COST OF REMEDIATION OF NITROGEN-CONTAMINATED SOILS UNDER CAFO IMPOUNDMENTS

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ABSTRACT

Wastewater in manure storage basins or anaerobic treatment lagoons at confined animal feeding operations (CAFOs) may contain high levels of nitrogen, primarily in the ammoniacal form. Kansas law allows seepage from such impoundments at a rate of 1/8 to 1/4 inch per day (3.2 to 6.4 mm/d). Kansas State University researchers have recently characterized an ammonia plume at a depth of 10 feet or more under several CAFO lagoons and have modeled the potential for deeper penetrations in sandy subsoils. If the plume is not removed or contained after wastewater is removed from the impoundment, then exposure to oxygen from air or dissolved in precipitation will drive the transformation of ammonium to nitrate, which is mobile in the vadose zone. Based on a cleanup standard of 25 mg/kg of NH_4-N, the total cost to remove or contain the nitrogen beneath federally permitted swine and dairy wastewater management basins now in operation in Kansas would be about $56 million. In most cases, the preferred remedial option would be the excavation and spreading of the contaminated material on farmland. However, deep plumes in sandy soils and limited access to farmland may dictate use of the backfill-and-cover option. The remedial cost for some operations not currently required to provide financial assurance for closure is estimated to range from $500,000 to $650,000.

Key words: lagoons, liners, ammonia, closure, costs

INTRODUCTION

Wastewater in manure storage basins or anaerobic treatment lagoons at confined animal feeding operations (CAFOs) may contain high levels of nitrogen, primarily in the ammonical form. Kansas law allows this wastewater to seep from such impoundments at a rate of 1/8 to 1/4 inch per day (3.2 to 6.4 mm/d). Miller et al., (1976) suggested that the accumulation of ammonium-N beneath lagoons presented a serious hazard. They found elevated NH_4-N levels beyond five feet deep (1.5 m) beneath two swine lagoons that had been used for less than 11 years. Kansas State University researchers have characterized an ammonium plume at a depth of 10 feet (3 m) or more under several CAFO lagoons and have modeled the potential for deeper penetrations in sandy subsoils (KSU Research & Extension, 1999-2001). If the plume is not removed or contained after wastewater and sludge are removed from the impoundment, then exposure to oxygen from air or dissolved in precipitation will drive transformation of ammonium to nitrate, which is mobile in the vadose zone. Existing national closure standards do not address the removal of this subsoil plume. Rather they focus only on the disposition of wastewater and sludge (NRCS, 2000).

There is growing evidence that nitrate contamination of groundwater is increasing in Kansas and in most areas of the High Plains Aquifer (Litke, 2001). Likewise, the Kansas Geological Survey reported that nitrates had increased, from the 1970's to the 1990's, in three-fourths of the wells they surveyed in central and western Kansas (Townsend and Young, 1999a), though they suggested that this could be a function of both agricultural pollution and poor well construction. The KGS analyzed 112 samples to determine the source of nitrogen in well water and found that 42% derived from animal waste, 29% from commercial fertilizer, 22% from mixed sources, and 7% other (Townsend and Young, 1999b). The USGS is also finding levels of nitrates exceeding the health standard at water table depths greater than 100 feet (30.5 m). In wells of their own construction near Garden City, Kansas, they found 54 mg/L nitrate-N at 121 feet (36.9 m), traced to animal waste by nitrogen 15 isotope analysis, and 22 mg/L at 161 feet (49.1 m) (McMahon, 2000). In 2001 the USGS conducted extensive analysis of 79 lagoon-monitoring well samples at 35 swine feeding operations in Oklahoma where previous sampling had revealed nitrate levels exceeding the 10 mg/l USEPA MCL (Becker, Peter and Masoner, 2002). The swine operations were constructed after 1992. Using ribotyping of E. coli isolates and swine wastewater organic compound indicators, the USGS identified nine of the 35 swine operations as possible sources of contamination. Depths to water in these instances were 6, 9, 10, 16, 25, 31, 34, 55, and 63 feet, respectively (1.8, 2.7, 3.0, 4.9, 7.6, 9.4, 10.4, 16.8, & 19.2 m). Nitrogen isotope 15 values from 76% of samples indicated an animal or mixed fertilizer/animal source of the nitrate.

