Updated Statistics on Leaks per ha, Based on 22 M m^2 ELL Surveys Conducted in Six Different Countries over the Last Decade

Silverio Prota, Anddes Argentina S.A./Anddes USA LLC, Argentina/USA
Chris Baldyga, HGI hydroGEOPHYSICS, USA
Juan Cabrera, Innova Check, Chile
Mauricio Campos, Innova Check, Chile

Abstract

Technology is constantly evolving at a high pace, decade after decade. This includes methodologies and equipment for geomembrane liner fabrication and installation, as well as for testing, both before and after placement on mining facilities. In fact, geomembranes are relatively new compared to other lining materials such as bitumen, clay, concrete and asphaltic concrete (Giroud and Bonaparte, 1989).

Geomembrane liners have been used significantly in the mining industry since about 1970 for lining solution and evaporation ponds, tailings impoundments and heap leach pads. The most extensive use of geomembrane liners has been, and remains, in the construction of evaporation ponds, starting in the early 1970s, and heap leach pads starting in the late 1970s.

Nowadays, the same questions asked forty years ago are still valid: how critical are the defects in the geomembrane due to punctures, inadequate seams, cracks, wrinkles, etc.? What range of "reasonable" leakage rates should be considered in regulations and specifications? How many holes should be expected when following state-of-the-art quality assurance practices? Is it possible to get a zero-leak facility?

Based on a number of Electric Leak Location (ELL) projects overviewed by the authors over the last ten years, and as an update to a previous research study conducted five years ago by some of the same authors, this paper provides a detailed analysis of the findings of ELL surveys of over 22 million square meters (M m2) of geomembrane liner installed in six different countries, including metal mining impoundments, lithium evaporation ponds, and other types of facilities. It also provides a benchmark to current liner installation practices and shows a number of leaks detected on each site, classified by type of facility, ELL methodology, geomembrane material, country, and liner installation stage.

In order to look for a trend line, current ELL results are compared with those of previous papers written by other authors in the past.

New facilities, where liner is installed following industry-standard construction-quality assurance practices, should expect, at least, not to exceed the average number of defects per hectare presented in this paper. Consequently, the statistics presented in this research work could be used to evaluate the construction quality of any new or existing facility in comparison to the 219 cases included in this study.

Introduction

Despite public perception, in the technical community it is commonly acknowledged that installed geomembranes typically contain holes, which in most cases can be located for repair using electrical leak location (ELL) technologies (Gilson-Beck, 2019; Thiel, 2013).

The main goal of this paper is to offer project record-based statistics to be used as a benchmark for predicting the number of holes to be expected under different scenarios, with an emphasis on the need for Construction Quality Assurance (CQA) and ELL during the installation of geomembrane liners. Reinforcement of these good practices certainly favours a reduction in the number of holes and mitigates the level of risk for future shutdown of facilities.

Data from previous research indicates that the average number of holes reported in sites where CQA was performed during the installation stage is about 0.5 per hectare, whereas the number of holes without CQA can increase up to 107.11 per hectare (Forget et al., 2005; Beck, 2006; Prota et al., 2017). A summary of these values is presented in the following table, where WL indicates Water Lance methods:

Table 1: Hole frequency from different authors

Type of facility/application/ construction phase	Holes per hectare with CQA	Holes per hectare without CQA	Source
Overall leak frequency	2.5	>25.0	1
Exposed geomembrane	4.0	22.0	2
Covered geomembrane	0.5	6.0	2
Pond	4.0	22.0 (small 10 mm^2)	3
Pad with both WL and dipole	4.0 (small 10 mm^2) 0.5 (big 1,500 mm^2)	22.0 (small 10 mm^2) 1.0 (big 1,500 mm^2)	3
Pad with WL only	4.0 (small 10 mm^2)	22.0 (small 10 mm^2)	3
Pad with dipole only	3.0 (small 10 mm^2) 0.5 (big 1,500 mm^2)	15.0 (small 10 mm^2) 3.0 (big 1,500 mm^2)	3
Leak frequency (holes/ha)	1.95	107.11	4
Leak frequency (holes/ha)	0.128		5

Sources: Giroud and Bonaparte, 1989; Forget et al., 2005; Beck, 2006; Prota et al., 2017; Gilson-Beck, 2019.

