Topical Session E: Nutrients

Hydrogeologic Settings of Earthen Waste Storage Structures Associated with Confined Animal Feeding Operations in Iowa

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Earthen Waste Storage Structures (EWSS) that store waste from animal feeding operations have raised serious concerns about ground-water and surface-water contamination risks. Thirty-four of 639 permitted EWSS in Iowa were investigated to characterize their hydrogeologic setting. Sites were selected to proportionally represent five aquifer vulnerability regions of Iowa. Data used in the analysis included digital-soils data from the Natural Resources Conservation Service, topographic data from the U.S. Geological Survey, and oblique aerial photographs taken at 1,000 feet (ft) altitude.

Nearly 18 percent of the 34 selected sites were constructed over alluvial aquifers. Contaminants reaching these aquifers could affect many water supplies in the State. Sites located on alluvial aquifers also lie in flood plains with a continual risk of flooding and contamination of surface water from manure application and structure failure. High and fluctuating water tables associated with floods may compromise EWSS liners increasing the risk of failure. Large areas within 2 miles of most sites have soils with a saturated permeability of $\geq$ 1 inch per hour (in/hr). These areas also include substantial well-drained soils or moderately- to well-drained soils. The dominance of EWSS depths exceeding 10 ft and areas with water tables less than 5 ft deep, suggests that most sites are below the water table. The frequency of sites with a combination of these indicators of contaminant movement indicates EWSS expose ground water to a substantial risk of contamination. Ephemeral streams were found within 500 ft at 21 percent of the sites, and perennial streams were found within 500 ft at 12 percent of the sites. One site had been built by impounding the valley of a small ephemeral stream, and one was immediately upstream from a major aquatic recreation area. Many sites had unmapped drainageways that led from the EWSS to ephemeral or perennial streams.

Reduction of risks to ground-water and surface-water resources by EWSS may be attained by using siting criteria that incorporate geologic, hydrogeologic, and soils data as outlined in this paper. EWSS sites built on alluvial aquifers should not be permitted unless measures are taken to ensure that the aquifer is not being contaminated. Controlling the timing of manure application and avoiding manure application on frequently flooded soils, such as those on flood plains, may reduce the risk of contamination of ground water and surface water. Application of well established, scientifically defensible ground-water-monitoring techniques should be used to locate the position of the water table during construction and throughout the life of the EWSS. These techniques may help identify whether the recommended hydraulic separation between the EWSS and the water table will be maintained. In many instances, a shallow water table should preclude siting of an EWSS. Setback distances from surface-water courses should be based on local hydrogeologic and topographic conditions. These considerations, used with appropriate construction designs, would reduce the potential for contamination of surface water resulting from seepage, overflow, or failure of EWSS. Uniform setback distances may not be appropriate for all topographic, hydrogeologic, and ecologic settings.

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Nutrients Available From Livestock Manure Relative To Land Use

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The U.S. Department of Agriculture in general, and the Natural Resources Conservation Service (NRCS) specifically, are required to conduct a periodic assessment of the state of the Nation's agricultural resources, commonly referenced as the Resource Conservation Assessment (RCA). These assessments vary in degree of complexity and the number of resources assessed, but generally focus on the following five resources--soil, water, plant, animal, and air.
During planning for the third RCA, the leadership of NRCS requested a comprehensive evaluation of the impacts of animal agriculture on the Nation's resources. With the rapid expansion of the poultry and swine industry into traditional locations and new locations, there was a general impression that adequate land resources for manure utilization could be a limiting factor.

This paper will describe the analysis process used to relate manure nutrient availability to the land resource as the animal population and location of production changed from 1992 to 1997. County level livestock numbers from the 1992 and 1997 Census of Agriculture were combined with nationally accepted values of manure characteristics to determine the amount of nitrogen and phosphorus available for use as nutrients in agricultural production. These nutrients were balanced against the potential uptake of nitrogen and phosphorus for agricultural production on acreage, also reported to the Census of Agriculture.

The analysis results in the identification of counties where manure nutrients meet or exceed the nutrient needs of the agricultural production in the county. This paper will conclude with a discussion of the shift in potential problem areas between 1992 and 1997 and the environmental ramifications of these shifts.

