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

A Report to the Legislature of the State of Iowa
January, 1999

by

William W. Simpkins[1]
Michael R. Burkart[2]
Martin F. Helmke[3]
Trenton N. Twedt[3]
David E. James[4]
Robert J. Jaquis[5]
Kevin J. Cole[6]

Associate Professor[1] and Graduate Research Assistant[3]
Department of Geological and Atmospheric Sciences
Iowa State University
Ames, Iowa 50011

Hydrologist[2], Geographic Information Specialist[4], Computer Assistant[5],
and Agricultural Research Technician[6]
USDA-ARS National Soil Tilth Laboratory
2180 Pammel Road
Ames, Iowa 50011

Executive Summary

Earthen Waste Storage Structures (EWSS) store waste generated by confined animal feeding operations. Concerns about the impact of EWSS on groundwater and surface water have increased in recent years. 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 the State. Data used in the analysis included soil maps from the NRCS, topographic maps from the USGS, and oblique aerial photographs taken at 1000 ft altitude for this study.

Nearly 18 percent of the 34 selected sites were constructed over alluvial aquifers, the most vulnerable aquifers in Iowa. Entry of contaminants into these aquifers could reach municipal and private water supplies. Sites located on alluvial aquifers also lie in flood plains where there is a continual risk of flooding and contamination of surface water from manure application and structure failure. Although regulations require that the top of the EWSS be 1 ft above the 100-year flood [Chapter 65.15(10)], high and often fluctuating water tables associated with frequent, small floods may compromise EWSS liners and increase the risk of failure. Large portions of the soils within 2 miles of most sites have a saturated permeability of $\geq$ 1 in/hr. Many of these areas also include substantial well or moderately to well drained soils and soils with seasonally high water tables less than 5 ft from the land surface. The frequency of site areas with a combination of these indicators of potential chemical leaching indicates EWSS expose groundwater to an increased risk of contamination. 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. This setting poses a risk for groundwater contamination and may violate the recommendations in Chapter 65.15(7)a. 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 of a major aquatic recreation area. Many sites had unmapped drainageways that led from the EWSS to ephemeral or perennial streams.

Further reduction of risks to groundwater and surface water resources by EWSS may be attained by using regulations that incorporate additional geologic, hydrogeologic, and soils data as outlined in this report. 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 groundwater and surface water. This analysis shows that many of the EWSS were constructed in areas with shallow water tables. Application of well established, scientifically defensible groundwater monitoring techniques should be used to locate the position of the water table during construction and throughout the life of the EWSS. These methods 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 based on local hydrogeologic and topographic conditions and EWSS construction methods 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 in Iowa.

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Introduction

Earthen Waste Storage Structures (EWSS), built of locally derived earth materials, are commonly used by livestock farmers to store waste water and manure for treatment or land spreading. The last decade has seen a rapid increase in the number of EWSS used for livestock waste, particularly for large swine confinement operations. This trend has been accompanied by an increase in spills, ruptures, and leaks that are associated with these structures. Not surprisingly, there has been an increase in public concern about the potential of these structures to leak or fail and contaminate water resources. As a result of this concern, the Iowa Legislature provided funds to Iowa State University in 1997 "...to determine the extent to which structures [EWSS] contribute to point and

The purpose of the overall study was to assess the potential for EWSS to contaminate water resources in Iowa. The purpose of this report is to characterize the hydrogeologic setting of representative EWSS and to determine their potential to affect water resources. For this report, water resources include both surface water and groundwater. Surface water (lakes, perennial streams, ephemeral streams, reservoirs, and wetlands) may be contaminated directly by spills, leaks, or flooding and indirectly by waste intercepted by tile drains. A perennial stream flows continuously throughout the year. An ephemeral stream flows only in response to precipitation (Bates and Johnson, 1980). Groundwater in aquifers and confining units may be contaminated directly by seepage through the bottom or sides of an EWSS, from leaching of contaminants in manure that is spread on land, from surface water contaminated during flooding, and by contamination of small tributary streams that lose water to alluvial aquifers.

Earthen Waste Storage Structure Trends in Iowa

Earthen waste treatment lagoons were originally used in Iowa for storage and later treatment of wastewater. Glanville et al. (1998) report that about 715 municipalities and semi-public entities in Iowa use earthen waste lagoons presently to treat and store wastewater. Medium to large-scale livestock producers adapted the earthen basin technology for on-farm manure management in the early 1990s in Iowa. As a result, permits for livestock-related EWSS issued by the Iowa Department of Natural Resources (IDNR) rose from less than 10 annually in the 1980s to 170 in 1994 (Agena, 1998). As of December 1997, there were 639 permitted livestock confinement operations with EWSS.

Swine production has driven the increase in EWSS at both the state and national levels. This increase has been fueled by a rapid expansion of confined animal feeding operations with more than 1,000 animals. The number of farms in Iowa that raise swine has decreased nearly 80 percent during the past 26 years, from 90,000 in 1970 to 18,000 in 1996 (Seigley and Quade, 1998). The number of animals per farm increased 332 percent (from 180 to 778 animals) during that time. Operations with greater than 13,333 animals comprise 1/6 of the total confinement facilities and nearly 50 percent of these facilities are located in north central Iowa (Seigley and Quade, 1998).

Regulation of Livestock Confinement Facilities

The IDNR maintains lead regulatory authority for confined animal feeding operations and EWSS. A confined feeding operation is defined as a totally roofed animal feeding operation in which manure is stored or removed as a liquid or semi-liquid. EWSS are uncovered earthen impoundments that are constructed from native materials on site rather than concrete or imported materials. The process of construction involves excavation, sidewall construction with berms, and liner compaction, all of which is important to the long-term hydrologic integrity of the structure. EWWS are generally of two types, basins and lagoons. Basins provide short-term storage of undiluted manure waste and can hold only 6 to 8 months prior to spreading. The IDNR requires that waste be removed at least twice a year and spread on the land. Solids and liquids in basins should be mixed prior to application in order to provide a uniform nutrient source. Because of its higher nutrient content, basins require more land than a lagoon in order to spread the waste and stay within the application guidelines.

Lagoons contain diluted manure waste, and provide partial treatment and long-term storage of the waste. Mixing it with water increases the volume of manure waste. Anaerobic conditions and bacteria reduce the nutrient content of the waste. Single-stage and multi-stage lagoon structures exist in Iowa. Multi-stage lagoons transfer effluent from the first cell to the second cell for additional biological treatment which further reduces nutrients, particularly nitrate. Liquid waste is removed and applied to land at least once annually as required by the IDNR. The nitrogen content of the stored material regulates the subsequent application of wastes on land. Because of the reduced nitrogen content, a greater volume of liquid from a lagoon can be applied per unit area than from a basin serving a similar number of animals.

Current regulations for EWSS are found in Chapter 65 of the Environmental Protection Commission Section 567 of the Iowa Administrative Code. Many of these regulations were copied from the regulations for municipal lagoons in the state. House File 519, enacted in 1995, required a manure management plan that identifies the application area for the manure. It also placed limits on the total nitrogen that could be applied on fields in excess of crop needs. More recent revisions to the Chapter 65 Animal Feeding Operations rules required stricter design and construction standards, restricted spray irrigation, and gave greater responsibilities to the site engineer during the construction process. Chapter 65 is presently being revised at the time of this writing.

Study Design

In 1997, public concern about groundwater and surface contamination from EWSS prompted the State of Iowa Legislature to pass HF 708. Section 11, entitled Animal Feeding Operations, appropriated $200,000 to Iowa State University to study the impact of EWSS. The study reported here is part of a three-part study between our research group (Department of Geological and Atmospheric Sciences and National Soil Tilth Laboratory) and those in the Department of

Agricultural and Biosystems Engineering (ABE) at Iowa State University. The objectives of the overall study were: 1- determine, using a mass balance approach, how well the maximum design seepage limitation of 0.0625 in/day is met in a representative sample of basins and lagoons (ABE); 2- characterize the hydrogeologic setting of representative basins and lagoons and determine their potential to seep into groundwater or enter surface water bodies (Geology); and 3- characterize the operating record of representative EWSS and determine whether those operation or maintenance procedures contribute to groundwater or surface water contamination (ABE).

