IFAI Geosynthetics Conference
Feb. 10-13, 2019 | Houston, TX USA

Electrical Leak Location Testing for Zero Leak Verification

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ABSTRACT

The ultimate goal of geomembrane-lined containment facilities is zero leakage. Electrical methods have been developed and field proven in order to locate leaks in installed containment facilities. However, all of the published standardized methodologies for locating leaks in installed geomembranes have limitations to their effectiveness and none of them detail a method for verifying that a geomembrane is free of leaks. A new methodology was introduced in 2018 as a new ASTM Standard Practice for geomembranes covered with soil and/or water. This standard practice includes a site response current measurement. “Site response current” is the current that flows from the cover material to the underlying conductive layer due to an applied voltage. If a site has perfect boundary conditions for electrical testing, meaning that the only electrical pathway through the geomembrane is through any leaks present in the geomembrane, then the site response current measurement can be used to quantify the presence of leaks in the geomembrane. This paper explores how to interpret the range of site response current measurements for large-scale containment facilities. Typical examples of site response current measurements for various field projects are presented. Results of the bench-scale testing of current through an intact geomembrane with varying geomembrane contact conditions are also reported. The results of the bench-scale testing are used to explain how the site response current is also a function of electrode contact and the conductivity of the overlying material. It is anticipated that the site response current measurement can be used to verify a zero leak condition and even perform a “quick test” during the life of the site so that facilities can instantly check for leaks in the geomembrane at any time.

BACKGROUND

The electrical leak location (ELL) methods known to the geomembrane-lined containment industry are based on the premise that geomembranes are excellent insulators. Therefore, when a current source is introduced on one side of the geomembrane and the return electrode is connected to the material on the other side of the geomembrane, then the current will flow through any existing leaks in the geomembrane. Various ELL methods can be used to track the path of the current flow so that the leaks can be located for repair.

All of the existing standardized ELL testing methodologies have technical limitations that can prevent leaks from being detected. For the high voltage-based testing methods on exposed geomembranes, the path through the leak can be too excessive for detection, or physical obstacles such as the presence of dirt and moisture can preclude detection. For the water-based exposed geomembrane methods, water has to actively travel through the hole(s) while the equipment is close enough to detect the increase in current draw.

For the soil-covered geomembrane methods, the leak(s) have to maintain good contact between the cover material and the subgrade. When an impoundment is not actively leaking, geosynthetic components and liner bridging can create a discontinuity between the cover material and the subgrade, even when an actual hole is present in the geomembrane. Liner bridging is when the geomembrane is not in good contact with the subgrade. This can occur at the toe of the slope if the geomembrane shrinks after placement, but it can occur anywhere that the subgrade has a slight depression. The problem is exasperated by thicker geomembranes whenever soil or water cannot get inside the breach to create electrical continuity through the leak.

In order for a leak to be detectable in addition to maintaining good electrical contact, the current needs to travel through the leak with an intensity that is significant compared to all other current paths available. This is why methods such as the dipole method (ASTM D7007) detail isolation of the cover material from the surrounding ground.

The new ASTM methodology aimed at detecting all existing leaks stresses the paramount importance of proper site conditions including isolation of the material above the geomembrane and the existence of a hydraulic gradient across the geomembrane. The current must be forced to travel through the leaks, and only the leaks. This would ensure detection. The new methodology is therefore only for covered geomembranes, and is presented as an enhanced alternative to ASTM D7007.

CURRENT THROUGH AN INTACT GEOMEMBRANE

Perfect insulators do not exist. All materials can be relatively conductive or insulative, depending on the material used as the reference for comparison. ELL is mostly practiced on environmentally-based containment facilities. The most widely chosen material for these types of projects due to a large range of chemical compatibility is high density polyethylene (HDPE). HDPE has a high value of electrical resistivity in comparison with polyvinyl chloride (PVC), and especially with ethylene propylene diene monomer (EPDM).

Current flows through an intact geomembrane as a function of the thickness of the geomembrane, the resistivity of the geomembrane and the contact area of the applied voltage potential (Lugli and Mahler, 2016). When current paths exist through the geomembrane (i.e. holes), most (or practically all) of the current will travel through the holes, since current always travels the path of least resistance. This can be modeled through the equation for parallel resistors. Thinner and/or more conductive geomembranes will experience more current flux through an intact geomembrane, but once at least one leak appears in the geomembrane, the current path(s) will shift to a concentration through the leak.

