Management and Maintenance of Earthen Manure Structures: Implications and Opportunities for Water Quality Protection

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Summary:

Earthen manure structures have attracted widespread concern about their potential for groundwater contamination. Thus far the regulatory response to this concern has emphasized structural and design requirements, but increasingly attention is being paid to issues related to management or maintenance. This study used a detailed on-site survey to observe actual operational practices and identify possible mechanisms for ground and surface water contamination at 33 earthen manure structures, including 19 storage basins, 13 anaerobic lagoons, and 1 aerobic lagoon. Case histories were developed for each site to help understand and explain leakage rates, soil nutrient levels, and groundwater quality measured by other researchers at the same sites.

Management and maintenance activities, or lack thereof, that posed a potential risk to water quality were observed at 76 percent of facilities surveyed. The most frequent risk items were minor spills during manure unloading (55%), erosion of compacted clay liners or berms caused by agitation or manure flow at inlets (27%), animal burrows around pipes or in the berm (24%), plugging or freezing of gravity flow inlet pipes (12%), tree growth in the berms (6%), and inadequate freeboard caused by overfilling with manure (6%). While most of these risk factors had not resulted in any significant water quality impacts, three of the 33 facilities (9%) had experienced major spills since construction.

This study identified several technical, educational and policy opportunities to reduce risks associated with the operation of earthen manure structures. Recommendations include 1) greater care in transfer of manure between the storage and application equipment; 2) improved operator training or technology modifications to reduce or eliminate erosion caused by manure agitation, 3) frequent mowing to reduce animal burrowing and eliminate tree growth; and 4) frequent visual checking to insure adequate freeboard. The first two recommendations can easily be incorporated in Iowa's new manure applicator's certification program, since the associated risks only occur during manure application. Because application is increasingly contracted out and not all livestock farmers will be certified, recommendations 3) and 4) may require targeted education of on-farm personnel.

Introduction

With the increasing size and concentration of livestock production, manure storage, treatment and utilization have attracted considerable attention from environmental regulators and the public. Liquid manure handling systems are of particular concern, given the occasional catastrophic failures of such systems and resulting environmental damage (Richard and Hinrichs, 1998). While most of the catastrophic failures result in surface runoff and stream or lake contamination, there is also considerable concern about unseen groundwater contamination. In the United States this concern has resulted in a number of regulatory requirements for the various types of earthen structures used for manure storage or treatment at many large livestock production facilities (Hegg, 1997). Most of these requirements relate to the physical design and construction of the facilities, but increasingly management and maintenance requirements are recognized as well. This study focuses on the later components which affect operation of the facilities after they are built.

There are three broad categories of earthen manure structures: earthen manure storages, anaerobic lagoons, and aerobic lagoons. In contrast to the lagoon systems, earthen manure storages are not designed to encourage microbial decomposition and treatment of the manure. Depending on the manure collection system (flush, scraper, or deep pit or pull-plug), the manure may be pumped and handled as a semi-solid, slurry or a more dilute wastewater (Melvin et al., 1989). In the absence of significant microbial degradation, manure nutrients are largely conserved, which is an advantage for farms with cropland and manure requirements. However, the lack of treatment also means that odors and BOD are not significantly reduced, which can be problematic during land application, particularly if there is any unintended release. This system is widespread in swine production today, and is currently the most common type of earthen manure structure in Iowa and the upper Midwest.

Anaerobic lagoons are the second most common type of earthen manure structure in Iowa. In order to reduce ammonia and other constituents to levels which do not inhibit microbial degradation, the systems must initially be filled half full of water. Manure additions slowly increase to the planned level, and are accompanied by additional dilution water. Manure collection is often via a flush system which provides the necessary dilution. A principal disadvantage of this system in Iowa is the high cost of nitrogen through volatilization, typically 70 to 80% of the initial nitrogen content (Zhang et al., 1995). Nonetheless, these systems remain popular, particularly in regions of the country with limited cropland where nitrogen losses are actually considered an advantage, and provide low-cost treatment which reduces odors during land application (USDA, 1997). Flush systems also offer improved air quality in livestock housing, are relatively low cost, and have minimal labor and management requirements (Barker et al., 1994; Chen et al., 1997).

Aerobic lagoons also require dilution to facilitate microbial activity, and either depend on an extremely large surface area or some type of mechanical aeration to supply oxygen for aerobic treatment. Aerobic lagoons are rare, in the case of natural aeration because of the high land requirement, and in the case of mechanical aeration because of high energy costs. Odors and BOD as well as nitrogen levels are reduced through aerobic decomposition and ammonia volatilization.

