A Miner's Guide to Electric Leak Location for Geomembrane-Lined Containment Systems

Shawn Calendine
hydroGEOPHYSICS, Inc., Tucson, Arizona, USA

Dr. Nigel Crook
hydroGEOPHYSICS, Inc., Irvine, California, USA

Brian Minkin
hydroGEOPHYSICS, Inc., Irvine, California, USA

ABSTRACT: Geosynthetic liners form an integral part of the mining process, existing principally as substrates for ponds, heap leach pads, and tailings piles. Geosynthetic liners function primarily as impermeable barriers between the substance it contains and the earth below, protecting the environment. Invariably, leaks occur throughout the life of a lined system. Damage can occur from inadequate installation procedures, improper usage, environmental factors, and age, creating tears, rips, or punctures. Undetected leaks result in lost revenue, reducing life-of-mine projections through repeated product loss, shutdowns, increased liabilities, and environmental degradation. Electrical leak location (ELL) methods have set the standard for finding breaches in non-permeable geosynthetic liners for over thirty years. However, mine operators often lack knowledge of leak location technology or how to prepare for a leak location survey when needed. This paper outlines the rudiments of the leak location process and describes preemptive steps every mine operator should take to ensure a successful survey.

1 INTRODUCTION

Mines across the globe depend upon impermeable geosynthetic liners to help reduce environmental impacts while extracting increasing quantities of valuable minerals. With the green energy revolution placing greater demand on critical materials such as copper, cobalt, and lithium, geosynthetic liners are more essential than ever. Primarily, impermeable geosynthetic liners act as competent barriers between the subsurface of the earth and the constituents these systems contain (Calendine 2016). These containment structures can be massive, on the order of tens to hundreds of acres. The contents are often hazardous and can pose significant environmental risks if leaks occur. Having a technology to locate leaks in these systems during the construction and operational phases is vital in maintaining the health and safety of the environment and industrial operations.

In the process of building and maintaining containment structures, leaks invariably occur. Fortunately, technology capable of locating leaks during construction and operational phases exists. Implementing ELL technology for impermeable geosynthetic liners is essential for managing and operating industrial containment systems. ELL surveys have been commercially available since 1985, with subsequent standards being developed and refined for various applications (Kemnitz 2013). ELL relies on the principle of electrolytic conduction, the ability of electrolytes in a solution to conduct electric current flow. Geomembranes are highly resistive and act as electrical sheet insulators, while the structure's contents are typically conductive. While simple in concept, applying this technology can be challenging and frustrating if the many factors needed for a successful survey are unmet. This paper consolidates the knowledge gained from more than two decades of performing ELL surveys. It outlines the essential tasks and questions for mining operators to consider prior to and throughout the survey process so that ELL surveys are conducted right the first time.

2 LINER LEAK LOCATION FUNDAMENTALS

2.1 The Bare Liner Electric Leak Location Methods

In the case of bare liner surveys, a current is imposed onto the liner itself using two different techniques: the water puddle method and the spark testing method. The water puddle method works by creating a circuit between the liner to be tested and its substrate using a power source, water, and an ammeter. Induced electric current is delivered via water through a mobile device that sprays the charged water source onto the liner. The power source provides the electrical current being grounded to the substrate below the liner. When the charged water flows through a hole in the liner and contacts the substrate, the circuit closes and the ammeter, detecting the closed circuit, emits an audible tone to alert the operator to mark the area for repair (Calendine 2016).

The spark testing method uses a high-voltage pulsed power supply to charge a capacitor created by the non-conductive liner surface, the underlying conductive layer of the geomembrane, and a coupling pad (ASTM D7240). A test wand is then passed over the surface of the liner to locate holes. When the wand encounters a hole in the liner, an electrical discharge occurs between the underlying conductive side of the liner and the test wand on the liner's resistive surface. The discharge event is converted into an audible alarm alerting the operator to the hole.

2.1.2 Covered Liner Electric Leak Location Methods

For covered liners, electric leak location works by inducing electrical current into the material or fluid contained within the liner. The contained material and fluid are often highly homogeneous; thus, current distribution across the media will usually be uniform over the intact and undamaged liner. When a hole breaks a liner's integrity, current flow increases, creating a region of high current density associated with a leak. Sensors or probes are deployed across the survey site to map areas of high current density associated with holes in the liner, indicating individual leak locations. The current source supplies electric current delivered via two electrodes (conventional current flow); one is placed into the soil or water column on top of a liner, and the other is grounded to the conductive media under the liner. For double-lined systems, the second electrode would be placed between the liners in the annulus.

