# 4D: Animal Feeding Operations (AFOs)

## Management Measure for Animal Feeding Operations

Animal feeding operations (AFOs) should be managed to minimize impacts on water quality and public health. To meet this goal, management of AFOs should address the following eight components:

1. *Divert clean water.* Siting or management practices should divert clean water (run-on from uplands, water from roofs) from contact with feedlots and holding pens, animal manure, or manure storage systems.
2. *Prevent seepage.* Buildings, collection systems, conveyance systems, and storage facilities should be designed and maintained to prevent seepage to ground and surface water.
3. *Provide adequate storage.* Liquid manure storage systems should be (a) designed to safely store the quantity and contents of animal manure and wastewater produced, contaminated runoff from the facility, and rainfall from the 25-year, 24-hour storm and (b) consistent with planned utilization or utilization practices and schedule. Dry manure, such as that produced in certain poultry and beef operations, should be stored in production buildings, storage facilities, or otherwise covered to prevent precipitation from coming into direct contact with the manure.
4. *Apply manure in accordance with a nutrient management plan that meets the performance expectations of the nutrient management measure.*
5. *Address lands receiving wastes.* Areas receiving manure should be managed in accordance with the erosion and sediment control, irrigation, and grazing management measures as applicable, including practices such as crop and grazing management practices to minimize movement of nutrient and organic materials applied, and buffers or other practices to trap, store, and "process" materials that might move during precipitation events.
6. *Recordkeeping.* AFO operators should keep records that indicate the quantity of manure produced and its utilization or disposal method, including land application.
7. *Mortality management.* Dead animals should be managed in a way that does not adversely affect ground or surface waters.
8. *Consider the full range of environmental constraints and requirements.* When siting a new or expanding facility, consideration should be given to the proximity of the facility to (a) surface waters; (b) areas of high leaching potential; (c) areas of shallow groundwater; and (d) sink holes or other sensitive areas. Additional factors to consider include siting to minimize off-site odor drift and the land base available for utilization of animal manure in accordance with the nutrient management measure. Manure should be used or disposed of in ways that reduce the risk of environmental degradation, including air quality and wildlife impacts, and comply with Federal, State and local law.

Animal Feeding Operations should be designed and operated to avoid waste discharge by having engineered runoff controls, waste storage, waste utilization, and nutrient management.

# USDA–EPA Unified National Strategy for Animal Feeding Operations

## USDA-EPA Unified National Strategy for Animal Feeding Operations

Animal feeding operations (AFOs) can pose a number of risks to water quality and public health, mainly because of the amount of animal manure and wastewater they generate. To minimize water quality and public health impacts from AFOs and land application of animal waste, the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA) released the Unified National Strategy for Animal Feeding Operations on March 9, 1999. The Strategy sets a national performance expectation that all AFO owners and operators develop and implement technically sound and economically feasible site-specific **Comprehensive Nutrient Management Plans (CNMPs)** by 2009.

A CNMP identifies actions that will be implemented to meet clearly-defined nutrient management goals at an agricultural operation. AFO owners and operators may seek technical assistance for the development, implementation and review of CNMPs from qualified specialists.

The following components may be contained in a CNMP:

- ❒ **Feed Management:** reducing nutrients in manure by modifying animal diets
- ❒ **Manure Handling and Storage:** proper handling and storage of manure
- ❒ **Land Application of Manure:** utilizing the nutrients and organic matter in manure while minimizing the risk to water quality and public health
- ❒ **Land Management:** installing best management practices to minimize movement of potential pollutants to surface or ground water
- ❒ **Record Keeping:** recording the quantity of manure produced and how the manure was utilized
- ❒ **Other Utilization Options:** finding alternative uses or markets (e.g., composting, sale to other farmers, power generation) for manure when land application is not feasible

Voluntary and regulatory programs serve complementary roles in providing AFO owners and operators and the animal agricultural industry with the assistance and certainty they need to achieve individual business and personal goals, and in ensuring protection of water quality and public health. For the vast majority of AFOs, voluntary efforts will be the principal approach to assist owners and operators in developing and implementing site-specific CNMPs and in reducing water pollution and public health risks associated with AFOs. While CNMPs are not required for AFOs participating only in voluntary programs, they are strongly encouraged as the best possible means of managing potential water quality and public health impacts from these operations.

Impacts from certain higher risk AFOs are addressed through National Pollutant Discharge Elimination System (NPDES) permits under the authority of the Clean Water Act. AFOs that meet certain specified criteria in the NPDES regulations are referred to as concentrated animal feeding operations or CAFOs. NPDES permits will require CAFOs to develop CNMPs and to meet other conditions that minimize the threat to water quality and public health and otherwise ensure compliance with the requirements of the Clean Water Act.

The Strategy identifies three categories of CAFOs that are priorities for the regulatory program:

- **Significant Manure Production:** large facilities (i.e., greater than 1000 animal units)
- **Unacceptable Conditions:** facilities that discharge through a man-made conveyance to waters or allow animals direct contact with waters
- **Significant Contributors to Water Quality Impairment:** facilities that are significantly contributing to the impairment of a waterbody

In addition, the Unified AFO Strategy addresses strategic issues to be addressed by the agencies. The discussion of each strategic issue identifies several action items that the agencies intend to pursue in implementing the Strategy. Some of these actions are listed below.

- Assure the availability of qualified specialists from the public or private sectors to assist in the development and implementation of CNMPs
- Review USDA's practice standards and revise as necessary
- Develop a CNMP guidance
- Strengthen and improve existing EPA regulations for CAFOs
- Coordinated research, technical innovation, and technology transfer activities
- Provide compliance assistance and establish a single point information center
- Promote the involvement of the animal agriculture industry in CNMP adoption
- Coordinate data sharing while protecting the relationship of trust between USDA and farmers and providing regulatory authorities with information that is useful in protecting water quality and public health
- Develop an approach for measuring the effectiveness of efforts to minimize the water quality and public health impacts of AFOs

**For additional information on the Strategy, see http://cfpub.epa.gov/npdes/home.cfm?program_id=7**

## AFOs, CAFOs, and CZARA

Existing regulatory definitions of AFOs and *concentrated animal feeding operations (CAFOs)* are given at 40 *CFR* 122.23 and Part 122, Appendix B (as revised February 12, 2003). These regulations define an AFO as a facility that meets the following criteria:

1. Animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
2. Crops, vegetation forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

As described in Chapter 1, EPA published guidance specifying management measures for sources of nonpoint pollution in coastal waters as required under section 6217(g) of CZARA. With regard to the management measures for livestock operations (EPA, 1993a), EPA defined a *confined animal facility* as a lot or facility that meet <u>the same two criteria</u> (1 and 2) specified above for AFOs. AFOs include the areas used to grow or house the animals, areas used for processing and storage of product, manure and runoff storage areas, and silage storage areas.

