5.0 TECHNOLOGY COST EQUATIONS

Technology cost equations calculate the direct capital and annual costs for installing, operating, and maintaining a particular technology or practice for an animal feeding operation. Each cost module determines an appropriate design of the system component based on the characteristics of the model farm and the specific regulatory option. Waste volumes generated in the wastewater, manure, and runoff input modules described in Section 4.0 are used to size equipment and properly estimate the direct capital costs for purchasing and installing equipment and annual operating and maintenance costs.

Estimates of capital and annual cost components are based on information collected from vendors, literary references, EPA site visits, and/or estimates based on engineering judgment. The following subsections describe each technology cost equation used as a basis for the regulatory options and specifically discuss the following:

- Description of the technology or practice;
- Design;
- Costs; and
- Results for component costs for the technology or practice.

Section 6 discusses the prevalence of the technology or practice in use at CAFOs. Appendix A contains output tables of capital and annual costs (in 1997 dollars) for each technology or practice component. Section 7.0 provides examples of how these component costs are used to calculate model farm costs.

5.1 Earthen Settling Basins

Earthen settling basins are used at animal feeding operations to remove manure solids, soil, and other solid materials from wastewater prior to storage (e.g., a pond) or further treatment (e.g., a lagoon). The cost model assumes that beef feedlots and heifer operations use earthen basins to collect runoff. Because high wastewater flows from flushing operations could cause erosion in an earthen basin, dairies and veal operations use concrete settling basins (discussed in Section 5.2) to collect barn and milking parlor wastewater. The cost model includes costs for an earthen settling basin for beef feedlots and heifer operations for all regulatory options.

5.1.1 Technology Description

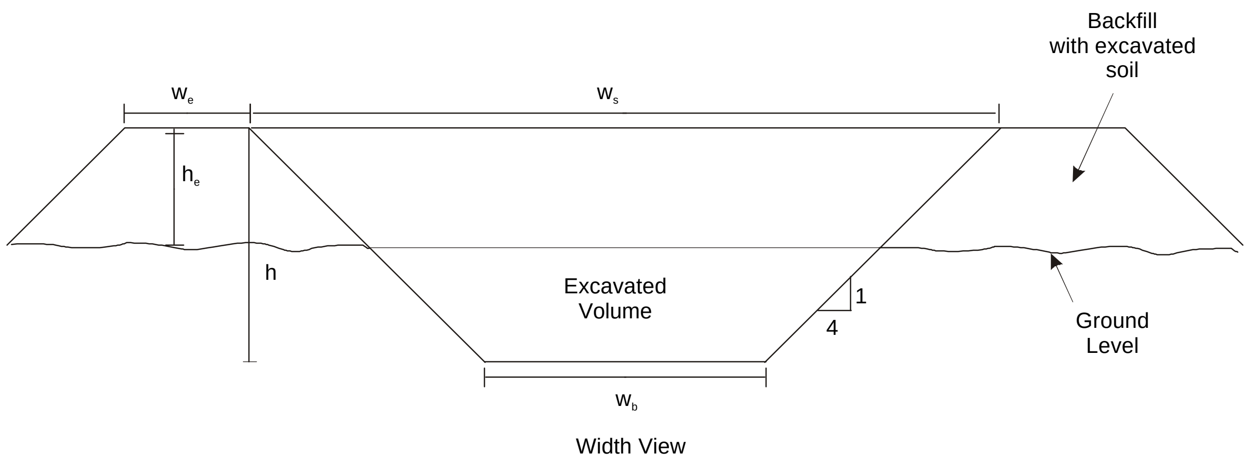
An earthen basin is a shallow basin that is designed to accumulate solids. The cost model assumes that earthen basins receive runoff from beef feedlots and heifer operations. The basin allows solids to settle and liquids to drain. Generally, the basin is designed to handle a wastewater flow velocity less than 1.5 feet per second, which is slow enough to allow solids to settle. Periodic removal of the accumulated solids is necessary; therefore, access to the earthen basin must be provided for a front-end loader or tractor. (The costs for periodic solids removal are included in the annual costs, which are presented as a percentage of the total capital costs.)

5.1.2 Design

Earthen basins are designed to capture runoff from the beef feedlot and are rectangular in shape. The four sides are sloped at a 4:1 (horizontal:vertical) ratio to prevent erosion and allow for front-end-loader access to remove solids. Earthen basins are constructed of soils that have a significant clay content (usually at least 10 percent). Figure 5.1.2-1 presents a cross-section of the basin.

The earthen basin is constructed by excavating part of the volume required and building embankments to construct the remaining basin volume. The variables in Figure 5.1.2-1 are defined as follows:

h_e = height of embankment
h = height (depth) of basin
w_e = width of embankment
w_b = width at bottom of basin
w_s = width at surface of basin
l_b = length at bottom of basin
l_s = length at surface of basin.



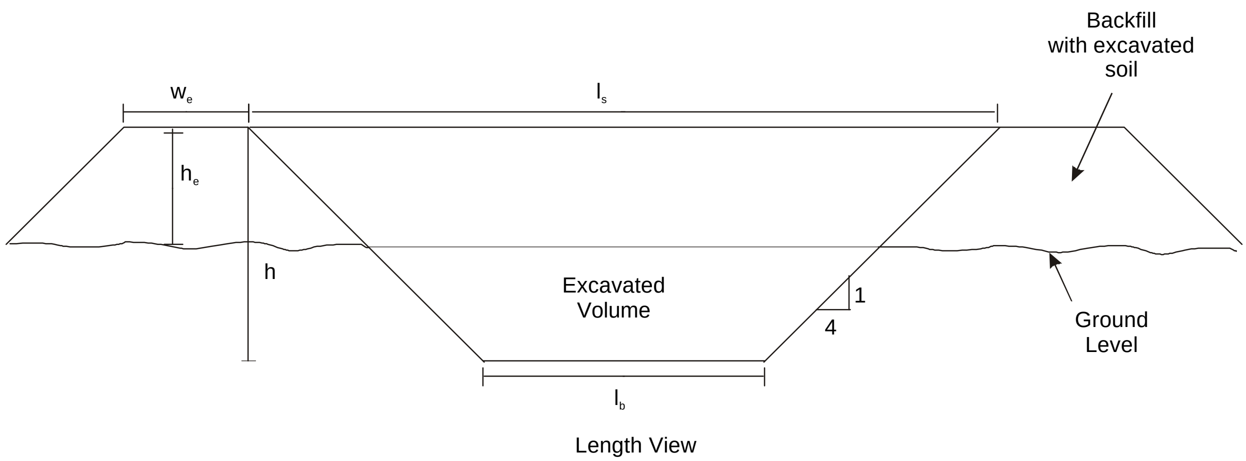


Figure 5.1.2-1. Cross-Section of an Earthen Basin

Table 5.1.2-1 summarizes the default design criteria used in the cost model.

Table 5.1.2-1

Design Parameters for Earthen Basins

Parameter	Value
Total height (depth) required (h)	4 feet
Side slopes (horizonal:vertical) (s)	4:1
Bottom width (w_b)	12 feet
Width of embankment (w_e)	6 feet

Source: Midwest Plan Service Structures and Environment Handbook, 1987.(MWPS, 1987)

The remainder of this subsection describes the methods used to calculate the earthen basin influent and effluent flows, volume, other dimensions, and excavation and embankment volumes, as listed on Figure 5.1.2-1.

Earthen Basin Influent and Effluent Flows

The design volume of the earthen basin is based on the peak runoff entering the basin, which is set equal to the peak runoff from a 10-year,1-hour rainfall event under all regulatory options. Section 4.7 describes the details of the runoff calculation. In addition, it is assumed that runoff contains 1.5 percent solids (MWPS, 1993). EPA assumes that all of the solids from the drylot are manure solids. Using these assumptions, the total amount of water and solids entering the earthen basin are calculated as follows:

$$\text{Water Entering, cubic feet} = (\text{Peak}) \times (1 - 0.015)$$

$$\text{Solids Entering, cubic feet} = (\text{Peak}) \times (0.015)$$

where:

Peak = Peak runoff during 10-year,1-hour storm event (cubic feet).

The cost model assumes that earthen basins have a settling efficiency of 50 percent, and the moisture content of the settled solids is 80 percent (Fulhage, C.D. and D.L. Pfost, 1995). The amounts of water and solids in the settled solids and basin effluent are calculated from the following equations:

$$\text{Settled Solids, cubic feet} = \text{Solids Entering} \times 0.5$$
$$\text{Water in Settled Solids, cubic feet} = \text{Settled Solids} \times \left[\frac{0.8}{(1-0.8)}\right]$$

$$\text{Solids Exiting, cubic feet} = \text{Solids Entering} - \text{Settled Solids}$$
$$\text{Water Exiting, cubic feet} = \text{Water Entering} - \text{Water in Settled Solids}$$

The above equations are used to calculate the amount of solids and water that leave the earthen basin and enter a storage pond (see Section 5.5), not the volume of the basin.

Earthen Basin Volume

The required volume of the basin is calculated from the following equation (MWPS, 1987):

$$\text{Volume}_{\text{basin}} = \text{Surface Area} \times h$$

where:

Surface Area	=	Peak ÷ 4
h	=	Basin depth (Table 5.1.2-1 value).

Because solids from the basin are removed frequently to prevent significant accumulation, the cost model does not include accumulated solids in the volume calculations. Table 5.1.2-2 summarizes the earthen basin design volumes calculated for all regulatory options by model farm.

Table 5.1.2-2

Earthen Basin Volume by Model Farm for All Regulatory Options

Animal Type	Size Class	Earthen Basin Volume (ft^3) by Region				
		Central	Mid-Atlantic	Midwest	Pacific	South
Beef	Medium 1	777	3,399	3,159	2,196	5,565
	Medium 2	1,367	5,297	4,923	3,506	8,505
	Medium 3	2,036	7,516	7,008	5,029	11,979
	Large 1	5,511	18,635	17,459	12,675	29,381
	Large 2	83,534	268,341	251,528	184,330	419,522
Heifer	Medium 1	777	3,453	3,212	2,250	5,645
	Medium 2	1,474	5,645	5,244	3,747	9,066
	Medium 3	2,223	8,077	7,543	5,404	12,862
	Large 1	4,121	14,145	13,236	9,600	22,351

NA - Not applicable. No regulatory options include this component for this model farm.

Earthen Basin Dimensions

The cost model assumes that the earthen basin has four sloped sides with a rectangular base. To determine the dimensions of the basin, the design volume of the basin from Table 5.1.2-2 is used with the design parameters shown in Table 5.1.2-1. The following equation is used to determine the length of the basin:

$$Volume_{basin} = ½\ h\ [A_1 + A_2 + (A_1\ A_2)^{0.5}]$$

$$Volume_{basin} = ½\ h\ [l_b w_b + l_s w_s + (l_b w_b l_s w_s)^{0.5}]$$

where:

A_1 = Area of the bottom base = $l_b\ w_b$
A_2 = Area of the top (surface area) = $l_s\ w_s$.

Earthen Basin Floor Surface Area

The surface area of the floor of the basin is calculated to determine the area for compaction. The surface area includes the bottom area plus the area of the four trapezoids that make up the sides of the basin. Figure 5.1.2-2 depicts the surfaces of the sloped sides.

The surface area of the sloped sides is calculated using the formula for the area of a trapezoid.

$$\text{Area of Side} = \tfrac{1}{2}\, HS\,(a + b)$$

where:

HS	=	Height of the side (see equation below)
a	=	Bottom width (1_b or w_b)
b	=	Top width (1_s or w_s).

The height of the side is calculated using the Pythagorean Theorem:

$$HS = (h^2 + (4h)^2)^{0.5}$$

The total surface area of the basin is:

$$\text{Surface Area}_{basin} = l_b w_b + 2\,[0.5 \times HS\,(l_b + l_s)\,] + 2\,[0.5 \times HS\,(w_b + w_s)]$$

Earthen Basin Excavation and Embankment Volumes

Earthen basins are constructed by excavating a portion of the necessary volume and building embankments around the perimeter of the basin to make up the total design volume. The cost model performs an iteration to maximize the use of excavated material used in constructing the embankments that minimizes the costs for construction. The excavation volume is represented by the following equation:

$$Vol_{excavated} = 0.5\,(h\text{-}h_e)\,[l_b w_b + l_s w_s + (l_b w_b l_s w_s)^{0.5}]$$

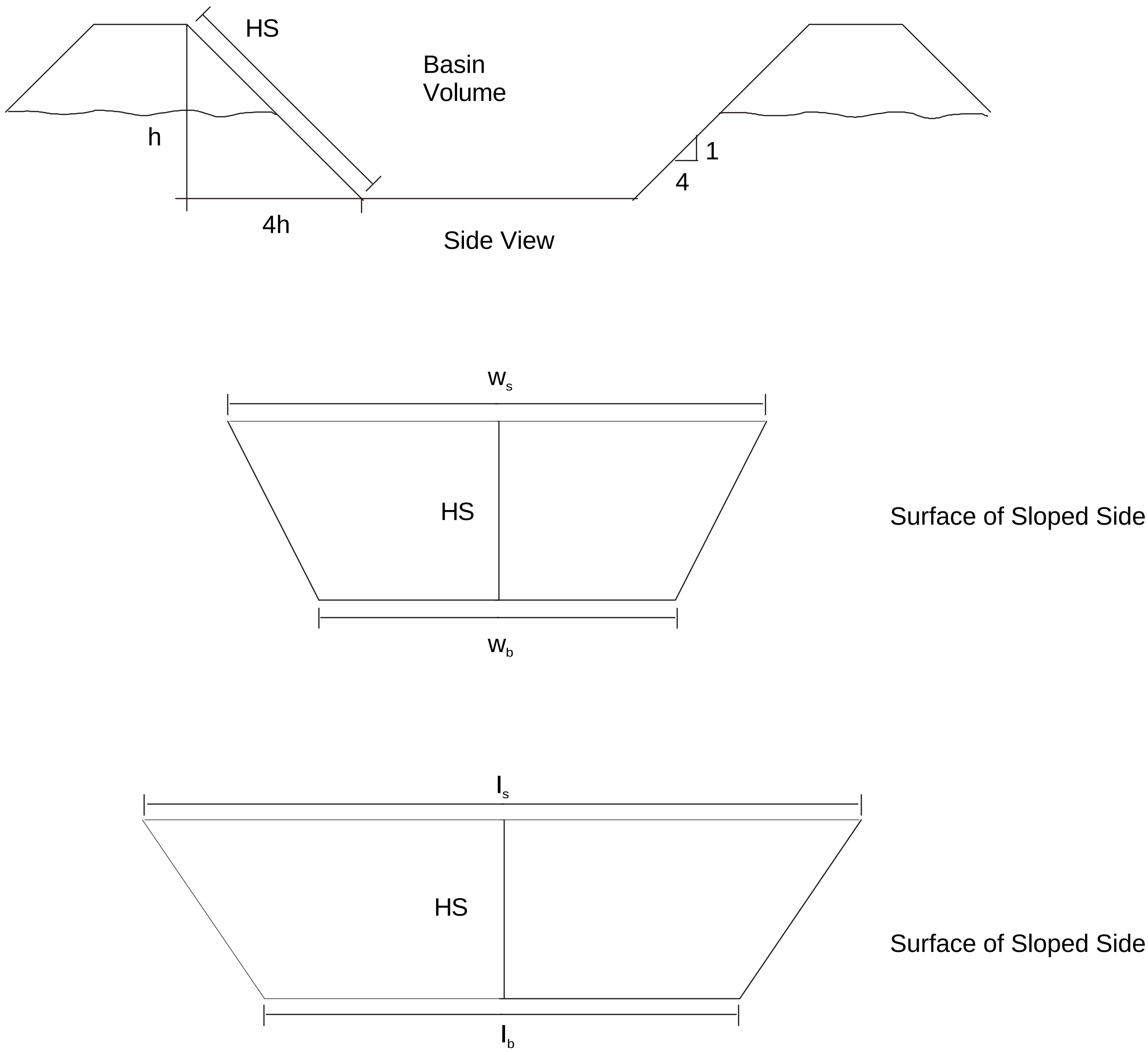


Figure 5.1.2-2. Sloped Sides of Earthen Basin

The excavated soil is used to build the embankments. Because the soil will settle somewhat, the cost model assumes that an extra 5 percent of volume is required. The embankment volume is represented by the following equation:

$$Vol_{embankment} = 2\,[(1.05\ h_e w_e + s\,(1.05\ h_e)^2)\ (l_b + 2\ \ sh)] + 2\,[(1.05\ h_e w_e + (1.05\ s)^2\ h_e^{\ 2})\ (w + 2sh)]$$

The cost model calculates the dimensions of the basin that yields the desired volume.

5.1.3 Costs

Capital costs to construct and install the earthen basin consist of mobilization, excavation, and compaction. Table 5.1.3-1 lists the unit costs for each of these elements.

Table 5.1.3-1

Unit Costs for Earthen Basins

Unit	Cost (1997 dollars)	Source[a]
Backhoe mobilization	$204.82/event	Means, 1999 (022 274 0020)
Excavation	$2.02/yd^3	Means, 1999 (022 238 0200)
Compaction	$0.41/yd^3	Means, 1996 (022 226 5720)

[a]Information taken from Means Construction Data. The numbers in parentheses refer to the division number and line number.

The excavation cost is calculated using the following equation:

$$\text{Excavation Cost (\$)} = \text{Excavation Unit Costs (\$ / yd}^3) \times \frac{\text{Volume}_{\text{excavated}}\ (\text{ft}^3)}{27\ (\text{ft}^3 / \text{yd}^3)}$$

The total volume of soil that is compacted includes the surface area times a 1-foot compaction depth plus the entire volume of the embankment because it is compacted as placed.

$$\text{Volume}_{\text{compacted}}\ (\text{ft}^3) = [\text{Surface Area}_{\text{basin}}\ (\text{ft}^2) \times 1\ \text{ft}] + \text{Volume}_{\text{embankment}}\ (\text{ft}^3)$$

$$\text{Compaction Cost (\$)} = \text{Compaction Unit Costs (\$ / yd}^3) \times \frac{\text{Volume}_{\text{compacted}} \text{ (ft}^3)}{27 \text{ (ft}^3 \text{ / yd}^3)}$$

Total Capital Costs

The total capital cost for the earthen basin is calculated using the following equation:

Capital Cost = Mobilization Cost + Excavation Cost + Compaction Cost

Total Annual Costs

Based on best professional judgement, it is estimated that annual operating and maintenance costs are 5 percent of the total capital costs.

$$\text{Annual Cost} = 0.05 \times \text{(Capital Cost)}$$

5.1.4 Results

Appendix A, Table A-1 presents the cost model results for constructing an earthen basin.

5.2 Concrete Settling Basins

Concrete settling basins, also called concrete sedimentation basins, are used at animal feeding operations to remove manure solids, soil, and other solid materials from wastewater prior to storage (e.g., a pond) or further treatment (e.g., a lagoon). Dairies use solids separation to increase the storage volume available for wastewater in lagoons or to reduce the moisture content of the waste to make it more suitable for transport, disposal, composting, and other uses, such as bedding materials. The cost model includes concrete settling basins in all options for dairies to collect barn and milking parlor wastewater because the higher wastewater flows characteristic of dairies could cause significant erosion in an earthen basin. Concrete settling basins were not included in the cost analysis for beef feedlots, heifer operations, swine operations, or poultry operations.

5.2.1 Technology Description

The settling basin is a shallow basin or pond that is designed to accumulate solids. The purpose of a settling basin is to slow wastewater flow sufficiently to allow solids to settle and liquids to drain. In general, reducing the flow velocity to less than 1.5 feet per second is enough to allow solids to settle. Access to the settling basin must be provided for periodic removal of solids. Solids separators can have a solids separation efficiency of between 30 percent (for mechanical separators) and 60 percent (gravity settling basins) (Fulhage, C. D. and D.L. Pfost, 1995). EPA estimated that most solids separators used in this industry are gravity settling basins, and used a settling efficiency of 50 percent.

Settling basins may be constructed from a variety of materials, including concrete. Concrete construction offers the advantage of added durability and stability of side slopes. Also, concrete construction facilitates the removal of solids with heavy equipment such as a front-end loader, which may drive onto a concrete settling basin floor. A concrete basin design is also advantageous in areas where soils are not suitable for earthen construction (e.g., areas where soils have a high sand content). Concrete basins are preferable to earthen basins to prevent erosion when high-velocity wastewater flows are anticipated, such as at flush dairies.

5.2.2 Design

Wastes entering the concrete settling basin include manure from the mature dairy cows, wastewater from the milk parlor, and flush or hose water from the freestall barns. A settling basin is designed to handle peak wastewater flows (NRAES, 1989); for a dairy operation, the peak flows are assumed to occur during the flushing of one freestall barn. Settling basin size depends upon the surface loading rate (i.e., the hydraulic load per unit of basin surface area) for agricultural wastewater; basin depth may be adjusted to allow for solids accumulation. It is assumed that wastewater flows to the settling basin via gravity.

The concrete settling basin design consists of a rectangular basin with a sloped ramp for front-end loader access (see Figure 5.2.2-1). The basin is 3 feet deep, allowing for 1 foot of solids accumulation. Rectangular concrete basins are typically designed with a 3:1 length-to-width ratio (NRAES, 1989). The sloped access ramp forms one side of the basin; however, it is longer than the other sides to allow the basin to have sufficient volume. The access ramp is sloped 1 inch fall per 1 foot run (MWPS, 1987). The concrete thickness is 6 inches (USDA NRCS, 1995). The sub-base for the concrete floor and access ramp consists of 6 inches of compacted gravel fill and 4 inches of graded sand fill. The concrete is shaped with wooden forms and reinforced with steel (#4 bars).

Concrete Basin Volume and Surface Area

The required area and volume of the basin are calculated from the Midwest Plan Service (MWPS, 1987) formulas below:

$$\text{Surface Area}_{basin} = \text{Peak} \div 4$$

$$\text{Volume}_{basin} = \text{Surface Area} \times h$$

where:

h	=	Basin depth = 3 ft (Recommended depth is 2 feet plus depth required for solids storage. Depth of solids should not exceed 1.5 feet; therefore, EPA assumes 1 foot.) (Fulhage, C. D. and D.L. Pfost, 1995).
Peak	=	Flow from flushing of confinement barn.

Using the Pythagorean Theorem,

$$\text{Ramp Length} = (h^2 + \text{Run}^2)^{1/2}$$

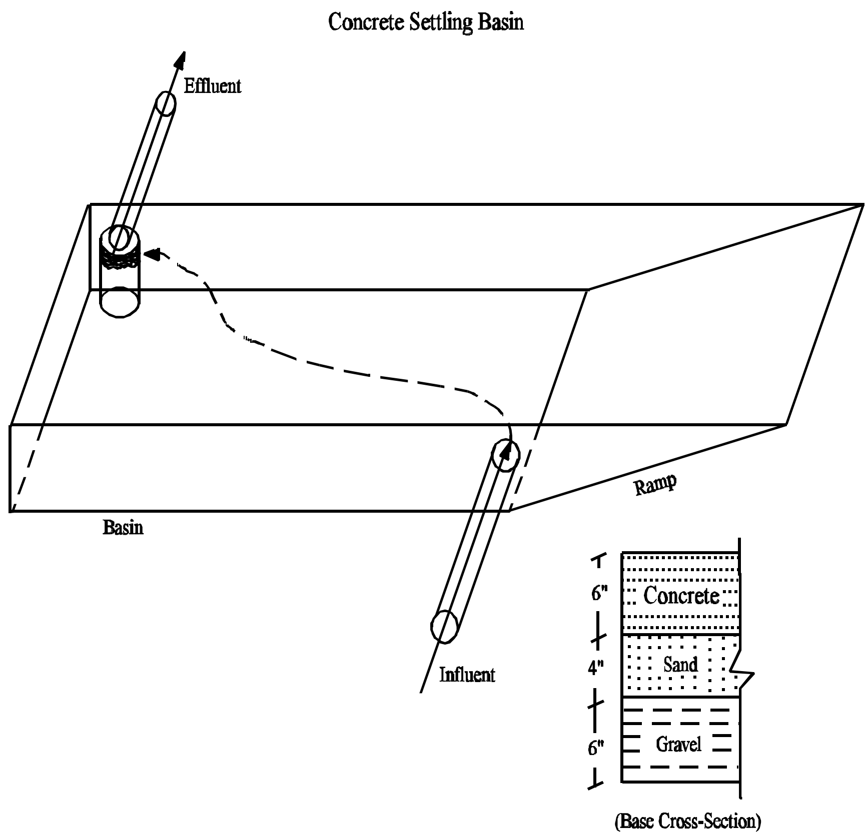


Figure 5.2.2-1. Concrete Settling Design

where:

Run	=	h × 12 in/ft × (1 ft run ÷ 1 in fall)
Surface Area of Ramp	=	Ramp Length × Basin Width
Volume Along Access Ramp	=	0.5 Fall × Run × Basin Width.

Additional basin length is needed to account for the slope of ramp.

$$\text{Length} = 0.5 \times \text{Run}$$

$$\text{Length}_{\text{settling basin}} \text{ (including access ramp)} = \text{Theoretical Length} + \text{Additional Length}$$

$$\text{Length}_{\text{settling basin}} \text{ (excluding access ramp)} = \text{Length of Basin} - \text{Run}$$

Table 5.2.2-1 summarizes of the concrete basin volumes calculated for flush and hose dairies by size group. Note that the basin design does not vary by region or regulatory option.

Table 5.2.2-1

Concrete Basin Volume by Model Farm for All Regulatory Options

Animal Type	Size Class	Concrete Basin Volume (ft^3)
Dairy - Flush	Medium 1	7,520
	Medium 2	12,784
	Medium 3	18,048
	Large 1	43,014
Dairy - Hose	Medium 1	416
	Medium 2	515
	Medium 3	614
	Large 1	825

5.2.3 Costs

The capital costs to construct and install the concrete settling basin include mobilizing the backhoe used for excavation, excavating soil, compacting the ground surface, hauling gravel and sand to the lot, purchasing the gravel and sand, grading the sand, the form work, reinforcement, and concrete for the walls, slab (including reinforcement), and finishing the slab. Table 5.2.3-1 presents the unit costs for each of these components.

Table 5.2.3-1

Unit Costs for Concrete Settling Basin

Unit	Cost (1997 dollars)	Source[a]
Backhoe mobilization	$204.82/event	Means 1999 (022 274 0020)
Excavating	$2.02/yd^3	Means 1999 (022 238 0200)
Hauling of material	$4.95/yd^3	Means 1996 (022 266 0040)
Compaction	$0.41/yd^3	Means 1996 (022 226 5720)
Gravel fill (6")	$9.56/yd^3	Means 1998 (022 308 0100)
Sand fill	$48.55/yd^3	Richardson 1996 (3-5 p1)
Grading sand	$1.73/ft^3	Means 1999 (025 122 1100)
Wall form work	$4.90/ft^2	Building news 1998 (03110.65)
Wall reinforcement bars	$0.45/ft	Richardson 1996 (3-5 p9)
Ready mix concrete	$63.70/yd^3	Means 1998 (033 126 0200)
Slab on grade	$116.29/yd^3	Means 1999 (033 130 4700)
Finishing slab (concrete)	$0.33/ft^2	Means 1999 (033 454 0010)

[a]For Means Construction Data, the numbers in parentheses refer to the division number and line number.

Mobilization

The mobilization costs are a fee per event (i.e., fee to mobilize all equipment on site). These costs are for moving the appropriate heavy machinery and equipment.

Excavation

The excavation cost is calculated from the following equations:

$$\text{Volume}_{\text{excavated}} = \text{Volume}_{\text{basin}} + \text{Volume}_{\text{ramp}} + \text{Volume}_{\text{subsurface}}$$

$$\text{Excavation Cost} = \text{Excavation Unit Costs (\$ / yd3)} \times \frac{\text{Volume}_{\text{excavated}} \text{ (ft3)}}{27 \text{ ft}^3 / \text{yd}^3}$$

Compaction

The total volume to be compacted includes the surface area of the basin and the ramp times a 1-foot compaction depth.

$$\text{Volume}_{\text{compacted}} = [\text{Surface Area}_{\text{basin}} \text{ (ft}^2) + \text{Surface Area}_{\text{ramp}} \text{ (ft}^2)] \times 1 \text{ ft}$$

Hauling

The total volume of gravel and sand needed is equal to the volume underneath the settling basin and the ramp.

$$\text{Volume}_{\text{gravel}} \text{(yd}^3) = [\text{Surface Area}_{\text{basin}} \text{ (ft}^2) + \text{Surface Area Ramp (ft}^2)] \times 0.5 \text{ ft} \times \left(\frac{1 \text{ yd}^3}{27 \text{ ft}^3}\right)$$

$$\text{Volume}_{\text{sand}} \text{(yd}^3) = [\text{Surface Area}_{\text{basin}} \text{ (ft}^2) + \text{Surface Area Ramp (ft}^2)] \times 0.33 \text{ ft} \times \left(\frac{1 \text{ yd}^3}{27 \text{ ft}^3}\right)$$

The volume of the material to be hauled includes the sand plus the gravel.

Reinforcement

The concrete wall form work is calculated as follows:

$$Area_{wall\ forms} = Area_{settling\ basin} + Area_{basin\ end} + Area_{ramp\ sides}$$

Assuming that reinforcements are spaced every 12 inches along the length and width of the basin, the total length of reinforcement is calculated as follows:

$$Length_{reinforcement} = 2\ bars/ft \times [Surface\ Area_{basin} + Surface\ Area_{ramp}]$$

The concrete volume for the walls and slab are calculated as follows:

$$Volume_{concrete} = Area_{wall\ forms} \times Concrete\ Thickness$$

$$Volume_{concrete\ slab} = [Area_{floor} + Area_{ramp}] \times Concrete\ Depth$$

The area of concrete to be finished is:

$$Area_{concrete} = [Area_{floor} + Area_{ramp}]$$

Total Capital Costs

The cost for construction of the concrete settling basin is calculated by summing the components above and multiplying them by the unit costs listed in Table 5.2.3-1. The total capital cost is:

Capital Cost = Mobilization + Excavation + Compaction + Hauling (sand and gravel) + Gravel Fill + Sand Fill + Grading Sand + Walls (form work, reinforcement, concrete) + Concrete Slab + Slab Finishing

Total Annual Costs

Based on best professional judgement, it is assumed that annual operating and maintenance costs are 5 percent of the total capital costs.

$$\text{Annual Cost} = 0.05 \times (\text{Capital Cost})$$

5.2.4 Results

Appendix A, Table A-2 presents the cost model results for constructing a concrete gravity settling basin.

5.3 Berms

Beef feedlots, dairies, heifer, and swine and dry poultry operations use berms to contain stormwater runoff and process water that fall within the animal handling and feeding areas and to divert clean stormwater that falls outside these areas. Because the handling and feeding areas contain manure, runoff from these areas needs to be contained and diverted to a waste management storage facility (e.g., a lagoon or a pond). Berms surrounding the handling and feeding area act as a physical barrier between the containment area and adjacent "clean" land. Berms are costed for all beef feedlots, heifer operations, and dairies for all regulatory options, but not costed for veal operations because they are assumed to be indoor operations.

Stormwater is diverted around poultry and swine storage structures by constructing berms on two adjacent sides up-gradient from the storage facility or lagoon. Berms are not included in the cost analysis for swine operations with pit systems.

5.3.1 Technology Description

Berms are earthen structures that divert clean runoff away from pollutant sources and channel runoff that falls within the area containing pollutant sources. Runoff that falls within the containment area at beef and dairy operations may become contaminated from contact with animal feed and fecal matter deposited in the feedlot or handling area. This runoff is channeled by the berms to a waste management storage facility (e.g., a pond or lagoon).

5.3.2 Design

The design of a berm system for a specific operation depends on the size of the outdoor feedlot area, lagoon, or dry waste storage area. The feedlot area is dependent upon the number of animals contained on drylots at the facility.

Beef Feedlots and Dairies

The cost model assumes for beef feedlots and dairies that berms are constructed as a 3-foot-high, 6-foot-wide compacted soil mound that surrounds the feedlot and animal handling areas. EPA assumes the feed storage area is part of the animal handling areas. Figure 5.3.2-1 depicts the cross-section of the berm assumed for this cost model.

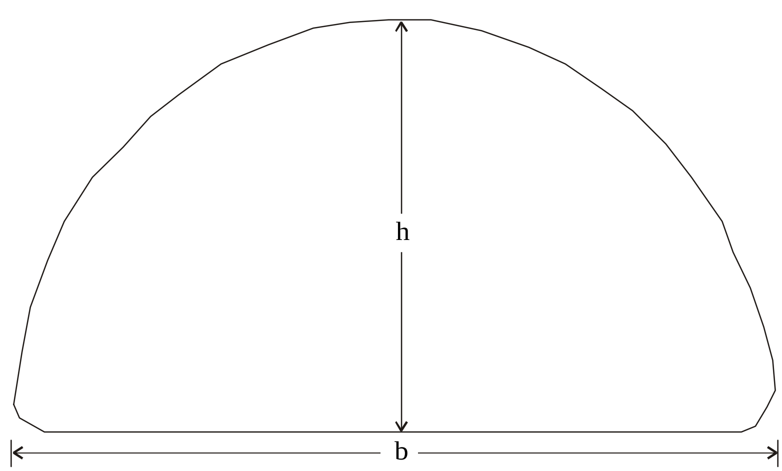


Figure 5.3.2-1. Cross-Section of Berm

The area of the cross-section of the berm is calculated using the following equation:

$$Area_{berm} = \mathbf{b} \times b \times h$$

where:

b	=	Base width (6 feet)
h	=	Total height (3 feet).

The total length of the berm system for beef feedlots and dairies varies according to the size of the feedlot area. The area required for each animal varies by animal type, because different sized animals require a different amount of space. Table 5.3.2-1 provides the recommended area per animal for a drylot, not including handling and storage areas. The beef and dairy cost model calculated the average area per animal on a drylot using the ranges presented in Table 5.3.2-1, and added 15 percent for handling areas (AEA, 1999).

Table 5.3.2-1

Space Requirements Assumed for Animals Housed on Drylots[a]

Animal Type	Drylot Area (ft^2/animal)	Handling Area (ft^2/animal)	Total Area (ft^2/animal)
Beef cattle	400	60	460
Mature dairy cows	400	60	460
Heifers	375	56	431
Calves	225	34	259

[a]Source: MWPS, 1993; AEA, 1999.

The total perimeter of the berm is calculated as follows:

$$L = 4 \times (Area_{feedlot} \times Head)^{0.5}$$

where:

L	=	Total perimeter (length of four sides of a square area) (feet)
$Area_{feedlot}$	=	Total area of drylot and handling areas per animal (ft^2) (Table 5.3.2-1 value)
Head	=	Average Head (Table 4.3.1-1 value).

Table 5.3.2-2 summarizes the perimeters of the berm calculated for all model farms. Note that the berm design does not vary by region or regulatory option.

Swine and Poultry Operations

For swine and poultry operations, berms were constructed in accordance with the standards of the American Society of Agricultural Engineers (ASAE, 1998). ASAE specifies a berm with a 1-foot top width, a height of 3 feet, and a 2:1 side slope. Assuming a trapezoidal shape, the berm cross-sectional area is determined by:

$$Area_{berm} = ½ \times H_{berm} \times (W_{bermbot} + W_{bermtop})$$

where:

H_{berm} = height of berm
$W_{bermbot}$ = width of berm bottom
$W_{bermtop}$ = width of berm top.

Table 5.3.2-2

Berm Perimeter by Beef and Dairy Model Farm for All Regulatory Options

Animal Type	Size Class	Berm Perimeter (ft)
Beef	Medium 1	1,650
	Medium 2	2,016
	Medium 3	2,374
	Large 1	3,679
	Large 2	13,806
Heifers	Medium 1	1,661
	Medium 2	2,077
	Medium 3	2,457
	Large 1	3,217
Dairy (Heifers and Calves)	Medium 1	910
	Medium 2	1,186
	Medium 3	1,410
	Large 1	2,176

With a side slope of 2:1 (H:V), a height of 3 feet (H_{berm}), and a top width of 1 foot ($W_{bermtop}$), the bottom width ($W_{bermbot}$) is 13 feet, and the cross-sectional area ($Area_{berm}$) is 21 square feet. The cross-sectional area is then multiplied by berm length (L_{berm}) to obtain cubic yardage for construction. Berm length is determined by the dimensions of the solid or liquid storage structure.

For solid poultry waste, the berm length is calculated from the dimensions of the litter storage shed (see 5.14). Shed width is assumed to be 68 feet and shed length is the same as the length of the litter stack. For liquid storage systems, lagoons or evaporative ponds, berm length is determined after a subroutine is executed to determine the lagoon or evaporative pond dimensions (see 5.4.5). Lagoons and evaporative ponds are assumed to be square, and berm length is calculated from the top width of these structures.

The two adjoining berms for swine and poultry operations are designed to extend 10 feet beyond each of two adjacent sides of the storage structure. The berms meet to form a corner, but since the berms are 13 feet wide at the base, there is substantial overlap at the corner. Based on a mathematical analysis of the extent of this overlap, it was determined that berm length should be calculated in the following manner to adjust for the overlap:

For lagoons and evaporative ponds: $L_{berm} = (2 \times W_{lagoontop} + 30)$

For solid storage structures: $L_{berm} = (Volume_{stack}/320 + 98)$

where:

$W_{lagoontop}$	=	Width of top of lagoon or evaporative pond
$Volume_{stack}$	=	Volume of litter stack
320	=	The cross-sectional area of the litter stack.

A more detailed discussion of berm and other calculations used for swine and poultry operations can be found in *Swine and Poultry Cost Model QA/QC Report* (Tetra Tech, 2002).

5.3.3 Costs

To construct the berm, the volume of material to construct the berm is excavated along the perimeter of the containment area. The excavated soil is mounded to form the berm and the soil is compacted. Table 5.3.3-1 presents unit costs for constructing the berm. A fixed earth moving cost of $2.60 per cubic yard was used in the calculation of similar expenses for berms at swine and poultry operations.

Table 5.3.3-1

Unit Costs for Constructing Berms

Unit	Cost (1997 Dollars)	Source[a]
Compaction	$0.41/yd^3	Means, 1996 (022 226 5720)
Excavation	$2.02/yd^3	Means, 1999 (022 238 0200)

[a]Information taken from Means Construction Data. The numbers in parentheses refer to the division number and line number. Different years were selected for the different components based on consultation with industry experts and best professional judgement.

The total volume of the berm for beef feedlots and dairies is calculated using the following equation:

$$\text{Volume}_{\text{berm system}} = \text{Area}_{\text{berm}} \times L \times 1.25 \times 1.05$$

where:

$\text{Area}_{\text{berm}}$	=	Cross-sectional area of berm (square feet)
L	=	Total length of berm around containment area (feet)
1.25	=	Factor accounting for volumetric expansion on soil for cut/fill (AEA, 1999)
1.05	=	Factor accounting for 5% settling after compaction.

$$\text{Compact Cost} = \frac{\$0.41/\text{yd}^3 \times \text{Volume}}{27\ \text{ft}^3/\text{yd}^3}$$

$$\text{Excavation Cost} = \frac{\$2.02/\text{yd}^3 \times \text{Volume}}{27\ \text{ft}^3/\text{yd}^3}$$

The volume of berms for swine and poultry operations is calculated using the following equation:

$$Volume_{berm} = Area_{berm} \times L_{berm}$$

With a cross-sectional area of 21 square feet, berm volume is:

$$Volume_{berm} = 21 \times L_{berm}$$

Total Capital Cost

The total capital cost for beef feedlots and dairies, therefore, is $2.43 per cubic yard of berm. To convert this cost to a cost per foot, the volume is divided by the berm area, taking into account the factors for expansion and settling as follows:

$$\text{Capital Cost} = \text{Cost / Linear Foot} = \frac{\$2.43/\text{yd}^3 \times \tfrac{2}{3} \times 6 \times 3 \times 1.25 \times 1.05}{27\ \text{ft}^3/\text{yd}^3} = \$1.41/\text{ft}$$

The cost of $1.41 per linear foot of berm is the cost included in the cost model.

A fixed earth moving cost of $2.60 per cubic yard was used to calculate the cost of berms for swine and poultry operations. This fixed cost was multiplied by the berm volume to determine total capital cost using the following equation:

$$\text{Capital Cost} = Volume_{berm}/27 \times 2.60$$

where the 27 converts volume from cubic feet to cubic yards.

Total Annual Costs

Based on best professional judgement, the total annual cost for berm maintenance is estimated at 2 percent of the total capital costs for all animal types.

$$\text{Annual Cost} = 0.02 \times (\text{Capital Cost})$$

5.3.4 Results

Appendix A, Table A-3 presents the cost model results for constructing and maintaining berms.

5.4 Lagoons

Anaerobic lagoons are used at dairies and veal, wet layer, and swine operations to collect process water and flush water, which contain manure waste. Anaerobic microbiological processes promote decomposition, thus providing treatment for wastes with high biochemical oxygen demand (BOD), such as animal waste. Manure, process water, and runoff are routed to the lagoon where the mixture undergoes treatment. New lagoons also provide storage capacity until the waste can be applied to cropland as fertilizer or irrigation water, or be transported off site. Section 5.9 discusses the costs associated with transporting waste off site, including solids and liquids.

Lagoons are included in all options for dairies and veal operations, except Option 6 which replaces the lagoon with an anaerobic digester and a pond for large dairies. Options 1, 2, 4, 5A, and 6 require zero discharge of manure, litter, or process wastewater pollutants from the production area with the exception of overflows from a facility designed to hold all process wastewater, including the direct precipitation and runoff from a 25-year, 24-hour rainfall event. CAFOs that already have storage in place are assumed to have sufficient capacity. Under Options 1, 2, and 4, CAFOs that have no storage on site are costed for the installation of naturally lined lagoons with 180 days of storage. Under Option 7, CAFOs are costed for the installation of naturally lined lagoons with a storage capacity that varies based on land application timing restrictions. For Options 3A/3B and 3C/3D, CAFOs expected to have a direct hydrologic connection from ground water to surface water are costed for the installation of anaerobic lagoons with an artificial liner to prevent seepage of wastewater into ground water.

Lagoons are assumed as part of the baseline scenario for wet layer operations and some swine operations with liquid-based systems. Other swine operations have pit storage or evaporative pond systems under baseline conditions, and all other poultry operations have solid-based manure management systems. Thus, lagoon construction is generally not included as a cost for swine and poultry operations, with five exceptions. Under Option 1A, increased storage is provided to handle chronic rainfall at wet layer operations and at swine operations with liquid or evaporative pond systems. Increased storage is provided for all swine facilities under Option 7, and secondary lagoons are included as part of the cost to recycle flush water at Category 2 liquid swine operations for all but Option 5. The cost model also includes construction of new, lined and covered anaerobic lagoons under Option 5 for swine operations currently using evaporative ponds. This alternative is less expensive than covering the evaporative ponds. In addition, secondary lagoons with storage for 20 days are constructed in conjunction with liner installation for liquid and evaporative pond systems.

5.4.1 Technology Description

Anaerobic lagoons provide storage for animal wastes while decomposing and liquefying manure solids. Anaerobic processes degrade high biochemical oxygen demand (BOD) wastes into stable end products without the use of free oxygen. Nondegradable solids settle to the bottom as sludge, which is periodically removed. The liquid is applied to on-site cropland as fertilizer or irrigation water, or it is transported off site. The sludge can also be land applied as a fertilizer and soil amendment. Anaerobic lagoons can handle high pollutant loading rates while minimizing manure odors. Properly managed lagoons have a musty odor.

Lagoons reduce the concentrations of both nitrogen and phosphorus in the liquid effluent. Phosphorus settles to the bottom of the lagoon and is removed with the lagoon sludge. Influent nitrogen is reduced through volatilization to ammonia.

Anaerobic lagoons are typically at least 6 to 10 feet in depth, although 8 to 20 foot depths are not unusual. Deeper lagoons typically have a smaller surface area to depth ratio, allow less area for volatilization, provide a more thorough mixing of lagoon contents by rising gas bubbles, and minimize odors.

Anaerobic lagoons offer several advantages over other methods of storage and treatment. Anaerobic lagoons can handle high loading rates and provide a large volume for long-term storage of liquid wastes. Lagoons treat the manure by reducing nitrogen and phosphorus in the effluent and allow manure to be handled as a liquid. Lagoons are typically located at a lower elevation than the animal barns; gravity is used to transport the waste to the lagoon, which minimizes labor.

Anaerobic lagoons are appropriate for use at operations that collect high BOD waste, such as milking parlor flush or hose water and flush barn water. Typically, dairies and veal operations operate in this manner and have lagoons for wastewater storage. The cost model assumes all dairies and veal operations use anaerobic lagoons, some swine and poultry operations require a lagoon, and beef feedlot and heifer operations use a storage pond (discussed in Section 5.5). The cost model also assumes that swine operations use either pit (Mid-Atlantic and Midwest regions), anaerobic lagoon (Mid-Atlantic and Midwest regions), or evaporative pond systems (Central region), while all wet layer operations use anaerobic lagoons. Broiler, turkey, and dry layer operations are assumed to not use anaerobic lagoons.

Based on site visits, EPA assumes all veal operations have sufficient storage, such as lagoons, currently in place. However, not all dairies are expected to have liquid storage currently in place. In addition, naturally lined lagoons are more prevalent at dairies and veal operations than synthetically lined lagoons. Section 6 provides EPA's estimates of the percentage of dairies and veal operations that would require the installation of a lagoon, a lagoon with a liner (for Options 3A/3B and 3C/3D), or a lagoon with additional capacity under Option 7. Also contained in Section 6.0 are EPA's estimates of the percentage of swine and wet layer operations that would require increased storage under Option 1A, liners under Options 3B and 3C, and increased storage for swine facilities under Option 7.

5.4.2 Design of Anaerobic Lagoons at Dairies and Veal Operations

The design of anaerobic lagoons for dairies and veal operations is described below. Considerations specific to the design of anaerobic lagoons and evaporative ponds for swine and poultry operations are discussed in Section 5.4.5.

