Earthen Waste Storage Structures in Iowa

A Study for the Iowa Legislature

August 1999

IOWA STATE UNIVERSITY

EDC-186

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Issued in furtherance of Cooperative Extension work. Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Stanley R. Johnson, director, Cooperative Extension Service, Iowa State University of Science and Technology, Ames, Iowa.

EXECUTIVE SUMMARY

Introduction

During the 1997 Legislative session, the Iowa Legislature passed legislation mandating an Iowa State University study of the extent to which earthen waste storage structures contribute to point and non-point pollution in this state. Iowa State University was to select representative earthen waste storage structures (EWSS) and obtain owner consent for on-site measurements using scientifically accepted test procedures. Information for any specific site in this study was to be kept confidential to protect cooperators.

A research team of interested scientists and engineers was formed in the fall of 1997. They evaluated alternative research approaches. Other U.S. researchers had monitored a relatively few structures. In most of these studies, data were collected for months or years following construction. In this study, time was limited and the legislative intent was to provide a statewide perspective. The team had to choose EWSS to be evaluated and decide what information to obtain.

The team agreed to study EWSS designed and built after 1987 and before Dec. 31, 1994. Each of these structures was constructed under a 1987 standard for soil permeability established by IDNR for agricultural EWSS. The 1987 standard permitted a leakage rate at the time of construction of no more than 1/16th of an inch per day at a 6-foot liquid depth. Prior to 1987, municipal and industrial EWSS had been required to meet that standard, but agricultural EWSS had been exempted. Concerns had been expressed regarding the impact of the erosion of earthen liners and the potential for poor management practices to affect the integrity of the compacted liners inside earthen structures. These structures had been in service long enough to experience the effects of time on the integrity of liners and to allow time for contaminant migration outside the immediate vicinity of the structure.

IDNR records indicated that 439 agricultural EWSS were built and permitted during the 1988 -1994 period. Facility operators at these EWSS were contacted by mail and 124 responded that they would cooperate with the study.

The research team limited the number of sites to the number that could be evaluated in one summer and fall testing season. They also wanted to test for differences in EWSS constructed in different groundwater vulnerability zones as described by Hallberg and Hoyer, 1991. Project geologists identified five major Iowa aquifers vulnerable to contamination: areas underlain by surficial aquifers, either (1) alluvial or (2) drift and aquifers overlain by (3) thin drift less than 100 ft, (4) moderate drift (100-300 ft) or (5) shale.

The final project encompassed four major areas of study: (a) the geologic setting of each construction site, (b) the construction and management of EWSS during the service period, (c) leakage measurements from the EWSS and (d) potential off-site migration of pollutants. Initially, 40 sites were selected for the study sample. Owners of five of the selected sites failed to sign a memorandum of understanding. One of the remaining sites had been abandoned and filled in. This left 34 sites in the sample. Leakage testing required that liquid in the EWSS be above ground line. Three of the 34 remaining sites could not be tested for leakage rate because the wastewater surface was below ground surface at the time of testing. However, geologic interpretations were made for all 34 sites, using soil and geologic database information and low-level aerial photography.

This report is a compilation of four reports developed by research groups addressing the four major researchable topics.

Geology

The geologic investigations characterized each site for the dominant surficial geologic material, local surface soil permeability, drainage conditions, flooding potential, expected water-table depths and distance to streams. Potential contamination pathways were examined for each site. Of the EWSS surveyed, 18 percent were constructed in areas over alluvial aquifers, the most vulnerable aquifers in the state. This study also predicted that some EWSS would be in areas with seasonal water table depths of less than five feet, so there is the potential for the bottom of these structures to be below water table during part of the year.

Management and history

On-site interviews were conducted with the operators of 33 EWSS to obtain historical information about operational and management practices that could result in water contamination. Management practices that could lead to higher water-quality risks were observed at 76 percent of the sites. Practices associated with increased water quality risks included minor spills during unloading of the structure (55 percent), erosion of compacted clay liners or berms (27 percent), plugging or freezing of flow inlet pipes (12 percent), tree growth on berms (6 percent), and inadequate freeboard maintenance (6 percent). A significant manure spill had occurred at three of the sites.

Nearly one-fifth (18 percent) of the EWSS had been built on sites with previous livestock or manure storage facilities. These activities could be expected to contaminate the groundwater in some nearby areas even with little seepage from the EWSS. Historic information was useful in interpreting the results of soil-core analyses.

Seepage

During the late summer and fall of 1998, 28 of 31sites were measured for seepage rates. Wind interference during measurement periods prevented collection of adequate data at three of the sites. To allow direct measure of seepage losses from EWSS, cooperators were asked to eliminate all discharges into the structure for a period of 5-10 days while very sensitive measurements were taken of the fluctuations of the liquid surface in the structure. Measuring the rate at which a liquid surface falls was challenging, particularly because of wind effects. A unique technique using recording electronic scales was developed to obtain the precision needed. Pan evaporation, precipitation, wind speed and direction, relative humidity and air temperature were measured along with the rate of fall of the liquid level in the structure. Theoretically, an evaporation rate should be subtracted from the liquid level drop rate to obtain true seepage values. However, because of inconsistencies in evaporation pan data, researchers did not subtract the effect of evaporation. Most liquid level seepage rates were taken at night, during low-wind conditions, with no rainfall and high relative humidity to minimize measurement error. Several seepage-rate measurements were desired at each site to obtain an estimate of measurement error. However, at six sites only one useable data sequence was obtained for analysis.

The seepage test results from the 28 structures indicated that the means of the total liquid level losses (seepage + evaporation) in basins were less than the existing construction standard of 1/16th of an inch per day at six-foot head for 18 out of the 28 EWSS measured. Measurement errors were estimated from a statistical analysis of the replicated measurements on the same structure. From this analysis, it was concluded that, with a confidence level of 95%, 12 of the 28 sites had total seepage rates lower than the construction standard, one had a significantly higher loss rate than the construction standard and the remaining 15 sites were not significantly different than the standard. Since true evaporation rates from the EWSS were not known, even after using an evaporation pan, data are presented in the report without subtracting evaporation. Because of relatively low evaporation (estimated at 0.2-0.3 mm/d but greater than zero), the estimates presented in this report probably are slightly higher than true seepage rates of the structures during the measurement period.

Soil core analysis

The study team also obtained soil cores surrounding the EWSS to estimate the off-site impact of seepage loss. Soil cores were used to gain a "snapshot" of the pollutant distribution around the structure. Soil cores were expected to be more useful than monitoring wells for a short-term study. Thirty-one of the 34 original sites were included in this portion of the study. Soil cores were made to a depth of 8 feet, approximately 3-6 feet from the outside toe of the berm of the structure at eight sites surrounding the EWSS. A ninth soil core also was collected at a site in the vicinity but upslope from the structure to represent background soil and water conditions not impacted by the EWSS.

Eight 1-foot sections from each soil core were used to evaluate impact of waste migration from the EWSS to localities, generally less than 50 feet horizontally from the stored liquid material. Each core section was analyzed for concentrations of (1) ammonium nitrogen (NH_4-N) attached to the soil; (2) ammonium nitrogen (NH_4-N) in the soil water; (3) nitrate nitrogen (NO_3-N); (4) chloride (Cl); and (5) sulfate (SO_4). Therefore, 40 analyses were run on each core, a total of 11,160 chemical analyses.

The top 2 feet of soil was believed to reflect conditions independent of the EWSS. Therefore, the concentrations of ions were averaged over the lower 6-foot core sections and compared with background measurements. Background concentrations of the different ions were found to be quite variable over the basin locations. Therefore, an average background concentration from all remote sites was used as a standard of comparison. If concentrations in EWSS soil cores exceeded three times the average of the background level, it was assumed that they were likely impacted by animal waste either from seepage from the EWSS or from some previous feedlot and/or manure spillage problems at the site. Unless records indicated another potential contamination source, elevated concentration values in soil cores were assumed to result from the migration of contaminants from EWSS to the outside berm of the EWSS, an average horizontal distance of 30-50 feet. Almost all of the sites had at least one soil core with a concentration ratio above three for at least one of the five concentrations determined. The most common high concentration ratios were for $NH_{4,}$ and Cl. NH_4 or Cl concentrations were found in ratios above three in at least one soil sample out of eight taken at 25 of the 31 basins.

Many of the sites with high NH_4 and/or Cl levels were previously used as open-lot areas for livestock production or were areas of frequent manure loading and/or unloading where minor spillage of waste had been observed. However, five of the sites with high ratios for NH_4 were not explained by previous use history. Data at these sites would indicate a migration of NH_4 from the liquid surface inside the EWSS to the outside of the berm, a distance of 30-50 feet. However, in no sample did NH_4-N concentrations approach saturation level, that is, the level that soil is capable of absorbing, estimated at 1000 ppm.

The average Cl concentration in soil samples around EWSS was statistically higher than the background soil samples. However Cl in and of itself is not a health concern.

The majority of soil cores did not exhibit increased concentrations of contaminants from waste materials, and they represented only localized migration of contaminants around the structure. One measured chemical, NO_3-N, was found at lower concentrations around the EWSS than in the background samples. NO_3-N has been measured at relatively high values (above drinking water standards) in shallow groundwater under corn and soybean fields for several years in the Cornbelt. (Baker and Johnson, 1981; Bjorneberg *et al*, 1998; Baker *et al*, 1998) The major cause is thought to be a combination of row cropping and possibly excessive rates of N inputs (Keeney and DeLuca, 1993; Baker, Mickelson and Crumpton, 1997).

Based on seepage rates and known contents of the EWSS, contaminants appeared in soil cores at lower levels than calculations predicted. There do not seem to be general contamination zones around EWSS. Researchers do note, however, that they are not certain that macropore flow or "fingering" of contaminants in soil was representatively sampled with the techniques used in this study. They also noted little correlation between chemical concentrations found outside EWSS and measured seepage rates.

Conclusions

This project has (a) evaluated geological potential for contamination from EWSS, (b) investigated the management of EWSS over time, (c) measured actual seepage rates and (d) evaluated the migration of contaminants from EWSS. The study was conducted to evaluate the potential for surface and groundwater contamination from EWSS and to determine the cause of contamination, e.g. poor design, construction and/or management of these structures. The data collected for this study indicate that the majority of EWSS are not leaking at a higher rate than their designed standard at the time of construction, and that there seems to be minimal impact of EWSS on the surficial aquifers in the immediate vicinity of the structures.

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

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January, 1999

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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 ≥ 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.

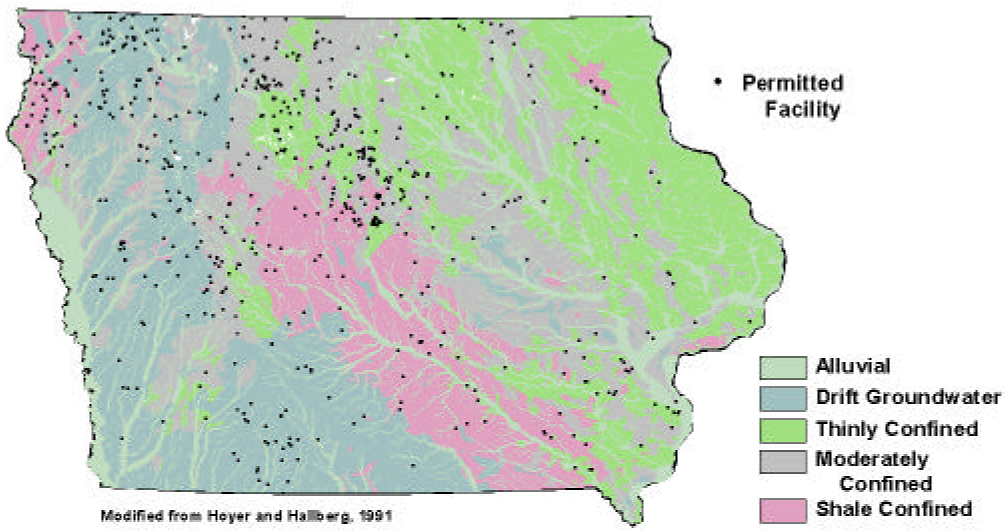

Figure 1. Permitted Earthen Waste Storage Structures (N = 639).

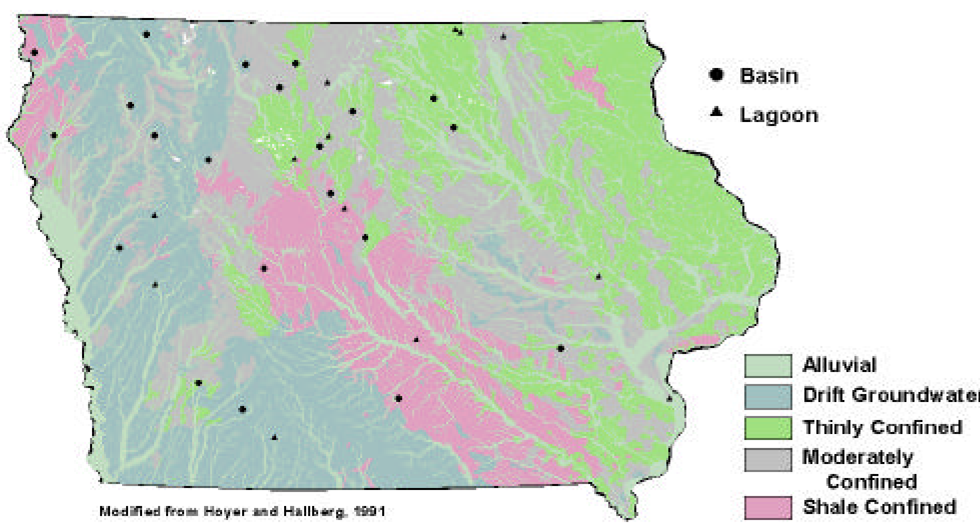

Figure 2. Distribution of study sites in the Aquifer Vulnerability regions.

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.

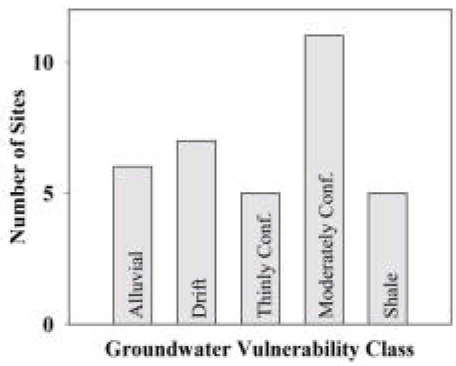

Figure 3. Distribution of selected EWSS within Aquifer Vulnerability classes.

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.

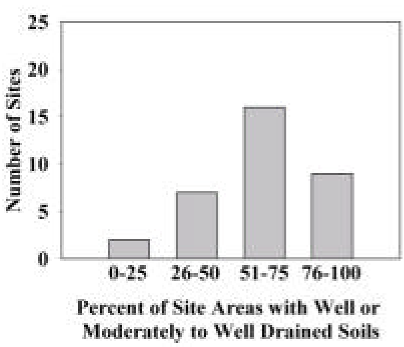

Figure 4. Distribution of well or moderately well drained soils (Hydrologic Groups A and B) in site areas surrounding Selected EWSS.

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.

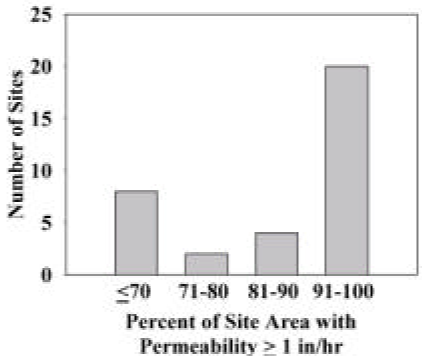

Figure 5. Distribution of soil permeability exceeding 1 in/hr in EWSS site areas.

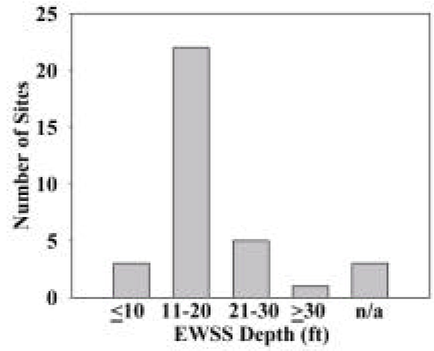

Figure 6. Total depths of EWSS in this study. Depths include height of the berm.

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.

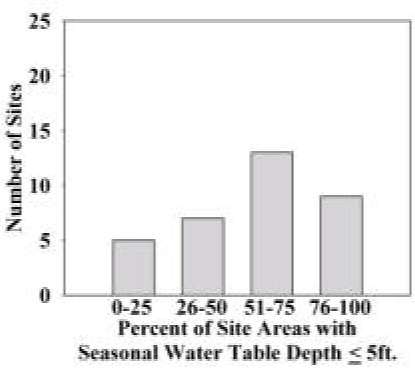

Figure 7. Percentage of soils with seasonal water-table depths less than 5 ft in site areas.

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.

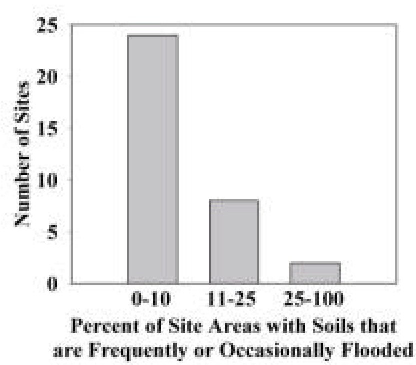

Figure 8. Percentage of soils that flood occasionally or frequently in EWSS site areas.

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.

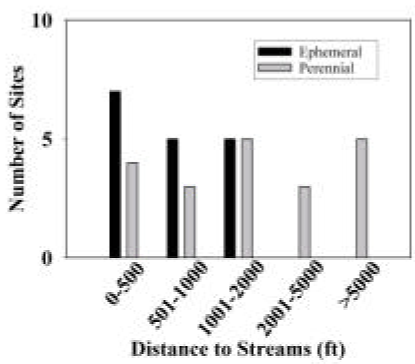

Figure 9. Distribution of setback distances of EWSS from ephemeral and perennial streams.

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.

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

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Summary:

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

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

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

Introduction

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

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

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

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

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

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

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

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

or later:

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

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

Materials and Methods

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

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

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

Results and Discussion

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

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

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

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

Figure 1. Manure spillage during tank loading operation

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

Figure 2. Berm erosion caused by agitation or backwash during pump-out.

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

Figure 3. Animal burrows in berms can become conduits for manure, especially if they are submerged as the earthen structure fills to capacity.

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

Figure 4. Tree growth in berms can create macropores for manure leakage.

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

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

Figure 5. Inadequate freeboard between berm and manure level.

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

Recommendations

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

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Acknowledgements

This project was supported by the Iowa State Legislature. Considerable assistance was provided by Tom Glanville, Jean Carter, Bill Simpkins, Stewart Melvin and Martin Helmke at Iowa State University, and Ubbo Agena of the Iowa Department of Natural Resources. Helpful insights were also provided by Mike Burkart of the USDA National Soil Tilth Laboratory and Kris Kohl of Iowa State Extension. We particularly appreciate the generous cooperation of the farmers who participated in the survey.

Measurement of Seepage from Earthen Waste Storage Structures in Iowa

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ABSTRACT

In 1997 the Iowa legislature mandated that Iowa State University conduct a statewide study of point and nonpoint pollution caused by earthen waste storage structures. As one indicator of environmental impact, researchers measured seepage in a representative sample of 28 earthen structures located within five aquifer vulnerability regions of the state. Study sites were instrumented to measure liquid levels, pan evaporation, rainfall, wind speed and direction, air temperature, and relative humidity at two-minute intervals during a 3 to10 day period during which no liquid was discharged into or out of the structures. Statistical analysis of the data indicates that 43% of the tested structures had seepage rates significantly (with 95% confidence) lower than the regulatory standard of 0.0625 inches/day (at six-foot liquid depth) specified by the State of Iowa at the time the basins were constructed. Earthen structures included in the study had been in service from 2.5 to 11.1 years. Regression analysis failed to confirm significant age-related trends in seepage for structures within the age range covered by this study. When grouped by general type of dominant geologic surficial material, structures located within glacial till have significantly lower seepage rates than those constructed at sites where sand and gravel, colluvium, or loess is the dominant surficial material. Comparison of slurry pits and lagoons showed no significant differences in seepage rate.

During the spring of 1997 the Iowa Legislature passed a bill mandating Iowa State University to conduct a statewide study of water quality impacts caused by earthen waste storage structures (EWSS). Based on reviews of previous EWSS studies conducted in Iowa and other states, ISU researchers concluded that statewide impacts of EWSS would be characterized most effectively through four coordinated subprojects designed to:

- measure whole-basin seepage at representative structures throughout Iowa and compare these values with State seepage regulations;
- examine soils in the vicinity of the tested structures for chemical evidence of seepage and contaminant migration;
- interview owners and/or operators of earthen structures to evaluate operation and maintenance practices that impact local water resources; and
- characterize the hydrogeologic settings of representative earthen structures using aerial photographs and published soils and topographic data, and evaluate the potential of the structures to affect water resources.

This report summarizes results of the seepage measurement study. Additional chapters in this report document the results of the other three phases of the project (Simpkins et al., chapter 1; Richard et al., chapter 2; Baker et al., chapter 4).

BACKGROUND

Due to their relatively low construction and maintenance costs, earthen waste storage structures have long been used for storage and treatment of municipal and industrial wastewater. Approximately 715 municipalities and semi-public entities in Iowa utilize earthen waste stabilization lagoons or aerated lagoons to store and treat wastewater. Following the lead of small municipalities and industries, many medium- and large-scale livestock producers have adapted earthen structures for storage and/or biological treatment of liquid manure.

The State of Iowa currently recognizes two types of earthen waste structures used for liquid animal manure. "Slurry pits" (also called "earthen basins") are used for short-term (typically 6 months) storage of undiluted manure prior to field application. Due to high concentrations of ammonia- and ammonium-nitrogen in undiluted manure, both of which are somewhat toxic to microorganisms, biological degradation of manure solids in slurry pits is relatively low. Volatilization of ammonia from manure stored in slurry pits can cause nitrogen losses of 15 to 30% depending on the rate of gas production and the amount of bedding and other floating organic material that is available to form a crust on top of the liquid. If additional biological treatment is desired manure is diluted with water and placed into earthen structures called “lagoons”. Conditions within the dilute manure favor growth of anaerobic microorganisms that decompose solids into ammonia, methane, carbon dioxide, and hydrogen sulfide. As decomposition occurs, 70-80% of the nitrogen is typically lost through ammonia volatilization. At the time this study was begun, the Iowa Department of Natural Resources

(IDNR) had granted operating permits to approximately 694 animal feeding operations. Of these, 602 were listed in the IDNR database as using earthen pits or lagoons as a component of their manure management system.

The impacts of EWSS on ground- and surface-water resources are not a new concern. In their 1983 survey of literature on seepage from earthen manure structures, Louden and Reece reviewed results of 22 studies that had been published between 1965 and 1982. A more recent review of research results and state regulations by Parker et al. (1994,1999) lists quantification of seepage rates, effects of soil type on seepage, and soil sealing effects of animal manure, as the three primary objectives of earthen structure research during the past 30 years.

The national trend toward large confined animal feeding operations has raised public concern about their potential environmental impacts, and has caused many state legislatures and environmental agencies to reassess their regulatory programs. In a review of livestock waste regulations in 13 southeastern states, Hegg (1997) reported that at least four states in that region were in the process of modifying their regulations. Jones and Sutton (1996) noted that current regulations in 12 Midwestern states were more stringent with regard to manure storage structure design and approval than they were in 1992 when a similar survey was conducted. More recently, Copeland and Zinn (1998) reported that at least 20 state legislatures considered bills to further regulate livestock production during their 1998 legislative sessions.

In an effort to bolster federal assistance and regulatory programs, two federal agencies have recently initiated new programs. The U.S. Environmental Protection Agency (USEPA) has recently released its *Draft Strategy for Addressing Environmental and Public Health Impacts from Animal Feeding Operations* (USEPA, 1998) which is intended to be a "blueprint for a significant expansion of USEPA's regulatory and voluntary efforts related to animal feeding operations." Similarly, the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture is providing additional technical guidance on design and construction of waste storage ponds and treatment lagoons through it's new *Geotechnical, Design, and Construction Guidelines* appendix to its Agricultural Waste Management Field Handbook (Natural Resources Conservation Service, 1997).

Responding to policymakers and regulators seeking more definitive information on the magnitude, frequency, and impact of seepage from EWSS, new studies have been initiated in several states. Soil sampling and groundwater monitoring have been the most common methods used to evaluate earthen structure seepage. Soil samples collected down gradient from eleven 10-20 year old lagoons in North Carolina indicated that five lagoons exhibited low seepage, while the remaining six were judged to have moderate or high seepage. Elevated ammonium-nitrogen in the soil was the strongest indicator of seepage (Huffman and Westerman, 1995). Monitoring wells near two new swine lagoons constructed in deep sandy soils in North Carolina exhibited significant seepage after 3-5 years, and significant spatial variation of contaminants within the seepage plumes were considered indicative of localized seepage from certain areas of the lagoons (Westerman, et al., 1995). The North Carolina Division of Water Quality Groundwater Section (1998) used monitoring wells to test the usefulness of groundwater vulnerability criteria in assessing the pollution potential of 11 animal manure lagoons. Groundwater monitoring near five lagoons located at sites judged to be "less vulnerable" showed no evidence of seepage. Three of four lagoons at sites judged "moderately vulnerable" showed increasing trends in nitrate-nitrogen or chloride concentrations, and monitoring wells near one of two lagoons located within "vulnerable" sites contained ammonia, potassium, and nitrate-nitrogen thought to originate from the lagoon. Libra and Quade (1997) have reported results of several years of groundwater monitoring near four earthen manure structures located in differing geologic settings in Iowa.

Several recent earthen structure studies have employed methods other than groundwater monitoring or soil sampling. A dairy manure lagoon in Minnesota was constructed with a special underdrain system that permitted capture and direct measurement of seepage through portions of the bottom and sidewall. Results showed significantly greater seepage through the sidewall than the floor during the first year of operation. Sealing of the bottom by solids deposition, and differential sidewall and floor compaction efficiencies during construction, were believed to be the most likely causes for these results (Hetchler and Clanton, 1996; Swanberg, 1997).

Relatively few studies have attempted measurement of seepage in operational earthen structures. Most recently Ham and Desutter (1998) used a water balance method to determine seepage from three recently constructed swine-waste lagoons in Kansas. Seepage rates ranged from 0.02 to 0.075 inches/day.

RATIONALE & OBJECTIVES for SEEPAGE STUDY

To date relatively few studies have attempted to measure whole-basin seepage in active earthen waste storage structures. The more typical approach to investigating groundwater impacts has been through sampling of water from groundwater monitoring wells. The decision to undertake a seepage study as part of the legislatively-mandated study of earthen waste storage structures in Iowa was motivated by a variety of considerations. Key among these was the project scope and duration, as set forth by the Iowa Legislature. The stated scope was broad, calling for a statewide assessment of point and nonpoint pollution caused by earthen waste storage structures. At the same time, the project duration was to be relatively brief. Results were to be reported to the legislature within 18 months.

With these project constraints in mind, installation and long-term monitoring of groundwater monitoring wells, the most common approach to this type of study, were ruled out. Groundwater monitoring efforts can easily take several years to complete, particularly if leakage is localized and difficult to locate, or contaminant migration rates are low.

With more than 600 agricultural basins located in a broad variety of geologic and topographic settings throughout Iowa, it became particularly important to identify indices of pollution potential that could be evaluated quickly at a sufficient number of sites to be representative of statewide conditions.

After due consideration, whole-basin seepage measurements were judged worthy of further work since they appeared to offer a variety of potential benefits. These include:

- rapid assessment…..it was believed that whole basin seepage measurements could be made at a study site in 3-10 days given favorable weather conditions (low wind and minimal rainfall);
- regulatory relevance…. whole-basin seepage measurements can be directly compared with state regulatory limits on earthen structure seepage;
- localized seepage can sometimes be difficult to detect using monitoring wells, but whole-basin measurements can quantify seepage without actually having to locate the structural defect;
- environmental impact assessment…..the annual mass of nutrients transported into the soil with seepage can be estimated by multiplying nutrient concentrations in the basin liquid by the predicted annual seepage; and
- future utility to the State of Iowa…..if seepage measurement techniques can be perfected, this would offer a potentially useful evaluation tool for periodic monitoring of earthen structures.

With the forgoing project goals in mind, specific project objectives for the seepage measurement portion of the overall research were reduced to the following:

- develop and test field seepage measurement techniques using off-the-shelf data collection and logging equipment;
- develop data analysis techniques for reducing weather and water-level data to seepage estimates;
- test the above techniques on approximately 10% of EWSS in the IDNR's electronic database of livestock facilities that obtained permits during the years from 1987 through 1994.

SITE SELECTION

As previously noted, some of the more recent earthen structure research suggests that natural processes may lead to increased seepage (primarily through the sidewall) with time. Potential aging factors include: sidewall cracking, caused by freezing and thawing or desiccation; penetration by roots and earthworms or rodents; erosion, caused by rainfall and wave action, poorly protected inlets, and improper agitation during pumping; and liner collapse due to external pressure and groundwater intrusion.

Based on the potential impacts of aging on seepage rates, and the fact that soil and groundwater contamination can take several years to migrate sufficiently far from a structure to be detected, the ISU project team concluded that study sites should be at least three years old. By focusing on structures that had been in service for several years, project planners hoped to evaluate the full range of long-term impacts on local water resources.

The Iowa Department of Natural Resources electronic database of permitted livestock facilities was used to identify potential study sites. A database query identified 439 facilities constructed during the period from 1/1/87 through 12/31/94. Facility owners were contacted by mail and invited to participate in the project. Potential cooperators were asked to fill out a questionnaire providing background information that would aid final site selection. Response to the call for participants was extremely good with 124 EWSS owners responding favorably.

To achieve the goal of testing a representative sample of approximately 10% of the target population, 40 earthen manure basins and lagoons was selected for the study so that the ratio of basins to lagoons was similar to that in the total population. Since assessment of impacts on groundwater was a key objective of the legislatively-mandated study, groundwater vulnerability also was a key criterion for site selection. Using Iowa's groundwater vulnerability map (Hoyer and Hallberg, 1991) project geologists identified five major aquifer vulnerability regions. These include areas underlain by surficial aquifers (alluvial or drift); and regions where confined aquifers are overlain by thin drift (less than 100 ft thick), moderate drift (100-300 ft thick), or shale. Here again, study sites were selected so that the proportion in each of the vulnerability regions was similar to that in the total population of earthen structures.