Research plans were finalized in the spring of 1998 and funds were made available to this part of the study in the summer of 1998 with a completion date of January, 1999. A unique requirement of this study was that "… the identity of a site…shall be confidential…and the findings…shall not be used in a case or proceeding brought against a person based upon a violation of state law." Because of this requirement of confidentially, certain data could not be published in this report. Habitual violators of regulations were excluded from the study.

The study was limited to sites with EWSS permitted between 1987 and 1994. This time period was chosen for two reasons. First, permits issued before 1987 were not easily accessible in the digital database needed for site selection. Second, evidence in the literature suggests that freeze-thaw, desiccation during low-water levels, bioturbation, overland flow, and groundwater inflow cause deterioration in liners and sidewalls of EWSS (Glanville et al., 1998). EWSS at least 4 and up to 11 years old were selected to allow time for these processes to occur and for evidence of outward seepage to manifest itself. The DNR issued 639 permits for EWSS that are recorded in a digital data base including 404 basins (65 percent) and 212 lagoons (35 percent). The type of structure was not defined in 23 permits and the number of sites actually constructed is not known (Figure 1, Table 1).

		Type of Structure			Type of Animals		
Aquifer Vulnerability Class	**Total**	**Lagoons**	**Basins**	**Other**	**Swine**	**Beef & Dairy**	**Poultry**
Alluvial aquifers	**57 (9%)**	**17**	**33**	**7**	**49**	**7**	**1**
Drift aquifers	**159 (25%)**	**41**	**114**	**4**	**147**	**7**	**5**
Aquifers confined by thin drift	**102 (16%)**	**49**	**50**	**3**	**98**	**2**	**2**
Aquifers confined by moderate drift	**221 (35%)**	**76**	**141**	**4**	**212**	**7**	**2**
Aquifers confined by shale	**100 (16%)**	**29**	**66**	**5**	**89**	**10**	**1**

Table 1. Classification of all permitted EWSS by aquifer vulnerability class.

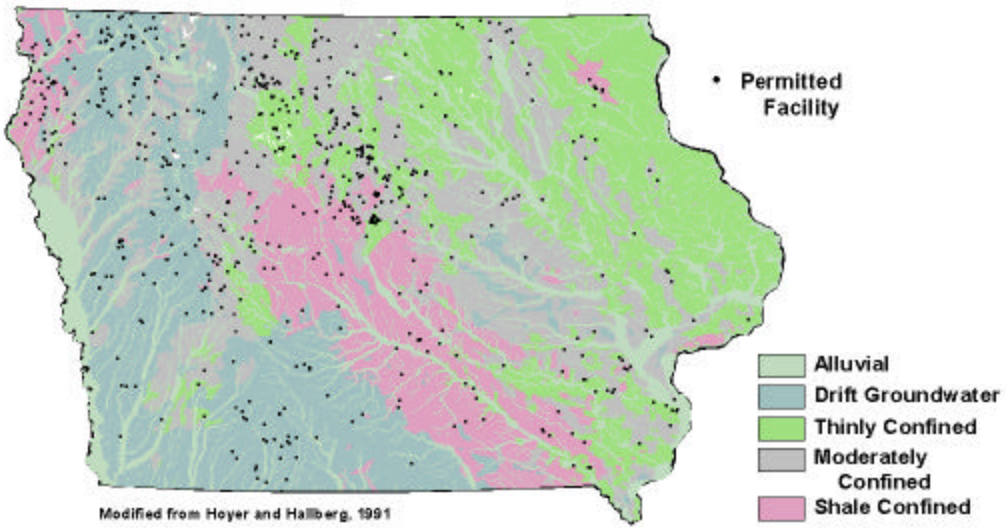

Figure 1. Permitted Earthen Waste Storage Structures (N = 639).

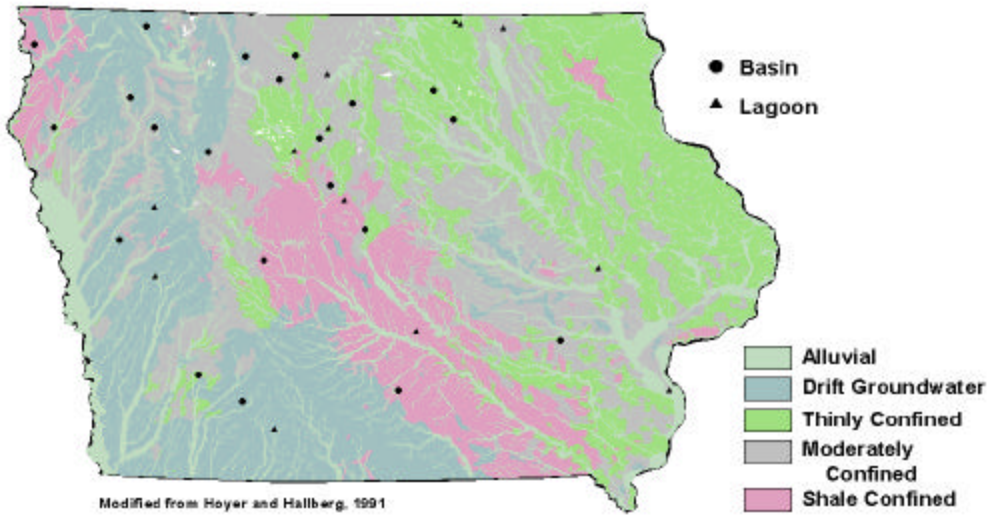

Figure 2. Distribution of study sites in the Aquifer Vulnerability regions.

A questionnaire was sent to 439 owner/operators of facilities permitted between 1987 and 1994 to acquire more information about specific practices and operations at sites and to seek initial permission for a site study. The project received 124 positive responses to the questionnaire. A digital map of the Groundwater Vulnerability Regions of Iowa (Hoyer and Hallberg, 1991) was used to classify the groundwater vulnerability region at each site that received a response. This initial screening provided the basis for selecting a sample distribution representative of the important hydrogeologic settings in Iowa. The classification provided by Hoyer and Hallberg (1991) was reduced to five categories, termed Aquifer Vulnerability regions in this report. The categories included Alluvial Aquifers, Drift Aquifers, and confined aquifers overlain by Thin Drift (< 100 ft), Moderate Drift (100 to 300 ft), and Shale. Fifty-six primary and secondary sites were selected for further investigation. Owner/operators were asked to sign a Memorandum of Understanding (MOU) that allowed ground and air access to the site. A final group of 40 sites was selected from the positive responses to the MOU. The 40 sites are a representative sample of the total number of sites located in each of the five Aquifer Vulnerability classes (Table 1). Six of these sites were subsequently eliminated from the study because field information showed they were not suitable for testing. The remaining 34 sites were used for the study (Figure 2).

Sources of Data

Three sources of data were used to interpret the hydrogeologic setting of each site: soils data, topographic data, and aerial photographs. Soils data were obtained from the Map Unit Identification Records (MUIR) digital data base for Iowa, which is maintained by the Soil Survey Division of the Iowa Department of Agriculture and Land Management and Iowa State University (www.statlab.iastate.edu/soils/muir/download.html). Digital topographic data and scanned images of topographic maps from the U.S. Geological Survey were also used in the analysis. These were digitally altered to remove unique, identifying features for each site. Oblique, low altitude (1000 ft) aerial photographs of each site area were taken from a fixed-wing aircraft.

Soil Variables

Soils data were used to assess the potential for manure from EWSS to leach to the water table or to run off from fields to which it may be applied. A 2-mile area around each EWSS, defined as the site area, was delineated as a means of indicating the area likely to receive manure applications from the EWSS. Soil variables selected for these analyses were permeability, Hydrologic Group, flood frequency, and depth to the water table.

