Soils Considerations for Earthen Impoundments

Many natural soils will tend to partly seal due to manure solids plugging pore spaces between soil particles. Chemicals (salts) in manure tend to disperse soil particles, which reduces permeability. Soil structure may be altered by biological processes as manure is degraded. Although manure does provide some sealing in most soils, this effect should not be expected to provide sufficient sealing to protect groundwater or to attain a target permeability rate by itself. The allowable seepage rate for waste storage impoundments is regulated in most states. A soil permeability coefficient of 10^{-7} cm/s (1.25 inches/year) is commonly used in state regulations. Many technical considerations are necessary for a complete evaluation of a soil material for earthen manure storage impoundments. The NRCS, through extensive laboratory research and field experience, has developed standards and recommendations for earthen storage impoundments. The following discussion outlines some of these standards and recommendations.

Seepage, permeability, Darcy's law

Darcy's law is the primary model used to design and evaluate the effectiveness of liners in earthen manure storage facilities. Darcy's law relates the amount of seepage expected to occur to particular soil characteristics (permeability), liner thickness, and depth of manure in the impoundment. In simple terms, Darcy's law can be described as follows:

$$v = k(H + d)/d$$

v = Amount of seepage through unit area of liner
k = Permeability coefficient of soil liner (often required to be 10^{-7} cm/s)
H = Depth of manure in impoundment
d = Thickness of liner

As can be seen in the above equation, increasing the liquid depth (H) increases the amount of seepage (v) through the liner. Conversely, increasing liner thickness (d) decreases the amount of seepage through the liner. A larger permeability coefficient (k) results in greater seepage, while a smaller (k) reduces seepage. The permeability coefficient depends on the particular characteristics of the soil material used for the liner. Soils in Group I (see next section) generally have a high permeability coefficient, while soils in Group IV have a low permeability coefficient. The permeability coefficient can often be modified (reduced), if needed, by adjusting soil moisture, increasing compaction, and/or adding an amendment such as bentonite or soda ash to the soil liner.

In using Darcy's law to design a liner for a manure storage structure, the engineer will usually assume an acceptable seepage (v), and the depth of liquid in the impoundment is known or assumed from other design and site conditions. A value of (k) is determined by analysis of the soil to be used for the liner. This analysis is usually performed by a qualified soil scientist, and in some cases, may be performed in a more detailed manner by a soil mechanics laboratory. The engineer then uses this information to calculate a minimum liner thickness to achieve the acceptable seepage rate.

Manure impoundment liners constructed of soil may be tested after

Required liner thickness depends on acceptable seepage rate, soil permeability characteristics, and manure depth according to Darcy's Law.

construction to ensure that the design goals are achieved. A core sample of the constructed liner can be removed and tested for permeability by a qualified soils laboratory. Alternatively, "in-place" tests may be used as an indicator of the permeability rate of the completed liner. In-place tests commonly include one of the following:

- Drive cylinder
- Sand cone
- Rubber balloon
- Nuclear density
- Barrel

The first three tests involve removing a precisely measured volume of soil from the liner and determining its in-place density. This density is an indicator of the degree of compaction and attainment of the acceptable seepage rate based on liner design and construction practices. The nuclear density test utilizes radioactive methods to determine in-place density. No soil is removed from the liner, although a probe is inserted into the liner to perform the test. The nuclear density test is more convenient to perform than the test involving removal of a volume of soil from the liner. The barrel test is a water-balance test in which the impoundment is filled with water and a barrel filled with water is placed within the impoundment. Water levels in the impoundment and barrel are closely monitored to determine if excess seepage is occurring. An advantage of the barrel test is that it is a direct measurement of seepage. Disadvantages include the requirement that the impoundment be filled to run the test. Additionally, climatic conditions such as high temperatures (evaporation effects) and rainfall/runoff can complicate the water balance. Also, the barrel test may require a relatively long period (30 days or more) to obtain meaningful data.

Group I and II soils may not have enough clay for a suitable liner, while Group III and IV soils can usually attain the target permeability rate with proper construction practices.

Soil permeability groups

The NRCS groups soils into four categories according to the permeability of the particular soil. Table 23-1 shows the four permeability groups and the particle size characteristics of each group. Group I soils (most often

Table 23-1. Grouping of soils according to their estimated permeability.

