Constructing a Zero Leak Landfill Cell

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Abstract. Engineered landfill barriers are the last line of defence in protecting precious groundwater resources from contamination. A landfill cell without any leaks at the conclusion of construction is the exception rather than the rule. From design to materials testing to installation practices and contractor care, all of these elements contribute to both the short and long-term integrity of the lining system. Electrical leak location (ELL) methods can be used to detect leaks in installed landfill cells after construction so that leaks can be repaired before a landfill cell begins filling operations. However, the thorough testing of landfill cells using ELL can be complicated by their complex configuration. The dipole method, employed after cover material placement, requires electrical isolation of the cover material, which is difficult to achieve with a landfill expansion cell configuration. Additionally, employing only this type of testing can leave the tie-in area untested, which is a critical area prone to damage. This paper provides solutions for complete landfill expansion cell testing, including a relatively new testing methodology (ASTM D8265, [1]), which provides protocol for verifying that a geomembrane has been successfully installed with no leaks. A case study is included to show how ASTM D8265 can be used to provide documentation of a zero-leak condition of a landfill cell after construction. Common elements of design, geomembrane installation, and quality assurance are discussed in order to provide a road map of how to reach a zero-leak condition at the end of a landfill expansion cell construction project. This paper can be used as a guide to constructing a zero-leak landfill cell using state-of-the art construction practices and ELL testing methodologies.

1 Introduction

It is possible to install a landfill lining system that will create a perfect barrier between contaminants and groundwater, but it is not a simple task. ELL methods can be used to locate leaks in lining systems at the conclusion of construction, but leaks can develop over time if proper construction methodologies have not been followed. The intent of this paper is to detail the design and execution of landfill cell construction with the goal of zero leaks in the lining system. Three categories are presented in this paper in order to reach the zero-leak goal; design, construction practices, and ELL testing. It does not include landfill

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operations, where damage can occur if care is not put into the first layer of waste placed into the landfill cell.

1.1 Design Considerations

Apart from landfill design criteria for catastrophic failure such as slope stability analysis, there are a number of more subtle design criteria that may pass muster on initial analysis and testing. One of these is the design of cushion geotextiles. Puncture damage is commonly detected through dipole method ELL but punctures start with small, localized stresses. Geotextile cushion specification through puncture testing is typically informed by the lack of puncture to the geomembrane at the completion of short-term testing, but studies have shown that areas of stress can become leaks over time [2].

The more difficult something is to construct, the more issues it is likely to have and some difficult-to-construct geometries are also particularly difficult to test using ELL. The booted pipe penetration is a prime example of being both difficult to construct and difficult to leak test. The ideal number of penetrations through a liner from a leak mitigation standpoint is zero. The fewer the better, and if they are unavoidable, prefabricated pipe boots are far better than field fabricated pipe boots. Along these lines extrusion welds should be minimized and fusion welds should be used instead wherever possible [3]. Sharp bends (for example 90 degree corners) should not be part of the design.

Minimizing wrinkles is important to reduce stress to the lining system but even more importantly, wrinkles break the intimate contact between the geomembrane and the underlying surface. With an air gap between the liner and the underlying subgrade, the electrical continuity is also broken and a leak can go undetected. If a leak is located on a wrinkle in a composite lining system, the wrinkle acts like a hydraulic conduit and fills up and the geomembrane will fail completely to restrict leakage in this area. A HDPE geomembrane with wrinkles (and 5 leaks per hectare) performs only slightly better than a low-permeability soil liner alone [4].

1.2 Construction Considerations

In order to minimize and/or eliminate leaks for both the long and short term, there are many important installation practices that should be used. Several of the most important ones are outlined here.

First, the subgrade of the geomembrane should be free of rocks or any sharp objects. Additionally, if a cushion geotextile or overlying geocomposite will be employed, careful attention should be paid to avoid any rocks or debris on the geomembrane before geotextile or geocomposite deployment. Particle size should be controlled for geomembrane cover material.

The use of straight (open) blades should be limited or ideally eliminated. The use of hooked blades are less likely to mistakenly cut the geomembrane while in use. Cuts to the geomembrane should be rounded and not straight wherever possible. Even a superficial cut to a geomembrane can propagate through the material over time if it has a crystalline structure such as HDPE. To prevent cuts to the lining system, all patches should be created on a rub sheet or off of the lined area entirely.