From a practical standpoint for ELL surveys, the current through one acre of installed geomembrane using the equation presented by Lugli and Mahler predicts that when 350 volts is applied, an intact 60 mil HDPE geomembrane should respond with 0.013mA, while a 60 mil PVC geomembrane should respond with 1.80 A. According to one case in the author’s experience, a four-acre survey on soil-covered PVC with non-ideal site isolation only responded with about 0.3 A. According to theory, ELL surveys on PVC should create conditions “unfavorable to the leak detection process” (Lugli and Mahler, 2016). However, industry practice and the author’s experience shown that ELL surveys are routinely and successfully performed on PVC (ASTM D6747).

This reveals a missing parameter in the Lugli and Mahler equation. Part of the reality of field conditions is that the electrical contact with the geomembrane is not always perfect. Soil-covered geomembrane typically have a geotextile cushion and the survey area is not always saturated. Even water-covered survey areas are commonly underlain with a geotextile or geocomposite. Common sense and practical experience tells us that the missing parameter in the Lugli and Mahler equation could be some kind of contact factor. Perhaps the Lugli and Mahler equation gives us the theoretical maximum for perfect contact across the geomembrane, but for various lining systems containing various geosynthetic and earthen materials, and even with varying levels of moisture and overburden pressure, the response current through the same intact geomembrane should also vary.

SITE RESPONSE CURRENT

A site response current is what is measured in an ELL field survey circuit when a voltage is applied across the geomembrane being tested. A field survey circuit includes a current injector electrode placed in the cover material, any earthen or geosynthetic components of the lining system, the geomembrane (either with or without breaches), the underlying semi-conductive layer, and the current return electrode. Water is commonly added to the cover material in order to increase the conductivity of the overlying layers and also to encourage leakage through the geomembrane.

The site response current should be stable unless site conditions change. These changing conditions include but are not limited to; rainfall, survey area desiccation, leaks being excavated and isolated from the cover material, artificial or actual leaks being introduced into the survey area, and even sometimes changing the position of the current injector electrode.

A few actual field examples of site response currents with different survey area conditions area are listed below.

Example Site 1. 350 volts was applied to a 10-acre gravel-covered HDPE-lined survey area, with a response current of 160 mA. A ¼” artificial leak was plugged in, resulting in a current draw of 170 mA. There were three holes encountered during the survey; an approximately 4-inch puncture and two approximately 1-inch punctures. After isolation and repair of the three holes, the site response current was 50 mA. Several locations along the perimeter were dirty and moist and clearly shown by the data mapping to be a source of current draw from the survey area.

Example Site 2. 350 volts was applied to a 5.5-acre gravel-covered HDPE-lined survey area, with a response current of 8 mA. A ¼” artificial leak was plugged in, resulting in a current draw of 18 mA. No holes were encountered in the survey area, but the excavated access road where the geotextile remained dirty and damp was clearly shown by the data mapping to be a source of current draw from the survey area.

Example Site 3. 350 volts was applied to a 9-acre soil-covered HDPE-lined survey area, with no measurable response current. A ¼” artificial leak was plugged in, resulting in a current draw of 4 mA. No holes were encountered in the survey area. The perimeter of the survey area was completely clean and dry.

For the Site 3 Example, one half of the site was surveyed with the 1/8” artificial leak plugged in and the second half of the site was mapped with the artificial leak unplugged. Figure 1 shows the drastic difference in electrical response of these two conditions. The first half is shown on the left and the second half is shown on the right. The contour interval for the map on the left is 2 volts and the contour interval for the map on the right is 0.1 volt.