The subset of AFOs within the section 6217 coastal management areas that are subject to the CZARA management measures for confined animal facilities is determined by the number of head at the operation and whether or not the operation is designated as a CAFO. Those facilities that are required by Federal regulation 40 CFR 122.23(c) to apply for and receive discharge permits, are *NOT* covered by section 6217 since they are CAFOs. CAFOs are defined generally as an AFO that:

- ❐ Confines the number of animals presented in the second column of Table 4d-1: or
- ❐ Confines the number of animals presented in the third column of Table 4d-1 and discharges pollutants:
  - Into waters of the U.S. through a man-made ditch, flushing system, or similar man-made device; or
  - Directly into waters of the U.S. that originate outside of and pass over, across, or through the facility or otherwise come into direct contact with the animals confined in the operation.

In addition, 40 CFR 122.23(c) provides that the Director of a National Pollutant Discharge Elimination System (NPDES) permit program may designate any AFO as a CAFO upon determining that it is a significant contributor of water pollution. AFOs containing fewer than the number of head listed in Table 4d-1 for small confined animal facilities are not subject to the CZARA management measures for confined animal facilities. Figure 4d-1 shows the relationship between AFOs, CAFOs, and large and small confined animal facilities under the NPDES and CZARA programs. Operators of confined animal facilities should contact their state or federal NPDES permitting authority for information on permit application procedures.

It is important to note that in December 2002 EPA finalized revised regulations for concentrated animal feeding operations under 40 CFR 122. The final regulations changed some of the definitions. Readers are encouraged to contact EPA's

**Table 4d-1. Comparison of CAFO and AFO Size Difinitions under the NPDES and CZARA Programs.**

| Animal Type | Defined as a CAFO by Size and must have a NPDES Permit | Defined as CAFO by Size and Site Conditions* and must have a NPDES Permit | Large Animal Feeding Operations under CZARA (that do not have a NPDES Permit) | Small Animal Feeding Operations under CZARA |
|---|---|---|---|---|
| | Number of Head | | | |
| Beef cattle or heifers | ≥1,000 | < 1,000 & ≥300 | ≥300 | 51 - 299 |
| Veal calves | ≥1,000 | < 1,000 & ≥300 | ND** | ND |
| Mature dairy cattle | ≥700 | < 700 & ≥200 | ≥70 | 20 - 69 |
| Swine | ≥2,500 (each 55 lbs or more) | < 2,500 & ≥750 (each 55 lbs or more) | ≥200 | 100 - 199 |
| Swine | ≥10,000 (each under 55 lbs) | < 1,000 & ≥300 (each under 55 lbs) | ND | ND |
| Turkeys | ≥55,000 | <55,000 & ≥16,500 | ≥13,750 | 5,000 - 13,749 |
| Chickens with liquid manure handling | ≥30,000 | < 30,000 & ≥9,000 | ND | ND |
| Chickens (except laying hens) with dry manure handling | ≥125,000 | < 125,000 & ≥37,500 | ≥15,000 (all broilers) | 5,000 - 14,999 (all broilers) |
| Laying hens with dry manure handling | ≥82,000 | < 82,000 & ≥25,000 | ≥15,000 (all laying hens) | 5,000 - 14,999 (all laying hens) |
| Horses | ≥500 | < 500 & ≥150 | ≥200 | 100 - 199 |
| Sheep or lambs | ≥10,000 | < 10,000 & ≥3,000 | ND | ND |
| Ducks with liquid manure handling | ≥5,000 | < 5,000 & ≥1,500 | ND | ND |
| Ducks with dry manure handling | ≥30,000 | < 30,000 & ≥10,000 | ND | ND |

*AFOs are defined as CAFOs if they have the number of animals shown above AND have a man-made ditch or pipe that carries manure or wastewater from the operation to surface waters OR the animals come into contact with surface water running through the area where they are confined.
**Not defined.

Office of Wastewater Management (www.epa.gov/owm) or their state NPDES permitting authority for the latest information on the final CAFO regulations.

## Management Measure for Animal Feeding Operations: Description

The water quality problems associated with confined animal facilities result from accumulated animal wastes, facility wastewater, and storm runoff, all of which may be controlled under this management measure (Figure 4d-2). The goal of this management measure is to minimize the discharge of contaminants in facility wastewater, runoff, and seepage to ground water, while at the same time preventing any other negative environmental impacts such as increased air pollution. Accumulated animal wastes include manure, litter, or other waste products that are deposited within the confinement area and are periodically removed by scraping, flushing, or other means and can be conveyed to a storage or treatment facility. Facility wastewater is water generated in the operation of an animal facility as a result of animal or poultry watering; washing, cleaning, or

# Management of Soil Phosphorus Levels to Protect Water Quality

## Phosphorus in Agriculture

Phosphorus (P) is important to and used extensively in both the crop production and confined livestock segments of agriculture, making it one of the most common elements used in agriculture today.

One of the most important functions of P in plants is the storage and transfer of energy. Phosphorus is essential for seed production, promotes increased root growth, stalk strength and early plant maturity, and aids in resistance to root rot diseases and winter kill.

In the confined livestock segment, producers use P as a diet supplement, in addition to the P already contained in feeds, to improve animal performance. To avoid excessive buildup of soil-P on the lands surrounding confined animal operations, consideration must be given to the amount of land available to absorb P from livestock.

## Environmental Impacts

In areas of intense crop and livestock production, continued inputs of fertilizer and manure P in excess of crop requirements have led to a build-up of soil P levels. This increases the potential for nonpoint source (NPS) runoff to carry excess phosphorus to surrounding streams and lakes.

Phosphorus is usually the limiting nutrient in freshwater aquatic systems. When excess phosphorus enters streams and lakes, creating P concentrations between the critical values of 0.01 and 0.02 ppm (Sawyer, 1947; Vollenweider, 1968), accelerated eutrophication occurs. Eutrophication, a natural process that usually occurs over a long period of time, is characterized by increased aquatic plant growth, oxygen depletion, and pH variability. It eventually leads to a decline in plant species quality and adverse food chain effects (Sharpley et al., 1994), all of which may reduce water quality.

## Transport Mechanism

Phosphorus enters the soil through mineral dissolution, desorption from clay and mineral surfaces, and biological conversion from organic materials to inorganic forms. As rainfall or irrigation water interacts with a thin layer of surface soil, P is either moved into agriculture runoff through dissolution from the soil and plant material, or is transported by erosion, remaining either attached to soil or in vegetation. The dissolved P is immediately available for uptake by aquatic biota (bioavailable), while the particulate P is available only after all of the dissolved P is consumed. Once bioavailable P moves from the field into receiving waters, it can contribute to eutrophication (Wood et al., 1998).

Another mechanism for P transport occurs when large accumulations of P occupy all available sites on the soil surface, causing additional P to leach downward through the soil column. When this leaching is followed by lateral movement of water under the soil surface, especially under high water table conditions, dissolved P may be added to the surface waters.

## Soil Testing

The prime goal of soil testing  methods have also been developed and tested to determine if they might more accurately predict the runoff and drainage P levels. Some of the most promising new methods are:

(1) Breeuswma et al., 1995 – developed to determine the degree of P saturation in soils

(2) Chardon et al., 1996 – using an iron oxide coated filter paper strip as an "infinite sink" to measure the amount of P in soils that is subject to runoff or leaching

(3) Pote et al., 1996 – using distilled water to extract readily desorbable soil P, simulating the rapid release of P to runoff water.