While making extrusion welds, technicians must be mindful of not overheating the extrudate or the liner. Overheated material can become brittle over time and cause stress cracking. Technician skill and attention to detail is paramount for not only extrusion welding, but also while checking for leaks using the vacuum test method [5]. Most issues can be successfully found on extrusion welds with a properly performed vacuum test.

1.3 Electrical Leak Location (ELL) Methods

1.3.1 Covered Geomembrane Testing

Installed geomembranes for landfill cells are always covered by a layer of material that provides protection for the geomembrane and drainage capacity for leachate. Earthen materials are typically used for this layer, making them electrically conductive with very minimal moisture content. It is important to note for landfill cell construction that in the first author's experience, tire chips (a.k.a. tire-derived aggregate) do not work as an overlying conductive layer. For ELL testing, a DC voltage source current injector electrode is inserted into the cover material, with the return electrode in contact with the material below the geomembrane (which must also be sufficiently conductive). The cover material must not be allowed to be in contact with the underlying layer along the entire perimeter of the testing area. In practical terms, the cover material cannot extend past the installed geomembrane to touch ground. The earthen materials are placed just short of the liner termination(s) and the tie-in to the existing landfill (if applicable). This results in the only electrical path from the current injector electrode to the current return electrode being through any leaks present in the geomembrane. For the dipole method, the direction of current flow throughout the testing area is measured using a dipole instrument, which measures the voltage differential between two points at the surface of the cover material. The systematic acquisition of voltage differentials in a grid pattern throughout the testing area creates an electrical map that reveals the current paths throughout the testing area. Leak locations will appear as discrete points of low voltage inside of the testing area, where the current is flowing out of the cover material.

The dipole method has been proven to be extremely effective at locating even the smallest leaks for this relatively thin cover material. However, pinhole-sized leak detection sensitivity is not reliable. Sensitivity is a function of testing area isolation, cover material and underlying substrate electrical conductivity, moisture content directly above the geomembrane, dipole instrument spacing, dipole method procedures, dipole instrument design, cover material chemistry, and cover material thickness, among other factors [6].

Because of the requirement for the cover material to be isolated from ground, a strip of installed geomembrane along the entire perimeter of the landfill does not get tested if only the dipole method is specified. This may not matter if this happens to be at the crest of a slope at the flat section leading to the anchor trench, which should not ever need to contain leachate. However, if the landfill cell being constructed is an expansion from an existing cell and the isolation gap encompasses the tie-in area where the new liner is being welded to the existing liner, it matters a lot. The only way to test that area effectively is while bare, unless some sort of isolation flap is incorporated into the design.

1.3.2 Exposed geomembrane testing

ELL testing of exposed geomembranes is technically simple and highly sensitive. The nuances of exposed geomembrane testing have been explained by Charpentier et. al. [7], but in general the pinhole-sized level of sensitivity is extremely reliable. There are two types of exposed geomembrane testing methods, one which applies water to carry a low voltage and another which uses a very high voltage to create an electrical arc through the air (up to about 3 cm long). If water-based methods are used (ASTM D7002 [8] and ASTM D7703 [9]), the applied water should be contained within the testing area. If the water flows to ground during the test, it will compromise method sensitivity. The high voltage based testing methods (ASTM D7953 [10] and D7240 [11]) are employed by scanning the surface of the geomembrane with a probe connected to a high voltage power supply. In the case of a leak, an electrical arc forms and the discharge of current causes the instrument to produce an alarm.

1.3.3 Method Application to Landfill cells

The dipole method should always be specified after cover material placement for landfill cells due to the potential for damage to be caused during cover material placement. At best, it will locate every leak in the liner under the cover material, and at worst it will only locate the major damage incurred during cover material placement (as long as perimeter isolation is good). The importance of this test coupled with the technical difficulty of it and the lack of transparency during testing demands a higher level of documentation. This includes the specification of ASTM D8265, which makes the results of soil-covered geomembrane testing completely reviewable by a third party. The original testing standard used for dipole method testing (ASTM D7007, [12]) has less stringent testing protocol and does not require enough documentation for third party review of testing results.