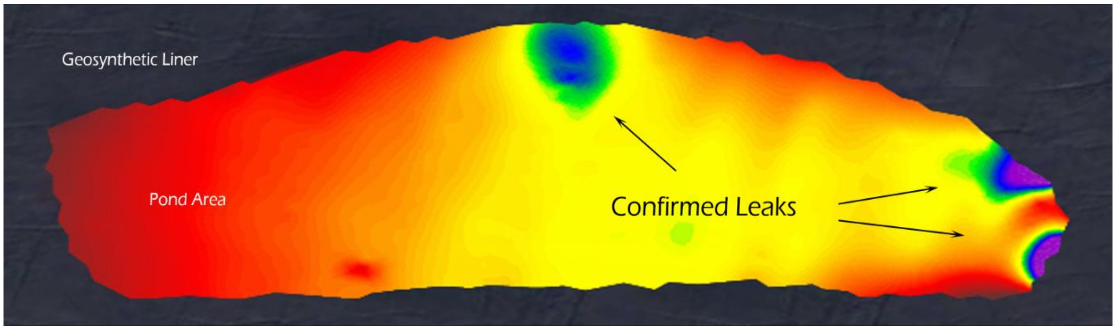

Figure 1: The plot above shows, in a plan map, the electrical response of an electrical leak location survey in a water-filled pond. The red and yellow colors indicate resistive regions of the liner that are intact without holes. The green, blue, and purple areas are electrical responses to leaks in the liner. Clients can easily visualize the location and magnitude of the leak response.

2.1.3 Leak Maps For Bare Liner Leak Location

In the case of bare liner methods, leak responses are marked and numbered in real-time using grease pencils and spray paint. A surveyor will GPS each mark and create a map of the holes by overlaying the GPS data on an aerial image of the survey area. Repair companies will use the maps to locate all holes and make repairs.

2.1.4 Voltage Maps For Covered Liner Leak Location

This author believes there needs to be a concerted effort to move away from traditional real-time leak location methods that rely exclusively on the subjective decision-making process of operators. Instead, a process of acquiring and storing data that is subsequently processed and analyzed for leak responses should be the norm for covered liner leak location results.

Electrical maps are created using the electrical measurements acquired from ELL surveys. Following the physical study, leak location data is processed, analyzed, and displayed in two-dimensional rainbow plots. The plots are analyzed for the presence of any characteristic responses representing a leak location (ASTM 8265). The ability to record data and review subtle details back in the office improves project success by allowing for a complete understanding of the entire dataset and the embedded trends and responses. Data processing and analysis to confirm leaks and reduce false positives are significant advantages to the leak location process, offering the highest quality results.

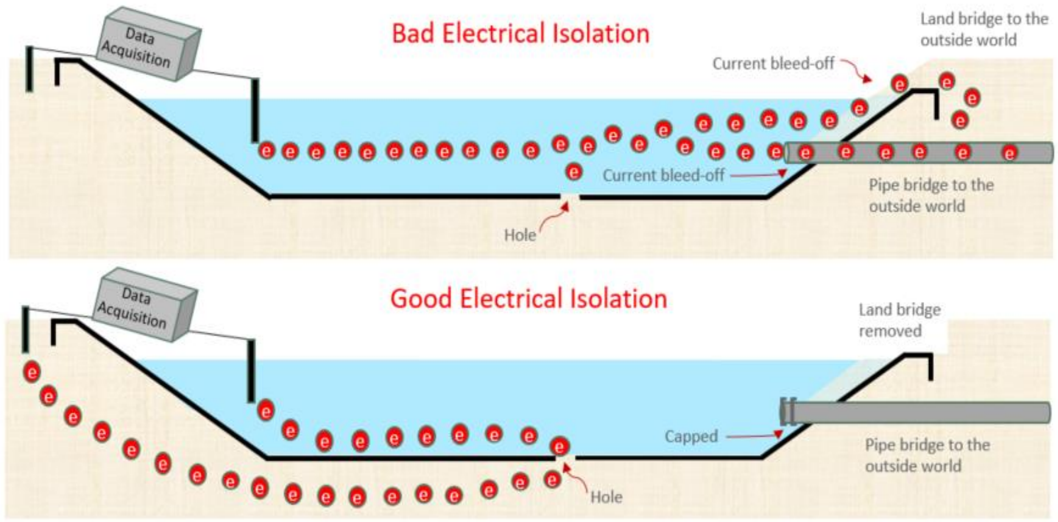

Figure 2: Top graphic shows elements of poor electrical isolation in a geomembrane structure. In the bottom graphic, barriers to quality electrical isolation are removed.