Soil permeability is the quality of the soil that enables water or air to move through it (Soil Survey Staff, 1996). Permeability is considered to be equivalent to saturated hydraulic conductivity. Equivalent vertical permeability was calculated for each soil using the formula in Fetter (1994). Soils with larger values of permeability possess a greater potential for transporting contaminants to groundwater. A value of 1 in/hr was used as a conservative threshold between high and low values of permeability for manure application.

Hydrologic Group is a variable that incorporates soil properties that influence runoff potential and infiltration (Soil Survey Staff, 1996). Soils with large to moderate infiltration rates (Groups A and B) have a high potential to transmit contaminants to groundwater. Soils with slow to very slow infiltration rates (Groups C and D) have a greater potential for contaminants to run off.

The depth to water table indicates the distance to the saturated free surface. Seasonally high water table is a measure of the shallowest depth to saturation that may be expected during a typical year (Soil Survey Staff, 1996). Soils with seasonally high water tables provide relatively short flow paths for contaminants to reach the water table (groundwater). Presently, Chapter 65 rules recommend that the top of the lagoon or basin liner be at least 4 ft above the water table. If the water table is less than 2 ft below the top of the liner, then, a synthetic liner shall be provided.

Flood frequency is the number of times flooding is likely to occur during a period of time (Soil Survey Staff, 1996). The values used in this analysis were for floods of a 1-year return period. Frequent floods have a 50 percent chance or more of occurring in any one year, while occasional floods have a probability of 5 to 50 percent in any year. Manure applied to soils with the high probability of flooding is most likely to contaminate nearby streams. Presently, Chapter 65 only requires that the top of the EWSS be above the 100-yr flood plain.

Topographic Maps

Topographic maps were used to identify hydrologic and cultural features in the immediate area surrounding each site, although proper names of unique, identifying features were removed to avoid identification of individual sites. The maps were also used to measure the approximate distance to important features that may influence or be affected by the operation of EWSS or the application of manure in the site area. Examples of such features included surface-water bodies, communities, institutions, and recreational facilities. The maps were also used to describe slopes and the landscape surrounding each site. Landscape features were used in combination with geologic and soils maps to interpret the surficial geologic material and the geologic material at the base of the excavated EWSS.

Aerial Photography

Oblique aerial photographs were taken from a fixed-wing aircraft at an altitude of approximately 1000 ft to facilitate interpretation of the geomorphologic and hydrogeologic features of the site and site areas. Flights occurred during the summer of 1998. A 35-mm automatic camera with a 28-105 mm zoom lens was used to take color slides, which were later scanned for inclusion in the report. The slides were useful for confirming the position of the site in relation to landscape and hydrologic features. Slides, topographic maps, and maps of soil drainage classes within two miles of a site were assembled to characterize each site.

Results

Hydrogeologic characterizations, including the Aquifer Vulnerability region, a description of the Soil Series, the geologic materials present, and the geomorphic setting were completed for both the permitted sites and the site area (Appendix I). A summary of these findings and selected variables used in the final interpretations is provided in Table 2.

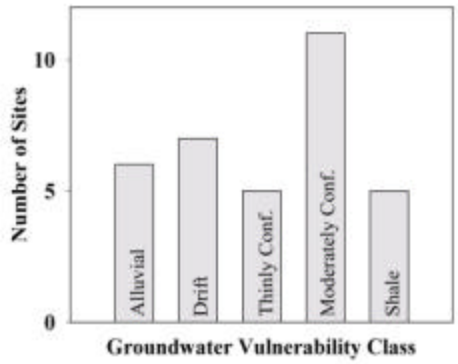

Figure 3. Distribution of selected EWSS within Aquifer Vulnerability classes.

The analysis indicated some interesting trends regarding the distribution of EWSS in the state (Figure 3). Almost 18 percent of the selected EWSS are located directly over an alluvial aquifer, which are generally recognized as the most vulnerable aquifers in Iowa and the Midwest (IGWA, 1990; Burkart and Kolpin, 1993). During the analysis, two sites were incorrectly classified and later found to be located on an alluvial aquifers. These aquifers are particularly vulnerable to surface application of potential contaminants, including those found in EWSS, because they are very close to the land surface. In addition, excavation of the EWSS assures that its bottom is likely to be below the water table and the top of the alluvial aquifer, thus increasing the potential for direct contamination of the aquifer. Liquids and solids stored in these structures may be hydraulically connected to a groundwater flow system that is used for water supplies.

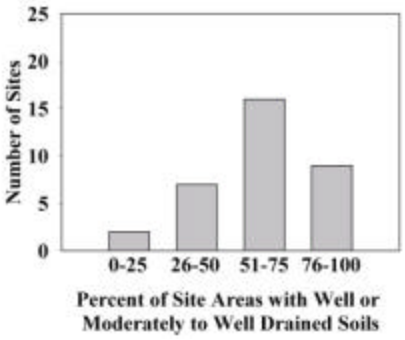

Figure 4. Distribution of well or moderately well drained soils (Hydrologic Groups A and B) in site areas surrounding Selected EWSS.

Leaching and runoff potential on the land available for manure application are important variables in assessing the vulnerability of water resources of an EWSS. Soils data for site areas within 2 miles of each storage site were used to quantify the potential for leaching or runoff of contaminants associated with manure. More than 75 percent (25 sites) of the site areas included a majority of well drained to moderately to well drained soils (Figure 4). Consequently, the land necessary to safely utilize manure would have to be greatly increased in these areas over poorly drained soils.

Table 2. Selected soil and hydrogeologic characteristics of site areas.

Aquifer Vulnerability Class	[1] Dominant Surficial Geologic Material	[2] Soil Permeability ≥ 1 in/hr	[2] Well or Moderately Drained Soils	[2] Occasional or Frequent Flooding	[2] Water Table ≤ 5 ft	[3] Structure Depth (ft)	[4] Distance to Nearest Stream (ft)
Alluvial	Alluvium	98	74	4	62	12	E 200
Alluvial	Alluvium	96	66	7	48	15	P 250
Alluvial	Loess	98	96	41	33	18	P 1500
Alluvial	Loess	96	82	12	30	11	E 1500, P 1800
Alluvial	Alluvium	99	99	13	14	na	P 750
Alluvial	Sand and gravel	96	63	11	65	7	P 800
Drift	Loess	98	98	12	12	25	P 1300
Drift	Fractured till and sand	97	74	6	46	12	E 700
Drift	Loess	39	47	19	72	27.5	E 1500
Drift	Loess	59	73	1	85	12	E 400
Drift	Loess	100	84	20	20	12/18	E 600
Drift	Fractured till and sand	92	47	4	78	25	> 5000
Drift	Fractured till	92	47	<1	69	14	> 5000
Thinly confined	Fractured till	84	87	6	16	15	E 1800
Thinly confined	Fractured till	94	68	3	56	25	E 0, P 2800
Thinly confined	Dune sand	99	81	<1	49	34	E 700
Thinly confined	Fractured till	100	48	4	76	19	E 450
Thinly confined	Colluvium	99	58	7	65	20	E 500
Moderately confined	Fractured till and sand	96	49	2	73	15/16	E 1000
Moderately confined	Fractured till	96	57	<1	76	17	> 5000
Moderately confined	Loess	83	72	9	46	13	E 2000
Moderately confined	Colluvium and lake sediments	98	24	<1	97	17	P 450
Moderately confined	Colluvium and fractured till	99	82	12	36	25/22	P 900
Moderately confined	Fractured till and sand	93	53	5	67	15	E 600
Moderately confined	Lake sediments	99	54	8	69	8	P 2500
Moderately confined	Colluvium	86	44	3	89	11/20	E 2000, P 3000
Moderately confined	Fractured till	94	53	3	84	na	> 5000
Moderately confined	Fractured till	79	69	6	89	10	P 400
Moderately confined	Loess	91	63	32	64	na	P 300
Shale confined	Fractured till	95	61	7	64	14	P 1200
Shale confined	Fractured till	16	9	7	75	14	E 1700
Shale confined	Colluvium and till	52	36	<1	86	19/19	> 5000
Shale confined	Loess	69	76	15	71	18	E 400
Shale confined	Loess	96	92	10	15	14	E 300

[1] Fractured till includes paleosol at one site.

