E3S Web of Conferences **569**, 04004 (2024) https://doi.org/10.1051/e3sconf/202456904004
GeoAmericas 2024

Case study on a contaminated soil landfill in Canada with a focus on geosynthetic materials and electrical leak location

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Abstract. Designing a double-lined landfill for contaminated soils certainly presents several challenges. Many design aspects are taken into consideration to comply with local regulations, including thickness of the natural clay layer, minimal slopes for leachate drainage, side slopes for soil stability, global design to lower stress on the geosynthetics, and much more. We will focus on the choice of geosynthetics used for the construction of a cell on a contaminated soil landfill during the summer of 2023, as well as quality control and quality assurance, including electrical leak location.
A multi-linear drainage geocomposite was selected to cover each layer of an HDPE geomembrane and a layer of natural sand was also installed. It was not practical to use sand on the secondary geomembrane in the slopes due to stability and damaging risks, therefore the drainage system solely relied on the drainage geocomposite. To carry on with the electrical leak location, a conductive mesh was added to the geocomposite installed in the slopes, allowing 100% of the installed geomembrane to be tested.

1 Introduction

Geosynthetics are used in a variety of projects and play a crucial role as barriers in most modern landfills. Geomembranes are especially useful when the available natural clay in the vicinity of a site is not suitable for containment. Drainage geocomposites are also great to replace layers of gravel or crushed stone for the same reason. There are many types and brands of geosynthetics and choosing the right one to fulfil a specific role can be arduous for a design company. They should not overdesign for maximal safety but rather aim for the cheapest option for the owner and to satisfy required criteria.

Certain containment facilities are said to be "passive" while others are "active". A passive containment will typically be a layer of naturally watertight clay or reworked clay, with a geomembrane over top. If the liner has a few leaks, the leachate will go through and sit on the clay, theoretically not being able to flow down to reach the groundwater.

This is why the system is called passive, there are no actions carried out to minimize the risk of contamination, besides monitoring wells around the site.

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An active site may or may not have a layer of clay but will have two layers of liner and a drainage layer in between (synthetic or natural). Should the top liner (primary barrier) have leaks, leachate will flow through and will then be drained towards a lower area where it will be pumped out.

This way, there is minimal pressure head on the bottom of the leachate liner (secondary barrier), thus lower risk of contamination. The active part means the owner needs to pump whenever liquid accumulates between both geomembranes.

Active systems are generally used for high-concentration or toxic applications. In the project described in this paper, the double-lined system was part of the requirements from regulators for a new contaminated soil cell built during the summer of 2023 in Canada.

2 Local Regulations

The present project was subject to provincial regulations. In the province of Québec, all new contaminated soil burial sites must meet the requirements of *Regulation "R 18"* from the Environment Quality Act, CQLR c Q-2.

The purpose of this regulation is to protect the environment, living species, and human health and safety regarding the final disposal of soil containing elements that fit the specified concentration of contaminants in the regulation.

To achieve its purpose, the regulations have many specifications regarding all the aspects of a contaminated soil burial site. More specifically, the regulations provide detailed requirements regarding the following points:

- Localization of the site
- Local land geotechnical and hydro geotechnical properties
- Tightness of the impervious system (cells and final covers)
- Collection and treatment of leachates
- Surface water
- General operating conditions
- Monitoring of surface water, groundwater, gas, and treated leachates
- Post-closure program

When requirements are not respected, the regulations include monetary administrative penalties. In the next section, we will focus on the natural, granular, and geosynthetic materials involved, in accordance with local regulations.

3 Natural, granular, and geosynthetic materials involved

The regulation is clear about the components required to obtain the desired quality and environmental performance. All the materials involved in the construction of this project have specific and important roles.

First, contaminated burial sites must be laid out where the natural ground composing the bed and the wall is made of a natural homogenous impermeable layer, with a hydraulic conductivity equal to, or less than, $1x10^{-6}$ cm/s and a minimum thickness of 3 m. In certain specific contexts, applicable to the present project, the hydraulic conductivity of the natural impermeable layer can be increased to $1x10^{-7}$ cm/s on half of the slope's length with the use of a geosynthetic clay liner (GCL).

Following the construction of the cell, specific granular and geosynthetic materials are installed to create the double liner and drainage system.

HDPE geomembrane layers, with a thickness of 1.5 mm minimum, are used as primary and secondary liners. In case of a leak on the primary liner, the secondary liner will prevent contamination to the environment.