3 STARTING THE PROCESS - SURVEY NEED & SCHEDULING

3.1 New Structure Survey

Every new pond and liner installed should include an ELL survey as part of the construction quality assurance process (CQA). Liner installation requires heavy equipment, tools, and a large workforce to lay the liner and seam it together. Human error, environmental factors, and a liner's industrial setting harbor the potential for unintentional breaches in newly lined facilities. ELL surveys complement state-mandated CQA testing, such as spark tests, providing an extra layer of assurance. In addition, holes located during installation are easily fixed by crews already on site.

3.1.1 Regulatory Required Survey

Depending on the type of material contained within a structure and its location, a regulatory agency may mandate that operators administer a leak test, referred to as an integrity assurance test. Because regulations constantly change, a structure not requiring testing currently may need it in the future. Regulatory agencies can request assurance tests yearly, every other year, or set customized requirements based on the contents contained within the structure. If you don't know your regulatory situation, it is essential to find out as soon as possible.

3.1.2 Suspected Leak Survey

Facility operators commonly initiate ELL surveys because of suspected leaks. Here facility operators suspect a system may leak following observed changes in fluid levels, fluid in leak detection sumps, changes in structural integrity, or an environmental or anthropogenic event potentially causing damage to the liner.

3.1.3 General Scheduling

When a leak situation is suspected or discovered, the race is on to find and fix the leaks. Facility operators must prioritize leak repairs based on the importance of a leaking structure and if leak rates are reportable to regulatory authorities. If conditions are severe enough, potential shutdowns could occur. Often facility operators call leak location providers wanting them on-site in a few days; however, contractors can rarely mobilize that fast. Survey design, proposal creation, and contracting may take a minimum of two weeks, or the surveyor may be unavailable. Inclement weather, site constraints, and schedules further complicate mobilization efforts. Extreme winter and summer weather limit the capability of providers to work efficiently. In extremely cold regions, surveys can only be done at specific times of the year. In desert areas, a leak location provider may need to work at night, as daytime temperatures may be too hot to operate safely. A site's hours of operation may expedite or extend surveys. Often leak location surveyors will work 10 to 12-hour days, including weekends. Sites operating 24/7 see results faster than those operating Monday through Friday, 8 to 5.

Additionally, lined containment system surveys are constrained by the area a leak location provider can survey per day. New liner installations commonly use the water puddle, spark test, or arc testing ELL methods for liner leak investigations. Typical production rates for an eight-hour day vary between methods: two acres using water puddle, one-acre using spark testing, and 1.7 acres with the arc testing method. For facilities smaller than 10 acres, testing can be completed in less than a week. More extensive facilities, hundreds of acres in size, could take weeks or months and require multiple mobilizations as leak testing can outpace construction. Site operators should coordinate efforts with construction management and leak detection providers to optimize testing schedules.

4 SITE LOCATION & STRUCTURE CONDITIONS

4.1 Where is the site location?

While conveying the location of your site to an ELL provider is an obvious first step, it is essential to understand that a site location can significantly impact scheduling, cost, survey design, and safety considerations. Different settings may require survey adjustments. For example, most liners used in the mining industry are made from high-density polyethylene, a plastic commonly referred to as HDPE. When the geomembrane is exposed to solar heating, prominent wrinkles, buckles, or waves can develop from thermal expansion (Chappel 2012). HDPE's black color also absorbs and radiates heat, making it hazardous to work on as liner surface temperatures can easily pass 130 degrees on a sunny day. Scheduling the study at night reduces thermal expansion effects and is safer for working upon. In contrast, rain and storms can be challenging if the site is in the tropics, and alpine environments can have problems with ice. High altitude sites can be especially challenging. For example, a crew at 14000 feet may only work 6 hours per day and have to take 15-minute breaks every hour to prevent altitude sickness. The examples mentioned are only a small number of situations when considering a facility's location. Be sure to provide the ELL service provider with an extensive profile of your site and a labeled google earth KMZ file. Google Earth images give a birds-eye view of your structure and pinpoint where crews can find supplies, housing, and food.

