New Jersey Department of Environmental Protection

Bureau of Release Prevention

SOIL PERMEABILITY TESTING FOR EARTHEN SECONDARY CONTAINMENT AREAS

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Introduction

The Discharges of Petroleum and Other Hazardous Substances (DPHS) rules (N.J.A.C. 7:1E) require, among other things, that the owner or operator of a major facility provide the facility's hazardous substances storage areas with secondary containment to prevent leaked hazardous substances from becoming discharges. All components of the secondary containment must be made of or lined with impermeable materials. There is one exception to this requirement. For aboveground storage tanks at a major facility utilizing earthen secondary containment systems that existed before the rules were adopted in 1991 for tanks that were built before that date, the requirements of N.J.A.C. 7:1E-2.6(c)3 can be met. These requirements are designed to provide protection for offsite areas and ground water.

In the past, the Bureau of Release Prevention (Bureau) has accepted a statement by the owner or operator that secondary containment at his/her facility meets the standards in N.J.A.C. 7:1E-2.6(c)3. However, when asked to support this statement with actual data, owners or operators often found that at least part of their secondary containment system(s) fell short of the requirements. The need to provide evidence in support of the alternate standard in N.J.A.C. 7:1E-2.6(c)3 is usually raised when a plan or plan renewal is being reviewed. Therefore, the Bureau now requires that, when requested, the owner or operator provide evidence of the ability to protect offsite areas and ground water. Obtaining and providing this information can be done in parallel with the plan review, or can be incorporated into the owner or operator's facility upgrade schedule, if a large area needs to be assessed. Part of this evidence is soil permeability measurements.

This permeability testing guidance document has been prepared to assist owners or operators of major facilities in preparing and executing a soil permeability testing program. It lays out acceptable soil sampling and permeability testing procedures, as well as what should be in a complete soil permeability testing report. It also provides guidance on acceptable means of upgrading those secondary containment systems that do not sufficiently protect the ground water.

It is highly recommended that the owner or operator work closely with the Bureau in developing a sampling plan and permeability testing methodology. Sampling and testing procedures can be costly and time consuming. The Bureau wants to ensure that the final results will provide the necessary information to support the conclusions drawn about the ability of earthen secondary containment to provide sufficient protection in the case of a leak.

Table of Contents

Background

The DPHS rules, at N.J.A.C. 7:1E-2.6(c)3, require that all secondary containment or diversion systems be impermeable. The regulatory standard for impermeability is 1 x 10^{-7} centimeters per second for the substance being stored, as defined in N.J.A.C. 7:1E-1.6. Because there are a large number of aboveground storage tanks in New Jersey that have been in use for decades, earthen secondary containment systems are commonly found at many petroleum and chemical storage facilities. To function properly, these systems must be impermeable to the product stored to prevent petroleum or chemical substances from reaching groundwater or migrating off-site.

In order to provide some regulatory relief, the owner or operator of a major facility utilizing an earthen secondary containment system that existed before the rules were adopted in 1991, for tanks that were built before that date, can either meet the impermeable standard or meet the alternative established in the rules at N.J.A.C. 7:1E-2.6(c)3i, which entails providing evidence of the ability of the secondary containment system to protect groundwater. This evidence must include, but is not limited to, soil permeability testing, measurements of the depth to groundwater beneath the secondary containment systems, and response times for cleaning up a leak of the entire contents of the largest tank utilizing the system.

During the review of Discharge Prevention, Containment and Countermeasure (DPCC) plans or plan renewals, the owner or operator of a major facility may be required to submit a report evaluating the ability of his or her earthen secondary containment systems to protect groundwater. Part of this analysis is the determination of soil permeability. Soil permeability is the property of the soil to transmit water and liquid substances. Soil permeability testing is used to determine the factors needed to calculate a soil's permeability.

Sampling

The first step in determining soil permeability is taking samples to be tested. The soil samples are the primary source of information about the permeability of the containment system. If they are not collected properly, they will not be representative of the system being tested. In that case, the soil permeability testing results will be of limited use.

The owner or operator of a major facility planning to perform soil permeability testing should submit a proposal for the sampling plan to the Bureau for review prior to conducting any sampling. The factors to be incorporated into such a plan are explained below.

The recommended procedure for collecting samples is the American Society for Testing and Materials (ASTM) method D1587, "Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes". This procedure uses a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests. Other procedures for collecting samples are available and may be appropriate; however, such sample collecting procedures must be clearly described in the owner or operator's sampling plan.

