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Design and Construction Guidelines For Considering Seepage From Agricultural Waste Storage Ponds and Treatment Lagoons

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Introduction

The protection of surface and ground water and the utilization or disposal of animal waste are the primary functions of waste storage ponds and treatment lagoons. The permeability of the soil in a constructed waste treatment lagoon or waste storage pond is an important property affecting the potential for downward or lateral seepage of the stored wastes. With the potential for seepage from the structure comes the associated risks of pollution of surface water and underground aquifers.

Research has indicated that most natural soils used as a foundation material in the construction of waste treatment lagoons and waste storage ponds will seal. Such sealing is thought to be a result of physical, chemical, and biological processes. Suspended solids settle or filter out of solution and physically clog the pores of the soil mass. Anaerobic bacteria produce byproducts that accumulate at the soil-water interface and reinforce the seal, and in the process of metabolizing organic material can alter the soil structure. Chemicals in animal waste, such as salts, can disperse soil, which may be beneficial in reducing seepage. Under these conditions researchers have reported that the permeability of the soil can be decreased several orders of magnitude in a few weeks following contact with animal waste in a waste storage pond or treatment lagoon.

The physical clogging of the soil has been considered to be a function of the type of waste and percent total solids, and the hydraulic conductivity and the size and geometry of soil pores. Until recent years research has focused on total solids of the waste as the most important factor in the physical sealing process. Research published in the late 1980's has convincingly shown that a soil's equivalent pore size computed as a function of particle size distribution and porosity is probably the more important aspect of the physical sealing mechanism. Generally, soils that have a clay content exceeding 5 or 15 percent for ruminant or monogastric animal manures, respectively, will seal with a final hydraulic conductivity approaching 10^{-7} cm/sec.

Many Soil Conservation Service (SCS) assisted waste storage and treatment facilities have been designed and constructed using the accepted state-of-the-art technique based on the prior research that most natural soils will seal. Some recent field observations of both new and old structures have shown that, in some instances, the sealing may not have been as effective as expected. Several recent literature reviews and appraisals pointed out that not all researchers agree with the sealing theory. Several of these reviews are summarized in appendix A. There is no doubt that manure does decrease the permeability of most soils. However, many do not believe that a permeability decrease induced by the manure should be counted on as the sole means of ground water protection.

Presently a joint research program is being conducted by the USDA Soil Conservation Service, Clemson University, and North Carolina State University to evaluate the effectiveness of earthen structures to contain animal waste. A technique to determine economically and quickly whether or not leakage is occurring is needed. At least one existing technology shows promise of being able to meet these requirements. Field validation is currently underway to evaluate the equipment and refine the procedures. A newly constructed lagoon will be monitored to detect the development and movement of any seepage plume.

Purpose

Until the results of the research program described above can be incorporated into the conservation practice standards, the following guidelines are provided for your consideration. These guidelines address the design and construction techniques needed to overcome certain soil limitations. They should be considered in the planning, design, construction, and operation of agricultural waste management practices, including Conservation Practice Standards: Waste Treatment Lagoon (No. 359), and Waste Storage Pond (No. 425) *(6)*. When predictable relationships among manure, soil types, and seepage reduction can be formulated, this technical note will be revised to include this technology.

Portions of this technical note were taken from Amendment N3 of the Agricultural Waste Management Field Manual distributed by the Northeast National Technical Center, March 29, 1988 *(3)*. Additional design information is contained in South National Technical Center Engineering Technical Note 711, March 1987 *(7)*.

General design considerations

Soil and foundation characteristics have always been critical items for consideration in the successful installation and safe operation of a waste treatment lagoon or waste storage pond. Present criteria in Practice Standard 359 states: "Locate the lagoon on soils of slow to moderate permeability or on soils that can seal through sedimentation and biological action. Avoid gravelly soils and shallow soils over fractured or cavernous rock. If self-sealing is not probable, the lagoon shall be sealed by mechanical treatment or by the use of an impermeable membrane."

The conscientious application of this criteria has resulted in many successful installations of waste storage facilities in a variety of soil and foundation conditions. Where specific problem areas have been identified special design modifications have been used successfully.

The majority of waste treatment lagoons and waste storage ponds can be successfully installed on properly selected sites without any special treatment other than good construction procedures. The increasing concern over the quality of ground water resources requires more emphasis on preventing and controlling seepage from lagoons and holding ponds.

Site investigation

The purpose of a site investigation with respect to this guide is to ascertain risk by evaluating soils, bedrock, ground water, climatic conditions, and local water uses.

Before any onsite investigation, the following should be examined: any special geology or ground water maps, published county soil surveys, previous designs in the same physiographical area, and any other information that helps in the assessment of the site. Specific data needed includes the presence of any water wells or any other water supply sources, depth to the seasonal high water table, general ground water gradient, general geology of the site, and depth to bedrock if appropriate. Any features that could impact on the hazards of the site, such as sole source aquifers, or important aquifers underlying the proposed site must be noted. Other guidelines, such as SEEPPAGE, NNTC Technical Note No. 5 *(2)*, are available to evaluate the relative geological problems.

An onsite investigation should always be conducted at a proposed lagoon or storage pond location. Determining the intensity of any detailed site investigation is the joint responsibility of the designer and the person who has engineering job approval authority. Their experience in a given area, the types of soils present, the size of the structure, the environmental sensitivity, and an assessment of the associated risks involved will enter into the level of investigation needed. State and local laws should be followed in all cases.

The subsurface investigation may consist of auger holes, dozer pits, or backhoe pits that should extend to at least 2 feet below the planned bottom of the excavation. These investigations are important records, and the information should be recorded and made a part of the design documentation. When using information gathered from auger holes, always consider that the augering process may have obscured the presence of clean sand or gravel lenses by mixing the different soil layers. Pits expose more of the foundation, which is helpful in detecting small, but important areas of permeable soil. The investigation can include field permeability testing, or taking samples for laboratory testing, or it may be limited to field classification of the soils. See Reference 8 for additional guidelines.

Soil properties

Foundation soils have been divided into four permeability groups based on their fines content and Atterberg Limits. These groups are shown in table 1. Fines are defined as the percent passing a U.S. Standard No. 200 Sieve calculated on a dry weight basis.

A discussion of the basic properties of each group is provided to explain the rationale for such a grouping.

Table 1 - ***Grouping of foundation soils according to their estimated field permeability***

Group	Description
I	Soils that have less than 20% passing a No. 200 Sieve and have a Plasticity Index (PI) less than 5
II	Soils that have 20 to 100% passing a No. 200 Sieve and have a Plasticity Index (PI) of 5 to 10.
III	Soils that have 20 to 100% passing a No. 200 Sieve and have a Plasticity Index (PI) of 11 to 30.
IV	Soils that have 20 to 100% passing a No. 200 Sieve and have a Plasticity Index (PI) of more than 30.

Group I - Generally these soils have the highest permeability rate and, in their natural state, could allow excessive seepage losses.

Group II - These soils generally are less permeable than the Group I soils and often lack sufficient clay to be included in Group III.

Group III - These soils generally a have very low permeability rate, good structural features, and only low to moderate shrink-swell behavior. See **Caution** that follows:

Group IV - Normally, these soils have a very low permeability rate. However, because of their sometimes blocky and fissured structure, they can often experience high seepage losses through cracks that can develop when the material is allowed to dry. They possess good attenuation properties if the seepage does not move through the cracks.