4.1.1 What are the size, type, and shape of your lined structure?

The size, type, and shape of containment structures are almost always unique, as their design and engineering are for specific requirements. These structures can also have highly unusual shapes, defined by terrestrial areas available to the facility. These three factors considerably impact survey cost, design, and safety. For example, the larger the lined structure, the longer the survey duration, and the more the survey will cost. The type of structure (pond, Heap Leach Pad, Tailings Pile) will determine which ELL method is used and reveal safety considerations unique to each site.

Often the operators requesting ELL surveys were not on site when the system was built and may have little knowledge of the complete design. Operators should forward engineering plans to the provider as these will give details not visible from initial assessments. It is also essential to provide current ground-level photos of the survey area. Industrial sites are constantly evolving, and google earth images may not reflect the current conditions of your structure. Images give ELL providers crucial, high-resolution visual information to develop a survey design and understand electrical isolation (see discussion below).

5 SURVEY DESIGN QUESTIONS

5.1.1 How Do You Know You Have A Leak?

Determining if a liner is leaking is not always obvious, especially if the structure is large or covered with soil or other materials. The first indication that a leak may be present is usually accompanied by empirical evidence: solution pooling outside a lined containment area, observed solution in leak detection sumps, or a drop in solution levels. However, industrial sites are highly complex, and much consideration must be given to understanding why a particular event occurs. Due diligence through testing and reviewing fluid level measurements and calculations can offer a more detailed view as to whether a structure is leaking or not.

5.1.2 What is the state and age of your structure?

How long a liner lasts is an open question. Knowing a bit about its history and getting a piece of the liner tested can tell you a lot about its stage of life. A liner's age prompts ELL providers with likely leak locations. Leaks in newly installed liners occur along seams or around penetrations where small liner pieces are welded together to fit around pipes, pillars, and other protrusions. Operator error is often the cause of leaks during their mid-life, where leaks occur during regular operation and maintenance. Damage can also occur from sudden environmental shocks such as major storms, earthquakes, or slope stability changes. In older structures' recurrent environmental stressors weaken the liner material causing cracks to develop along wrinkles and folds, while punctures happen more frequently as the HDEP softens and becomes less ridged.

5.1.3 How is the structure lined, and what kind of liner is used?

Determining if the structure is single or double-lined or uses conductive backed liner material dictates ELL survey design. A reference electrode will go into the ground just outside the pond for single-lined systems, while a reference electrode will go between the liners in a double-lined structure. Additionally, in a double-lined system, the space between the liners will need to be flooded with water to carry electrical current for the leak detection survey, while in a single-lined system, the soil below the liner carries the current for leak detection. Conductive backed liners occur when one side of HDEP liner material is made with a conductive backing. This material is typically used in new double-lined systems so that bare liner surveys can be performed on the top liner during the CQA process. Mining operations commonly use single geomembrane liners for copper leach pads, and composite liners are more common for gold and silver leach pads (Breitenbach). Process ponds are usually double-lined systems with a geonet between the two liners.

5.1.4 Is the liner exposed or covered?

In most mining situations, liners are covered with materials such as dirt and rock in heap leach pads and tailings piles or by solutions in process ponds. Bare liner situations usually only occur during construction or if the site has stormwater catchment basins that only fill with seasonal precipitation. Leak location procedures differ based on the type of cover materials or whether there is no cover material. For example, if the structure is covered with fluid, it's essential to remember that clean, pure water is a resistor and that impurities containing positive ions in the water make it conductive. If a pond contains rainwater or snowmelt, electrical leak location may be challenging as few ions are available to move current. On the other extreme, if the solution has many ions, it can be too conductive for some leak location methods to work because the electrical signal may attenuate to such an extent that sensors in the pond may not be able to detect the location of holes. If the liner is covered with soil, ELL providers need to know what type of soil and rocks are present to determine if the material is conductive or not. In some cases, water will need to be added to the material to increase conductivity. The depth of material is also significant as the ability to detect leaks through soil cover material is depth limited.

