Why covered geomembrane leak location (dipole) is crucial on any impervious work

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ABSTRACT: To protect geomembranes from heavy machinery damage during site operations, most impervious works will include a natural material layer (for drainage and/or protection) overtop of the geosynthetic layer. Whether the natural material is sand, clay, gravel, or comprised of multiple types of material, a covered liner electrical leak location (ELL) survey, or dipole survey, can be performed on it to verify the integrity of the geomembrane underneath. Certain limitations would obviously need to be considered, such as the thickness of the protection layer, and will be discussed later in this paper.
The integrity of a geomembrane can also be verified prior to it being covered; an exposed liner leak location survey verifies the quality of the geomembrane installation phase and the skill of the installer. If only the dipole survey is conducted then there is room for argument when the time comes to decide who should pay for the repairs. The dipole survey should be prioritized because of the nature of holes it detects. Exposed geomembrane leak location methods will detect pinholes, bad extrusions, knife cuts, and other equivalently small defects. The dipole survey, however, will detect rock punctures, tears from heavy machinery, and other larger defects that allow for greater leakage.
This paper will explain how the dipole survey works, and, based on more than 15 years of field experience, will discuss the types of damage and size of holes that can be found with the dipole method, statistics on the number of defects found, and the main parameters that affect its efficiency. Information will be given to understand better how to improve a site's conditions for performing the survey, in order to attain maximum sensitivity and thereby increase the potential of finding smaller holes.

Keywords: Electrical Leak Location, Liner Integrity Survey, Water Puddle, Spark Test, Arc Test

1 INTRODUCTION

Based on personal experience as a leak location technician, it is very hard to believe in the dipole method until after the first hole has been uncovered. Prior to that, it is a concept; electricity flowing through a geomembrane defect, creating an electrical signature to signify the presence of a leak makes sense theoretically. However, since not all impervious works have holes, a leak location technician may end up surveying for weeks before actually detecting a real leak. This can also make it difficult for an owner to believe in the necessity of a dipole survey, particularly if the survey was required but no leaks were found.

During a survey, a technician will see countless fluctuating values, mostly due to:

- Variations in the cover material's moisture content (dry spots, puddles);
- The skill of the installer and general contractor;
- Variations in the cover material thickness;
- The composition of the cover (soil type, multi-layer system, heterogeneous areas);
- Preferential paths in the cover material (drains with water, electrical sensors, etc).

It can be difficult to determine when a variation is significant enough to stop everything and start digging. However, there are ways to tweak a site's conditions prior to performing the survey in order to drastically improve the efficacy and sensitivity without greatly affecting other parties.

Regardless of the reasons why a dipole survey is performed—whether mandatory or voluntary—everything possible should be done to improve the chances of finding all of the leaks. It is crucial that an effective and accurate dipole survey be performed after the cover material has been placed as many, often significant, leaks can be created during soil placement activities. This paper will discuss the reasons why dipole surveys are currently performed, how best to improve their efficacy, and will also provide information on the leaks that have been found in order to illustrate why, regardless of whether a dipole survey is currently mandatory or not, it should be performed for all types of geomembrane works.

2 DIPOLE METHOD DESCRIPTION

The dipole geoelectrical method (ASTM D7007) relies on the intrinsic insulation properties of geomembranes for the detection of perforations created during the installation of the cover material (see following figure). This means that geomembranes that are electrically conductive, such as EPDM (Ethylene Propylene Diene Terpolymer) due to its large concentration of carbon black, or that are impermeable but non-isolating, such as geocomposite clay liner (GCL), are also incompatible.

To perform a dipole survey, a current of about 500 V DC (direct current) is injected into the cover material (usually sand, clay, gravel or crushed stones), and a grounding electrode is placed outside the limits of the geomembrane. Under normal circumstances electricity will flow from a different potential to a ground to discharge and reach equilibrium, however with a non-conductive geomembrane, it is confined within the cell. However, if a defect is present, the current will pass through the hole to reach the ground (electrode). This will then generate a distinct electrical signature that can be identified and located by a specialized technician.