Caution: One important, but common exception to the soils that would normally be included in the Group III category is high calcium clays. They are difficult to identify in the field and in the laboratory except by using expensive tests. Additional assistance may be available though the local soil scientist or published soil surveys. These soils may have an open structure, referred to as "flocculated" or "aggregated," caused by the presence of calcium. Such soils often have much higher permeability rates than expected based on texture. Often, dispersants, such as tetrasodium polyphosphate, can reduce the tendency to flocculate by replacement of the calcium with sodium on the soil particles. Because manure contains salts, it can be used to disperse soils, but the primary benefit of clogging pores makes this difficult to evaluate.

Table 2 provides some assistance in converting from the Unified Soil Classification to one of the four permeability groups.

Table 2. ***Unified Classification versus Soil Group for permeability***

Unified Classification	Permeability Group I	II	III	IV
CH	N	N	S	U
MH	N	S	U	S
CL	N	S	U	S
ML	N	U	S	N
CG	N	S	U	S
CM	S	U	S	S
GW	A	N	N	N
SM	S	U	S	S
SC	N	S	U	S
SW	A	N	N	N
SP	A	N	N	N
GP	A	N	N	N
CL-ML	N	A	N	N

A = Always in this permeability group.
N = Never in this permeability group.
S = Sometimes in this permeability group.
U = Usually in this permeability group.

In situ soils with acceptable permeabilities

Natural soils that are classified in permeability Groups III or IV usually have inplace permeability rates that result in acceptable seepage looses. Introduction of manure will provide a further decrease in permeability rates. No special design measures are necessary when agricultural waste storage ponds or treatment lagoons are constructed in these soils, provided that a minimum thickness of at least 2 feet below the deepest excavation is maintained and sound construction procedures are utilized.

When to consider a liner

Listed below are five conditions that help determine when a designer should consider seepage reduction beyond that provided by the natural soil at the excavation boundary. This does not mean that these conditions always dictate a need for a liner. Specific site conditions may be such that risks are very slight. For example, the site may have a seasonal high water table, but minimal lateral water movement, and shallow ground water which is never used for human or animal consumption. A thin layer of soil over high quality rock is a much less risk than if the thin layer is over fractured or fissured rock. In these situations the designer may weigh the data and elect not to specify a liner. If local experience indicates that seepage is not a problem on a similar soil, a liner would not be needed; however, documentation to support this should be on file.

1. If a proposed site is located near a water well, spring, or other vulnerable water supply.

Distance directly affects the time of travel for a pollutant to move from the source area to a water supply. The greater the distance, the greater the opportunity for attenuation of the pollutant through filtering, decay, dilution, volatilization, and adsorption.

2. If the excavation boundary of a site is underlain by less than 2 feet of soil over bedrock.

Bedrock near the surface is often fractured or jointed because of weathering and stress relief. Many rural domestic and stock water wells are developed in fractured rock at a depth of less than 300 feet. Some rock types, such as limestone and gypsum, may have very wide, open solution channels caused by chemical action of the water. However, even hairline openings in rock can provide avenues for seepage to move downward and contaminate subsurface water supplies. Thus a site that is shallow to bedrock can pose a potential problem and merits the consideration of a liner.

3. If the excavation boundary of a site is underlain by soils in Group I.

Coarse grained soils with less than 20 percent fines generally have higher permeability rates and have the potential to allow the movement of polluted water rapidly. The soils are also deficient in adsorptive properties because of their lack of clay.

In areas where seepage reduction because of manure is a recognized technique, care should be exercised when Group I soils are encountered. If the clay content of the soil is less than 5 or 15 percent for ruminant or monogastric animal manure, respectively, manure may not provide adequate seepage reduction.

4. If the excavation boundary of a site is underlain by some soils in Group II or problem soils in Group III (flocculated clays)and Group IV (highly plastic clays that have a blocky structure).

Soils in Group II may or may not require a liner. Documentation through laboratory or field permeability testing or by other acceptable alternatives is advised. An acceptable alternative would be correlation to similar soils in the same geologic or physiographic areas for which test data is available. Certain loess soils have a very high vertical permeability rate because of their unique structure. Higher than normal permeability rates for flocculated clays and clays that have a blocky structure have been discussed. These are special cases, and most soils in Groups III, and IV will not need a liner.

Liners or blankets

Liners are relatively impervious barriers used to reduce seepage losses to an acceptable level. Soil, concrete, and geomembranes are materials commonly used for liners. When soil is used as a liner it is often called a "blanket" or "impervious blanket."

Concrete has both advantages and disadvantages for use as a liner. It will not flex to conform to settlement or shifting of the earth. In addition, some concrete aggregates may be susceptible to attack by the continued exposure to the chemicals contained in or generated by the animal wastes. Concrete does serve as an excellent floor from which to scrape solids, and provides a good base for supporting such equipment as tractors or loaders.

Geomembranes are the most impervious type of liner if they are designed and installed correctly. Extreme care must be exercised both during construction and operations to prevent puncture, tears, or overexposure to sunlight. Caution should be exercised when considering geomembranes because there is some question about their durability with time.

Soils that contain more than 15 percent clay make excellent material for liners, but the liners must be designed and installed correctly. Soil has an added benefit in that it provides an attenuation medium for the pollutants. Soil liners can often be constructed of some onsite soils using disking and compaction by farm equipment *(5)*. Even those onsite soils considered unsuitable can usually be treated with bentonite (Group I soils) or dispersants (Group III flocculated clays) to obtain a satisfactory soil liner. Additional guidance is provided in the Field Office Technical Guide, section IV, under the standard for pond sealing.

Design and construction of a compacted soil liner

A. Determination of specific discharge:

1. Given: $Q = k\,(h/d)\,A$ (Darcy's Law)

2. Where: Q = discharge (seepage)
   k = hydraulic conductivity (coefficient of permeability)
   h/d = hydraulic gradient
   h = maximum vertical distance measured from liquid level and the liner bottom. See figure 1 and Appendix C.
   d = depth of the soil liner
   A = cross-sectional area of flow

3. Rearrange terms:
   $Q/A = k\,(h/d)$ or
   $v = k\,(h/d)$

4. Where: v = specific discharge or seepage per unit area; v has the dimensions of velocity, (distance/time).

Specific discharge, with units of velocity, is a theoretical flow rate through the full cross-sectional area (composed of pores and solids). Actual flow moves only through the soil pores, the areas of which can be computed by multiplying the full cross-sectional area (A) by the porosity (n). A seepage front moves at the rate of specific discharge divided by porosity (v/n). In compacted liners, the porosity usually ranges from 0.3 to 0.5. This gives an average linear velocity of the seepage front approximately 2 to 3 times the specific discharge.

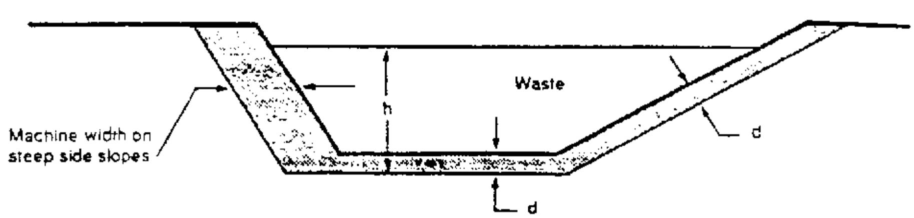

Figure 1. Schematic relationship of liner to hydraulic gradient

B. Recommended Design Limits

1. Allowable specific discharge; v equal to or less than 1×10^{-5} cm/sec. This is approximately 0.028 feet per day.

2. Allowable hydraulic gradient; *h/d* never greater than 8
3. Allowable soil liner depth; *d* never less than 1 foot

To meet the allowable specific discharge, the product of the hydraulic conductivity of a soil times the hydraulic gradient must be less than or equal to 1 x 10^{-5} cm/sec. At the maximum allowable hydraulic gradient of 8, the hydraulic conductivity of the liner must be less than or equal to 1.25 x 10^{-6} cm/sec (0.003 feet per day).