Anaerobic lagoons are designed based on volatile solids loading rates (VSLR). Volatile solids represent the amount of wastes that will decompose. The cost model assumes the lagoon receives runoff directly from the calf and heifer drylots, wastewater from the barns, wastewater from the parlor, and manure from the parlor and flush barns. The manure supplies the volatile solids into the lagoon. Lagoons are typically constructed by excavating a pit and building berms around the perimeter. The berms are constructed with an extra 5 percent in height to allow for settling. The sides of the lagoon are typically sloped with a 2:1 or 3:1 (horizontal:vertical) ratio.

Considerations are also made to avoid ground water and soil contamination. Options 1, 2, 4, 5, 5A, and 7 assume the bottom and sides of the lagoon are constructed of soil that is at least 10 percent clay compacted with a sheepsfoot roller. Options 3A/3B and 3C/3D require additional ground water protection; therefore, CAFOs that are located in areas of high risk for ground-water contamination have costs for installation of an synthetic liner over a compacted clay liner.

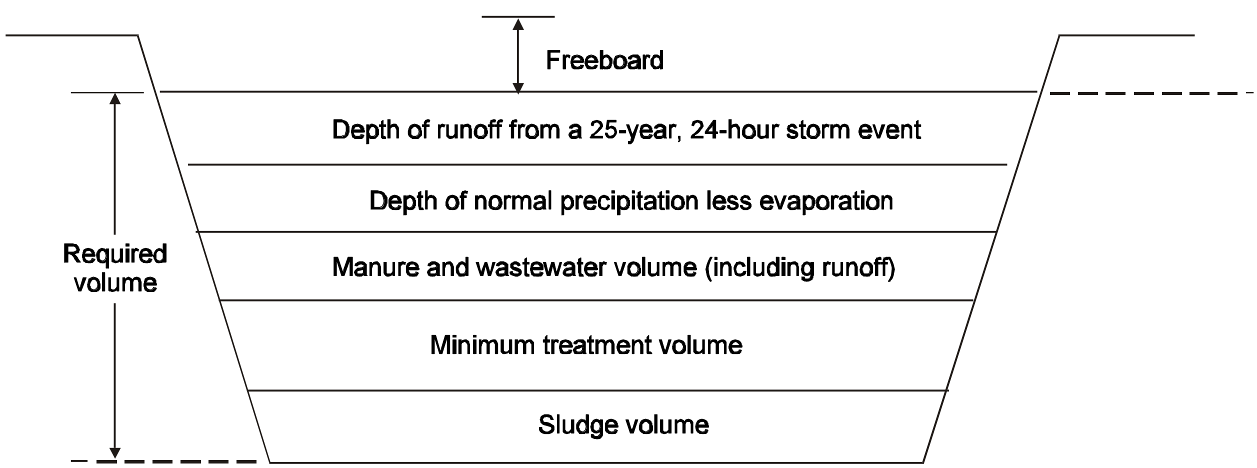
Lagoons are designed using the following steps:

1) Determine the necessary storage volume of the lagoon. Lagoons are designed to contain the following volumes (see Figure 5.4.2-1):

- — Sludge Volume: Volume of accumulated sludge between cleanouts (depends on the type and amount of animal waste),
- — Minimum Treatment Volume: Volume necessary to allow anaerobic decomposition to occur,
- — Manure and Wastewater: Milk parlor and flush barn wastewater and manure and runoff from drylots,
- — Net Precipitation: Annual precipitation minus the annual evaporation,
- — Design Storm: The depth of the peak (e.g., 25-year, 24-hour) rainfall event,
- — Freeboard: A minimum of one foot of freeboard, and
- — Dilution volume (for swine and poultry operations).

2) Determine the dimensions of the lagoon, given the required storage volume depending on the regulatory option.

3) Determine the costs for constructing the lagoon, using the dimensions calculated in Step 2.



Source: Agricultural Waste Handbook, USDA, 1996.

Figure 5.4.2-1. Cross-Section of an Anaerobic Lagoon

Step 1) Determination of Lagoon Volume

The lagoon volume is determined by the following equation:

Pond Volume = Sludge Volume + Minimum Treatment Volume + Manure and Wastewater
+ Runoff + Net Precipitation + Design Storm + Freeboard

The determination of each volume is discussed below.

Sludge Volume

The amount of sludge that accumulates between lagoon cleanouts varies based on the type and amount of animal waste. As manure decomposes in the lagoon, portions of the total solids do not decompose. A layer of sludge accumulates on the floor of the lagoon, which is proportional to the quantity of total solids that enter the lagoon. The sludge accumulation period is equal to the storage retention time of the lagoon. The rate of sludge accumulation is 0.0729 ft^3/lb solids for dairy cattle (USDA NRCS, 1996). The calculation of the separator solids is based on a 50 percent settling rate. The calculation of the runoff solids is discussed in Section 4.7.

Sludge Volume = Sludge Accumulation × (Separator Solids + Runoff Solids)

where:

Sludge Volume	=	Volume of accumulated sludge in the lagoon between cleanouts (depends on the type and amount of animal waste), ft^3
Sludge Accumulation	=	0.0729 ft^3/lb
Separator Solids	=	Amount of solids entering the lagoon from the separator, lb
Runoff Solids	=	Amount of solids entering the lagoon from runoff, lb.

Minimum Treatment Volume (MTV)

The minimum treatment volume is the minimum volume of the lagoon to insure anaerobic treatment for a given volatile solids loading. The minimum treatment volume is based on the volatile solids loading rate (VSLR), which varies with regional temperature. The minimum treatment volume is calculated using the influent daily volatile solids loading from all sources, and a regional volatile solids loading rate per 1,000 ft^3. The influent daily volatile solids loadings is calculated using the manure volatile solids and settling basin efficiency. The quantity of volatile solids (VS) entering the lagoon is calculated using the following equation:

$$\text{Influent VS} = \text{Manure VS} - (\text{Manure VS} \times \text{Settling Basin Efficiency})$$

where:

Influent VS	=	Daily volatile solids loading from all sources entering the lagoon, lbs/day
Manure VS	=	Volatile solids excreted as part of the manure, lbs/day (see Technical Development Document for manure characteristics)
Settling Basin Efficiency	=	0.50 (i.e., percent of solids that settled in the settling basin).

Therefore, the minimum treatment volume is calculated as follows:

$$\text{MTV} = \frac{\text{Influent VS}}{\text{VSLR}}$$

where:

MTV	=	Minimum treatment volume (i.e., minimum volume required for treatment to occur in the lagoon), ft^3
Influent VS	=	Daily volatile solids loading from all sources entering the lagoon, lbs/day
VSLR	=	Volatile solids loading rate, lb VS/1000 ft^3/day.

The VSLR varies by region, as shown in Figure 5.4.2-2, because the rate of solids decomposition in anaerobic lagoons is a function of temperature (USDA NRCS, 1996).

Manure and Wastewater Volume

Lagoons are designed to store manure and wastewater that is generated over a specific period of time, typically 90 to 365 days. For all options except Option 7, the storage period used in the cost model is 180 days.

Figure 10–22 Anaerobic lagoon loading rate

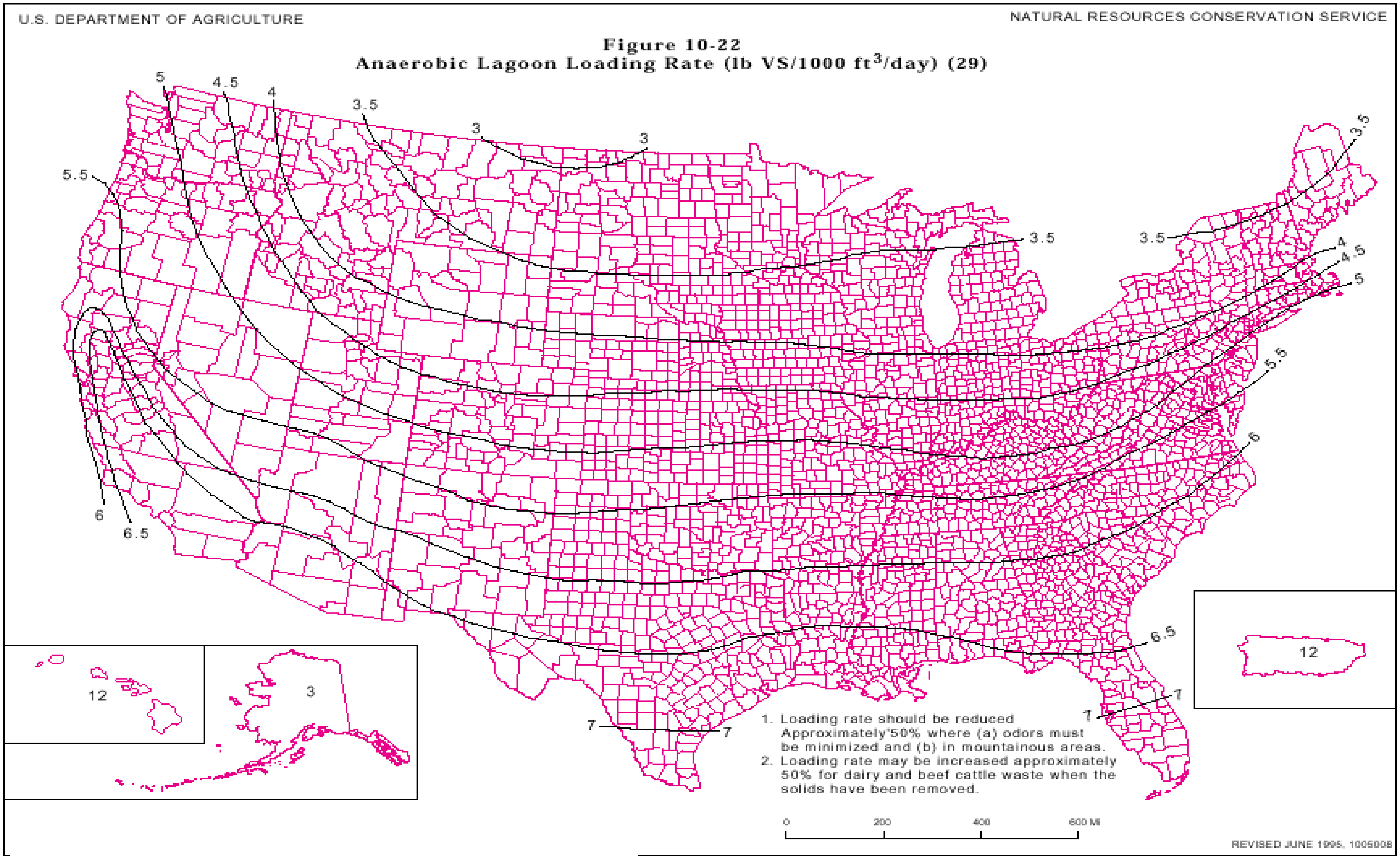


Figure 5.4.2-2. Volatile Solids Loading Rate (Source: USDA, 1996)

All of the manure and wastewater that is flushed or hosed from the dairy parlor or barn is washed to a concrete settling basin (or separator) before it enters the lagoon (see Section 5.2). To calculate the influent to the lagoon over the storage period, the daily effluent from the separator is multiplied by the number of days of storage required. It is assumed that the barn flush water is recycled back to the barns from the lagoon; therefore, only one storage volume of barn flush water is added to the total influent over the whole storage period. It is assumed that the settling basin has a 50-percent solids removal efficiency, and the removed solids have a moisture content of 80 percent (based on best professional judgement). The following equations are used to calculate the influent to the lagoon:

$$\text{Lagoon Influent} = (\text{Parlor Wash} + \text{Barn Wash} + \text{Manure Water}) \times \text{Storage Days}$$

where:

Lagoon Influent	=	Effluent from the separator entering the lagoon, gallons, gal
Parlor Wash	=	Wastewater that is flushed or hosed from the parlor, gallons per day, gpd
Barn Wash	=	Wastewater that is flushed or hosed from the barn, gpd
Manure Water	=	The portion of manure that enters the lagoon that is not solid, gpd
Storage Days	=	Retention time of the lagoon (varies by option).

See Section 4.5 for more information regarding calculating the parlor wash and barn wash and Section 4.6 for manure water.

$$\text{Recycled Barn Water} = \text{Barn Wash} \times (\text{Storage Days} - 1)$$

where:

Recycled Barn Water	=	Wastewater recycled from the lagoon to use as barn flush water, gpd
Barn Wash	=	Wastewater that is flushed or hosed from the barn, gpd
Storage Days	=	Retention time of the lagoon (varies by option).

$$\text{Lagoon Storage} = [(\text{Parlor Wash} + \text{Barn Wash} + \text{Manure Water}) \times \text{Storage Days}] - \text{Recycled Barn Water}$$

where:

Lagoon Storage	=	Separator wastewater entering the lagoon for storage, gal
Parlor Wash	=	Wastewater that is flushed or hosed from the parlor, gpd
Barn Wash	=	Wastewater that is flushed or hosed from the barn, gpd
Manure Water	=	The portion of manure that enters the lagoon that is not solid, gpd
Storage Days	=	Retention time of the lagoon (varies by option).
Recycled Barn Water	=	Wastewater recycled from the lagoon to use as barn flush water, gpd.

$$\text{Lagoon Solids} = \text{Manure Solids} - (\text{Manure Solids} \times \text{Separator Efficiency})$$

where:

Lagoon Solids	=	Solids entering the lagoon from the separator, ft^3
Manure Solids	=	Manure solids entering the separator, ft^3
Separator Efficiency	=	0.50 (i.e., percent of solids that settled in the separator).

Net Precipitation

The lagoon depth is increased to allow for the six-month precipitation minus the six-month evaporation, as discussed in Section 4.7. The net precipitation contribution to the lagoon depth is equal to the average precipitation minus the average evaporation.

Design Storm

The depth of the peak storm event is added to the depth of the lagoon. For all options except Option 1A, this peak rainfall event is the 25-year, 24-hour rainfall. For Option 1A, a sensitivity analysis done by EPA to account for chronic rainfall, the peak storm is defined as the 25-year, 24-hour rainfall plus the 10-year, 10-day rainfall (see Section 8.0).

Peak Precipitation = 25-year, 24-hour Rainfall or 25-year, 24-hour + 10-year, 10-day Rainfall

where:

Peak Precipitation	=	Precipitation depth that falls directly on the lagoon from the peak rainfall event, inches
25-Yr, 24-Hr Rainfall	=	Depth of the 25-year, 24-hour peak rainfall (used for Option 1 through 7), inches
10-Yr, 10-Day Rainfall	=	Depth of the 10-year, 10-day chronic rainfall (used for Option 1A), inches.

Freeboard

A minimum of one foot of freeboard is added to the depth.

Runoff

The amount of runoff from the drylot entering the lagoon is determined from the net precipitation and area of the drylot, as discussed in Section 4.7. The amount of runoff is determined by estimating the precipitation for the number of days of storage assumed for each option. New lagoons are costed under Options 1 through 6 for 180 days of storage. Option 7 storage requirements are presented in Table 5.4.2-1. In addition, the runoff contribution to the lagoon is reduced by the amount of water retained by the solids that settle out in the basin. The solids entering the lagoon are 1.5 percent of the total runoff from the drylot (MWPS, 1993). The peak storm runoff is also included in the storage requirements. Section 4.7 describes the details of the precipitation and runoff calculations.

Table 5.4.2-1

Lagoon Storage Capacities at Dairies for Option 7

Region	Estimated Storage Capacity for Option 7 (days)	Estimated Existing Storage Capacity (days)	Additional Lagoon Capacity Costed for Existing Ponds (days)
Central	180	60	120
Mid-Atlantic	225	30	195
Midwest	225	90	135
Pacific	135	30	105
South	45	30	15

Source: EPA, 2000a and ERG, 2002.

$$\text{Influent Runoff Solids}_{6\text{-month}} = \text{Runoff}_{6\text{-month}} \times \%\ \text{Runoff Solids}$$

where:

Influent Runoff Solids$_{6\text{-month}}$	=	Amount of solids entering the lagoon from the drylot (i.e., solids exiting the settling basin), ft^3
Runoff$_{6\text{-month}}$	=	Amount of the total runoff entering the lagoon from the drylot, ft^3
% Runoff Solids	=	1.5% (i.e., the percent of runoff entering the lagoon that consists of solids).

Step 2) Dimensions and Configuration of the Lagoon

The lagoon is designed in the shape of an inverted pyramid with a flat bottom, containing the required volume. The depth of the lagoon is set as follows:

$$h = \text{Initial Depth} + \text{Net Precipitation} + \text{Freeboard}$$

where:

h	=	Depth of the lagoon, ft
Initial Depth	=	10 ft

Net Precipitation	=	Six-month precipitation depth that falls directly on the pond minus the amount that evaporates from the pond, ft
Freeboard	=	1 ft.

For dairies and veal operations, the initial depth of the lagoon is set at 10 feet, based on discussions with industry consultants. This initial depth is assumed to include depth for the runoff and solids. This depth is used as the starting value for the dimensions calculations using the required volume of the lagoon. The lagoon is assumed to be square, and the final depth and length is solved by iteration, knowing the lagoon volume and the other variables in the equation.

Lagoon Excavation and Embankment Volumes

Lagoons are constructed by excavating a portion of the necessary volume and building embankments around the perimeter of the lagoon to make up the total design volume. The cost model performs an iteration to maximize the use of excavated material used in constructing the embankments that minimizes the costs for construction. The excavation volume is represented by the following equation:

$$Volume_{extracted} = C_1\ (h-h_e)\ [l_b w_b + l_s w_s + (l_b w_b l_s w_s)^{0.5}]$$

where:

$Volume_{extracted}$	=	Total volume of soil extracted from the lagoon, ft^3
C_1	=	constant equaling ½ for dairy cost model
h	=	Depth of the lagoon, ft
h_e	=	Height of embankment, ft
l_b	=	Length of the base of the lagoon, ft
W_b	=	Width of the base of the lagoon, ft
l_s	=	Length of the top of the lagoon, ft
W_s	=	Width of the top of the lagoon, ft.

The excavated soil is used to build the embankments. Because some settling of the soil will occur, it is assumed that an extra 5 percent of volume is required. The embankment volume is represented by the following equation:

$$Volume_{embankment} = 2\,[(1.05\,h_e w_e + s\,(1.05\,h_e)^2)\,(l_b + 2\,sh)] + 2\,[(1.05\,h_e w_e + (1.05\,s)^2\,h_e^2)\,(w + 2sh)]$$

where:

$Volume_{embankment}$	=	Total volume of soil used for the embankment, ft^3
h_e	=	Height of embankment, ft
w_e	=	Width of embankment, ft
l_b	=	Length of the base of the lagoon, ft
s	=	Slope of sidewalls
w	=	Width of the floor of lagoon.

The dimensions of the basin which yield the desired volume are calculated by the cost model using these equations.

Lagoon Liners

For Options 3A/3B and 3C/3D, lagoons are designed with a synthetic liner for those operations located in areas requiring ground water protection. The costs assume that clay is brought on site in a truck (locally) and applied as a slurry to the lagoon basin. The liner system consists of clay soil with a synthetic liner cover. The dimensions are equal to the surface area of the floor and sides of the lagoon.

The surface area of the floor of the lagoon is calculated to determine the area for compaction and for the lagoon liner. The surface area includes the bottom area plus the area of the four trapezoids that make up the sides of the lagoon.

The surface area of the sloped sides is calculated using the formula for the area of a trapezoid.

$$\text{Area of Side}_l = \tfrac{1}{2}\,HS \times (1_b + 1_s)$$

$$\text{Area of Side}_w = \tfrac{1}{2}\,HS \times (w_b + w_s)$$

where:

Area of $Side_l$	=	Area of length side of the lagoon, ft^2
Area of $Side_w$	=	Area of width side of the lagoon, ft^2
HS	=	Height of the side on the lagoon (see equation below), ft
l_b	=	Bottom length of the lagoon, ft
l_s	=	Top length of the lagoon, ft
w_b	=	Bottom width of the lagoon, ft
w_s	=	Top width of the lagoon, ft.

The height of the side is calculated using the Pythagorean Theorem.

$$HS = (h^2 + (4h)^2)^{0.5}$$

where:

HS	=	Height of the side on the lagoon, ft
h	=	Depth of the lagoon, ft.

The total surface area of the basin is:

$$\text{Surface Area}_{lagoon} = l_b\ W_b + 2\ [\text{Area of Side}_l] + 2\ [\text{Area of Side}_w]$$

where:

Surface $Area_{lagoon}$	=	Total surface area of the pond floor, including the bottom and sides, ft^2
l_b	=	Bottom length of the pond, ft
w_b	=	Bottom width of the pond, ft
Area of $Side_l$	=	Area of length side of the pond, ft^2
Area of $Side_w$	=	Area of width side of the pond, ft^2.

5.4.3 Costs for Constructing a Dairy Lagoon

The construction of the storage lagoon includes a mobilization fee for the heavy machinery, excavation of the lagoon area, compaction of the ground and walls of the lagoon, and the construction of conveyances to direct runoff from the drylot area to the storage lagoon. Table 5.4.3-1 presents the unit costs used to calculate the capital and annual cost for constructing the storage lagoon.

Table 5.4.3-1

Unit Costs for Storage Lagoon

Unit	Cost (1997 dollars)	Source
Mobilization	\$205/event	Means 1999 (022 274 0020)[a]
Excavation	\$2.02/yd^3	Means 1999 (022 238 0200)[a]
Compaction	\$0.41/yd^3	Means 1996 (022 226 5720)[a]
Flush Wash Conveyance	\$11,025/system	ERG, 2000c
Hose Wash Conveyance	\$7,644/system	ERG, 2000c
Clay Liner (shipped & installed)	\$0.24/ft^2	AEA, 1999
Synthetic Liner (installed)	\$1.50/ft^2	Tetra Tech, 2000c

[a]Information taken from Means Construction Data. The numbers in parentheses refer to division and line numbers.

The calculations for the cost associated with these items are shown below.

Mobilization

The mobilization costs are for transporting the heavy machinery and equipment. The Means Construction Data reports that this cost is \$205/event.

Excavation

To calculate the lagoon excavation costs, the volume of material that is excavated is first calculated, as described previously. The excavated material is expected to be used to construct embankments around the lagoon, which will provide additional storage other than that volume which is excavated; therefore, the excavated volume is not equal to the lagoon volume. Instead, it is equal to the pond volume minus the storage that the embankments provide.

The excavation cost is calculated with the following equation:

$$\text{Excavation} = \text{Cost} \times \text{Volume}_{\text{excavated}} \div \text{Conversion Factor}$$

where:

Excavation	=	Total cost to excavate the lagoon, $
Cost	=	$2.02/yd^3$ (i.e., cost per the volume of soil excavated)
$Volume_{excavated}$	=	Amount (volume) of soil excavated, ft^3
Conversion Factor	=	27 ft^3/yd^3 (conversion from ft^3 to yd^3).

Compaction

To calculate compaction costs, the volume for compaction is calculated, as described in Section 5.1.3. The compaction cost is calculated using the following equation:

$$\text{Compaction} = \text{Cost} \times \text{Volume}_{compacted}\ (ft^3) \div \text{Conversion Factor}$$

where:

Compaction	=	Total cost to compact the lagoon, $
Cost	=	$0.41/yd^3$ (i.e., cost per volume of soil compacted)
$Volume_{compacted}$	=	Amount (volume) of soil compacted, ft^3
Conversion Factor	=	27 ft^3/yd^3 (conversion from ft^3 to yd^3).

Conveyance

The conveyance costs are for constructing conveyances to direct runoff from the drylot area to the lagoon. According to the Means Construction Data, this cost is $11,025/system for flush wash conveyance and $7,644/system for hose wash conveyance.

Clay and Synthetic Liners

To calculate liner costs, the surface area of the basin flow and sidewalls is calculated, as described previously. The liner cost includes both clay and synthetic liners, and is calculated using the following equations:

$$\text{Clay Liner} = \text{Cost} \times \text{Surface Area}$$

where:

Clay Liner	=	Cost to install a clay liner, $
Cost	=	$0.24/ft^2 (i.e., cost per the surface area of the pond)
Surface Area	=	Surface area of the basin floor and the sidewalls, ft^2.

$$\text{Synthetic Liner} = \text{Cost} \times \text{Surface Area}$$

where:

Synthetic Liner	=	Cost to install a synthetic liner, $
Cost	=	$1.50/ft^2 (i.e., cost per the surface area of the pond)
Surface Area	=	Surface area of the basin floor and the sidewalls, ft^2.

Total Capital Costs

The total capital cost for construction of the naturally lined storage lagoon is the following:

$$\text{Capital Cost} = \text{Mobilization} + \text{Excavation} + \text{Compaction} + \text{Conveyance}$$

The total capital cost for construction of the synthetically lined lagoon is the following:

$$\text{Capital Cost} = \text{Mobilization} + \text{Excavation} + \text{Compaction} + \text{Conveyance} + \text{Clay Liner} + \text{Synthetic Liner}$$

Total Annual Costs

Based on best professional judgement, annual operating and maintenance costs for both naturally lined and synthetically lined lagoons are estimated at 5 percent of the capital costs.

$$\text{Annual Cost} = 5\% \times \text{Capital Cost}$$

5.4.4 Dairy Lagoon Results

The cost model results for constructing a naturally lined lagoon, a synthetically lined lagoon, and additional lagoons for extra capacity (Option 7) at dairies are presented in Appendix A, Table A-4, Table A-5 , and Tables A-6a and 6b, respectively.

5.4.5 Design of Lagoons and Evaporative Ponds for Swine and Poultry Operations

Basic volume requirements for liquid storage are determined by calculating the manure volume generated for the storage period and multiplying that number by a dilution factor. The dilution factor is intended to address process dilution, net direct precipitation (precipitation minus evaporation over lagoon surface), freeboard (1 foot), and storage for the 25-year, 24-hour rainfall event.

Design

The basic design steps employed for dairy and veal lagoons are also used for swine and poultry lagoons. Unique lagoon dimensions are calculated for each model facility based upon the required storage volume. The cost model applies berms on two sides of liquid storage structures to eliminate runoff into storage facilities (see Section 5.3).

USDA's design approach provides storage for manure, clean water used in dilution, accumulated solids and wastewater, net precipitation (precipitation - evaporation), the 25-year 24-hour rainfall event, and 1 foot of freeboard (USDA NRCS, 1996). In cases where there are watersheds draining to the lagoon, USDA adds volume for runoff. Basic volume requirements for storage of liquid wastes from swine and wet layer operations are determined by calculating the manure volume generated for the storage period and multiplying that number by a dilution factor. The dilution factor is intended to address process dilution, net direct precipitation (precipitation minus evaporation over lagoon surface), freeboard (1 foot), and storage for the 25-year 24-hour rainfall event. Solids accumulation is assumed to not occur since it is assumed that waste is agitated and mixed before application to fields.

The suitability of the modeled lagoons to handle all inputs was tested in an exercise to determine if overflows would occur due to chronic and 25-year, 24-hour rainfall events. No capacity problems were found in this testing, so it is concluded that lagoons designed using the cost model approach are reasonable approximations of those designed using USDA's approach.

The storage period for lagoons is assumed to be six months, except for those options and scenarios where storage is increased. The required storage volume ($Volume_{storage}$) is therefore calculated as:

$$Volume_{storage} = Volume_{manure} \times dilution/2$$

where:

$Volume_{manure}$	=	annual volume of manure produced
dilution	=	dilution factor (ranges from 1 to 3)
2	=	12 months/6 months storage.

The cost model addresses five cases for which lagoon construction costs are included: (1) Option 1A, where increased storage is provided to handle chronic rainfall events at wet layer operations and at swine operations with liquid or evaporative pond systems, (2) increased storage for all swine facilities under Option 7, (3) the construction of secondary lagoons for settling as part of the installation of flush-water recycling systems for Category 2 liquid swine facilities under all options other than Option 5, (4) the replacement of evaporative ponds with lined and covered lagoons under Option 5, and (5) the construction of a secondary lagoon with storage for 20 days in conjunction with liner installation for liquid and evaporative pond systems. In all other cases, the storage facility is designed for the purpose of deriving costs for liners, covers, and diversions only, and lagoon construction costs are not included.

Under Option 1A, the storage volume is increased to handle chronic rainfall, ranging from 5 to 11 inches (see Table 5.4.5-1). The extra lagoon for flush-water recycling systems is designed to handle storage for 20 days, the same design volume used for extra lagoons constructed when liners are added to existing lagoons and evaporative ponds. Increased storage under Option 7 is set to 90 days for the Mid-Atlantic region and 135 days for the Midwest and

Central regions. Lagoons constructed to replace evaporative ponds are designed to handle the same volume as the evaporative ponds, and then 6 inches of depth is removed to account for the covers which keep direct precipitation from entering the lagoon.

Table 5.4.5-1

Chronic Rainfall Amounts for Option 1A for Swine and Poultry

Region	Chronic Rainfall Amount (inches)
Central	5
Mid-Atlantic	11
Midwest	7
South	10

Dimensions and Configuration

The shape assumed for lagoons and evaporative ponds is an upside-down frustrum, which is a pyramid with the top chopped off. The shape and parameters of a frustrum are given in Figure 5.4.5-1. The cost model assume that lagoons and evaporative ponds are square (a=b and c=d).

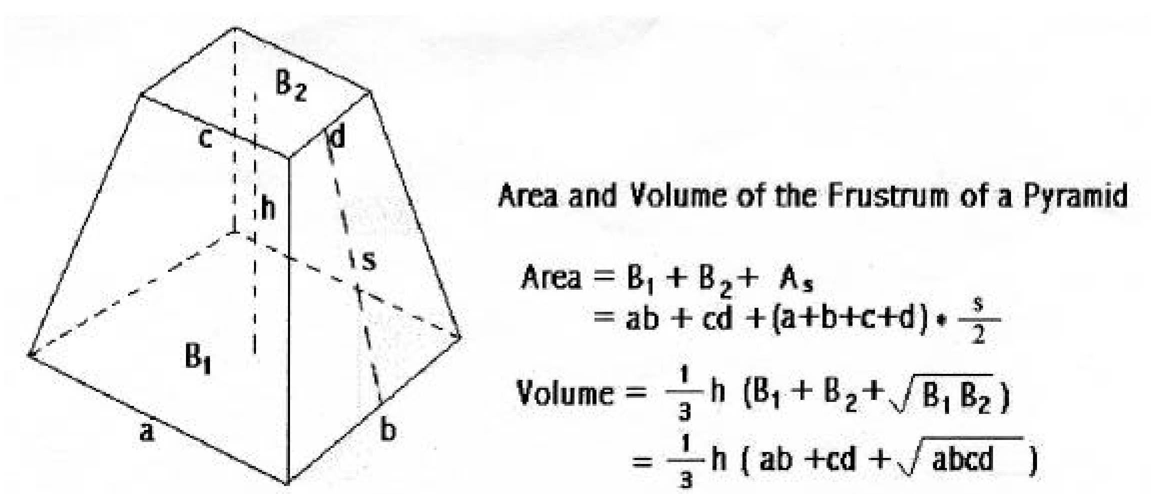


Figure 5.4.5-1. Frustrum

Because lagoons have sloping sides, the minimum volume associated with a lagoon 12 feet deep with side slopes (H:V) of 2 is 9,216 cubic feet. For an evaporative pond with a depth of 4 feet and side slopes of 2, the minimum volume is 341 cubic feet. Since the cost model calculates lagoon dimensions from lagoon volume, which can be very small for secondary lagoons, there is the potential that calculations result in negative bottom widths and lengths if the depth and side slopes are fixed values. To prevent these negative values from occurring, an analysis of lagoon dimensions resulting from various volumes, lagoon depths, and side slopes was conducted. The results from this analysis are presented in Table 5.4.5-2. When applying the information contained in Table 5.4.5-2 to the design of anaerobic lagoons in the cost model, the default depth is 12 feet, and a preference is given to maintaining a depth of at least 10 feet wherever possible, but no less than 6 feet (see Table 5.4.5-3). This approach is consistent with USDA guidelines specifying that 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 (USDA NRCS, 1996). USDA also recommends that internal slopes be no less than 1.5:1 (H:V) for liquid storage (USDANRCS, 1996).

According to the American Society of Agricultural Engineers standards (ASAE, 1998), a minimum lagoon depth of 5 feet is necessary for construction of anaerobic lagoons, and approximately 20 feet is considered the maximum depth to ensure proper biological activity.

Table 5.4.5-2

Relationships Among Depth, Side Slope, Volume, And Bottom Width of Lagoons

Depth	Side Slope	Volume Below Which Calculations Result In Negative Value for Bottom Width of Lagoon
12	4	36,864
12	3	20,736
12	2	9,216
11	4	28,395
11	3	15,972
11	2	7,099
10	4	21,334
10	3	12,000
10	2	5,334
9	4	15,552
9	3	8,748
9	2	3,888
8	4	10,923
8	3	6,144
8	2	2,731
7	4	7,318
7	3	4,116
7	2	1,830
6	4	4,608
6	3	2,592
6	2	1,152
6	1	288
5	4	2,667
5	3	1,500
5	2	667
5	1	167
4	4	1,365
4	3	768
4	2	342
4	1	86

Table 5.4.5-3

Depth and Side Slopes for Lagoons and Evaporative Ponds

Volume (cubic feet)	Lagoons		Evaporative Ponds	
	Depth	Slope	Depth	Slope
> 0 and < 342	NA	NA	4	1
>=342	NA	NA	4	2
>0 and <167	4	1	NA	NA
>=167 and <288	5	1	NA	NA
>=288 and <1,152	6	1	NA	NA
>=1,152 and <1,830	6	2	NA	NA
>=1,830 and <2,731	7	2	NA	NA
>=2,731 and <3,888	8	2	NA	NA
>=3,888 and <5,334	9	2	NA	NA
>=5,334 and <7,099	10	2	NA	NA
>=7,099 and <9,216	11	2	NA	NA
>=9,216	12	2	NA	NA

NA: Not applicable.

Because some of the modeled lagoons are very small, a depth of 4 feet is allowed for volumes less than 167 cubic feet, and a depth of 5 feet is allowed for volumes of 167-287 cubic feet. This allowance for shallow anaerobic lagoons is particularly important in calculations of the costs for extra storage.

Lagoon dimensions are calculated from volume using the following basic equations:

$$W_{lagoonbottom}=[(-2h^2s)+((4\times(h^4)\times(s^2))-4\times h\times((4/3)\times(h^3)\times(s^2)-Volume_{storage}))^{0.5}]\div 2h$$
$$L_{lagoonbottom}=W_{lagoonbottom}$$
$$W_{lagoontop}=W_{lagoonbottom}+(2\times s\times depth)$$
$$L_{lagoontop}=L_{lagoonbottom}+(2\times s\times depth)$$

where:

$W_{lagoonbottom}$	=	Width of bottom of lagoon or evaporative pond, ft
$W_{lagoontop}$	=	Width of top of lagoon or evaporative pond, ft
$L_{lagoonbottom}$	=	Length of bottom of lagoon or evaporative pond, ft
$L_{lagoontop}$	=	Length of top of lagoon or evaporative pond, ft
s	=	Slope of sidewalls
h	=	Depth of the lagoon, ft.

To simulate increased storage volume for chronic rainfall under Option 1A, the cost model increases the top width (and length since it is assumed to be square) of the lagoon with the following equation:

$$W_{lagoontop} = W_{lagoontop} + (2 \times s \times chronic \div 12)$$

where:

$W_{lagoontop}$	=	Width of top of lagoon or evaporative pond, ft
s	=	Slope of sidewalls
chronic	=	Chronic rainfall, in
12	=	12 inches per foot
2	=	Two sides.

The equation essentially builds additional storage above the existing lagoon, resulting in a wider, longer, and deeper lagoon. The new top width and length are used to calculate the new lagoon volumes, liner areas, berm dimensions, and cover areas for Option 1A. The increase in lagoon volume is calculated by subtracting the original volume from the new volume.

An additional 20 days of storage is provided by both the extra lagoons for flush-water recycling systems and the extra lagoons constructed when liners are added to existing lagoons and evaporative ponds. This additional storage volume ($Volume_{20\text{-day storage}}$) is calculated with the following equation:

$$Volume_{20\text{-day storage}} = Volume_{annual} \times 20 \div 365 \div 7.481 \div 27$$

where:

$Volume_{annual}$	=	12-month storage volume in gallons
20/365	=	Fraction of year covered by 20 days
7.481 converts to cubic feet		
27 converts to cubic yards.		

Increased storage under Option 7 is set to 90 days for the Mid-Atlantic region and 135 days for the Midwest and Central regions. The storage volume is calculated using the same equation as above, with the exception that 20 is replaced with 90 or 135.

Under Option 5, the cost model builds a new lagoon to replace evaporative ponds since this approach is less expensive than covering the large but shallow evaporative ponds. First, the dimensions of the new lagoon are determined using the basic equations from above. Then, lagoon depth is decreased by 6 inches. The typical annual rainfall in the central region where evaporative ponds are used is 1 foot, and 6 inches is selected since the storage period is six months. The lagoon bottom width and length remain the same, but the width and length of the lagoon top are then recalculated using the following equations:

$$W_{lagoontop} = W_{lagoontop} - (2 \times s)$$
$$L_{lagoontop} = L_{lagoontop} - (2 \times s)$$

where:

$W_{lagoontop}$	=	Width of top of lagoon or evaporative pond, ft
$L_{lagoontop}$	=	Length of top of lagoon or evaporative pond, ft
s	=	Slope of sidewalls.

Volume is then calculated using the frustrum equation with the original bottom dimensions, the new depth, and the new top dimensions.

Lagoon Liners

The surface area of lagoons and evaporative ponds for swine and poultry operations is calculated using the same basic equations described in Section 5.4.2 for dairies and veal operations. The cost for a lagoon is calculated using the same costs shown in Table 5.4.3-1.

5.4.6 Costs for Lagoons at Swine and Poultry Operations

Capital Costs

The excavation cost of \$2.60 per cubic yard for swine and poultry operations is multiplied by the volume or volume change (e.g., Option 1A) to determine total excavation costs. When a liner is present, unit liner costs are the same as shown in Table 5.4.3-1, and are multiplied by liner area to determine total liner cost.

$$\text{Capital Cost} = \text{Excavation Cost} \times \text{Volume Excavated} + \text{Liner Cost}$$

where:

Excavation Cost	=	\$2.60 per cubic yard
Volume Excavated	=	Volume or volume change of lagoon
Liner Cost	=	Clay liner + synthetic liner.

Annual Costs

The annual maintenance and operation cost is assumed to be 2 percent of the capital costs.

$$\text{Annual Cost} = 2\% \times \text{Capital Cost}$$

5.5 <u>Ponds</u>

Waste storage ponds are frequently used at animal feeding operations to contain wastewater and runoff from contaminated areas. Manure and runoff are routed to the storage pond where the mixture is held until it can be used for irrigation or can be transported elsewhere. Solids settle to the bottom of the pond as sludge, which is periodically removed and land applied on site or off site. The liquid can be applied to cropland as fertilizer/irrigation, used for dust control, reused as flush water for animal barns, or transported off site. Section 5.9 discusses the costs associated with transporting waste off site, including the solids and liquids.

Ponds are included in all regulatory options for beef feedlots, heifer operations, and as a holding pond for effluent from an anaerobic digester in Option 6. Options 1, 2, 4, 5A, and 6 require zero discharge of manure, litter, or process wastewater pollutants from the production area with the exception of overflows from a facility designed to hold all process wastewater, including the direct precipitation and runoff from a 25-year, 24-hour rainfall event. CAFOs that already have storage ponds in place are assumed to have sufficient capacity. CAFOs that have no storage on site are costed for the installation of naturally lined ponds with 180 days of storage. Under Option 7, CAFOs are costed for the installation of naturally lined ponds with a storage capacity that varies based on land application timing restrictions. For Options 3A/3B and 3C/3D, CAFOs expected to have a direct hydrologic connection from ground water to surface water are given costs for the installation of storage ponds with a liner to prevent seepage of wastewater into ground water.

5.5.1 Technology Description

Storage ponds provide a location for long-term storage of water and are appropriate for the collection of runoff. Ponds are typically located at a lower elevation than the animal pens or barns; gravity is used to transport the waste to the pond, which minimizes labor. Although ponds are an effective means of storing waste, no treatment is provided. Because ponds are open to the air, odor can be a problem.

Although ponds are not designed for treatment, there is some reduction of nitrogen and phosphorus in the liquid effluent due to settling and volatilization. Influent phosphorus settles to the bottom of the pond and is removed with the sludge. Influent nitrogen is reduced through volatilization to ammonia. Pond effluent can be applied to cropland as fertilizer/irrigation, reused as flush water for the animal barns, or transported off site. The sludge can also be land applied as a fertilizer and soil amendment.

Storage ponds are appropriate for use at operations that collect runoff and do not collect process water or manure flush water. Typically, beef feedlots and heifer operations operate in this manner and have storage ponds for runoff collection. All cost options for beef feedlots and heifer operations include a storage pond. Dairies and veal operations typically operate lagoons (discussed in Section 5.4) to provide treatment for the barn and milking parlor flush water; however, a storage pond is included in the costs for large dairies under Option 6, where the pond receives effluent from an anaerobic digester.

Not all beef feedlots and heifer operations are expected to have liquid storage currently in place. In addition, ponds without a synthetic or clay liner are currently more prevalent at beef feedlots and heifer operations than are lined ponds. Section 6.0 provides EPA's estimates of the percentage of beef feedlots and heifer operations that are costed for the installation of a pond, a pond with a liner (for Options 3A/3B and 3C/3D), or a pond with additional capacity (for Option 7).

5.5.2 Design

The cost model assumes only direct precipitation or runoff that has gone through a settling basin (or separator) enters the storage pond. Runoff will contain a portion of manure solids from the beef drylots. Ponds are typically constructed by excavating a pit and using the excavated soil to build embankments around the perimeter. An additional 5 percent is added to the required height of the embankments to allow for settling. The sides of the pond are sloped with a 1.5:1 or 3:1 (horizontal:vertical) ratio.

Considerations are also made to avoid ground-water and soil contamination. Options 1, 2, 4, 5A, 6, and 7 assume the bottom and sides of the pond are constructed of soil that is at least 10 percent clay compacted with a sheepsfoot roller. Under Options 3A/3B and 3C/3D, some CAFOs will require additional ground-water protection; therefore, a synthetic liner is included in the lagoon costs in addition to a compacted clay liner.

Storage ponds are designed using the following steps:

1) Determine the necessary pond volume. Storage ponds are designed to contain the following volumes (see Figure 5.5.2-1):

   — Sludge Volume: Volume of accumulated sludge between clean-outs (depends on the type and amount of animal waste),

   — Runoff: The runoff from drylots for normal and peak precipitation,

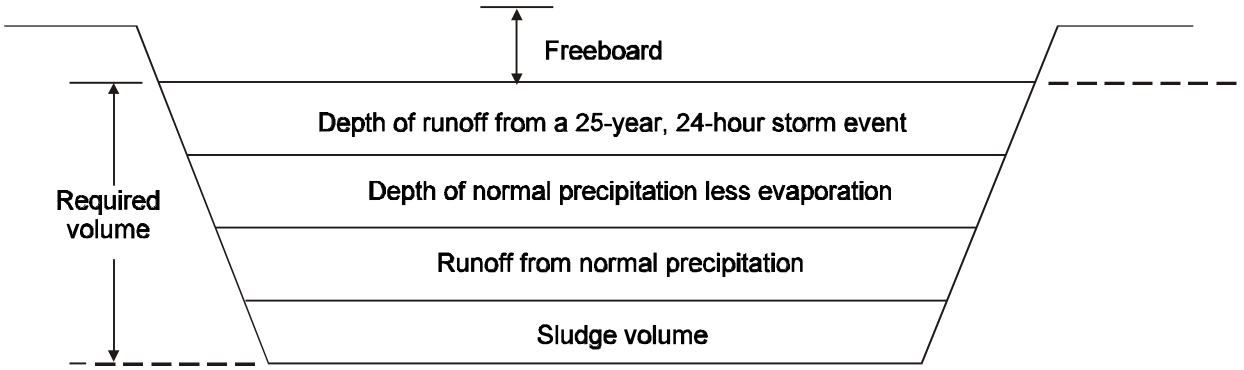
   — Net Precipitation: Annual precipitation minus the annual evaporation,

   — Design Storm: The depth of the peak (e.g., 25-year, 24-hour) rainfall event, and

   — Freeboard: A minimum of 1 foot of freeboard.

2) Determine the dimensions and configuration of the pond, depending on the regulatory option.

3) Determine the costs for constructing the pond, using the dimensions calculated in Step 2.



Source: Agricultural Waste Handbook, USDA, 1996.

Figure 5.5.2-1. Cross-Section of a Storage Pond

Step 1) Determination of Pond Volume

The pond volume is determined by the following equation:

Pond Volume = Sludge Volume + Runoff + Net Precipitation + Design Storm + Freeboard

The determination of each volume is discussed below.

Sludge Volume

The amount of sludge that accumulates between pond cleanouts varies based on the type and amount of animal waste. As manure decomposes in the pond, portions of the total solids do not decompose. A layer of sludge accumulates on the floor of the pond, which is proportional to the quantity of total solids that enter the pond. The sludge accumulation period is equal to the storage retention time of the pond. A rate of sludge accumulation is not available for beef cattle but is estimated to be the same as dairy cattle: 0.0729 cubic feet per pound (ft^3/lb) (USDA NRCS, 1996). The calculation of the separator solids is discussed in Section 5.2, assuming 50-percent settling rate. The calculation of the runoff solids is discussed in Section 4.7.

$$\text{Sludge Volume} = \text{Sludge Accumulation} \times \text{Runoff Solids}$$

where:

Sludge Volume	=	Amount of sludge that accumulates between pond cleanouts, ft^3
Sludge Accumulation	=	0.0729, ft^3/lb
Runoff Solids	=	Quantity of total solids that enter the pond following separation, pounds, lb.

Runoff

The amount of runoff entering the pond is determined from the net precipitation and area of the drylot, as discussed in Section 4.7. The amount of runoff is determined by estimating the precipitation for the number of days of storage assumed for each option. New ponds are costed under Options 1 through 6 for 180 days of storage. Option 7 storage requirements are presented in Table 5.5.2-1. In addition, the runoff contribution to the pond is reduced by the amount of water retained by the solids that settle out in the basin. The solids entering the earthen basin are 1.5 percent of the total runoff (see Section 4.7 for more information), while the solids entering the pond are 50 percent of the basin solids (i.e., the efficiency of the settling basin is assumed to be 50 percent).