5.1.5 What are the physical conditions of the survey site?

The physical conditions of the structure are essential to note, as survey operators will have to traverse the survey area to perform an ELL study. For exposed liners, slopes greater than 3 to 1 pose a safety risk unless the liner material is textured. Additionally, dust and condensation can make liner surfaces slick, requiring the surveyor to use a harness and rope. Likewise, for liners covered with materials, the angle of repose may be variable based on the flowability properties of the cover materials and the terrain the structure was built over. The ability to traverse a covered slope safely depends on the type of material and slope angle. Slope work impacts the safety and the time it takes to complete the survey. Survey speed on slopes can vary greatly depending on the pitch and walkability of the materials.

6 ELECTRICAL ISOLATION SURVEY DESIGN

One of the most critical tasks the client will need to perform for a successful ELL survey is understanding the survey area's electrical isolation needs. In a geosynthetic containment system, the solution or material covering the liner is used to carry current throughout the survey area, while the liner acts as the current resistor. Maintaining a high level of electrical isolation ensures that current is available for the leak location process. The presence of electrical pathways grounded to the outside world within the survey area will bleed off the electrical current needed for the leak location process. Thus, a temporary electrical isolation state for the survey area must be prepared in order to increase and maintain leak detection sensitivity. The level of electrical isolation will determine the difference between finding every hole or none at all.

Recall that with covered geomembranes, the material filling the system distributes current throughout the survey area. For a leak to be detectable current needs to travel through the leak with an intensity that is significant and measurable relative to all other current paths available.

In the example below, the top graphic shows two conductive bridges, a land bridge and a pipe. Both allow the current to escape from the survey area. Strong current paths link the current injector to the outside world. The bleed-off of electrical current from the survey area reduces the leak detection sensors' ability to detect leaks.

The bottom example displays a survey with quality electrical isolation. The leak within the survey circuit creates a strong current path between the current injector and the leak, allowing the operator to detect the hole in the liner.

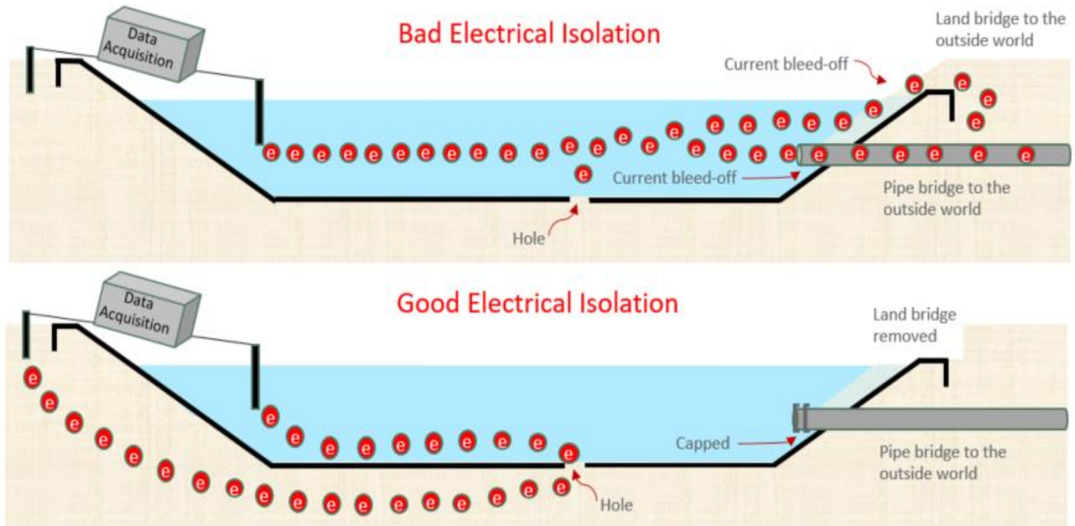

Figure 3: Top graphic shows elements of poor electrical isolation in a geomembrane structure. In the bottom graphic, barriers to quality electrical isolation are removed.