A Draintube is a multi-linear drainage geocomposite that is installed as a primary leachate collection system (on the primary liner) and as a secondary leachate collection system (on the secondary liner), and also protects the geomembranes against punctures. On the slopes, with the absence of drainage sand over the Draintube, an electrically conductive drainage geocomposite is used to allow leak detection operations. The drainage geocomposite helps reduce the quantity of drainage sand required to achieve the total hydraulic conductivity required.

When used over the drainage geocomposite, the drainage sand shall have a hydraulic conductivity of $1x10^{-2}$ cm/s minimum and be free of any big rocks. Its role is to drain the leachates toward the pumping station, and to protect the primary liner from the first layer of buried contaminated soil that could contain coarse materials.

Clean stones are used around the pumping station and the perforated drainage pipes. They increase the hydraulic conductivity of the system and protect the drainage pipes from clogging with fine materials.

A separation geotextile is used around the clean stone and on top of the sand layer in contact with the contaminated soil to prevent the migration of fine materials that could potentially clog the drainage system.

Finally, a protection geotextile is used where the HDPE is in contact with clean stones.

When installed properly, following strict quality control before and during installation, combined with the right slopes and an active leachate pumping system, this double liner system composed by these materials is excellent at preventing the contaminants from migration to the environment. Figure 1 presents the cross section and the materials involved in the project mentioned in this paper.

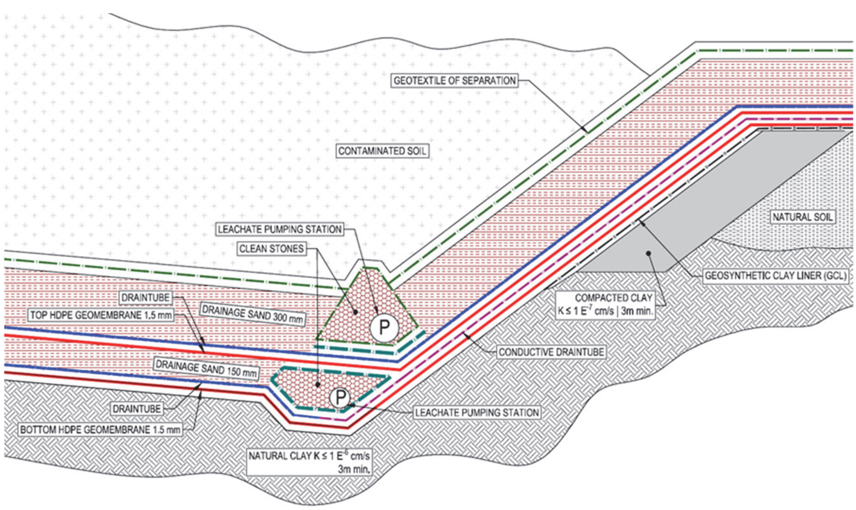


Fig. 1. Cross section of the cell.

4 Sustainability

The Life Cycle Assessment (LCA) of geosynthetic materials shows that their use reduces the environmental impact of civil engineering projects compared to the use of natural materials for all the pollutants concerned (EAGM, 2019).

The main impact category indicators are:

- cumulative energy demand,
- GHG emissions,

- photochemical ozone formation,
- particulate formation,
- acidification,
- eutrophication,
- land competition, and
- water use

In this paragraph, we will focus on GHG emissions pertaining to the different materials involved in the construction of cells, using their respective Embodied Carbon (EC) values. The EC of a material is the amount of CO_2 equivalent emissions released in the extraction, manufacture, and transport of this material. It relies on energy measurements as well as embodied data for the materials. This value is theoretically specific to the location of the manufacturer, the manufacturing process, the type of product, etc. We will provide average EC for a family of materials, until the factory gate (cradle to gate). The emissions related to transportation, installation, and end of life are highly dependent on the site/project type and location. Publications and studies provide EC for several materials. Table 1 presents data from several sources of literature, for the materials involved in the project.

Table 1. Embodied Carbon from cradle to gate for several geosynthetics

Material	Embodied Carbon (kg CO_2e/kg) from cradle to gate				
	Hammond, 2011	Raja, 2015	Koerner, 2019	Stucki, 2019	Durkheim, 2011
High density Polyethylene (HDPE)	1.93				
Non-woven polypropylene geotextile		2.35	2.7	3.2	
Multi-linear drainage geocomposite					3.34

The EC value for the sand material is 0.0051 kg CO_2e/kg (Hammond, 2011). Even if the EC value per kg of natural materials is approximately 500 times lower than geosynthetics, the weight of geosynthetics is a least 1,500 lower than natural materials, for the same performance. Therefore, the use of geosynthetics in replacement of natural materials will allow a reduction of GHG emissions (from cradle to gate) by a minimum factor of 3.

