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Closure of Earthen Manure Structures (Including Basins, Holding Ponds and Lagoons)

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ABSTRACT

This paper is a summary of what is known scientifically about the closure of earthen manure structures without artificial liners, including lagoons, storage basins, and runoff holding ponds, and what needs to be examined further to increase our understanding of the dynamics of closing them in an environmentally safe manner. This information should be useful as a guide for state regulatory agencies considering rules for closure and for academicians and consultants who work with livestock production facilities.

Keywords: *Lagoons, Manure storage, Earthen storages, Seepage, Closure, Groundwater contamination.*

INTRODUCTION

When a livestock production unit ceases operation, proper procedures need to be undertaken to properly close earthen manure structures without artificial liners (including lagoons, storage basins, and runoff holding ponds), in order to assure protection of surface and ground water. There are three primary environmental risks associated with such earthen structures: nutrients and pathogens, which can be a concern for both surface and ground water quality, and degradable organic matter, which is a concern for surface water due to runoff from structure overflow during the closure process or from land application of the contents.

Earthen manure structures, properly designed, installed and operated according to accepted engineering standards (such as those defined by USDA-NRCS *Agricultural Waste Management Field Handbook* and ASAE Standard EP393.2, "Manure Storage," and ANSI/ASAE EP403.2, "Design of Anaerobic Lagoons for Animal Waste Management"), should pose little risk to water quality. A well maintained earthen structure should show:

- Limited erosion of sidewalls due to wave action,
- Lack of erosion in the vicinity of a manure inlet pipe,
- Lack of erosion near areas used for contents agitation and removal,
- Well maintained sod on berms and exterior sidewalls (weed and tree growth controlled),
- No signs of burrowing animals in or around the berms or sidewalls, and
- Lack of seepage around pipes through the sidewall and along the toe of the berm.

The addition of manure to an earthen structure further reduces seepage rates due to physical, chemical, and biological processes that contribute to the clogging of soil pores. The NRCS *Animal Waste Management Field Handbook (1992)* acknowledges a reduction in the coefficient of permeability by a factor of at least 10. This suggests that, for a properly designed and constructed facility, maintaining an intact structure and liner after abandonment should be an environmentally sound practice to protect against seepage. However, this may or may not be considered environmentally sound for other reasons, e.g., if the structure is allowed to overflow.

Poorly designed or poorly constructed earthen liners, as well as badly eroded ones, can allow significant movement of contaminants into the soil adjacent to or below the structure before the time

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time of closure. Soil borings may be necessary to accurately assess the movement of nutrients below inadequate earthen structures at the time of closure and to determine the proper procedures necessary for closure.

This White Paper will examine what is known about closing earthen manure structures without artificial liners (such as lagoons, storage basins, and runoff holding ponds) and what needs to be examined further to increase our understanding of the dynamics of closing them in an environmentally safe manner. It will first provide the authors' general recommendations for closure, and then review the methods available for removing the contents of the structure and discuss in more detail the options for closure or alternative uses of the site. It also includes a literature review of water quality risks and identifies areas where further research is needed.

GENERAL CLOSURE RECOMMENDATIONS

Based on a review of available literature and the professional judgment of the authors, several fundamental principles should be applied to the abandonment of earthen manure structures, without artificial liners, that were reasonably well designed and constructed, and properly maintained during their useful life.

The preparation of an earthen manure structure for closure involves three critical principles:

1. Protection during the closure process of the soil/organic matter interface layer that forms a relatively impermeable natural liner around the structure contents.
2. Removal of all liquids and pumpable slurry.
3. Land application of removed liquids and sludge at agronomic rates.

After liquids and sludge are removed and utilized in an environmentally sound manner, there are four generally acceptable options for completing the closure process. Check with local and state regulatory agencies since the closure of earthen manure structures is sometimes governed by specific state or local regulations. In some states, the producer is required to complete a closure report. Generally acceptable options for closure of an earthen manure storage include:

Option A: Permanent elimination of an earthen manure structure.

- Diversion of all surface water away from storage site;
- Filling of the storage structure with soil to a mounded surface that sheds rainwater;
- Establishment of a growing crop or sod.

Option B: Permanent conversion to a fresh water pond.

- Establishment of a maximum water level;
- Rinsing of the storage structure several times, with irrigation of the contents onto cropland;
- Refilling storage with fresh water.

Option C: Breaching of the berm.

- Diversion of all surface water away from the storage site;
- Breaching of the berm;
- Establishment of a growing crop or sod on the bottom and sides of the structure.

Option D: Managing earthen manure structures at temporarily depopulated operations.

- Preventing overflow from the structure;
- Minimizing runoff of contaminated material into the structure.

The procedures outlined here assume that the liner has been adequately protected from erosion and other threats to liner integrity. If these assumptions are not correct, soil borings are needed to determine if a more extensive cleanup is required. Regardless of the intended end use, all conveyances (pipes and ditches) used to convey manure to the basin should be removed and replaced with compacted soil. A more complete explanation of each of these principles is given later in this paper.

PRINCIPLES OF PREPARING EARTHEN MANURE STRUCTURES FOR CLOSURE

Protecting the Integrity of the Existing Earthen Liner During Closure

No matter which closure method is chosen, maintaining an intact liner is likely less of a danger to the environment than attempting its removal. As much sludge and solids should be removed from the basin as can be accomplished without endangering the integrity of the liner. In the event of poor liner design, construction, or management, or where the liner has been damaged, nitrogen movement may be found in soil borings beneath the storage. In these cases, removal of several inches of the soil liner may be necessary. However, this should be the exception rather than the rule, and a knowledgeable consultant should determine the need for such measures after soil borings and inspection.

Sludge Sampling

Sheffield et al. (2000) states that measuring and sampling sludge should be done from a boat. For safety reasons, at least three people should be present: two in the boat and one on the lagoon bank. The extra person on the boat assists with entering and exiting the boat, and the extra person(s) on shore may be needed as a rescuer(s), should anything go awry. Flat-bottom boats are recommended over canoes or V-bottom boats. Everyone in the boat should wear appropriate flotation devices.

Sheffield et al. (2000) recommends measuring the amount of sludge and solids in a lagoon by lowering a lightweight, rigid, 1.27 to 2.54 cm diameter (0.5 to 1 inch) wooden or capped aluminum pole slowly into the lagoon until the liquid seems to become denser and thicker. Record the water level on the pole and continue to push the pole down until you feel you have reached the bottom of the lagoon. Again, record the water level on the rod, and remove it from the lagoon. The difference between the readings is the depth of the sludge and solids. Commercially available sludge samplers are useful for collecting samples, but do not work well for estimating sludge volume because of the density of anaerobic lagoon sludge. The sludge layer in a lagoon is a "mobile" fluid that forms peaks and valleys within the lagoon. Sheffield et al. (2000) recommends that at least 10 depth measurements be taken randomly. For a more detailed assessment of sludge volume, a formal grid should be established over the surface of the structure. US EPA recommends at least 4 grids per cell with no grids larger than 930 cu m (10,000 sq ft). Plot depth measurements at grid points to develop a contour map of sludge deposits on the bottom of the storage to estimate the amount of sludge and solids beneath the liquid.

Sheffield et al. (2000) also states that the best time to take a sludge sample is while measuring for volume of sludge in a lagoon. This allows samples to be collected from several points around the interior of the lagoon. Depending on density and nutrient concentration, the samples may differ by as much as 100% from point to point. To draw a sample, insert a 1.3 to 1.9 cm diameter (0.5 to 0.75 inch) PVC pipe into the lagoon sludge until the pipe reaches the bottom. Wearing plastic or latex gloves, cap the end of the pipe to create a vacuum and slowly withdraw it from the lagoon. This will capture a core or profile of lagoon effluent and sludge. Once the pipe outlet is over a clean container, slowly break the vacuum and allow it to drain. Place several samples in the container and mix thoroughly. Use a plastic, wide-mouth bottle and follow laboratory instructions when shipping samples for analysis.