For some landfill configurations, the dipole method is the only test necessary. Some landfill cells are designed with rain or gas flaps welded between the existing cell and any adjacent cells. With these geomembrane flaps in place, they provide the necessary perimeter isolation so that the installed geomembrane can be tested all the way up to the flap. Even if the cover material is placed short of the flap, the gap between the cover material and the flap can be flooded with a thin layer of water and it can be testing along with the soil-covered area (as in the case study presented here).

The effectiveness of the dipole method requires an electrically isolated survey area. If a landfill cell does not have welded isolation flaps along the perimeter (which is not usual), the cover material must be placed just short of all of the edges of the landfill cell. There should be a clean, dry strip of geosynthetics visible around the entire perimeter. Typical landfills include “tie-in” areas, where the new liner is welded to the older liner of an existing cell. This tie-in area commonly falls inside of the perimeter isolation required for dipole method testing, leaving this area untested. The best way to test this area is by using the arc testing method (ASTM D7953). The high voltage method does not require the use of water to carry current, so the testing area is limited to where the probe is touching the liner. This test can either be done immediately after liner installation, or it can wait until dipole method testing is performed, as long as this area is left uncovered. Overlying geotextile or geocomposite can be folded back until this test is complete (See Figure 1).

It should be noted that the electrical arc used for arc testing can and will cause a fire if methane in sufficient quantity is present. It should therefore not be used if methane is present above the lower explosive limit.

It may not be sufficient to simply specify ASTM D8265 for the covered portion of the cell. Knife slices can be difficult to detect, since they must be thoroughly wet in order to be detected. However, knife slices are routinely found by the dipole method in wet site conditions. When site conditions are not guaranteed to be wet, as the case in arid climates, where the contractor is unprepared to thoroughly water the cover material to the extent where the irrigation reaches the top of the geomembrane, or where the landfill configuration makes it difficult to achieve a hydraulic gradient across the liner (steep slopes), a bare geomembrane method should be used before any overlying materials are placed.

The price of ELL testing is a tiny fraction of the project cost and most testing methods can cover 1-4 hectares per day, so schedule and cost are not practical deterrents.

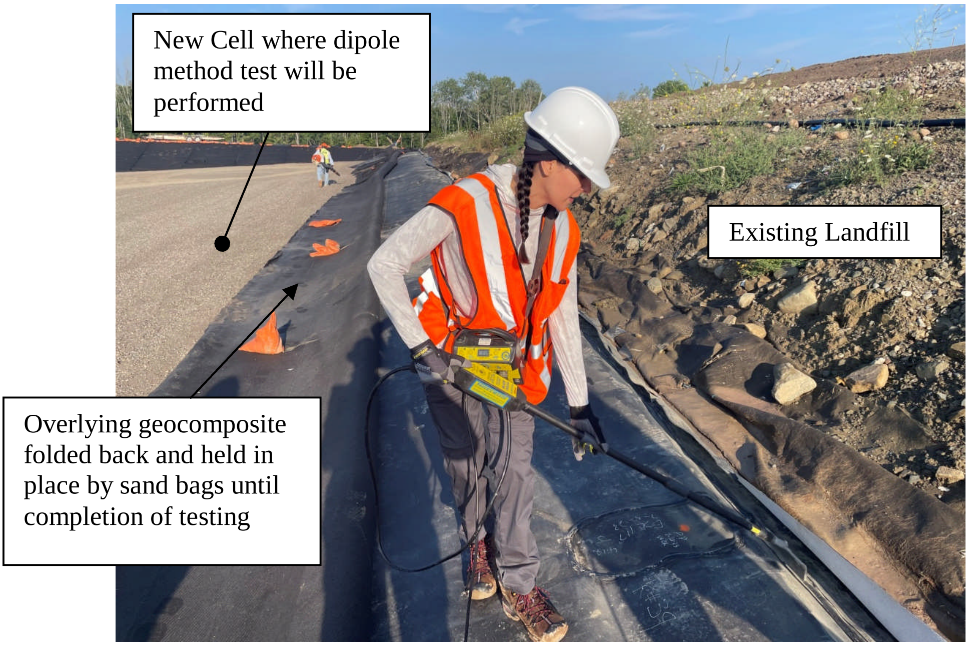

Fig. 1. Arc Testing method being performed on tie-in area.