Table 5.5.2-1

Pond Storage Capacities at Beef Feedlot and Heifer Operations for Option 7

Region	Estimated Storage Capacity for Option 7 (days)	Estimated Existing Storage Capacity (days)	Additional Pond Capacity Costed for Existing Ponds (days)
Central	180	50	130
Mid-Atlantic	225	80	145
Midwest	225	190	35
Pacific	135	30	105
South	45	45	0

Source: ERG, 2000a and ERG 2002.

$$\text{Influent Runoff Solids}_{6\text{-month}} = \text{Total Runoff Solids}_{6\text{-month}} \times (1\text{-Settling Basin Efficiency})$$

where:

Influent Runoff $\text{Solids}_{6\text{-month}}$	=	Amount of solids entering the pond (i.e., solids exiting the settling basin), ft^3
Total Runoff $\text{Solids}_{6\text{-month}}$	=	Amount of the total runoff entering the settling basin that consists of solids, ft^3
Settling Basin Efficiency	=	50% (i.e., percent of solids that settled in the settling basin).

$$\text{Settled Solids}_{6\text{-month}} = \text{Total Runoff Solids}_{6\text{-month}} \times \text{Settling Basin Efficiency}$$

where:

Settled $\text{Solids}_{6\text{-month}}$	=	Amount of solids that settled in the settling basin from the runoff entering the basin, ft^3
Total Runoff $\text{Solids}_{6\text{-month}}$	=	Amount of the total runoff entering the settling basin that consists of solids, ft^3
Settling Basin Efficiency	=	50% (i.e., percent of solids that settled in the settling basin).

Note that:

$$\text{Total Runoff Solids}_{6\text{-month}} = \text{Influent Runoff Solids}_{6\text{-month}} + \text{Settled Solids}_{6\text{-month}}$$

For the cost model calculations, it is assumed that settled solids have a moisture content of 80 percent (based on best professional judgement); therefore, the runoff entering the pond is:

$$\text{Influent}_{\text{runoff}} = \left[\left(\frac{\text{Runoff}_{6\text{-month}}}{180\text{ days}}\right) \times \text{Storage Days}\right] - \left[\frac{\text{Settled Solids}_{6\text{-month}} \times \text{Solids}_{\text{moisture}}}{1\ \text{Solids}_{\text{moisture}}}\right] + \text{Peak Rainfall Runoff}$$

where:

$\text{Influent}_{\text{runoff}}$	=	Amount of runoff entering the pond from the settling basin and drainage area, ft^3
$\text{Runoff}_{6\text{-month}}$	=	Total runoff entering the settling basin calculated using the average monthly precipitation amounts from the wettest six-month consecutive period (see Section 4.7), ft^3

180 days	=	Number of storage days for runoff
Storage Days	=	Required number of storage days for the specific option, days
Settled $Solids_{6\text{-month}}$	=	Amount of solids that settled in the settling basin from the runoff entering the basin, ft^3
$Solids_{moisture}$	=	80% (i.e., moisture content percentage in the settled solids)
Peak Rainfall Runoff	=	Total runoff from the peak rainfall event (either 25-year, 24-hour or 25-year, 24-hour plus 10-year, 10-day).

Section 4.7 describes the details of the precipitation and runoff calculations.

Net Precipitation

The pond depth is increased to allow for direct net precipitation, as discussed in Section 4.7. The net precipitation contribution to the pond depth is equal to the average precipitation minus the average evaporation.

Design Storm

The depth of the peak rainfall event is added to the depth of the pond to account for direct precipitation. For all options except 1A, this peak rainfall event is the 25-year, 24-hour rainfall. For Option 1A, a sensitivity analysis conducted by EPA to account for chronic rainfall, the peak storm is defined as the 25-year, 24-hour rainfall plus the 10-year, 10-day rainfall. Precipitation information for these storms was also extracted from the NCDC database.

$$\text{Peak Precipitation} = \text{25-Yr, 24-Hr Rainfall or 25-Yr, 24-Hr} + \text{10-Yr, 10-Day Rainfall}$$

where:

Peak Precipitation	=	Precipitation depth that falls directly on the pond from the peak rainfall event, inches
25-Yr, 24-Hr Rainfall	=	Depth of the 25-year, 24-hour peak rainfall, inches
10-Yr, 10-Day Rainfall	=	Depth of the 10-year, 10-day chronic rainfall, inches.

Freeboard

A minimum of 1 foot of freeboard is added to the depth.

Step 2) Dimensions and Configuration of Pond

The pond is designed approximately in the shape of an inverted frustum (i.e., an inverted pyramid with a flat bottom), containing the required volume. The initial depth of the pond is set as follows:

h = Initial Depth + Net Precipitation + Freeboard + Peak Precipitation

where:

h	=	Depth of the pond, ft
Initial Depth	=	10 ft
Net Precipitation	=	Six-month precipitation depth that falls directly on the pond minus the amount that evaporates from the pond, ft
Freeboard	=	1 foot
Peak Precipitation	=	Precipitation depth that falls directly on the pond from the peak rainfall event, ft.

The initial depth of the pond is set at 10 feet, based on discussions with industry consultants. This initial depth is assumed to include depth for the runoff and solids. This depth is used as the starting value for the dimensions calculations using the required volume of the pond. The pond is assumed to be square, and the final depth and length is solved by iteration, knowing the pond volume and the other variables in the equation.

Pond Dimensions

For the cost model calculations, it is assumed that the pond has four sloped sides with a rectangular base. To determine the dimensions of the pond, the design volume of the pond is used with the design parameters discussed previously. The following equation is used to determine the length of the basin:

$$\text{Pond Volume} = \tfrac{1}{2}\, h\, [A_1 + A_2 + (A_1\, A_2)^{0.5}]$$

$$\text{Pond Volume} = \tfrac{1}{2}\, h\, [l_b\, W_b + l_s\, W_s + (l_b W_b l_s W_s)^{0.5}]$$

where:

Pond Volume	=	Necessary volume of the pond calculated in Step 1), ft^3
h	=	Depth of the pond, ft
A_1	=	Area of the bottom base of the pond, assuming the pond is square (this equals $l_b\, W_b$)
A_2	=	Area of the top (surface area) of the pond, assuming the pond is square (this equals $l_s\, W_s$)
l_b	=	Length of the base of the pond, ft
W_b	=	Width of the base of the pond, ft
l_s	=	Length of the top of the pond, ft
W_s	=	Width of the top of the pond, ft.

Pond Excavation and Embankment Volumes

Ponds are constructed by excavating a portion of the necessary volume and building embankments around the perimeter of the pond to make up the total design volume. The cost model performs an iteration to maximize the use of excavated material used in constructing the embankments that minimizes the costs for construction. The excavation volume is represented by the following equation:

$$\text{Volume}_{\text{excavated}} = 0.5\, (h - h_e)\, [l_b w_b + l_s w_s + (l_b w_b l_s w_s)^{0.5}]$$

where:

$\text{Volume}_{\text{excavated}}$	=	Total volume of soil extracted from the pond, ft^3
h	=	Depth of the pond, ft
h_e	=	Height of embankment, ft
l_b	=	Length of the base of the pond, ft
W_b	=	Width of the base of the pond, ft
l_s	=	Length of the top of the pond, ft
W_s	=	Width of the top of the pond, ft.

The excavated soil is used to build the embankments. Because some settling of the soil will occur, it is assumed that an extra 5 percent of volume is required. The embankment volume is represented by the following equation:

$$Volume_{embankment} = 2\,[(1.05\,h_e w_e + s\,(1.05\,h_e)^2)\,(l_b + 2\,sh)] + 2\,[(1.05\,h_e w_e + (1.05\,s)^2\,h_e^2)\,(w + 2sh)]$$

where:

$Volume_{embankment}$	=	Total volume of soil used for the embankment, ft^3
h_e	=	Depth embankment, ft
w_e	=	Width embankment, ft
l_b	=	Length of the base of the pond, ft
s	=	slope of walls of pond, ft/ft
w	=	width of the base of the pond, ft.

The dimensions of the basin which yield the desired volume are calculated by the cost model.

Pond Liners

For Options 3A/3B and 3C/3D, ponds are designed with a synthetic liner for those operations located in areas requiring ground water protection. The liner consists of clay soil with a synthetic liner cover. The dimensions of the liner are equal to the surface area of the floor and sides of the pond.

The surface area of the floor of the pond is calculated to determine the area for compaction and for the pond liner. The surface area includes the bottom area plus the area of the four trapezoids that make up the sides of the pond.

The surface area of the sloped sides is calculated using the formula for the area of a trapezoid.

$$\text{Area of Side}_l = \tfrac{1}{2}\,HS \times (1_b + 1_s)$$

$$\text{Area of Side}_w = \tfrac{1}{2}\,HS \times (w_b + w_s)$$

where:

Area of $Side_l$	=	Area of length side of the pond, ft^2
Area of $Side_w$	=	Area of width side of the pond, ft^2
HS	=	Height of the side on the pond (see equation below), ft
l_b	=	Bottom length of the pond, ft
l_s	=	Top length of the pond, ft

w_b	=	Bottom width of the pond, ft
w_s	=	Top width of the pond, ft.

The height of the side is calculated using the Pythagorean Theorem.

$$HS = (h^2 + (4h)^2)^{0.5}$$

where:

HS	=	Height of the side on the pond, ft
h	=	Depth of the pond, ft.

The total surface area of the basin is:

$$\text{Surface Area}_{pond} = l_b\, W_b + 2\,[\text{Area of Side}_l] + 2\,[\text{Area of Side}_w]$$

where:

$\text{Surface Area}_{pond}$	=	Total surface area of the pond floor, including the bottom and sides, ft^2
l_b	=	Bottom length of the pond, ft
w_b	=	Bottom width of the pond, ft
Area of Side_l	=	Area of length side of the pond, ft^2
Area of Side_w	=	Area of width side of the pond, ft^2.

5.5.3 Costs

The construction of the storage pond includes a mobilization fee for the heavy machinery, excavation of the pond area, compaction of the ground and walls of the pond, and the construction of conveyances to direct runoff from the drylot area to the storage pond. Table 5.5.3-1 presents the unit costs used to calculate the capital and annual cost for constructing storage ponds.

Table 5.5.3-1

Unit Costs for Storage Pond

Unit	Cost (1997 dollars)	Source
Mobilization	$205/event	Means 1999 (022 274 0020)[a]
Excavation	$2.02/yd^3	Means 1999 (022 238 0200)[a]
Compaction	$0.41/yd^3	Means 1996 (022 226 5720)[a]
Conveyance	$7,644/event	ERG, 2000c
Clay Liner (shipped & installed)	$0.24/ft^2	AEA, 1999
Synthetic Liner (installed)	$1.50/ft^2	Tetra Tech, 2000c

[a]Information taken from Means Construction Data. The numbers in parentheses refer to division and line numbers.

The calculations for the costs associated with these items are shown below:

Mobilization

The mobilization costs are $205/event (i.e., $205 to mobilize all equipment on site). These costs are for moving the appropriate heavy machinery and equipment.

Excavation

To calculate the pond excavation costs, the volume of material that is excavated is first calculated, as described previously. The excavated material is expected to be used to construct embankments around the pond, which will provide additional storage other than that volume which is excavated; therefore, the excavated volume is not equal to the pond volume. Instead, it is equal to the pond volume minus the storage that the embankments provide.

The excavation cost is calculated with the following equation:

$$\text{Excavation} = \text{Cost} \times \frac{\text{Volume}_{\text{excavated}}}{\text{Conversion Factor}}$$

where:

Excavation	=	Total cost to excavate the pond, $
Cost	=	$2.02/yd^3$ (i.e., cost per the volume of soil excavated)
$Volume_{excavated}$	=	Amount (volume) of soil excavated, ft^3
Conversion Factor	=	27 ft^3/yd^3 (i.e., conversion from ft^3 to yd^3).

Compaction

To calculate compaction costs, the volume for compaction is calculated, as described in Section 5.1. The compaction cost is calculated with the following equation:

$$\text{Compaction} = \text{Cost} \times \frac{\text{Volume}_{\text{compacted}}\ (\text{ft}^3)}{\text{Conversion Factor}}$$

where:

Compaction	=	Total cost to compact the pond, $
Cost	=	$0.41/yd^3$ (i.e., cost per volume of soil compacted)
$Volume_{compacted}$	=	Amount (volume) of soil compacted, ft^3
Conversion Factor	=	27 ft^3/yd^3 (i.e., conversion from ft^3 to yd^3).

Conveyance

The conveyance costs are for constructing conveyances to direct runoff from the drylot area to the storage pond. According to the Means Construction Data, this cost is $7,644/event.

Clay and Synthetic Liners

To calculate liner costs, the surface area of the basin floor and sidewalls is calculated, as described in Section 5.1. The liner cost includes both a clay and synthetic liner, and is calculated using the following equations:

$$\text{Clay Liner} = \text{Cost} \times \text{Surface Area}$$

where:

Clay Liner	=	Cost to install a clay liner, $
Cost	=	$0.24/ft^2 (i.e., cost per the surface area of the pond)
Surface Area	=	Surface area of the basin floor and the sidewalls, ft^2.

$$\text{Synthetic Liner} = \text{Cost} \times \text{Surface Area}$$

where:

Synthetic Liner	=	Cost to install a synthetic liner, $
Cost	=	$1.50/ft^2 (i.e., cost per the surface area of the pond)
Surface Area	=	Surface area of the basin floor and the sidewalls, ft^2.

Total Capital Costs for Naturally Lined and Synthetically Lined Ponds

The total capital cost for construction of the naturally-lined storage pond is the following:

$$\text{Capital Cost} = \text{Mobilization} + \text{Excavation} + \text{Compaction} + \text{Conveyance}$$

The total capital cost for construction of the synthetically lined pond is the following:

$$\text{Capital Cost} = \text{Mobilization} + \text{Excavation} + \text{Compaction} + \text{Conveyance} + \text{Clay Liner} + \text{Synthetic Liner}$$

Total Annual Costs

Based on best professional judgement, annual operating and maintenance costs for both naturally lined and synthetically lined storage ponds are estimated at 5 percent of the total capital costs.

$$\text{Annual Cost} = 5\% \times \text{Capital Cost}$$

5.5.4 Results

The cost model results for constructing a naturally lined storage pond, a synthetically lined storage pond, and additional ponds for extra capacity (Option 7) are presented in Appendix A, Table A-7, Table A-8, and Tables A-9a and 9b, respectively.

5.6 <u>Nutrient Management</u>

The cost model assumes that as part of the regulation, CAFOs will be required to conduct certain practices to appropriately manage their nutrients. These practices include: the development of a nutrient management plan, soil sampling, manure sampling, recordkeeping and reporting costs, purchase of nitrogen fertilizer, lagoon depth marker, establishment of setback areas, and calibration of a manure spreader. Each of these are described in this section. The sum of the nutrient management costs are presented for beef feedlots, dairies, heifer and veal operations in Appendix A, Tables A-10a and 10b. Tables A-10c through A-10g present costs for buffers at swine and poultry operations.

5.6.1 Nutrient Management Plan Development and Associated Costs

The cost model assumes that all but Category 3 animal feeding operations covered by this regulation will need to develop and implement a nutrient management plan for their operation. To this end, there is an initial cost for the owner/operator of the farm to be trained in nutrient management planning. Further, for all but Category 3 farms, it is assumed that the owner/operator develops or updates their nutrient management plan every 5 years.

On-Farm Nutrient Management Plan (NMP) Development

The cost to develop an on-farm NMP is calculated by multiplying the farm size (number of tillable acres) by a NMP rate in dollars per acre. NMP rates vary depending on the level of services (e.g., soil sampling, manure sampling, and analysis). EPA selected a NMP rate of $5 per tillable acre, assuming that costs for soil and manure testing were estimated separately from NMP development and the higher costs for NMP development are usually attributed to testing costs. While the final regulation requires that NMPs be rewritten at a minimum of every 5 years; therefore, the cost models for all operations include costs to revise the NMP every 5 years. Costs for an annual review of the NMP are included under the recordkeeping requirements for all facilities.

EPA also assumes that there will be a one-time fixed cost for documenting the manure generation, collection, storage, and treatment systems at animal operations that require nutrient management planning. EPA assumes that this documentation will be prepared by a nutrient management specialist as the first step in the nutrient management planning development process. Labor hours for both the farmer and the nutrient management specialist are required. EPA assumes this documentation will require 8 hours of time by the farmer at \$10 per hour and 16 hours of time by the nutrient management specialist at \$55 per hour. This cost is:

$$\text{One-time Fixed Cost} = (8 \text{ hours} \times \$10/\text{hr}) + (16 \text{ hours} \times \$55/\text{hr}) = \$960.$$

5.6.2 Soil Sampling

As part of nutrient management planning requirements, the cost model includes costs for soil sampling and analysis to determine the nutrient balance of the soil prior to manure application. Costs associated with soil sampling include a fixed cost for equipment purchase and soil sampling costs every 3 years.

Soil Sampler

The one time capital cost for equipment was estimated to be \$25 for a soil auger (ASC Scientific, 1999). Category 3 facilities do not incur this cost since they have no land.

Soil Sampling

The cost model assumes that on-farm soil sampling will occur at least once every 3 years. EPA selected a soil sampling rate of one composite sample per 20 tillable acres, based upon a review of federal and state soil sampling recommendations. A composite soil sample was estimated to take 1 hour because of the distance between samples, and labor costs for soil sampling were estimated to be $10/hr. Costs for soil analysis for major nutrients and important soil characteristics were estimated at $10 per sample based on a review of costs by state NRCS labs. Category 3 facilities do not incur this cost since they have no land.

5.6.3 Manure Sampling

As part of nutrient management planning requirements, the cost model includes costs for manure sampling and analysis to determine the nutrient balance of the manure prior to application to cropland. Costs associated with manure sampling apply to all facilities and include a fixed cost for equipment purchase and semiannual manure sampling costs.

Manure Sampler

The one-time cost for equipment to sample liquid manure waste is estimated at $30 for a manure sampler. The manure sampler consists of a hollow conduit long enough to extend to the bottom of the lagoon, pit, or other storage structure. In the case of solid manure, a shovel or similar device is sufficient to obtain a representative sample and therefore no cost is assumed.

Manure Sampling

Manure sampling costs are based on sampling twice per year. The cost of manure sampling includes the labor required and the manure nutrient analysis. For all poultry and swine facilities, 1 hour is required to sample the main storage area. For dry poultry, an additional 0.25 hour per house is required to collect a composite sample from each house. Beef feedlots and dairies are assumed to have two samples of the liquid waste and two samples of solid waste collected per year, for a total of four samples per year.

Labor rates are estimated at $10/hr. Manure analysis was estimated at $40 per sample based on a review of costs by state soil conservation service labs.

5.6.4 Recordkeeping and Reporting

As part of implementing a nutrient management plan, the cost model assigns annual costs to each facility for recordkeeping and reporting time. Recordkeeping costs ($880/year) for all facilities include the cost of recording animal inventories, manure generation, field application of manure and other nutrients (amount, rate, method, incorporation, dates), manure and soil analysis compilation, crop yield goals and harvested yields, crop rotations, tillage practices, rainfall and irrigation, lime applications, findings from visual inspections of feedlot areas and fields, lagoon emptying, and other activities on a monthly basis.

EPA estimated that large facilities incur an additional cost of $140/ year to maintain records of manure that is transferred to a third party. The average number of transfers per large CAFO is 16,900, based on excess manure estimates in Simons (2002). Using the 100-ton transfer estimate from Simons (2002), the average annual number of transfers per CAFO of 169 (16,900 ÷ 100). It should not require more than five minutes per transfer to record the four data items: the name of the recipient, the data of the transfer, the quantity of manure, and its nutrient content. Therefore, the annual burden estimate will be approximately 14 hours (169 transfers × 5 minutes/transfer ÷ 60 minutes/hour). The additional $8.50 cost per 20-ton load to weight a truck (Simons, 2002) is not a required cost of the rule and, therefore, is excluded from the offsite transfer cost estimate.

Records may include manure spreader calibration worksheets, manure application worksheets, maintenance logs, soil and manure test results, and documentation of corrective actions taken in response to findings from visual inspections. EPA assumed 8 hours were needed to prepare an annual report on animal inventories, manure generation, and overall manure application. Monthly write-ups and field observations are assumed to require 3 hours each (72 hours annually). Thus, a total of 80 hours annually was estimated for recordkeeping at $10/hour. Other costs associated with recordkeeping, including obtaining signed certifications of proper manure application from off-site manure recipients, were estimated at 10 percent of labor costs.

5.6.5 Commercial Nitrogen Fertilizer

The nitrogen-to-phosphorus ratio in manure is typically much lower (approximately 2:1) than harvested crop nutrient removal ratios (approximately 6:1). Therefore, facilities that must land apply their manure on a phosphorus basis rather than a nitrogen basis incur additional costs because a commercial source of nitrogen must be applied to their fields (termed sidedressing) to compensate for the nitrogen not supplied through manure application. The cost model assumes a cost of 12.3¢ per pound of additional nitrogen is required, based upon the cost data shown in Table 5.6.5-1. No veal operations are assumed to need commercial fertilizer. Appendix A, Table A-11 presents the cost model results for purchasing commercial nitrogen fertilizer for beef feedlots, dairies, heifer, and veal operations.

Table 5.6.5-1

Retail Cost of Nitrogen Fertilizer

Fertilizer	Retail Cost Per Pound of Nitrogen
Anhydrous Ammonia	14¢
Urea	12¢
Ammonium Nitrate	11¢
U.S. Average	12.3¢

Source: The Fertilizer Institute, 1999.

5.6.6 Lagoon Depth Marker

EPA believes that all facilities with liquid waste impoundments should have a gauge to measure the remaining storage capacity. A lagoon depth marker can be manufactured by purchasing PVC pipe, fittings, and cement to construct a length of incrementally marked pipe long enough to reach the bottom of the lagoon and extend above the freeboard. EPA estimated that building and installing a lagoon depth marker would cost $30.

5.6.7 Establishment of Setback Areas

The final rule requires either (1) a 100-foot manure application setback from surface waters, sinkholes, open tile drain inlets, or (2) a 30-foot vegetated buffer from surface waters, sinkholes, open tile drain inlets, or (3) one or more NRCS field practices providing an equal or better level of protection (a certified CNMP is deemed to meet this requirement).

However, EPA believes that in addition to manure application setbacks from surface waters, operations should also establish buffer strips or their equivalent to control erosion and treat field runoff. Thus, EPA estimated the costs of 100-foot buffer strips for fields used for manure application that are adjacent to streams, discussed below.

The costs of the buffer should be thought of as an allowance for the AFO to implement site specific field control practices such as conservation management. In other words, controls other than buffer strips may be more effective in certain situations (Sims J., A. Leytem, F. Coale, 2000), and this cost basis is considered an allowance that can be used to implement other runoff control practices.

Initial Fixed Costs

EPA calculated the ratio of stream length to land area based on national estimates of land area (3 million square miles of land in the contiguous United States (ESRI,1998) and stream miles (3.5 million miles of streams (USEPA, 2000). This ratio was converted to miles per acre (0.00144 mile of stream per acre of land). EPA then calculated the amount of land needed for buffer construction by multiplying the average acres of cropland for each model farm by the ratio of stream miles per acre of land, which determined the length of stream on each farm. EPA further assumed that the farm is square and the stream runs down the middle of the farm, and the width of the buffer (on both sides of the stream) is 100 feet. The cost of 100-foot buffers was based on information collected from a total of 914 filter strip projects in 28 states with an average cost of $106.62/ac (1999 dollars; USEPA, 1993). The net loss of tillable land to establish a buffer was estimated at 3.5 percent of the cropland (0.00144 mile of stream per acre × 5,280 feet per mile × 200 ft^2 of buffer per foot of stream length ÷ 43,560 ft^2/ac). Thus, the cost for stream buffers was estimated at approximately $3.72/ac of total cropland.

Annual Costs

EPA assumed that the land taken out of production for installation of buffer strips was previously farmed. The rental value for land taken out of production was added to standard O&M costs. The rental value for cropland used as a stream buffer was estimated at $64.00/ac/yr based on analysis by North Carolina State University (NCSU, 1998).

5.6.8 Manure Spreader Calibration

EPA assumed that regular calibration of the manure spreader is part of implementing the nutrient management plan. To meet this need, EPA assumed that Category 1 and 2 facilities will purchase two calibration scales to weight the manure spreader before and after land application.

In cases where states require calibration of manure spreaders at broiler and turkey facilities, EPA assumed that calibration scales (or an equivalent calibration technology or method) are available to the facility, and therefore no costs were assumed. Solid manure spreaders can be calibrated in a number of ways, some of which are based on volume instead of weight. Liquid-based systems can also be calibrated in terms of volume. Section 8 of the Technical Development Document describers methods for calibration of manure spreaders in greater detail.

Weighing the spreader before and after application is the ideal methodology for wet or dry manure calibration because it is relatively quick and produces accurate results. This approach is unsuitable for manure application devices such as umbilical applicators. Instead, the volume of manure injected must be first be determined. The procedure includes collecting pumped material into a bucket to determine the flow rate, which decreases initial calibration costs. Some operations that handle their manure in a drier form may be able to use a less expensive calibration method. For example, spreading manure on a tarp and weighing it on a less expensive hanging balance would reduce initial calibration costs.

Fixed One-Time Costs

EPA assumed the one-time cost for equipment is $500 for a scale to weigh the manure spreader (one under each wheel at $250 each).

Annual Costs

EPA estimated the cost for manure spreader calibration to be $100 based on 4 hours of labor, at $10 per hour, for both wet and dry applicators and 2 hours of tractor time at $30 per hour. EPA assumed that the time required for calibration included gathering required equipment, loading manure, weighing the spreader before and after land application, and applying manure to a known area of cropland. Category 3 facilities do not incur this cost since they have no land.

5.7 Screen Solid-Liquid Separation for Swine Operations

Solid-liquid separation systems are used by many livestock operations as a way to manage waste. Solid-liquid separation is the partial removal of organic and inorganic solids from a mixture of animal wastes and process-generated wastewater (known as liquid manure). Separating the solids from the liquid manure makes the liquids easier to pump and handle. The cost model assigns costs to swine operations for screen separation.

5.7.1 Technology Description and Design

Typically, screens are used to separate the solids from the liquids. As the liquids pass through the screen, the solids accumulate, and are eventually collected. After collection, the solids may be handled more economically for hauling, composting, refeeding or generating biogas (methane). EPA assumes that the separator efficiency is 30 percent and that the solids content of the separated manure is 23 percent.

The approach taken in the cost model is to separate the solid from the liquid portion of the manure to concentrate the nutrients thus reducing the costs associated with hauling the excess nutrients. Both Category 2 and 3 swine facilities are given costs for solid-liquid separation with screens.

5.7.2 Costs

Costs for solid/liquid separation are estimated as a one-time, fixed cost and an annual cost, based on the following calculations. Costs include a tank with sufficient capacity to store solids for six months, a mechanical solids separator, piping, and labor for installation.

Capital Cost

The following equation determines the initial cost to install a separator on a swine operation:

$$\text{Sepinitial} = (\text{Solids} \times \text{Safety} \times \text{Tankcost}) + \text{Separator} + \text{Pipelen} \times \text{Pipecost} + \text{Seplabor} \times \text{Labor}$$

where:

Sepinitial	=	Initial cost ($) to install a separator system
Solids	=	Volume of solids separated from the manure every 6 months, gal
Safety	=	Safety factor providing additional storage for the separator (115%)
Tankcost	=	Cost of installing a steel storage tank ($0.18/gallon)

Separator	=	Cost of a separation device was estimated at $13,000 for medium-sized operations and $28,000 for large operations, (USDA NRCS, 2002a)
Pipelen	=	Pipe length needed to connect the lagoon to the separator (250 feet)
Pipecost	=	Cost of pipe ($2.13/foot)
Seplabor	=	Time required to install the pipe and separator (4 hours)
Labor	=	Labor rate per hour ($10).

Annual Costs

The annual cost of operation and maintenance of solid-liquid separation systems was estimated to be 2 percent of the total cost of installing the system.

5.8 Land Application

The purchase of land application equipment is a primary component of the compliance costs for beef feedlots and dairies estimated by the cost model. The cost model estimates costs for the purchase of irrigation equipment to apply liquid from ponds and lagoons to the fields. The model assumes that all facilities already have equipment to apply solid manure and, therefore, includes no cost for this. As described in Section 4.10, the cost model calculates the total crop acreage used for application of liquid waste based on the nutrient assimilative capacity of the crops and the total waste generated, and uses this total acreage to cost irrigation equipment. The cost model includes no costs for application equipment for swine and poultry operations.

The cost model uses two forms of irrigation, center pivot and traveling gun. Center pivot irrigation is ideal for applying liquid waste to a large number of acres but is not as cost-effective for smaller acreage. Therefore, the cost model estimates costs for center pivot irrigation for facilities applying liquid manure to crop acreage greater than or equal to 30 acres and for traveling gun irrigation for facilities applying liquid manure to less than 30 acres.

5.8.1 Center Pivot Irrigation

Center pivots are a method of precisely irrigating virtually any type of crop over large areas of land. This technology is more expensive than other methods of irrigation, and therefore, costs included in the cost model for center pivot irrigation are conservative. A center pivot can effectively distribute liquid animal waste and supply nutrients to cropland at agronomic rates because they have a high level of control. The center pivot design is flexible and can be adapted to a wide range of site and wastewater characteristics. Center pivots are also advantageous because they can distribute the wastewater quickly, uniformly, and with minimal soil compaction. In a center pivot, an electrically driven lateral assembly extends from a center point where the water is delivered, and the lateral circles around this point, spraying water. A center pivot irrigation system is costed for all operations applying liquid manure to more than 30 acres of cropland under all regulatory options.

Technology Description

A center pivot generally uses 100 to more than 150 pounds of pressure per square inch (psi) to operate, which requires a 30- to 75-horsepower motor. The center pivot system is constructed mainly of aluminum or galvanized steel and consists of the following main components:

Pivot: The central point of the system around which the lateral assembly rotates. The pivot is positioned on a concrete anchor and contains various controls for operating the system, including timing and flow rate. Wastewater from a lagoon, pond, or other storage structure is pumped to the pivot as the initial step in applying the waste to the land.

Lateral: A pipe and sprinklers that distribute the wastewater across the site as it moves around the pivot, typically 6 to 10 feet above the ground. The lateral extends out from the pivot and may consist of one or more spans depending on the site characteristics. A typical span may be from 80 to 250 feet long, whereas the entire lateral may be as long as 2,600 feet.

Tower: A structure located at the end point of each span that provides support for the pipe. Each tower is on wheels and is propelled by either an electrically driven motor, a hydraulic drive wheel, or liquid pressure, which makes it possible for the entire lateral to move slowly around the pivot.

Figure 5.8.1-1 shows a schematic of a center pivot irrigation system.

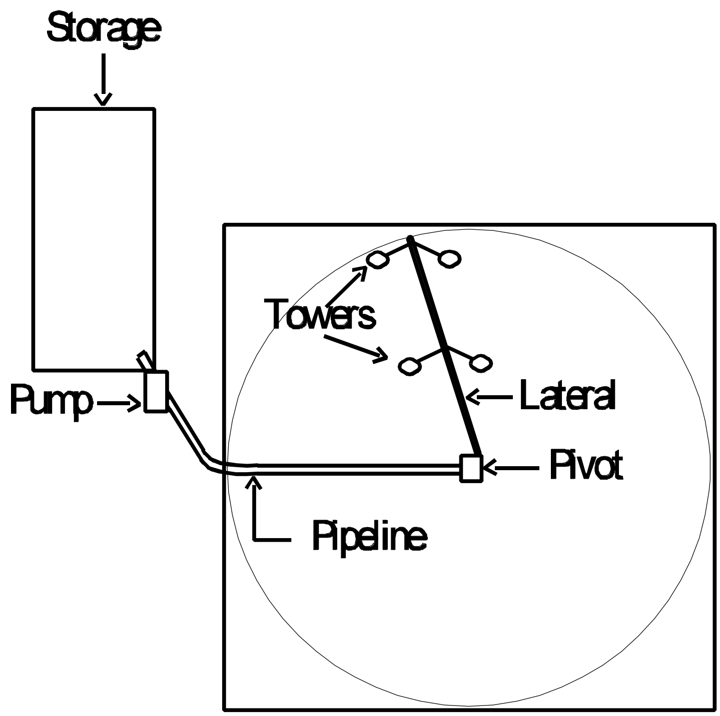


Figure 5.8.1-1. Schematic of Center Pivot Irrigation System

All regulatory options are based on the installation of irrigation equipment at beef feedlots, dairies, and heifer operations that land apply waste on site (i.e., Category 1 and 2 facilities). EPA developed frequency factors for center pivot irrigation based on the frequency factors for an unlined pond or lagoon. EPA assumed that if a facility has an unlined pond or lagoon on site, the facility would also already have some method of land application equipment to land apply the wastewater from this lagoon. These frequency factors are presented in Section 6.0. The cost model does not include costs for veal operations for center pivot irrigation because they are assumed to have sufficient storage capacity and therefore the necessary irrigation equipment.

Design

The center pivot is designed specifically for each operation, based on wastewater volume and characteristics, as well as site characteristics such as soil type, parcel geometry, and slope. The soil type (i.e., its permeability and infiltration rate) affects the selection of the water spraying pattern. The soil composition (e.g., porous, tightly packed) affects tire size selection as to whether it allows good traction and flotation. Overall site geometry dictates the location and layout of the pivots, the length of the laterals, and the length and number of spans and towers. Center pivots can be designed for sites with slopes of up to approximately 15 percent, although this depends on the type of crop cover and methods used to alleviate runoff. The costs assume a regular-shaped parcel (square), a water requirement of 7 gallons per minute per acre, and 1,000 operating hours per year.

5.8.2 Traveling Gun Irrigation

Based on industry expert opinion and literature, farms can irrigate relatively small areas using a traveling gun (USDA NRCS, 1996). Traveling guns are also useful in oddly shaped fields. These systems can be installed rapidly and are easily transported. However, the operation of traveling gun systems is more labor intensive than the operation of center pivot systems. Another disadvantage of traveling gun systems is low application efficiency. Water is sprayed high into the air, causing wind and evaporation losses up to 30 percent (Clemson Extension, 2002). The traveling gun system requires higher capital, annual, labor, and energy costs per irrigated acre than the center pivot system (Agriculture and Agri-Food Canada, 2002). Despite the disadvantages, traveling gun irrigation systems remain the best alternative for small acreages. A traveling gun system is costed for all operations with less than 30 acres of cropland under all regulatory options.

Technology Description

Traveling gun systems consist of a large sprinkler, a wheeled cart, a hose reel, and an irrigation hose. The sprinkler is also referred to as the “gun” or “big gun.” The sprinkler is moved during irrigation, hence the name "traveling gun." Traveling gun sprinklers discharge 50 to 1,000 gallons per minute with operating pressures from 60 to 120 psi (USDA NRCS,1996). A traveling gun sprinkler is mounted on a wheeled cart to allow for mobility. An irrigation hose is connected to the sprinkler on the wheeled cart and contained in a hose reel. There are two types of traveling gun operations depending on the type or irrigation hose used:

> **Hard-Hose** - This type of traveling gun operation utilizes a hard, high-pressure, polyethylene hose. The hose is pulled out some distance from the hose reel. As the sprinkler operates, the hose reel begins to reel in the cart and sprinkler.
>
> **Soft-Hose** - This system may also be called a Cable-Tow system. A soft, flexible hose similar to a fire hose is used. The entire hose must be unwound from the hose reel before use. The wheeled cart is placed in the field and anchored by a cable. A winch on the cart pulls reels the cable, pulling the cart closer to the anchor. The hose drags behind the cart and must be manually reeled after use.

The sprinkler travels a straight path, wetting a 200-400 foot wide strip of land (USDA NRCS, 1996). When one path is complete, the unit must be moved to an adjacent path to make another pass at the field. This process is repeated until the entire field is irrigated.

EPA developed frequency factors for traveling gun irrigation based on the frequency factors for an unlined pond or lagoon. These frequency factors are presented in Section 6.0. EPA assumed that if a facility has an unlined pond or lagoon on site, the facility would also already have some method of land application equipment to land apply the wastewater from this lagoon. The cost model does not include costs for veal operations because they are assumed to have sufficient storage capacity.

Design

The traveling gun is designed specifically for each operation, based on wastewater volume and characteristics, as well as site characteristics such as soil type, parcel geometry, and slope. The soil type and composition affects the selection of the water spraying volume.

5.8.3 Beef and Dairy Irrigation Costs

The only variable the cost model uses to determine costs for a center pivot and traveling gun irrigation systems are total acres irrigated.

Center Pivot

EPA derived annual and capital costs for center pivots from cost curves created from data available at a vendor web site (Zimmatic, Inc., 1999). Number of irrigated acres (61, 122, and 488) are plotted on the x-axis and costs (capital and annual) are plotted on the y-axis. Capital costs include the pivot, lateral, towers, pumps, piping, generator and power units, and erection. Annual costs include power consumption and routine maintenance of mechanical parts. Table 5.8.3-1 presents the costs for each of these points.

Table 5.8.3-1

Costs for Data Points from Center Pivot Irrigation Cost Curves

Number of Irrigated Acres	Capital Costs	Annual Costs
61	$58,741	$3,453
122	$64,130	$5,616
488	$122,414	$11,559

Source: http://www.Zimmatic.com.

Traveling Gun

Traveling gun costs are based on information provided by Kifco, Inc., an agricultural irrigation company. The cost model assumes that 250-gpm applicators would provide adequate coverage for cropland comprising less than 30 acres. Table 5.8.3-2 presents the capital costs for a 250-gpm applicator. Annual costs are estimated at five percent of the capital costs.

Table 5.8.3-2

Costs for 250-gpm Liquid Applicators

Model	Flow Rate (gpm)	Capital Cost
37M/1220	225-415	$28,990
40A/1320	250-480	$31,400

Source: (Kifco, 2002)

Total Capital Costs

A polynomial curve with a regression coefficient of 1 is drawn through the capital cost points. The cost model uses the resulting curve to estimate costs for the various acreages. The equation is:

$$y = 0.166x^2 + 57.958x + 54{,}588$$

where:

y = Capital cost
x = Irrigated acreage.

Total Annual Costs

A logarithmic curve with a regression coefficient of 0.9947 is drawn through the annual cost points. The cost model uses the resulting curve to estimate costs for various acreages. The equation is:

$$y = 3954 \ln(x) - 13{,}033$$

where:

y = Annual cost
x = Irrigated acreage.

Results

Appendix A, Tables A-12a and A-12b present the cost model results for implementing center pivot or traveling gun irrigation systems at beef feedlots, dairies, and heifer operations.

5.9 Transportation

Animal feeding operations use different methods of transportation to remove excess manure waste and wastewater from the feedlot operation. The costs associated with transporting excess waste off site are calculated using two methods: contract hauling waste or purchasing transportation equipment. EPA evaluated both methods of transportation for all regulatory options. The least expensive method for each model farm and regulatory option is chosen as the basis of the costs. Hauling at swine and poultry operations is assumed to be accomplished via contract hauling.

5.9.1 Technology Description

Many animal feeding operations use manure waste and wastewater on site as fertilizer or irrigation water on cropland; however, nutrient management plans (discussed in Section 5.6) require that facilities apply only the amount of nutrients agronomically required by the crop. When a facility generates more nutrients in its manure waste and wastewater than can be used for on-site application, they must transport the remaining manure waste and wastewater off site.

Beef feedlots, dairies, swine operations, and poultry operations are divided into three categories, as discussed in Section 1.3. Category 1 operations have sufficient cropland to agronomically apply all of their generated waste on site. Category 2 operations do not have sufficient cropland and may only agronomically apply a portion of their generated waste. Category 3 operations have no cropland and must transport all of their waste off site. The number of operations in each category depends on the nutrient application requirements, because more land is required for nitrogen-based application than for phosphorus-based application.

The amount of excess waste that requires transport depends on the nutrient basis used for land application, as well as the practices and technologies employed at the facility (e.g., feeding strategies). Option 1 requires that animal waste be applied on a nitrogen basis to cropland, and Options 2 through 7 require application on a phosphorus basis as dictated by site-specific conditions. In general, the amount of waste transported off site increases under a phosphorus-based application option. Section 4.9 discusses the methodology used to determine the amount of excess waste at beef feedlots, dairies, swine operations, and poultry operations.

Manure is transported as either a solid or liquid material. The cost model assumes that solid waste is transported before liquid waste because it is less expensive to haul solid waste. This assumption means that operations apply liquid manure (i.e., lagoon and pond effluents) to cropland on site before solid waste.

In addition, some operations are located in states that already require them to apply manure to cropland on an agronomic nitrogen basis; therefore, these operations will not incur additional transportation costs under the N-based scenario. The percentage of facilities that are expected to incur transportation costs was based on EPA's Interim Final Report: *State Compendium: Programs and Regulatory Activities Related to Animal Feeding Operations - Interim Final Report* (EPA, 1999) and is discussed in detail in Section 6.0 of this report.

Contract Hauling

One method evaluated for transporting manure waste off site is contract hauling, whereby the operation hires an outside firm to transport the excess waste. This method is advantageous to facilities that do not have the necessary capacity to store excess waste on site or the cropland acreage to agronomically apply the material. In addition, this method is useful for operations that do not generate enough excess waste to warrant purchasing their own waste transportation trucks. Contract haulers can transport waste from multiple operations.

Equipment Purchase

Another method evaluated for transporting manure waste off site is to purchase transportation equipment. In this method, the operation owner purchases the necessary trucks to haul the waste to an off-site location. Depending on the type of waste transported, a solid waste truck, a liquid tanker truck, or both types of trucks are required. In addition, the owner is responsible for determining a suitable location for the waste, as well as all costs associated with loading and unloading the trucks, driving the trucks to the off-site location, and maintaining the trucks.

5.9.2 Design and Costs of Contract Hauling

In determining costs for the contract-hauling option, the cost model considered three major factors:

1) Amount of waste transported;
2) Type of waste transported (semisolid or liquid); and
3) Location of the operation.

Additional factors that relate to these three major factors include:

- Hauling distance;
- Weight of the waste;
- Rate charged to haul waste ($/ton-mile); and
- Percentage of operations in each region and category that incur transport costs.

Using these factors, the cost model uses the following three steps to determine costs for a model farm:

Step 1) Determine constants, based on region, animal type, and waste type;

Step 2) Determine the weight of the transported waste, accounting for water losses during storage or composting; and

Step 3) Determine the annual waste transportation costs.

Each of these steps is explained in detail below.

Step 1) Determine constants, based on region, animal type, and waste type

Constants used in this evaluation include the hauling distance, the moisture content of stockpiled manure, the moisture content of composted manure, and the hauling rate ($/ton-mile).

Hauling Distance

The one-way hauling distance for a Category 2 or 3 operation depends on the region in which it is located. The one-way hauling distance considers the size of the county, whether the county has a potential for excess manure nutrients, and the proximity of other counties that have a nutrient excess. The cost model assumes that Category 3 operations have always transported all of their waste; however, the cost model also assumes that the distance required for transport would increase under the P-based scenario. Therefore, the distance assigned to Category 3, P-based facilities is an incremental distance, representing the difference in distance a facility would have to transport under the P-based option. (For more details, see *Revised Transportation Distances for Category 2 and 3 Type Operations,* Tetra Tech, 2000.)

The P-based hauling distance is reduced where feeding strategies are used to reduce swine manure-P by 40 percent. EPA assumes that if total manure P is reduced by 40 percent, facilities will not have to haul their excess manure as great a distance. The cost model counted all major animal types in determining counties with nutrient excess. (Analysis based on Kellogg, R. et al., 2000.) Table 5.9.2-1 presents the Category 2 and Category 3 hauling distances by region.

Table 5.9.2-1

Hauling Distances for Transportation

Region	One-Way Hauling Distance (miles) for Category 2			One-Way Hauling Distance (miles) for Category 3		
	N-Basis	P-Basis	P-Basis*	N-Basis	P-Basis	P-Basis*
Central	11.0	16.5	NA	0	5.5	NA
Mid-Atlantic	5.5	30.5	18	0	25.0	18
Midwest	6.5	10.0	NA	0	3.5	NA
Pacific	12.5	21.5	NA	0	9.0	NA
South	6.0	14.5	NA	0	8.5	NA

Source: For detailed information on the calculation of one-way hauling distances, see *Revised Transportation Distances for Category 2 and 3 Type Operations.* Tetra Tech, 2000.
*P-Basis when feeding strategies are used to reduce total P by 40 percent.

Moisture Content of Waste

Based on available information, the cost model assumes that the moisture content of stockpiled manure is 35.4 percent and the moisture content of composted manure is 30.8 percent (Sweeten, J.M. and S.H. Amosson, 1995).

Hauling Rate

The $/ton-mile rates for liquid and solids wastes for Category 2 and 3 beef feedlots and dairies are estimated based on information obtained from various contract haulers and presented in Table 5.9.2-2. The hauling rates used for swine and poultry operations are presented in Table 5.9.2-3.

Table 5.9.2-2

Rates for Contract Hauling for Category 2 and 3 Beef Feedlots and Dairies

Type of Waste	Category 2 Rates		Category 3 Rates	
	N-Based Application	P-Based Application	N-Based Application	P-Based Application
Solid ($/ton-mile)	0.24	0.15	0	0.08
Liquid ($/ton-mile)	0.53	0.10	0	0.26

Source: For additional detail on the calculation of contract hauling rates, see *Methodology to Calculate Contract Hauling Rates for Beef and Dairy Cost Model, ERG 2000.*

Table 5.9.2-3

Hauling Rates for Category 2 and 3 Swine and Poultry Operations

Type of Waste	Rate
Liquid - First Mile ($/gallon-mile)	0.008
Liquid - Beyond First Mile ($/gallon-mile)	0.0013
Solid - Less than 90 Miles ($/ton-mile)	0.10
Solid - 90 to 1230 Miles ($/ton-mile)	0.23
Solid - Beyond 1230 Miles ($/ton-mile)	0.18

Source: Tetra Tech, 2002.