Group	Description	Potential for Constructing a Liner
I	Soils that have less than 20% passing a no. 200 sieve and have a plasticity index (PI) less than 5.	Poor
II	Soils that have 20% or more passing a no. 200 sieve and have PI less than or equal to 15. Also included in this group are soils with less than 20% passing the no. 200 sieve with fines having a PI of 5 or greater.	Poor to fair. May be possible to construct a liner with special practices.
III	Soils that have 20% or more passing a no. 200 sieve and have PI of 16 to 30.	Fair to good with a few possible exceptions. May require some special construction practices.
IV	Soils that have 20% or more passing a no. 200 sieve and have a PI of more than 30.	Good, with a few possible exceptions.

associated with sands) have high permeability and may not attain the target permeability rate, even with the sealing effects of manure. Group II soils (most often associated with silt loams) are less permeable than Group I but do not have sufficient clay content to be classed with Group III. Group III soils have low permeability, and with a few exceptions, can attain the target permeability rate. Group IV soils are the least permeable and can usually easily attain the target permeability rate. However, their blocky and fissured structure can result in cracks if allowed to dry. Seek the assistance of a qualified individual to classify a particular soil into the proper soil permeability group. The county soil survey reports available from NRCS can provide general information on the suitability of soils for earthen manure impoundments (see activity at the end of this lesson).

Most soils in Groups III and IV will attain a permeability of 10^{-6} cm/s or less with proper construction practices. The sealing effect of manure will typically further decrease permeability at least one order of magnitude (to 10^{-7} cm/s), which is acceptable in most cases.

Soil tests and specifications

Some states may require certain tests for soils used in liner construction for earthen impoundments. These tests may provide the regulatory agency with information deemed necessary in issuing permits or other documentation verifying that adequate facilities will be constructed. Table 23A-2 in Appendix A contains shows some of the soil tests commonly used in constructing earthen liners.

The tests and analyses described in this table may or may not be required in your state. Contact your regulatory agency or a qualified professional for assistance in determining what tests and analyses are required. The tests should be performed by a qualified soil laboratory so that the results are acceptable to the regulatory agency.

Some states have certain specifications for soils to qualify as liner material. Table 23-2 lists some specifications commonly used for accepting a soil as a liner material.

All, some, or none of the tests and specifications described in the tables may be required by your state regulatory agency. Regardless of regulatory requirements, these tests and specifications represent good practice in the design of earthen manure impoundments, and consideration should be given to performing at least some of these tests to ensure that water quality will be protected. If questions, controversy, or litigation arises concerning the integrity of a manure storage structure, a documented record of these tests can be valuable in demonstrating that proper design and construction practices were followed.

Plasticity index, Proctor density, permeability coefficient, particle size analysis, and Unified Soil Class are characteristics and specifications often used in determining a soil's suitability as a liner.

Table 23-2. Some specifications commonly used to qualify soils as acceptable liner materials.

Specification	Required in my State	
Soil classified as CS, CL, CH, GC, or SC according to the Unified Soil Classification System	__Yes	__No
More than 50% of soil particles pass through a no. 200 sieve	__Yes	__No
Liquid Limit greater than or equal to 30	__Yes	__No
Plasticity Index greater than or equal to 20	__Yes	__No
Coefficient of permeability less than or equal to 10^{-7} cm/sec when compacted to 90% of Proctor density	__Yes	__No
Minimum liner thickness of 12 inches	__Yes	__No

For earthen manure impoundments, the presence of shallow groundwater, fractured bedrock, or excessively porous soils may dictate that a liner be constructed.

Clay liners constructed with suitable clay soils are the most common method of providing reduced seepage in earthen impoundments.

Evaluation of the soil profile for earthen impoundments

The attainment of a target permeability rate requires a careful evaluation of the soil material available at the construction site. The natural soil at the excavated boundary of an earthen impoundment may possess suitable properties that will provide adequate sealing or may require some processing or amendment to provide adequate sealing. The following conditions suggest the need to consider potential seepage reduction through implementation of an impoundment liner:

- An underlying aquifer is at a shallow depth and not confined, or the aquifer is a water supply via a well or spring.
- The excavation boundary of the impoundment is underlain by less than 2 ft of soil over bedrock. Bedrock near the surface is often fractured or jointed, and these openings can provide nearly direct conveyance of pollutants to groundwater. Even soil liners may not be adequate to ensure against seepage in extreme cases of fractured bedrock. Some types of bedrock (low permeability, structurally sound) may not pose a seepage hazard, but these characteristics may be difficult to determine.
- The excavation boundary is underlain by soils in Group I. The sealing effect of manure will likely not be sufficient for soils in Group I, and a liner should be used.
- The excavation boundary is underlain by some soils in Group II or problem soils in Groups III or IV. Group II soils may or may not require a liner. Testing of the soil or correlation with performance at other sites in the area can determine the need for a liner. Excessively flocculated, blocky, and highly plastic clay soils in Groups III and IV may require a liner. Often a liner may be constructed by treating a determined thickness of undesirable soils occurring at the excavation boundary.

