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# Geosynthetics in Antarctica: Performance of a composite barrier system to contain hydrocarbon-contaminated soil after three years in the field☆,☆☆

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ABSTRACT

An overview of the design and performance of geosynthetics in composite barrier systems for biopiles used to remediate hydrocarbon-contaminated soil at Casey Station, Antarctica, is presented. Seven instrumented biopiles were constructed over three field seasons. To minimize the risk of hydrocarbon migration to groundwater, composite barrier systems were used (each using different combinations of geosynthetic clay liners (GCLs), high density polyethylene (HDPE) geomembranes (GMB), and geotextiles (GTXs)). One biopile used a co-extruded geomembrane (HDPE with an ethylene vinyl alcohol (EVOH) core). The liner system was subject to a combination of coupled phenomena that could interact and affect the GMB–GCL composite barrier performance. The exposure conditions involved potential freeze–thaw cycling, hydration–desiccation cycles, cation exchange, direct and diffusive exposure to hydrocarbons. The effect of these phenomena was investigated by monitoring GCL and GMB sacrificial coupons. GCL coupons were placed between the main GCL component and the main geomembrane component of the composite liner and GMB coupons placed between the main GMB sheet and the GTX protection layer. Coupons were exhumed from the biopiles each year. The exhumed GCL field moisture content values ranged from 162% to 22%. After three (3) years in the field, GCL coupons that had undergone at least one hydration/desiccation cycle showed no significant change in swell index values or fluid loss values. The measured hydraulic conductivity of exhumed GCL coupons from Biopiles 1 and 2 ($3 \times 10^{-11}$ m $s^{-1}$) was within the expected range and not significantly different from the values for virgin GCL. GMB coupons exhumed after three years from Biopiles 1 and 2 showed no significant change in oxidative induction time (OIT), melt flow index or tensile properties. Diffusion tests were performed as an index test for establishing the performance of the GMBs as a diffusive barrier to hydrocarbons, with permeation parameters for BTEX contaminants ranging from $P_g = 0.9–9.2 \times 10^{-13}$ $m^2$ $s^{-1}$ for the exhumed GMB (with values depending on the contaminant and GMB). These values were similar to the parameters obtained for virgin GMBs and there was no significant change with field exposure, with GMBs appearing to be performing well.



## 1. Introduction

Hydrocarbon contaminated soil from two separate fuel spills that occurred in 1999 and 2012 underwent remediation at Australia's Casey Station, Antarctica (66°17′ S 110°31′ E). The remediation approach for both sites required an initial economic assessment of techniques suitable for Antarctic conditions that met the Australian government clean-up obligations under the Protocol

☆ This paper is a modified and expanded version of a paper by McWatters et al. (2014) initially presented at the 7th International Congress on Environmental Geotechnics (7ICEG), Melbourne, Australia, 10–14 November 2014. Any material from the earlier paper is reproduced here with the permission of the ICEG committee.

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on Environmental Protection of the Antarctic Treaty (Sànchez and McIvor, 2007). An integrated, three stage, remediation strategy was developed for these sites. The first stage was to control off-site migration of contaminants on or in groundwater by installing permeable reactive barriers (PRBs) (Mumford et al., 2013). The second stage involved the excavation of contaminated soil from the fuel spill sites and placement in seven biopiles, constructed over the austral summer seasons of 2011–13 (Fig. 1). The biopile site (Fig. 2) is located 200 m from the coastline and is 28–30 m above sea level. The site slopes from the bottom of Fig. 2 to the sea visible in the upper third of the photo.

The biopiles are so called because they were designed to optimise the management of soil conditions to enhance biodegradation of fuel by native microorganisms present in the Antarctic soil (Winsley et al., 2012). The process was enhanced by nutrient addition to the soil, installation of aeration/extraction systems, leachate recirculation and yearly mechanical aeration. Airborne migration during remediation was minimised using a geotextile (GTX) cover system over the biopiles. When the soil is adequately remediated, the third stage will involve returning the soil for reuse on-station in building foundations or road construction subject to an appropriate human health and environmental risk assessment.

The biopiles required a base composite barrier system capable of withstanding the dry and cold Antarctic environment (daily average temperature ranges from 5 °C at the warmest in summer and −34 °C in winter (BOM, 2016)), to contain contaminated soil above the uncontaminated ground surface, and to protect the surrounding soil, melt water and groundwater areas. This barrier system is the focus of this paper. The base barrier system design was developed based on the authors' experience gained from municipal solid waste landfills (Rowe et al., 2004b; Rowe, 2005, 2012) and Canadian Arctic barriers (Bathurst et al., 2006; Rowe et al., 2006, 2007, 2008, 2010; Kalinovich et al., 2008, 2012; Paudyn et al., 2008). Six biopiles were designed with a geosynthetic composite barrier system using geosynthetic clay liners (GCL), high density polyethylene (HDPE) geomembranes (GMB) and GTXs (Fig. 2). The seventh biopile was designed using a GCL, co-extruded GMB, and GTXs. The co-extruded GMB has an inner ethyl vinyl alcohol (EVOH) barrier covered on either side with HDPE. This study represents the first documented field site using this novel GMB and ultimately the performance will be compared with the other GMBs used on site.