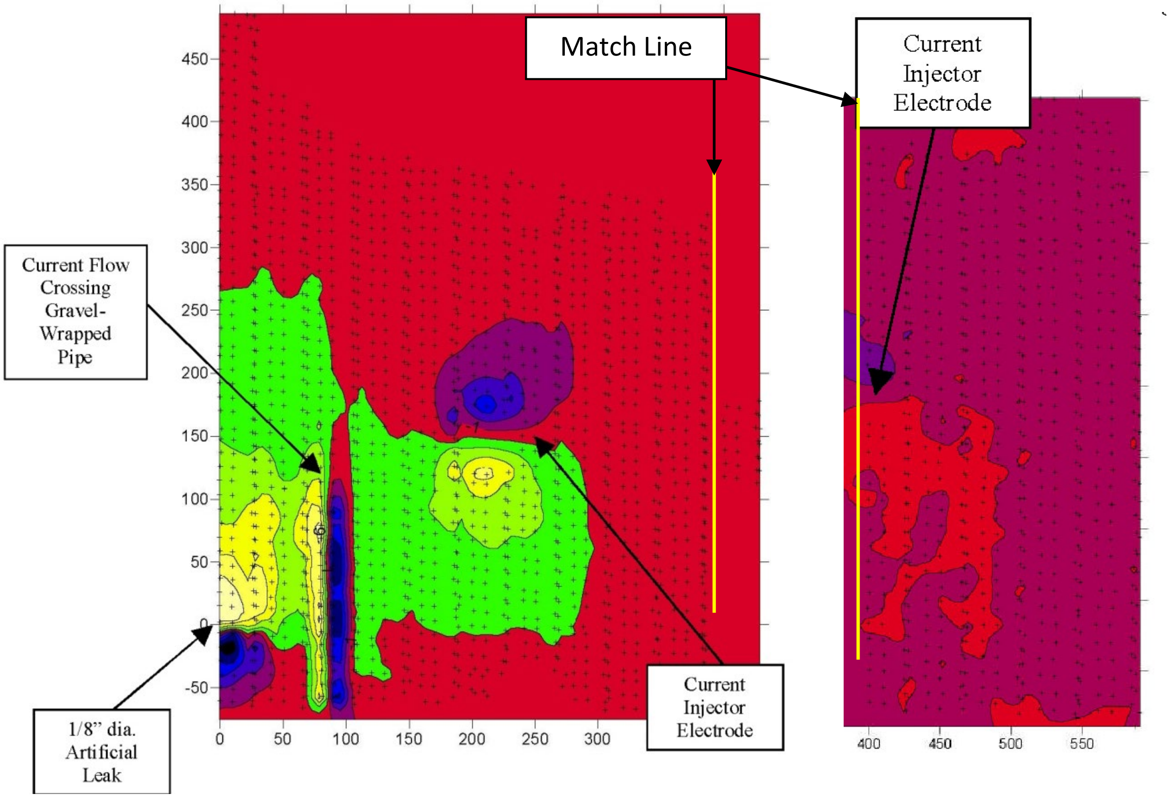

Figure 1. Voltage Mapping at a No-leak Site.

When the leak is connected to the survey area, it creates a strong current path between the current injector and the artificial leak, even creating a current eddy across a gravel-wrapped pipe location. When it is not, there is barely a visible current draw from the current injector.

Current draw can be caused by survey area isolation issues *or* an actual hole in the geomembrane. The only way to tell the difference between these two possibilities is to electrically map the entire survey area in order to pinpoint the source(s) of the current draw.

Site Isolation Issues. Moisture and dirt, especially when the geomembrane is overlain by other geosynthetics, can make it practically impossible to perfectly isolate a survey area. The access road location is one example. In order for placement of cover material, an access road must be in place. If a road is installed directly over something like a geotextile without any kind of rub sheet or plywood to keep the underlying geosynthetics clean, it is practically impossible to get this location back to the point of perfect isolation. Figure 2 shows the removal of an access road in progress before starting an ELL survey. Notice the fines left behind the excavation. If the site has experienced rainfall, this area is often a strip of mud embedded in the geotextile.

Figure 2. Excavation of Access Road to Survey Area.

If rainfall occurs at a site with a geomembrane overlain by a geotextile, it is likely impossible to regain isolation unless the geotextile is cut and pulled back. ELL surveys are routinely performed with issues like these present during the surveys. The key is to minimize these locations as much as practical and also to verify that the current draw is an isolation breach rather than a hole through the geomembrane. Figure 3 shows an example of electrical mapping created by voltage measurements taken during a dipole survey. Each area where current draw is noted is investigated and documented. The leak pinpointing process after review of the voltage map reveals the precise source(s) of the current draw.