Because soil permeability can vary from one area to another within a containment system, soil samples must be taken across the entire system, and the number of samples obtained must be adjusted to represent the variation in the soil permeability of the overall area. The locations of the sampling points should be wide-spread to ensure that different soil conditions in the containment area will be captured. Unusual site configurations or highly variable soil may require more sample locations. If some locations within the secondary containment are not accessible because of aboveground or underground pipes or narrow spaces between containment walls and tanks, then samples should be collected from locations close to the inaccessible areas as an alternative. The factors necessitating such an alternative must be described in the proposed sampling plan. The number of samples per containment system and the distribution of the sampling locations within each containment system are approved on a site-by-site basis. Also, more sampling may be required if the soil permeability test results from proximate locations show a large variation.

Soil samples should be collected to a three-foot depth below any cover material or down to the water table from the ground surface, whichever is the greater depth, or from the ground surface to the water table if it is less than three feet down. Soil permeability is largely dependent on the void between soil particles. Small changes in the void ratio, in the process of retrieving a soil sample, or recompacting a sample in a test chamber will greatly affect the permeability rate. Therefore, it is important that soil stratification remain undisturbed in order to accurately determine the permeability rate. Undisturbed samples must be handled and sealed in accordance with the standard used for their collection. They then must be preserved and transported such that the soil in the sample will maintain the composition, density and moisture content it had *in situ* until it is tested. Soil samples should never be blended and each individual sample must be tested separately.

Once the sampling plan has been developed, it should be submitted to the Bureau for review before beginning sampling. The proposed sampling plan must contain, at a minimum, information on:

- what was considered in determining the number and size of samples to be taken
- where to collect samples, and
- when to collect them.

The sampling plan should explain how the collected samples represent the entire system. For example, for a small containment area encompassing a half acre or less, four to six sampling points may be sufficient, while for a containment area encompassing several acres a much larger number of samples, perhaps 20 to 25, would be more appropriate. Also, rainfall and ambient temperatures can affect when sampling should occur.

After the sampling plan has been reviewed and approved by the Bureau, the sample collection process can begin. If during the sampling process, conditions are encountered that require a change in the sampling plan, the Bureau must be notified as soon as possible about the proposed change.

Testing Methods

In addition to a sampling plan, the owner or operator of a major facility planning on doing soil permeability tests on existing earthen secondary containment systems must submit a proposal for the soil permeability testing methodology to the Bureau for review prior to conducting any testing procedures. The sampling and testing plans must be submitted for simultaneous review. Two standard soil permeability testing procedures that have been frequently utilized at major facilities and accepted by the Bureau are ASTM D5084, "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter", and ASTM D5856, "Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction Mold Permeameter." However, the testing procedure in ASTM D5084 is more commonly utilized. Please note that testing is not limited to these methods. Other test methods are available and may be proposed.

Owners or operators of major facilities are free to propose for Bureau approval the use of the test they believe will be most appropriate. However, certain types of tests, such as slug tests, pump tests, and percolation tests are not generally useful for determining soil permeability with regard to protecting groundwater. These tests are designed to measure soil permeability in areas of high permeability and specifically to test the aquifer. They are not able to accurately measure soil permeability in areas of low permeability, such as the existing soil in its existing condition from the ground surface down to the aquifer.

Once the proposal for the permeability testing methodology has been reviewed and approved, it is recommended that an independent certified soil-testing lab perform the tests on the collected samples. Laboratory tests such as that in ASTM D5084 are designed to determine the variables needed to calculate a soil's hydraulic conductivity. For this test, water is used as the test fluid and the hydraulic conductivity (the ability of the water to flow through a soil by traveling through the void space, also known as soil permeability) is calculated on the basis of Darcy's law. Darcy's law defines hydraulic conductivity by the equation:

$$K = q/(iA)$$

where K is the hydraulic conductivity of the soil
q is the rate of discharge through a soil of cross-section area A
i is the hydraulic gradient, and
A is the area perpendicular to direction of q.

The hydraulic conductivity of a soil depends primarily on the size and shape of the soil grains, the void ratio of the soil, the shape and arrangement of the voids, and the degree of saturation.

The ASTM D5084 test procedure can use one of two common hydraulic systems applying Darcy's law to measure the hydraulic conductivity. Those two system types are "constant-head" and "falling-head".