**Soil test extractants now used for phosphorus in the U.S.** (Kamprath and Watson, 1980)

| Soil Test Category | Common Soil Test | Regions in the U.S. Where Commonly Used |
|---|---|---|
| Dilute concentrations of strong acids: Solvent nature of acids primarily extracts Al and Fe bound P, plus some Ca-P.  Best for soils with pH < 7.0 | Mehlich 1 | Southeast and Mid-Atlantic |
| Dilute concentrations of strong acids plus a complexing ion: Extractants remove P by solvent action of acids and complexing ability of fluoride ion for Al-P.  Best on acidic soils. | Bray P1<br>Mehlich 3 | Bray: North Central and Midwest<br>Mehlich 3: Widespread use in U.S. |
| Dilute concentrations of weak acids: Anion replacement | Morgan and Modified Morgan | Northeast |
| Buffered Alkaline Solutions: Extract P by hydrolysis of cations binding P. Precipitate $CaCO_3$ from calcareous, alkaline, and neutral soils, reducing Ca and increasing P concentrations in solution, making P more accurately and easily measured. | Olsen<br>AB-DTPA | West and Northwest |

## Other Control Options

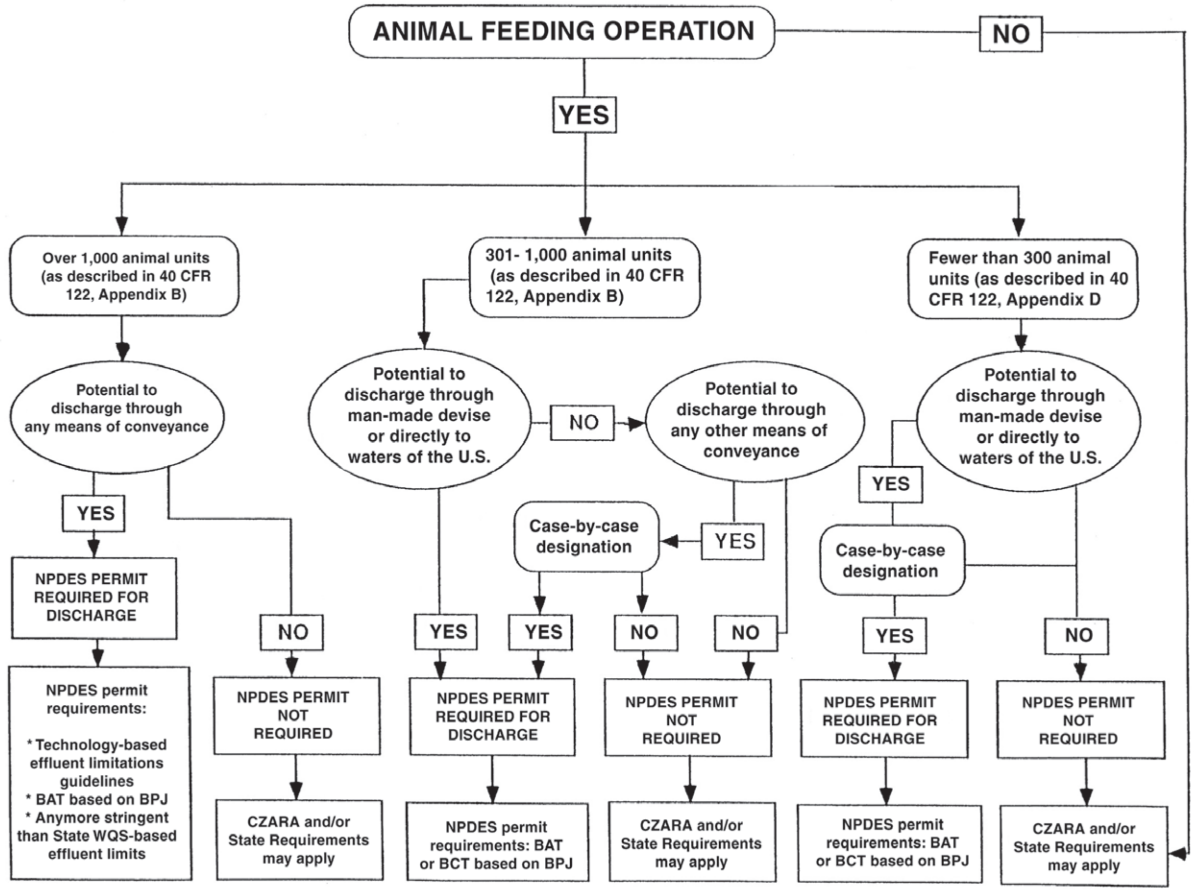
One reason for high phosphorus levels in runoff from fields fertilized with poultry or swine litter is that these animals lack phytase enzymes, making most of the phytate P (65% of total P) in corn and soybeans unavailable to these animals. In order for normal growth and development, other forms of P must be added to the diet. This addition of inorganic P results in much higher levels of P in manure.

*Phytase products* - One way to reduce the level of inorganic P fed to these animals, thus lowering the level of P in manure, is to add phytase enzyme to the feed aiding the breakdown of phytate P.

*Low phytic acid or high available P (HAP) corn* - Another way to reduce the amount of additional P needed in the animal diets, thus reducing amounts of P in manure, is to feed the animals a corn hybrid containing lower amounts of phytate P or higher amounts of available P.

While some studies have shown that P levels in runoff decrease with the use of these products in livestock diets, more comprehensive research must be done before any conclusions can be drawn.