Methodology

The authors have shared their own field project experience, resulting from 22.5 million square meters of geomembrane liner surveyed over 219 ELL projects, where key data from each of them has been recorded, including type of facility, surveyed area, number of leaks and/or electrical anomalies (e.g., potential leaks) detected, among other aspects.

The analysis includes projects executed in Argentina, Bolivia, Chile, the Dominican Republic, Peru, and the USA with the use of ELL technologies such as the Dipole method (ASTM D 7007) (ASTM Subcomittee D35.10, 2016), Arc Testing (ASTM D 7953) (ASTM Subcomittee D35.10, 2020), the Water Lance method (ASTM D7703) (ASTM Subcomittee D35.10, 2022), the Water Puddle Method (ASTM 7002) (ASTM Subcomittee D3510, 2022) and hydroGEOPHYSIC'S proprietary ELL Methodology for geomembranes covered with a highly conductive solution.

The facilities in the analysis include tailings dams, leach pads, water ponds, solutions ponds, evaporation ponds, swimming pools, biodigestors, landfills, and other facilities, surveyed from 2010 through 2022, some of them with double or triple liner systems.

The analysis has also taken into consideration whether the liner system has been installed under proper CQA supervision, and if covered or exposed geomembrane liner has been evaluated.

Finally, the results have been compared with previous papers, both from others and from the same authors.

Table 2: Paper database details

Aspect	Details
Number of projects	219
Surveyed area (m²)	22,561,911
Countries	Argentina, Bolivia, Chile, Dominicana Republic, Peru, USA
ELL technologies	Exposed geomembrane Arc testing, water lance Covered geomembrane Dipole on soil-covered materials, Dipole on water-covered materials, HGI alternative proprietary dipole methodology
Type of facility	Tailings dams, leach pads, water ponds, process ponds, solution ponds, evaporation ponds, landfills, biodigesters, swimming pools

Data and discussion

Overall results

The overall leak frequency is 9.45 holes per ha, based on the total surveyed area and the total number of leaks detected, as summarized in Table 3.

Table 3: Overall leak frequency results

Number of surveys	Total surveyed area (m²)	Number of leaks detected	Leaks per ha (average)	Max. (leaks/ ha)	Min. (leaks/ ha)
219	22,561,911	28,221	9.45	4,903.8	0.0

Although the average value of leaks per ha is close to those obtained by previous authors, some specific cases present a significant deviation from those figures: six projects registered over 1,000 leaks per ha, with a maximum of 4,903 leaks per ha. It should be noted that those sites are very small, with installed geomembrane surface areas ranging from 100 m^2 to 1,100 m^2, where strict CQA procedures were not followed.

This in turn triggers a relatively high value for the standard deviation (512.4), as a result of the significant dispersion of the leak-per-ha value across the different projects.

The following graphs illustrate the dispersion in the number of leaks per hectare:

