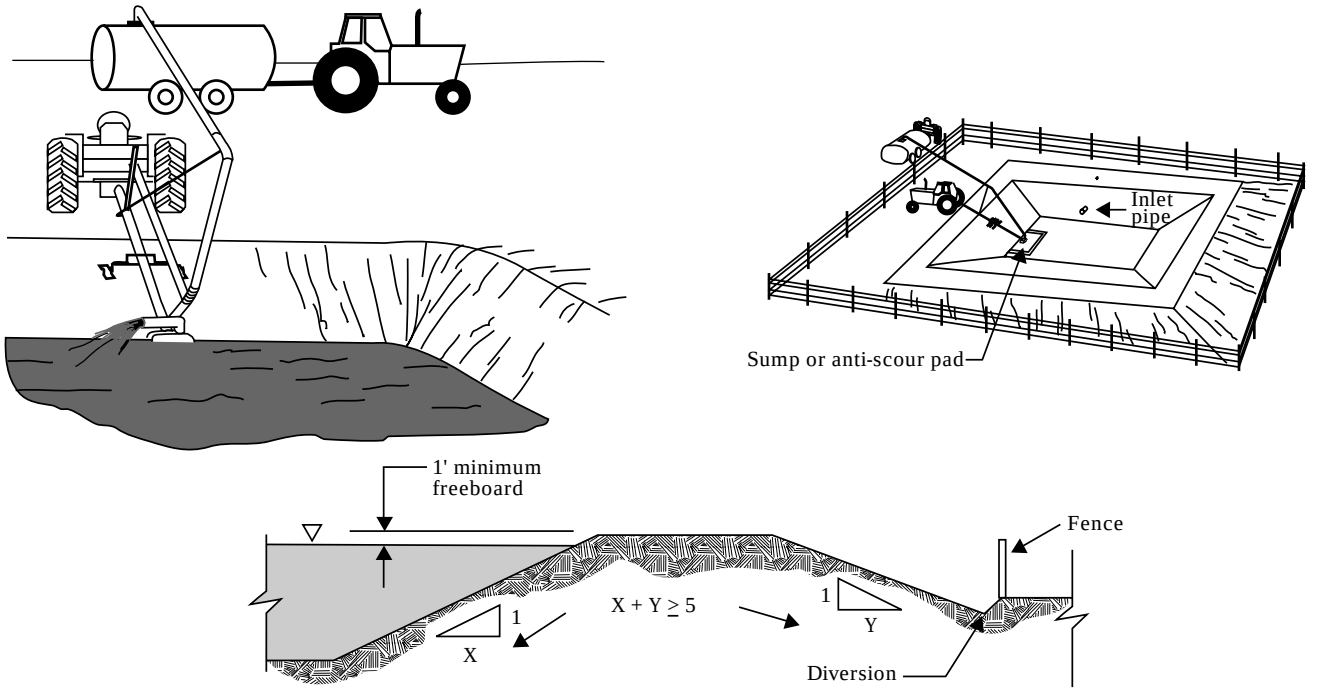


Figure 10–15 Cross section of waste storage pond with watershed



*or other outflow device

Figure 10–16 Waste storage ponds



Cross-section earth embankment

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 wastes will be pumped, adequate access must be provided to thoroughly agitate the contents of the pond. 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. See Appendix 10D, Geotechnical design and construction guidelines for waste impoundment Liners, for detail on clay liners. Concrete also provides a wear surface if unloading equipment will enter the pond.

Figures 10–17, 10–18, and 10–19 represent various kinds of storage ponds and tanks.

Liquid manure can be stored in aboveground (fig. 10-18) or below-ground (fig. 10–19) tanks. Liquid manure storage tanks can be constructed of metal, concrete, or wood. Below-ground 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 waste 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. Wastes are allowed to collect for several days, typically 1 to 2 weeks, before the pits are gravity drained.

Figure 10–17 Layout of waste storage pond

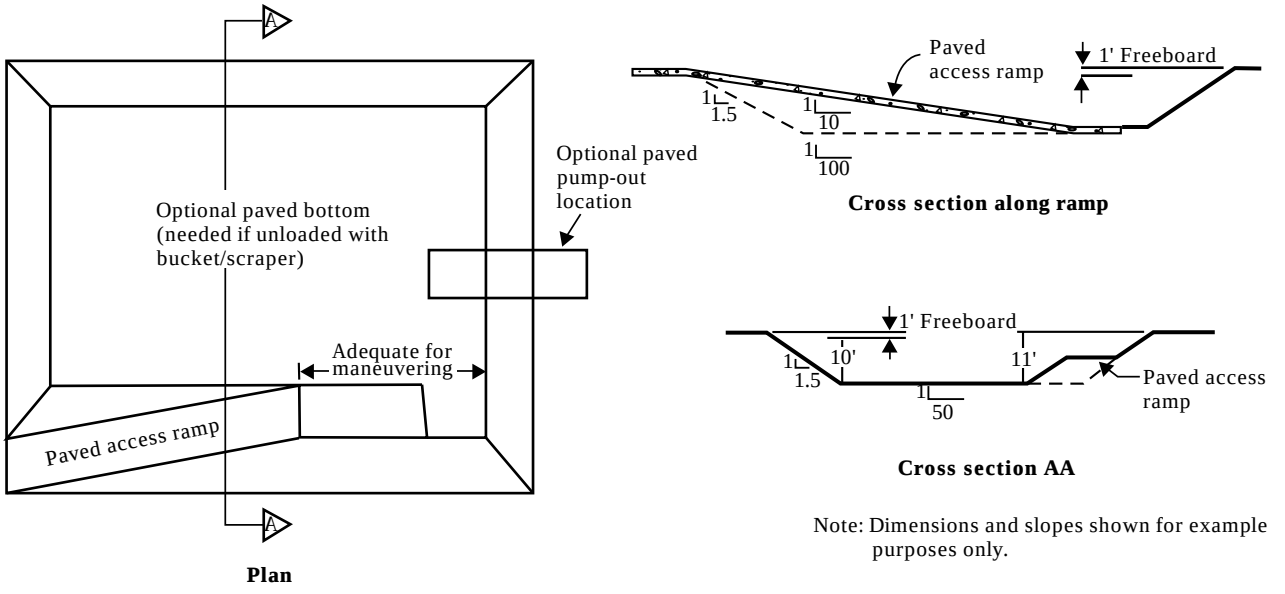


Figure 10–18 Aboveground waste storage tank

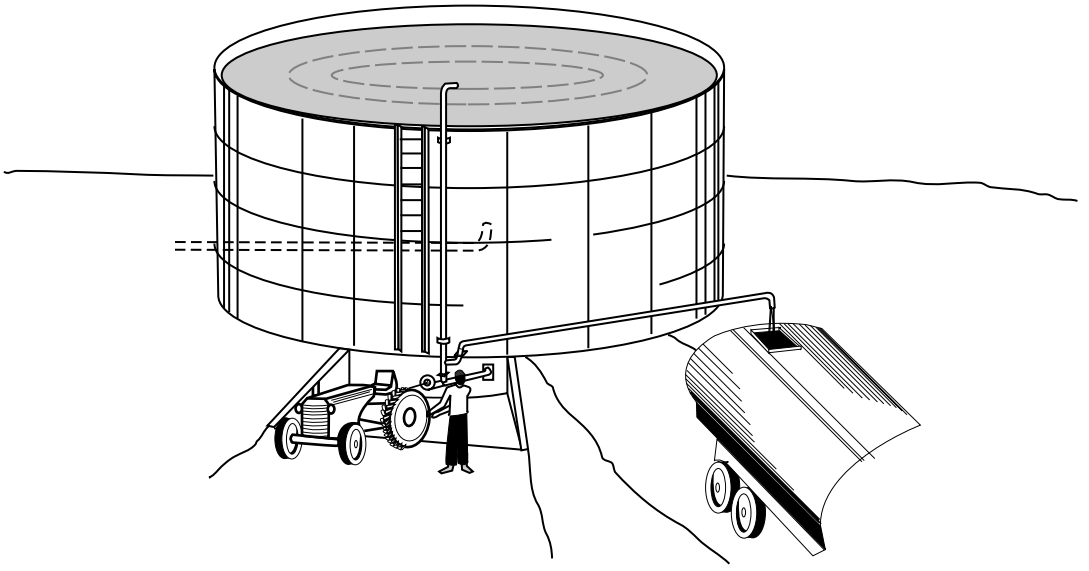
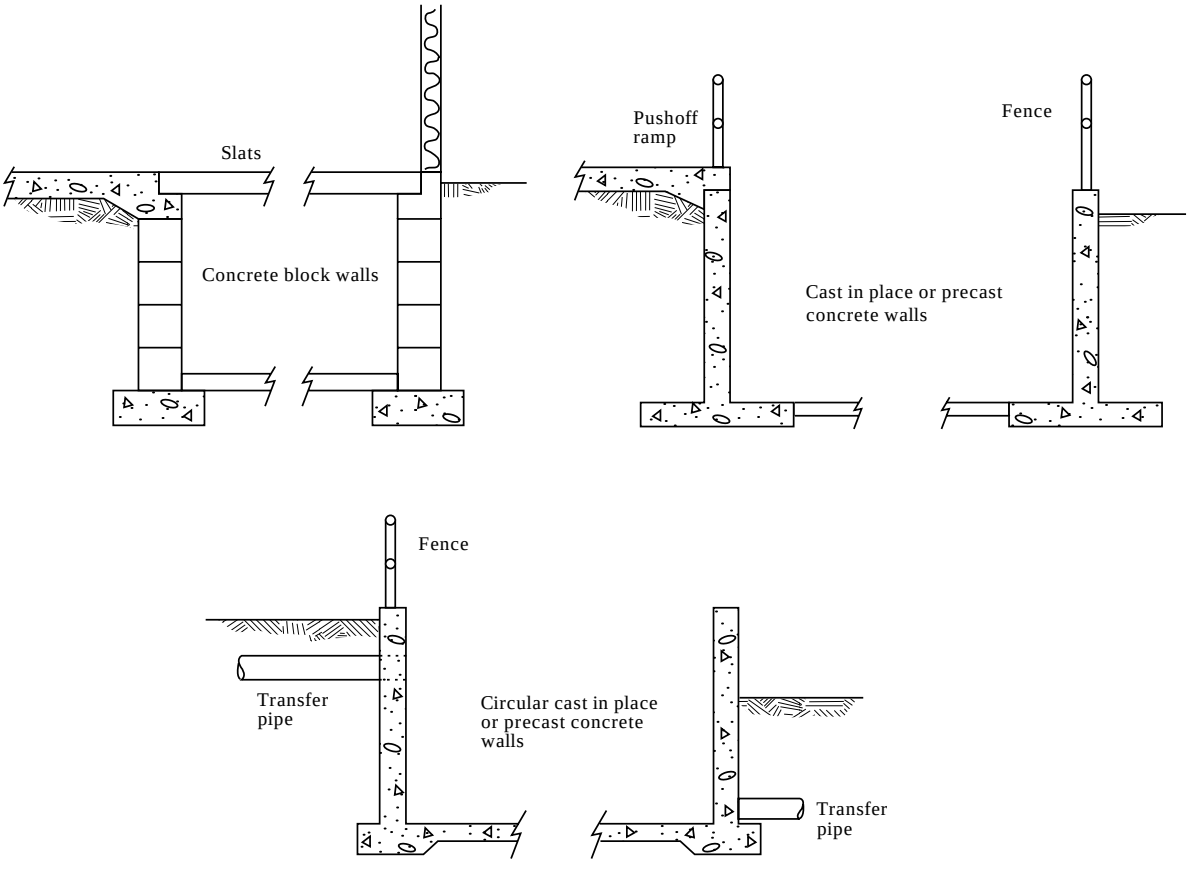


Figure 10–19 Below-ground waste storage structure



(1) Design considerations

Tank material types—The primary materials used to construct manure tanks are reinforced concrete, metal, and wood. 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.

Cast-in-place, reinforced concrete, the principal material used in below-ground tanks, can be used in above-ground 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 above-ground 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.

At least one company offers a wooden above-ground tank for liquid storage. The preservative treated boards have tongue-and-groove edges and are held in place using metal hoops similar to those used for concrete panel tanks. All manure tanks should meet the standards identified in the section on solid manure storage.

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

$$WV = TVM = TWM = TBV \qquad [10–3]$$

where:

WV = Waste volume for storage period, ft^3

TVM = Total volume of manure for storage period, ft^3 (see equation 10–1)

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

TBV = Total bedding volume for storage period, ft^3 (see equation 10–2)

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

In addition to the waste volume, waste 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. Waste 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.

Waste 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, waste 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 Engineering Handbook for Conservation Practice, chapter 2, 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 in section 651.1003(a) on solid manure storage material 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—Waste 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 Appendix 10D, Geotechnical design and construction guidelines for waste impoundment liners, for detail on determining need for and design of clay liners. Also refer to Chapter 7, Geology and Ground Water Considerations, for more information on site evaluation, investigations, and testing.

(3) Design example 10–3—Waste storage tank

Mr. Bill Walton of Middlesburg, Tennessee, has requested assistance on a waste management system. The selected alternative includes a below-ground, covered, slurry storage tank for his Holstein dairy herd. He has 150 milkers that average 1,400 pounds and 75 heifers that are about 1,000 pounds each. 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 wash water 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 waste.

Manure production—The animal type, average weight, and number are entered on **lines 1, 2,** and **3.** The equivalent 1,000 pound animal units (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 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 wastewater volume per animal unit description (DWW) is selected from table 4–6 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 **(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.

Total solids content—The initial TS content of the manure is given in table 4–5 in chapter 4. Because there are two sources of manure, the solids content of the total manure must be weighted by the contribution from each animal type. The adjusted total solids content of the stored manure is determined from figure 10–40 using the added water from the milkhouse and parlor, the runoff (none in this example), and the net rainfall during the storage period. Because the total solids content of milking center wastewater is so low, it can be ignored.

$$\text{Initial TS} = \frac{(12.5\% \times 210\text{AU}) + (10.7\% \times 75\text{AU})}{210\text{AU} + 75\text{AU}}$$
$$= 12\%$$

Added water:

$$\left[9{,}450\ \text{ft}^3 + \left(0.3\ \text{ft} \times 33{,}580\ \text{ft}^3\right)\right] \times 7.48\ \text{gal / ft}^3$$
$$= 78{,}720\ \text{gal}$$

Added water/ft³ manure:

$$\frac{78{,}20}{20{,}472 + 7{,}313} = 2.8\ \text{gal / ft}^3$$

From figure 10–40, adjusted TS = 8.8%.

Completed worksheet for Design example 10–3

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)= *1.3* | *1.3* | _____
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 = *20,475* | *7,312* | _____
8. Total manure production for storage period, ft^3 (TVM) *27,787*

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, ff^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 = *27,787* + *9,450* + *0* = *37,237*

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. – *0*
(uncovered tanks only)
Less depth allowance for accumulated solids, ft – *0.5*
(0.5 ft. minimum)
Less depth for freeboard (0.5 ft. recommended), ft – *0.5*
Effective depth, ft (EH) = *11*

21. Surface area required, ft^2 SA = $\frac{WV}{E\ H}$ = *3,385*

22. Rectangular tank dimensions
Total height, ft (H) = *12* Selected width, ft (WI) = *30*
Length, ft L = $\frac{SA}{WI}$ = *112.8* *(USE 115)*

23. Circular tank dimensions
Total height, ft H = *12*
Diameter, ft DIA = $(1.273 \times SA)^{0.5}$ = *65.6* *(USE 66)*

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.

(4) Design example 10–4—Waste storage pond

Mr. Joe Green of Silverton, Oregon, has requested assistance in developing an agricultural waste management system for his dairy. He has selected an alternative that includes a waste storage pond component. He has a Holstein herd composed of 500 milkers averaging 1,400 pounds; 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 waste storage pond and to allow recycling of the flush water. 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 units for each animal type (AU) is calculated and entered on **line 4**. The volume of daily manure production (DVM) from table 4–5 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 flush water is recycled. The daily wastewater volume per animal unit (DWW) from table 4-6 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 waste storage pond does not have a watershed and storage for runoff is not needed. However, waste 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 Engineering Field Manual for Conservation Practices. 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.

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). Waste 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 waste storage pond must be sized to store this volume plus additional depth as explained in "depth adjustment."

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)= *1.30* | *1.30* | *1.30*
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 = *163,800* | *49,140* | *35,100*
8. Total manure production for storage period, ft^3 (TVM) *248,040*

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
= *248,040* + *75,600* + *0* + *0* + *0* = *323,640*

Pond sizing

16. Sizing by trial and error

Side slope ratio, (Z) = *3* V must be equal to or greater than WV = *323,640* 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)
1	100	500	6	367,392
2	100	400	6	296,592
3	100	425	6	314,292
4	100	425	6.2	326,903

≈ *WSV OK*

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) *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*

Waste storage pond sizing—The waste storage pond is sized by trial and error for either a rectangular or circular shaped pond by using the procedure on **line 16**. Figure 10-20 is a simple BASIC computer program that can be used to compute the volume by inputting the bottom width, bottom length, and depth.

Depth adjustment—The depth required to store the waste 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**.

Figure 10–20 BASIC computer program for determining pond volume

```
100  REM*************************************************
110  REM * BASIC program for solving the rectangular pond volume *
120  REM * equation                                              *
130  REM*************************************************
140  INPUT "Side Slope Ratio, Z";Z
150  INPUT "Trial No.";T
160  INPUT "Trial Bottom Width, BW";W
170  INPUT "Trial Bottom Length, BL";L
180  INPUT "Trial Depth, d";D
190  V = (W*L*D)+(Z*D^2*L)+(Z*D^2*W)+((4*Z^2*D^3)/3)
200  PRINT "V = ";V;"cubic feet"
210  GOTO 150
220  END
```

```
100  REM ********************************************
110  REM * BASIC program for solving the circular pond volume *
120  REM * equation                                           *
130  REM ********************************************
140  INPUT "Side Slope Ratio, Z";Z
150  INPUT "Trial No.";T
160  INPUT "Trial Bottom Diameter, DIA";W
170  INPUT "Trial Depth, d";D
180  V = (1.05*Z^2*D^3)+(1.57*W*Z*D^2)+(.79*W^2*D)
190  PRINT "V = ";V;"cubic feet"
200  GOTO 150
210  END
```

651.1004 Treatment

In many situations it is necessary to treat agricultural waste before final utilization. The purpose of treatment is to reduce pollution potential of the waste through biological, physical, and chemical processes using such components as lagoons, oxidation ditches, and composting. These types of components reduce nutrients, destroy pathogens, and reduce total solids. Composting also reduces the volume of the waste. Treatment also includes any step that might be considered pretreatment, such as solids separation, drying, and dilution that prepares the waste for facilitating another function. By their nature, treatment facilities require a higher level of management than that of storage facilities.

(a) Anaerobic lagoons

Anaerobic lagoons are widely accepted in the United States for the treatment of animal waste. Anaerobic treatment of animal waste helps to protect water quality by reducing much of the organic concentration (BOD, COD) of the waste. Anaerobic lagoons also reduce the nitrogen content of the waste through ammonia volatilization and effectively reduce animal waste odors if the lagoon is managed properly.

(1) 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)

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 10–21. 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 10-22 indicates the maximum VSLR's for the United States. If odors need to be minimized, VSLR should be reduced by 25 to 50 percent.

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

$$MTV = \frac{TVS}{VSLR} \qquad [10–4]$$

where:

MTV = Minimum treatment volume, ft^3
TVS = Total daily volatile solids loading (from all sources), lb/day
VSLR = Volatile solids loading rate, lb/1,000 ft^3/day (from fig. 10–22)

Daily volatile solids production for various wastes can be determined using tables in 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, flush water 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.

$$WV = TVM + TWW + CW \qquad [10–5]$$

where:

WV = Waste volume for treatment period, ft^3

TVM = Total volume of manure for treatment period, ft^3

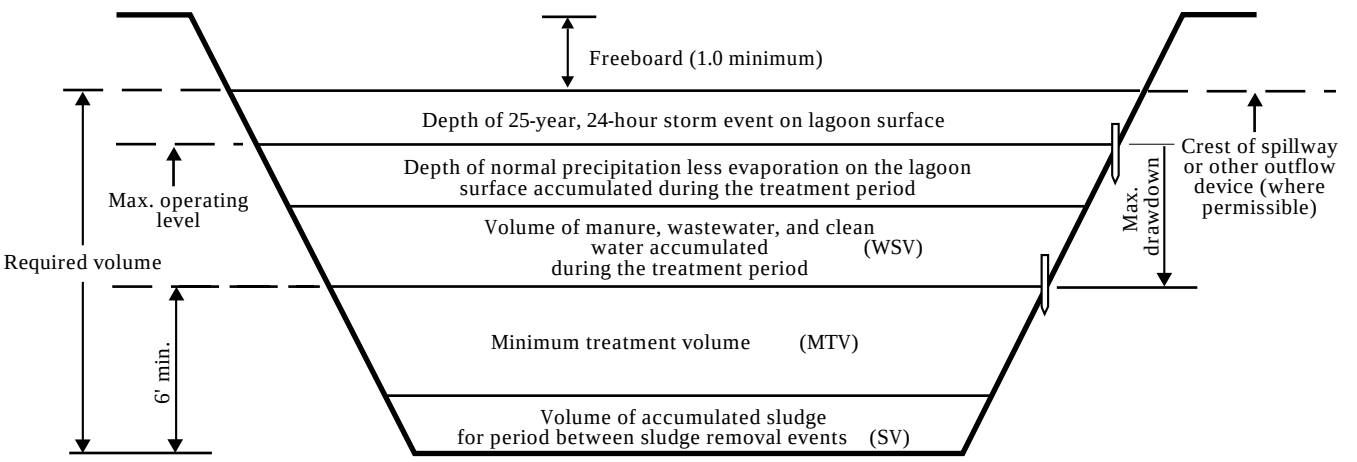
TWW = Total volume of wastewater for treatment period, ft^3

CW = Clean water added during treatment period, ft^3

In the absence of site-specific data, values in chapter 4 may be used to make estimates of the volumes.

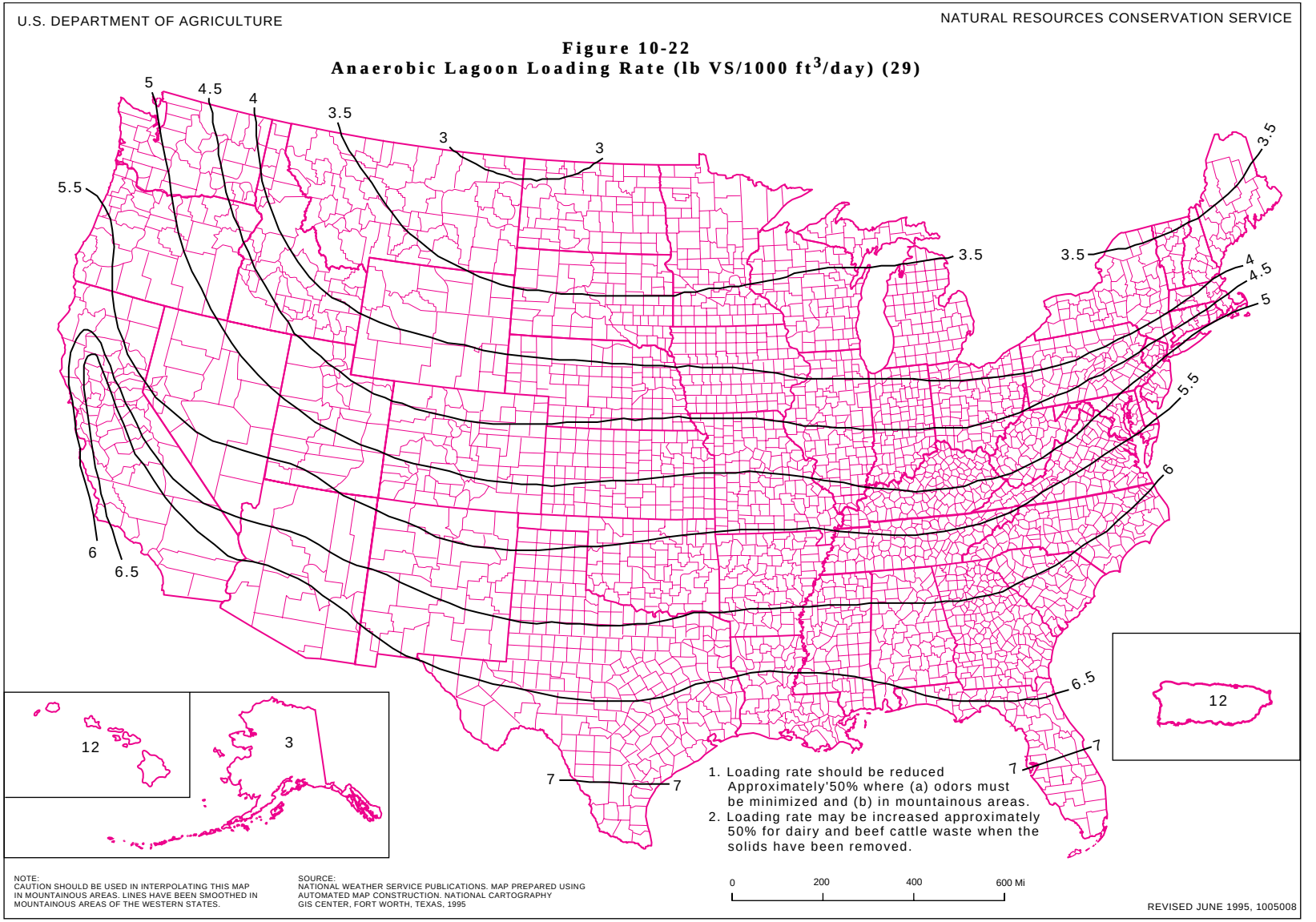
As the manure is decomposed in the anaerobic lagoon only part of the total solids (TS) is reduced. Some of the TS is mineral material that will not decompose, and some of the VS require a long time to decompose. These materials, referred to as sludge, gradually accumulate in the lagoon. To maintain the minimum treatment volume (MTV), the volume of sludge accumulation over the period of time between sludge removal

Figure 10–21 Anaerobic lagoon cross section



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

Figure 10–22 Anaerobic lagoon loading rate



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.

$$SV = 365 \times AU \times TS \times SAR \times T \qquad [10–6]$$

where:

SV = Sludge volume (ft^3)
AU = Number of 1,000-pound animal units
T = Sludge accumulation time (years)
TS = Total solids production per animal unit per day (lb/AU/day)
SAR = Sludge accumulation ratio (ft^3/lb TS)

Total solids values can be obtained from the tables in chapter 4. Sludge accumulation ratios should be taken from table 10-4. 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 minimum treatment volume, the sludge volume, and the waste volume for the treatment period. This is expressed in equation 10–7.

$$LV = MTV + SV + WV \qquad [10–7]$$

where:

LV = Lagoon volume requirement, ft^3
MTV = Minimum treatment volume, ft^3 (see equation 10–4)
SV = Sludge volume accumulation for period between sludge removal events, ft^3 (see equation 10–6)
WV = Waste volume for treatment period, ft^3 (see equation 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.

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 as shown in table 10–5, although a width of 8 feet and less is difficult to construct.

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

Table 10–4 Sludge accumulation ratios (Barth 1985)

Animal type	SAR
Poultry	
Layers	0.0295
Pullets	0.0455
Swine	0.0485
Dairy cattle	0.0729

Table 10–5 Minimum top width for lagoon embankments (USDA 1984, Waste...)

Maximum height of embankment, ft	Top width, ft
10 or less	6
11–14	8
15–19	10
20–24	12
25–34	14
35 or more	15

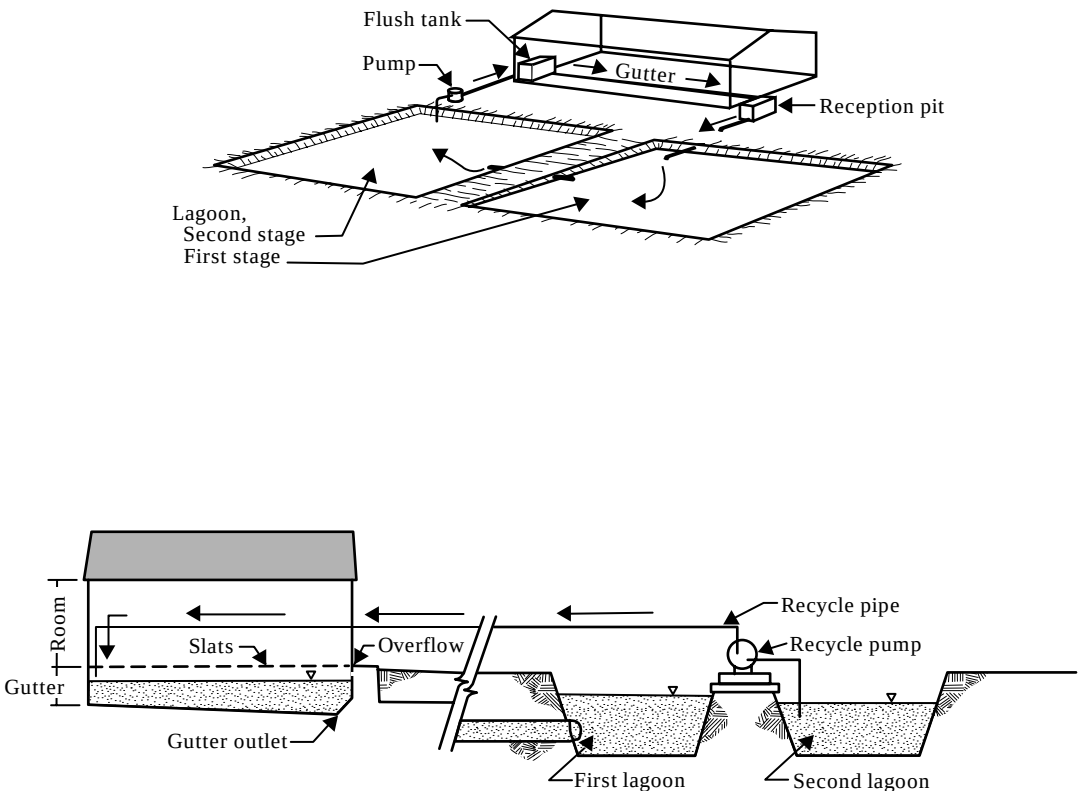
and bank stabilization. The minimum elevation of the top of the settled embankment should be 1 foot above the maximum design water surface in the lagoon.

A lagoon should be constructed to avoid seepage 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 Appendix 10D, Geotechnical design and construction guidelines for waste impoundment liners, can be used. Also refer to Chapter 7, Geology and Ground Water Considerations, for more information on site evaluation, investigations, and testing. Figure 10–23 shows a 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. 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.

Figure 10–23 Anaerobic lagoon recycle systems



(2) 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 10–21. 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 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 all of the expected waste load 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 flush water. 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.

(3) 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)= *1.0*
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 = *162,000*
8. Total manure production for treatment period, ft^3 (TVM) = *162,000*

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 = *162,000* + *0* + *0* = *162,000*

Manure total solids

14. Daily manure total solids production, lbs/AU/day (MTS) = *6.34*
15. Daily manure total solids production for animal type, lbs/day MTSD = MTS x AU = *5706*
16. Total manure total solids production, lbs/day (TMTS) = *5706*

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 (*5706*)(*5*)(*0.0485*) = *505,052*

Minimum lagoon volume requirement

29. Minimum lagoon volume requirements, ft^3 (MLVR) = MTV + SV + WV = *810,000* + *505,052* + *162,000* = *1,477,052*

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 = 1,477,052 ft^3

Trial no.	Bottom width ft (BW)	Bottom length ft (BL)	Depth* ft (d)	Volume ft^3 (V)
1	150	1000	8	1,349,931
2	150	1200	8	1,615,531
3	150	1100	8	1,482,731 ≈ 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, ft^3 (use equation in step 30) 2,014,299

(b) Aerobic lagoons

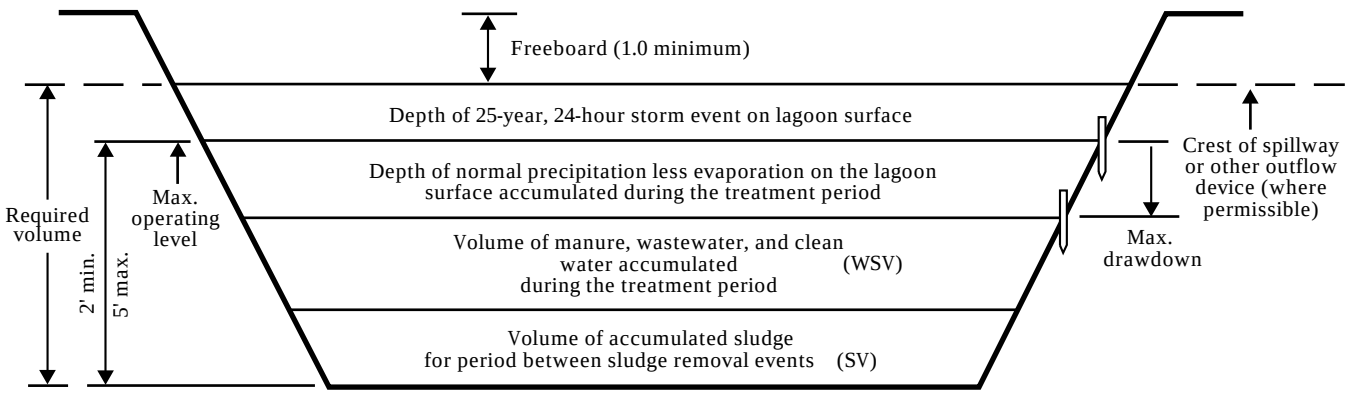
Aerobic lagoons can be used if minimizing odors is critical (fig. 10–24). These lagoons operate within a depth range of 2 to 5 feet to allow for the oxygen entrainment that is necessary for the aerobic bacteria.

The design of aerobic lagoons is based on the amount of BOD_5 added per day. If local data are not available, use the BOD_5 values from the tables in chapter 4. Figure 10–25 shows the acceptable aerobic loading rates for the United States in lb-BOD_5/acre/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 10–24 demonstrates these volume depth requirements.

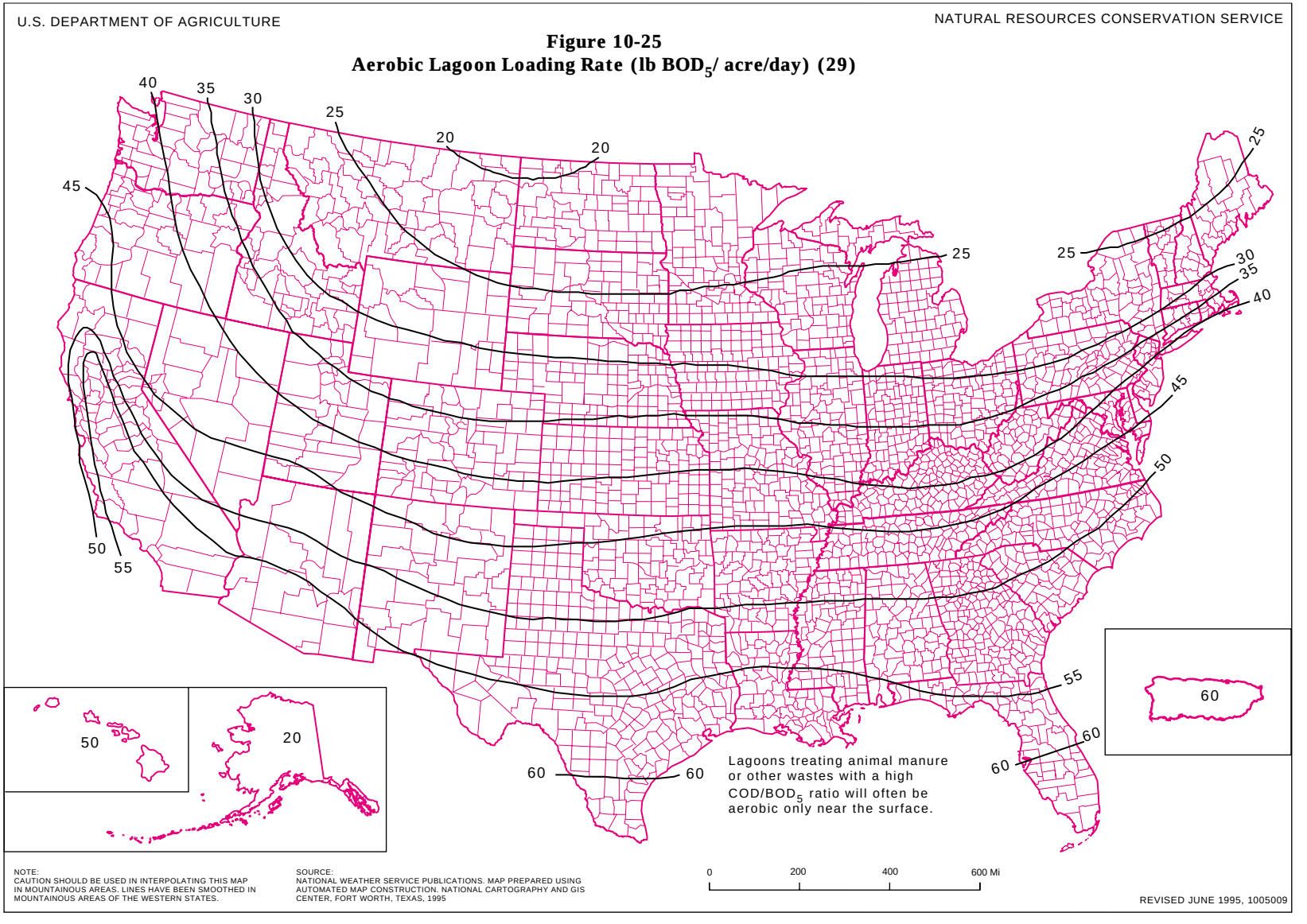
Aerobic lagoons need to be managed similarly to anaerobic lagoons in that they should never be overloaded with oxygen demanding material. The lagoon should be filled to the minimum operating level, generally 2 feet, before being loaded with waste. The maximum liquid level should not exceed 5 feet. The 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 10–24 Aerobic lagoon cross section



Note: An aerobic waste treatment lagoon has a required minimum surface area based on BOD_5

Figure 10–25 Aerobic lagoon loading rate



(1) 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) = 15.1
15. Daily manure total solids production for animal type, lb/day MTSD = MTS x AU = 3020
16. Total manure total solids production, lbs/day (TMTS) = 3020

Manure 5-day biochemical oxygen demand

17. Daily manure BOD_5 production per AU, lbs/AU/day (MBOD) = 3.7
18. Daily manure BOD_5 production for animal type per day, lbs/day MBOD = AU x BOD = 740
19. Total manure production, lbs/day (TMBOD) 740

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 = 740 + 0 = 740

Minimum treatment surface area

24. Selected lagoon BOD_5 loading rate, lbs BOD_5/acre (BODLR) = 50
25. Minimum treatment surface area, acres MTA = $\frac{TBOD}{BODLR}$ = $\frac{(740)}{(50)}$ = 14.8

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 (3020)(5)(0.0295) = 162,589

Minimum lagoon volume requirement

29. Minimum lagoon volume requirements, ft^3 MLVR = SV + WV = 162,589 + 33,480 = 196,069

Worksheet 10A-4—Aerobic Lagoon Design—Continued

Lagoon sizing

30. Sizing by trial and error:

Side slope ratio, (Z) = 2

V must be equal to or greater than MLVR = 196,069 ft^3

SA must be equal to or greater than MTA = 14.8 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	600	1100	1	663,405	15.3 OK

** Depth must be adjusted in Step 31*

Depth adjustment

31. Depth adjustment

Depth , ft (d) ---------- 1.0

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 ---------- 3.1

32. Compute total volume using final depth, ft^3
(use equation in step 30) ---------- 2,146,991=79,518

(c) Mechanically aerated lagoons

Much of this material was taken directly from technical notes on the design of mechanically aerated lagoons for odor control (Moffitt 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.

(1) Lagoon loading

Lagoon loading should be based on 5-day biochemical oxygen (BOD_5) or carbonaceous oxygen demand (COD). NRCS designs on the basis of BOD_5. The tables in chapter 4 show recommended BOD_5 production rates, but local data should be used where available.

(2) 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 per 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 psi), dissolved oxygen equal to 0 percent, and water at 20 °C. The actual transfer rate expected in field operation can be determined by using equation 10–8.

$$FTR = CWTR \times \frac{\left(B \times C_{dc}\right) - DO}{C_{sc}} \times O^{t-20} \times a \quad [10\text{-}8]$$

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 10–26 and 10–27.

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 = The 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 10–28 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.

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.

$$HP = \frac{BOD_5}{FTR \times HO} \qquad [10–9]$$

where:

HP = Horsepower

BOD_5 = 5-day biochemical oxygen demand loading of waste, lb/day

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.

Figure 10–27 Relation of dissolved oxygen saturation to elevation above mean sea level

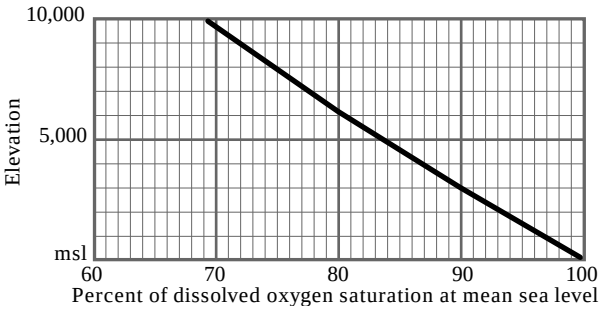


Figure 10–26 Relation of dissolved oxygen saturation to water temperature (clean water at 20 °C and sea level)

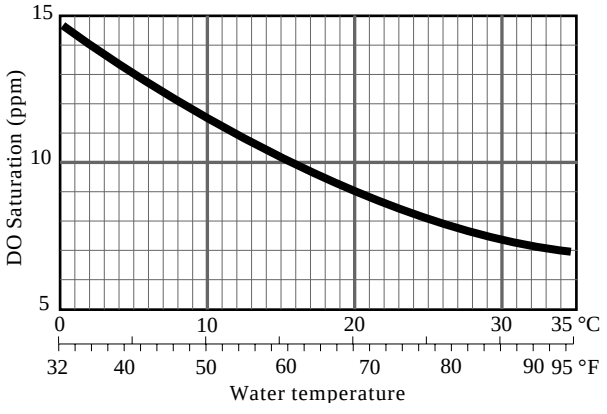
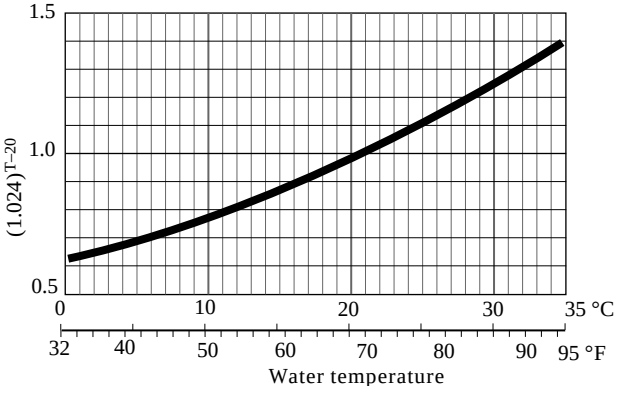


Figure 10–28 Numeral values for O^{t-20} at different temperatures where O=1.024



(d) 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. 10–29). 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.