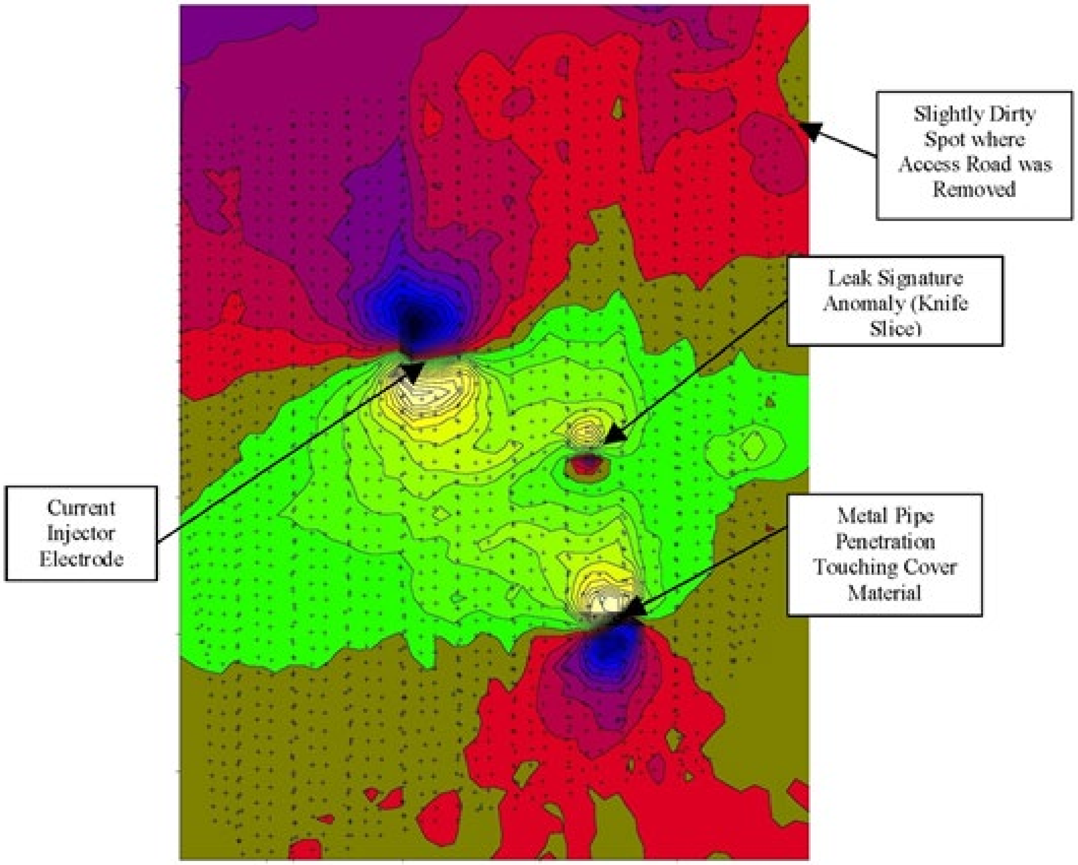

Figure 3. Electrical Map Created by Dipole Survey to Document Source(s) of Current Draw.

BENCH-SCALE TESTING

In order to assess the variability of the current through an intact geomembrane as a function of contact with the material against the geomembrane, a bench-scale testing apparatus was constructed. The bench-scale testing apparatus allowed for precise control over the applied voltage and the measurement of current while varying the material placed directly above the geomembrane.

Testing Apparatus. An apparatus was constructed in order to apply a voltage across a geomembrane and measure the current flowing through the intact geomembrane (shown in Figure 4). The apparatus is capable of retaining earthen materials and/or water over the geomembrane while maintaining complete isolation between the material(s) above and below the geomembrane, except directly through the geomembrane. The current injector and return electrodes were fabricated of circular ¼”-inch thick stainless steel disks measuring 6 inches in diameter. The geomembrane exposed to the voltage differential measured 12” in diameter. An ammeter capable of reading 0.1μA was placed in series with the DC power supply. The return electrode contact was ensured by using electrically conductive gel placed between the stainless steel disk and the overlying geomembrane. Only the contact of the electrode above the geomembrane was varied.

The apparatus was checked for functionality by filling the top receptacle with water and then measuring the response current through an intact HDPE geomembrane. No measurable current was observed at an applied voltage of 500 volts. The cross sectional area for current flow was too small to allow enough current flow to be measurable through HDPE. Therefore, EPDM geomembrane was used, since it proved conductive enough for the current through it to be measurable with this testing apparatus.

The different configurations included variables that would change the contact between the electrode and the geomembrane, the electrode and the cover material, the cover material and the geomembrane, and the bulk electrical resistivity of the cover material. Several similar testing configurations were repeated in order to assess repeatability.