Step 2) Determine the weight of the transported waste

The amount of waste to be transported is estimated as the sum of separated solids, lagoon's pond effluent, lagoon's pond accumulated solids, and process and rainwater not applied to land.

Step 3) Determine the annual cost of transporting the waste

The annual cost of hiring a contractor to haul the waste is based on the amount of waste (in either semisolid or liquid form), the distance traveled, and the haul rate. The following equation incorporates both the solid and liquid annual hauling costs:

$$\text{Annual Cost} = (\text{Weight of Solids} \times \text{Solid Hauling Rate} \times \text{Hauling Distance}_{\text{Round-trip}}) + (\text{Weight of Liquids} \times \text{Liquid Hauling Rate} \times \text{Hauling Distance}_{\text{Round-trip}})$$

There are no capital costs associated with contract hauling. All hauling costs for swine and poultry operations are calculated using this basic approach for contract hauling.

5.9.3 Design and Cost of Purchase Equipment Transportation Option

In determining costs for the purchase truck transportation option, the cost model considered three major factors:

1) Amount of transported waste;
2) Type of waste transported (semisolid or liquid); and
3) The location of the operation.

Additional factors that relate to these three major factors include:

- Hauling distance;
- Number of hauling trips required per year;
- The waste volume;
- Average speed of the truck;
- Cost of fuel;
- Cost of maintenance;
- Cost of purchasing the truck;
- Cost for labor for the truck driver; and
- Percentage of facilities in each region and category that incur transport costs under the proposed regulatory options.

Using these factors, the cost model completes the following six steps to determine costs for a model farm:

Step 1) Determine constants, based on region, animal type, and waste type;

Step 2) Determine the weight of the waste transported, accounting for water losses during storage or composting;

Step 3) Determine the number of trucks and number of trips required to haul all of the waste each year;

Step 4) Determine the number of hours required to transport waste each year;

Step 5) Determine the purchase cost for the trucks required to transport the waste; and

Step 6) Determine the annual cost to transport the waste.

Each of these steps is explained in detail below.

Step 1) Determine constants, based on region, animal type, and waste type

Constants used in this evaluation include the hauling distance, the average speed of the truck, the moisture content of stockpiled manure, the moisture content of composted manure, the hours spent hauling per day, the loading and unloading time, the fuel rate, the maintenance rate, the hourly hauling rate, the volume of waste the truck can haul, and the purchase price of the truck.

Hauling Distance

The one-way hauling distance for an operation depends on the region in which it is located and what category operation is being evaluated. For each region, the average distance the waste must be hauled varies according to regional factors. Table 5.9.2-1 presents these distances.

Average Speed

The average speed of the truck is estimated to be 35 miles per hour (USEPA, 1995).

Moisture Content of Waste

Based on available information, the moisture content of stockpiled manure and composted manure is estimated to be 35.4 percent and 30.8 percent, respectively Sweeten, J.M. and S.H. Amosson, 1995).

Working Schedule

The cost model estimated that one laborer requires 25 minutes to load and unload the truck and hauls waste for 7 hours per day (USEPA, 1995).

Fuel Rate

The diesel fuel is estimated to cost $1.35 per gallon (Jewell, W.J., P.E. Wright, N.P. Fleszar, G. Green, A. Safinski, A. Zucker, 1997).

Maintenance Rate

The estimated maintenance rates for liquid and solid waste trucks are $0.63 per hauling mile and $0.50 per hauling mile, respectively (Jewell, W.J., P.E. Wright, N.P. Fleszar, G. Green, A. Safinski, A. Zucker, 1997; USEPA, 1995).

Labor Rate

The rate used in the cost model for the laborer to load, unload, and haul the waste is $10 per hour.

Capacity and Prices of Trucks

The size of the solid waste trucks vary, depending on the amount of waste that is hauled. The standard sizes and purchase prices for solid waste trucks used in the cost model are (USEPA, 1995):

7-cubic-yard truck = $91,728

10-cubic-yard truck = $137,593

15-cubic-yard truck = $183,457

25-cubic-yard truck = $241,054

The size of the liquid waste trucks also varies, depending on the amount of waste that is hauled. The standard sizes and purchase prices for liquid waste trucks used in the cost model are (USEPA, 1995):

1,600-gallon truck = $84,262

2,500-gallon truck = $113,061

4,000-gallon truck = $140,792

Step 2) Determine the weight of the waste transported

The amount of waste to be transported is estimated as the sum of separated solids, lagoon's pond effluent, lagoon's pond accumulated solids, and process and rainwater not applied to land.

Step 3) Determine the number of trips required to haul all of the waste per year

To determine the number of trips per year required to haul all of the waste, the cost model performs the following calculations. First, the size of the truck is determined. Then, the maximum possible number of trips per year is calculated, given the hauling schedule and the number of days the truck is available for transport per year. A test is then performed to see if the truck size selected is large enough to transport all of the waste requiring transport within the time frame calculated as the maximum number of trips per year. If the truck is not large enough, then the cost model assumes that multiple trucks are purchased, and recalculates the equations based on the larger capacity.

The equation for the maximum number of trips per year is:

$$\text{Maximum Trips / yr} = \frac{(\text{Haul Schedule} \times \text{Haul Days})}{(\text{Truck Loading Time} + \text{Truck Unloading Time} + \text{Truck Haul Time})}$$

The capacity of the truck is determined through an iterative process that substitutes the size of the truck (10 cubic yards (CY), 15 CY, and 25 CY) and the number of trucks (1 or 2) into the following equation until the number of trips per year is greater than the maximum number of trips per year:

$$\text{Number of Trips / yr} = \frac{\text{Solid Waste}_{\text{(as collected)}}}{(\text{Number of Trucks} \times \text{Capacity of Truck})}$$

The equation for the actual number of trips per year is:

$$\text{Actual Trips / yr} = \frac{\text{Solid Waste}_{\text{(as collected)}}}{(\text{Number of Trucks} \times \text{Capacity of Truck})}$$

(Note: The number of trucks is rounded up to the nearest whole number.)

Step 4) Determine the number of hours required to transport waste each year

The number of hours required to transport all of the waste each year is based on the hauling time, the loading and unloading time, and the actual number of hauling trips per year, as shown below:

$$\text{Transport Hours} = (\text{Truck Loading Time} + \text{Truck Unloading Time} + \text{Truck Haul Time}) \times \text{Number of Trips}$$

Step 5) Determine the purchase cost of the trucks required to transport the waste

The purchase cost of the truck(s) depends on the number of trucks needed and the cost for that size of truck, as shown below:

$$\text{Purchase Cost} = \text{Number of Trucks} \times \text{Cost of Truck}$$

Step 6) Determine the annual cost to transport the waste

The annual operating and maintenance cost for owning and operating the trucks is based on the fuel spent, the maintenance rate per mile driven, and the labor costs. This is calculated for both the liquid waste transport and the solid waste transport. The equation for the annual cost is:

$$\text{Annual Cost} = (\text{Maintenance Rate} \times \text{Hauling Distance}_{\text{Round-trip}} \times \text{Number of Trips} + \text{Transport Hours} \times \text{Labor Rate} + \text{Hauling Distance}_{\text{Round-trip}} \times \text{Number of Trips} / \text{Fuel Rate}) \times \text{Number of Trucks}$$

5.9.4 Transportation Cost Test

When evaluating costs to transport waste off site, the cost model considered purchasing a truck to transport waste and hiring a contractor to haul waste as the two scenarios for the model beef feedlots, dairies, and veal operations. Because the weight and volume of the manure directly impact the transportation costs, each scenario was also considered with composting the waste prior to hauling and without composting. This section discusses the test used to determine which scenario is least costly for each model farm.

Purpose of the Cost Test

When animal feeding operations are unable to apply all of their waste on site at the appropriate agronomic rate, the waste is transported off site to a location where the waste is applied at the agronomic rate. EPA considered two methods of off-site transport: 1) hiring a contractor to haul the waste; or 2) purchasing a truck to move the waste without third-party assistance. In addition, animal feeding operations can choose to compost their waste before hauling to reduce the weight and volume of the waste and to improve the quality of the end product (see Section 5.12). EPA assumes that operations will choose the transportation and composting pair that is least expensive. To determine which method a beef feedlot, dairy, or veal operation will choose, the cost model conducts a test that compares the costs annualized over 10 years.

For each model farm that transports waste off site under Options 1 through 4, 6, and 7, the cost model assumes that the operation uses one of four transportation scenarios:

1) Composting with contract haul;
2) Composting with purchase truck;
3) No composting with contract haul; and
4) No composting with purchase truck.

For Option 5A, only transportation scenarios with composting are considered.

Cost Test Methodology

The transportation scenario that is costed for each operation is the least costly when annualized over 10 years. To determine this, each transportation scenario is costed separately. The cost for each transportation scenario is then added to the weighted farm costs to create four possible model farm costs, with capital costs and annual costs. Each of these is annualized, using the following equation:

$$A(n) = P \times I \times (1 + I)^n / [(1 + I)^n - 1] + A$$

where:

A(n)	=	Annualized cost over n years
P	=	Capital cost
I	=	Interest rate
n	=	Number of years
A	=	Annual cost.

The least expensive annualized cost of the four transportation scenarios is selected as the preferred scenario.

5.9.5 Results

Appendix A, Table A-13a presents the cost model results for transporting manure waste using contract hauling or purchasing transport equipment when applying on a nitrogen basis for beef feedlots, dairies, and heifer operations. Appendix A, Table A-13b presents the cost model results for transporting manure waste using contract hauling or purchasing transport equipment when applying on a phosphorus basis for beef feedlots, dairies, and heifer operations. Appendix B presents the selected transportation method for each of these model farms.

5.10 Ground-Water Assessment and Monitoring

Storing or treating animal waste at or below the ground surface has the potential to contaminate ground water. Ground-water wells may be used at animal feeding operations to monitor ground-water contamination. For Option 3A/3B, a ground-water assessment is used to determine whether a direct hydrologic connection to surface water exists. Ground-water well installation and associated monitoring is then costed for all model farms where there is a direct hydrologic connection between ground water and surface water.

5.10.1 Technology Description

Manure and waste that infiltrates into the soil, and is not taken up by crops, may contaminate underlying aquifers with nutrients, bacteria, viruses, hormones, and salts. Irrigation of manure may also contaminate aquifers with salt and high levels of total dissolved solids. In turn, such manure and waste may contaminate surface water which has a direct hydrologic connection to the ground water. Ground-water wells can be installed to monitor for these pollutants.

Geologic conditions, as well as the elevation and shape of the water table, vary based on region. A hydrogeologic site investigation may occur prior to well installation to determine site conditions and to determine the number and location of samples as well as the sampling depth.

5.10.2 Design and Costs

The design for the ground-water wells does not vary according to animal type or size of facility. It is assumed that each facility determined to have a direct hydrologic connection will install four 50-foot ground-water monitoring wells, one up-gradient and three down-gradient from the manure storage facility, as shown in Figure 5.10.2-1.

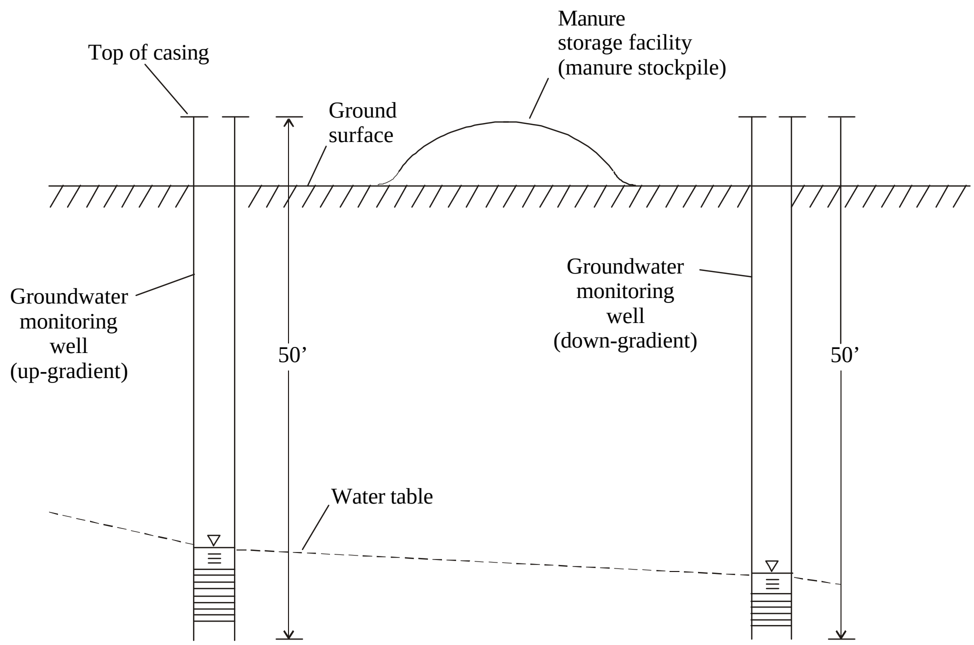


Figure 5.10.2-1. Schematic of Ground-Water Monitoring Wells

Assessment of Crop Field and Ground-Water Links to Surface Water

Because the assessment of ground-water links to surface water requires professional expertise, EPA estimates pay rates of $75 per hour for field work and report writing, and $65 per hour for research related to this task. Assessment activities include a limited review of local geohydrology, topography, proximity to surface waters, and current animal waste management practices. EPA estimates that the assessment activities would require 2 days of work at the operation, 2 days of office work, and 2 days to compile the data into a final report. In addition, EPA assumes that a farmhand spends 8 hours assisting in the assessment. EPA estimated that miscellaneous expenses, including travel time, photocopying, purchasing, maps, and report generation are 15 percent of total costs. This one-time assessment does not vary with the size or type of operation; therefore, the cost is the same for each model farm. The one-time labor cost does not vary by model farm and is calculated as follows:

Professional Labor Cost	=	Field Labor + Research Labor + Report Labor
	=	(2 Days × 8 hr/day) × \$75/hr + (2 Days × 8 hr/day) × \$65/hr + (2 Days × 8 hr/day) × \$75/hr
	=	\$3,440
Farmhand Labor Cost	=	(Time Assisting) × Labor Wage
	=	(1 Day × 8 hr/day) × \$10/hr
	=	8 hrs × \$10/hr
	=	\$80
Total Labor Cost	=	Professional Labor Cost + Farmhand
	=	\$3,440 + \$80
	=	\$3,520

The miscellaneous expenses are 0.15 × \$3,520 = \$528; therefore, the total fixed cost for the assessment of ground-water links to surface water is \$3,520 + \$528 = \$4,048 per model farm. No annual costs are associated with the ground-water assessment.

Total Capital Cost of Well Installation and Initial Sampling

Capital costs for well installation of each well include well drilling at \$21 per foot, well casing at \$2 per foot for the upper 30 feet, well screening of the lower 20 feet at \$3 per foot, gravel for the entire 50 feet at \$1 per foot, surface completion at \$225 per well, and well development at \$100 per well. Additional capital costs include mobilization at \$400 and surveying at \$1,000 (ERG, 2001).

To determine baseline concentrations, an initial ground-water sample is required for each well in the first year after installation to determine baseline concentrations (\$210 per sample, including 3 hours of labor at \$45 per hour and \$75 per well for laboratory analyses of the water sample for total coliform, fecal coliform, nitrate-N, ammonia-N, chloride, and total dissolved solids). Four bailers costing \$35 each and a sounder costing \$25 per day are used to test all wells on the farm. Additionally, there is a \$40 sample shipping fee to send the sample to the laboratory. Subsequent ground-water monitoring costs are incurred as annual costs. An additional sample per well is collected and analyzed in the first year in addition to the initial sample (ERG, 2001).

Capital Cost	=	4 Wells × [Well Drilling + Well Casing + Well Screening + Gravel + Surface Completion + Well Development + Bailer] + Mobilization + Surveying + Sounder + Initial Sampling + Shipping Fee
	=	4 Wells×[($21/ft × 50 ft) + ($2/ft × 30 ft) + ($3/ft × 20 ft) + ($1/ft × 50 ft) + $225 + $100 + $35] + $400 + $1,000 + $25 + (2 samples × $210/sample × 4 wells) + $40
	=	$9,465

Total Annual Cost of Well Installation

Ground water monitoring operational and maintenance (O&M) costs are estimated at 2 percent of capital costs. Additional annual costs include two samples per year for each well, with 3 hours of labor required for each sample at $45 per hour and $75 per sample for laboratory analyses. There is also a $40 sample shipping cost for each sampling event. The total annual cost for ground water monitoring is $1,949 (ERG, 2001).

Annual Cost	=	Sampling + O&M + Labor + Shipping Cost
	=	[4 wells × ($75/sample × 2 samples)] + (0.02 × Capital Cost) + [4 wells × ($45/hour × 3 hour/well × 2 samples)] + ($40/event × 2 events)
	=	$1,949

5.10.3 Results

The cost model results for installing ground water monitoring wells are $4,048 for fixed costs, $9,465 for capital costs, and $1,949 for annual costs for each model facility, regardless of animal type or region.

5.11 Concrete Pads

Animal feeding operations sometimes use pads made of concrete or other similarly impervious material to provide a temporary storage surface for solid and semisolid wastes that would otherwise be stockpiled directly on the feedlot. These wastes include solids separated from the waste stream in a solids separator and manure scraped from drylots and housing facilities. Concrete pads are included as part of a proposed ground water protection option.

5.11.1 Description of Concrete Pads

The pads provide a centralized location for the operation to accumulate excess manure for later use (e.g. bedding, land application, or transportation off site). A centralized location for stockpiling the waste also allows the operation to better control stormwater runoff (and potential associated pollutants). Rainwater that comes into contact with the waste is collected on the concrete pad and is directed to a pond or lagoon, thereby preventing it from being released on the feedlot. Additionally, the pad provides an impermeable base to minimize or prohibit seepage of rainfall leaching through the waste and infiltrating the soil underneath the waste.

The pad serves as a pollution prevention measure. The waste is not treated once it is on the concrete pad; however, through the regular handling of the waste, the nitrogen loadings in the waste will decrease due to volatilization, and both nitrogen and phosphorus may run off the pile into ponds or lagoons after storm events. Pathogen content, metals, growth hormones, and antibiotics loadings are not expected to decrease significantly on the concrete pad.

Based on observations during site visits, only a small number of beef feedlots, dairies, and veal operations have concrete pads, and that number varies by region and not by animal type or size group.

5.11.2 Design

The design for the concrete pad varies according to the type of waste stored on the pad. For dairies that flush the manure, the waste targeted for the concrete pad includes the settled solids from the settling basin, including flushed manure from mature dairy cows in the milking parlor and flush barns. The concrete pad design has two walls to assist in containing the waste, and the maximum height of the manure pile is 4 feet due to the semiliquid state of the waste. Bucking walls are 3.5 foot walls used to help contain semiliquid manure on the concrete pad.

For dairies that hose and scrape the manure, the wastes targeted for the concrete pad are the settled solids from the settling basin and the scraped manure from the barn, including bedding. The concrete pad design has two bucking walls, and the maximum height of the manure pile is 4 feet due to the semiliquid state of the waste.

For beef feedlot and heifer operations, the waste targeted for the concrete pad is the scraped manure from the drylots, including bedding. The concrete pad design has no bucking walls, and the maximum height of the manure pile is 15 feet, because the manure is dryer and can be stacked more easily.

Concrete pads are 6 inches thick, and contain reinforced concrete to support the weight of a loading truck. The concrete pad is underlain by 6 inches of gravel and 4 inches of sand. Additionally, the sides of the concrete pad are sloped, which will divert stormwater runoff from the pile to the on-site waste management system, such as a lagoon or a pond. Bucking walls are 8 inches thick and 3 feet to 4 feet tall, and made with reinforced concrete. Figure 5.11.2-1 presents the detail of these specifications (MWPS, 1987; USDA NRCS, 1996).

The design of the concrete pad is primarily based on the volume of waste that is costed for storage. First, the dimensions of the waste pile are calculated, assuming that the pile is in the shape of a paraboloid (see Figure 5.11.2-1). Then, using the waste pile dimensions, pad dimensions are calculated.

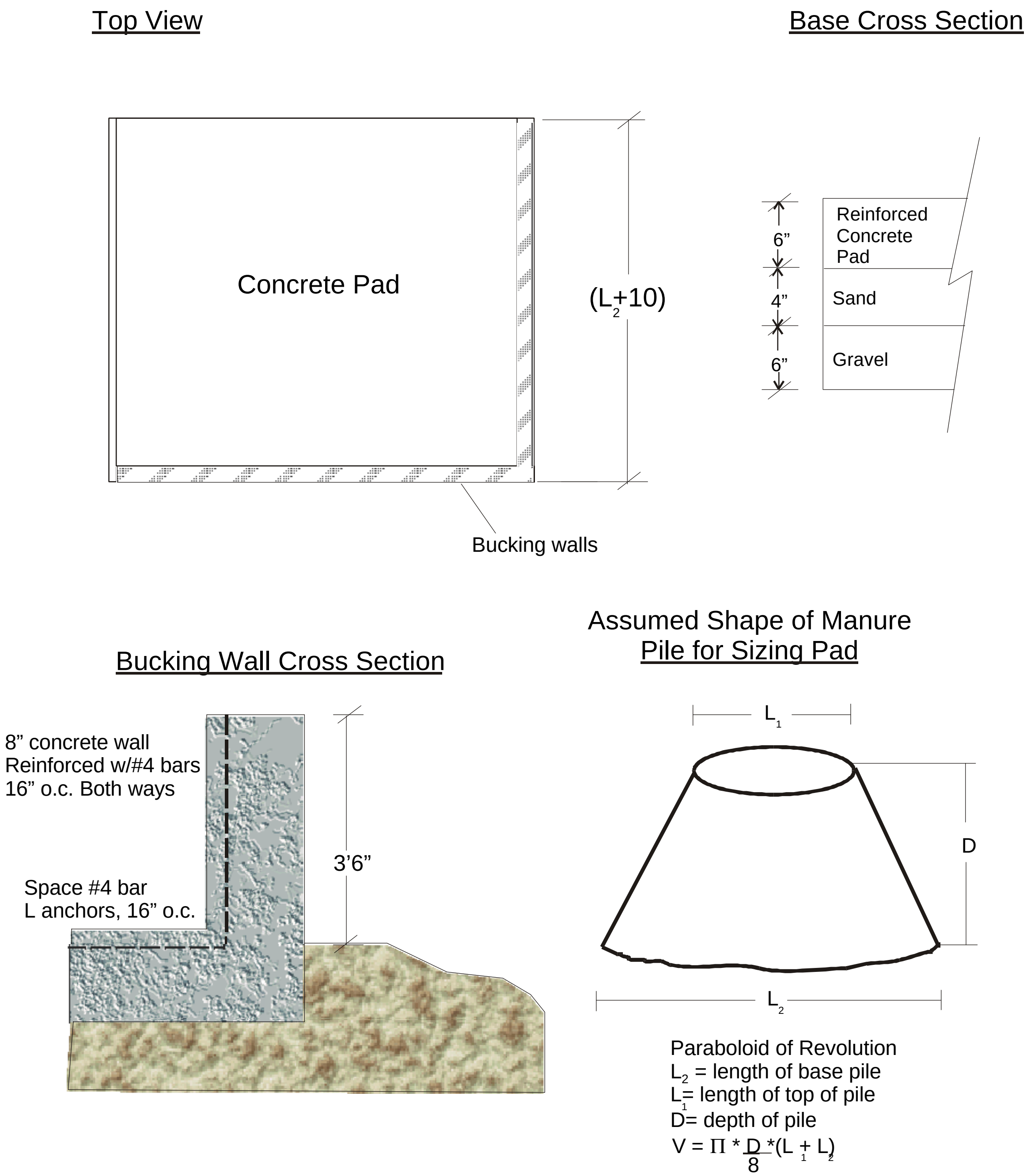


Figure 5.11.2-1. Concrete Pad Design

Dimensions of the Waste

To estimate the volume of waste the pad must store over the storage period, the following parameters are needed: the storage period, the volume of waste, the volume of bedding in the waste, the moisture content of the waste, and the unit weight of the waste.

Beef Feedlots and Stand-Alone Heifer Operations

For beef feedlots and heifer operations, the model assumes that all cattle are kept on drylots. These lots are periodically scraped, and the manure is removed to the stockpile. Some of the manure solids are lost in the runoff from the feedlot (runoff contains 1.5 percent solids (MWPS, 1993) before the waste is stockpiled. For Options 3 and 4, which require ground water protection, drylot wastes are stockpiled on a pad. Because beef waste on the drylot is fairly dry, the maximum stacking height assumed for the stockpile is 15 feet. The model assumes that the necessary waste storage period for beef waste is 90 days.

Manure scraped from drylots includes bedding. Bedding is assumed to have a unit weight of 6 lb/ft (USDA NRCS, 1996). For this cost model, it is assumed that 2.7 pounds of bedding are used per 1,000-lb animal per day. The volume of bedding collected from the drylot is calculated by the following equation:

$$\text{Bedding} = \text{Average Head} \times \frac{2.7 \text{ lb bedding}}{1{,}000\text{-lb animal}} \times \text{Animal Weight} \times \frac{\text{ft}^3}{6 \text{ lb}} \times 0.50$$

where:

0.50 = The void ratio of the bedding.

The maximum volume of beef feedlot waste stored on the concrete pad is calculated as follows:

$$\text{Volume}_{\text{to pad}} = \text{Drylot Manure} \times \frac{90 \text{ days}}{62 \text{ lb / ft}^3} + \text{Bedding} \times 90 \text{ days} - \text{Runoff Solids}$$

where:

Runoff Solids = 0.015 × 90-day Runoff (see Section 4.7).

Hose Dairies

For hose dairies, the model assumes that the milking cows are kept in confinement barns 85 percent of the day and in the milking parlor 15 percent of the day (USDA NRCS, 1996). Manure deposited in the milking parlor is hosed down and sent to a concrete gravity settling basin (see Section 5.2). For Options 3 and 4, which require ground water protection for some operations, the separated solids are stockpiled. The settling efficiency of the basin is estimated to be 50 percent (i.e., the settling basin removes 50 percent of the solids from the waste). The moisture content of excreted dairy manure is 87.2 percent (Lander, C.H. D. Moffitt, and K.Alt, 1998). Settled solids are assumed to enter the stockpile at 65 percent moisture (NCSU, 1993). Manure deposited in the confinement barns is scraped along with the bedding and also stockpiled on the pad. Waste from heifers and calves is deposited and remains on a drylot. Because dairy waste from the settling basin is fairly wet, the maximum stacking height assumed for the stockpile is 4 feet. The model assumes that the necessary waste storage period for dairy waste is 180 days.

The maximum volume of hose dairy waste stored on the concrete pad is calculated as follows:

$$\text{Volume}_{\text{to pad}} = \text{Barn Manure} \times \frac{180 \text{ days}}{62 \text{ lb/ft}^3} + \text{Bedding} \times 180 \text{ days} + \text{Separated Solids}$$

where:

Separated Solids = Milking Parlor Manure × 180 days / (62 lb/ft^3) × (1-0872) / (1-0.65) × Efficiency

Efficiency = 0.50.

Flush Dairies

For flush dairies, the model assumes that the milking cows are kept in confinement barns 85 percent of the day and in the milking parlor 15 percent of the day (USDA NRCS, 1996). Manure deposited in the confinement barns and the milking parlor is flushed to a concrete gravity settling basin (see Section 5.2) (Because of the configuration of the flush alleys, no bedding is assumed to be flushed with the manure.) For Options 3 and 4, which require ground water protection for some operations, the separated solids are stockpiled on a concrete pad. The model uses a settling efficiency of 50 percent (i.e., the settling basin removes 50 percent of the solids from the waste). The moisture content of excreted dairy manure is 87.2 percent. Settled solids are assumed to enter the stockpile at 65 percent moisture. Waste from heifers and calves on drylots is not moved to the stockpile. Because dairy waste from the settling basin is fairly wet, the maximum stacking height assumed for the stockpile is 4 feet. The model uses a 180-day storage period for dairy waste is 180 days.

The maximum volume of flush dairy waste stored on the concrete pad is calculated as follows:

$$\text{Volume}_{\text{to pad}} = \text{Separated Solids}$$

where:

Separated Solids = (Barn Manure + Milking Parlor Manure) × 180 days/ (62 lb/ft^3) × (1-0.872) / (1-0.65) × Efficiency.

Shape of the Stockpile

The shape of the stockpile is assumed to be parabolic, as shown in Figure 5.11.2-1. Using the volume calculated for each animal and farm type and the assumed maximum depth, the shape of the stockpile at maximum concrete pad capacity is calculated as shown in the following equation:

$$Volume_{to\ pad} \frac{\Pi \times D}{8} \times (L_1^2 + L_2^2)$$

$$\text{Assume } L_1 = 0.5 \times L_2$$

$$L_2 = \sqrt{\frac{8 \times Volume_{to\ pad}}{1.25 \times \Pi \times D}}$$

As shown in Figure 5.11.2-1, L_2 is the bottom diameter of the pile. Assuming the concrete pad is square, its minimum dimensions are $L_2 \times L_2$.

Dimensions of Concrete Pad

To account for walking and moving equipment around the pile, 10 feet are added to the minimum dimensions; therefore, the concrete pad dimensions are determined using the following equation;

$$\text{Area} = (L_2 + 10) \times (L_2 + 10)$$

The perimeter of the area is then:

$$\text{Perimeter} = (L_2 + 10) \times 2 + (L_2 + 10) \times 2$$

The walls for the pad run the length of two sides of the pad. The walls are 3 feet 6 inches high and 8 inches thick, built with concrete reinforced with #4 bars, 16 inches o.c. both ways. Figure 5.11.2-1 presents a cross-section of the bucking wall design. The equation for calculating the volume of concrete needed to construct the bucking walls is:

$$\text{Wall Volume} = 2 \times ((L_2 + 10) \times 3.5 \times 8 / 12)$$

5.11.3 Costs

Table 5.11.3-1 presents the unit costs are used to calculate the capital and annual costs for constructing the concrete pad.

Table 5.11.3-1

Unit Costs for Concrete Pad

Unit	Cost (1997 dollars)	Source[a]
Compaction	$\$0.41/yd^3$	Means 1996 (022 226 5720)
Gravel Fill	$\$9.56/yd^2$	Means 1998 (022 308 0100)
Sand Fill	$\$48.55/yd^3$	Richardson 1996, (3-5 p1)
6" Concrete Pad	$\$116.29/yd^3$	Means 1999 (033 130 4700)
Concrete Finishing	$\$0.33/ft^2$	Means 1998 (033 454 0010)
Concrete Bucking Walls	$\$300.41/yd^3$	Means 1999 (033 130 6200)
Sand Grading	$\$1.73/ft^3$	Means 1999 (025 122 1100)
Hauling Gravel and Sand	$\$4.95/yd^3$	Means 1998 (022 266 0040)

[a]For information taken from Means, the numbers in parentheses refer to the division number and line number.

Concrete Pad Costs

The costs for the concrete pad include the compaction of the ground surface, hauling gravel and sand to the lot, purchasing the gravel and sand, grading the sand, constructing the 6-inch pad, and finishing the concrete on the 6-inch pad. These calculations are shown below:

$$\text{Compaction (to 12 inches)} = \$0.41/yd^3 \times \frac{\text{Pad Area } (ft^2) \times 1 \text{ ft}}{27\ ft^3/yd^3}$$

$$\text{Hauling Cost for Sand and Gravel} = \frac{(\text{Gravel volume} + \text{Sand volume})}{27\ ft^3/yd^3} \times \$4.95/yd^3$$

$$\text{Volume of Gravel for 6-inch Layer} = \frac{\text{Pad Area } (ft^2) \times 6 \text{ in}}{12 \text{ in/ft}}$$

$$\text{Volume of Sand for 4-inch Layer} = \frac{\text{Pad Area } (ft^2) \times 4\text{-inch}}{12 \text{ inches/ft}}$$

Gravel Cost = Gravel (ft^3)/ft × \$9.56/yd^2/0.5 ft^2 × 1 yd^2/9 ft^2

Sand Cost = Sand (ft^3) × \$48.55/yd^3 × 1 yd^3/27 ft^3

Grading Sand = Sand (ft^3) × \$1.73/ ft^3

6-Inch Pad = Pad Area (ft^2) × \$116.29/yd^3 × 0.5 ft/yd^3 × 1 yd^3/27 ft^3

Concrete Finishing = Pad Area (ft^2) × \$0.33/ft^2

Bucking Wall Costs

The cost for bucking walls is the volume of the bucking walls multiplied by the cost per cubic yard. (This cost is only added for dairies.)

Walls Cost = Wall Volume (ft^3) × \$300.41/yd^3 × 1 yd^3/27 ft^3

Total Capital Costs

The cost for construction of the concrete pad (and walls, if applicable) is calculated using the following equation:

Capital Cost = Compaction + Hauling + Gravel + Sand + Grading Sand + 6-inch Pad + Concrete Finishing + Bucking Walls

Total Annual Costs

Based on best professional judgement, annual costs are estimated at 2 percent of the total capital costs based on best professional judgment.

Annual Cost = 2% × Capital Cost

5.11.4 Results

The cost model results for constructing a concrete pad are presented in Appendix A, Table A-14.

5.12 Composting

Some animal feeding operations use composting to biologically stabilize and dry waste for use as a fertilizer or soil amendment. Composting reduces the weight and moisture content of manure, which can lower transportation costs. Although many operations stockpile manure, a true composting operation is rare. Composting is evaluated as a method of handling animal waste on site at beef feedlots, heifer operations, and dairies for all regulatory options. The cost model includes composting if the cost benefit of composting exceeds the costs for that model farm. However, for Option 5A, composting is included for all beef feedlots, heifer operations, and dairies. Mortality composting facilities are included for all swine and poultry operations under groundwater options.

5.12.1 Technology Description

Composting is an aerobic process in which microorganisms decompose organic matter into heat, water, carbon dioxide, and a more stable form of organic matter (compost). Composting, which reduces the initial volume, weight, and particle size of raw materials, results in a relatively uniform, dry, odorless end product that can be used as a soil amendment. The elevated temperatures in the interior of properly operated compost piles kill weed seeds, pathogens, and fly larvae.

Because composting is an aerobic process, a continuous supply of oxygen must be available for the microorganisms to break down the organic matter. Aeration can be accomplished either by natural convection and diffusion or forced aeration. Aeration reduces the chance of the pile becoming anaerobic, at which point decomposition is slower and compounds with strong odors are produced. Aerating the pile also helps to remove excess heat and trapped gases from the composting pile.

Composting time and efficiency are affected by the amount of oxygen, the energy source (carbon) and amount of nutrients (nitrogen) in the raw materials, the moisture content, and the particle size and porosity of the materials. The amounts of carbon, nitrogen, and moisture should be properly balanced in the initial compost mix. Moisture levels should be in the range of 40 to 65 percent. Water is necessary to support biological activity; however, if the moisture content is too high, water displaces air in the pore spaces and the pile can become anaerobic. Moisture content gradually decreases during the composting period. The carbon to nitrogen ratio (C:N) should be between 20:1 and 40:1. If the C:N ratio is too low, the carbon is used before all the nitrogen is stabilized and the excess nitrogen can volatilize as ammonia and cause odor problems. If the ratio is too high, the composting process slows as nitrogen becomes the limiting nutrient. Manure typically needs to be mixed with drier, carbonaceous material to obtain the desired moisture and C:N levels.

The length of time required for composting depends on the materials used, the composting management practices, and the desired compost characteristics. Composting is judged to be complete by characteristics related to its use and handling such as C:N ratio, oxygen demand, temperature, and odor. A curing period of about one month during which resistant compounds, organic acids, and large particles are further decomposed, follows composting.

5.12.2 Design

The cost methodology for all considered options included windrow composting at beef feedlots, dairies, and heifer operations. If the volume reduction resulting from composting resulted in a more cost effective option, then composting was selected as a waste management technology. The cost methodology for swine and poultry operations included mortality composting under ground water options. Each of these composting methods are described below.

Windrow Composting for Beef Feedlots, Dairies, and Heifer Operations

Windrow composting systems are designed for use at beef feedlots, heifer operations, and dairies. Manure and other raw materials are formed into windrows and periodically turned. The size and shape of the windrow depends on the type of turning equipment used by the site. The cost model assumes that sites use a tractor attachment for turning made by Valoraction, Incorporated (NRAES, 1992) (see Figure 5.12.2-1). This type of windrow turner can turn windrows 10 feet wide by 4.2 feet tall. Windrow composting requires less labor and equipment than other types of composting and allows greater flexibility with respect to location and composting amendments.

Beef feedlots and heifer operations can compost the manure collected from the drylots. Because dairies and veal operations use flush and hose systems, their waste is too wet for composting. However, the manure from calves and heifers kept on drylots at dairies can be composted. Separated solids from sedimentation basins can also be added to the compost pile.

A typical mortality composting facility consists of two stages, primary and secondary (USDA NRCS, 1996). The first stage consists 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 usually just one bin or concrete area 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.

Volume of Manure

The cost model calculates the volume of waste transferred to the compost pile from drylots and from settling basins.

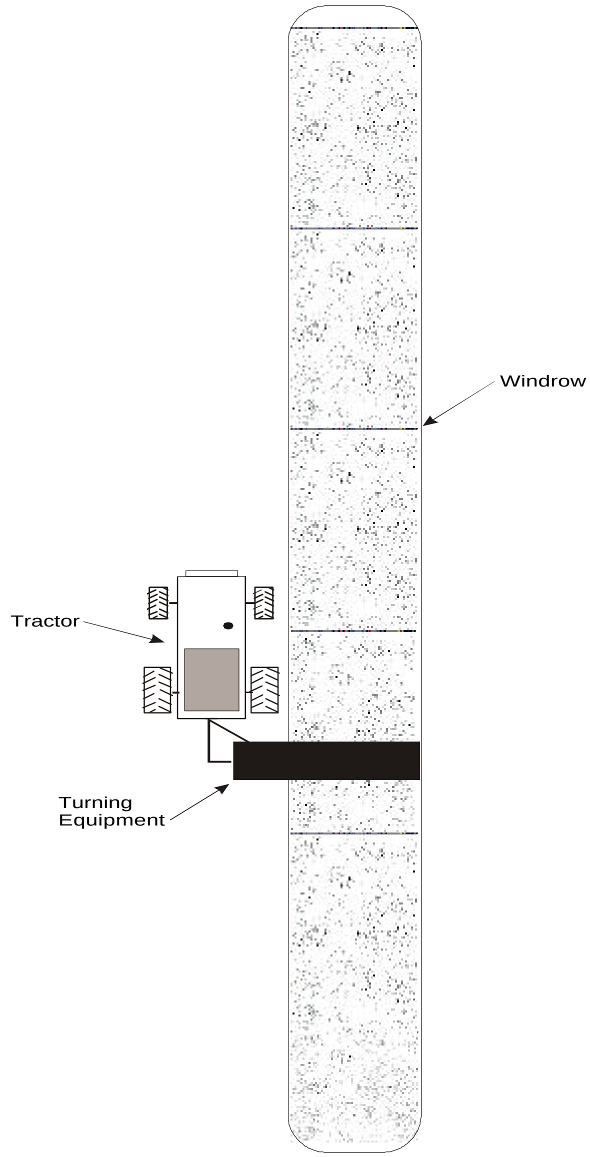


Figure 5.12.2-1. Windrow Composting

Drylots

The cost model assumes that all beef cattle, dairy calves, and heifers are kept on drylots. Manure from drylots is periodically scraped and moved to the compost pile. The amount of manure generated (as-excreted) is calculated using the information and equations in Section 4.6. The volume of manure collected from the drylot is less than the as-excreted volume because the manure moisture content decreases on the drylot. Because the volume of solids in the as-excreted manure is the same as in the collected manure, the volume of manure collected from the drylot can be calculated using a mass balance on solids using the following equations:

$$\text{Volume Solids}_{\text{collected}} = \text{Volume Solids}_{\text{excreted}}$$

$$\text{Volume Solids} = \text{Total Volume} \times (1 - \text{Moisture})$$

$$\text{Volume}_{\text{collected}} (1 - \text{Moisture}_{\text{collected}}) = \text{Volume}_{\text{excreted}} (1 - \text{Moisture}_{\text{excreted}})$$

$$\text{Volume}_{\text{collected}} = \frac{[\text{Volume}_{\text{excreted}} (1 - \text{Moisture}_{\text{excreted}})]}{(1 - \text{Moisture}_{\text{collected}})}$$

The cost model estimates that manure collected from the drylot has a moisture content of 35.4 percent (Sweeten, J.M. and S.H. Amosson, 1995). The values of the parameters used to compute the volume of manure are contained in the manure reference table and cost run information in the cost model.

Some of the manure solids that accumulate on drylots are lost in the runoff from the feedlot before the waste is composted; therefore, the solids lost in runoff are subtracted from the total volume of manure. The amount of solids lost in runoff is estimated at 1.5 percent of the total drylot runoff (MWPS, 1985).

Settling Basins

Option 5A includes the addition of separated solids from the settling basin to the compost pile. Because wastes from dairy flush barns have a high moisture content, they are generally not composted; however, the settled solids from sedimentation basins can be added to the compost pile. Therefore, a fraction of the manure from mature dairy cows barns is added to the compost pile after some drying has occurred. For beef feedlots, only runoff enters the sedimentation basins; therefore, a fraction of the solids entering the basin as runoff is added to the compost pile.

For dairies, the cost model calculates the amount of separated solids by computing the amount of manure generated in the barn and parlor and multiplying by the settling efficiency of

50 percent (see Section 5.1). For beef and heifer feedlots, the additional volume added to the compost pile from the settling basin is the annual solids in runoff multiplied by the settling efficiency.

Volume Reduction

One of the major benefits of composting is waste volume reduction, which can reduce transportation costs. Finished compost is estimated to contain 30.8 percent moisture (Sweeten, J.M. and S.H. Amosson, 1995). This moisture content is used in the following equation to determine the weight of finished compost:

$$\text{Final Weight} = \text{Initial Weight} \times \frac{(1 - \text{Initial Moisture})}{(1 - \text{Final Moisture})}$$

Mortality Composting for Swine and Poultry Operations

The volume needed for mortality composting includes the dead animals and the other materials included in the compost mix. This mix of animals and compost ingredients is addressed in the cost model by using the factor of 2 cubic feet per pound of dead bird in the following equation:.

$$\text{MortVolume} = \text{nohead} \div \text{deadlen} \times \text{deadwt} \times \text{pctdead} \times 2 \times 1.5$$

where:

MortVolume	=	Total volume required, ft^3
Nohead	=	Number of animals
Deadlen	=	Lifespan of the animal, days/cycle
Deadwt	=	Market weight of the animal, lbs/head
Pctdead	=	Mortality rate (%/cycle expressed as a decimal fraction)
2	=	Primary plus secondary storage cubic feet per pound of dead animal (Barker, J.C., 2000)
1.5	=	Safety factor for catastrophic events.

Compost Recipe

As stated in Section 5.12.1, manure must be mixed with composting amendments to obtain the proper C:N ratio and moisture content. The cost model assumes that wheat straw is used as the composting amendment. Wheat straw has a moisture content of 10 percent and a C:N ratio of 130. Manure collected from drylots has a moisture content of 35.4 percent. The carbon content is calculated from the volatile solids composition of manure. It is estimated that manure has a volatile solids composition of 564.6 lb/ton (Sweeten, J.M. and S.H. Amosson, 1995). The carbon content is calculated using the following equation (USDA NRCS, 1996):

$$Carbon_{manure} = \frac{Volatile\ Solids_{manure}}{1.8} = \frac{564.6}{1.8} = 314$$

The nitrogen content of manure is estimated to be 25.71 lb/ton (Sweeten, J.M. and S.H. Amosson, 1995). The carbon and nitrogen contents are converted to a percent basis. The C:N ratio of the manure is calculated using the percent composition and the volume of manure. Wheat straw and water are added to the compost mix until the C:N ratio is between 25:1 and 40:1 and the moisture content is between 40 and 65 percent. The cost model simulates this method in the composting cost module, performing an iteration to determine the proper mix of manure, wheat straw, and water.

5.12.3 Costs

Capital costs for windrow composting include turning equipment and thermometers to monitor the pile temperature. Annual costs include the labor to turn the pile and any required composting amendment (in this case, wheat straw and water). Additionally, EPA assumes that operations would be able to recoup some costs of composting by selling composted manure. EPA assumes that the cost recouped equals the difference between the selling price of uncomposted manure and composted manure. Table 5.12.3-1 presents the 1997 unit costs for these items.

Table 5.12.3-1

Unit Costs for Composting

Unit	Cost (1997)	Source
Windrow turning equipment (Valoraction 510 rotary drum turner tractor attachment)	$8,914	On-Farm Composting Handbook, NRAES-54
Thermometers	$242.27 (for set of two)	Omega Engineering
Turning labor	$2.69/ton	On-Farm Composting Handbook, NRAES-54
Water	$0.00203 per gallon	EPA, Technical Development Document for Metal Products and Machinery Effluent Limitation Guidelines, in progress.
Value of manure fertilizer (based on nitrogen and phosphorus)	$4.99 per ton	Manure Quality and Economics, J.M. Sweeten, S.H. Amosson, and B.W. Auverman.
Value of composted manure (based on nitrogen and phosphorus)	$6.69 per ton	
Wheat straw	$72.68/ton	Case's Agworld.com

Capital costs for mortality composting are calculated assuming a depth of 5 feet. Then, the square footage of the composting facility is calculated from the volume. The cost model uses a construction cost of $7.50 per square foot for mortality compost facilities, based on the price of a poultry drystack/composter with concrete floor and wooden walls (USDA NRCS, 2002a). The capital cost is determined with the following equation:

$$\text{Capital Cost} = \text{MortVolume} \div 5 \times 7.50$$

Total Capital Costs

The following equation is used to calculate the windrow composting capital cost:

$$\text{Capital Cost} = \text{Windrow Turning Equipment} + \text{Thermometers}$$
$$= \$8,914 + \$242.27$$

The total capital costs for windrow composting is $9,156.27.