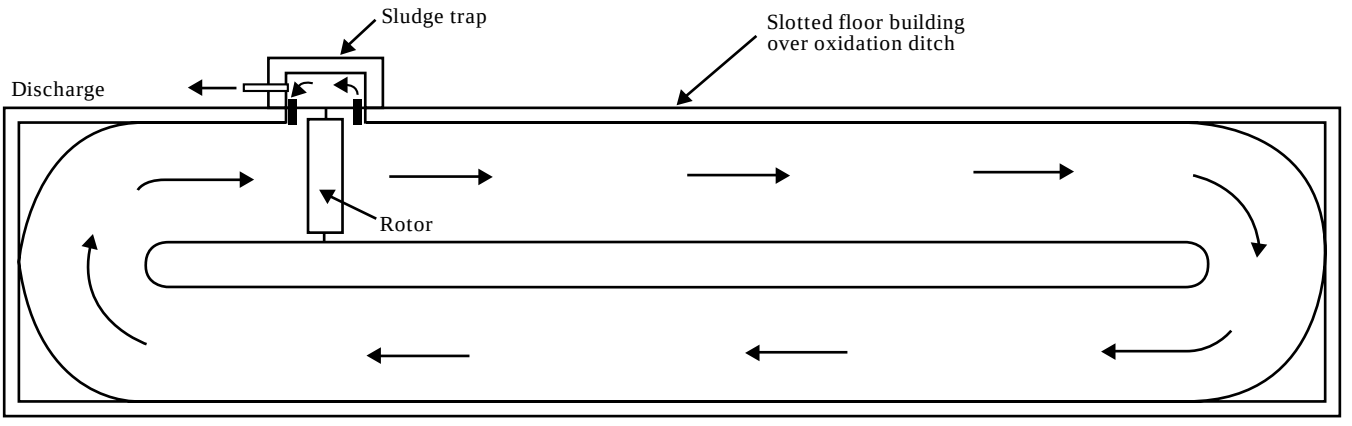
(e) Drying/dewatering

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 redried 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.

Figure 10–29 Schematic of an oxidation ditch



(f) 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.

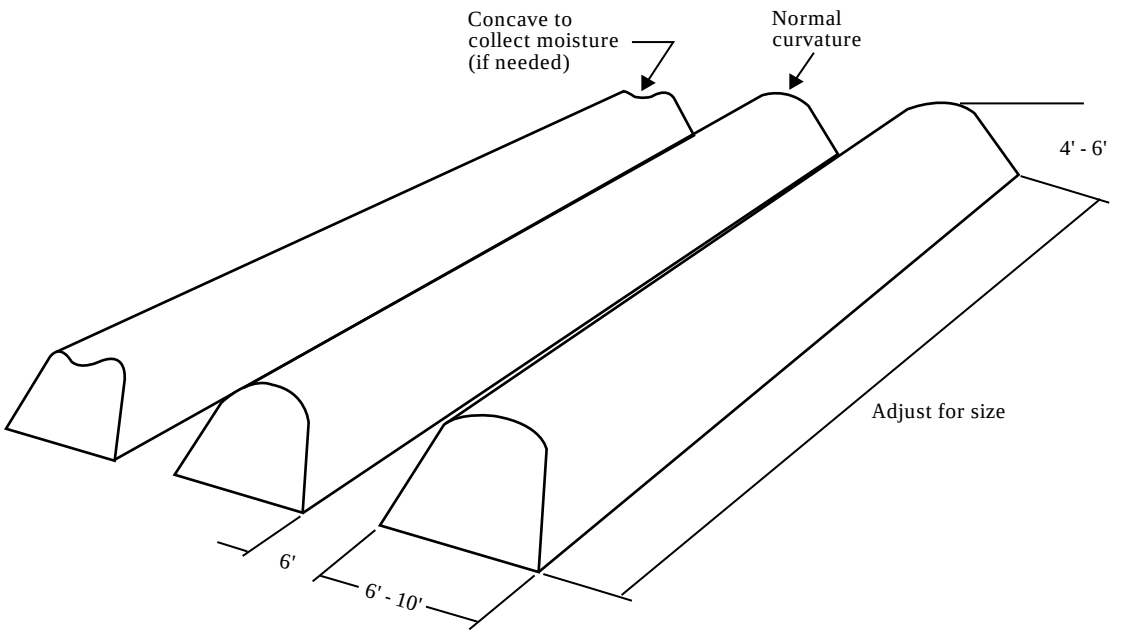
(1) Composting methods

Three basic methods of composting—windrow, static pile, and in-vessel—are described below.

(i) Windrow method—The windrow method involves the arrangement of compost mix in long, narrow piles or windrows (fig. 10–30). 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 the 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 a automatic mechanical turner. Windrows generally are 4 to 6 feet deep and 6 to 10 feet wide.

Figure 10–30 Windrow schematic



Some advantages and disadvantages of the windrow method include:

Advantages:
- Rapid drying with elevated temperatures
- Drier product, resulting in easier product handling
- 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

(ii) 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.

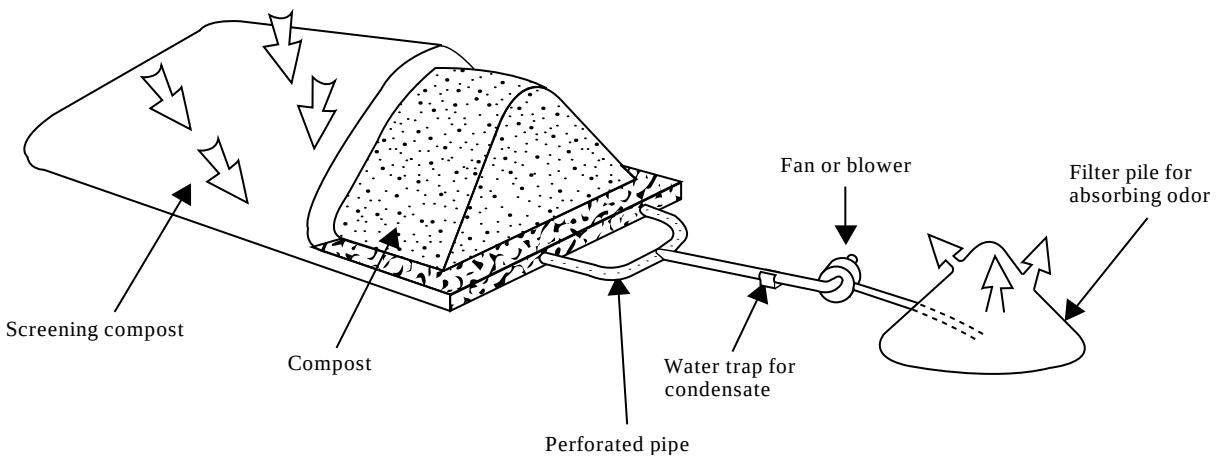
With forced air systems, air movement through the pile occurs by suction (vacuum) or by positive pressure (forced) through perforated pipes or tubing. A filter pile or material is normally used to absorb odor if air is sucked through the pile (fig. 10–31).

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 10–31 Static pile composting schematic



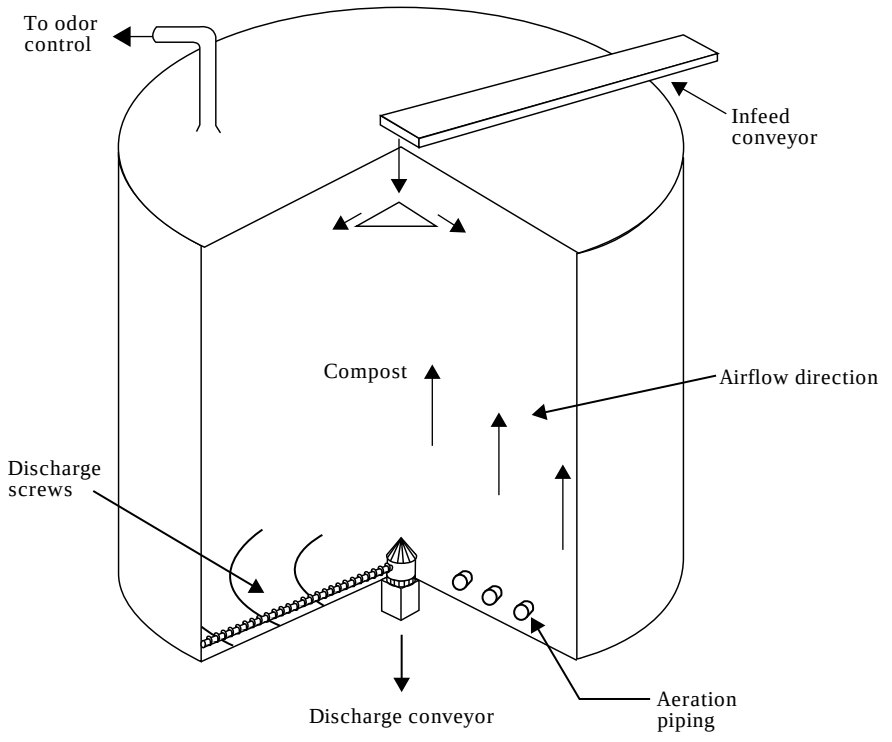
***(iii) In-vessel method*—**The in-vessel method involves the mixing of manure or other organic waste with a bulking agent in a reactor, building, container, or vessel (fig. 10–32) and may involve the addition of a controlled amount of air over a specific detention time. This method has the potential to provide a high level of process control because moisture, aeration, and temperature can be maintained with some of the more sophisticated units. Dead animal composting in a composting bin as discussed in section 651.1007(b), Dead animal disposal, is an example of unsophisticated in-vessel composting.

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 10–32 In-vessel composting schematic



(2) 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:

(i) 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.

(ii) 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.

(iii) Site features—If a limited amount of space is available, then 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, then 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.

(iv) Compost utilization—If the compost is to be marketed commercially, then 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.

(v) 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.

(vi) 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.

(3) 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 are discussed below.

(i) 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.

(ii) 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.

(iii) 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.

***(iv) 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 cubit 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.

***(v) Existing areas*—**To reduce the initial capital cost, existing roofed, concrete, paved, or gravel areas should be used if possible as a composting site.

(4) 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 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. Refeeding of the poultry compost as a food supplement is currently being tested and may prove to be an acceptable use of poultry compost.

(5) 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 10–6 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.

(i) Compost design parameters—To determine the recipe, the characteristics of the waste and the amendments 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, micro-organisms 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

Table 10–6 Typical carbon to nitrogen ratios of common composting amendments*

Material	C:N ratios	Material	C:N ratios
Alfalfa (broom stage)	20	Pig manure	5–8
Alfalfa hay	12–18	Pine needles	225–1000
Asparagus	70	Potato tops	25
Austrian pea straw	59	Poultry manure (fresh)	6–10
Austrian peas (green manure)	18	Poultry manure (henhouse litter)	12–18
Bark	100–130	Reeds	20–50
Bell pepper	30	Residue of mushroom culture	40
Breading crumbs	28	Rice straw	48–115
Cantaloupe	20	Rotted manure	20
Cardboard	200–500	Rye straw	60–350
Cattle manure (with straw)	25–30	Saw dust	300–723
Cattle manure (liquid)	8–13	Sawdust (beech)	100
Clover	12–23	Sawdust (fir)	230
Clover (sweet and young)	12	Sawdust (old)	500
Corn & sorghum stover	60–100	Seaweed	19
Cucumber	20	Shredded tires	95
Dairy manure	10–18	Soil organic matter	10–24
Garden wastes	20–60	Soybean residues	20–40
Grain rice	36	Straw	40–80
Grass clippings	12–25	Sugar cane (trash)	50
Green leaves	30–60	Timothy	80
Green rye	36	Tomato leaves	13
Horse manure (peat litter)	30–60	Tomatoes	25–30
Leaves (freshly fallen)	40–80	Watermelon	20
Newspaper	400–500	Water hyacinth	20-30
Oat straw	48–83	Weeds	19
Paper	173	Wheat straw	60-373
Pea vines (native)	29	Wood (pine)	723
Peat (brown or light)	30–50	Wood chips	100–441

* For further information on C:N ratios, see chapter 4 of this handbook.

decomposition and volatilization of ammonia. If it is high, the composting time increases because the nitrogen becomes the limiting nutrient for growth.

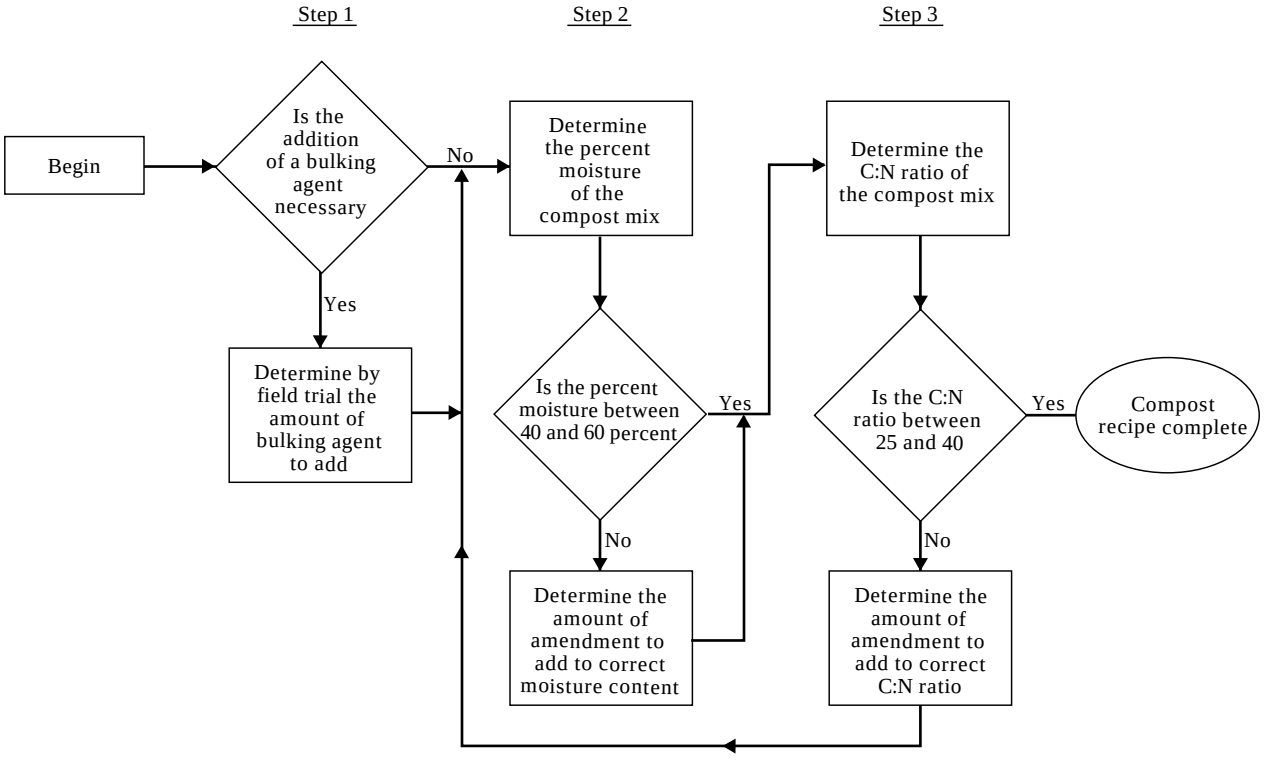
Moisture—Micro-organisms need moisture to convert the carbon source to energy. Bacteria generally can tolerate a moisture content as low as 12 to 15 percent; however, with less than 40 percent moisture, the rate of decomposition is slow. At greater than 60 percent moisture, the process turns from one 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.

***(ii) 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 10–33 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

Figure 10–33 Compost mixture design flow chart



compost mix design. These steps follow the mixture design process flow chart shown in figure 10-33.

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. Chapter 4 of this handbook 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 moisture content of the mix. Using this procedure the moisture content can be calculated as follows:

$$M_i = \frac{\text{Wet weight - Dry weight}}{\text{Wet weight}} \times 100 \qquad [10–10]$$

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.)

$$M_M = \frac{\dfrac{(W_w \times M_w) + (W_b \times M_b) + (W_a \times M_a)}{100}}{W_m} + H_2O \qquad [10–11]$$

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 x 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 a 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 a 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.

$$W_{aa} = \frac{W_{mb} \times \left(M_{mb} - M_d\right)}{M_d - M_{aa}} \qquad [10–12]$$

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% 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 chapter 4 of this handbook. The C:N ratios for various waste products and amendments are also shown in table 10–6. 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.

$$\%C = \frac{100 - \%FS}{1.8} \qquad [10–13a]$$

$$W_c = \frac{VS}{1.8} \qquad [10–13b]$$

$$C:N = \frac{\%C}{\%N} = \frac{W_c}{W_n} \qquad [10–14]$$

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 chapter 4 of this handbook, and typical values for percent nitrogen (dry basis) for many agricultural crops are reported in 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.

$$R_m = \frac{W_{cw} + W_{cb} + W_{ca}}{W_{nw} + W_{nb} + W_{na}} \qquad [10–15]$$

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:

$$W_w = \%N \times W_{dry} \qquad [10–16a]$$

$$W_n = \frac{W_c}{C:N} \qquad [10–16b]$$

$$W_c = \%C \times W_{dry} \qquad [10–17a]$$

$$W_c = C:N \times W_n \qquad [10–17b]$$

where:
W_{dry} = Dry weight of material in question

The dry weight of material can be calculated using equation 10–18.

$$W_{dry} = W_{wet} \times \frac{100 - M_{wet}}{100} \qquad [10–18]$$

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 3a 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.

$$W_{aa} = \frac{W_{nm} \times \left(R_d - R_{mb}\right) + 10{,}000}{N_{aa} \times \left(100 - M_{aa}\right) \times \left(R_{aa} - R_d\right)} \qquad [10\text{–}19]$$

$$W_{aa} = \frac{N_m W_{mb} \times \left(100 - M_{mb}\right) \times \left(R_d - R_{mb}\right)}{N_{aa} \times \left(100 - M_{aa}\right) \times \left(R_{aa} - R_d\right)} \qquad [10\text{–}20]$$

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:

$$W_{nd} = \frac{W_{cw} + W_{cb} + W_{ca}}{R_d} - \left(W_{nw} + W_{nb} + W_{na}\right) \qquad [10\text{–}21]$$

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.

(6) Design example 10–7—Compost mix

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 herd is in the barn for an average of 6 hours. The average weight of a cow is 1,200 pounds. Ten 60-pound bales of straw (chopped) are added daily for bedding. It has been determined that in this case 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 10–6)
Percent N	= 0.67% (from chapter 6 of this handbook)

Manure:

Number of cows	= 100
Size of cows	= 1,200 lb
Number of animal units (AU)	= 100 x 1,200/1,000 = 120
Moisture content	= 87.5% (from chapter 4 of this handbook)
Manure production	= 80 lb/day/1000 lb (from chapter 4 of this handbook)
Fraction in barn	= 6 hrs/24 hrs = 0.25
Nitrogen production	= 0.45 lb/1000 lb/day (from chapter 4 of this handbook)
Volatile solids	= 8.5 lb/1000 lb/day (from chapter 4 of this handbook)

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 2a: Determine the moisture content of the waste. To determine the quantity of waste:

Manure in barn:

$$120\,\text{AU} \times 80\ \text{lb / day} \times 0.25 = 2{,}400\ \text{lb}$$

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.

$$M_n = \frac{\dfrac{(2{,}400 \times 87.5) + (600 \times 15)}{100}}{3{,}000\ \text{lb}} \times 100 = 73\%$$

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.

$$W_{aa} = \frac{3{,}000\ \text{lb} \times (73\% - 60\%)}{60\% - 15\%} = 867\ \text{lb}$$

$$W_m = 3{,}000\ \text{lb} + 867 = 3{,}867\ \text{lb}$$

New weight of compost mix:

Step 3: Determine the C:N ratio of the compost mix. Determine the carbon and nitrogen content of the straw:

Total weight of straw:

$$600\ \text{lb} + 867\ \text{lb} = 1{,}467\ \text{lb}$$

Straw dry weight (equation 10–18):

$$1{,}467\ \text{lb} + \frac{(10 - 15)}{100} = 1{,}247.9\ \text{lb}$$

Weight of nitrogen in straw:

$$W_{na}\ \frac{(0.67 \times 1{,}247.9\ \text{lb})}{100} = 8.4\ \text{lb}$$

Weight of carbon in straw (equation 10–17b) :

$$W_{ca} = 8.4 \times 80 = 672.0\ \text{lb}$$

Determine the carbon and nitrogen content in manure:

Volume of volatile solids in barn:

$$120\,\text{AU} \times 8.5\ \text{lb / day / AU} \times 0.25 = 2.55\ \text{lb}$$

Weight of carbon in manure (using equation 10–13b):

$$\frac{255\ \text{lb}}{1.8} = 141.7\ \text{lb}$$

Weight of nitrogen in manure:

$$120\,\text{AU} \times 0.45 \times 0.25 = 13.5\ \text{lb}$$

C:N ratio of manure:

$$\frac{141.7}{13.5} = 10.5$$

Determine C:N ratio of mixture (equation 10–15):

$$\text{C:N} = \frac{141.7\ \text{lb} + 672.0\ \text{lb}}{13.5\ \text{lb} + 8.4\ \text{lb}} = 37.2$$

A compost mix that has a C:N ratio of 37.2 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:

$$\left(13.5\ \text{lb} + 8.4\ \text{lb}\right) = 21.9\ \text{lb}$$

Dry weight of manure (equation 10-18):

$$2,400 \times \frac{\left(100 - 87.5\right)}{100} = 300\ \text{lb}$$

Percent nitrogen in manure:

$$\frac{13.5}{300} \times 100 = 4.5\%$$

Pounds of manure to add to bring mix to 30:1 (using equation 10–19):

$$W_{aa}\ \frac{21.9 \times \left(30.0 - 37.2\right) \times 10,000}{4.5 \times \left(100 - 87.5\right) \times \left(10.5 - 30\right)} = 1,437\ \text{lb}$$

Pounds of nitrogen to add to bring compost mix to 30:1 (using equation 10–21)

$$W_{nd}\ \frac{141.7 + 672}{31} - \left(13.5 + 8.4\right) = 5.2\ \text{lb}$$

Adding 5.2 pounds of nitrogen is easier than adding 1,437 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:

Waste scraped from the barn — 3,000 lb
Additional straw to correct moisture — 867 lb
Nitrogen added to lower C:N ratio — 5.2 lb

(7) Design example 10–8

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 animal units (AU)	= 400 x 1400/1000=560
Manure production	= 80 lb/day/1000 lb
Nitrogen production	= 0.43 lb/day/1000 lb
Fixed solids	= 1.5 lb/day/1000 lb
Percent moisture	= 87.5%

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:

$$600\ \text{tons} \times 2000\ \text{lb / ton} = 1,200,000\ \text{lb}$$

Manure weight:

$$560\ \text{AU} \times 80\ \text{lb / day / AU} \times 14\ \text{days} = 67,200\ \text{lb}$$

Moisture content (M_m) of straw and manure (equation 10–11):

$$\frac{\dfrac{\left(1,200,000 \times 7\right) + \left(627,000 \times 87.5\right)}{100}}{1,200,00 + 627,200} \times 100 = 34.6$$

The 34.6 percent moisture content of the mix is less than 40 percent; therefore, water needs to be added 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}).

$$\frac{(1,200,000 \times 627,200) \times (34.6 - 50)}{50 - 100} = 562,778 \text{ lb}$$

$$\frac{562,778}{8.33 \text{ lb / gal}} = 67,560 \text{ gal}$$

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:

$$W_{na} = 600 \text{ ton} \times 6 \text{ lb / ton} = 3,600 \text{ lb}$$

Carbon in straw (equation 10–17b):

$$W_{ca} = 3,600 \text{ lb} - (\text{N}) \times 100 = 360,000 \text{ lb}$$

Determine the amount of carbon and nitrogen in the manure:

Nitrogen in manure (use chapter 4 values for N):

$$560 \text{AU} \times 0.45 \times 14 \text{ days} - 3,528 \text{ lb}$$

Assume a 20 percent loss of nitrogen in handling manure. Nitrogen left in manure:

$$W_{nw} = 3,528 \times \frac{100 - 20}{100} = 2,822 \text{ lb}$$

Volume of solids in manure (use chapter 4 values):

$$560 \text{AU} \times 8.5 \times 14 \text{ days} - 66,640 \text{ lb}$$

Carbon in manure (using equation 10–13b):

$$W_{cw} = \frac{66,640 \text{ lb}}{1.8} = 37,022 \text{ lb}$$

C:N ratio of straw and manure mix (equation 10–15):

$$\frac{360,000 + 37,022}{3,600 + 2,822} = 62{:}1$$

A C:N ratio of 62:1 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 (equation 10–21):

$$N_a = \frac{36,000 + 37,022}{40} - (3,600 + 2,822)$$
$$= 3,504 \text{ lb}$$

The final design mix is:

Rye grass straw	= 600 tons
Manure (14 days)	= 313.6 tons
Commercial nitrogen	= 3,504 lb

(8) 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.

(i) 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.

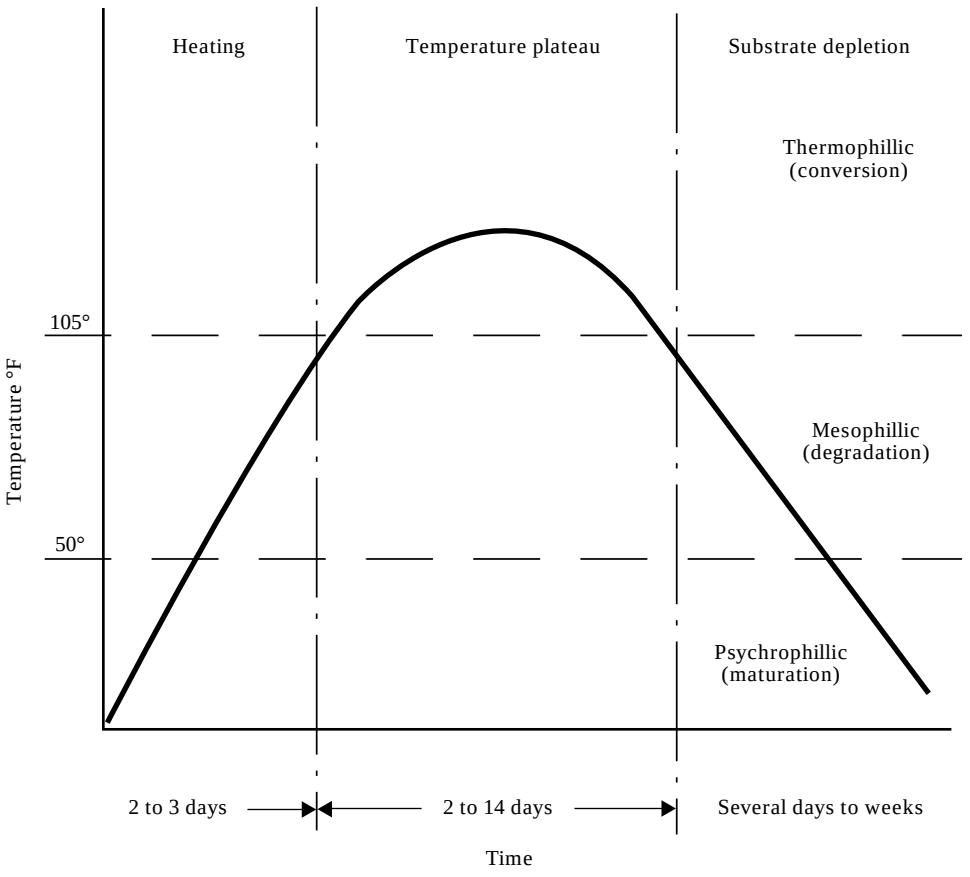
(ii) Temperature—Consideration should be given to how the compost temperature is going to be monitored. The temperature probe should be long enough to penetrate a third of the distance from the outside of the pile to the center of mass. The compost temperature should be monitored on a daily basis if 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 micro-organisms 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 10-34 illustrates the relationship between time, temperature, and compost phase. If the temperature is less than 50 °F, the compost is said to be in the psychrophillic stage. If it is in the range of 50 °F to 105 °F, the compost is in the mesophillic stage. If the compost temperature exceeds 105 °F, the compost is in the thermophillic stage. For complete pathogen destruction, the compost temperature must exceed 135 °F.

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

Figure 10–34 Composting temperature



method of aerating, a temperature rhythm often develops with the turning of the compost pile (fig. 10–35).

***(iii) Moisture*—**The moisture content of the compost mixture should be monitored periodically during the process. A low or high moisture content can slow or stop the compost process. A high moisture content generally results in the process turning anaerobic and foul odors developing. A high temperature drives off significant amounts of moisture, and the compost mix may become too dry, resulting in a need to add water.

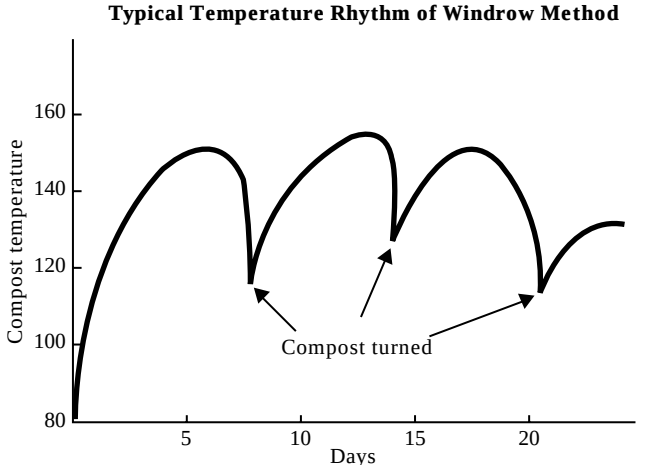
***(iv) Odor*—**The odor given off by the composting operation is a good indicator of how the compost operation is proceeding. Foul odors may mean that the process has turned from aerobic to anaerobic. Anaerobic conditions are the result of insufficient oxygen in the compost. This may be caused by excessive moisture in the compost or the need for turning or aerating of the compost.

(9) Compost process steps

The composting operation generally follows these steps (fig. 10–36):

***(i) 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.

Figure 10–35 Typical temperature rhythm of windrow method



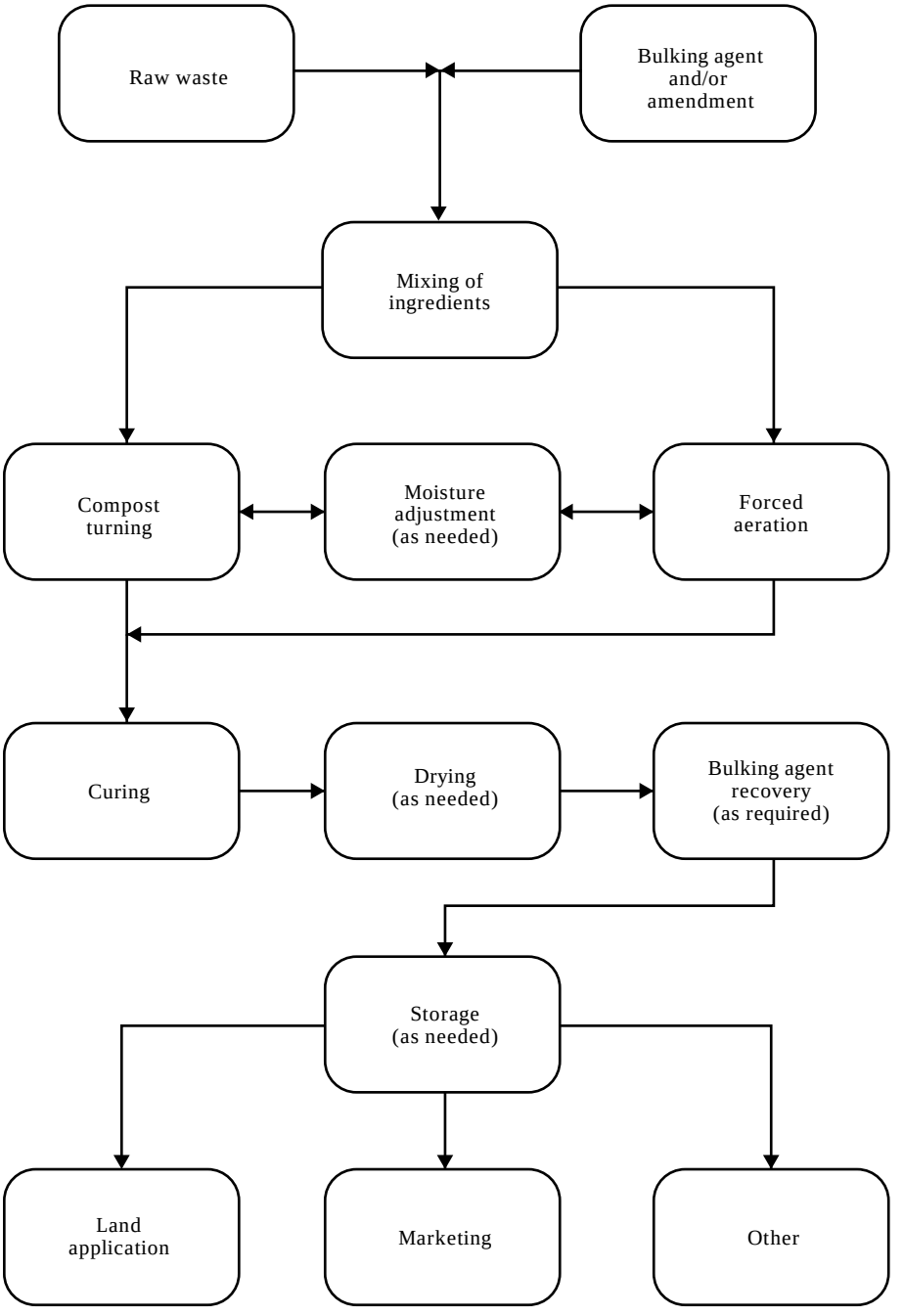
***(ii) Mixing of the waste with a bulking agent or amendment*—**A typical agricultural composting operation involves mixing the raw waste with a bulking agent or amendment, or both, according to a prescribed mix or design. The prescribed mix should detail the quantities of raw waste, amendments, and 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.

***(iii) 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 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.

***(iv) 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.

***(v) 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.

Figure 10–36 Agricultural composting process flow



(vi) 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.

(vii) 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.

(viii) 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.

(10) Dead animal 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. Some operators have composted dead animals weighing as much as 100 pounds by grinding or cutting them into smaller pieces.

Composting of dead animals should be considered when—

- A preferred use, such as rendering, is not available.
- The mortality rate as a result 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.

(i) 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.

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 °F 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.

(ii) Sizing dead animal composting facilities**—**A typical dead animal 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 from 1.0 to 2.5 cubic feet

per pound, depending on the type of composter, local conditions, and experences. Equation 10–22 can be used to calculate the volume for each stage in the compost facility.

$$Vol = B \times \frac{M}{T} \times W \times \frac{VF}{100} \qquad [10–22]$$

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 (days)
W = Market weight of animals (lb)
VF = Volume factor

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 (equation 10–23).

$$\#\ \text{Bins} = \frac{\text{Total 1st stage volume } \left(ft^3\right)}{\text{volume of } sin\text{gle bin } \left(ft^3\right)} \qquad [10–23]$$

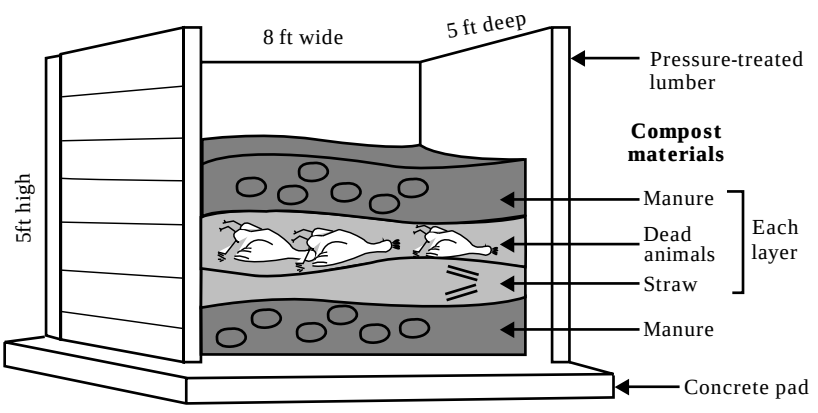
Bins are typically 5 feet high, 5 feet deep, and 8 feet across the front. The width across the front should be sized to accommodate the equipment used to load and unload the facility. To prevent spontaneous combustion and to allow for ease of monitoring, a bin height of no more than 6 feet is recommended. 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 one-half the width. Shallow bins are easier to unload and load; therefore the bin depth should be no more than the width. Figure 10–37 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 10–7 gives typical mortality rates, flock life, and market weights for poultry.

(iii) 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

Figure 10–37 Dead animal composting bin



(drawing not to scale)

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 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 discussed 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 10–38 is an example of commonly recommended layering of manure, straw, and dead poultry.

Table 10–8 is a typical recipe for composting dead birds. The ingredients are presented by volume as well as weight.

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

Table 10–7 Poultry mortality rates

Poultry type	Loss rate %	Flock life (days)	Cycles per year	Market weight (lb)
Broiler	4.5–5.5	42–49	5.5– 6.0	4.2
Roaster				
females	3	42	4	4.0
males	8	70	4	7.5
Laying hens	14	440	0.9	4.5
Breeding hens	10–12	440	0.9	7–8
Breeder males	20–25	300	1.1	10–12
Turkey females	5–6	95	3	14
Turkey male	9	112	3	24
Turkey feather prod.	12	126	2.5	30

Table 10–8 Broiler compost mix

Ingredient	Volumes (parts)	Weights (parts)
Straw	1.0	0.1
Broiler	2.0	1.0
Manure	2.0	1.5
Water*	0.5	0.75

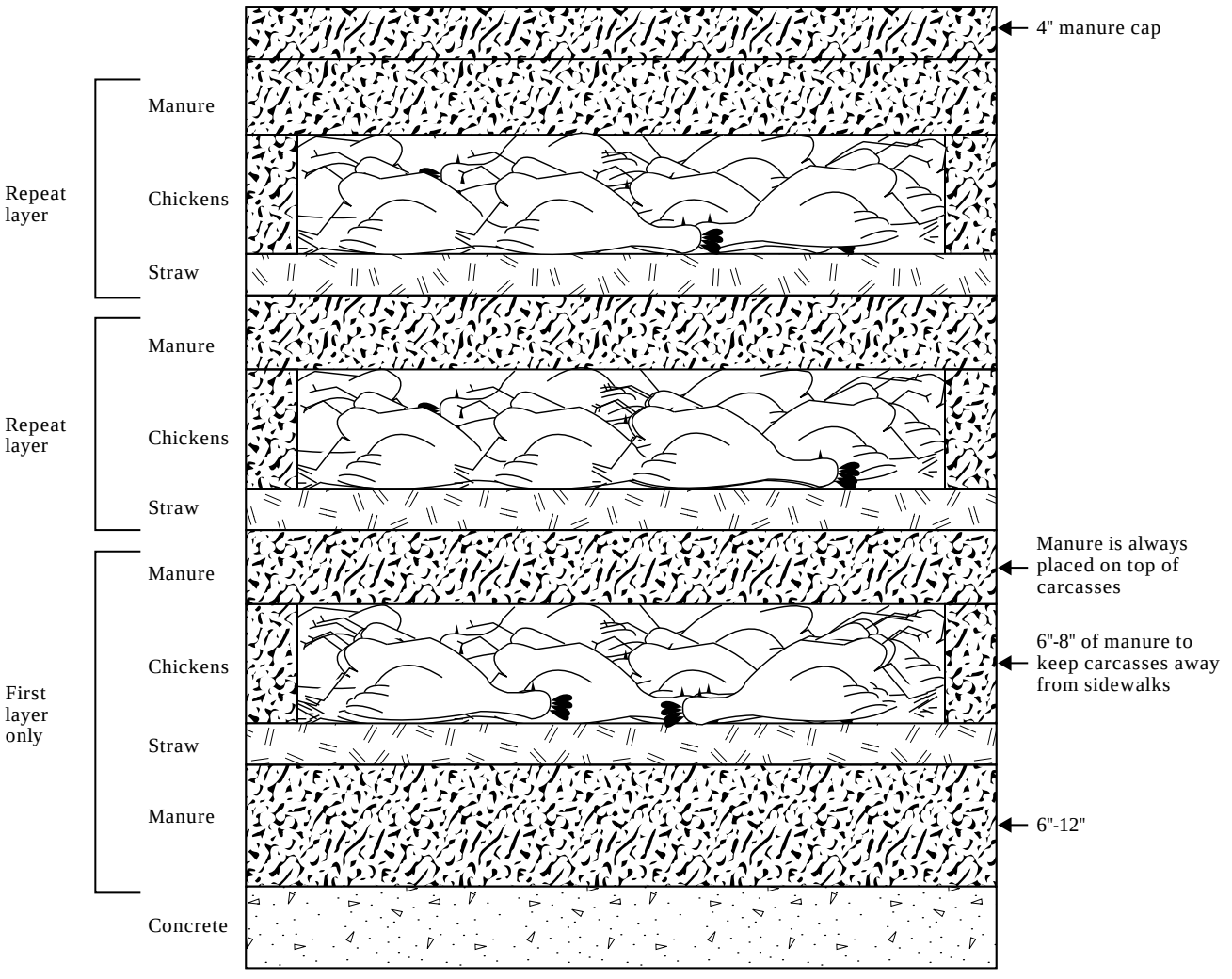
* More or less water may be necessary depending on the moisture content of the straw and manure.

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.

(iv) 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 moni-

Figure 10–38 Recommended layering for dead bird composting



tor 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 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 °F 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 °F 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 °F 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 °F. If the temperature exceeds 170 °F, 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 stops 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.

(g) Mechanical separation

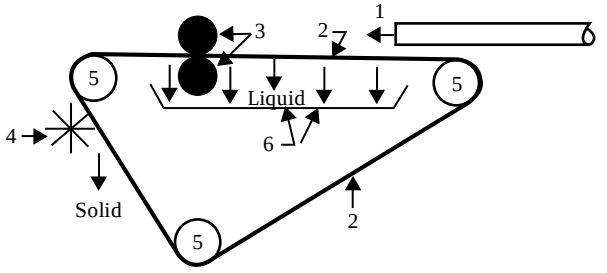
Animal manure contains material that can often be reclaimed. Much of the partly digested feed grain can be recovered from manure of poultry and livestock fed high grain rations. This material can be used as a feed ingredient for other animals. Solids in dairy manure from animals fed a high roughage diet can be removed and processed for use as good quality bedding. Some form of separation must be used to recover these solids. Typically, a mechanical separator is 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 waste storage ponds and treatment lagoons. For example, it eliminates the accelerated filling of storage volumes with solids and also minimizes agitation requirements.

Several kinds of mechanical separators can be used to remove by-products from manure (fig. 10–39). 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

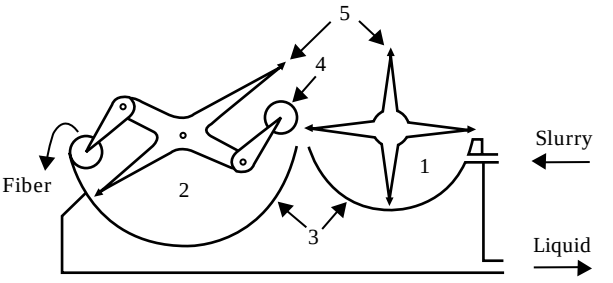
Figure 10–39 Schematic of mechanical solid-liquid separators

Flat belt separator



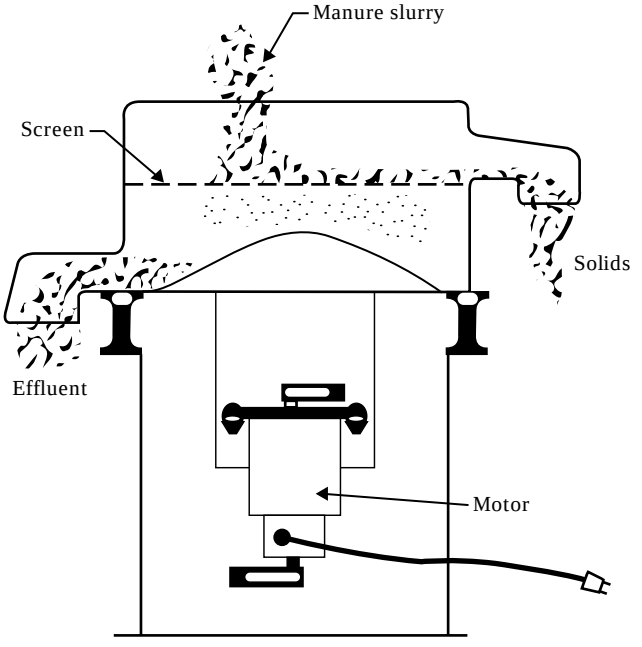
1 Slurry input
2 Polyester mesh belt
3 Press rollers
4 Rotary brush
5 Belt guide rollers
6 Liquid collection trough

Roller-press separator

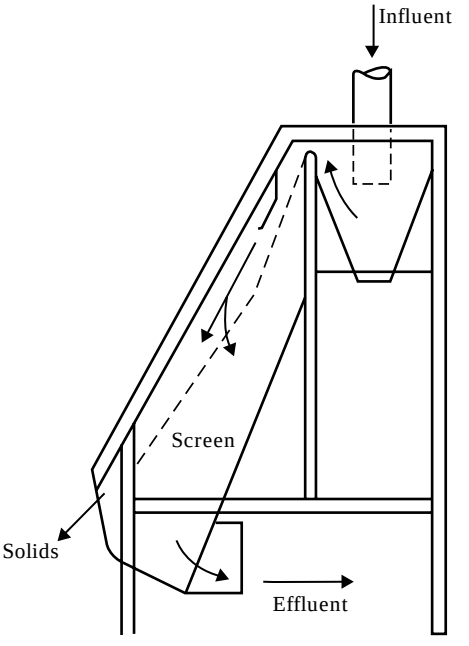


1 Screening stage
2 Roller pressing stage
3 Screens
4 Spring loaded press roller
5 Brushes

Vibrating screen separator



Stationary inclined screen separator



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 waste from the solid part.