[2] Soil variables expressed in percent of site area.

[3] Two depths are listed where sites with multiple lagoons or basins have different depths.

[4] E = ephemeral stream, P = perennial stream or ditch, > 5000 = no stream observed.

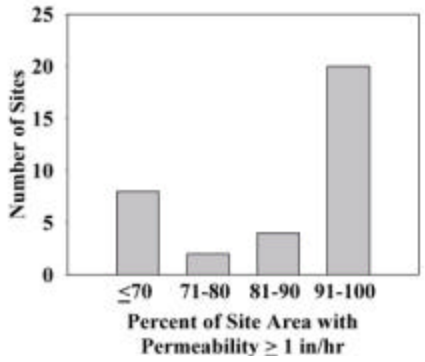

Figure 5. Distribution of soil permeability exceeding 1 in/hr in EWSS site areas.

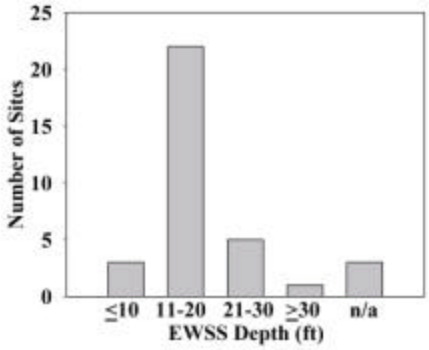

Figure 6. Total depths of EWSS in this study. Depths include height of the berm.

Moderately to poorly drained soils dominate in 20 percent (7 sites) of the site areas. In these areas, manure application followed by rainfall or snow melt may increase the potential for run off and transport of contaminants to surface water or to tile intakes. Site areas are dominated by soils with permeability exceeding 1 in/hr (Figure 5). Constructing a storage site or applying manure on permeable soil creates a potential risk to groundwater.

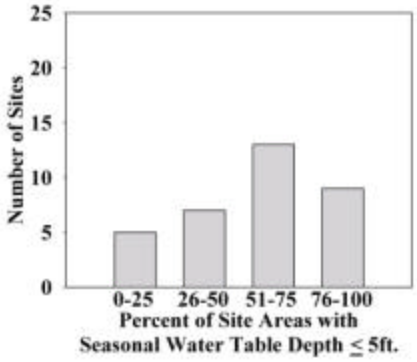

Figure 7. Percentage of soils with seasonal water-table depths less than 5 ft in site areas.

An analysis of the total depths the EWSS indicate some surprisingly deep excavations. Ninety percent of the EWSS (28) with depth information were deeper than 10 ft (Figure 6, Table 2). Only three EWSS were 10 ft deep or less, and one of these was located in sand and gravel and adjacent to a sand and gravel pit. These data, along with soils data on seasonally high water tables, suggest that a large percentage of EWSS in this study and in the state are probably below the water table or at least in contact with the water table. Almost 65 percent of the site areas (22, Figure 7) include a majority of soils with seasonally high water table depths of less than 5 ft from the ground surface. In these areas, locating an EWSS and applying manure on permeable soils poses a substantial risk for contaminants to reach the water table. The site areas investigated are also generally dominated by soils with permeability exceeding 1 in/hr (Figure 7). Seepage from the lagoons, which is allowed at 0.0625 inch/day, will likely saturate any liner material separating the EWSS from the ambient water table and maintain a hydraulic connection. Many EWSS will form periodic recharge mounds for the water table.

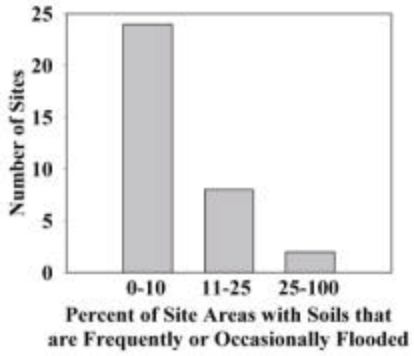

Figure 8. Percentage of soils that flood occasionally or frequently in EWSS site areas.

All EWSS that were located on alluvial aquifers were also located on flood plains (Figure 3). A flood plain setting provides the greatest potential for direct contamination of the nearby stream when discharge is above flood stage. More than 10 of the 34 site areas include 10 percent or more frequently flooded soils (Figure 8). Not all of these flood-prone areas are in the flood plain of a stream, but areas of potential flooding provide opportunities to transport contaminants to nearby streams or tile inlets, resulting in a decline in downstream water quality. In addition, an average of 37 percent of the soils within the site areas of EWSS in a flood plain also had seasonally high water tables within 5 ft of the land surface (table 2). The combination of increased stream stage and the associated rising water table in the flood plain would pose a large risk to groundwater and streams where EWSS are located in flood plains.

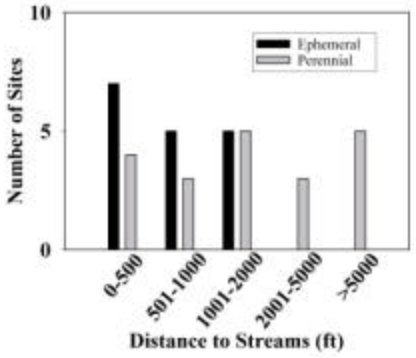

Figure 9. Distribution of setback distances of EWSS from ephemeral and perennial streams.

All investigated EWSS appear to be located beyond the recommended setback distance of 200 ft from a navigable waterway. However, most sites were located within 1000 ft of at least one ephemeral stream (Figure 9, Table 2). One site used an engineered structure in a natural depression formed by the stream channel as the EWSS. More than 75 percent (26) of the sites were also located within 2000 ft of a perennial stream, some of which are not included in the list of navigable waterways in Chapter 65. Ephemeral streams were found within 500 ft at 21 percent of the sites and perennial streams were found within this distance at 12 percent. The proximity of an EWSS to a stream channel, whether ephemeral or perennial, increases the potential for contamination resulting from leakage, spillage, and catastrophic failure. Streams are very efficient in transporting contaminants to fragile ecosystems, even though most streams in Iowa are not currently useable for recreation or navigation.

Conclusions

This study examined a representative sample of 34 EWSS used to store animal waste. These sites were constructed between 1987 and 1994 and included proportional representation of sites located in five Aquifer Vulnerability regions of Iowa.

Nearly 18 percent of the sites were constructed over alluvial aquifers, considered to be the most vulnerable type of aquifer in Iowa. Entry of manure waste into these aquifers could contaminate municipal and private water supplies.

Sites located on alluvial aquifers also lie in flood plains, where there is a continual risk of flooding and entry of contaminants from manure application and structure failure into surface water. Although regulations require that the top of the EWSS be 1 ft above the elevation of the 100-year flood, high and often fluctuating water tables associated with frequent, small floods may

compromise EWSS liner integrity and increase potential for failure.

Large portions of the soils within a 2 mile radius of the majority of sites have a saturated permeability of $\geq$ 1 in/hr. Many of these site areas also include substantial well or moderately-well drained soils and soils with seasonally high water tables less than 5 ft from the land surface. The frequency of site areas with a combination of two or more of these indicators of potential chemical leaching indicates groundwater is being exposed to an increased potential for contamination.

The dominance of EWSS depths exceeding 10 ft combined with the high incidence of areas dominated by water tables less than 5 ft from the land surface, suggests that most of the sites are constructed below the water table. This setting poses a risk for groundwater contamination and may violate the construction guidelines.

Ephemeral streams were found within 500 ft at 21 percent of the sites and perennial streams were found within this distance 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 of a major aquatic recreation area. Many sites had unmapped drainageways that led from the EWSS to ephemeral or perennial streams.

Recommendations

Further reduction of risks to groundwater and surface water resources by EWSS may be attained by using regulations that incorporate additional geologic, hydrogeologic, and soils data as outlined in this report.

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 groundwater and surface water.