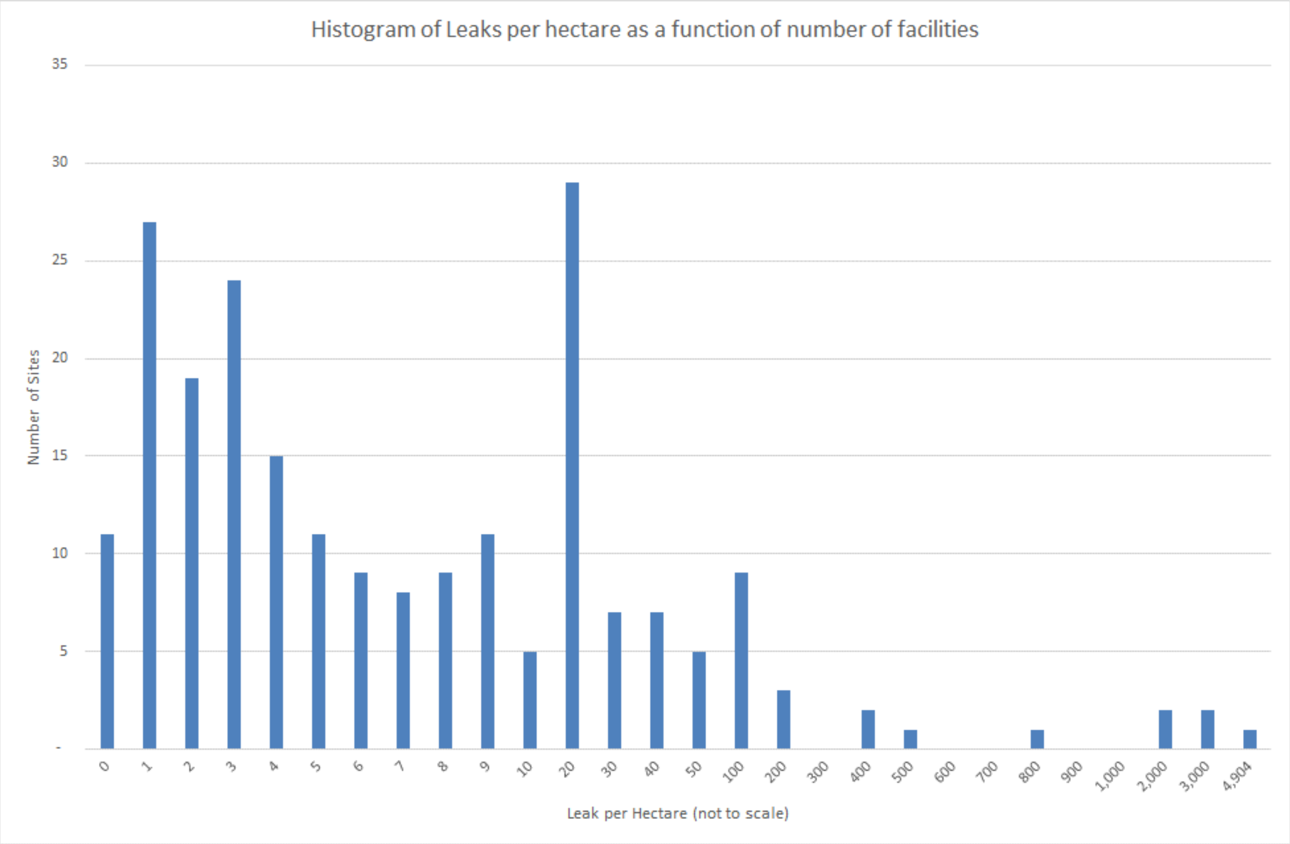

Figure 1: Histogram of leak-per-hectare frequencies

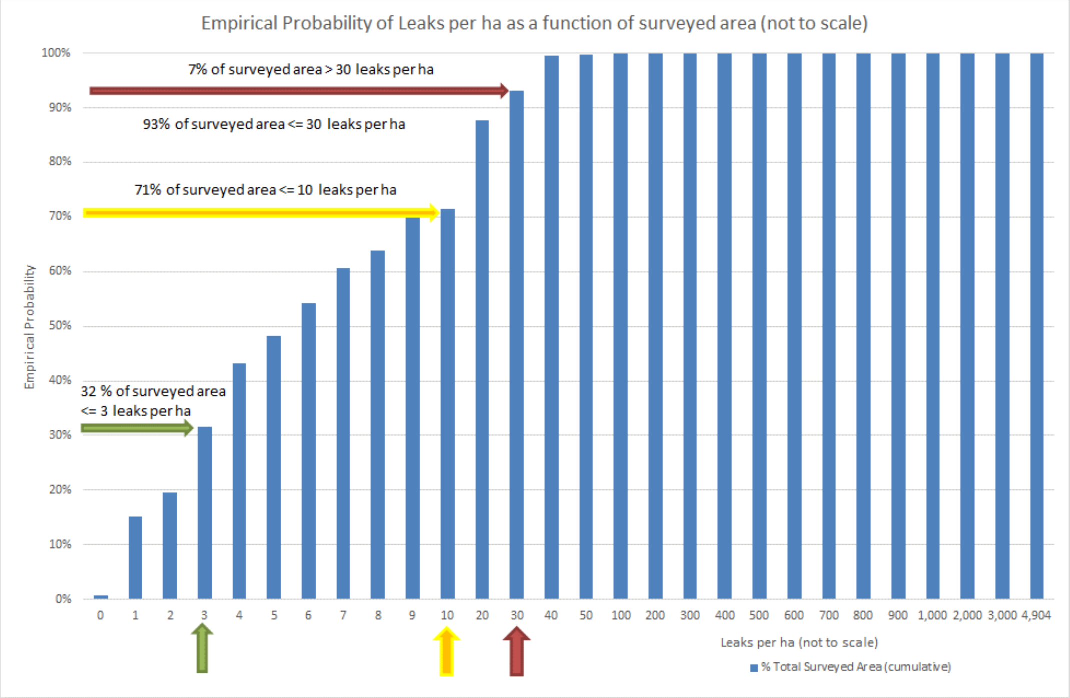

Figure 2: Empirical probability of leak

Based on surveyed data, approximately 32% of the installed geomembrane should have less than 3 holes per ha; around 71%, less than10; 93%, less than 30, and 7% might exceed 30 holes per ha.

Results grouped by categories

In the following tables and figures, we provide a detailed evaluation of the field data.

CQA considerations

In addition to the big dispersion driven by a few projects with a high hole frequency, as outlined by previous