Removal of Liquids, Pumpable Sludge and Solids

Removing sludge and solids from earthen manure structures can be accomplished by several methods:

- Agitate and remove the combined contents of the structure and land-apply.
- Remove and land-apply liquids; agitate, remove and land-apply sludge.
- Remove and land-apply liquids; dredge and land-apply sludge.
- Agitate and remove the structure contents, concentrate and remove solids, and land-apply.
- Use a sludge dredge and land-apply without dewatering.

Agitate the Combined Contents of the Structure and Land-Apply

In this method, liquid and sludge are mixed with an agitator or a chopper-agitator impeller pump. High-volume pumps (11,500 to 19,000 liters per minute; 3,000 to 5,000 gallons per minute) specifically designed for agitation and loading provide for suspension of solids. However, agitation equipment is generally only effective in suspending solids within about 15 m (50 feet) of the agitator. Because agitation equipment can erode earthen liners near the agitator, it should be used cautiously. Direct the agitation flow away from the liner and keep the agitation unit at least three feet away from the soil surface. The mixed contents can be pumped through a large-bore sprinkler irrigation system onto nearby cropland. At many sites, the removed material should be soil-incorporated to minimize odor, nitrogen volatilization, and runoff potential.

Remove and Land-Apply Liquids; Agitate, Remove and Land-Apply Sludge

The liquid portion of the earthen structure is dewatered by irrigation onto nearby cropland or forage-land. The remaining sludge is then agitated and pumped into a sludge applicator. The sludge can be spread onto cropland or forage land or soil-incorporated. This method may not work as well with dairy manure due to its fibrous nature, larger particle sizes and higher solids contents, compared to swine and poultry manure structures. After the liquid and most of the sludge is removed, depending on the condition of the liner, it may be necessary to remove any remaining solids with a small track-type dozer or farm tractor with a bucket.

Remove and Land-Apply Liquids, Dredge and Land-Apply Sludge

The earthen structure is dewatered by irrigation onto nearby cropland or forage land. Sludge is then removed with a dragline or sludge dredge (Figure 1). Note that the dragline must be used very cautiously to avoid damage to the organic liner. With more fibrous manure, it may be practical to establish a gently sloping bermed area beside the structure to receive the dredged sludge and allow liquids to drain back into the earthen structure to provide additional dewatering. This may not be feasible with swine or other non-fibrous sludge that does not stack well. After air-drying to produce a semisolid or solid material, the sludge is hauled and spread with a solid manure equipment onto cropland or forage-land at agronomic rates. Soil-incorporation should be used where feasible to better retain and utilize the nutrients in the sludge.

When removing sludge, the pumper or dragline operator must pay close attention to protect the organic liner. Any damage may not be noticeable until the liquid level drops. If the soil liner is disturbed, stop the activity immediately and do not continue until operations are modified to prevent further damage. A damaged liner should be repaired with suitable soil material as soon as possible.

Agitate and Remove the Structure Contents, Concentrate and Remove Solids, and Land-apply

The entire contents of the manure structure is thoroughly agitated and removed. Solids are separated from the mixture of sludge and liquid and the liquid is land-applied. The solids are land-applied, composed or otherwise utilized. (See later section on Sludge Reduction Alternatives.)

Use of Sludge Dredge and Land-Apply without Dewatering

Pumping dredges are commonly used to remove solids from municipal and industrial wastewater lagoons and holding ponds. A pumping dredges is typically a floating barge with a variable-depth-pumping head to remove sludge from the bottom of the structure (Figure 1). Power units can either be located on the barge or may be hydraulically operated pumping heads with power units located on the berm.

Figure 1. Pumping dredge operating in a lagoon in North Carolina.

A higher concentration of solids can be removed from a lagoon with the sludge dredge because sludge is removed without agitation or dilution, thus reducing transportation cost. With the assistance of guide cables, dredges work back and forth across a lagoon, working their way down the earthen structure, until the solids are removed. Since the dredges do not use aggressive agitation or cleaning nozzles, equipment manufacturers and operators claim that pumping dredges do not negatively impact the condition of earthen liners.

Pumping dredges are best suited for large structures or where large amounts of solids must be removed. Because of their size and weight, dredges may be placed into and removed from an earthen structure with a crane.

Sludge Reduction Alternatives

Chastain and Darby (2000) studied a thickening process for lowering the cost of removing sludge from a dairy lagoon. By settling sludge from mixtures of sludge and water (1.93 and 3.99% total solids) for 7 hours and draining the supernatant back to the lagoon, the volume of sludge was reduced by an average of 60%.

Several companies offer various lagoon additives intended to reduce the volume of sludge in anaerobic lagoons. These products provide a mix of various microorganisms, enzymes, proteins, or catalysts to stimulate the microbial degradation of accumulated sludge. The Animal and Poultry Waste Management Center at North Carolina State University has evaluated several of these products since 1997. To date, these studies have been unable to verify significant reductions in sludge volume. This may be due to differences in dosage of product, method of application, or type of operation where the products were tested.

Anecdotal information from producers in the Midwest, however, continues to indicate that some of these products may be effective. Some producers have used baker's yeast effectively to suspend solids by spreading 120 gm/L of fresh baker's yeast mixed (1 lb/gal) of lukewarm water (32-38 C° [90-100°F]) at a rate of one L per 1.84 sq m (1 gal/75 sq ft) of liquid surface with the storage agitated and pumped after two weeks later (Sheffield et al, 2000).

Estimated Cost of Liquid and Sludge Removal

The cost of closing an earthen manure structure is often a concern. In many cases, the operation is closing because of financial difficulties and there are simply no funds remaining to properly close the manure structures. Some states have handled this issue at the time the storage is initially approved by requiring a bond to be posted to cover all or part of closure costs. According to the Environmental Review Commission of the North Carolina General Assembly (2000), Oklahoma, Iowa and Missouri already have legal mechanisms in place to ensure that owners have the funding available for lagoon closure and have legislation that holds producers responsible for closing facilities through one-time fees, annual fees and financial sureties (statement of assets, irrevocable letter of credit, cash or cashier's check).

In 2000, the North Carolina Department of Environmental and Natural Resources (DENR) reported there were 1142 inactive lagoons on 745 farms and that 39 were considered high risk. They assigned 93% of the inactive lagoons a medium risk (requiring further study) because of the uncertainty over the behavior of nutrients contained in inactive lagoons and limited data regarding groundwater levels and surface water contamination. The primary source of pollutants in inactive lagoons was assumed to be the sludge because of high N and P levels. Using NRCS standards for lagoon closure, DENR estimated the cost of closure at $105,000/hectare ($42,000/acre), or $30,000,000 to close all inactive lagoons in the state. Actual closure costs in North Carolina were between $1.32 and $8.47 per cu m ($5 and $32/1000 gal) of waste removed, according to the Environmental Review Commission of the North Carolina General Assembly (2000). The estimated closure costs for a 3,785 cu m (1,000,000 cu ft) lagoon would thus range from $5000 to $32,000. This is high enough that producers cannot be expected to voluntarily close their inactive lagoons.

Lindemann et al. (1985) studied sludge removal from three dairy lagoons. A tractor-PTO propeller agitator, a two-stage portable solids handling and irrigation pump worked well to remove high-solids sludge from both dairy and poultry lagoons. The nutrient value of the sludge was sufficient to offset 30 to 50% of the cost of pumping.

Hiring a custom applicator is often a feasible method of managing sludge. The high cost of sludge removal equipment is prohibitive for most producers, especially due to the infrequency of sludge removal. Also, many lagoons can accumulate sludge for up to 10 years or more before their treatment ability declines. The cost of hiring a contractor is largely based on the amount of sludge to be removed. A 1999 survey of custom applicators in eastern North Carolina (Sheffield et al, 2000) showed that prices ranged from 0.4 to 1.3 cents per liter of sludge (1.5 - 5.0 cents/gal) of sludge. The difference in cost depended on the size of lagoon to be pumped, lagoon accessibility, distance to available application sites, and whether the sludge was to be irrigated, broadcast, or injected.