Of 40 sites selected for participation, owners of five structures ultimately failed to sign a memorandum of understanding with ISU permitting project staff to enter their property. Of the remaining 35 sites one was ultimately found to have been abandoned and filled in. Further site investigation revealed that liquid levels at four sites were below the surrounding ground elevation. Since excavation would have been necessary to monitor these structures, they were dropped from the study. A considerable body of monitoring data also was collected on an ISU research farm during field testing of monitoring instruments. Although the earthen structure did not meet the three-year minimum age criterion, these data were added to the project results, bringing the total number of sites monitored for seepage to 31.

FIELD MEASUREMENTS AND DATA ANALYSIS

Instrumentation and Data Collection

At the time planning for the seepage measurement project was begun, Iowa regulations specified a <u>maximum</u> seepage rate of 1/16 inch per day (0.0052 ft/day) at a liquid depth of 6 feet. To determine if commercially available transducers could reliably measure such small fluctuations in liquid level, the ISU project team reviewed scientific literature relevant to a variety of research projects where small changes in water level were necessary. Manufacturers or vendors of water-level monitoring devices (Campbell Scientific, Druck Incorporated, Kobold Instruments) also were consulted. Based on these investigations, it was concluded that the most sensitive water level sensors readily available at a reasonable cost were designed to monitor water level fluctuations over a range of 2 - 5 feet. With advertised full-scale accuracies of 0.1%, these devices were only capable of detecting water level fluctuations of 0.002 feet or greater, and these capabilities were further qualified by manufacturer's application guidelines specifying that the devices be used in "clean" water to avoid plugging and other operational problems.

Since it was anticipated that some basins would exhibit seepage rates less than the regulatory maximum, it was desirable to find instrumentation capable of detecting water level fluctuations considerably smaller than 0.002 ft/day. Furthermore, it was quite clear that whatever system was employed, it would need to be able to function in liquids other than clean water. Lacking knowledge of, or ready access to, a suitable commercial system, the research team proceeded with design and testing of custom-designed instrumentation that could meet project requirements.

The specially designed system illustrated in figure 1 was conceived and field-tested in the spring of 1998 by ISU researchers. This system employs a siphon tube that provides a hydraulic connection between liquid in the earthen structure and water in a beaker located on a portable electronic balance that is housed inside an instrument cabinet (figure 2). Liquid-level fluctuations within the basin are transmitted through the siphon tube, producing fluctuations of equal magnitude within the beaker. The diameter of the beaker dictates the sensitivity of this system. For the setup employed in the study, a 1-millimeter (mm) rise in liquid level causes an 8-gram increase in the mass of water inside the beaker. Since the electronic balances are capable of reliably detecting mass changes as small as 0.1 gram, the liquid level monitoring system is theoretically capable of detecting water level changes of 0.0125 mm. In practical application, the system more realistically detects fluctuations of 0.0250 mm which is equivalent to less than 0.0001 ft. As such, the sensitivity of this instrumentation is approximately 20 times greater than that offered by commercial water level sensors readily available at the time the project was begun.

In addition to logging water level fluctuations inside the earthen structures over a period of 3-10 days, each monitoring site was equipped with a tipping bucket rain gage and apparatus for measuring wind speed and direction, air temperature, and relative humidity. These data were collected using commercially available weather instruments. In addition, a second siphon tube and balance system was used to measure evaporation from a 22-inch diameter evaporation pan located on the outside of the berm (figure 3).

Seepage Determination

Several processes cause liquid level fluctuations within an earthen structure. These include liquid inputs, such as rainfall and pumping into the structure; and liquid outputs, which include evaporation, seepage, and pumped withdrawals.

The interrelationships of these factors can be described by the general water balance formula:

Inputs - Outputs = Change in storage

By agreement with the cooperating facility owners, pumping into and out of the EWSS was curtailed during seepage monitoring. With these inputs and outputs eliminated, the water balance relationship becomes:

Precipitation(cm/day)-[Evaporation(cm/day)+Seepage(cm/day)] = Liquid level change(cm/day)

Input

Outputs

Although seepage is labeled as an "output" here, seepage <u>into</u> an EWSS will occur whenever the elevation of the local groundwater table rises above the liquid inside an earthen structure. Evaluations of hydrogeologic settings of the EWSS in this study indicate that the floors of a large percentage are probably below seasonally high water tables (Simpkins et al., chapter 1 of this report). At the time seepage monitoring was conducted, however, liquid levels in the study structures were approaching design depth. When compared with water levels observed in soil core holes near the structures, interior liquid levels at all sites appeared to be at or above the local water table.

By further restricting measurement of liquid level changes to time periods when no precipitation occurs, precipitation can be dropped from this equation. Through algebraic reorganization of the three remaining terms, the formula shows that the rate of seepage can be calculated by subtracting the evaporation rate from the rate of liquid level change.

Seepage rate = Rate of liquid level change - Evaporation rate

To further illustrate how the water balance equation is applied, figure 4 shows a sample of liquid level data collected at one of the earthen structures tested during the ISU seepage study. The linear regression line drawn through the data shows that the liquid level declined approximately 1.6 mm (0.0394 inches) during the 8-hour period from midnight to 8:00 AM. When extrapolated to a 24-hour basis, the estimated rate of liquid level decline is 4.8 mm/day (0.1890 inches/day). Evaporation measurements during the same time period indicate an evaporation rate of about 0.4 mm/day (0.0157 inches/day). Subtracting this rate of evaporation from the rate of liquid level decline, the seepage rate is calculated to be 4.4

mm/day (0.1733 inches/day). Under favorable weather conditions, several data sequences were collected at each site, and the mean value (converted to units of inches per day, to be dimensionally consistent with Iowa's seepage regulations) was used as the best estimate of seepage.

Wind effects are a major cause of variability in measurements of whole-basin seepage. Sudden changes in wind speed or wind direction can cause short-term fluctuations in liquid levels that obliterate the subtle effects of seepage and evaporation. Examples include "wind setup," a phenomenon observed when wind-driven water piles up along the downwind shoreline of a body of water. When this occurs, a gradual increase in liquid levels will be observed at downwind monitoring stations although no liquid is being added to the structure. Even at wind speeds too low to cause wind setup, surface waves of varying velocity and amplitude can create oscillating water levels that must be identified and removed from the data stream before the effects of seepage and evaporation can be quantified.

To illustrate some of the complications caused by wind-induced waves, the sample data in figure 5 show relatively minor (less than 1 mm) liquid level oscillations caused by average wind speeds of only 1.5 meters/second (3.35 miles/hour). Despite these wind effects, the regression line through the data show that liquid fluctuations caused by waves are superimposed over a gradually declining trend line indicating a constant liquid level decline at a rate of nearly 0.6 mm/day (0.0236 inches/day). Data collected at another time, under different conditions of wind, temperature, relative humidity, and other factors will yield slightly different estimates of liquid level decline. This variability is inevitable when collecting data under field conditions where external influences cannot be fully controlled.

Because wind and other uncontrolled influences can play such a crucial role in the measurement of minute liquid level fluctuations, realistic assessment of seepage must recognize the variability caused by these factors. Although results of several measurements can be averaged to obtain a single estimate of seepage at each study site, this average value is only an estimate of the "true value" which realistically lies somewhere within a range of values. To reflect this reality, figures 6 and 7 in the "Results" section of this report show both a mean value and a 95% confidence interval for the mean. The confidence interval illustrates the range that is 95% likely to contain the true seepage value.

Readers will note that some sites have broader 95% confidence intervals than others. Differences in the widths of the 95% confidence intervals are caused by two factors. Favorable wind, precipitation, and relative humidity conditions at some sites permitted collection of several useful nighttime data sequences. Under less favorable conditions, only one or two useful data sequences were obtained. Since larger amounts of data permit a better estimate of the mean value, the likely range of values is smaller for sites with more data. Statistical analysis also revealed that data variability was not uniform across the study sites, but instead is proportional to the estimated value of the mean loss rate for each site. As a result, sites with higher estimated mean loss rates tend to have broader 95% confidence intervals.

Evaporation Determination

As noted earlier, evaporation data were collected by measuring the rate of water level decline within an evaporation pan installed at each study site. Pan measurements are a common method for approximating evaporation from large, open bodies of water, but it is widely recognized that pan data often overestimate the true rate of evaporation from ponds and lakes. Differences between lake and pan conditions that can bias the pan data include (Burman and Pochop, 1994):

- differing water temperature variations with depth;
- storage of heat within the pan;
- differences in wind exposure;
- differences in the turbulence, temperature, and humidity of air above the water surface; and
- heat transfer through the sides and bottom of the pan.

Since pan evaporation normally exceeds evaporative losses from larger water bodies, researchers commonly adjust the pan data to obtain a more realistic estimate of lake evaporation. Adjustment is accomplished by multiplying pan data by a "pan coefficient," which is the ratio of lake or reservoir evaporation to the evaporation indicated by pan data. Typical pan coefficients range from 0.7 to 0.9 (Brutsaert, 1982) depending on the pan and its surrounding environment.

In the special case of evaporation of liquid from earthen structures containing livestock manure, selecting an appropriate pan coefficient is further complicated by two additional factors. In some instances livestock waste forms a floating scum layer that reduces the exposure of the liquid surface to wind and solar energy. When present, this layer impedes water transfer to the atmosphere, increasing the difference between pan evaporation and actual evaporative loss from an EWSS. Elevated salt concentrations, which are typical in liquid animal wastes, also may suppress evaporation to a limited extent. This effect appears to be minor, however, as studies of evaporation from saline lakes and reservoirs in western states (Harbeck, 1955) indicate that suppression does not become significant until salinity levels are much higher than typically found in liquid manure.

Preliminary evaluation of evaporation pan data and liquid level data within the earthen structures showed that daytime pan and EWSS evaporation losses can be considerably higher than those observed at night. In some instances pan measurements over-estimated evaporation to the extent that the evaporative loss exceeded the basin loss measurements (which include seepage and evaporation). Overestimation of evaporation causes the water balance equation described earlier to predict negative seepage rates, implying net seepage into the structure rather than out of it. As noted earlier, however, seepage monitoring was conducted at a time of year when most EWSS were approaching design depth. When compared with water levels observed in soil core holes located near the structures, interior liquid levels at all sites appeared to be at or above the local water table, thereby precluding the possibility of groundwater seepage into the structures.

Even when daytime pan losses did not exceed the measured basin loss, evaporative losses were sometimes sufficiently large to interfere with seepage calculations. When estimated evaporation rates are large, even relatively small errors can lead to large errors in the seepage estimate. In some instances, underestimation of daytime evaporation (probably caused by high winds) resulted in preliminary seepage estimates that exceeded the estimated daily discharge from the livestock facilities. Since continuous seepage rates of this magnitude would preclude an earthen structure from filling, preliminary results of this nature initiated a review of data analysis methods.

To further reduce the potential for error in determining seepage, a revised data analysis strategy was devised. Since wind and evaporation are the two factors that interfere most with field measurements of seepage and liquid level fluctuations, the revised procedure uses only data collected at times when evaporation rates and wind speed are minimal. To accomplish this, a computer program was written to scan data at each study site and select data sequences when relative humidity exceeded 90%, maximum wind speed was less than 3 meters/second, and no precipitation occurred.

This "filtering" strategy typically identifies data sequences collected at night and/or in the early morning, ideal times in the sense that solar energy is non-existent or very low, and wind velocities are typically low. Furthermore, nighttime air temperatures also are normally lower than during the day. This leads to cooling of water surfaces, another factor in reduced evaporation. Cooler nighttime conditions also favor increased humidity levels and, as humidity increases, the amount of additional moisture that air can hold decreases, further suppressing evaporation.

Analysis of nighttime pan data produced useful evaporation data for about 60% of the basin loss measurements made during the study. Wind interference prevented acquisition of acceptable data at other times. The successful evaporation determinations had an overall mean value of 0.56 mm/day (0.0216 inches/day) and a standard deviation of 0.43 mm/day (0.0169 inches/day).

Since about 40% of the basin loss data (the measured decline in liquid level within an EWSS) lacked concurrent evaporation data necessary for seepage determinations, several alternative sources of evaporation data were considered. Since all evaporation data were collected under similar atmospheric conditions (relative humidities exceeding 90% and peak wind less than 3 meters/sec) one approach considered was to apply a pan coefficient to the mean of all the successful evaporation determinations and use this estimate for all sites. Applying typical pan coefficients of 0.7 to 0.9 to the mean evaporation yields nighttime estimated EWSS evaporation ranging from 0.39 to 0.50 mm/day (0.0153 - 0.0199 inches/day).

Since meteorologists and hydrologists are often faced with making evaporation estimates based on relatively scarce meteorological data, a variety of evaporation prediction equations have been developed. One of the more common formulas reported by Dingman (1994) is:

$$E = K_E \nu_a (\rho_s - \rho_a)$$

where E is the predicted evaporation rate (cm/day);
K_E is a mass transfer coefficient of approximately 1.26 x 10^{-4} (sec/mb-day)
ν_a is measured wind speed (cm/sec); and
ρ_s and ρ_a are vapor pressures measured in millibars (mb) at the liquid surface and in the air (calculated based on temperature and relative humidity measurements)

At air temperatures ranging from 10 to 20 °C, average wind speeds of 1.5 to 2.0 meter/second, and a relative humidity of 95%, evaporation rates in the range of 0.15 to 0.35 mm/day are predicted by this formula. These predictions agree reasonably well with the previously discussed coefficient-adjusted mean evaporation rates of 0.39 - 0.50 mm/day. Furthermore, since evaporation from EWSS may be suppressed further by the effects of floating debris, the true nighttime evaporation rate may be as low as 0.1 to 0.2 mm/day (0.0039 - 0.0079 inches/day).

PROJECT RESULTS

Perspectives on the Data

Evaporation Considerations. From a scientific standpoint evaporative losses are very important when using a mass balance approach to determine seepage and, as previously discussed, evaporation has received careful consideration in this study. As noted earlier, however, evaporation and seepage calculations presented in this study are based on data collected at times (typically at night) when evaporation is estimated to be only 0.2 to 0.3 mm/day. In most instances this is less than the inherent variability of the liquid level fluctuation data, as illustrated by the 95% confidence intervals shown in figures 6 and 7. From a practical standpoint then, correcting liquid level data for evaporation does not significantly improve the accuracy of seepage estimates. With this in mind, evaporation corrections have not been applied and statistical comparisons presented in this section are based on measurements of total liquid loss rates (i.e. seepage plus evaporation). Consistent with this approach, the data shown graphically in figures 6 and 7 are slight overestimates of seepage and are referred to as "liquid loss" to distinguish them from true seepage.

Background on Regulatory Seepage Limits. At the time the study basins were constructed (1987-1994), Iowa's EWSS regulations permitted 1/16th inch (0.0625 inches) of seepage per day at a liquid depth of 6 feet. Early in 1999, the IDNR adopted new rules limiting maximum seepage in new earthen structures to 1/16th inch/day when filled to design depth (maximum allowable depth). Although the quantity of allowable daily seepage is the same, the new rule is considerably more stringent due to the increased regulatory depth at which it applies and the fact that maximum seepage from an earthen structure occurs at maximum liquid depth.

Before comparing data from this study with Iowa's regulatory seepage limits, it should be noted that the whole-basin seepage measurement methodology devised especially for this project differs in both timing and technique from the methods normally employed to substantiate regulatory compliance. Current regulations require proof of compliance to be submitted prior to start-up of new earthen structures. As such, Iowa's seepage regulations are used primarily to evaluate new construction, as opposed to performance monitoring of structures already in service. Furthermore, seepage tests for regulatory purposes are generally conducted in the laboratory on small cores extracted from the floor and sidewalls. Whole-basin measurements, as the name implies, test a major portion of the structure if conducted when a lagoon or basin is nearly full. Recognizing these fundamental differences in seepage measurement methods, whole-basin measurements that fail to meet current or past seepage limits do not necessarily imply that a structure failed to meet state requirements at the time of construction.

Estimating Losses at Past and Current Regulatory Depths. Field seepage measurements were obtained during late summer or fall as liquid depths approached design depth. Of the 28 study sites for which loss rates have been estimated, nearly 80% were filled to within three feet or less of design depth. Since seepage rates increase with increasing liquid depths, field measurements must be adjusted to be comparable with regulatory seepage limits at six-feet or design depth. Adjustment to a common depth also is necessary to make meaningful comparisons between structures or to evaluate seepage trends with age or other physical factors. Figure 6 charts estimated liquid loss rates at a liquid depth of 6 feet (depth specified by Iowa seepage regulations prior to 1999), while figure 7 shows estimated loss rates when structures are filled to design depth (depth specified in Iowa's current seepage regulations).

Field measurements were converted to estimated loss rates at design depth and six feet using Darcy's law, a relationship that predicts the velocity of flow through soil or other porous media based on the material's hydraulic conductivity and on the hydraulic gradient across the material. Darcy's law is described by the equation:

$$V = KI$$

where

V= velocity of flow;
K= hydraulic conductivity;
I = hydraulic gradient.

For the purposes of estimating flow rates through the compacted soil liner of an EWSS, hydraulic gradient is defined by the equation:

$I = H/L$

where

H = hydraulic head loss across the soil liner of the EWSS; and

L = thickness of the soil liner.

Head loss (H) across the soil liner is defined by:

$H = D+L-h$

where

D = depth of liquid in EWSS;

L = thickness of compacted soil liner; and

h = hydraulic head beneath the soil liner.

If the soil liner has uniform hydraulic conductivity and thickness throughout the structure, the seepage rate (V_2) at any desired head loss (H_2) can be estimated from field measurements of seepage (V_1) made at a known head loss (H_1) using:

$V_2 = V_1 [H_2/H_1]$

Due to project time limitations, depth-adjusted seepage rates in this report are based on liquid depth (D) and liner thickness (L). Sufficient field data were not available to reliably determine h. Structures were surveyed to determine liquid levels (with respect to the top of the berm) at the time seepage monitoring was conducted. The distance from the liquid level to the top of the berm was subtracted from the total height of the structure (bottom to top of berm height) reported by the owner or manager to determine liquid depth. Liner thickness, which constitutes only a small fraction of H, was assumed to be one foot.

Assessment of local water table elevations, an important factor in determining the third component (h) of total head (H), was limited, due to time constraints, to single observations. These were made in eight-foot deep holes created when soil core samples were extracted at eight locations around the outer toe of the EWSS. At slightly more than one-third of the study sites, a water table was not intersected by the eight-foot core holes at the time of observation. In addition to their depth limitation, the one-time core hole observations do not portray seasonal changes in groundwater elevations or the effects caused by cyclical fluctuations of liquid levels within the EWSS. Longer-term studies, using monitoring wells constructed at greater depths, would be necessary to assess the full range of seasonal water table fluctuations.

Though a lack of complete water table data causes some error when estimating seepage rates at the past and current regulatory depths, these errors are well understood and do not prevent useful interpretation of the results. Some typical examples are the easiest way to clarify this. When a water table is present above the bottom of the soil liner, this condition reduces the total head across the soil liner. Failure to include this reduction results in overestimation of seepage rates for liquid depths less than the original depth (H_1). Consider an earthen structure that is located totally above the water table and has a liner thickness of 1 foot. If, this structure exhibits a seepage rate (V_1) of 0.1 inches/day when measured in the field at a liquid depth of 13 feet, then the head loss (H_1) for this condition is 14 feet. The same structure operating at a liquid depth of six feet would experience head loss of seven feet, and the estimated seepage rate ($V_2 = V_1$ [7/14]) is 0.05 inches/day. Under the same two liquid depth conditions, but with a constant water table 4 feet above the bottom of the soil liner, H_1 becomes 10 feet, H_2 is 3 feet, and the estimate for V_2 is ($V_2 = V_1$ [3/10]) 0.03 inches/day. In this case, failure to consider the effects of a water table leads to an estimate of V_2 that is 1.67 times greater than the true value in those cases when such a water table condition is present. This pattern of overestimation always holds true (if the water table elevation remains constant) when estimating V_2 at liquid depths less than the depth at which V_1 was originally measured. In situations where H_2 is not constant but decreases as the depth of liquid inside the structure decreases, the degree of overestimation is reduced.

The opposite occurs when converting field measurements to estimated seepage rates at depths greater than H_1. If the earthen structure in the previous example has a design depth of 15 feet (the average design depth for the structures monitored in this study), then the estimated seepage rate (ignoring a water table if present) at design depth would be 0.11 inches/day (V_1 [16/14]). As before, with a water table 4 feet above the bottom of the soil liner the estimated full-depth seepage rate is 0.12 inches/day (V_1 [12/10]). Here, failure to consider a water table leads to underestimates of V_2. As before, in situations where the height of the water table is influenced by the liquid level within the structure, then the degree of underestimation of seepage that results from failure to consider the water table is reduced.

Regardless of whether field measurements of seepage are being adjusted to greater or lesser depths, as the difference between H_1 and H_2 increases, so do the errors introduced by missing or inaccurate water table elevation data. Since seepage monitoring at most research sites was done at a time when liquid depths were approaching design depth, this means that estimated seepage at the six-foot regulatory depth should have the greatest error. Since failure to include water table effects lead to overestimation of seepage rates at reduced depths, the data in figure 6 are high, and the proportion of study sites that meet the former state seepage regulation (1/16 inch/day at 6-foot liquid depth) is somewhat understated. At the same time, the seepage estimates for design depth shown in figure 7 are underestimates for those situations where a water table exists above the bottom of the soil liner. Since field measurements for most sites were made when liquid depths were close to design depth, however, the degree of underestimation is often quite small, as illustrated by the previous example. As a result, the proportion of sites estimated to be meeting the current seepage regulation may be slightly overstated.

Comparisons with Former and Current Seepage Regulations

Former Regulatory Limit. Figure 6 shows estimated liquid loss rates when EWSS contain six feet of liquid (matching the former regulatory seepage limit). To determine whether a site is significantly above or below the former regulatory seepage limit, a one-sided statistical hypothesis test was conducted. Results of this procedure indicate that 12 of 28 sites (43%) have loss rates significantly ($p < 5\%$) less than the regulatory limit. The same type of statistical test indicates that only one site is significantly above the seepage limit. Loss rates at the remaining 15 sites are quite close to the $1/16^{th}$ inch/day regulatory limit and are neither significantly larger nor significantly smaller than the limit. Recognizing that the data in figure 6 are overestimates of true seepage (due to inclusion of evaporation at all sites, and possible water table effects at some sites), the true number of sites meeting the seepage limit may be more than the 43% cited above.

Current Regulatory Limit. Figure 7 displays loss rates adjusted to reflect conditions when EWSS are filled to the design depth (matching the recent change in Iowa's regulatory seepage limit). Since design depths for the study sites ranged from 6 to 32 feet (average of 15 feet), estimated design depth loss rates for deep basins can be several times the loss rate at 6 feet of liquid depth. Figure 7 displays data in the same basin order as shown in figure 6, making it possible to compare predicted loss rates at six feet and full depth for the same basin.

As before, statistical tests were conducted to estimate the likely number of study sites that meet the current seepage limit. Results indicate that four sites (15%) have loss rates significantly less than the new seepage limit ($p < 5\%$), while ten sites (36%) appear to have loss rates significantly greater than the seepage limit. The remaining 14 sites have loss rates sufficiently close to the seepage limit that one cannot say, with 95% confidence that they are either significantly less than or greater than the limit. Like the data in figure 6, small amounts of evaporation included in figure 7 lead to slight overestimation of seepage. For earthen structures that are consistently influenced by water tables, however, the previously described lack of water table data creates a concurrent tendency toward slight underestimation of seepage at design depth that, in part, offsets overestimates caused by evaporation.

Analysis of Potential Factors Affecting Seepage

In their recent overview of research results and state regulations relating to earthen structures, Parker et al. (1999) note that long-term effects of manure sealing, soil type, and climatological factors on seepage are yet to be fully understood. Though seepage rates in fine-grained soils are typically lower than in coarse-grained materials, this trend has apparently not been universal. Similarly, experiments designed to evaluate soil sealing mechanisms of animal manure have demonstrated seal formation in some cases and not in others.

To evaluate siting and design factors that may affect long-term seepage from earthen structures in Iowa, mean seepage values were statistically tested for evidence of trends with age, soil type, and manure type (pit versus lagoon). So that seepage rates from all structures are comparable, seepage estimates at a uniform liquid depth of six feet are used in these tests.

It should be noted that data from only 27 sites are used in the following trend analyses. Data from the site with the highest mean seepage (roughly three times greater than at any other site) have been omitted. While the seepage estimate for this site is considered to be valid, the abnormally high value suggests that this structure is affected by seepage mechanisms that are quite different from those affecting most basins. As such, the variability introduced by the large values at this structure makes it nearly impossible to draw statistical conclusions about more subtle differences in seepage among the other sites.

Relationship of Loss Rates to Soil Type. Based on soils data, topographic maps, and aerial photography, geologists participating in the ISU EWSS project classified each of the study sites according to their dominant surficial geologic materials (Simpkins et al., chapter 1 of this report). Ten materials groupings were originally identified but, since some included only one or two study sites, these were regrouped into four general surficial materials categories (note that these groupings differ from the five aquifer vulnerability regions originally used in site selection) for the purposes of this statistical analysis. The general categories include sand and gravel, colluvium, loess, and till.

As shown in figure 8, mean loss rates were highest at study sites where sand and gravel are the dominant surficial geologic material, and loss rates are lowest where glacial till dominates the site. Statistical analysis indicates that mean loss rates for till sites are significantly ($p < 5\%$) lower than mean loss rates for structures in the other three materials groupings. There is no statistically significant difference, however, among observed loss rates for sites where loess, colluvium, or sand and gravel are the dominant surficial geologic material.

Relationship of Loss Rates to Structure Age. One of the key questions concerning use of earthen structures is whether there is a sealing effect over time. Early thoughts on the subject suggested that EWSS filled with manure would "self seal" over time as deposited solids block pores or cracks in the floor or sidewalls. As noted in background information presented earlier, however, recent research also suggests that seepage through the sidewalls of earthen structures is greater than through the bottom. This suggests that natural processes such as freezing and thawing, wetting and drying, wave erosion, and intrusion by earthworms, roots, or rodents may lead to increased seepage as earthen structures age.

When loss rates are graphed versus age, the ISU data (figure 9) suggest a possible trend toward declining liquid loss rates with time. Two statistical approaches were used to test the significance of this apparent trend. In the first, linear regressions of loss-rate versus age were determined for each of the four major soil groupings. Since “till” and “non-till” sites were previously found to have significantly different loss rates, regression results for the three non-till groupings were pooled to obtain a single regression representing non-till sites. Subsequent statistical analysis showed that the slopes of the till and non-till regression lines were significantly ($p < 5\%$) different from zero, substantiating the likely existence of a relationship between age and loss rates. In the second method of analysis, the data were aggregated into "till" and "non-till" groupings, as shown in figure 9, before performing the regression analysis. Using this approach, the slopes of the till and non-till regression lines fell slightly short ($p = 0.0632$) of being significantly different from zero, indicating no significant trend with age. The inconsistent results of these two analytical approaches indicate that earthen structures in the 3 to 11 year age range represented by sites in this study are unlikely to exhibit significant trends in loss rate with age. Since this project was designed to examine structures that were at least three years old, no conclusions can be drawn regarding trends in seepage rate immediately following construction.

Comparison of Slurry Pits and Lagoons. Since slurry pits contain largely undiluted manure, the sealing potential for pits might reasonably be expected to be higher than for lagoons. Among the 12 lagoons and 15 slurry pits for which loss rates could be determined (excludes the single site with extreme seepage, as previously noted), mean loss rates at a uniform liquid depth of 6 feet were 0.0479 inches/day and 0.0472 inches/day respectively. As such, there was no significant difference in loss rates between the pits and lagoons tested in this study.

RECOMMENDATIONS

Results of this project suggest several possible courses of action for future consideration as Iowa's EWSS regulatory program continues to evolve.

While only one (3.6%) of 28 study sites clearly exceeded the previous seepage standard, 10 sites (36%) exceeded the more strict regulatory limit enacted in 1999. The higher failure rate under the more stringent rules points to a need for continued review and evolution of siting, design, and construction methods that can meet the revised seepage regulations.

Differences between loss rates for structures constructed in till, and for those located where sand and gravel, colluvium, or loess are the dominant surficial geologic materials, further emphasize the need for detailed siting, design, and construction guidelines that recognize differences in the performance potential of various soils and geologic materials. The recently revised *Geotechnical, Design, and Construction Guidelines* (NRCS, 1997), which use soil characteristics such as plasticity index and percent fines to help evaluate site suitability, may provide a useful starting point for continuing development of siting, design, and construction procedures that match varying soil conditions found throughout Iowa.

The lack of a clear-cut relationship between whole-basin seepage rates and structure age raises questions regarding how and when seepage should be measured to prove compliance with Iowa's seepage limit. Current rules describing Iowa's seepage limit for livestock lagoons and earthen basins mention collection and submission of seepage data only in the context of construction evaluation prior to start-up. This wording would seem to suggest that the regulatory limit is intended for evaluation of new construction only, and that it is not relevant to lifetime performance. The intent of the seepage rules should be clarified in this regard and, if applicable to lifetime performance monitoring, acceptable techniques (such as ground water monitoring, liner sampling and permeability testing, and/or whole-basin seepage testing) for evaluating seepage in operational structures should be articulated.

Much could be learned about long-term performance of EWSS through more intensive study of structures included in this study that have exhibited relatively high seepage losses. Monitoring of soil and groundwater beneath and around these structures could prove useful in developing site-specific, risk-based seepage and design guidelines that recognize important differences in pollution potential caused by variations in facility size and depth, waste strength, soil chemistry and permeability, and aquifer use and vulnerability.

Follow-up evaluation of temporal seepage variations in selected structures included in the ISU study also is recommended. Seepage measurements made at various liquid depth conditions during the operating cycle could help to pinpoint where leakage is taking place (floor, lower sidewall, upper sidewall) and to formulate design and construction methods that further reduce seepage potential.

ACKNOWLEGEMENTS

Project investigators and staff offer their sincere thanks to the managers and owners of the earthen waste storage structures that were evaluated. Without their cooperation and patience this project could not have been conducted.

Many thanks also to Mr. Maxime Hunez, agricultural engineering student from France, who contributed many long hours in the field to this project during his undergraduate internship in the Department of Agricultural and Biosystems Engineering.