This analysis shows that many of the EWSS were constructed in areas with shallow water tables. Application of well established, scientifically defensible groundwater monitoring techniques should be used to locate the position of the water table during construction and throughout the life of the EWSS. These methods may help identify whether the recommended hydraulic separation between the EWSS and the water table will be maintained. EWSS construction at a site with a shallow water table should be avoided.

Setback distances based on local hydrogeologic and topographic conditions and EWSS construction methods 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 in Iowa.

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APPENDIX I : Site Descriptions

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

Site A contains an earthen waste storage basin (14,400 ft^2) that is 14 ft deep and receives input from a dairy operation permitted for 420,000 lbs. (live weight). It lies within the Northwest Iowa Plains landform region and within the Shale Confined Aquifer vulnerability classification. Soils in the site area are classified in the Moody association. The surficial geologic material at the site is loess of the Peoria Formation (Moody Series), although the base of the lagoon was likely excavated into fractured till of the Wolf Creek Formation. An ephemeral stream lies within 300 ft of the site. The site area is characterized an integrated drainage pattern with relatively steep slopes. Within the site area, maximum soil permeability is greater than 1 in/hr in 96 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (92 percent), followed by poorly drained soils of Hydrologic Group D (6 percent). The seasonally high water table is less than 5 ft deep in 15 percent of the site area and 10 percent is susceptible to annual flooding.

Site B contains an earthen waste storage basin (34,225 ft^2) that is 12 ft deep and receives input from a swine operation permitted for 540,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Drift Groundwater Aquifer vulnerability classification. Soils in the site area are classified in the Nicollet-Clarion-Webster or the Clarion-Nicollet-Storden associations. Hummocky topography and poorly integrated drainage associated with the Algona moraine characterize the site area. The surficial geologic material at the site is likely fractured till and sand of the Morgan Member of the Dows Formation (Clarion Series). An ephemeral stream and drainage ditch lie within 700 ft and 1 mile, respectively. Within the site area, maximum soil permeability is greater than 1 in/hr in 97 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (74 percent), followed by poorly drained soils of Hydrologic Group D (25 percent). The seasonally high water table is less than 5 ft deep in 46 percent of the site area and 6 percent is susceptible to annual flooding.

Site C contains an earthen waste storage basin (22,500 ft^2) that is 25 ft deep and receives input from a swine operation permitted for 448,400 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Drift Groundwater Aquifer vulnerability classification. Soils in the site area are classified in the Clarion-Nicollet-Canisteo and Clarion-Nicollet associations. Low-relief, hummocky topography and poorly integrated drainage associated with the Algona moraine characterize the site area. The surficial geologic material at the site is fractured till and sand of the Morgan Member of the Dows Formation (Nicollet Series). Within the site area, maximum soil permeability is greater than 1 in/hr in 92 percent of the area. Poorly drained soils of Hydrologic Group D dominate (51 percent), followed by moderately well to well drained soils of Hydrologic Group B (47 percent). The seasonally high water table is less than 5 ft deep in 78 percent of the site area and 4 percent is susceptible to annual flooding.

Site D contains an earthen waste storage basin (38,850 ft^2) that is 7 ft deep and receives input from a swine operation permitted for 310,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region. The site actually lies on an Alluvial Aquifer, although it is mapped within the Thinly Confined Aquifer vulnerability classification. Soils in the site area are classified in the Clarion-Storden-Colo, Spillville-Estherville-Storden, and Clarion-Nicollet-Canisteo associations. The surficial geologic material at the site is sand and gravel (Darfur Series) that is part of a laterally extensive outwash terrace. The topography is flat and the site has been constructed on part of a modern floodplain. As can be seen in the photograph below, a major river lies within 800 ft and makes the site susceptible to annual flooding. In the site area, maximum soil permeability is greater than 1 in/hr in 96 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (60 percent), followed by poorly drained soils of Hydrologic Group D (36 percent) and Hydrologic Group A (3 percent). The seasonally high water table is less than 5 ft deep in 65 percent of the site area and 11 percent is susceptible to annual flooding.

Site E contains an earthen waste storage basin (18,000 ft^2) that is 17 ft deep and receives input from a swine operation permitted for 308,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Nicollet-Canisteo-Webster and the Clarion-Nicollet-Canesteo associations. The surficial geologic materials at the site include fractured till of the Dows Formation and sediments derived from it in toe slope positions (Webster Series). Topography is gently undulating and typical of that of the Des Moines Lobe. In the site area, maximum soil permeability is greater than 1 in/hr in 96 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (57 percent), followed by poorly drained soils of Hydrologic Group D (43 percent). The seasonally high water table is less than 5 ft deep in 76 percent of the site area and less than 1 percent is susceptible to annual flooding.

Site F contains two earthen waste storage lagoons (27,225 ft^2 and 99,225 ft^2) that are 15 and 16 ft deep, respectively, and receive input from a swine operation permitted for 656,250 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Canisteo-Nicollet-Clarion and the Fielden-Harcot-Ridgeport associations. Hummocky topography and poorly integrated drainage with closed depressions associated with the Algona moraine characterize the site area. The surficial geologic material at the site includes fractured till and sand of the Morgan Member of the Dows Formation and sediments derived from it (Canisteo Series). The site lies less than 1000 ft from an ephemeral stream. In the site area, maximum soil permeability is greater than 1 in/hr in 96 percent of the area. Poorly drained soils of Hydrologic Group D dominate (51 percent), followed by moderately to well drained soils (Hydrologic Group B, 49 percent). The seasonally high water table is less than 5 ft deep in 73 percent of the site area and about 2 percent is susceptible to annual flooding.

Site G contains an earthen waste storage basin (166,896 ft^2) that it 15 ft deep and receives input from a swine operation permitted for 1,012,500 lbs. (live weight). The site lies within the Iowan Erosion Surface landform region and the Alluvial Aquifer vulnerability classification. Soils in the site area include the Jacwin-Limecreek-Mottland, Saude-Coland-Lawler, and Clyde-Kenyon-Floyd associations. The site is located on the floodplain, within 250 ft of a perennial stream, and it is subject to annual flooding. The surficial geologic material at the site is stratified loamy alluvium (Coland Series). In the site area, maximum soil permeability is greater than 1 in/hr in 96 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (66 percent), followed by poorly drained soils of Hydrologic Group D (33 percent). The seasonally high water table is less than 5 ft deep in 48 percent of the site area and 7 percent is susceptible to annual flooding.

Site H contains two earthen waste storage lagoons (both 110,000 ft^2) that are both 34 ft deep and receive input from a swine operation permitted for 1,620,000 lbs. (live weight). The site lies within the Iowan Erosion Surface landform region and the Thinly Confined Aquifer vulnerability classification. It is underlain by a karst aquifer. Sinkholes, which provide a direct hydraulic connection to the aquifer, are abundant in the area. Soils in the site area include the Dickinson-Ostrander-Schley, Wapsie-Alluvial land-Marshan, and the Dinsdale-Klinger-Maxfield associations. The surficial geologic material at the site is fine-grained dune sand that is generally quite permeable (Dickinson Series). Gentle slopes characterize the topography and an ephemeral stream lies within 700 ft. In the site area, maximum soil permeability is greater than 1 in/hr in more than 99 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate the site area (81 percent), followed by poorly drained soils of Hydrologic Group D (18 percent). The seasonally high water table is less than 5 ft deep in 49 percent of the site area and less than 1 percent is susceptible to annual flooding.

Site I contains an earthen waste storage lagoon (31,200 ft^2) that is 12 ft deep and receives input from a cattle operation permitted for 90,000 lbs. (live weight). The site lies within the Iowan Erosion Surface landform region and the Alluvial Aquifer vulnerability classification. It is underlain by a karst aquifer. Sinkholes, which provide a direct hydraulic connection to the aquifer, are abundant in the area. Soils in the site area include the Dickinson-Ostrander-Schley, Clyde-Floyd-Kenyon, and the Dinsdale-Klinger-Maxfield associations. The site lies on a flat floodplain of an ephemeral stream that is within 200 ft. The surficial geologic material at the site is loamy alluvium (Clyde Series), although the base of the lagoon was likely excavated into fractured till of the Wolf Creek Formation. A small community lies within 2000 ft of the site. In the site area, maximum soil permeability is greater than 1 in/hr in 98 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (74 percent), followed by poorly drained soils of Hydrologic Group D (22 percent). The seasonally high water table is less than 5 ft deep in 62 percent of the site area and 4 percent is susceptible to annual flooding.