In Iowa earthen storage structures at large livestock production facilities are required to meet a variety of permit requirements. Design and construction requirements include hydrogeologic siting constraints (such as well and stream setbacks and groundwater table separation), liner specifications, compaction and leakage rate tests. During the time permits were issued for the structures in this study (1983 – 1995), the standard operational requirements written into the permits were:

1) Waste materials removed from the waste storage facilities (or lagoon) shall be disposed of by land application in a manner which will not cause surface or groundwater pollution. Land application should be conducted in accordance with the land disposal policies of the Environmental Protection Commission (attached as an appendix to each permit).
2) A minimum of XXX acres of land area suitable for waste disposal shall be available at all times that disposal of waste from theses facilities becomes necessary. Waste shall be spread as evenly as possible over the acreage to prevent nitrogen overloading of the soil.
3) Collected waste materials shall be removed from the (waste storage basin or lagoon) as required to maintain a minimum of 2.0 feet of freeboard.

Earthen waste slurry storage structures, designed for only six months of storage, must meet two additional requirements which were modified over time in two forms:

4) Prior to entering the winter season, a sufficient volume of waste material shall be removed from the waste storage basin to provide adequate volume of storage of wastes produced in the livestock production facilities during the winter season.
5) Water usage in the confinement facilities that results in dilution of wastes entering the waste storage basin shall be minimized.

or later:

4) Dilution water shall not be added to the waste storage basin except during semi-annual disposal operations when required to facilitate complete emptying of the basin.
5) The waste storage basin shall be completely emptied of collected waste materials at least twice per year, semi-annually.

There are a number of additional management and maintenance activities which are informally recommended and may be required on a site by site basis, but which do not appear in the regulations directly. These include: regular mowing to eliminate trees and reduce the potential for animals burrowing in the berm; care to minimize erosion on the berm during agitation and pumping, and care during pumping to minimize spills. The last of these items is proposed in the 1999 revisions to the regulations, in that certified commercial manure applicators shall have an obligation to insure "pumps and associated piping on manure handling equipment shall be installed with watertight connections to prevent leakage." These recommendations are widely recognized by professionals and regulators as good or "best" management practices. The objective of this study was to document whether such recommendations are actually implemented by the managers or operators of earthen manure structures in Iowa.

Materials and Methods

This study was implemented in conjunction with parallel studies of the hydrogeology, leakage rates, and water quality impacts of thirty-three earthen manure structures in Iowa (Melvin et al., 1999; Simpkins and Burkart, 1999). Study sites were selected from 124 volunteers solicited by a mailing to all 439 earthen manure structures permitted by the Iowa Department of Natural Resources (DNR) between 1987 and 1994 (Melvin et al., 1999). The final selections were made to insure a representative sample of the diversity of hydrogeologic settings in Iowa (Simpkins and Burkart, 1999). Volunteers were protected by from prosecution and enforcement related to this survey by a confidentiality agreement.

A survey was developed, pre-tested, and then administered on site through a semi-structured interview including both fixed choice and open-ended questions. Prior to each interview, interviewers familiarized themselves with the site by reviewing aerial photos and the DNR permit, as well as other public information in the DNR file. The aerial photos were used in the interview to clarify locations of the manure pipes, valves, and inlets, nearby surface or underground drainage systems, and any past or current structures or activities which might have water quality implications. Interviews took between 45 minutes and 2 hours, and included a tour of the earthen structure where design measurements were confirmed, and evidence of management and maintenance activities observed. Photographs were taken at most sites to document observations, particularly of conditions which might effect water quality.

Survey responses were coded and entered into a spreadsheet database, and the aerial and on-site photographs were annotated and collated for each site. These summary materials were used in the conjugate water quality studies to identify possible mechanisms for excessive leakage or other water quality impacts.

Results and Discussion

The earthen structures surveyed had been operating an average 6 years. During that time, three of the 33 had experienced significant spills. Management and maintenance activities, or lack thereof, that posed a potential risk to water quality were observed at 76 percent of facilities surveyed. Table 1 indicates the number and percentage of facilities experiencing each type of potential risk. Several facilities exhibited more than one risk factor, so the total percentages sum to more than 76 percent.

The most common potential risk resulted from inadequate containment of manure during transfer operations, with minor spills reported or observed at 55% of the facilities surveyed. While most of these spills had not resulted in any obvious soil or water quality degradation, many were evidenced either by dead vegetation or significant deposits of manure solids on the soil surface. Most of the spills occurred during manure transfer operations, where pumps discharged into the open tops of the tank vehicles used for liquid manure transport and/or application. Since the manure pump is usually not directly connected to the tank, the operator must initially position the pump discharge accurately, and subsequently visually check the tank level to avoid overfilling. If the operator is not diligent, manure can easily spill out of a tank onto the ground (see Figure 1). With high volume manure pumps capable of pumping several hundred to over one thousand gallons per minute (USDA, 1997), even a few moments of neglect can result in a significant spill.

Table 1. Risk factors in the management and maintenance of earthen manure structures.