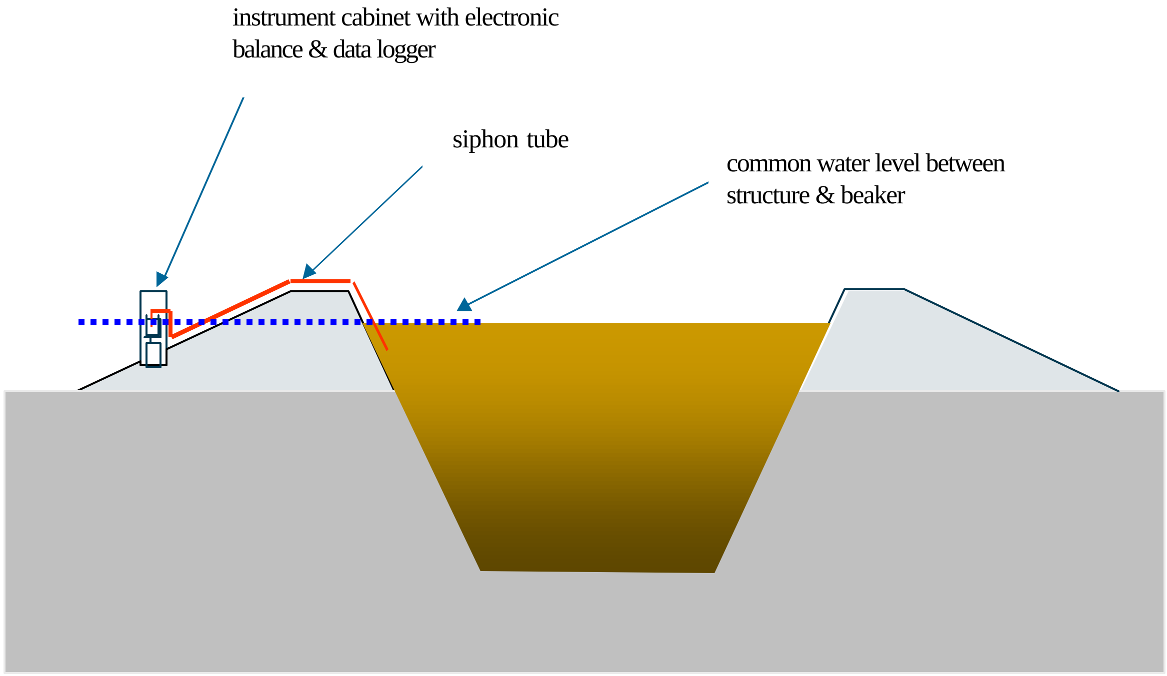

Figure 1. Schematic of water level measurement system using a siphon tube, battery-powered electronic balance, and data logger.

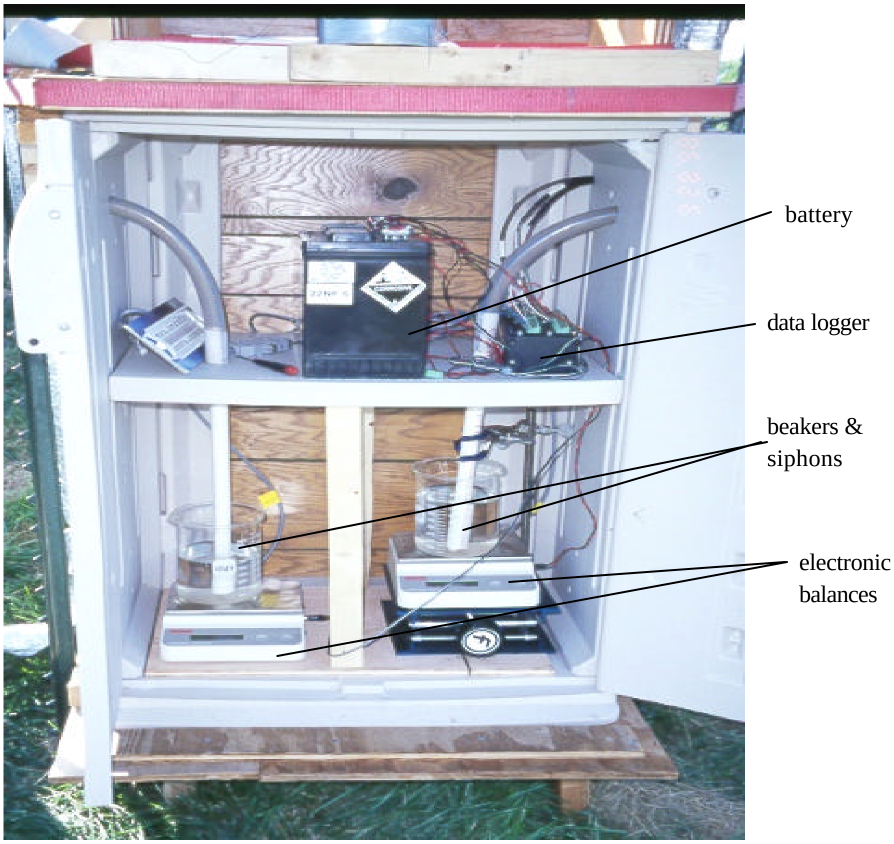

Figure 2. Electronic balances and data logging equipment used to record water level fluctuations within earthen structure and evaporation pan.

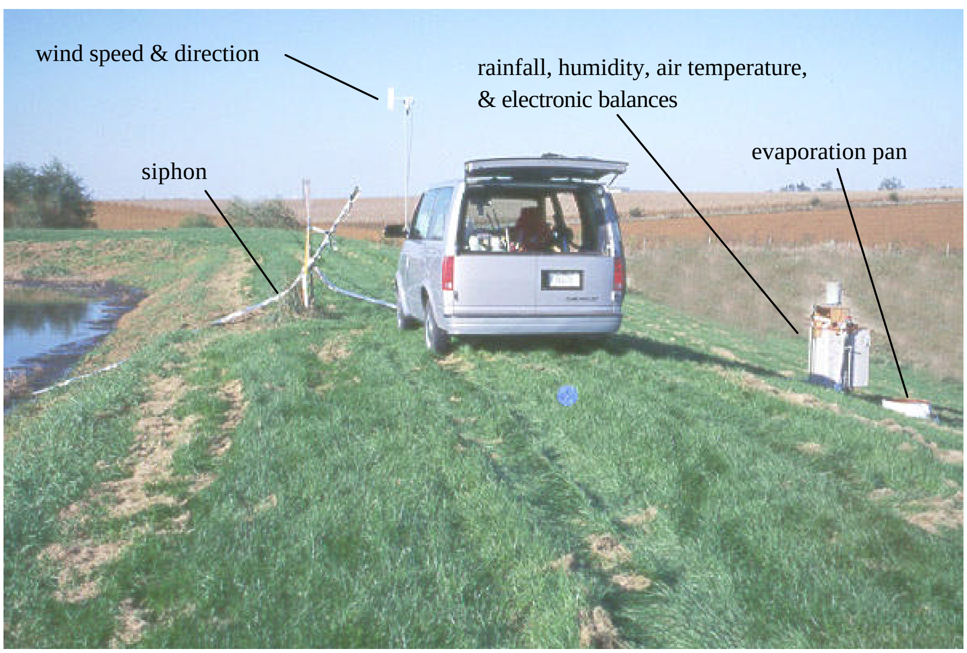

Figure 3. Typical liquid level and weather monitoring instrumentation at study sites.

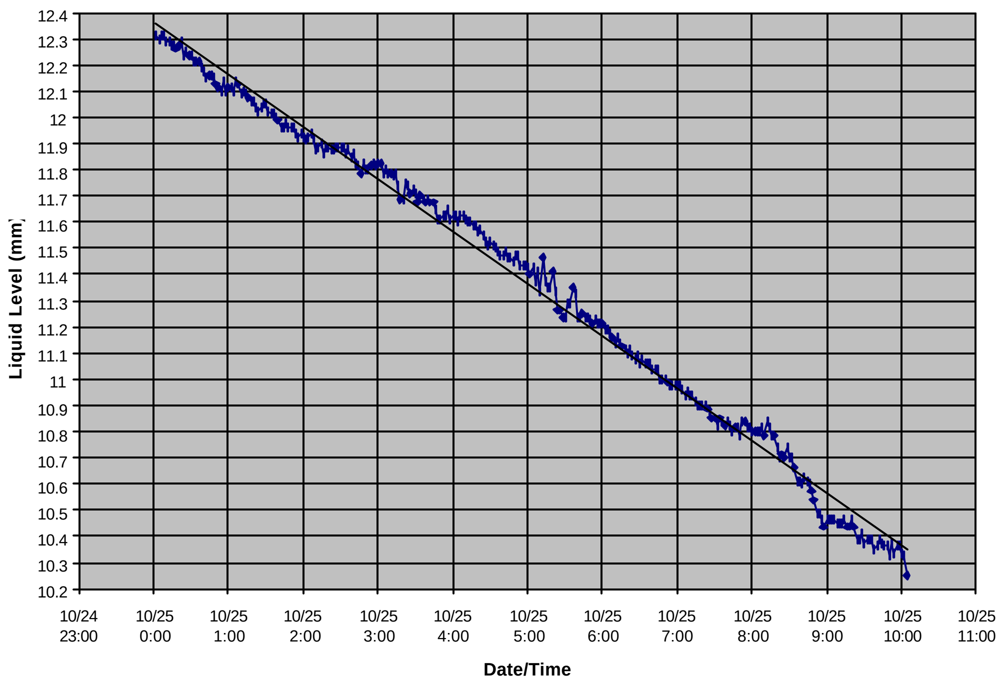

Figure 4. Sample data illustrating liquid level decline measurements under low wind conditions.

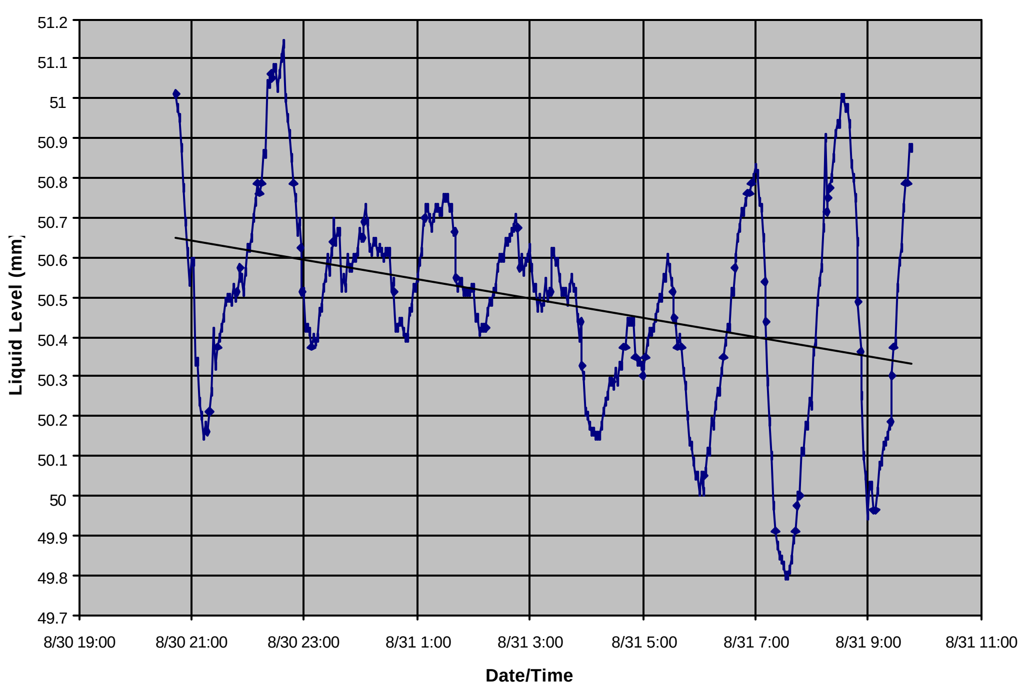

Figure 5. Sample data illustrating variability in liquid level decline data caused by wind-induced waves.

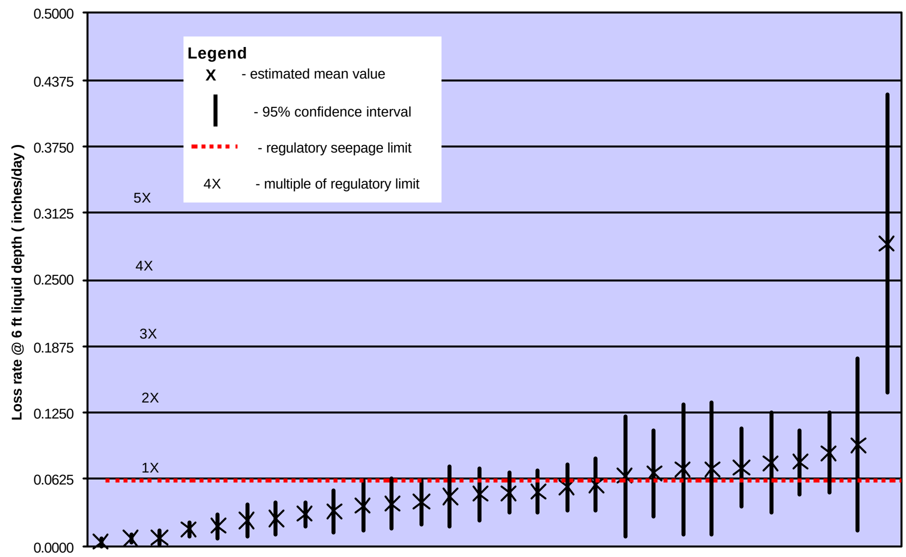

Figure 6. Estimated mean liquid loss rates and 95% confidence intervals for 28 EWSS at a liquid depth of 6 feet.

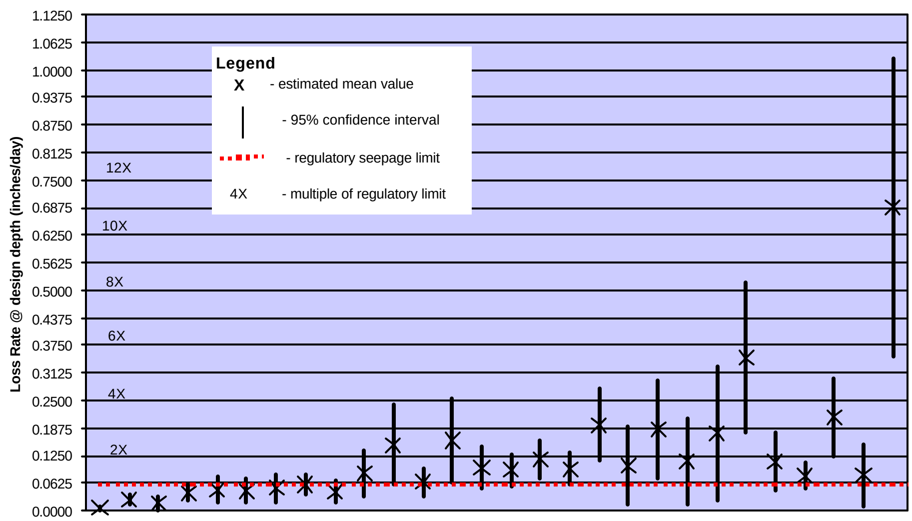

Figure 7. Estimated liquid loss rates and 95% confidence intervals for 28 EWSS filled to design depth.

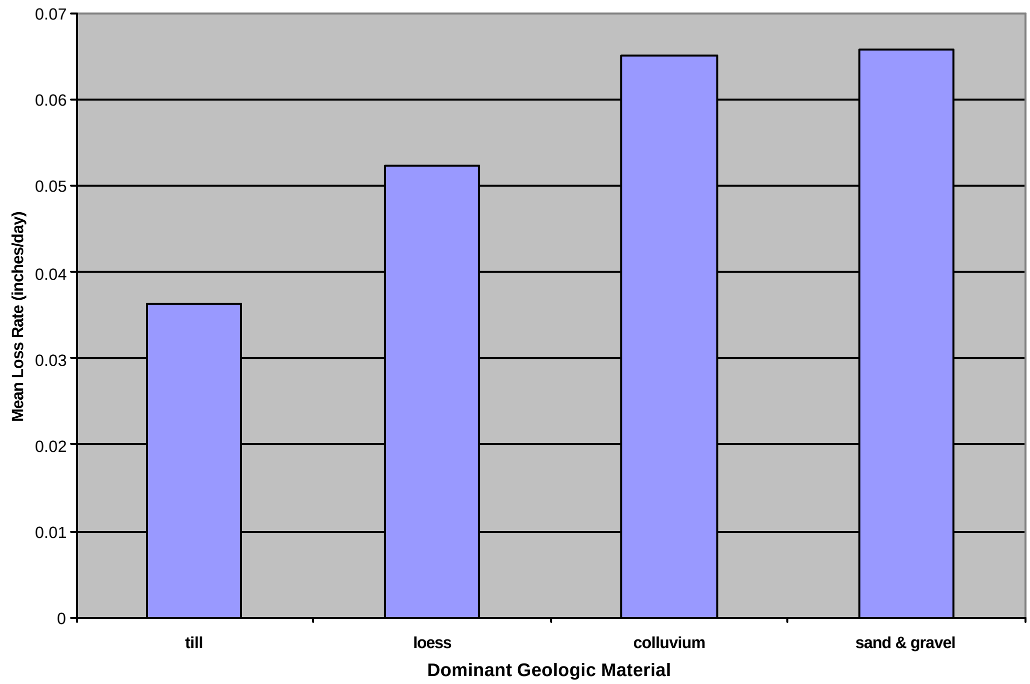

Figure 8. Mean seepage rates (at six-foot liquid depth) for structures grouped by dominant surficial geologic material (adjusted for age).

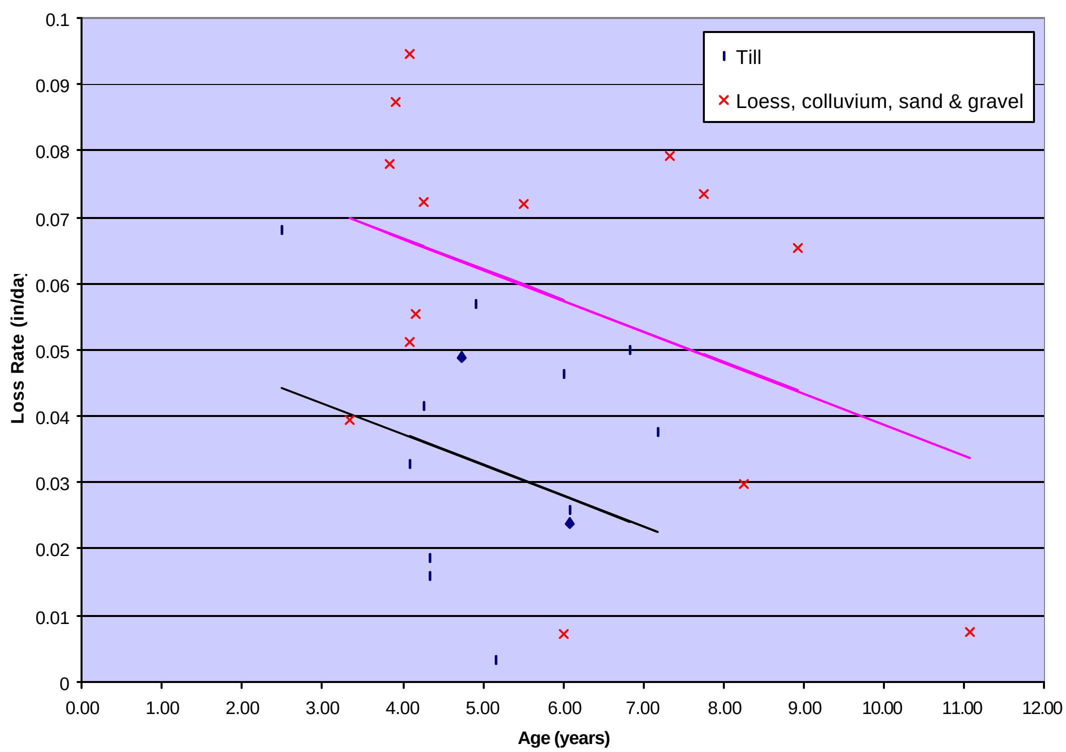

Figure 9. Mean liquid loss rates (at six-foot liquid depth) vs structure age for EWSS located in till and non-till settings.

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Table of Contents

Soil Sampling and Analysis Around Earthen Waste Storage Structures in Iowa

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ABSTRACT

To determine the impact of possible seepage from earthen waste storage structures/basins on the soil and water quality in the vicinity of the basins, eight soil samples to a depth of eight feet were taken around the perimeter of each of 31 basins studied. A ninth sample was taken in a nearby, unslope area to obtain "background data." Samples cut into one-foot increments were analyzed for ammonium-nitrogen (NH_4-N) in soil and water; and for nitrate-nitrogen (NO_3-N), chloride (Cl), and sulfate (SO_4) in water. The samples were taken just beyond the berm of the basin, usually within 50 feet of the liquid surface. Based on a seepage rate of 1/16 inch per day, with a minimum age of four years, contamination from lateral seepage movement should be detectable. Elevated concentrations of the "conservative" Cl ion, and possibly of NH_4-N and/or NO_3-N, would indicate the influence of seepage. Concentration ratios (the average concentration in samples from 2 to 8 feet for a particular chemical, at a particular soil sampling site, and for a particular basin; divided by the corresponding value averaged for all the background samples for all the basins) were used in making assessments. A ratio of greater than or equal to three was used as a definition of an elevated concentration. Elevated NH_4-N, NO_3-N, and/or Cl concentrations occurred somewhere around the perimeter of almost all the basins, but generally at only one or two of the eight sampling sites indicating localized contamination. For all but five of the sites the presence of a previous feedlot and/or spillage during manure handling was also a possible cause of the elevated concentrations. The elevated Cl concentrations that occurred for half of the basins by and of themselves are not a health concern. Nine of the 17 basins that had elevated NH_4-N concentrations did not have concurrent elevated Cl concentrations indicating that current seepage could not be responsible for the elevated concentrations. Considering measured rates of seepage and NH_4-N concentrations in liquid manure in the basins, the amounts of NH_4-N and/or NO_3-N found around the basin perimeters were less than expected (nowhere did NH_4-N concentrations in soil approach "saturation"). Average NO_3-N concentrations around basins were generally less than for background samples (eight of 31 were elevated, but four of those were not concurrent with elevated Cl concentrations), possibly the result of denitrification enhanced by organic carbon dissolved in seepage water. In general, NO_3-N concentrations in background samples averaged almost 20 mg/L, (and three basins had elevated concentrations for their background sites), likely the result of row-crop agriculture and possibly excessive use of N inputs. Because of the limitations of this study in terms of a single time sampling to the 8-foot depth, a single distance from the basin, and eight samples around the basin perimeter, it is possible that some water quality effects of seepage were missed. Time constraints prevented performing a more "typical" groundwater monitoring project. A more detailed soil and water sampling around some of the basins may be warranted. In particular, it would be of interest to measure the quality of water just beneath a basin to help answer the question of what is happening to the N that would be expected to move out of the basin with the seepage water, but seems to be lost.

Introduction

As was discussed in the previous chapter (number 3) by Glanville, et al., EWSS study sites were chosen from basins built in the 1987-1994 time frame, with the inclusion of one additional site at the ISU Bilsland farm, for a total of 31 (28 of which had successful seepage measurements made). Data on soil sampling and analysis are presented here for the 31 sites, with additional information on surficial geologic materials taken from the first chapter by Simpkins, et al., and on history and management from the second chapter by Richard, et al.

Methods

In an attempt to determine the impact of possible seepage from earthen waste storage structures/basins on the soil and water quality in the vicinity of the structures, eight soil samples to a depth of eight feet (8') from the soil surface were taken around the perimeter of each structure studied. The locations of the sample sites were generally 3 to 6' beyond any construction or the "toe" of the structure, in an area that should not have been disturbed at the time of construction. If the basin was square or nearly square, two samples were taken on each side; if it was rectangular, three samples were taken on each long side and one on each end. To provide a "background" sample, a ninth soil sample was taken to the 8' depth in an area remote (100 to 1000' away) and upslope from the structure, often being in a corn or soybean field.

The upper 4' portion of each soil sample was taken with a 1.25" diameter, lined "zero contamination" sample probe, with a plastic liner that could be removed and capped. To facilitate extraction of the core from the 4-8' depth, the lower 4' portion was taken with a 0.75" diameter probe, again with the sample contained in a plastic liner. The probes were driven into the ground using a 1200-watt jackhammer. In a few cases, it was not possible to obtain a full 4' sample for the lower portion.

The same day the soil samples were collected they were taken to the Agricultural and Biosystems Engineering water quality laboratory (ISU) and stored in a cooler at 4°C until extraction and analyses. Soil samples subsequently were cut into one-foot sections, and each section was analyzed for moisture content by drying duplicate 20-g portions of the well-mixed soil at 105°C for 24 hours. The soil moisture content is needed to calculate chemical concentrations in soil and soil water when "wet" samples are extracted. A 2N potassium chloride (KCl) solution was used to extract ammonium-nitrogen (NH_4-N; termed "exchangeable") from the soil in a subsample of each of the one-foot samples. This extract was also used to determine the nitrate-nitrogen (NO_3-N) content in soil water because the KCl facilitated the separation of soil and the KCl extracting solution before chemical analysis of the extract. Deionized water was used to extract NH_4-N (termed "water-soluble"), chloride (Cl), and sulfate (SO_4) from additional subsamples of the same soil samples. For exchangeable NH_4-N and NO_3-N, 25-g portions of soil were extracted with about 150 mL of the KCl solution; for water-soluble NH_4-N, Cl, and SO_4, 50-g portions of soil were extracted with 150 mL of deionized water. NH_4-N in both KCl and water extracts was analyzed using the automated Lachat Flow Injection system and the salicylate colorimetric method; NO_3-N in the KCl extracts using the automated Techincon system and the cadmium reduction colorimetric method, Cl in the water extracts using the automated Techincon system and the ferricyanide colorimetric method, and SO_4 in the water extracts using the Lachat system and the methylthymol blue colorimetic method.

Concentrations of exchangeable NH_4-N in soil were calculated in mg/kg by multiplying the NH_4-N concentrations in solution by the volume of the solution (KCl extract volume plus the volume of soil water originally present in the "wet" soil sample) divided by the dry weight of soil. Both the volume of water and dry weight of soil were determined from the previously measured soil moisture content. Concentrations of water soluble NH_4-N, NO_3-N, Cl, and SO_4 were calculated in mg/L by multiplying their respective concentrations in the KCl extract (for NO_3-N) or in the water extract (for NH_4-N, Cl, and SO_4) by the respective volumes of the extracts (plus the volumes of water in the soil samples) divided by the volume of water in the soil sample.

Theoretical Rates of Contaminant Migration

Information in the following section is provided to help understand the factors affecting the movement of water, and chemicals dissolved in it, as seepage from on EWSS. One seepage scenario is developed to place bounds on what might reasonably be expected to occur. This provides a basis for assessing the soil and water concentration data collected in the soil sampling study.

Moisture Content/Movement

The dry bulk density of surface and near-surface soils (top 4') usually increases with depth, starting at about 1.1 g/cc at the soil surface and increasing to about 1.4 g/cc; in the next 4', it may remain more nearly constant at the 1.4 g/cc value. At a typical soil particle density of 2.65 g/cc, the saturated moisture content is about 34% on a gravimetric basis or 47% on a volumetric basis for the deeper soils. Thus assuming a 1-acre basin with an average seepage rate of 1/16" a day, the basin would release enough water in a year to saturate 176,200 ft^3 of soil (at 47% porosity) in the vicinity.

Without extensive study, little is known about the exact flow paths of this water, but it is improbable that seepage from the basin moves uniformly either vertically or laterally. In situations with high water tables and/or low soil permeability, a situation likely to occur in glacial till, most of the seepage is lateral through the sides of the basin and beyond. In deep loess soil settings without high water tables or impermeable layers, seepage out of the sides or bottom may be equally probable, with generally downward movement after the water has "escaped" the basin. Another aspect of this water movement is that water flow through soil is not as "plug" flow, but rather there are "fingers" of faster or preferential flow, so that existing water in the soil is not completely replaced by the "new" water, but instead there is some mixing. However, despite the extreme uncertainty associated with all the variability, it can be helpful in interpreting soil and water quality data to consider some possible water movement scenarios. One that might be considered is that all of the water moved horizontally through one 10' deep wall of a square 1-acre basin 210' on a side in a plug-flow mode; this would mean each year the wall of basin water would move 84' laterally. Thus in four years it would influence the soil and water quality at least 320' from the basin.

Ammonium Nitrogen (NH_4-N)

Ammonium-nitrogen typically makes up 50 to 75% of the total N in a manure storage pit or lagoon. The concentration in a pit (undiluted manure) typically averages 2500 mg/L, while in a biologically active lagoon 1000 mg/L is common. Much of the non-ammonium-nitrogen is organic-N associated with solid material, which does not move with seepage water. Because of fixed negative charges on clay surfaces and organic matter, soil can adsorb the positively changed NH_4^+ cation. For example, the NH_4-N concentration in rainwater in Iowa averages about 0.8 mg/L, whereas surface runoff from a field not recently treated with N will likely only be 0.5 mg/L. Furthermore, water passing through the root zone and appearing as tile drainage will likely have less than 0.2 mg/L NH_4-N. The amount of NH_4-N adsorption by soil is dependent in part on the number or "concentration" of negatively charged sites on the soil termed "cation exchange capacity" (CEC) and quantified as milliequivalents per 100 g of soil. A subsoil might have a typical value of 10 meq/100 g of CEC and as the word "exchange" implies in CEC, there is some exchange and therefore competition for the negative sites by other cations in the soil solution, primarily sodium (Na^+), potassium (K^+), calcium (Ca^{++}), and magnesium (Mg^{++}).

Both the size of the hydrated NH_4^+ cation and its charge and concentration in relation to other competing cations determines how competitive NH_4^+ is for the sites of adsorption. At NH_4-N concentrations of ≥ 1000 mg/L, it would be expected that 70-75% of the adsorption sites would hold NH_4-N. With the equivalent weight of N being 14.0 g, using a fraction of 71% for the sites holding NH_4-N and 10 meq/100 g for the CEC of soil would give an adsorption capacity of 1000 mg/kg. Therefore building on the example given for water movement, NH_4-N at 1000 mg/L moving laterally through one face of a 1-acre lagoon with the water at a seepage rate of 1/16" per day would in effect "saturate" the soil with 5,200 lb of N as NH_4^+ out to a distance of 28', about a third the distance the water would move. For pit manure, with a concentration about 2.5 times that for a lagoon, the potential zone of saturation would nearly equal the water distance moved.