Site J contains two earthen waste storage lagoons (10,000 ft^2 and 120,000 ft^2) that are 11 and 20 ft deep, respectively, and receive input from a swine operation permitted for 432,000 lbs. (live weight). The site lies within the Iowan Erosion Surface landform region and the Moderately Confined Aquifer vulnerability classification. It is underlain by a karst aquifer. Soils in the site area include the Cresco-Clyde-Protivin, Clyde-Floyd-Schley, and the Kenyon-Clyde-Floyd associations. The surficial geologic material at the site is loamy colluvial sediment (Lourdes or Protovin Series), although the bottoms of the lagoons were likely excavated into fractured till of the Wolf Creek Formation. Topography at the site is moderately steep. The site lies on a watershed divide immediately upgradient from an ephemeral stream (2000 ft) and a perennial stream (3000 ft). In the site area, maximum soil permeability is greater than 1 in/hr in 86 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (44 percent), followed by poorly drained soils of Hydrologic Group D (29 percent) and moderately to poorly drained soils of Hydrologic Group C (26 percent). The seasonally high water table is less than 5 ft deep in 89 percent of the site area and 3 percent is susceptible to annual flooding.

Site K contains two earthen waste storage basins, the oldest of which is 19,200 ft^2 and is 18 ft deep. They receive input from a swine operation permitted for 160,000 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Alluvial Aquifer vulnerability classification. Soils in the site area include the Kennebec-Radford-Colo, Ida-Monona, and Galva-Ida associations. The site is located on a flat loess-capped, outwash terrace adjacent to a modern floodplain. The surficial geologic material at the site is loess of the Peoria Formation (Galva Series), although the bottom of the basin was excavated into coarse sand and gravel that comprises the alluvial aquifer. The site lies less than 1500 ft upgradient from a perennial stream. In the site area, maximum soil permeability is greater than 1 in /hr in 98 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (96 percent), followed by poorly drained soils of Hydrologic Group D (2 percent). The seasonally high water table is less than 5 ft deep in 33 percent of the site area and 41 percent is susceptible to annual flooding.

Site L contains an earthen waste storage basin (18,144 ft^2) that is 11 ft deep and receives input from a swine operation permitted for 432,400 lbs. (live weight). The site lies within the Northwest Iowa Plains landform region and the Alluvial Aquifer vulnerability classification. Soils in the site area include the Calco-Colo-Galva, Galva-Primghar, and Sac-Galva-Primghar associations. The site is located on a flat outwash terrace adjacent to a modern floodplain. The surficial geologic material at the site is loess of the Peoria Formation or loamy alluvium (Fairhaven Series), although the bottom of the basin was excavated into sand and gravel that comprises the alluvial aquifer. Active sand and gravel operations surround the site on all sides. It lies less than 1500 ft and 1800 ft upgradient from ephemeral and perennial streams, respectively. In the site area, maximum soil permeability is greater than 1 in/hr in 96 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate the site area (82 percent), followed by poorly drained soils of Hydrologic Group D (18 percent). The seasonally high water table is less than 5 ft deep in 30 percent of the site area and 12 percent is susceptible to annual flooding.

Site M contains an earthen waste storage basin (15,933 ft^2) that is 13 ft deep and receives input from a swine operation permitted for 224,400 lbs. (live weight). The site lies within the Northwest Iowa Plains landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Galva-Primghar and Colo-Calco-Spillville associations. The surficial geologic material at the site is loess of the Peoria Formation (Galva Series). The site lies on a side slope where topography is moderately steep. It is about 2000 ft upgradient from an ephemeral stream. In the site area, maximum soil permeability is greater than 1 in/hr in 83 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (72 percent), followed by poorly drained soils of Hydrologic Group D (27 percent). The seasonally high water table is less than 5 ft deep in 46 percent of the site area and 9 percent is susceptible to annual flooding.

Site N contains two earthen waste storage lagoons (18,450 ft^2 and 37,800 ft^2) that are 12 and 18 ft deep, respectively, and receive input from a swine operation permitted for 243,750 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Drift Groundwater Aquifer vulnerability classification. Soils in the site area belong primarily to the Marshall-Exira association. The surficial geologic material at the site is loess of the Peoria Formation (Marshall Series), although the bottoms of the lagoons were likely excavated into fractured till of the Wolf Creek Formation. The site is located on a watershed divide and topography is steep. It lies 600 ft upgradient from an ephemeral stream and about 1500 ft upgradient from a river. In the site area, maximum soil permeability is greater than 1 in/hr in the entire area. Moderately to well drained soils of Hydrologic Group B dominate (84 percent), followed by poorly drained soils of Hydrologic Group D (16 percent). The seasonally high water table is less than 5 ft deep in 20 percent of the site area and 20 percent is susceptible to annual flooding.

Site O contains an earthen waste storage basin (about 17,000 ft^2) of unknown depth that receives input from a swine operation permitted for 455,200 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region. It occurs within the Alluvial Aquifer vulnerability classification, although it is mapped within the Drift Groundwater classification. Soils in the site area include the Monona-Ida and Kennebec-Nodaway-Colo associations. The site lies directly in a floodplain with a major perennial stream less than 750 ft away. The surficial geologic material is stratified alluvium (Kennebec or Nodaway Series), although the bottom of the basin was likely excavated into the underlying sand and gravel that comprises the alluvial aquifer. In the site area, maximum soil permeability is greater than 1 in/hr in 99 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (99 percent). The seasonally high water table is less than 5 ft deep in 14 percent of the site area and 13 percent is susceptible to annual flooding.

Site P contains an earthen waste storage basin (18,750 ft^2) that is 14 ft deep and receives input from a swine operation permitted for 224,000 lbs. (live weight). The site lies within the Des Moines Lobe Landform Region and the Drift Groundwater Aquifer vulnerability classification. Soils in the site area include the Clarion-Nicolet-Canisteo association. Hummocky topography, poorly integrated drainage, and closed depressions associated with the Altamont moraine characterize the site area. There are no through-flowing streams in the site area, which suggests that tile drains remove excess water from the landscape. The surficial geologic material at the site is till-derived sediment (Canisteo Series), although the bottom of the basin was likely excavated into fractured till and sand of the Morgan Member of the Dows Formation. In the site area, maximum soil permeability is greater than 1 in/hr in 92 percent of the area. Poorly drained soils of Hydrologic Group D dominate (51 percent), followed by moderately well to well drained soils of Hydrologic Group B (47 percent). The seasonally high water table is less than 5 ft deep in 69 percent of the site area and less than 1 percent is susceptible to annual flooding.

Site Q contains an earthen waste storage basin (30,000 ft^2) that is 15 ft deep and receives input from a swine operation permitted for 675,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Canisteo-Nicollet-Clarion and Bode-Kossuth-Ottosen associations. The site lies adjacent to the Altamont moraine and topography is hummocky to somewhat dissected. The surficial geologic material at the site is fractured till and sand of the Morgan Member of the Dows Formation (Clarion Series). The site is less than 0.5 and 1mi upgradient, respectively, from a large recreational lake and a major river. In the site area, maximum soil permeability is greater than 1 in/hr in 93 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (53 percent), followed by poorly-drained soils of Group D (42 percent). The seasonally high water table is less than 5 ft deep in 67 percent of the site area and about 5 percent is susceptible to annual flooding.