We will evaluate the CO_2e emissions related to the construction of the cell by focusing on the active barrier and leachate collection system. GCL, compacted clay, and leachate pumping stations will not be covered in this example. Table 2 summarizes the GHG emissions per m^2 for the bottom and the slopes, using the cross section presented in Figure 1. The distance from the geosynthetic manufacturer to the site is equal to 160 km, and the distance from the carrier to the site is 20 km.

Table 2. GHG emissions (kg CO2e/m^2) for the construction of the active barrier of the cell

	Sand layers	Draintube layers	Geomembrane layers	Geotextile layer
Bottom of the cell				
EC	4.131	3.086	5.444	0.55
Transportation	0.873	0.038	0.116	0.008
Installation	1.494	0.218	0.348	0.073
Total GHG emissions ($kgCO_2e/m^2$)	**6.498**	**3.342**	**5.908**	**0.631**
Slopes of the cell				
EC	2.754	3.257	5.444	0.55
Transportation	0.582	0.040	0.116	0.008
Installation	0.996	0.218	0.348	0.073
Total GHG emissions ($kgCO_2e/m^2$)	**4.332**	**3.515**	**5.908**	**0.631**

Considering that the bottom of the cell covers an area of 12,000 m^2 and that the slopes cover 2,900 m^2, the cumulative GHG emissions for the construction of the active barrier of the cell are 238.3 tCO_2e.

5 QC/CQA

To help clarify the terms used in this paper, the term "quality control", or QC, describes the inspection of the quality of the geomembrane installation, including repairs and testing, performed by the geosynthetics installation company, and included in a standard lining installation. The term "construction quality assurance", or CQA, describes the validation of those tests and measurements used on the geomembrane and repairs made by an independent third-party company.

Construction Quality Control (CQC) is defined by the Geosynthetics Institute (GSI) as: "A planned system of inspections that is used to directly monitor and control the quality of a construction project. Construction quality control is normally performed by the geosynthetics installer, or for natural soil materials by the earthwork contractor, and is necessary to achieve quality in the constructed or installed system. Construction quality control (CQC) refers to measures taken by the installer or contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project."

In other words, QC or CQC, represents all the measures performed on the field by the installer to ensure imperviousness and longevity of the geomembrane. It includes calibrations twice a day, air channel pressurization tests, destructive samples, vacuum boxes, and more. Groupe Alphard performed the CQA portion of the project, closely supervising every measurement, ensuring it was done according to specifications, and that results were better than minimal requirements.

6 Electrical Leak Location

The last step to prevent leaks is the Electrical Leak Location, also called "liner integrity survey". Below you will find a summary of the two most used methods in North America: the water puddle method on an exposed geomembrane and the dipole method on a geomembrane covered with soils.

6.1 Water puddle method

The water puddle geoelectrical method (as described in ASTM D7002) uses the intrinsic insulation properties of a geomembrane to locate perforations that enable water to pass from one side of the liner to the other (see following figure). A continuous DC voltage is applied into the metallic water lance structure, while a grounded electrode is placed outside of the geomembrane limits to intercept any current passing through a perforation. In this case, a visual and auditory signal indicates the presence of a leak. This technique requires only a thin film of water on the surface of the geomembrane and provides a validation of the entire exposed surface.

6.2 Dipole method

The dipole geoelectrical method (as in ASTM D7007 standard practice) uses the intrinsic insulation properties of geomembranes to localise perforations that enable water to go from one side of the liner to the other (see following figure). A current of approximately 500 V is injected into the covering material and a grounding electrode is placed outside the geomembrane limits. Thus, the current must pass through a leak in order to reach the ground (electrode), which generates a distinct electrical field that can be identified and located by a specialized technician.

When applied to a covered geomembrane, the dipole method requires that the covering material be moist enough to allow the electric current to penetrate from above to under the geomembrane in the presence of a leak. Should the calibration of the surface indicate that the material is not sufficiently humid, the surface must be sprayed with water prior to prospection. To have a good-quality signal, it is also important that the extremities of the covering materials be electrically isolated from the ground outside the limits of the geomembrane, otherwise the diameter of the size of leak that can be detected becomes larger the closer the technician is to the perimeter of the survey area.

Since the dipole method uses geoelectrical properties of the ground, the survey is impossible to perform if the covering or the foundation material is frozen, and less effective if the thickness of the covering material exceeds 1 m.