investigations, there is a significant distinction between the projects with CQA and those with no CQA.

Table 4: Leaks classified by quality control status during construction

Leaks per ha category	With CQA	Without CQA
Exposed geomembranes (average)	7.4	28.3
Covered geomembranes (average)	1.4	3.2
Total exposed and covered geomembrane (average)	6.6	26.9
Maximum	1,056.3	4,903.8
Minimum	0.0	0.0

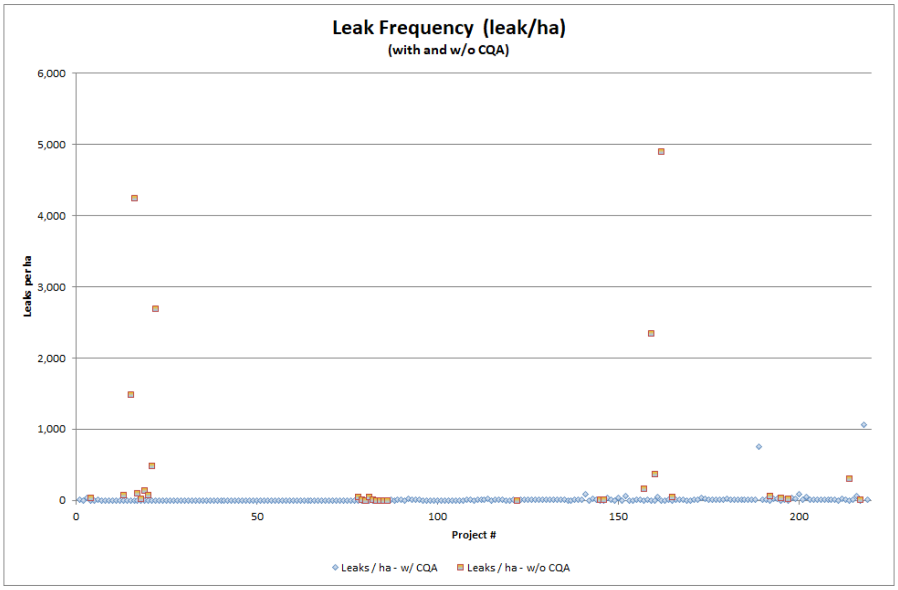

Figure 3: Leak frequency categorized by CQA

In the next graph the vertical axis is switched to a log scale, in order to get better visibility of the sites with less than 100 leaks/ha.