**Figure 4d-1. Management of Animal Feeding Operations**



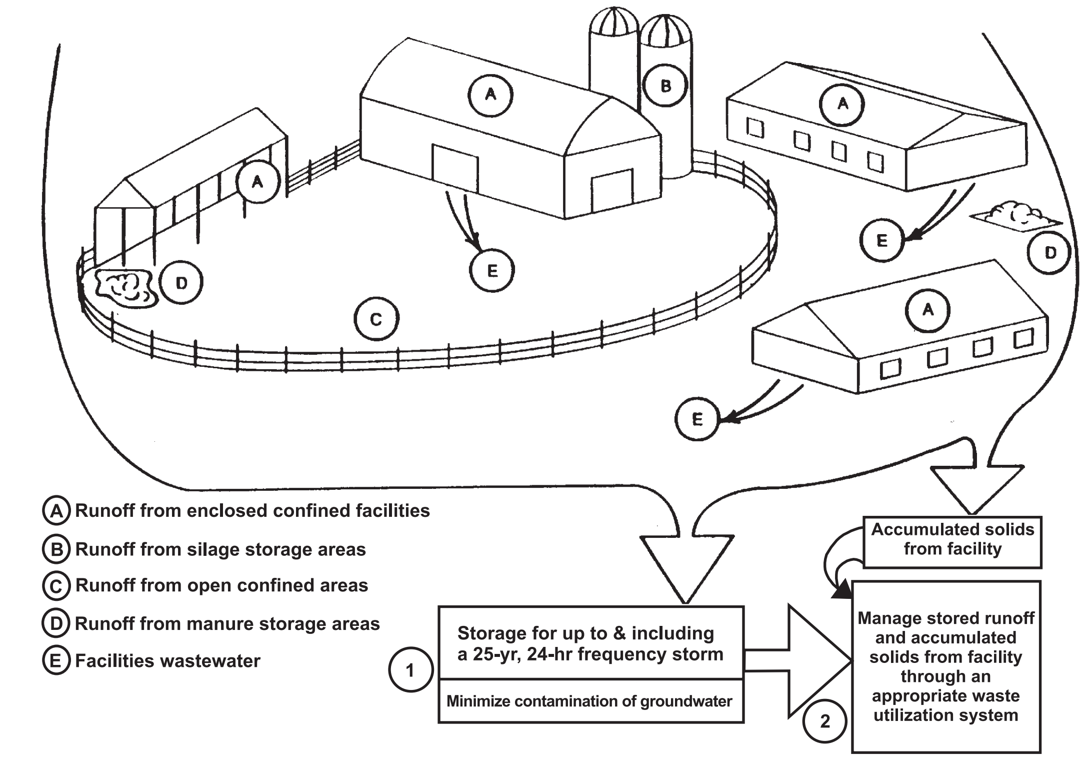

Source: Guide Manual on NPDES Regulations For Concentrated Animal Feeding Operations. Final. 1995. US Environmental Protection Agency, Office of Water. EPA833-B-95-001.

flushing pens, barns, manure pits, or other facilities; washing or spray cooling of animals; and dust control. Animal lot runoff includes any precipitation (rain or snow) that comes into contact with manure, feed, litter, or bedding and may potentially leave the facility either by overland flow or by infiltration.

Diverting clean water from upslope areas and roof runoff away from the animal lot and waste storage structure can reduce waste volume and storage requirements.

Implementation of this management measure greatly reduces the volume of runoff, manure, and facility wastewater reaching a water body due to structural practices such as solids separation basins in combination with vegetative practices and other techniques that reduce runoff while also protecting ground water. The measure can be implemented by using practices that divert clean runoff water from upslope sites and roofs away from the facility, thereby minimizing the amount of contaminated water to be stored and managed. Accumulated animal wastes should be protected as much as possible from runoff and stored in such a way that any runoff water, seepage, or leachate can be captured and managed with runoff and wastewater. Runoff water and facility wastewater should be routed through a settling structure or debris basin to remove solids, and then stored in a pit, pond, or lagoon for application on agricultural land in accordance with the Nutrient Management Measure. If manure is managed as a

**Figure 4d-2. Management measure for animal feeding operations (large units) (EPA, 1993a).**




liquid, all manure, runoff, and facility wastewater can be stored in the same structure and there is no need for an additional debris basin. In some areas, certain systems may be preferred over others due to competing environmental concerns (e.g., liquid systems may raise concerns regarding air quality), and innovative alternatives that achieve the management measure goals should be considered.

This management measure is consistent with, yet more specific than the CZARA management measure for large confined animal facilities, and it goes beyond the expectation for small confined animal facilities under CZARA by calling for storage. This does *NOT* change, however, the performance expectations for either large or small facilities that are subject to the CZARA management measures.

Animal feeding operations have the potential to contribute large pollutant loads to waterways. Because they may be located near streams and water supplies, AFOs require well-planned and maintained systems of practices to minimize human health and aquatic ecosystem impacts.

## Contaminant Movement from Animal Feeding Operations into Surface and Ground Water

The concentration of livestock production and housing in large systems has resulted in large accumulations of animal wastes with the potential to contribute nutrients, suspended solids, pathogens, oxygen-demanding materials, and heavy metals to surface and ground waters. Animal operations can also be a source of atmospherically transported pollutants, particularly ammonia, via volatilization (Harper and Sharpe, 1997). The pollution potential of such accumulations is influenced by the number and type of animals in the operation, the facilities and practices used to collect and store the wastes, and the methods chosen to manage the wastes (e.g., application to the land).

### *Movement to Surface Waters*

The volume of runoff from animal facilities is influenced by several major factors including: (1) *water inputs*, dependent on rain storm intensity and duration, time since last runoff, snowpack accumulation and melting, and runoff entering from outside the facility and (2) *runoff generation* from impervious surfaces such as roofs and paved areas. While precipitation inputs cannot usually be managed, the diversion of clean water from upgradient areas, and the reduction and diversion of runoff from impervious areas (e.g. installation of roof gutters on facility buildings) to avoid contact with pollutants can affect the volume of runoff that needs to be controlled. In regions of the country with very high rainfall, some animal facilities are entirely roofed to prevent precipitation from coming into contact with animal wastes and to minimize the total volume of stored wastes that must be managed.

The pollutant load carried in runoff from animal facilities is affected by several additional factors, including: (1) pollutants *available* for transport in the facility; (2) the rate and path of runoff-*movement* through the facility; and (3) passage of runoff through *settling or filtering* practices before exiting the facility. Management activities like scraping manure from pavement areas or proper storage of feeds and bedding can significantly reduce the availability of pollutants for transport. Structures such as detention basins can affect pollutant transport by regulating runoff movement and increasing settling within the facility. Vegetated filter strips, riparian buffers, or other vegetated areas located around animal facilities can reduce delivery of pollutants to surface waters by infiltrating, settling, trapping, or transforming nutrients, sediment, and pathogens in runoff leaving the facility.

The ranges in concentrations of pollutants from some typical sources on a dairy farm are shown in Table 4d-2. The total pounds of pollutants that could come from a typical 100-cow dairy is shown in Table 4d-3. These values were obtained by multiplying the concentrations by the typical volume in Table 4d-2. The pounds per year from these concentrated sources may be small but represent significant pollutant sources if not controlled. Each farm is different, as shown by the range in concentration and amount of pollutants from the various sources. Some of the variation is under the control and management of the farmer and their day-to-day operations, while some of it is due to the type and layout of the facility.

Facility wastewater volumes and pollutant loads are controlled primarily through the design and operation of the facilities involved in watering, washing, and cleaning. Frequency of wash-downs and the volume of water used, for example, will influence both total volume of wastewater to be managed and the concentrations of pollutants in the wastewater. In dairy milking center wastewater, both volume and concentrations of pollutants in the wastewater are controlled by the type of milking and plumbing systems and the formulation of cleaning compounds used.