The Oklahoma study indicated significant incidence of pollution relatively early in the life of the swine lagoons. However, on a spatial scale, it is likely that application of manure and commercial fertilizer to crop lands is more often the source of nitrate pollution in Kansas rather than wastewater impoundments. Nonetheless, the recent influx of large swine and dairy CAFO's situated over the High Plains Aquifer suggests that safeguards need to be applied for the long term.

Kansas law requires a closure plan and financial assurance only for swine CAFOs of 3725 animal units (9313 mature head) capacity or more. As yet, no specific guidelines have been developed for remediation of contaminated soils beneath CAFO wastewater impoundments. Cost of remediation will be a function of the size and depth of the impoundments and depth of the nitrogen plume underneath. For the "excavate and spread" alternative, the total mass of nitrogen will determine the amount of land needed for disposal. The objectives of this study are to 1) review remediation alternatives, 2) suggest cleanup standards, 3) develop example cost models, and 4) assess the long-term economic implications for the state of Kansas.

SOURCES OF DATA AND METHODS

Characterization of subsoil ammonium contamination is based primarily on data developed by Kansas State University (KSU Research & Extension, 1999-2001). Recommendations for remediation alternatives and cleanup standards were obtained from Agronomy Solutions, LLC., based on their experience with industrial cleanup of ammonium-contaminated soils and groundwater. A profile of federally permitted swine and dairy CAFOs (1000 animal units or larger) in Kansas was developed from (1) a current list of such facilities obtained from Kansas Department of Health and Environment (KDHE), and (2) from design data for 88 swine and dairy facilities collected by Spectrum Technologists from KDHE permit files during the years 1997 to 2002. The profile was segmented between basins sited in typical Kansas loess-derived silt loam and silty clay loam soils and those sited in aeolian or alluvial sandy soils found in some parts of western Kansas, by analyzing soil boring reports on 74 lagoons obtained from KDHE permit files (Volland, 2000). The CAFO profile was analyzed to develop a set of representative impoundment designs. These were submitted to Engineering Solutions and Design for estimation of remediation costs. The estimates were normalized to the cost per animal unit. The least expensive remediation alternative was multiplied by the number of animal units in each category to obtain the total expected cost for the state of Kansas. Cost of removing wastewater and sludge prior to remediation was not considered.

CHARACTERIZATION OF NITROGEN PLUME

Wastewater Characteristics

Wastewater in manure storage basins or anaerobic treatment lagoons at confined animal feeding operations (CAFOs) may contain high levels of nitrogen, primarily in the ammoniacal form. Kansas State University researchers collected lagoon wastewater samples from 20 swine sites and

20 cattle sites from 1997 to 2000. The average ammonium-N concentration was 910 mg/L (range 180 to 3540 mg/L) for swine and 171.5 mg/L (range 10 to 510 mg/L) for cattle feedlots (Ham, 2001). In another series of measurements taken in the year 2000 from 42 swine lagoons, to distinguish between production phases and time of year, other KSU researchers obtained a mean ammonium-N concentration of 1142 mg/L, for all facilities. Grower and finishing facilities had means of 1506 and 1469 mg/L, respectively (DeRouchey, et al., 2001).

Mean total nitrogen concentrations for the two swine data sets were 1080 mg/L and 1402 mg/L, respectively. Since nitrates are negligible under these anaerobic conditions, the difference between total nitrogen and ammonium-N is the organic nitrogen component. The percentage of organic nitrogen will be influenced by the loading applied to the waste management facility and the surface area available for ammonia volatilization. Mean total nitrogen for cattle feedlot impoundments was 303.8 mg/L.

The difference in nitrogen concentration in swine and cattle CAFO wastewater can be explained by design function. Notwithstanding a few cases where pre-sedimentation basins are used to capture solids, swine storage basins and lagoons receive all the wastes produced in a swine confinement building. In contrast, cattle feedlot impoundments receive only precipitation runoff from the open lots and frequently use a primary sedimentation stage to capture solids.

Large confinement dairies generally route all wastes to sedimentation basins followed by deep anaerobic treatment lagoons. However, runoff from a few open lots may also be directed to these lagoons. Three of the nine facilities whose files we examined were open-lot dairies whose lagoon wastewater would resemble that of a cattle feedlot. The previously cited KSU researchers obtained only a few samples (n=3) from two dairy lagoons at their Southwest Kansas Research Center. Mean ammonium-N was 397 mg/L and total nitrogen was 607 mg/L (DeSutter, Ham and Trooien, 2000). However, more extensive data is available from Strahm et al., (2000). In this analysis of seven Kansas dairies that use flush systems to clean forestalls and holding pen areas, the average ammonium content of lagoon wastewater was 398 mg/L, and total nitrogen was 816 mg/L. Wastewater characteristics for open-lot dairies were assumed to be the same as that of cattle feedlots.