Several design factors should be considered when selecting a mechanical separator. One factor is the amount of liquid waste 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.

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 are 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. If the solids are intended for animal feed, they may need to be mixed with other feed ingredients and ensiled before feeding to prevent bacteriological disease transmission. A feed ration using manure must be proportioned by an animal nutritionist so that it is both nutritious and palatable.

A planner/designer needs to know the performance characteristics of the separator being considered for the type of waste 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 waste 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 10–9 and 10–10 can be used to estimate performance characteristics. Table 10–9 gives data for separating different wastes using different separators, and table 10–10 presents general operational characteristics of mechanical separators.

(h) 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 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. It is positioned between the waste source and the waste storage or treatment facilities. Most readily settleable solids will settle from the flow if the velocity of the liquid is below 1.5 feet per second.

The basins should be planned and designed in accordance with SCS Conservation Practice Standard, Sediment Basin, Code 350 (USDA 1978). 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.

Table 10–9 Operational data for solid/liquid separators

Waste type	Separator	TS concentration (%) Raw waste	Separated liquids	Separated solids	% Retained in separated 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 gpm	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	—	—	—	—
Beef	Static inclined screen	4.4	3.8	13.3	15	—	—	—	—
	Vibrating screen	1–2	—	—	40–50	—	—	—	—
Swine	Decanter centrifuge								
	3 gpm	7.6	2.6	37	14	—	—	—	—
	Vibrating screen 22 gpm/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

Table 10–10 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 (gpm)	to 30	to 300	to 1,000

* Removed in separated solids

(i) Dilution

Dilution is often used to prepare the waste to facilitate another function. This involves adding clean water or another waste that has less total solids to the waste, resulting in a waste that has a desired percentage of total solids. A common use of dilution is to prepare the waste to facilitate utilization by land application using a sprinkler system. Figure 10–40 is a design aid for determining the amount of clean dilution water required to lower the TS concentration.

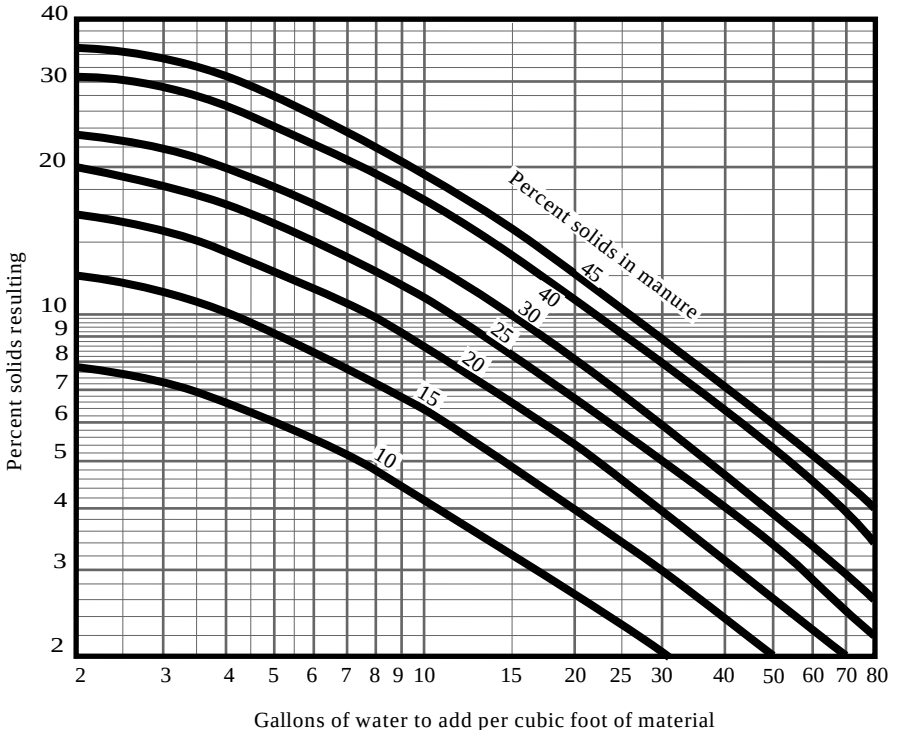
(j) Vegetative filters

A vegetative filter can be a shallow channel or a wide, flat area of vegetation used for removing suspended solids and nutrients from concentrated livestock area runoff and other liquid wastes. The filters 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.

Vegetative filters rely on infiltration to remove nitrates and micro-organisms that are in solution because these waste constituents are very mobile in water. Provision for rest periods between loadings is recommended. In cases where a large volume of solids is expected, settling basins are needed above the filter area or channel. "Clean" water must be diverted from the filter. Installation and maintenance are critical.

Vegetative filters are planned and designed according to Conservation Practice Standard, Filter Strip, Code 393 (USDA 1982), which gives more detailed planning considerations and design criteria. See section 651.0605(c) for additional information. If State or local government has restrictions on the use of vegetative filters, the requirements must be met before design and construction. This is especially true if the outflow from the vegetative filter will flow into a stream or waterway. Unless permitted by State regulations, wastewater treatment by vegetative filters is not sufficient to allow discharge to surface water.

Figure 10–40 Design aid to determine quantity of water to add to achieve a desired TS concentration (USDA 1975)



651.1005 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 waste from storage or treatment to the point of utilization. This may involve pumps, pipelines, and tank wagons.

(a) Reception pits

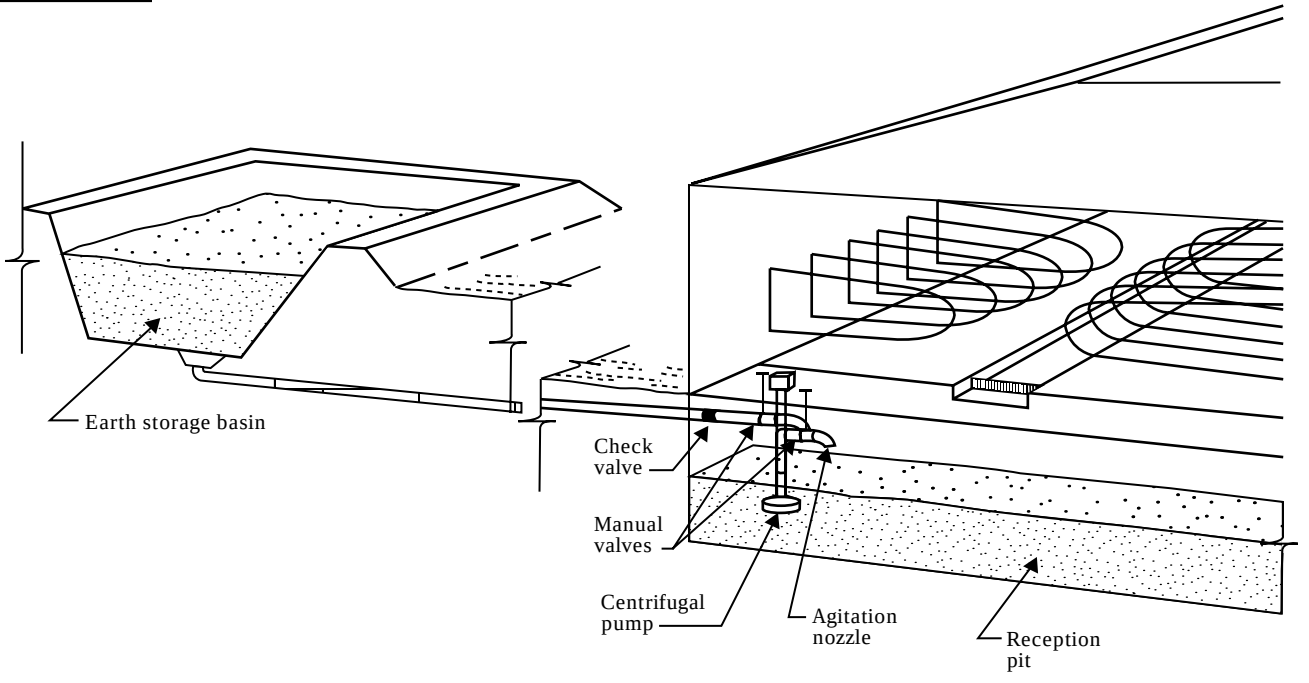
Slurry and liquid manure collected by scraping, gravity flow, or flushing are often accumulated in a reception pit (fig. 10–41). Feedlot runoff can also be accumulated. These pits can be sized to hold all the waste produced for several days to improve pump efficiency or to add flexibility in management. 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 gallons/day x 7 days) 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.

Waste can be removed with pumps or by gravity. Centrifugal pumps can be used for agitating and mixing the manure 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,

Figure 10–41 Reception pit for dairy freestall barn



but if possible, this should be done remotely from outside the pit. The pit should be well ventilated before entering. If waste 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 semi-solid 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 4 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%) 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 10–42 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

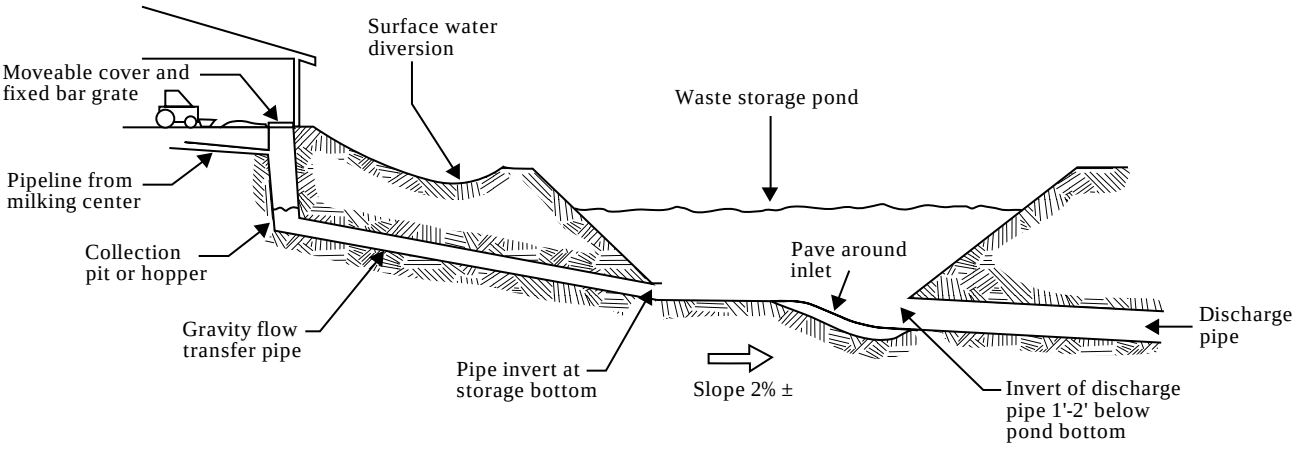
Manure that is scraped from open lots can be loaded into manure spreaders or storage and treatment facilities using push-off ramps (fig. 10–43) or docks. A ramp is a paved structure leading to a manure storage facility. It can be level or inclined and usually includes a retaining wall. A dock is a level 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) Picket dams

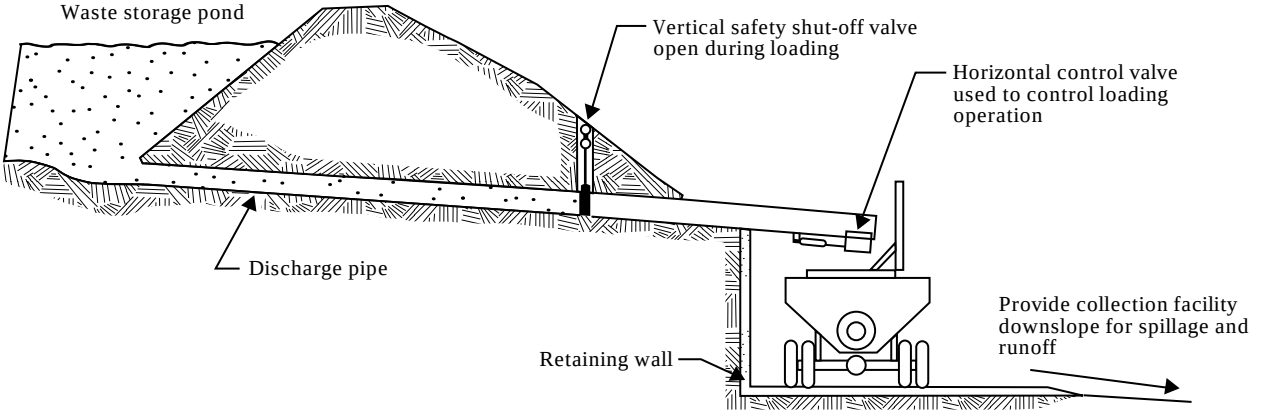
Manure that has considerable bedding added can be stored as a solid or semi-solid. If the manure is stored uncovered, precipitation can accumulate in the storage area. Picket dams can be used to drain runoff from the storage area while retaining the solid manure and bedding within the storage area. Any water drained should be channeled to a waste 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.

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.

Figure 10–42 Examples of gravity flow transfer



Gravity flow transfer



Gravity flow from storage

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 10–44 shows different aspects of picket dam design.

(e) 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 are 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.

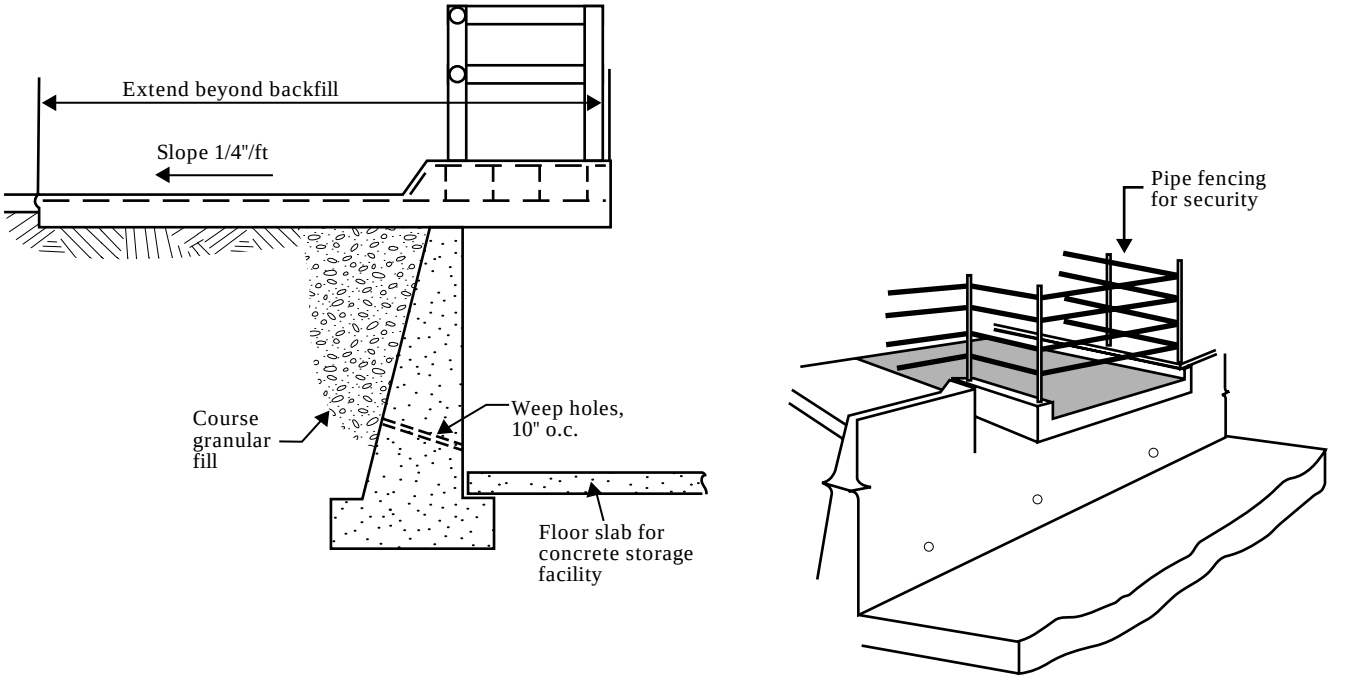
The centrifugal group is vertical shaft, horizontal shaft, and submersible pumps. They can be used for agitation and transfer of liquid manure; however, only vertical and horizontal shaft pumps are used for irrigation because of the head that they can develop.

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.

(f) Equipment

Other equipment used in the transfer of agricultural wastes include a variety of pumps including chopper/agitator, centrifugal, ram, and screw types. Elevators, pipelines, and hauling equipment are also used. See chapter 12 for information about specific equipment.

Figure 10–43 Push-off ramp



651.1006 Utilization

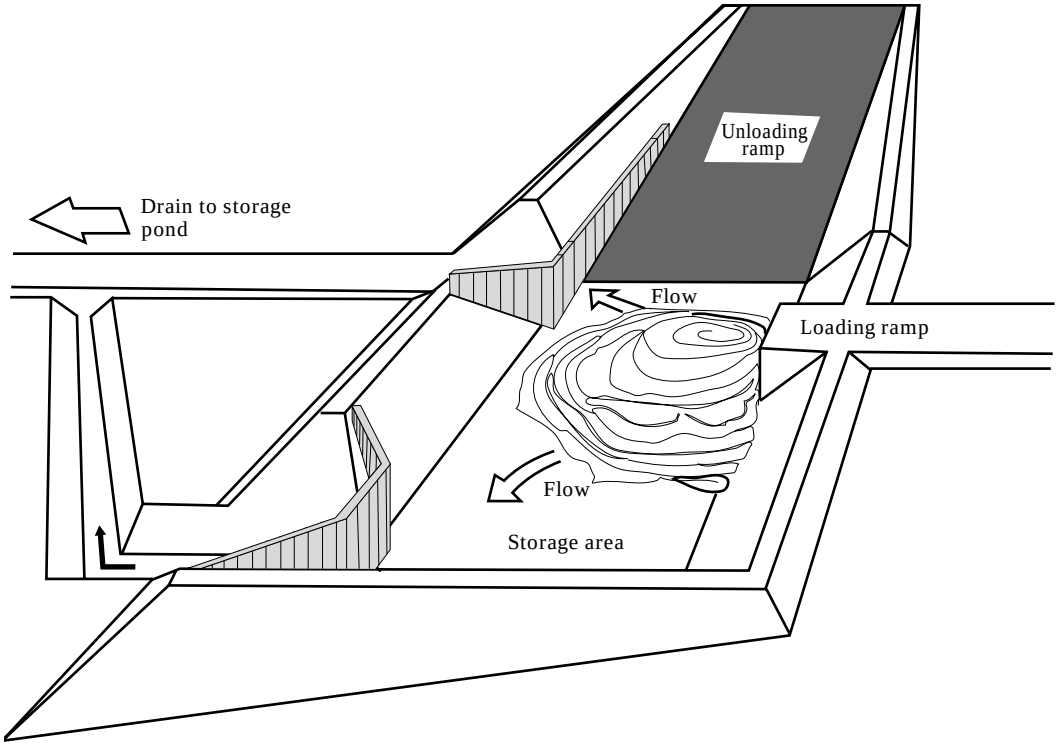
Utilization is a function in a waste management system employed for a beneficial purpose. The typical method is to apply the waste to the land as a source of nutrients for plant growth and of organic matter to improve soil tilth and water holding capacity and to help control erosion. The vast majority of animal waste 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. An anaerobic digester used for biogas production is considered a utilization function component because the waste is being managed for use even though further management of the digester effluent is required.

(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.

Figure 10–44 Solid manure storage with picket dam



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.

(b) Land application equipment

Animal waste is land applied using a variety of equipment. The kind of equipment used depends on the TS concentration of the waste. 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 wastes are applied using tank wagons or flail spreaders. Some tank wagons can be used to inject the waste directly into the soil. Slurry spreaders are typically used for waste that is stored in above or below ground storage structures, earthen storage structures, and sometimes lagoons.

Waste 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.

(c) Land application of municipal sludge

Municipalities in the United States treat wastewater biologically using either 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) Biogas production

Some of this material was taken directly from "Tentative guidelines for methane production by anaerobic digestion of manure" (Fogg 1981).

Liquid manure confined in an air-tight vessel decomposes and produces methane, carbon dioxide, hydrogen sulfide, and water vapor as gaseous by-products. This process is known as anaerobic digestion. Many municipalities use this technique to treat sludge generated in wastewater treatment. Many livestock and poultry producers have become interested in the process because of the potential for onsite energy production.

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). Pure methane is a highly combustible gas that has an approximate heating value of 994 BTU/ft^3. 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 onfarm energy use rates vary substantially. Because compression and storage of biogas is expensive, economical use of biogas as an onfarm energy source requires that farm use must closely match the energy production from the anaerobic digester.

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. 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 °F, depending on the climate and the amount of insulation used. Below ground digesters require less insulation than those above ground. 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 waste storage ponds or treating in lagoons. Initial start-up of a digester is critical. The digester should be partly filled with water (50 to 75 percent 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.

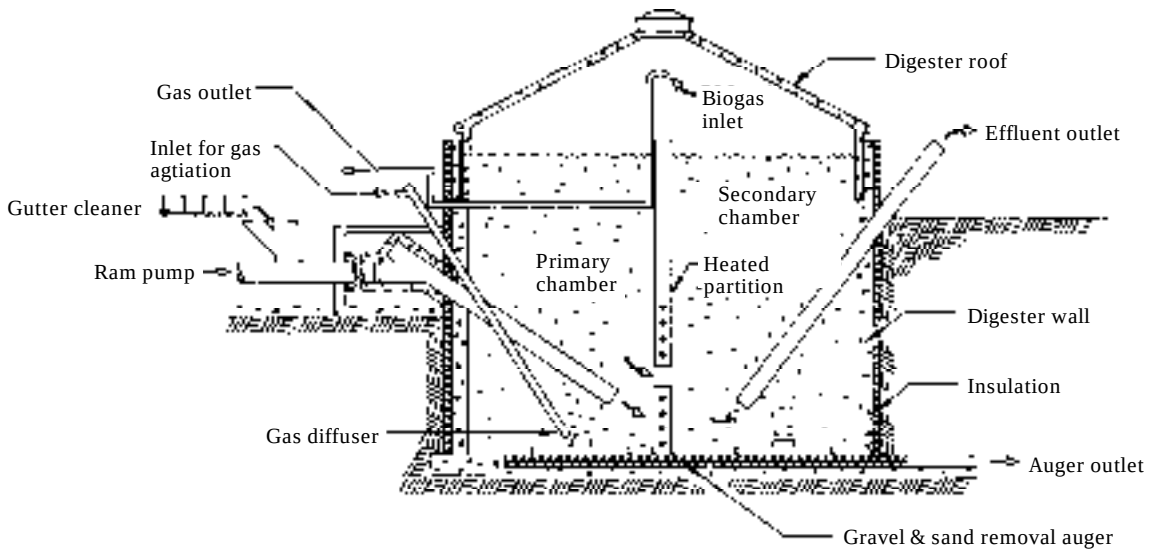
(1) Design procedure

Because of the safety issues and economic and operational complexities involved, SCS 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. 10–45, 10–46, 10–47). The mixed tank is a concrete or metal cylindrical vessel constructed aboveground. If the manure is

Figure 10–45 Two stage, mixed tank anaerobic digester



highly liquid (low TS), the digester must be periodically mixed to get good 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 to 14 percent TS), such as dairy manure. The manure is introduced at one end and theoretically 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.

For any digester, the influent must be managed for consistency in frequency of feeding as well as in the VS concentration. 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.

(i) Determine manure production—Manure production can be based on the tables in chapter 4 or on reliable local data. The following data will be needed:

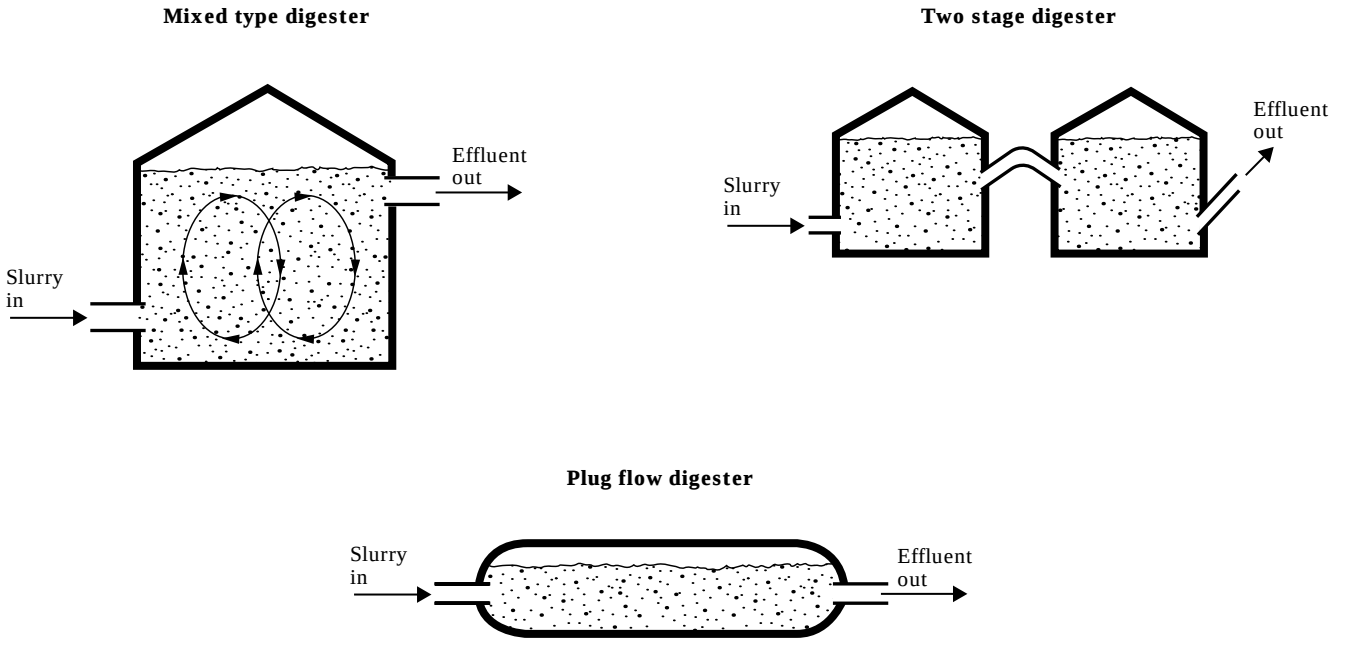
Volume of manure produced	=	_____	ft^3/day
Wet weight of manure produce	=	_____	lb/day
Total solids (TS)	=	_____	lb/day
Volatile solids (VS)	=	_____	lb/day
Percent solids (TS/wet weight)	=	_____	percent

Fresh manure is desirable for digestion. Characteristics of beef feedlot manure must be determined for each operation.

(ii) 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 %

Figure 10–46 Typical anaerobic digester types



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.

(iii) 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.

$$DMI = \frac{TMTS \times 100}{DDFSC \times 62.4} \qquad [10–24]$$

where:
DMI = Daily manure inflow, ft^3
TMTS = Total manure total solids production, ft^3/day
DDSFC = Desired digester input total solids concentration, %

The necessary digester volume in cubic feet can be determined using equation 10–25.

$$DEV = DMI \times 20 \qquad [10–25]$$

where:
DEV = Digester effective volume, ft^3
20 = Recommended detention time, days

(iv) 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. True plug flow will not occur.

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:

$$H = \left(\frac{DEV}{8}\right)^{0.33}$$
$$WI = 2 \times H$$
$$L = 4 \times H$$

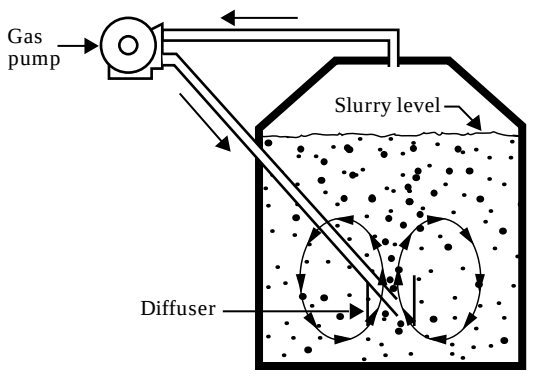
where:
H = height, ft
WI = width, ft
L = length, ft

Dimensions should be adjusted to round numbers to fit the site and provide economical construction.

(v) Estimate biogas production—Biogas production is dependent on VS destruction within the digester. An efficient digester that has a 20-day retention should reduce VS by 50 percent. Some research indicates a reduction of 55 percent of VS in swine manure and 60 to 65 percent in poultry manure. Biogas production from poultry manure may vary significantly from the estimates presented below. Animals fed a high roughage ration produce less biogas than those fed a high concentrate ration. Estimated VS reductions are:

Dairy and beef 50%
Swine 55%
Poultry 60%

Figure 10–47 Gas agitation in an anaerobic digester



Estimated daily biogas production rates are:

Dairy	12 ft^3/lb VS destroyed
Beef	10 ft^3/lb VS destroyed
Swine	13 ft^3/lb VS destroyed
Poultry	13 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	6 x daily VS input
Beef	5 x daily VS input
Swine	7.2 x daily VS input
Poultry	7.8 x 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 °F for continuous and uniform biogas production. Hot water tubes within the digester can serve this purpose.

(2) Other considerations

Biogas is difficult to store because it can't be compressed at normal pressures and temperatures. Storage pressures above 250 psi 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.

(3) Design example 10–9—Biogas digester

Mr. Joe Sims of Hamburg, Pennsylvania, has requested assistance on development of an agricultural waste 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.

Completed worksheet for Design example 10–9

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)= 1.30
6. Total volume of daily manure production for animal type, ft^3/day MPD = AU x DVM: 156
7. Total daily manure production volume, ft^3/day (TMP): 156

Manure total solids

8. Daily manure total solids production, lbs/AU/day (MTS) = 10.0
9. Daily manure total solids production for animal type, lb/day MTSD = MTS x AU = 1200
10. Total manure total solids production, lbs/day (TMTS) = 1200

Manure volatile solids

11. Daily manure volatile solids production per AU, lbs/AU/day (MVS) = 8.5
12. Daily manure volatile solids production for animal type per day, lbs/day MVSD = AU x MVS = 1020
13. Total manure volatile solids production, lbs/day (TMVS): 1020

Percent solids

14. Percent solids, % (PS)

$$PS = \frac{TMTS \times 100}{TMP \times 62.4} = \frac{(1200) \times 100}{(156) \times 62.4} = 12.33$$

Digester feed solid concentration

15. Desired digester feed solids concentration, % (DDFSC) = 12.0

Daily manure inflow

16. Daily manure inflow, ft^3

$$DMI = \frac{TMTS \times 100}{DDFSC \times 62.4} = \frac{(1200) \times 100}{(12) \times 62.4} = 160.2$$

Digester effective volume

17. Digester effective volume, ft^3

DEV = DMI x 20 = (160.2) x 20 = 3205

Digester dimensions

18. Digester depth, ft

$$H = \left(\frac{DEV}{8}\right)^{0.33} = \left(\frac{(3205)}{8}\right)^{0.33} = 7.37$$

19. Digest width, ft WI = 2 x H = 2 x (7.37) = 14.74
20. Digest length, ft L = 4 x H = 4 x (7.37) = 29.48

Estimated energy production

21. Biogas per unit (VS), ft^3/lb (BUVS) = 6
22. Estimated biogas production ft^3/day EBP = BUVS x TMVS = (6) x (1020) = 6120
23. Estimated energy production BTU/day EEP = EBP x 600 = (6120) x (600) = 3,672,000

651.1007 Ancillary components

(a) Fences

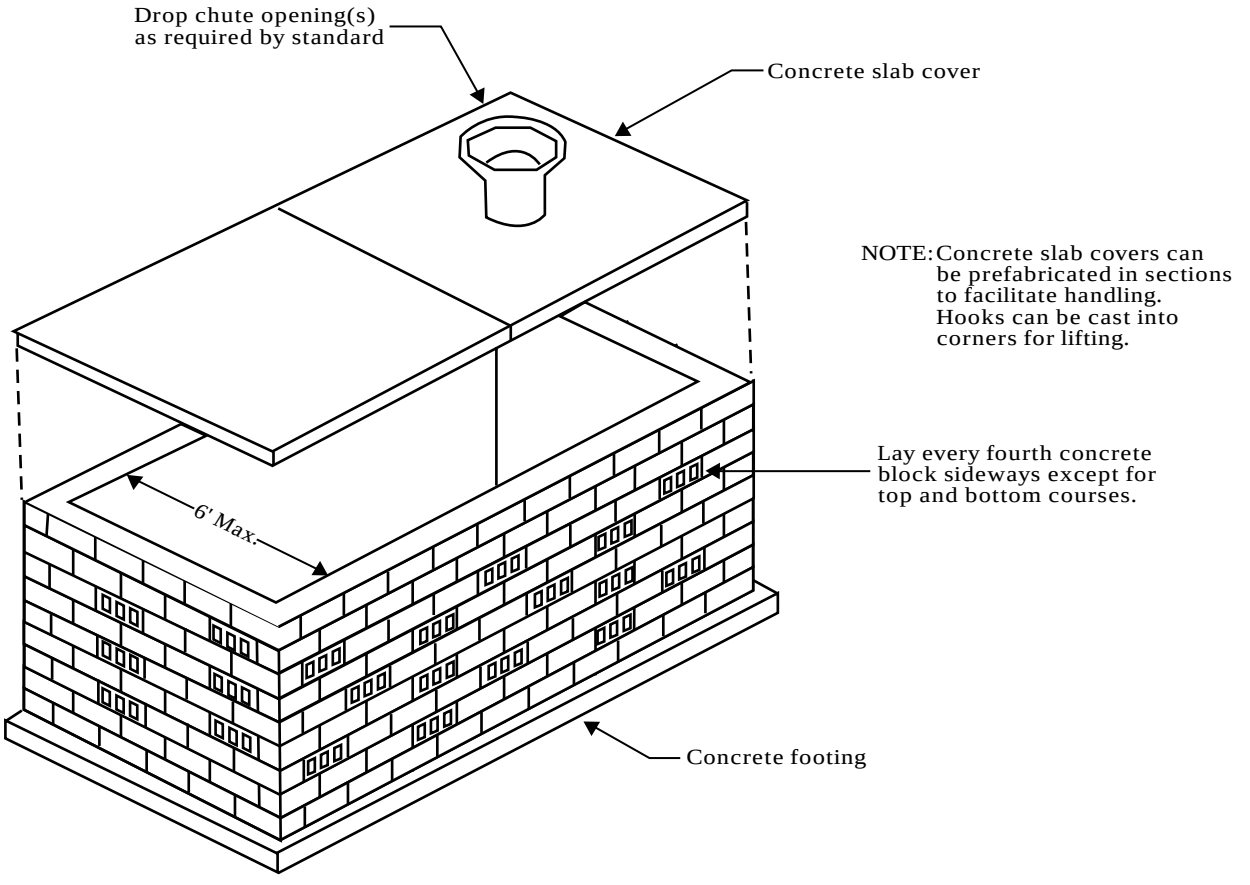
Fences are an important component in some agricultural waste management systems. They are planned and designed in accordance with Conservation Practice Standard, Fencing, Code 382 (USDA-SCS 1980). As they apply to agricultural waste management, fences are used to:

- 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.

(b) Dead animal disposition

Every livestock and poultry facility experiences loss of animals by death. Regardless of the method used, the disposition of dead animals should be accomplished in

Figure 10–48 Poultry and suckling pig disposal pit constructed with 8" x 8" x 16" concrete blocks



a sanitary manner and in accordance with all State and local laws.

Utilization of the energy contained in the dead animals should be given first consideration. Rendering and composting of dead animals both result in by-products that can used. Refer to 651.1004(g) for discussion on composting animal carcasses. If utilization is not viable, consideration can be given to disposal by incineration or burial. Incineration can cause odor problems unless an afterburner or excess air system is used.

A common method for onsite dead animal disposal is burial. 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.

For large animals (cattle and mature swine), individual pits should be opened for each occasion of burial. The pits should be closed and marked after burial. For small animals (poultry and small pigs), pits can be constructed for use over a period of time.

Typical pit sizes for small animals are 4 to 6 feet wide, 4 to 12 feet long, and 4 to 6 feet deep. The sides of the pit should be constructed of concrete block, treated timber, or pre-cast concrete. The side walls must have some openings to allow for pressure equalization. The bottom of small animal pits is not lined. The top should be airtight with a single capped opening to allow for adding dead animals. Figure 10–48 illustrates one possible disposal pit configuration.

Disposal pits should have adequate capacity. The recommended capacity for broilers is 100 cubic feet per 10,000 broilers. For small pigs, the capacity is 1 cubic foot per sow. The pit size for layers and turkeys can be determined using figure 10–49.

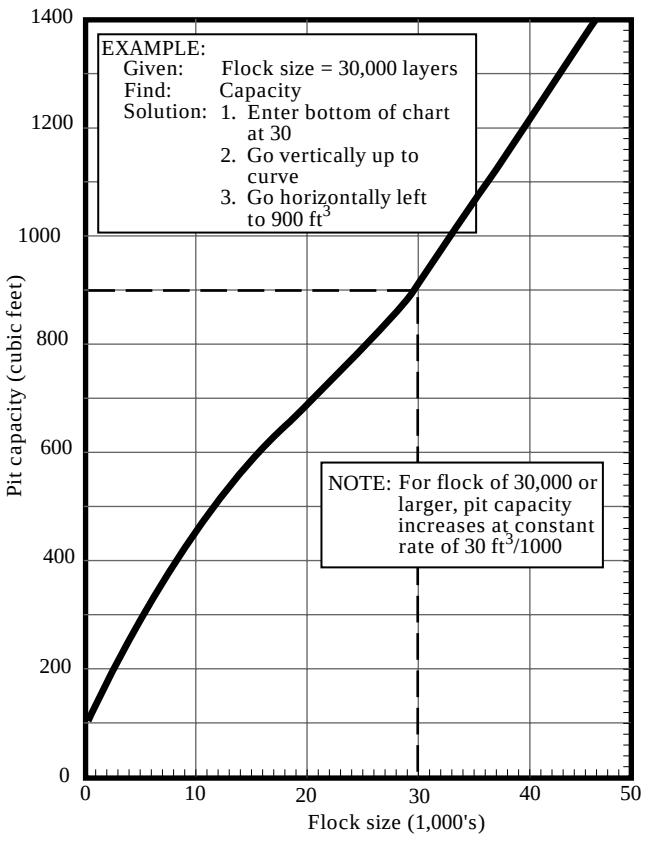
(c) Human waste management

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. SCS does not design human waste management systems, but some States have extension specialists or environmental engineers that can assist in designing suitable systems.

Figure 10–49 Capacity requirements for poultry disposal pits for laying hens and turkeys



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 judgement, 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 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 ppm. 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 ppm for exposures over 30 minutes. Hydrogen sulfide concentrations above 800 ppm can lead to unconsciousness and death through paralysis of the respiratory system.

Methane is also an asphyxiant; however, it's 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 then only if (1) the pit is first ventilated, (2) you have air supplied to a mask or a self contained breathing apparatus, and (3) you have on a safety harness and attached rope and have 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, or you might also become a victim. 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 "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.

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) _____

Solids accumulation

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

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.