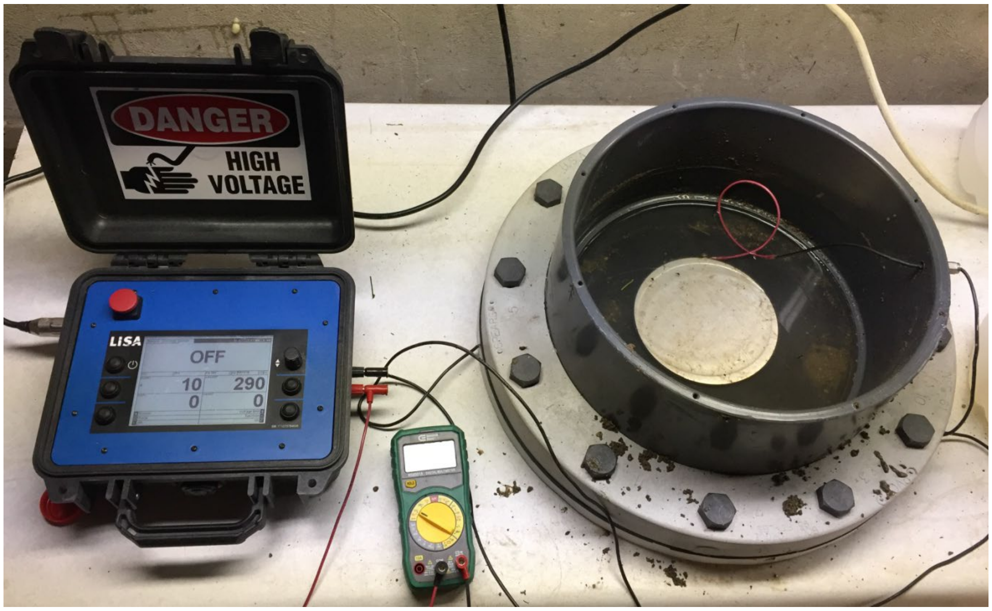

Figure 4. Bench-Scale Testing Apparatus.

Procedures. Voltages ranging from 1 volt to 200 volt were applied to each testing configuration. Only one variable was changed with each testing configuration, and similar configurations were tested sequentially after changing one parameter. For each applied voltage, the response current was recorded. The testing configurations are listed in the order that they were conducted in Table 1.

Results of Bench-Scale Testing. An applied voltage of 10 volts was chosen to compare all of the results. The response current through the intact EPDM geomembrane is shown in Table 1.

Table 1. Summary of Current Responses at 10V DC Applied.

Testing Sequence Number	Configuration	Current Response (mA)
1	Electrode placed directly on geomembrane	0.04
2	Gel added to electrode and then placed directly on geomembrane	9.83
3	Electrode placed on top of ~2" layer of dry sand	0.001
4	Gel added to electrode and placed on top of ~2" layer of dry sand	0.002
5	Test 4, with bottom layer of sand (against geomembrane) wet	0.13
6	Test 4, with water added to sand up to the level of the electrode	8.64
7	Test 4, with water covering the electrode	10.8
8	Electrode placed directly on geomembrane and covered with water	54.2
9	Electrode placed directly on geomembrane and covered with brine solution	109
10	Gel added to electrode and placed on top of ~1" layer of dry sand	0.007
11	Test 10, with a thirty pound weight placed on top of the electrode.	0.016
12	Electrode placed on top of ~1-1/2" layer of dry sand	0.001
13	Test 12, with water completely covering electrode	36.7

Discussion of Results. The bench-scale testing successfully showed how the contact variables analyzed can affect the response current through an intact geomembrane.

The first two trials show how increasing the contact directly between the electrode and the geomembrane, with no cover material between them, increased the current draw by 24,500%.

Improving only the contact between the electrode and the cover material can be assessed by observing the increase in current draw after the addition of the layer of conductive gel (Test 4 vs. Test 3). The increase in current from 0.001 mA to 0.002 mA represents a 100% increase in current draw. The second trial that illustrates this effect is the comparison between Tests 6 and 7, when the water was raised to above the electrode from just touching the bottom of it. This resulted in a 25% increase in current flow. The increase in current flow was attributed to more area of the electrode being exposed to the cover material.