C. Hydraulic conductivity of soils

Generally, *k* values are less than 0.003 feet per day when the following soils are compacted at a water content equal to or greater than optimum, and at the following dry densities:

Group III and IV.............. 90% of Standard Proctor (obtainable with dozers)
Group II .... Requires documentation by laboratory or field permeability tests or other acceptable alternative.

The above statements are based on the results of several hundred constant and falling head permeability tests run at the Fort Worth and Lincoln Soil Mechanics Laboratories during the past 40 years on samples from throughout the United States and Caribbean Area ***(4)***, and do not consider the additional seepage reduction resulting from manure. The tests also included Standard Proctor Compaction, gradation, Atterberg limits, and the determination of the Unified Soil Classification ***(1)***.

The *k* value of 0.003 feet per day does not consider any seepage reduction due to manure. Using a very conservative assumption that manure will reduce the permeability rate by at least one order of magnitude, a resulting *k* of 1 x 10^{-7} cm/sec is certainly tenable.

The water content of a soil at the time of compaction has a significant influence on its hydraulic conductivity. A Group III soil compacted at a water content 2 or 3 percent below Standard Proctor optimum could have a permeability rate from 10 to 100 times greater than that for the same soil compacted at a water content wet of optimum, even though both are compacted to the same dry density.

To assure the most favorable hydraulic conductivity (least permeable), in situ soils should be disked to a depth of 6 inches and then compacted.

Horizontal hydraulic conductivity can be influenced by a lack of bonding between soil lifts. Good bonding can be achieved by proper water content and scarifying between lifts.

The maximum particle size allowed for any soil used as a liner is 6 inches. Oversize rock should be removed before compacting.

D. Detailed design sequence

The suggested steps and sequence for design of a compacted soil liner are:

1. Size the structure within the available construction limits and determine the height (*h*) needed to achieve the desired storage requirements.

2. Calculate a preliminary liner thickness (*d*) to meet the hydraulic gradient minimum of *d* equal to or greater than *h*/8.

3. If the liner thickness calculated in Step 2 is less than 1 foot, use 1 foot for the trial thickness (*d*) in step 4.

4. Calculate the allowable specific discharge, $v = k\ h/d$. Use $k = 0.003$ fpd when no permeability test data is available. If v is less than 0.028 fpd, the thickness (*d*) in Step 3 should be used if it is greater than 1. If v is greater than 0.028 fpd, then *d* must be increased or *h* decreased until the allowable specific discharge is less than 0.028 fpd.

Cautions

Soil liners may not provide adequate confidence in Karst areas. The designer of waste storage ponds and treatment lagoons located in these areas should consider the use of structural liners of reinforced geomembranes or concrete.

Nonstructural liners must be protected from such things as puncture from animal traffic, roots from trees and large shrubs, and maintenance equipment. Also, soil blankets must be protected from drying cracks during periods when the lagoon is empty because of cleaning or routine pumping. If a clay liner is allowed to dry excessively, it may develop drying cracks or a blocky structure and will then have a much higher permeability. This condition may require disking and compaction for correction

Additional factors to consider

1. When a soil liner is needed, suitable soil may not be available locally or may need to be treated using bentonite or a dispersant. Induced gleization also provides seepage reduction comparable to soil liners.

2. To obtain adequate compaction on steep slopes, overexcavation of the slopes may be required so that the soil liner can be installed in horizontal lifts to accommodate equipment widths. (See figure 1.)

3. Soil testing may be required for design. The Fort Worth Soil Mechanics Laboratory will do the testing at no cost. Allow 3 to 4 weeks for obtaining gradation and Atterberg limits and 6 to 8 weeks for permeability and sealing tests results. Samples for which only gradation analysis and Atterberg Limit data are required should be about the following size:

Estimated gravel content (%) (plus No. 4 (approx. 1/4") material)	Soil amount (lbs moist)
0-10	5
10-50	20
> 50	40

Samples for which gradation analysis, Atterberg Limit, and compaction and permeability testing are desired should be about the following size:

Estimated gravel content (%) (plus No. 4 (approx. 1/4") material)	Scil amount (lbs moist)
0-10	50
10-50	75
> 50	100

4. The installation of a soil liner may require some documentation of compaction and water content testing during construction.

Summary

1. Soil permeability reductions caused by manure in waste storage ponds and treatment lagoons are well documented, but may not be adequate in all instances.

2. Soils can be divided into one of four permeability groups based on their gradation and plasticity. Soils in Groups III and IV generally do not require a liner. Group I soils will generally require a liner. Soils in Group II will need permeability tests or other documentation to determine whether or not a liner is advisable.

3. Guidance is given on when to consider a liner.

4. Recommended limits for allowable specific discharge, hydraulic gradient, and minimum liner thickness are given.

5. Flexibility is built into the design process. The depth of the liquid and thickness of the soil liner can be varied to provide an acceptable specific discharge.

6. A method of documenting the design rationale for inclusion in the design file is provided.

7. A practical means for evaluating, in quantitative terms, the level of ground water protection that can be achieved with a soil liner is also provided.

8. Summaries of literature reviews and appraisals of applicable research are in appendix A.

9. Sample construction specifications are in appendix B.

The guidelines provided in this technical note result in a somewhat conservative, but reasonable level of protection to important ground water resources. This guidance covers an area where many uncertainties exist, but where the agency is sponsoring additional research. As the level of understanding increases, our guidelines and practice standards will be updated to reflect this state-of-the-art knowledge.

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Appendix A

Summary of Literature Appraisals

LITERATURE REVIEW
by G. Gangbazo, D. Cluis, and M. Vallieres

Modern farming methods and economic pressures have concentrated the larger dairy and hog farms in certain areas of Quebec. Because of their size, these farms generate very large quantities of manure, and the resulting cost of storage and spreading is significant.

It is known that hog and cattle manure contains soluble nutrients, the most important in terms of quantity being ammonia. When ambient conditions permit, ammonia is transformed into nitrates in the soil and water. Nitrogen in the form of ammonia or nitrates represents a serious risk to the environment. In effect, all countries have developed standards for these parameters (Simard and Des Rosiers, 1979; Gouin and Malo, 1977). During the last two decades, several studies have been carried out in different parts of the world to evaluate the risk of contamination of ground-water due to the storage of manure in earth storage tanks. The aim has been not only to understand the way in which the manure seals the tanks (self clogging property), but also to improve the construction guidelines designed to protect the ground-water around the tanks.

Nordsedt et al. (1971) studied the aquifer 15 m from a cattle manure tank situated on a clay soil. He found above normal nitrate concentrations in the aquifer at a depth of between 2.0 and 3.0 m. The tank had been in service for 8 months.

Miller et al. (1976) found that the concentrations of ammonia (NH4) at more than 1.40 m below two hog manure storage tanks was higher than that before their installation. The tanks were in operation for 8 years, one on a soil of medium texture and the other on a coarse soil.

Sewell et al. (1978) observed increasing concentrations of chlorides in the aquifer at a depth of 6 m and a distance of 5 to 15 m from a cattle manure storage tank. However, these concentrations returned to normal two months after the tank was put into service. The soil at the tank site was silty to sandy loam from 0 to 1.0 m and sandy from 1.0 to 4.0 m.