7 THE SAFETY PLAN

In the mining industry, safety is easily the biggest concern for any project. It is critical to consider the specific safety needs for your site related to your lined structures. For instance, what type of safety training is required to work on your site, MSHA, OSHA, safe driving certifications, and first aid? What about fall protection (Rope & Harness Training), Lockout/Tagout, or electrical safety? Depending on the type of survey a site needs and site safety concerns, contractors' could need some or all and more of the training listed here. It's important to note that Safety requirements can drastically differ from site to site. For example, a site may require a leak detection team to receive several safety certifications via in-person and online training before arriving on site and then additional site-specific training after arrival.

7.1.1 Site-specific training.

Site-specific training can be challenging for contractors; they will want to know how long and when training is offered. For some sites, site-specific training can be as little as an hour to an all-day event on the first day of site work. Additionally, some sites will only offer the training on specific days a few times a month. ELL contractors have been stranded when they have shown up on site only to find out that the next training is days or weeks away. Safety training misalignment can cause much confusion and delay your project.

7.1.2 Equipment and vehicle inspections.

Inspection of work vehicles, safety gear, tools, and electrical equipment may be required upon arrival at a site. Operators should convey estimated time allotments for inspections so that providers can arrive early enough so that work can begin on time.

7.1.3 Hazard awareness.

Knowing the potential hazards before contractors show up on site will help the survey design process by incorporating any mitigation needs. For example, sites requiring dosimeters and radiological training and sites with biohazards and chemical hazards require special personal protective equipment. This type of safety equipment can increase survey time. Additionally, it is critical to understand dangerous weather conditions such as extreme hot or cold weather. For example, a black liner can reach more than 150 degrees on a hot summer day. The survey design may incorporate working at night to reduce heat stress in this situation.

7.1.4 PPE requirements.

Providers work at level "D" PPE but may be required to have additional safety equipment such as chemical suits, rubber gloves, or special boots for walking on liners. It's essential to advise your contractor well in advance, as procuring specific PPE items may take significant time due to their specialized nature.

7.1.5 Communication requirements.

Site radios | Cell phones | Sat phones| Special phone numbers & phone trees

Often the sites are isolated in wilderness areas and out of cell phone range, so it's essential to understand the communication requirements for your site. If cell phones have no signal, then emergency services can't be reached, and site radios should be provided. Lastly, it's critical to monitor contractors to ensure they are safe and have what they need to perform the survey safely; daily site visits are encouraged.

8 CONCLUSION

This paper may seem to focus on the obvious regarding preparing for a leak location survey. However, the value of this discussion is that all the information you need to work through the leak location process is here in one place; we have thought through the obvious for you. We framed the knowledge of the process to highlight the known challenges that those unfamiliar with leak location technology may encounter when needing a survey, especially when the process is new. It outlines many essential tasks and questions to consider throughout the process so that your survey is done right and on time the first time. Unfortunately, it is not uncommon for multiple leak location surveys to be performed on the same structure because survey preparations were done incorrectly, the wrong leak location method was applied, or human error spoiled the results. The more information we have about any process before the process begins enables everyone involved to perform at the highest possible level seeking the best possible results. It is crucial to be prepared because all liners will eventually leak.

REFERENCES

ASTM D7240 Standard Practice for Leak Location using Geomembranes with an Insulating Layer in Intimate Contact with a Conductive Layer via Electrical Capacitance Technique (Conductive Geomembrane Spark Test)

ASTM D8265 Standard Practices for Electrical Methods for Mapping Leaks in Installed Geomembranes.

Breitenbach, A.J., Smith, M. E., P.E. 2006. Overview of geomembrane history in the mining industry. *Proceedings of the 8th bi-annual meeting of the International Geosynthetics Society (8IGS).*

M. J. Chappel; R. W. I. Brachman, M.ASCE; W. A. Take; and R. K. Rowe, F.ASCE 2012. *Large-Scale Quantification of Wrinkles in a Smooth Black HDPE Geomembrane*. ***Journal of Geotechnical and Geoenvironmental Engineering*** *Vol. 138, Issue 6.*

Kemnitz, M.P. 2013. Removing Human Error from Geomembrane Leak Location Surveys. *Geosynthetics 2013 April 1-4 Long Beach, CA*

Calendine, S., Crook, N., Baldyga, C. 2016. Electric leak detection and leak location on geosynthetic liners in the mining industry. *Tailings and Mine Waste 2016 Conference Proceedings, Keystone, Colorado*