Case study of water evacuation from a waste cover via evapotranspiration and a drainage geocomposite

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ABSTRACT
The performance of a tubular drainage geocomposite has been investigated in a waste cover test pad located north of Montreal, Quebec, over a three year period. The average annual infiltration to the geocomposite was 45% of precipitation. It was found that the pore size and texture differences between the topsoil and the geotextile under the topsoil formed a capillary break that held water in the topsoil. It was concluded that evapotranspiration eliminated infiltration through the cover to the geocomposite during the growing season from May to September. The geocomposite performed as designed when required to drain water from October to April, during periods when the cover system was not frozen.

RÉSUMÉ
La performance des géocomposites de drainage avec mini-drains a été évaluée pendant 3 ans dans le cadre de la couverture de lieu d'enfouissement technique situé au Nord de Montréal, Québec. Il a été relevé que 45% des précipitations se sont infiltrés et ont été captés par le géocomposite. Il a été également démontré que la granulométrie et les différents types de sols entre l'engazonnement et les géotextiles forment un bris capillaire qui retient temporairement l'eau dans la couverture. Il a été conclu que l'évapotranspiration a empêché l'infiltration d'eau vers le géocomposite au travers de la couverture pendant la saison chaude entre mai et septembre. Le géocomposite a quant à lui remplit pleinement sa fonction telle que dimensionnée pour drainer les eaux d'infiltration, lorsque nécessaire, entre octobre et avril, lorsque le système de couverture n'était pas gelé.

1 INTRODUCTION

Final landfill covers are not only required to minimize the infiltration of precipitation into a landfill, but also collect biogas, prevent veneer slope failure, and generally prevent the landfill from being an eyesore.

In Quebec, the Règlement sur l'enfouissement et l'incinération des matières résiduelles (REMR) requires (from bottom to top) a 0.3-m-thick layer for sensing and collecting landfill gasses, a 0.45-m-thick layer with low hydraulic conductivity or a 1-mm-thick geomembrane to isolate the landfill, a 0.45-m-thick soil protection layer, and 0.15 m of topsoil. The regulation allows for other materials to replace all of the barrier and drainage layers of the cover, provided that the replacement material has equivalent performance (2006). At the case study herein, a tubular drainage geocomposite was installed as a drainage layer above the geomembrane (Figure 1).

In this paper, the efficiency of the tubular drainage geocomposite to remove infiltration from the slope at a test pad is observed throughout a year of operation, in order to determine if the geocomposite is performing as designed.

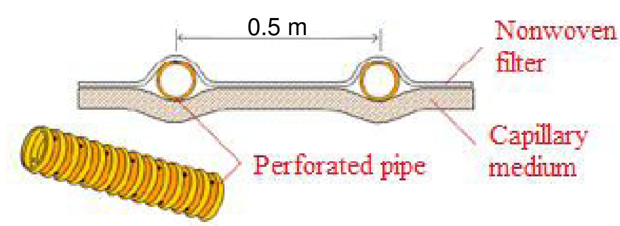

Figure 1. Draintube drainage geocomposite

2 SITE DETAILS

The site located at 45°N, 74°W was a landfill cover with a cross section as seen in Figure 2 on a 30% slope. A nonwoven geotextile was used for separating the topsoil from the protection soil. The nonwoven geotextile was 1.4 mm thick, with a filtration opening size of 45-90 µm and a permeability of 0.11 cm/s. According to the construction records, the protection soil was compacted to 1480 kg/m³ (90% Modified Proctor) and had a range of measured hydraulic conductivities from $1x10^{-3}$ to $5 x10^{-3}$ cm/s. 100% of the protection soil passed the 5 mm sieve, and 0-20% passed the 0.08 mm sieve. The geocomposite was placed above the 1.0 mm low density polyethylene (LDPE) geomembrane to drain precipitation that infiltrated the cover. The sand layer under the geomembrane was for biogas collection.