An important part of the management of milking center waste is to reduce the volume of water and the amount of material that must be handled. The amount of waste can be affected by management as shown by the variability of both the flows and the concentrations in Tables 4d-2 and 4d-3. Reducing the volume of wastewater to be treated will reduce the cost of wastewater treatment. Energy

**Table 4d-2. Waste characteristics from dairy farms (Wright, 1996).**

| Potential Pollutant Source | Biochemical Oxygen Demand[a] ppm | Nitrogen ppm | Phosphorus ppm | Volume gallons per 100 cows[b] |
|---|---|---|---|---|
| Milking Center Waste | 400-10,000 | 80-900 | 25-170 | 73,000 |
| Silage Leachate | 12,000-90,000 | 4,400[c] | 500[c] | 105,000 |
| Barnyard Runoff | 1,000-10,000 | 50-2,100 | 5-500 | 80,000 |
| Dairy Manure | 20,000[c] | 5,600[c] | 900[c] | 660,000 |
| Domestic Waste | 150-250 | 20-30 | 5-10 | 365,000 |

[a] 5 day BOD
[b] yearly volumes assuming: 2 gallons/cow/day milking center waste
bunk silo, 25% DM, no drainage water, 36" precipitation
70 ft$^2$/cow, 36" precip., scraped daily, good solid retention
22,000 LB/cow/yr. milk production, 18 gal./cow/day
10 people producing 100 gal./day/person
[c] Typical values

**Table 4d-3. Annual waste production on a typical[b] 100 cow dairy (Wright, 1996).**

| Potential Pollutant Source | Biochemical Oxygen Demand[a] lb. | Nitrogen lb. | Phosphorus lb. |
|---|---|---|---|
| Milking Center Waste | 250-6,100 | 50-550 | 15-100 |
| Silage Leachate | 10,500-79,000 | 3900[c] | 440[c] |
| Barnyard Runoff | 670-6,700 | 30-1,400 | 3-330 |
| Dairy Manure | 110,000[c] | 31,000[c] | 5,000[c] |
| Domestic Waste | 450-760 | 60-90 | 15-30 |

[a] 5 day BOD
[b] yearly volumes assuming: 2 gallons/cow/day milking center waste
bunk silo, 25% DM, no drainage water, 36" precipitation
70 ft$^2$/cow, 36" precip., scraped daily, good solid retention
22,000 LB/cow/yr. milk production, 18 gal./cow/day
10 people producing 100 gal./day/person
[c] Typical values

savings for reduced pumping costs and water heating can also be realized. Using only the amount of cleaners that are necessary and using low phosphorus detergents can significantly decrease the amount of phosphorus in the wastewater. Using automated systems appropriately and water treatment where needed can result in a cost savings. Manure reduction methods for milking centers are shown in Table 4d-4 and methods for phosphorus reduction are described in Table 4d-5.

**Table 4d-4. Manure reduction methods and costs for milking centers (Wright, 1996).**

| Manure Reduction Methods | Reduction Potential | Estimated Cost |
|---|---|---|
| Schedule the cleaning of alleys and holding areas to minimize the amount of manure tracked into parlors | High | <$300 to >$1,200 |
| Scrape the cow platforms before hosing down parlors | High | <$300 |
| Don't install drains in the cow platform | High | >$1,200 |
| Slope the floors of the parlor to facilitate scraping to the holding area | High | >$300 |
| Install deep traps in drains | Low | $300-$1,200 |
| Keep traffic from manure areas out of the milk house | Low | <$300 |

**Table 4d-5. Phosphorus reduction methods and costs (Springman, 1992).**

| Phosphorus Reduction Methods | Reduction Potential | Estimated Cost |
|---|---|---|
| Install water softener and/or increase softening time | High | <$1,200 |
| Install an iron filter if needed | Low | <$300 |
| Install automatic, programmable CIP dispensing system | Medium | >$1,200 |
| Use low or no phosphorus containing detergents and acid rinses | High | <$300 |
| Reuse CIP detergent and/or acid rinse water | Medium | >$300 |
| Install water conservation methods in CIP | Medium | >$300 |

## *Movement to Ground Water*

Implementation of some surface runoff controls may increase the potential for movement of water and soluble pollutants through the soil profile to the ground water. The intent of this measure is not to address a surface water problem at the expense of ground water. Facility wastewater and runoff control systems can and should be designed to protect against the contamination of ground water. Ground water protection will also be provided by minimizing seepage of stored, contaminated water to ground water, and by implementing the nutrient and pesticide management measures.

Most parts of AFOs are either paved or highly compacted, and therefore relatively impervious. Thus, in most cases, threats to ground water by infiltration at the feedlot are low, and most actions for ground water protection will occur on land application sites and should be approached through the Nutrient Management Measure. There are, however, a few important concerns within the feedlot and storage areas. Unpaved feedlots and earthen impoundments are generally believed to be “self-sealing” through compaction or with fine organic matter and bacterial cells after a few months of operation. The rate and effectiveness of sealing varies with waste and soil type. Cattle manure generally seals better than swine waste; fine-textured soils generally seal more quickly and effectively than do more porous soils. This sealing, however, is neither immediate nor 100% effective. Significant leaching of pathogens or soluble pollutants such as nitrate may occur early in the life of a facility, and the very slow seepage after “sealing” may still pose a long-term threat to ground water. Additional sealing by compaction, soil additives, or impermeable membranes is often required over porous soils or fractured bedrock. Whenever possible, liners made of clay or synthetic materials should be used in the original design and construction of the facility. Construction with concrete or use of closed storage tanks are effective means of preventing seepage.

Vegetated filter strips located within or adjacent to the facility may sometimes represent an additional ground water concern. When such areas receive a high pollutant load and infiltration occurs, ground water levels of nitrate may be increased. While it may not be necessary to implement a nutrient management plan on the vegetative control practices themselves, ground water should be protected by taking care to not exceed the capacity of the practices to assimilate nutrients.

Finally, wells within the facility represent a direct path to ground water and may be vulnerable to direct contamination by runoff water or by accidental spills of wastes. Wells are a particular concern where drinking water may be threatened by nitrates, bacteria, viruses, or other pathogens. Care should be taken to protect wells from routine or accidental contamination. Wells should be properly cased, grouted, and sealed, and abandoned wells should be properly filled and sealed. Participation in Farm*A*Syst, a voluntary farmstead pollution risk assessment program, is an excellent way to identify ways to prevent contamination of wells (Jackson et al., undated).

## Animal Feeding Operation Management Practices and Their Effectiveness

### *AFO Management Practices*

One of the most important considerations in preventing water pollution from AFOs is the location of the facility. For new facilities and expansions to existing facilities, consideration should be given to siting the facility:

- ❒ Away from surface waters;
- ❒ Away from areas of shallow ground water;
- ❒ Away from areas with high leaching potential;
- ❒ Away from sinkholes and other critical or sensitive areas;
- ❒ To avoid odor drift to homes, churches, and communities; and
- ❒ In areas where adequate land is available; to apply animal wastes in accordance with the nutrient management measure.

Combinations of the following practices can be used to satisfy the requirements of this management measure. The Natural Resources Conservation Service (NRCS) practice number and definition are provided for each management practice, where available. Additional information about the purpose and function of individual practices is provided in Appendix A. In some emergency situations, such as extreme animal mortality or structure failure, certain management methods such as commercial rendering, incineration, or approved burial sites may be necessary.

A large set of management practices are available to custom fit most facilities for an effective pollution prevention system.