Some states may require the construction of a liner of specified thickness and permeability regardless of the profile conditions noted above.

Clay liners. Compacted clay liners are the most common method of providing seepage reduction and ensuring that a target permeability rate is attained in earthen impoundments. Such liners can often be developed using the soils existing at the excavated grade. The thickness of a compacted clay liner is determined based on the permeability of the soil material and the hydraulic pressure (head) of water in the impoundment. Often, a minimum thickness of 1 ft is recommended for clay liners.

Since a clay liner represents a seepage barrier of only finite thickness, consideration must be given to conditions and practices that might cause this thickness to be compromised.

1. Underlying soil. The underlying soil must be capable of supporting the liner without piping, or movement of the liner material into the soil below. This condition can occur if underlying material is very coarse, such as poorly graded gravels or sand.
2. Mechanical damage. Clay liners in manure impoundments must be protected against possible damage by agitation of the manure, excessive velocities at inlet pipes, or other practices that might compromise the integrity of the seal.
3. Collapse potential. In extreme cases (karst, sinkhole regions), bedrock fractures may be large enough to allow the overlying soil to collapse

when sufficient hydraulic pressure is applied, as might be the case with a manure impoundment. This represents, perhaps, the most hazardous possibility for groundwater contamination because large amounts of manure can flow into the groundwater in a very short length of time. Some states do not permit earthen manure impoundments, regardless of design, in areas with collapse potential.

4. Puncture. Since a liner is relatively thin, it must be protected from puncture during and after construction. Animal traffic, rocks, stumps, and roots can cause puncture opening in a clay liner. Carefully clearing the subgrade of these materials prior to liner construction is necessary.
5. Drying. If a clay liner is allowed to dry out, shrinkage cracks may occur, and permeability will be compromised. Measures should be taken after a liner is constructed to maintain proper moisture content until the liner is submerged. Consideration might be given to placing an "insulating" soil cover over the liner to minimize drying. Some states require a minimum liquid depth to be maintained over the liner to prevent drying.

Soil amendments. Some manure storage sites may not have suitable on-site soil materials for constructing a clay liner. In these cases, a soil amendment that modifies the existing soil properties may provide a means to attain the required permeability.

The most common soil amendment used in such cases is sodium bentonite. Sodium bentonite is a volcanic clay that swells to about 15 times its original volume when placed in water. When properly mixed with non-clay soils, the resulting mixture will exhibit properties of a clay soil and can attain the required permeability. When a liner is constructed using bentonite as a soil amendment, the bentonite is usually mixed with existing soil at the excavation boundary at the rate of 1 to 3 lbs/sq ft. Minimum recommended thickness for a bentonite liner is 6 inches.

Some soils in Group III containing high amounts of calcium may not attain the required permeability. Soil dispersants containing sodium (soda ash, tetrasodium pyrophosphate, and sodium tetraphosphate) may be used to disperse the blocky structure of such soils so that they attain the required permeability. Recommended rates of dispersant use are 10 to 20 lbs/100 sq ft for soda ash and 5 to 10 lbs/100 sq ft for the phosphates. Minimum recommended thickness for a dispersant liner is 6 inches.

Synthetic liners. Synthetic liners made of reinforced plastics, HDPE, or other synthetic materials may be used as a seepage barrier in some cases. Usually these liners are not as cost effective as a clay liner or liner constructed with soil amendments. However, in some cases soil with the necessary characteristics may simply not be available on-site or within a practical hauling distance. In such cases, a synthetic liner may offer a solution. Installation of such liners may require special procedures such as providing a geotextile or layer of sand below the liner to prevent puncture or tearing by the underlying material. Synthetic liners are usually installed with seams that must be closed by heating or vulcanizing as the liner is installed. The performance characteristics, installation procedures, and maintenance of synthetic liners are highly specific to the particular liner. If you anticipate using a synthetic liner, consult with the liner manufacturer or a qualified individual experienced in synthetic liner selection and installation.

Soil amendments such as bentonite can be used to modify existing soil properties, reducing seepage to target levels.

When soils with the needed permeability characteristics are not available, a synthetic liner may be required.

Liners should be constructed in "lifts," and each lift should be compacted with the appropriate equipment to attain the target permeability rate.

Construction practices for earthen impoundments

After soils evaluation, construction practices are the most important factor in developing an earthen manure storage facility that will be effective in protecting groundwater. Good construction practices require knowledge of equipment and compaction procedures.

Equipment. Typical earthmoving equipment used in constructing earthen manure storage facilities includes bulldozers and scrapers. Conventional disks or rototillers may be used for reducing soil structure and mixing soil amendments. Compaction equipment includes the hauling equipment, sheepsfoot or tamping rollers, and perhaps smooth rollers.