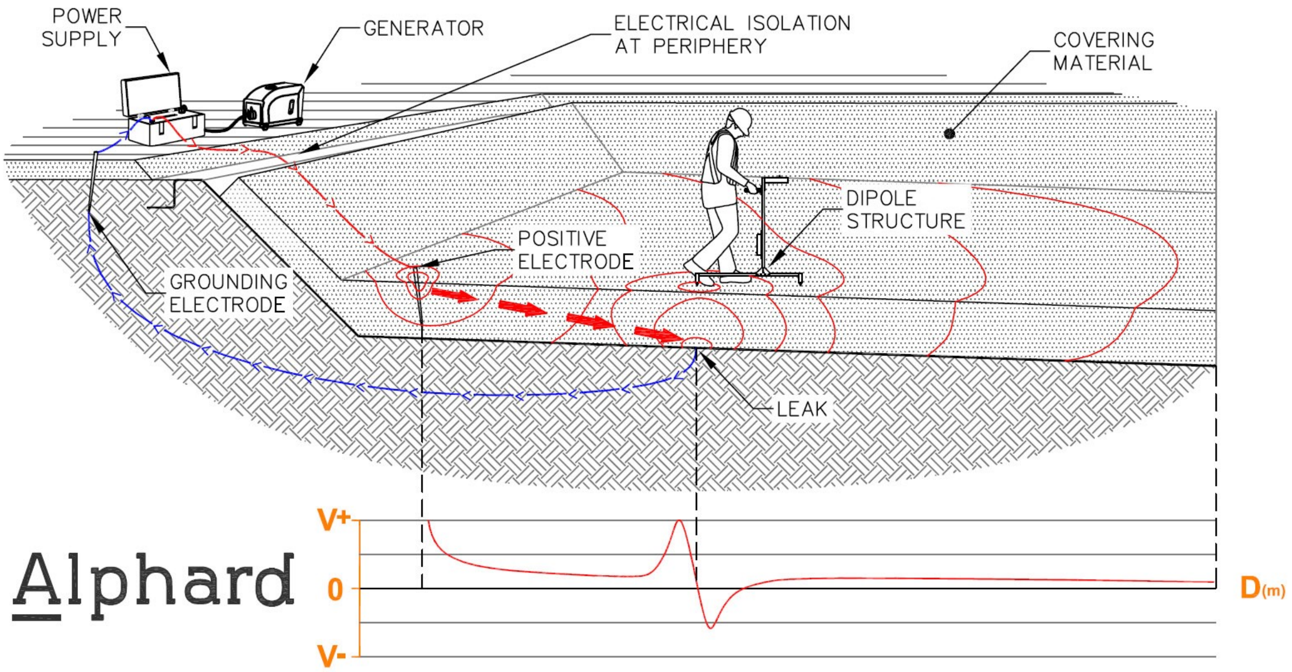

Figure 1. Dipole method schematic

3 THREE CRITICAL SITE PARAMETERS FOR DIPOLE SENSITIVITY

The dipole method relies on being able to read voltage variations at the surface of the natural material cover layer. To do so, the cover material ideally should be thin, homogenous, uniformly humid, and electrically isolated from the exterior. Under these conditions, it is obvious when a variation in the signal is due to a defect in the geomembrane and even small holes can be detected. If one of these conditions is not met, or is not ideal, then the other conditions must be optimal in order to increase the chances of finding the smallest possible holes in the liner.

3.1 Thickness

The cover material thickness is the most important factor in determining a dipole survey's efficacy and precision. The closer the dipole structure is to a defect, the greater the precision when locating a hole. For example, with a thin cover layer (300 mm) the defect can be located to within roughly 150 mm, however if the cover material is thick (1 m), the defect can be located anywhere within a one to two meter perimeter. This means more material to uncover, and thus increased labour costs, a slower survey speed, and a greater chance of damaging the liner, particularly if heavy equipment is used. Ultimately, if the cover material is too thick, even big holes will be impossible to find.

3.2 Homogeneity

3.2.1 Heterogeneous cover material

A heterogeneous cover material causes variations in the electrical resistivity of the cover system, this commonly includes varying thicknesses or moisture contents, water pooling underneath the cover material, the presence of pipes/flanges, or simply poor cover material, filled with rocks, waste, etc. A heterogeneous cover material will generate random signals despite there being no actual defects in the geomembrane.

3.2.2 Multi-layers systems

Multi-layer drainage or cover systems are often used in impervious works. Clients will often request that the test be performed on the final layer, once the heavy machinery work has been completed and the risk to the geosynthetics is minimal. However, since the different layers will have different electrical conductivities as a reflection of their ability to retain water, from an electrical point of view it is best to perform the survey on the first layer, otherwise it will result in a poor dipole survey with little electrical sensitivity.