The total capital cost for mortality composting structures varies with the size of the operation, and is calculated as follows:

$$\text{Capital Cost} = \frac{\text{Mortality Volume}}{\text{5 ft depth}} \times \$7.50 \text{ per square foot.}$$

Total Annual Costs

The volume of wheat straw required is used to determine the cost of the composting amendments. The total volume of the compost pile is used to calculate the labor costs for turning. The following equation is used to calculate the composting annual costs (Sweeten, J.M. and S.H. Amosson, 1995):

$$\text{Annual Cost} = (\$2.69/\text{ton} \times \text{Volume}_{\text{collected}}) + (\$72.68/\text{ton} \times \text{Volume}_{\text{wheat straw}}) + (\$1.75/100\text{cf} \times \text{Volume}_{\text{water}}) - (\$1.70 \times \text{Selling Weight}/2000)$$

where:

$\text{Volume}_{\text{collected}}$	=	Volume of manure collected for compost
$\text{Volume}_{\text{wheat straw}}$	=	Volume of wheat straw added to balance carbon/nitrogen ratio
\$1.75	=	Cost of water per 100 cubic feet
$\text{Volume}_{\text{water}}$	=	Volume of water added to mixture
\$1.70	=	Net value of compost as a fertilizer, subtracting value of manure as fertilizer (Sweeten, J.M. and S.H. Amosson, 1995)
Selling weight	=	Final composted weight of manure mixture.

Manure solids are expected to be reduced after composting; however, with the addition of the carbon amendments, the weight of compost to be transported or land applied is not significantly different than that manure that is not composted. The cost model calculates these differences, however, and considers them in calculating transportation costs, described in Section 5.9.

At poultry operations, annual costs include both operation and maintenance costs. It is assumed that a sufficient supply of amendments is available on site. EPA estimates that mortality transportation, loading, and turning in compost bins requires 90 hours per year. The value of tractor usage is $30/hour, and the labor rate is set at $10/hour. The capital cost of the mortality composting facility is multiplied by .02 to estimate the annual maintenance cost of the facility. The total annual cost for mortality composting is therefore determined from the following equation:

$$\text{Annual Cost} = 90 \times (30 + 10) + .02 \times \text{Capital Cost}$$

5.12.4 Results

Appendix A, Table A-15 presents the cost model results for composting at each model farm.

5.13 <u>Anaerobic Digestion with Energy Recovery</u>

Anaerobic digesters are sometimes used at animal feeding operations to biologically decompose manure while controlling odor and generating energy. In the United States, as of 1998 there were about 94 digesters that were installed or were planned for working dairy, swine, and caged-layer poultry operations (Lusk, P., 1998). Of these 94 digesters, more than 60 percent of plug flow and complete mix digesters and 12 percent of the covered lagoon digesters have failed (Lusk, P., 1998). Many of these failures were of systems constructed prior to 1984; since that time, more simplified digester designs have been implemented, which have greatly improved reliability. Very few dairies in the United States have operable digesters with energy recovery.

Anaerobic digestion with energy recovery is used as the cost basis for Option 6. Under this option, only large dairies and large swine operations are costed for installation of an anaerobic digester, with energy recovery system.

5.13.1 Technology Description

Anaerobic digestion is the decomposition of organic matter in the absence of oxygen and nitrates. Under these anaerobic conditions, the organic material is stabilized and is converted biologically to a range of end products, including methane and carbon dioxide. Anaerobic treatment reduces BOD, odor, and pathogens, and generates biogas (methane) that can be used as a fuel. The methane-rich gas produced during digestion may be collected as a source of energy to offset the cost of operating the digester. Liquid and sludge from the system are applied to on-site cropland as fertilizer or irrigation water, or are transported off site.

Anaerobic digesters are specially designed tanks or concrete basins that can anaerobically decompose volatile solids in the manure to produce biogas. Manure and/or process wastewater may be routed to these digesters for storage and treatment. Depending on the waste characteristics, one of the following main types of anaerobic digesters may be used:

- Plug flow;
- Complete mix; and
- Covered lagoon.

Plug flow digesters are applicable for treating wastes with high (>10 percent) solids content, while covered lagoons are appropriate for treating wastes with low (<2 percent) solids content. Complete mix digesters are used for treating wastes with a solids content between 2 and 10 percent. The plug flow and the complete mix digesters are applicable in virtually all climates as they use supplemental heat to ensure optimal temperature. Covered lagoons generally do not use supplemental heat and are most effectively used in warmer climates (USEPA, 1996).

A plug flow digester is a constant volume, flow-through long tank with a gas-impermeable expandable cover. Manure waste is added to the digester daily, slowly pushing the older manure plugs through the tank. Average manure retention times range from 15 to 20 days. The gas-impermeable cover maintains anaerobic conditions inside the tank and collects the biogas through attached pipes (USEPA, 1997b).

A complete mix digester is a heated, constant volume, mechanically-mixed tank with a gas-impermeable collection cover. Manure waste is preheated and added daily to the digester, where it is intermittently mixed to prevent formation of a crust and to keep solids in suspension. Average manure retention times range from 15 to 20 days. The gas-tight cover maintains anaerobic conditions inside the tank and collects the biogas through attached pipes. The heat generated by burning the collected biogas is used to heat the digester (USEPA, 1997a).

A covered lagoon digester is the simplest type of methane recovery system. This digester consists of two basins, one of which is topped with a gas-impermeable cover. This floating impermeable cover is typically made of high density polyethylene (HDPE) or polypropylene. The cover may be designed as a "bank-to-bank" cover, which spans the entire lagoon surface with a fabricated floating cover, or as a "modular" cover, in which the cover comprises smaller sections. Biogas collects under the cover and is recovered for use in generating electricity. The second basin is uncovered and is used to store effluent from the digester. Often, manure waste is treated through a solids separator prior to the covered lagoon digester to ensure the solids content is less than 2 percent (USEPA, 1996).

Selection of the type of digester is dictated by the percent solids expected in the manure waste. To estimate the costs for a digester system, dairies that operate flush cleaning systems are assumed to use a covered lagoon system following a settling basin, while dairies that operate scrape systems are assumed to use a complete mix digester following a settling basin. The design of the digester and methane recovery system is based on the AgSTAR FarmWare model (EPA, 1997a). The design and cost of the concrete settling basins are discussed in Section 5.2.

5.13.2 Design

Dairy

Inputs to the FarmWare model are based on the model farm characteristics for a large dairy. The FarmWare model requires input data on the livestock type, number of animals, geographic location, method of manure collection, and the type of waste management system. Table 5.13.2-1 summarizes the inputs used for both the covered lagoon and complete mix digesters. User-selected input values are noted with the letter “S” in brackets, [S]. Default input values that are selected are noted with an [S,d].

The representative region used for the large dairy is Tulare County, California. The model farm is assumed to have 1,450 cows, 435 heifers, and 435 calves in free stalls. The farm is evaluated for both a covered lagoon digester and a complete mix digester.

Based on the input data provided, FarmWare calculates the influent and effluent waste to and from the digester and the specific design and operating parameters. For the large dairy, the FarmWare model calculates a total manure generation of about 187,000 lb/day. With an average volatile solids (VS) production of 8.5 lb/day per 1,000 pounds of animal, the FarmWare program estimates a total VS production of about 18,000 lb/day. The model also generates the design specifications for each system as shown in Table 5.13.2-2.

Table 5.13.2-1

FarmWare Input Table

Input Data	Type of Digester	
	Covered Lagoon Digester	Complete Mix Digester
Climate Data		
County, State	Tulare, California [S]	
Rainfall	Determined by FarmWare [S,d]	
Recommended Minimum Lagoon Hydraulic Retention Time	42 days	
Recommended Maximum Lagoon Loading	10 lb VS/1,000 cu ft	
25-yr, 24-hr Storm	3.5 inches	
Annual Runoff Unpaved	23% of precipitation	
Annual Runoff Paved	50% of precipitation	
Annual Evaporation	55 inches	
Farm Type		
Farm Type	Dairy: Freestall [S]	
Farm Size (Farm Number)	1,450 milking cows [S] 435 heifers [S] 435 calves [S]	
Manure Collection Method	Flush parlor/ Flush freestall barn [S]	Flush parlor/ Scrape freestall barn [S]
Waste Treatment System	Methane recovery lagoon [S]	
Pretreatment	Settling basin [S]	NA

[S] = User selected input.
[d] = Default input.
NA - Not applicable.

Table 5.13.2-2

FarmWare Design Information

Design Information	Type of Digester	
	Covered Lagoon Digester	Complete Mix Digester
Waste Characteristics		
Amount of Influent Manure (lb)	1,656,696	239,325
Rainfall (lb)	14,883	NA
Amount Digested (lb)	23,642	76,285
Effluent (lb)	1,647,937	163,040
Design Parameters		
Hydraulic Retention Time (days)	42	20
Depth (ft)	20	20
Dimension (ft)	285 × 285	73 diameter
Freeboard (ft)	1	1
Slope (hor/ver)	2	NA
Total Volume (ft^3)	1,211,167	84,272

NA- Not applicable.

5.13.3 Costs

FarmWare calculates the cost to construct the digester, with or without energy recovery equipment. Option 6 costs were calculated including the cost for energy recovery equipment, the cost for water use, as well as an additional 15 percent of the capital costs estimated by FarmWare to account for contingency items.

The biogas that is collected during the digestion process may be used to produce electricity and propane. FarmWare allows the user to assign a unit value for electricity to estimate the amount of cost savings the farm would receive by recovering biogas for energy use. For Option 6 costs, a national average unit price for electricity of 7.4 cents per kilowatt hour (kWh) is used (USDOE, 1998).

The model also allows the user to assign a dollar value for benefits such as odor and pathogen reduction. For the Option 6 costs, no dollar value is assigned for these benefits.

Large Dairy - Covered Lagoon System

For this analysis, it is assumed that the cows spend 4 hours per day in the milking parlor and 20 hours per day in the barn, and the heifers and calves spend 24 hours per day in drylots. The milking parlor and the barn use a flush system for manure removal, and the wastewater is sent to a covered anaerobic lagoon through a settling basin. The manure from the feed apron and the drylots is scraped and applied to cropland.

The total lagoon digester volume is calculated to be about 1,200,000 cubic feet. With a lagoon depth of 20 feet, the linear surface dimensions are estimated to be 285 feet by 285 feet, representing a total area of about 81,225 square feet that requires an industrial fabric cover, such as an HDPE cover. Table 5.13.2-2 presents the design information for the covered lagoon digester, as determined by the FarmWare model.

The capital cost of a primary digester lagoon with cover is $111,000 and the engine generator is $80,000. Other engineering costs total $25,000. The total capital cost is $216,000. Annual costs include the FarmWare estimated operating savings, water costs for dilution water, and an estimated 15 percent of the total capital costs. The net annual operating cost is estimated to be ($63,994) per year (i.e., a net savings). This annual operating cost does not reflect additional potential decreases in transportation costs, due to the reduction in solids a digester causes. (Transportation costs are considered in Section 5.9 of this report).

Large Dairy - Complete Mix Digester System

For this analysis, it is assumed that the cows spend 4 hours per day in the milking parlor, which uses a flush system for manure removal and 20 hours per day in the freestall barn, and the heifers and calves spend 24 hours per day in drylots. The wastewater from the milking parlor goes through a mix tank before going to the complete mix digester. The manure in the freestall barn and the drylots is scraped and applied to cropland.

The total digester volume is calculated to be about 84,000 cubic feet. With a digester depth of 20 feet, the diameter is estimated to be 73 feet, with a total area of 4,200 square feet. Table 5.13.2-2 presents the design information for the complete mix digester, as determined by the FarmWare model.

The capital costs for the complete mix digester is $127,000, the mix tank is $26,000, and the engine generator is $187,000. Other engineering costs total $25,000. The total capital cost is $364,857. Annual costs include the FarmWare estimated operating savings, water costs for dilution water, and an estimated 15 percent of the total capital costs. The net annual operating cost is estimated to be ($85,969) per year (i.e., a net savings). This annual operating cost does not reflect potential decreases in transportation costs, due to the reduction in solids a digester causes. (Transportation costs are considered in Section 5.9 of this report.)

Swine Operations

The capital and annual costs for digesters were determined from the following two equations using data from Table 5.13.3-1:

$$\text{Capital Cost} = \text{nohead} \times \text{capheadcost}$$

$$\text{Annual Cost} = \text{nohead} \times \text{annheadcost}$$

where:

Nohead	=	Number of animals
Capheadcost	=	Capital cost per animal
Annheadcost	=	Annual cost per animal.

Table 5.13.3-1

Digester Costs for Swine

Manure Type	Operation Type	Region	Capital Cost ($ per Head)	Annual Cost ($ per Head)
Pit	Grower-Feeder	Mid-Atlantic	41.3	-6.31
	Grower-Feeder	Midwest	42.1	-5.77
	Farrow-Feeder	Mid-Atlantic	39.09	-2.08
	Farrow-Feeder	Midwest	39.37	-2.42
Liquid	Grower-Feeder	Mid-Atlantic	38.73	-6.18
	Grower-Feeder	Midwest	39.45	-5.57
	Farrow-Feeder	Mid-Atlantic	33.81	-1.97
	Farrow-Feeder	Midwest	34.79	-2.13
Evaporative Pond	Grower-Feeder	Central	37.62	-5.55
	Farrow-Feeder	Central	33.81	-2.13

5.13.4 Results

Appendix A, Table A-16 presents the cost model results for constructing anaerobic digesters with methane recovery at large dairies.

5.14 Litter Storage Sheds

Litter storage is included in the costing for all dry poultry operations. Requirements for poultry litter storage structures are similar to those for mortality composting facilities in that they require a roof, foundation and floor, and suitable building materials for side walls. Storage facilities are assumed to be 68 feet wide and 8 feet tall. Litter is assumed to be stacked to the top in a trapezoidal pile 48 feet wide at the base and 32 feet wide at the top. There are aisles 10 feet wide on either side of the stack. It is assumed that poultry litter storage facilities include a roof with a 0.75 pitch, a concrete floor 16 feet wide, and a 12-foot height from floor to roof (NCSU, 1998). The width and height were designed for piling manure to its angle of repose to minimize space. The length of the structure is variable.

The size of a poultry manure storage facility was calculated based on the volume of both manure and litter produced from the various poultry operations. Manure production for all poultry types, when designing manure storage facilities, was assigned a value of 0.00169 ft^3 per bird per day (or 0.6169 ft^3 per bird per year) (NCSU, 1998). The basic equation for calculating manure production is:

$$Volume_{Manure} = 0.00169 \times Nohead \times 365$$

where:

$Volume_{Manure}$	=	Annual volume of manure, ft^3
Nohead	=	Number of animals
365	=	Days in year.

Litter production was calculated as the number of houses (25,000 chickens or 6,250 turkeys per house) multiplied by the shaving material application depth (3.0 inches), multiplied by the area of the house (16,000 ft^2), adjusted for the amount of house floor area to receive shavings (zero percent for layers, 33 percent for pullets, and 100 percent for the remaining poultry types), and multiplied by the frequency of litter storage emptying (no more than two times per year). The basic equation for calculating litter production is:

$$Volume_{Litter} = Houses \times Depth_{Shavings} \times Area_{House} \times Coverage$$

where:

$Volume_{Litter}$	=	Volume of litter in houses, ft^3
Houses	=	Number of animal houses
$Depth_{Shavings}$	=	Depth of litter, ft
$Area_{House}$	=	Area of house floor, ft^2
Coverage	=	Portion of floor covered with litter (decimal fraction).

The volumes of manure and litter production are summed to arrive at the total volume produced annually. The cost model assumes storage for six months. The volume of storage required for the facility is calculated from the following:

$$Volume_{Storage} = (Volume_{Litter} + Volume_{Manure}) \times Duration \div 12$$

where:

$Volume_{Storage}$	=	Storage facility volume
Duration	=	Time period for storage (months)
12	=	Months per year.

Assuming a height of 8 feet, the square footage of the litter storage facility is calculated from the volume. EPA uses a construction cost of $8.50 per square foot based upon the cost of a structure with concrete floors and walls since there is a risk of spontaneous combustion at a stacking height of 8 feet (USDA NRCS, 2002a). The capital cost is determined from the following equation:

$$Capital\ Cost = Volume_{Storage} \div 8 \times 8.50$$

The cost model includes no operating cost for storage facilities since manure and litter management are considered part of the baseline scenario. Appendix Tables 17a through 17c present capital costs for storage at dry poultry operations.

5.15 Lagoon Covers

The cost of lagoon covers is estimated as a technology that complies with Option 5 for Category 2 and 3 swine, layer, and veal operations. Flares are added to covered lagoons for swine and poultry operations. In addition to covering lagoons under Option 5, evaporative pond systems at swine operations are assumed abandoned and replaced with a new covered lagoon and berms. These new lagoons are designed for a volume that does not include direct precipitation since they are covered. Berms are not constructed around the abandoned evaporative pond. For wet layer operations, lagoons for egg washing waste are also covered, but flares are not added.

Design

As discussed in Section 5.4, lagoon shape is assumed to approximately be a frustrum with top length and width equal and bottom length and width equal. Lagoon cover size is estimated as the square footage of the top surface of the lagoon. Lagoon cover size is calculated as:

$$Cover = W_{lagoontop} \times L_{lagoontop}$$

where:

$W_{lagoontop}$	=	Width of top of lagoon or evaporative pond, ft
$L_{lagoontop}$	=	Length of top of lagoon or evaporative pond, ft.

Lagoons for egg wash water at wet layer operations are designed to provide storage for six months in accordance with the procedure described in Section 5.4.5 for swine and poultry operations. The volume required for egg wash water is determined from the following equation:

$$Volume_{EggWash} = Nohead \times 0.057756619$$

where:

Nohead	=	Number of layers
0.05776	=	Egg wash water volume per head per 6 months.

Layers produce an average of 256 eggs per year (USDA NASS, 1998). A value of 4.6 liters per case is used based upon the quantity of wash water used for table eggs (Hamm, D., G. Searcy, and A. Mercuri. 1974). There are 360 eggs per case (United Egg, 2002), so 0.000451238 cubic feet of water is used per egg (4.6/360 × 0.03531435 cubic feet/liter). Since storage is for six months, the volume of egg wash water per head is 0.05776 (256 × 0.000451238 ÷ 2).

Fixed One-Time Costs

Several lagoon cover manufacturers were contacted to identify costs of purchasing and installing lagoon covers. The results of the survey are shown in Table 5.15-1. Installed lagoon covers range from \$1.20 to \$4.81 per square foot, with lower costs per square foot expected at larger installations and depending upon whether insulation is required. Thus, to develop costs for installation of insulated lagoon covers, a cost of \$4.00 per square foot was assumed. The capital cost of a flare is estimated to be \$2,500, and the cost for a cover and flare is calculated using the following equation:

$$\text{Capital Cost} = \text{Area of Cover} \times \$4/\text{ft}^2 + \$2,500$$

Table 5.15-1

Manufacturer-Suggested Costs of Lagoon Covers for ½-Acre Lagoons

Dealer	Description	Cost
Lange Containment Systems, Inc.	30 mil PVC liner, 36 mil reinforced Hypalon cover system	\$1.28/ft^2
	installation	\$34,665
CW Neal	½-acre lagoon, 32-mil polypropylene, installed	\$3-4/ft^2
Environmental Fabrics, Inc.	½-acre lagoon, 40 mil HDPE uninsulated cover, gas, and rain collection	\$0.85/ft^2
	½-acre lagoon, 40 mil HPDE R-6 insulated cover, gas, and rain collection	\$2.25/ft^2
Reef Industries	Permalon®, ply X-210 reinforced floating cover system (not including foam float logs)	\$0.40/ft^2
Geomembrane Technologies, Inc.	½-acre cover system installed, 30 mil reinforced modified PVC layer (XR-5) and ½-inch sublayer	\$105,000
Environmental Protection Inc.	36 mil reinforced cover	\$0.45 - \$0.50/ft^2

Annual Costs

Operation and maintenance costs for lagoon covers were estimated at 2 percent of capital costs. Appendix Table A-18 presents costs for lagoon covers at veal operations.

5.16 Feeding Strategies

Feeding strategies designed to reduce nitrogen (N) and phosphorus (P) losses include more precise diet formulation, enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility and improved quality control. These strategies increase the efficiency with which the animals use the nutrients in their feed and decrease the amount of nutrients excreted in the waste. With a lower nutrient content, more manure can be applied to the land and less cost is incurred to transport excess manure from the farm. Strategies that focus on reducing P concentrations, thus reducing overapplication of P and associated runoff into surface waters, can turn manure into a more balanced fertilizer in terms of plant requirements.

5.16.1 Technology Description

Feeding strategies that reduce nutrient concentrations in waste have been developed for specific animal sectors, and those for the swine and poultry industries are described below. The application of these types of feeding strategies to the beef industry has lagged behind other livestock sectors and is not discussed here.

Swine

Lenis and Schutte (1990) showed that the protein content of a typical Dutch swine ration could be reduced by 30 grams per kilogram without negative effects on animal performance. They calculated that a 1-percent reduction in feed N could result in a 10-percent reduction in excreted N. Monge et al. (1998) confirmed these findings by concluding that a 1-percent reduction in feed N yielded an 11-percent reduction in excreted N. Experts believe that N losses through excretion can be reduced by 15 to 30 percent in part by minimizing excesses in diet with better quality control at the feed mill (NCSU, 1998).

Poultry

Precision nutrition entails formulating feed to meet more precisely the animals' nutritional requirements, causing more of the nutrients to be metabolized, thereby reducing the amount of nutrients excreted. For more precise feeding, it is imperative that both the nutritional requirements of the animal and the nutrient yield of the feed are fully understood. Greater understanding of poultry physiology has led to the development of computer growth models that take into account a variety of factors, including strain, sex, and age of bird, for use in implementing a nutritional program. By optimizing feeding regimes using simulation results, poultry operations can increase growth rates while reducing nutrient losses in manure.

Phytase can be used to feed all poultry. Phosphorus reductions of 30 to 50 percent have been achieved by adding phytase to the feed mix while simultaneously decreasing the amount of inorganic P normally added (NCSU, 1999). Addition of phytase to feed significantly reduces P levels in poultry manure. The high cost of phytase application equipment has discouraged more widespread use. Phytase is in use at many poultry operations.

5.16.2 Costs

The cost model applies feeding strategies to all Category 2 and 3 swine and poultry operations under all options. Hauling costs are compared for the cases with and without feeding strategies under a range of technology scenarios, including separators, retrofit scraper systems, sludge cleanout, highrise hog houses, hoop houses for hogs, and lagoon covers.

The basic approach to estimating the costs of feeding strategies involves six steps:

1. Determine P-based and N-based feeding strategy costs for animal type;
2. Determine the quantity of N and P in the applied manure;
3. Determine the acreage required to spread manure under N-based or P-based management;

4. Determine the quantity of nutrient in excess of on-farm needs;

5. Determine hauling costs; and

6. Add hauling costs to feeding strategy costs.

Feeding Strategy Costs

Feeding strategy costs for both swine and poultry are provided in Table 5.16.2-1 (Tetra Tech, 2000c). EPA estimates that it costs $10 per ton ($0.005 per pound) to reduce nitrogen in feed. It is assumed that layers consume the same quantity of feed per day as do broilers, which consume 11 pounds of feed, costing $0.055, to achieve market weight. Since broiler turnover is 5.5 flocks per year, versus 1 flock per year for layers, the quantity of feed for layers is estimated as 5.5 × 11, bringing the cost to $0.3025 per layer (5.5 × 0.055). Turkeys consume 46 pounds of feed, at a cost of 46 × 0.005, or $0.23 per turkey.

Phosphorus feeding strategy costs for broilers and layers are assumed to be zero since integrators supply the feed to the growers, and phytase is commonly used at these operations. The cost of phytase is estimated at $1 per ton, or $0.0005 per pound. For turkeys, the feeding cost is therefore 46 × 0.0005, or $0.023 per turkey.

Table 5.16.2-1

Feeding Strategy Costs for Swine and Poultry

Animal	Turns	Feeding Strategy Costs ($ Per Animal)	
		N Strategy	P Strategy
Broiler	5.5	0.055	0
Layer	1	0.3025	0
Turkey	2.5	0.23	0.023
Pig - FF	2.1	2.70	0.36
Pig - GF	2.8	2.70	0.36

Feeding costs are calculated using the following equations:

Swine - P-Based: $Cost_{FS} = Nohead \times UnitCost \times Turns \times 0.7$

Other: $Cost_{FS} = Nohead \times UnitCost \times Turns$

where:

$Cost_{FS}$	=	Cost of feeding strategies
UnitCost	=	Cost per animal for feeding strategy (Table 5.16.2-1)
Turns	=	Number of flocks or turnovers per year (Table 5.16.2-1).

Quantity of Nutrients Applied

Implementation of feeding strategies reduces the quantity of nutrients excreted. The cost model assumes a 40-percent reduction in phosphorus excretion and a 20-percent reduction in nitrogen excretion under P-based and N-based feeding strategies, respectively. The following equation is used to calculate nutrient production resulting from feeding strategy implementation:

$$Nutrient_{FS} = Nutrient \times (1\text{-}Reduction)$$

where:

$Nutrient_{FS}$	=	Total nutrient (N or P) in manure under feeding strategies
Nutrient	=	Total nutrient (N or P) in manure without feeding strategies
Reduction	=	Feeding strategy nutrient reduction (N or P).

Acreage Required for Spreading

The acreage required to spread manure is calculated based upon nutrient content of the manure, nutrient losses occurring during transport of the manure to the field, crop uptake of the nutrient, and the portion of manure given away by the operation. The cost model assumes that all nutrients are available to the crops, which is a conservative estimate with regard to acreage requirements. The values for nutrient uptake by crops are given in Table 5.16.2-2 (Tetra Tech, 2000c). The following equation is used to determine the acreage required for spreading:

$$Acreage_{FS} = Nutrient_{FS} \times Efficiency \times (1\text{-}Given) \div Uptake$$

where:

$Acreage_{FS}$	=	Acreage required to spread manure under feeding strategies, acres
$Nutrient_{FS}$	=	Total nutrient (N or P) in manure under feeding strategies, pounds per year
Efficiency	=	Portion of nutrient (N or P) available to crop, decimal fraction = 1
Given	=	Portion of manure given away, decimal fraction
Uptake	=	Crop uptake of nutrient (N or P), pounds per acre per year (Section 4.9).

Table 5.16.2-2

Crop Nutrient Uptake

Animal Type	Region	N Uptake (pounds per acre per year)	P Uptake (pounds per acre per year)
Poultry	Mid-Atlantic	183	20
	Midwest	141	10
	South	141	10
Swine	Central	185	24
	Mid-Atlantic	138	14
	Midwest	198	19

Excess Nutrients

The cost model assumes that nitrogen feeding strategies are used under N-based management, while phosphorus feeding strategies are used under P-based management. Excess nutrients result when the acreage required to spread the manure at either N-based or P-based agronomic rates exceeds the acreage available at the operation. The cost model requires hauling for cases where there are excess nutrients. The following equation is used to calculate the quantity of excess nitrogen and phosphorus under P-based management where phosphorus feeding strategies are employed:

$$Excess_{N} = N_{NoFS} \times (1- Acreage_{Farm} \div Acreage_{FS\text{-}P}) \times (1\text{-}Given)$$

$$Excess_{P} = (P_{FS} - P_{Farm}) \times (1\text{-}Given)$$

where:

$Excess_N$	=	Excess nitrogen, lb/yr
$Excess_P$	=	Excess phosphorus, lb/yr
N_{NoFS}	=	Nitrogen in manure without feeding strategies, lb/yr
P_{FS}	=	Phosphorus in manure with feeding strategies, lb/yr
P_{Farm}	=	Phosphorus required on farm to meet crop nutrient requirements, lb/yr
$Acreage_{Farm}$	=	Acreage on farm available to spread manure, acres
$Acreage_{FS\text{-}P}$	=	Acreage required to spread manure under P feeding strategies, acres
Reduction	=	Feeding strategy nutrient reduction (N or P)
Given	=	Portion of manure given away, decimal fraction.

A similar set of equations is used to determine excess nitrogen and phosphorus amounts under N-based nutrient management. In simple terms, the amount of manure spread on the farm is based upon the quantity of the target nutrient (N or P) available in the manure after feedings strategies for that nutrient are implemented. The nutrients in the leftover manure are considered excess nutrients.

Hauling Costs

Hauling costs are determined using the basic approach described for contractor hauling costs in Section 5.9.2. The portion of manure to be hauled is determined from the following equation:

$$HaulPct = 1- (Acreage_{Farm} \div Acreage_{FS})$$

where:

HaulPct	=	Portion of manure hauled away, decimal fraction
$Acreage_{Farm}$	=	Acreage on farm available to spread manure, acres
$Acreage_{FS}$	=	Acreage required to spread manure under (N or P) feeding strategies, acres.

The quantity of manure to be hauled is calculated from the following equations for liquid and solid manure:

Liquid: $$Volume_{LiquidManure} = Volume_{Manure} \times HaulPct \times (1\text{-}Given) \times (1\text{-}Mangive)$$

Solid: $$Weight_{SolidManure} = Weight_{Manure} \times HaulPct \times (1\text{-}Given) \times (1\text{-}Mangive)$$

where:

$Volume_{LiquidManure}$	=	Annual volume of liquid manure to haul, gallons/year
$Weight_{SolidManure}$	=	Annual weight of solid manure to haul, tons/year
$Volume_{Manure}$	=	Annual volume of manure produced, gallons/year
$Weight_{Manure}$	=	Annual weight of manure produced, tons/year
Given	=	Portion of manure given away, decimal fraction
HaulPct	=	Portion of manure hauled away, decimal fraction
Mangive	=	Frequency factor for giving manure away.

EPA assumes that Category 3 operations incur no cost to haul manure under N-based management since that is the baseline scenario. For all other Category 2 and 3 liquid-based swine and poultry operations, the cost of hauling the sludge is determined using the following equation:

$$Cost_{Liquid} = (Volume_{LiquidManur} \times LiquidFirst) + (LiquidAdd \times Volume_{LiquidManur}) \times (Transport\text{-}1))$$

where:

$Cost_{Liquid}$	=	Annual cost of hauling liquid manure
$Volume_{LiquidManur}$	=	Annual volume of liquid manure to haul, gallons/year
LiquidFirst	=	Liquid hauling cost for first mile
LiquidAdd	=	Liquid hauling cost beyond first mile
Transport	=	Transport distance for hauling manure.

Transport distances are given in Table 5.9.2-1. For the Mid-Atlantic region, the transport distances for liquid hauling are changed if feeding strategies are employed. If the hauling percentage (HaulPct) is less than 20 percent (0.20), the transport distance is set at 5.5 miles, the distance for N-based management at Category 2 facilities (see Table 5.9.2-1). Otherwise, the transport distance is set to 18 miles in the Mid-Atlantic region.

For all other Category 2 and 3 solid-based operations, the cost of hauling the manure is determined using the following equation:

$$Cost_{Solid} = Weight_{SolidManure} \times HaulRate \times Transport$$

where:

$Cost_{Solid}$	=	Annual cost of hauling solid manure
$Weight_{SolidManure}$	=	Annual weight of solid manure to haul, tons/year
HaulRate	=	Hauling rate based upon hauling distance (Table 5.17.3-3)
Transport	=	Transport distance for hauling manure.

Total Feeding Strategy Costs

The cost model assessed the relative cost of feeding strategies by summing the costs for feeding strategies and the associated hauling. This cost can be compared versus hauling without feeding strategies to determine which is less expensive. Similarly, hauling associated with other nutrient reduction technologies (e.g., scraper systems) is costed with and without feeding strategies. The total cost of feeding strategy implementation is estimated with the following equation:

$$Cost = Cost_{FS} + Cost_{Hauling}$$

where:

$Cost_{FS}$	=	Cost of feeding strategies
$Cost_{Hauling}$	=	Cost of hauling with feeding strategies.

5.17 Options to Retrofit Swine and Wet Layer Systems to Dry Systems

In addition to the use of lagoon covers to comply with the requirements of Option 5, EPA investigated retrofitting swine and wet layer systems to replace lagoons as the waste management practice. Retrofitting to a "scraper system" was assessed for swine and wet layer facilities. In addition, retrofitting to high-rise and hoop houses for swine operations was assessed. The scraper system and high-rise house retrofit options require the cleanout and closure of the existing lagoon.

5.17.1 Lagoon Cleanout and Closure Costs

Lagoon closures were used as part of the cost test for BAT option 5, and were also considered as part of a proposed permit requirement to have a closure plan or a bond to ensure closure. These options were not selected.

USDA NRCS developed an interim standard that has been use for closure of lagoons used in North Carolina. NCDENR (1999) prepared a list of 65 lagoon closures that have been cost-shared by the North Carolina Agriculture Cost Share Program. The smallest lagoon was 0.11 acres, and the largest was 2.5 acres. The range of closure costs on a per acre basis was generally in the $15K/acre to $60K/acre range. The average cost to clean out and close 65 dairy, beef, poultry, and swine lagoons was $0.031 per gallon. This value is used to estimate the cost of lagoon cleanout and closure nationally using the following equation:

$$\text{Cleanout Cost} = \text{Volume}_{\text{Manure}} \times 0.031$$

where:

$\text{Volume}_{\text{Manure}}$ = Volume of manure for one year, gallons

Cleanout Cost = VolumeManure × 0.031

Where,

VolumeManure = Volume of manure for one year (gallons)

5.17.2 Retrofit to Scraper System

Mechanical scrapers are dedicated to a specific alley, propelled by electrical devices, and attached by cables or chains (USDA NRCS, 1996). Scrape alleys range from 3 to 8 feet wide for swine and poultry operations.

Scraper systems are applied to both swine and wet-layer facilities in the cost model . One retrofit unit is required for each 1,250 hogs or 25,000 layers, with a minimum of one unit per operation. Components of scraper systems costed in the model include a motor, blades, and a steel tank for storage of scraped material for one year. There is also a setup cost and a cost for cleanout of the existing lagoon (see Section 5.4). When facilities are retrofitted to a scraper system, the dilution factor is set to 1, no additional water is added, and scraped material is moved to a covered steel tank to limit dilution by precipitation.

It is assumed that each animal house has a single alley requiring one scraper system (Figure 5.17.2-1). Each scraper has two blades. Steel scraper blades last for 10 years (MDS, 2002). Since costs are amortized over 20 years, four steel blades are purchased at $177 each as capital costs. This cost is based upon $29.50 per foot for 6-foot blades (MDS, 2002). EPA assumes a setup cost of $36,000 per house, and $200 for a 1/4 HP motor. The volume of waste to be stored in the tank is calculated from the following equation:

$$Volume_{ManureUndiluted} = nohead \times weight \div 1{,}000 \times volume \times 365 \times 7.481$$

where:

$Volume_{ManureUndiluted}$	=	Annual volume of undiluted manure, gallons/year
nohead	=	Number of head
weight ÷ 1000	=	Animal weight divided by 1,000 = Number of animal units
volume	=	Cubic feet of manure produced per animal unit per day

365	=	Days per year
7.481	=	Gallons per cubic foot.

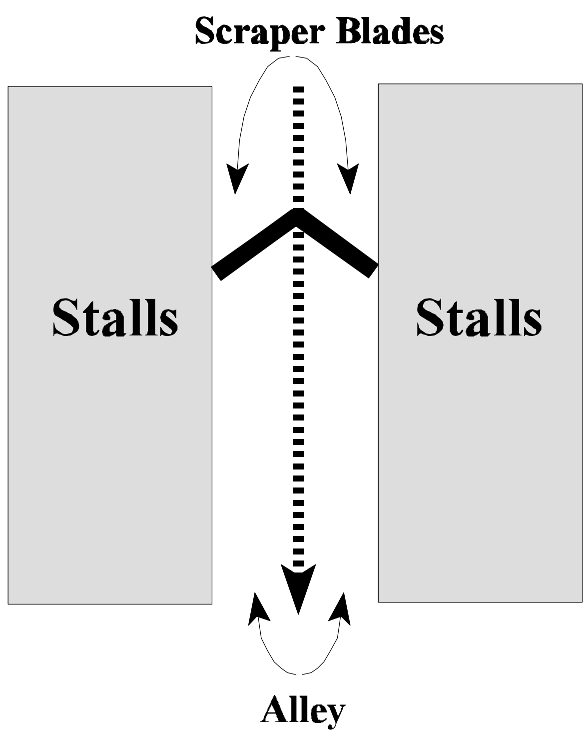


Figure 5.17.2-1. Scraper System

Capital Costs

Retrofit costs (minus lagoon cleanout costs) are calculated using the following equation:

$$\text{Capital Cost} = ((\text{Setup} + \text{Motor}) + (\text{Blades} \times 177)) \times \text{Number} + (\text{Volume}_{\text{ManureUndiluted}} \times \text{Tankcost})$$

where:

Setup	=	Setup cost of $36,000
Motor	=	Motor cost of $200
Blades	=	Number of steel scraper blades (4)
177	=	Cost of steel scraper blades

Number	=	Number of retrofit units
Tankcost	=	Cost of steel tank ($0.18 per gallon).

Annual Costs

Annual operation and maintenance include labor, electricity, replacement blades and standard maintenance. EPA estimates motor usage for each unit to be 897 kWh at $0.095 per kWh. Labor for each unit is estimated to be 52 hours per year at $10 per hour, and maintenance is estimated at 2 percent of initial costs, including cleanout of the lagoon ($724). Annual costs are calculated using the following equation:

$$\text{Annual Cost} = (\text{Electricity} \times \text{Rate} + \text{Hours} \times \text{Labor}) \times \text{Number} + \text{Capital Cost} \times 0.02$$

where:

Electricity	=	Annual electricity usage per unit
Rate	=	Cost of electricity
Hours	=	Labor per unit
Labor	=	Labor rate
Number	=	Number of retrofit units
CapitalCost	=	Capital Cost (including lagoon cleanout)
0.02	=	Standard maintenance rate.

5.17.3 Retrofit to High Rise Hog Houses

Menke, et al. (2000) evaluated the construction costs for a two-story confinement housing design. Material falls through open slots onto the first floor where it is composted with carbon-rich material. A high-rise house for 1,000 head of finishing pigs is 44 feet × 190 feet. On a per pig basis, a traditional deep pit house in Indiana/Ohio costs $155 to 160 per animal; a lagoon style flush house costs $145 per animal; and the high-rise building costs $185 per animal. The high-rise building costs include professional engineering design that meets NRCS design standards. Building a deep-pit house to these standards is estimated to increase the construction cost of a deep-pit house by $15,000 ($15 per animal).

Operation and maintenance costs for a high-rise hog facility are estimated at 2 percent of initial costs. Additional costs include energy costs and drying agents. Energy costs for a traditional confinement building are estimated at $2,500 to $2,800 per year. The high-rise building has average monthly costs of approximately $400 or $4,800 annually. Drying agents evaluated include wheat straw, corn stalks, and wood shavings. Around 50 to 60 tons of wood shavings are needed to cover the house at a depth of 2 feet at an annual cost of $4,000 to $5,000 per year. In contrast, 5 feet of straw or corn stalk material are needed to absorb similar amounts of moisture. Even at a lower cost of $9 to $10 per 1,200 pound bale of corn stalks, the higher volumes required offset the unit cost savings. Straw and corn materials also tend to degrade and compost more rapidly than wood, requiring more frequent addition of drying material to the house.

The cost of feed and manure handling are assumed to be no different from baseline. Therefore, the initial cost of high-rise buildings for hogs is calculated using the following equation:

$$\text{Capital Cost} = \text{Nohead} \times \text{Construction}$$

where:

Nohead	=	Number of head
Construction	=	Cost of construction ($185 per pig space).

Annual costs are estimated with the following equation:

$$\text{Annual Cost} = \text{Nohead} \times \text{Operation} + \text{Capital Cost} \times 0.02$$

where:

Nohead	=	Number of head
Operation	=	Cost of confinement fuel, repairs, and utilities ($3.22 per pig).

5.17.4 Retrofit to Hoop Houses

Hoop structures are low-cost, Quonset-shaped swine shelters with no form of artificial climate control. Wooden or concrete sidewalls 4 to 6 feet tall are covered with an ultraviolet and moisture-resistant, polyethylene fabric tarp supported by 12- to 16-gauge tubular steel hoops or steel truss arches placed 4 to 6 feet apart. Hoop structures with a diameter greater than 35 feet generally have trusses rather than the tubing used on narrower hoops. Some companies market hoops as wide as 75 feet. Tarps are affixed to the hoops using ropes or winches and nylon straps.

Generally, the majority of the floor area is earthen, with approximately one-third of the south end of the building concreted and used as a feeding area. Approximately 150 to 200 finisher hogs or up to 60 head of sows are grouped together in one large, deep-bedded pen. Plentiful amounts of high-quality bedding are applied to the earthen portion of the structure, creating a bed approximately 12 to 18 inches deep. The heavy bedding absorbs animal manure to produce a solid waste product. Additional bedding is added continuously throughout the production cycle. Fresh bedding keeps the bed surface clean and free of pathogens and sustains aerobic decomposition. Aerobic decomposition within the bedding pack generates heat and elevates the effective temperature in the unheated hoop structure, improving animal comfort in winter conditions.

The costing for hoop houses is similar to that for high-rise houses. Capital costs are estimated using the following equation:

$$\text{Capital Cost} = \text{Nohead} \times \text{Construction}$$

where:

Nohead	=	Number of head
Construction	=	Cost of construction ($55 per pig space).

Annual costs are estimated with the following equation:

$$\text{Annual Cost} = \text{Nohead} \times (\text{Operation} + \text{Bedding} + \text{Hours} \times \text{Labor}) + \text{Capital Cost} \times 0.02$$

where:

Nohead	=	Number of head
Operation	=	Cost of confinement fuel, repairs, and utilities ($1.40 per pig)
Bedding	=	Cost of bedding ($4.20 per pig)
Hours	=	Labor (1.12 hours per pig)
Labor	=	$10 per hour.

5.18 Recycling of Flush Water

In liquid-based systems, fresh water can be used for flushing or water from a secondary lagoon can be recycled as flush water. This technology is applied to Category 2, lagoon-based swine operations for all options except Option 5.

Costing for this technology includes piping, labor, and an extra lined lagoon designed to provide an additional 20 days of storage. The design of the extra lagoon is discussed in Section 5.4.5, and lagoon liners are described in Section 5.4.2. EPA assumes that 250 feet of pipe are required to connect the extra lagoon to the pump, at a cost of $2.13 per foot. It is estimated that 4 hours of labor is required to install the pipe and set up the pump, at a cost of $10/hour.

Capital Cost

The capital costs are estimated with the following equation:

$$\text{Capital Cost} = \text{Pipelength} \times \text{Pipecost} + \text{Hours} \times \text{Labor} + \text{ExtraLagoon} + \text{Liner}$$

where:

Pipelength	=	Length of pipe
Pipecost	=	Cost per foot of pipe
Hours	=	General labor hours to install pipe and pump
Labor	=	$10/hour

ExtraLagoon	=	Cost to build lagoon with storage for 20 days
Liner	=	Cost of liner for extra lagoon.

The cost to build the extra lagoon is estimated by multiplying the lagoon volume by the earth moving cost of $2.60 per cubic yard. The cost of the liner is determined by multiplying the surface area of the liner (bottom plus sides) by the liner cost of $1.84 per square foot (clay plus synthetic).

Annual Costs

The annual cost is calculated with the following equation:

$$\text{Annual Cost} = \text{Capital Cost} \times 0.02$$

5.19 Sludge Cleanout

Sludge must be removed from lagoons periodically to keep storage capacity available. The cost model accounts for sludge cleanout annually for beef feedlots, dairies, and heifer operations and once every five years for liquid-based swine operations for all considered options.

5.19.1 Technology Description

Nondegradable solids settle to the bottom of lagoons as sludge, which is periodically removed. The liquid is applied to on-site cropland as fertilizer or irrigation water, or it is transported off site. The sludge can also be land applied as a fertilizer and soil amendment.

Compared with lagoon liquids, lagoon sludges have higher concentrations of all pollutants that are not completely soluble. Some organic N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-organic N fraction of total Kjeldahl N (TKN) in settled solids.

Beef and Dairy Model

For the beef, dairy, and sludge operations, sludge removal is assumed to occur annually because of the higher capacity requirements associated with liquid storage receiving runoff from open lots. Cost for removing the sludge is determined using a cost test against three options:

1) Lagoon or pond is pumped to a traveling gun. Sludge is applied to land on site using the traveling gun.

2) Lagoon or pond is pumped to a tanker truck owned and operated by the operation owner. The tanker truck ships the sludge to an off-site location.

3) A custom applicator brings equipment on site, removes the sludge, and ships the sludge off site.

Hauling costs incurred by the owner/operator are included in Section 5.9.

5.19.2 Beef and Dairy Costs

Capital Costs

The cost model assumes that facilities with less than 30 acres may choose to purchase a traveling gun or contract with a custom applicator to remove sludge from their lagoons. The model assumes that facilities with 30 or greater acres may choose to purchase a tanker truck to haul their own waste or will contract with a custom applicator to remove sludge from their lagoons. Costs for a traveling gun are outlined in Section 5.8 and costs to purchase a tanker truck are outlined in Section 5.9. Contracting with a custom applicator has no assumed capital costs.

Annual Costs

Annual costs for traveling guns and tanker truck hauling are estimated at 5 percent of the capital costs. Annual costs for contracting with a custom applicator are estimated at $0.05 per gallon of sludge. Appendix Table A-19 presents sludge removal costs for beef feedlots, dairies, and heifer operations.

5.19.3 Swine Costs

For the swine cost model, zero cost is assumed for sludge cleanout, but hauling costs are estimated. The volume of sludge to be hauled is determined using the following equation:

$$Volume_{Sludge} = Volume_{Manure} \times (1\text{-}Given) \times Solids \times 0.924 \times HaulPct \times (1\text{-}mangive)$$

where:

$Volume_{Sludge}$	=	Annual volume of sludge to haul, gallons/year
$Volume_{Manure}$	=	Annual volume of manure produced, gallons/year
Given	=	Portion of manure given away, decimal fraction
Solids	=	Solids content of manure, decimal fraction
0.924	=	Moisture content of sludge
HaulPct	=	Portion of manure hauled away, decimal fraction
Mangive	=	Frequency factor for giving manure away.