Land Application of Liquid and Sludge at Agronomic Rates

Material removed from the bottom of the storage will have significant quantities of nutrients. Producers should obtain a nutrient analysis, estimate the proper application rate based on soil tests and crops to be grown on the application site, and monitor the actual application rate. The accumulation of phosphorus in the sludge commonly determines the minimum land requirement, based on agronomic needs of crops. For this reason, nutrient management plans should consider that all P added to the structure is available for land application eventually, and not underestimate life cycle land area requirements.

Factors influencing land area required to apply sludge during closure:

- Nutrient analysis of sludge,
- Nutrient analysis of supernatant,
- Crop to be grown,
- Soil type,
- Soil fertility level (Phosphorus),
- Local/State regulations, and
- Application method.

The application rate should not exceed the annual crop nitrogen requirements (consult your local NRCS or your local land grant university Extension Service for assistance in determining recommended land application rates in your location). Tables 1 and 2 can be used to determine land

Table 1. Estimate of phosphorus removal by various crops.

Crop	P_2O_5 Removal per Unit of Crop Yield*		Estimated Crop Yield Kg/ hectare (bu or tons per acre)		P to be Supplied for ? Years (3 to 5 years suggested)	P_2O_5 Application Rate Kg/Hectare** (lb/acre)
Example: Grain corn	*6.25 g/Kg (0.35 lb/bu)*	× ×	*9,535 (150)*	× ×	*3 =*	*179 Kg/hectare (160 lb/acre)*
Corn (grain)	*6.25 g/Kg (0.35 lb/bu)*	× ×		× ×	=	
Corn silage	*6.25 g/Kg (3.5 lb/ton)*	× ×		× ×	=	
Sorghum (grain)	*6.25 g/Kg (0.35 lb/bu.)*	× ×		× ×	=	
Wheat	*22.5 g/Kg (1.35 lb/bu)*	× ×		× ×	=	
Alfalfa	*5 to 12.5 g/Kg (10 to 25.0 lb/ton)*	× ×		× ×	=	
Most grasses	*12.5 to 15 g/Kg (25 to 30 lb/ton)*	× ×		× ×	=	
Bermuda hay	*57.5 g/Kg (115 lb/ton)*	× ×		× ×	=	
Soybeans	*13.3 g/Kg (0.8 lb/bu)*	× ×		× ×	=	

* Phosphorous removal rates may vary by climate and region in U.S. Consult your local CES, NRCS or crop consultant for accepted local values.
** Grams converted to kilograms.

Table 2. Estimate of land requirements for sludge or slurry application at phosphorus removal rate.*

Source of Nutrients	Total P_2O_5 in Sludge & Solids (from Table 6)		Portion Removed from Storage (between 0 and 1)		Desired P_2O_5 Application Rate (from Table 1)		Application Area Needed hectares (acres)
Example: Swine lagoon sludge from 10 yr. accumulation	*61,200 Kg (135,000 lb)*	×	*0.5*	÷	*179 Kg/hectare (160 lb/acre)*	=	*172 hectares (422 acres)*
		×		÷		=	
		×		÷			

* The application rate should not exceed the annual crop nitrogen requirements. Note that the portion removed would approach 1.0 if the storage is being emptied for closure, assuming that no sludge had been removed during the 10 years of accumulation.

requirements, assuming that sludge is applied to meet crop phosphorus needs. These tables are based on phosphorous removal rates from the soil—not crop growth recommendations. Producers should check soil phosphorus levels at the application site for the next several years to determine when commercial phosphorus application is needed.

Application sites should be evaluated for their current soil phosphorous level and risk of runoff or erosion contaminating surface water. State regulations and best management practices should be followed in selecting suitable land application sites.

Specific Earthen Manure Storage Closure Procedures

Option A. Permanent Elimination of Earthen Storage Structure

1. Divert all surface water runoff away from the storage. This includes runoff from building roofs, abandoned feedlots, and cropland.
2. Remove any pipes and structures adding runoff or manure to the storage.
3. Remove all liquid, pumpable sludge and solids. Refer to dewatering procedures discussed earlier for details.
4. Fill the structure with soil. Fill with soil by pushing in existing dams or berms and bringing in additional fill as needed. The backfill height should exceed the design finished grade by five percent to allow for settlement. The degree of compaction required for backfill material will depend on the anticipated future use of the site. For example, a higher compaction would be needed for building construction than for animal pasture or cropland. The degree of compaction must be sufficient that settlement does not create a depression that collects rainwater (NRCS, 2000).
5. Establish a crop cover or sod. The final surface should be tilled and a vegetation cover established to minimize soil erosion. A crop with a deep root zone such as alfalfa is preferred because of its ability to harvest remaining nutrients.

Option B. Permanent Conversion to a Fresh Water Pond

1. Set maximum water level. An overflow spillway (if one does not currently exist) or a standpipe should be added to set a maximum water level at least 0.3 m (12 in) below the lowest point in the berm or dam. A Professional Engineer should be consulted to design an adequate overflow.
2. Remove any pipes and structures adding runoff or manure to the storage.
3. Remove all liquid, pumpable sludge and solids. Refer to dewatering procedures discussed earlier for details.
4. Rinse the structure with water. The lagoon should be refilled with water after pumping all sludge and liquid, and allowed to sit for several months. During the next growing season the lagoon should be agitated and completely emptied and its contents applied based upon crop water needs. Nutrient concentration should be very low by this time and should be a factor in determining application rate.
5. Refill structure with water. The dissolved oxygen (DO) concentration should be checked after the second refill. If levels are less than 3 mg/liter, continue the rinsing (fill and dewater) cy-

cles. If DO levels are 3 mg/liter or higher, the earthen structure can be managed as a farm pond. Alternatively, available nitrogen levels can be checked and rinsing continued until available nitrogen levels as measured by a laboratory or a nitrogen meter are less than 10 mg nitrate-N/liter. Clean runoff or other fresh water should be added to the lagoon to maintain the pond near capacity. A high water level is helpful to minimize liner degradation due to desiccation, burrowing animals and vegetation growth. Water from the unit should not be used for livestock consumption without first testing for pathogens and nitrate levels, and consultation with your veterinarian.

Option C. Breaching the Berm

1. Divert all surface water runoff away from the structure. This includes runoff from building roofs, abandoned feedlots, and cropland.
2. Remove any pipes and structures adding runoff or wastewater to the structure.
3. Remove all liquid, pumpable sludge and solids. Refer to dewatering procedures discussed earlier for details.
4. Breach the berm. After removing as much liquid and sludge as possible, allow the remaining solids to dry. If more than about 12 inches of solids remain after pumping, remove them while making every effort to maintain liner integrity. Ideally, paved pads should have been installed at the agitation points at the time of construction. If this was not done, make sure the agitator directs its flow away from the liner and keep the agitator at least three feet away from the liner. The remaining solids can be removed by agitating and removing contents at a time when climatic conditions are favorable for drying the remaining solids sufficiently for removal with earth-moving equipment. Alternatively, settled material can often be removed by refilling with water, agitating, and emptying again and again, until most solids are removed. A section of the existing lagoon berm or dam should then be removed. The breach should be low enough on the slope of the dam to allow any water that enters the structure to quickly drain away.
5. Establish a growing crop or sod. The final surface should be tilled and planted with vegetation to minimize soil erosion and extract nutrients.

Option D. Managing Manure Storages at Temporarily Depopulated Operations

Livestock facilities are sometimes depopulated temporarily for a variety of reasons, with the intention of restarting production at a later time. The length of inactivity may be defined by state regulations, before they are declared "abandoned" and closure required.