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Predicting Surface-Water Impacts from Concentrated Animal Feeding Operations: A National Analysis

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The U.S. Environmental Protection Agency has developed a methodology to quantify national-level water-quality impacts due to nutrient loads from concentrated animal feeding operations (CAFOs). The methodology provides a screening-level analysis of impacts to reservoirs, based on trophic status and hypolimnetic dissolved-oxygen concentration. The methodology incorporates various watershed model results, databases, and water-quality models. The watershed portion of the model is based on the eight-digit hydrologic cataloging unit and utilizes previously published nutrient export estimates generated by the U.S. Geological Survey's SPARROW model. The watershed-export estimates are adjusted using data from a manure-nutrient database, which was developed to estimate the amount of nutrients generated by livestock type and farm size in each watershed. A lake-response model is used to predict long-term responses of hypolimnetic dissolved-oxygen concentrations. A stream model also is being developed to estimate ammonia and dissolved-oxygen concentrations. Effects of policy changes on nutrient runoff are estimated externally, using a field-scale model, and then incorporated into the water-quality analysis.

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Phosphorus Geochemistry in Two Coastal Plain Watersheds with Different Land Management Practives: Processes Involving Organophosphorus Compounds

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Popes Creek, Virginia, is the site of the National Park Service's George Washington Birthplace Monument. The intensity of agricultural activities in this watershed has diminished in this century. The Pocomoke River, Maryland, is the location of major poultry industry where more than 82 million chickens are raised each year. The manure from these chickens is used to fertilize fields in the Pocomoke watershed and water from agricultural fields drains into the upper Pocomoke River. To evaluate the condition of downstream sediments in areas where each stream empties into a larger body of water, box cores were taken of bottom sediment: (1) where Popes Creek empties into the Potomac River, and (2) where the Pocomoke River empties into the Chesapeake Bay.

Box cores were collected in August and November of 1998, and in April 1999, in the Pocomoke River. Box cores were collected in April 1999 in Popes Creek. One to two centimeter intervals of sediment were separated in a nitrogen-filled glove bag. Sediment samples were centrifuged and interstitial water filtered through a 0.2-micrometer membrane. Solids were analyzed for total phosphorus, aluminum, calcium, and iron. Anion analyses of the interstitial water included soluble-reactive phosphate, orthophosphate, chloride, nitrate, and sulfate. Cation analyses of the interstitial water included aluminum, calcium and iron. Concentration gradients from the sediment water-interface to a depth of 20 centimeters show that iron and phosphate concentrations are larger in interstitial water in sediments from Pocomoke River than in interstitial water in sediments from Popes Creek. Because the total phosphorus concentrations in sediments from the two watersheds are similar, a difference in bacterial populations was tested.

The manure of chickens contains phytic acid (inositol hexaphosphoric acid) because chickens can digest less than 30 percent of phytic acid found in the corn in their diets. Microbiological experiments were done to test the response of bacteria in downstream sediments from each watershed to the presence of phosphorus-containing compounds in poultry diets. Incubations of sediment from both watersheds used a medium containing no phosphorus or a medium to which either phytic acid or pyridoxal-5-phosphate, a phosphate-containing compound of the vitamin B-6 complex found in animal feeds, was added as a sole source of phosphorus. Phytic acid or pyridoxal-5-phosphate stimulated the growth of bacteria in sediments from Popes Creek but did not stimulate the growth of bacteria in sediments from the lower Pocomoke River. The sediment from Pocomoke River bacteria were able to grow with, or without, phosphorus in the medium, suggesting that these bacteria are not phosphorus limited.

Similarities and differences in the bacterial population with respect to phosphorus cycling are being investigated. Hypotheses that might explain different responses of the bacterial populations to nutrient adequacy or limitation include: (1) differences in the amount and speciation of phosphorus in the two watersheds, (2) different responses to various nutrient conditions by bacteria in sediments from these two watersheds, (3) differences in redox conditions at sampling sites reflect different bacterial communities, and, (4) antibiotics might be having an affect on microbial populations in the watersheds.