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

$$MTV = \frac{TVS \times 1000}{VSLR} = \frac{(\quad\quad) \times 1000}{(\quad\quad)} = _____$$

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

$$MTA = \frac{TBOD}{BODLR} = \frac{(\quad)}{(\quad)} =$$ _____

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 ( )( )( ) = _____

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 x 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 x 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 x MVS* _____ _____ _____

=

13. Total manure volatile solids production, lbs/day (TMVS) _____

Percent solids

14. Percent solids, % (PS)

$$PS = \frac{TMTS \times 100}{TMP \times 62.4} = \frac{(\quad)\ \times 100}{(\quad)\ \times 62.4} = _____$$

Digester feed solid concentration

15. Desired digester feed solids concentration, % (DDFSC) = _____

Daily manure inflow

16. Daily manure inflow, ft^3

$$DMI = \frac{TMTS \times 100}{DDFSC \times 62.4} = \frac{(\quad)\ \times 100}{(\quad)\ \times 62.4} = _____$$

Digester effective volume

17. Digester effective volume, ft^3

DEV = DMI x 20 = ( ) x 20 _____

=

Digester dimensions

18. Digester depth, ft

$$H = \left(\frac{DEV}{8}\right)^{0.33} = \left[\frac{(\quad)}{8}\right]^{0.33} = _____$$

19. Digest width, ft *WI* = 2 x *H* = 2 x ( ) _____

=

20. Digest length, ft *L* = 4 x *H* = 4 x ( ) _____

=

Estimated energy production

21. Biogas per unit (*VS*), ft^3/lb (*BUVS*) _____

=

22. Estimated biogas production ft^3/day

EBP = *BUVS* x *TMVS* = ( ) x ( ) _____

=

23. Estimated energy production BTU/day

EEP = EBP x 600 = ( ) x (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

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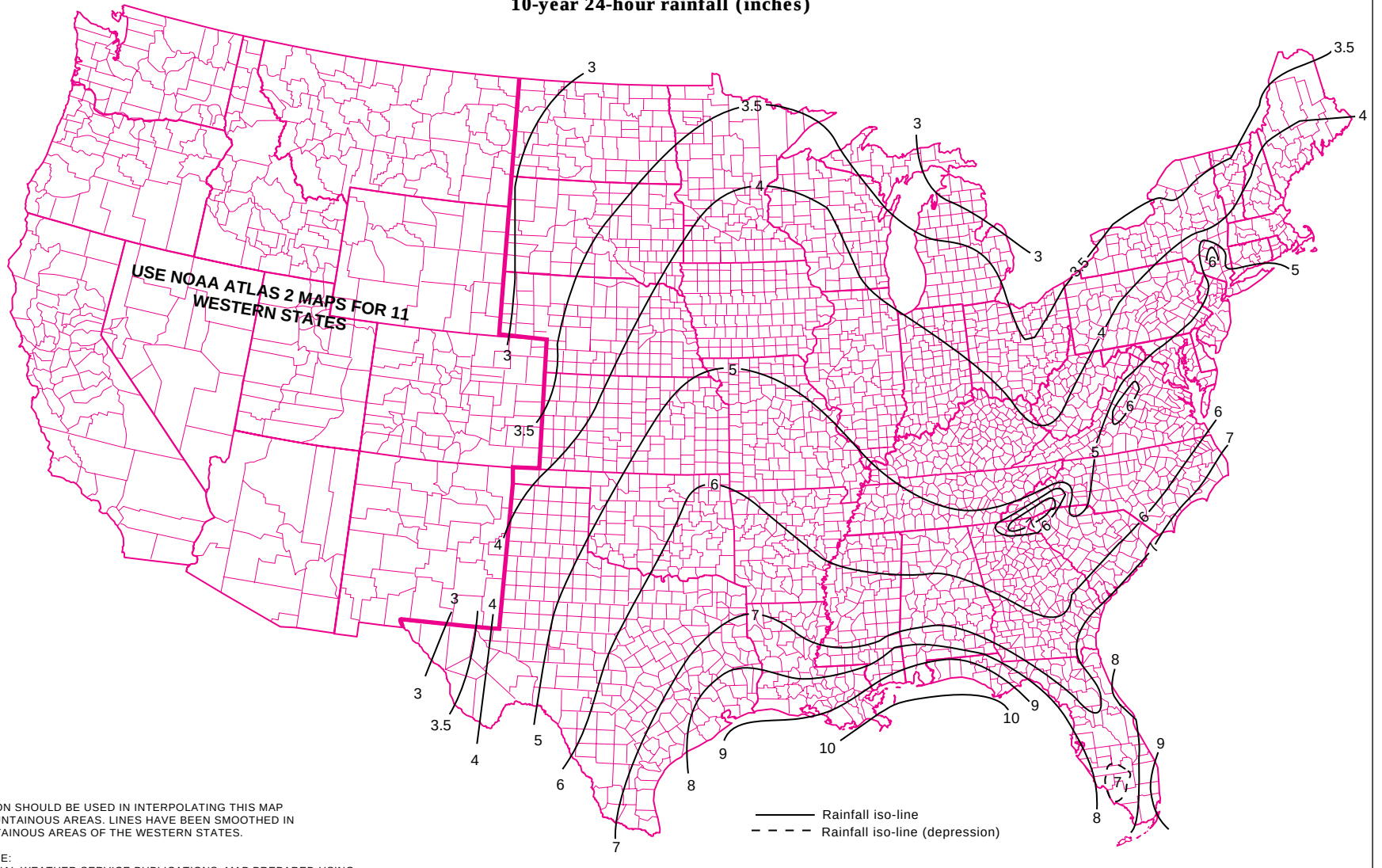
NATURAL RESOURCES CONSERVATION SERVICE

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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Figure 10B-2
25-year 24-hour rainfall (inches)

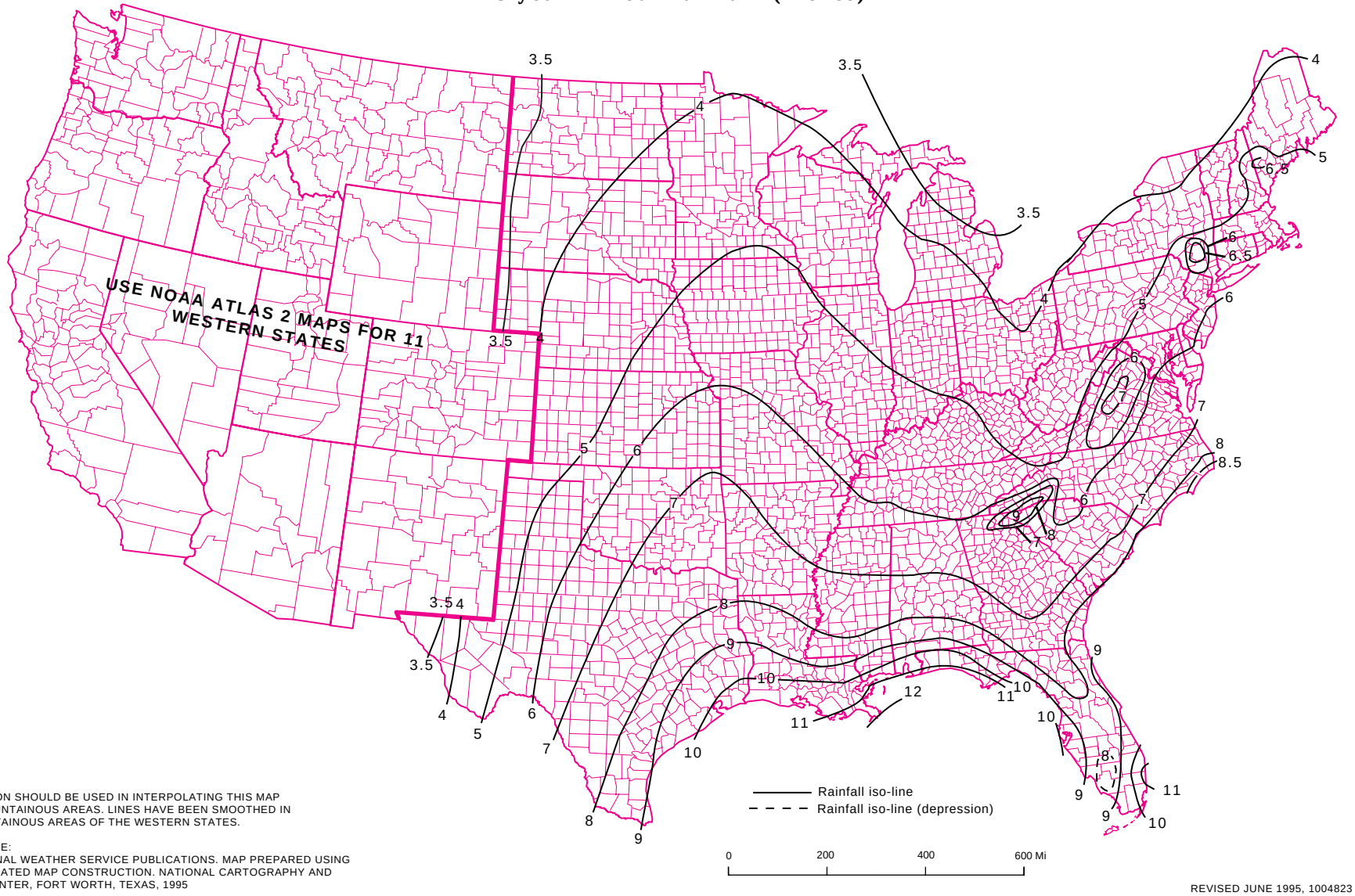

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Figure 10B-3
10-year 5-minute rainfall (inches)

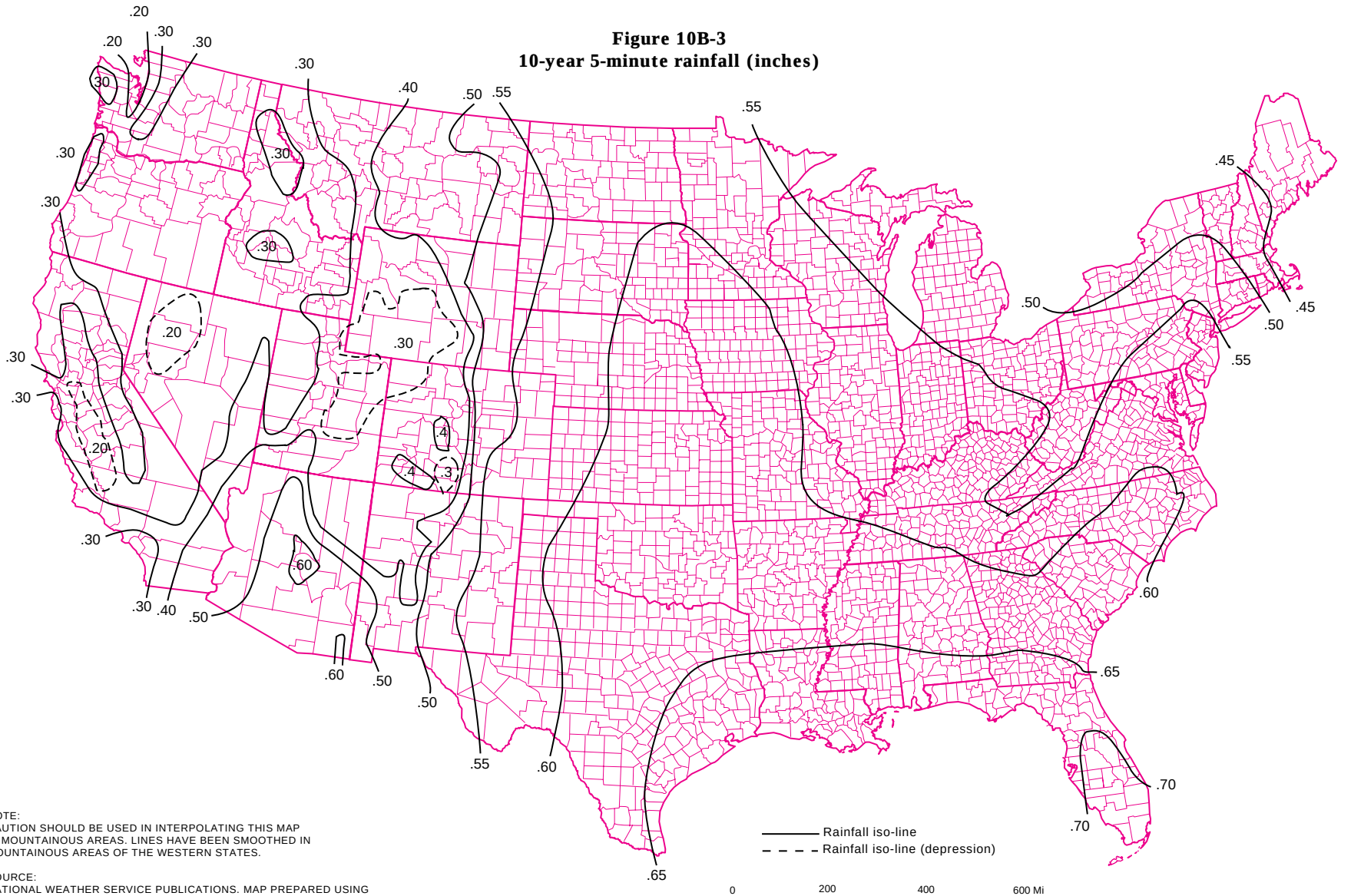

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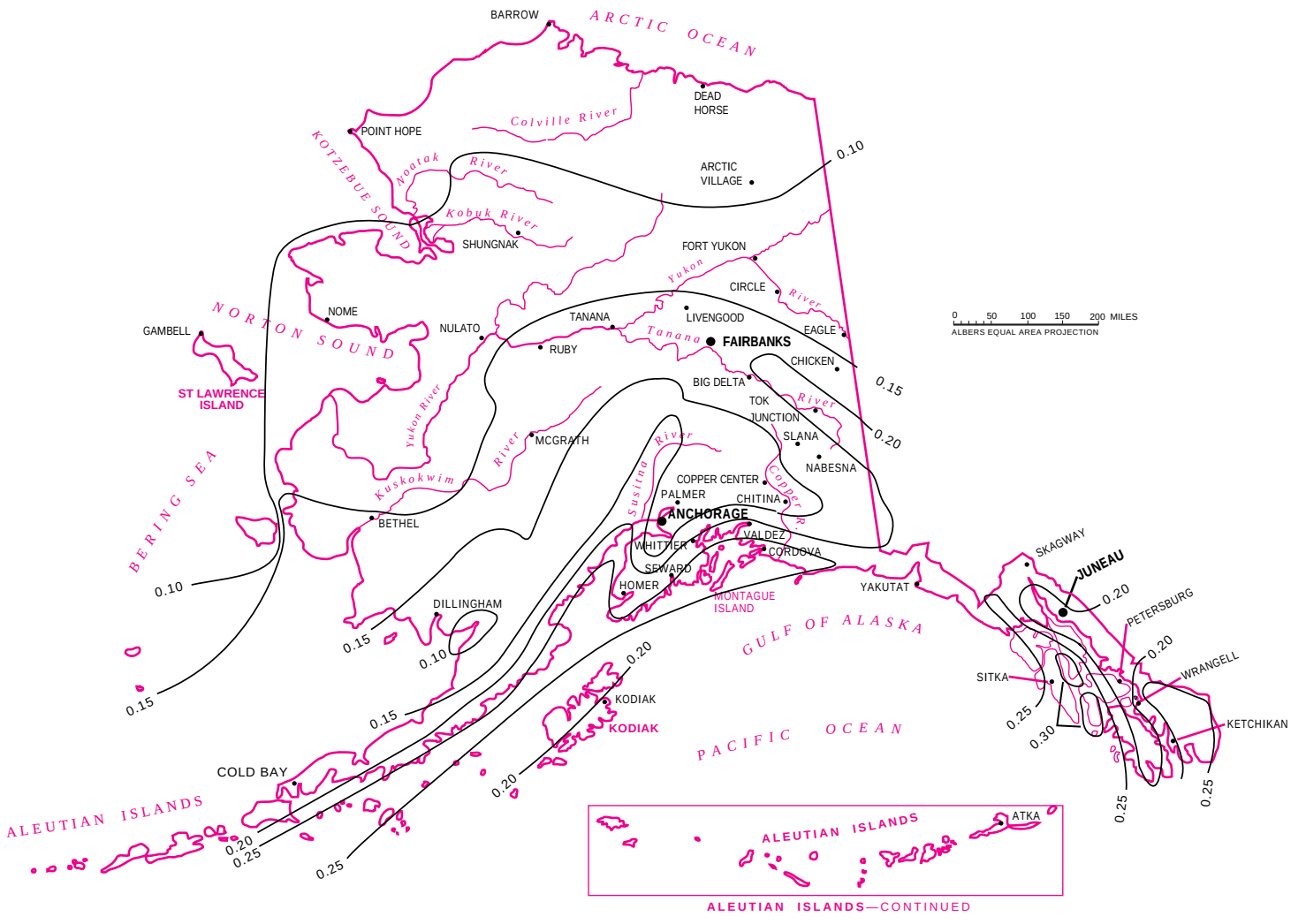
FIGURE 10B-3a
10-YEAR 5-MINUTE RAINFALL (INCHES)
ALASKA



ALEUTIAN ISLANDS—CONTINUED

SOURCE:
DATA PROVIDED BY SCS FIELD PERSONNEL
NATIONAL CARTOGRAPHY AND GIS CENTER,
FORT WORTH, TEXAS

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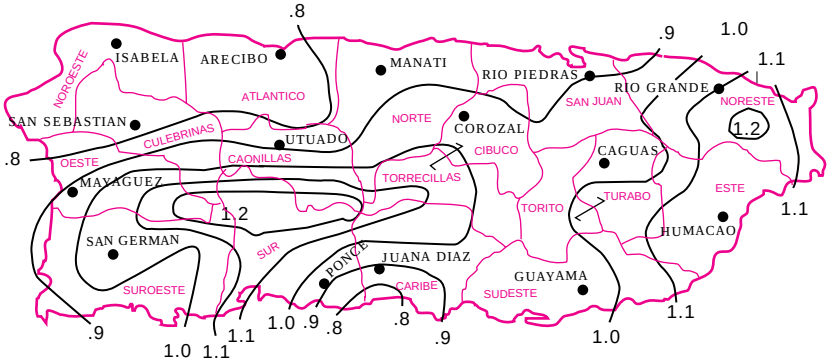
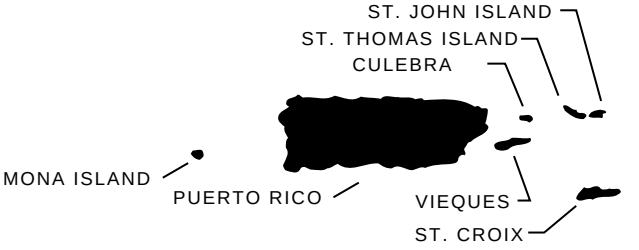
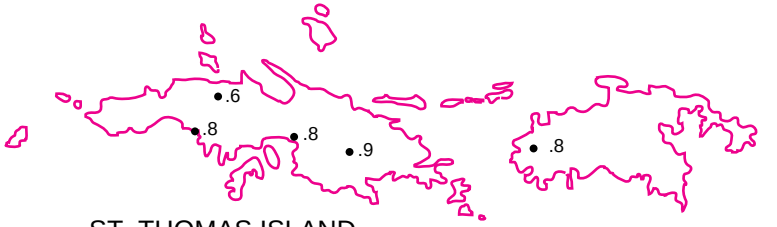
FIGURE 10B-3b
10-YEAR 5-MINUTE RAINFALL (INCHES)



PUERTO RICO



LOCATION MAP



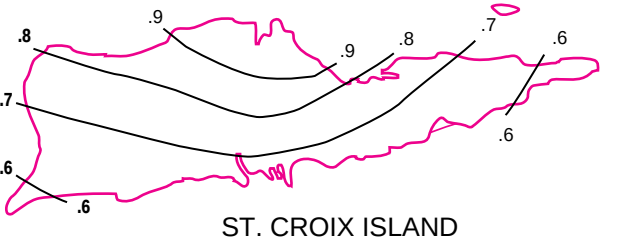
ST. THOMAS ISLAND

ST. JOHN ISLAND

MONA ISLAND

CULEBRA ISLAND

VIEQUES ISLAND



ST. CROIX ISLAND

0 10 20 30 40 50 MILES

0 5 10 15 20 MILES

SOURCE:
DATA PROVIDED BY SCS FIELD PERSONNEL.
NATIONAL CARTOGRAPHY AND GIS CENTER,
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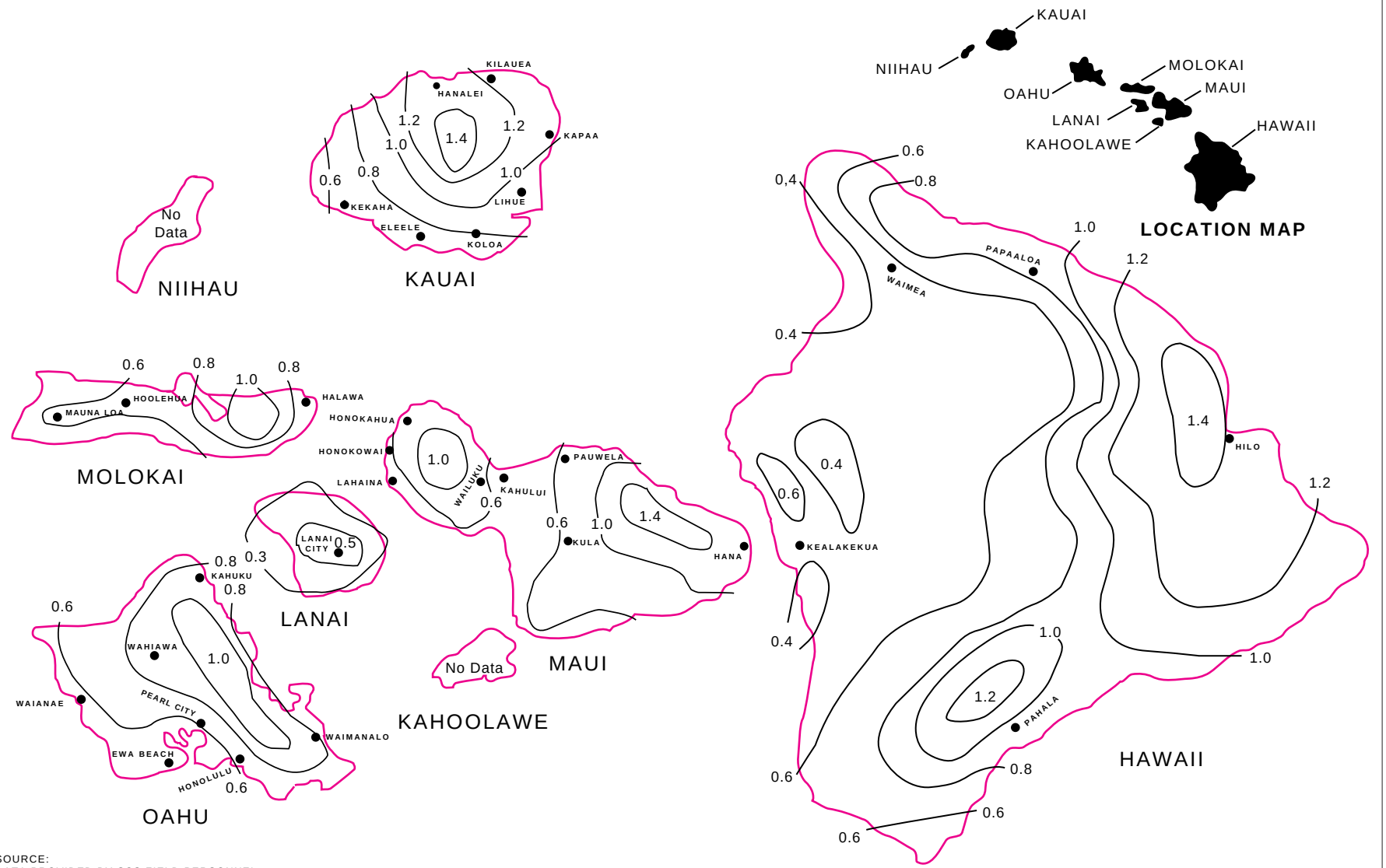
SOIL CONSERVATION SERVICE

FIGURE 10B-3c
10-YEAR 5-MINUTE RAINFALL (INCHES)



SOURCE:
DATA PROVIDED BY SCS FIELD PERSONNEL
NATIONAL CARTOGRAPHY AND GIS CENTER,
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0 10 20 30 40 MILES

FEBRUARY 1994 1007914

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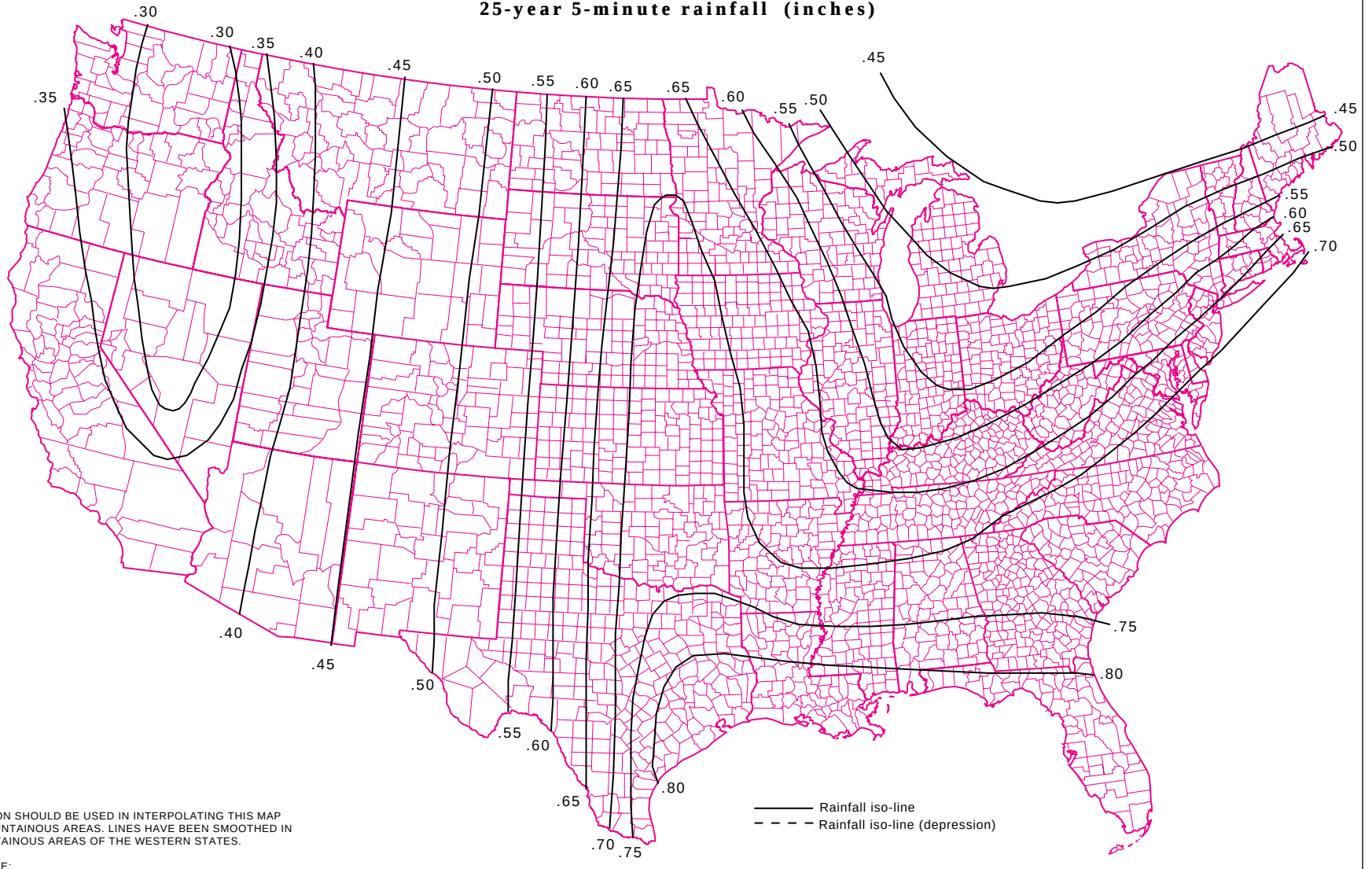
NATURAL RESOURCES CONSERVATION SERVICE

Figure 10B-4
25-year 5-minute rainfall (inches)



NOTE:
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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 %	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 -	Percent of annual													
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May thru Oct	Nov thru Apr
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

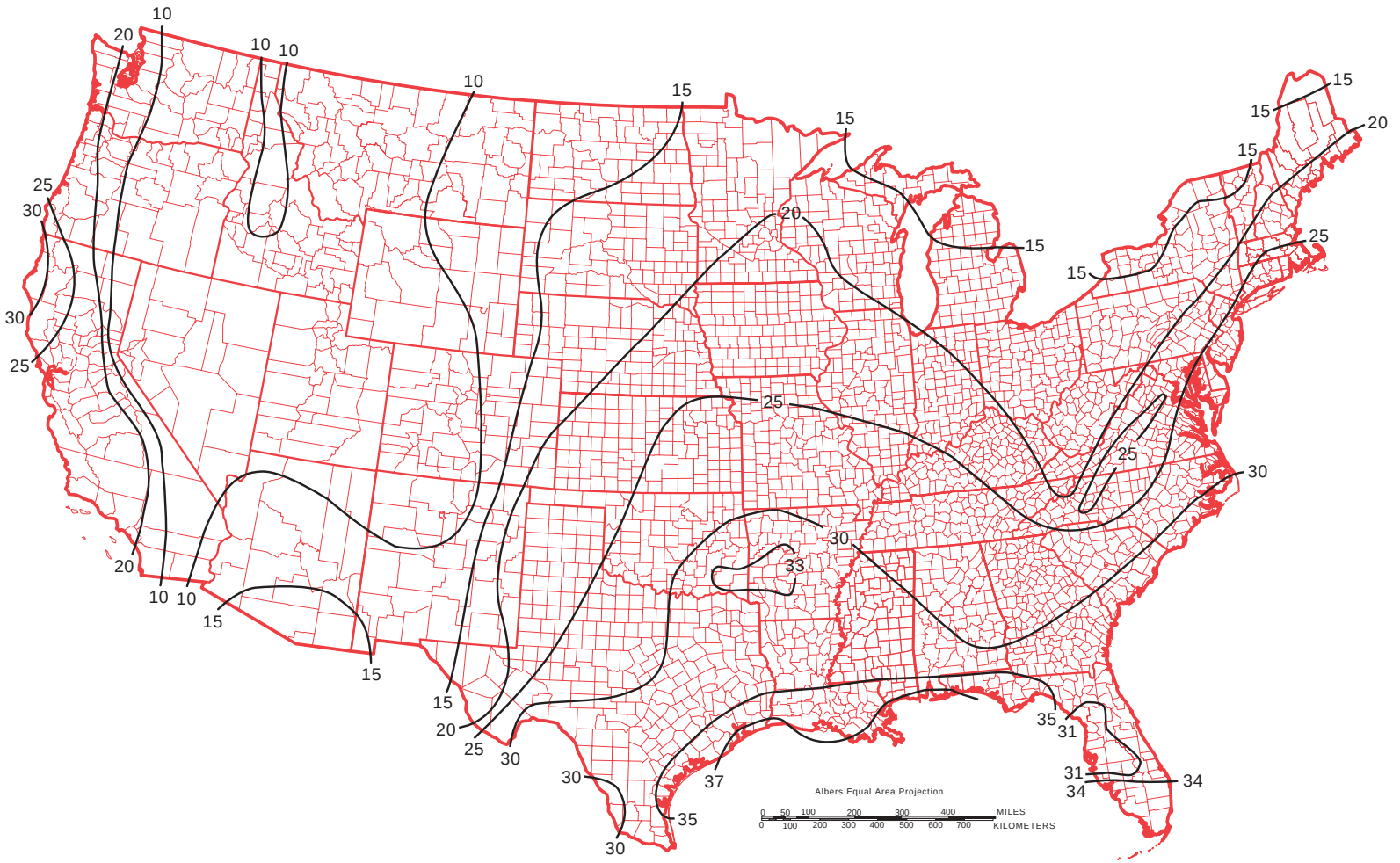
Source: Adapted from Evaporation Atlas for the Contiguous 48 United States, NOAA Technical Report NWS 33, Table 3-Adjusted mean monthly Class A pan evaporation for selected stations, 1956-70.

U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

ANNUAL RUNOFF
FROM UNSURFACED FEEDLOTS (CN-90)
AS PERCENT OF MEAN ANNUAL PRECIPITATION

FIGURE 10C-1



SOURCE:
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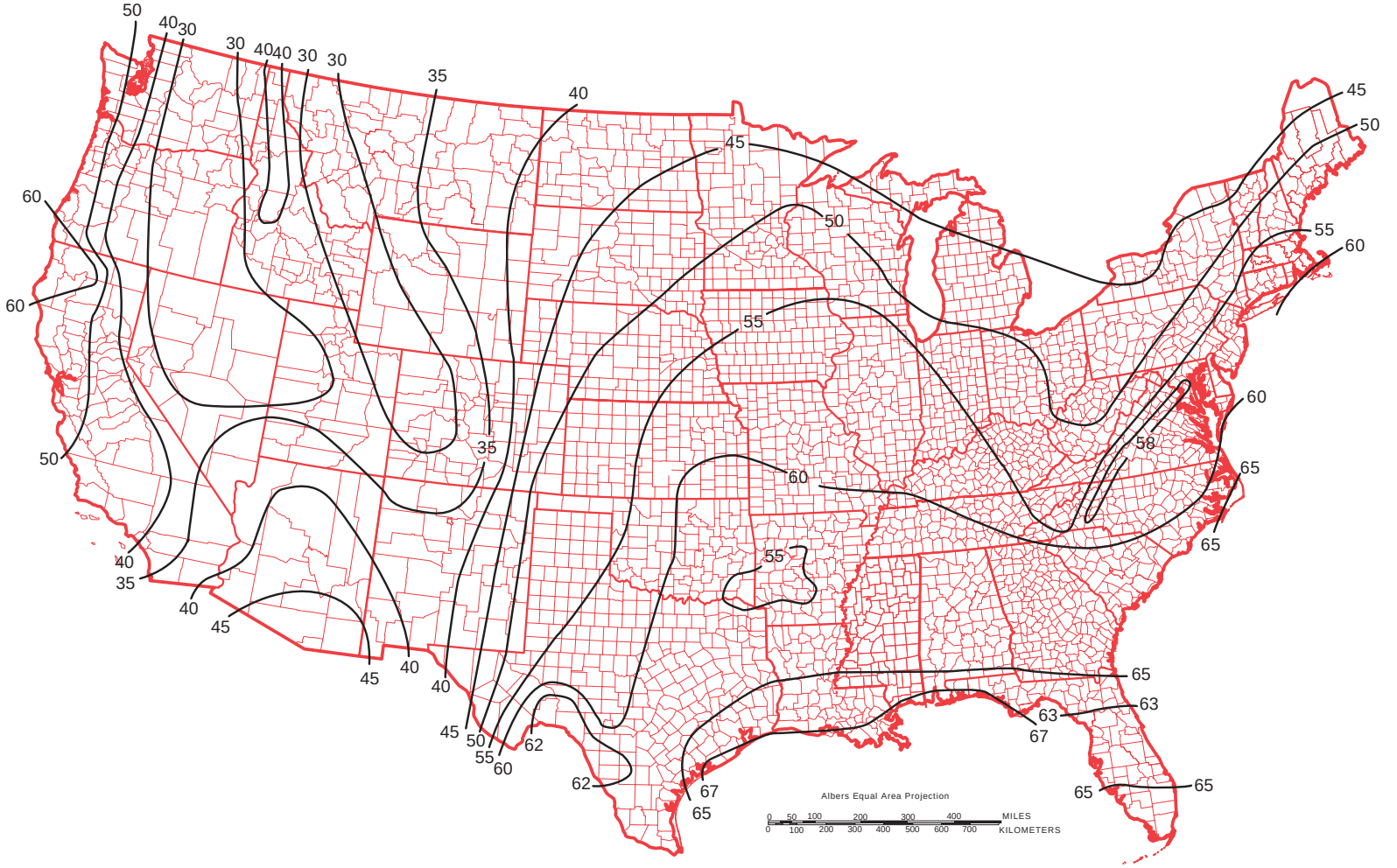
SOIL CONSERVATION SERVICE

ANNUAL RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-2



SOURCE:
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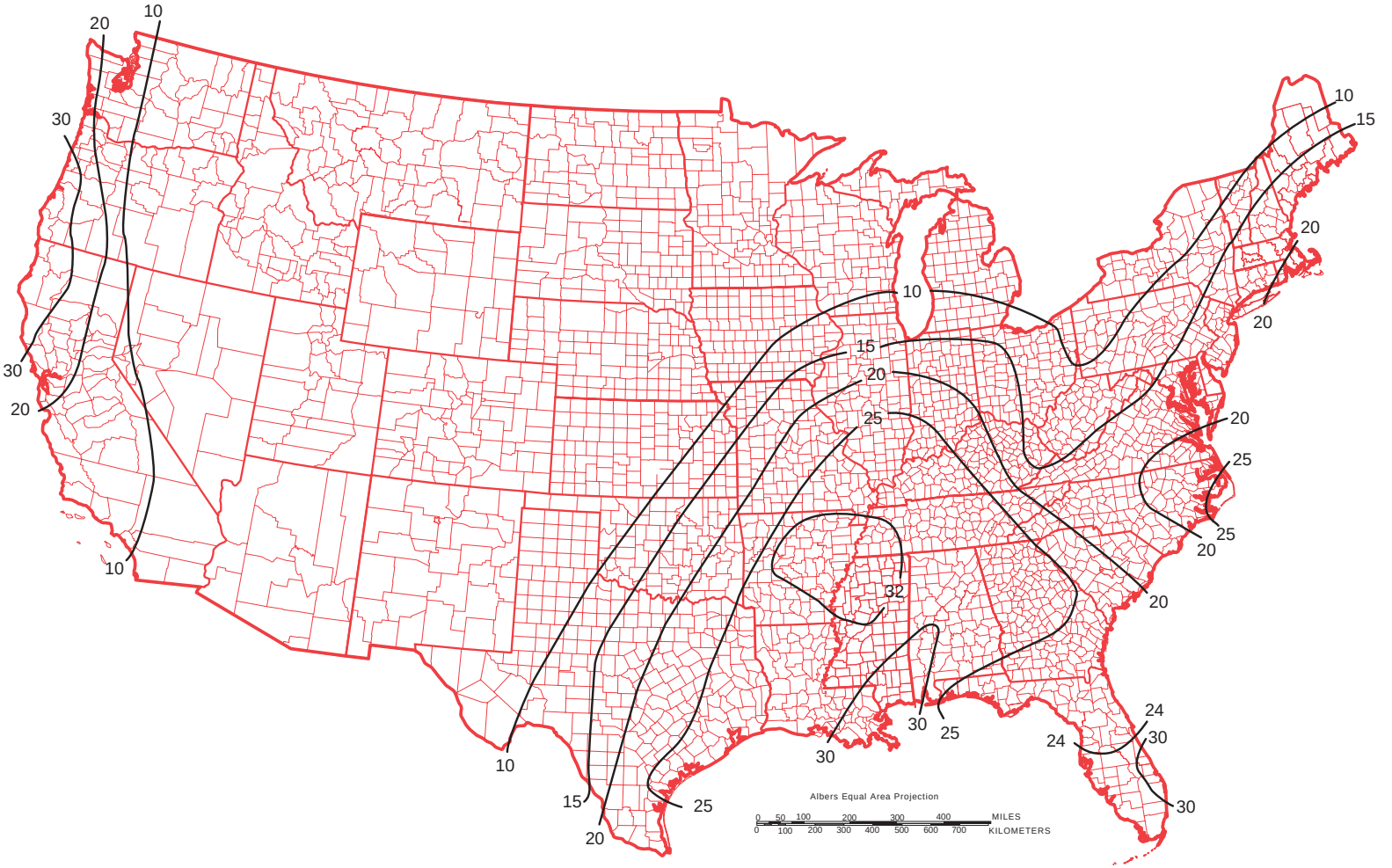
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

JANUARY RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-3



SOURCE:
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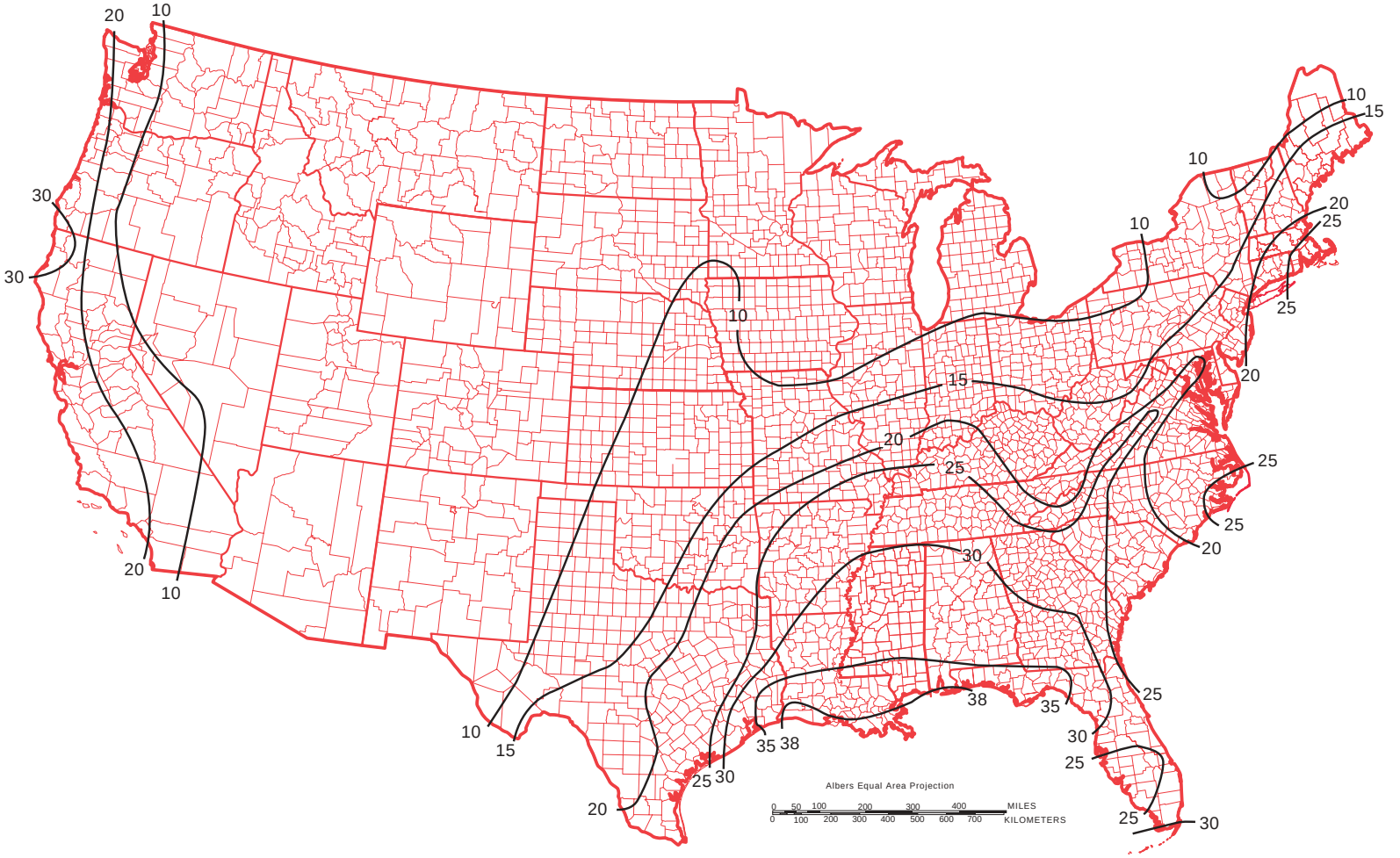
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

FEBRUARY RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-4



SOURCE:
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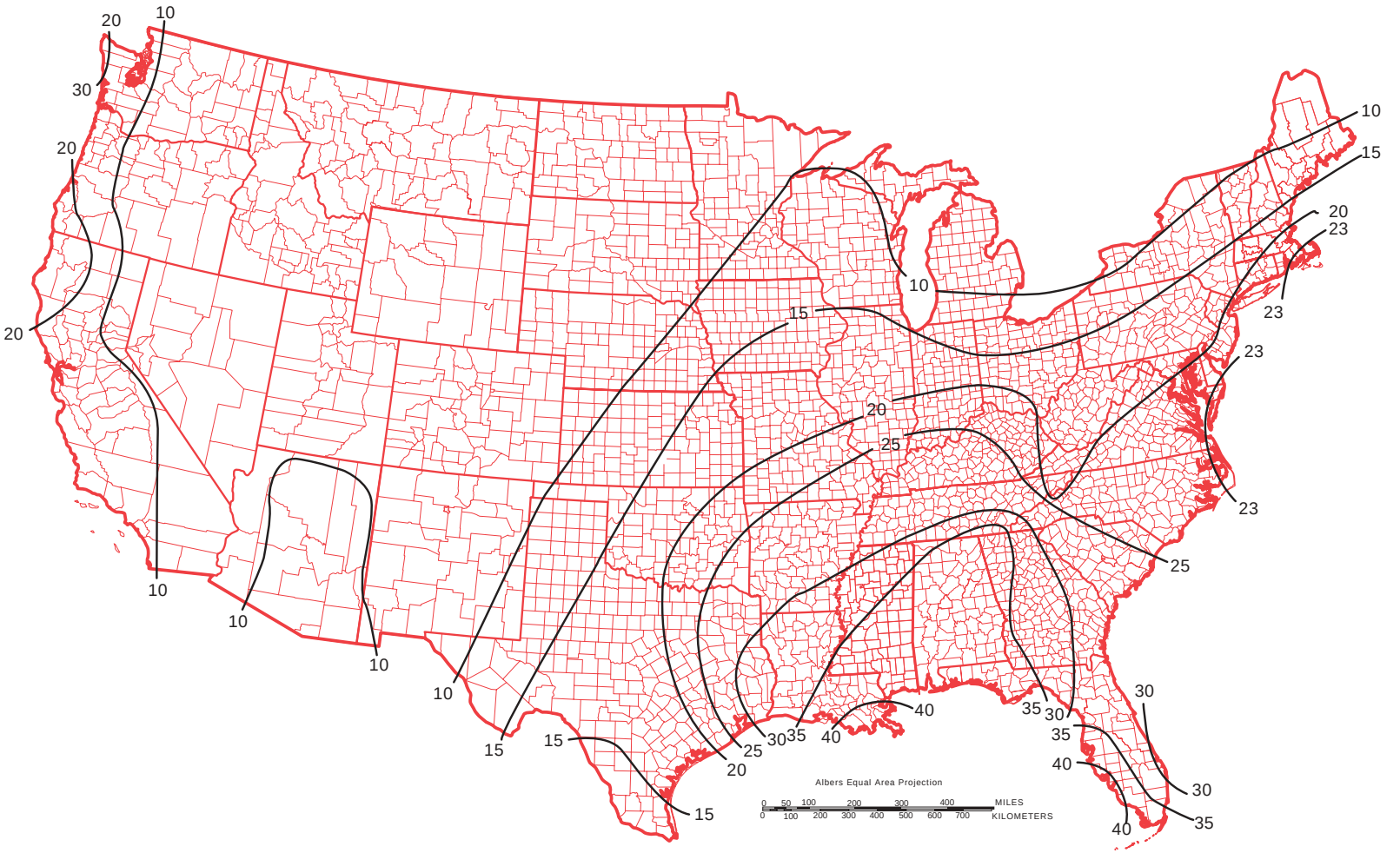
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

