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FIGURE 1 After cover soil placement, a dipole-method ELL survey gathers GPS-based voltage data to provide a complete electrical map of the site, which reveals where electrical current is traveling through holes in the geomembrane. These locations can then be excavated for repair.

Achieving zero leaks on a budget

By Abigail Gilson-Beck and Glen Toepfer

For more than 30 years, the geomembrane industry has been told that "all geomembranes leak" (Giroud 1984), as if this were some foregone conclusion no matter what might happen from geomembrane manufacturing to the time it is put into service. But recently, the idea of "zero leaks" has been a hot topic at industry conferences, and a whole spectrum of products, technologies, and practices has emerged to support this end goal (Beck 2015). The truth is that the amount of leakage at a site will depend on many factors, especially the level of construction quality assurance (Forget, Rollin, and Jacquelin 2005). Zero leaks are certainly possible, but not probable, unless an entire system of checks and balances is in place, including state-of-the-art practice methods and technologies. However, not all site owners are willing to pay for such a system.

With the increasing requirement for double-lined facilities where leakage is painfully apparent, and more regions mandating zero leaks, the industry can no longer hide from geomembrane leakage. Of course, a site owner can request the most expensive products, hire a nationally recognized engineer and construction quality assurance (CQA) firm, and bring in one of the industry's top installers with a requirement for the most senior manager from that company to always be on-site, which would undoubtedly result in superior performance. But the more likely scenario is that the owner hires the lowest-bidding installer and general contractor, and then contracts a local engineer who provides the advantage of proximity to the site but is not necessarily the industry's top expert in designing with geosynthetics.

Common bad practices repeatedly noted in the field by the authors on numerous sites under these conditions include cutting on top of the installed geomembrane (**Figure 2**), the vacuum test method not being performed correctly (**Figure 3**), straight-line damage remaining under repair patches, and a lack of a paper trail or cross-checking documentation to avoid unacceptable construction practices, such as failing trial seams before welding.

Cutting directly on top of the installed geomembrane should never happen on a job because it creates an unnecessary risk for damage. Even with a hook blade, gouges and cuts can and will occur. If they are found and fixed, having to complete extra repairs compromises the integrity of the liner.

In **Figure 3** there is an obvious gap in the weld, which is present on the bottom side of the photograph where the weld crosses the orange paint. The entire patch is

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All figures courtesy of the authors.

FIGURE 2 Two knife slices through an installed geomembrane located during dipole ELL survey (after cover soil placement)—likely due to cutting either a patch or geotextile on top of the geomembrane installation at that location

FIGURE 3 Poor execution of the extrusion weld and subsequent vacuum test

shown because the acronym "VTOK" is a common industry abbreviation for "Vacuum Test Okay" (meaning it passed the vacuum test). However, given that the vacuum chamber would have been placed directly over the gap in this weld, a passing test is impossible if the test was performed correctly.

Tears and cuts are straight-line damage types that can propagate through a properly performed extrusion repair patch under stress, which is why appropriately detailed specifications call for keyhole terminations and installation guidelines call for removal altogether with rounded radii (GSE Environmental 2015). **Figure 4** shows an example of properly prepared damage that has rounded radii to reduce the likelihood of damage propagation under stress.

It is important to understand that installation defects can have not only short-term impacts, such as delays and increased project costs, but also increased long-term risks and liabilities where remedial costs are exponentially higher than spending the time and money to do it right in the first place. Even small defects can have large impacts. The associated potential leakage rate for the damage shown in **Figure 3** underlain by a drainage layer with an average depth of 10ft is approximately 104,533 gallons per day (Giroud, Khire, and Soderman 1997).

A zero-leak geomembrane installation is built from the ground up like a pyramid. The firm foundation set by the owner should translate into superior design and detailed specifications, which not only incorporate best practices, but also result in a design that is truly constructible in the field. Building upon the design is selecting the proper materials and equipment for the project, and carefully vetting the vendors to ensure they can carry out the design through their construction while still meeting the owner's quality objectives. Fieldwork lies at the top of the pyramid and includes all vendors associated with the final product. A project that achieves the zero-leak challenge within budgetary constraints can be used as a model for the industry's future. But how can a project prove that it is leak-free? For double-lined sites, leakage through the primary geomembrane is apparent once the facility is put into service. For single-lined sites, the only final check that can be made is with electrical leak location (ELL).

Zero leaks can be achieved by throwing every bell and whistle at a project, but knowledgeable site owners can leverage their investment by targeting the most effective CQA measures to make sure that every stone in the pyramid has been properly placed. A developing trend is for owners to perform a construction audit combined with an ELL survey. Smart project practices like these should be able to identify any missing or poorly placed building blocks in the construction pyramid for a modest additional investment. **Table 1** illustrates the financial leverage of the two key practices described in this article. One ELL survey typically costs 0.4–1.2% of the overall construction cost, while a construction audit typically costs 1.1–1.8%.