EPA assumes that Category 3 swine operations incur no cost to haul sludge under N-based management since that is the baseline scenario. For all other Category 2 and 3 liquid-based swine operations, the cost of hauling the sludge is determined using the following equation:

$$Cost_{Sludge} = (Volume_{Sludge} \times LiquidFirst) + (LiquidAdd \times Volume_{Sludge} \times (Transport - 1))$$

where:

$Cost_{Sludge}$	=	Annual cost of hauling sludge
$Volume_{Sludge}$	=	Annual volume of sludge to haul, gallons/year
LiquidFirst	=	Liquid hauling cost for first mile
LiquidAdd	=	Liquid hauling cost beyond first mile

Transport = Transport distance for hauling sludge.

The values of LiquidFirst ($0.008/gallon-mile) and LiquidAdd ($0.0013/gallon-mile) are taken from Table 5.9.2-3. In cases where feeding strategies are employed (see Section 5.21.9), sludge volume is reduced by the factor (1-FSRed) to account for the reduced quantity of solid waste produced under feeding strategies. The value of FSRed is 0.40. Further, for the Mid-Atlantic region, the transport distances are changed if feeding strategies are employed. If the hauling percentage (HaulPct) is less than 20 percent (0.20), the transport distance is set at 5.5 miles, the distance for N-based management at Category 2 facilities (see Table 5.9.2-1). Otherwise, the transport distance is set to 18 miles in the Mid-Atlantic region for swine facilities that use feeding strategies to reduce manure-P production.

5.20 Surface Water Monitoring

Option 4 requires animal feeding operations to monitor nearby water bodies for contaminants.

5.20.1 Practice Description

Surface water monitoring is used to evaluate the nutrient loading of waterways near animal feeding operations. The primary purpose of this monitoring is to determine the effectiveness of implemented technologies and practices at preventing contamination of surface water. Possible sources of excess loading include uncontained runoff and lagoon overflow during peak storm events.

The best time to monitor the effectiveness of runoff control systems is immediately following storm events; therefore, sampling events are not scheduled in advance. Animal feeding operations are costed for sampling water bodies going through or adjacent to feeding operations immediately following storm events, up to 12 times per year.

5.20.2 Prevalence of the Practice in the Industry

It is assumed that beef feedlots, dairies, and veal operations do not have surface water monitoring programs in place, therefore, the cost model assigns the cost of surface water monitoring to every operation evaluated under Option 4. Note that Option 4 is the only option in the cost model that includes surface water monitoring.

5.20.3 Design

The design for surface water monitoring is based on the sampling program and includes monitoring at the surface impoundment (pond or lagoon) and the stockpile. The requirements of the sampling program are:

- Twelve sampling events per year at surface water bodies;
- One sampling event per year at the lagoon or pond and at the stockpile;
- Four grab samples and one quality assurance (QA) sample per sampling event (Table 5.20-1 shows the total number of samples over a one-year period);
- Sampling will coincide with rain events in excess of 0.5 inches precipitation; and
- Analysis of each sample for nutrients (nitrite, nitrate, total Kjeldahl nitrogen, total phosphorus) and total suspended solids (TSS).

An alternative analysis considered ambient monitoring for metals (zinc, arsenic, copper), BOD_5, and biological organisms (fecal coliforms, enterococcus, salmonella, and escherichia coli). Due to high costs and limited holding times for BOD and pathogen samples, these parameters were not costed for Option 4. EPA believes the uncertainty of precipitation events prevents the CAFO owner from being prepared to rapidly sample; therefore, accurate sample collection and shipping would be very difficult for these additional constituents.

Table 5.20-1

Number of Samples

Number of sampling events per year	12
Number of samples per sampling event (4 grab + 1 QA)	5
Total annual samples	60

5.20.4 Costs

Initial cost estimates, shown in Table 5.20-2, include training, coolers, and reusable sampling equipment. Annual costs, shown in Table 5.20-3, include sterile containers and sampling supplies for each sampling event, labor costs associated with sampling, sample overnight shipment, and lab processing fees.

Table 5.20-2

Capital Costs for Surface Water Sampling

Description	Unit Cost	Capital Cost
Training (8 hr)	$10/hr	$80
Course fee	$40	$40
Misc. other costs (15% of labor)	--	$12
Coolers (2)	$30/cooler	$60
Sampling equipment (pipet, etc.)	$200	$200
	Total Capital Cost	**$392**

Table 5.20-3

Annual Costs for Surface Water Sampling

Description	Unit Cost	Annual Cost
250-mL bottles (2 per sample)	$2/bottle	$240
500-mL bottles (1 per sample)	$2.70/bottle	$162
Overnight shipping (30-lb cooler)	$60/sampling event	$720
Misc. supplies and transportation	$30	$30
Laboratory costs	$79/sample	$4,740
Sample collection (2 hrs/sampling event)	$10/hr	$240
QA & recordkeeping (1 hr/sampling event)	$10/hr	$120
	Total Annual Cost	**$6,252**

REFERENCE: Tetra Tech, 1999

5.20.5 Results

The cost model results for the surface water monitoring option do not vary between animal type, region, or size group. The capital cost for surface water monitoring is $392, and the annual cost is $6,252.

5.21 References

AEA, 1999. George, John. Telephone discussion regarding drylot areas and clay liners. September 1999.

Agriculture and Agri-Food Canada, 2002. *Choosing a Sprinkler Irrigation System.* <www.www.agr.gc.ca/pfra/water/systems.htm> Accessed August 20, 2002.

ASAE, 1998. *ASAE Standards 1998, 45th Edition*. American Society of Agricultural Engineers, St. Joseph, MI.

ASC Scientific, 1999. *ASC Scientific: Soil Augers and Sampling Tools.* *<www.ascscientific.com>* . Accessed September 30, 1999.

Barker, J.C., 2000. *Worksheet to Determine Size of Poultry Mortality Composter*, EBAE 177-93, http://www.bae.ncsu.edu/programs/extension/publicat/wqwm/ebae177_93.html, retrieved 5/21/2000.

Building News, 1998. *Home Builder's 1998 Costbook.* 6th Edition.

Case's Ag-world.com, 2000. *The Haymarket.* Website Marketplace. December 13, 2000.

Clemson Extension, 2002. *Irrigation Equipment: Traveling Gun Systems.* <www.clemson.edu/irrig/Equip/Trav.htm> Accessed August 11, 2002.

ERG, 2000a. *Methodology to Calculate Storage Capacity Requirements Under Option 7.* Internal memorandum from Eastern Research Group, Inc.

ERG, 2000b. *Methodology to Calculate Contract Hauling Rates for Beef and Dairy Cost Model*. Internal memorandum by Eastern Research Group, Inc.

ERG, 2000c. *Methodology to Cost Conveyances for Feedlots.* Internal Memorandum from Eastern Research Group, Inc.

ERG, 2001. *Ground Water Assessment & Sampling Cost Comment.* Memorandum from T. Curry at Eastern Research Group, Inc. to P. Shriner at EPA. February 6, 2002.

ERG, 2002. *Estimates of Existing Storage for Beef and Dairy Model Farms.* Memorandum from D. Bartram of Eastern Research Group, Inc. to Feedlots Rulemaking Record. December 10, 2002.

ESRI, 1998. *ESRI Data & Maps CD No. 2: United States (Detailed).* Environmental Systems Research Institute, Inc. Redlands, CA.

Fulhage, C. D. and D.L. Pfost, 1995. *Settling Basins and Terraces for Dairy Waste.* University of Missouri-Columbia, Department of Agricultural Engineering.

Hamm, D., G. Searcy, and A. Mercuri. 1974. "A study of the waste wash water from egg washing machines." *Poultry Science*. 53:191-197.

Jewell, W.J., P.E. Wright, N.P. Fleszar, G. Green, A. Safinski, A. Zucker, 1997. *Evaluation of Anaerobic Digestion Options for Groups of Dairy Farms in Upstate New York.* Department of Agricultural and Biological Engineering, Cornell University. June 1997.

Kellogg, R.et al., 2000. *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the U.S.*

Kifco, 2002. Telephone discussion regarding traveling gun irrigation systems.

Lander, C.H. D. Moffitt, and K.Alt, 1998. *Nutrients Available from Livestock Manure Relative to Crop Growth Requirements.* Resource Assessment and Strategic Planning Working Paper 98-1.

Lenis, N.P., and J.B. Schutte. 1990. "Aminozuurvoorziening van biggen en vleesvarkens in relatie tot stikstofuitscheiding." In: *Mestproblematiek: aanpak via de voeding van varkens en pluimvee* (A.W. Jongbloed and J. Coppoolse, eds.), pp. 79-89. Onderzoek inzake de mest en ammoniakproblematiek in de veehouderij 4, Dienst Landbouwkundig

Onderzoek, Wageningen.

Lusk, P., 1998. *Methane Recovery from Animal Manures: a Current Opportunities Casebook.* 3rd Edition. NREL/SR-25145. National Renewable Energy Laboratory. Golden, Colorado.

MDS 2002. MDS Hog Confinement Systems & Products. Email from Brad Hohn (mds@santel.net) quoting price of steel blades. November 5, 2002.

Means, R.S., 1996. *Heavy Construction Cost Data*. 10th Annual Edition.

Means, R.S., 1998. *Building Construction Cost Data.* 56th Annual Edition.

Means, R.S., 1999. *Building Construction Cost Data.* 56th Annual Edition.

Menke, T, H. Keener, and G. Lefevre. 2000. Highrise Hog Housing Cost Information. Emailed on to Tetra Tech on April 25, 2000.

Monge, H., P.H. Simmins, and J. Weigel, 1998. Reduction du taux proteique alimentaire combinee avec differents rapports methionine:lysine. Effet sur le bilan azote du porc maigre en croissance et en finition. Journees de la Recherce Porcine en France 29:293-298.

MWPS, 1987. *Midwest Plan Service: Structures and Environment Handbook,* MWPS-1. Iowa State University. Ames, Iowa. 1987.

MWPS, 1993. *Midwest Plan Service: Livestock Waste Facilities Handbook.* Second Edition. MWPS-18. Iowa State University. Ames Iowa. April 1993.

NCDENR. 1999 Lagoon closure information. North Carolina Department of Environmental and Natural Resources, Division of Soil and Water Conservation. Raleigh, North Carolina.

NCSU, 1993. North Carolina State University. *Livestock Manure Production and Characterization in North Carolina.* North Carolina Cooperative Extension Service. 1993.

NCSU. 1998. *Draft of Swine and Poultry Industry Characterization, Waste Management Practices and Modeled Detailed Analysis of Predominantly Used Systems*. North Carolina State University, September 30.

NCSU. 1999. Nitrogen and Phosphorus Excretion in Poultry Production. Unpublished. February 1999. North Carolina State University, Animal Waste Management Program

NRAES, 1989. Northeast Regional Agricultural Engineering Service. *Liquid Manure Application Systems Design Manual.* Dougherty, Mark, Larry Geohring, and Peter Wright. National Regional Agricultural Engineering Service.

NRAES, 1992. Northeast Regional Agricultural Engineering Service. *On-Farm Composting Handbook*. Rynk, Robert (editor).NRAES-54. Ithica, New York. 1992.

Omega Engineering, *The Temperature Handbook.* Omega Engineering, Inc. 1999.

Richardson Engineering Services, Inc., 1996. *Process Plant Construction Estimating Standards.* Volume 1. Sitework, Piping, Concrete.

Sims J., A. Leytem, F. Coale, 2000. Implementing a Phosphorus Site Index: The Delmarva Experience. In Proceedings of 2000 National Poultry Waste Management Symposium.

Simons, C. 2002. Excess manure recordkeeping costs. Memorandum on April 23 from C. Simons, DPRA Inc. to V. Kibler, EPA and J. Waddell, Tetra Tech.

Sweeten, J.M. and S.H. Amosson, 1995. *Total Quality Manure Management.* Texas Cattle Feeders Association. June 1995.

Tetra Tech, Inc., 1999. *Costs Associated with surface water sampling.* Memorandum to Paul Shriner (EPA). December 17, 1999.

Tetra Tech, Inc., 2000a. *Costs of Storage, Transportation, and Land Application of Manure.* February 2000.

Tetra Tech, Inc. 2000b. *Revised Transportation Distances for Category 2 and 3 Type Operations*. Memorandum to Paul Shriner (EPA), January 7, 2000.

Tetra Tech, Inc., 2000c. *Cost Model for Swine and Poultry Sectors.* May 2000.

Tetra Tech, Inc., 2002. *Swine and Poultry Cost Model QA/QC Report*. December, 2002.

United Egg, 2002. *Statistics*, http://www.unitedegg.org/statistics.htm, retrieved 11/7/2002.

USDA APHIS, 1995. *National Animal Health Monitoring System (NAHMS), Swine '95: Part I: Reference of 1995 Swine Management Practices.*

USDA APHIS, 1996a. *National Animal Health Monitoring System (NAHMS), Part 1: Reference of 1996 Dairy Management Practices.*

USDA APHIS, 1996b. *National Animal Health Monitoring System (NAHMS), Swine '95: Part II: Reference of 1995 Grower/Finisher Health and Management.*

USDA NASS, 1998. *Chickens and Eggs Final Estimates 1994-1997, Statistical Bulletin Number 944*, Washington, DC.

USDA NRCS, 1992. *Agricultural Waste Management Field Handbook, National Engineering Handbook (NEH), Part 651*. 1992.

USDA NRCS, 1995. *Conservation Practice Standard: Waste Storage Facility Code 313*, April 1995.

USDA NRCS, 1996. *Agricultural Waste Management Field Handbook, National Engineering Handbook (NEH), Part 651 - Chapter 10.* 1996.

USDA NRCS, 1998. *Chickens and Eggs Final Estimates 1994-1997, Statistical Bulletin Number 944*, Washington, DC. 1998.

USDA NRCS, 2002a. *Cost Estimator (2002)*, Alabama NRCS, http://www.al.nrcs.usda.gov/FOTG/ICOST/CostEstimator2002.xls, retrieved 4-1-2002.

USDA NRCS, 2002b. *Cost List for USDA Cost-Share Programs (2/15/02)*, Alabama NRCS, http://www.al.nrcs.usda.gov/pdf/EQIP_HB.pdf, retrieved 8-22-2002.

USDOE, 1998. United States Department of Energy (DOE): *Monthly Electric Utility Sales and Revenue Report with State Distributions.* Energy Information Administration, Form EIA-826.

USEPA. 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. January 1993.

USEPA, 1995. U.S. Environmental Protection Agency. *Process Design Manual: Land Application of Sewage Sludge and Domestic Septage.* EPA/625/R-95/001.Office of Research and Development: National Risk Management Research Laboratory, Center for Environmental Research Information. September 1995.

USEPA, 1996. U.S. Environmental Protection Agency. *Agstar Technical Series: Covered Lagoon Digesters.* EPA 430-F-96-007. Office of Air and Radiation. March 1996.

USEPA, 1997a. U.S. Environmental Protection Agency. *Agstar Technical Series: Complete Mix Digesters.* EPA 430-F-97-004. Office of Air and Radiation. February 1997.

USEPA, 1997b. U.S. Environmental Protection Agency. *Agstar Technical Series: Plug Flow Digesters.* EPA 430-F-97-006. Office of Air and Radiation. February 1997.

USEPA, 1999. *Identification of Acreage of U.S. Agricultural Land with a Significant Potential for Siting of Animal Waste Facilities and Associated Limitations from Potential of Ground Water Contamination-draft.* Office of Water. Sobecki, T.M., and M. Clipper. December 15, 1999.

USEPA. 2000. Water Quality Conditions in the United States. U.S. Environmental Protection Agency, Office of Water. EPA841

Zimmatic, Inc. 1999. *Cost Estimate for Center Pivot Irrigation Systems,* http://www.Zimmatic.com.

6.0 FREQUENCY FACTORS

EPA recognizes that most individual farms are currently implementing certain waste management techniques or practices that are called for in the regulatory options considered. Only costs that are the direct result of the regulation are included in the cost model. Therefore, costs already incurred by operations are not attributed to the regulation.

Frequency factors are used in the cost model to simulate a cost allowance by reducing the expenditures necessary to bring a farm into compliance with the regulatory options considered. In other words, compliance costs are set to less than 100 percent of the cost of needed practices if farms are already implementing all or part of these practices or equivalent practices. The resulting cost could be viewed as an allowance. The degree to which costs are reduced is directly linked to the extent to which the required practices are already being implemented.

To reflect baseline industry conditions, EPA developed technology frequency factors to describe the percentage of the industry that already implements particular operations, techniques, or practices that may be used to meet the requirements of the final rule. In some cases, these frequency factors are based on an assumed performance category (i.e., high, medium, and low performance) as estimated by U.S. Department of Agriculture (USDA). EPA also developed ground water control frequency factors based on the location of the facility and current state requirements for permeabilities of waste management storage units. In addition, EPA developed nutrient basis frequency factors describing the distribution of farms that would apply manure to soils on a nitrogen or phosphorus basis, land availability frequency factors describing the distribution of farms with and without sufficient cropland to land apply the manure and wastewater generated at the farm, and transportation frequency factors describing the distribution of farms transporting excess manure and wastewater off site.

Some technologies included in the cost model, including composting and anaerobic digestion, were assumed not to be present under baseline industry conditions. Therefore, EPA assumed all of the facilities incur the cost of implementing the technologies and did not develop frequency factors for these technologies.

This section presents the frequency factors and the methodologies used to develop them in the following subsections:

- Section 6.1 - Beef and Dairy Technology Frequency Factors;
- Section 6.2 - Beef and Dairy Nutrient Basis Frequency Factors;
- Section 6.3 - Beef and Dairy Land Availability Frequency Factors;
- Section 6.4 - Swine and Poultry Technology Frequency Factors;
- Section 6.5 - Swine and Poultry Nutrient Basis Frequency Factors;
- Section 6.6 - Swine and Poultry Land Availability Frequency Factors; and
- Section 6.7 - Ground Water Control Frequency Factors.

6.1 Beef and Dairy Technology Frequency Factors

Technology frequency factors reflect the percentage of operations that have a particular operation, technique, or practice (e.g., settling basin) in place at baseline (i.e., prior to implementation of the regulation). Frequency factors are based on geographic location, type and size of operation, existing regulatory requirements, and overall status of the industry. EPA developed technology frequency factors for practices or technologies included in the cost model, including:

- Solids separation using earthen settling basins;
- Runoff controls (i.e., berms);
- Liquid land application (e.g., center pivot irrigation);
- Nutrient management planning (i.e., setbacks, lagoon markers, soil sampling, manure sampling, recordkeeping, document preparation);
- Solids separation using concrete settling basins;
- Naturally lined ponds and lagoons; and
- Transportation.

Frequency factors were developed to represent the current implementation rate of various practices used on operations. Since current implementation can vary significantly across operations in a given sector, the frequency factors were developed to represent low, medium, and high implementation costs based on farm performance. For example, operations classified as "low implementation cost" generally tend to have already implemented the practice and thus "low" (or no) additional costs are expected for such operations. Conversely, "high implementation cost" operations are assumed to have little or low levels of implementation and are expected to have "high" additional costs to implement a given practice or meet a certain standard. EPA assumed that 50 percent of all facilities would incur "medium" costs, 25 percent of facilities would incur "low" costs, and 25 percent would incur "high" costs.

EPA developed technology frequency factors that vary by farm performance using the same methodology and source of USDA data. Section 6.1.1 discusses the development of these frequency factors for beef feedlots, dairies, heifer operations, and veal operations. Frequency factors for some technologies were not included in USDA's data. The development of factors that were not presented in the USDA data that were assumed to vary by level of performance is described in Section 6.1.2 for beef feedlots, dairies, heifer operations, and veal operations. The remaining technology frequency factors are not assumed to vary by farm performance. EPA developed these remaining technology frequency factors using several different data sources. Section 6.1.3 discusses these frequency factors for beef feedlots, dairies, heifer operations, and veal operations. Section 6.1.4 discusses the frequency factors developed for the swine and poultry cost model.

6.1.1 Performance-Based Frequency Factors Based on USDA Data

EPA received frequency factors from USDA as part of a document entitled *Estimation of Private and Public Costs Associated with Comprehensive Nutrient Management Plan Implementation: A Documentation* (April 23, 2001). This document includes frequency factors for three performance-based categories of facilities (low-performing, medium-performing, and high-performing) for a series of "representative" farms defined by USDA in eight USDA defined regions. USDA defined high performers to be 25 percent of the facilities, medium performers to be 50 percent of the facilities, and low performers to be 25 percent of the facilities. EPA also used these percentages to calculate the number of facilities that are high, medium, and low performers.

To use USDA's frequency factors in the cost models, EPA "mapped" USDA's representative farms to its model farms and then weighted the frequency factors by the percent distribution of farms within each region. The general methodology used to perform this translation is provided below. See ERG's memorandum to the record *Methodology to Incorporate USDA Frequency Factors into Beef and Dairy Cost Model Methodology (ERG, 2001)* for a more detailed description of the methodology and USDA data used for beef feedlots, dairies, and heifer and veal operations.

Mapping USDA Representative Farms to EPA Model Farms

To use these performance-based frequency factors for beef feedlots, heifer operations, dairies, and veal operations, EPA correlated the USDA representative farms and regions to EPA's model farms and five geographic regions. To do this, EPA divided each USDA region into individual states and then weight-averaged the frequency factors from each state in that region to calculate the frequency factors for that region, according to the total number of operations in each state.

EPA's cost methodology for beef feedlots and heifer operations uses a single model farm to represent the costs of the majority of beef feedlots and heifer operations in the country with greater than 300 head. USDA's frequency factors for beef are based on two representative farms in eight geographic regions. The USDA factors are presented for the following size groups:

- >30;
- >100;
- 30 - 500;
- >500;

- 30 - 1,000; and
- >1,000 head.

EPA correlated these size groups to the Agency's size groups of 300 - 499 (Medium 1), 500 - 999 (Medium 2 and 3), and $\geq$1,000 (Large 1) head. EPA applied USDA's assumptions for beef feedlots to heifer operations since USDA's data did not include information for heifer operations.

EPA's cost methodology for dairies uses two model farms to represent the costs of the majority of dairies in the country with greater than 200 head. The USDA methodology uses five representative farms to reflect the current state of the industry. No dairies with greater than 200 head are represented by USDA's farm #1 and only a small portion are represented by USDA's farm #2. Therefore, EPA used frequency factors from only USDA farms #3, #4, and #5.

The Agency did not compare veal operations because EPA assumes that all veal operations currently have appropriate waste management practices in place and would require nutrient management planning.

Tables 6.1.1-1 and 6.1.1-2 present the correlation of EPA model farm components to the USDA representative farm components for beef feedlots and dairies, respectively.

Weighting USDA Frequency Factors

To use USDA's frequency factors at EPA model farms, EPA first weighted the frequency factors by the percent distribution of farms in a given USDA region. For example, if a USDA region was described using representative farm #1 and representative farm #2, and the USDA weighting factors indicate that 30 percent of operations in this region are represented by farm #1 and 70 percent of operations are represented by farm #2, then the weighted frequency factor for that region is:

$$\text{Weighted frequency factor} = \text{Frequency factor}_{\text{Farm\#1}} \times 0.3 + \text{Frequency factor}_{\text{Farm\#2}} \times 0.7$$

Next, EPA determined the states included in the USDA regions and estimated how many USDA facilities were in each state. EPA then calculated the percentage of the total number of EPA facilities in each USDA region using its estimates of the number of facilities in each state. These percentages provide the basis for weighting the USDA frequency factors to create the frequency factor for the EPA region. Table 6.1.1-3 presents the portion of beef feedlots and heifer operations and Table 6.1.1-4 presents the portion of dairies from the USDA region that fall within the corresponding EPA region, expressed as a percentage of the total EPA beef feedlots, heifer operations, and dairies in that region.

Table 6.1.1-1

Correlation of EPA Beef Model Farm Components and USDA Representative Farm Components

Animal Type	EPA Model Farm	USDA Representative Farm[a]	
		#1	#2
Beef	Partially paved drylot	Lot with smooth, hardened surface	Graded, curbed, fenced lots
	Concrete pad (Options 3 & 4)	Concrete slab for manure storage	Not listed
	Berms	Adequate clean water diversion system	Adequate clean water diversion system
	Stormwater pond	Adequate runoff storage pond	Adequate runoff storage pond
	Earthen settling basin	Not listed	Adequate settling basin
	Solids land application	Appropriate solids collection/ spreading/transfer equipment	Appropriate solids collection/ spreading/transfer equipment
	Liquid land application	Appropriate liquid collection/ spreading/transfer equipment	Appropriate liquid collection/ spreading/transfer equipment
	Nutrient management planning	Manure and soil testing	Manure and soil testing
		One-time documentation of facility	One-time documentation of facility
		Routine recordkeeping	Routine recordkeeping
	Off-site transportation	Off-farm export	Off-farm export

[a]This list includes all components included for that representative farm in all regions.

Table 6.1.1-2

Correlation of EPA Dairy Model Farm Components and USDA Representative Farm Components

Animal Type	EPA Model Farm	USDA Representative Farm[a]		
		#3	#4	#5
Dairy	Berms	Adequate clean water diversion system	Adequate clean water diversion system	Adequate clean water diversion system
	Concrete settling basin	Separator or settling basin[b]	Separator or settling basin[b]	Separator or settling basin[b]
	Anaerobic lagoon	Adequate liquid storage	Adequate liquid storage	Adequate liquid storage
	Liquid land application	Appropriate liquid spreading/transfer equipment	Appropriate liquid spreading/transfer equipment	Appropriate liquid spreading/transfer equipment
	Nutrient management planning	Manure and soil testing	Manure and soil testing	Manure and soil testing
		One-time documentation of facility	One-time documentation of facility	One-time documentation of facility
		Routine recordkeeping	Routine recordkeeping	Routine recordkeeping
	Off-site transportation	Off-farm export	Off-farm export	Off-farm export

[a]This list includes all components included for that representative farm in all regions.
[b]A footnote on the USDA tables indicates that 30 percent of operations have a separator or settling basins.

Using the percentages in Tables 6.1.1-3 and 6.1.1-4, EPA calculated the weighted frequency factors for each of the five EPA regions. For example, for beef feedlots in the EPA Central region, a frequency factor can be calculated using the following formulas:

USDA Region A Frequency Factor × 0.10 = USDA portion A
USDA Region B Frequency Factor × 0.19 = USDA portion B
USDA Region C Frequency Factor × 0.15 = USDA portion C
USDA Region D Frequency Factor × 0.56 = USDA portion D

Sum of USDA portions = EPA regional frequency factor

Table 6.1.1-3

Percentage of EPA Beef Feedlots and Heifer Operations in USDA Regions

Animal Type	EPA Region	USDA Regions[a]							
		A	B	C	D	E	F	G	H
Beef	Central	0.10	0.19	0.15	0.56	0	0	0	0
	Mid-Atlantic	0	0	0	0	0.05	0	0.45	0.50
	Midwest	0.13	0	0.16	0	0	0.70	0	0
	Pacific	0	1	0	0	0	0	0	0
	South	0	0	0	0	0	0	0	1
Heifer	Central	0.02	0.48	0.13	0.38	0	0	0	0
	Mid-Atlantic	0	0	0	0	0	0	0	0
	Midwest	0.27	0	0.15	0	0	0.54	0	0
	Pacific	0	1	0	0	0	0	0	0
	South	0	0	0	0	0	0	0	0

[a]Region A: MT, WY, ND, MN
Region B: CA, AZ, AK, HI, UT, NV, WA, OR, ID
Region C: CO, KS, NE, SD
Region D: TX, OK, NM
Region E: MA, RI, CN, VT, NH, ME
Region F: MO, IL, IN, OH, MI, WI, IA
Region G: PA, NY, NJ
Region H: VA, WV, MD, DE, NC, TN, KY, SC, GA, AL, MS, FL, AR, LA

Table 6.1.1-4

Percentage of EPA Dairies in USDA Regions

Animal Type	EPA Region	USDA Regions [a]		
		Dairy Belt	Southeast	West
Dairy	Central	0	0	1
	Mid-Atlantic	0.74	0.26	0
	Midwest	1	0	0
	Pacific	0	0	1
	South	0	1	0

[a]Dairy Belt Region - MN, IA, MO, WI, IL, MI, IN, OH, PA, NY, VT, ND, SD, NE, KS, NJ, MD, DE, MA, CT, RI, NH, ME
Southeast Region - KY, TN, FL, VA, WV, NC, SC, GA, AL, MS, AR, LA
West Region - CA, OR, WA, ID, NM, TX, HI, AK, AZ, UT, NV, MT, WY, CO, OK

Frequency Factors for Earthen Settling Basins

All regulatory options assume that beef feedlots and heifer operations require an earthen basin to collect runoff. The regulatory options also assumed that dairies and veal operations have concrete basins instead of earthen basins due to the higher flow of water from the barn and parlor cleaning operations that enter the settling basin. Table 6.1.1-5 lists the percentage of beef feedlots and heifer operations that would incur costs for earthen basins by size class, region, and requirements.

Frequency Factors for Runoff Controls

Under all regulatory options, CAFOs are required to contain any runoff collecting in potentially contaminated areas. For the purpose of estimating compliance costs, EPA assumes that facilities will use berms to control runoff. Table 6.1.1-6 presents estimates of beef feedlots, heifer operations, and dairies that will incur costs to install berms based on size class, requirements, and regional location. EPA assumes that veal, swine, and poultry operations do not require berms.

Table 6.1.1-5

Percentage of Beef Feedlots and Heifer Operations Incurring Earthen Basin Costs for All Regulatory Options

Animal Type	Size Class	Performance	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef and Heifers	Medium 1 Medium 2 Medium 3	High	100%	100%	100%	100%	100%
		Medium	80%	80%	80%	80%	80%
		Low	40%	40%	40%	40%	40%
	Large 1 Large 2[a]	High	100%	100%	100%	100%	100%
		Medium	80%	80%	80%	80%	80%
		Low	40%	40%	40%	40%	40%

[a]Large 2 size class represents only beef feedlots.

Frequency Factors for Liquid Land Application

Under all regulatory options, beef feedlots, heifer operations, and dairies are assumed to land apply their liquid manure and process wastewaters. Table 6.1.1-7 presents estimates of beef feedlot, heifer operations, and dairies that will incur costs (i.e, purchase liquid land application equipment) to apply liquid manure and wastewaters to their cropland based on size class, requirements, and regional location. EPA assumes that all veal operations have appropriate equipment for liquid land application and, therefore, do not incur any additional costs.

Frequency Factors for Nutrient Management Planning

Under all regulatory options, beef feedlots, heifer operations, and dairies are assumed to incur costs associated with nutrient management planning. Nutrient management planning includes setbacks, lagoon depth markers, soil sampling, manure sampling, recordkeeping, and document preparation. Table 6.1.1-8 presents estimates of beef feedlots, heifer operations, and dairies that will incur costs to comply with the nutrient management planning requirements based on size class, requirements, and regional location. All veal operations (100 percent) are assumed to incur costs for nutrient management planning.

Table 6.1.1-6

Beef Feedlots, Heifer Operations, and Dairies Incurring Costs to Install and Maintain Berms for All Regulatory Options

Animal Type	Size Class	Performance	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef and Heifers	Medium 1	High	74%	92%	59%	50%	85%
		Medium	56%	32%	46%	40%	65%
		Low	32%	21%	12%	0%	43%
	Medium 2	High	71%	92%	55%	50%	84%
		Medium	54%	32%	43%	40%	65%
		Low	29%	21%	6%	0%	43%
	Medium 3	High	74%	92%	59%	50%	85%
		Medium	56%	32%	46%	40%	65%
		Low	32%	21%	12%	0%	43%
	Large 1	High	67%	92%	50%	50%	85%
		Medium	51%	32%	40%	40%	65%
		Low	23%	21%	0%	0%	43%
	Large 2[a]	High	50%	92%	50%	50%	85%
		Medium	40%	32%	40%	40%	65%
		Low	0%	21%	0%	0%	43%
Dairy	Medium 1	High	30%	34%	59%	30%	40%
		Medium	10%	21%	36%	10%	20%
		Low	0%	7%	14%	0%	0%
	Medium 2	High	30%	34%	59%	30%	40%
		Medium	10%	21%	36%	10%	20%
		Low	0%	7%	14%	0%	0%
	Medium 3	High	30%	34%	59%	30%	40%
		Medium	10%	21%	36%	10%	20%
		Low	0%	7%	14%	0%	0%
	Large 1	High	30%	33%	58%	30%	40%
		Medium	10%	20%	38%	10%	20%
		Low	0%	8%	18%	0%	0%

[a]Large 2 size class represents only beef feedlots.

Table 6.1.1-7

Beef Feedlots, Heifer Operations, and Dairies Incurring Costs for Liquid Land Application for All Regulatory Options

Animal Type	Size Class	Requirements	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef and Heifers	Medium 1	High	100%	80%	100%	100%	97%
		Medium	70%	56%	70%	70%	67%
		Low	32%	26%	37%	40%	24%
	Medium 2	High	100%	80%	100%	100%	97%
		Medium	70%	56%	70%	70%	67%
		Low	33%	26%	38%	40%	24%
	Medium 3	High	100%	80%	100%	100%	97%
		Medium	70%	56%	70%	70%	67%
		Low	32%	26%	37%	40%	24%
	Large 1	High	100%	80%	100%	100%	97%
		Medium	70%	56%	70%	70%	67%
		Low	34%	26%	40%	40%	24%
	Large 2[a]	High	100%	80%	100%	100%	97%
		Medium	70%	56%	70%	70%	67%
		Low	40%	26%	40%	40%	24%
Dairy - Flush	Medium 1 Medium 2 Medium 3 Large 1	High	50%	55%	92%	50%	65%
		Medium	30%	40%	57%	30%	51%
		Low	10%	21%	14%	10%	37%
Dairy - Hose	Medium 1 Medium 2 Medium 3	High	50%	57%	91%	50%	65%
		Medium	30%	39%	55%	30%	51%
		Low	10%	19%	13%	10%	37%
	Large 1	High	50%	55%	92%	50%	65%
		Medium	30%	40%	57%	30%	51%
		Low	10%	21%	14%	10%	37%

[a]Large 2 size class represents only beef feedlots.

Table 6.1.1-8

Beef Feedlots, Heifer Operations, and Dairies Incurring Costs for Nutrient Management Planning for All Regulatory Options

Animal Type	Size Class	Requirements	Region: Central	Mid-Atlantic	Midwest	Pacific	South
Beef and Heifers	Medium 1 Medium 2 Medium 3	High	100%	100%	100%	100%	100%
		Medium	90%	95%	90%	90%	93%
		Low	80%	79%	80%	80%	80%
	Large 1 Large 2[a]	High	100%	100%	100%	100%	100%
		Medium	90%	95%	90%	90%	93%
		Low	80%	79%	80%	80%	80%
Dairy - Flush	Medium 1 Medium 2 Medium 3 Large 1	High	100%	63%	100%	100%	100%
		Medium	90%	57%	90%	90%	90%
		Low	80%	50%	80%	80%	80%
Dairy - Scrape	Medium 1 Medium 2 Medium 3	High	100%	64%	100%	100%	100%
		Medium	90%	58%	90%	90%	90%
		Low	80%	51%	80%	80%	80%
	Large 1	High	100%	63%	100%	100%	100%
		Medium	90%	57%	90%	90%	90%
		Low	80%	50%	80%	80%	80%

[a]Large 2 size class represents only beef feedlots.

6.1.2 Other Performance-Based Frequency Factors

For some technologies, USDA did not provide data based on farm performance. Therefore, EPA used implementation rates identified in literature, which are provided as single values rather than a range of values. Because EPA believes that the implementation of these technologies varies according to farm performance, EPA used the single values to calculate the range of frequency factors for these technologies using the following methodology:

1) Identify the overall frequency of implementation of the technology or practice.

Let X = the overall implementation, or frequency factor.

2) If X   25%, then

Low Frequency factor	=	0%
Medium Frequency Factor	=	0%
Highest Frequency Factor	=	X ÷ 25%

If 25% < X < 75%, then

Low Frequency factor	=	0%
Medium Frequency Factor	=	(X - 25%) ÷ 50%
Highest Frequency Factor	=	100%

If X ≥75%, then

Low Frequency factor	=	(X - 75%) ÷ 25%
Medium Frequency Factor	=	100%
Highest Frequency Factor	=	100%

Thus, it was assumed that low implementation cost operations had a frequency factor of 100 percent (100 percent of facilities had implemented the practice) and high implementation cost operations had a frequency factor of 0 percent. “Medium implementation cost” was then calculated by assuming that 25 percent of the operations incurred low implementation cost, 25 percent incurred high implementation cost, and the remaining 50 percent incurred medium implementation cost. For example, if literature reported the actual implementation rate to be 65 percent, the low and high implementation cost frequency factors were assumed to be 100 and 0 percent, respectively. The medium implementation cost frequency factor would be computed as 80 percent.

The frequency factors for concrete settling basins in the beef and dairy cost model was calculated in this way, as shown in Table 6.1.2-1.

Table 6.1.2-1

Frequency Factors Identified from Literature and Used to Calculate Low, Medium, and High Frequency Factors for Beef and Dairy Cost Model

Technology or Practice	Size Class	Overall Frequency Factor	Implementation Cost Frequency Factor		
			Low	Medium	High
Concrete Settling Basin	Medium	20%	0%	0%	80%
	Large	33%	0%	16%	100%

6.1.3 Other Technology Frequency Factors

Some of the technology components of EPA's cost models are not based on USDA's performance-based data. Frequency factors for naturally lined ponds, lagoons, and transportation costs are based on several different data sources and are described below.

Naturally Lined Pond and Lagoon Frequency Factors

The cost models for beef feedlots, heifer operation, dairies, veal operations, swine operations, and wet layer operations include naturally lined ponds and lagoons. This subsection presents the frequency factors for beef feedlot, dairies, heifer and veal operations.

Using information from site visits and state and federal regulations, EPA assumed that all large-sized beef feedlots and all large dairies have adequate storage for process wastewater consistent with the 1974 regulation. EPA developed frequency factors for medium-sized beef feedlots with naturally lined ponds using site visit information and best professional judgment. Based on discussions with the Professional Dairy Heifer Growers Association, EPA assumed that heifer operations operate like beef feedlots; therefore, the Agency used the same frequency factors for naturally lined ponds for both types of operations.

Frequency factors for medium-sized dairies with naturally lined ponds are based on site visit information, NAHMS data, and current state and federal regulations. According to NAHMS, 13.5 percent of dairies in the 500-to-699-head group and 4.3 percent in the greater than 700 head group do not have any kind of waste storage facility. Of the sites visited by EPA, only one dairy had neither a lagoon nor large storage tank. Therefore, EPA assumes that the larger the dairy, the more likely it is to have a lagoon or other waste storage facility. According to NAHMS, dairies of 200 head and above in the East and Midwest (31.4 and 16.9 percent, respectively) are less likely to have lagoons or storage than dairies in the West (7.9 percent). EPA assumes that the smaller dairies (less than 700 mature dairy cows) comprise the largest percentage of dairies without waste storage in each region.

Based on site visits and discussions with the American Veal Association, EPA assumes that all veal operations have sufficient lagoon capacity to manage all of the manure and wastewater generated. Table 6.1.3-1 presents the percentage of beef feedlots, heifer operations, dairies, and veal operations that would incur costs to install a naturally lined pond or lagoon under Options 1, 2, 4, 5A, and 6. The percentages do not vary by region. EPA also used these frequency factors to determine the percentage of facilities requiring additional storage capacity under Option 7.

Transportation Frequency Factors

EPA developed frequency factors for facilities requiring the off-site transportation of excess manure and waste for all animal types using information from existing state regulations (ERG, 2000; EPA, 1999). Frequency factors were developed only for Category 2 facilities because the percentage of Category 1 and 3 facilities transporting excess manure and waste remains the same under all regulatory options. EPA assumes that facilities required by their states to land apply at agronomic rates are using nitrogen-based application rates and already incur the cost of transporting excess manure and waste off site. EPA assumes that no facilities are currently meeting phosphorus-based agronomic application of manure and, therefore, assumes that all operations costed for phosphorus-based application will incur costs to transport excess manure.

Table 6.1.3-1

Percentage of Beef Feedlots, Heifer Operations, Dairies, and Veal Operations Incurring Costs to Install a Naturally Lined Pond or Lagoon

Animal Type	Size Class	Percentage of Facilities
Beef and Heifers	Medium 1	50%
	Medium 2	50%
	Medium 3	50%
	Large 1	0%
	Large 2[a]	0%
Dairy	Medium 1	10%
	Medium 2	10%
	Medium 3	10%
	Large 1	0%
Veal	All	0%

[a]Large 2 size class represents only beef feedlots.

To calculate the frequency factors for Category 2 beef feedlots and dairies, EPA determined the threshold requirements for nitrogen-based agronomic application of manure for 22 major dairy and beef-producing states based on state regulations. The Agency then used industry profile and Census of Agriculture data to determine the number of facilities in each state above both the state threshold and EPA's proposed threshold. EPA recorded the number of facilities above both thresholds by region; these facilities are assumed to already incur transportation costs for excess manure. EPA compared the number of facilities assumed to incur transportation costs with the number of facilities above the proposed threshold to arrive at regional frequency factors representing transportation costs. States other than the 22 included in the analysis were assumed not to require nitrogen-based agronomic application of animal wastes. EPA assumes that heifer operations operate the same as beef feedlots and, therefore, heifer operations use the same frequency factors as beef feedlots. EPA assumes that all veal operations are Category 1 operations and therefore, did not develop transportation frequency factors for these operations. Table 6.1.3-2 presents the percentage of Category 2 beef feedlots, heifer operations, and dairies incurring costs for transporting excess manure and waste off site.

Table 6.1.3-2

Percentage of Category 2 Beef Feedlots, Heifer Operations, and Dairies Incurring Costs for Transporting Excess Manure and Waste Off Site

Animal Type	Size Class	Region				
		Central	Mid-Atlantic	Midwest	Pacific	South
Beef	Medium 1 Medium 2 Medium 3	100%	100%	78%	100%	100%
	Large 1 Large 2	13%	6%	33%	100%	100%
Heifer	Medium 1 Medium 2 Medium 3	100%	100%	82%	100%	100%
	Large 1	13%	6%	33%	100%	100%
Dairy	Medium 1 Medium 2 Medium 3	100%	100%	82%	100%	100%
	Large 1	46%	34%	77%	100%	54%

6.2 <u>Beef and Dairy Nutrient Basis Frequency Factors</u>

Several cost modules compute component costs separately for both nitrogen- and phosphorus-based application and are adjusted based on frequency factors that indicate the use of the component in the industry. For Options 1 and 1A, the cost model estimates costs for all operations for nitrogen-based application, and for Option 2A, estimates costs for all operations for phosphorus-based application. However, under the remaining options, EPA used the soil test map from USDA's *Agricultural Phosphorus and Eutrophication* book (USDA ARS, 1999) to determine the percentage of facilities in each state that would require nitrogen-based versus phosphorus-based application rates. The soil map identified the percentage of soil samples in each state that had soil test P (phosphorus) levels in the "high or above" categories. States colored red on the map reported high or above soil test P levels in more than 50 percent of the samples. Phosphorus levels of greater than 50 parts per million are generally considered "high." States colored pink/orange reported high or above soil test P levels in 25 to 50 percent of the samples, and states colored green reported high or above soil test P levels in less than 25 percent of the samples.

Using these results for soil test P levels, EPA made the following assumptions:

- Facilities located in "green" states would require only nitrogen-based applications;
- Facilities located in "pink/orange" states would require 40 percent phosphorus-based and 60 percent nitrogen-based applications; and
- Facilities located in "red" states would require 60 percent phosphorus-based and 40 percent nitrogen-based applications.

EPA adopted this 40/60 and 60/40 split of applications to account for areas within a given state that would have soils with low phosphorus levels.

Using these determinations, EPA calculated the percentage of operations that would require phosphorus-based applications under Options 2 through 7 for each region. These percentages were calculated by animal type, size class, and regions using the following equation:

$$\text{P Facs\%} = \left(\frac{\text{State FacR}}{\text{Total Fac}} \times \text{60\% PBased}\right) + \left(\frac{\text{State FacO}}{\text{Total Fac}} \times \text{40\% PBased}\right) \qquad [6\text{-}2]$$

where:

P Facs%	=	Percentage of facilities, by region, that would require phosphorus-based application
State FacR	=	Number of facilities in a red state
State FacO	=	Number of facilities in an orange/pink state
Total Fac	=	Total number of facilities in that size class and region

%Pbased = Percentage of facilities that would require phosphorus-based application for that given state.

EPA calculated the percentage of nitrogen-based application facilities in each region and size class using the following equation:

$$N\ Facs = 100\% - P\ Facs \quad [6\text{-}3]$$

where:

N Facs = Percentage of facilities that would require nitrogen-based application

P Facs = Percentage of facilities that would require phosphorus-based application.

Table 6.2-1 presents the percentages of nitrogen-based and phosphorus-based facilities by animal type, by size class, and by region for Options 2 through 7.

6.3 <u>Beef and Dairy Land Availability Frequency Factors</u>

All operations fall into one of three land availability categories depending on the amount of on-site cropland available for manure application:

- Category 1 operations have sufficient land to land apply all of their generated manure and wastewater at appropriate agronomic rates. No manure is transported off site.
- Category 2 operations do not have sufficient land to land apply all of their generated manure and wastewater at appropriate agronomic rates. The excess manure after agronomic application is transported off site.
- Category 3 operations do not have any available land for manure application. All generated manure and wastewater is transported off site.

Facility counts for swine and broiler operations were provided by USDA NRCS including land availability category; therefore, these model farms did not require disaggregation using the land availability frequency factors. However, facility counts for layers, pullets, turkeys, and cattle operations were not provided by land availability category. Therefore, EPA applied the land availability categories to the facility counts for these operations.