Nitrate-Nitrogen (NO_3-N)

Nitrate-nitrogen concentrations are typically low (often less than 5 mg/L) in liquid manure in a storage pit or lagoon, because anaerobic conditions prevent the oxidation (nitrification) of NH_4-N. However, if NH_4-N moves with seepage into the soil surrounding an earthen storage structure and that soil is or becomes aerobic, the NH_4-N can be converted first to NO_2-N and then to NO_3-N. Because NO_3-N is a negative ion (being very soluble) and is not adsorbed by soil, it moves readily with water. For example, NO_3-N concentrations in tile drainage from cropped fields are usually in the 10-20 mg/L range. In a statewide rural well-water survey (Kross et al., 1990) the overall average was 6.3 mg/L, being as high as 13.9 mg/L for the northwest region average. However, if NO_3-N resides in a soil zone that sometimes becomes anaerobic, and there is decomposable organic matter present, NO_3-N can act as an oxidizing agent in place of oxygen, and in that case is converted to nitrogen or nitrogen oxide gases (denitrification). The dissolved organic matter that can move with manure seepage can both cause anaerobic conditions and dentrification, so it is not uncommon in soils that are being affected by manure seepage water for NO_3-N concentrations in the soil water to decrease with time. Therefore, depending on the "aeration history" of the soil, seepage may cause NO_3-N concentrations to either increase or decrease.

Chloride (Cl)

Chloride concentrations in liquid manure in a storage pit or lagoon are usually quite high (> 300 mg/L) compared to what is in rainfall (usually 1-3 mg/L), surface runoff from agricultural land (3-8 mg/L), and in subsurface drainage or soil water (15-35 mg/L). The statewide average in the rural well-water survey (Kross et al., 1990) was 19.1 mg/L, with a maximum value for an individual well of 269 mg/L. Cl is also a negative (and soluble) ion, is not adsorbed to soil, and moves readily with water; but unlike NO_3-N, Cl does not undergo transformations that reduce its concentration in the soil. Chloride is often applied to agricultural land as part of KCl fertilizer. However, if Cl concentrations are high in an unfertilized soil, it is quite likely that animal manures are the source. Therefore, Cl is one of the best indicators of manure seepage, although by and of itself, Cl does not represent pollution since it is not toxic at the concentrations usually measured.

Sulfate (SO_4)

Sulfate concentrations in liquid manure in a storage pit or lagoon are usually quite low because anaerobic conditions favor growth of sulfate-reducing bacteria as well as prevent the oxidation of the reduced forms such as sulfide that may already be present. The sulfur content of liquid swine manure is estimated at about 565 mg/L, and if it escaped with seepage water and was oxidized, it would result in a SO_4 concentration of about 1,700 mg/L. SO_4 concentrations in well-water samples taken in the statewide survey (Kross et al., 1990) were more variable than for NO_3-N or Cl ranging from 0.1 to 1,938 mg/L with an overall average of 132 mg/L. Highest average concentrations were found in the north central (188 mg/L), northwest (230 mg/L), and south central (160 mg/L) regions of the state.

Concentration Scenarios and Interpretations

When considering NH_4-N, NO_3-N, and Cl analytical results for a soil sample possibly exposed to seepage from an earthen waste storage structure as the only source of contamination from manure, there are eight scenarios to consider (because of the high variability of background SO_4 concentrations, they are not considered in these scenarios; NH_4-N in soil and water are considered together because of the correlation between their concentrations in soil and water, i.e. generally if one is high, or low, the other is too). Qualitative interpretations are given below:

•	low NH_4-N; low NO_3-N; low Cl: no likelihood of seepage water having reached the point of sampling.
•	low NH_4-N; low NO_3-N; elevated Cl: good possibility that seepage water has reached the point of sampling, but not at a rate/duration that has resulted in significant NH_4-N movement and groundwater contamination at that point with N.
•	low NH_4-N; elevated NO_3-N; low Cl: some possibility that seepage water reached the point of sampling in the past at a rate/duration that transported NH_4-N, however, in more recent time, seepage must have stopped allowing time for aeration/nitrification to occur and for flushing of the Cl that would have accompanied the original seepage.
•	low NH_4-N; elevated NO_3; elevated Cl: good possibility that seepage water has reached the point of sampling, with some of the NH_4-N concurrently transported with Cl having had the time and opportunity (aerobic conditions) to be converted to NO_3-N.
•	elevated NH_4-N; low NO_3-N; low Cl: some possibility that seepage has reached the point of sampling in the past at a rate/duration that transported NH_4-N; however, in more recent time, seepage must have stopped allowing for flushing of the Cl that would have accompanied the original seepage.
•	elevated NH_4-N; low NO_3-N; elevated Cl: strong possibility that seepage water has reached and is continuing to reach the point of sampling.
•	elevated NH_4-N; elevated NO_3-N; low Cl: good possibility that seepage water reached the point of sampling in the past at a rate/duration that transported NH_4-N and with conditions (aerobic) that allowed some nitrification; however, in more recent time seepage must have stopped allowing for flushing of the Cl that would have accompanied the original seepage.
•	elevated NH_4-N; elevated NO_3-N; elevated Cl: strong possibility that seepage water has reached and is continuing to reach the point of sampling.

In these interpretations, evidence of any effects, past or current can be influenced by spills during emptying or filling of the existing earthen structure and/or influence of previous activities in the area such as an open feedlot that existed in the past but is no longer evident. Each soil sample also only represents one point (down to 8') in the space/volume near an earthen structure, and so it is possible that eight samples around a structure may not adequately represent all that volume. Therefore it needs to be emphasized that the data from soil sampling are only a qualitative part of the total determination of the amount and impact of any seepage.

Results and Discussion

Analytical results for the liquid manure in the 31 earthen basins studied using soil sampling are given in Table 1. The NH_4-N concentrations averaged 2204 and 1438 mg/L, respectively, for pits and lagoons, with the statistically higher value for pits resulting from lower dilution and limited NH_3 volatilization (these concentrations represent 18.3 and 12.0 lb NH_4-N/1000 gallons, respectively). As discussed earlier, because of anaerobic conditions in liquid manure, little NH_4-N is nitrified, and average NO_3-N concentrations for pits and lagoons were both very low and not statistically different, averaging less than 1 mg/L. Mainly because of Cl in feed and additional dietary inputs, Cl concentrations in liquid manure are much higher than the roughly 15-35 mg/L in soil water, averaging 826 and 593 mg/L, respectively, for pits and lagoons, with the pits being statistically higher. The ratio of Cl in pits to lagoons was 1.39 versus 1.53 for NH_4-N. This lower value for Cl would be expected because Cl is "conservative;" whereas, NH_4-N can be transformed or lost, with losses expected to be higher in lagoons than pits. Because of analytical interference caused by phosphorus (P), SO_4 in liquid manure was not determined.

The average results of analyses of soil samples around the 31 earthen basins studied are given in Table 2, separated into "background" and "around basins" locations, and into 0-2 and 2-8' depths. Separation into those two depth intervals was done to help distinguish effects due to surface contamination (e.g., by spills at times of emptying the current basin, or by past activities such as an open feedlot) from contamination originating from potential deeper subsurface seepage from the basin. To help understand how the data in Table 2 and the data presented later in the schematic figures were generated, soil sampling concentration data for Cl for one basin are given in Table 3 as a function of depth and sample site number (there are a total of 31 data sets like that given in Table 3 for each of the five ion determinations). Therefore, for the background location (Table 2, sample site number 9) for the 0-2' depth, the overall average represents an average of 62 values (31 basins by 1 sample site by 2 one-foot intervals), and for the around basin location (sample sites 1 through 8) for the 0-2' depth, 496 (31 x 8 x 2). Corresponding values for the 2-8' depth are 186 (31 x 1 x 6) and 1,488 (31x 8 x 6). These average results will be discussed first, with results for some specific basins given later.

As shown in Table 2 for exchangeable NH_4-N (in soil), the overall average concentration of 2.84 ppm in the soil samples for the 2-8' interval around basins was very low compared to the potential of being as great a 1000 ppm if the soil was "saturated" with NH_4-N. And while this average concentration around basins was slightly higher than for the 2-8' background soil samples (2.44 ppm), the difference was not statistically significant. Likewise, the average concentration in the soil samples at the 0-2' depth around basins (2.16 ppm) was slightly higher than for the 0-2' background soil samples (1.51 ppm), but the difference again not statistically significant. Because the difference is greater for the 0-2' interval, if these small differences are real, they are more likely the result of surface contamination than seepage. The same is also true for NH_4-N concentrations measured in soil water (column 4 in Table 2).

As shown in Table 2, the overall average concentration of NO_3-N for the 2-8' interval around basins (14.9 mg/L) was lower than for the 2-8' background soil samples (19.2 mg/L). This difference is not large and not statistically significant, but it possibly indicates less NO_3-N contamination around the basins (although the reason for lower NO_3-N concentrations could be enhanced denitrification caused by soluble organic carbon in seepage water, or the fact that a number of background samples were taken in row-crop areas likely receiving N fertilizer). The overall average concentrations of NO_3-N in the 0-2' intervals are essentially equal for background (25.1 mg/L) and around basin (23.8 mg/L) samples.

As shown in Table 2, the overall average concentration of Cl for the 2-8' interval around basins (46.8 mg/L) was statistically higher than for the 2-8' background soil samples (31.4 mg/L). This would indicate that in general there is the possible influence of seepage water with high Cl. However, the fact that there is nearly the same difference for the 0-2' interval around basins (49.7 mg/L) compared to background samples (37.8 mg/L) indicates some of the difference probably resulted from surface contamination.

As shown in Table 2, the overall average concentration of SO_4 for the 2-8' interval around basins (152 mg/L) was not statistically higher than for the 2-8' background samples (129 mg/L). Concentrations were generally higher in the top 2' for both the background and around basins locations.

The relationships of average ion concentrations with depth from the soil surface (to 8') are shown in Figures 1 and 2 for background samples (NO_3-N data are common to both graphs, but the graphs are plotted on different scales) and in Figures 3 and 4 for around basin samples. As shown, concentrations were fairly constant with depth for all five data sets for the background samples; but for the around basin samples, concentrations, particularly for NO_3-N, Cl, and SO_4, were generally higher in the top 1 or 2'.

To show how concentrations can change with depth and soil sample site for an individual basin location, the data for Cl from Table 3 for one example basin are plotted in Figure 5. As shown, there were four adjacent soil sample sites that had high Cl concentrations somewhere in the 8' soil profile with one in particular, number 5, having very high concentrations in the top 2'. It can be seen in data presented later that sites 5 and 6 did not have elevated NH_4-N or NO_3-N concentrations (although the background sample did have elevated NO_3-N concentrations), but site 7 had elevated NH_4-N concentrations and site 8 somewhat elevated NO_3-N concentrations. These data are fairly indicative of some influence of manure, but it is not possible to say for certain whether the Cl is from pit seepage, surface contamination, or both.

The format in Figure 6 for presenting the massive amount of soil sampling data for each of the 31 basins sampled (Figures 7 through 37) shows how ground and water-table elevations (if one exists within 8' of the soil surface) are given within a scale of $\pm$ 20' of the basin liquid elevation. Also illustrated in Figure 6 is the format for displaying the concentrations, averaged from 2 to 8' for the five ion determinations made, in the form of a ratio to the overall average background concentration. For simplicity this ratio is truncated after the decimal; so for example, if the ratio is 2.4, it is shown as a 2.

Data for each of the 31 basins sampled are given in Figures 7 through 37 in increasing rank order of each basin's seepage rate (i.e. #1 has the lowest seepage rate). Basin numbers 29 through 31 (in Figures 35 through 37, as well as in Table 4) are for sites where soil samples were taken, but for which it was not possible to obtain a seepage rate value. These data are then summarized in Table 4 in terms of the number of soil sample sites around each basin that had excessive concentrations (somewhat arbitrarily defined as ≥ 3 times the background concentration) for NH_4-N (in soil and/or water), NO_3-N, Cl, and SO_4. Also given is any information available for the potential for other sources of contamination. From observation of these data, there does not appear to be a trend of an increasing number of sites exceeding the ratio of 3 with increasing seepage rate. Based on the earlier discussion of the eight possible concentration scenarios, those 15 sites without evidence of elevated Cl concentrations do not show evidence of seepage, even though some may show elevated NH_4-N or NO_3-N concentrations.

Summary

Soil sampling was performed in the vicinity of the earthen waste storage structure basins to determine if seepage was affecting the shallow soil/water system. With eight sample sites (down to 8') around each basin, it is quite possible to miss evidence of seepage/contamination because of non-uniform lateral and/or nearly totally vertical seepage flows. However, the water table was within 8' of the soil surface for at least one perimeter soil sample site at 24 of the 31 basins sampled. There was evidence of elevated (defined as three times the background concentration) Cl concentrations for at least one site of eight soil samples taken around the perimeter of 16 of the 31 basins (at one basin, no. 30, the background level was also higher). As was discussed in relation to the matrix of possible concentration scenarios, presence of elevated Cl is a necessary, but not sufficient, condition of the influence of manure. Of the 16 basins with elevated Cl, nine also had elevated NH_4-N or NO_3-N concentrations which increases the likelihood that there is influence of manure. Of these nine, seven had elevated Cl concentrations at only one or two of the eight perimeter sampling sites (the other two, had three and four), indicating the influence was localized. In addition, for all nine of these basins there was information collected (chapter 2; Richard et al.) that previous feedlots and/or spillage during manure handling could be responsible for these elevated concentrations.

Based on measured seepage rates and NH_4-N concentrations in the liquid manure in the basins, more evidence of elevated NH_4-N and/or NO_3-N concentrations would be expected (for example, seepage at the rate of 1/16" per day from a one-acre basin with 1000 mg NH_4-N/L should transport 4000 lb NH_4-N a year). None of the soil samples, which were all taken in close proximity to the basin, approached the 1000 ppm theoretical value (the overall average for the 2-8' depth interval for all sites/basins was 2.84 ppm). Thus it seems likely that some sort of physical, chemical, and/or biological "processing" such as denitrification is occurring that reduces contamination from nitrogen.

NO_3-N concentrations were elevated at seven of the 31 basins (for from one to three of the eight perimeter soil sampling sites). For four of those sites, Cl concentrations were not elevated, indicating that current basin seepage could not be responsible. In addition, at three basins the background NO_3-N concentration was elevated. This, in addition to the fact that the average background concentration for the 2-8' depth interval was 19.2 mg/L, indicates that there may be a more general NO_3-N problem.

The following in "bulleted" format are the findings/conclusions:

- Elevated NH_4-N, NO_3-N, and/or Cl concentrations occurred somewhere around the perimeter of almost all the basins, but generally at only one or two of the eight sampling sites indicating localized contamination.

- For all but five of the sites the presence of a previous feedlot and/or spillage during manure handling was also a possible cause of the elevated concentrations.

- The elevated Cl concentrations that occurred for half of the basins by and of themselves are not a health concern.

- Nine of the 17 basins that had elevated NH_4-N concentrations did not have concurrent elevated Cl concentrations indicating that current seepage could not be the responsible for the elevated concentrations.

- Considering measured rates of seepage and NH_4-N concentrations in liquid manure in the basins, the amounts of NH_4-N and or NO_3-N found around the basin perimeters were less than expected (nowhere did NH_4-N concentrations soil approach "saturation").

- Average NO_3-N concentrations around basins were generally less than for background samples (eight of 31 were elevated, but four of those were not concurrent with elevated Cl concentrations) possibly the result of denitrification enhanced by organic carbon dissolved in seepage water.

- In general, background NO_3-N concentrations were high, averaging almost 20 mg/L, (and three basins had elevated concentrations for their background sites), likely the result of row-crop agriculture and possibly excessive use of N inputs.

ACKNOWLEDGEMENTS

Project investigators and staff offer their sincere thanks to the managers and owners of the earthen waste storage structures that were evaluated. Without their cooperation and patience this project could not have been conducted.

Many thanks also to David Baker, Victor Ella, Shuguang Jiang, Betsy Warnemuende, and Larry Wulf, agricultural engineering staff and students, who contributed many hours soil sampling in the field during this project. Special thanks go to Paul Boyd who helped develop procedures, ordered and maintained the soil sampling equipment, and analyzed the survey data; and to Peter Lawlor who organized and plotted the numerous data sets.

Table 1. Average ion concentrations in solution in earthen basin "liquid"

Basin	NH_4-N	NO_3-N	C1	SO_4[1]
	------------------------------mg/L------------------			
pit	2204 a[2]	0.30 a	826 a	-
lagoon	1438 b	0.37 a	593 b	-
(ratio)	(1.53)	(0.81)	(1.39)	

[1]Not determined due to analytical interference caused by phosphorus in liquid manure.
[2]Means with the same letter are not significantly different (at the 0.05 level of significance).

Table 2. Average ion concentrations in soil samples at 31 EWSS

location	depth ft	NH_4-N (soil) ppm	NH_4-N (water)	NO_3-N	C1	SO_4
			---------------------------------mg/L[1]----------------------------			
background[2]	0-2	1.51 a[3]	0.63 a	25.1 a	37.8 a	157 a
background	2-8	2.44 a	0.45 a	19.2 a	31.4 a	129 a
(ratio 0-2 to 2-8')		(0.62)	(1.40)	(1.31)	(1.22)	(1.22)
around basins[3]	0-2	2.16 a	1.05 a	23.8 a	49.7 a	267 a
around basins	2-8	2.84 a	0.69 a	14.9 a	46.8 b	152 a
(ratio 0-2 to 2-8')		(0.76)	(1.52)	(1.60)	(1.06)	(1.76)

[1]Concentrations in soil water are based on the soil water content.
[2]One background sample (upslope) and eight perimeter samples around the basin were taken to the 8' depth and divided into one-foot increments at each site; the concentrations are averaged over 31 sites for the 0-2' and 2-8' depth intervals.
[3]Means (of background versus around basins at a given depth) with the same letter are not statistically different (at the 0.05 level of significance).

Table 3. Cl concentrations in soil samples taken at one example basin (seepage rank # 27)

Depth interval feet	Soil core sample site no.[1] 1	2	3	4	5	6	7	8	9
	mg/L								
0-1	21	17	44	42	680	46	37	35	26
1-2	72	35	15	78	314	100	179	62	40
avg.	46	26	30	60	497	73	108	48	33
ratio[2]	1.2	0.7	0.8	1.6	13.1	1.9	2.9	1.3	0.9
2-3	84	69	12	55	270	239	160	37	48
3-4	41	24	12	24	252	295	65	54	39
4-5	15	34	12	23	255	295	73	49	42
5-6	35	16	16	21	164	188	137	114	47
6-7	78	22	16	24	115	140	166	131	48
7-8	93	24	17	21	109	134	105	113	59
avg.	58	32	14	28	194	215	118	83	47
ratio[2]	1.8	1.0	0.5	0.9	6.2	6.9	3.8	2.7	1.5

[1]Sites 1 through 8 are around perimeter of basin; site 9 is the "background" sample.
[2]The ratio is the core site average for this basin divided by the overall average for the background samples from all basins given in Table 2 for the 0-2' interval (37.8 mg/L) or the 2-8' (31.4 mg/L).

Table 4. Summary of soil sample sites (out of a maximum of 8) with elevated contaminant concentrations

Basin Seepage Rank # (from Glanville et al.)	Surficial Geologic Material (from Simpkins et al.)	No. of sample sites with elevated[1] concentrations NH_4-N	NO_3-N	Cl	SO_4	Other known sources (from Richard et al.):
1	till			2		previous cattle feedlot
2	non-till[3]			2		none
3	non-till	2	3		2	open hog lot and frequent unloading area
4	till				1	none
5	till	8/B[4]			2	none (background NH_4-N elevated too)
6	till	1	3	1		previous hog pasture, solid manure storage
7	till		1	2		frequent loading areas
8	non-till					frequent loading area
9	till			2		frequent loading area
10	till	3	1		3	minor spillage of solid manure, frequent loading area
11	non-till	1/B				none (high water table; background elevated too)
12	till					none
13	till	1		2		old facility
14	till	2		4		spillage runoff; frequent loading areas
15	till			3	1	frequent loading area, small spill
16	non-till	1		1	1	frequent loading area
17	non-till	2		1		spillage area; frequent loading area
18	till	2				none
19	non-till		1		1/B	frequent loading area (background SO_4 elevated too)
20	till	1			B	none
21	non-till			1		frequent loading area
22	non-till	1				none
23	non-till		1/B			none (background NO_3-N elevated too)
24	non-till	2/B		1	1	spillage and frequent loading areas; previous basin (background NH_4-N elevated too)
25	non-till			1		spillage areas
26	non-till	1				none
27	non-till	1	B	3	1	drainage from previous livestock operation over area
28	non-till	2				frequent loading area
29	non-till				4	spillage at loading areas
30	till	1	2/B	1/B	1	overflow occurred one area; frequent loading area (background NO_3-N and Cl elevated too)
31	non-till			2		manure spill area; frequent loading area

[1]Concentrations averaged over the 2-8' interval that were ≥ 3 times average background concentrations.
[2]NH_4-N concentrations in soil and/or water.
[3]Non-till materials are sand/gravel, colluvium, or loess.
[4]B indicates that the background site concentration at the individual basin was ≥ 3 times the average background concentration for all sites.

References

Kross, B.C., G.R. Hallberg, D.R. Bruner, R.D. Libra, K.D. Rex, L.M.B. Weih, M.E. Vermace, L.F. Burmeister, H.H. Hall, K.L. Cherryholmes, J.K. Johnson, M.I. Selim, B.K. Nations, L.S. Seigley, D.J. Quade, A.G. Dudler, K.D. Sesker, M.A. Culp, C.F. Lynch, H.F. Nicholson, and J.P. Hughes. 1990. The Iowa state-wide rural well water survey, water quality data: Initial analysis. Technical Information Series 19. Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, IA.

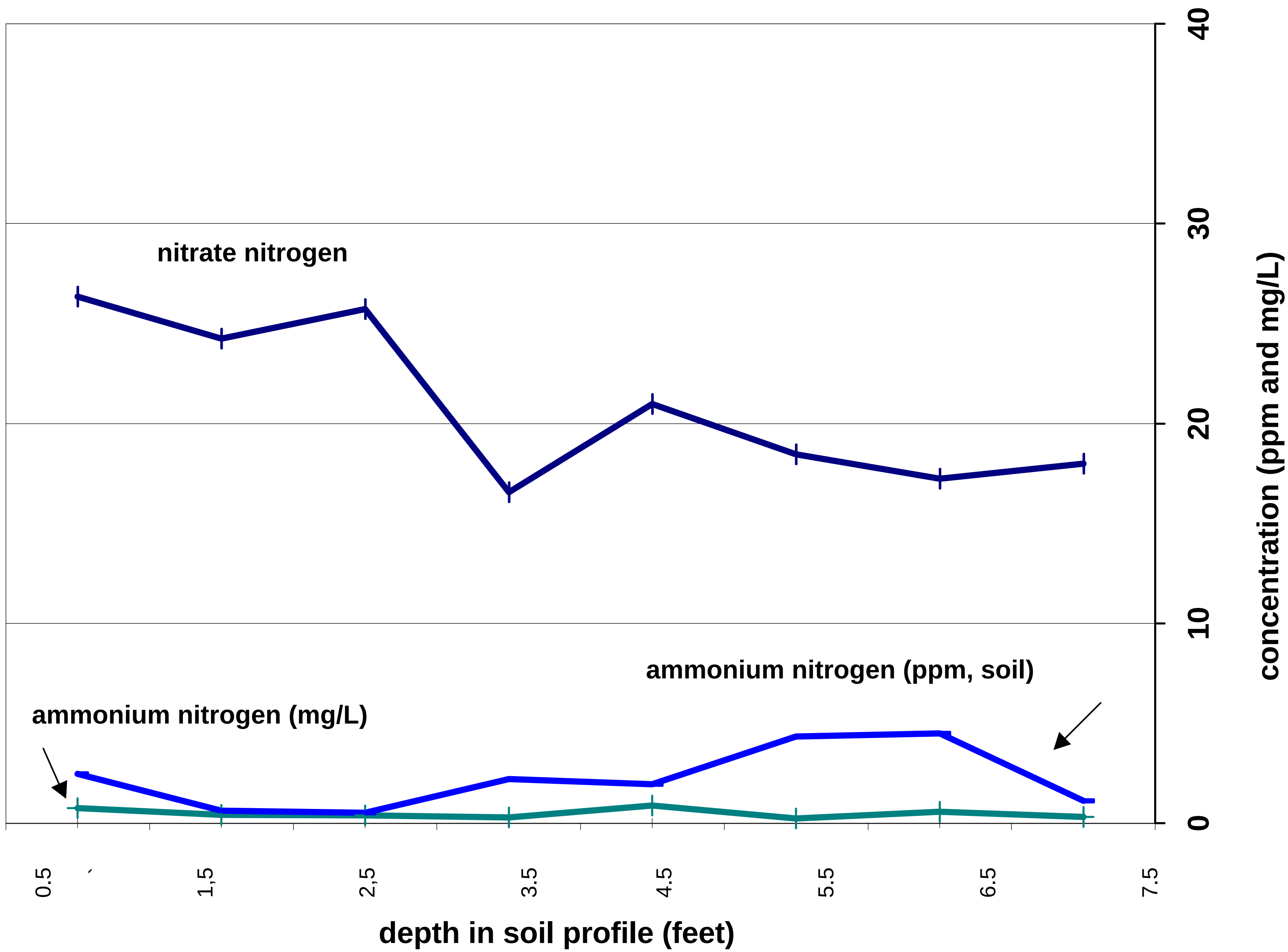


Figure 1. Average NH_4 (in soil and water) and NO_3-N concentrations as a function of depth for background samples.

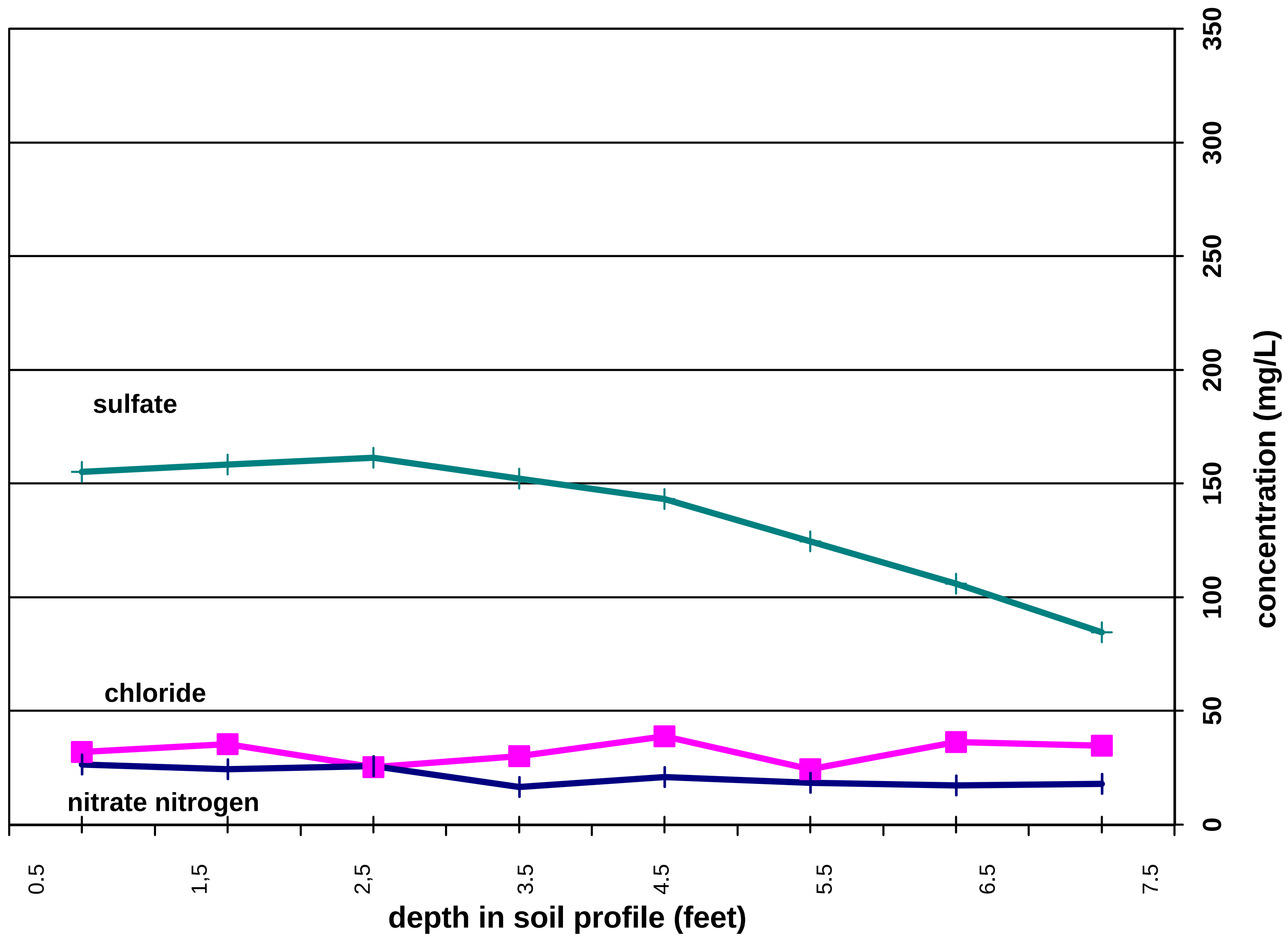


Figure 2. Average Cl, SO4, and NO3-N concentrations as a function of depth for background

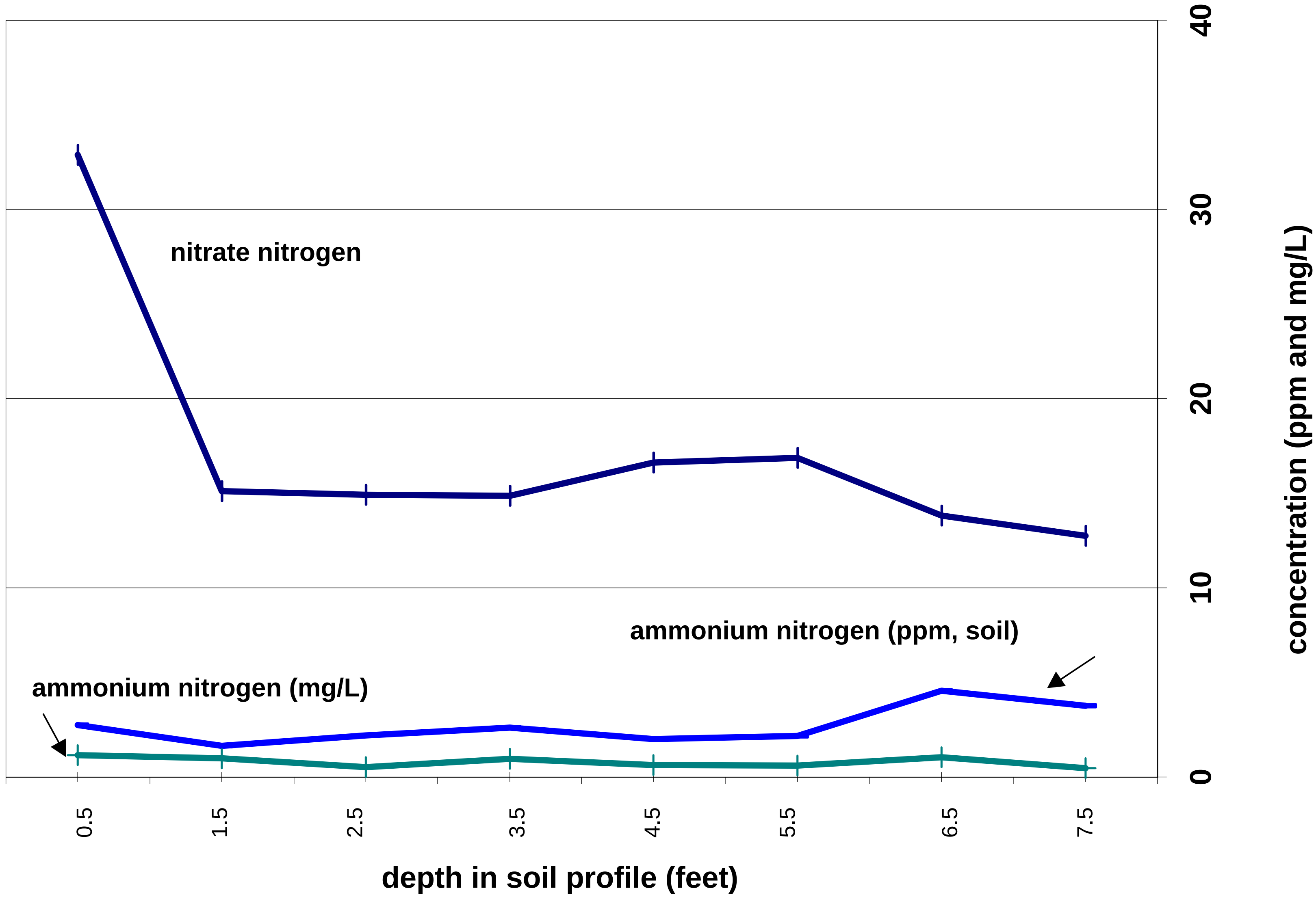


Figure 3. Average NH4 (in soil and water) and NO3 concentrations as a function of depth for basin perimeter samples.