The constant-head test is used mostly for coarse-grained soils, such as clean sands and gravels. In this type of test, a sample of the material is placed in a cylindrical mold, and a continuous supply of water is fed through the sample. The water is introduced at the top of the cylinder and passes through the sample of cross sectional area A, in time t, collected at a flow rate q into a container beneath the sample. After measuring all these variables, Darcy's law is then applied to calculate the hydraulic conductivity. The form of the equation used is:

$$K = q/(iA) \text{ or } (QL)/(Aht)$$

where
K = hydraulic conductivity of the soil in centimeters per second (cm/s)
Q = quantity of water flow in cubic centimeters (cm^3)
L = length of specimen in centimeters (cm)
A = area of sample perpendicular to direction of Q in square centimeters (cm^2)
h = average head loss in centimeters (cm)
t = interval of time in seconds over which the flow Q occurs (s)
q = Q/t, and
i = h/L.

The falling-head test is generally used for less pervious soils, such as fine sands to fat clays. This test is similar to the constant-head test because it measures the amount of water passing through a sample of the material. The difference is the falling-head test uses a standpipe to introduce water into the sample and the head of water is not maintained constant but is permitted to fall. Applying Darcy's Law, the form of the equation used is:

$$K = 2.303(aL)/(At) \log_{10}(h_1/h_2)$$

where
K = hydraulic conductivity of the soil in centimeters per second (cm/s)
a = inside area of the standpipe in square centimeters (cm^2)
L = length of the specimen in centimeters (cm)
A = cross-sectional area of the specimen in square centimeters (cm^2)
t = interval of time it took for the water to fall in seconds (s)
h_1 = initial height in the standpipe in centimeters (cm)
h_2 = final height in the standpipe in centimeters (cm)

Both constant-head and falling-head tests measure the hydraulic conductivity for water. Because the secondary containment must be impermeable for the substance contained, the calculated hydraulic conductivity results must be converted to that substance by means of a ratio using viscosity and density. The general equation is

$$K_x = K_{water} (V_{water} / V_x) (D_x / D_{water})$$

where
K = hydraulic conductivity of the soil sample in centimeters per second (cm/s)
V = the fluid viscosity in centipoise (cP)
D = the fluid density in grams per cubic centimeter (g/cm^3).

Because laboratory hydraulic conductivity testing uses water and the density and viscosity of water are 1.0 g/cm^3 and 1.0 cP respectively, a hydraulic conductivity correction factor for actual stored substances can be the ratio of fluid density divided by the fluid viscosity. For example, if the worst case substance is gasoline and the ratio, $D_{gasoline}/V_{gasoline}$, is 1.5 at ambient temperature, the corrected hydraulic conductivity, $K_{gasoline}$ will be equal to 1.5 (K_{water}).

The hydraulic conductivity correction factor used in the final report must be for the worst case hazardous substance stored in the containment area. To analyze for the worst case substance, tanks should be reviewed for sizes and substances stored. The substance with the highest hydraulic conductivity correction factor will travel more quickly through the soil, thus lessening the time to groundwater. However, the largest tank will produce the highest leak height which produces the highest head pressure and also shortens the time to reach groundwater. Moreover, the maximum height of the leaked substance must take into account six inches of rainwater. Therefore, the height of a leak from a given tank can be calculated from

$$h = T/(7.48ACA) + 0.5$$

where h = the maximum height of the leak within containment in feet
T = the volume of the tank in gallons
ACA = available containment area footprint, accounting for any area consumed by the tanks within the containment area in square feet

Using the hydraulic conductivity correction factors and leak height information for each tank, a worst-case combination must be determined for each containment area based on these parameters. Then, the actual soil permeability, taking into account the hydraulic head, substance travel distance from the soil surface to ground water, and soil porosity, can be calculated using

$$v = (K_x / P)\ (h/l + 1)$$

where v = the actual soil permeability (cm/s)
K_x = corrected hydraulic conductivity (cm/s)
P = soil porosity (determined by the void ratio)
h = the maximum height of the leak within containment (cm)
l = substance travel distance from the soil surface to ground water (cm)

With this information, the retention time of the soil can be calculated as

$$(t) = l / v$$

where (t) = the retention time
l = the depth to groundwater
v = the actual soil permeability

These calculations are conservative in that they assume a constant head pressure, which is the equivalent of no clean up of the leak occurring. If the owner or operator wishes to simulate a more realistic scenario of ongoing removal of leaked hazardous substance, the above equations can be modified to reflect substance removal as a reduction in hydraulic head. Thus, the time to reach ground water can be integrated over time. The final result for retention time is the average of the calculated time intervals.

Soil permeability over a large area can often be significantly different. Therefore, to be protective of the groundwater, the calculated soil permeabilities for different locations within secondary containment areas may not be averaged, and the worst case permeability must be used in all calculations.