1.3.4 ASTM D8265: Electrical Methods for Mapping Leaks in Installed Geomembranes

One of the reporting criteria that distinguishes this testing standard from other ELL testing methods is the requirement to provide the complete testing results in the form of maps that clearly show the measured values throughout the survey area so that testing results can be easily and thoroughly reviewed by a third party.

For dipole method testing, a survey direction is chosen and the dipole must remain in the same orientation as it collects voltage data in a grid pattern throughout the survey area. All voltage maps presented here are with the dipole travel direction from bottom to top, with voltage measurements obtained between the front foot and back foot as the dipole is facing the direction of travel. Negative voltage values are coded by changing from red to blue to black with increasing magnitude. Positive voltage values are coded by changing from green to yellow to white with increasing magnitude. If current is traveling from the current injector, the dipole will measure a negative/positive polarity throughout the survey area, with positive values below the current injector and negative values above the current injector. Locations where current is exiting the survey area (e.g. leaks) will appear as the opposite; a negative area directly below a positive area. These negative/positive areas will form circles above and below the leak location, separated by tightly spaced contour lines, looking a bit like a butterfly on its side. An example voltage map is provided as Figure 2. The applied voltage and site response current must be reported along with the corresponding voltage map(s).

The requirement for mapping is the main feature of this standard, but there are several other measures in effect to uphold survey quality. In order to standardize method sensitivity across multiple dipole sizes used by practitioners, the measurement grid spacing is not allowed to be larger than the width of the dipole used. Leaks can be missed along the edges of a survey area if they occur at the ends of the survey transects because it is the positive/negative pattern that makes a leak detectable, which means that the dipole must gather data on both sides of the leak. This is why the standard also requires transects parallel to each edge of a survey area. The standard also requires that the dipole apparatus use measurement probes that are not reactive with the cover material. Simple probes such as stainless steel cause voltage offsets in many common earthen and liquid materials. Finally, the site response current both with and without an artificial leak must be quantified. If the artificial leak draws more than 10% of the site response current, then the survey must be performed with the artificial leak disconnected. This is because a significant amount of current is being drawn to the artificial leak, which could compromise testing sensitivity.