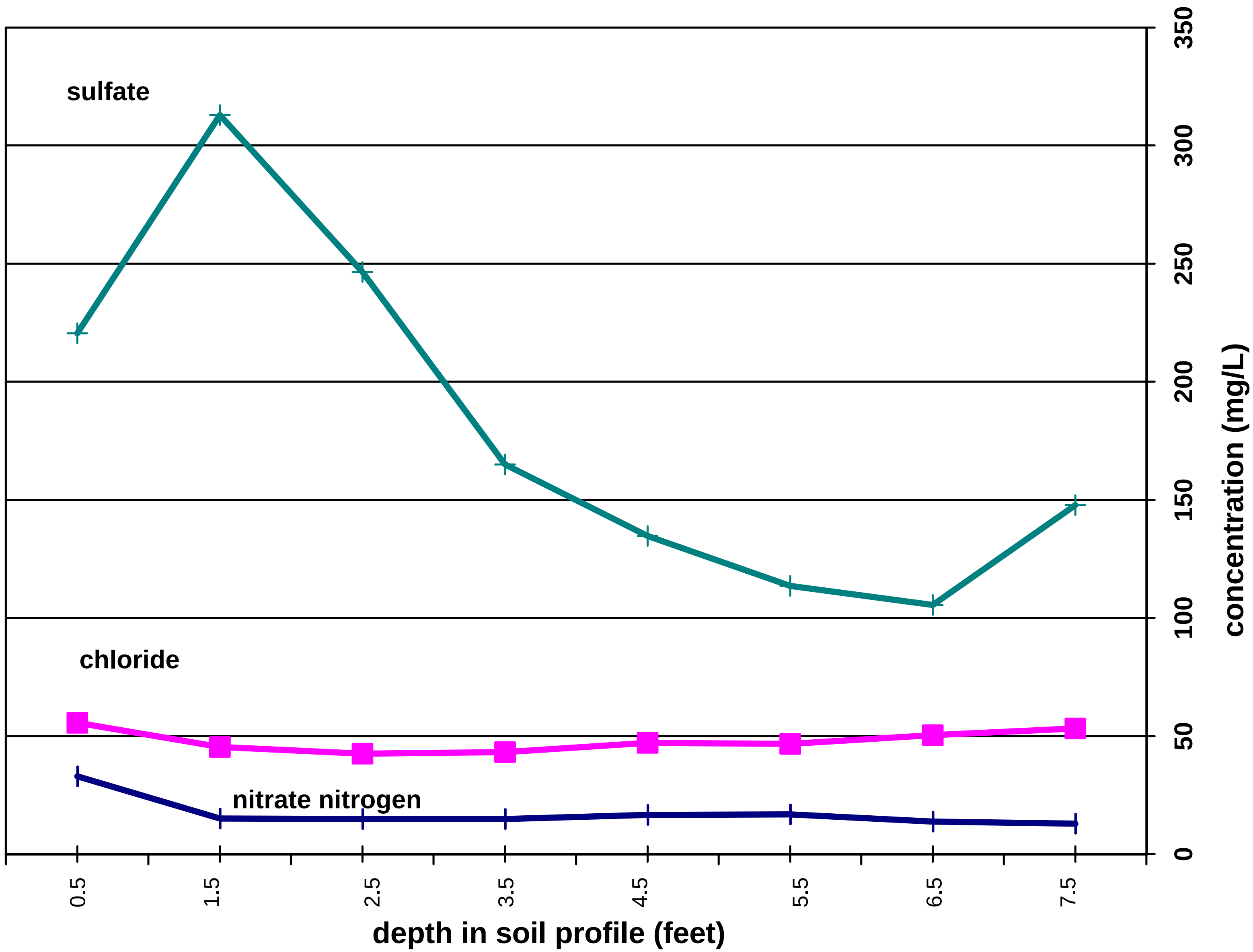


Figure 4. Average Cl, SO_4, and NO_3-N concentrations as a function of depth for basin perimeter

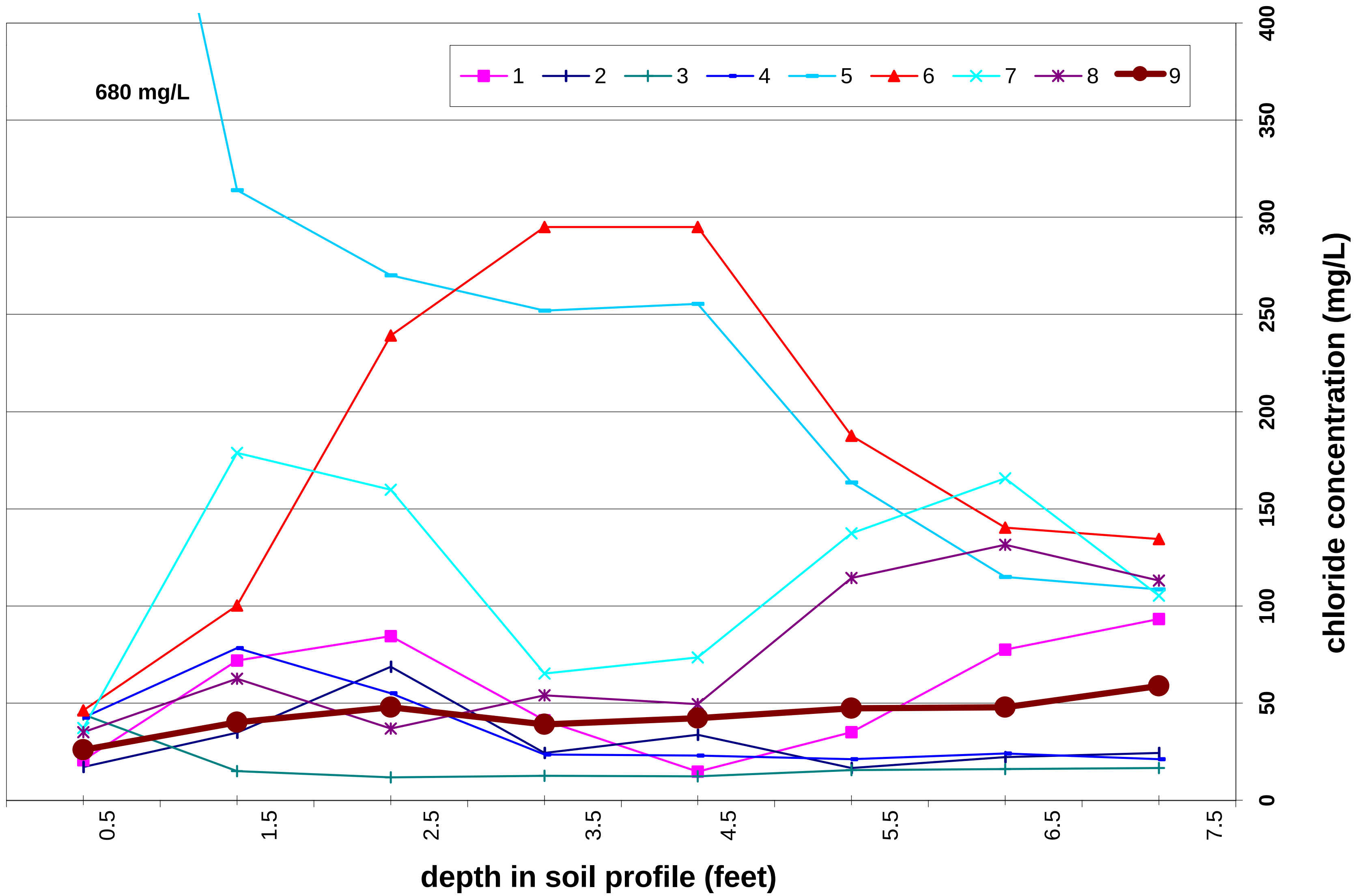
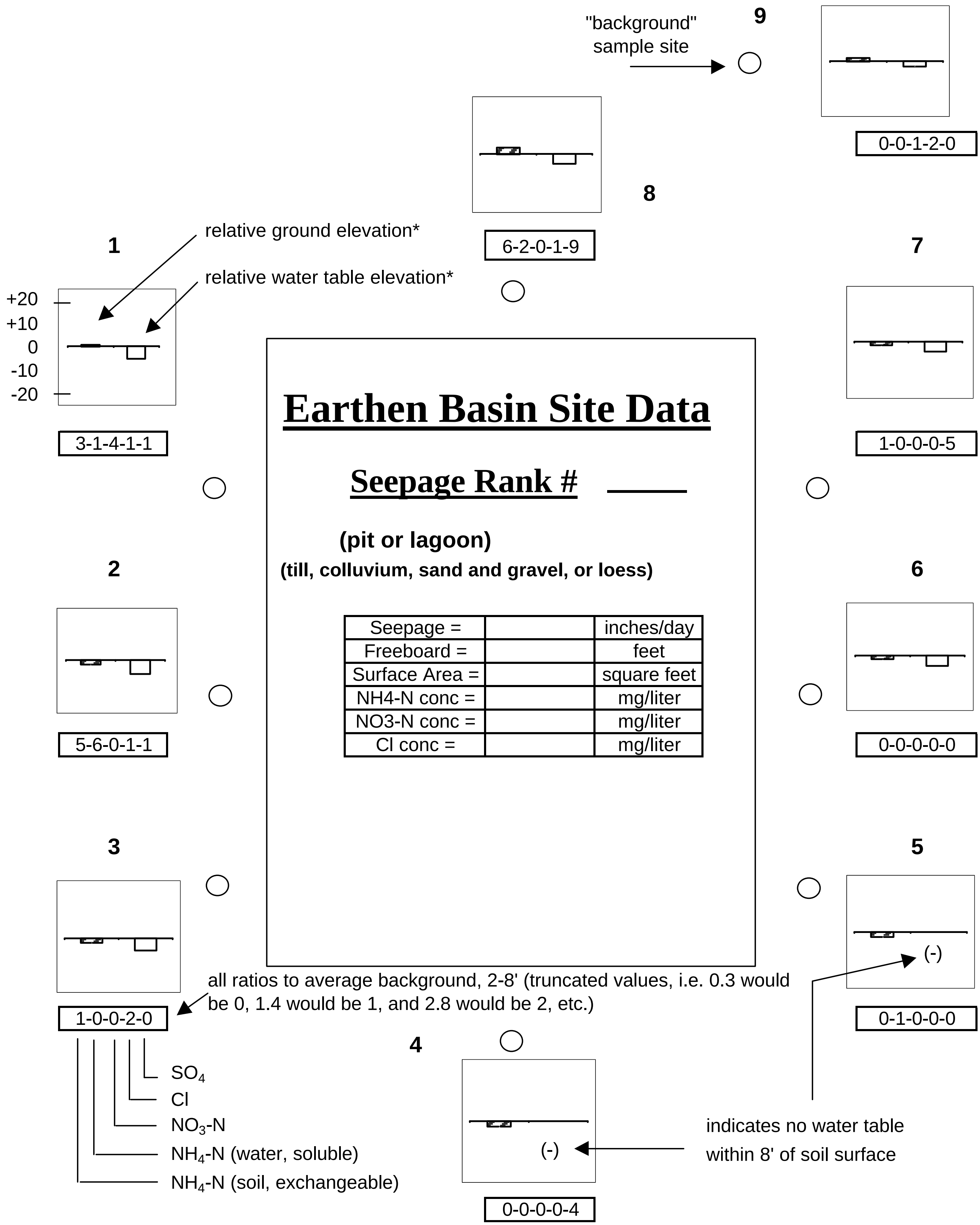


Figure 5. Cl concentrations as a function of depth for individual soil sampling sites (1-8 around

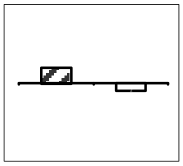


Seepage =		inches/day
Freeboard =		feet
Surface Area =		square feet
NH4-N conc =		mg/liter
NO3-N conc =		mg/liter
Cl conc =		mg/liter

* relative to basin liquid surface elevation.

Figure 6. Explanation of format for elevation and chemical data presented in Figures 7-31 for the basins sampled.

9



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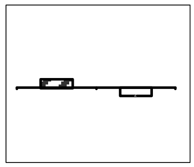

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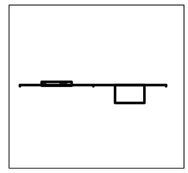

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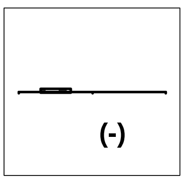

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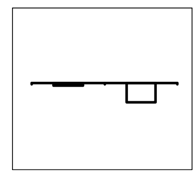
Earthen Basin Site Data

Seepage Rank # 1

(pit;till)

Seepage =	0.0034	inches/day
Freeboard =	2.3	feet
Surface Area =	19410	square feet
NH4-N conc =	1855	mg/liter
NO3-N conc =	0.8	mg/liter
Cl conc =	551	mg/liter

6



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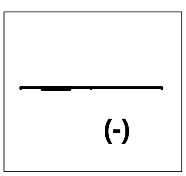

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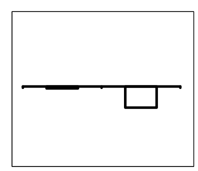

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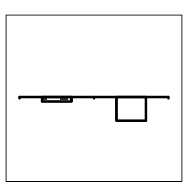

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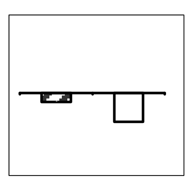

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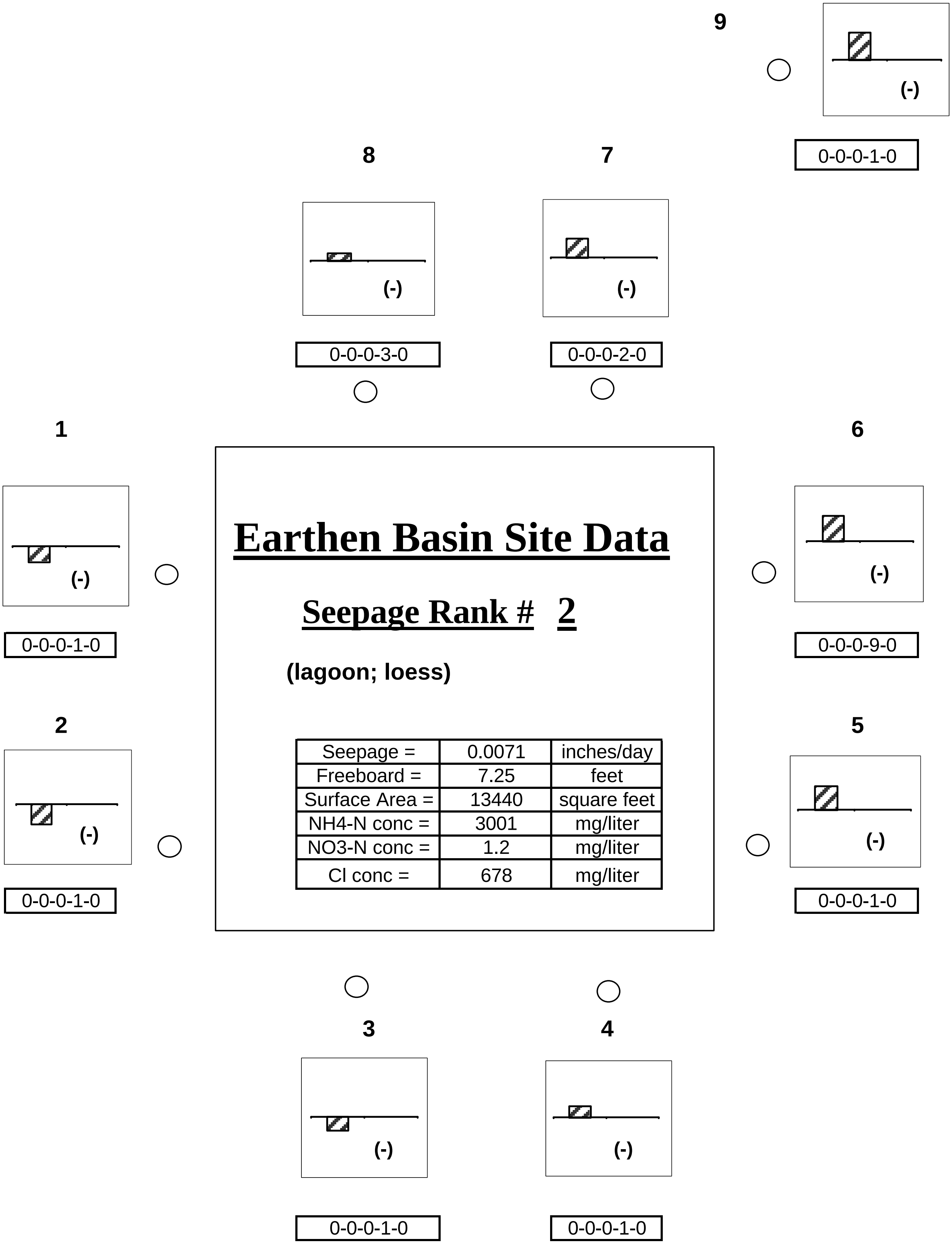
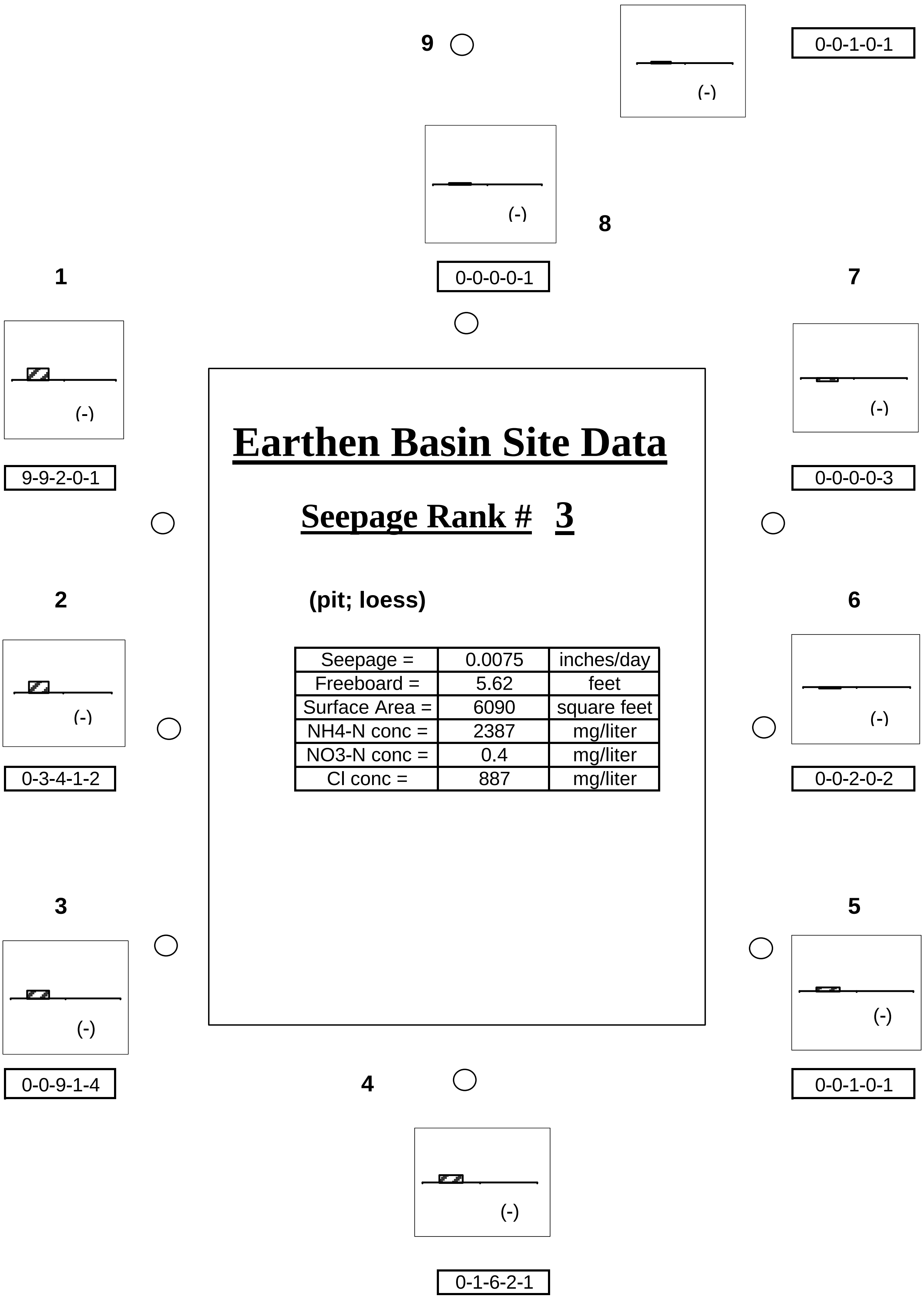
Figure 7. Chemical and elevation data for basin #1.



Seepage =	0.0071	inches/day
Freeboard =	7.25	feet
Surface Area =	13440	square feet
NH4-N conc =	3001	mg/liter
NO3-N conc =	1.2	mg/liter
Cl conc =	678	mg/liter

Figure 8. Chemical and elevation data for basin #2.



Earthen Basin Site Data

Seepage Rank # 3

(pit; loess)

Seepage =	0.0075	inches/day
Freeboard =	5.62	feet
Surface Area =	6090	square feet
NH4-N conc =	2387	mg/liter
NO3-N conc =	0.4	mg/liter
Cl conc =	887	mg/liter

Figure 9. Chemical and elevation data for basin #3.

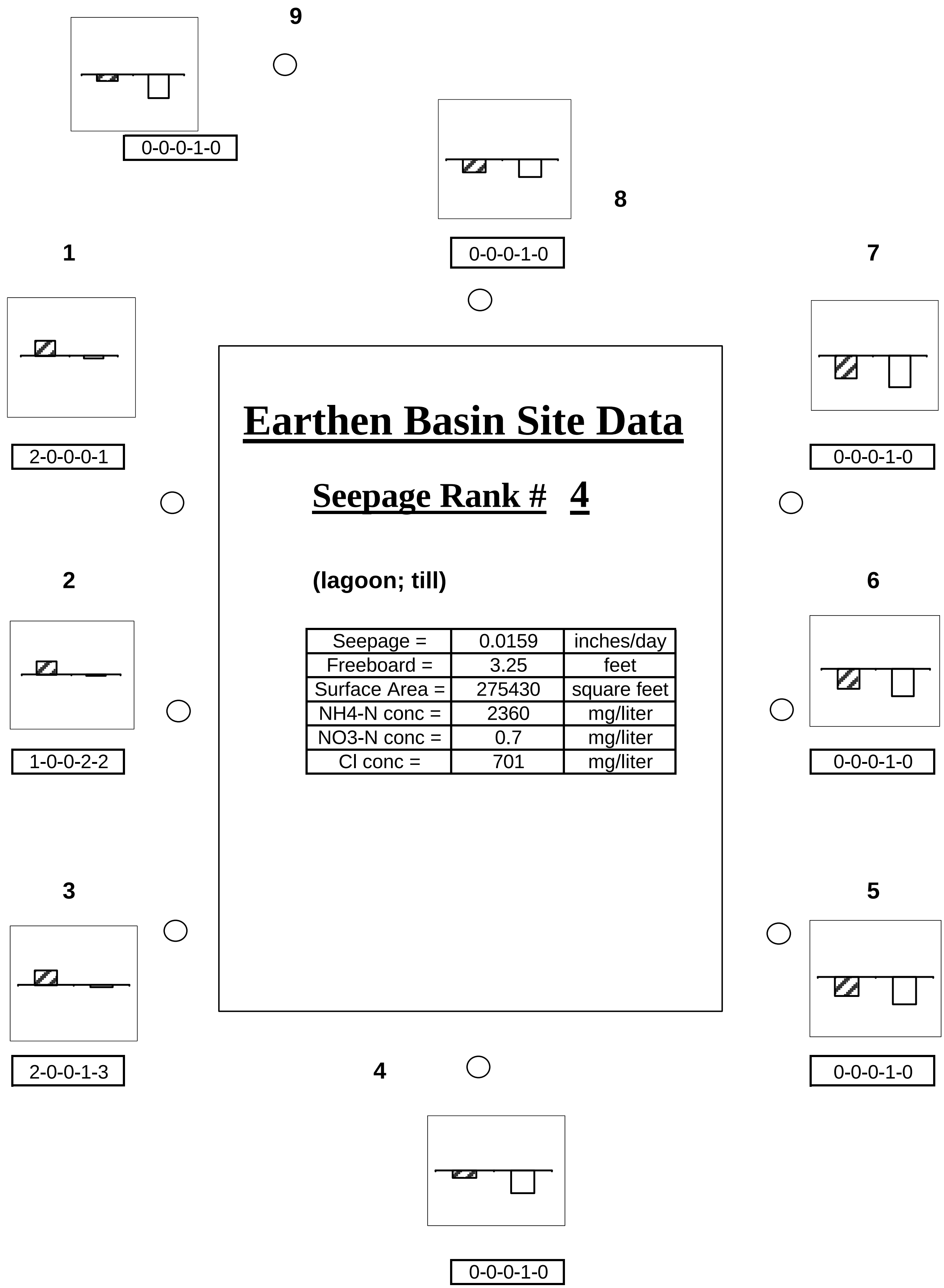
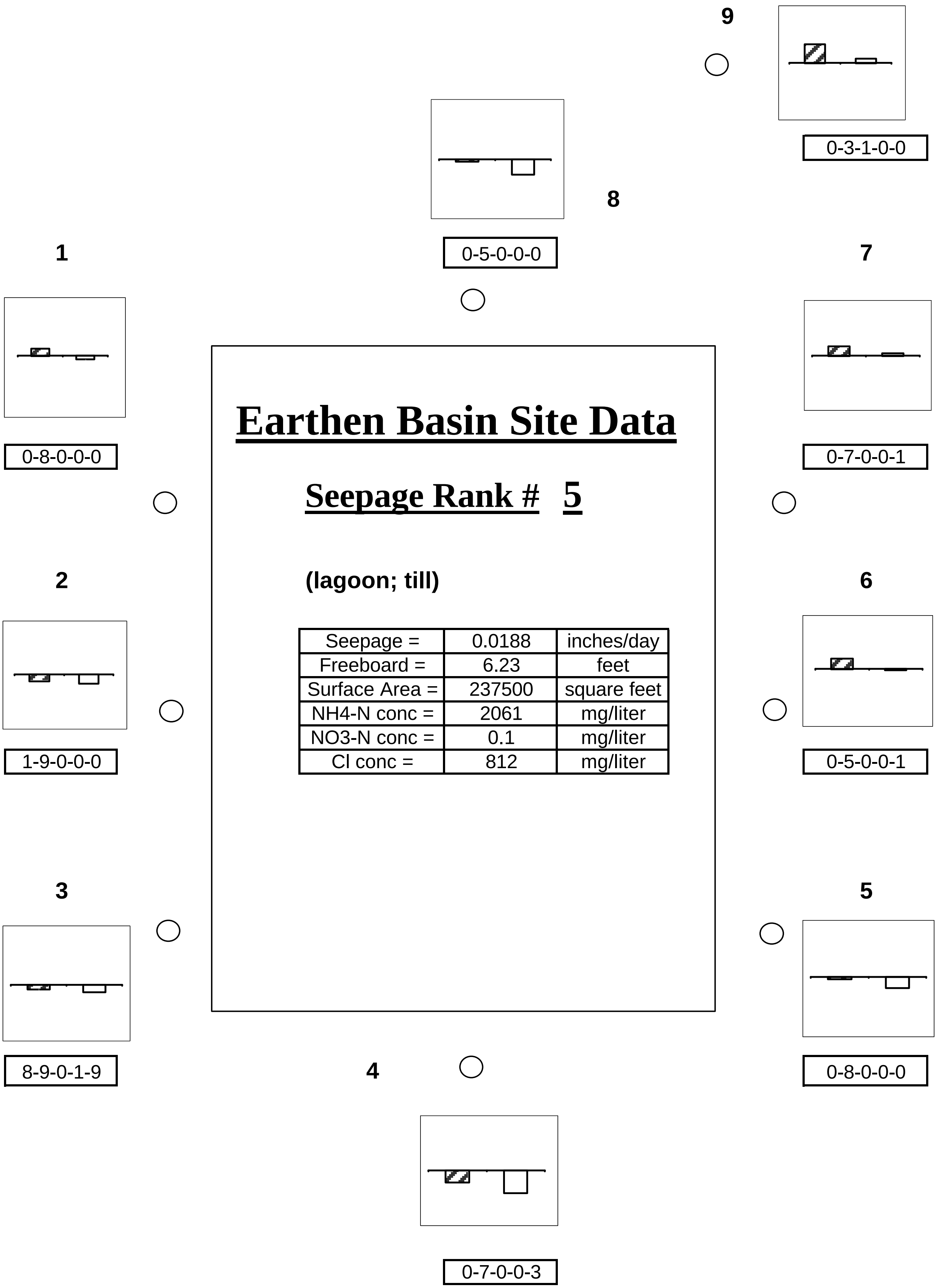
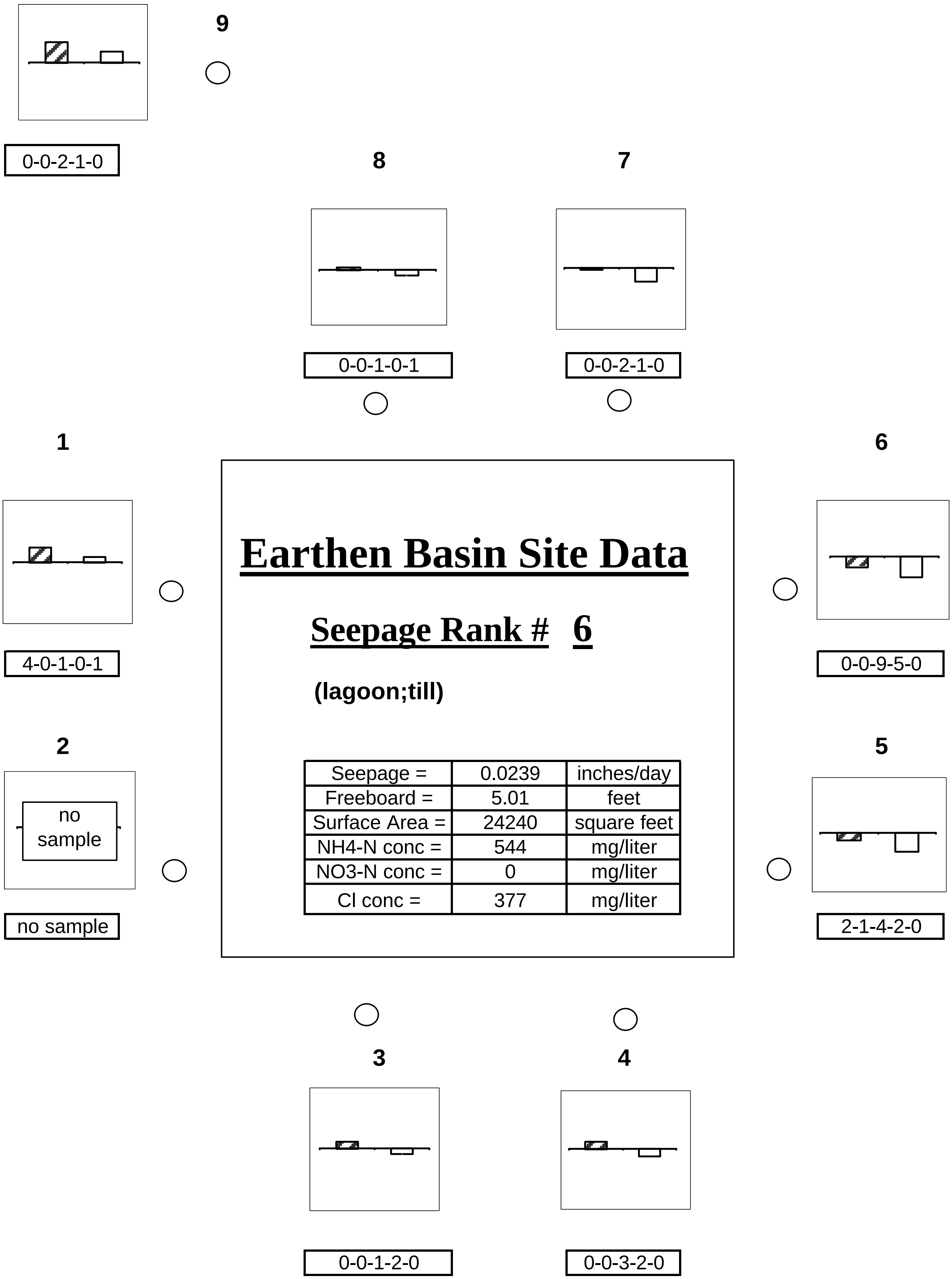