Lagoon Seepage and Soil Contamination

Kansas law allows wastewater to seep out of lagoons at a rate up to 0.25 inch (6.4 mm) per day, except for large swine lagoons which are limited to 0.125 inch (3.2 mm) per day. Based on measurements taken by KSU researchers at 14 swine lagoons and six cattle feedlot runoff impoundments (Ham, 2001), swine lagoons seeped at an average rate of 0.05 inch (1.2 mm) per day and cattle feedlots, 0.04 inch (1.0mm) per day. Researchers attributed the difference between the rate expected from soil-liner characteristics and the measured rate to the attenuation of seepage by the lagoon sludge layer.

Noting the reduced rate of seepage, KSU researchers determined that a large plume of ammonium saturated soil would build up under swine lagoons during the life of the facility (assumed to be 25 years). Using an overall average seepage rate of 0.044 inch (1.13 mm) per day, Ham estimated that about 9.1 kg/m^2 or 81,200 lb of ammonium-N per acre of surface area would build up beneath a typical swine lagoon during the 25-year life of a facility. For cattle feedlot impoundments, the estimate was 1.7 kg/m^2 or 15,200 lb per acre (Ham, 2001). Ham concluded that the eventual cost of remediation may justify use of a plastic liner to reduce closure costs.

Depth of the ammonium plume is a critical factor in the difficulty and cost of remediation. Plume depth is a function of clay content of the soil, soil density, cation exchange capacity (CEC), and the concentration in the wastewater of calcium and magnesium ions that might compete with ammonia for adsorption sites (Ham and DeSutter, 1999). To estimate this depth, we utilized the model developed by Ham and DeSutter. Values used for NH_4-N^+, Ca^{+2}, and Mg^{+2} were the average of the two data sets published by KSU researchers. Ham noted that the CEC for most sites examined ranged from 15 to 25 cmol/kg. Thus for a CEC of 20 cmol/kg in the soil underlying the basin, we calculated that the plume depth for swine would be 12 feet (3.7 m) after 25 years; for confinement dairies, seven feet (2.1 m); and for open lot dairies and cattle feedlots, four feet (1.2 m).

These values are fairly consistent with actual measurements taken by KSU researchers from borings beneath empty CAFO basins (Ham, 2001). A 20-year-old abandoned swine lagoon in McPherson County, Kansas, produced soil concentrations of over 1100 mg/kg ammonium-N at 2 inches (0.05 m) below the surface of the liner, which declined to 56 mg/kg at 10.5 feet (3.2 m) below the surface. The average CEC of the soils underlying this site was about 20 cmol/kg. CEC's at the McPherson County site varied according to clay levels, ranging in identifiable layers from 6.5 cmol/kg in 10% clay and 80% sand, 15.4 cmol/kg in 23% clay and 59% sand, to 52.3 cmol/kg in 72% clay and 16% sand.

Soil NH_4-N measurements at another 20-year-old swine lagoon declined from over 900 mg/kg at 6 inches (0.15m) below the surface of the liner, to near zero at 10 feet (3.0 m) of depth. A 12-year-old cattle feedlot in Scott County, Kansas, approached zero at 2.4 feet (0.7 m) of depth. The average CEC through the relevant depths at this site was 19 cmol/kg. However, ammonium concentrations at an 11-year-old cattle feedlot in Grant County did not approach background levels until a depth of about 10 feet (3.0 m), perhaps a very sandy site or one with a leaky soil liner with preferential pathways (CEC and soil classification was not reported). A 20-year-old dairy site yielded NH_4-N levels of 30 mg/kg or above, to 11 feet (3.4 m) of depth.

Based on our review of numerous soil borings submitted for permits at swine sites in western Kansas, we estimate that about 30% of sites in western Kansas overlying the High Plains Aquifer will exhibit a CEC of 10 or less, which is characteristic of sandy soils. Accordingly, in our statewide cost projections, we doubled the estimated plume depth for 30% of CAFO facilities located over the High Plains Aquifer. Miller et al., (1976) measured ammonium-N exceeding 300 mg/kg in very sandy soils (3% clay and 72% sand) 14 feet (4.3m) below an eight-year-old swine lagoon. So deeper plumes can be expected in such soil conditions over a 25-year site life.