Table 6.2-1

Percentage of Nitrogen-Based and Phosphorus-Based Application Facilities

Animal Type	Size Class	Application Percentage Basis	Region				
			Central	Mid-Atlantic	Midwest	Pacific	South
Beef and Heifers	Medium 1	Nitrogen	53%	51%	60%	40%	49%
		Phosphorus	47%	49%	40%	60%	51%
	Medium 2	Nitrogen	54%	51%	60%	40%	55%
		Phosphorus	46%	49%	40%	60%	45%
	Medium 3	Nitrogen	48%	49%	60%	40%	50%
		Phosphorus	52%	51%	40%	60%	50%
	Large 1	Nitrogen	45%	49%	61%	40%	0%
		Phosphorus	55%	51%	39%	60%	0%
	Large 2	Nitrogen	46%	60%	61%	40%	0%
		Phosphorus	54%	40%	39%	60%	0%
Dairy	Medium 1	Nitrogen	46%	47%	47%	40%	56%
		Phosphorus	54%	53%	53%	60%	44%
	Medium 2	Nitrogen	47%	46%	47%	40%	57%
		Phosphorus	53%	54%	53%	60%	43%
	Medium 3	Nitrogen	49%	44%	49%	40%	48%
		Phosphorus	51%	56%	51%	60%	52%
	Large 1	Nitrogen	56%	44%	50%	40%	47%
		Phosphorus	44%	56%	50%	60%	53%
Veal	Medium 1	Nitrogen	40%	60%	44%	0%	0%
		Phosphorus	60%	40%	56%	0%	0%
	Medium 2	Nitrogen	40%	0%	44%	0%	0%
		Phosphorus	60%	0%	56%	0%	0%
	Medium 3	Nitrogen	40%	0%	44%	0%	0%
		Phosphorus	60%	0%	56%	0%	0%

EPA calculated the percentage of facilities in each of these categories using USDA data. USDA conducted a national analysis of the 1997 Census of Agriculture data to estimate the manure production at livestock facilities (Kellogg, R. et al, 2000). As part of this analysis, USDA estimated the number of confined livestock facilities that produce more manure than they can land-apply on their available cropland and pasturelands at agronomic rates for nitrogen and phosphorus and the number of confined livestock operations that do not have any available cropland or pastureland. This analysis also identified the amount of excess manure at the facilities with insufficient land.

EPA used USDA's facility counts to develop the percentage of facilities that are classified as Category 2 and 3 under a 100-percent nitrogen-based application scenario and a 100-percent phosphorus-based application scenario. EPA estimated the percentage of facilities classified as Category 2 and 3 using the following equations:

$$\text{Percent Category 2 Facs} = \frac{\text{No. Farms with Excess Manure (N or P) and Cropland}}{\text{Total No. Confined Livestock Farms}} \qquad [6\text{-}4]$$

$$\text{Percent Category 3 Facs} = \frac{\text{No. Farms with Excess Manure (N or P) and No Cropland}}{\text{Total No. of Confined Livestock Farms}} \qquad [6\text{-}5]$$

where:

Percent Category 2 Facs	=	Percentage of facilities classified as Category 2
Percent Category 3 Facs	=	Percentage of facilities classified as Category 3
No. Farms with Excess Manure (N or P) and Cropland	=	Number of facilities with excess manure on a nitrogen or phosphorus basis and some cropland for land application
No. Farms with Excess Manure (N or P) and No Cropland	=	Number of facilities with excess manure on a nitrogen or phosphorus basis and no cropland for land application
Total No. of Confined Livestock Farms	=	Total number of confined livestock farms

EPA estimated the percentage of facilities classified as Category 1 using the following equation:

$$\text{Percent Category 1 Facs} = 100\% - \text{Percent Category 2} - \text{Percent Category 3} \quad [6\text{-}5]$$

where:

Percent Category 1 Facs	=	Percentage of facilities classified as Category 1
Percent Category 2	=	Percentage of facilities classified as Category 2
Percent Category 3	=	Percentage of facilities classified as Category 3

Option 1 uses only nitrogen-based application factors, while Options 2 through 7 use a combination of both nitrogen- and phosphorus-based factors. Table 6.3-1 presents EPA's estimated percentage of Category 1, 2, and 3 facilities using nitrogen- and phosphorus-based applications.

Table 6.3-1

Percentage of Category 1, 2, and 3 Facilities Using Nitrogen- and Phosphorus-Based Applications

Animal Type	Size Class	Nitrogen-Based Application			Phosphorus-Based Application		
		Category 1	Category 2	Category 3	Category 1	Category 2	Category 3
Beef	Medium 1 Medium 2 Medium 3	84%	9%	7%	62%	31%	7%
	Large 1	68%	21%	11%	22%	67%	11%
	Large 2	8%	53%	39%	1%	60%	39%
Dairy	Medium 1 Medium 2 Medium 3	50%	36%	14%	25%	61%	14%
	Large 1	27%	51%	22%	10%	68%	22%
Heifer	Medium 1 Medium 2 Medium 3	84%	9%	7%	62%	31%	7%
	Large 1	68%	21%	11%	22%	67%	11%
Veal	Medium 1 Medium 2 Medium 3	100%	0%	0%	100%	0%	0%

6.4 Poultry and Swine Technology Frequency Factors

Frequency factors were developed to represent the current implementation rate of various practices used on operations. Since current implementation can vary significantly across operations in a given sector, the frequency factors were developed to represent low, medium, and high implementation costs. For example, operations classified as "low implementation cost" generally tend to have already implemented the practice and thus "low" (or no) additional costs are expected for such operations. Conversely, "high implementation cost" operations are assumed to have little or low levels of implementation and are expected to have "high" additional costs to implement a given practice or meet a certain standard. Data received from USDA were presented in this manner for some technologies and practices, including manure testing, soil testing, record keeping, mortality composting, and adequate mortality storage (Kellogg, 2002).

In some cases, implementation rates in the literature are provided as single values rather than a range of values. Thus, it was assumed that low implementation cost operations had a frequency factor of 100 percent (100 percent of facilities had implemented the practice) and high implementation cost operations had a frequency factor of 0 percent. "Medium implementation cost" was then calculated by assuming that 25 percent of the operations incurred low implementation cost, 25 percent incurred high implementation cost, and the remaining 50 percent incurred medium implementation cost. For example, if literature reported the actual implementation rate to be 65 percent, the low and high implementation cost frequency factors were assumed to be 100 and 0 percent, respectively. The medium implementation cost frequency factor would be computed as 80 percent. In those cases where the medium implementation factor calculation produced results that were not possible, the low or high frequency factor would be adjusted down or up, as appropriate, until a realistic medium frequency factor resulted. For example, if the literature-reported implementation rate was 80 percent, the low and medium frequency factors would be 100 percent and the high frequency factor would be adjusted up to 20 percent (rather than 0 percent).

Where data from USDA were not available, EPA used frequency factors obtained from other sources, which varied by sector, component, or practice. Industry and USDA data were used as the basis for most of the frequency factors for layers and swine; analysis of state and federal regulations was used primarily for broilers and turkeys. EPA's report on state regulatory programs (USEPA, 1999) was also used for all animal sectors. Costs were not attributed to CAFO model farms when state regulations specify standards or require practices equal to or more stringent than the proposed technology options.

Because the literature and industry provided data for the broiler and turkey sectors were generally not detailed enough to generate frequency factors, EPA reviewed the specific regulatory language and summaries of regulations for 12 major poultry-producing states regarding requirements for nutrient management plans (NMPs) at broiler and turkey farms (Tetra Tech, 2000). Requirements were considered for farms in two size groups: 300 to 1,000 animal units (AU) and greater than 1,000 AU. All broiler and turkey farms were assumed to use dry waste management systems.

From the analysis of state and federal regulations, EPA determined that a few states already require broiler and turkey farms to implement some of the components of an NMP. Except as specified for groundwater and surface water requirements, and in cases where select frequency factors could be based on available industry data, the analysis from these 12 states was used to calculate regional frequency factors. These regional frequency factors approximate the number of farms that are currently required to implement NMP components and therefore already incur costs for these components.

Weighted averages were used to estimate frequency factors for each NMP component (for 300 to 1,000 AU and >1,000 AU), as illustrated in the example in Table 6.4-1. The weight reflects the percentage of operations in the entire region already incurring the costs of that component.

Table 6.4-1

Illustration of Method to Calculate Frequency Factors from Weighted Averages

State	Number of Farms[a]	Component Required?[b]	Weight
A	10	Yes	10
B	40	No	0
C	20	Yes	20
D	20	No	0
Regional Total	100		(30/100) = 0.30

[a] The number of farms for broilers and turkeys differs within each state, so the overall regional frequency factors may be different for broilers versus turkeys. 1997 Census of Agriculture data (USDOC, 1999) were used to determine the number of farms in each state within the two size ranges, 300 to 1,000 AU and >1,000 AU.
[b] Components were assumed *not* to be required for states other than the 12 reviewed.

Technology Frequency Factors for Poultry and Swine

Data used to determine frequency factors for poultry and swine varied upon the sector and component or practice. Industry and USDA data were used as the basis for most of the frequency factors for layers (United Egg Producers/United Egg Association and Capitolink, 1999) and swine (USDA APHIS, 1995 and NPPC, 1998), whereas analysis of state and federal regulations was used primarily for broilers and turkeys. In addition, frequency factors were also derived from data provided by USDA NRCS (2002) provided to EPA electronically on February 6, 2002. USDA NRCS data included frequency factors for three performance-based categories of facilities (low performing, medium performing, and high performing) for a series of "representative" farms defined by USDA. Frequency factors are presented in Tables 6.4-2 through 6.4-8 for the various combinations of sector, region, size class, and performance level.

Literature and industry data for the broiler and turkey sectors was generally not detailed enough to generate frequency factors. Instead, EPA reviewed the specific regulatory language and summaries of regulations for 12 major poultry-producing states regarding requirements for nutrient management plans (NMPs) at broiler and turkey facilities (Tetra Tech, 2000). Requirements were considered for both medium and large facilities. All broiler and turkey facilities were assumed to use dry waste management systems. From the analysis of state and federal regulations, EPA determined that a few states already require broiler and turkey facilities to implement some of the components of a NMP. Except as specified for ground water and surface water requirements, and in cases where select frequency factors could be based on available industry data, the analysis from these 12 states were used to calculate regional frequency factors. These state regulation based frequency factors approximate the number of facilities that are currently required to implement NMP components and, therefore, must already incur costs for these components. Weighted averages were used to estimate frequency factors for each component.

Assessment of Ground Water Link to Surface Water. The frequency factors for these assessments at layer (United Egg Producers/United Egg Association and Capitolink, 1999) facilities was based upon industry data, while the frequency factors for broiler and turkey facilities were conservatively assumed to be zero. The frequency factors for swine facilities was based upon a review of state regulations that already require lagoons to be lined.

Surface Water Monitoring and O&M. The frequency factors for surface water monitoring at layer facilities were assumed to be zero based on site visits, those for swine were based upon industry data (USDA APHIS, 1995), and those for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000).

Soil Augers. The frequency factors for soil augers at layer (United Egg Producers/United Egg Association and Capitolink, 1999) and swine (NPPC, 1998) facilities were based upon industry data, while the frequency factors for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000). In cases where states require soil testing at broiler and turkey facilities, it was assumed that soil augers (or an equivalent technology) are also required or otherwise available to the facility, and thus not costed.

Table 6.4-2

Broiler Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities By Region That Already Incur Costs

Description	Region	Mid-Atlantic								South								Source
	Size Class	Large				Medium				Large				Medium				
	Performance	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	
Already assess GW link to SW		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Conserv. Assump.
SW monitoring; O&M		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Soil auger		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Manure sampler		45	1.7	0	12.1	65	0.7	0	16.6	90	1.2	0	23.1	85	1.5	0	22	State Regulations
Scales (2) for spreader calibration		45	1.7	0	12.1	65	0.7	0	16.6	0	0	0	0	0	0	0	0	State Regulations
Initial NMP development and NMP on-farm recurring		45	1.7	0	12.1	65	0.7	0	16.6	90	1.2	0	23.1	85	1.5	0	22	State Regulations
Calibration of manure spreader		45	1.7	0	12.1	65	0.7	0	16.6	0	0	0	0	0	0	0	0	State Regulations
Storm water diversions		0	0	0	0	0	0	0	0	90	1.2	0	23.1	85	1.5	0	22	State Regulations
Storm water—O&M		0	0	0	0	0	0	0	0	90	1.2	0	23.1	85	1.5	0	22	State Regulations
Stream buffer and O&M		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Visual inspection		0	0	0	0	0	0	0	0	90	1.2	0	23.1	85	1.5	0	22	State Regulations
Feeding strategies		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	Site visits and industry consult.
Operations that sell or trade		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	UEP, 2002
Adequate storage		90	60	0	52.5	90	60	0	52.5	90	60	30	60	90	60	30	60	USDA NRCS
Soil testing		20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing		20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping		20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting		95	85	75	85	95	55	20	56.3	95	85	75	85	95	55	20	56.3	USDA NRCS
Mortality—O&M		95	85	75	85	95	55	20	56.3	95	85	75	85	95	55	20	56.3	USDA NRCS

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance

[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Table 6.4-3

Turkey Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities That Already Incur Costs

Region	Midwest								Mid-Atlantic								
Size Class	Large				Medium				Large				Medium				
Description / Performance	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	Source
Already assess GW link to SW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Conserv. Assump.
SW monitoring; O&M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Soil auger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Manure sampler	40	0.2	0	10.1	100	26.6	0	38.3	5	0.1	0	1.3	1	0.3	0	0.4	State Regulations
Scales (2) for spreader calibration	40	0.2	0	10.1	100	26.6	0	38.3	5	0.1	0	1.3	1	0.3	0	0.4	State Regulations
Initial NMP development and NMP on-farm recurring	0	0	0	0	0	0	0	0	5	0.1	0	1.3	1	0.3	0	0.4	State Regulations
Calibration of manure spreader	40	0.2	0	10.1	100	26.6	0	38.3	5	0.1	0	1.3	1	0.3	0	0.4	State Regulations
Storm water diversions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Storm water—O&M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Stream buffer and O&M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Visual inspection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	State Regulations
Feeding strategies	10	5	0	5	20	0	0	5	10	5	0	5	20	0	0	5	Site visits and industry consult.
Operations that sell or trade	100	56	0	53	100	56	0	53	100	56	0	53	100	56	0	53	UEP, 2002
Adequate storage	90	50	0	47.5	90	50	0	47.5	90	50	0	47.5	90	50	0	47.5	USDA NRCS
Soil testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting	70	40	10	40	70	40	10	40	70	40	10	40	70	40	10	40	USDA NRCS
Mortality—O&M	70	40	10	40	70	40	10	40	70	40	10	40	70	40	10	40	USDA NRCS

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance
[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Table 6.4-4

Layer Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities That Already Incur Costs

Region	Midwest								South								
Size Class	Large				Medium				Large				Medium				
Description / Performance	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	Source
Already assess GW link to SW	40	1.8	0	10.9	40	1.8	0	10.9	100	30	0	40	100	30	0	40	UEP/UEA
SW monitoring; O&M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	EPA site visits
Soil auger	100	18.6	0	34.3	100	18.6	0	34.3	100	50	0	50	100	50	0	50	UEP/UEA
Manure sampler	100	91.2	0	70.6	100	91.2	0	70.6	100	100	0	75	100	100	0	75	UEP/UEA
Scales (2) for spreader calibration	100	73.6	0	61.8	100	73.6	0	61.8	100	50	0	50	100	50	0	50	UEP/UEA
Initial NMP development and NMP on-farm recurring	100	88.8	0	69.4	100	88.8	0	69.4	100	100	0	75	100	100	0	75	UEP/UEA
Calibration of manure spreader	100	73.6	0	61.8	100	73.6	0	61.8	100	50	0	50	100	50	0	50	UEP/UEA
Storm water diversions	100	99.3	25	80.9	100	99.3	25	80.9	100	90	0	70	100	90	0	70	UEP/UEA
Storm water—O&M	100	99.3	25	80.9	100	99.3	25	80.9	100	90	0	70	100	90	0	70	UEP/UEA
Stream buffer and O&M	100	99.3	25	80.9	100	99.3	25	80.9	100	90	0	70	100	90	0	70	UEP/UEA
Visual inspection	100	0	0	25	100	0	0	25	100	0	0	25	100	0	0	25	AFO strategy
Feeding strategies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Conserv. Assump.
Operations that sell or trade	100	29.4	0	39.7	100	29.4	0	39.7	100	29.4	0	39.7	100	29.4	0	39.7	UEP, 2002
Lagoon depth marker (wet manure handling system)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	0	0	0	0	0	0	Conserv. Assump.
Adequate storage (dry manure handling system)	95	80	70	81.3	90	60	40	62.5	90	70	60	72.5	80	40	20	45	USDA NRCS
Adequate storage (wet manure handling system)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	80	60	40	60	80	60	40	60	USDA NRCS
Soil testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting	95	85	75	85	90	55	20	55	95	85	75	85	90	55	20	55	USDA NRCS
Mortality—O&M	95	85	75	85	90	55	20	55	95	85	75	85	90	55	20	55	USDA NRCS

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance

[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Table 6.4-5

Swine Farrow-to-Finish Operations (Lagoon and Evaporative Lagoon) Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities That Already Incur Costs

Region	Midwest/Central								Mid-Atlantic								
Size Class	Large				Medium				Large				Medium				
Description / Performance	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	Source
Already in compliance with lagoon liner requirements	90	1.2	0	23.1	4	0.2	0	1.1	45	2.1	0	12.3	25	2.3	0	7.4	State Regulations
SW monitoring; O&M	100	5.8	0	27.9	18.4	0	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	USDA APHIS
Soil auger	100	98	80	94	0	0	0	0	100	98	80	94	0	0	0	0	NPPC, 1998
Manure sampler	100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Scales (2) for spreader calibration	100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Initial NMP development and NMP on-farm recurring	100	43.8	0	46.9	40	1.4	0	10.7	100	88.8	0	69.4	95	2.3	0	24.9	USDA APHIS
Calibration of manure spreader	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Storm water diversions	100	50	0	50	0	0	0	0	100	50	0	50	0	0	0	0	Site visits
Storm water diversions—O&M	100	5.8	0	27.9	15	1.7	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	Site visits
Stream buffer and O&M	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	Site visits and State Regulations
Visual inspection	100	0	0	25	0	0	0	0	100	0	0	25	0	0	0	0	AFO strategy
Feeding strategies	100	85.4	0	67.7	55	2.3	0	14.9	100	95.4	0	72.7	70	0.6	0	17.8	USDA APHIS
Transportation (N-based)	0	0	0	0	0	0	0	0	100	100	98.4	99.6	100	99.9	15	78.7	State Regulations
Lagoon depth marker	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Soil testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting	100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	Sobecki and Clipper, 1999
Mortality—O&M	100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance

[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Table 6.4-6

Swine Farrow-to-Finish Operations (Deep Pits) Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities That Already Incur Costs

Description	Region	Midwest								Mid-Atlantic								Source
	Size Class	Large				Medium				Large				Medium				
	Performance	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	
Already in compliance with lagoon liner requirements		90	1.2	0	23.1	4	0.2	0	1.1	45	2.1	0	12.3	25	2.3	0	7.4	State Regulations
SW monitoring; O&M		100	5.8	0	27.9	18.4	0	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	USDA APHIS
Soil auger		100	98	80	94	0	0	0	0	100	98	80	94	0	0	0	0	NPPC, 1998
Manure sampler		100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Scales (2) for spreader calibration		100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Initial NMP development and NMP on-farm recurring		100	43.8	0	46.9	40	1.4	0	10.7	100	88.8	0	69.4	95	2.3	0	24.9	USDA APHIS
Calibration of manure spreader		100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Storm water diversions		100	50	0	50	0	0	0	0	100	50	0	50	0	0	0	0	Site visits
Storm water diversions—O&M		100	5.8	0	27.9	15	1.7	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	Site visits
Stream buffer and O&M		100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	Site visits and State Regulations
Visual inspection		100	0	0	25	0	0	0	0	100	0	0	25	0	0	0	0	AFO strategy
Feeding strategies		100	85.4	0	67.7	55	2.3	0	14.9	100	95.4	0	72.7	70	0.6	0	17.8	USDA APHIS
Transportation (N-based)		0	0	0	0	0	0	0	0	100	100	98.4	99.6	100	99.9	15	78.7	State Regulations
Lagoon depth marker		100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Soil testing		20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing		20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping		20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting		100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	Sobecki and Clipper, 1999
Mortality—O&M		100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance

[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Table 6.4-7

Swine Grow/Finish Operations (Lagoon and Evaporative Lagoon) Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities That Already Incur Costs

Region	Midwest/Central								Mid-Atlantic								
Size Class	**Large**				**Medium**				**Large**				**Medium**				
Description / Performance	**H**	**M**	**L**	**A[a]**	**H**	**M**	**L**	**A[a]**	**H**	**M**	**L**	**A[a]**	**H**	**M**	**L**	**A[a]**	**Source**
Already in compliance with lagoon liner requirements	90	1.2	0	23.1	4	0.2	0	1.1	45	2.1	0	12.3	25	2.3	0	7.4	State Regulations
SW monitoring; O&M	100	5.8	0	27.9	18.4	0	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	USDA APHIS
Soil auger	100	98	80	94	0	0	0	0	100	98	80	94	0	0	0	0	NPPC, 1998
Manure sampler	100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Scales (2) for spreader calibration	100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Initial NMP development and NMP on-farm recurring	100	43.8	0	46.9	40	1.4	0	10.7	100	88.8	0	69.4	95	2.3	0	24.9	USDA APHIS
Calibration of manure spreader	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Storm water diversions	100	50	0	50	0	0	0	0	100	50	0	50	0	0	0	0	Site visits
Storm water diversions—O&M	100	5.8	0	27.9	15	1.7	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	Site visits
Stream buffer and O&M	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	Site visits and State Regulations
Visual inspection	100	0	0	25	0	0	0	0	100	0	0	25	0	0	0	0	AFO strategy
Feeding strategies	100	85.4	0	67.7	55	2.3	0	14.9	100	95.4	0	72.7	70	0.6	0	17.8	USDA APHIS
Transportation (N-based)	0	0	0	0	0	0	0	0	100	100	98.4	99.6	100	100	18	79.5	State Regulations
Lagoon depth marker	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Soil testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting	100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	Sobecki and
Mortality—O&M	100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	Clipper, 1999

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance

[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Table 6.4-8

Swine Grow/Finish Operations (Deep Pits) Frequency Factors: Percent of High (H), Medium (M), Low (L) Performance Facilities That Already Incur Costs

Region	Midwest/Central								Mid-Atlantic								
Size Class	Large				Medium				Large				Medium				
Description / Performance	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	H	M	L	A[a]	Source
Already in compliance with lagoon liner requirements	90	1.2	0	23.1	4	0.2	0	1.1	45	2.1	0	12.3	25	2.3	0	7.4	State Regulations
SW monitoring; O&M	100	5.8	0	27.9	18.4	0	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	USDA APHIS
Soil auger	100	98	80	94	0	0	0	0	100	98	80	94	0	0	0	0	NPPC, 1998
Manure sampler	100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Scales (2) for spreader calibration	100	93.8	0	71.9	0	0	0	0	100	93.8	0	71.9	0	0	0	0	NPPC, 1998
Initial NMP development and NMP on-farm recurring	100	43.8	0	46.9	40	1.4	0	10.7	100	88.8	0	69.4	95	2.3	0	24.9	USDA APHIS
Calibration of manure spreader	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Storm water diversions	100	50	0	50	0	0	0	0	100	50	0	50	0	0	0	0	Site visits
Storm water diversions—O&M	100	5.8	0	27.9	15	1.7	0	4.6	70	0.8	0	17.9	20	1.4	0	5.7	Site visits
Stream buffer and O&M	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	Site visits and State Regulations
Visual inspection	100	0	0	25	0	0	0	0	100	0	0	25	0	0	0	0	AFO strategy
Feeding strategies	100	85.4	0	67.7	55	2.3	0	14.9	100	95.4	0	72.7	70	0.6	0	17.8	USDA APHIS
Transportation (N-based)	0	0	0	0	0	0	0	0	100	100	98.4	99.6	100	100	18	79.5	State Regulations
Lagoon depth marker	100	100	96	99	0	0	0	0	100	100	96	99	0	0	0	0	AFO strategy
Soil testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Manure testing	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Record keeping	20	10	0	10	20	10	0	10	20	10	0	10	20	10	0	10	USDA NRCS
Mortality—composting	100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	Sobecki and Clipper, 1999
Mortality—O&M	100	95.1	0	72.5	100	95.1	0	72.5	100	99.7	5	76.1	100	99.7	5	76.1	

Note: GW = ground water, SW = surface water, NMP = nutrient management planning, O&M operation and maintenance

[a] Weighted average computed as 0.25 × High (H) + 0.50 × Medium (M) + 0.25 × Low (L)

Manure Sampler. The frequency factors for manure samplers at layer (United Egg Producers/United Egg Association and Capitolink, 1999) and swine (NPPC, 1998) facilities were based upon industry data, while the frequency factors for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000). In cases where states require manure testing at broiler and turkey facilities, it was assumed that manure samplers (or an equivalent technology) are also required or otherwise available to the facility, and thus not costed.

Scales for Spreader Calibration. The frequency factors for calibration scales at layer (United Egg Producers/United Egg Association and Capitolink, 1999) and swine (NPPC, 1998) facilities were based upon industry data, while the frequency factors for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000). In cases where states require calibration of manure spreaders at broiler and turkey facilities, it was assumed that calibration scales (or an equivalent calibration technology or method) are also required or otherwise available to the facility, and thus not costed. Calibration of solid manure spreaders can be performed in a number of ways, some of which are based on volume instead of weight, and liquid-based systems can also be calibrated in terms of volume.

Initial NMP Development and NMP Recurring. The frequency factors for development of an on-farm NMP at layer (United Egg Producers/United Egg Association and Capitolink, 1999) and swine (USDA APHIS, 1995) facilities were based upon industry data, while the frequency factors for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000). Revision of plans at broiler and turkey facilities was considered to occur only if explicitly mentioned in the state regulations.

Calibration of Manure Spreader. The frequency factors for spreader calibration at layer facilities were based upon industry data (United Egg Producers/United Egg Association and Capitolink, 1999), those for swine facilities were based upon data from the AFO Strategy (USEPA, 1999), and those for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000).

Storm Water Diversions and Storm Water O&M. The frequency factors for storm water diversions at layer facilities (United Egg Producers/United Egg Association and Capitolink, 1999) were based upon industry data, those for swine facilities were based upon site visits, and those for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000). The frequency factors for operation and maintenance of field runoff controls were assumed to be equal to those for initial implementation of the controls.

Stream Buffer and O&M. The frequency factors for stream buffers at layer facilities were based upon industry data (United Egg Producers/United Egg Association and Capitolink, 1999), those for swine facilities were based upon site visits and state regulations, and those for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000).

Visual Inspection. The frequency factors for visual inspection at layer and swine facilities were based upon the AFO Strategy (USEPA, 1999), while the frequency factors for broiler and turkey facilities were derived from an analysis of state regulations (Tetra Tech, 2000).

Feeding Strategies. The frequency factors for feeding strategies at swine facilities were based upon USDA data (USDA APHIS, 1995), while the frequency factors for broiler and turkey facilities were provided by site visits and conversations with industry. Most broiler facilities have phase diets, and an increasing number of broiler operations utilize feed additives such as phytase. All broiler operations were all assumed to have phytase additions to their diet, thus no benefit is observed. Phytase use is less common in turkey production where debates exist that the skeletal structure of poults is affected by phytase interactions with calcium. EPA assumed few if any layer facilities incorporated phased diets or feeding strategies beyond nutritional requirements of the birds and molting (if any), and assumed the frequency factor was zero.

Operations that Sell or Trade Manure. The frequency factors for the percentage of swine operations that already sell, trade, or otherwise transport manure off-site for swine is conservatively set to zero based on the small fraction of operations that report transporting manure off site (USDA APHIS, 1995). The frequency factors for poultry are based on recent data submitted to the EPA (United Egg Producers, 2002).

Lagoon Marker. The frequency factors for lagoon depth markers at swine facilities were based upon the AFO Strategy (USEPA, 1999). It was assumed that no layer facilities had lagoon depth markers, and dry manure facilities do not need depth markers.

Adequate Storage, Soil Testing, Manure Testing, Record Keeping, Mortality (Composting and O&M). The frequency factor for these components were primarily based on data provided by USDA NRCS (2002). These frequency factors are from USDA's input files entitled *Summary of CNMP needs and total cost per component for Manure and Wastewater Storage and Handling* provided to EPA electronically on February 6, 2002. The input file includes frequency factors for three performance-based categories of facilities (low performing, medium performing, and high performing) for a series of "representative" farms defined by USDA. Data describing the exact methods for handling swine mortality were not available, however, EPA believes all Large CAFOs already have technologies/BMPs in place to handle routine mortalities. Since additional controls of mortalities were only considered for Option 3, EPA only calculated incremental costs for those operations with a direct hydrologic link to surface waters from the ground water beneath the production area. The portion of facilities required to implement additional swine mortality controls was based on an assessment of ground water risk (USEPA, 2000). Thus, the frequency factors for swine mortality represent the percent of operations that would not have to implement additional mortality practices because they do not have a hydrologic link from the ground water to the surface water rather than the actual percentage of swine operations that have adequate mortality handling facilities.

6.5 Poultry and Swine Nutrient Basis Frequency Factors

EPA estimated the number of facilities that will have to land-apply their manure on a phosphorus basis by using state soil test data (Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, R. Parry, 1999). Consistent with EPA acknowledgment of site-specific differences, these data clearly show that high soil phosphorus levels are a regional problem. Distinct areas of general phosphorus deficit and surplus exist within states and regions and can be correlated to areas of intensive animal production. To develop the percentage of agricultural soils testing high in phosphorus on a regional basis, the percentage of soils testing high or above in phosphorus was weighted with the number of facilities in each state. Table 6.5-1 shows the results of the facility-weighted soil test values by region and animal type. The label "P" indicates that more than half of the facility-weighted soils tested high or above for phosphorus. An "N" indicates that less than half of the facility-weighted soil tests in the region were high in phosphorus. If the facility weighted soil test values indicated that more than half of the soils in the region tested high for phosphorus, it was assumed that 60 percent of the facilities will require a phosphorus-based manure application rate and 40 percent can use a nitrogen-based rate. If the facility-weighted soil test values indicated that less than half of the soils in the region tested high for phosphorus, it was assumed that 40 percent of the facilities will require a phosphorus-based manure application rate and 60 percent can use a nitrogen-based rate. This approach reflects the potential fluctuations in phosphorus soil tests in a given state.

Table 6.5-1

AFO Nutrient Management Planning Basis by Animal Sector and Region Based on Percentage of Agricultural Soils Analyzed by Soil Test Laboratories in 1997 That Tested High or Above for Phosphorus

Sector Industry	Farm Size	Regions				
		Central	Mid-Atlantic	Midwest	Pacific	South
Broilers	Medium	P	P	P	P	N
Layers (dry)	Medium	P	P	P	P	N
Layer (wet)	Medium	N	P	P	P	N
Swine	Medium	N	P	P	P	P
Turkey	Medium	N	P	P	P	P
Broilers	Large	P	P	P	P	N
Layers (dry)	Large	P	P	P	P	N
Layers (wet)	Large	P	P	P	P	N
Swine	Large	N	P	P	P	P
Turkey	Large	N	P	P	P	P

Key: N = less than half of the facility-weighted soil tests in the region were high in phosphorus.
P = more than half of the facility-weighted soils tested high or above for phosphorus.

6.6 Poultry and Swine Land Availability Frequency Factors

All operations fall into one of three land availability categories depending on the amount of on-site cropland available for manure application.

- Category 1 operations have sufficient land to land-apply all of their generated manure and wastewater at appropriate agronomic rates. No manure is transported off site.

- Category 2 operations do not have sufficient land to land-apply all of their generated manure and wastewater at appropriate agronomic rates. The excess manure after agronomic application is transported off site.

- Category 3 operations do not have any available land for manure application. All generated manure and wastewater is transported off site.

For broilers and swine, the number of operations by land availability category was provided by the USDA NRCS (2002) at the state or group-of-state level. Section 4.3 provides details on how these data were processed for broilers and swine. For layers and turkeys, the number of operations by land availability category was provided by USDA NRCS (2002) at the national level by size class. Percentages were computed using the number of operations by land availability category with the results provided in Table 6.6.1. Due to data disclosure issues the number of Category 1 operations using a phosphorus based application rate was not made available. Lacking this data, EPA heuristically assumed that 20 percent of the Category 1 operations using nitrogen based application rates would be Category 1 using phosphorus based application rates.

Table 6.6-1

Percentage of Category 1, 2, and 3 Operations for Layers and Turkeys

Sector	Size Class	Nitrogen Based Applications			Phosphorus Based Applications		
		Category 1	Category 2	Category 3	Category 1	Category 2	Category 3
Layers	Medium 1	25.64%	44.97%	29.38%	4.25%	66.37%	29.38%
Layers	Medium 2	19.28%	40.36%	40.36%	3.86%	55.78%	40.36%
Layers	Medium 3	14.71%	40.34%	44.96%	2.94%	52.10%	44.96%
Layers	Large 1	10.88%	41.43%	47.69%	2.18%	50.13%	47.69%
Layers	Large 2	10.88%	41.43%	47.69%	2.18%	50.13%	47.69%
Turkeys	Medium 1	16.11%	53.03%	30.86%	3.22%	65.92%	30.86%
Turkeys	Medium 2	7.32%	60.46%	32.22%	1.46%	66.32%	32.22%
Turkeys	Medium 3	10.69%	53.05%	36.26%	2.14%	61.60%	36.26%
Turkeys	Large 1	7.47%	53.87%	38.66%	0.00%	61.34%	38.66%

6.7 Ground Water Control Frequency Factors

EPA developed two sets of frequency factors for all animal types for ground water control costs. The first set of frequency factors corresponds to Options 3A/3B and includes ground water monitoring, ponds and lagoons with engineered liners, concrete pads for solid waste storage areas, and a hydrological assessment. The second set of frequency factors corresponds to Options 3C/3D and includes permeability standards for waste storage units.

EPA developed the frequency factors for Option 3A/3B using an analysis of soil types and ground water depths across the country (USEPA, 2000). Based on this analysis, EPA determined that, under Option 3A/3B, facilities located in areas with sandy soils, shallow depths to ground water, and karst or karst-like terrains would require ground water controls and all other facilities would incur only the costs for the ground water assessment. Table 6.2-1 presents the frequency factors for facilities located in areas requiring controls and facilities requiring only a ground water assessment under Options 3A/3B.

Table 6.2-1

Percentage of Facilities Incurring Ground Water Costs Under Option 3A/3B

Animal Type	Size Class	Region	Facilities Requiring All Ground Water Controls	Facilities Requiring Only a Hydrologic Assessment
All	All	Central	13%	87%
		Mid-Atlantic	24%	76%
		Midwest	27%	73%
		Pacific	12%	88%
		South	22%	78%

EPA developed the frequency factors for Option 3C/3D using an analysis of state regulations. Facilities located in states with permeability standards for waste storage units and in locations identified under Option 3A/3B as high-risk areas were assumed to already be in compliance with Option 3C/3D and therefore would not incur costs. EPA determined that existing permeability standards applied only to large facilities and, therefore, assumed that all medium facilities located in areas with a high risk of ground water contamination would incur costs. To develop regional frequency factors for facilities that would incur costs under Option 3C/3D, EPA used the following equation:

$$FacPermeability = (1 - \%FacState) \times \%FacGW \quad [6\text{-}1]$$

where:

FacPermeability	=	Percentage of facilities located in the region that incur ground water costs under Option 3C/3D
%FacState	=	Percentage of facilities in the region that are located in states with existing permeability standards
%FacGW	=	Percentage of facilities in the region that are located in areas with a high risk of ground water contamination.

Table 6.2-2 presents the percentage of facilities requiring ground water costs under Option 3C/3D.

Table 6.2-2

Percentage of Beef Feedlots, Dairies, and Heifer Operations Incurring Ground Water Costs Under Option 3C/3D

Animal Type	Size Class	Region				
		Central	Mid-Atlantic	Midwest	Pacific	South
Option 3C						
Beef and Heifer	Medium 1 Medium 2 Medium 3	13%	24%	27%	12%	22%
	Large 1 Large 2	6%	20%	26%	10%	22%
Dairy	Medium 1 Medium 2 Medium 3	13%	24%	27%	12%	22%
	Large 1	7%	22%	13%	12%	22%
Veal	Medium 1 Medium 2 Medium 3	13%	24%	27%	12%	22%
Option 3D						
Beef and Heifer	Medium 1 Medium 2 Medium 3	87%	76%	73%	88%	78%
	Large 1 Large 2	94%	80%	74%	90%	78%
Dairy	Medium 1 Medium 2 Medium 3	87%	76%	73%	88%	78%
	Large 1	93%	78%	87%	88%	78%
Veal	Medium 1 Medium 2 Medium 3	13%	24%	27%	12%	22%

6.8 References

ERG, 2000. *State Requirements for Land Application at Agronomics Rates.* January 13, 2000.

ERG, 2001. *Methodology to Incorporate USDA Frequency Factors into Beef and Dairy Cost Model Methodology*. December 2002.

Kellogg, R.et al., 2000. *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the U.S.*

NPPC. 1998. Environmental Assurance Program Survey. National Pork Producer Council.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, R. Parry, 1999. Agricultural Phosphorus and Eutrophication. ARS-149. United States Department of Agriculture: Agricultural Research Service. July, 1999.

Tetra Tech, Inc., 2000. *Cost Model for Swine and Poultry Sectors.* May 2000.

United Egg Producers, 2002. *Statistics*, http://www.unitedegg.org/statistics.htm, retrieved 11/7/2002.

United Egg Producers/United Egg Association and Capitolink, 1999. Data submission to EPA.

USDA, 1999. Fax from Lindsey Garber, USDA/NAHMS-Center for Animal Health Monitoring, August 1999.

USDA, 2001. *Estimation of Private and Public Costs Associated with Comprehensive Nutrient Management Plan Implementation: A Documentation*. April 23, 2001.

USDA APHIS, 1995. Swine '95. Part 1. Reference of 1995 Swine Management Practices. USDA, Animal and Plant Health Inspection Service, National Animal Health Monitoring System.

USDA ARS, 1999. *Agricultural Phosphorus and Eutrophication, ARS-149*.

USDS NRCS, 2002. *Summary of CNMP needs and total cost per component for Manure and Wastewater Storage and Handling.* Electronic files received by EPA on February 6, 2002.

USEPA. 1999. *State Compendium: Programs and Regulatory Activities Related to Animal Feeding Operations - Interim Final Report*. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA, 2000. *Identification of Acreage of U.S. Agricultural Land with a Significant Potential for Siting of Animal Waste Facilities and Associated Limitations from Potential of*

Groundwater Contamination-draft 12/15/99. Memorandum from Mike Clipper and Terry Sobecki, EPA, to the Feedlots Rulemaking Record. October 3, 2000.

USEPA. 1999. *Unified National Strategy for Animal Feeding Operations*, http://www.epa.gov/owm/finafost.htm. Accessed on September 23, 1999.

7.0 EXAMPLE MODEL CALCULATIONS

This section includes an example calculation of model farm costs for the beef and dairy cost model.

7.1 Beef and Dairy Model Farm Example Calculation

This subsection uses the information presented previously in this report to provide an example calculation of model farm costs. The beef and dairy cost model calculates the total model farm costs using the waste management system component costs with the frequency factors. This subsection presents an example of this calculation for the following model farm for Option 2:

- Animal type = Dairy;
- Size class = Large 1 (i.e., >700 head);
- Regional location = Central;
- Farm type = Flush; and
- Performance level = Medium.

Under Option 2, the cost model estimates costs for a Large dairy operation in the Central region for the following waste management system components:

- Runoff control berms;
- Concrete settling basin;
- Lagoon;
- Accumulated sludge removal;
- Composting;
- Liquid land application equipment;
- Commercial fertilizer application;
- Nutrient management planning; and
- Off-site waste transportation.

This example does not show how each of these component costs is calculated. Instead, this example uses these component costs (Appendix A) and frequency factors to calculate the final weighted model farm cost.

The costs presented in this example represent the expected costs for this model farm for the final rule. Appendix C presents the model farm costs (in 1997 dollars) for Options 1, 2 and 5.

7.1.1 Unit Component Costs

The first step in the cost calculation is the generation of costs for each component included in the regulatory option. As noted in Section 7.1, EPA is not showing how these costs are calculated here; instead, these component costs are provided as the starting point for this example. The methodology for calculating these costs is presented in corresponding sections of this report.

Component costs are classified based on whether they vary by nutrient application basis and land availability category. Nutrients may be applied on site according to either the nitrogen needs of the crops or the phosphorus needs of the crops. Additionally, all model farms are classified into three land availability categories:

- Category 1 facilities have enough cropland to apply all of their waste on site;
- Category 2 facilities have some cropland, and apply some of their waste on site and haul the other portion of waste off site; and
- Category 3 facilities have no cropland and haul all of their waste off site.

The cost model calculates costs for seven possibilities for each farm type, region, size group, and performance level:

1) Component cost does not vary by nutrient basis or category;
2) Component cost varies by category and nutrient: Nitrogen basis, Category 1 facility;
3) Component cost varies by category and nutrient: Phosphorus basis, Category 1 facility;

4) Component cost varies by category and nutrient: Nitrogen basis, Category 2 facility;

5) Component cost varies by category and nutrient: Phosphorus basis, Category 2 facility;

6) Component cost varies by category and nutrient: Nitrogen basis, Category 3 facility; and

7) Component cost varies by category and nutrient: Phosphorus basis, Category 3 facility.

The cost model calculates a weighted model summary cost for each category by summing the component costs that do not vary with the category costs, weighted according to the nutrient basis and category.

Table 7.1.1-1 presents component costs that do not vary by nutrient application basis (i.e., nitrogen- versus phosphorus-based application). Table 7.1.1-2 presents component costs that do vary by nutrient application basis. Finally, Table 7.1.1-3 presents the component costs for the four transportation scenarios considered for both Category 2 and Category 3 flush dairies.

Table 7.1.1-1

Component Costs for Option 2 That Do Not Vary by Nutrient Application Basis Flush Dairy, Large 1, Central

Component	Flush Dairy	
	Capital	Annual
Runoff control berms	$3,069	$61
Concrete settling basin	$130,713	$2,614
Lagoon	$201,552	$10,078
Accumulated sludge removal	$122,426	$6,121
Composting	$9,157	$7,995

Table 7.1.1-2

Component Costs for Option 2 That Vary by Nutrient Application Basis
Flush Dairy, Large 1, Central

	Nitrogen-Based Application			Phosphorus-Based Application		
	Capital	Fixed	Annual	Capital	Fixed	Annual
Category 1						
Nutrient Management Planning	$0	$3,648	$2,453	$0	$9,316	$5,750
Commercial Nitrogen Fertilizer	$0	$0	$0	$0	$0	$25,361
Liquid Land Application	$70,454	$0	$7,510	$125,115	$0	$11,541
Category 2						
Nutrient Management Planning	$0	$2,151	$1,581	$0	$3,194	$2,188
Commercial Nitrogen Fertilizer	$0	$0	$0	$0	$0	$7,300
Liquid Land Application	$64,925	$0	$6,212	$104,562	$0	$10,669
Category 3						
Nutrient Management Planning	$0	$1,035	$1,089	$0	$1,035	$1,089
Commercial Nitrogen Fertilizer	$0	$0	$0	$0	$0	$0
Liquid Land Application	$0	$0	$0	$0	$0	$0

NOTE: Nutrient Management Planning includes the following costs: nutrient plan development, soil and manure sampling, land application equipment calibration, recordkeeping and reporting, lagoon depth markers, and identification of setback areas.

Table 7.1.1-3

Transportation Costs for Option 2 Flush Dairy, Large 1, Central

Category[a]	Transportation Scenario	Nitrogen-Based Application		Phosphorus-Based Application	
		Capital	Annual	Capital	Annual
2	Purchase truck	$171,724	$21,932	$373,312	$46,494
	Contract haul	$0	$68,850	$0	$30,400
	Purchase truck (composted manure)	$171,724	$21,909	$373,312	$46,426
	Contract haul (composted manure)	$0	$68,831	$0	$30,363
3	Purchase truck	NA	NA	$373,312	$106,031
	Contract haul	NA	NA	$0	$130,758
	Purchase truck (composted manure)	NA	NA	$373,312	$105,997
	Contract haul (composted manure)	NA	NA	$0	$130,751

[a]Category 1 operations do not incur transportation costs because they have sufficient land to apply all waste on site.
NA - Not applicable; Category 3 operations do not incur transportation costs under N-based scenarios because they are already assumed to transfer all waste off site under N-based scenarios.

7.1.2 Calculation of Weighted Component Costs

The cost model then weights the component costs to reflect the percentage of operations that already have some components in place. The following equation is used to weight the component costs:

$$Cost_{weighted} = Cost_{component} \times (1 - \text{Frequency Factor}) \quad [7\text{-}1]$$

where:

$Cost_{weighted}$ = Weighted component cost
$Cost_{component}$ = Component cost (from Table 7.1.1-1)
Frequency Factor = Percentage of operations that have component in place.

Table 7.1.2-1 presents the frequency factors used for large flush dairy operations in the Central region.

Table 7.1.2-1

Percentage of Operations Assumed to Have Equivalent Technology In Place Flush Dairy, Large 1, Central

Component	Performance Category of Operation		
	High	**Medium**	**Low**
Runoff control berms	100%	90%	70%
Concrete settling basin	33%	33%	33%
Lagoon	100%	100%	100%
Accumulated sludge removal	100%	100%	100%
Composting	0%	0%	0%
Nutrient management planning	20%	10%	0%
Commercial nitrogen fertilizer	0%	0%	0%
Liquid land application	90%	70%	50%
Transportation (N-Based)	54%	54%	54%

Equation 7-1 is used to calculate the weighted component costs for the model farm for all land availability categories (Categories 1, 2, and 3) and performance categories (high, medium, and low). For example, capital weighted costs for liquid land application in Category 2 at a medium performing facility are calculated as follows:

$$\begin{aligned} Cost_{weighted} &= Cost_{component} \times (1 - \text{Frequency Factor}) \\ &= \$64,925 \times (1 - 0.70) \\ &= \$19,477 \end{aligned}$$

where:

$64,924	=	Category 2 liquid land application cost, Table 7.1.1-2
0.70	=	Frequency factor for liquid land application from Table 7.1.2-1.