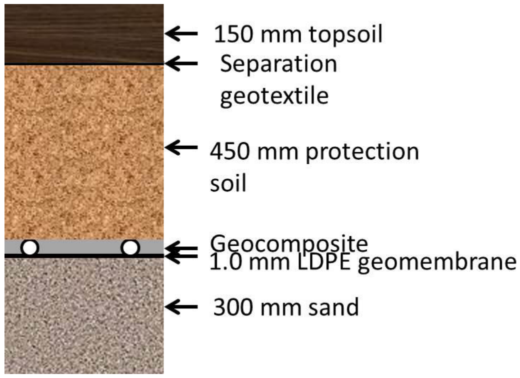

Figure 2. Cross section of landfill cover

The drainage geocomposite installed had 25-mm-diameter parallel polypropylene pipes with a spacing of 0.5 m, that were designed by the design engineer to drain 3.2×10^{-6} m/s of water with a maximum hydraulic head of 0.01 m between the pipes at this site (Figure 1), and no pressure build up in the tubes. Figure 3 shows the geocomposite installed on the slope.

Figure 3. Exposed drainage geocomposite during installation.

A collection pipe was installed at the bottom of the 30% slope in the test pad area of 1980 m². The collection pipe was connected to a flowmeter and the instantaneous flow rate and the volume of flow was recorded. The flowmeter, manufactured by Endress and Hauser, had an input pipe of 50 mm, to obtain flow rates within the recommended measurement range.

The slope was initially hydroseeded in October 2009, and touch-ups were completed during spring 2010 after erosion gullies had formed in the topsoil. Vegetation covered the slope by spring 2011 (Figure 4).

Data is reported from July 2010 to April 2013. The flow volume was measured and recorded every 30 seconds from July 2010 to January 2012, then every five minutes thereafter. Daily precipitation and weather data was taken from the meteorological station at St-Jerome from July 2010 to March 2013, which is about 9 km from the landfill (Environment Canada). The test pad was designed and monitored by the engineering consultant and the landfill operator, and the resulting data was analyzed and reported by the authors for knowledge dissemination.

Figure 4. Image of study area one year after installation.

3 RESULTS

Figure 5 shows the volume of water collected from the geocomposite, as well as the calculated volume of precipitation in each month. The volume of rain was calculated by multiplying the number of millimetres of rainfall by the area of the test pad. The greatest volume of rain was 550 m³ during April 2013, but was usually between 50 – 100 m³, during months that there was measureable flow.

The volume measured in the flowmeter during each month does not correlate to the volume of rainfall (Figure 5). There was little to no flow during the winter months of January and February, as well as from June to August in the summer. In July and August 2010 when there was the greatest rainfall, there was no measurable flow from the geocomposite. In December 2010, and often in the months of March and April, the flow from the geocomposite exceeded the volume of rainfall. Environment Canada (2010) did not report any significant melting events in December 2010. Precipitation can be stored within soil covers, and therefore measured rainfall may not flow through the cover in the same time period as it fell (Yanful et al. 1999).

It is noted that there are periodic gaps in the rainfall data from Environment Canada (2010), such as on December 1, 2010. This creates an analysis problem because 60 m³ of water was recorded through the flowmeter on that day, which is 70% of the volume for the month of December, but there is no corresponding precipitation data. This was not a significant melting event, because Environment Canada (2010) reported 3 cm of snow on the ground on November 30, and the maximum daily temperature for November 29 and 30 was 5°C.

The difference between the volumes of rain and flow through the geocomposite can be explained by the capillary break that was created by the geotextile placed between the topsoil and the protective soil which trapped water within the geotextile, then evapotranspiration removing the water from the topsoil.

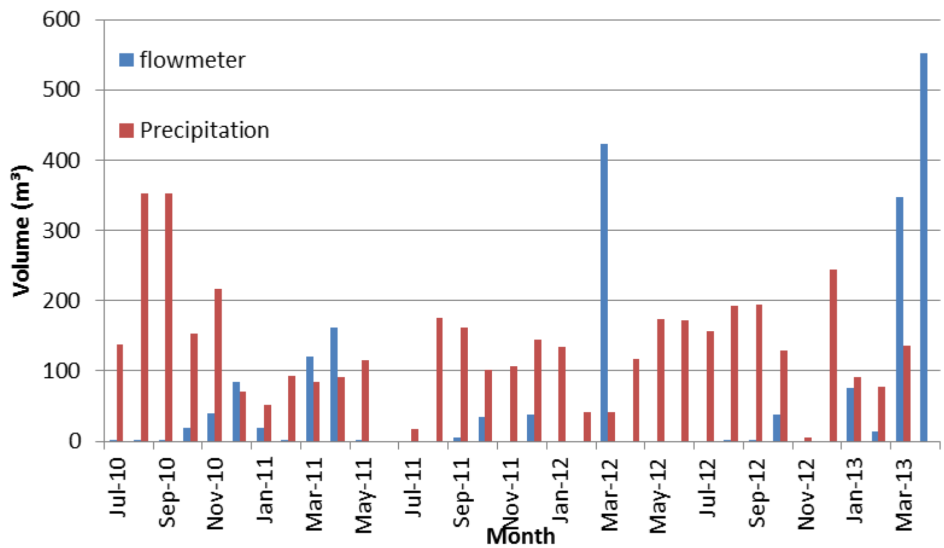

Figure 5. Volume of monthly flow through flowmeter, and calculated volume of rainfall over the area of the test pad.