For example, if the top layer is a material that cannot retain water, such as rocks, it will act as an insulator. The current will remain in the moist bottom layer and no electrical signals will reach the dipole structure. In this case, the only option is to sufficiently wet the top layer prior to surveying, so that the layers will be equally conductive and the voltage variations can reach the top of the gravel layer. This option however requires significant amounts of water and labour, particularly when it is sunny and windy.

3.3 Electrical isolation

If the cover material is not isolated from the exterior soil (a continuous band of exposed geomembrane or geotextile around the perimeter of the works), then the electrical current injected into the cover material will take the most direct path to reach the grounding plate. It will pass directly from the cover material to the exterior soil rather than through any holes in the liner. In this case, only a small portion of the current will pass through a leak, thus generating a weak signal. "A dipole survey without electrical isolation can still be conducted however the efficacy of the survey may be disappointing. Any features that conduct electricity out of the survey area can reduce the survey sensitivity or completely preclude a survey. These features include but are not limited to access roads, concrete inlet or outlet structures, and conductive (i.e. metal or concrete) pipe penetrations" (Beck 2016).

Prior to surveying, a calibration is performed using hole simulations to determine the size of the smallest hole that can be detected under the given conditions. With poor isolation, the smallest detectable leak is often much larger than expected. Under very poor conditions, the leak simulation cannot be detected at all even when it is a one-square foot grounding plate.

The isolation along the periphery is more important on smaller works, since the direct, easy path that the electricity will take from the injection plate to the grounding plate is shorter. On larger works, it might be easier for electricity to flow through a leak and the moist subgrade in order to reach the grounding plate rather than run through the top.

4 REASONS TO REQUEST A DIPOLE SURVEY

There are many reasons why a dipole electrical leak location (ELL) survey may be requested. It could be environmental, money-driven, due to regulations, or, on occasion, because the site owner questions the imperviousness of the structure. Whatever the reason, a dipole survey helps to lower the risk of leakage through geomembranes.

4.1 *Imperviousness*

4.1.1 *Pollution prevention*

Probably the number one reason a dipole survey is requested is to prevent liquid from leaving its contained environment and contaminating the groundwater. A plethora of chemicals can be stored in a pond, ranging from domestic waste leachate, to mining waste, contaminated soils, plant process chemicals, and even nuclear waste. An environmentally focused client may voluntarily choose to have a dipole survey performed in order to help minimize the risk of contaminating the environment.

4.1.2 *Prevent valuable product loss*

Heap leach pads in the mining industry do not contain waste, but rather the valuable product to be extracted. If the geomembrane is not impervious then a portion of the ores dissolved in the acid will be lost, meaning a direct loss in profits. This can also be applied to large evaporation ponds and clean water reservoirs.

ELL can be used on operational ponds to detect leaks. The leaks can be found and fixed rather than having to decommission the works and rebuild a similar structure right beside it.

4.2 *Mandatory leakage reporting in regulations*

In some countries, the dipole method is recognized by the state and is required for certain applications, including landfills and landfill extensions (California and New York), and new contaminated soil storage facilities.

When managing chemicals in cells, double-lined systems are often used in order to collect leachates and measure their flow. If the flow is too great, the owner must take action. To lower the owner’s risk of downtime, a dipole survey can be performed on the primary geomembrane prior to operation.

4.3 *Reputation*

4.3.1 *Pro-Active*

A site owner or designer may choose to institute additional, non-mandatory controls to proactively ensure a good reputation with the affected population. They may also do so in order to be perceived as diligent by the environmental associations that deliver permits. It is easier to convince officials to grant permission for a project when history shows a concern for the quality of said types of projects.

4.3.2 *Reactive*

Conversely, companies involved in environmental scandals must redeem their reputation reactively. It is a tedious task to rebuild a bad reputation, and, in some cases, adding a dipole survey to a new project can be one of the tools used to show the company’s new policies and initiatives for preventing any future spills or mishaps.