Improving only the contact between the cover material and the geomembrane can be assessed by observing the increase in current draw after the addition of the water in the bottom layer of sand (Test 5 vs. Test 4). The increase in current from 0.002 mA to 0.13 mA represents a 6400% increase in current draw. When nothing was changed other than adding weight to the electrode, which forced the sand into more intimate contact with the geomembrane, the current increased by 129% (Test 11 vs. Test 10).

Increasing the electrical conductivity of the cover material by adding salt to the water over the geomembrane increased the current draw by 101% (Test 9 vs. Test 8).

The EPDM sample used for this comparison testing was subjected to laboratory resistivity testing in general accordance with ASTM D257. The resistivity value obtained was 2.35 x 10^5 Ohm-m. This falls roughly in the middle of the published range for EPDM (Donnelly, 2000). When this laboratory-obtained value is used to calculate the current draw through an intact geomembrane using the Lugli and Mahler equation, the bench-scale testing device testing should have resulted in a current draw of 0.68 mA at an applied voltage of 10V DC. The range of 0.001 to 109 mA through the geomembrane in the testing device shows that the theoretical current through an intact geomembrane can be several orders of magnitude different from the values obtained with the actual field conditions of installed geomembranes.

CONCLUSIONS AND DISCUSSION

The results of the bench-scale testing were reflective of the Author's experience in the field after over a decade of observing site response current with changing field conditions. This indicates that there is indeed a missing variable in the Lugli and Mahler equation for addressing the contact path of the electricity through the geomembrane. This factor would be necessary for calculating the theoretical current draw through an intact geomembrane subjected to an ELL survey. However, due to the extreme variability in the response current when varying the electrical contact of the various components of the testing apparatus, a theoretical value would likely not be accurate enough.

Due to the nearly limitless number of variables that can affect the contact of the overlying material with the geomembrane, it would be much more appropriate to develop an index of site response currents for various conditions of a particular impoundment. This would have to be done along with electrical mapping in order to verify that the current response truly represents current through the intact geomembrane. If it can be verified that a survey area is properly isolated, the site response current should represent current leakage directly through the lining system. If there are discrete breaches in the geomembrane, these locations will show up on an electrical map. Leaks can be simulated through the use of grounded wires that show the difference between a survey area with and without leaks, as illustrated by Figure 1. The current draw and supporting mapping through an intact geomembrane is significantly different than the current draw through a geomembrane with at least one leak as shown.

The goal of the new standard is to aim for perfect isolation of the survey area and subject the geomembrane to hydraulic head. The site response current is then measured and the entire survey area is electrically mapped to locate the source(s) of the current draw. Each leak and/or isolation breach is then systematically eliminated and/or accounted for and a comprehensive map shows the electrical response of the survey area. The survey is then repeated once the leaks have been repaired to either locate even smaller leaks, or eventually to show how the site responds electrically with no leaks in place, keeping a log of site response current measurements at each step in the process.

The utility of the site response current measurement may then be expanded, but only for sites that can remain electrically isolated for their operational life or at least for brief testing events. For example, if a leak enters a circuit, then the current will abruptly increase. If the site response current is known for a zero-leak condition at a particular site, a "quick test" may be performed consisting simply of a current response measurement. If the current increases while the survey area remains isolated, then electrical mapping is warranted. If it remains steady, then no new leaks are likely to have developed. Of course, it would require several initial testing events in order to gain confidence in the results, but such an efficient testing methodology could allow sites to be tested daily or annually for leaks while it would otherwise be cost prohibitive and not practical to do this with existing testing methodologies.

ACKNOWLEDGEMENTS

This research could not have been completed without the bench-scale testing device built by Richard Lacey (TRI Environmental). Laboratory testing for the resistivity of the EPDM geomembrane sample was performed by Ajay Shah (TRI International).

REFERENCES

Donnelly, P., (2000), Cancarb Technical Bulletin: Electrical Resistivity, *ACS Rubber Division Meeting,* Cincinnati, OH, USA.

Lugli, F. and Mahler, C.F. (2016), Analytical study of the performance of a geomembrane leak detection system, *Waste Management & Research,* Vol. 34(5) 482-486.

ASTM D 257. Standard Test Methods for DC Resistance or Conductance of Insulating Materials, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

ASTM D 6747. Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

ASTM D 7007. Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

McMahon, E. J. (1987). *Engineering Dielectrics Volume IIB,* ASTM International, Edited by R. Bartnikas, Chapter 1.