1. Divert all surface water runoff away from the earthen structure. This includes runoff from building roofs, abandoned feedlots, and cropland.
2. Remove all liquid, pumpable sludge and solids. Refer to dewatering procedures discussed earlier for details.
3. Refill the storage with water. Keep liquid levels at least 24 inches below the top of the storage, or at the maximum level allowed by state regulations. The added water will help to limit damage to the sidewalls from weed growth, erosion, and burrowing animals.
4. Manage the structure to prevent liquid overflow. Land-apply excess liquid from the structure in a manner that protects water quality. It must not be discharged into surface waters.

Incremental Closure Procedures

Incremental closure is a modification of Option A listed above. It has been used to close abandoned lagoons in the Southeastern US. Incremental closure is well suited for the permanent elimination of lagoons in the following situations:

- Large surface areas (greater than 2 acres) where agitation is difficult,
- Earthen manure structures with narrow embankments that are unable to support tractors and agitators to suspend settled solids and sludge,
- Earthen manure structures with degraded embankments or slopes,
- Earthen manure structures with bottoms below groundwater table,
- Large length to width ratios that are difficult to properly mix or access with agitator,
- Soil or fill material unavailable locally to completely fill existing structure, and
- Earthen manure structures that will ultimately have their sidewalls removed and the facility filled in with soil or reshaped to match the existing contour.

An earthen manure structure that is incrementally closed would generally undergo the following steps (Figure 2):

1. Agitation equipment is located at one end or corner of the structure. Sludge is agitated, removed from the structure and land applied.
2. Once the depth of settled/accumulated material is reduced to less than about 0.3 m (1 ft) by agitation and pumping or with a sludge dredge, bulldozers or other earth moving equipment slowly move the sidewalls by adding fill at a rate of approximately 3 to 4.5 m (10-15 ft) at a time toward the center of the structure.
3. As the embankment is pushed inward, the agitated sludge will be displaced by the fill and pushed toward the center of the structure, rather than being covered with soil.
4. Soil cores should be taken to monitor the process and ensure that the fill encloses a minimal amount of sludge. Borings, with a soil auger, should be made and the depth of sludge remaining in the structure after the previous movement of the lagoon embankment estimated. No chemical analysis is required. Rather, the soil cores serve as a quality control practice to ensure that the sludge is being moved toward the "open" portion of the lagoon, rather than being buried. Cores should be taken along the "filled-in area" to depths corresponding to the previous bottom elevation of the structure. Each core should represent approximately 70 sq m (750 sq. ft.) of area. A record should be kept of where the cores were taken as well as a measure of amount of sludge remaining.
5. Agitation equipment is moved across fill surface as the earthen structure is filled in. Agitation, solids removal, embankment movement and soil core samples continue until the structure is reduced to a size manageable by agitation equipment alone or until all contents are removed.

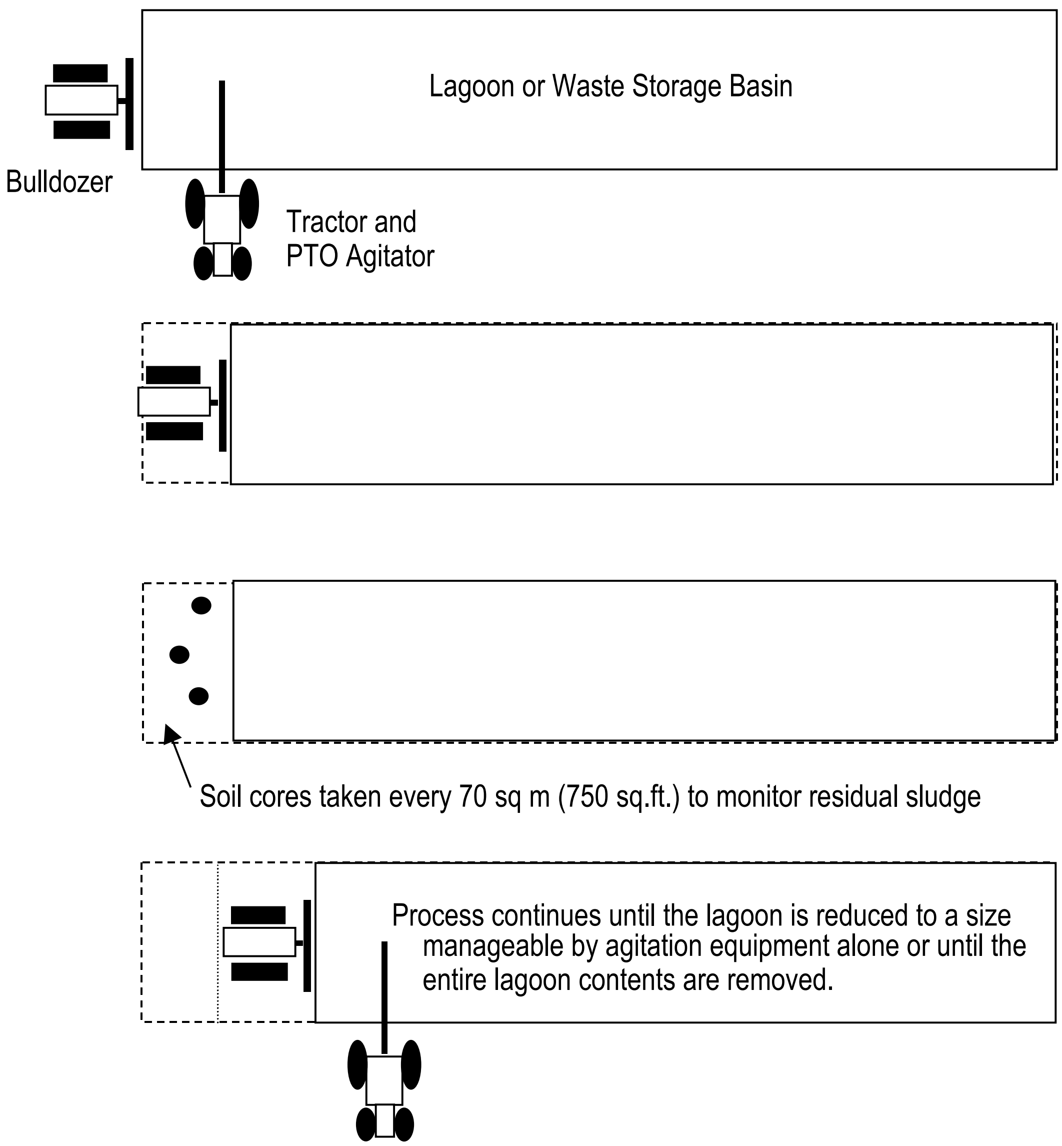

Figure 2. Incremental closure procedures for closing lagoons and storage basins.

The goal of incremental closure is to remove the vast majority of sludge material while avoiding handling thick layers of sludge greater than 0.13 m (>5 inches) and potentially damaging the liner. To minimize the sludge layer thickness while closing the unit:

- Agitate sludge and solid material periodically, as the structure is closed,
- Move embankment a shorter distance, or
- Place the bulldozer blade lower in the existing soil to push sludge material over from beneath.

Timing of Closure

The proper timing of earthen lagoon or manure storage structure closure continues to be debated. Should it be closed immediately upon cessation of operation or would it be better to wait 3 to 5 years? While environmental concerns remain after operation ceases, the level of risk tends to decrease over time if the structure is properly maintained. A number of advantages and disadvantages, both economically and environmentally, exist for either scenario. Allowing more time for closure gives more flexibility in applying the sludge. Applying at agronomic rates may be very difficult given the high concentration of nutrients in the sludge layer, and applying the sludge over a period of years instead of all at once may be more environmentally friendly. The structure must be maintained during this time of disuse just as it was during operation, including regular inspections, controlling burrowing animals, maintaining proper vegetation on berms, and pumping when necessary to maintain safe water levels. Continued maintenance, along with the potential increased cost for setting up equipment to pump sludge multiple times rather than all at once, may represent a significant cost to the operation.

Advantages of immediate closure include:

- Expense of maintaining berms and pumping lagoon ends quickly.
- Possibility of overtopping or leakage ends quickly.
- Closing it in one operation should minimize expense of pumping and hauling sludge.