MARCH RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-5



SOURCE:
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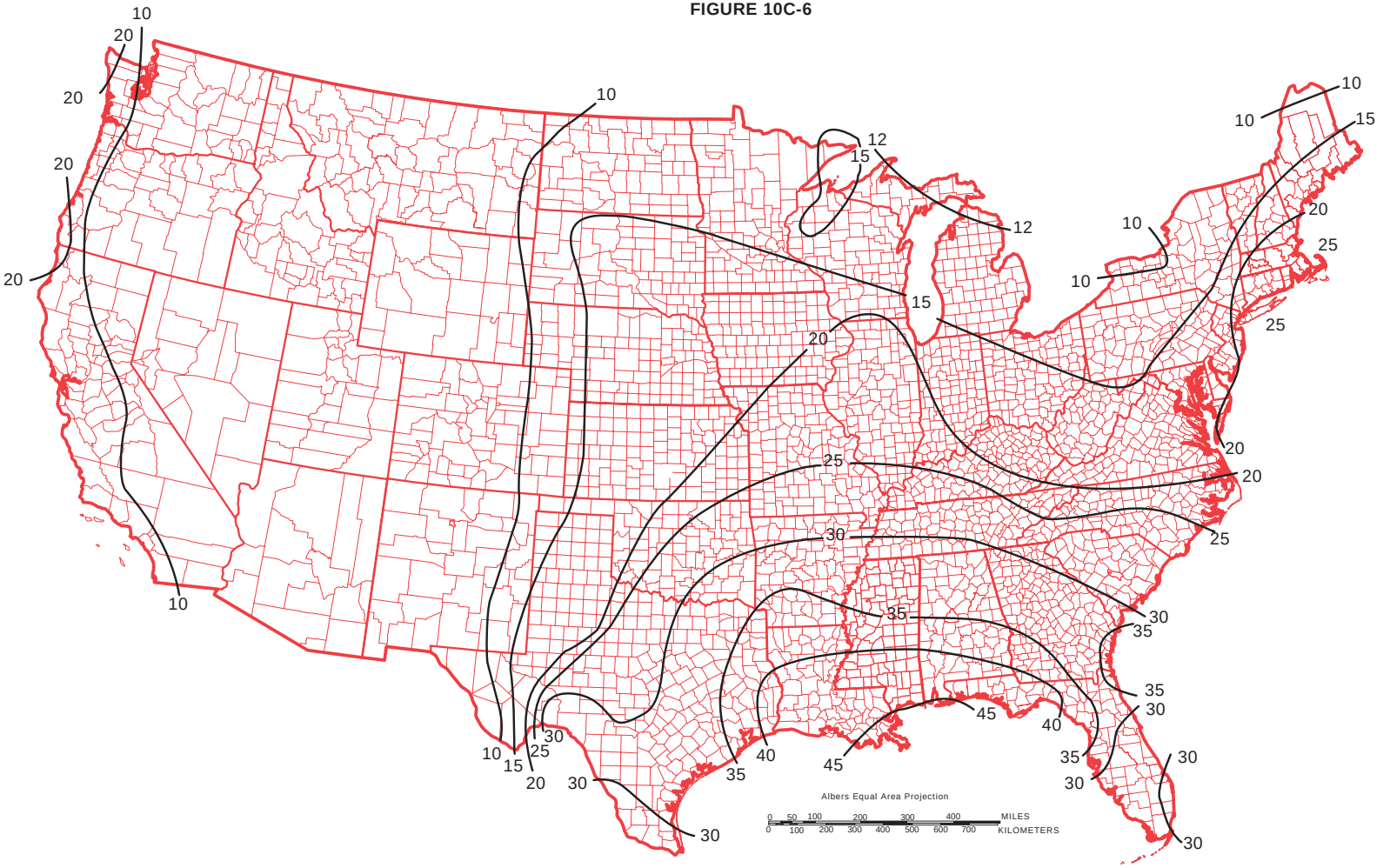
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

APRIL RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-6



SOURCE:
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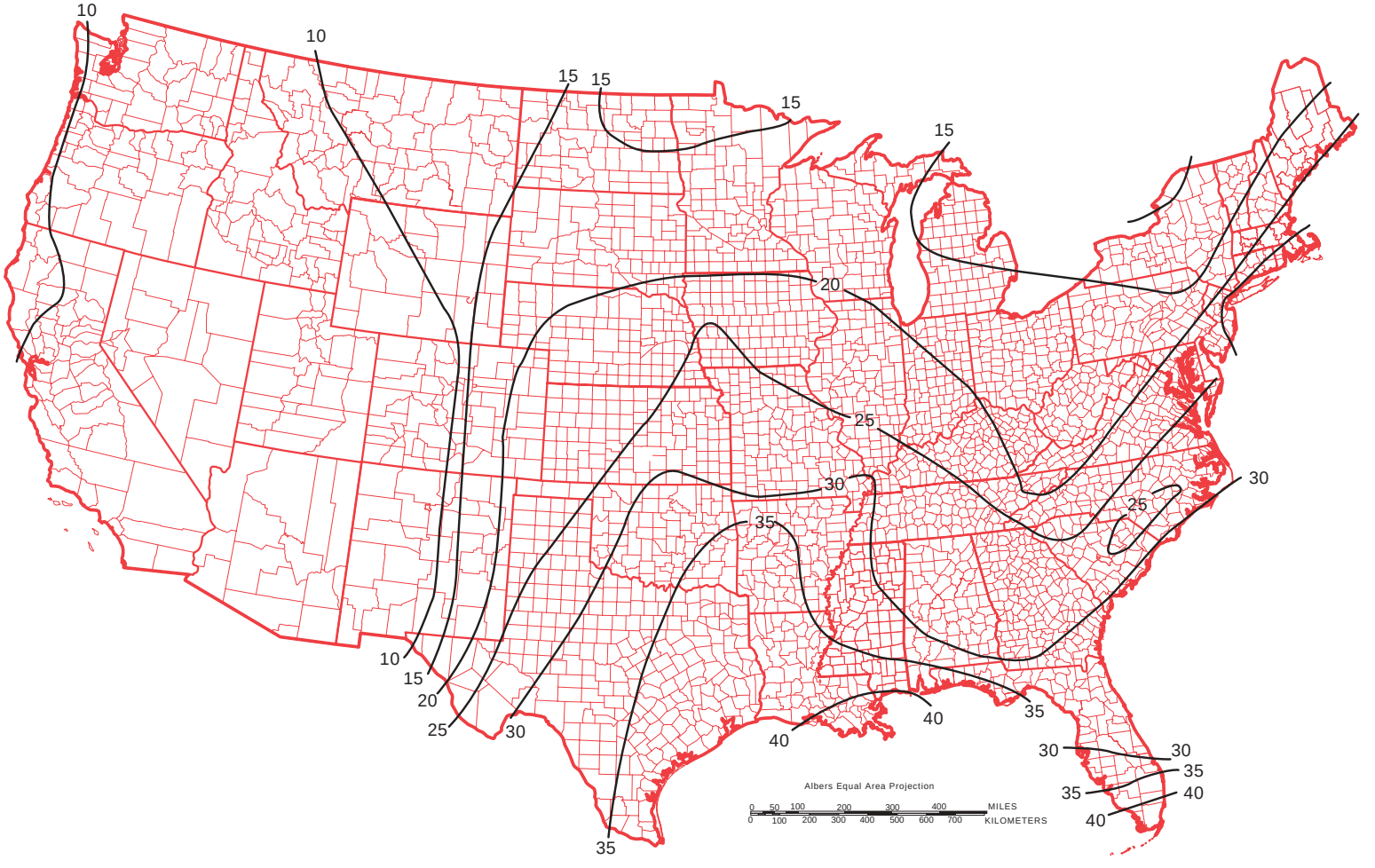
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

APRIL RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-7



SOURCE:
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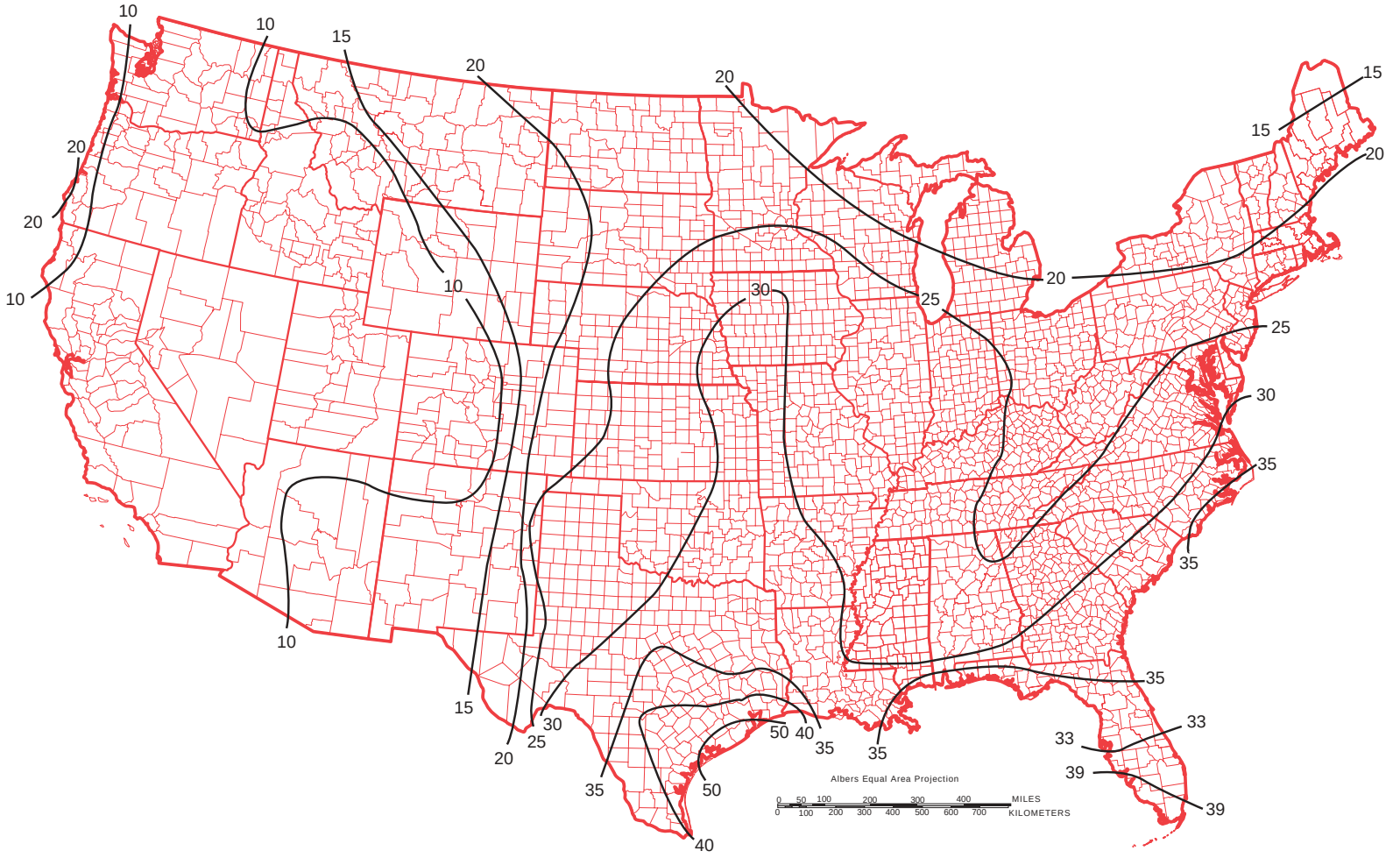
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

JUNE RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-8



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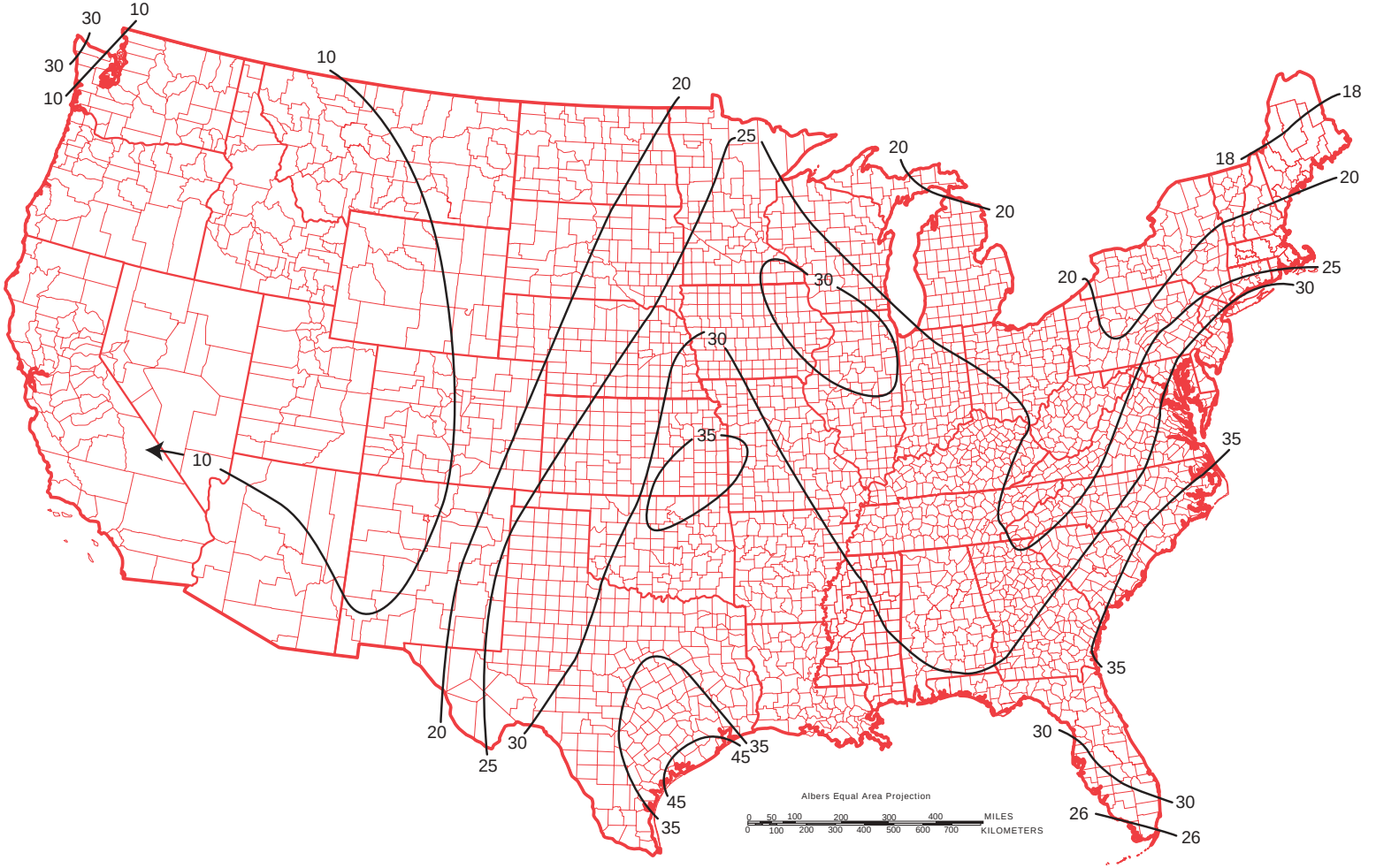
SOIL CONSERVATION SERVICE

JULY RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-9



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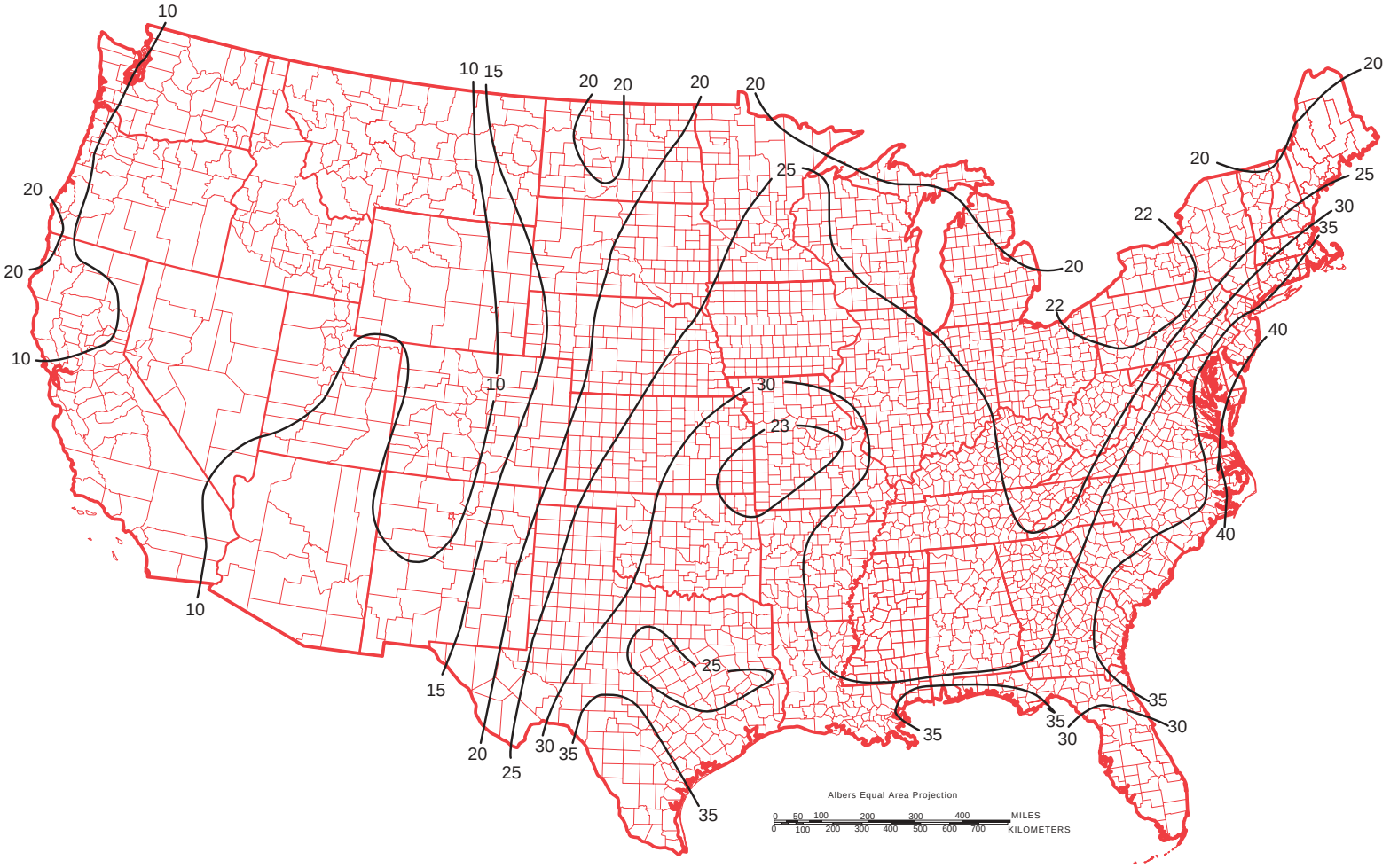
SOIL CONSERVATION SERVICE

AUGUST RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-10



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U.S. DEPARTMENT OF AGRICULTURE

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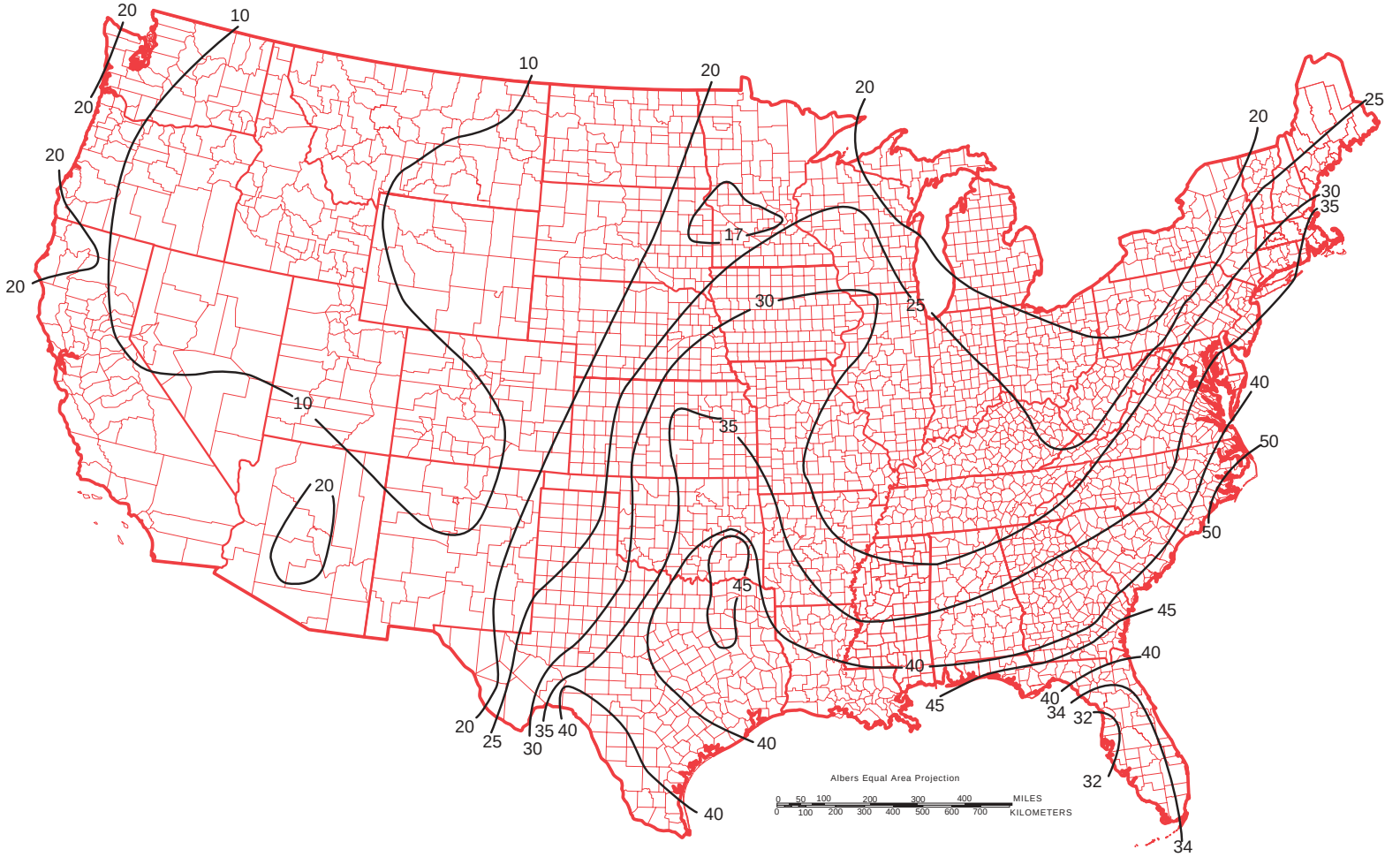
SEPTEMBER RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-11



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U.S. DEPARTMENT OF AGRICULTURE

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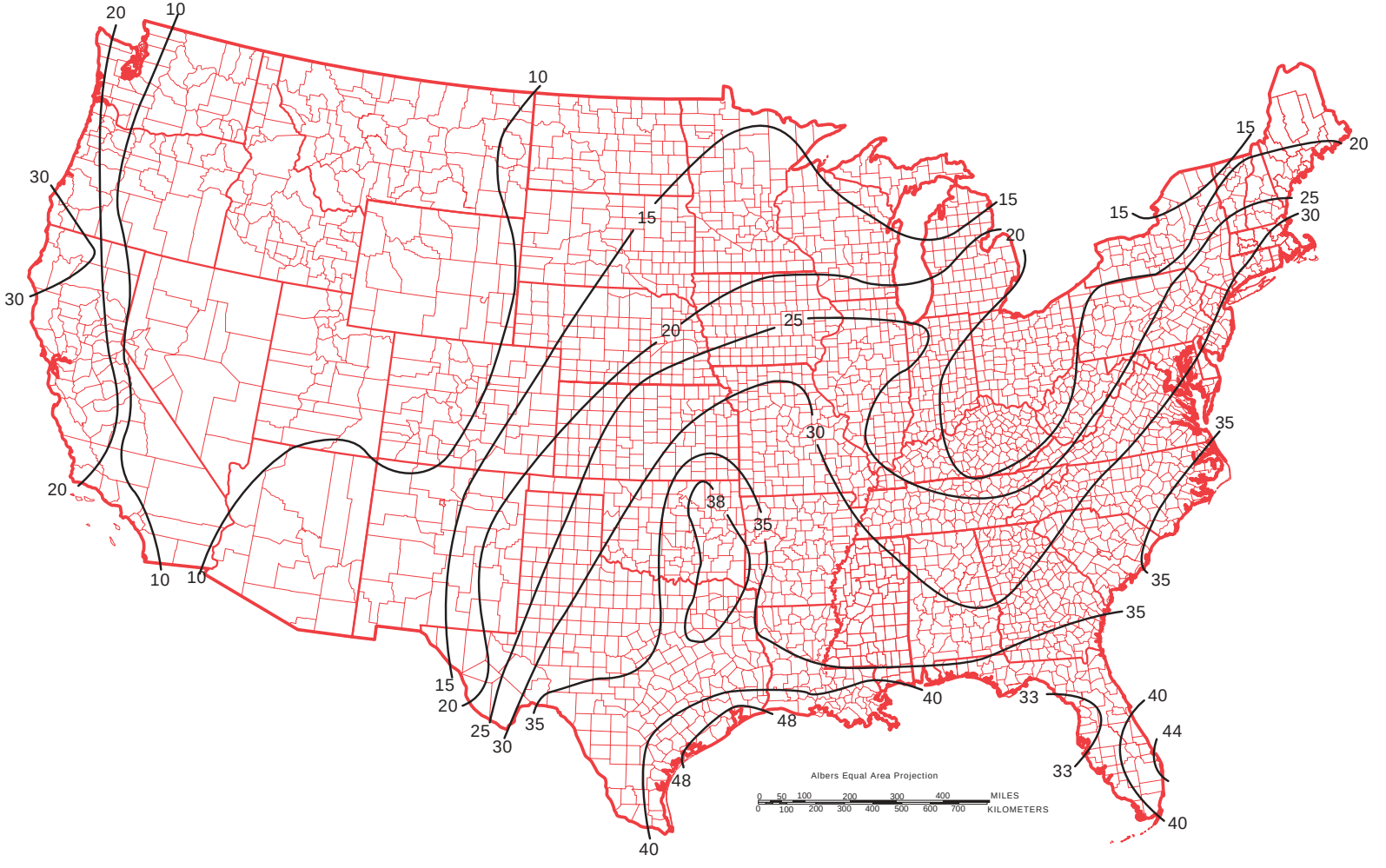
OCTOBER RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-12



SOURCE:
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U.S. DEPARTMENT OF AGRICULTURE

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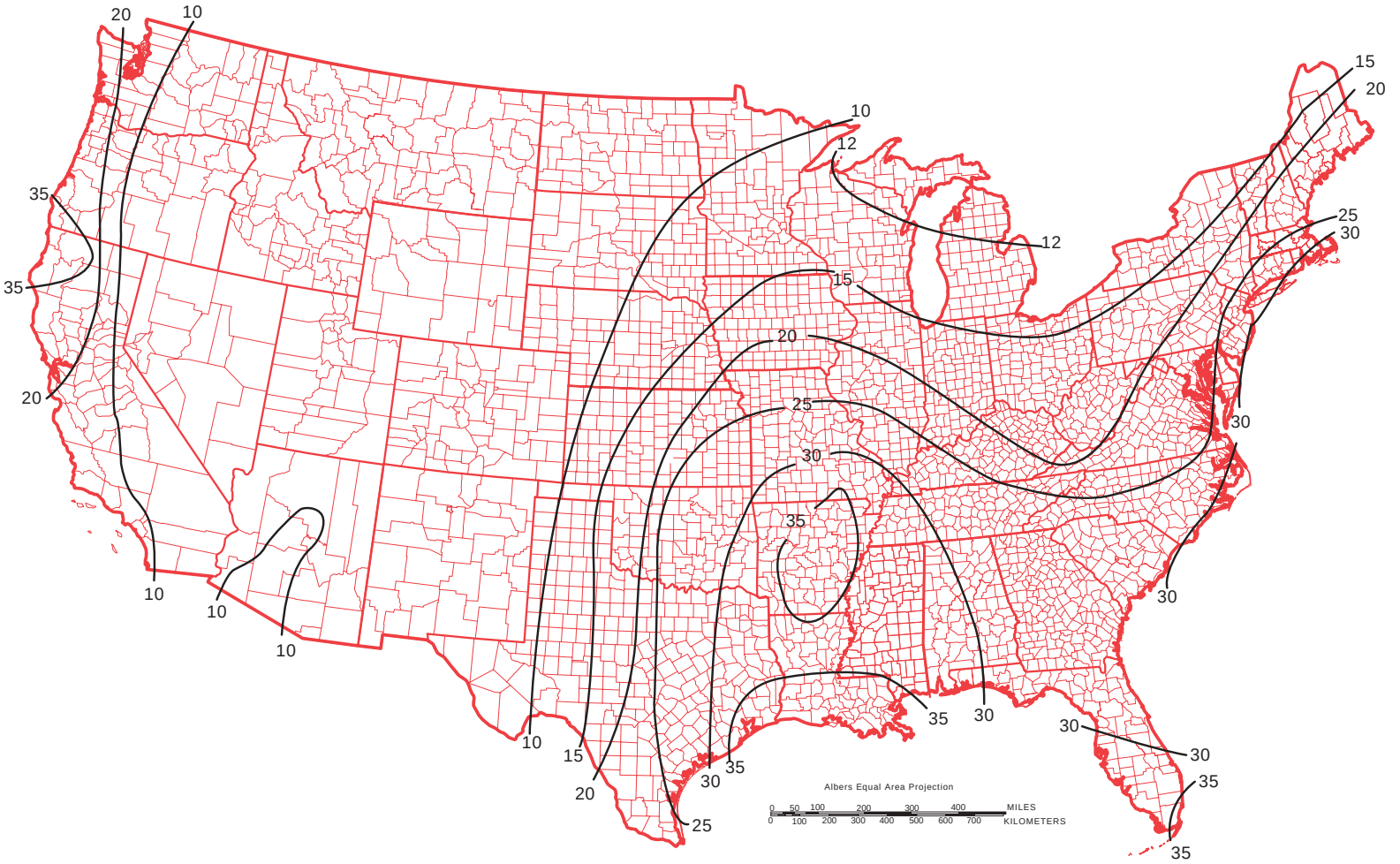
NOVEMER RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-13



SOURCE:
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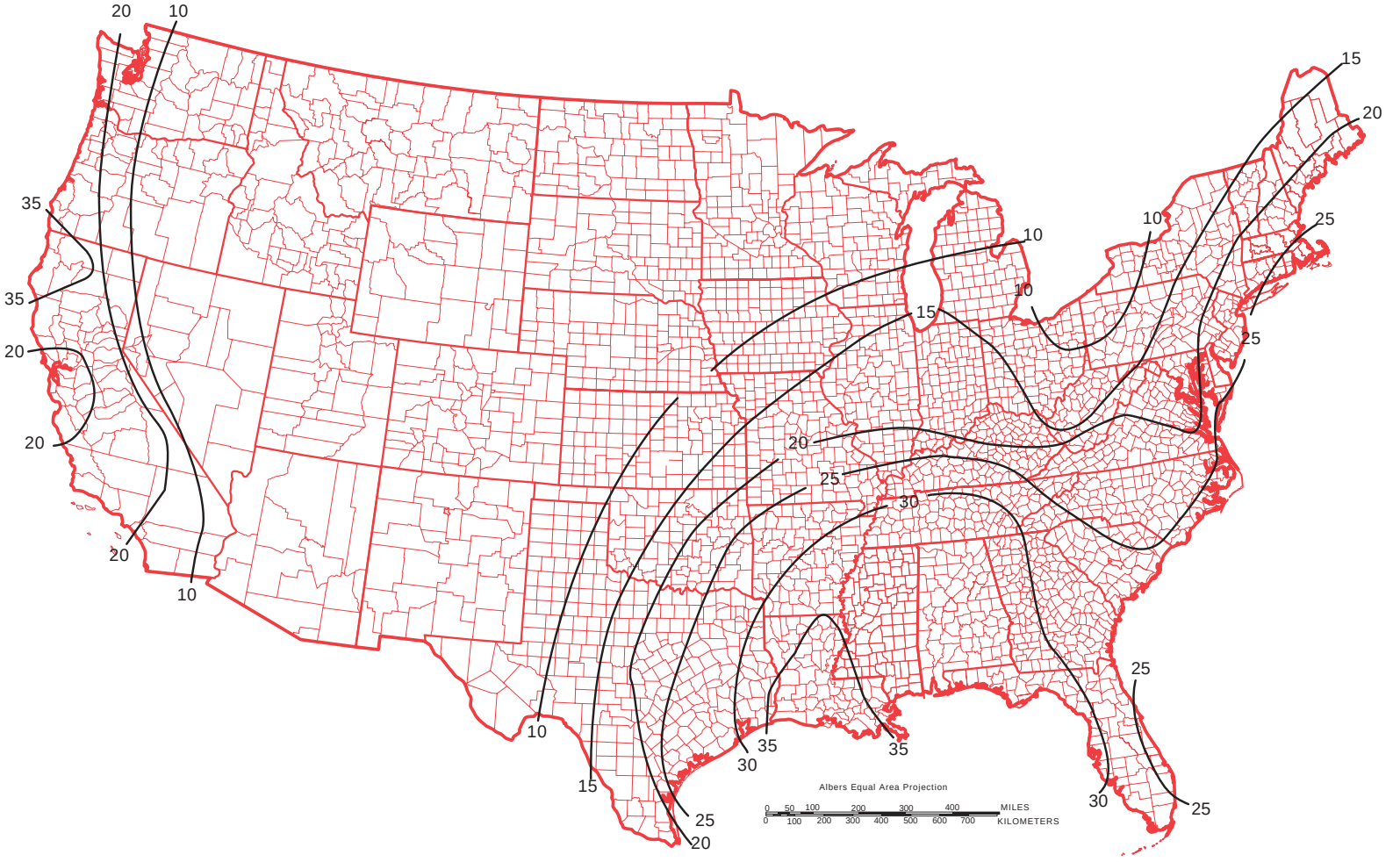
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

DECEMBER RUNOFF FROM UNSURFACED FEEDLOTS (CN-90) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-14



SOURCE:
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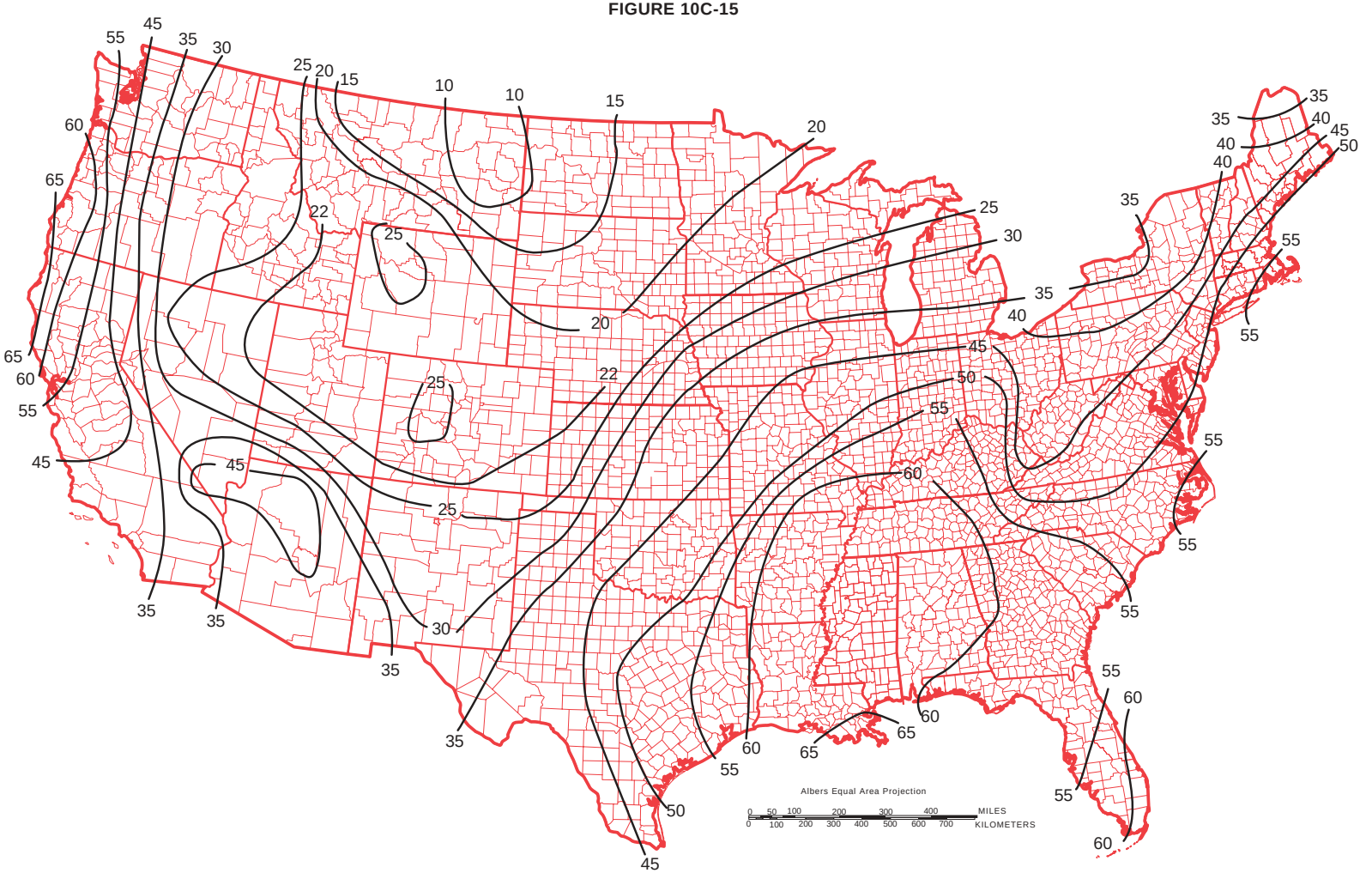
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

JANUARY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-15



SOURCE:
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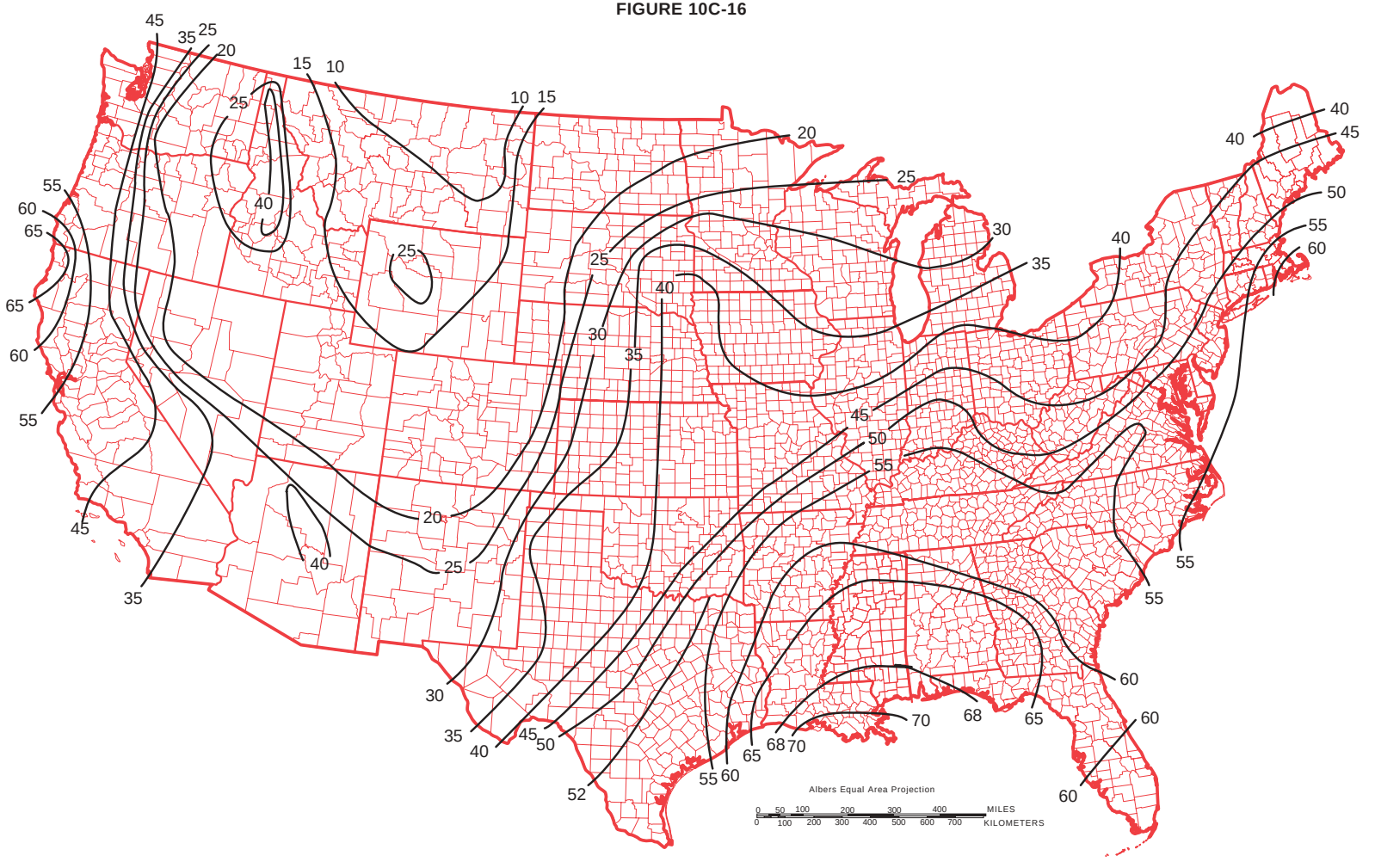
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

FEBRUARY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-16



SOURCE:
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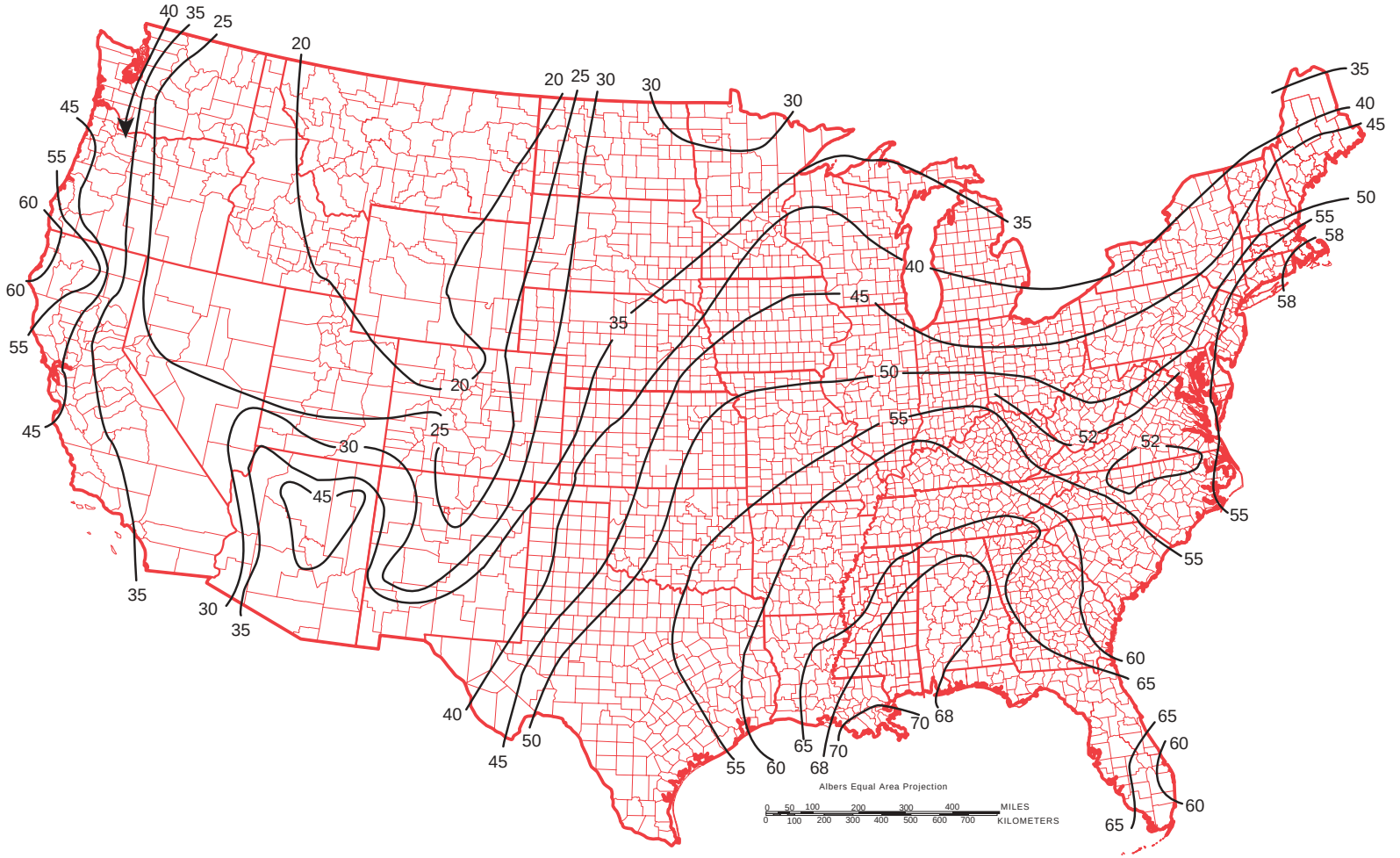
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