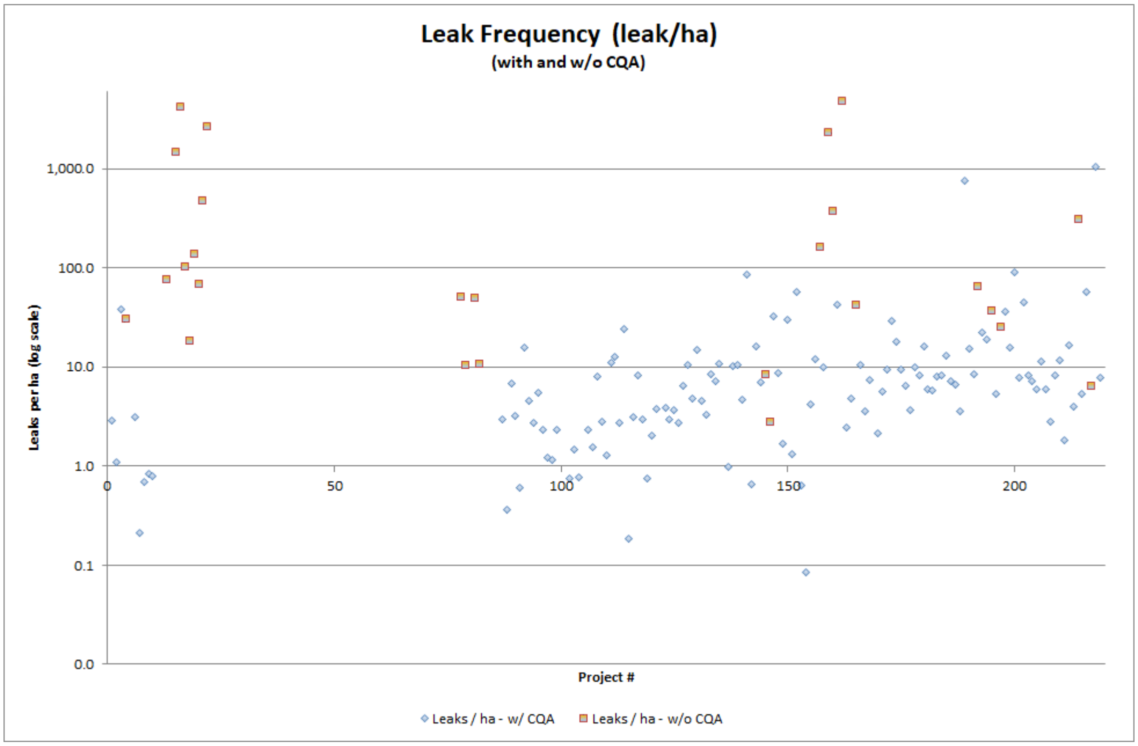

Figure 4: Leak frequency categorized by CQA (log scale)

Note: When using the log scale, it is not possible to include data points with a zero value on the y axis; therefore, projects with zero leaks are not represented in the upper graph.

The majority of the projects with no CQA during liner installation are above the 100 leak/ha frequency, while most of the projects with CQA are below that threshold.