Advantages of slower closure include:

- Pathogens existing in sludge are more likely to die or be reduced to insignificant levels.
- Nutrients in sludge can more easily be applied at agronomic rates over a longer period of time.

BACKGROUND AND LITERATURE REVIEW

Solids Profile in Typical Earthen Lagoon

In a manure storage or basin, the contents are likely to be relatively uniform throughout, with solids content ranging from 2 to 10%. In an anaerobic lagoon, however, three different zones are likely to be found (Figure 3). These zones seldom have distinct boundaries and are difficult to determine.

1. Relatively inert solids accumulate near the manure inflow points (Figure 3). This material may be high in phosphorus, with a discernible interface between the solids and the sludge. Complete removal of these solids is difficult without damaging the liner. Therefore, maintaining liner integrity should be of even greater concern than removal of all solids. There is typically more solids buildup in lagoons receiving manure from poultry and dairy operations than from swine.

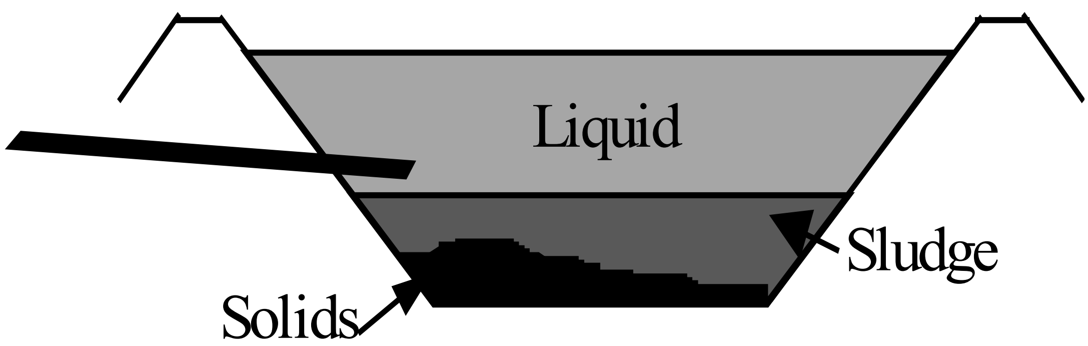

Figure 3. Cross-section of an anaerobic lagoon.

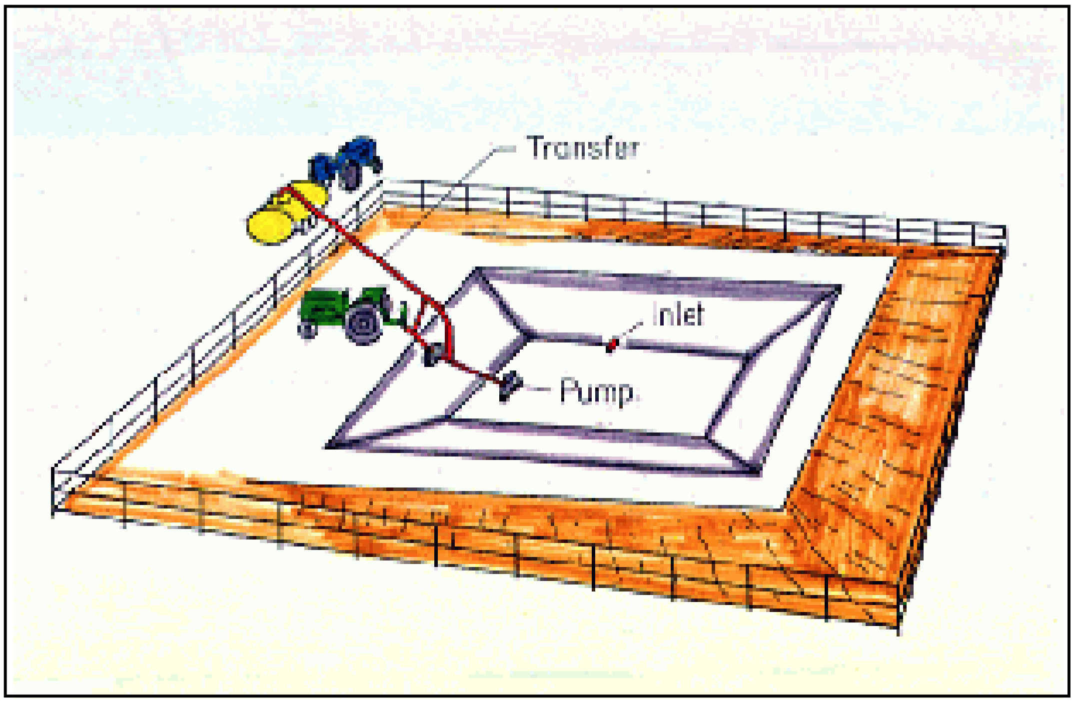

Figure 4. Removal of sludge from an earthen storage of lagoon for application to cropland.

2. A thick sludge, high in nutrients, bacteria, and organic matter, is normally located just above the solids zone. Pumps designed to handle high solids content can remove this material (Figure 4). While much of the readily degradable organic matter in the sludge should be broken down, it is still biologically very active and a likely source of much of the anaerobic degradation of incoming manure occurring in a lagoon.
3. Above the sludge is a liquid layer that is low in solids and moderately rich in nutrients. It is easily pumpable with conventional chopper-agitators or irrigation pumps. The liquid and most of the sludge can be removed by pumping while maintaining the integrity of the liner. The liquid can be irrigated onto cropland, but it may be necessary in some cases to move sludge using tanker wagons (Figure 4).

The settled solids and sludge layers of an anaerobic lagoon can contain a significant amount of phosphorus that has settled out over the years (Table 3). According to Barker (1996), organic nitrogen compounds tend to accumulate in the sludge at levels that are up to 13 times higher than in the liquid while phosphorus accumulate at rates that are up to 55 times higher. In addition, the sludge may also contain significant concentrations of heavy metals, salts and other trace elements. These factors dictate the need for laboratory analysis and for expert agronomic advice prior to land application. Sheffield (2000) found sludge volumes and total nutrients to be highly variable in a study of thirty single-cell swine lagoons in North Carolina. He concluded that volume and concentration could not be estimated accurately based on values from other lagoons. Likewise, the land area needed to apply the sludge at agronomic rates was highly variable. Mukhtar (2000) found relatively high levels of all nutrients in a mixture of sludge and supernatant for dairy manure lagoons in Texas (Table 4).

Published sludge accumulation rates are highly variable, but estimates can be made using Table 5 if field measurements are not available. Periodic sludge removal over the life of the anaerobic lagoon enables the phosphorus accumulation (Table 6) to be managed more easily at the time of closure. Purdue Extension recommendations (ID-120, “Design and Operation of Livestock Waste Lagoons”) call for sludge agitation and removal from first-stage or single-stage lagoons every three to five years.

Table 3. Livestock anaerobic lagoon sludge characteristics (units g/L (lbs/1,000 gal).