Report to the Program

Once the soil permeability testing and all calculations have been completed, the owner or operator must prepare and submit a complete secondary containment evaluation report to the Bureau for review. This report will demonstrate one of three things: that the existing earthen secondary containment system(s) can meet the impermeable standard; that the existing earthen containment system(s) can protect groundwater for the period of time needed to clean up and remove the worst case hazardous substance leak, up to the entire volume of the largest tank; or that groundwater cannot be adequately protected. To meet the definition of "impermeable", the test results must show that the soil permeability rates for all samples tested for a given containment area are 1×10^{-7} centimeter per second or less for the worst case hazardous substance stored within the containment area. The results of all the samples taken within a given area cannot be averaged to show compliance. Each sample must satisfy the definition on its own.

A complete secondary containment evaluation report should include, but is not limited to, the following items:

- Sampling and testing method documentation;
- Soil descriptions and logs of each sample location;
- A detailed map showing each sample location. The sample locations should be identified so that it is clear which test results apply to samples from each location;
- A table listing all aboveground storage tanks located in the tested secondary containment areas with their contents;
- A table listing the depth to ground water at each sample location and containment area. The depth to a perched water table cannot substitute for the depth to ground water because a perched water table is an aquifer that occurs above the regional water table, in an unsaturated zone;

- A table listing the densities and viscosities of the substances stored in each containment area, and the hydraulic conductivity correction factor with a storage temperature for each substance;

- A table listing corrected hydraulic conductivity, the maximum product height plus six inches of rainwater, and the porosity of the soil;

- Detailed soil permeability and retention time calculations for each sample in each secondary containment area, including all computing steps, equations, data, variables, and references;

- A table listing the permeabilities and retention times of the soil for each hazardous substance stored in a containment area; and

- A list of all companies and personnel with business addresses, email addresses (optional), and telephone numbers who performed the sampling and calculations, and a brief description of their qualifications.

To demonstrate that groundwater can be protected for the period of time needed to clean up and remove a worst case leak, the report must show that the total length of response time is less than the retention time for all samples taken. In determining response time, the total length of response time consists of the following components, at a minimum:

- time it would take for a leak into containment to be discovered,
- time needed to initiate a response, and
- time needed to remove the entire leak.

The report must clearly explain how the owner or operator determined the claimed total length of response time, from the initial stage of discovering a leak to the final stage of cleaning up and remediating the containment area. To do so, the owner or operator must provide the following data, at a minimum:

- Containment system inspection schedules;
- Commitments from a discharge cleanup organization to arrive on the scene with certain equipment within a given period of time, or a list of appropriate equipment owned by the owner or operator;
- Information on the time needed to deploy clean up and removal equipment, whether owned by the owner or operator of the facility or by a discharge cleanup organization;
- Any documents regarding past leaks that were cleaned up or calculations based on measured data that demonstrate how long it takes to remove the worst case leak from the containment area, and clean-up and remediate the site; and
- Any other supporting documents.

If it is found that the total length of time needed to clean up and remove a worst case potential leak is longer than the time needed for a leak to travel through the soil and reach ground water, the ground water will not be protected and the DPCC plan must contain a commitment to upgrade the secondary containment system with specific dates for completion.

Upgrading Secondary Containment

If the secondary containment evaluation report shows that one or more of the tested containment systems cannot meet the definition of impermeable and cannot protect ground water as required, then the DPCC plan or plan renewal must contain a schedule for upgrading the containment system.

The upgrading standard applied to those containment systems that cannot protect groundwater is the same standard applied to any other systems required to be impermeable, which is 1×10^{-7} centimeter per second. In the past, the bureau has accepted the following means of upgrading secondary containment:

a) Retrofitting the current structure and surface of the containment system with concrete or other type of material that meets the definition of impermeable;

b) Installing clay, geotextile or synthetic liners; and

c) Upgrading those parts of a secondary containment system that do not protect groundwater to meet the regulatory standard for impermeability, ensuring that they are properly tied into the existing protective elements of the secondary containment. For example, a facility may tie a new section of clay liner to an existing section of a soil clay layer within secondary containment to assure that the whole containment system meets the regulatory standard for impermeability.

Please note that the acceptable means of upgrading containment systems are not limited to those described above, and these methods may not be appropriate for all sites. Other means are available and may be appropriate. The owner or operator can propose a method of achieving compliance with the permeability standard to the Bureau for approval.

For Site Specific Information

If you have any questions or need information specific to your facility, please contact your project manager at (609) 633-0610. Copies of the current rules and DPHS guidance documents are available on the web at http://www.nj.gov/dep/rpp/brp.