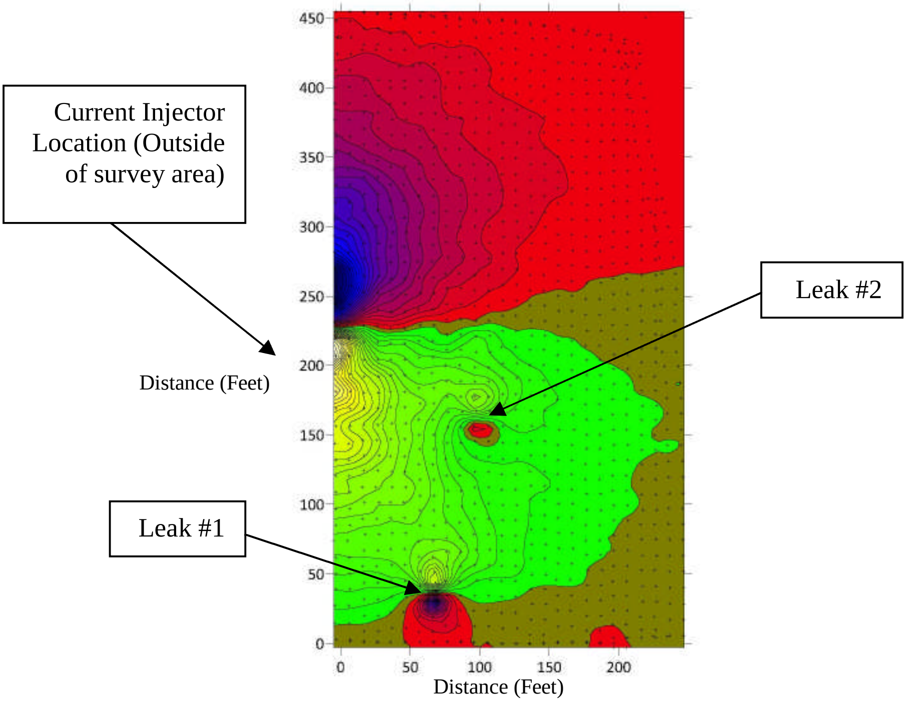

Fig. 2. Dipole Method Voltage Map as required by ASTM D8265

2 Zero-Leak Case Study

If site conditions are not ideal at the time of a dipole method test, which is typically scheduled exactly when needed in spite of whatever weather might have preceded the test, it will likely not be possible to provide a zero-leak verification. Landfill cells practically always have a geotextile or geocomposite above the geomembrane, which traps moisture after a rain event. There must be sufficient moisture inside of the testing area, but if the perimeter of the testing area is not completely dry, there will be current flow through the isolation gap. This does not mean that the test will not be effective. With sufficient moisture and reasonably good isolation, it is typical that all leaks can be detected. However, when there is no path that the current can travel, whether through leaks or through suboptimal perimeter isolation, a barely detectable amount of current is emitted from the current injector electrode. The circuit would be completely broken if the geomembrane were a perfect insulator. In fact, HDPE is an excellent insulator but it will allow a very small amount of current through the intact geomembrane [13]. When even one leak is introduced to the system, it behaves completely differently and this is very evident in the electrical mapping and measurements required by ASTM D8265. The following describes testing protocol and results for using ASTM D8265 to verify that no leaks exist in a landfill lining system installed by Chenango Contracting.

Figure 3 shows dipole method equipment during testing at the landfill expansion cell. Items to note in the photo are the standing water present at the low end of the cell and the welded isolation flap separating the new cell from the existing one. The standing water present in the cell (resulting from a significant rain event within days of testing) ensures that even the smallest leaks have good contact with the underlying conductive layer. The isolation flap ensures electrical isolation of the cell. All other edges of the cell had excellent isolation from the sunny weather, which dried out the geotextile present in the perimeter isolation gap. Clean, dry geosynthetics are sufficiently electrically insulative.

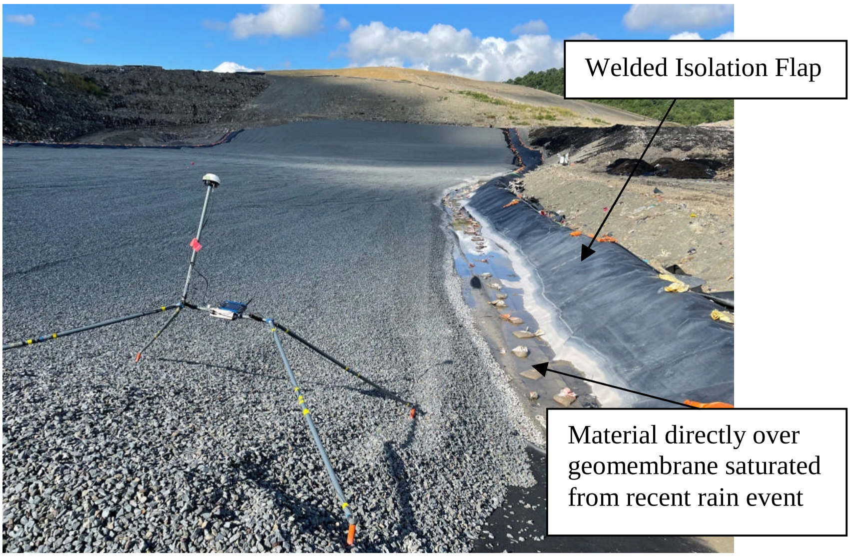

Fig. 3. Landfill expansion cell with proper site preparation for zero-leak verification

2.1 Functionality Testing

Method functionality testing begins with introducing an artificial leak into the survey area, which behaves electrically like a leak but can be disconnected. It is buried under the cover material and sits just above the geomembrane. A voltage is introduced to the survey area to measure the site response current. Then the artificial leak is connected, the same voltage applied, and the site response current measured again. When a relatively small simulated leak makes a large difference in the site response current, it is an indicator of very good site conditions, since a significant amount of current is flowing though the simulated leak (and not through other leaks or locations with isolation issues). At this site, the application of 500 V resulted in a site response current of 0.5 mA, and 20 mA with the artificial leak connected. The first directive of ASTM D8265 is to calculate the increase in the site response current with the artificial leak connected and to perform the testing with the artificial leak disconnected if it results in an increase of over 10%. Leaving it connected during the test would affect method sensitivity (i.e. the ability to detect smaller leaks).