Ciravolo et al. (1979) studied the effect of three hog manure storage tanks of the quality of the adjacent aquifer. They concluded that soil texture has a large effect on the contamination of the aquifer: a fine textured soil reduces the risk of contamination compared to a coarse soil.

Barrington (1985) published the results of a study designed to determine the criteria for site selection and standards for the construction of earth-built manure storage tanks which would ensure the maximum protection of the environmental quality. As many other authors have, she found that the sealing of the soil pores was related to the pads of solid manure which accumulate at the soil-manure interface. This mechanism allows the soil to become almost instantaneously impermeable as long as the soil can retain the solid manure at its surface. The results of the study showed that this seal could be achieved even in soils as coarse as sand. Rates of infiltration as low as 3×10^{-6} cm/s were maintained over a period of 12 months under such conditions. In addition, this author suggested that the rates of infiltration obtained were relatively independent of the initial hydraulic conductivity at the site. Based on these results, she recommended the use of the effective diameter of the soil voids as the main criteria for the selection of sites for the construction of earth-built manure storage tanks. The maximum diameter for such sites should be 2.0 microns for cattle manure and 0.5 microns for hog manure storage tanks.

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LITERATURE REVIEW OF SEALING MECHANISMS
by S. Barrington and R. Broughton

The mechanisms of soil sealing by manure have been categorized into three distinct groups: physical, biological and chemical. The physical mechanisms of clogging soil pores by manure solids have generally been considered predominant. Nevertheless, the relative strength and origin of each of the three mechanisms was not investigated until the late 1070s.

De Tar (1979) observed the infiltration of dairy manure of various total solids content (TS) into clays and sandy loams. He demonstrated that the slurry TS was the primary factor controlling the long-term seepage rate and that the soil's steady state infiltration rate with water was much less significant. Rowsell (1980) used laboratory columns to measure infiltration rates of natural and sterilized screened feedlot runoff into soils of various textures. As a main sealing mechanism, he suggested the formation at the soil surface of an impermeable layer of manure solids. Rowsell et al. (1985) confirmed this by examining the sealed surface under microscope and finding solids lodged between the soil particles.

Barrington et al. (1987a,b) investigated separately the physical, biological and chemical sealing mechanisms and found the first process to be predominant. Biological and chemical mechanisms were found to intervene, under ambient temperatures exceeding 10°C, to strengthen the physical clogging rather than to create a new seal. Through the use of piezometers, they also demonstrated that the sealing layers were at the organic solid mat above the soil surface and at the manure-soil interface. This suggests that the soil acts basically as a screen holding at its surface the manure solids forming the seal. The finer the diameter of the soil pores with respect to manure solids, the more extensive the sealing process. Barrington et al. (1987a,b) found little correlation between the soil's k value and the extent of the sealing process. Finally, they demonstrated that the low volumes of manure liquids seeping into the soil are highly contaminated and can result in groundwater contamination if the soil is of low cation exchange capacity (CEC).

These findings suggest the use of soil pore diameters rather than soil k values as design criteria for earthen storage facilities.

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LITERATURE APPRAISAL
by John Sweeten

Seepage from livestock waste treatment lagoons and runoff holding ponds has been studied by researchers for at least two decades. In essence, it has been determined that bacterial cells and fine organic matter generally clog soil pore spaces along the bottom and sides of lagoons and holding ponds (Barrington and Jutras, 1985) making them effectively "self-sealing" (Davis et al., 1973).

After several months of storage, coefficients of permeability of the bottom soil in ponds storing liquid manure, wastewater and runoff from livestock operations have usually been from one to three orders of magnitude lower (i.e. 10 to 1000 times) for wastewater than for clean water, as indicated in Figure 2(Robinson, 1973; Lehman and Clark, 1975; Barrington and Jutras, 1983). When the soil bottom and sides of manure storage ponds and lagoons have a moderate to fine-textured soil (such as silt clay loam or clay), the final permeability coefficient is usually of the order of magnitude of 10^{-6} to 10^{-7} centimeters per second (cm/sec), or 0.0014 inches per hour (in/hr), respectively (Barrington and Jutras, 1985). However, final permeabilities of a sand usually exceed 10^{-6} cm/sec (0.0014 in/hr) (Dye et al., 1984). Cattle manure has generally shown better self-sealing properties than swine manure (Barrington and Jutras, 1985).

Livestock manure and wastewater provide significant beneficial self-sealing on the bottom and sides of lagoons and holding ponds. However, some regulating agencies feel this phenomenon should not be counted on as the sole means of groundwater protection, and that lagoons should also be placed in relatively impermeable subsoils (Dye et al., 1984).

Many feedlots in Texas are built on playa lakes, which have a clay bottom (Randall clay) of several feet that is underlain by much more permeable soil material (of Pleistocene origin) resembling caliche. Lehman and Clark (1975) determined that undisturbed cores of the clay surface soil in playas had permeability values with clear water of 2.8×10^{-5} cm/sec (0.04 in/hr), as compared to 1.1×10^{-3} cm/sec (1.6 in/hr) for the buried Pleistocene materials. However, the addition of feedyard runoff reduced permeabilities within 45 days to only 8.3×10^{-4} in/hr (5.6×10^{-7} cm/sec) through the Randall clay after 10 days and 0.0025 in/hr (1.7×10^{-6} cm/sec) for the underlying buried soil.

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LITERATURE REVIEW
by David Brune

The use of lagoons as a treatment technique for managing animal waste has become a widespread and common practice, primarily because it is an economical means of treating highly concentrated wastes from confined livestock operations. In the late 1960's, considerable attention was paid to the impact of lagoons on surface water quality; since the mid 1070s that attention has shifted to the potential impacts on groundwater quality.

Sewell (1) found in his studies on an anaerobic dairy lagoon that the lagoon bottom seals within two months of start up, and little or no pollutants were found in the groundwater after this time. Ritter (2) studied a two-stage anaerobic swine lagoon for four years and determined that the contaminant concentration increased in wells (50 m from the lagoon) the first year and then steadily decreased afterwards. His data lead him to speculate that biological sealing takes place over a period of time depending on the loading rate to a lagoon. Collins (3) studied three swine lagoons, each within a high water table area. He found that there was no significant effect on groundwater beyond 3 m from the lagoon edge. Miller (4) studied the performance of beef lagoons in sandy soil and found that the lagoons had effectively sealed to infiltration within 12 weeks of addition of manure. Humenik (5) summarized research conducted by others on the subject on lagoon sealing, and he concluded that the studies indicated that lagoon sealing may be expected within about six months after which the area of seepage impact becomes restricted to approximately 10 m.

On the other hand, Hegg (6-7) collected data from a dairy lagoon and from newly established swine lagoons and found that some of the monitoring wells became contaminated while others did not. This led him to conclude that seepage does not occur uniformly over the entire wetted perimeter of the lagoon, but at specific unpredictable sites where sealing has not taken place. Similarly Ritter (8) monitored an anaerobic two-stage swine lagoon for two years, and found that one of the wells showed contamination which indicated localized seepage, while the other monitoring well indicated the lagoon system produced a minimum impact on groundwater quality and that sealing had gradually taken place.