Species	Units	Total Nitrogen		Total Phosphorus (P_2O_5)		Potassium (K_2O)		Copper		Zinc	
		Total Nitrogen	Std. Dev.	Aver-age	Std. Dev.	Aver-age	Std. Dev.	Aver-age	Std. Dev.	Aver-age	Std. Dev.
Swine – active[a]	mg/l (lbs/1,000 gal)	2,930 (24.4)	1,620 (13.5)	6,310 (52.6)	4,120 (34.3)	780 (6.5)	470 (3.9)	36 (0.3)	36 (0.3)	96 (0.8)	72 (0.6)
Swine – inactive[b]	mg/l (lbs/1,000 gal)	2,690 (22.4)	1,320 (11)	1,550 (12.9)	940 (7.8)	170 (1.4)	170 (1.4)	144 (1.2)	160 (1.3)	140 (1.2)	72 (0.6)
Dairy[a]	mg/l (lbs/1,000 gal)	2,290 (19.1)	1,040 (8.7)	5,020 (41.8)	3,940 (32.8)	1,100 (9.2)	860 (7.2)	60 (0.5)	48 (0.4)	84 (0.7)	48 (0.4)
Dairy[c] – complete mix, sludge and super-natant	mg/l (lbs/1,000 gal)	1,990 (16.6)	830 (6.9)	1,070 (8.9)	540 (4.5)	1,750 (14.6)	600 (5)	13 (0.11)	15 (0.12)	19 (0.16)	11 (0.1)
Poultry – layer[a]	mg/l (lbs/1,000 gal)	2,500 (20.8)	1,420 (11.8)	9,260 (77.2)	4,790 (39.9)	1,180 (9.8)	920 (7.7)	12 (0.1)	12 (0.1)	130 (1.1)	120 (1)

[a] Barker, J.C., J.P. Zublena, and C.R. Campbell. 1994. Livestock manure production and characterization in North Carolina. Agri-Waste Management Bulleting. Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, NC.

[b] Sheffield, R. E. 2000. Sludge and Nutrient Assessment of Inactive Lagoons in North Carolina. Presented at the 2000 ASAE Annual International Meeting. ASAE Paper No. 004121. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA.

[c] Mukhtar, S. 2000. Assessment of Nutrients and Sludge from Dairy lagoons in Texas. (Unpublished data.)

Table 4. Texas dairy lagoon sludge and supernatant mixture data (Mukhtar, 2000).

County	% Total Solids	% Volatile Solids	pH	TKN	P_2O_5	K_2O	No. of Samples*	No. of Lagoons
				mg/l (lb/1000gal), as is				
Erath	4.3	2.4	7.4	1765(14.7)	935(7.8)	1540(12.8)	30	8
Hamilton	7.1	3.9	7.6	2485(20.7)	1465(12.2)	2245(18.7)	10	2
Comanche	2.5	1.5	7.7	1730(14.4)	1105(9.2)	1475(12.3)	15	3

* Each sample represented supernatant and suspended sludge mixture from the primary lagoon.

Nutrient Issues

Planning for the proper utilization of nutrients should be done when the animal manure management system is designed. Nitrogen is the contaminant that is most likely to affect ground water. Movement of nitrogen from an abandoned storage facility can be estimated by measuring organic, nitrate and ammonium nitrogen in the ground water, both up and down slope of the structure. Nitrates are rarely found in stored manure due to anaerobic conditions. (Lightly loaded feedlot runoff storage ponds may be the exception.) However, other forms of nitrogen can be converted to nitrates if they encounter aerobic conditions. Westerman et al. (1995) found significant levels of ammonia and nitrate in wells near unlined lagoons constructed in sandy soils. Heavier soils with a high cation exchange capacity or a properly constructed and maintained liner should restrict the movement of ammonium and organic nitrogen.

When closing an earthen manure structure, the producer must handle a large quantity of liquids and manure solids. The land application area required will be significantly more than in normal operation. Often a producer must devise other methods of utilizing the manure, such as applying on land owned by neighbors, or developing a multi-year closure plan. If an anaerobic lagoon or runoff holding pond is left unused for a period of time, the nutrient level in the liquid layer becomes less concentrated, but the nutrients in the sludge layer are relatively stable and tend to remain as long as the sludge layer is covered with water (Sheffield, 2000).

Table 5. Rates of sludge/solids accumulation in lagoons. (Modified from USDA-NRCS, 1992.)

	Sludge Accumulation in l/hd/yr (ft^3/hd/yr)		Sludge Accumulation in l/hd/yr (ft^3/hd/yr)
Swine		**Poultry**	
Nursery	85 (3)	Layer	14 (0.5)
Grow/Finish**	452 (16)	Broiler	17 (0.6)
Sows and litter	1500 (53)	Turkey	23 (0.8)
Sows (gestation) and boars	395 (14)	**Dairy**	
Beef		Lactating cows	10,755 (380)
Feeder (high energy diet)	4,955 (175)	Dry cow	7,500 (265)
Feeder (high forage diet)	5,660 (200)	Heifers	4,530 (160)

** Bicudo et al. (1999) found a value of 203 l/hd/yr (7.2 cu ft/hd/yr).

Table 6. Calculation of phosphorus accumulation in the sludge and settled solids in a first-stage or single-stage anaerobic lagoon.*

	Number of Animals (average capacity) (A)	Average Animal Weight, kg (lb) (B)	Sludge P_2O_5 Accumulation (unit P_2O_5/unit of animal weight per year, kg/kg or lb/lb)* (C)	Years Accumulation of Sludge and Solids (E)	Total P_2O_5 in Sludge and Solids, kg (lb) (A×B×C×E)
Example: Finish	*1000* ×	*68 (150)* ×	*0.09*** ×	*10* =	*61,200 (135,000)*
Swine					
Nursery	×	×	0.2 ×	=	
Grow/finish	×	×	0.09** ×	=	
Sows and litter	×	×	0.08 ×	=	
Sows (gestation) and boars	×	×	0.03 ×	=	
Dairy					
Lactating cow	×	×	0.07 ×	=	
Dry cow	×	×	0.05 ×	=	
Heifer	×	×	0.02 ×	=	
Beef					
Feeder (high energy diet)	×	×	0.05 ×	=	
Feeder (high forage diet)	×	×	0.06 ×	=	
Poultry					
Layer	×	×	0.07 ×	=	
Broiler	×	×	0.08 ×	=	
Turkey	×	×	0.07 ×	=	

* Assumes 65% of the phosphorus excreted by the animals settles into the sludge or settled solids. This table does not apply to manure storages or runoff holding ponds for outdoor lots that are normally cleaned each time manure is removed. Sludge accumulation rates are highly variable, depending on climate, animal species, ration and management, and sampling is needed for reliable nutrient estimates.

** Bicudo (99) found 0.03

Table 7. Pathogen inactivation with time for lagoon stored anaerobically stabilized biosolids (Reimers et al., 1990).

Pathogen	Time (months)	Log Reduction
Ascaris eggs	15	>3 log
Total coliforms	9	2 log
Fecal coliforms	6	> 4 log
Fecal streptococcal organisms	3	1 to 3 log
Salmonella livingston	2	> 7 log
Poliovirus	6	> 5 log

Pathogen Issues

Most soils are effective filtering media for pathogens. (This has been the rationale for septic system design in the US for many years.) Phosphorus chemically binds to soil to form a variety of non-soluble complexes. Phosphorus and pathogens should not be a significant problem in soils around an abandoned storage unless the water table is within 0.61 m (24 in) of the bottom of the facility, based on the requirement of 0.61 m (24 in) of unsaturated (aerobic) flow used to design septic system absorption trenches in most states.

Earthen manure structures not only provide storage but also treatment (Reimers et al., 1999). Significant removal of live pathogens usually occurs in stored manure over time, particularly in lagoons. The concentration of pathogens varies depending on the source. In biosolids, infectious agents are generally divided into four classifications: bacteria, viruses, protozoa, and helminths. The most resistant pathogens are the helminth eggs of *Ascaris* and *Toxocara.* In most manures, resistant helminth *Ascaris* eggs have not been detected, and usually only found in swine manure where the hogs are not confined (Bicudo and Olezkiewicz, 1996). *Toxocara* eggs are found only in cat and dog feces. The predominant resistant pathogens in manures are probably viruses and protozoa oocysts, microorganisms that should be less resistant than *Ascaris* and *Toxocara.*

Biological treatment, aerobic and anaerobic digestion, has been shown to be an effective method of pathogen inactivation. Reimers et al. (1990) monitored anaerobic lagoon stabilized biosolids that were spiked by *Ascaris* eggs, *Salmonella livingston* and poliovirus over a two-year period. The data from their study (Table 7) showed the time in months for total die off or for log reductions. The temperature in these lagoon studies was observed to be in the range of 26° to 25°C (79° to 77°F) from April to October and 20° to 17°C (68° to 63°F) from November to March. They concluded that pathogens tend to die off at a much greater rate in lagoons than in soils. Therefore, as a general rule, it can be concluded that lagoon treatment facilities and waste storage ponds that have been idle for several years will likely be stable and not pose a threat to human safety due to pathogens (Reimers et al., 1999). However, if there is any question or doubt, bioassays of the material can be taken within the structure (both water and manure biosolids) to verify the levels of pathogens and the course of disinfection if concentrations exceed the human infective dose (Henry and Reimers, 2000).