MARCH RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-17



SOURCE:
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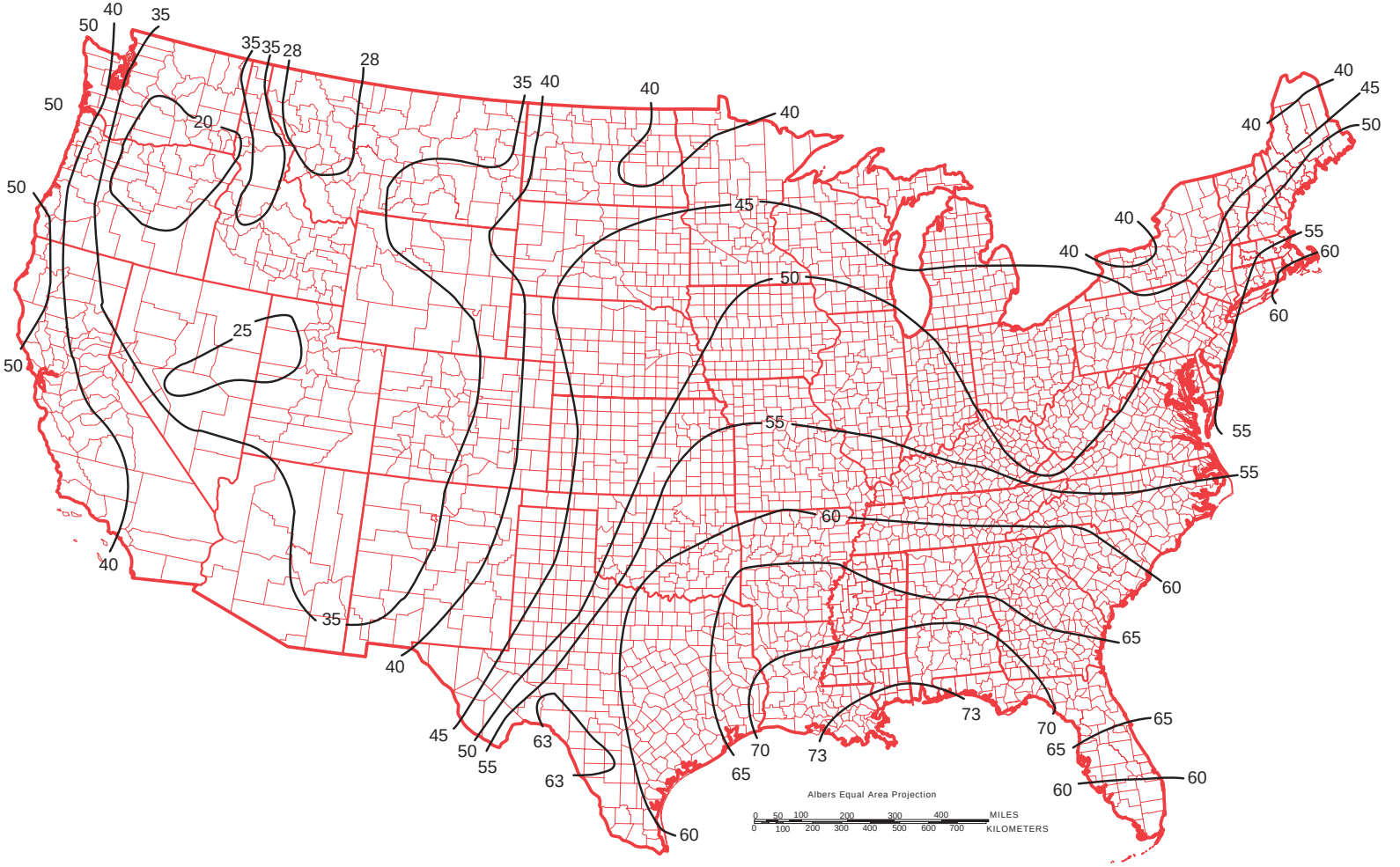
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

APRIL RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-18



SOURCE:
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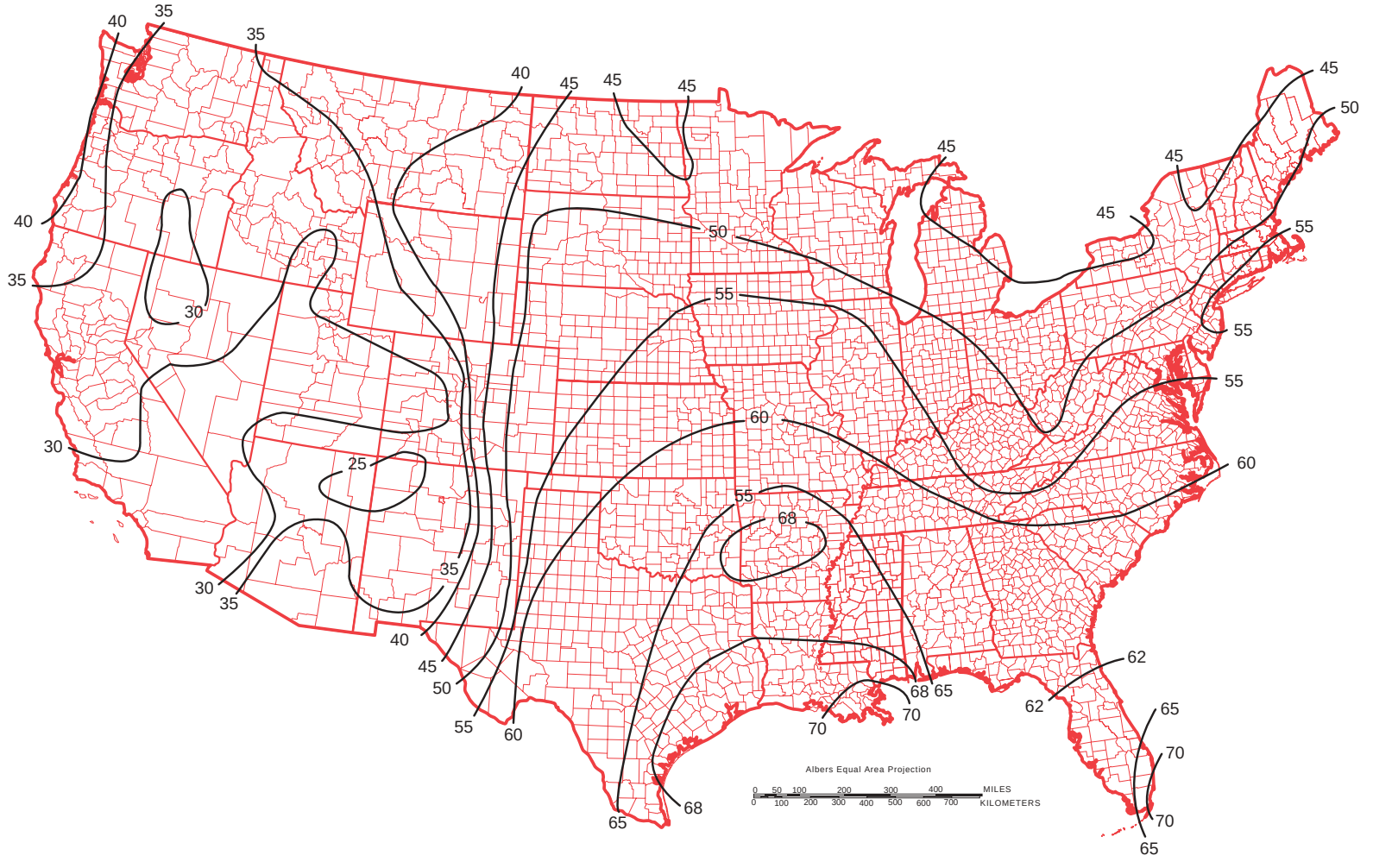
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

MAY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-19



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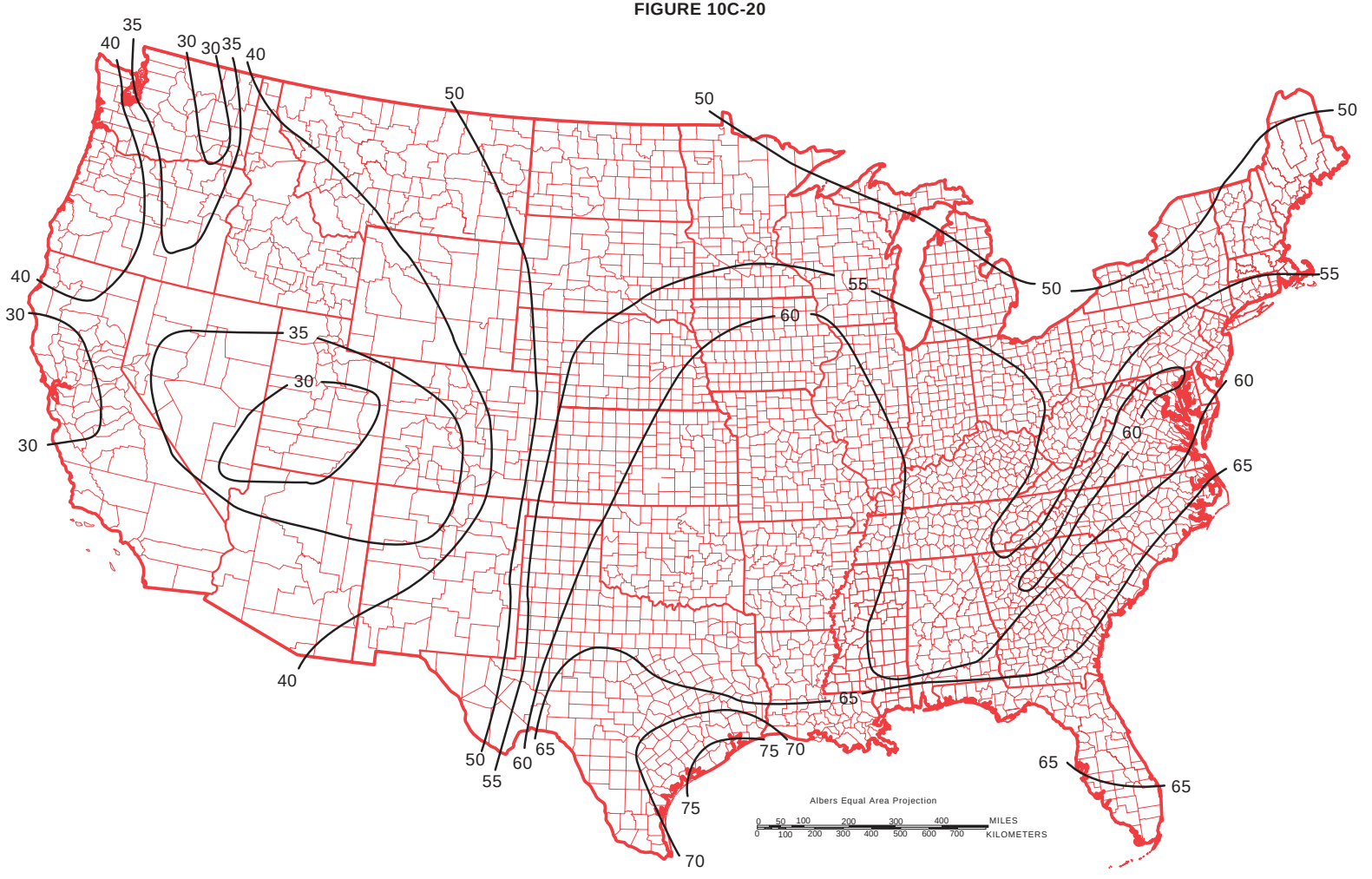
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

JUNE RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-20



SOURCE:
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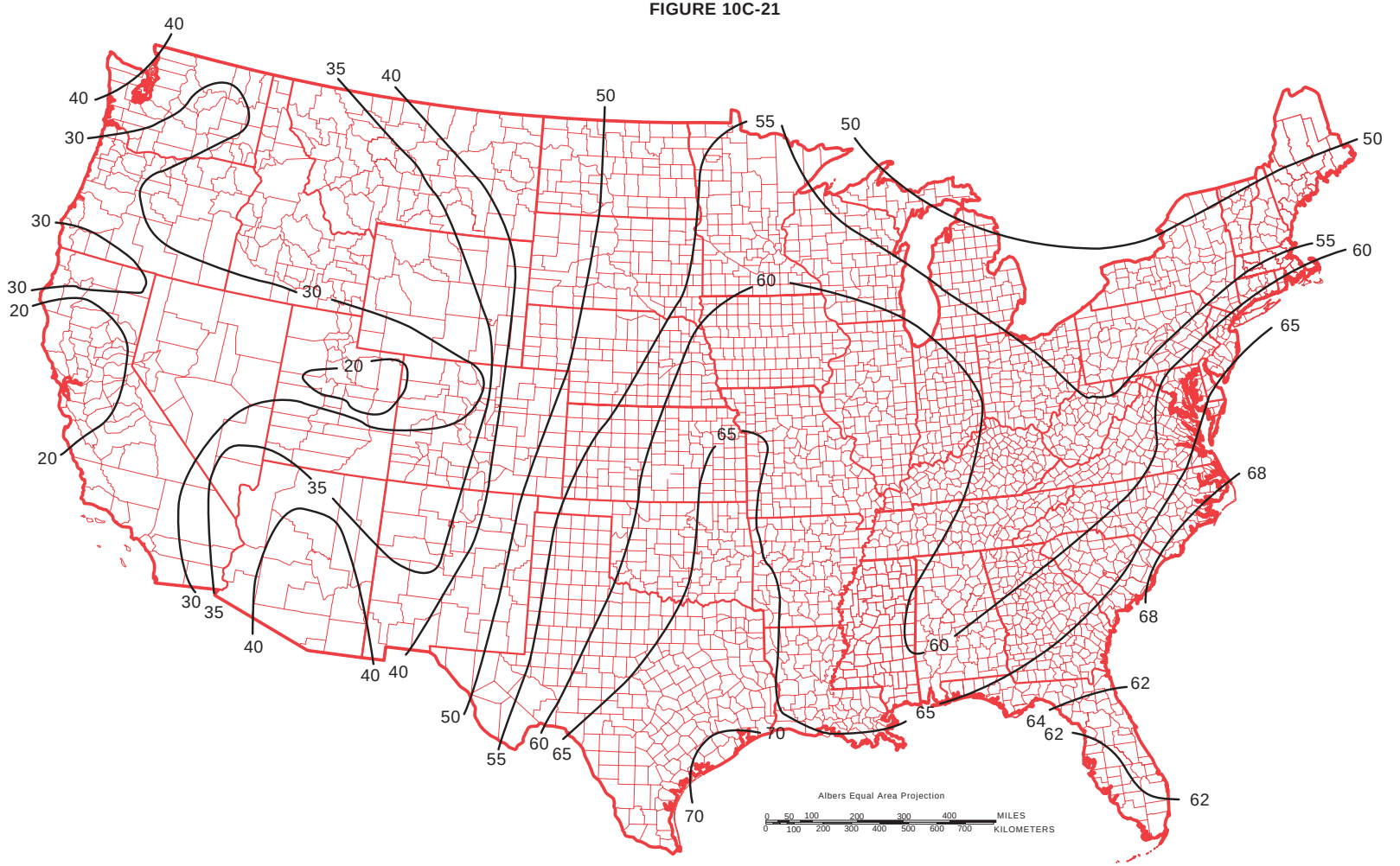
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

JULY RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-21



SOURCE:
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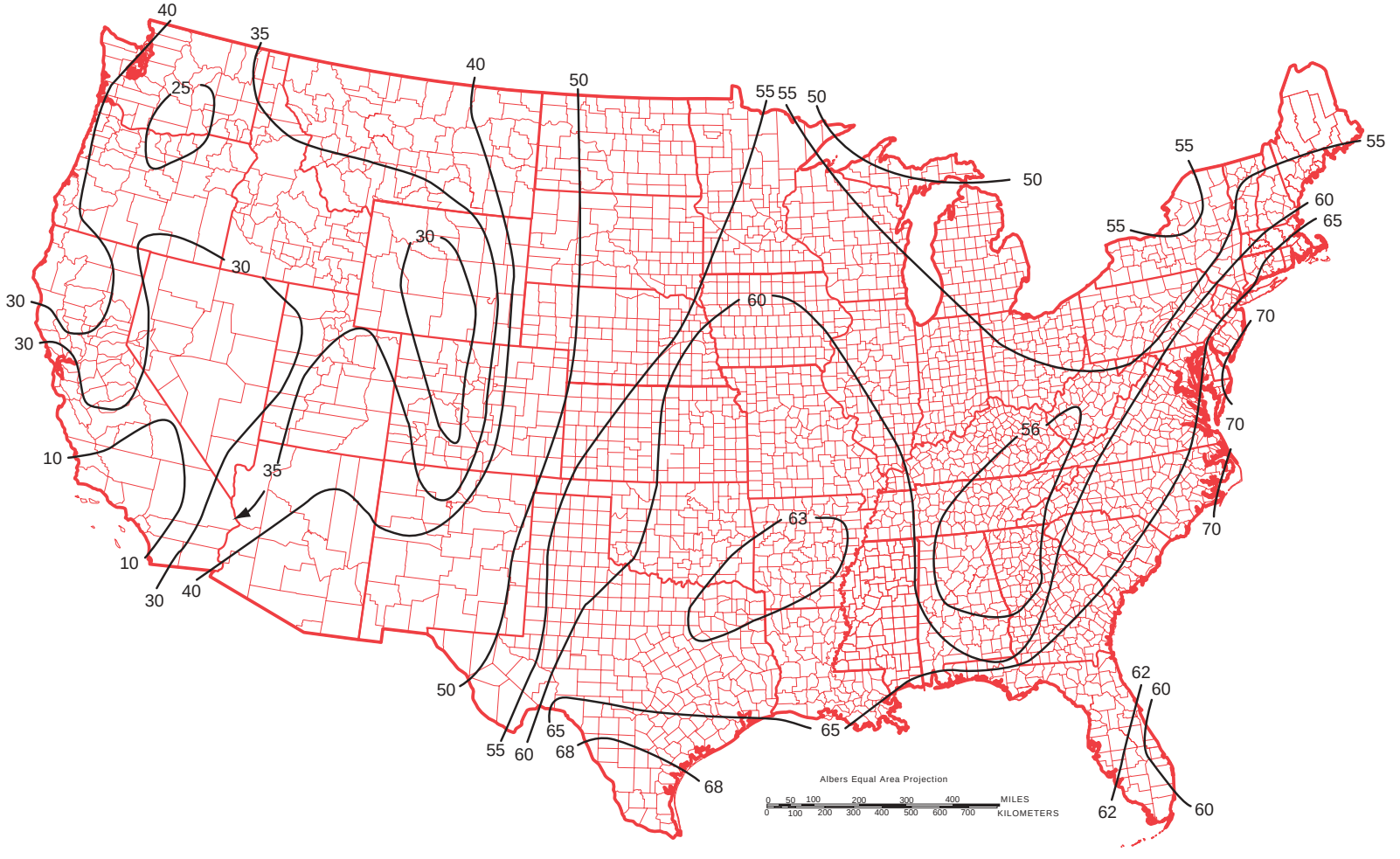
SOIL CONSERVATION SERVICE

AUGUST RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-22



SOURCE:
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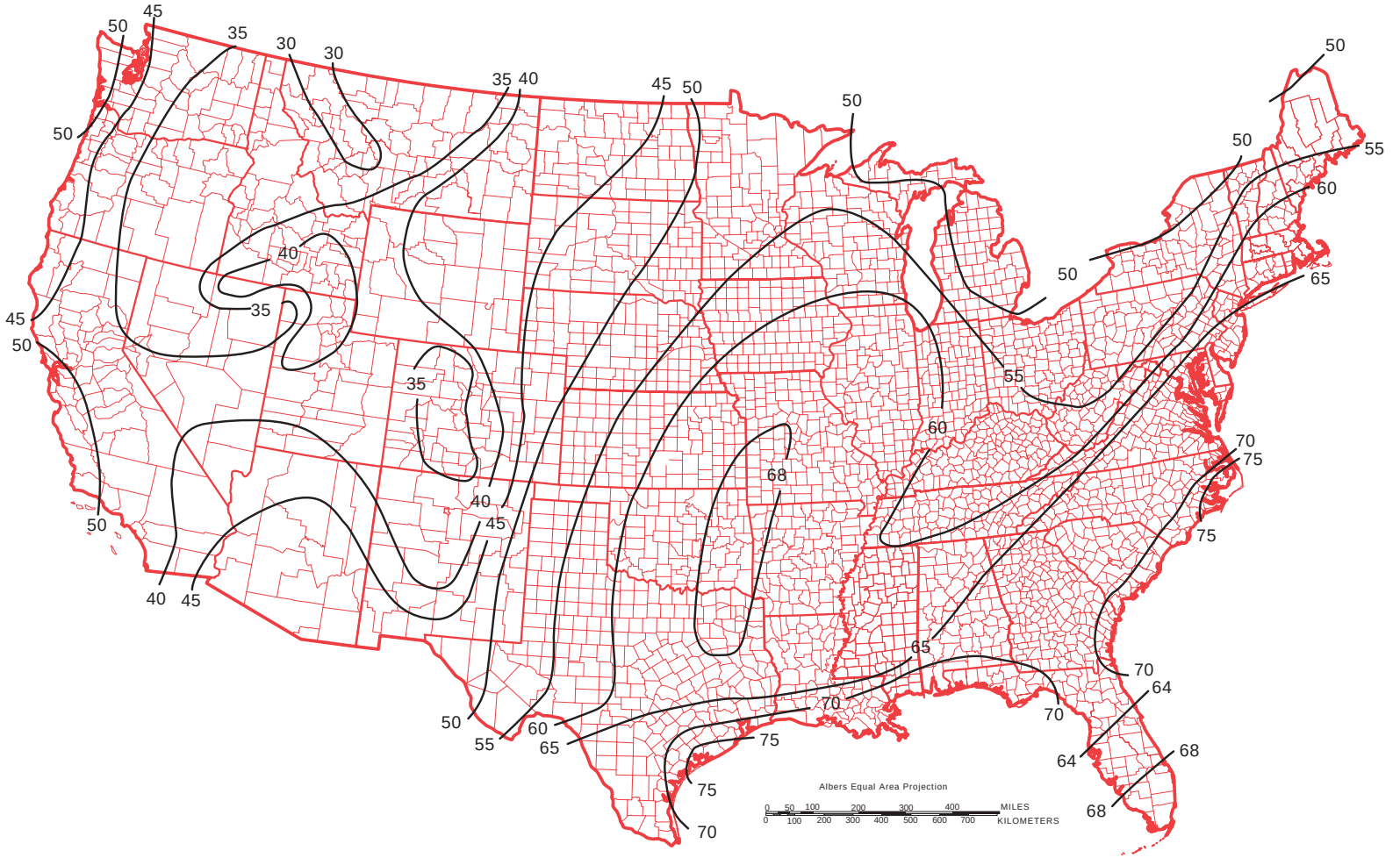
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

SEPTEMBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-23



SOURCE:
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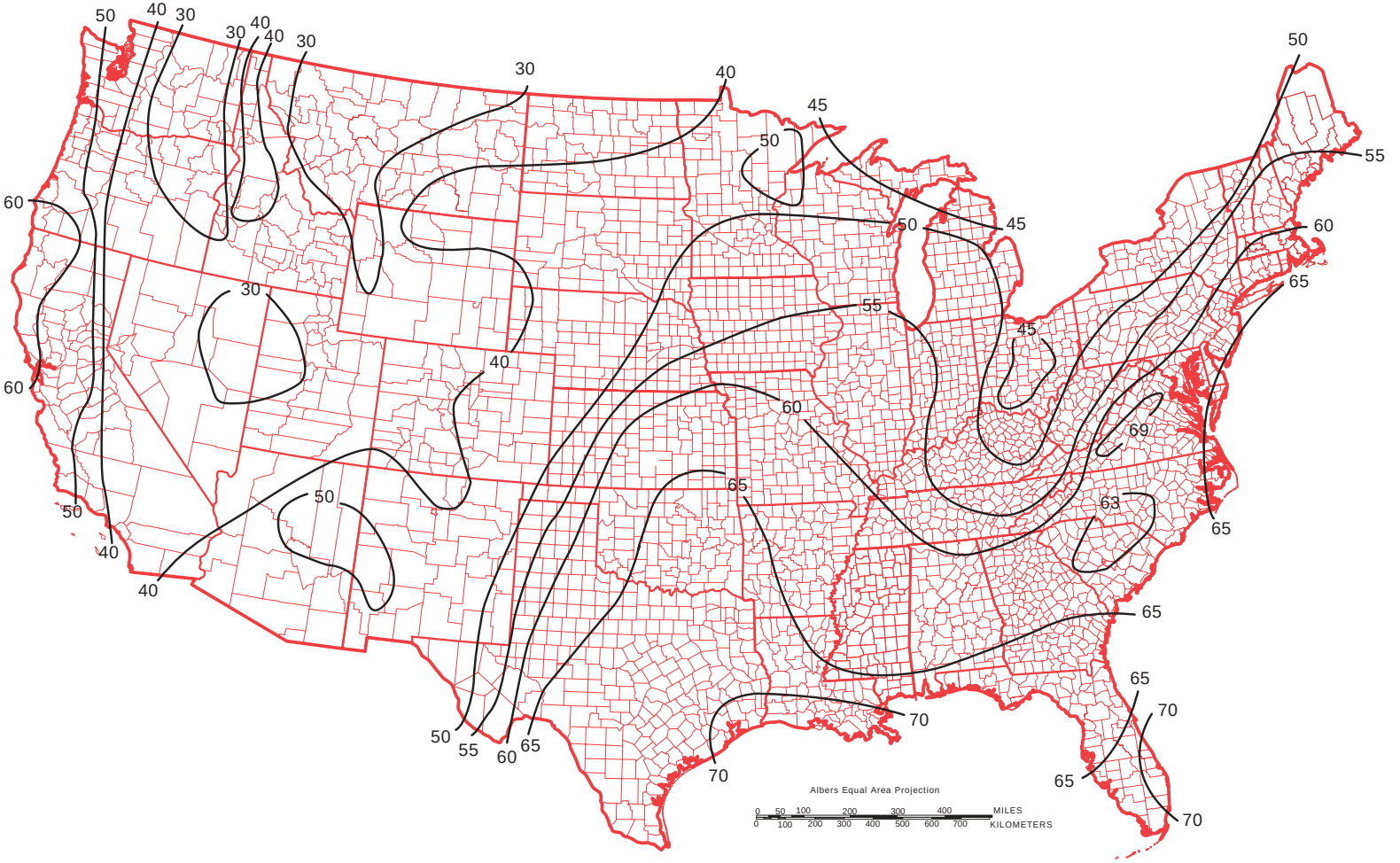
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

OCTOBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-24



SOURCE:
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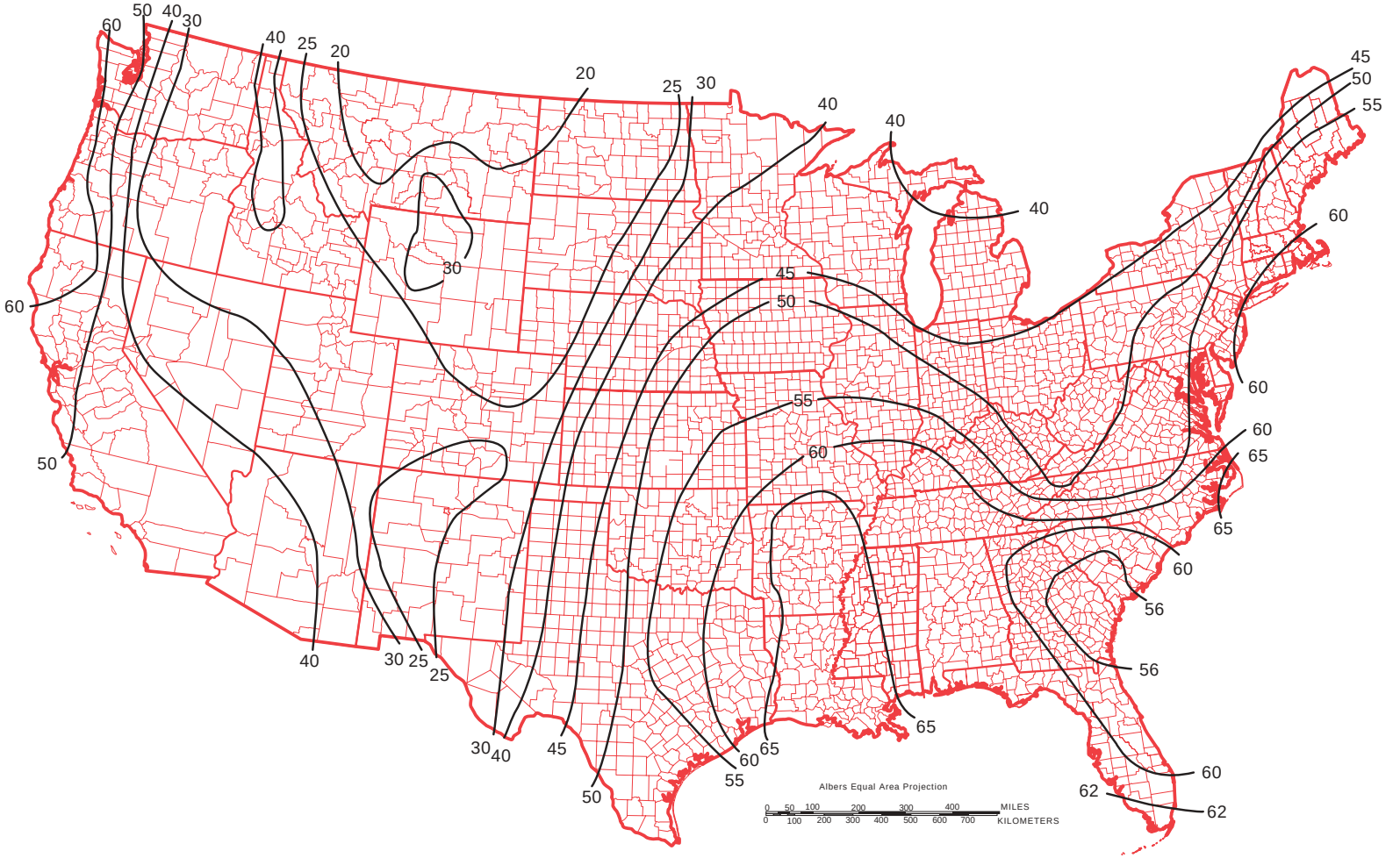
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

NOVEMBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-25



SOURCE:
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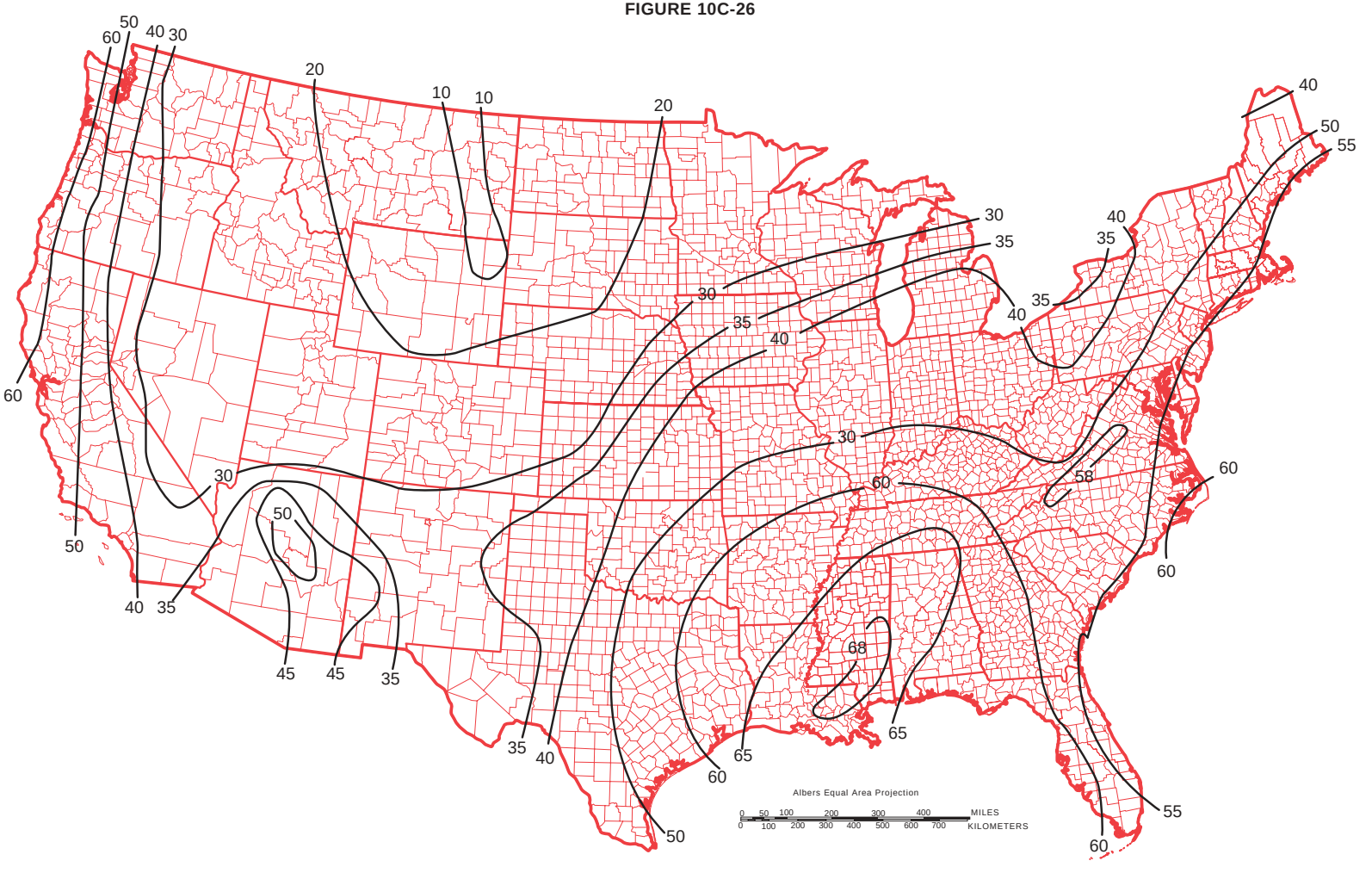
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

DECEMBER RUNOFF FROM CONCRETE FEEDLOTS (CN-97) AS PERCENT OF MEAN MONTHLY PRECIPITATION

FIGURE 10C-26



SOURCE:
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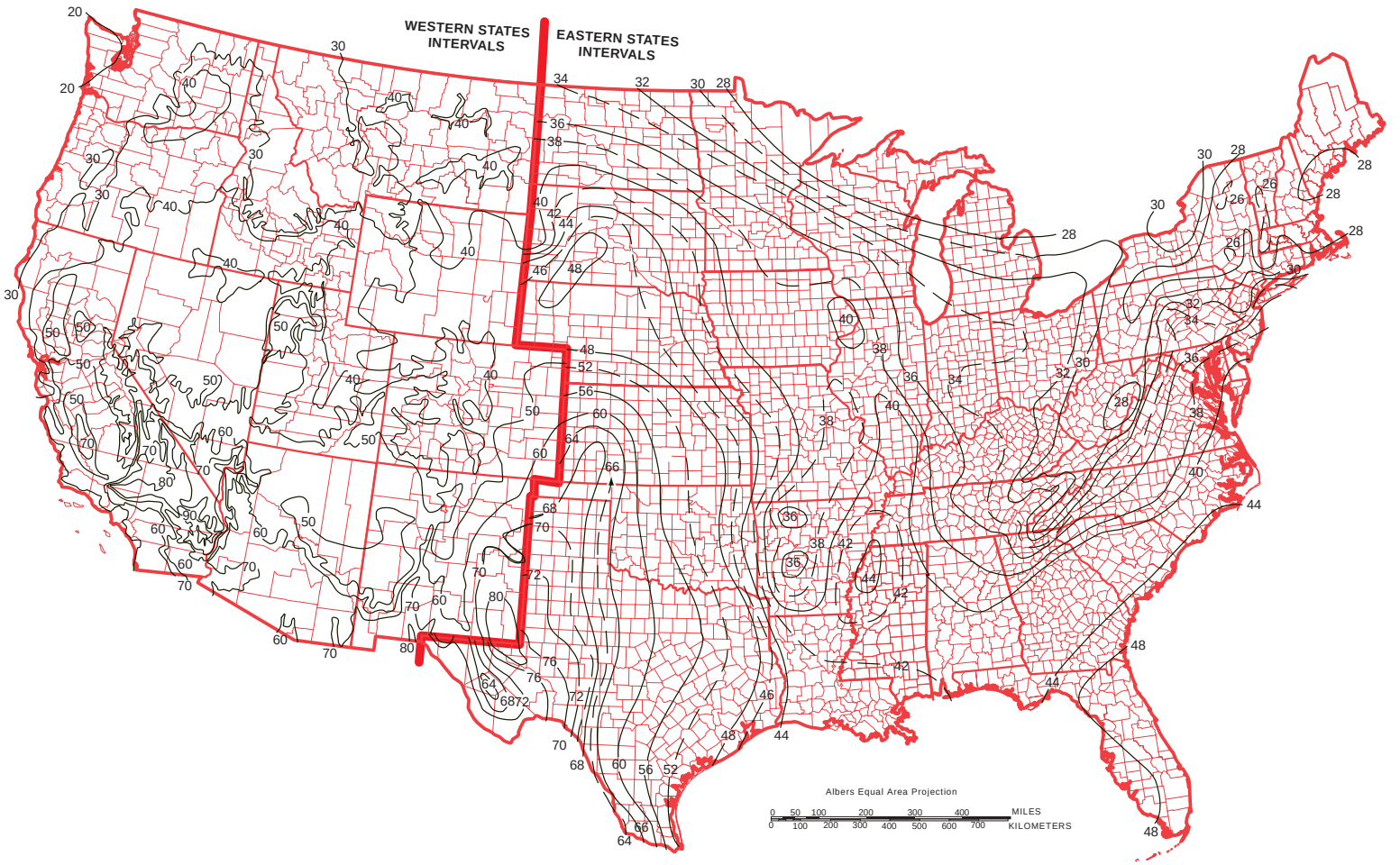
U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

ANNUAL
FREE WATER SURFACE EVAPORATION
FIGURE 10C-27



SOURCE:
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651.1080 Appendix 10D—Geotechnical, Design, and Construction Guidelines

Appendix 10D Geotechnical, Design, and Construction Guidelines

Introduction

The protection of surface and ground water and the proper utilization of wastes are the primary goals of waste storage ponds and treatment lagoons. Seepage from these structures creates potential risks of pollution of surface water and underground aquifers. The permeability of the soil in the boundaries of a constructed waste treatment lagoon or waste storage pond directly influences the potential for downward or lateral seepage of the stored wastes.

Many natural soils on the boundaries of waste treatment lagoons and waste storage ponds at least partly seal as a result of introduction of manure solids into the reservoir. Physical, chemical, and biological processes 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 be beneficial in reducing seepage. Researchers have reported that, under the right conditions, the permeability of the soil can be decreased by up to several orders of magnitude in a few weeks following contact with waste in a waste storage pond or treatment lagoon. These guidelines have been developed under the premise that the permeability decrease induced by the manure should not be counted on as the sole means of ground water protection. However, the guidelines do propose recognition of sealing to the extent of one order of magnitude for soils with a clay content exceeding 5 percent for ruminant manures and 15 percent for monogastric animal manures.

General design considerations

The following guidelines[1] address the design and construction techniques needed to overcome certain soil limitations. These guidelines should be considered in the planning, design, construction, and operation of agricultural waste management components including waste treatment lagoons and waste storage ponds.

Soil and foundation characteristics are critical to design, installation, and safe operation of successful waste treatment lagoons or waste storage ponds. Waste impoundments must be located in soils with acceptable permeabilities or be lined.

[1] These guidelines are an update and augmentation of material previously published in SNTC Technical Note 716, "Design and Construction Guidelines for Considering Seepage from Agricultural Waste Storage Ponds and Treatment Lagoons." SNTC Technical Note 716 has been canceled.

Soil properties

NRCS soil mechanics laboratories have a data base of permeability tests performed on over 1,100 compacted soil samples. Experienced NRCS engineers have analyzed these data and correlated permeability rates with soil index properties and degree of compaction of the samples. Tables 10D–1 to 10D–3 are based on this analysis and provide general guidance on the probable permeability of the described soil groups. The grouping of soils in table 10D–1 is based on the percent fines and Atterberg limits of the soils. Fines are those particles finer than the No. 200 sieve. Table 10D–2 provides assistance in converting from the Unified Soil Classification to one of the four permeability groups.

Table 10D–1 Grouping of soils according to their estimated permeability

Group	Description
I	Soils that have less than 20% passing a No. 200 sieve and have a Plasticity Index (PI) less than 5.
II	Soils that have 20% 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% or more passing a No. 200 sieve and have a PI of 16 to 30.
IV	Soils that have 20% or more passing a No. 200 sieve and have a PI of more than 30.

Table 10D–2 Unified classification versus soil permeability groups 1/

Unified classification	Permeability group 2/ 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 Unified Soil Classification System.

2/ 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–3 shows the percentage of each group for which a permeability test measured a k value of 0.0028 feet per day (1 x 10^{-6} cm/s) or less. The table also shows the median k value for the group in feet per day. A value of the coefficient of permeability of 0.0028 feet per day (1 x 10^{-6} cm/s) was selected for the median value studied. For typical NRCS designed structures, this value results in an acceptable seepage loss. As discussed later in this section, sealing by manure solids and biological action will most likely produce an additional order of magnitude reduction in permeability in the soils at grade.

Table 10D–3 summarizes a total of 1,161 tests. Where tests are shown at 85 to 90 percent of maximum density, over 75 percent of the tests were at 90 percent of maximum dry density. Where 95 percent degree of compaction is shown, data include both 95 and 100 percent degree of compaction tests. Over 80 percent of this group of tests was performed at 95 percent of maximum density. Based on these data, the following general statements can be made for the four soil groups:

Group I—These soils have the highest permeability and could allow unacceptably high seepage losses. Because the soils have a low clay content, permeability values may not be substantially reduced by manure sealing, and will probably exceed 10^{-6} centimeters per second.

Group II—These soils generally are less permeable than the Group I soils, but lack sufficient clay to be included in Group III.

Group III—These soils generally have a very low permeability, good structural features, and only low to moderate shrink-swell behavior.

Caution: Some soil in Group III is more permeable than indicated by the percent fines and PI value because they contain a high amount of calcium. The presence of a high amount of calcium results in a flocculated or aggregated structure in the soils. These soils often result from the weathering of high calcium parent rock, such as limestone. Soil scientists and published soil surveys are helpful in identifying these soil types. Dispersants, such as tetrasodium polyphosphate, can alter the flocculated structure of these soils by replacement of the calcium with sodium on the clay particles (See the section, *Design and construction of clay lines treated with soil dispersants*). Because manure contains salts, it can be helpful in dispersing the structure of these soils, but design should probably not rely solely on manure as the additive for these soil types.