Following ASTM D8265 protocol for this case study, a map of the artificial leak was created while it was connected to document the signal strength (See Figure 4). The measurements were taken at the "worst-case" measurement positions of the prescribed measurement density. The artificial leak was then disconnected to begin landfill cell testing.

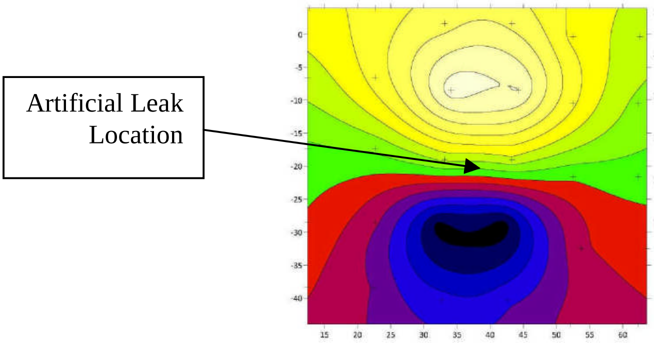

Fig. 4. Artificial leak map, Contour Interval 0.50 V

2.2 Landfill Cell Testing in the Absence of Leaks

The voltage map of the survey area is presented as Figure 5.

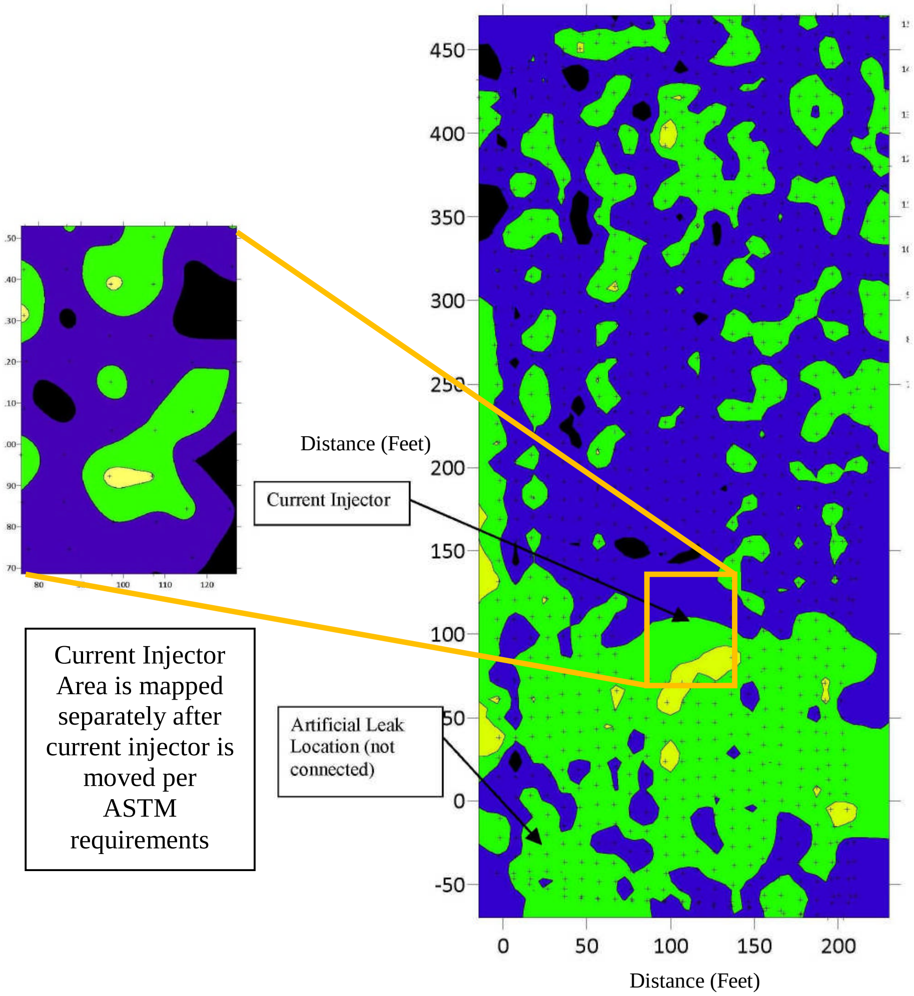

Fig. 5. Survey Area Voltage Map, Contour Interval 0.05 V

The first noticeable difference between this map and a typical dipole method voltage map is that there is no strong positive/negative polarity created by the current injector throughout the survey area. In fact, there are no locations throughout the survey area that have any strong voltage values. The contour interval was decreased by a factor of 10 to be able to see any contour lines, essentially magnifying the measured voltages by an order of magnitude in comparison with the Figure 2 map of the artificial leak. The voltage field is slightly mottled by the imperfect contact between the dipole feet and the granular cover material. This type of slight instrument "noise" is typically overpowered by voltages obtained throughout the survey area originating from the current injector, as shown in Figure 1, but on this map it is the only voltage oscillations of note. This map is indicative of an extremely resistive path from the current injector to the return electrode. In other words, there are no leaks in the survey area to provide an electrical path through the liner. If there was a leak anywhere in the survey area to draw a measurable amount of current, the current coming out of the current injector would be measurable (i.e. visible on the map throughout the survey area).

2.2.1 Additional Map of Current Injector