Geraght (9) presented a general discussion on how contaminated groundwater moves in plumes and how the plumes can be controlled. His presentation outlined work dealing with the soil water interface in the lagoon and core sampling techniques and work in which soil columns were used to simulate lagoon conditions. Chang (10) concluded that there are two mechanisms that cause sealing. The primary mechanism is the trapping of suspended matter in the soil pores which physically cause clogging. The secondary mechanism is caused by microbial growth which produces by-products that bind the soil particles together. Allison (11) noticed a correlation between polyuronide (a polysaccharide produced by most microorganisms in the sand under a pond and the extent of clogging. Additionally, in laboratory studies McCalla (12, 13) found that very little clogging occurred when microorganisms were not present at high numbers. He also found that as microorganisms act upon organic matter in the soil they tend to stabilize soil structure units.

Unfortunately, however, some isolated area in lagoon do not seal, resulting in a pollutant plume which can contaminate groundwater down gradient from the lagoon. The nature of these "non-sealing events" is sporadic and unpredictable. Most of the literature tends to agree that, in general, animal waste lagoons tend to self-seal within 6 months to one year depending on loading rates and soil conditions. The sealing mechanism seems to be both physical and biological. The suspended particles in the lagoon water filter out in the soil pores clogging them. The biological action of the microorganisms produce by-products (polysaccharides) which aggregate the soil and bind it together.

The problem remains that lagoons have the unpredictable potential to affect both groundwater and surface water. Because of the sporadic and site specific nature of such leakage, it is not possible to draw conclusions about the degree of hazard to groundwater without surveying a large number of lagoons. Given the non-uniformity of lagoon seepage, it is important that the technique used to study the lagoons involve a global or areal sensing of the groundwater, as opposed to a localized or point sampling technique as represented in the standard practice of installing monitoring wells.

The techniques which have been used in the past, and other techniques which appear to offer promise include:

A) Passive Areal Techniques

1) ground penetrating radar
2) electromagnetic survey

B) Interactive Areal Techniques

1) surface resistivity
2) downhole resistivity
3) tracers
4) water balance

C) Interactive Point Techniques

1) boreholes
2) seepage meters
3) water mounding

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Appendix B

Sample Construction Specifications

CONSTRUCTION SPECIFICATION
FOR
WASTE TREATMENT LAGOONS (359)
&
WASTE STORAGE PONDS (425)

Foundation preparation

The foundation area shall be cleared of trees, logs, stumps, roots, brush, boulders, sod and rubbish. The topsoil and sod are to be stockpiled. After stripping, the foundation area will be prepared to assure a bond with the fill by removing loose dry material, scarifying, disking, adjusting water content, and compacting as necessary.

Cutoff trench

A cutoff trench under the embankment area shall be constructed when shown on the construction drawing. Final depth of cutoff trench shall be determined by observation of the foundation materials. Sand, gravel, and other more permeable materials shall be removed to prevent leakage under the embankment.

Excavation

The completed excavation for the storage area shall conform to the lines, grades, and elevations shown on the plans or as staked in the field.

Fill placement

The material placed in the fill shall be free of detrimental amounts of sod, roots, frozen soil, stones over 6 inches in diameter, and other objectional material. To the extent they are suitable, excavated materials are to be used as fill. The distribution and gradation of materials shall be such that there will be no lenses, pockets, streaks, or layers of material differing substantially in texture or gradation from the surrounding material.

The fill shall be brought up in approximately horizontal layers not to exceed 9 inches in thickness when loose and prior to compaction. Each layer will be compacted by complete coverage with the hauling and spreading equipment or two passes of standard tamping roller, or other equivalent method approved by the engineer. Compaction will be considered adequate when fill material is observed to consolidate to the point that settlement is not readily detectible.

Placement of topsoil

Available topsoil should be placed on the top and the exposed slopes of the lagoon embankment.

Water control

The minimum water content of the fill material and foundation shall be such that, when kneaded in the hand, the fill material will form a ball that does not readily separate. The

CONSTRUCTION SPECIFICATION
FOR A SOIL LINER
FOR
WASTE TREATMENT LAGOONS (359)
&
WASTE STORAGE PONDS (425)

Scope

This specification covers the lining of these facilities with a designated soil material at the time of initial installation, or as repair or remedial work.

Foundation preparation

The fou: 'ation area shall be cleared of trees, logs :tumps, roots, brush, boulders, sod and rubbish. When a liner is being installed after the facility has been in use, care should be taken to remove sludge and sediments down to the original soil material. Foundation preparation must also extend deep enough to eliminate any effects from drying that may have occurred during previous operations. The topsoil and sod are to be stockpiled. After stripping, the foundation area will be prepared to assure a bond with the fill by removing loose dry material, scarifying, disking, adjusting moisture, and compacting.

Liner placement

The material placed in the fill shall be free of detrimental amounts of sod, roots, frozen soil, stones over 6 inches in diameter, and other objectionable material. The materials will be from those designated borrow areas. The distribution and gradation of materials shall be such that there will be no lenses, pockets, streaks, or layers of material differing substantially in texture or gradation from the surrounding material.

The fill shall be brought up in approximately horizontal layers not to exceed 9 inches in thickness prior to compaction. Each layer will be compacted by a minimum of complete coverage with the hauling and spreading equipment or two passes of standard tamping roller, or other equivalent methods approved by the engineer. Compaction will be considered adequate when fill material is consolidated to the point that settlement is not readily detectable.

Water content control

The minimum water content of the liner material and foundation shall be the optimum water content that relates to the specified dry density or such that, when kneaded in the hand, the fill material will form a ball which does not readily separate. The maximum water content is when soil compaction efforts do not properly consolidate the soil, or when conditions are too wet for efficient use of the hauling and compaction equipment.

Installation

Installation shall be conducted in a skillful and workmanlike manner. Extreme caution must be exercised in backfill and compaction around structures or conduits to prevent damage, movement or deflection. A consistent homogeneous fill is necessary. The installation shall be done with proper moisture content and with adequate mixing of the soil materials to accomplish this.

General

Construction operations shall be carried out in such a manner and sequence that erosion and air and water pollution will be minimized and held within legal limits.

The completed job shall present a workmanlike appearance and shall conform to the line, grades and elevation shown on the drawings or as staked in the field.

All operations shall be carried out in a safe and skillful manner. Safety and health regulations shall be observed and appropriate safety measures used.

Appendix C

Calculation of Hydraulic Gradient

Appendix C

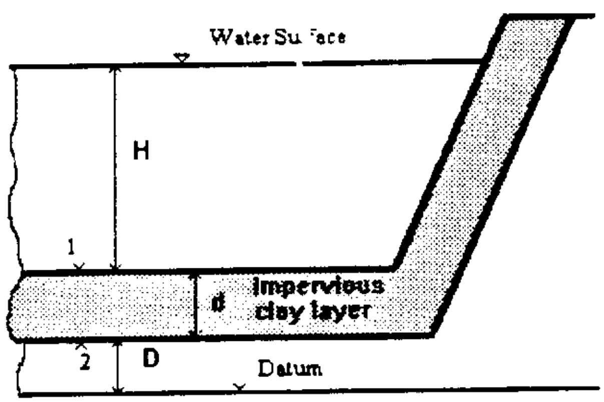
Illustration for Calculation of Hydraulic Gradient for Compacted Liner

From drawing below, define terms as follows:

H = Head of water in lagoon

d = Thickness of liner

D = Distance from datum to bottom of liner



To determine the hydraulic gradient across the clay layer:

Hydraulic gradient is defined as the energy loss across the layer, or between points 1 and 2 on the drawing.