Organic Nitrogen and Subsoil Transformations

In calculating the plume depths, we conservatively assumed that organic nitrogen in the wastewater would be filtered out at the soil interface. However, Dr. Ham and associates also measured organic nitrogen comparable to the concentration of ammonium-N beneath most of the closed lagoons tested. Two abandoned swine lagoons contained organic nitrogen equal to about 80% of the mass of ammonium-N. The abandoned dairy lagoon was 60%. Ham stated that this organic N consisted of small manure solids, soluble organic acids and nitrogen in the microbial biomass beneath the lagoon.

To establish the land requirement for the "excavate and spread" remedial alternative, it was necessary to address the fate of the ammonium exported from the lagoon. The amount of stored nitrogen was about as expected at one closed cattle feedlot lagoon examined by KSU researchers. However, at a swine lagoon only about a third of the nitrogen was found that would have been expected by modeling the typical facility. Dr. Ham noted that the abandoned swine lagoons he and his associates studied were small and unrepresentative of newer facilities where ammonium-N soil concentrations would likely be higher and extend to much lower depths (Ham, 2001).

The soil core at the abandoned swine lagoon for which detailed data was presented by Ham contained a five-foot (1.5 m) layer of very sandy soil (CEC = 6). It is possible that a significant amount of the exported ammonium had already changed to nitrate and moved on. In Miller's study, soil cores were taken immediately after the level of an active lagoon was lowered to near empty. Miller returned two months later to do a deeper core in one lagoon and found that a significant amount of ammonium had already been transformed to nitrate in the top layer. The mass of ammonium under Miller's lagoon was roughly what would be expected from Ham's model, if we assumed a proportion of organic nitrogen similar to what Ham found.

On the other hand, KSU lab investigations suggested that some microbial uptake of ammonia NH_4-N would be expected (Reddi et al, 2000). This is supported by the substantial amounts of organic nitrogen found beneath these old lagoons. What happens to this organic nitrogen is unknown. However, its presence needs to be accounted for in our remediation cost model. Denitrification has been detected beneath lagoons sitting in groundwater. However, conditions for extensive denitrification would not be expected to be favorable in the vadose zone in the more typical setting. Despite the fact that these transformations are not well understood, we felt some subsoil loss of nitrogen needed to be incorporated into our assumptions. We reduced the modeled nitrogen export by a fourth and estimated the nitrogen species to be roughly in proportion to that found under the old lagoons examined by KSU researchers. Our calculations also incorporated individual average seepage rates for swine and cattle as measured by Ham.

CAFO PROFILE

A list of all federal permits (1000 animal units and larger) for swine and dairy facilities in Kansas, as of June 1, 2002, was obtained from KDHE (Newquist, 2002). Animal units (a.u.) relate to head as follows: dairy cow = 1.4 a.u., mature swine = 0.4 a.u., and piglet = 0.1 a.u. The list contained 109 swine permits and 25 dairy permits. Lagoon design data was extracted from KDHE files for 43 of these swine permits. Additional data was used from eight other swine permits, mostly nursery units just below 1000 animal units. A total of 101 swine storage basins and lagoons were examined.

Nine of the 25 dairy permits were selected to be representative of the study population size distribution. A total of 27 storage basins and lagoons were examined. Sedimentation channels at the dairies were typically only two to four feet deep (0.6 to 1.2 m) and were not considered. The average permitted size of the CAFO study population, which may include multiple lagoons, was 4,600 animal units (11,500 mature head) for swine and 5,000 animal units (3,571 head) for dairies. Averages for the selected samples were 4030 and 5580 animal units, respectively.

Average depth of the dairy lagoons was 17.3 feet (5.5 m) with a median of 20 ft (6.1 m). Average depth of the swine lagoons was 16.3 feet (5.0 m) with a median of 18 ft (5.5 m). The "footprint" in acres at the maximum liquid depth was recorded for each lagoon. Average surface area of swine lagoons was 3.1, acres (1.26 ha) and 3.0 acres (1.21 ha) for dairies. Average lagoon surface areas per 1000 animal units was 1.60 and 1.62 acres, respectively (0.65 and 0.66 ha). Approximately 60 % of the basins were constructed with internal side slopes of 3 to1 and 40% were 4 to1.