Results by ELL standards

Table 5: Leaks classified by ELL technology

Technology	Surveyed area (m^2)	Number of leaks detected	Leaks per ha (average)	Number of facilities	Standard deviation
Arc testing	18,106,977	20,177	11.1	118	679.2
Arc testing and water lance	357,481	457	12.8	4	18.9
Dipole	2,172,933	337	1.6	41	11.2
Dipole in water	40,000	7	1.8	1	–
Alternative dipole	1,884,519	345	1.8	55	10.8
Total	**22,561,911**	**21,323**	**9.5**	**219**	

Direct methodologies, such as the arc testing and the water lance, show a much higher leak detection frequency than the indirect ones, such as the dipole. However, and based on the authors' experience, the size of the leaks detected with the dipole might be extremely large (over several cm^2), while the ones detected with arc testing or the water lance are usually below 1 cm^2.

Results by project location

Table 6: Leaks classified by project location

Country	Surveyed area (m^2)	Number of leaks detected	Leaks per ha (average)	Number of facilities	Standard deviation
Argentina	12,083,006	8,714	7.21	71	614.4
Bolivia	1,185,372	642	5.42	1	n/a
Chile	6,071,539	10,947	18.03	78	620.0
Dominican Republic	101,172	7	0.69	1	n/a
Peru	1,466,974	680	4.64	15	21.7
USA	1,653,848	333	2.01	53	10.9

Note: Data for Chile includes both QC and QA survey results, while data from the other countries is only QA. The authors assume this explains most of the increase in the leaks frequency detection, when compared to other countries in this paper.

When analyzing by country, there is significant variation in the leak-per-ha frequency, presumably driven by differences in liner installation procedures, CQA or QC, and/or enforcement practices.

Results by facility type

Table 7: Leaks classified by type of facility

Type of facility	Surveyed area (m^2)	Number of leaks detected	Leaks per ha (average)	Number of facilities	Standard deviation
Tailings dam	221,360	510	23.04	5	32.4
Leach pad	4,003,159	1,306	3.26	31	2.0
Pond	4,541,027	3,363	7.41	104	35.2
Evaporation pond	13,403,477	15,728	11.73	62	649.9
Landfill	6,000	5	8.33	1	n/a
Other	386,887	411	10.62	16	1,303.6
Total	**22,561,911**	**28,221**	**12.5**	**219**	

Over the last ten years, the number of sites and total installed area for lithium evaporation ponds has consistently increased, except for 2020, and has become the predominant market compared to other minerals and type of facilities.

Results by liner material

Table 8: Leaks classified by type of geomembrane liner material

Material	Surveyed area (m^2)	Number of leaks detected	Leaks per ha (average)	Number of facilities	Standard deviation
Bituminous	68,028	626	92.02	4	131.3
HDPE	5,029,201	7,825	15.56	65	667.1
PVC	1,561,201	2,608	16.71	9	9.4
Polyurethane	578	61	1,056.28	1	–
LLDPE	12,889,382	8,078	6.27	55	4.8

Note: The material specification was not available for some of the projects; therefore, the total surveyed area in this table is smaller than the total in Table 1.

In the installation of most of the lithium evaporation ponds surveyed by the authors, LLDPE geosynthetic liner is being used, which drives the dominant position of this material in these statistics.

This material is offering the lowest leak-per-ha leak average value.

Chronological evolution of ELL

Table 9: Surveyed area classified by year

Year	Surveyed area (m^2)	Number of leaks	Leaks per ha
2010	40,000	7	1.75
2011	–	–	N/A
2012	1,093,904	819	7.49
2013	1,281,980	1,023	7.98
2014	2,165,304	1,329	6.14
2015	604,265	599	9.91
2016	1,541,910	4,927	31.95
2017	1,338,225	3,310	24.73
2018	1,584,247	677	4.27
2019	2,912,260	2,568	8.82
2020	601,772	85	1.41
2021	6,206,046	3,719	5.99
2022	5,068,769	4,374	8.63

Figure 5: ELL annual data

Note: The 2022 annual survey and leak data was extrapolated based on 2022 S1 actual figures.