Liner construction and compaction procedures. Liners are constructed by laying down "lifts" of the desired soil material. A lift is a layer deposited (usually by a hauling scraper) on the bottom or sides of the impoundment. The thickness of a lift is an important factor in developing a liner with the necessary permeability characteristics. The thickness of a lift should allow nearly complete penetration of the teeth on a tamping roller to the compacted lift or soil below. If smooth rollers or wheeled compaction equipment is being used, the lift thickness should allow complete compaction through the vertical profile of the lift. A "loose lift" thickness of 9 inches compacted to a thickness of 6 inches is typically effective in providing the desired compaction.

Lifts are usually placed using one of two approaches. With the "bathtub" approach, a continuous thickness of liner material is compacted up and down or across the inside slopes and bottom of the impoundment. With the "stair-step" approach, the liner material is compacted in a series of horizontal lifts on the inside slopes of the impoundment. Figure 23-1 illustrates these two approaches. The bathtub approach is preferred due to the fewer lifts required but is limited to slopes of 3:1 or less. Steeper slopes result in shearing of the soil because equipment tends to slide on the slope. The stair-step approach can be used on a steeper slope, but the greater number of lifts may provide more pathways for seepage between lifts if adequate bonding is not present.

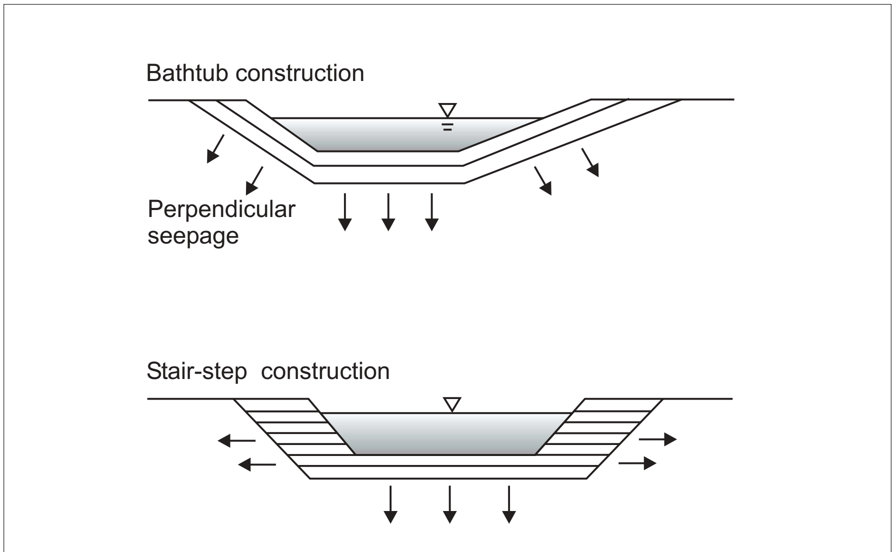

Figure 23-1. Methods of linear construction.
Source: Adapted from the NRCS Agricultural Waste Management Field Handbook 1996.

Lifts should be staggered and/or placed in alternate directions to minimize the possibility of creating preferential flow paths where lift edges coincide.

Compaction procedures are perhaps the most important mechanical operation in construction of an earthen manure storage impoundment. The combination of proper soil types or amendments along with compaction provides confidence that the desired permeability goal will be reached. Compactive energy depends upon the number of passes made, weight of the roller, thickness of the lift, and other factors. Roller weight should be sufficient to provide penetration of the tamping teeth to the compacted lift. Enough passes should be made to attain coverage, break up soil structure or clods if needed, and provide full compaction of the lift. Additional passes cannot substitute for a tamping roller of insufficient weight.

Tamping rollers, depending on size, typically provide contact pressures of 200 to 400 lbs per square inch. The number of passes required to attain the desired compaction depends upon many site-specific factors. Generally, four to eight passes with contact pressures in the 200 to 400 lbs per square inch range will provide sufficient compaction. The length and “footprint” shape of tamping roller teeth should be appropriate for the roller size and weight. Teeth should be long enough to penetrate to the compacted lift below with the weight of roller used. Tamping rollers operated at excessive speed can cause shearing of the soil being compacted, resulting in higher permeability. Rubber-tired or smooth wheeled rollers rather than tamping rollers should be used for compacting bentonite-treated liners. Tamping rollers can cause dimpling and reduced thickness on this type of liner.

A qualified professional should supervise the construction, ensuring that the contractor follows the proper and specified construction practices, providing evidence, if needed at a later date, that proper procedures were followed.