4.4 *Performance measurements*

Electrical leak location is the only option for measuring the performance of the various contractors constructing the impervious works. By having an exposed geomembrane survey performed (e.g. water puddle, spark test, arc test), an owner can gauge the quality of the liner installation. Once all of the defects have been repaired, the general contractor can then install the protective layer—typically sand, gravel, or sometimes clay. The contractor’s performance can then be evaluated by having a dipole survey performed immediately following the cover material placement. Any holes found can then be directly imputed to the soil placement operations.

4.5 *Leaking pond*

Finally, ELL can be used when a pond is known to be leaking. This may be determined from contamination being recorded in groundwater samples near the works, or from excessive flow into the secondary leachate collection system. The owner must then take action to repair the imperviousness.

Dipole surveys can be difficult to perform in these conditions: the thickness of the natural materials can exceed the limits (much thicker than one meter), electrical isolation can be hard or impossible to achieve, and/or the soil may be highly heterogeneous, and thus have different electrical resistances, causing great variation in the voltages. It is therefore ideal to perform the survey prior to commissioning the pond.

Another method for determining if a pond leaks is by conducting a classic water charge test whereby the pond is filled with water and any decreases in the water level are recorded. However, with this method there are many variables (evaporation, precipitation, winds) that can affect the precision and outcome of the test. Additionally, if the pond does leak, this test does not indicate the location of the leak and a leak location survey would nevertheless need to be performed.

5 DESCRIPTION AND DEFINITION OF LEAKS FOUND

The most commonly asked questions when discussing ELL surveys is how many and what sizes of leaks are generally found and how were they created in the first place. Unfortunately, these answers are highly dependent on many factors:

- Quality of the design, including product specifications, subgrade and cover materials, ease of access for heavy machinery during geosynthetics installation and cover material placement;
- Skill of the installer and general contractor;
- Weather—work can sometimes be performed under light rain, freezing condition—and subgrade dryness; and
- Global budget of the works, a greater budget can allow for higher quality products and more time and care given to the installation.

These questions and answers are necessary however for underlining the importance of having a dipole survey performed. By analysing and discussing the data it can be easier to determine how to best improve upon the above-mentioned factors thereby decreasing the size and number of leaks created.

5.1 *Number of leaks*

The table below provides information regarding the number of leaks found by our company during dipole surveys. The information is presented based on project size: small (less than 5,000 m²), medium (between 5,000 and 25,000 m²), and large projects (over 25,000 m²). Also shown is the percentage of the projects in which leaks were found.

Table 1. Number of leaks found with dipole

	# Projects	Total Area	# of Leaks	Leaks/ha	% projects with leaks
Small projects (< 5,000 m²)	12	25 932	13	5.01	33%
Medium projects (5,000 – 25,000 m²)	25	304 792	54	1.77	44%
Large projects (> 25,000 m²)	14	788 930	60	0.76	50%
TOTAL:	**51**	**1 119 654**	**127**	**1.13**	**43%**

Generally speaking, the fact that the “small projects” category had a large number of leaks per hectare can be attributed to skewing due to their small surface area and due to two projects having a large number of leaks. This is backed by it having a lower percentage of projects with leaks. That being said, when considering leakage loss, even a small number of leaks in a pond can be impactful depending on leak size and the size of the pond. The two projects with numerous leaks were affected primarily by design/construction issues – poor choice of cover material and installation methods – and foreign materials piercing the membrane. These are common issues encountered when discussing projects with particularly a high number of leaks.

While it is not uncommon for there to be no leak found during a dipole campaign, particularly if an exposed liner leak location survey was conducted first, it is interesting to note that regardless of project size category nearly half of all projects surveyed with the dipole method had leaks.

Of the total 51 projects surveyed with the dipole method, 27 had an exposed liner survey performed first, one-third of which then had leaks detected during the dipole survey. While it is not surprising that first performing an exposed liner ELL survey will reduce the number of leaks and the chances of finding any leaks during a dipole survey, there are still a likelihood that a hole will be created after the exposed liner survey. In fact, 31 of the 127 (24%) leaks were found post-exposed ELL survey.

Therefore, one cannot rely solely on an exposed liner survey for leakage prevention, particularly since many leaks caused during cover material activities are large, as will be discussed in section 5.3. Although not the focus of this paper, it should be noted that a dipole survey ought to be performed in conjunction with an exposed liner survey because if there are any issues with dipole sensitivity smaller leaks may not be detectable.

5.2 *Types of leaks*

When attempting to mitigate the creation of holes during construction, it is also important to consider the most common types of leaks found with the dipole method. Typically, the cause of the leak, leak type, and leak size correlate.