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Nutrient Imports to Support AFOs in the Black River Basin, North Carolina

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Animal Feeding Operations (AFOs), primarily swine and poultry-production facilities, have become particularly concentrated in the basin of the Black River, a coastal plain tributary of the Cape Fear River in eastern North Carolina. The concentration of AFOs in this small area drives a need for imports from outside the basin of substantial amounts of corn, wheat, and soy meals used as the base of animal feeds. Calculation of net imports of nitrogen and phosphorus, based on net feed material imports and manure nutrient outputs, shows that very high percentages and quantities of these imported nutrients are deposited in the basin. These quantities exceed the amounts of commercial fertilizer used in the basin but have not substantially replaced those fertilizers. Consequently, nutrient imports to the Black River basin now greatly exceed those occurring in the 1980s, with as yet incompletely understood consequences for regional air and water quality. However, studies to date have already documented a variety of impacts that may be attributed to AFOs.

The geographic concentration of AFOs and the consequent net imports of very large amounts of "new" nutrients to small areas pose important management challenges. Efforts should be made to determine the fates of imported nutrients and their impacts on regional ecosystems. Comprehensive nutrient-management plans that incorporate nutrient-export strategies should be considered. Regulatory efforts should include consideration of the spatial and temporal cumulative effects of concentrated AFOs.

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Interaction Between Surface and Ground Water in the Transport of Nutrients from Animal Wastes in Karst Terrain

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Animal wastes contain nutrients that, if delivered in sufficient quantities, have potential to negatively impact surface and subsurface water quality. The Savoy Experimental Watershed (SEW) was established as a site for long-term studies of animal-waste impacts on surface and subsurface water quality in karst terrain such as the Ozark Highlands. The SEW is a collaborative effort between the University of Arkansas; U.S. Department of Agriculture, Agricultural Research Service; U.S. Geological Survey; and the Arkansas Department of Environmental Quality and involves an interdisciplinary team of scientists. The most intense monitoring activities have been directed at Basin 1 of the SEW, a 147-hectare watershed immediately adjacent to the Illinois River. Surface cover in Basin 1 is divided between forest (60%) and pasture (40%), and the entire watershed is grazed by beef cattle (*Bos taurus*). Poultry litter (bedding material and manure) is applied at varying intervals and amounts to pastures within the basin.

Weirs were installed on two continuously flowing springs (Langle and Copperhead) adjacent to Basin 1 and at the basin outlet to measure flow and water-quality parameters. Over 20 shallow, 5-centimeter diameter monitoring wells have been installed primarily in alluvial areas near the outlet of Basin 1 while 3 deep [>30-meter (m)] wells allow sampling of the shallow aquifer above the regional confining layer. Additional sampling sites including several small springs, a nearby tributary (Clear Creek) and the Illinois River also are monitored for several water-quality parameters including nitrate (NO_3-N), ammonia (NH_3-N), and dissolved reactive phosphorus (DRP).

Nitrate and DRP concentrations in spring baseflow samples are consistently higher for Copperhead Spring as compared to Langle Spring. This trend may be related to higher animal waste applications in the Copperhead Spring recharge basin. Concentrations for NO_3-N and DRP range from 1 to 9 milligrams per liter (mg L^{-1}) and from 0.02 to 0.05 mg L^{-1}, respectively, with the higher NO_3-N observed during low-flow conditions in late summer. Only very low concentrations of NH_3-N have been detected (<0.005 mg L^{-1}). Samples collected during two storm events in February 1999 indicated that NO_3-N concentrations peak at the leading edge of storm hydrographs. Very little organic N or NH_3-N was transported during these events. Nitrate concentrations ranged from 3 to 8 mg L^{-1} for Copperhead Spring and 1.5 to 3.5 mg L^{-1} for Langle Spring, respectively. Phosphorus concentrations were less than 0.055 mg L^{-1} during the storm events with elevated total P levels early in the storm hydrograph. Dye-tracing studies and analyses of runoff data indicate that surface runoff is routinely captured by both springs and that the degree of capture varies with runoff volume.

Results of monitoring activities at the SEW indicate significant transport of NO_3-N in Basin 1 via surface and subsurface flow paths while low concentrations of DRP in spring and runoff water indicate effective retention of P in soil layers. Low concentrations of sediment-bound N and P suggest that erosion is not a significant factor in nutrient transport within this basin. Langle and Copperhead Springs capture surface runoff, a process that effectively bypasses further nutrient retention by surface soil layers.