**Practices to Divert Clean Water**

- ❒ **Diversions (362)**: A channel constructed across the slope with a supporting ridge on the lower side.
- ❒ **Field Border (386):** A strip of perennial vegetation established at the edge of a field by planting or by converting it from trees to herbaceous vegetation or shrubs.
- ❒ **Filter strip (393)**: A strip or area of vegetation for removing sediment, organic matter, and other contaminants from runoff and wastewater.
- ❒ **Grassed waterway (412)**: A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.
- ❒ **Lined waterway or outlet (468)**: A waterway or outlet having an erosion-resistant lining of concrete, stone, or other permanent material. The lined section extends up the side slopes to a designed depth. The earth above the permanent lining may be vegetated or otherwise protected.
- ❒ **Roof runoff management (558)**: A facility for controlling and disposing of runoff water from roofs.
- ❒ **Terrace (600)**: An earthen embankment, a channel, or combination ridge and channel constructed across the slope.

**Practices for Waste Storage**

- ❒ **Dikes (356)**: An embankment constructed of earth or other suitable materials to protect land against overflow or to regulate water.
- ❒ **Sediment basin (350)**: A basin constructed to collect and store debris or sediment.
- ❒ **Water and sediment control basin (638)**: An earth embankment or a combination ridge and channel generally constructed across the slope and minor water courses to form a sediment trap and a water detention basin.
- ❒ **Waste storage facility (313):** A waste impoundment made by constructing an embankment and/or excavating a pit or dugout, or by fabricating a structure.
- ❒ **Waste treatment lagoon (359)**: An impoundment made by excavation or earth fill for biological treatment of animal or other agricultural wastes.

**Practices for Waste Management**

- ❒ **Constructed wetlands (656)**: A wetland that has been constructed for the primary purpose of water quality improvement.

- **Heavy use area protection (561)**: Protecting heavily used areas by establishing vegetative cover, by surfacing with suitable materials, or by installing needed structures.
- **Waste utilization (633)**: Using agricultural wastes or other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources.
- **Composting facility (317)**: A facility for the biological stabilization of waste organic material.
- **Application of manure and/or runoff water to agricultural land**: Manure and runoff water are applied to agricultural lands and incorporated into the soil in accordance with the Nutrient Management Measure.

**Practices for Mortality Management**

- **Composting facility (317)**: A facility for the biological stabilization of waste organic material.

## *Practice Effectiveness*

The effectiveness of practices to control contaminant losses from confined livestock facilities depends on several factors including:

- The contaminants to be controlled and their likely pathways in surface, subsurface, and ground water flows;
- The types of practices and how these practices control surface, subsurface, and ground water contaminant pathways; and
- Site-specific variables such as soil type, topography, precipitation characteristics, type of animal housing and waste storage facilities, method of waste collection, handling and disposal, and seasonal variations. The site-specific conditions must be considered in system design, thus having a large effect on practice effectiveness levels.

The gross effectiveness estimates reported in Table 4d-6 simply indicate summary literature values. For specific cases, a wide range of effectiveness can be expected depending on the value and interaction of the site-specific variables cited above. When runoff from storms up to and including the 24-hour, 25-year frequency storm is stored, there should be no release of pollutants from an AFO via surface runoff. Rare storms of a greater magnitude or sequential storms of combined greater magnitude may produce runoff, however.

Table 4d-7 shows reductions in pollutant concentrations that are achievable with solids separation basins that receive runoff from small barnyards and feedlots. Concentration reductions may differ from the load reductions presented in Table 4d-6 since loads are determined by both concentration and discharge volume. Solids separation basins combined with drained infiltration beds and vegetated filter strips (VFS) provide additional reductions in contaminant concentrations. The effectiveness of solids separation basins is highly dependent on site variables. Solids separation; basin sizing and management (clean-out); characteristics of VFS areas such as soil type, land slope, length, vegetation type, vegetation quality; and storm amounts and intensities all play important roles in the performance of the system.

**Table 4d-6. Relative gross effectiveness[a] (load reduction) of animal feeding operation control measures (Pennsylvania State University, 1992b).**

| Practice[b] Category | Runoff Volume | Total[d] Phosphorus (%) | Total[d] Nitrogen (%) | Sediment (%) | Fecal Coliform (%) |
|---|---|---|---|---|---|
| Animal Waste Systems[e] | reduced | 90 | 80 | 60 | 85 |
| Diversion Systems[f] | reduced | 70 | 45 | NA | NA |
| Filter Strips[g] | reduced | 85 | NA | 60 | 55 |
| Terrace System | reduced | 85 | 55 | 80 | NA |
| Containment Structures[h] | reduced | 60 | 65 | 70 | 90 |

NA = not available.
[a] Actual effectiveness depends on site-specific conditions. Values are not cumulative between practice categories.
[b] Each category includes several specific types of practices.
[d] Total phosphorus includes total and dissolved phosphorus; total nitrogen includes organic-N, ammonia-N, and nitrate-N.
[e] Includes methods for collecting, storing, and disposing of runoff and process-generated wastewater.
[f] Specific practices include diversion of uncontaminated water from confinement facilities.
[g] Includes all practices that reduce contaminant losses using vegetative control measures.
[h] Includes such practices as waste storage ponds, waste storage structures, waste treatment lagoons.

**Table 4d-7. Concentration reductions in barnyard and feedlot runoff treated with solids separation.**

| Site Location | Constituent Reduction (%) | | | |
|---|---|---|---|---|
| | TS | COD | Nitrogen | TP |
| Ohio - basin only[a,b] | 49-54 | 51-56 | 35 | 21-41 |
| Ohio - basin combined w/infiltration bed[a] | 82 | 85 | — | 80 |
| VFS[b] | 87 | 89 | 83 | 84 |
| Canada - basin only[c] | 56 | 38 | 14(TKN) | — |
| Canada - basin w/VFS[c] | (High 90's in fall and spring) | | | |
| Ilinois - basin w/VFS[d] | 73 | | 80(TKN) | 78 |

[a] Edwards et al., 1986.
[b] Edwards et al., 1983.
[c] Adam et al., 1986.
[d] Dickey, 1981.

Constructed wetlands have been developed and evaluated for animal waste treatment. These constructed wetlands use the same plants, soils and microorganisms as natural wetlands to remove contaminants, nutrients and solids from the wastewater. Constructed wetlands have been used for years to treat municipal wastewater, industrial wastewater, and stormwater. More recently, they have been used for animal wastewater treatment. A literature review cited in Constructed Wetlands and Wastewater Management for Confined Feeding Operations published by the Gulf of Mexico program (Alabama Soil and Water Conservation Committee et al., 1997) identified 68 different sites using constructed wetlands to treat wastewater from confined animal feeding operations.

Overall, the wetlands reduced the concentration of wastewater constituents such as 5-day biochemical oxygen demand, total suspended solids, ammonia nitrogen, total nitrogen, and total phosphorus. Table 4d-8 shows the average treatment performance.

Of the 68 sites identified, 46 were at dairy and cattle feeding operations. The herd sizes ranged from 25 to 330, with an average of 85 head. Dairy wastewater often included water from milking barns and from feeding/loafing yards with varying characteristics. Cattle feeding wastewater typically came from areas where animals were confined. Usually, dairy and cattle wastewaters were pretreated or diluted before being discharged to constructed wetlands.

Swine operations accounted for 19 of the wetland systems in the study. Swine wastes were collected using flush water from solid floor barns and paved lots, or they were collected directly from slatted floors in farrowing or nursery barns. In many cases, the wastewater was pretreated in lagoons and then discharged to a wetland system to further reduce concentrations to a level that could be applied to the land.