Figure 10. Chemical and elevation data for basin #4.



Seepage =	0.0188	inches/day
Freeboard =	6.23	feet
Surface Area =	237500	square feet
NH4-N conc =	2061	mg/liter
NO3-N conc =	0.1	mg/liter
Cl conc =	812	mg/liter

Figure 11. Chemical and elevation data for basin #5.



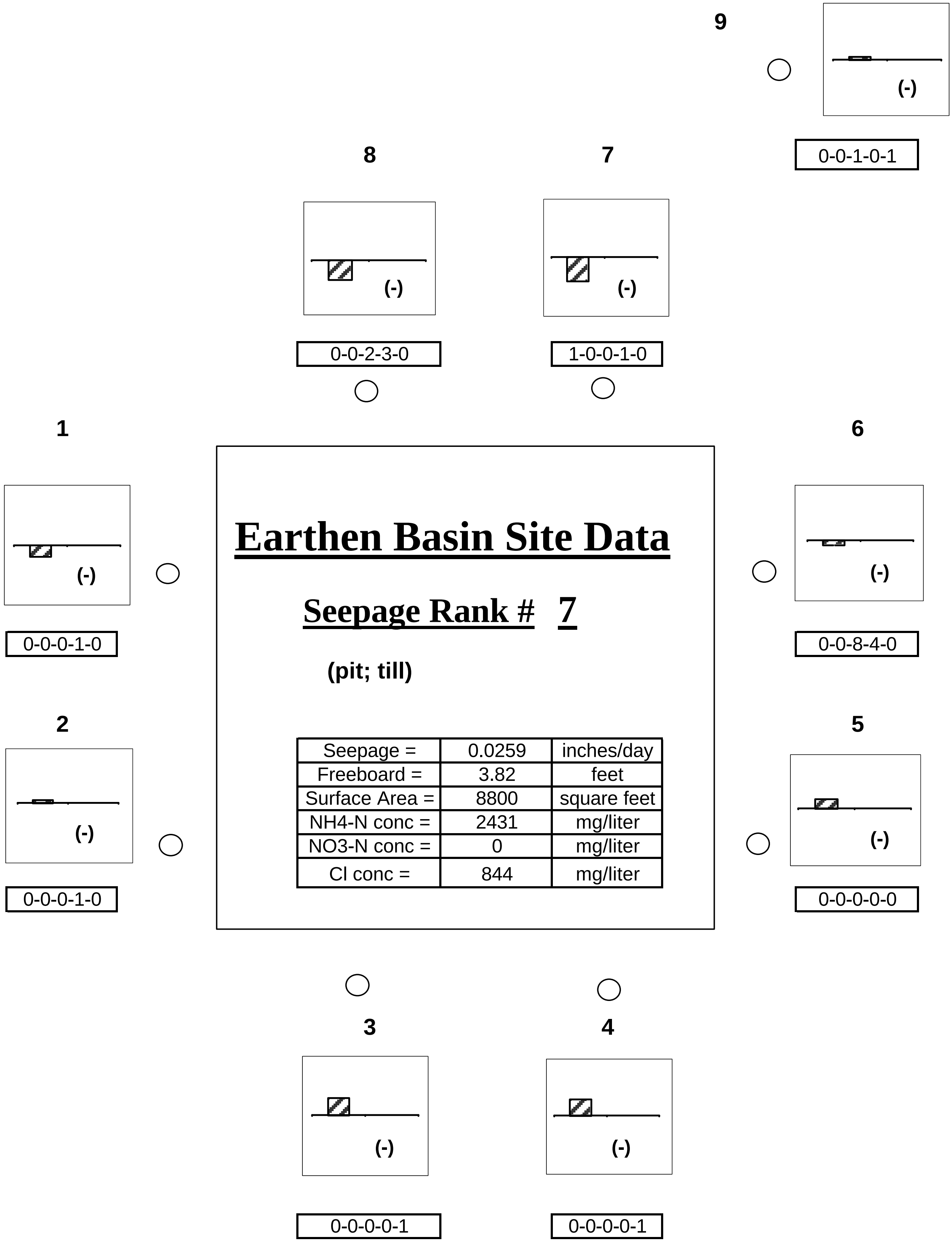
Earthen Basin Site Data

Seepage Rank # 6

(lagoon;till)

Seepage =	0.0239	inches/day
Freeboard =	5.01	feet
Surface Area =	24240	square feet
NH4-N conc =	544	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	377	mg/liter

Figure 12. Chemical and elevation data for basin #6.



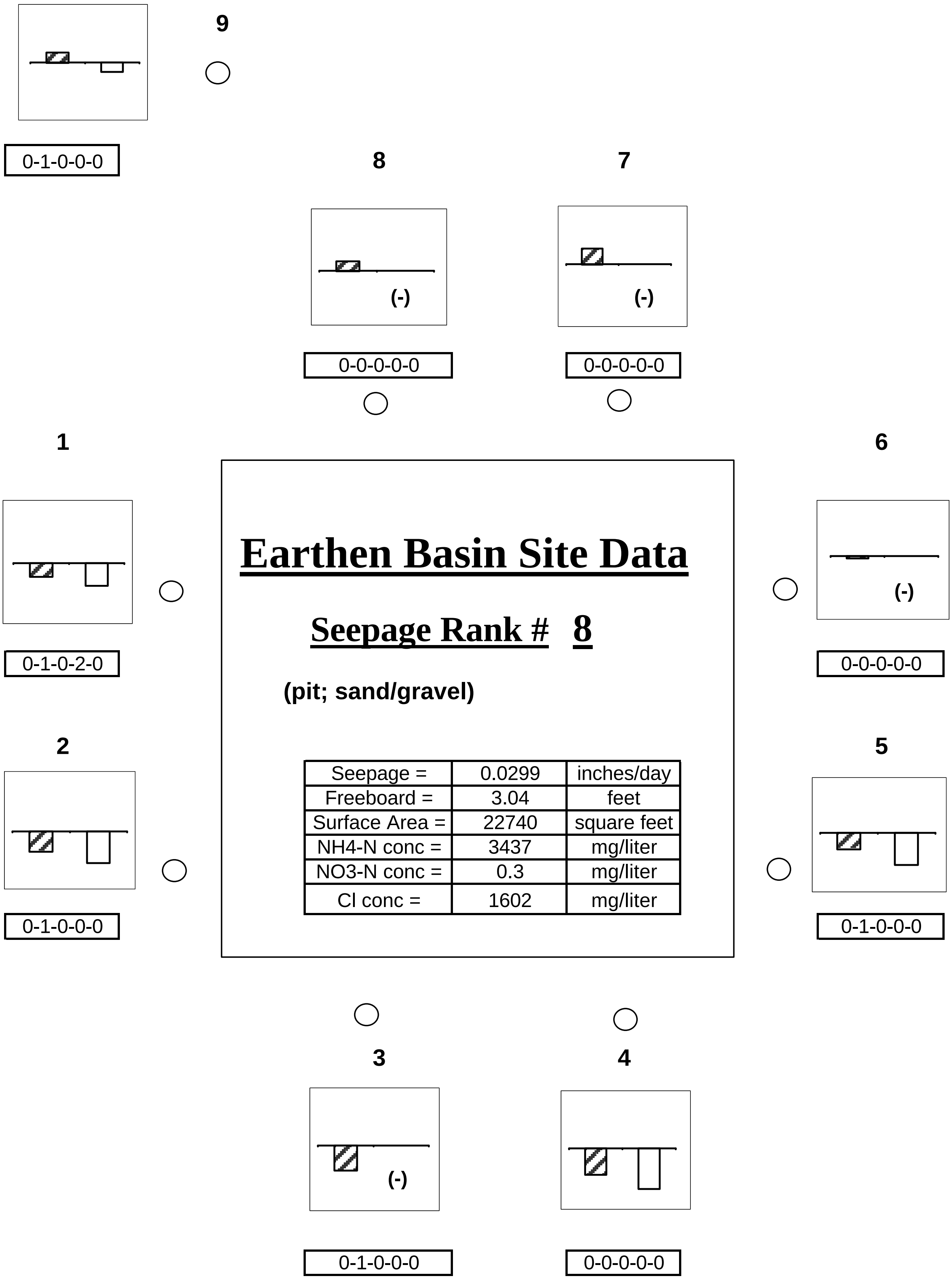
Earthen Basin Site Data

Seepage Rank # 7

(pit; till)

Seepage =	0.0259	inches/day
Freeboard =	3.82	feet
Surface Area =	8800	square feet
NH4-N conc =	2431	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	844	mg/liter

Figure 13. Chemical and elevation data for basin #7.



Earthen Basin Site Data

Seepage Rank # 8

(pit; sand/gravel)

Seepage =	0.0299	inches/day
Freeboard =	3.04	feet
Surface Area =	22740	square feet
NH4-N conc =	3437	mg/liter
NO3-N conc =	0.3	mg/liter
Cl conc =	1602	mg/liter

Figure 14. Chemical and elevation data for basin #8.

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(Page 91 does not exist in original)

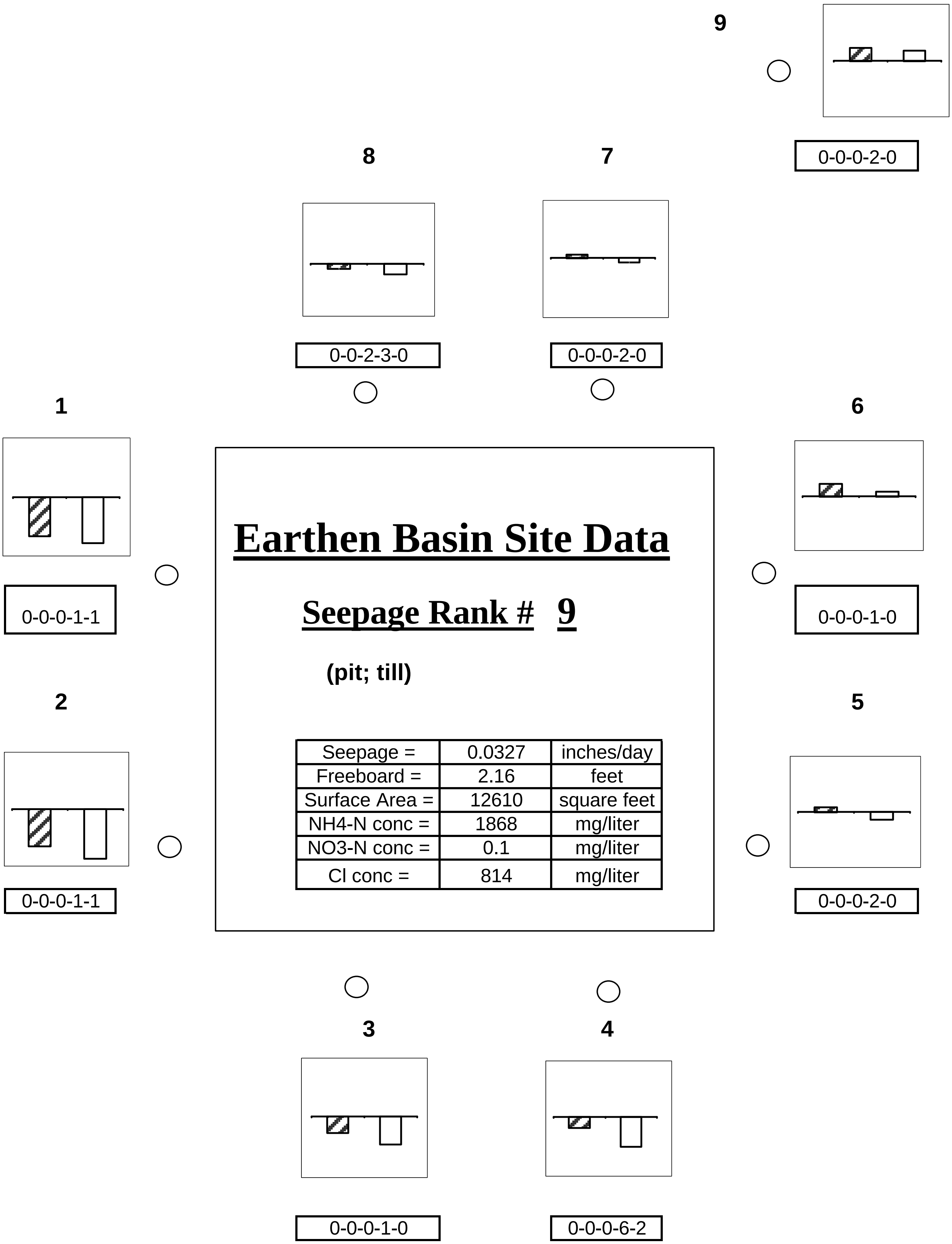


Figure 15. Chemical and elevation data for basin #9.

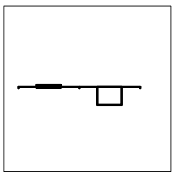
Earthen Basin Site Data

Seepage Rank # 10

(pit; till)

Seepage =	0.0377	inches/day
Freeboard =	2.38	feet
Surface Area =	27080	square feet
NH4-N conc =	2248	mg/liter
NO3-N conc =	0.1	mg/liter
Cl conc =	734	mg/liter

1



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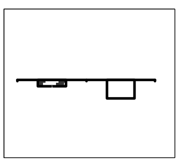

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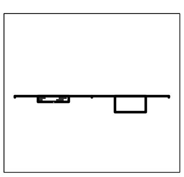

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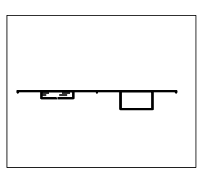

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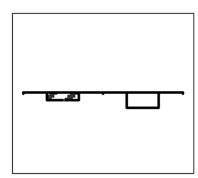

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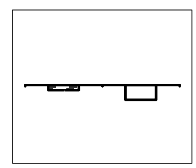

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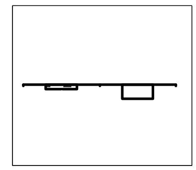

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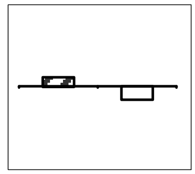

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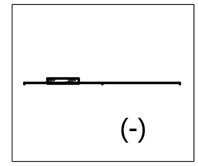

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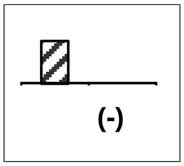
Figure 16. Chemical and elevation data for basin #10.

9



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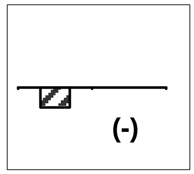

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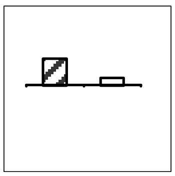

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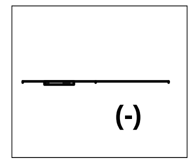

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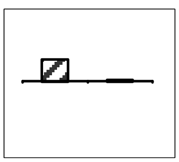
Earthen Basin Site Data

Seepage Rank # 11

(lagoon; loess)

Seepage =	0.0395	inches/day
Freeboard =	8.67	feet
Surface Area =	52,230	square feet
NH4-N conc =	731	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	357	mg/liter

2



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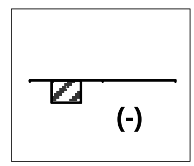

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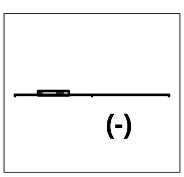

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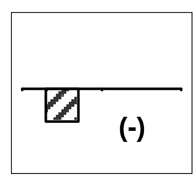

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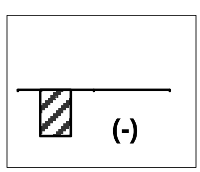

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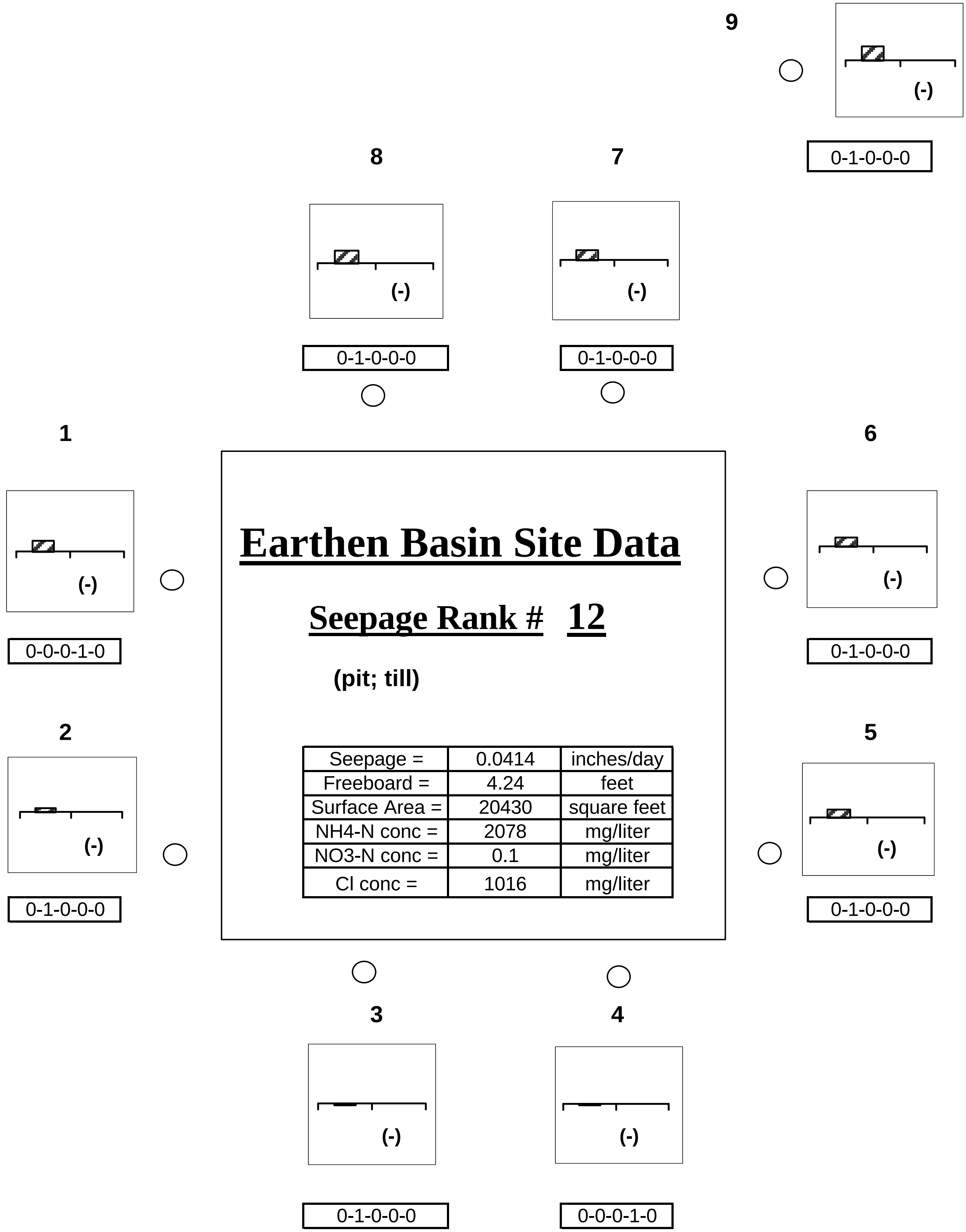
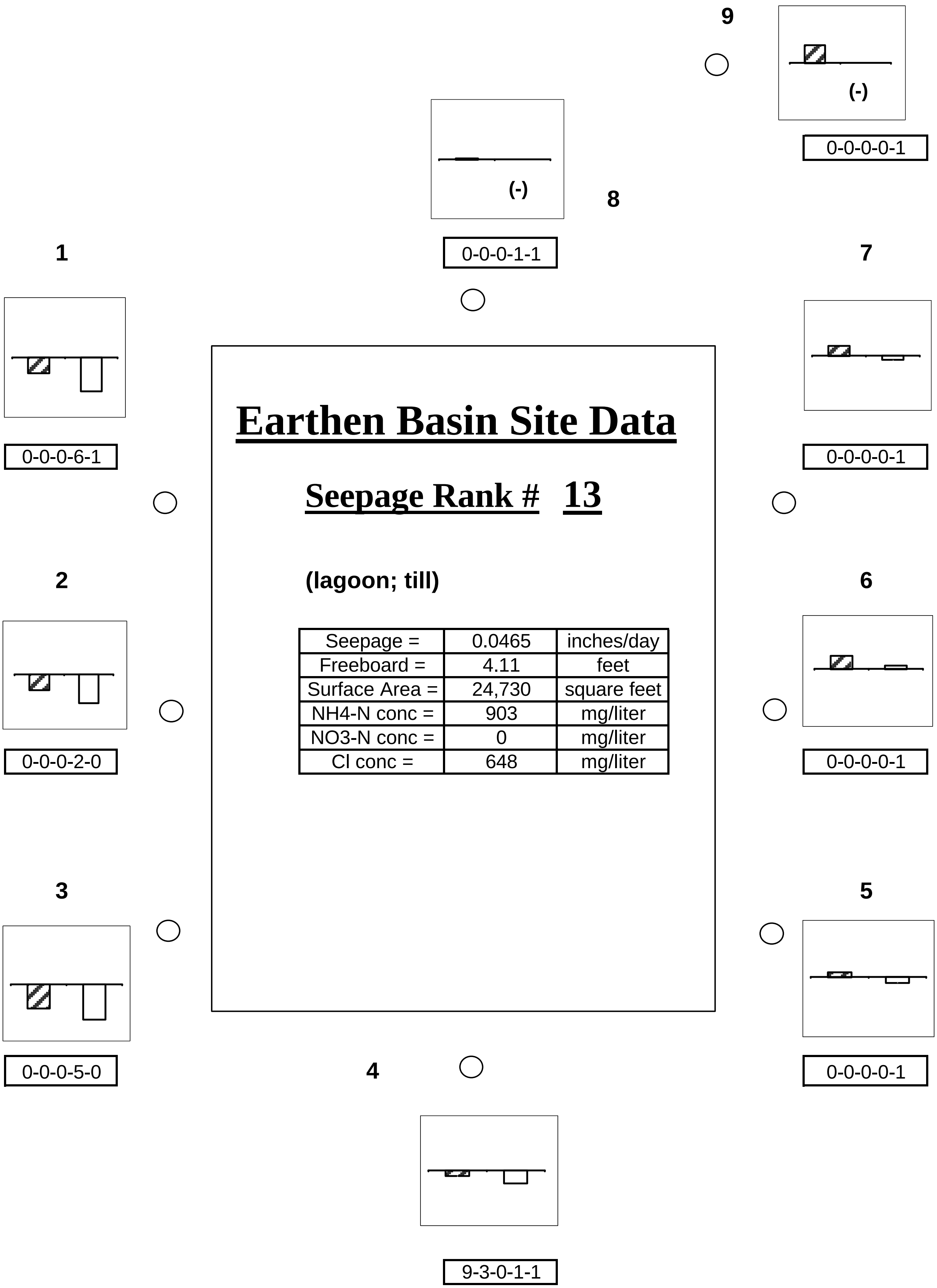
Figure 17. Chemical and elevation data for basin #11.



Seepage =	0.0414	inches/day
Freeboard =	4.24	feet
Surface Area =	20430	square feet
NH4-N conc =	2078	mg/liter
NO3-N conc =	0.1	mg/liter
Cl conc =	1016	mg/liter

Figure 18. Chemical and elevation data for basin #12.



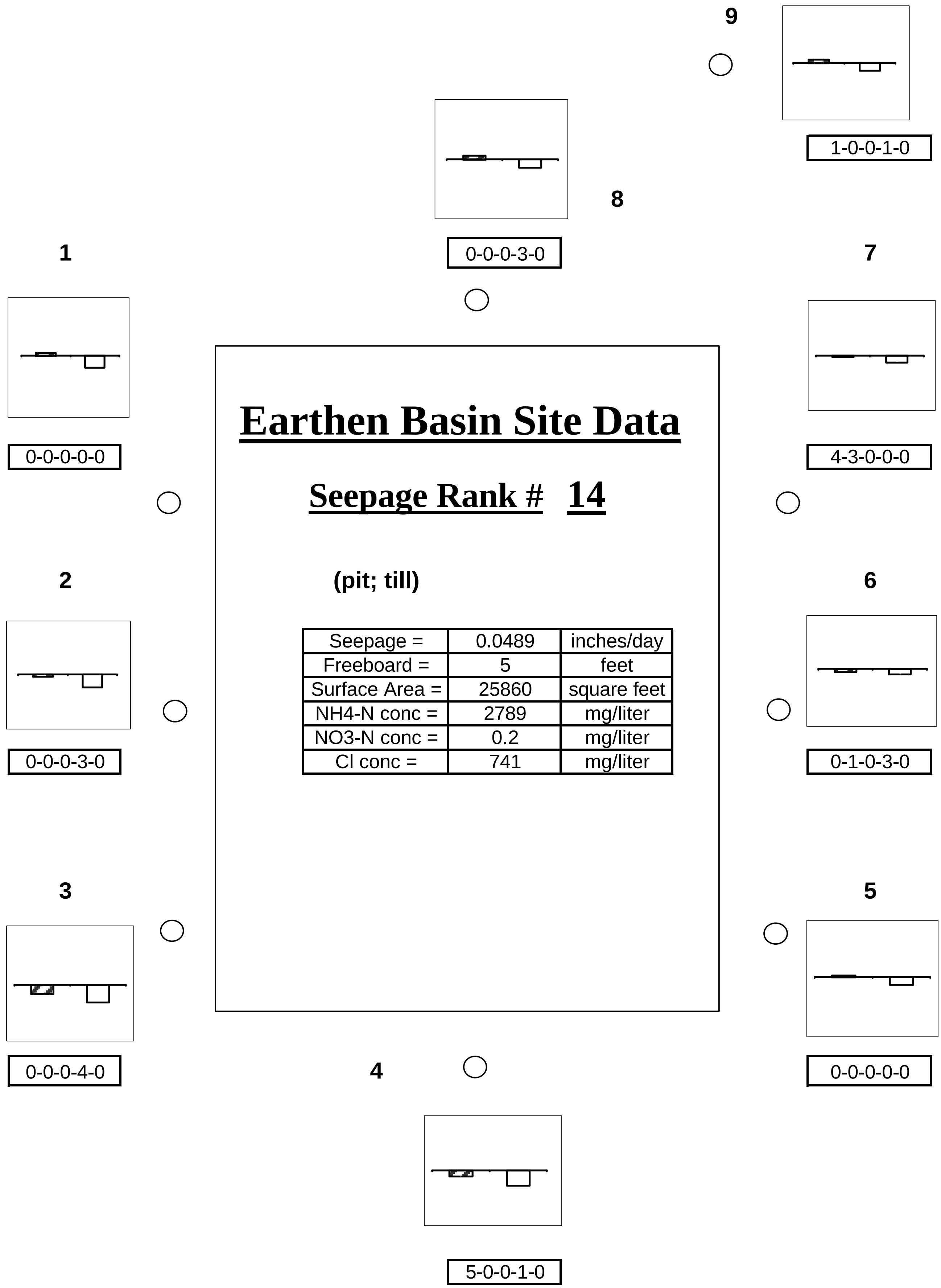
Earthen Basin Site Data

Seepage Rank # 13

(lagoon; till)

Seepage =	0.0465	inches/day
Freeboard =	4.11	feet
Surface Area =	24,730	square feet
NH4-N conc =	903	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	648	mg/liter

Figure 19. Chemical and elevation data for basin #13.