Layouts and depths of cattle feedlot runoff impoundments are almost infinitely variable because they are usually designed to fit the contours of the site, and because their capacity is a function of expected rainfall. The time required to accumulate a sufficient database to produce a defensible estimate of average lagoon acreage and depth was deemed excessive. Given also that the nitrogen plumes are considerably smaller than those associated with swine and dairy lagoons, cattle feedlot runoff impoundments were excluded from further analysis. Nonetheless, cleanup costs for cattle feedlot impoundments in certain geological settings may be significant.

APPLICABLE KANSAS REGULATIONS

Proper closure of CAFO impoundments is required only for swine facilities of 3,725 animal units and larger (9,312 mature head) under KAR 28-18a-22, effective January 1999. So far no impoundments have been closed under this rule, and detailed guidelines for cleanup have not been established (Friese, 2002). This rule states that, after the removal of “swine and other process wastes,” an impoundment may be closed as follows: (1) remove berms, level, and revegetate; (2) leave in place as a freshwater pond or reservoir, (3) retain for future use as part of a swine waste management facility or (4) other method approved by KDHE. Financial assurance is required based on a cost estimate in the closure plan. Kansas rules would seem to require removal of the solids and sludge in addition to the liquid.

Our review of KDHE permit files indicates that KDHE has not considered the cost of removing the plume of nitrogen contamination under the swine lagoons. For example, a swine CAFO operator in Norton County, Kansas, estimated it would cost only $4,100 to close his three-acre (1.2 ha) lagoon by turning it into an irrigation water storage pond. Likewise an operator in Pratt County estimated it would cost $73,000 to remove wastes and reclassify his 10 (4 ha) acres of lagoons as freshwater ponds. Removal of subsoil was not anticipated.

Use of an abandoned CAFO lagoon for freshwater storage would be risky since a substantial head of oxygenated, clean water is applied to the bottom of the impoundment saturated with ammonium. Indeed, a multi-university study group recently recommended that lagoons converted to freshwater ponds should be rinsed and refilled until a dissolved oxygen level can be maintained at 3 mg/l or greater (Jones et al., 2001). While considerable research (Ham, 2001) describes the process by which waste solids clog soil pores at the soil-sludge interface on the lagoon bottom, we are unaware of research that documents what happens when the lagoon contents are removed and replaced with clean water. The concern would be that particles in the soil pores would break down under aerobic conditions and not be replaced by new material. Thus seepage rates may increase over those previously described.

REMEDIATION ALTERNATIVES

Potential alternatives would be (1) phytoremediation in the lagoon bottom, (2) backfill and cover with clay and vegetation such as poplar trees, and (3) excavation and disposal as crop nutrients. KSU researchers conducted lab research on growing crops in soil obtained from the bottom of lagoons (Mankin et al., 2001). Though the crops grew well, they were able to take up less than one percent of the NH_4-N in a single growing season (KSU Research & Extension, 2001: Executive Summary). We would expect to see some inhibition of plant growth due to the salinity imparted by typical wastewater. Soil acidification caused by the nitrification process could also inhibit plant growth.

The researchers suggested that soil be excavated and spread on land after sampling to 12 feet (3.7 m) of depth at several locations on the lagoon bottom. It was noted that the introduction of plants into the lagoon bottom may aerate the soils through drying, tillage, and development of soil macropores from root channels. Since many years would be required for crops to take up all the nitrogen, deeper nitrogen would have plenty of time to nitrify and escape to groundwater. Thus, we did not further consider this option.

Backfill and Cover

This approach would isolate the plume and prevent further leaching of nitrogen. The cap would be constructed so that the surface would drain and excess moisture would be utilized by vegetative cover. Poplars or other deep-rooted trees could be established using the TreeWell® system (Quinn et al., 2001) to exert hydraulic control over moisture movement beneath the cap to a depth of 30 feet (9.1 m) or more from the surface. The trees would remove a limited amount of nitrogen in a single growing season, but over the course of 20 to 50 years, they should have greater impact.

Use of trees to maintain hydraulic control is recommended because of the many incidences, we are aware of, where ordinary fill and cap installations have failed. We believe that soils at the bottom and along the sides of lagoons at time of closure will be in a water-saturated state, and any additional moisture leaking through the cap would cause leaching through the accumulated mass of nitrogen. It may be possible to forgo the tree system in arid areas with annual rainfall below 20 inches. However, the cost saving is not sufficient to change the outcome of the analysis.