Group IV—Normally, these soils have a very low permeability. However, because of their sometimes blocky structure, they can experience high seepage losses through cracks that can develop when the soil is allowed to dry. They possess good attenuation properties if the seepage does not move through cracks in the soil mass.

Table 10D–3 Summary of soil mechanics laboratories permeability test data

Soil group	Percent of ASTM D698 dry density	Number of observations	Median K (cm/s)	Median K (ft/d)	Percent of tests where k < 0.0028 (ft/d)
I	85-90	27	7.2 x 10^{-4}	2.0	0
I	95	16	3.5 x 10^{-4}	1.0	0
II	85-90	376	4.8 x 10^{-6}	0.014	30
II	95	244	1.5 x 10^{-6}	0.004	45
III	85-90	226	8.8 x 10^{-7}	0.0025	59
III	95	177	2.1 x 10^{-7}	0.0006	75
IV	85-90	41	4.9 x 10^{-7}	0.0014	72
IV	95	54	3.5 x 10^{-8}	0.0001	69

In situ soils with acceptable permeability

Natural soils that are classified in permeability Groups III or IV generally have permeability characteristics that result in acceptable seepage losses. NRCS permeability data bases show these soils usually have coefficients of permeability of 1 x 10^{-6} centimeters per second (0.0028 ft/d) or less if the soils are at dry densities equivalent to at least 90 percent of their Standard Proctor (ASTM D698) maximum dry densities. Based on the literature reviewed, introduction of manure provides a further decrease in the permeability rate of at least 1 order of magnitude. Such sealing is thought to be a result of physical, chemical, and biological processes. Suspended solids settle or filter out of solution and physically clog the pores of the soil mass. Anaerobic bacteria produce by-products that accumulate at the soil-water interface and reinforce the seal, and in the process of metabolizing organic material can alter the soil structure. Chemicals in animal waste, such as salts, can disperse soil, which may be beneficial in reducing seepage. Special design measures generally are not necessary where agricultural waste storage ponds or treatment lagoons are constructed in these soils, provided that the satisfactory soil type is at least 2 feet thick below the deepest excavation limits and sound construction procedures are used. This also assumes that no highly unfavorable geologic conditions, such as limestone formations with extensive caves or solution channels, occur at the site.

Soils in Groups III and IV that have a blocky structure or desiccation cracks should be disked, watered, and recompacted to destroy the structure in the soils and 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 calcium clays should be modified with soil dispersants to achieve the target permeability goals based on the guidance given in the section, *Design and construction of clay liners treated with soil dispersants*.

Definition of pond liner

Liners are relatively impervious barriers used to reduce seepage losses to an acceptable level. A liner for a waste impoundment can be constructed in several ways. When soil 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 the soils at the excavated grade by disking, watering, and compacting them to a thickness indicated by guidelines in following sections. 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.

The three options when the soil at the excavated grade is unsuitable to serve as a liner for a waste impoundment are:

- Treat the soil at grade with bentonite or a soil dispersant.
- Construct the soil liner by compacting imported clay from a nearby borrow source onto the bottom and sides of the waste impoundment.
- Use concrete or synthetic materials, such as geosynthetic clay liners (GCL's) and geomembranes.

Treat the soil at grade with bentonite or a soil dispersant. Problem soils in Group III may be treated with dispersants to attain a satisfactory soil liner. (See the section, *Design and construction of clay liners treated with soil dispersants*.) Soils in Groups I and II that are unsuitable in their natural state for use as liners can often be treated with bentonite to produce a satisfactory soil liner. Bentonite or soil dispersants should be added and mixed well into a soil prior to compaction. Brown (1991) describes techniques for constructing bentonite treated liners.

High quality sodium bentonite with good swell properties should be used for construction of clay liners using Group I and II soils. The highest quality bentonite is mined in Wyoming and Montana. NRCS soil mechanics laboratories have found it important to use the same type and quality of bentonite that will be used 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 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.

Construct the soil liner by compacting imported clay from a nearby borrow source onto the bottom and sides of the waste impoundment—Compaction is often the most economical method for constructing liners if suitable soils are available nearby.

Use concrete or synthetic materials, such as geosynthetic clay liners (GCL's) and geomembranes—Concrete has advantages and disadvantages for use as a liner. 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. Concrete serves as an excellent floor from which to scrape solids. It also provides a solid support for equipment, such as tractors or loaders. 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 existence of sinks or openings is known or identified during the site investigation, these areas should be avoided and proposed facility located elsewhere. However, when these conditions are discovered during construction or alternate sites are not available, concrete liners may be required to bridge the openings, but only after the openings have been properly treated and backfilled.

Geomembranes and GCL's 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. Forming seams in the field for geomembranes can require special expertise. GCL's have the advantage of not requiring field seaming, but the overlap required to provide a seal at seams is an extra expense. Geomembranes and GCL's must contain ultraviolet inhibitors if they will be exposed. Designs should include provision for their protection from damage during cleaning operations.

Four conditions where a liner should be considered

Four conditions for which a designer should consider seepage reduction beyond that provided by the natural soil at the excavation boundary are listed below.

Proposed site 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 structure within a given distance from such features.

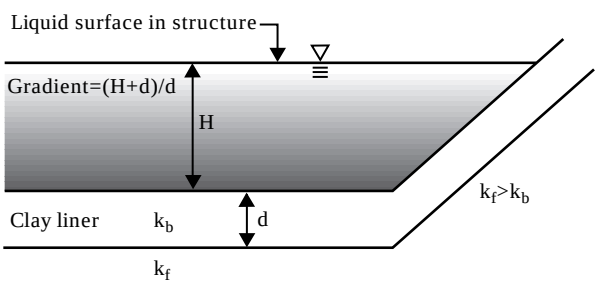
Excavation boundary of a site is underlain by less than 2 feet of soil over bedrock. Bedrock that is near the soil surface is often fractured or jointed because of weathering and stress relief. Many rural domestic and stock water wells are developed in fractured rock at a depth of less than 300 feet. 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 a site 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 1 to 3 orders of magnitude, the final resultant seepage losses are still likely to be excessive, and a liner should be used.

Excavation boundary of a site 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 or by other acceptable alternatives is advised. An acceptable alternative would be correlation to similar soils in the same geologic or physiographic areas for which test data are available. Higher than normal permeability for flocculated clays and clays that have a blocky structure has been discussed. These are special cases, and most soils in Groups III and IV will not need a liner. Note that a liner may be constructed by treating a determined required thickness of unfavorable soils occurring at grade.

The above 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 is over fractured or fissured rock.

Figure 10D–1 Definition of terms for clay liner and seepage calculations



where:
- H = Head of waste liquid in waste impoundment
- k_f = Permeability of foundation
- d = Thickness of liner
- k_b = Permeability of liner

Specific discharge

(a) Introduction

No soil or artificial liner, even concrete or a geomembrane liner, can be considered impermeable. To limit seepage to an acceptable level, regulatory agencies may specify a maximum allowable permeability value in liners. A criterion often used for clay liners is that the soils at grade in the structure, or the clay liner if one is used, must have a permeability of 1×10^{-7} centimeters per second or less. However, using only permeability as a criterion ignores other factors defining the seepage from an impoundment. Seepage is calculated from Darcy's Law (covered in the following section), and seepage calculations consider the permeability of the soil and the hydraulic gradient for a liner at a site.

(b) Definition of specific discharge

The term *specific discharge*, or unit seepage, is the seepage rate for a unit cross-sectional area of a pond. It is defined as follows from Darcy's Law. The hydraulic gradient for a clay liner is defined in figure 10D–1.

Given:

$$Q = k\left(\frac{(H+d)}{d}\right)A \quad \text{(Darcy's Law)}$$

Where:

Q	= Total seepage through area A	(L^3/T)
k	= Coefficient of permeability (hydraulic conductivity)	$(L^3/L^2/T)$
$\frac{(H+d)}{d}$	= Hydraulic gradient	(L/L)
H	= Vertical distance measured between the top of the liner and required volume of the waste impoundment (figs. 10D–1, 10D–14, 10D–15, and 10D–21)	(L)
d	= Thickness of the soil liner (fig. 10D–1)	(L)
A	= Cross-sectional area of flow	(L^2)
L	= Length	
T	= Time	

Rearrange terms:

$$\frac{Q}{A} = \frac{k(H+d)}{d} \qquad (L/T)$$

By definition, unit seepage or specific discharge, ν, is Q/A:

$$\nu = \frac{k(H+d)}{d} \qquad (L^3/L^2/T)$$

The units for specific discharge are $L^3/L^2/T$. However, these units are commonly reduced to L/T.

If a coefficient of permeability of 1 x 10^{-7} centimeters per second is regarded as acceptable, then an allowable specific discharge value can be calculated. Typical NRCS waste impoundments have a depth of waste liquid of about 9 feet and a liner thickness of 1 foot. Then, a typical hydraulic gradient of (9+1)/1 = 10 is a reasonable assumption. To solve for an allowable specific discharge, using previous assumptions that an acceptable permeability value is 1 x 10^{-7} centimeters per second, and a hydraulic gradient of 10, substituting in the equation for ν:

$$\begin{aligned}\nu_{allowable} &= k\frac{(H+d)}{d}\\ &= 1\times10^{-7}\ cm/s\times10\\ &= 1\times10^{-6}\ cm/s\\ &= 0.0028\ ft/d\end{aligned}$$

However, if one assumes at least one order of magnitude of reduction in permeability will occur, the initial permeability can be 10 times greater (1 x 10^{-6} centimeters per second) and the final value for permeability will approach 1 x 10^{-7} centimeters per second after sealing. Then, an allowable initial specific discharge of will be:

$$\begin{aligned}\nu_{initial\ allowable} &= k\frac{(H+d)}{d}\\ &= 1\times10^{-6}\ cm/s\times10\\ &= 1\times10^{-5}\ cm/s\\ &= 0.028\ ft/d\end{aligned}$$

As noted previously, allowable specific discharge actually has units of cubic feet per square foot per day, but for convenience the units are often stated as foot per day. Note that some State or local regulations may not permit taking credit for an order of magnitude reduction in permeability resulting from manure sealing. The State or local regulations should be used in design for a specific site.

Specific discharge or unit seepage is the quantity of water that flows through a unit cross-sectional area composed of pores and solids per unit of time. It has units of $L^3/L^2/T$ and is often simplified to L/T. 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 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, v, divided by the porosity of the soil, n. Seepage velocity = (v / n). In compacted liners, the porosity usually ranges from 0.3 to 0.5. The result is that the average linear velocity of the seepage flow is two to three times the specific discharge value. The units of seepage velocity are L/T.

(c) Design of compacted clay liners

To determine the required thickness of clay liner, rearrange the above equation for specific discharge using test values for permeability and the depth of waste liquid in the waste impoundment. Alternatively, a given value for the thickness of liner to be constructed may be assumed, and the minimum permeability required to meet a target specific discharge for the depth of waste liquid in the facility can be determined. Detailed design examples and equation derivations are shown later in this section.

Detailed design steps for clay liners

The suggested steps for design of a compacted soil liner are:

Step 1—Size the structure to achieve the desired storage requirements within the available construction limits and determine this depth or the height, H, of storage needed.

Step 2—Either estimate the permeability from the previous information showing estimated permeability values for Groups III and IV, or use the value attained in laboratory permeability tests. Field tests on compacted liners could also supply permeability design information. Use a value for allowable discharge of $v = 1 \times 10^{-5}$ centimeters per second (0.028 ft/d) if manure sealing can be credited, or 1×10^{-6} centimeters per second (0.0028 ft/d) if it is not credited. Calculate a preliminary liner thickness (d) to meet the allowable specific discharge criterion using the following equation. Derivation of the equation is shown later in this section. Terms are defined in figure 10D–1.

$$d = \frac{k \times H}{v - k}$$

Step 3—If the k value used 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 equation above. 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.

Step 4—The calculated thickness of liner required is very sensitive to the value of permeability used and the assumed allowable specific discharge value. Often, the required liner thickness can be reduced most economically by decreasing the soil permeability. Small changes in the soil liner specifications, including degree of compaction, rate of bentonite addition, and water content at compaction, can drastically affect the permeability of the clay liner soil.

Step 5—An alternative design approach is to use a predetermined desirable thickness for the liner; for example, 1 foot, and then calculate what permeability is required to meet the specific discharge target. The equation used is derived later in this section, and is as follows:

$$k = \frac{v \times d}{H + d}$$

This design approach requires that measures, such as special compaction or addition of bentonite or other soil additives, be then taken to ensure the calculated allowable permeability or a lesser value is attained.

Step 6—Cautions

The liner soil must be filter-compatible with the natural foundation upon which it is compacted. Filter compatibility is determined by criteria in NEH Part 633 (chapter 26). As long as the liner soil will not pipe into the foundation, no limit need be placed on the hydraulic gradient across the liner. Filter compatibility is most likely to be a significant problem when very coarse soil, such as poorly graded gravels and sands, occurs at a site and a liner is being placed directly on this soil.

The minimum recommended thickness of a compacted natural clay liner is 1 foot. Clay liners constructed by mixing soil dispersants or bentonite with the natural soils at a site are recommended to have a minimum thickness of 6 inches. 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 only a 7-inch thickness of compacted natural clay is needed to meet suggested seepage criteria, a 1-foot-thick blanket would still be recommended because constructing a 7-inch natural clay blanket with integrity would be difficult.

Natural and constructed liners must be protected. Natural and constructed liners must be protected against damage by mechanical agitators or other equipment used for cleaning accumulated solids from the bottoms of the structures. Liners should also be protected from the erosive forces of waste liquid flowing from pipes during filling operations.

Soil liners may not provide adequate confidence against ground water contamination if foundation bedrock relatively near the pond waste impoundment bottom contains large, connected openings, where collapse of overlying soils into the openings could occur. These bedrock conditions were discussed in detail previously. 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 is allowed to dry, it may develop drying cracks or a blocky structure and will then have a much higher permeability. 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. A protective insulating blanket of less plastic soil may be effective in protecting underlying more plastic soil from desiccation during these exposure periods.

State and Federal 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.

Construction considerations for compacted clay liners

(a) 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 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. Thinner lifts could significantly affect construction costs.

(b) Method of construction

(1) Bathtub

This method of construction consists of a continuous thickness of soil compacted up and down or across the slopes (fig. 10D–2). This construction is clearly preferable to the stair step method because inter-lift seepage flow through the sides of the excavation is less. This method also lends itself well to the thinner lifts used by NRCS. Side slopes should be 3H:1V or flatter to use this method. Shearing of the soil by the equipment on steeper slopes is a problem. To prevent shearing of the compacted soil, the slope used must be 3H:1V or flatter so that equipment will exert more normal pressure on the slope than downslope pressure.

(2) Stair step

This method of construction is illustrated in figure 10D–2. It would probably be needed for side slopes steeper than about 3H:1V. A much thicker blanket, measured normal to the slope, will result compared to the bathtub method of construction. This is a positive factor in seepage reduction, but it will probably be more expensive because of the larger volume of soil required. Another advantage of this method is that the thicker blanket reduces the impact of shrinkage

cracks, erosive forces, and potential mechanical damage to the liner. If the main concern is leakage through the bottom of the lagoon rather than the sides, the method has fewer advantages over the bathtub method. Another disadvantage of this method is that a larger volume of excavation is required to accommodate the thicker blanket.

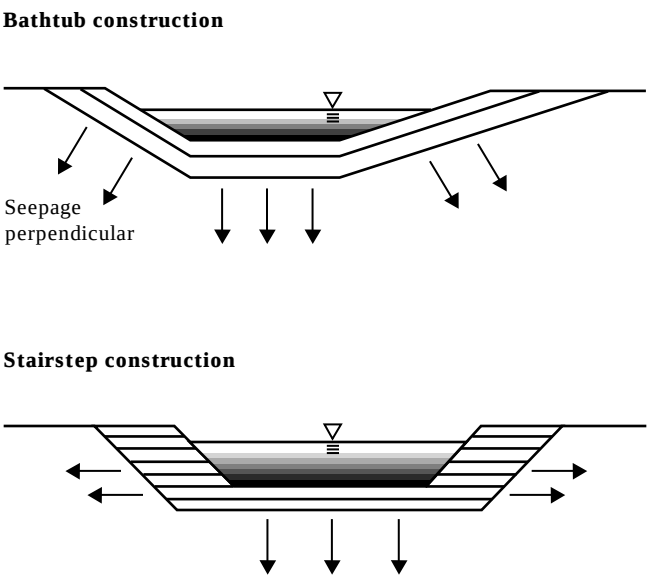
(c) Soil type

(1) Classification

Group IV soil has a plasticity index (PI) greater than 30 and is usually considered desirable. However, soil that has a PI value greater than 40 is not desirable for several reasons. Although more highly plastic clays may have very low laboratory test permeability values, these clays can develop severe shrinkage cracks. Preferential flow through the desiccated soil often results in a higher than expected permeability. Figure 10D–3 illustrates the structure that can occur with plastic clays where clods are present.

Highly plastic clays 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 the problems illustrated with figure 10D-3.

Figure 10D–2 Methods of liner construction (After Boutwell, 1990)

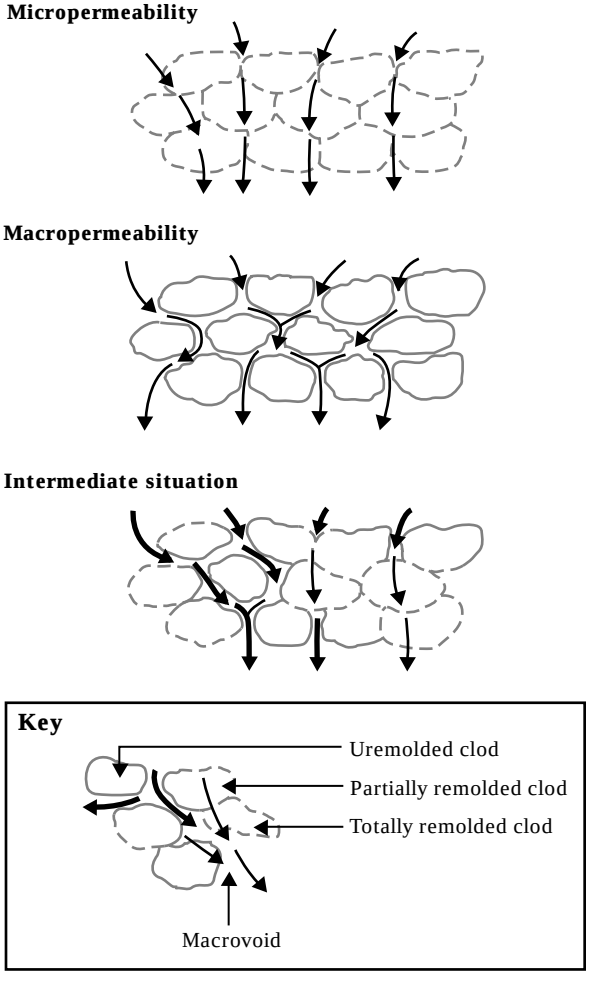


High plasticity clays may be covered with a blanket of insulating soil, such as an SM soil, to protect the liner from desiccation while the waste impoundment is being filled, particularly if filling will occur during hot, dry months.

(2) 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. Large, dry clods of plastic clays are extremely difficult to degrade and moisten thoroughly. High speed rotary pulverizers are sometimes needed if conditions are especially unfavorable. Adding water to the soil is difficult because water penetrates the clods slowly.

Figure 10D–3 Macrostructure in highly plastic clays with poor construction techniques (from Hermann 1987)



(d) Natural water content of borrow

(1) Dry conditions in the borrow

Dry, highly plastic clays are most likely extremely cloddy. Time must be allowed for added water to penetrate larger clods before processing. Prewetting the borrow area may reduce the severity of this problem. Because water slowly penetrates any clods, adding significant amounts of water to a plastic clay is difficult if this addition is delayed until processing on the compacted fill.

(2) 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 a wet condition may be present.

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—Measure the maximum dry density and optimum water content of the soil by the appropriate Proctor test (generally ASTM D 698, method A).

Step 3—Determine from suggestions in this guidance document, or from laboratory permeability tests, to what degree of compaction are the clay soils to be compacted (generally 90, 95, or 100 percent of maximum dry density).

Step 4—Calculate the theoretical saturated water content at the design dry density of the liner:

$$w_{sat}(\%) = \left(\frac{\gamma_{water}}{\gamma_d} - \frac{1}{G_s}\right) \times 100$$

Step 5—Calculate 90 percent of the theoretical saturated water content.

Step 6—If the natural water content of the soil is more than 1 or 2 percent wet of this calculated upper feasible water content, the clays will be difficult to compact to the design density without drying. In most cases drying clay soils simply by disking is somewhat ineffective. It would 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.

(e) Method of excavation and methods of processing

(1) Clods in borrow soil

If borrow soil is plastic clays at a low water content, it will probably have large, durable clods. Disking may be effective for some soils at the proper water content, but pulverizer machines may be required. To attain the highest quality liner, the transported fill should be processed with either a disk or a pulverizer before using a tamping roller. Equipment requirements depend on the severity of the clodiness and the water content of the soil.

(2) Placement of lifts

Preferential flow paths can be created if lifts of the clay liner are not staggered or placed in alternating directions. Continuous processing in one direction without adequate disking and bonding can also result in flow paths between lifts. Careful planning of the liner construction will avoid these problems.

(f) Macro-structure in plastic clay soils

Clods can create a macro-structure in a soil that results in higher than expected permeability because of preferential flow along the interfaces between clods. Figure 10D–3 illustrates a 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.

(g) Dry density and optimum water content

(1) Introduction

Compaction specifications 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 may not be as applicable to design of clay liners. A given permeability value can be attained for many combinations of compacted density and water contents (Daniels 1990). Dry density/water combinations that result in compaction at a relatively high degree of saturation are most effective in minimizing permeability for a given soil.

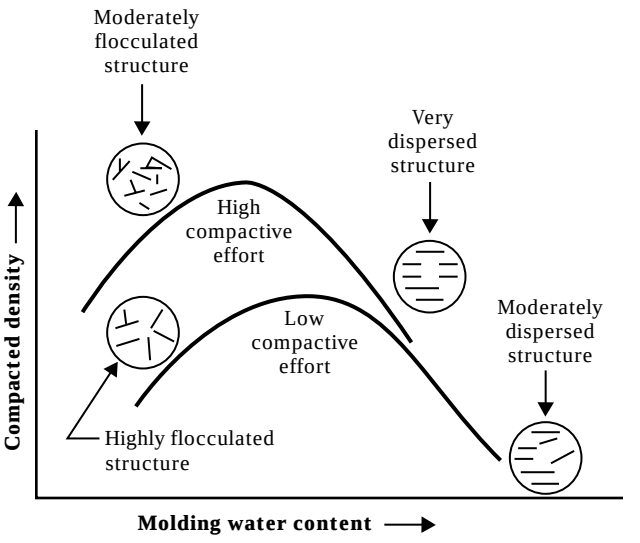
(2) Percent saturation criteria

A given value of permeability may be attained at any number of combinations of dry density and molding water content. Generally, for any given value of dry density, a lower permeability is attained if soils are compacted wet of optimum. However, many combinations of dry density and molding water content result in acceptably low permeability if the degree of saturation is high enough and a certain lower bound dry density value is met. For instance, a soil compacted at 90 percent of maximum Standard Proctor dry density at a water content 2 percent wet of optimum may have about the same permeability as a soil compacted to 95 percent of maximum Standard Proctor dry density at a water content equal to optimum water content.

Daniels (1990) describes a method of specifying combinations of dry density and water content to meet a certain permeability goal. Extensive testing may be required to establish the range of acceptable dry density and molding water content for a particular sample or site using this method. To limit soil mechanics testing complexity, generally no more than three combinations of dry density and placement water content are investigated to arrive at a design recommendation. More detailed analyses are usually reserved for large sanitary landfills or hazardous waste sites.

Figure 10D–4 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.

Figure 10D–4 Effect of water content and compactive effort on remolding of soil structure in clays (from Lambe 1958)



(h) 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 is actually for the particular energy used in the test to measure it.

Compactive energy is a function of the weight of the roller used, the thickness of the lift, and the number of passes of the roller over each lift. Rollers must be heavy enough to cause the teeth on the roller to penetrate or almost penetrate the compacted lift. Enough passes must be used to attain coverage and break up any clods. As such, additional passes cannot be used to compensate for rollers that are too light for the job.

Roller size is often specified in terms of contact pressure exerted by the feet on 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.

(i) Equipment considerations

(1) Size and shape of teeth on roller

Tamping rollers should have teeth that protrude an appreciable distance from the drum surface, as the older style sheepsfoot rollers do. The newer types of tamping rollers have square pads that do not protrude far from the drum surface. They appear less desirable than the older style rollers because less bonding and destruction of clay clods probably result.

(2) 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 teeth. Many modern rollers have contact pressures that are too great to compact soils appreciably wet of optimum water content. When the specified compaction water content is approaching 90 percent theoretical saturation at the specified dry density, lighter rollers are essential. Permeability of clays is minimized by compaction at water contents wet of optimum.

(3) Speed of operation

Heavy rollers operated at excessive speed can shear the soil lifts being compacted. This can result in higher permeability. Close inspection of construction operations should indicate when this problem occurs, and adjustments to equipment or the mode of operation should then be made.

(4) Vibratory versus nonvibratory

Vibratory type tamping rollers appear to have few advantages in constructing clay liners. These rollers may be counterproductive when the base soil is saturated and lower in plasticity because the vibration can induce pore pressures in the underlying base soil and create free water. Smooth-wheeled vibratory rollers should never be used in compacting clay liners. They are suitable only for relatively clean, coarse-grained soil.

Design and construction of bentonite clay liners

Some waste impoundment sites may not have soils within a practical distance that are suitable to serve as a clay liner. When this is the situation, there are generally two alternatives:

- Construct a synthetic liner.
- Import bentonite for treating the in situ soil on the sides and bottom of the impoundment.

(a) Bentonite type and quality

Bentonite is a volcanic clay that swells to about 15 times its original volume when placed in water. There are a number of bentonite suppliers, primarily located in the Western States. A sodium type bentonite should be used for constructing bentonite treated liners for waste impoundments. Another type of bentonite, calcium bentonite, should not be used. For bentonite to be suitable for use in constructing a liner for a waste impoundment, it must have two important qualities. One quality is that it possess a minimum level of activity or the ability to swell. The other quality bentonite must possess is an appropriate fineness.

The two primary ways of determining if a bentonite under consideration has an adequate level of activity are:

- Determine its level of activity based on its Atterberg limit values as determined in a soil testing laboratory. High quality sodium Wyoming bentonite has LL values greater than 600 and PI values greater than 550.
- Determine its level of activity based on a test of its free swell. Bentonite should have a free swell of at least 22 mL as measured by ASTM Standard Test Method D 5890. A brief summary of the free swell test follows. However, the ASTM Standard Test Method should be reviewed for detailed instructions on performing the test.
  - — Prepare a sample for testing that consists of material from the total sample that is finer than a #100 sieve with at least 65 percent finer than a #200 sieve.
  - — Add 90 mL of distilled water to a 100 mL graduated cylinder.
  - — 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.
  - — Rinse any particles adhering to the sides of the cylinder into water while raising the water volume to the 100 mL mark.
  - — 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 16 hours.

Bentonite is furnished in a wide range of particle sizes for different uses including clarification of wine. Fineness provided by the bentonite industry ranges from very finely ground, almost like face powder, to a granular form, with particles about the size of a #40 sieve. Laboratory permeability tests have shown that even though the same quality of 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 specify the same quality and fineness as was used by the soils laboratory for the permeability tests to arrive at recommendations. An appropriate fineness for use in treating liners for waste impoundment can be obtained specifying an acceptable bentonite by supplier and designation. An example specification is Wyo Ben type Envirogel 200, CETCO type BS-1, or equivalent.

(b) Design details for bentonite liner

The criteria given in NRCS Practice Standard, 521C, Pond Sealing or Lining, Bentonite Sealant, requires a 4-inch-thick bentonite treated layer for water depths in the impoundment of 8 feet or less. The criteria infers that a thicker liner should be used for deeper impoundments. Although not directly stated in the standard, the thickness of the liner should be proportional to the head of water in the impoundment for depths of

more than 8 feet. For waste impoundment liners, a minimum thickness liner of 6 inches is recommended for constructibility.

The design procedure using the laboratory permeability k value of treated samples is the preferred method to arrive at a required liner thickness. This procedure uses the depth of liquid in the impoundment, the k value of the treated soil, and an allowable seepage rate. The procedure is covered in the examples in this appendix. The calculated thickness is recommended unless it is less than 6 inches; then, the minimum thickness liner would be used regardless.

Consideration should be given to providing a soil cover over the bentonite treated compacted liner in waste impoundments. There are several reasons why a soil cover should be provided:

- The potential for 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.
- The potential for erosion of the thin bentonite treated liner that could occur during periods when the impoundment has been drawn down. Rilling due to rainfall on the exposed slopes can also seriously impair the water tightness of the liner.
- Over excavation by mechanical equipment during sludge removal. A minimum thickness of 6 inches measured normal to the slope and bottom is recommended for a protective cover. The protective cover should be compacted to reduce its erodibility.

(c) Construction specifications for bentonite liner

The best equipment for compacting bentonite treated liners is rubber-tired or smooth wheeled steel rollers, or crawler tractor treads. Practice Standard 521-C 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 rototiller as is used on lime treated earthfills is the best method of obtaining the desired mix. A minimum of two passes of the equipment is recommended to assure good mixing.

Another construction consideration is the moisture condition of the subgrade into which the bentonite is to be mixed. Unless the subgrade is somewhat dry, the bentonite will most likely ball up and be difficult to thoroughly mix with the underlying soils. Ideally, bentonite should be spread on a relatively dry subbase, mixed thoroughly with the native soil, then watered and compacted.

A sheepsfoot or tamping type of roller should not be used for compacting a bentonite treated liner. Dimples in the surface developed by these rollers cause the effective liner thickness to be significantly less than planned.

Other construction considerations are also important. For some equipment, tearing of the liner during compaction can occur on slopes even as flat as 3:1. On the other hand, compacting along rather than up and down the slopes could be difficult on slopes as steep as 3:1. For some sites, slopes as flat as 3.5:1 or 4:1 should considered for this factor alone.

A design may occasionally call for a liner thickness of more than 6 inches. A 6-inch-thick liner can probably be satisfactorily constructed in one lift, mixing in the required amount of bentonite to a 9-inch-thick loose depth, and then compacting it to the suggested 6 inches. Thicker liners should be constructed in multiple lifts, with the final compacted thickness of each lift being no greater than 6 inches. For instance, to construct an 8-inch-thick liner, use two 4-inch-thick compacted lifts.

Design and construction of clay liners treated with soil dispersants

The *Permeability of soils* section cautions that soils in Group III containing high amounts of calcium may be more permeable than indicated by the percent fines and PI values. Group III soils predominated by calcium require some type of treatment to serve as an acceptable liner. The most prevalent method of treatment to reduce the permeability of these soils is use of a soil dispersant additive containing sodium in some form.

(a) Types of dispersants

The dispersants most commonly used to treat high calcium clays are soda ash (Na_2CO_3), TSPP (tetrasodium pyrophosphate), and STPP (sodium tetra phosphate). Common salt (NaCl) has been used, but it is considered less long-lasting than the other chemicals. All these dispersants may be obtained from commercial suppliers. NRCS experience has shown that usually about twice as much soda ash is required to effectively treat a given clay than the polyphosphates. However, because soda ash may be less than half as expensive, it may be the most economical choice in many applications.

(b) Design details for dispersant treated clay liner

The criteria given in NRCS Practice Standard, 521B, Pond Sealing or Lining, Soil Dispersant, requires a 6-inch-thick dispersant treated layer for water depths in the impoundment of 8 feet or less. The criteria infers that a thicker liner should be used for deeper impoundments. Although not directly stated in the standard, the thickness of the liner should be proportional to the head of water in the impoundment for depths of more than 8 feet. To illustrate, for a liquid depth of 12 feet, a minimum liner thickness of one and one-half the minimum thickness should be used. For waste impoundment liners, a minimum thickness liner of 6 inches is recommended for constructibility.

Design procedures using the laboratory permeability k value of treated samples are the preferred method to arrive at a required liner thickness, using the depth of liquid in the impoundment, the k value of the treated soil, and an allowable seepage rate. Laboratories should be requested to perform trials with various amounts of a given additive to determine the most economical design. This procedure is covered in the examples in this appendix. The calculated thickness is recommended unless it is less than 6 inches, then the minimum thickness liner would be used regardless.

For planning purposes, the information given in NRCS Practice Standard, 521B, Pond Sealing or Lining, Soil Dispersant, may be used to determine approximate amounts of dispersants that will be required. Preliminary estimates given for soda ash are 10 to 20 pounds per 100 square feet (mixed into a compacted 6-inch layer). For STPP or TSPP, 5 to 10 pounds per 100 square feet is recommended.

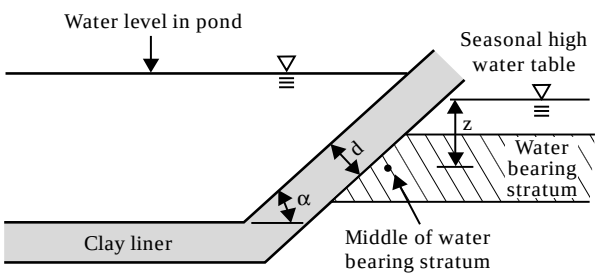
(c) Construction specifications for dispersant treated clay liner

The best equipment for compacting clays treated with dispersants is a sheepsfoot or tamping type of roller. Practice Standard 521-B specifies that the material shall be thoroughly mixed to the specified depth with disk, rototiller, or similar equipment. Because small quantities of soil dispersants are commonly used, intimate mixing of the dispersants is essential to constructing an effective liner. If a standard disk is used, several passes should be specified. A high speed rototiller as is used on lime treated earthfills is the best method of obtaining the desired mix. A minimum of two passes of the equipment is recommended to assure good mixing.

Other construction considerations are also important. For some equipment, tearing of the liner during compaction can occur on slopes even as flat as 3:1. On the other hand, compacting along rather than up and down the slopes could be difficult on slopes as steep as 3:1. For some sites, slopes as flat as 3.5:1 or 4:1 should be considered for this factor alone.

A design may occasionally call for a liner thickness greater than 6 inches. A 6-inch-thick liner generally can be satisfactorily constructed in one lift 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. For instance, to construct an 8-inch-thick liner, use two 4-inch thick compacted lifts.

Figure 10D–5 Uplift calculations for high water table (from Oakley 1987)



Uplift pressures beneath clay blankets

In some situations a clay blanket is subject to uplift pressure from a seasonal high water table in the foundation soil behind or beneath the clay liner. The uplift pressure in some cases can exceed the weight of the clay liner, and failure in the clay blanket can occur. This problem can occur particularly during the period before the waste impoundment is filled and during periods when the impoundment may be emptied for maintenance and cleaning. Figure 10D–5 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 may be needed to attain satisfactory safety factors.

The safety factor 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_w = Unit weight or density of water
- γ_{sat} = Saturated unit weight of clay liner
- z = Vertical distance from middle of water bearing stratum to the seasonal high water table

A safety factor 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.

Soil mechanics testing

(a) Sample size needed for testing

Laboratory soil testing may be required by regulations for design, or a designer may not be comfortable relying on correlated permeability test values. The NRCS National Soil Mechanics Center Laboratories have equipment and the ability to perform the necessary tests. Similar testing is also available at many commercial labs. Allow 3 to 4 weeks for obtaining gradation and Atterberg limits, and 6 to 8 weeks for permeability and sealing tests results. Contact the labs for more detailed information on documentation needed and for procedures for submitting samples.

Sample size based on percent gravel content for gradation analysis and Atterberg Limit only should be as follows:

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).

Sample size based on percent gravel content for gradation analysis, Atterberg Limits, and for compaction and permeability testing 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).

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 Part 646 (section 19), Construction Inspection.

(b) Factors in laboratory permeability testing for clay liners

Laboratory permeability testing is often used for design of compacted clay liners. The following sections describe factors that are important in laboratory testing and in writing construction specifications. However, the clay liner must be constructed properly for these laboratory tests to reflect accurately the actual permeability of the completed liner. Previous sections discuss many additional construction considerations.

(1) Placement dry density or degree of compaction

For a given soil, many different combinations of dry density and molding water content can result in an acceptable permeability value. For a given value of molding water content, increasing the degree of compaction will usually reduce the permeability. Degree of compaction is the percentage of the soil's maximum Standard Proctor dry density. Specimens remolded to a higher density, at the same water content, will have a lower permeability than specimens remolded to a lower density. The following table summarizes test data from an NRCS laboratory that illustrates this:

Percent maximum γ_d	Water content referenced to optimum	k value (cm/s)
90.1	Optimum + 1.7 %	9.6×10^{-6}
95.1	Optimum + 1.7 %	3.4×10^{-6}
100.1	Optimum + 1.7 %	6.0×10^{-8}

Compacting a soil to a higher degree is usually more economical than including additives, if compaction achieves the required permeability. However, some soils cannot be compacted sufficiently to create a satisfactorily low permeability. Then, additives are the only choice. Both the cost of additives and the cost of application must be considered in comparisons. One must also include the cost of quality control in verifying a higher degree of compaction when comparing this alternative.

The minimum degree of compaction that one should consider for clay liners is 90 percent. Usually, this degree of compaction is easily obtained if thin lifts are used and the water content is in the proper range. This degree of compaction may not require specialized compaction equipment for many soils.

The maximum degree of compaction that one should usually consider for clay liners in NRCS designs is 100 percent of Standard Proctor dry density. This degree of compaction is achievable, but for clay soils, probably only by using sheepsfoot or tamping rollers. For a bentonite treated liner, pneumatic rollers may be preferable. While achieving a degree of compaction higher than 100 percent of Standard Proctor dry density is possible, specifying higher values is not common. An intermediate degree of compaction that is commonly specified is 95 percent of maximum Standard Proctor dry density.

(2) Molding water content

Usually, for a given value of dry density or degree of compaction, increasing the molding water content will reduce the permeability. The following summary of tests performed at an NRCS Laboratory illustrates this point:

Percent maximum γ_d	Water content + or - optimum	k value cm/s
95	Optimum - 2 %	4.0×10^{-4}
95	Optimum	5.0×10^{-5}
95	Optimum + 2 %	9.0×10^{-6}

The in situ water content of borrow soils should be carefully considered in a preliminary design for a compacted clay liner. One should know what construction equipment is commonly available. If the in situ water content of borrow soils is high, compacting soils to a high degree may be impractical. If the in situ water content of borrow soils is low, it may be easier to compact the soils to a higher degree and require less water to be added during construction.

A previous section of appendix 10D includes steps for determining the upper water content at which a given dry density is achievable. The highest placement water content that one should consider for a given degree of compaction, or dry density, corresponds to 90 to 95 percent of theoretical saturated water content. Compaction of soils results primarily from expulsion of air from the soil voids. Expelling the last 5 to 10 percent of air in soils with significant fines content by compaction is difficult. Even repeated applications of energy seldom result in increased degrees of saturation when soils are very wet. Example 10D-6 illustrates calculations.

Most clay liners should be compacted at optimum water content or wetter to minimize permeability. However, for high degrees of compaction, allowing placement at 1 to 2 percent dry of optimum may be necessary to allow some range in placement water contents and give flexibility to contractors' operations. Laboratory tests should usually consider the least favorable conditions in evaluating permeability for conservatism.

It must be possible to attain the required degree of compaction over a range of placement water contents. If the specified minimum placement water content is near 90 percent saturation at the required dry density, there will be little flexibility in obtaining the required dry density during construction. Specifications should enable the desired densification to be obtained within a range of 2 to 4 percent in placement water contents. Specifications cannot require both a high degree of compaction and a high placement water content and be practical. Example 10D-5 illustrates calculations.

(3) Soil Additives - Bentonite

It may be obvious for a given soil that an acceptably low permeability cannot be obtained by compaction alone. An example is a sand with relatively low fines content. For other soils, usually clays with a high calcium content, it may not be immediately obvious that compaction alone will be inadequate. For either case, if soil additives are needed, the following guidelines should be considered.

- Sodium bentonite should be the additive selected to be investigated if the soil has a low percentage of fines, less than 50 percent, or, if the soil has low plasticity fines (PI less than about 7). NRCS Conservation Practice Standard 521C suggests that bentonite should be used for soils with less than 50 percent fines. The Standard shows preliminary application rates, as follows:

Soil type	Application rate, lb/ft^2
Silty sand	1.5 - 2.0
Clean sand	2.0 - 2.5

The rate given is based on the bentonite being mixed and compacted into a finished layer that is 4 inches thick. Then, a volumetric rate, in pounds per cubic feet, would be triple the rate given in the table.

- The quality and fineness of bentonite used for laboratory permeability testing is important. Previous sections of appendix 10D also discuss quality of bentonite. The bentonite used for laboratory tests should be comparable to that which will be used in construction. Bentonite processors furnish bentonite in a range of particle sizes, ranging from very finely ground, with most of the particles finer than the #200 sieve, to granular bentonite, with most of the particles larger than about the #40 sieve. NRCS laboratories have found a significant difference in permeability between specimens prepared using the same application rate of the fine compared to the coarse bentonites, for some soils.
- Each grade of bentonite has its advantages. The very finely ground bentonite usually is more effective in reducing permeability. However, the material is prone to dusty conditions during construction, and may ball up when applied to a wet sub-grade. The coarsely ground bentonite is easier to spread and mix, but may require a higher application rate to achieve a given target permeability.
- Permeability tests to evaluate bentonite should assumine a relatively low degree of compaction, usually no more than 95 percent of maximum Standard Proctor dry density. At least 2 or 3 tests should be requested, to determine the minimum quantity of bentonite required to obtain the desired permeability. A range of bentonite application rates of from 0.5 to 2.5 pounds per square foot (mixed into a compacted 4 inch layer), equivalent to1.5 to 7.5 pounds per compacted cubic foot, should be considered.
- The following example test results were obtained in a test on a relatively clean sand in an NRCS laboratory

Test γ_d % max	Test w % ref. to opt.	Additive type	Additive rate lb/ft^2	k cm/s
90	Opt + 1.5 %	Fine Bentonite	0.5	3.5×10^{-4}
90	Opt. + 1.8 %	"	1.0	5.5×10^{-7}
90.1	Opt. + 2.0 %	"	1.5	9.6×10^{-8}

(4) Soil additives - dispersants.

A soil dispersant should be selected for the additive to be investigated if the soil has more than about 50 percent fines, if the soil has at least 15 percent clay content (percent finer than 2 microns), and has a PI value of 7 or higher. Soil dispersants are usually considered when previous tests or experience in an area show that compaction alone will not produce a satisfactorily low permeability. The two preferred types of soil dispersant chemicals are soda ash (Na_2CO_3) and sodium polyphosphate (STPP or TSPP). Recommended preliminary application rates are as follows:

Dispersant type	Application rate, lb/100 ft^2
Soda ash	10–20
Polyphosphates	5–10

- The stated application rate is based on the given amount of dispersant being mixed and compacted into a finished layer that is 6 inches thick. Then, a rate, in pounds per cubic feet, would be double the rate given in the above table.
- Either soda ash or polyphosphates are most commonly used. About twice as much soda ash is required to produce a given permeability, other factors being equal, than polyphosphates. However, if the product cost of soda ash is less than half that of polyphosphates, or it is more readily available, then soda ash should be selected. The cost of application and incorporating the additive into the soil should be the same for both chemicals. NRCS laboratories have supplies of either of these soil dispersants, and it is not necessary to provide supplies for testing when this option is being explored.
- Permeability tests using soil dispersants should be performed for a range of assumed degrees of compaction, probably in the range of 90 to 100 percent of maximum Standard Proctor dry density. At least two or three tests should be requested, to determine the minimum quantity of dispersant required to obtain the desired permeability. A range of dispersant application rates of from 5 to 20 pounds per 100 square feet (mixed into a compacted 6-inch layer), or from 0.1 to 0.4 pounds per compacted cubic foot, should be considered.