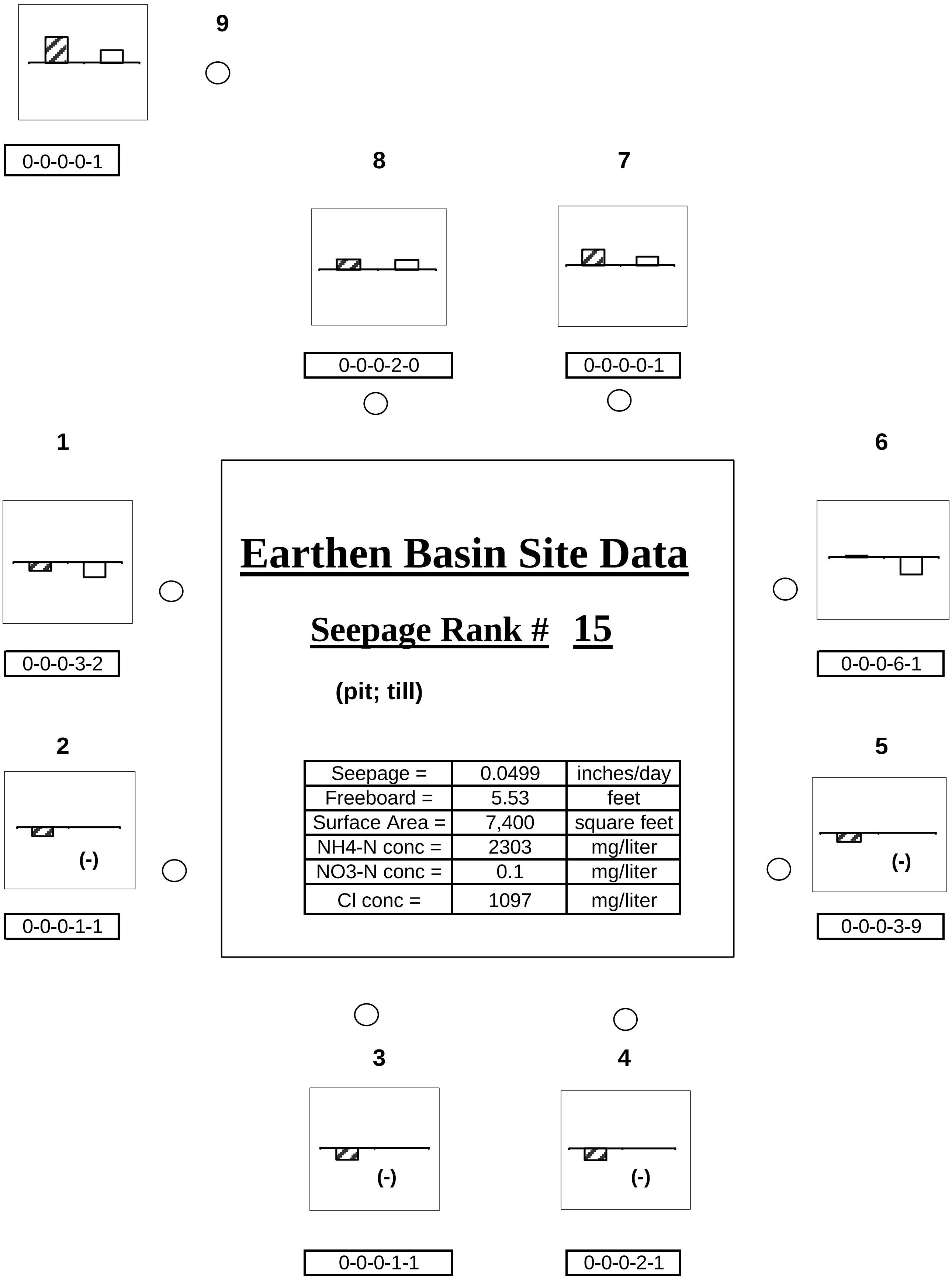
Earthen Basin Site Data

Seepage Rank # 14

(pit; till)

Seepage =	0.0489	inches/day
Freeboard =	5	feet
Surface Area =	25860	square feet
NH4-N conc =	2789	mg/liter
NO3-N conc =	0.2	mg/liter
Cl conc =	741	mg/liter

Figure 20. Chemical and elevation data for basin #14.



Earthen Basin Site Data

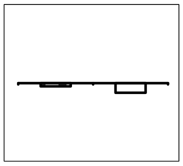
Seepage Rank # 15

(pit; till)

Seepage =	0.0499	inches/day
Freeboard =	5.53	feet
Surface Area =	7,400	square feet
NH4-N conc =	2303	mg/liter
NO3-N conc =	0.1	mg/liter
Cl conc =	1097	mg/liter

Figure 21. Chemical and elevation data for basin #15.

9



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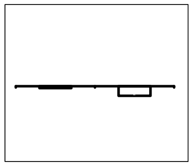

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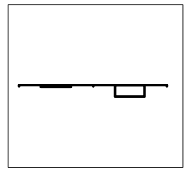

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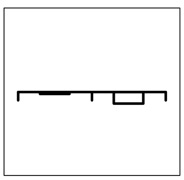

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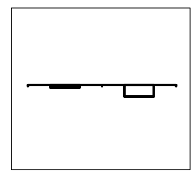

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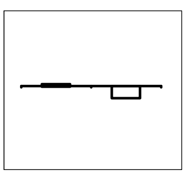
Earthen Basin Site Data

Seepage Rank # 16

(pit; colluvium)

Seepage =	0.0511	inches/day
Freeboard =	1.3	feet
Surface Area =	20,300	square feet
NH4-N conc =	1298	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	565	mg/liter

2



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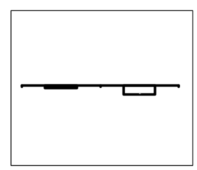

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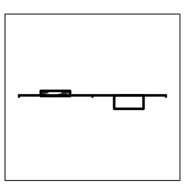

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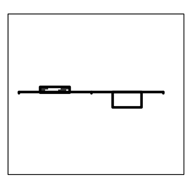

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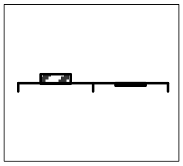
Figure 22. Chemical and elevation data for basin #16.

9



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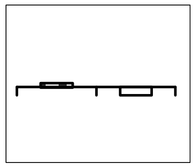

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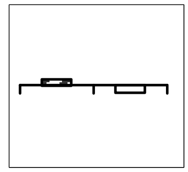

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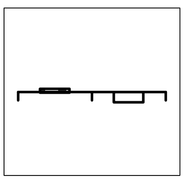


0-0-1-0-1

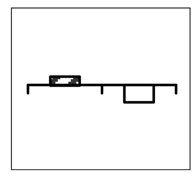
Earthen Basin Site Data

Seepage Rank # 17

(pit; loess)

Seepage =	0.0553	inches/day
Freeboard =	4.03	feet
Surface Area =	9,030	square feet
NH4-N conc =	3175	mg/liter
NO3-N conc =	0.9	mg/liter
Cl conc =	732	mg/liter

6



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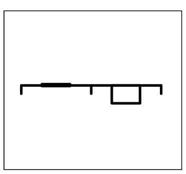

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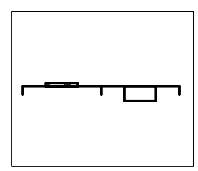

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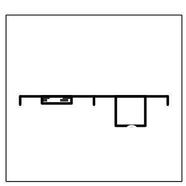

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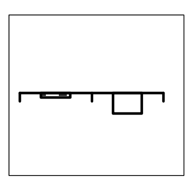


0-0-0-3-0

Figure 23. Chemical and elevation data for basin #17.

Earthen Basin Site Data

Seepage Rank # 18

(lagoon; till)

Seepage =	0.0569	inches/day
Freeboard =	3.99	feet
Surface Area =	94,330	square feet
NH4-N conc =	898	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	494	mg/liter

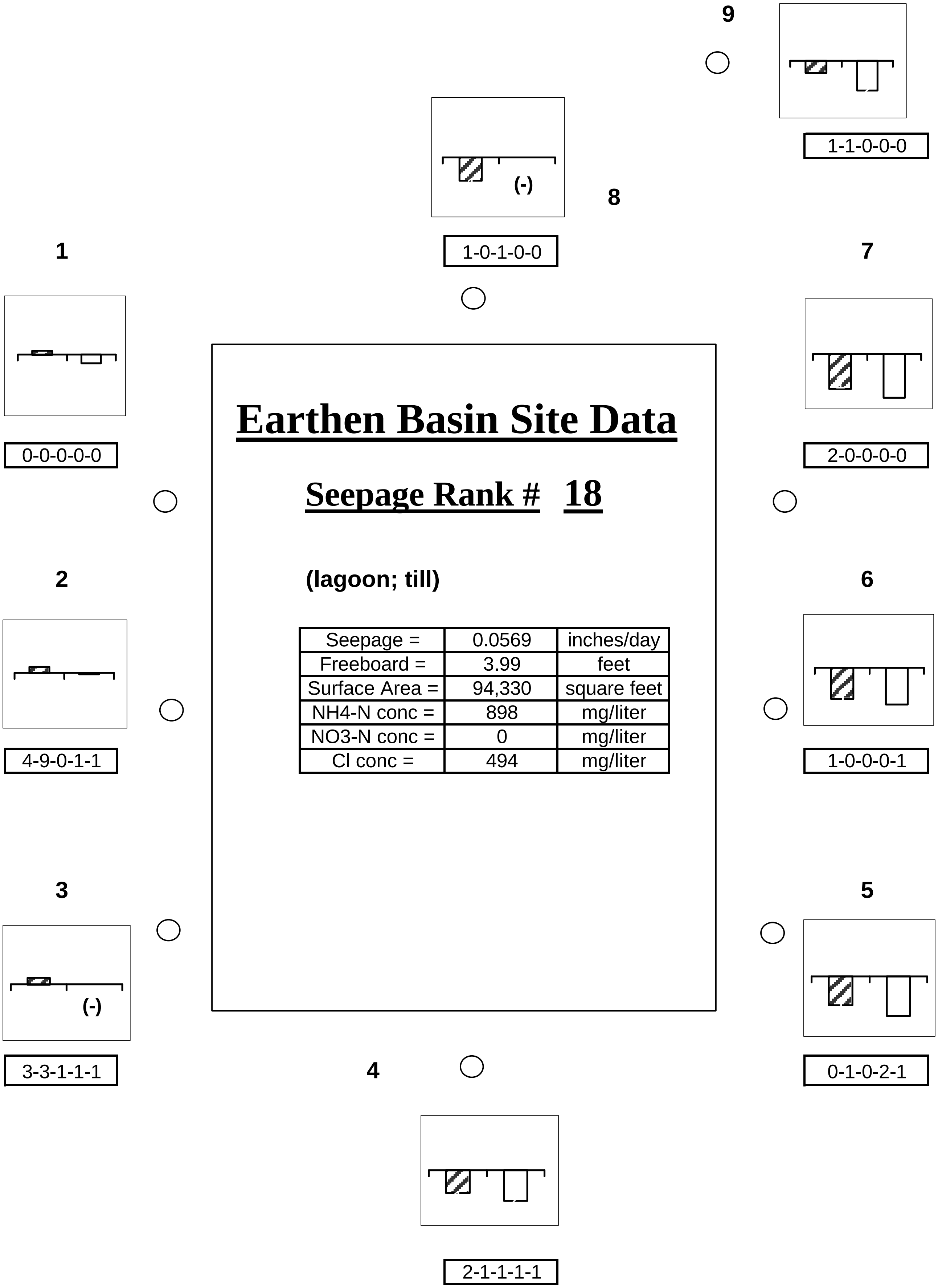
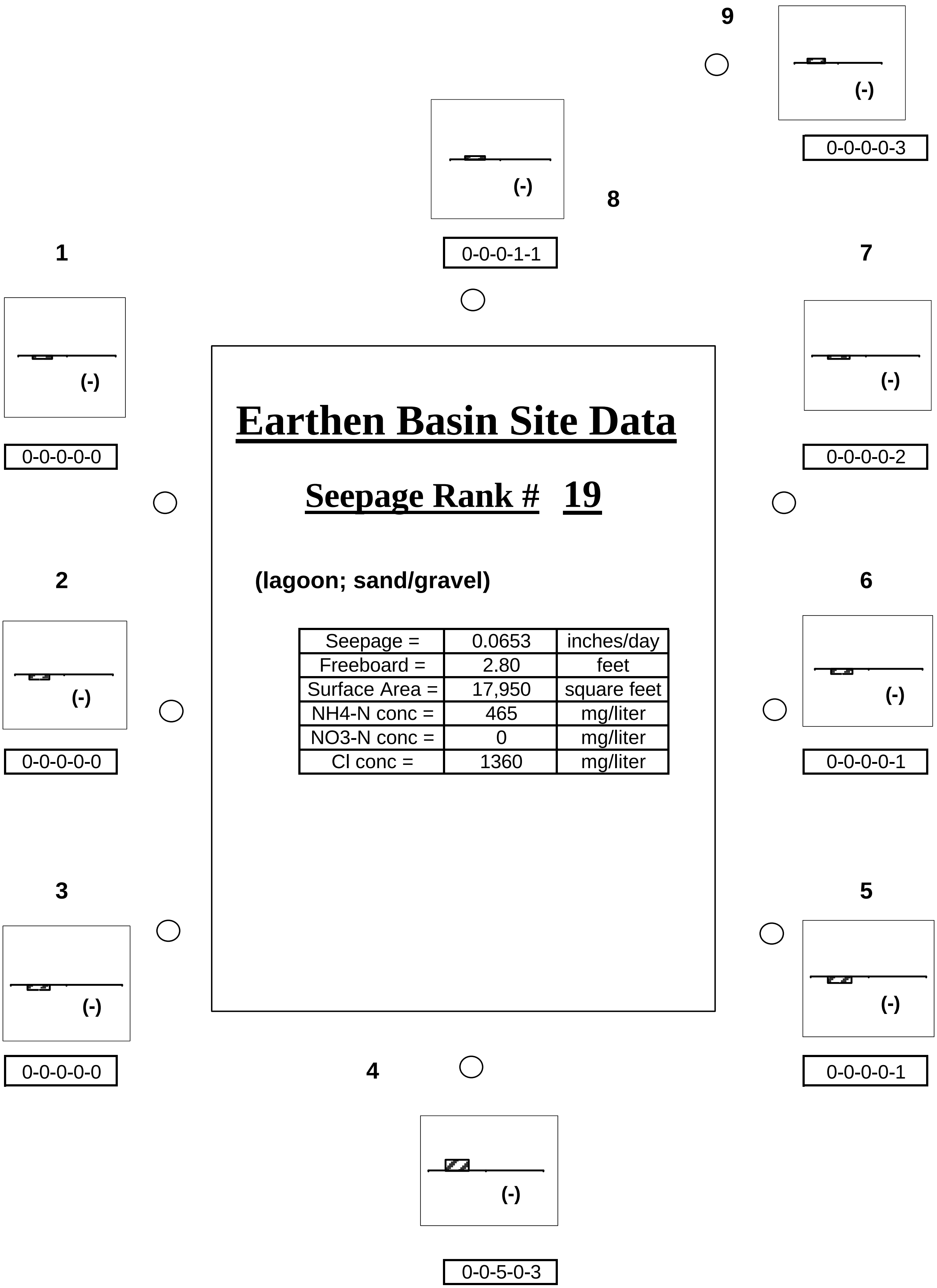


Figure 24. Chemical and elevation data for basin #18.



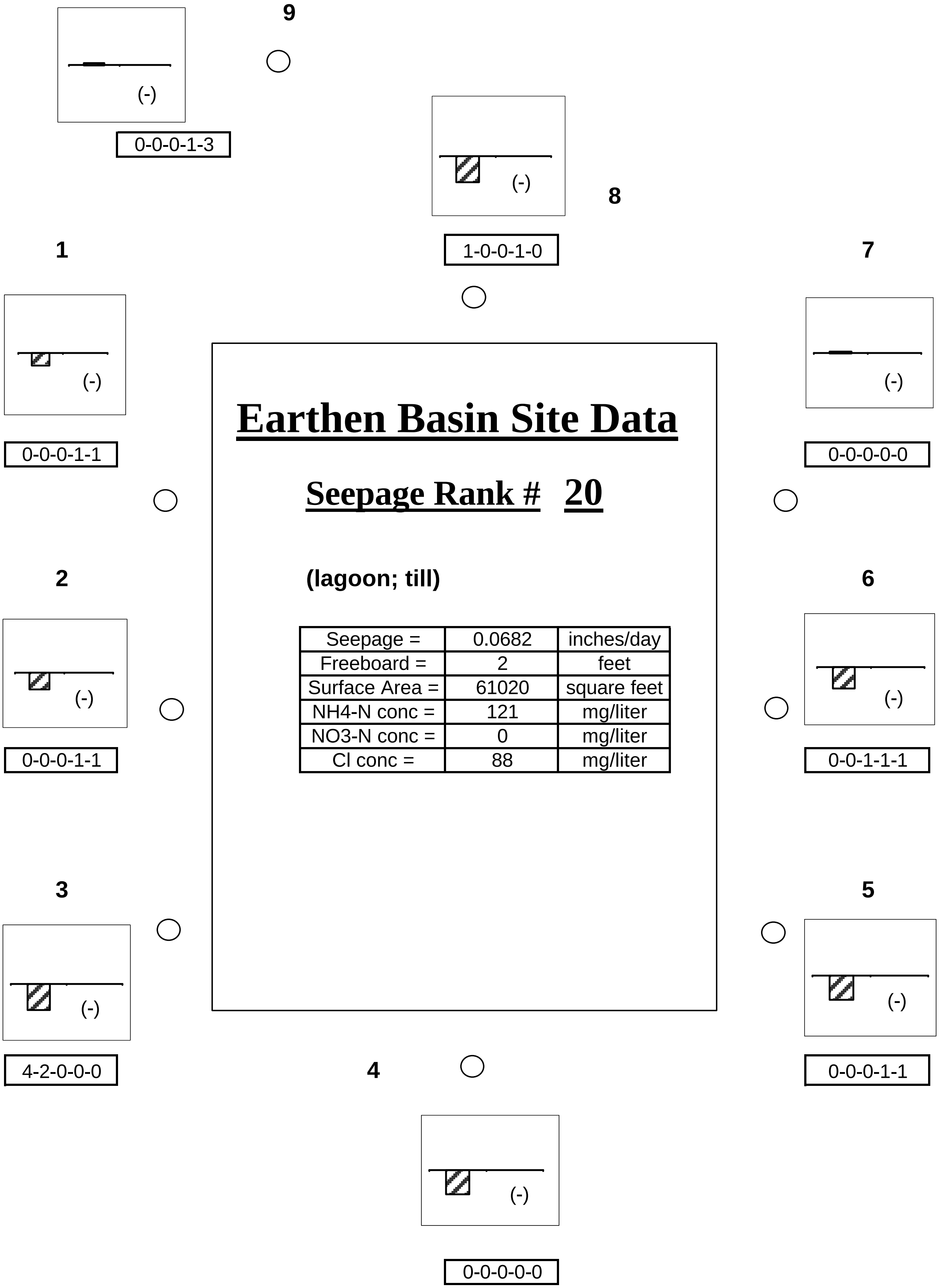
Earthen Basin Site Data

Seepage Rank # 19

(lagoon; sand/gravel)

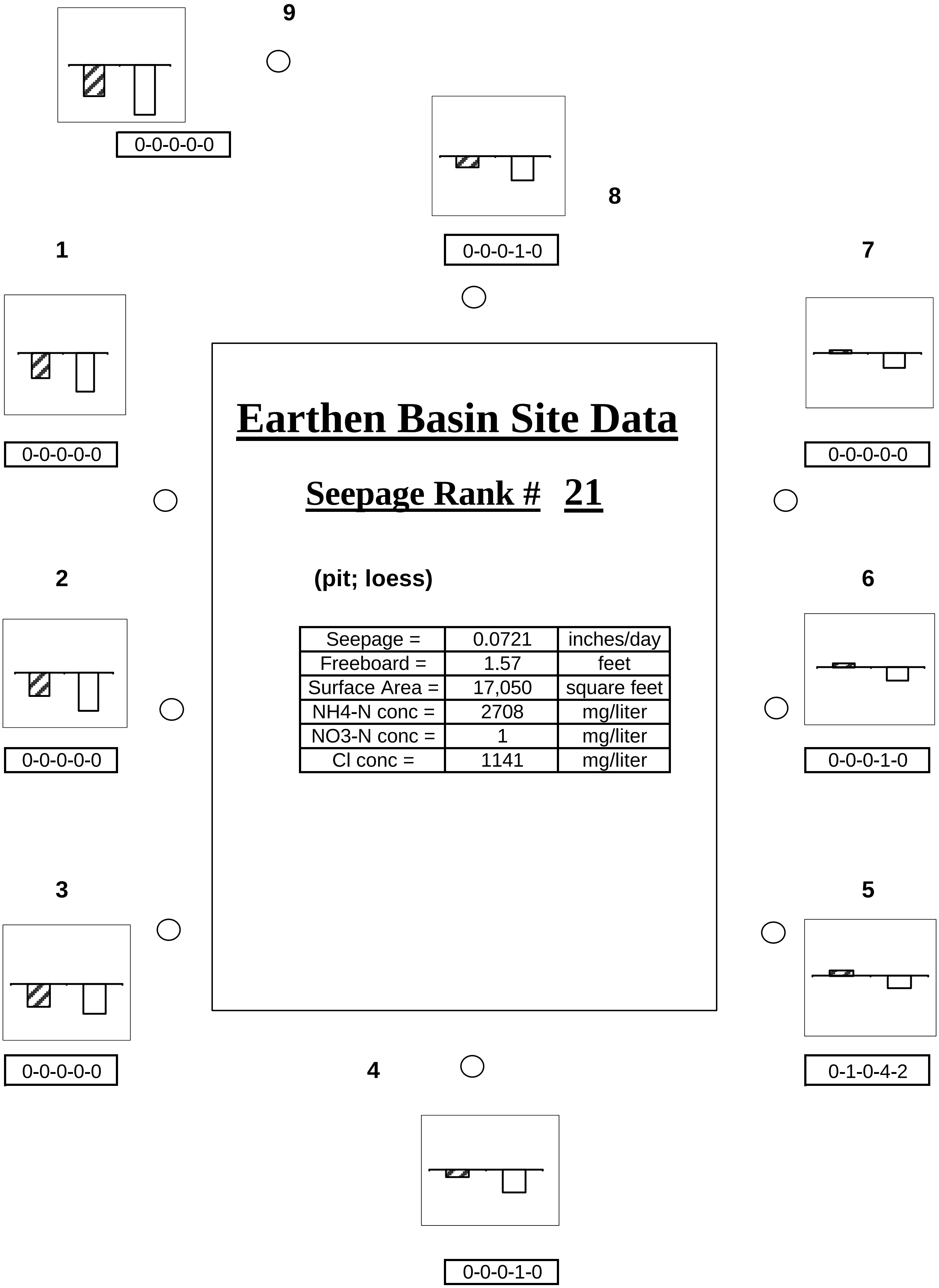
Seepage =	0.0653	inches/day
Freeboard =	2.80	feet
Surface Area =	17,950	square feet
NH4-N conc =	465	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	1360	mg/liter

Figure 25. Chemical and elevation data for basin #19.



Seepage =	0.0682	inches/day
Freeboard =	2	feet
Surface Area =	61020	square feet
NH4-N conc =	121	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	88	mg/liter

Figure 26. Chemical and elevation data for basin #20.



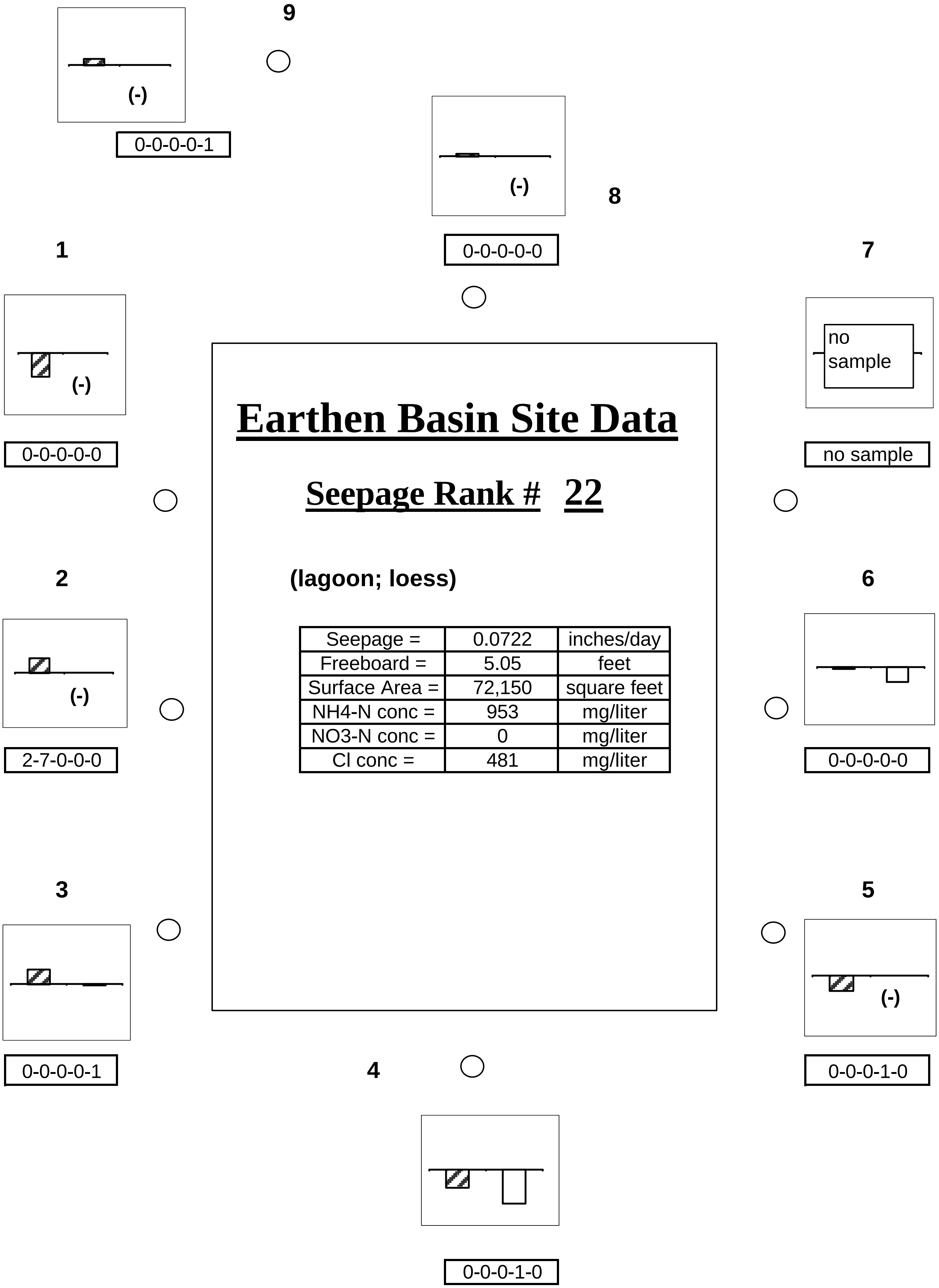
Earthen Basin Site Data

Seepage Rank # 21

(pit; loess)

Seepage =	0.0721	inches/day
Freeboard =	1.57	feet
Surface Area =	17,050	square feet
NH4-N conc =	2708	mg/liter
NO3-N conc =	1	mg/liter
Cl conc =	1141	mg/liter

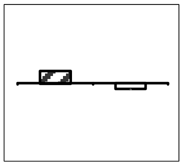
Figure 27. Chemical and elevation data for basin #21.



Seepage =	0.0722	inches/day
Freeboard =	5.05	feet
Surface Area =	72,150	square feet
NH4-N conc =	953	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	481	mg/liter

Figure 28. Chemical and elevation data for basin #22.