Excavate and Spread on Crop Land

The extent to which the excavated soil could be spread would be limited by crop uptake capacity and practical physical constraints related to land application. Material with higher concentrations would need to be spread on more acres. In a practical land application scenario, ammonium-laden soil would be excavated and laid out in windrows to dry. The various depth layers would be piled according to their inorganic-N concentration and eventually mixed to create a uniform product for spreading. Once adequately dried and blended, the material would be loaded into a truck-mounted manure spreader and applied to fields. Fields near CAFO's are often nutrient-saturated, and thus it would likely be necessary to export to other fields within a five-mile radius of the operation.

The act of excavation, windrowing, and occasional turning would encourage the process of nitrification. One could expect all of the ammonium-N and about 35 percent of the organic-N to become plant-available nitrogen (PAN) within 12 months (Moore et al., 2001; Midwest Plan Service, 1993). In subsequent years, the remaining organic-N would be sparingly available and of little consequence.

In the case of the swine lagoon with a 12-foot (3.7 m) deep plume, we predicted that 44,900 pounds NH_4-N and 30,000 pounds organic-N per acre of lagoon surface area (50,400 and 33,700 kg/ha) would need to be land-applied. We assumed that all of the NH_4-N and 35 percent, or 10,500 pounds per acre (11,795 kg/ha), of the organic-N would be plant-available within the first year of application. Thus a total of 55,400 pounds PAN and 48,000 cubic yards of soil per acre of lagoon surface area (62,195 kg/ha and 90,646 m^3/ha) would need to be land-applied. It would be impractical to apply more than 80 tons or 72.7 yds^3 of contaminated soil per acre (179.3 mt or 137.3 m^3/ha) because of the excessive soil compaction created by overlapping of manure spreader tire tracks. Thus application of the 48,000 yds^3 (36,700 m^3) of material would be physically limited to 660 acres (267 ha). Most Kansas crops can utilize 150 pounds PAN per acre-year (168.4 kg/ha-yr) and, at that rate, 1145 acres (464 ha) would be needed to receive the excavated lagoon soil. Thus crop nutrient needs controlled the acreage calculation in this case. See Table 1. On the other hand, physical limitations would control the amount of land needed to spread the less concentrated nitrogen in the material from open-lot dairies and confinement dairies with deep plumes in sandy soils.

RECOMMENDED CLEANUP STANDARD

We suggest that the lagoons be excavated to a depth where the NH_4-N concentration of the soil does not exceed 25 mg/kg. Background soil levels are typically less than 5 mg/kg. The recommended maximum of 25 mg/kg is similar to the Kansas Department of Health and Environment remedial level for nitrate in soils below eight inches in depth (KDHE, 1996), and it represents a level (90 lbs PAN/acre-foot or 331 kg/ha-m) that can be removed through phytoremediation techniques.

REMEDIATION COSTS

Costs for the backfill-and-cover alternative are outlined in Table 2. Table 3 outlines costs for the excavate-and-spread option. Both tables include costs for design, testing, on-site supervision, inspections, and reports. For the excavation and spread calculation, the depth of the nitrogen plume on the side slopes was assumed to increase in proportion to depth from zero at the maximum water level to the plume depths shown in Table 3. The earth moving costs are conservative in that they include additional costs associated with mobilizing equipment and labor to rural sites.

The cost of land application includes windrowing, turning with a front-end loader, loading into the manure spreader, and spreader expense. Combined material preparation and handling

Table 1. Land requirements for spreading waste from average-size lagoon.

Impoundment type	Surface acres per avg. lagoon	Basin depth (ft)*	N Plume depth (ft)**	Volume to excavate (cy)***	NH4-N (lb/surface acre)	Org-N (lb/surface acre)	PAN per surface acre	PAN per avg. lagoon	Acres needed for land app. @ max. of 150 lb PAN/ac avg. lagoon	Acres needed for land app. @ max. of 72.7 cy max/ac avg. lagoon
Swine	3.1	16	12	48,000	44,900	30,000	55,400	171,740	1,145	660
Dairy confinement	3.0	17	7	25,600	15,978	10,652	19,706	59,118	394	352
Dairy - open lot	3.0	17	4	14,500	5,182	5,182	6,996	20,988	140	199

* at maximum water level, add ft. to top of berm
** double this depth for sandy sites (CEC<11)
*** assume 3:1 slopes

conversion factors:
1 foot = 0.305 meters
1 acre = 0.405 hectacres
1 cy = 0.765 cubic meters
1 lb = 0.454 kilograms

expense would be about $1.50 per cubic yard ($1.96/cu. m). Spreading expense within a five-mile radius of the lagoon would cost about $2.20 per yard or $2.87 per cubic meter (Page, 2002). We have included in Table 3 a fertilizer credit for PAN at the current value of 18 cents per pound (40 cents per kg). Actual credits, if any, will vary according to patterns of land ownership and local market conditions. Some farmers may charge a fee for access to their land.