Seepage and Contamination Potential

Seepage, expressed as flow volume per unit area and time (cm/day or inch/day), is defined as the loss of liquid by infiltration or percolation from canals, reservoirs or manure storage, and treatment structures (ASAE, 2000). For decades, anaerobic lagoons have been built to store and biologically treat manure and wastewater from livestock and poultry operations. Properly designed and operated lagoons are efficient in liquefying and volatilizing organic solids and are a convenient method of manure and wastewater handling, storage, and disposal. Despite these attributes, the residual material in lagoons contains nitrogen, salts, bacteria, viruses, pharmaceuticals, and other potential contaminants (Bitton, 1999). While lagoons built after about 1990 may have well-compacted clay or synthetic liners, many older lagoons relied upon native soil properties and self-sealing processes to reduce seepage. Sidewalls of these earthen structures may have a higher seepage rate than the bottom due to fluctuating liquid levels causing shrink/swell cracks or due to macropores created by worm, rodent, and root activity. Sidewall seepage rates can also be higher if the structure was excavated using the "stair step" or incremental method vs. the "bath tub" or "all at once" approach (NRCS Field Handbook).

Gas release from microbial activity in soil beneath the seal can cause rupture of the lagoon seal (Ciravolo et al., 1979). This is why proper construction of unlined earthen manure structures requires the removal of all organic materials down to mineral earth. Another likely area for seepage is at the junction of the sidewalls and the floor of the structure.

Research indicates that manure has sealing characteristics that becomes more effective over the operational life of the earthen structure. Ham and DeSutter (1999) cited investigations of three modes of sealing: physical clogging of soil pores by manure particles, biological sealing by microbial products, and chemical sealing from salt-induced dispersion of particles in clay liners. Most studies have concluded that physical clogging of soil pores was the primary sealing mechanism. Barrington et al. (1987) suggested that biological mechanisms could also intervene to strengthen physical seals where ambient temperatures exceed 15°C (59°F). They observed that swine manure, because of its granular and easily biodegradable character, required a finer soil to effectively seal than did more fibrous, fermentation-resistant dairy manure solids. Soil sealing by dairy manure was found to be almost instantaneous.

Davis et al. (1973) measured infiltration rate of the floor of a newly constructed dairy manure storage basin using 20 cm (8 in)-diameter cylinders. Seepage of fresh water was measured at 120 cm/day (47.2 in/day). For the same structure, seepage for dairy manure and wastewater was 5.8cm/day (2.3 in/day) after two weeks and decreased to 0.5 cm/day (0.2 in/day) after four months. The concluded from this 240:1 seepage reduction that dairy waste ponds sealed effectively over time.

Robinson (1973) measured seepage from a storage pond at a beef cattle operation. The existing pond was cleaned out with a backhoe prior to the experiment. Seepage rates were measured by monitoring wastewater level fluctuations and subtracting estimated evaporation rates from the wastewater levels (water balance approach). Initially, the seepage rate was 11 cm/day (4.3 in/day) but reduced to 0.3 cm/day (0.12 in/day) after six months, for a 36:1 drop. Other full-scale field studies have measured seepage losses of varying magnitudes from earthen lagoons and ponds for dairy (Demmy, 1993; Ham et al., 2000), and swine (Glanville et al., 1999; Ham et al., 2000) lagoons and earthen storage structures built on coarse or fine soils and with or without liners. Ham et al. (2000) concluded that although measured seepage rates were small (0.02 cm/day or 0.008 in/day), as much as 111,900 kg N/Hectare (100,000 lb N/ac) could seep into the subsoil under lagoons over a period of 20 to 30 years. Glanville et al. (1999) calculated seepage from 28 earthen manure storages using a mass balance approach. Only 4% showed leakage significantly greater than the 0.159 cm/day ($^{1}/_{16}$ in/day) standard in use when the storages were built. They could find no significant difference in seepage between lagoons and earthen manure slurry storages and determined that structures in glacial till showed significantly lower leakage rates than those constructed in sand and gravel, colluviums or loess. Brune et al. (1994) concluded that the "water balance" approach did not adequately estimate seepage from earthen structures. Feng et al. (1992) found that a mathematical model, calibrated and validated using data from a field study site in NC, agreed well with field monitoring. Long-term simulations indicated that ammonium was the dominant form of nitrogen in the soil around the study site. The contaminant front was predicted to advance by 60 m (197 ft) per year in sandy soil.

Ham et al (1999) collected soil core samples from an abandoned cattle feedlot lagoon in KS where the sludge had been allowed to dry and had been removed. The cores showed ammonium nitrogen levels of 400 ppm near the original lagoon bottom, decreasing to 30 ppm at 5 m (16.4 ft) below the bottom, with 90% of the nitrogen within 3 m (9.8 ft) of the lagoon liner. In one area where the soil was very sandy, ammonium levels at 5 m (16.4 ft) were 66 ppm. Chloride levels did not decrease with depth because the negatively charged chloride ions were not attracted to the negatively charged clay particles in the soil. Their report suggested that aquifer depth and vulnerability should influence the closure procedure chosen. Nordstedt et al. (1971) installed monitoring wells at a three-stage dairy lagoon system to a depth of 2.43 m (8 ft) below the ground surface at distances of 4.6 (15 ft), 15.2 m (50 ft), and 30.48 m (100 ft) from the lagoons and found evidence of lagoon seepage by sampling biochemical oxygen demand (BOD), salts, and nitrate-nitrogen (NO3-N). Sewell (1978) used monitoring wells near a new dairy lagoon and found elevated levels of NO3-N in water samples immediately after loading the lagoon with manure and wastewater. After a six-month period, however, these levels had declined to near those measured before loading. Sealing of the lagoon was cited for this decrease. Hoffman and Westerman (1995) studied 11 well-established, unlined swine manure lagoons in the lower coastal plain of North Carolina for evidence of seepage. At five of the lagoons, estimated losses were low and likely not a threat to groundwater. Four lagoons showed moderate losses and two were severe. They concluded that a large number of similarly constructed lagoons in North Carolina might also have unacceptable levels of seepage. A five-year monitoring of ground water near two newly constructed swine lagoons, located in areas with shallow groundwater, indicated elevated concentrations of several chemicals including ammonium and chloride (Westerman et al., 1995).

Soil samples collected from in and around lagoons and earthen storage structures suggest that the magnitude of contaminant losses from lagoons varied from site to site due to the differences in waste chemistry, type of animal feeding operation, soil type, and liner construction. Baker et al. (2000), reported results from a study that analyzed soil from around earthen swine manure storage structures in Iowa. Soil was sampled to a depth of 2.4 m (8 ft) around the perimeter of 31 earthen manure structures, along with an upslope background sampling point to estimate leaching. A contaminant concentration ratio of three times the background levels was considered to be "elevated." They found elevated nutrient levels on only one or two samples around the perimeters of each lagoon, indicating that seepage was localized rather than widespread. Nine of the seventeen basins had elevated ammonium levels compared to background levels but did not have concurrent levels of chloride, indicating that the contamination was not recent.