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Field Evaluation of Animal-Waste Lagoons: Seepage Rates and Subsurface Nitrogen Transport

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Earthen lagoons are an integral part of the waste-management plan at many animal feeding operations (AFOs). Lagoon waste contains high concentrations of N, P, salts, and other nutrients that, in many cases, are applied to farmland as liquid fertilizer. However, while the waste is being stored and treated in the lagoon, subsurface-seepage losses may affect soil and water quality near the facility. Research was conducted to develop water-balance methods and instrumentation for measuring whole-lagoon seepage from large-scale, commercial AFOs. Seepage(s) losses were calculated as the difference between changes in waste depth (D) and evaporation (E) when all other inflow and outflow were precluded. Waste-level recorders were developed that could measure D to within 0.16 millimeter (mm). Evaporation was quantified using floating evaporation pans and meteorological models. Different strategies for calculating E and S were compared. Results showed that S from lagoons could be determined to within ± 0.5 millimeter per day (mm d^{-1}) by making precision water-balance measurements over short periods (5 to 10 days), if E was less than 6 mm d^{-1} (Ham, in press).

Water-balance methods were used to study seepage losses and nitrogen export from soil-lined lagoons at ten different swine and cattle feedlots in southwestern Kansas. Lagoons ranged in size from 0.5 to 2.5 hectare (ha) and had waste depths between 1.5 and 5.6 meters (m). Compacted-soil liners were between 0.30 to 0.46 m thick and built with native soil or, in some cases, a soil-bentonite mixture. Seepage rates from the lagoons ranged from 0.02 to 2.5 mm d^{-1}, with an overall average of rate of 1.2 mm d^{-1}. At some locations, seepage results were combined with data on lagoon geometry and liner construction to estimate the in-situ permeability of the compacted liner. In lagoons built with silt loam liners (no bentonite), permeabilities on a whole-lagoon basis were about five times less than those measured from soil cores collected prior to the addition of waste. Results imply that permeability was reduced by organic sludge on the bottom of the lagoons. The average ammonium-N (NH_4^+-N) concentrations in the swine-waste and cattle-feedlot lagoons were 673 and 98 milligrams per liter, respectively. Calculated NH_4^+-N export rates (seepage losses) from the swine waste lagoons were between 2,000 and 3,000 kilograms per hectare per year (Ham and DeSutter, in press). Analysis of soil cores collected beneath 11- to 20-year-old lagoons showed that a large fraction of the NH_4^+-N in the leachate remained in a shallow (for example, 6 m) adsorption zone directly beneath the lagoon. When lagoons are closed, emptied, and dry; NH_4^+-N could convert to nitrate and more readily move towards the ground water. More information is needed regarding the fate of NH_4^+-N deposited in soil (vadose zone) beneath lagoons.

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Treating Livestock Manure: Available Technology, Effectiveness, and Costs

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Recycling of livestock manures by land application for plant uptake and crop production is a traditional and proven technique. When properly carried out, targeted land application enabling crop uptake can be the basis of an environmentally safe and friendly method of manure management. However, the pressures on animal farming are increasing every day, and in some cases, existing methods are not adequate for dealing with the environmental problems arising from livestock manure. Farms located close to housing can expect odor nuisance complaints and those near rivers, streams, and lakes are all too aware of the penalties of pollution following runoff or spillage. The problems related to manure production and handling run deeper, with a range of less apparent pollution issues now becoming evident. Of increasing concern is the potential for spread of diseases (air or waterborne) and emissions to air, especially odor of hydrogen sulfide and ammonia.

Processing and/or biological treatment of manure is a step beyond currently accepted good agricultural practice in the Midwest that may be justified only when odor problems or water-pollution risks have been identified in a manure/nutrient management plan. The cost and level of management skill required for the implementation and operation of treatment schemes should not be underestimated and must be added to the cost of collecting, storing, and spreading the manure.

In this paper, we summarize existing information on: (1) alternative treatment technologies for livestock manure (mechanical solid separation, physical-chemical treatment, and biological treatment), (2) effectiveness of systems in reducing odor and gaseous emissions, organic matter (COD, BOD and solids), nutrients (N and P), and bacterial indicators; and (3) systems capital and operational costs.

Although there is still much debate on the advantages and disadvantages of different treatment strategies, a range of perceived benefits may include abatement of odor, stabilization of organic matter and nutrients, improvement of handling characteristics in storage and during spreading, and control of pathogens. The implementation of manure-treatment systems has a clear role in the overall management scheme, but most of these systems remain to be proven as either effective and/or economical enough and practical at the farm level.

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