Site R contains two earthen waste storage lagoons (291,400 ft^2 and 164,500 ft^2) that are both 19 ft deep and receive input from a swine operation permitted for 2,475,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Thinly Confined Aquifer vulnerability classification. Soils in the site area include the Canisteo-Nicollet-Webster and Wadena-Coland (alluvial soil) associations. The site area topography is moderately dissected and includes large outwash channels and hummocky ground moraine features. The surficial geologic material at the site is fractured till of the Dows Formation (Clarion Series). The site is less than 450 ft and 1 mi upgradient, respectively, from an ephemeral stream and a perennial stream. In the site area, maximum soil permeability is greater than 1 in/hr in the entire area. Poorly drained soils of Hydrologic Group D dominate (52 percent), followed by moderately to well drained soils of Hydrologic Group B (48 percent). The seasonally high water table is less than 5 ft deep in 76 percent of the site area and about 4 percent is susceptible to annual flooding.

Site S contains two earthen waste storage lagoons (about 4,000 and 20,000 ft^2) that are of unknown depths. They receive input from a swine operation permitted for 325,160 lbs. (live weight). The site lies within the Des Moines Lobe landform region and within the Moderately Confined Aquifer vulnerability classification. The site area includes soils of the Canisteo-Nicollet-Webster and Hayden-Storden-Hanlon (alluvial soils) associations. The landscape in the site area is characterized by low relief topography and by numerous closed depressions. The surficial geologic material at the site is fractured till of the Dows Formation (Clarion Series). There are no ephemeral streams in the immediate area of the site; however, numerous wetlands surround the site. In the site area, maximum soil permeability is greater than 1 in/hr in 94 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (53 percent), followed by poorly-drained soils of Hydrologic Group D (46 percent). The seasonally high water table is less than 5 ft deep in 84 percent of the site area and 3 percent is susceptible to annual flooding.

Site T contains an earthen waste storage basin (22,500 ft^2) that is 17 ft deep and receives input from a swine operation permitted for 360,640 lbs. (live weight). The site lies within the Des Moines Lobe landform region and within the Moderately Confined Aquifer vulnerability classification. The site area includes soils of the Canisteo-Nicollet-Webster association. The site lies adjacent to the Altamont moraine, and the topography is characterized by hummocky and flat topography. The surficial geologic material at the site is primarily colluvial sediment derived from the Dows Formation or glacial lake sediment (Okiboji Series); however, the bottom of the basin was likely excavated into fractured till of the Dows Formation. Numerous drainage ditches were constructed in the site area, one of which drains directly to a river 10 mi downstream and is less than 450 ft downgradient from the site. In the site area, maximum soil permeability is greater than 1 in/hr in 98 percent of the area. Poorly-drained soils of Hydrologic Group D dominate (75 percent), followed by moderately to well drained soils of Hydrologic Group B (24 percent). The seasonally high water table is less than 5 ft deep in 98 percent of the site area and less than 1 percent is susceptible to annual flooding.

Site U contains two earthen waste storage lagoons (148,472 ft^2 and 304,700 ft^2) that are both 19 ft deep and receive input from a swine operation permitted for 2,475,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Shale Confined Aquifer vulnerability classification. The site area includes soils of the Brownton-Ottosen-Bode association. Hummocky topography and poorly integrated drainage associated with the Altamont moraine characterize the site area. The surficial geologic material at the site is till-derived colluvial sediment (Ottosen Series), although the base of the lagoons were likely excavated in fractured till and sand of the Morgan Member of the Dows Formation. In the site area, maximum soil permeability is greater than 1 in/hr in 52 percent of the site area. Poorly-drained soils of Hydrologic Group D dominate (64 percent), followed by moderately to well drained soils of Hydrologic Group B (36 percent). The seasonally high water table is less than 5 ft deep in 86 percent of the site area and less than 1 percent is susceptible to annual flooding.

Site V contains an earthen waste storage basin (45,000 ft^2) that is 8 ft deep and receives input from a dairy operation permitted for 698,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Kossuth-Ottosen-Bode and Clarion-Storden-Coland associations. The site lies adjacent to the Altamont moraine and within an area of a former glacial lake. The topography is relatively flat with many undrained depressions that contain water on a seasonal basis. The surficial geologic material at the site is thin glacial lake sediment overlying fractured till of the Dows Formation (Kossuth Series). A drainage ditch lies within 0.5 mi and a major perennial stream lies within 1 mi of the site. In the site area, maximum soil permeability is greater than 1 in/hr in 99 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (54 percent), followed by poorly-drained soils of Group D (44 percent). The seasonally high water table is less than 5 ft deep in 69 percent of the site area and 8 percent is susceptible to annual flooding.

Site W contains an earthen waste storage basin (19,600 ft^2) that is 20 ft deep and receives input from a swine operation permitted for 450,000 lbs. (live weight). The site lies within the Iowan Erosion Surface landform region and the Thinly Confined Aquifer vulnerability classification. The site area is underlain by a karst aquifer and sinkholes, which can provide a direct hydraulic connection to the aquifer, are abundant. Soils in the site area include the Kenyon-Clyde-Floyd, Marshan-Coland-Flagler, and Cresco-Kenyon-Clyde associations. The site lies on sideslope with moderately steep topography. The surficial geologic material at the site consists of thin colluvial sediment (Floyd Series), although the bottom of the basin was likely excavated into fractured till of the Wolf Creek Formation. Ephemeral streams lie at distances of 500 and 1800 ft downgradient from the site. In the site area, maximum soil permeability is greater than 1 in/hr in 99 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (58 percent), followed by poorly drained soils of Hydrologic Group D (27 percent) and moderately to poorly drained soils of Hydrologic Group C (15 percent). The seasonally high water table is less than 5 ft deep in 65 percent of the site area and 7 percent is susceptible to annual flooding.

Site X contains an earthen waste storage lagoon (30,625 ft^2) that is 25 ft deep and receives input from a swine operation permitted for 90,000 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Drift Groundwater Aquifer vulnerability classification. Soils in the site area include the Monona-Marshall and Kennebec-Nodaway-Colo associations. The surficial geologic material at the site is loess of the Peoria Formation (Monona Series), although the base of the lagoon was likely excavated into fractured till of the Wolf Creek Formation. The site lies on sideslope where topography is moderately steep. It is connected by a drainageway to a perennial stream that is less than 1300 ft away and that flows to within 3000 ft of a small town. In the site area, maximum soil permeability is greater than 1 in/hr in 98 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (98 percent), followed by poorly drained soils of Hydrologic Group D (2 percent). The seasonally high water table is less than 5 ft deep in 12 percent of the area and 12 percent is susceptible to annual flooding.

Site Y contains an earthen waste storage basin (21,720 ft^2) that is 14 ft deep and receives input from a swine operation permitted for 252,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and the Shale Confined Aquifer vulnerability classification. Soils in the site area include the Clarion-Nicollet-Webster and Clarion-Coland-Storden, and Canisteo-Webster-Nicollet associations. The surficial geologic material at the site is fractured till of the Dows Formation (Clarion Series). The topography at the site is relatively flat and includes many undrained depressions that store water on a seasonal basis. A drainageway connects the site to a perennial stream that is 1200 ft away. In the site area, maximum soil permeability is greater than 1 in/hr in 95 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (61 percent), followed by poorly-drained soils of Hydrologic Group D (39 percent). The seasonally high water table is less than 5 ft deep in 64 percent of the site area and 7 percent is susceptible to annual flooding.

Site Z contains an earthen waste storage basin (22,500 ft^2) that is 15 ft deep and receives input from a swine operation permitted for 224,000 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Thinly Confined Aquifer vulnerability classification. Soils in the site area include the Marshall, Marshall-Shelby-Adair, Shelby-Adair, and Nodaway-Zook-Colo associations. The surficial geologic material at the site is loess of the Peoria Formation (Marshall Series), although the bottom of the basin may have been excavated into a buried paleosol and/or fractured till of the Wolf Creek Formation. The site lies on a flat divide that is about 1800 ft upgradient from two ephemeral streams. In the site area, maximum soil permeability is greater than 1 in/hr in 84 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (87 percent), followed by moderately to poorly drained soils of Hydrologic Group C (9 percent), and poorly drained soils of Hydrologic Group D (3 percent). The seasonally high water table is less than 5 ft deep in 16 percent of the site area and 6 percent is susceptible to annual flooding.