E = Total engery head = Pressure head + Elevation head + Velocity head

At point 1 $\quad E = H + (d + D) + 0$
At point 2 $\quad E = 0 + D + 0$

The difference then,
$= H + d$ or h (see figure 1)

Therefore the hydraulic gradient is the energy loss (H + d), divided by the length of the flow path, d

$$i = (H + d)/d \text{ or } h/d$$

Appendix D

Statistical Data for Group Permeabilities

Appendix D

Statistical Data for Group Permeabilities

As a result of doubling the size of our database since Technical Note 716 was issued in 1990, the statistical results for each Group were re-evaluated.

Histograms for Group I, II, III, and IV soils compacted to various percentages of their ASTM D698 dry densities are shown in Figures 1-6. The ordinate scale for the histograms is the number of observations and the abscissa scale is $\log_{10}$ of the permeability rate in cm/sec. The log scale was selected due to the scalar effects caused by the wide variations in permeability encountered. Representative data are shown in Table 1. Mean values were deemed to be more representative than average values since the data does not fit a normal distribution pattern.

Table 1 - Median permeabilities by group and percent compaction[1]

Soil Group	Percent of ASTM D698 Dry Density	Number of Observation	Median K (cm/sec)	Median K (fpd)
I	All	32	6.6×10^{-4}	1.9×10^{0}
II	90	37	1.8×10^{-6}	5.0×10^{-3}
II	95	27	1.2×10^{-6}	3.5×10^{-3}
III	85	20	3.5×10^{-6}	1.0×10^{-3}
III	90	101	6.5×10^{-7}	1.8×10^{-3}
IV	85	----[2]	----	----
IV	90	17	4.0×10^{-7}	1.1×10^{-3}

1 Data from actual laboratory permeability tests made by the Soil Conservation Services Laboratories in Fort Worth, TX and Lincoln, NE.

2 Insufficient number of observations to calculate meaningful statistical relationships.

The Group II soils had a median permeability of 1.8×10^{-6} cm/sec when compacted to 90% of their maximum ASTM D698 dry unit weight. The median permeability for these soil decreased to 1.2×10^{-6} cm/sec when compacted to 95% of their maximum ASTM D698 dry unit weight. However, almost half (14 out of 27) of the observations were greater than the acceptable value of 1.25×10^{-6} cm/sec.

The Group III soils had a median permeability of 6.5×10^{-7} cm/sec when compacted to 90% of their maximum D698A dry unit weight. Approximately 75% (74 out of 101) of the observations in this Group were less than 1.25×10^{-6} cm/sec. For the same degree of compaction, the Group IV soils had a median permeability rate 4×10^{-7} cm/sec.

Figure 1- Histogram of Log_{10} Permeability (cm/sec) for Group 1 Soils at All Densities

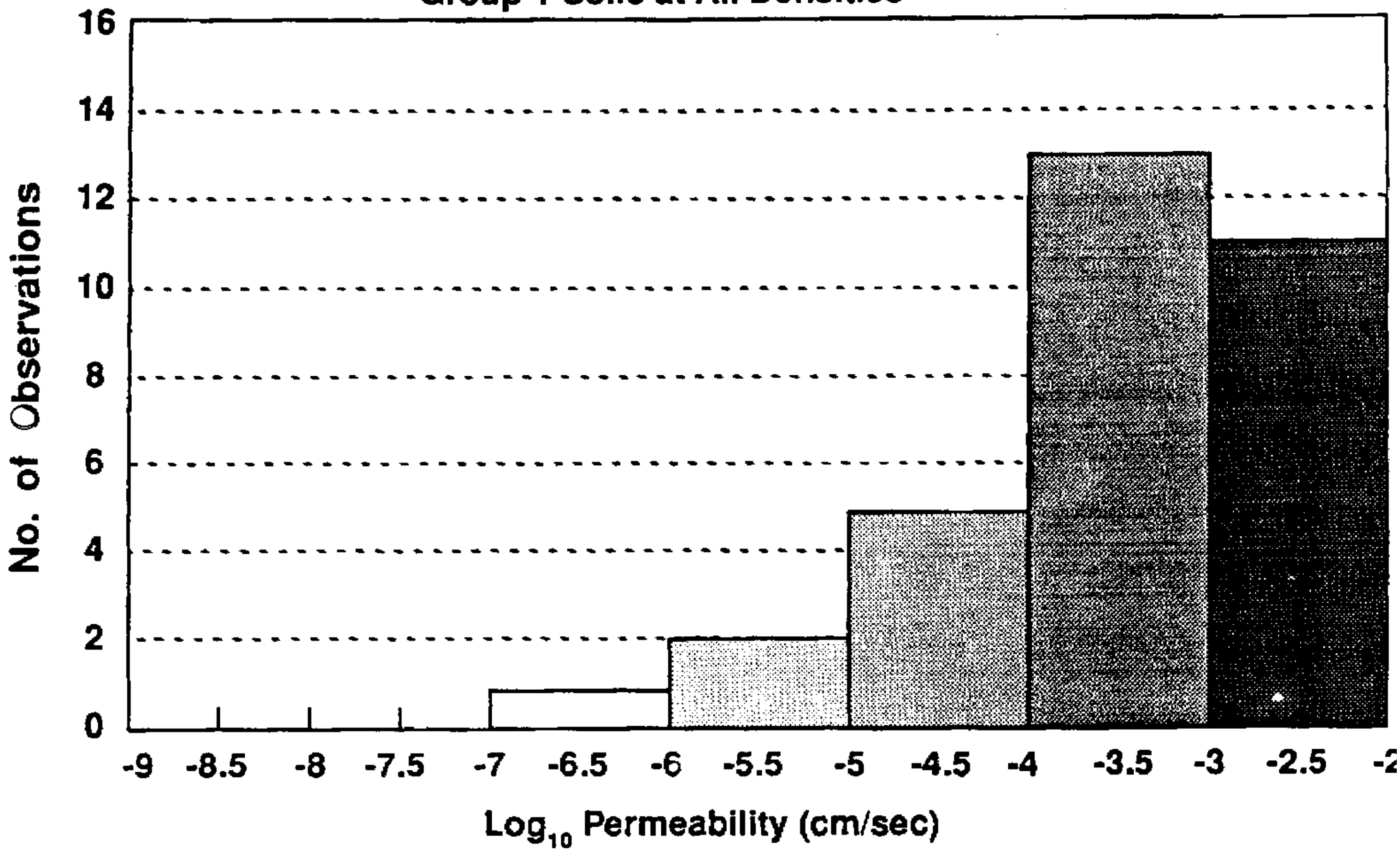


Figure 2 - Histogram of Log_{10} Permeability (cm/sec) for Group 2 Soils at 90 percent Maximum Density