A construction audit entails asking an industry expert to observe the construction and CQA practices, ideally toward the beginning of work, to audit all parties involved in the project. Typically, the audit begins with an in-depth review of any documents governing the construction and includes interviews (either pre- or postaudit) with the owner. Cross-checking these documents gives the auditor the background information to accurately access if there are potential discrepancies in the governing documents that could cause problems/delays during construction as well as the background for determining whether the installation activities are accurately following the governing documents.

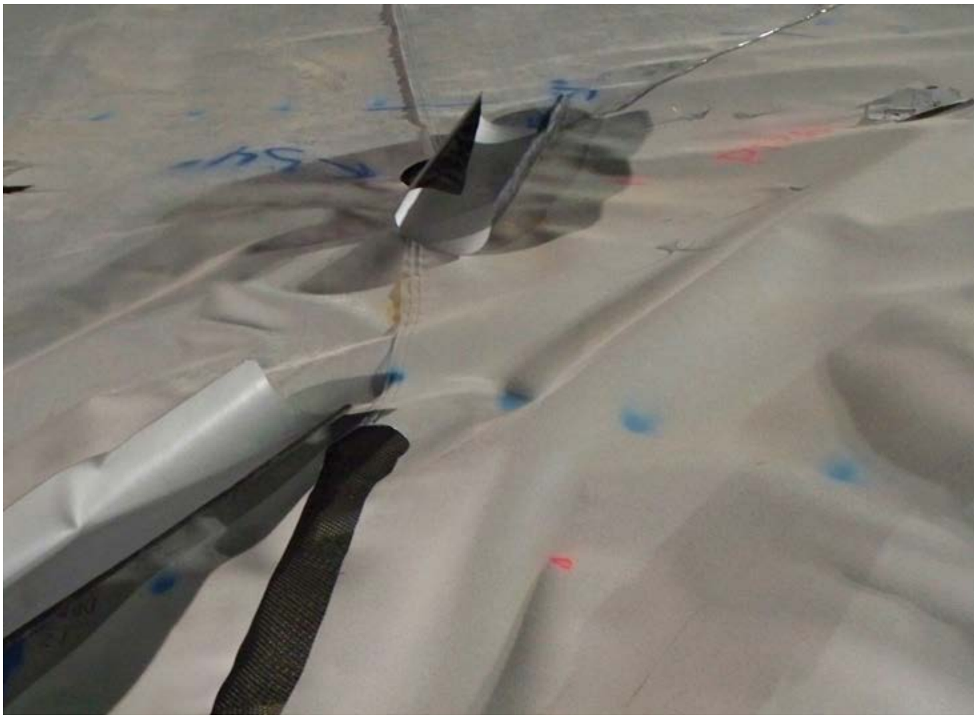

FIGURE 4 Damage prepared for repair using rounded corners instead of straight-line cuts/edges

TABLE 1 Financial implications of "zero leaks"

Total Construction Cost	$1.65–1.8 million
Rigorous CQA Component	$150,000
Geomembrane CQA Portion (included in the $150,000 total)	$25,000–30,000
Construction Audit	$20,000–30,000
ELL Survey (bare geomembrane method—directly after geomembrane installation to locate smallest installation defects)	$10,000–20,000
ELL Survey (dipole method—after cover soil placement to locate damage incurred during cover material placement)	$8,000–16,000

ELL surveys are probably the best return on investment for geomembrane installation CQA, since they get straight to the heart of geomembrane leakage: holes.

The audit also includes time spent in the field observing daily tailgate meetings and weekly progress meetings, as well as the installer and the CQA personnel during all phases/activities of a normal installation. The observations are evaluated on whether the parties are meeting the specification or governing documents, and/or industry standards. An installer or CQA firm can spend years training individuals and spend dozens of classroom hours learning broad practices that may or may not apply to the site he/she is going to be working on. But the reality is that most personnel on-site don't get any level of classroom training and/or opportunities to attend national conferences where installation and CQA issues are discussed and resolved. Part of the construction audit is an exchange of knowledge. The owner, installer, contractor, and CQA firm are all apprised of better practices. The expertise is brought to the site to improve all construction operations and provide site-specific, crew-specific knowledge transfer. An owner's local crew who typically performs the work would then benefit from this kind of on-site training for all ensuing projects for that owner.

ELL surveys are probably the best return on investment for geomembrane installation CQA, since they get straight to the heart of geomembrane leakage: holes. Installing a geomembrane without checking it for leaks after the end of construction makes no sense. ELL can be performed by the geomembrane installer as part of construction or by a third-party testing company. It can be performed while the geomembrane is bare or after cover material placement, or both. There is an appropriate ELL method for virtually any kind of geomembrane installation. One example is shown in **Figure 5**.