Table 3 shows that costs for remediation of the average size swine operation, 4,600 animal units, in typical silty clay-loam soils, would be $620,000. Similarly, the cost for a swine facility with a permitted capacity of 3,700 animal units, just under the size where financial assurance for closure is required in Kansas, would be $498,000. The data in Table 2 indicates that the same operations in sandy soils with deep plumes would use the backfill-and-cover option at $810,000 and $651,000, respectively. If we assume that a 3700 a.u. (9250 head) finishing unit is operated for 20 years with 2.5 cycles per year and a 6% loss/cull rate, the per head closure cost would be $1.14. However, closure costs should be eligible for substantial matching funds under the USDA's EQIP program. The cost for such a facility in sandy soils would be $1.50/head.

If the TreeWell® system is eliminated, as might be suggested for arid sites, the savings is about 9% of the total cost of remediation by the backfill-and-cover method as shown in Table 2. This is not sufficient to change the selected options in Table 4. We consider trees to be inexpensive insurance to maintain hydraulic control where the backfill-and-cover method is used.

Tables 2 and 3 do not include the cost of the initial closure steps already required by most state regulatory agencies, i.e. removal of the wastewater and sludge. This cost is significant. Based on

Table 2. Remediation costs in U.S. dollars for average-size lagoon by backfill-and-cover method.

Impoundment type	Surface area (acres)	Engineering design and oversight	Backfill material and earth work volume (cy)	Backfill cost ($3.75/cy)	Recontour volume (cy)	Recontour cost ($3.50/cy)	Seeding cost ($500/ac)	TreeWell® install (70 trees/ac) ($150/TW)	Maintenance cost for 25 yrs ($800/yr)	Total remediation cost	Cost per animal unit
Swine	3.1	11,800	60,000	225,000	14,100	49,350	1,550	32,550	20,000	340,250	175.61
Dairy	3.0	11,600	61,7000	231,375	14,000	49,000	1,500	31,500	20,000	344,975	186.29

* Lagoon surface acres per 1,000 animal units is 1.60 for swine and 1.62 for dairy.

the NRCS standard for lagoon closure, the North Carolina DENR estimated the cost of closure to be $42,000/acre ($103,740/ha) based on an estimate of $5 to $32/1000 gal ($1.32 to $8.45/cu. m) to remove lagoon contents (Jones et al., 2001). This figure compares to $84,000/acre ($207,500/ha) to remove a 12-foot (3.7 m) deep nitrogen plume ($261,253 in Table 3 divided by 3.1 acres).

SWINE AND DAIRY CAFOS IN KANSAS

Total population of federally permitted (1000 animal units or greater) swine and dairy CAFOs, obtained from KDHE records, is shown in Table 4. Total animal unit capacity for sites known to use synthetic liners in wastewater lagoons is also shown. This count also includes a large hoop-house facility that has no lagoon. We are not aware of any synthetic liners used at dairy sites. Sandy sites are estimated to comprise 30% of all sites in counties where the High Plains Aquifer lies in significant part. On this basis, 83% of all federally permitted swine facilities and 97% of all such dairies are situated over the High Plains Aquifer.

PROJECTION OF TOTAL COSTS

Costs for each remedial option are summarized in Table 4. In the third column, the most likely option in each category is selected and tabulated. Based on a cleanup standard of 25 mg/kg of NH_4-N, total cost to remove or contain the nitrogen beneath federally permitted swine and dairy wastewater management basins now in operation in Kansas would be about $55.9 million. If no credit is allowed for fertilizer value of the material, then the cost rises to $60 million. This figure is

Table 3. Remediation costs in U.S. dollars for average-size lagoon by excavate-and-spread method.