3.1 Capillary Break

It has been observed that in unsaturated soil, nonwoven geotextiles do not allow water to drain until the soil is almost saturated (Richardson 1997). This is because there is a capillary barrier between a material with a small pore size and an adjacent material with a large pore size (McCartney et al. 2008). For water to flow from the material with a small pore size to the material with a large pore size, the negative pressure (suction) that holds water within the smaller pores must be close to zero, when the material is almost saturated (McCartney et al. 2008). Suction is created when a liquid is pulled into an adequately small space between solid materials with a combination of surface tension and adhesion between the liquid and the solid. This often occurs when the hydraulic conductivities of the two materials are similar. The net effect of a capillary barrier is water is stored within smaller pores until the finer grained material is almost saturated (McCartney et al. 2008).

In this case study, the pore size of the geotextile is larger than the pore size of the topsoil, and therefore water is held within the topsoil, as long as the geotextile is not saturated. McCartney et al. 2008 found that a 2.54-mm-thick nonwoven geotextile (polypropylene with a mass per unit area of 0.2 kg/m^2) slowed the rate of capillary suction until water entered the geotextile, then the hydraulic conductivity of the geotextile was greater than the soil and subsequently allowing the soil to drain.

Iryo and Rowe (2005) found that under positive pore pressure, nonwoven geotextiles have a hydraulic conductivity that is greater than soil and therefore act as drains, and under negative pore pressure (suction), geotextiles have a lower hydraulic conductivity than soil.

One of the implications of this effect is that when a geotextile acts as a hydraulic barrier, the volume of water stored in the soil could cause surface erosion (the formation of gullies). It should be noted that this was a very minor problem that took place before vegetation grew in the first year. It was thus considered to be a temporary problem, and as a matter of fact, after the vegetation grew in after reseeding, the slope performed satisfactorily.

In a soil waste cover test pad in southern Ontario with a similar climate as the current study, Yanful et al. (1999) found that a capillary break was generated at the interface between topsoil (low hydraulic conductivity) and underlying gravel (high hydraulic conductivity) which prevented water from infiltrating the cover system. Although no geosynthetics were used, the capillary break effect between the two materials with different textures was the same as in this case. This comparison is significant because it demonstrates that even if there were no geosynthetics at this test pad, the same phenomenon would most likely occur at the interface between fine and coarse grained soils.

3.2 Evapotranspiration

Evapotranspiration is the processes of water being removed from the surface of the ground by the evaporation of water on the surface and in the capillary fringe, and the transpiration of water by plants. Plant transpiration depends on air temperature, wind speed and humidity, sun, rainfall, and soil type and water content (USGS 2013). Evapotranspiration can be an important process for removing water from a cover system, depending on the weather, climate and time of year.

Figure 6 is a monthly comparison of the amount of average amount of evapotranspiration, and amount collected from the geocomposite from the three year time period. The units are millimetres because evapotranspiration is reported in millimetres (the height of water collected in the geocomposite was averaged over the area of the test pad). The evapotranspiration data was a monthly average over 42 years from the nearby city of Montreal (Martin and Gray). Note that the volume of evapotranspiration is an average value with no reported standard deviation, and the data is for a nearby urban centre and the landfill is in a nearby rural setting. Therefore it is used here only as a guide for relative monthly trends, and not for definitive quantities. Figure 6 shows that there is no evapotranspiration in January and February, as expected in Quebec when plants are dormant or dead, and the soil is usually frozen and often covered with snow. In March, snow melts after winter which exposes the surface of the earth to evaporation, and starts the early growing season to start evapotranspiration. The rate increases in April to the annual peak rate in May, the midpoint between the annual peak rainfall in the spring, and peak plant growth in July and August (Martin and Gray). There is a high rate of evapotranspiration from June to August, and then the rate slows in September at the end of the growing season, and reduces further until no measureable evapotranspiration in December.