FIGURE 5 High-voltage arc testing, which was formalized in the U.S. in 2014 as ASTM D7953, has enabled bare geomembrane testing on applications that were previously unfeasible, such as this geomembrane-faced concrete dam.

At the conclusion of the project, ELL is the final safety net for locating leaks. It can also be considered a report card, pointing out failures of the geomembrane installer, general contractor, construction CQA firm, and/or engineer. For example, locating leaks on extrusion-welded patches means that the installer wasn't using the vacuum test correctly and that the CQA firm did not perform the proper check of the performance of the vacuum test. Finding several areas of puncture from the cover material means that the engineer did not ask for site-specific materials to be used for puncture testing, that puncture testing was not part of the project specifications, or that the contractor did not use the correct cover material. Dozer damage to the liner indicates the general contractor lacked control of material placement. Knife slices in the geomembrane shows that the installer was cutting patches on the geomembrane and was likely using an open blade. All holes caused during installation can be traced back to mistakes made by the various parties involved. The holes left behind by these mistakes can then be repaired before the facility is put into operation.

If the geomembrane is to be covered by soil or water, a voltage map can be created as part of dipole testing, providing a valuable CQA document showing that the lining system was constructed free of leaks or that the leaks were identified for repair, as shown in **Figures 1** and **6**.

Unfortunately, site owners sometimes rely on ELL surveys to fix a project once issues arise after a site is put into service without understanding the site requirements for a successful ELL survey. An ELL survey can locate leaks for repair only at the time of the survey and only if the ELL method has been properly specified and executed. Extrusion-welded patches are the weak link for a lining system. Even if all holes are located by ELL at the end of a project, the end product after all of the extrusion-welded patches will not be as good as if the holes had not been created in the first place. ELL should not replace a strong CQA program.

The large-scale containment industry is enamored by geomembranes; they are the most economical way to contain liquid and prevent ground and surface water contamination. But if the industry is dependent on this extremely thin barrier, it is crucial that it also adopts the means and methods of ensuring that geomembranes will perform as expected. Those with financial restraints will always struggle with saying yes to the Cadillac approach for mitigating risk, but by targeting the most effective CQA methods, site owners may achieve the highest-quality installations without the highest cost. This smart investment approach to a project raises the bar at one site and then sends ripples throughout the industry, building momentum every year. As an industry, we do not have to accept that the 4–20 holes per hectare of yesterday will be our tomorrow, given the cost-effective solutions available today.

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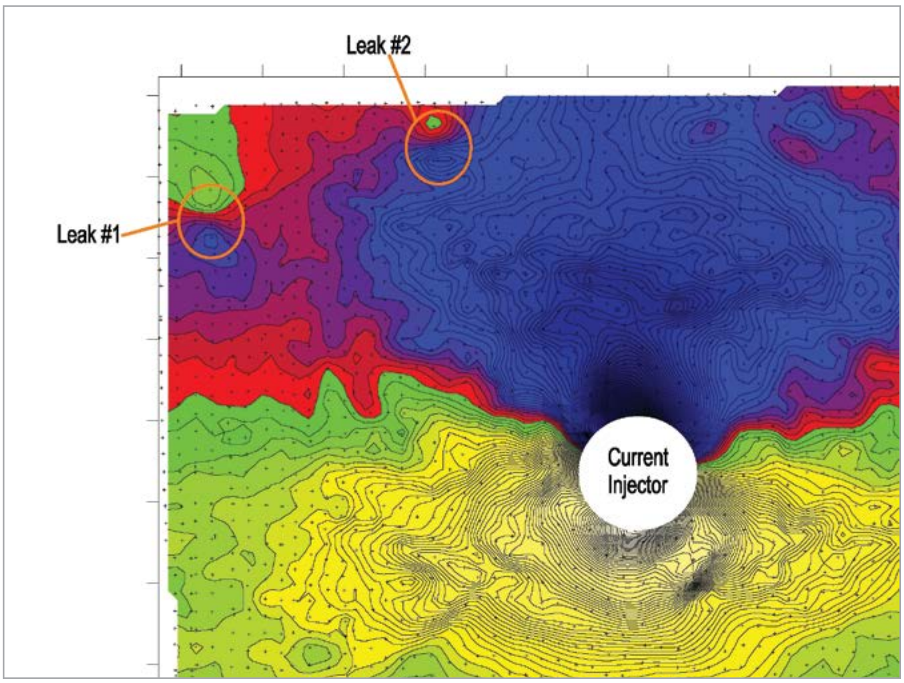

FIGURE 6 An electrical map of a soil- or water-covered survey area pinpoints leak locations with high confidence and provides documentation that the dipole method was performed thoroughly and correctly.