Risk Factor	Number of facilities (33 total in survey)	Percentage of facilities
Minor spills during handling and transfer	18	55
Erosion of compacted liner	9	27
Animal burrows in berm	8	24
Plugging of inlet pipes	4	12
Tree growth in berms	2	6
Inadequate Freeboard	2	6

<u>GO TO FIGURE 1</u>

Manure spillage during tank loading operation

The second most common concern identified by this survey was erosion of the compacted soil or clay liner, with significant impacts at 27% of the sites surveyed. Erosion was found at inlet pipes, pump out locations, and along the sides of the berm where agitation jet streams had been stationary for extended periods (see Figure 2). Inlet pipe erosion can easily be addressed with the installation of stone rip-rap or concrete at critical locations, and is recommended wherever inlet pipes could discharge onto the berm when manure levels are low. The causes of erosion at pump-out locations were not always obvious, but may be associated with cleaning out manure transport and application equipment. Agitation induced erosion results when the agitation jet stream is not kept in constant motion near the berm of the storage. Even a few moments of high-volume flow directly on the soil surface are capable of considerable liner erosion. Although effective agitation requires attention to the corners and recesses of the storage to insure adequate suspension of manure solids (USDA, 1997), agitator operators must pay particular attention to the damage this operation can cause.

GO TO FIGURE 2

Berm erosion caused by agitation or backwash during pump-out

Evidence of animal burrowing was observed at 24% of the sites. Burrows were found on both inner and outer sides of the berm (see Figure 3), as well as adjacent to inlet pipes, valves, and other manure control structures. Fluctuating manure levels make these burrows particularly problematic, since a burrow can be built directly through the berm in dry soil when the liquid level is low, and become an effective pipeline when liquid levels are high. Even if burrows do not result in surface leakage outside the berm, they can compromise the compacted liner and allow manure movement to more permeable zones adjacent to the structure. Inspection and maintenance to detect and eliminate burrowing animals should be a regular part of earthen manure structure management (USDA, 1997).

GO TO FIGURE 3

Animal burrows in berms can become conduits for manure, especially if they are submerged as the earthen structure fills to capacity

Inspection for animal burrowing is obviously facilitated by frequent mowing of the berms. Although the facilities surveyed generally indicated they mowed their berms at least once a year, several had extremely high grass growth, particularly on the inside of the berms. The inner slope of many earthen structures is relatively steep, with design recommendations ranging from 1.5:1 to 3:1 (horizontal to vertical)(USDA, 1997). This slope was often considered two steep to mow by facility operators. At 6% of the sites, neglect of mowing had allowed the establishment of trees on the berm (see Figure 4). As with burrowing, fluctuating storage levels make tree growth a particular concern, since root channels established during low liquid levels can serve as conduits when manure levels rise. The risk associated with this factor is expected to increase when trees die and decompose.

GO TO FIGURE 4

Tree growth in berms can create macropores for manure leakage

Pump plugging or freezing had occurred at 12% of the facilities surveyed. Plugging can back manure up into livestock buildings causing problems with air quality as well as structural concerns, and in extreme cases can overflow out of buildings, manholes, or vents. A clean water flush is recommended to minimize solids buildup in pipes (USDA, 1997). Protection from freezing requires attention to both design and management. Pipes and valves should be buried below frost line during installation, and inlets should be submerged during winter storage if possible.

Inadequate freeboard was either directly observed or indicated by the operators at two (6%) of the facilities surveyed (see Figure 5). Although this was an uncommon problem, at one of the sites it had resulted in a major spill. The need for routine monitoring of manure liquid levels is widely recognized (USDA, 1997) and was one of the few management requirements included in permit conditions (see above).

<u>GO TO FIGURE 5</u>

Inadequate freeboard between berm and manure level

The six risk factors identified in Table 1 offered clear opportunities to improve current manure management practices at earthen manure structures. However, it is also important to remember that current operations, while relatively easy to observe, may not be the only factor contributing to water quality concerns. In this study, 18 percent of the earthen structures were built on sites with previous livestock or manure storage facilities, including feedlots, manure piles, and other uncontained systems. These historical facilities and associated management factors may also play a role in any observed degradation of surface or groundwater quality.

Recommendations

This study identified several technical, educational and policy opportunities to reduce risks associated with the operation of earthen manure structures. Recommendations include 1) greater care in transfer of manure between the earthen structure and application equipment; 2) improved operator training or technology modifications to reduce or eliminate erosion caused by manure agitation, 3) frequent mowing to reduce animal burrowing and eliminate tree growth; and 4) frequent visual checking to insure adequate freeboard. The first two recommendations can easily be incorporated in Iowa's new manure applicators certification program, since the associated risks only occur during manure application. Because application is increasingly contracted out and not all livestock farmers will be certified, recommendations 3) and 4) may require targeted education of on-farm personnel.

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