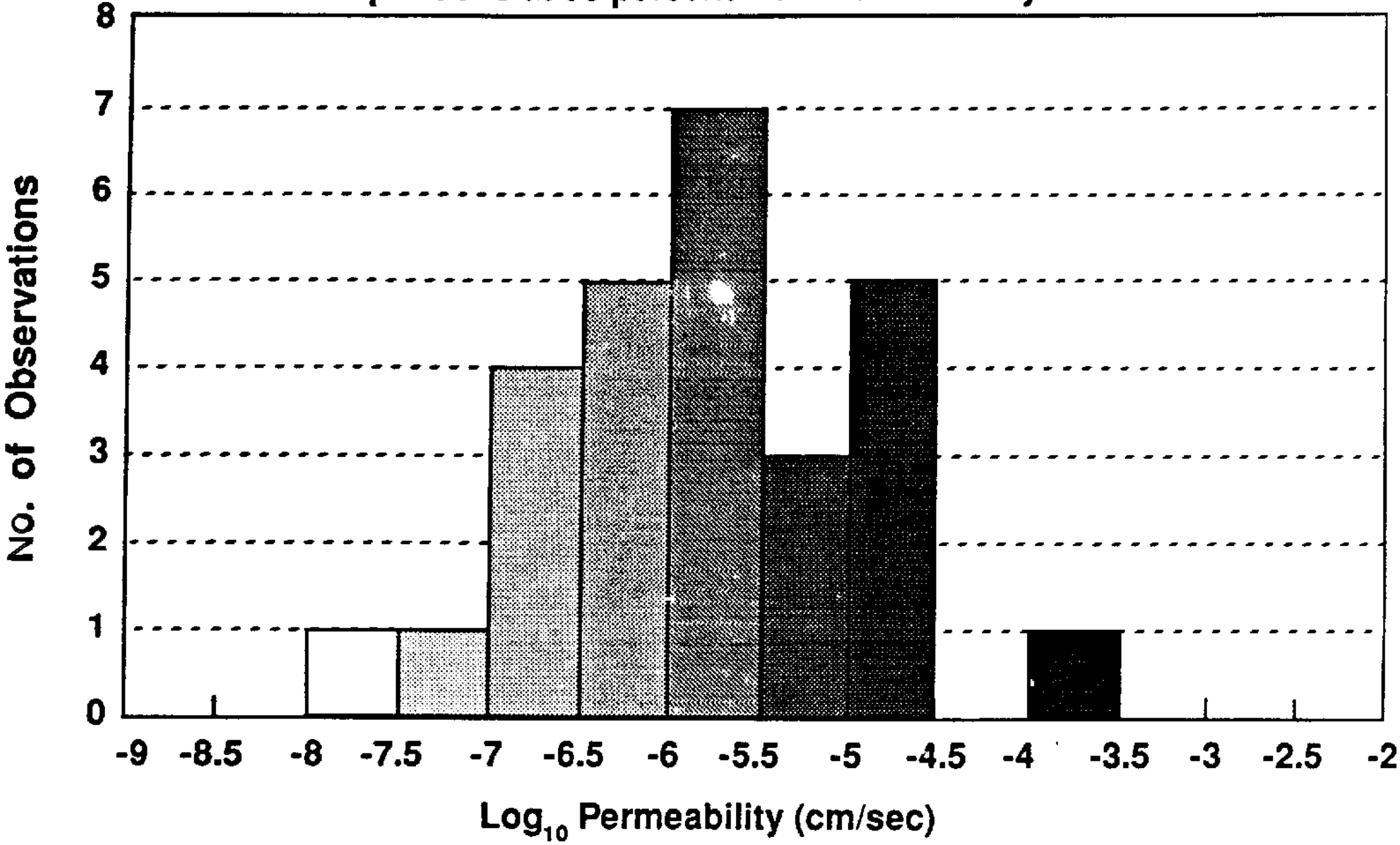


Figure 3 - Histogram of Log_{10} Permeability (cm/sec) for Group 2 Soils at 95 percent Maximum Density

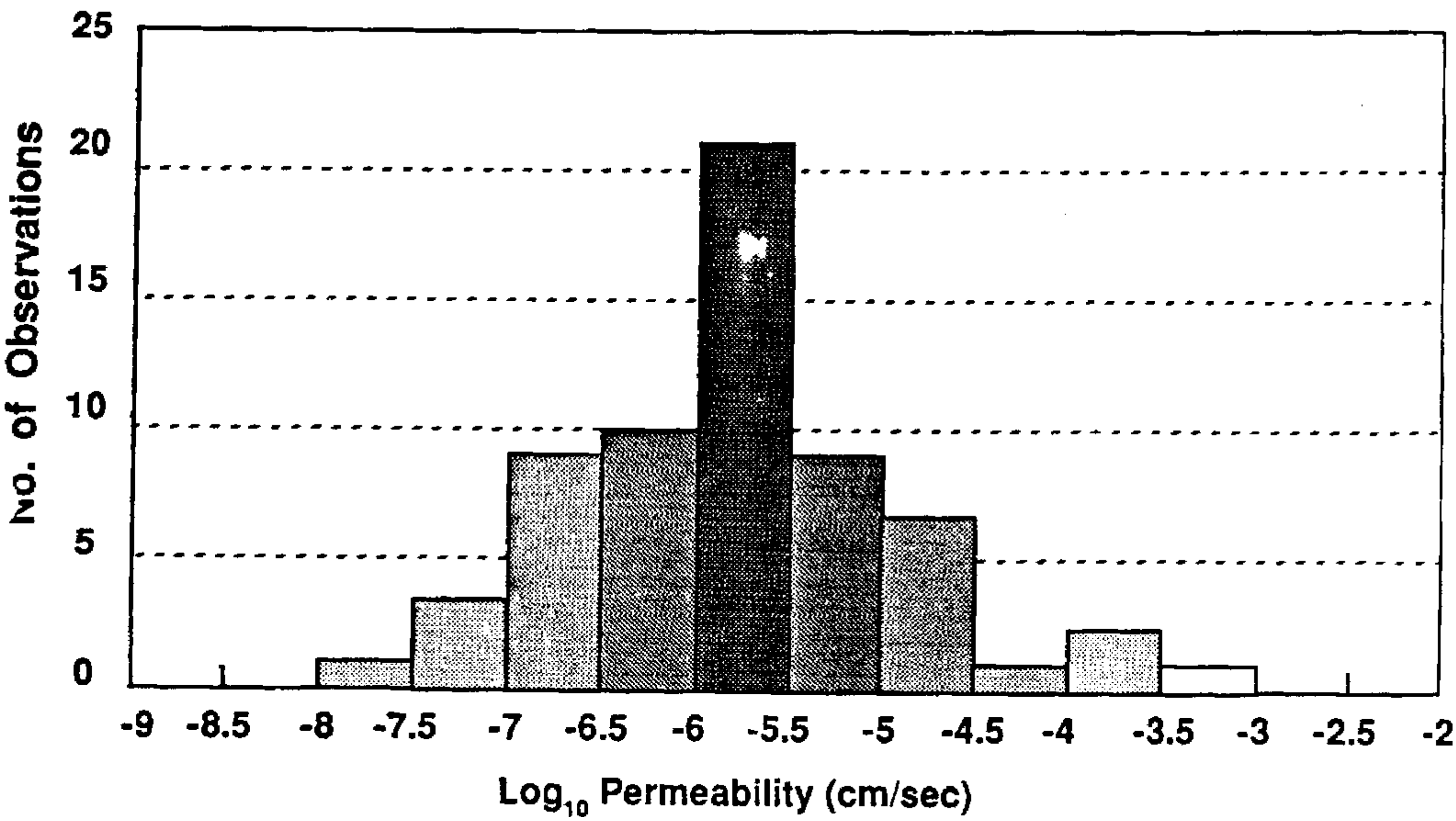


Figure 4 - Histogram of Log_{10} Permeability (cm/sec) for Group 3 Soils at 90 percent Maximum Density