Impoundment type	Surface acres	Plume depth (ft)	Engineering design and oversight	Excavation volume (cy)	Excavation cost ($1.90/cy)	Regrading volume (cy)	Regrading cost ($.35/cy)	Handling, hauling, spreading ($3.70)	Fertilizer N credit ($.18/lb PAN)	Total remediation cost	Cost per animal unit
Swine	3.1	12.0	15,250	48,000	91,200	23,200	8,120	177,600	(30,913)	261,257	134.81
Swine	3.1	24.0	19,250	101,500	192,850	32,000	11,200	375,550	(30,913)	567,937	293.05
Dairy confinement	3.0	7.0	11,200	25,600	48,640	20,000	7,000	94,720	(10,641)	150,919	81.50
Dairy confinement	3.0	14.0	15,000	52,900	100,510	24,900	8,715	195,730	(10,641)	309,314	167.03
Dairy open lot	3.0	4.0	7,550	14,500	27,550	18,000	6,300	53,650	(3,778)	91,272	49.29
Dairy open lot	3.0	8.0	11,400	29,500	56,050	21,000	7,350	109,150	(3,778)	180,172	97.29

constrained somewhat by utilizing the backfill-and-cover option in sandy settings. The backfill-and-cover option has greater risks than the excavate-and-spread option in such settings. Its success is contingent on extended maintenance of the cover and plants, since it's unlikely that roots of plants like poplar trees or alfalfa can retrieve all or even most of the nitrogen under the lagoon bottom. On the other hand, use of excavate-and-spread could be limited by the very large land requirements needed for larger swine operations.

No costs were assigned to facilities currently using synthetic lagoon liners. Small nitrogen plumes may develop from pin-hole leaks. However, these are expected to be relatively insignificant, especially if operators use protective layers of low grade sand or soil to prevent major damage or otherwise employ means of leak detection. We did not address the desirability of leaving a large land depression after the plume is excavated and the basin recontoured. Depending on local

Table 4. Comparison of cost in millions of U.S. dollars of remediation of swine and dairy lagoons for Kansas by backfill-and cover versus excavate-and spread methods.

	Animal units in Kansas	**Backfill-and--cover method (x$1,000,000)**	**Excavate-and--spread method (x$1,000,000)**	**Selected option (x$1,000,000)**
Swine				
Soil liners				
Silt/clay loam	240,900	42.3	32.5	32.5
Sandy	67,400	11.8	19.8	11.8
Synthetic liners	196,600	NA	NA	NA
Sub-total swine	504,900	54.1	52.2	44.3
Dairy				
Confinement				
Silt/clay loam	59,600	11.1	4.9	4.9
Sandy	24,300	4.5	4.0	4.0
Open lot				
Silt/clay loam	29,400	5.5	1.5	1.5
Sandy	12,000	2.2	1.2	1.2
Sub-total dairy	125,300	23.3	11.6	11.6
Total	630,200	77.4	63.8	55.9

conditions, it may be possible to use the properly closed facility as a freshwater pond or to grow crops on the slopes.

AVOIDING FUTURE PROBLEMS

The obvious step is to incorporate into the design of CAFO wastewater impoundments provisions to prevent or minimize formation of the nitrogen plume. Seaboard Farms, Inc. has installed synthetic liners in lagoons sited at their very large finishing facilities built since 1998 in western Kansas. This decision may have been made at least in part to avoid very significant liabilities from the formation of nitrogen plumes under their four-to-eight acre (1.6 to 3.2 ha) lagoons.

Where suitable materials are available, size of the plume can be greatly diminished by building a liner consisting of heavy clays with CEC's of 30 or more, optimally compacted to a depth of two or more feet (0.6 m). In effect, many more sites for ammonium adsorption are provided at the sludge interface. This liner must also be covered with a low-grade sand protective layer to prevent puncture damage and drying and cracking. We would recommend incorporating preventative measures into Kansas regulations for CAFOs, at least those built above unconfined aquifers. This would seem preferable to requiring financial assurance from smaller operators who may have difficulty obtaining bonds or letters of credit.

CONCLUSIONS

Based on a cleanup standard of 25 mg/kg of NH_4-N, the total cost to remove or contain the nitrogen beneath federally permitted swine and dairy wastewater management basins now in operation in Kansas would be about $55.9 million. If no credit is allowed for fertilizer value of the material, then the cost rises to $60 million. In most cases, the least costly remedial option would be the excavation and spreading of the contaminated material on farmland. However, deep plumes in sandy soils and limited access to farmland may dictate use of the backfill-and-cover option. The remedial cost for some swine operations not currently required to provide financial assurance for closure is estimated to range from $500,000 to $650,000, not counting the cost of wastewater and sludge removal. These figures suggest that a potential risk exists for county and/or state taxpayers if some of these facilities are abandoned without a thorough cleanup. These risks may be significantly reduced if new facilities are required to install suitably protected synthetic liners or thick soil liners with a high clay content.

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