The following pie charts show the distribution of 127 holes found in the last five years with respect to leak type and size.

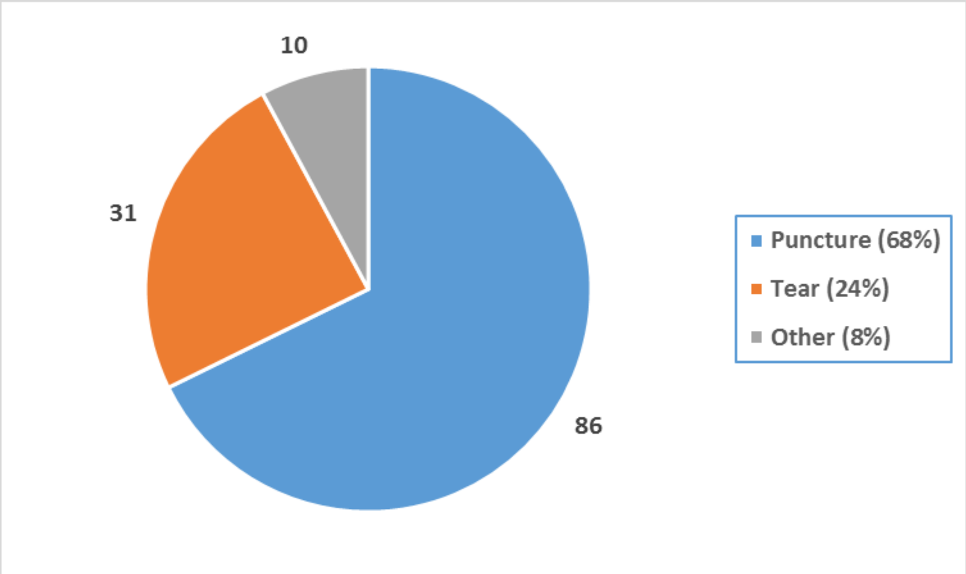

Chart 1. Types of leaks found with dipole

Not surprisingly, the most common types of leaks located during a dipole survey are those created or likely to have been created during soil placement activities. This makes sense particularly if an exposed ELL survey was performed first, and because these types of leaks are generally larger and therefore more easily identifiable as a leak, even with poor sensitivity.

Punctures are the most commonly found type of defect and are often caused by sharp rocks and traffic over the liner. Tools or surveyor stakes, and even metal scrap found in the subgrade or cover material, have also been known to damage the geomembrane. In short, nearly any sharp or hard objet can damage the liner; this can be near impossible to completely avoid on a construction site.

Tears, generally created by heavy machinery, are the second most common. Some common causes include a bulldozer's blade hitting the geomembrane at the toe of the slope, an excavator working too closely to the liner, or a rock-truck turning too sharply over the geomembrane causing enough stress to damage it. Tears can be fairly significant as they are often the largest types of leaks, as will be discussed in the next section.

The "Other" category contains bad seams (fusion and extrusion), knife cuts, and thermal leaks from a hot tool in proximity of the geomembrane melting it. These are generally found when an exposed ELL survey is performed first. These defects are normally very small and therefore, unless the conditions are ideal for performing a dipole survey (as discussed in section 3), may not necessarily be found with the dipole survey.

It might be of interest to add that the question of how many leaks were not found is often posed. Alas, this information is impossible to know unless a second dipole survey were to be conducted, and even then, the leaks missed would be either really small or dry, and not easily detectible. However, a hole simulation is always used prior to performing the survey in order to calibrate the device, therefore the minimal size of leak that is detectable given the site parameters is known.

5.3 *Sizes of leaks*

The distribution of leak sizes (ranging from less than 1 cm^2 to greater than 100 cm^2) found in the last five years is shown in the chart below.

The majority of the leaks found were greater than 1 cm^2, which can be consequential in terms of flow through the impervious layer. Surprisingly, and alarmingly, eight percent of the leaks were greater than 100 cm^2. In general, the largest leaks found were tears. In fact, the largest hole found was a tear greater than 12 meters across. It may be surprising that these large holes are not noticed prior to the survey, however, once natural materials cover them, the dipole method is the only way to detect them.