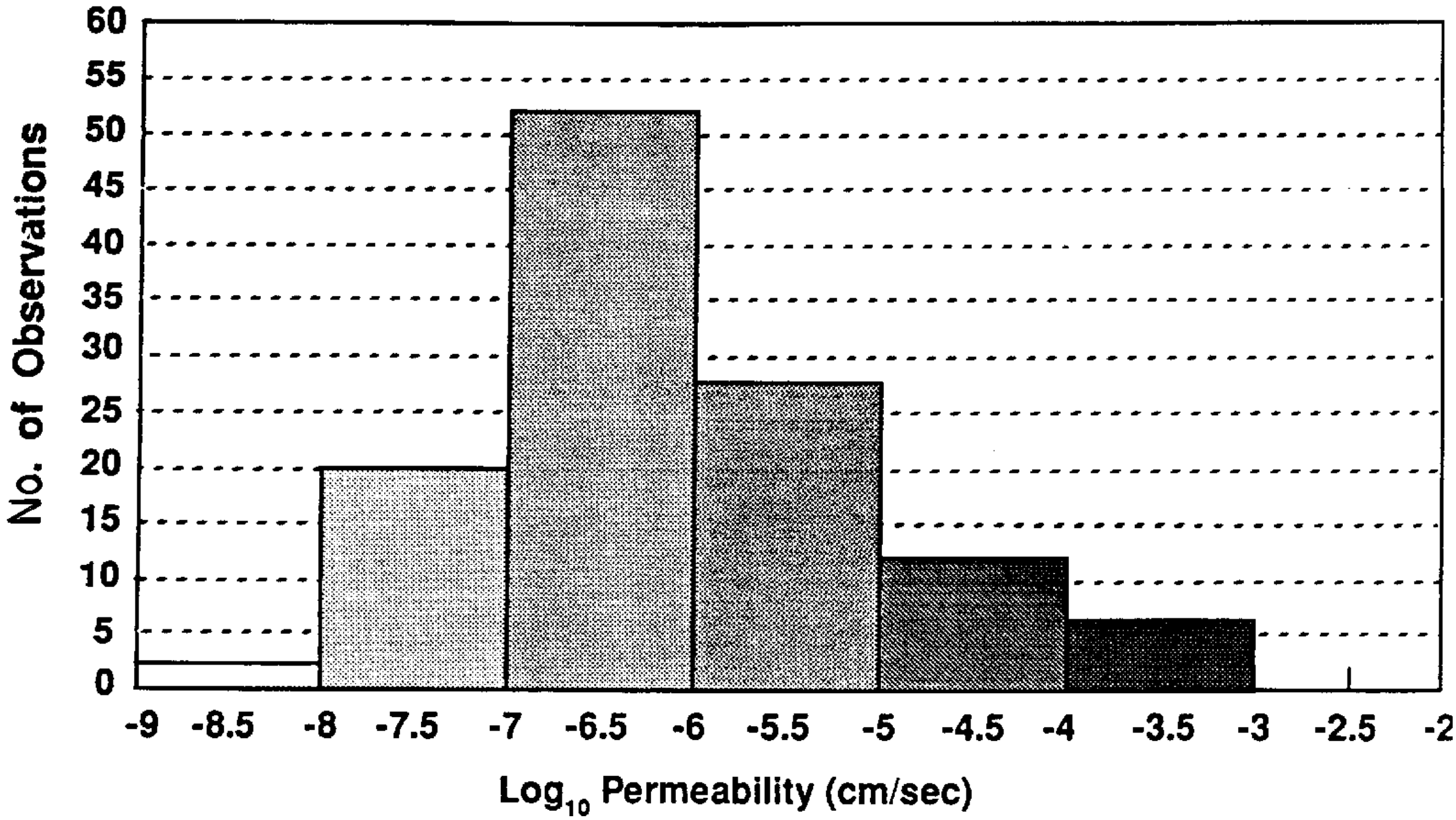


Figure 5 - Histogram of Log_{10} Permeability (cm/sec) for Group 3 Soils at 85 percent Maximum Density

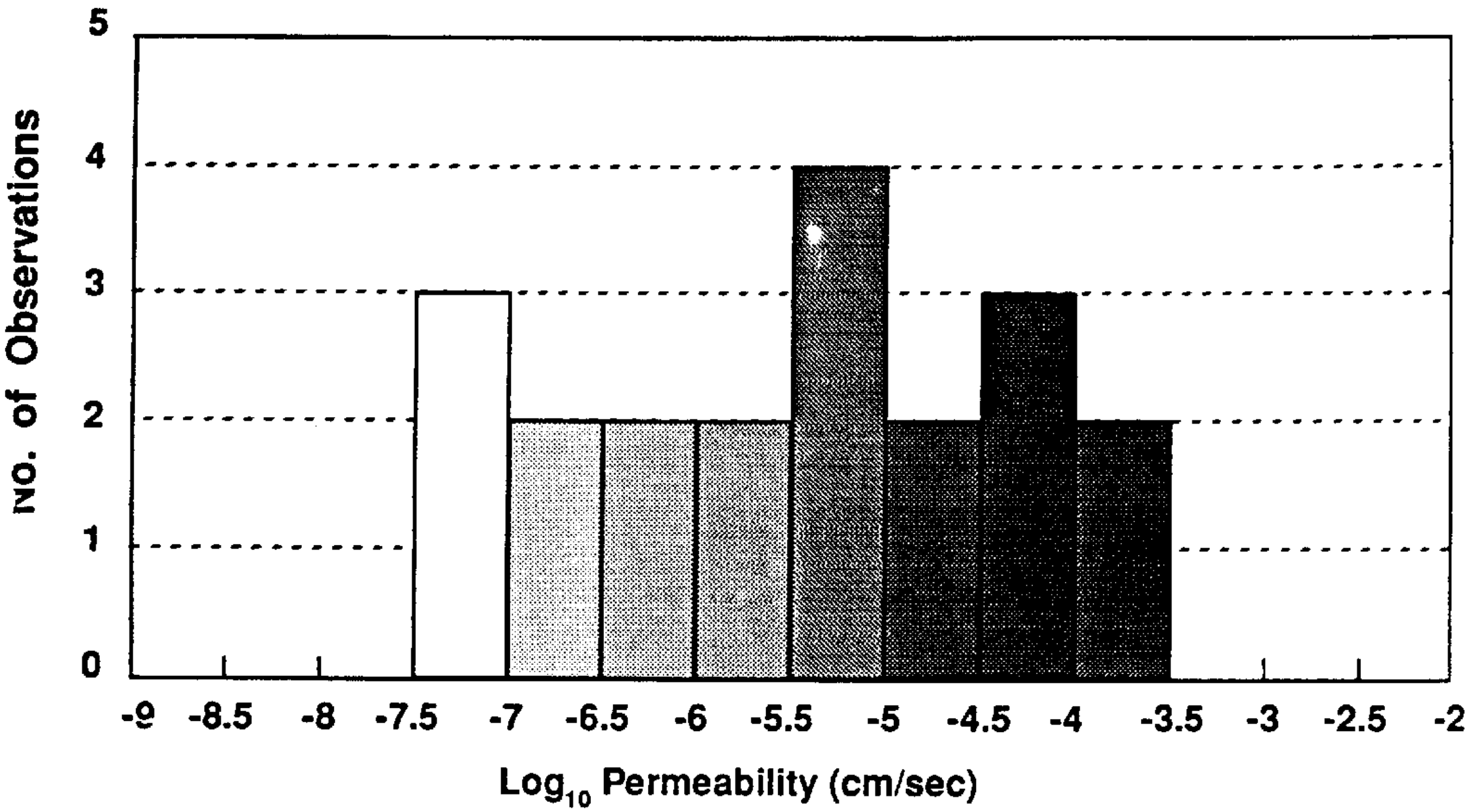


Figure 6 - Histogram of Log_{10} Permeability (cm/sec) for Group 4 Soils at 90 percent Maximum Density