Figure 6 indicates that evapotranspiration is the main process that removed water from the soil between May and October, with a peak in May. In fact, during these months, evapotranspiration removed so much water to the atmosphere that precipitation was not able to infiltrate the cover through to the geocomposite. Therefore, the geocomposite was only necessary to drain the system during the months of March and April (and to a lesser extent November and December) when there was little or no evapotranspiration and the ground is not frozen.

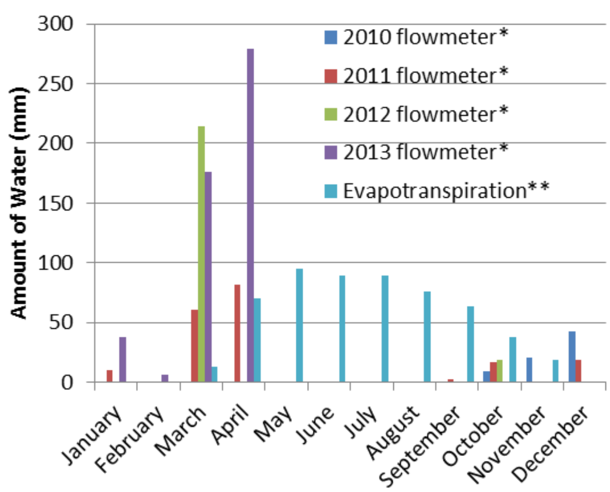

Figure 6. Comparison of 42-year average evapotranspiration, and amount of water calculated from monthly flowmeter volume. *Flowmeter data is the volume of water collected in the geocomposite divided by the test pad area.**Evapotranspiration data from Martin and Gray.

The natural process of evapotranspiration works with the engineered cover system by removing water from the topsoil above the geotextile, and stabilizes it with the tensile strength of the root mass and suction.

3.3 Infiltration Rate

The percentage of rainfall that percolates through the cover soil and reaches the geocomposite is important for evaluating the performance of the geocomposite, the cover as a system and for runoff water management. The average infiltration as measured from the volume collected from the geocomposite for the year was 45%, although this is not consistent over the year. Table 1 shows percentage of infiltration measured by the flowmeter compared to the volume of precipitation in each month. During July to September of 2010 and May to July 2011, the percentage of infiltration compared to precipitation was negligible. After the growing season in the fall, the infiltration increased in October and November to a peak in December. In December, there is usually no evapotranspiration, but the ground may not be frozen for the entire month, so all of the precipitation, as well as some stored water, was removed from the slope with the geocomposite. In January, there was some infiltration, but less than 40% of the precipitation. In February, there was almost no infiltration, and it is expected that the cover was frozen during this month. In March and April, about one and a half times the volume of water that fell as precipitation was measured at the flowmeter. This discrepancy could be due to water from the snowmelt or water from the top of the landfill cover.

The average flow rate through the flowmeter during 5 minute measurement periods during the first three weeks in April is shown in Figure 7. The average flow rate was calculated by dividing the volume of water measured through the flowmeter over the period by the area of the test pad. At the time of writing this paper, the weather data was not available from Environment Canada. The month of April 2013 was chosen because the total volume of flow through the month was three times greater than the second highest monthly flow in April 2011. Although the average flow rate for the time period was 1.7×10^{-7} m/s, the flow rate was actually intermittent and variable. Periods with flow rates greater than the average lasted less than twelve hours, and usually the flow rate increased and decreased at roughly the same rate with a defined peak. There were 14 periods with a greater than average flow rate.

The greatest flow rate was 7.5×10^{-7} m/s, which is 23% of the maximum design flow rate. This indicates that the flow to the geocomposite is unsaturated, as designed. Since there is no available weather data, it is not clear what the volume or rate of precipitation was, so it is difficult to compare to previous data. It is noteworthy that the greatest flow occurred at the beginning of April, after the soil thawed, but before plant growth and associated evapotranspiration. The lack of gully formation after spring 2010 indicates that the permeability of the cover system is adequate to prevent large volumes of overland flow.

Table 1. Infiltration as a percentage of precipitation by month.