Site AA contains an earthen waste storage basin (19,600 ft^2) that is 12 ft deep and receives input from a swine operation permitted for 540,000 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Drift Groundwater Aquifer vulnerability classification. Soils in the site area are in the Sharpsburg-Shelby-Adair association. The surficial geologic material at the site is loess of the Peoria Formation (Sharpsburg Series), although the bottom of the basin was likely excavated into fractured till of the Wolf Creek Formation. The site lies near the topographic divide and is 400 ft upgradient from a farm pond which comprises the headwaters of an ephemeral stream. In the site area, maximum soil permeability is greater than 1 in/hr in 59 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (73 percent), followed by moderately to poorly drained soils of Hydrologic Group C (22 percent) and poorly drained soils of Hydrologic Group D (5 percent). The seasonally high water table is less than 5 ft deep in 85 percent of the site area and about 1 percent is susceptible to annual flooding.

Site BB contains two earthen waste storage lagoons (36,100 and 40,000 ft^2) that are both 18 ft deep and receive input from a swine operation permitted for 1,147,600 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Shale Confined Aquifer vulnerability classification. Soils in the site area include the Otley-Mahaska and Ladoga-Gara associations. The surficial geologic material at the site is loess of the Peoria Formation (Ladoga Series), although the bases of the lagoons were likely excavated into fractured till of the Wolf Creek Formation. The site lies at the head of a steep ravine and on the edge of a topographic divide. It is 400 ft upgradient from an ephemeral tributary that empties into a major surface water recreational area. In the site area, maximum soil permeability is greater than 1 in/hr in 69 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (76 percent), followed by moderately to poorly drained soils of Hydrologic Group C (19 percent) and poorly drained soils of Hydrologic Group D (4 percent). The seasonally high water table is less than 5 ft deep in 71 percent of the site area and 15 percent is susceptible to annual flooding.

Site CC contains an earthen waste storage basin (15,625 ft^2) that is 14 ft deep and receives input from a swine operation permitted for 197,950 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Shale Confined Aquifer vulnerability classification. Soils in the site area include the Tama-Downs-Fayette and Fayette-Lindley associations. The surficial geologic material at the site is either a buried paleosol or fractured till of the Wolf Creek Formation (Adair or Shelby Series, respectively). The site lies at the head of a steep ravine on a sideslope and is less than 300 ft upgradient from a farm pond. In the site area, maximum soil permeability is greater than 1 in/hr in 16 percent of the area. Moderately to poorly drained soils of Hydrologic Group C dominate (69 percent), followed by poorly drained soils of Hydrologic Group D (17 percent) and moderate to well drained soils of Hydrologic Group B (9 percent). The seasonally high water table is less than 5 ft deep in 75 percent of the site area and 7 percent is susceptible to annual flooding.

Site DD contains two earthen waste storage lagoons (11,000 and 35,200 ft^2) that are 22 and 25 ft deep, respectively, and receive input from a swine operation permitted for 177,233 lbs. (live weight). The site lies within the Iowan Erosion Surface landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Kenyon-Dinsdale, Dinsdale-Klinger, loamy alluvial land-Sparta-Spillville, and Fayette-Downs-Chelsea associations. The surficial geologic material at the site is mapped as thin colluvial sediment (Kenyon Series), although the lagoons were likely excavated into fractured till of the Wolf Creek Formation. Site topography is moderately steep. The site lies within 900 ft of a perennial stream and the grounds of a large public school. In the site area, maximum soil permeability is greater than 1 in/hr in more than 99 percent of the area. Moderately well to well drained soils of Hydrologic Group B dominate (79 percent), followed by poorly drained soils of Hydrologic Group D (17 percent) and well drained soils of Hydrologic Group A (3 percent). The seasonally high water table is less than 5 ft deep in 36 percent of the site area and about 12 percent is susceptible to annual flooding.

Site EE contains an earthen waste storage basin (5,625 ft^2) that is 10 ft deep and receives input from a swine operation permitted for 252,000 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Moderately Confined Aquifer vulnerability classification. The site area includes soils of the Ladoga-Givin-Gara, Otley-Clarinda-Adair, and Amana-Alluvial land-Nodaway associations. The surficial geologic material at the site consists of a buried paleosol (Adair Series), although the bottom of the basin may have been excavated into fractured till of the Wolf Creek Formation. The site lies at the head of a steep ravine that drains to a perennial stream less than 400 ft away. In the site area, maximum soil permeability is greater than 1 in/hr in 79 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (68 percent), followed by moderately to poorly drained soils of Hydrologic Group C (18 percent) and poorly drained soils of Hydrologic Group D (14 percent). The seasonally high water table is less than 5 ft deep in 89 percent of the site area and 6 percent is susceptible to annual flooding.

Site FF contains two earthen waste storage lagoons (both 62,500 ft^2) of unknown depth that both receive input from a swine operation permitted for 1,258,240 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and the Moderately Confined Aquifer vulnerability classification. Soils in the site area include the Downs-Fayette, Atterberry-Muscatine-Stronghurst, and Ambraw-Shaffton-Nodaway associations. The site area contains alluvium and outwash sediments associated with a major navigational and recreational river. The surficial geologic material at the site is thick loess of the Peoria Formation (Fayette Series). Site topography is moderately flat to very steep in the ravines. The site lies less than 300 ft upgradient from a perennial stream. Maximum soil permeability is greater than 1 in/hr in 91 percent of the site area. Moderately well to well drained soils of Hydrologic Group B dominate (57 percent), followed by poorly drained soils of Hydrologic Group D (27 percent), well drained soils of Hydrologic Group A (7 percent) and moderately to poorly drained soils of Hydrologic Group C (3 percent). The seasonally high water table is less than 5 ft deep in 64 percent of the site area and about 32 percent is susceptible to annual flooding.

Site GG contains two earthen waste storage lagoons (210,000 and 105,000 ft^2) that are both 27.5 ft deep and receive input from a swine operation permitted for 1,462,500 lbs. (live weight). The site lies within the Southern Iowa Drift Plain landform region and within the Drift Groundwater Aquifer vulnerability classification. Soils in the site area include the Nira-Sharpsburg-Shelby and Gara-Armstrong-Ladoga associations. The surficial geologic material at the site is loess of the Peoria Formation (Nira or Sharpsburg Series), although the bases of the lagoons were likely excavated into fractured till of the Wolf Creek Formation. The site lies on a topographic divide and the surrounding topography is steep. It lies less than 400 ft upgradient from a farm pond, and less than 1500 ft upgradient from three ephemeral streams. A drainage ditch lies within 0.5 mi and a major perennial stream lies within 1 mi. In the site area, maximum soil permeability is greater than 1 in/hr in 39 percent of the site area. Moderately to well drained soils of Hydrologic Group B dominate (47 percent), followed by moderately to poorly drained soils of Hydrologic Group C (28 percent) and poorly-drained soils of Hydrologic Group D (23 percent). The seasonally high water table is less than 5 ft deep in 72 percent of the site area and 19 percent is susceptible to annual flooding.

Site HH contains two earthen waste storage lagoons (99,000 and 104,500 ft^2) that are both 25 ft deep and receive input from a swine operation permitted for 525,000 lbs. (live weight). The site lies within the Des Moines Lobe landform region and within the Thinly Confined Aquifer vulnerability classification. Soils in the site area include the Storden-Hayden-Wadena and Webster-Clarion-Nicollet associations. The surficial geologic material at the site is fractured till of the Dows Formation (Storden Series). Site topography is relatively flat. The site sits in the valley of an ephemeral stream, which flows directly into a major river less than 0.5 mi away. Damming of the ephemeral stream appears to have been involved in creating the lagoons and a downgradient farm pond. In the site area, maximum soil permeability is greater than 1 in/hr in 94 percent of the area. Moderately to well drained soils of Hydrologic Group B dominate (68 percent), followed by poorly-drained soils of Hydrologic Group D (30 percent). The seasonally high water table is less than 5 ft deep in 56 percent of the site area and 3 percent is susceptible to annual flooding.