- The following example test results were obtained in a test on a CL soil in an NRCS laboratory

Test γ_d % max	Test w % ref. to opt.	Additive type	Additive rate lb/100 ft^2	k cm/s
94.8	Opt. + 2.0 %	None	**	4.9×10^{-6}
99.9	Opt. + 2.0 %	None	**	1.6×10^{-6}
95.0	Opt. + 2.0 %	Soda Ash	10	2.5×10^{-6}
95.0	Opt. + 2.0 %	Soda Ash	15	9.5×10^{-8}

(5) Construction quality control and procedures

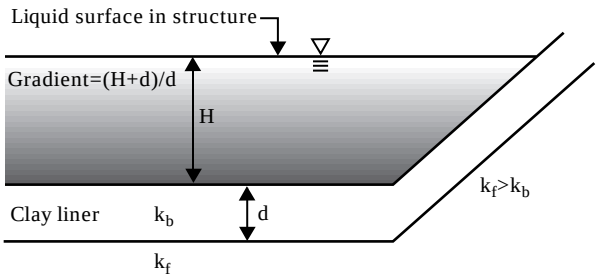
One should consider which construction equipment and methods are commonly available when selecting combinations of dry density and molding water in the design of clay liners. Some of these considerations are summarized as follows. The discussion specifically applies to Standard Proctor compaction (ASTM D698). Different guidelines would apply to designs using Modified Proctor (ASTM D1557) compaction tests.

- It may be difficult to obtain a degree of compaction greater than about 90 percent for many clay soils unless a sheepsfoot or tamping type roller, together with thin lifts is employed. If laboratory tests show that 95 or 100 percent of Proctor dry density is required to obtain a satisfactorily low permeability, plans should require this equipment for the clay liner construction.
- It will usually be more economical to specify a lower degree of compaction and a higher water content, unless the in situ water content of borrow soils is low, and water must be incorporated prior to compaction. If the in situ water content of borrow soils is excessive, it may be impossible to achieve higher degrees of compaction, as detailed in previous sections.
- The field quality control testing effort required to verify that soils are compacted to a higher degree must be considered. Achieving 90 percent of maximum Standard Proctor dry density is relatively easily accomplished, and observations of construction operations may be sufficient verification. Using thin lifts and thorough coverage of the equipment usually results in this degree of compaction. Higher degrees of compaction, greater than 90 percent, are more difficult to achieve, and field quality control testing probably should be a part of documentation. Qualified personnel and appropriate testing equipment are necessary for this effort.
- In the absence of previous experience in an area, the following initial trials are suggested for laboratory permeability tests. Some of these trials may not be necessary, or other trials should be assigned if factors dictate.

Degree of compaction	Placement water content ref. to opt.
90	Opt. + 3
95	Opt. + 2
100	Opt. or Opt. + 1

Exhibit 10D–1 Derivation of equations

Definition sketch for clay liner in waste storage pond or treatment lagoon



where:

H = Head of waste liquid in waste impoundment
k_f = Permeability of foundation
d = Thickness of liner
k_b = Permeability of liner

Derivation of equation for calculating required thickness of liner

Using the equation for specific discharge, ν

$$\nu = \frac{\left[k \times \left(H + d\right)\right]}{d} \qquad [8a]$$

The units for specific discharge in the English system are cubic feet per square foot per day. The coefficient of permeability, k, also has units of cubic feet per square foot per day. These units are usually simplified to units of feet per day. Using metric units, specific discharge and the coefficient of permeability are generally expressed in cubic centimeters per square centimeter per second, simplified to centimeters per second. Units for H and d cancel, but the same basic units should be used as used for permeability to reduce confusion (either feet or centimeters).

Then:

$$\nu = \frac{\left[\left(k \times H\right) + \left(k \times d\right)\right]}{d} \qquad [8b]$$

$$\nu \times d = \left(k \times H\right) + \left(k \times d\right) \qquad [8c]$$

$$\left(\nu \times d\right) - \left(k \times d\right) = k \times H \qquad [8d]$$

$$d \times \left(\nu - k\right) = k \times H \qquad [8e]$$

$$d = \frac{\left(k \times H\right)}{\left(\nu - k\right)} \qquad [8f]$$

Exhibit 10D–1 Derivation of equations—Continued

Derivation of equation for calculating required permeability of liner

To solve for the required k value, given an allowable specific discharge, a liner thickness, and a height of waste liquid in the impoundment, begin with equation 8d:

$$(v \times d) - (k \times d) = k \times H \qquad [8d]$$

$$(v \times d) = (k \times H) + (k \times d) \qquad [9b]$$

$$v \times d = k(H + d) \qquad [9c]$$

$$k = \frac{v \times d}{(H + d)} \qquad [9d]$$

Example 10D–1 Example calculations for required minimum thickness of compacted soil liner

Given: Site design has resulted in 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 3.0×10^{-7} centimeters per second (0.00085 ft/d) for soils compacted to 95 percent of maximum Standard Proctor dry density. Another test on a sample compacted to 90 percent of maximum density resulted in a measured k value of 6×10^{-6} centimeters per second (0.017 ft/d).

Assume: Allowable specific discharge of 1×10^{-5} centimeters per second (0.028 ft/d) is satisfactory because manure sealing will produce an order of magnitude reduction in permeability.

Solution:

Step 1: Design a liner assuming soils are to be compacted to 95 percent of maximum Standard Proctor dry density. It is given that the k value at this density is 0.00085 foot per day. Calculate the required minimum thickness of compacted liner as follows:

The equation for required d is:

$$d = \frac{k \times H}{v - k}$$

Using English system units, substituting the given values for H and k, assuming an allowable specific discharge, v, of 0.028 foot per day, then

$$d = \frac{0.00085 \times 12}{0.028 - 0.00085}$$

$$d = 0.38 \text{ ft.}$$

A 1-foot-thick minimum thickness is suggested for a soil liner because thinner clay liners are difficult to construct with confidence.

Step 2: For the case of the liner being compacted to about 90 percent of maximum density, the calculated required d, using a given value for k at this density of 0.017 foot per day and the given value of H of 12 feet, is:

$$d = \frac{k \times H}{v - k}$$

$$d = \frac{0.017 \times 12}{0.028 - 0.017}$$

$$d = 18.5 \text{ ft}$$

Conclusion: The final calculation shows that the design based on 90 percent degree of compaction results in a liner thickness that is impractical. Other options could be explored for reducing the permeability including compaction at higher water contents. Including provisions for extra effort in attaining the required 95 percent of maximum density or adding extra water in compaction generally is far more economical than using thick liners. Sheepsfoot rollers would probably be required to attain 95 percent of maximum Standard Proctor dry density for a clay soil.

Example 10D–2 Example calculations for required minimum thickness of compacted soil liner

Given: Site design has resulted in a required depth of waste liquid, H, in the constructed waste impoundment of 10 feet. A soil sample was obtained and submitted to a soil mechanics laboratory for testing. Based on Atterberg limits and gradation analyses, the soil to be used for a liner is in Group III. Based on guidance following table 10D–2, a soil in Group III if compacted to at least 90 percent of maximum dry density will probably have a permeability value of 0.0028 foot per day or less. Assume that an allowable specific discharge of 0.028 foot per day is satisfactory.

Solution: Calculate the required minimum thickness of compacted liner assuming that the above information is accurate. The equation for required d is:

$$d = \frac{k \times H}{v - k}$$

Using English system units, then

$$d = \frac{0.0028 \times 10}{0.028 - 0.0028}$$

$$d = 1.2\,\text{ft}$$

A 1.2-foot minimum thickness would be used for this liner.

Example 10D–3 Example calculations for required minimum thickness of compacted soil liner

Given: Site design has resulted in a required depth of waste liquid, H, in the constructed waste storage pond impoundment of 9 feet. A soil sample was obtained and submitted to a soil mechanics laboratory for testing. Based on Atterberg limits and gradation analyses, the soil to be used for a liner is in Group I. Laboratory tests show that if bentonite is added to the soil at the rate of 3 pounds per square foot, mixed into a 4-inch-thick compacted layer, that a coefficient of permeability of 5.0 x 10^{-7} centimeters per second is achievable.

Determine: Minimum required thickness of the bentonite treated liner assuming that an allowable specific discharge of 0.028 foot per day is satisfactory.

Solution: Calculate the required minimum thickness of compacted liner.
Convert the stated coefficient of permeability of the liner to feet per day. The conversion from centimeters per second to feet per day is:

$$\frac{1\,\text{cm}}{\text{s}} \times \frac{86,400}{1\,\text{d}} \times \frac{1\,\text{ft}}{30.48\,\text{cm}} = 2,835\,\text{ft / d}$$

$$5 \times 10^{-7}\,\text{cm / s} \times 2,835 = 0.0014\,\text{ft / d}$$

The equation for required d is:

$$d = \frac{k \times H}{\nu - k}$$

Using English system units, then

$$d = \frac{0.0014 \times 9}{0.028 - 0.0014}$$

$$d = 0.47\,\text{ft}$$

Based on previous material, a 6-inch minimum thickness would be used for this liner, but only because it is a bentonite treated material. Otherwise, a compacted soil liner would require a minimum thickness of 1 foot.

Example 10D–4 Example calculations for required permeability of compacted soil liner

Given: The information is the same as that for example 10D–3 except it is given that a particular policy or regulation does not permit taking credit for a 1 order of magnitude reduction in permeability for manure sealing. The assumed value for allowable specific discharge then becomes 1 x 10^{-6} centimeter per second, or 0.0028 foot per day. Assume the same permeability value as that in example 10D–3.

Solution: The equation for required d is:

$$d = \frac{k \times H}{v - k}$$

Using English system units, then

$$d = \frac{0.0014 \times 9}{0.0028 - 0.0014}$$

$$d = 9\,\text{ft}$$

Because this is an impractical design, the value of permeability that would be required to attain a more realistic design would be of interest. The above equation can be rearranged to solve for k, given values for specific discharge, H, and an assumed liner thickness. The rearranged equation is show as follows:

$$k = \frac{v \times d}{H + d}$$

If a realistic liner thickness of 1 foot is assumed, use this equation to determine the required coefficient of permeability for a bentonite/soil mixture.

$$k = \frac{1 \times 0.0028}{1 + 9}$$

$$k = 0.00028$$

A designer could then work with a soil testing laboratory to determine the amount of bentonite and the degree of compaction required to attain this k value

Example 10D-5 Example calculations for upper placement water content of compacted soil liner

This example assumes that a soil to be used for constructing a clay liner has a maximum dry density of 113.0 pcf and an optimum water content of 14.5 percent. The specific gravity of the soil solids, Gs, is 2.68. Assume that the soil will be compacted to 90 percent of maximum Standard Proctor dry density. Determine the following:

(a) The minimum acceptable dry density

$$\gamma_{d\,min} = 0.9 \times 113.0 \text{ pcf} = 101.7 \text{ pcf}$$

(b) The upper limit of water content at which a soil can be compacted to this dry density.

(1) First, calculate the saturated water content at this dry density:

$$w_{sat} = \left(\frac{\gamma_{water}}{\gamma_d} - \frac{1}{G_s} \right) \times 100$$

$$w_{sat} = \left(\frac{62.4}{101.7} - \frac{1}{2.68} \right) \times 100 = 24.0\%$$

(2) A good rule of thumb is that soils are difficult to compact if the water content exceeds 90 percent of the theoretical saturated water content. Determine the water content that is 90 percent of the saturated water content is 0.9 x 24.0 % = 21.6%.

(3) Then if soils in the borrow are much wetter than 21.6 % water content, it will be difficult to obtain the required compaction.

(c) Assume that permeability tests show the soil should be compacted at least at a water content 3 percent wet of optimum. Then, what is the minimum water content permissible, and, given the solution above, what is the range in practical placement water content for this situation.

(1) The minimum water content is 3 percent wet of optimum, and optimum water content is 14.5 percent, so the minimum acceptable water content is 17.5 percent. The wettest the soil can be compacted to the required degree is 21.6 percent from the previous step. Then, the range of water content within which the specifications can be met is from 17.5 to 21.6 percent, a range of about 4 percent. This gives adequate flexibility during construction. Similar computations for considering placement of the soil to 100 percent of maximum Standard Proctor dry density are as follows:

(2) The minimum required dry density is 100 percent of maximum dry density, which is 113.0 pcf, and the saturated water content, calculated with the equation above, at this density is 17.9 percent. The upper feasible placement water content is 90 percent of saturation, or 16.1 percent. If one is to allow a 3 percent spread in attainable placement water contents, the lowest water content would be about 13 percent, which is 1.5 percent dry of optimum. A lab permeability test should be performed at this dry density/water content to verify that an acceptably low permeability is attainable.

Example 10D-6 Example calculations for placement water content of compacted soil liner

Given: The in situ water content of soils in the borrow is 22.0 percent. The soil has a maximum dry density of 113.0 pcf and an optimum water content of 14.5 percent. The specific gravity of soil solids, G_s, is 2.68. Determine whether it is feasible to compact the soils to at least 95 percent of maximum Standard Proctor dry density.

Solution: (a) Given the maximum Standard Proctor dry density of the soil is 113.0 pcf, the minimum acceptable dry density is then 0.95 x 113.0 pcf, or 107.4 pcf. To determine the upper feasible placement water content, use the rule of thumb that 90 percent degree of saturation is the wettest a soil can be reasonably compacted. The saturated water content of a soil is calculated from the following equation, using the given values of dry density and specific gravity of solids.

$$w_{sat}(\%) = \left(\frac{\gamma_{water}}{\gamma_d} - \frac{1}{G_s}\right) \times 100$$

$$w_{sat}(\%) = \left(\frac{62.4}{107.4} - \frac{1}{2.68}\right) \times 100 = 20.8\%$$

(b) The wettest you should consider compacting the soil is 90 percent of theoretical saturated water content, or 0.9 x 20.8, or 18.7 percent.

(c) Then, the in situ water content of the soils in the borrow area, given as 22.0 percent, is greater than the highest water content at which the required density can be obtained. To achieve the required compaction, the soils will probably have to be dried by about 22.0–18.7, or 3.3 percent.

(d) This amount of drying may be attainable by disking repeatedly during hot, dry weather for some soils, but, highly plastic soils may be more difficult to dry. In some cases, a site should be constructed only during dry weather or the borrow area should be drained several months prior to construction.

Summary

The reduction in soil permeability by manure sealing in waste storage ponds and treatment lagoons is well documented. However, for this phenomenon to produce acceptable low permeability requires the soils at grade to have a minimum clay content (percent finer than 2 microns). A minimum clay content of 15 percent is required for sealing to occur if manures are from monogastric animals, and a minimum clay content of 5 percent is required for sealing if manures are from ruminant animals.

Soils can be divided into four permeability groups based on their percent fines (minus #200 sieve) and plasticity index (PI). Soils in Group III and IV generally do not require a liner. Group I soils will generally require a liner. Soils in Group II will need permeability tests or other documentation to determine whether or not a liner is advisable.

Guidance is given on when to consider a liner. Four conditions are listed in which a liner should definitely be considered.

Recommended values for allowable specific discharge and minimum liner thickness are given. A methodology is presented to calculate a minimum blanket thickness based on design parameters.

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.

A method of documenting the design rationale for inclusion in the design file is provided.

A practical means for evaluating, in quantitative terms, the level of ground water protection that can be achieved with a soil liner is also provided.

The guidelines provided in this chapter result in a somewhat conservative, but reasonable level of protection to important ground water resources. This guidance covers an area where uncertainties may exist. Additional research may produce better information, and practice standards will be updated to reflect this state-of-the-art knowledge.

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**Soil
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Field Handbook

Chapter 11 Waste Utilization

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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.

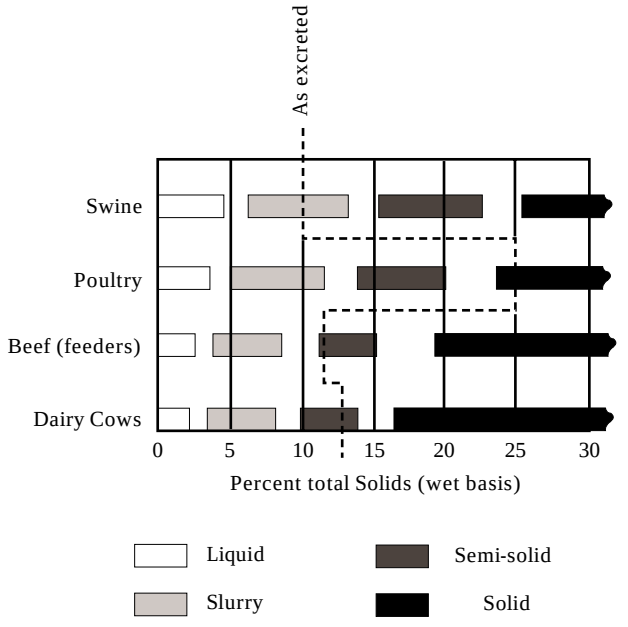
Utilization of waste agrichemicals is not in the scope of this chapter. The chapter on pesticide management describes how to properly manage and dispose of waste agrichemicals (to be added).

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

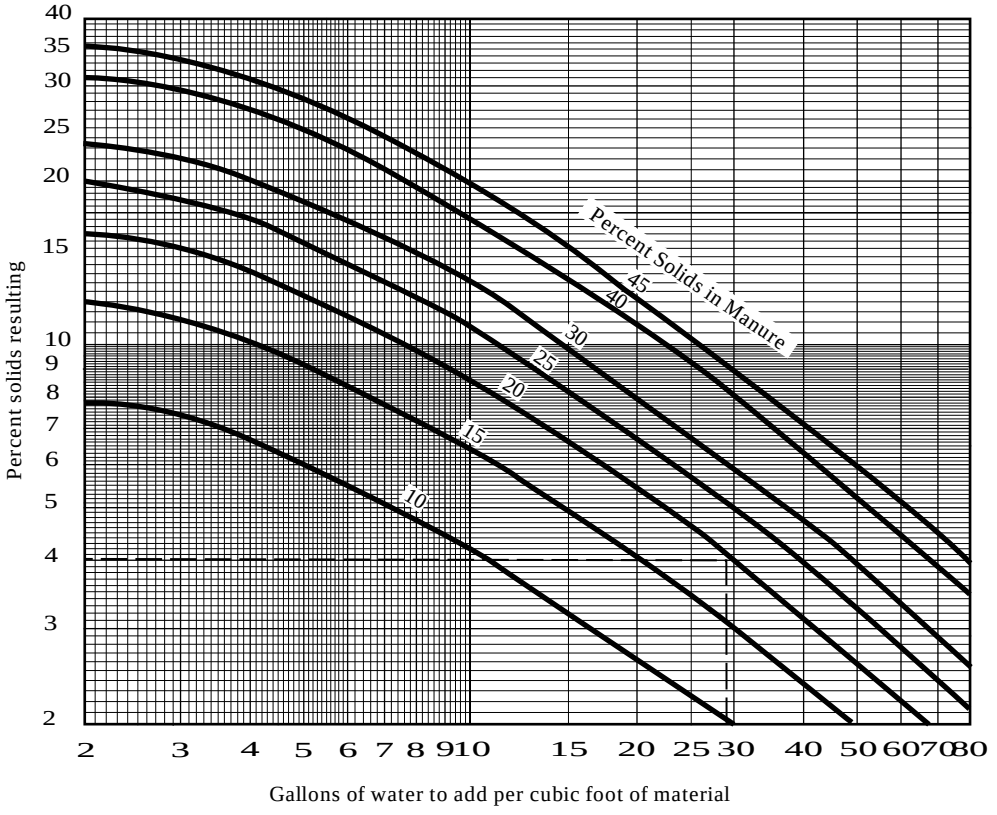


Figure 11–2 is based on the equation:

$$G = \frac{7.48\left(P_o - P_d\right)}{P_d}$$

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 fps	Percent solids 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—

$$\text{Storage} = \frac{34{,}000\ \text{ft}^3 \times 12\ \text{in}}{43{,}560\ \text{ft}^2/\text{ac} \times 1\ \text{ft}} = \frac{34{,}000 \times 12\ \text{in}}{43{,}500} = 9.4\ \text{ac-in}$$

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.

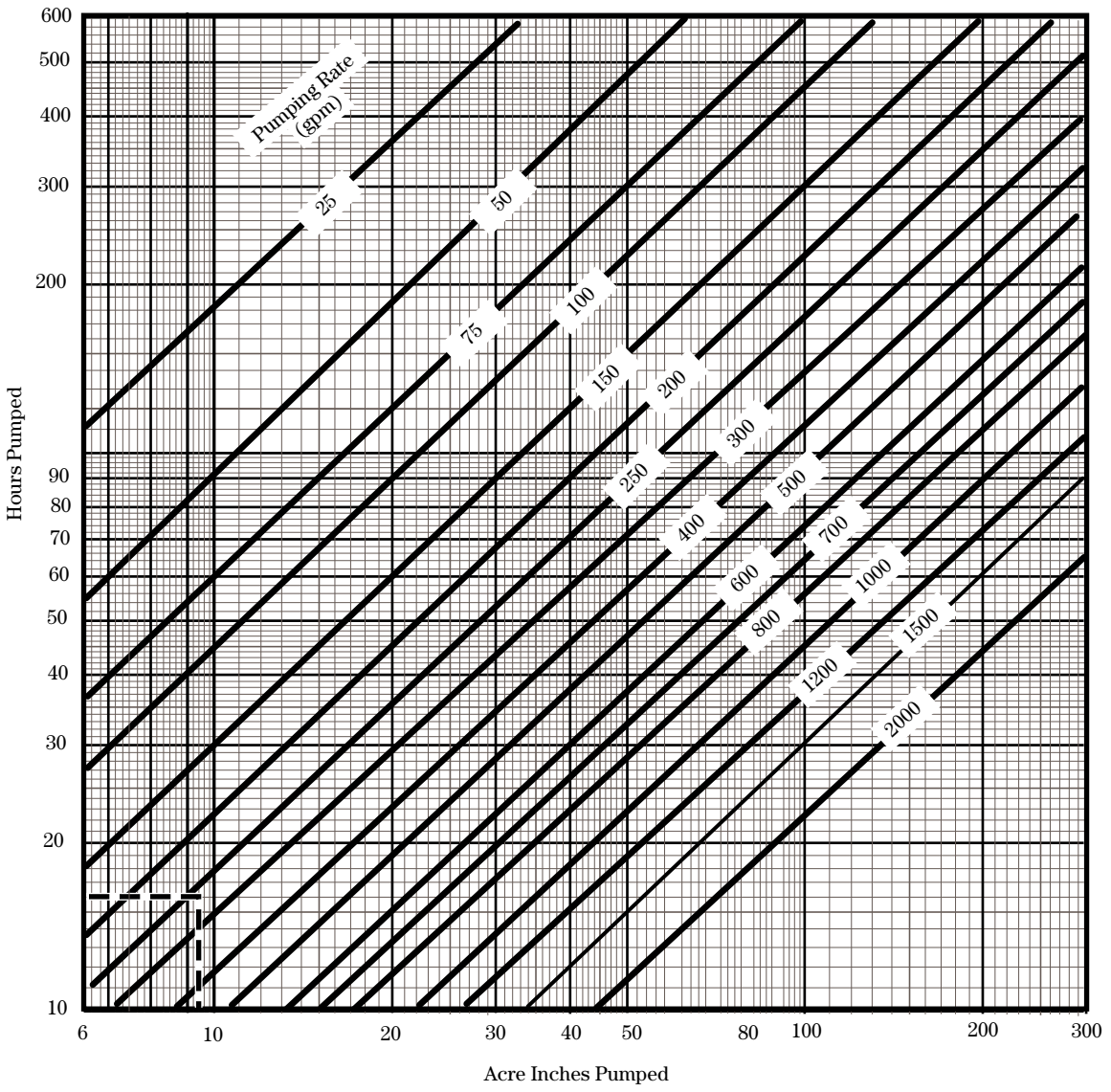
$$\text{Labor cost} = 9.4\ \text{hr} \times \$7/\text{hr}$$
$$= \$65.80$$

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



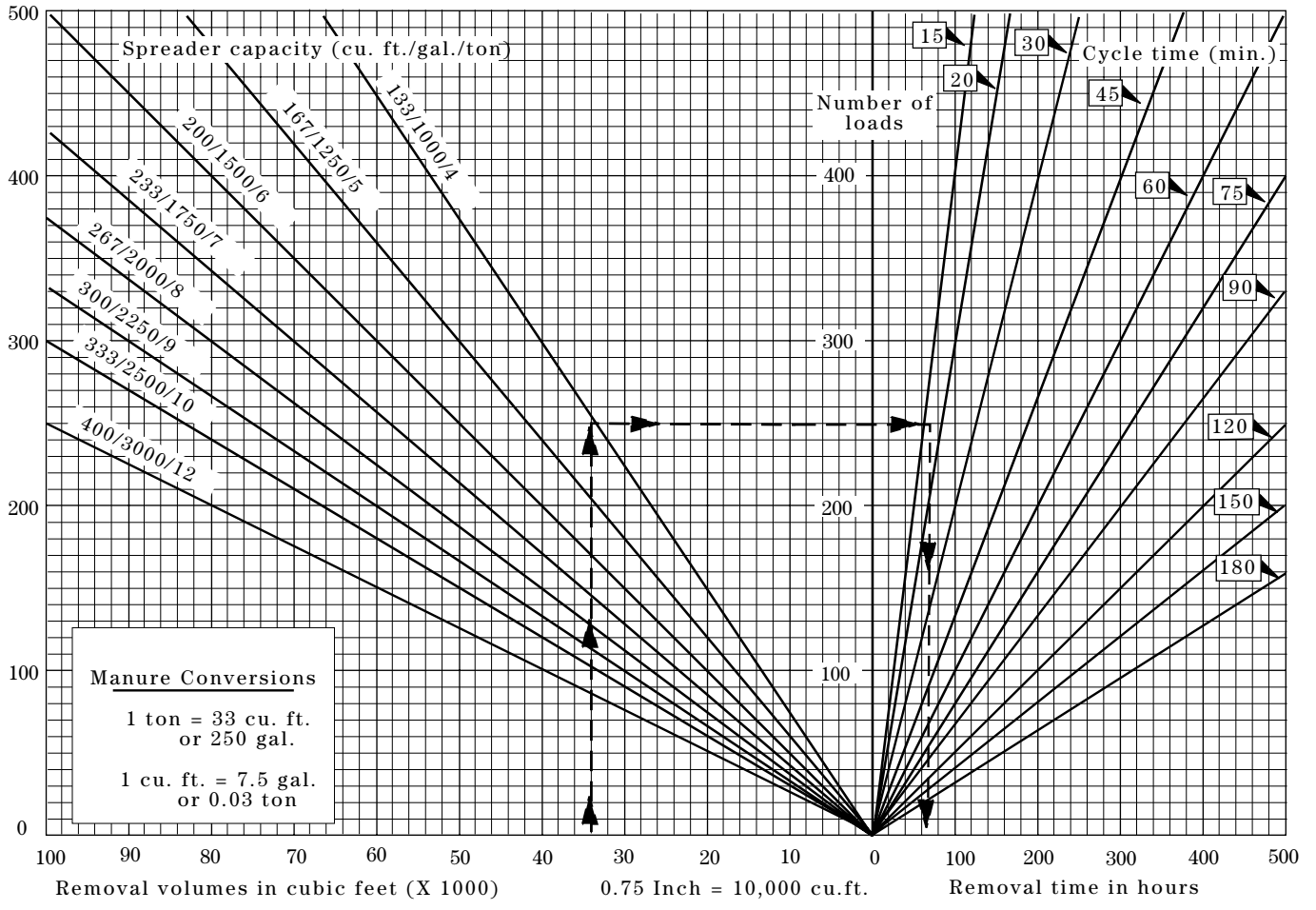
The actual cost of pumping as compared to hauling involves much more than just an analysis of labor cost, even though labor may be the largest component in many cases. Other factors include fuel costs, capital investment, maintenance, and availability of power. Even though a worker may not be physically 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

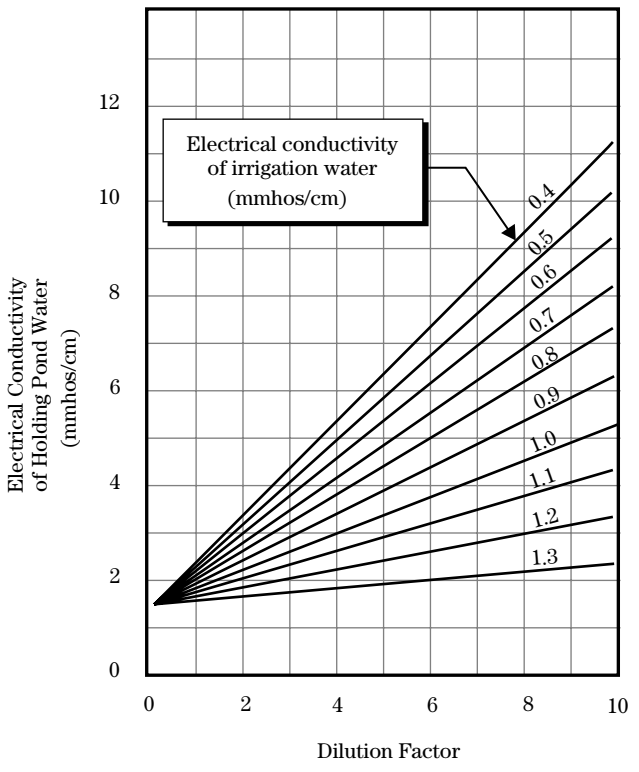
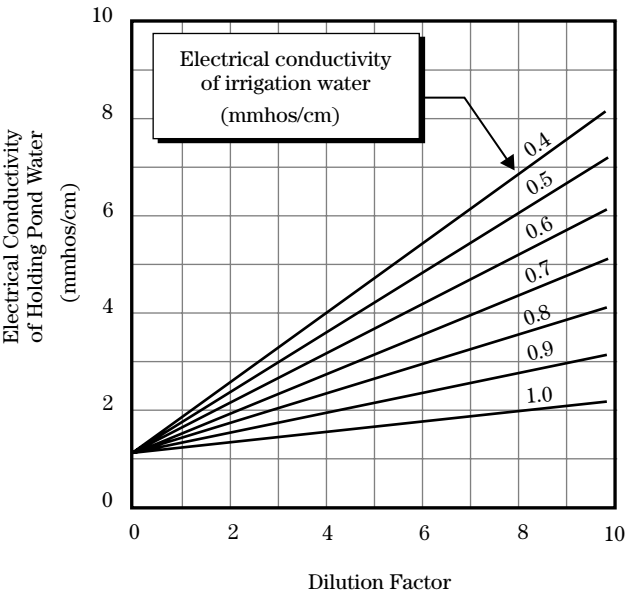


Figure 11–6 Waste storage pond dilution factors for resulting low salinity on medium textured soils



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

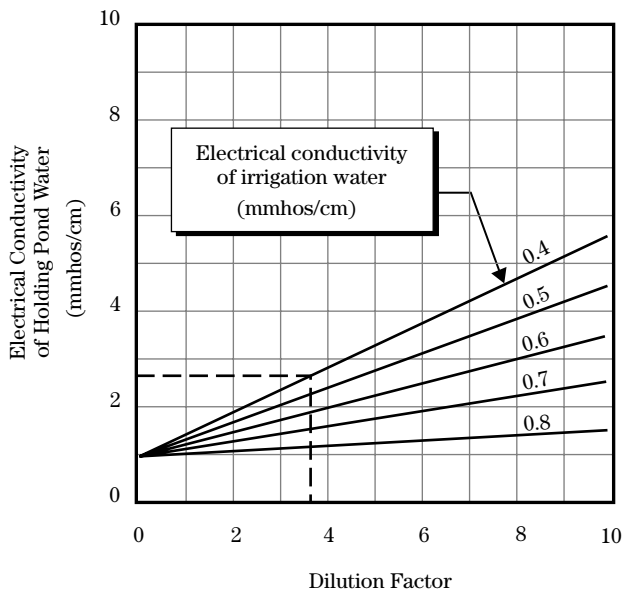
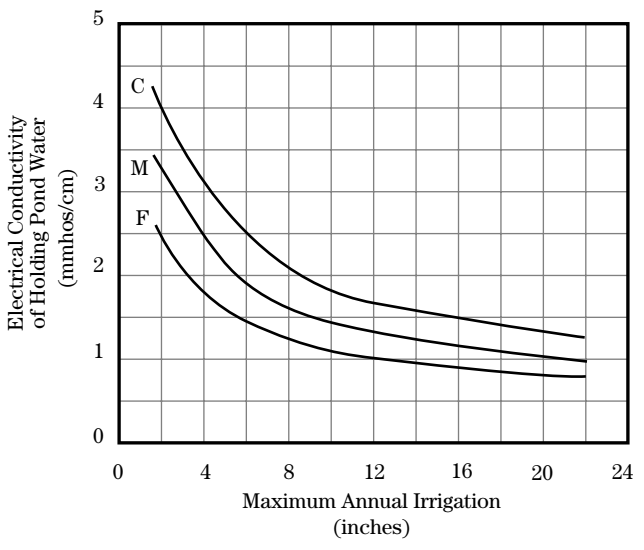


Figure 11–8 Maximum annual amount of undiluted waste storage pond water that can be added to a coarse (C), medium (M), or fine textured (F) soil



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:

$$= \frac{\text{pond vol. (ac - ft)} \times 12 \text{ in/ft}}{\text{annual irrigation (in.)}}$$

$$= \frac{5 \text{ ac - ft} \times 12 \text{ in/ft}}{2 \text{ in}}$$

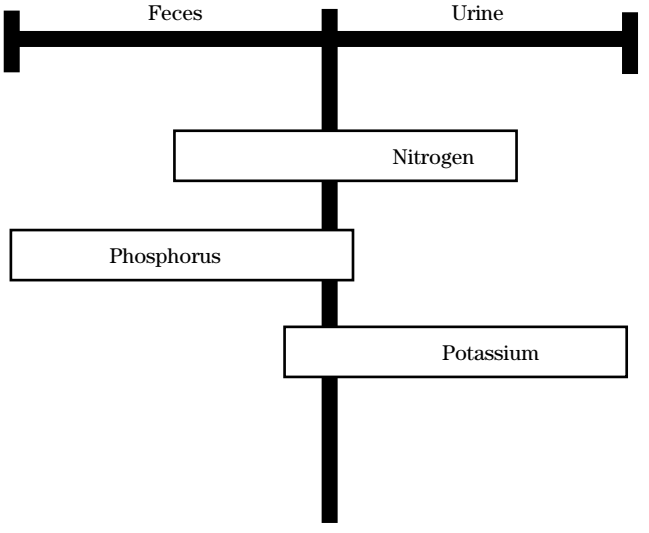
$$= \frac{60 \text{ ac - in}}{2 \text{ in}}$$

$$= 30 \text{ acres}$$

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).

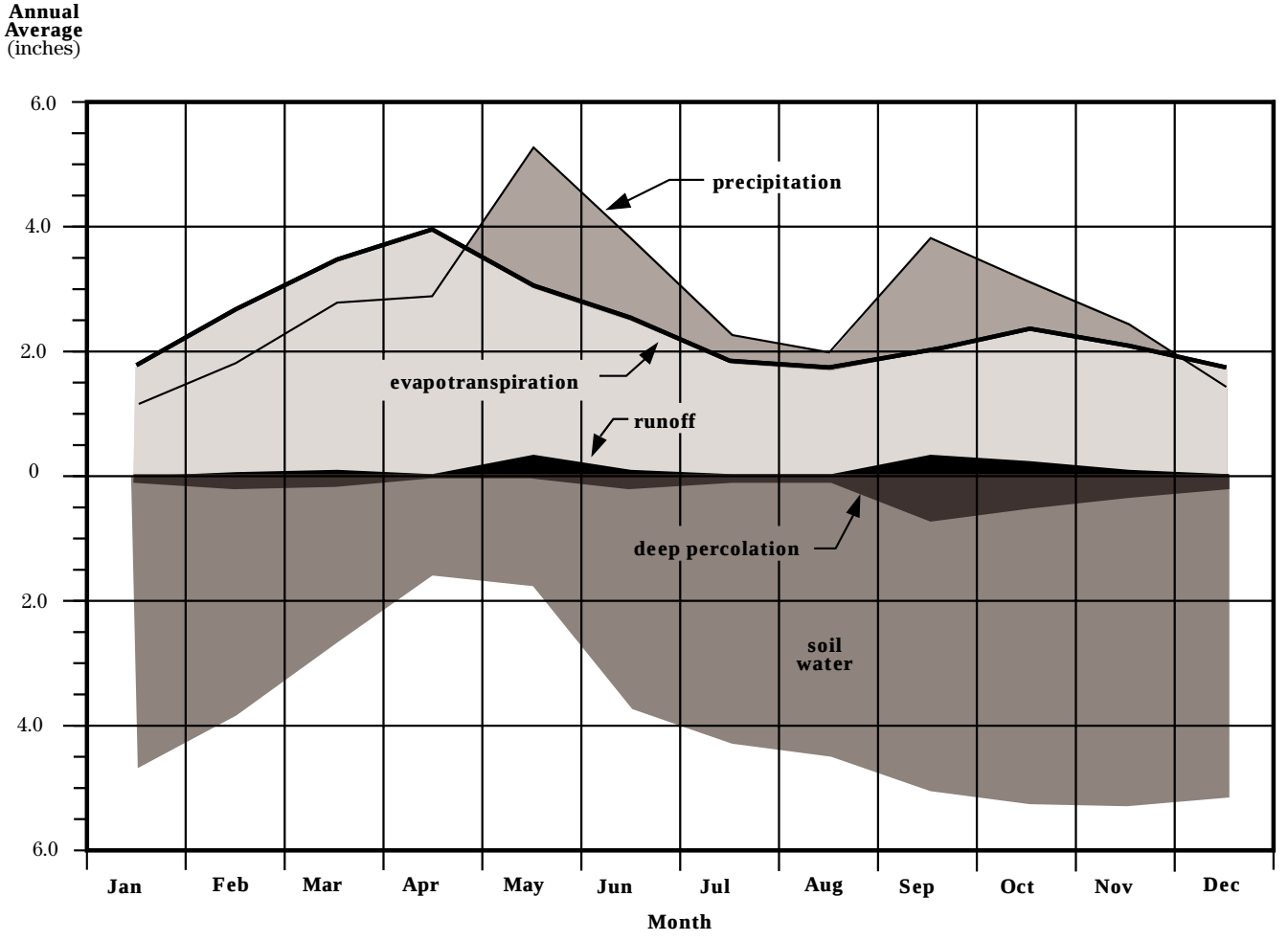
The optimum time for nutrient application based on figure 11–10 would be late in winter or early in spring so the nutrients will be readily available to plants. If the nutrients in a waste material are less available, such as with manure solids mixed with bedding giving a higher C:N ratio, incorporating 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 seasonally 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	Soil conditions		
and incorporation	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	Years after initial application								
	1	2	3	1	2	3	1	2	3
	Nitrogen			Phosphorus			Potassium		
	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.

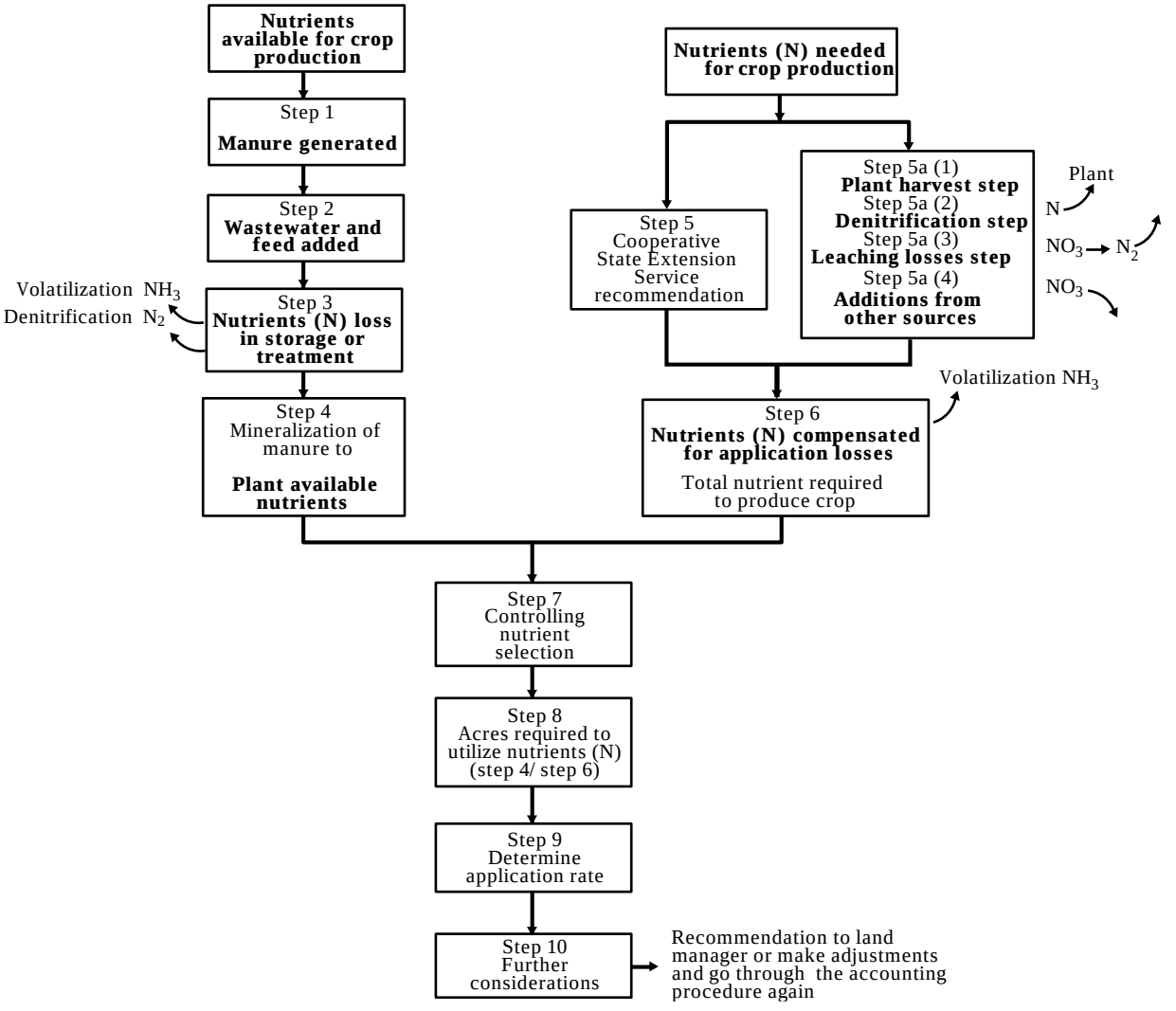
Use State Cooperative Extension Service information, if available, to determine the fraction of the plant available nutrients that will be released by the manure over the first crop growing season. A manure analysis that gives results as plant-available nutrients is preferred. A large fraction of the 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:

$$N = 185 \text{ lb/ac}$$
$$P_2O_5 = 46$$
$$K_2O = 35$$

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.

$$K_2O = 21,281 \text{ lb } (\text{PAN})$$
$$K_2O = 35 \text{ lb/ac}$$

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:

$$\frac{3{,}000 \text{ gal} \times 8.34 \text{ lb/gal}}{2{,}000 \text{ lb/ton} \times 1.21 \text{ ac}} = 10.3 \text{ tons/ac}$$

$$\# \text{ passes} = \frac{\text{application rate (total)}}{1 \text{ pass}}$$

$$= 10.3 \text{ tons/ac}$$

$$= \frac{81}{10.3}$$

$$= 7.9 \text{ passes (8 tank loads/3,500 ft run)}$$

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):

$$N = \frac{176 \text{ lb/ac}}{0.75} = 235 \text{ lbs/ac}$$

$$P_2O_5 = 46 \text{ (no change)}$$

$$K_2O = 35 \text{ (no change)}$$

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:

$$\text{Volume} = 57 \text{ ac-in} + \frac{5.6 \text{ gal/ft}^3 \times 207{,}190 \text{ ft}^3}{27{,}154 \text{ gal/ac-in}}$$

$$= 57 + 43$$

$$= 100 \text{ ac-in}$$

$$\text{Depth} = \frac{100 \text{ ac-in}}{61 \text{ ac}}$$

$$= 1.64 \text{ in}$$

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.

$$\text{Rate} = \frac{150 \text{ lb N } (\text{State nutrient guide rate})}{25 \text{ lb N/ton}}$$
$$= 6 \text{ tons/ac}$$

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:

$$\text{Area} = \frac{1{,}570 \text{ ton/yr}}{6 \text{ ton/ac } (\text{from question 1})}$$
$$= 262 \text{ acres required}$$

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

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