Parker et al. (1999) collected soil samples from borings made to a depth of 6.1 m (18.8 ft) from underneath a 22-year-old beef feedlot runoff storage pond. Elevated levels of chloride, ammonium, and organic nitrogen were found. Also, isolated areas of nitrate were found beneath sidewalls of the pond containing lot runoff. Core samples taken during closure at seven different locations in the berm and bottom of a two-stage swine manure lagoon that had received runoff from shed and lot finishing facilities indicated wide variations in seepage (Hawkins and Boyer, 2000). As indicated by organic matter content and Bray P tests, seepage was not apparent below 61 cm (24 in) in either storage. Ritter et al. (1984) monitored a two-stage anaerobic swine lagoon for four years without finding a significant impact on groundwater. In an animal manure lagoon water quality study, Ham et al. (2000) sampled soil cores between 3 m (10 ft) and 4.6 m (15 ft) beneath several cattle and swine lagoons that had been in use between 11 and 30 years. The highest ammonium levels were found immediately under the soil liner. Ammonium decreased rapidly with depth and was essentially contained in a 1.5-3 m (5-10 ft) soil zone under the lagoons. They cautioned that when a lagoon is closed and allowed to dry, ammonium could convert to NO_3-N and move more rapidly towards the groundwater. They also noted the importance of knowing as much as possible about the history of a soon-to-be-closed earthen manure structure. Any facility that was improperly sited, designed, and constructed would have a greater risk of groundwater contamination due to excessive seepage losses. The feedlot catchments studied by Clark (1975) lost water by seepage. Chemical analyses of cores from naturally occurring playa lakes in the Southern High Plains used to collect runoff from cattle feedlots indicated that the seepage had moved past the 3.5 m (11.5 ft) depth. However, this was indicated only by an increase in the chloride content from 25 to 125 ppm at 3 m when the surface was inundated with water containing over 1000 ppm chloride for 5 years. Little nitrate or nitrite moved below 1 m. Clark concluded that while small amounts of seepage reached groundwater, it was low in nitrate.

Culley and Phillips (1989) monitored small-scale unlined earthen dairy manure storages, 100 cu m (3,530 cu ft) and 1.5 m (5 ft) deep, in sand, sandy loam and clay loam soils for five years. They looked at N, P and mineral content of water in the undisturbed clay underlying the storages. Nutrient content increased at 1.75 m (5.7 ft), 2.5 m (8.2 ft) and 3.5 m (11.5 ft) below the berms and pits in all cases over time indicating that the small-scale storages did not seal effectively during the study. The waterborne inorganic N, P and mineral levels found in clay soils of similar hydraulic conductivity were strongly affected by the properties of the overlying soil. The greatest increases were in storages constructed in acidic sands. There were considerable increases in both total P and PO_4, but no changes in inorganic N contents beneath clay loam storages. Westerman et al. (1995) investigated two new swine manure lagoons located in sandy, unlined coastal plain soil for 3.5 to 5 years after receiving waste. Monitoring wells indicated broad seepage plumes; with ammonia levels from as low as 1 mg/l to as high as 143 mg/l. The authors concluded from the highly variable results that it is extremely difficult to predict seepage rates from lagoons. Results of studies by Ciravolo et al. (1979) clearly indicated the importance of properly siting earthen structures by the increased seepage found at three sites with sandy surface layer soils and either sand or heavier subsurface layers. Page and Loudon (1983) summarized and compared ten lagoon seepage studies and found a great deal of variation. They concluded that future research was needed to determine the effect of pumping on the lagoon seal.

Liquid and Sludge Removal

The Minnesota Pollution Control Agency recommends agitation, suspension and removal of the sludge in the bottom of abandoned earthen storages, scraping out the solids layer left in the bottom and land-applying the removed material at agronomic rates. The remaining structure should be filled in using earthen berm material and other material permitted for this purpose by state and federal regulations. Abandoned concrete pits should also be cleaned and filled in.

Natural Resources Conservation Service Conservation Practice Standard Code 360 states that assuming the structure was properly constructed and that the liner is intact, the following applies: "All structures used to convey waste to waste impoundments shall be removed and replaced with compacted earth material or otherwise rendered unable to convey waste. Liquid and slurry wastes shall be agitated and pumped to the extent conventional pumping will allow. Clean water shall be added as necessary to facilitate the agitation and pumping." The Indiana closure standard states that "the sludge remaining on the bottom and sides of the waste treatment lagoons or waste storage ponds shall be removed to the fullest extent practical without damaging the liner . . . ."

When cut-and-fill structures are closed, the contents should be removed before the embankment is breached. Final side slopes should be no steeper than 3 to1. In excavated impoundments, backfill height should exceed the design finished grade by 5% to allow for settlement. The finished surface should be constructed of the most clayey material available at the site, covered by topsoil and mounded to shed rainfall.

Putnam (1998) stated that "Although risks associated with lagoons are assumed to remain until wastes within the impoundment are either removed or stabilized, risks also exist with closing lagoons. Under the current Natural Resources Conservation Service (NRCS) Lagoon Closure Standard used in the state [North Carolina], all wastes in a lagoon must be removed and land applied. A cleaned lagoon can be filled with an inert material such as sand or if the structural integrity of the impoundment allows, it may be used as a freshwater pond. Land application of removed waste can create nonpoint source pollution through nutrients carried by runoff and, if not removed by crops, may also pose risks to ground water. Irrigated wastes also produce odors that may be offensive to nearby residents. Additionally, the accumulated solid waste (sludge) in the bottom of a lagoon contains high concentrations of heavy metals. When sludge is land applied, these metals may accumulate in soils and limit the ability of the soil to produce certain crops."

ADDITIONAL RESEARCH NEEDS

This paper summarizes what is known about the closure of earthen manure structures and attempts to outline safe procedures to do so. Still, there are several issues that are not well understood and would benefit from additional research.

- Proper closure procedures for poorly maintained earthen structures?
- Proper closure procedures for earthen structures in environmentally high-risk areas, e.g. sandy soils, shallow water tables, karst areas, etc.?
- Economic and engineering study of sludge removal and utilization.
- Study of viability, fate, and transport of pathogens, hormones, and pharmaceuticals in seepage and sludge of lagoons and earthen waste storage structures.
- The types of pathogenic organisms found in animal manure structures, and their longevity when spread on soil, injected into soils, or left in the lagoon or storage basin is poorly understood. Most pathogen research has been done with human biosolids, which are similar, but not identical to animals.
- Soil sampling/monitoring techniques to decide how much of the sludge and liner to remove during closure.

- Do economically viable methods for remediation of soil contamination sites around a structure exist?
- Research is needed to identify economically viable methods to determine whether unacceptable levels of seepage have occurred around an earthen basin. For instance, how closely spaced and how deep should soil borings be taken?
- Fate of nitrogen in the soil beneath an earthen manure structure after closure.
- Sludge characteristics and accumulation rates in different types of manure structures.

SUMMARY AND CONCLUSIONS

A thorough review of the literature dealing with closure of animal manure lagoons and earthen manure storages shows quite varied results and indicates the need for a site-specific evaluation in order to accurately evaluate the potential environmental damage from closure. Still, there are several conclusions that can be reached:

The overall potential for environmental contamination should be taken into account when closing a structure. Application on land with crops that can utilize the nutrients without damage to ground or surface water must be available. It may be important to properly schedule the removal and land application of sludge over a period of several crop years to ensure this happens. If land is not available to apply the sludge, other means of utilization must be available.

A site-specific evaluation is important to ensure that the structure was properly sited, designed, constructed and operated. If it was not and if an investigation shows contamination of the site is ongoing, closure procedures should be completed as soon as possible.

There are a number of questions that remain after our literature search. Specifically:

- What is the most versatile and suitable equipment to efficiently dewater/desludge lagoons in an environmentally safe fashion?
- Are there chemical/biological additives that can reduce/liquefy sludge effectively?
- How much reduction in the sludge accumulation rate can be expected due to a solid-liquid separation system in the manure stream ahead of an earthen structure?
- Can models be developed to more accurately estimate sludge buildup?
- What is the mineralization rate of nitrogen and other nutrients to be land applied from sludge and what is the salt content of sludge?
- What is the feasibility of composting very high moisture sludge removed from a lagoon?

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