Constructed wetland systems which provided high levels of nitrogen removal for swine wastewater was recently reported by Rice et al. 1998. Three sets of two 3.6 x 33.5 m wetlands received lagoon liquid from a 2600-pig nursery operation. In these wetlands, mass reduction of total nitrogen was 94% when the low nitrogen loading rate of 3 kg/ha specified for advanced treatment for stream discharge was used. However, discharge requirements for nitrogen and phosphorus could not consistently be achieved at this low loading rate, so the goal was changed to determine the maximum loading and nitrogen removal that could be achieved. At the current loading rate of approximately 25 kg/ha/day, the mean nitrogen removal efficiency was 87%. The nitrogen loading rates and mass removal efficiencies for these investigated loading rates are shown in Table 4d-9.

It was determined that there was not enough nitrate in the wetlands for denitrification; hence, treatment experiments were also conducted with nitrified wastewater, for which the nitrogen removal rate was 4 to 5 times higher than when non-nitrified wastewater was added. Also, wetlands with plants were more effective than those with bare soil. These results suggest that vegetative wet-

**Table 4d-8. Summary of average performance of wetlands treating wastewater from confined animal feeding operations[a].**

| Wastewater Constituent | Average Concentration (mg/L)[b] Inflow | Outflow | Average Reduction (%) |
|---|---|---|---|
| 5-Day biochemical oxygen demand ($BOD_5$) | 263 | 93 | 65 |
| Total suspended solids (TSS) | 585 | 273 | 53 |
| Ammonium nitrogen ($NH_4$-N) | 122 | 64 | 48 |
| Total nitrogen (TN) | 254 | 148 | 42 |
| Total phosphorus (TP) | 24 | 14 | 42 |

[a] Data from the Livestock Wastewater Treatment Wetland Database (LWDB), which includes wetland systems at dairy, cattle, swine, poultry, and aquaculture sites (Knight et al., 1996).
[b] Average concentration is based on a hydraulic loading rate of 1.9 inches per day (50,000 gallons per day per acre [gpd/ac]). Averages were calculated from data for 30 to 86 systems.
mg/L = milligrams per liter

**Table 4d-9. Nitrogen loading rates and mass removal efficiencies for the constructed wetlands, Duplin Co., NC (June 1993–November 1997) (Rice et al., 199).**

| Nitrogen | System | % Mass Removal |
|---|---|---|
| 3 kg/ha/day | Rush/bulrush | 94 |
| | Cattails/bur-reed | 94 |
| 8 kg/ha/day | Rush/bulrush | 88 |
| | Cattails/bur-reed | 86 |
| 15 kg/ha/day | Rush/bulrush | 85 |
| | Cattail/bur-reed | 81 |
| 25 kg/ha/day | Rush/bulrush | 90 |
| | Cattail/bur-reed | 84 |

% Mass Removal = % mass reduction of N ($NH_3$-N + $NO_3$-N) in the effluent with respect to the nutrient mass inflow.

lands with nitrification pretreatment is a viable treatment alternative for the removal of large quantities of nitrogen from swine wastewater.

Major conclusions of these studies were that wetlands by themselves cannot remove sufficient amounts of nitrogen and phosphorus to meet stream discharge requirements but do show promise for high rates of nitrogen mass removal. Since wetlands are nitrate limited, the mass removal rate can be increased by nitrifying the wastewater prior to wetland application. With nitrification pretreatment, wetlands have the potential to annually remove more than 14,000 kg N/ha. By sequencing nitrification and denitrification unit processes, advanced wastewater treatment levels can be achieved. Such systems could provide a safer alternative to anaerobic lagoons, with reduced ammonia volatilization and odor.

## *Operation and Maintenance*

Appropriate operation and maintenance are critical to achieving the full environmental benefits of this management measure. Holding ponds and treatment lagoons should be operated such that the design storm volume is available for storage of runoff. Facilities filled to or near capacity should be pumped. Solid separation basins should be pumped or cleaned out according to design specifications. Pollutant loads can be reduced by managing manure to prevent or minimize accumulation on open lots.

It is appropriate to evaluate the waste management capabilities and interests of the grower, herdsman, or stock manager. Factor this information into the daily and periodic site operation requirements for facility design.

It is appropriate to evaluate the waste management capabilities and interests of the grower, herdsman, or stock manager. Factor this information into the daily and periodic site operation requirements for facility design.

Diversions will need periodic reshaping and should be free of trees and brush growth. Gutters and downspouts should be inspected annually and repaired when needed. Established grades for lot surfaces and conveyance channels should be maintained at all times.

Channels should be free of trees and brush growth. Periodic cleaning of debris basins, holding ponds, and lagoons will be needed to ensure that design volumes are maintained. Clean water should be excluded from the storage structure unless it is needed for further dilution in a liquid system.

Infiltration areas or vegetative filter areas need to be maintained in permanent vegetative cover, with vegetation harvested when conditions permit. Where possible, runoff should be alternated between two infiltration areas to provide alternating use and rest periods.

To protect ground water, it is important to avoid disturbing the manure-soil seal when cleaning or emptying a feedlot, barnyard, or waste storage structure.

## Factors in the Selection of Management Practices

The first priority in the selection of management practices should be clean water diversion. Diverting as much precipitation, snowmelt, and overland flow as possible away from the facility before the water can come into contact with wastes will greatly reduce the volumes of contaminated runoff and wastewater requiring later management. Once all clean water sources are diverted, facility runoff and wastewater should be collected and conveyed to the management systems. Simple facilities may have a single outlet that makes collection relatively easy; large facilities with complex topography and layout may require regrading, curbs, diversions, dikes, channels, or pipes to effectively collect and convey runoff and wastewater.

Proper design and construction are essential to the performance of settling basins, storage structures, and filter strips. Management practices and components must be physically compatible with the functional layout of the facility itself. Impoundments should always be located so that gravity flow can be employed; however, clean water or runoff should be diverted from the site as a precaution. It is also desirable to position buildings and waste treatment systems so that prevailing winds do not immediately transport dust and odors to sensitive areas. Distance and topography play a major role in determining what portions of the site will receive direct land application of waste or irrigation of lagoon liquid. State and local NRCS offices, Cooperative Extension Service offices, State agriculture departments, State Land Grant Universities, and the American Society of Agricultural Engineers are good sources of information for size and layout requirements for management practices.

Wastewater management systems must protect water, soil and air quality. Therefore, consideration also needs to be directed to storage, treatment and land application techniques that minimize odor and ammonia volatilization. Nitrogen loss during land application of manure by ammonia volatilization for various waste management techniques is shown in Table 4d-10. Concerns also exist regarding uncontrolled methane released from animal waste because it is considered to be an important factor in gases that cause global warming. Odor has become one of the major concerns of the general public and livestock producers. Therefore, techniques to reduce in-house odors, such as alternative manure collection and emptying techniques and dietary studies which reduce waste volume and odor have received increased attention. Major soil quality concerns include the buildup of phosphorus. Concern also exists about other constituents that accumulate in the soil, such as copper and zinc. Therefore, management practices should be selected that are both compatible with a given facility and protective of water, air and soil quality.