7 Field results VS internal statistics

To comply with environmental requirements, all installed geomembranes needed to be tested with both methods, when applicable. With the use of a conductive geotextile in the slopes, electrical current return poses no issue under the primary geomembrane even without sand between both liners. The only area of the cell that cannot be tested twice is the slopes of the secondary geomembrane since the dipole method doesn’t work directly on a conductive geotextile, and there is no work done in the area after the water puddle test, besides unrolling geotextiles.

Table 3 summarizes the number of defects found with each method, on each layer, including the previous cell results from 2020:

Table 3. Leaks found.

	Leaks per hectare 2020	Leaks per hectare 2023	Leaks per hectare (statistics)
Exposed liner	0,35 (1 leak)	1,34 (4 leaks)	7,09
Covered liner	0,48 (1 leak)	0,80 (2 leaks)	4,53

Useful data regarding leak types and sizes are reported in figures 2 and 3. This data pertains to this project (new and existing cells) in comparison to our overall averages.

Fig. 2. Types of defects founds.

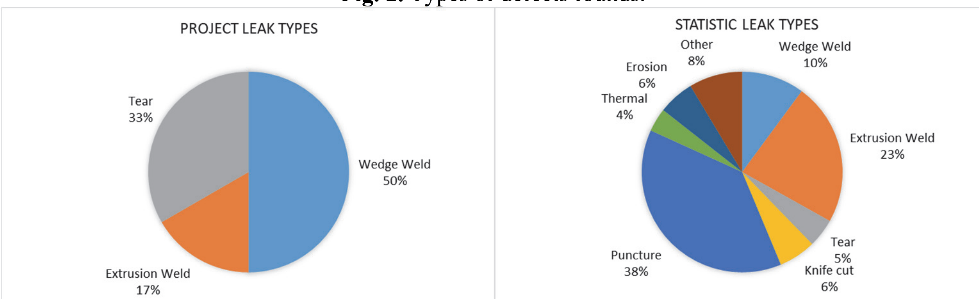
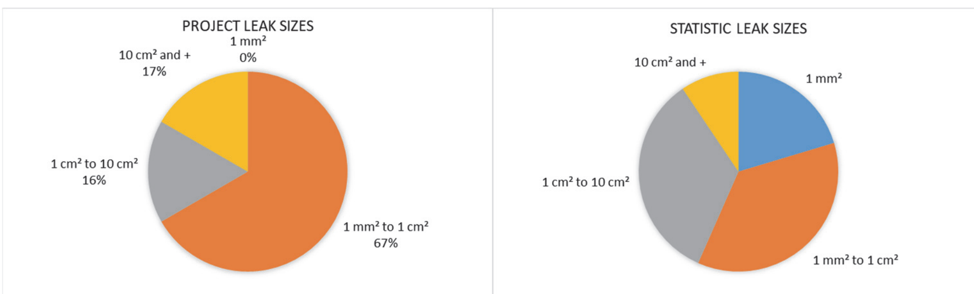


Fig. 3. Sizes of defects found.



It is important to understand that the data used for statistics includes projects with and without CQA, and even without QC in certain cases. The more effort put on the quality of the geosynthetics design, characteristics, and installation, the less chances leakage will happen. When all precautions are met with good materials, third party CQA, and electrical leak location, the chance a leak will be detected after doing both exposed and covered surveys is about 0.00001% (Gilson-Beck, 2015).

8 Conclusion

The design and construction of a new contaminated soil landfill is challenging. While this paper focuses on the geosynthetic aspect of the project, there are numerous challenges that were dealt with outside of the cell, such as leachate pumping, treatment ponds, operations, and all-natural material resource management.

A great deal of work was done years before the actual construction to meet legislation requirements, as well as the client's needs. The whole project was carefully planned using best practices and engineers' own experience to complete the construction within schedule and budget.

All installed materials were sampled and tested to make sure they met the designs criteria and could be safely taken to the next stage. This also included full-time third-party quality assurance on-site and leak location surveys after each geomembrane had been installed and covered with a drainage layer. Each control reduced the risk of leaks in the future, even though the cell is double lined and the owner will pump eventual leachate in the secondary drainage system, which at the same time raises the tolerance to leakage.

It is worth mentioning that promoting CQA and leak location surveying has a certain effect on the quality of the project: knowing they will be watched and that the quality of their work will be assessed, contractors and subcontractors focus more on quality for the duration of the project. Defects on geomembranes may still happen and the leak location survey is the only in-situ feedback for the client, besides environmental contamination after some time.

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