In order to verify that the barely detectable current flow is due to the lack of leaks rather than a non-functioning circuit, an additional map is required to document the current injector in the presence of a leak. Figure 6 shows the additional map that is required in order to document measured voltages around the current injector while the artificial leak is connected to the survey area.

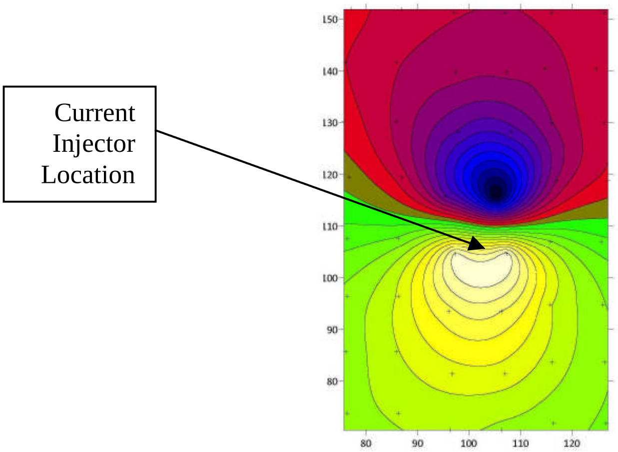
Current Injector Location

Fig. 6. Current Injector Location while Artificial Leak is Connected, Contour Interval 0.50 V

3 Conclusions

A leak-free landfill starts in the design phase and continues through construction with good installation practices. ELL methods can locate all leaks at the conclusion of construction with highly controlled site conditions and proper testing procedures, but even with poor site conditions the most significant damage can be found. At a minimum, the dipole method (ASTM D8265) should be specified. Project-specific geometries and local climate should factor in to the specification of ELL methods. In arid climates, a bare liner testing method should be used before cover material placement. The tie-in area should be tested using the arc testing method if it cannot be tested using the dipole method. Landfill design should avoid pipe penetrations, provide for sufficient geotextile cushion, and make provisions for minimizing wrinkles and extrusion welds. Subgrade for liner installation should be free of rocks or sharp objects, the use of open blades should be minimized or eliminated, all cuts should be made outside the lined area if possible, and care should be taken not to overheat extrusion welds.

Although it sounds merely aspirational to achieve zero leaks, the technology currently exists to document a zero-leak condition, as shown by the case study presented. But even if a zero-leak condition cannot be verified, the more design, construction, and testing practices that are implemented that are geared toward minimizing or eliminating leaks, the more likely the zero-leak target will be achieved.

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