Tears can also be significant enough to penetrate through multi-layer systems. When a geocomposite clay liner (GCL) is used, a false sense of security may be felt. Given that it can block pinhole leaks, one may assume that no dipole survey is required, as the GCL will abate the flow through the hole. However, if the GCL is ripped or sufficiently damaged it may be useless in blocking the flow. This was the case with a 4-meter long tear that penetrated the puncture resistant geotextile, 1.5 mm thick HDPE geomembrane, and the GCL. Had no dipole been performed, the leakage through this tear would have been costly.

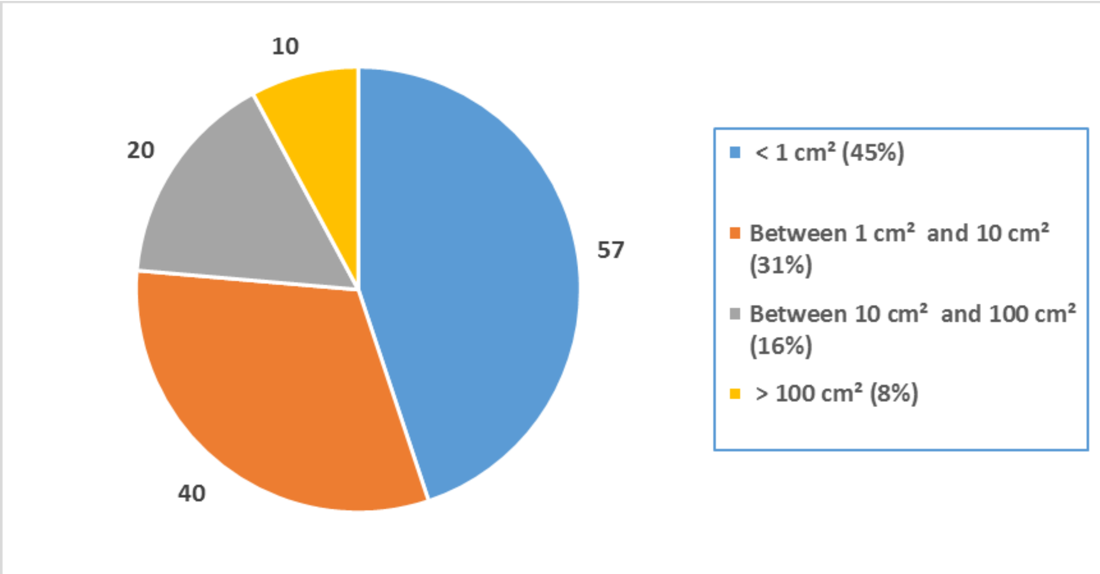

Chart 2. Sizes of leaks found with dipole

6 CONCLUSION

Dipole surveys are performed for a multitude of reasons: they can be mandated by regulations or be performed as part of good practice. They can prevent the loss of valuable liquid or contaminants into the environment, can help evaluate the performance of the installer and the general contractor, and should ideally be used gather knowledge and improve designs. Sadly, they are also often performed reactively on leaking ponds that must be fixed.

Planning for an ELL survey not only saves money it also increases survey accuracy and the speed at which the survey is conducted. When the leak location company is consulted at the outset of the project minor changes can be made to the construction methods or to other conditions that will affect positively the dipole sensitivity. It is nearly impossible to remove a layer of cover material if it is too thick or has poor conductivity, and while it may be possible to dig an isolation trench all around the works, this can damage the geomembrane significantly. Although less risky options are available, such as using a vacuum-truck to clear the peripheral cover material, it is nevertheless cheaper to plan for this in advance.

Only a dipole survey can give an accurate vision of the integrity of a geomembrane once it has been covered. With the dipole survey, the number of defects found on our projects has ranged from zero to 14 per hectare, with an average of just under two leaks per hectare. Generally, larger projects had a smaller defect rate likely due to better planning and design decisions, operators and contractors who are more familiar with the requirements of these types of projects, and less manipulation and traffic over the same area. Also, with larger surfaces full rolls of geomembrane can be installed, reducing the number seams, cuts, and extrusions.

In our case, finding all geomembrane holes is important, regardless of the size, because they would otherwise have contributed to the overall leakage rate. Locating pinhole leaks convinces clients and owners that dipole surveys can be very precise when the conditions are favourable, and locating large tears has a significant impact on the effectiveness of the site and may prevent severe groundwater contamination.

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