GCLs are manufactured liners and a good option for barriers in sites where access to low permeability soil (e.g., clay) is unavailable, such as Antarctica. When the bentonite layer is well hydrated (degree of saturation > 70%) and under a confining load, GCLs can be an excellent advective, and a modest diffusive, barrier to hydrocarbon contaminant migration (Rowe et al., 2004a, 2005, 2006). Hydration is achieved through uptake of moisture from the underlying subsoil (Beddoe et al., 2011; Rayhani et al., 2011; Chevrier et al., 2012). However, the coarse granular subgrade, extreme cold ambient temperatures, high winds and arid climate of Antarctica provides challenges for effective hydration of the GCL to provide a good hydraulic barrier, and hence containment.

A composite barrier system comprised of (from bottom up) a GCL, GMB and GTX (protection layer) provides a superior hydraulic and diffusive barrier in contrast to a single liner (e.g., Rowe, 1998, 2005, 2012). The emphasis on robust protection is especially important in the Antarctic, where the environmental risks are high because the ecosystem is sensitive and unique and soil health recovery is difficult (Winsley et al., 2012). A barrier to provide containment for hydrocarbons-contaminated fuel, water (leachate) and soil, must minimize advective and diffusive transport of contaminants. In the present context, advective transport is the migration of contaminants with a hydraulic gradient from the leachate level in the biopile to the free draining underlying granular soil. The GMB represents the primary barrier to advection with the GCL minimizing leakage through any holes in the GMB (e.g., Rowe et al., 2004b; Rowe, 2005, 2012). Diffusion is the net movement of

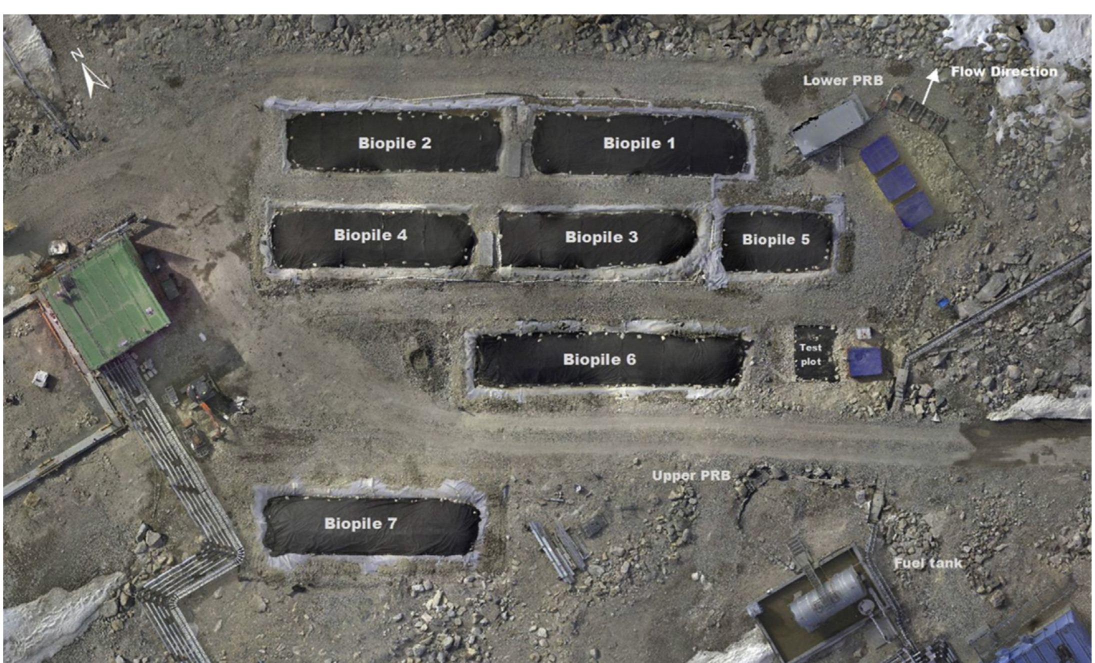


**Fig. 1.** Remediation site showing: fuel tank (source of the 1999 fuel spill), contaminant flow direction, upper and lower PRBs, seven biopiles and test plot. Black upper covers shown are GTX2 or GTX4 (see Table 1).
(Photo after Lucieer and Wilkins, 2014; reproduced with permission).