Table 7.1.2-2 presents the weighted component costs for components that do not vary by nutrient application basis and land availability category. Costs are shown for all performance categories. Table 7.1.3-1 presents the weighted costs for components that vary by nutrient application basis and land availability category.

Table 7.1.2-2

Weighted Component Costs for Option 2 That Do Not Vary by Nutrient Application Basis and Land Availability Category Medium Performance, Flush Dairy, Large 1, Central

Component	Capital	Annual
Runoff control berms	$307	$6
Concrete settling basin	$87,578	$1,752
Lagoon	$0	$0
Accumulated sludge removal	$0	$0
Composting	$9,157	$7,995

7.1.3 Calculation of Weighted Farm Costs

Some weighted component costs vary depending on the nutrient application basis and land availability category, as shown in Table 7.1.3-1. To calculate weighted farm costs, the cost model applies farm-type frequency factors to the weighted component costs to represent the portion of operations that can be characterized within each nutrient management basis and land availability category.

Table 7.1.3-1

Weighted Component Costs for Option 2 That Vary by Nutrient Application Basis and Land Availability Category Medium Performance, Flush Dairy, Large 1, Central

Component	Nitrogen-Based Application		Phosphorus-Based Application	
	Capital Costs	Annual Costs	Capital Costs	Annual Costs
Category 1				
Nutrient management planning	$3,283	$2,207	$8,384	$5,175
Commercial nitrogen fertilizer	$0	$0	$0	$25,361
Liquid land application	$35,227	$3,755	$62,557	$5,771
Transportation - Purchase truck option	$0	$0	$0	$0
Transportation - Contract-hauling option	$0	$0	$0	$0
Transportation - Purchase truck option with composting	$0	$0	$0	$0
Transportation - Contract-hauling option with composting	$0	0$0	$0	$0
Category 2				
Nutrient management planning	$1,935	$1,423	$2,875	$1,969
Commercial nitrogen fertilizer	$0	$0	$0	$7,300
Liquid land application	$32,462	$3,106	$52,281	$5,335
Transportation - Purchase truck option	$171,724	$21,932	$373,312	$46,494
Transportation - Contract-hauling option	$0	$68,850	$0	$30,400
Transportation - Purchase truck option with composting	$171,724	$21,909	$373,312	$46,426
Transportation - Contract-hauling option with composting	$0	$68,831	$0	$30,363
Category 3				
Nutrient management planning	$1,035	$1,089	$1,035	$1,089
Commercial nitrogen fertilizer	$0	$0	$0	$0
Liquid land application	$0	$0	$0	$0
Transportation - Purchase truck option	$0	$0	$373,312	$106,031
Transportation - Contract-hauling option	$0	$0	$0	$130,758
Transportation - Purchase truck option with composting	$0	$0	$373,312	$105,997
Transportation - Contract-hauling option with composting	$0	$0	$0	$130,751

The first farm-type weighting factor applied adjusts the weighted component costs for the land availability category (Category 1, Category 2, or Category 3). Section 6.0 presents the calculation of the land availability category frequencies, and Table 7.1.3-2 provides these frequency factors for dairies under the nitrogen-based and phosphorus-based application scenarios.

Table 7.1.3-2

Land Availability Category Frequency Factors
Dairies, Large 1

	Nitrogen Basis	Phosphorus Basis
Category 1	27%	10%
Category 2	51%	68%
Category 3	22%	22%

The second farm-type weighting factor applied adjusts the weighted component costs for the type of nutrient-based application used. Because all operations are required to land apply using a nitrogen-based application rate under Option 1, the weighted farm costs are equal to the nitrogen-based weighted component costs. Likewise, because all operations are required to land-apply using a phosphorus-based application rate under Option 2A, the weighted farm costs are equal to the phosphorus-based weighted component costs. For the remaining options, EPA assumed that each model farm would apply waste based on both a nitrogen and phosphorus basis. Section 6.0 presents the percentage of costs that are attributed to an N-based application basis versus a P-based application basis for each model farm. For this example, the nutrient-based frequency factors for large dairies in the Central region are 56 percent of operations require nitrogen-based application and 44 percent of operations require phosphorus-based application.

The cost model uses these two farm-type factors to calculate the weighted farm costs using the following equation:

$$\text{Category X}_{\text{weightedcost}} = \frac{[(\%N \times \%N{-}\text{Cat X} \times \text{Cat1(N)Cost}) + (\%P \times \%P{-}\text{Cat X} \times \text{Cat1(P)Cost})]}{[(\%N \times \%N{-}\text{Cat X}) + (\%P \times \%P{-}\text{Cat X})]} \quad [7\text{-}3]$$

where:

%N	=	Percentage of land that requires N-based application
%N-Cat X	=	Category X frequency factor under an N-based application scenario
%P	=	Percentage of land that requires P-based application
%P-Cat X	=	Category X frequency factor under an P-based application scenario.

For example, capital weighted costs for liquid land application in Category 2 at a medium-performing facility are calculated as:

$$\text{Land Application}_{\text{cat2}} = \frac{[(56\% \times 54\% \times \$19{,}477) + (44\% \times 68\% \times \$31{,}369)]}{[56\% \times 54\% + 44\% \times 68\%]} \quad [7\text{-}4]$$

The cost model uses each of the weighted model farm components to calculate the weighted model farm costs using Equation 7-3 for each possible category and transportation option. The transportation cost test is then used to determine which transportation option is the least costly, as described in Section 5.17 of this report. The selected transportation option for this example is contract hauling without composting for both Category 2 and 3 operations.

Table 7.1.3-3 presents the weighted farm costs for the example model, including the selected least-cost transportation scenario.

Table 7.1.3-3

Weighted Farm Costs for Option 2
Medium Performance, Flush Dairy, Large 1, Central

Component	Category 1		Category 2		Category 3	
	Capital	Annual	Capital	Annual	Capital	Annual
Concrete basin	$87,578	$1,752	$87,578	$1,752	$87,578	$1,752
Berms	$307	$6	$307	$6	$307	$6
Composting[b]	$0	$0	$0	$0	$0	$0
Lagoon	$0	$0	$0	$0	$0	$0
Nutrient management planning[c]	$4,433	$2,877	$2,416	$1,702	$1,035	$1,089
Liquid land application	$24,833	$2,526	$25,561	$2,548	$0	$0
Commercial fertilizer application	$0	$5,717	$0	$3,735	$0	$0
Selected Transportation Scenario						
Purchase truck	$0	$0	$0	$49,178	$0	$57,533

[a]Costs are weighted by farm type (hose versus flush) and by application basis (nitrogen versus phosphorus).
[b]Composting costs were not selected as part of the model farm costs.
[c]Nutrient management planning capital costs are fixed costs; 3-year recurring costs are also incurred, but are not shown in this table.

7.1.4 Final Model Farm Costs

The weighted farm costs are summed and annualized for each of the transportation scenarios, and the least costly scenario is selected. The cost model sums these costs to generate the final model farm capital, annual, fixed, and 3-year recurring costs by category. Table 7.1.4-1 presents the weighted farm costs selected for the model farm. Commercial fertilizer costs are listed as a separate cost item in the model farm result tables presented in Appendix C.

Table 7.1.4-1

Model Farm Costs by Category
Medium Performance, Flush Dairy, Large 1, Central

Component	Capital	Annual	Fixed
Category 1			
Total Model Farm Costs	$112,718	$56,658	$4,926
Commercial Fertilizer Application	$0	$5,717	$0
Category 2			
Total Model Farm Costs	$113,446	$63,731	$2,685
Commercial Fertilizer Application	$0	$3,735	$0
Category 3			
Total Model Farm Costs	$87,885	$2,968	$1,150
Commercial Fertilizer Application	$0	$0	$0

7.2 Swine and Poultry Model Farm Cost Example

This section uses the information presented previously in this report to provide an example calculation of model farm costs. The total model farm costs are calculated using the waste management system component costs with the frequency factors. This section presents an example of this calculation for the following model farm for Option 2 (manure land-applied on a P-basis):

- Animal type = Swine;
- Size class = Large 1 (i.e., 2,500 to 4,999 head);
- Regional location = Mid-Atlantic;
- Farm type = Grow-Finish;
- Waste storage system = lagoon; and
- Performance level = Medium.

Under Option 2, the following components are costed for the above model farm:

- Nutrient management planning (NMP) one time costs (soil auger, manure sampler, scales for manure spreader calibration, initial NMP development).

- NMP reoccurring costs (on-farm NMP development every 5 years, soil testing every 3 years).
- NMP annual costs (record keeping, manure spreader calibration, manure testing twice per year).
- Facility upgrades (lagoon depth marker, berms to divert storm water from entering lagoon, field runoff controls).
- Facility annual costs (visual inspection, operation and maintenance of berms, operation and maintenance of field runoff controls, and land rental value).
- Practices to remove excess manure nutrients from the operation site (secondary lagoon to decrease dilution and the least expensive scenario of the following: feeding strategies; hauling, with or without feeding strategies; solid liquid separation and hauling, with or without feeding strategies; retrofit to scraper system and hauling, with or without feeding strategies; retrofit to high rise and hauling, with or without feeding strategies; retrofit to hoop house and hauling, with or without feeding strategies; sludge cleanout every 5 years, with or without feeding strategies).
- Commercial fertilizer costs that replace manure nutrients in some situations.

The methodologies used to calculate the costs for each of these waste management system components are presented in Chapter 5. This example demonstrates how these methodologies are used to calculate the costs for one model farm. This example also demonstrates how the frequency factors are used to calculate the final, weighted, model farm cost.

7.2.1 Unit Component Costs

As in the previous dairy example, the first step in the cost calculation is the generation of costs for each component included in the regulatory option. This example does not include calculating the component level costs; instead, these component costs are provided as the starting point for this example. The methodology for calculating each of these costs is presented in corresponding chapters of this report.

Component costs are classified based on whether they vary by nutrient application basis and land availability category. Nutrients may be applied on site according to either the nitrogen needs of the crops or the phosphorus needs of the crops (the examples below assume that manure nutrients are applied to meet the phosphorus needs of the crops). Additionally, all model farms are classified into three land availability categories:

- Category 1 facilities have enough cropland to apply all of their manure nutrients on site;
- Category 2 facilities have some cropland, and apply some of their manure nutrients on site and can use a variety of practices to remove the remaining manure nutrients; and
- Category 3 facilities have no cropland and must remove excess manure nutrients from the operation site.

Costs are calculated for six possibilities for each farm type, region, size group, and performance level:

1) Component cost that do not vary by nutrient basis and category;
2) Component costs that do not vary for facilities that apply manure on site;
3) Component costs that vary in direct proportion to the number of animals at the facility;
4) Component costs that vary by the acreage at the facility (Category 1 and 2 facilities);
5) Component costs for Category 2 facilities that vary by regulatory option; and
6) Category 3 facility costs for moving manure nutrients an additional distance under option 2.

A weighted model summary cost is calculated for each category by summing the component costs that do not vary with the category costs, weighted according to the nutrient basis and category.

Table 7.2-1 presents component costs that do not vary by option, facility category, or nutrient application basis (i.e., nitrogen- versus phosphorus-based application). Table 7.2-2 presents component costs that do vary for facilities that apply manure on-site. Table 7.2-3 presents the component costs that vary only based upon the number of head at the facility. Table

7.2-4 presents component costs that vary by the acreage at the facility (Category 1 and 2 facilities). Table 7.2-5 presents component costs for Category 2 facilities that vary by regulatory option.

Table 7.2-1

Component Costs for That Do Not Vary by Option, Facility Category, or Manure Nutrient Application Basis Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Component	Capital	Annual
Manure sampler	$30	None
Record keeping	None	$1,020
Lagoon depth marker	$30	None
Manure testing	None	$100
Visual inspection	None	$130

Table 7.2-2

Component Costs That Do Not Vary for Facilities That Land Apply Manure On-site Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Component	Capital	Annual
Soil auger	$25	None
Two scales for spreader calibration	$500	None
Calibrate manure spreader	None	$40

Table 7.2-3

Component Costs That Vary by Facility
Based on Head Count
Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Model Farm Description	Number of Head	Storm Water Diversions (berms)	
		Capital	Annual
Category 1			
Option 1 (N-based application)	2,664	$816	$16
Option 2 (P-based application)	2,500	$795	$16
Category 2			
N-based application	4,581	$863	$17
P-based application	4,581	$863	$17
Category 3			
All options	4,424	$1,008	$20

Table 7.2-4

Component Costs for Options 1 and 2 That Vary by Facility Based on Acreage (Category 1 and 2 only) Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Cat	Component	Nitrogen-Based Application						Phosphorus-Based Application					
		Acres	Capital	Fixed	Annual	3-year	5-year	Acres	Capital	Fixed	Annual	3-year	5-year
1	Cost to develop initial NMP	76	NA	$1,343	NA	NA	NA	702	NA	$4,475	NA	NA	NA
	NMP development every 5 years	76	NA	NA	NA	NA	$383	702	NA	NA	NA	NA	$3,515
	Soil testing every 3 years	76	NA	NA	NA	$26	NA	702	NA	NA	NA	$234	NA
	Field runoff controls	76	$285	NA	NA	NA	NA	702	$2,616	NA	NA	NA	NA
	Runoff controls – O&M, rental	76	NA	NA	$177	NA	NA	702	NA	NA	$1,623	NA	NA
2	Cost to develop initial NMP	76	NA	$1,341	NA	NA	NA	175	NA	$1,807	NA	NA	NA
	NMP development every 5 years	76	NA	NA	NA	NA	$381	175	NA	NA	NA	NA	$847
	Soil testing every 3 years	76	NA	NA	NA	$25	NA	175	NA	NA	NA	$56	NA
	Field runoff controls	76	$284	NA	NA	NA	NA	175	$630	NA	NA	NA	NA
	Runoff controls – O&M, rental	76	NA	NA	$176	NA	NA	175	NA	NA	$162	NA	NA

O&M = operation and maintenance
NA = Not Applicable.

Unique Category 2 Facility Costs

Practices that reduce or remove excess manure nutrients are only used for Category 2 facilities. The least expensive scenario of the following is selected:

- Feeding strategies;
- Install secondary lagoon to reduce manure dilution and hauling with or without feeding strategies;
- Solid liquid separation and hauling with or without feeding strategies;
- Retrofit to scraper system and hauling with or without feeding strategies;
- Retrofit to high rise and hauling with or without feeding strategies;
- Retrofit to hoop house and hauling with and without feeding strategies; or
- Install secondary lagoon to reduce manure dilution and sludge cleanout and hauling every five years with and without feeding strategies.

Under option 2, Category 2 facilities that are required to apply their manure on site using P-based application rates incur costs to apply commercial fertilizer. Table 7.2-5 presents the unique component costs for Category 2 facilities by manure nutrient application basis.

Table 7.2-5

Component Costs That are Unique to Category 2 Facilities
Options 1 and 2, Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Option	Selected BMPs	Nitrogen-Based Application					Phosphorus-Based Application				
		Capital	Fixed	Annual	3-year	5-year	Capital	Fixed	Annual	3-year	5-year
1	Secondary lagoon with pipe and pump	$8,633	NA	NA	NA	NA	NA	NA	NA	NA	NA
	O&M for secondary lagoon, pipe, pump	NA	NA	$173	NA	NA	NA	NA	NA	NA	NA
	Sludge removal and hauling every 5 years	NA	NA	NA	NA	$129	NA	NA	NA	NA	NA
2	Secondary lagoon with pipe and pump	$8,633	NA	NA	NA	NA	$6,461	NA	NA	NA	NA
	O&M for secondary lagoon, pipe, pump	NA	NA	$173	NA	NA	NA	NA	$129	NA	NA
	Sludge removal and hauling every 5 years	NA	NA	NA	NA	$129	NA	NA	NA	NA	$6,787
	Commercial N fertilizer applied on site to replace manure N	NA	NA	NA	NA	NA	NA	NA	$2,580	NA	NA

NA = Not Applicable.

Category 3 Facility Costs for Option 2 P-based Manure Application

Under option 2 (P-based land application) Category 3 facilities are assumed to haul their manure farther than they do under option 1 (N-based application) because more land is required. As stated previously, facilities are assumed to apply their manure off site on a N-basis. Thus it is assumed that costs are only applicable to the regulation for moving manure from Category 3 facilities under option 2. The costs are calculated by multiplying the additional mileage by the commercial hauling rate and the mass of the manure to be hauled. The model selects the least expensive practice for moving the manure nutrients the additional distance from the facility. The least expensive practice for Category 3 grow-finish facilities under option 2 in the Mid-Atlantic region is hauling lagoon sludge every 5 years at a cost of $8,496.

7.2.2 Calculation of Adjusted Component Costs

As stated in section 7.1, the component costs are then adjusted to reflect the percentage of operations that already have some components in place. The following equation is used to adjust the component costs:

$$Cost_{adjusted} = Cost_{component} \times (1 - \text{Frequency Factor})$$

where:

$Cost_{adjusted}$	=	Adjusted component cost
$Cost_{component}$	=	Component cost
Frequency Factor	=	Percentage of operations that have component in place.

Table 7.2-6 presents the frequency factors used for Large 1 grow-finish operations in the Mid-Atlantic Region.

Table 7.2-6

Percent Operations Assumed to Have Equivalent Technology In Place Swine Grow-Finish Operations with Lagoons, Large 1, Mid-Atlantic Region

Component	Performance Category of Operation*		
	High	Medium	Low
Soil auger	100%	98%	80%
Manure sampler	100%	94%	0%
Scales for manure spreader calibration	100%	94%	0%
Development NMP initial and recurring	100%	89%	0%
Calibration of manure spreader	100%	100%	96%
Visual inspections	100%	0%	0%
Soil testing	20%	10%	0%
Manure testing	20%	10%	0%
Recordkeeping	20%	10%	0%
Lagoon depth marker	100%	100%	96%
Stream buffers and O&M	100%	100%	96%
Feeding strategies	100%	95%	0%
Runoff control berms	100%	50%	0%
Runoff control berm O&M	70%	1%	0%
Transportation (N-Based)	100%	100%	98%

* H = the high performing facilities (top 25%), M = the medium performing facilities (middle 50%, and L = the low performing facilities (bottom 25%).

Equation 7-2 is used to calculate the adjusted component costs for each model farm. For example, the annual costs for recordkeeping at a Category 2 medium performing facility are calculated as follows:

$$\begin{aligned} Cost_{adjusted} &= Cost_{component} \times (1 - \text{Frequency Factor}) \\ &= \$1{,}020 \times (1 - 0.10) \\ &= \$918 \end{aligned}$$

where:

$1,020	=	Annual recordkeeping costs from Table 7.2-1.
0.10	=	Frequency factor for medium performer from Table 7.2-6.

Table 7.2-7 presents the adjusted component costs for components that do not vary by nutrient application basis and land availability category. Costs are shown for all performance categories. Table 7.2-8 presents the adjusted component costs for components that do not vary for facilities that apply manure on site. Table 7.2-9 presents the adjusted component costs that vary only based upon the number of head at the facility. Table 7.2-10 presents adjusted component costs that vary by the acreage at the facility (Category 1 and 2 facilities). Table 7.2-11 presents adjusted component costs for Category 2 facilities that vary by regulatory option. Note that the frequency factors for Category 2 facilities that already reduce or remove excess manure nutrients is zero for high, medium, and low performance facilities. It is also assumed that no facilities use commercial N on site (zero frequency factor). Thus the costs do not vary by performance level.

Table 7.2-7

Adjusted Component Costs That Do Not Vary by Option, Facility Category, or Manure Nutrient Application Basis
Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Component	Capital			Annual		
	H	M	L	H	M	L
Manure sampler	$0	$1	$6	$0	$0	$0
Record keeping	$0	$0	$0	$816	$918	$1,020
Lagoon depth marker	$0	$0	$1	$0	$0	$0
Manure testing	$0	$0	$0	$80	$90	$100
Visual inspection	$0	$0	$0	$0	$130	$130

Table 7.2-8

Adjusted Component Costs for Option 2 That Do Not Vary for Facilities That Land Apply Manure On Site Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Component	Capital			Annual		
	H	M	L	H	M	L
Soil auger	$0	$1	$5	$0	$0	$0
Two scales for manure spreader calibration	$0	$31	$500	$0	$0	$0
Calibrate manure spreader	$0	$0	$0	$0	$0	$2

Table 7.2-9

Adjusted Component Costs That Vary by Facility Based on Head Count Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Model Farm Description	Number of Head	Storm Water Diversions (berms)					
		Capital			Annual		
Category 1		**H**	**M**	**L**	**H**	**M**	**L**
Option 1 (N-based application)	2,664	$0	$408	$816	$5	$16	$16
Option 2 (P-based application)	2,500	$0	$398	$795	$5	$16	$16
Category 2		**H**	**M**	**L**	**H**	**M**	**L**
N-based application	4,581	$0	$432	$863	$5	$17	$17
P-based application	4,581	$0	$432	$863	$5	$17	$17
Category 3		**H**	**M**	**L**	**H**	**M**	**L**
All options	4,424	$0	$504	$1,008	$6	$20	$20

Table 7.2-10

Adjusted Component Costs by Performance Level for Options 1 and 2 That Vary by Facility Based on Acreage (Category 1 and 2 only) Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Cat	Component	Nitrogen-Based Application					Phosphorus-Based Application				
		Acres	Cost type	H	M	L	Acres	Cost type	H	M	L
1	Cost to develop initial NMP	76	Fixed	$0	$148	$1,343	702	Fixed	$0	$492	$4,475
	NMP development every 5 years	76	5-year	$0	$43	$383	702	5-year	$0	$387	$3,515
	Soil testing every 3 years	76	3-year	$20	$23	$26	702	3-year	$187	$211	$234
	Field runoff controls	76	Capital	$0	$0	$11	702	Capital	$0	$0	$105
	Runoff controls – O&M, rental	76	Annual	$0	$0	$7	702	Annual	$0	$0	$65
2	Cost to develop initial NMP	76	Fixed	$0	$150	$1,341	175	Fixed	$0	$202	$1,807
	NMP development every 5 years	76	5-year	$0	$43	$381	175	5-year	$0	$95	$847
	Soil testing every 3 years	76	3-year	$20	$23	$25	175	3-year	$45	$51	$56
	Field runoff controls	76	Capital	$0	$0	$11	175	Capital	$0	$0	$25
	Runoff controls – O&M, rental	76	Annual	$0	$0	$7	175	Annual	$0	$0	$6

NA = Not Applicable.

Table 7.2-11

Adjusted Component Costs That are Unique to Category 2 Facilities Options 1 and 2, Swine Grow-Finish with Lagoons, Large 1, Mid-Atlantic

Option	Selected BMPs	Nitrogen-Based Application				Phosphorus-Based Application			
		Cost type	H	M	L	Cost type	H	M	L
1	Secondary lagoon with pipe and pump	Capital	$8,633	$8,633	$8,633	Capital	NA	NA	NA
	O&M for secondary lagoon, pipe, pump	Annual	$173	$173	$173	Annual	NA	NA	NA
	Sludge removal and hauling every 5 years	5-year	$129	$129	$129	5-year	NA	NA	NA
2	Secondary lagoon with pipe and pump	Capital	$8,633	$8,633	$8,633	Capital	$6,461	$6,461	$6,461
	O&M for secondary lagoon, pipe, pump	Annual	$173	$173	$173	Annual	$129	$129	$129
	Sludge removal and hauling every 5 years	5-year	$129	$129	$129	5-year	$6,787	$6,787	$6,787
	Commercial N fertilizer applied on site to replace manure N	Annual	NA	NA	NA	Annual	$2,580	$2,580	$2,580

NA = Not Applicable.

7.2.3 Calculation of Weighted Farm Costs by Nutrient Application Basis for Option 2

The final step in calculating farm costs is to weight the adjusted component costs depending on the nutrient application basis. To calculate weighted farm costs, frequency factors are applied to the adjusted component costs to represent the portion of operations that use each nutrient management basis as shown in Table 7.2-12. Because all operations can land-apply using a nitrogen-based application rate under Option 1, the weighted farm costs are equal to the nitrogen-based weighted component costs. Likewise, because all operations are required to land-apply using a phosphorus-based application rate under Option 2A, the weighted farm costs are equal to the phosphorus-based weighted component costs. For the remaining options, it is assumed that model farms would apply waste based on a weighted nitrogen and phosphorus basis. For this example, the nutrient-based frequency factor for a large 1, swine, grow-finish operation in the Mid-Atlantic Region is 60 percent of operations use phosphorus-based application and 40 percent of the operations use nitrogen-based application. This frequency factor is applied such that the total number of category 1, 2, and 3 facilities that apply manure on a P-basis is equal to 60 percent of the total facilities.

Table 7.2-12

Assumed Nutrient Land Application Frequency For Total Facilities For Key Swine Regions Under Option 2

Key Regions	**Nitrogen Basis**	**Phosphorus Basis**
Mid-Atlantic	40%	60%
Midwest	40%	60%

The weighted farm costs using the following equation:

$$Cost_{weighted} = (Cost_N \times \%N) + (Cost_P \times \%P)$$

where:

%N	=	Percent of total facilities by performance level and facility category that are required to use N-based application
Costs $_N$	=	Adjusted component costs of N-based practice
%P	=	Percent of total facilities by performance level and facility category that are required to use P-based application
Costs $_P$	=	Adjusted component costs P-based practice.

For example, the weighted costs for initial NMP development at a Category 2 facility, medium performing facility are calculated as:

$$Cost_{weighted} = (\$150 \times (26/77)) + (\$202 \times (51/77))$$
$$= \$50.65 + \$133.79$$
$$= \$184.44$$

7.2.4 Final Model Farm Costs

The weighted farm costs are summed for each option, facility type, size, land availability category, and performance level. The final model farm costs are summed separately for capital, fixed, annual, 3-year recurring, and 5-year recurring costs. Table 7.2-13 presents the weighted farm costs for the model farms presented in this example. A complete lists of the costs of the swine and poultry model farms is presented in Appendix C.

Table 7.2-13
Final Weighted Costs for Large 1 Grow-Finish Swine Operations With Lagoons in the Mid-Atlantic Region Under Options 1 and 2

Perform Level	Option	Category	Capital	Fixed	Annual	3-year recurring	5-year recurring	BMPs selected
H	1	1	$0	$0	$896	$20	$0	None
H	1	2	$8,720	$0	$1,069	$20	$0	Already haul at N
H	1	3	$0	$0	$896	$0	$0	Already haul at N
M	1	1	$422	$150	$1,146	$23	$43	None
M	1	2	$7,670	$150	$1,289	$23	$43	Already haul at N
M	1	3	$487	$0	$1,148	$0	$0	Already haul at N
L	1	1	$1,320	$1,343	$1,274	$26	$383	None
L	1	2	$8,592	$1,341	$1,418	$25	$510	Sludge Removal
L	1	3	$1,002	$0	$1,269	$0	$0	Already haul at N
H	2	1	$0	$0	$896	$58	$0	None
H	2	2	$8,353	$0	$1,062	$37	$4,507	Sludge Removal
H	2	3	$0	$0	$896	$0	$5,098	Sludge Removal
M	2	1	$420	$229	$1,146	$66	$122	None
M	2	2	$7,339	$185	$1,282	$42	$4,584	Sludge Removal
M	2	3	$487	$0	$1,148	$0	$5,098	Sludge Removal
L	2	1	$1,337	$2,052	$1,287	$73	$1,092	None
L	2	2	$8,259	$1,650	$1,417	$46	$5,240	Sludge Removal
L	2	3	$1,002	$0	$1,269	$0	$5,098	Sludge Removal

8.0 SENSITIVITY ANALYSES

The model-farm approach that EPA used to estimate costs for this regulation provides an average cost that a facility is projected to incur under the regulatory options. As discussed in Section 6.0, EPA used frequency factors to reflect baseline industry conditions for high-, medium-, and low-performing farm operations. For example, some facilities may already meet the proposed regulatory requirements; therefore, those facility costs will be zero. Alternatively, some facilities may currently meet very few of the proposed regulatory requirements, and these operations will incur costs that are much higher than the average model facility cost. By estimating compliance costs for each type of operation, EPA has effectively calculated the range of costs that would be incurred by facilities within each model farm.

Following the calculation of costs for each option, EPA performed sensitivity analyses on the cost model to identify major drivers for the model farm costs under various scenarios. EPA performed several sensitivity runs. These sensitivity analyses included the following modifications of the regulatory options:

- For Option 1A, EPA evaluated the costs associated with including capacity for a chronic storm event for all animal operations with liquid storage;
- EPA conducted a cost driver analysis on Options 2 and 5 to determine which waste management components were the major contributors to costs for beef feedlots, dairies, and heifer and veal operations;
- For Option 2A, EPA evaluated the costs associated with requiring all facilities to apply manure on an agronomic phosphorus basis for beef, dairy, heifer, and veal operations; and
- For Option 2B, EPA evaluated the costs associated with requiring the development of nutrient management planning for off-site manure recipients for beef feedlots, dairies, and heifer and veal operations.

8.1 Option 1A

The cost basis for all of the regulatory options evaluated for this rulemaking includes liquid storage capacity for a 25-year, 24-hour rainfall event. In addition to this rainfall event, the cost basis for Option 1A includes liquid storage capacity for a chronic storm event, classified as a 10-year, 10-day storm. Because there is a higher chance of a 10-year, 10-day storm event occurring in any given year, they have a higher amount of precipitation associated with them than 25-year, 24-hour rainfall events. The 10-year, 10-day storm event can make a difference of two inches or more per rainfall. If a lagoon or pond is only sized to contain process wastewater plus the runoff from a 25-year, 24-hour rainfall event, there is a greater chance of wastewater overflows due to a chronic storm event.

EPA assumes that facilities that require liquid storage as well as facilities that already have liquid storage incur costs to construct and maintain additional capacity to contain precipitation and runoff from the 10-day,10-year chronic storm event.

> *Facilities with no existing liquid storage:* Under Option 1A, lagoon and ponds are sized for facilities that require new liquid storage to account for 6 months of average precipitation, the peak storm event (25-year, 24-hour rainfall event), and the chronic storm event (10-year, 10-day). Both direct precipitation and runoff resulting from the precipitation are included in the capacity of the lagoon or pond.
>
> *Facilities with existing liquid storage:* Under Option 1A, additional lagoon or pond storage is sized for facilities that are assumed to already have liquid storage to account for the 10-year,10-day storm event. Both direct precipitation and runoff resulting from precipitation are included in the additional capacity of the pond or lagoon.

The increase in wastewater volume also affects the calculation of costs for liquid land application and transportation. These are waste management components downstream of the lagoon or pond that are dependent on liquid volume.

The model facility costs are significantly higher for Option 1A as a result of including capacity for the chronic rainfall event, ranging from 10 percent to multiple times the cost of Option 1.

8.2 Cost Driver Analysis

EPA performed an analysis on Options 2 and 5, as well as Option 3, to determine the primary cost drivers under each regulatory scenario for the beef, dairy, heifer, and veal animal groups. EPA used the weighted model farm output from the cost model to compare the weighted cost of each component that comprised the model farm costs. Table 8.2-1 summarizes the results of this analysis.

Additionally, EPA performed two sensitivity runs to identify the cost drivers for the swine and poultry cost model: the first compared the effects of nitrogen-based nutrient management verses phosphorus-based nutrient management on the costs, and the second compared the effects of ground water monitoring requirements on the costs. By running the model both with and without frequency factors, EPA was able to identify the costs of the technologies and practices that are most sensitive to the Agency's modeling assumptions. EPA was then able to identify the model elements and cost components that were cost drivers and would thus merit further analysis: the availability of cropland for manure utilization, the incremental costs of phosphorus-based application over nitrogen-based application, the costs of ground water controls, and the costs of incremental storage for timing constraints.

EPA had already developed an approach to reflect nitrogen- and phosphorus-based requirements and had developed three categories of land availability to capture the wide range of land application and hauling costs. EPA's sensitivity analysis concluded that the costs generated by the refined cost models were stable over a wide range of modeling. To further examine the cost impacts under different financial assumptions, such as varying revenue, farm performance, and net returns, EPA conducted sensitivity analyses.

Table 8.2-1

Results of Cost Driver Analysis

Animal	Size	Option	Primary Driver(s)[a]
Beef	Large	2	Nutrient management planning/transportation
		Ground water	Clay-lined pond/ Transportation/concrete pad
	Medium	2	Nutrient management planning/land application
		Ground water	Nutrient management planning/land application/clay-lined pond
Dairy	Large	2	Concrete settling basin/transportation
		Ground water	Clay-lined lagoon/transportation
	Medium	2	Nutrient management planning/transportation
		Ground water	Clay-lined lagoon/nutrient management planning
Heifers	Large	2	Nutrient management planning/transportation
		Ground water	Nutrient management planning/land application/clay-lined pond
	Medium	2	Nutrient management planning/land application
		Ground water	Nutrient management planning/land application
Veal	Medium	5	Covered lagoon

a All drivers are listed that make up the top 50% of costs.

8.3 Option 2A

Under the regulatory options, facilities will be required to follow either nitrogen-based nutrient management or phosphorus-based nutrient management. More cropland is required to land apply manure waste at agronomic phosphorus-based rates than nitrogen-based rates; therefore, phosphorus-based nutrient management incurs more costs for land application, irrigation, nutrient management planning, and off-site transportation of manure waste than nitrogen-based nutrient management.

To evaluate the significance of the nutrient application basis on the costs, EPA performed a sensitivity analysis named Option 2A, based on Option 2. Option 2 costs are based on a combination of nitrogen-based and phosphorus-based nutrient management. Option 2A represents a modification of this option by assuming 100 percent of facilities would be located in a phosphorus-based nutrient management area.

Because more cropland is required for phosphorus-based application, operations that are Category 1 operations under nitrogen-based nutrient management may be reclassified as Category 2 operations under phosphorus-based nutrient management. That is, a facility with enough land to apply all of the manure waste on site under nitrogen-based application may not have enough land to apply all of their manure waste on site under phosphorus-based nutrient management. Because of this, the most dramatic comparison of the effects of changing the agronomic basis from nitrogen to phosphorus is seen by comparing the results of Option 1 (N-based application), Category 1 facilities to the sensitivity run for Option 2A (P-based application), Category 2 facilities.

Comparing these results shows an increase of between 200 to 500 percent in the costs from Option 1, Category 1 to Option 2A, Category 2 for most model farms. This increase is due to the following factors:

- Shift in the number of facilities from Category 1 to Category 2 (thereby incurring transportation costs);

- A portion of Category 2 facilities under N-based application are assumed to not incur transportation costs because they already apply manure at N-based rates, while they do incur these transportation costs under P-based application; and

- Larger acreage for phosphorus-based facilities, requiring more irrigation, soil sampling, and nutrient management planning costs.

8.4 Option 2B

Under the regulatory options, facilities will be required to design and implement a nutrient management plan for the use of manure waste on site. EPA performed a sensitivity analysis to assess the estimated cost of developing a nutrient management plan for the use of manure off site as well as on site. The cost model assumed that off-site recipients of manure waste would apply the waste on a nitrogen-based agronomic basis.

The cost of a nutrient management plan is based on the number of acres on which manure waste would be applied. Therefore, the cost model calculated the cost of the off-site nutrient management plan by first estimating the amount of manure waste that would be transported off site, then the nutrient content of that waste, and finally, estimating the agronomic rate of application on a nitrogen basis. The cost model used these data to calculate the number of acres required to land apply all of the waste transported off site on a nitrogen basis. This acreage was the basis for the off-site nutrient management plan development costs.

The resulting cost to develop a nutrient management plan for recipients of waste transported off site was insignificant compared to the total weighted model farm cost, typically less than 5 percent of the weighted model farm cost.

8.5 Applications to Frozen Ground

Winter is the least desirable time for land application of manure. Although there are some benefits to winter applications of manure, the negative impacts outweigh the advantages. Winter applications might be advantageous because of greater labor availability and improved driving capabilities on frozen soils. In addition, although there may be significant losses of available nitrogen, the organic fraction will still be available for plant uptake. However, applying manure in winter creates a potential for nutrient runoff because the manure cannot be incorporated into frozen soil. Winter manure applications should include working the manure into the soil either by tillage or by subsurface injection to reduce the runoff potential. Another disadvantage of winter manure application is low nutrient utilization during the winter months.

In northern areas where frozen soil and snow cover are common conditions, winter manure application should be avoided. In fact, winter manure application is prohibited in a number of northern states and in most Canadian provinces. There may be some justification for winter manure application, such as reduced ammonia volatilization and odor problems (Steenhuis, T.S., G.D. Bubenzer, and J.S. Converse, 1979), reduced runoff due to a mulching effect of solid manure (Young, R.A. and R.F. Holt, 1977; Clausen, J.C., 1990), enhanced die-off of some microorganisms in freeze-thaw cycles (Kibby, H.J., C. Hagedorn, and E.L. McCoy, 1978; Stoddard et al. 1998), avoidance of soil compaction, and simplified farm management schedules. However, considerable research has demonstrated that runoff from manure application on frozen or snow-covered ground has a high risk of negative water quality impact.

Extremely high runoff N and P concentrations have been reported from plot studies of winter-applied manure. Runoff concentrations as high as 23.5-1086.0 mg TKN /L and 1.6-15.4 mg TP/L have been observed (Thompson, D.B., T.L. Loudon, and J.B. Gerrish, 1979; Melvin, S. and J. Lorimor, 1996). In two Vermont field studies, Clausen (Clausen, J.C., 1990; Clausen, J.C., 1991) reported the following nutrient increases in runoff resulting from winter application of dairy manure:

- 165%-224% in total P concentrations;
- 246%-1480% in soluble P concentrations;
- 114% in TKN concentrations; and
- Up to 576% in NH3-N.

Runoff mass losses of up to 22 percent of applied N and up to 27 percent of applied P from winter-applied manure have been reported (Midgeley, A.R. and D.E. Dunklee, 1945; Hensler, R.F., R.J. Olsen, S.A. Witzel, O.J. Attoe, W.H. Paulson, and R.F. Johannes, 1970; Phillips, P.A., A.J. MacLean, F.R. Hore, F.J. Sowden, A.D. Tenant, and N.K. Patni, 1975; Converse, J.C., G.D. Bubenzer, and W.H. Paulson, 1976; Klausner, S.D., P.J. Zwerman, and D.F. Ellis, 1976, Young, R.A. and C.K. Mutchler, 1976, Clausen, J.C., 1990; Clausen, J.C., 1991; Melvin, S. and J. Lorimor, 1996). Much of this loss can occur in a single storm event (Klausner, S.D., P.J. Zwerman, and D.F. Ellis, 1976). Such losses may represent a significant portion of annual crop nutrient needs.

Runoff from winter-applied manure can be a major source of annual nutrient loading to water bodies. In a Wisconsin lake, 25 percent of the annual P load from animal waste sources was estimated to be from manure applied in winter (Moore, I.C. and F.W. Madison, 1985). In New York, snowmelt runoff from winter spreading on cropland contributed more P to a local reservoir than did runoff from poorly managed barnyards (Brown, M.P., P. Longabucco, M.R. Rafferty, P.D. Robillard, M.F. Walter, and D.A. Haith, 1989). Clausen and Meals (1989) estimated that 40 percent of Vermont streams and lakes would experience significant water quality impairments from the addition of just two winter-spread fields in their watersheds.

Winter application of manure results in increased microorganism losses in runoff from agricultural land (Reddy, K.R., R. Khaleel, and M.R. Overcash, 1981). Studies have shown that cool temperatures enhance survival of fecal bacteria (Reddy, K.R., R. Khaleel, and M.R. Overcash, 1981, Kibby, H.J., C. Hagedorn, and E.L. McCoy, 1978). However, research results are conflicting; some researchers have reported that freezing conditions are lethal to fecal bacteria (Kibby, H.J., C. Hagedorn, and E.L. McCoy, 1978, Stoddard et al. 1998). Kudva et al. (1998) found that E. coli can survive longer than 100 days in frozen manure at –20 degrees C. Vansteelant (2000) observed that freezing and thawing of a soil/slurry mix reduced E. coli levels by about 90 percent. Research has found that winter application of manure does not guarantee die-off of Cryptosporidium oocysts (Carrington, E.G. and M.E. Ransome, 1994; Fayer, R. and T. Nerad, 1996).

Furthermore, microorganism losses in winter application are increased due to the lack of incorporation or injection of applied manure into the soil. Therefore, filtration and adsorption of manure through soil contact is prevented. Both mechanisms are important for attenuating microorganism losses (Gerba, D., C. Wallis, and J. Mellnick, 1975; Patni, N.K., H.R. Toxopeus, and P.Y. Jui, 1985).

There are several additional disadvantages to winter manure application. Runoff from winter-spread fields during winter thaws or spring snowmelt occurs before the growing season. Riparian buffers or vegetated filter strips are relatively inactive at this time and therefore ineffective in removing pollutants from runoff before delivery to surface waters. Also, winter application may occur due to lack of adequate manure storage. Since the manure must be applied frequently, a loss of management flexibility occurs which makes good nutrient management difficult.

Although several studies have reported little water quality impact from winter-spread manure (Klausner, S.D., P.J. Zwerman, and D.F. Ellis, 1976; Young, R.A. and R.F. Holt, 1977; Young, R.A. and C.K. Mutchler, 1976), such findings typically result from fortuitous circumstances of weather, soil properties, and timing/position of manure in the snowpack. The spatial and temporal variability and unpredictability of such factors makes the possibility of ideal conditions both unlikely and impossible to predict.

8.6 References

Brown, M.P., P. Longabucco, M.R. Rafferty, P.D. Robillard, M.F. Walter, and D.A. Haith, 1989. Effects of animal waste control practices on nonpoint-source phosphorus loading in the West Branch of the Delaware River watershed. J. Soil and Water Conserv. 44(1):67-70.

Carrington, E.G. and M.E. Ransome, 1994. Factors influencing the survival of Cryptosporidium oocysts in the environment. Report No. FR 0456. Foundations for Water Research. Marlow, Bucks.

Clausen, J.C., 1990. Winter and Fall application of manure to corn land. Pages 179 – 180 in Meals, D.W. 1990. LaPlatte River Watershed Water Quality Monitoring and Analysis Program: Comprehensive Final Report. Program Report No. 12. Vermont Water Resource Research Center, University of Vermont, Burlington.

Clausen, J.C., 1991. Best manure management effectiveness. Pages 193 – 197 in Vermont RCWP Coordinating Committee. 1991. St. Albans Bay Rural Clean Water Program, Final Report. Vermont Water Resources Research Center, University of Vermont, Burlington

Clausen, J.C. and D.W. Meals, 1989. Water quality achievable with agricultural best management practices. J. Soil and Water Conserv. 44(6):593-596.

Converse, J.C., G.D. Bubenzer, and W.H. Paulson, 1976. Nutrient losses in surface runoff from winter spread manure. Trans. ASAE 19:517-519.

Fayer, R. and T. Nerad, 1996. Effects of low temperature on viability of Cryptosporidium parvum oocysts. Appl. and Environ. Microbiol. 62(4):1431-1433

Gerba, D., C. Wallis, and J. Mellnick, 1975. Fate of wastewater bacteria and viruses in soil. J. Irr. Drain. Div. ASCE 101:157-174.

Hensler, R.F., R.J. Olsen, S.A. Witzel, O.J. Attoe, W.H. Paulson, and R.F. Johannes, 1970. Effect of method of manure handling on crop yields, nutrient recovery, and runoff losses. Trans ASAE 13(6):726-731.

Kibby, H.J., C. Hagedorn, and E.L. McCoy, 1978. Use of Fecal Streptococci as indicators of pollution in soil. Appl. and Environ. Microbiol. 35(4):711-717.

Klausner, S.D., P.J. Zwerman, and D.F. Ellis, 1976. Nitrogen and phosphorus losses from winter disposal of dairy manure. J. Environ. Qual. 5(1):47-49.

Kudva, I.T., K. Blanch, and C.J. Hovde, 1998. Analysis of Escherichia coli O157:H7 in ovine or bovine manure and manure slurry. Appl. and Environ. Microbiol. 64(9):3166-3174.

Melvin, S. and J. Lorimor, 1996. Effects of winter manure spreading on surface water quality. 1996 Research Report, Agricultural & Biosystems Engineering, Iowa State University Extension, Ames, IA. (http://www.nppc.org/Research/?96Reports/?96Melvin-manure.html)

Midgeley, A.R. and D.E. Dunklee, 1945. Fertility runoff losses from manure spread during the winter. Univ. of Vermont, Agric. Exp. Station, Bulletin 523, 19 p.

Moore, I.C. and F.W. Madison, 1985. Description and application of an animal waste phosphorus loading model. J. Environ. Qual. 14(3):364-368.

Patni, N.K., H.R. Toxopeus, and P.Y. Jui, 1985. Bacterial quality of runoff from manured and non-manured cropland. Trans. ASAE 28():1871-1884.

Phillips, P.A., A.J. MacLean, F.R. Hore, F.J. Sowden, A.D. Tenant, and N.K. Patni, 1975. Soil water and crop effects of selected rates and times of dairy cattle liquid manure applications under continuous corn. Engineering Research Service Contribution No. 540. Agriculture Canada, Ottawa, Ontario.

Reddy, K.R., R. Khaleel, and M.R. Overcash, 1981. Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. J. Environ. Qual. 10(3):255-266.

Steenhuis, T.S., G.D. Bubenzer, and J.S. Converse, 1979. Ammonia volatilization of winter spread manure. Trans. ASAE 22: 153-157.

Stoddard et al. 1998.

Thompson, D.B., T.L. Loudon, and J.B. Gerrish, 1979. Animal manure movement in winter runoff for different surface conditions. Pages 145-157 in R.C. Loehr et al., eds. Best Management Practices for Silviculture and Agriculture. Ann Arbor Science, Ann Arbor, MI.

Vansteelant, JY., 2000. Personal communication, Institut National de la Recherche Agronimique, Thonon les Bains, France.

Young, R.A. and R.F. Holt, 1977. Winter-applied manure: effects on annual runoff, erosion, and nutrient movement. J. Soil and Water Conserv. 32(5):219-222.

Young, R.A. and C.K. Mutchler, 1976. Pollution potential of manure spread on frozen ground. J. Environ. Qual. 5(2):174-179.