Soil and manure testing data must be considered along with fertilizer recommendations to be sure that the proper amount of manure is applied to land. Land

**Table 4d-10. Nitrogen volatilization losses during land application of manure (percent of nitrogen applied that is lost within 4 days of application).**

| Application method | Type of waste | Percent of nitrogen lost |
|---|---|---|
| Broadcast | Solid | 15 to 30 |
| | Liquid | 10 to 25 |
| Broadcast with immediate cultivation | Solid | 1 to 5 |
| | Liquid | 1 to 5 |
| Injection | Liquid | 0 to 2 |
| Drag-hose injection | Liquid | 0 to 2 |
| Sprinkler irrigation | Liquid | 15 to 35 |

This table shows typical nitrogen losses due to volatilization—evaporation into the air. Remember, practices that reduce volatilization losses will also reduce surface runoff losses.

Source: Hirschi et al., 1997, adapted from Livestock Waste Facilities handbook, MWPS-18, 3rd edition, 1993. ©MidWest Plan Service, Ames, IA 50011-3080.

application techniques which minimize ammonia volatilization and thus loss of fertilizer value need to be employed. These techniques will also protect air quality so that ammonia volatilization and odor are minimized. Calibration methods to assist in the proper land application of manure are given in Table 4d-11.

The management of stored runoff and accumulated solids through an appropriate waste utilization system can be achieved under a range of options, including land application, composting, biogas generation, recycling as feedstuffs, aquaculture, and biomass production (Hauck, 1995). Early efforts to conserve animal waste nutrients and other valuable components for fertilizer are directing renewed interest to conserve and process waste into value-added products. These strategies involve using manure and dead animals in conjunction with other materials such as sawdust, soybean and corn products, culled sweet potatoes, soybean hulls, and other organic waste products processed by rendering, extrusion, fluid bed cook-dehydration procedures and other techniques to produce value-added products. Crab bait is one successful value-added byproduct produced from animal waste at the North Carolina State University Animal and Poultry Waste Processing Center which has successfully utilized these waste nutrients and reduced the use of bait fish. Any stored water, accumulated solids, processed dead animals, or manure should be applied in accordance with the Nutrient Management Measure.

## Cost of Practices

Construction costs for control of runoff and manure from confined animal facilities are provided in Table 4d-12. The annual operation and maintenance costs average 4% of construction costs for diversions, 3% of construction costs for settlement basins, and 5% of construction costs for retention ponds (DPRA, 1992). Annual costs for repairs, maintenance, taxes, and insurance are estimated to be 5% of investment costs for irrigation systems (DPRA, 1992).

**Table 4d-11. Calibration methods (some common ways to calculate the application rate of manure spreaders) (Hirschi et al., 1997).**

| Manure source | What you need to know | Calculations |
|---|---|---|
| Liquid manure in a tank | 1. Tank load size (gallons of manure)<br>2. Acreage over which manure is spread at even rate | $\frac{\text{gallons}}{\text{acreage}}$ = application rate (gallons per acre) |
| Liquid manure in spreader: volume method | 1. Spreader load size (gallons of manure)<br>2. Distance driven and width spread (feet) | $\frac{\text{gallons x 43,560}}{\text{distance x width}}$ = application rate (gallons per acre) |
| Liquid manure in spreader: weight method* | 1. Spreader load size (pounds of manure)<br>2. Distance driven and width spread (feet) | $\frac{\text{pounds x 5,248}}{\text{distance x width}}$ = application rate (gallons per acre) |
| Solid manure in spreader: spreader volume method** | 1. Spreader struck-level load size (bushels of manure)<br>2. Distance driven and width spread (feet) | $\frac{\text{bushels x 1,688}}{\text{distance x width}}$ = application rate (tons per acre) |
| Solid manure in spreader: plastic sheet weight method | 1. Pounds of manure on the sheet after drive-over<br>2. Square footage of plastic sheet | $\frac{\text{pounds x 21.78}}{\text{square footage of plastic sheet}}$ = application rate (tons per acre) |
| Shortcut method #1 with plastic sheet: for lighter application rates (use a 9' x 12' sheet) | 1. Pounds of manure on the sheet after drive-over | pounds ÷ 5 = application rate (tons per acre) |
| Shortcut method #2 with plastic sheet: for heavier application rates (use a 4'8" x 4'8" sheet or 87" x 3' sheet) | 1. Pounds of manure on the sheet after drive-over | pounds of manure collected on the sheet = application rate (tons per acre) |

*The calculation for this method assumes that a gallon of manure will weigh a certain number of pounds. An average figure is used.

**The calculation for this method assumes that a bushel of manure will weigh a certain number of pounds. An average figure is used.

**Table 4d-12. Costs for runoff control systems (DPRA, 1992; USDA, 1998).**

| Practice [a] | Unit | Cost/Unit Construction in 1997 Dollars[b, c, d] |
|---|---|---|
| Diversion | foot | 2.38 |
| Irrigation | | |
| - Piping (4-inch) | foot | 2.35 |
| - Piping (6-inch) | foot | 3.02 |
| - Pumps (10 hp) | unit | 2,350 |
| - Pumps (15 hp) | unit | 2,690 |
| - Pumps (30 hp) | unit | 4,030 |
| - Pumps (45 hp) | unit | 4,700 |
| - Sprinkler/gun (150 gpm) | unit | 1,180 |
| - Sprinkler/gun (250 gpm) | unit | 2,350 |
| - Sprinkler/gun (400 gpm) | unit | 4,300 |
| - Contracted service to empty retention pond | 1,000 gallon | 3.68 |
| Infiltration[e] | acre | 2980 |
| Manure Hauling | mile per 4.5-ton load | 2.64 |
| Dead Animal Composting Facility | cubic foot | 5.96 |
| Retention Pond | | |
| - 241 cubic feet in size | cubic foot | 3.08 |
| - 2,678 cubic feet in size | cubic foot | 1.48 |
| - 28,638 cubic feet in size | cubic foot | 0.72 |
| - 267,123 cubic feet in size | cubic foot | 0.37 |
| Settling Basin | | |
| - 53 cubic feet in size | cubic foot | 5.08 |
| - 488 cubic feet in size | cubic foot | 3.27 |
| - 5,088 cubic feet in size | cubic foot | 2.04 |
| - 49,950 cubic feet in size | cubic foot | 1.29 |

a Expected lifetimes of practices are 20 years for diversions, settling basins, retention ponds, and filtration areas and 15 years for irrigation equipment.
b Table is derived from DPRA estimates presented in an earlier edition adjusted by USDA price indices.
c Table does not present annualized costs.
d Costs for pumps, sprinklers, and infiltration are rounded to the nearest 10 dollars.
e Does not include land costs.

Sources:
* DPRA. Draft Economic Impact Analysis of Coastal Zone Management Measures Affecting Confined Animal Facilities, DPRA, Inc., Manhattan, KS, 1992.
* United States Department of Agriculture (USDA), Agricultural Prices - 1997 Summary, National Agricultural Statistics Service, July 1998.