9



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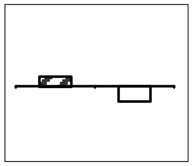

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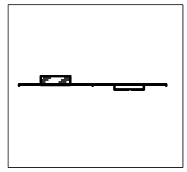

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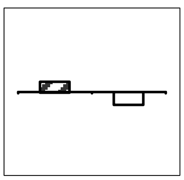


0-0-0-0-0

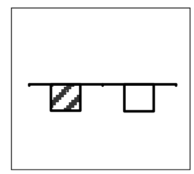
Earthen Basin Site Data

Seepage Rank # 23

(lagoon; sand/gravel)

Seepage =	0.0735	inches/day
Freeboard =	4.26	feet
Surface Area =	79,700	square feet
NH4-N conc =	3727	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	931	mg/liter

6



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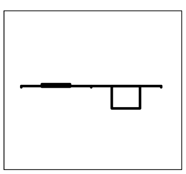

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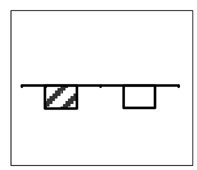

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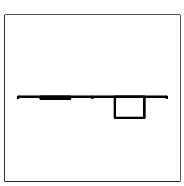

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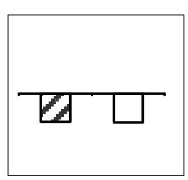

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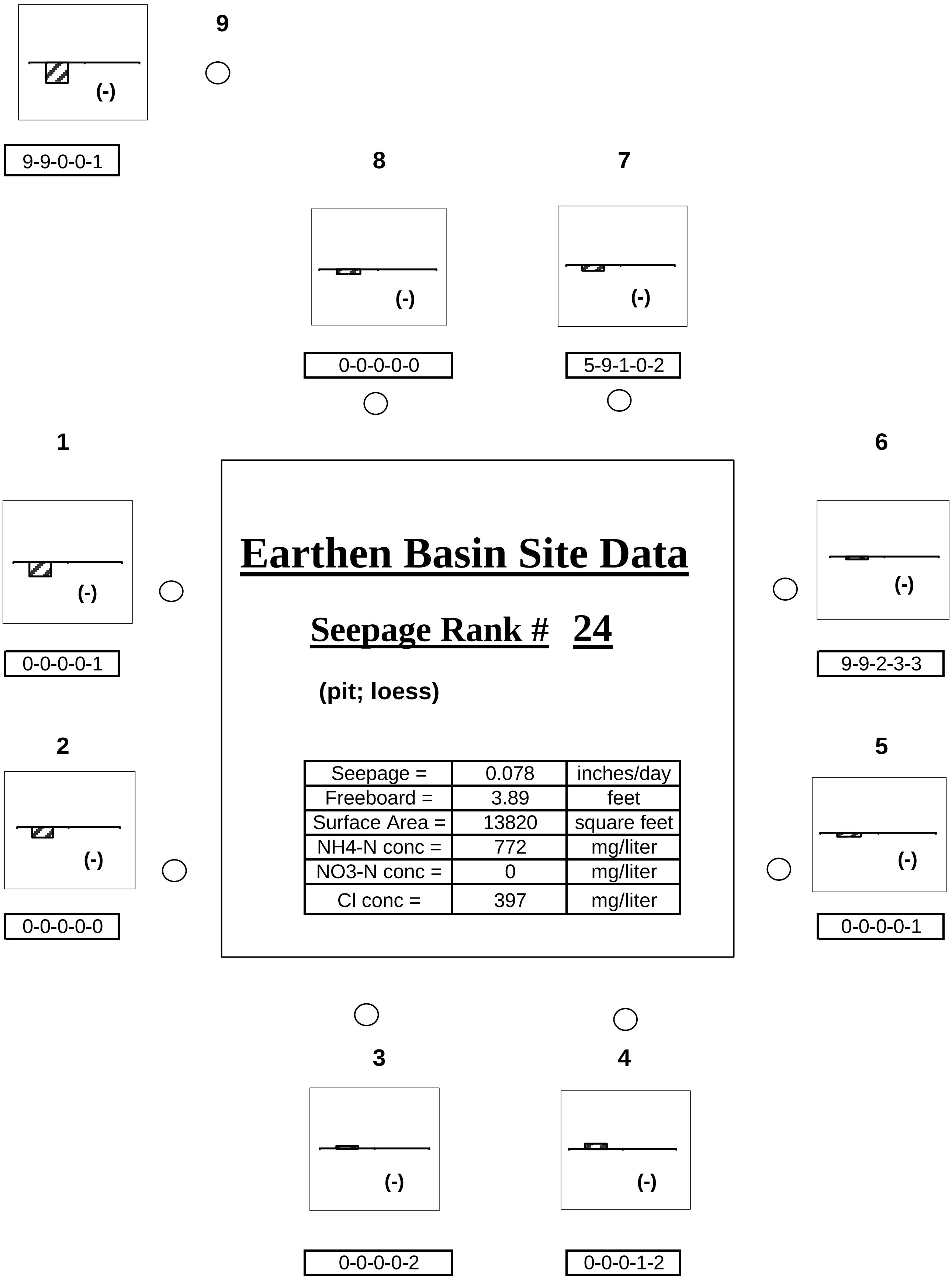
Figure 29. Chemical and elevation data for basin #23.



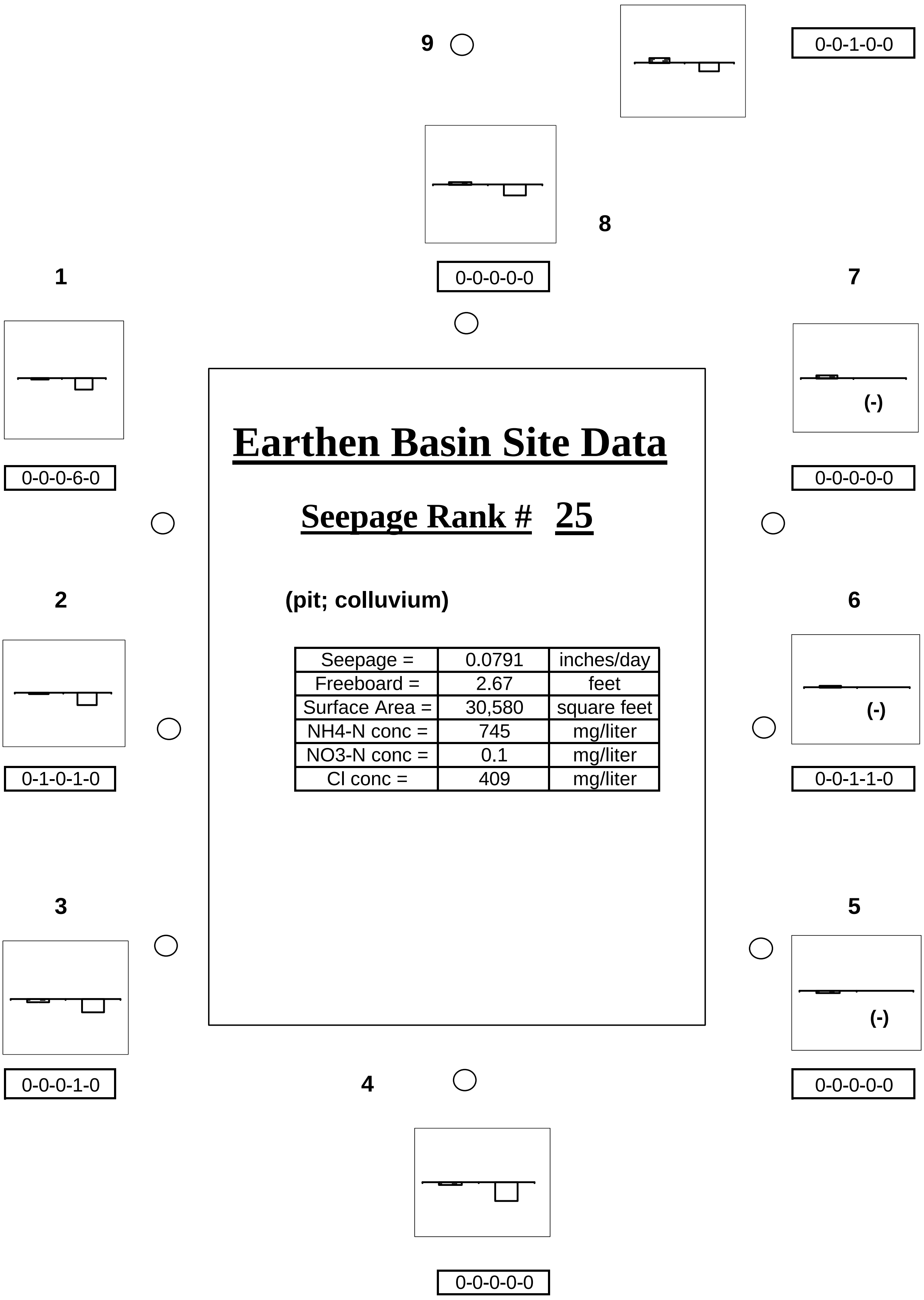
Earthen Basin Site Data

Seepage Rank # 24

(pit; loess)

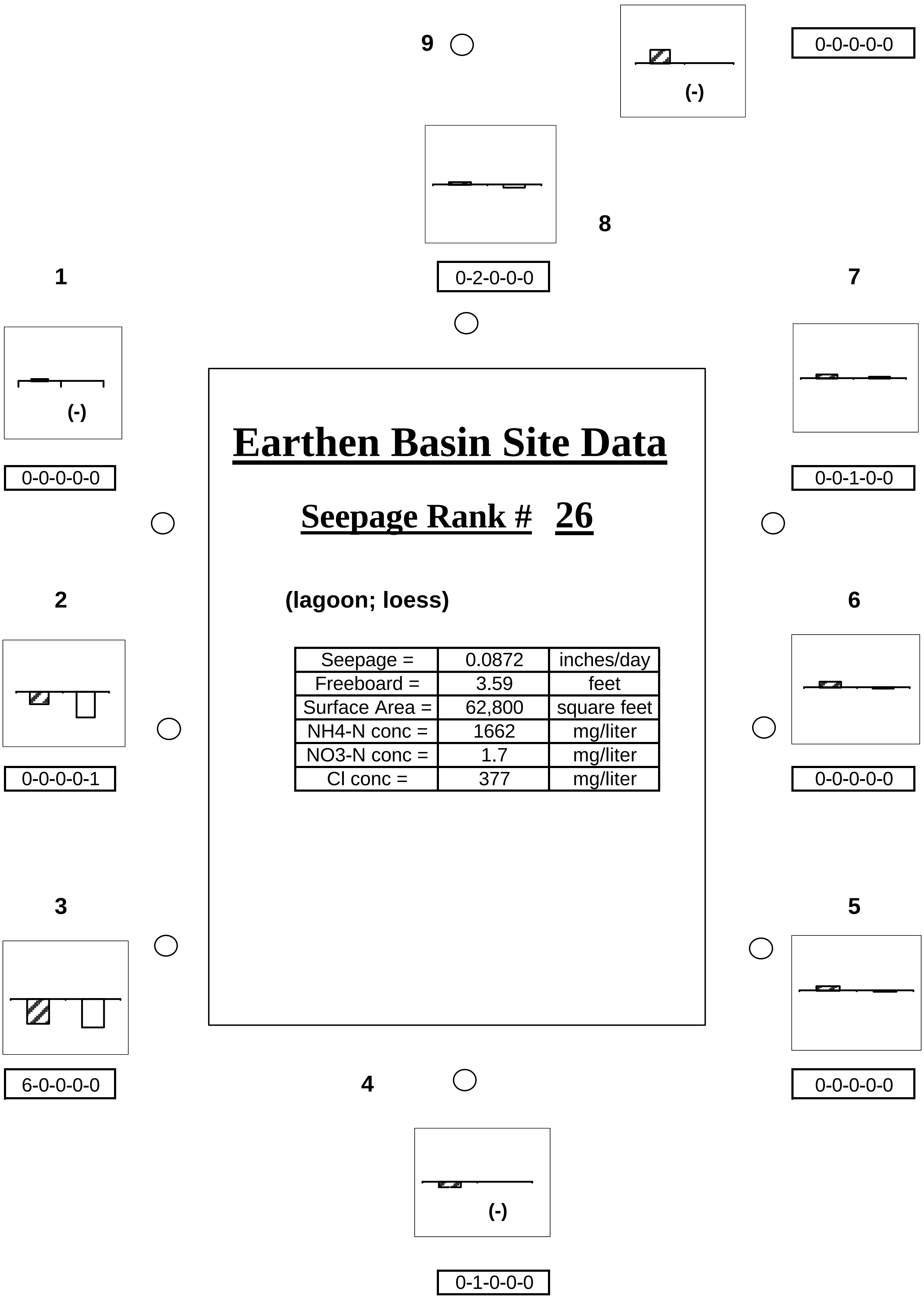
Seepage =	0.078	inches/day
Freeboard =	3.89	feet
Surface Area =	13820	square feet
NH4-N conc =	772	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	397	mg/liter

Figure 30. Chemical and elevation data for basin #24.



Seepage =	0.0791	inches/day
Freeboard =	2.67	feet
Surface Area =	30,580	square feet
NH4-N conc =	745	mg/liter
NO3-N conc =	0.1	mg/liter
Cl conc =	409	mg/liter

Figure 31. Chemical and elevation data for basin #25.



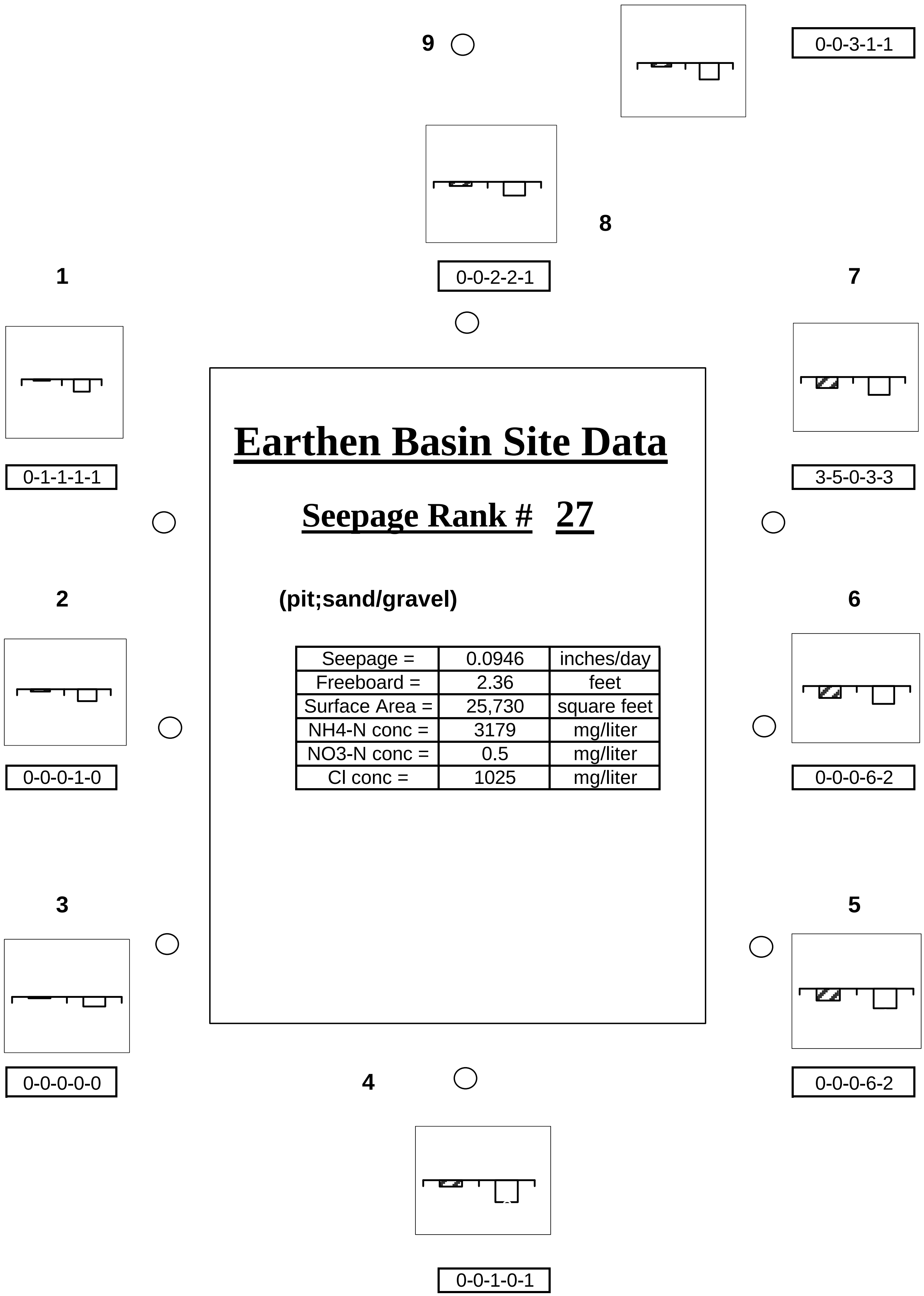
Earthen Basin Site Data

Seepage Rank # 26

(lagoon; loess)

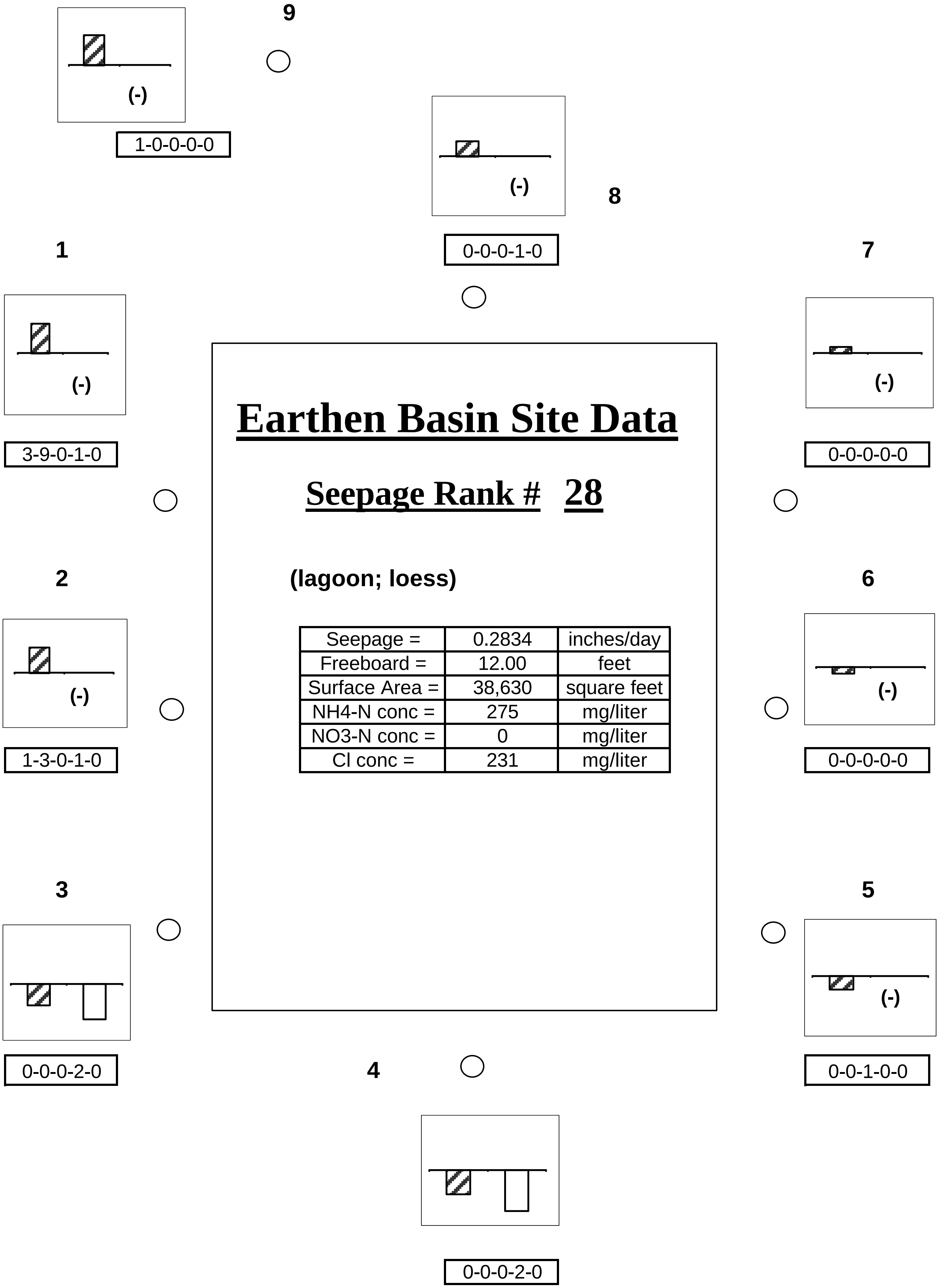
Seepage =	0.0872	inches/day
Freeboard =	3.59	feet
Surface Area =	62,800	square feet
NH4-N conc =	1662	mg/liter
NO3-N conc =	1.7	mg/liter
Cl conc =	377	mg/liter

Figure 32. Chemical and elevation data for basin #26.



Seepage =	0.0946	inches/day
Freeboard =	2.36	feet
Surface Area =	25,730	square feet
NH4-N conc =	3179	mg/liter
NO3-N conc =	0.5	mg/liter
Cl conc =	1025	mg/liter

Figure 33. Chemical and elevation data for basin #27.



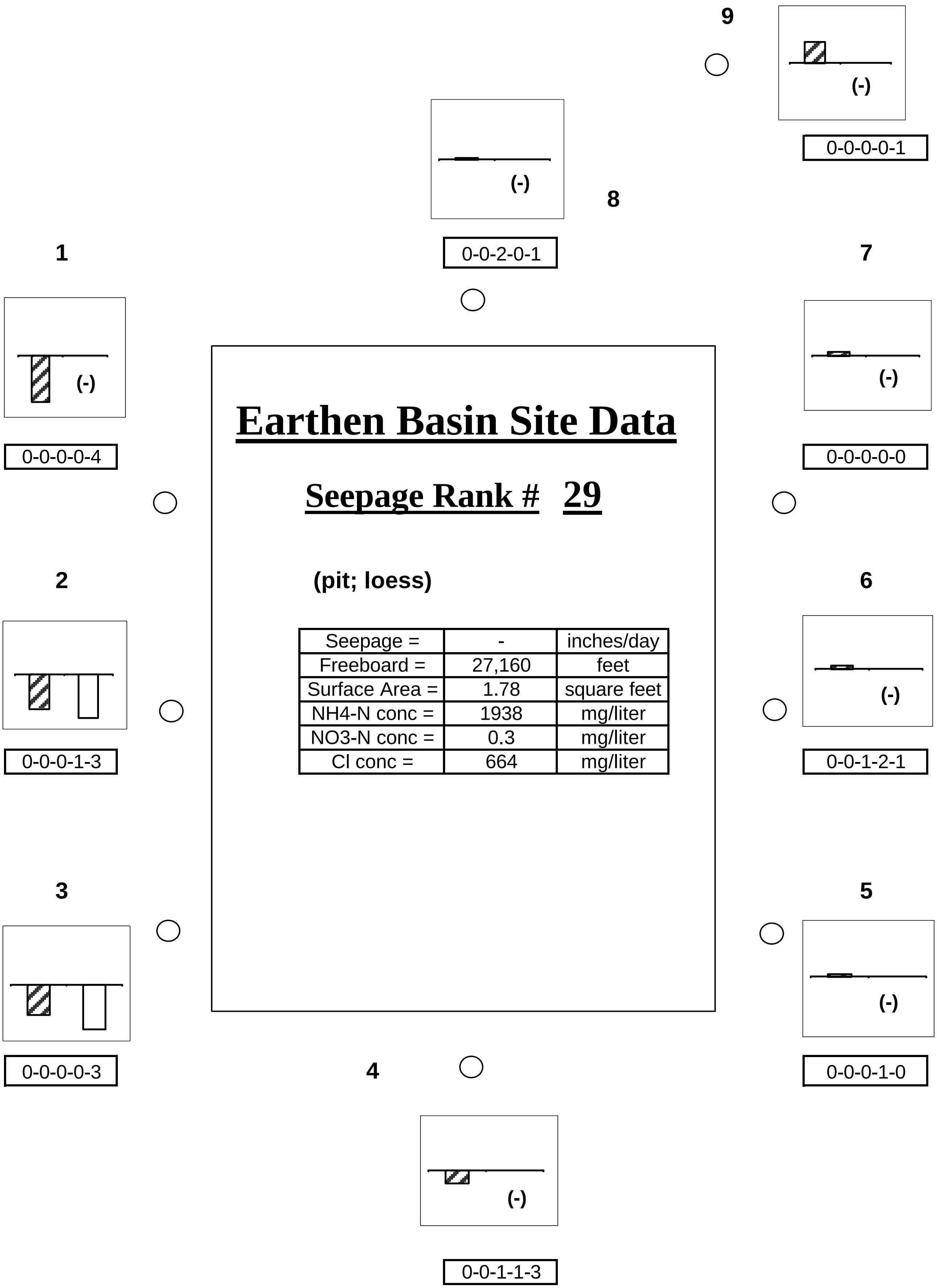
Earthen Basin Site Data

Seepage Rank # 28

(lagoon; loess)

Seepage =	0.2834	inches/day
Freeboard =	12.00	feet
Surface Area =	38,630	square feet
NH4-N conc =	275	mg/liter
NO3-N conc =	0	mg/liter
Cl conc =	231	mg/liter

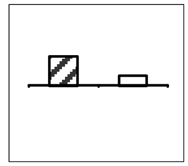
Figure 34. Chemical and elevation data for basin #28.



Seepage =	-	inches/day
Freeboard =	27,160	feet
Surface Area =	1.78	square feet
NH4-N conc =	1938	mg/liter
NO3-N conc =	0.3	mg/liter
Cl conc =	664	mg/liter

Figure 35. Chemical and elevation data for basin #29.

9



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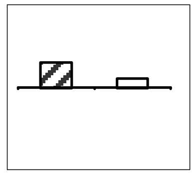

0-1-3-1-1

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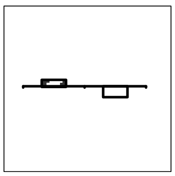

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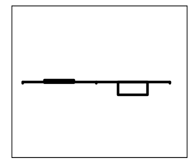


0-1-3-3-6

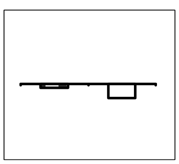
Earthen Basin Site Data

Seepage Rank # 30

(lagoon; till)

Seepage =	-	inches/day
Freeboard =	10.14	feet
Surface Area =	19,970	square feet
NH4-N conc =	2856	mg/liter
NO3-N conc =	1.8	mg/liter
Cl conc =	981	mg/liter

2



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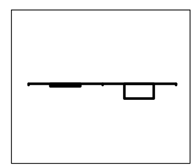

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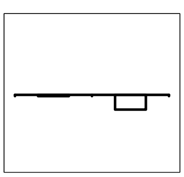

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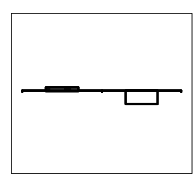

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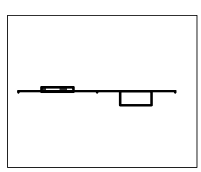

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Figure 36. Chemical and elevation data for basin #30.

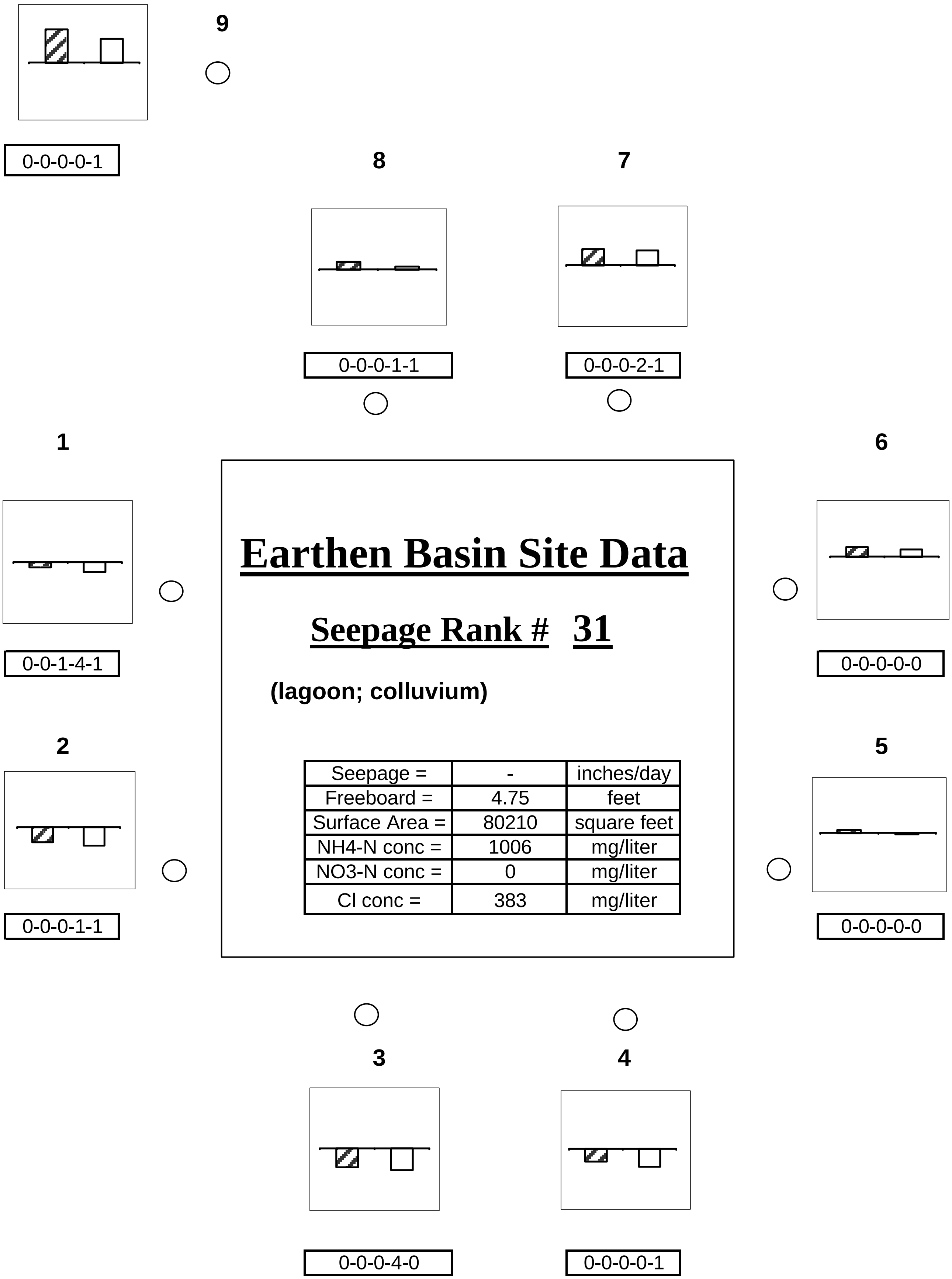

Figure 37. Chemical and elevation data for basin #31.