Although there is no linear correlation for any of the variables, there is a clear positive trend on the number of square meters surveyed per year, except for 2020, when the COVID-19 pandemic impacted all activities worldwide. In terms of leaks per ha, it is very difficult to establish a defined trend, with consecutive peaks and valleys. This is not what would be expected for an activity where the installation companies are supposed to be going up the learning curve, and might rather be associated with the lack of experience of the new welders joining the labour market every year, in the clearly demanding sector of geomembrane liner installation, mainly driven by lithium exploration and production booming.

Conclusion

Multiple conclusions can be drawn from the above results.

Significant variations in the leak-per-ha occurrence have been detected when evaluating the available data from different perspectives, which indicates that several parameters such as material type, proper QC/QA, project location, facility type, liner material, geomembrane application and ELL methodology can lead to very different results.

Even when proper QC and QA practices are observed, leaks may be present in installed geomembrane liner, with an average of 6.6 leaks/ha. This parameter rises to 26.9 leaks/ha when no proper QC/QA has been conducted.

From a statistical perspective, the leak-per-ha function cannot be defined as normal distribution and in fact shows a significant dispersion.

The results might indicate that installation quality varies significantly from one country to another, and apparently in some countries installation practices are not improving over the years.

The rapid expansion of lithium extraction projects might not be accompanied by an appropriate increase in the number of trained and qualified field engineers and technicians, whose work is key for the zero-leak goal.

Leak-per-ha data recording methodology presents significant variations among consultants, which makes it difficult to group results from the surveys of different companies and obtain wider and representative statics based on comparable and compatible data. It might be useful to develop a voluntary uniform data recording protocol, in order to facilitate future updates of this kind of statistic.

Acknowledgements

The authors would like to thank each of their clients for their continuous support and their belief in the value of ELL as a tool to increase productivity, reduce costs and protect the environment.

The development of the ELL to the state-of-the-art technology level in some countries would not have materialized without the help of Abigail Gilson-Beck, who generously shares her knowledge and provides valuable support as needed.

We would also like to acknowledge the commitment of our employees towards quality improvement even under extreme and adverse field conditions.

References

ASTM Subcommittee D35.10. 2016. ASTM D7007 Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials. USA: ASTM International.

ASTM Subcommittee D35.10. 2020. ASTM D7953 Standard Practice for Electrical Leak Location on Exposed Geomembranes Using the Arc Testing Method. USA: ASTM International.

ASTM Subcommittee D35.10. 2021. ASTM D8265. Standard Practices for Electrical Methods for Mapping Leaks in Installed Geomembranes. USA: ASTM International.

ASTM Subcommittee D35.10. 2022. ASTM D7703. ASTM D7703-16 Standard Practice for Electrical Leak Location on Exposed Geomembranes Using the Water Lance Method. USA: ASTM International.

ASTM Subcommittee D3510. 2022. ASTM D7002. Standard Practice for Electrical Leak Location on Exposed Geomembranes Using the Water Puddle Method. USA: ASTM International.

ASTM Subcommittee: D35.10. 2021. ASTM D6747. Standard Guide for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes. USA: ASTM International.

Beck, Abigail. 2006. The end of heap leach solution loss. *The Mining Record*.

Forget, B., A.L. Rollin and T. Jacquelin. 2005. *Lessons Learned from 10 Years of Leak Detection Surveys on Geomembranes*. Sardinia 2005. Sardinia.

Gilson-Beck, A. 2019. Controlling leakage through installed geomembranes using electrical leak location. *Geotext. Geomembr.* 47(5):697–710.

Giroud, J. and R. Bonaparte. 1989. Leakage through liners constructed with geomembranes. *Geotext. Geomembr.* 27–67.

Prota, Silverio, C. Baldyga and J. Meléndez. 2017. Leaks per hectare detected for liners placed on different countries and facilities. *Geosynthetics 2017.* Santiago de Chile: GECAMIN Ltda.

Thiel, R. 2013. *A 25-year perspective on waste containment liner and cover design using geosynthetics.* Thiel Engineering, Oregon House, CA, USA.