Month	Infiltration Compared to Precipitation (%)
July 2010	0
August 2010	0
September 2010	0
October 2010	12
November 2010	19
December 2010	117
January 2011	37
February 2011	0
March 2011	143
April 2011	176
May 2011	0
June 2011	0
July 2011	0
August 2011	0
September 2011	3
October 2011	33
November 2011	0
December 2011	26
January 2012	0
February 2012	0
March 2012	1018
April 2012	0
May 2012	0
June 2012	0
July 2012	0
August 2012	1
September 2012	0
October 2012	29
November 2012	0
December 2012	0
January 2013	84
February 2013	17
March 2013	255
April 2013	--

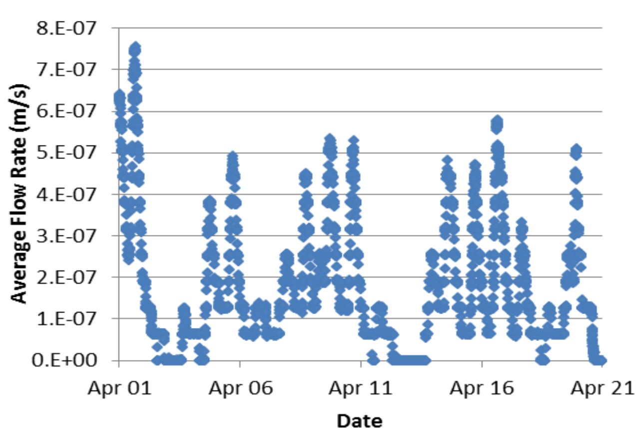

Figure 7. Average flow rate of infiltration over 5 minute intervals in April 2013.

3.4 10 year Rainfall Event for 12 Hour Duration

Luckily for this investigation, there was a 10 year return period rainfall event for a 12 hour duration on September 30, 2010. It occurred after a moderate rainfall event two and three days previously (Figure 8). Although 120 m^3 of rain fell on the area of the test pad on September 30, no flow was measured in the flowmeter until 10 m^3 was measured on October 1st, and 5 m^3 on October 2. No flow from the geocomposite after October 2.

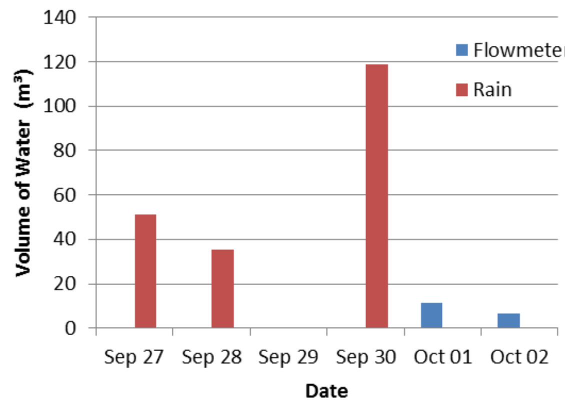

Figure 8. Volume of rain and water measured with the flowmeter surrounding the 10 year return period for a 12 hour rainfall event.

It would appear from the rainfall and flowmeter data that 10% of the rainfall reached the geocomposite. This value is reasonable considering the effect of the slope, the runoff and the effect of evapotranspiration, as explained by ADEME (2001). The volume of rainfall on a slope is:

$$Q_{slope} = Q_{rainfall} \times \cos(\alpha) \qquad [1]$$

where Q_{slope} is the rainfall rate that reaches the surface of the slope, $Q_{rainfall}$ is the rate that is measured on a horizontal surface, and cos α is the angle of the slope.

Runoff and evapotranspiration reduce the rate of water that reaches the drainage layer (Figure 9):

$$Q_{in} = Q_{slope} - Q_{ev} - Q_r \qquad [2]$$

where Q_{in} is the rate of infiltration into the drainage layer, Q_{ev} is the rate of evapotranspiration and Q_r is the rate of runoff. Assuming that the rate of evapotranspiration and runoff depend on the rainfall rate:

$$Q_{in} = Q_{slope} \times f \qquad [3]$$

where f is a reduction factor based on the slope, type of backfill soil, temperature, location, etc. For a slope greater than 2%, a conservative value will be 0.5 (ADEME 2001). In temperate climates and for α=18.5°, it is assumed that f = 0.15 to 0.25.

The rain events of September 27, 28 and 30 and resulting flow through the geocomposite suggest that the percentage of water that infiltrates the cover system may be greater for a large volume of rain over a long period of time with a longer return period. This event demonstrates that when the topsoil is near saturation and water flows through the geotextile, the geocomposite effectively removes the excess water from the slope.

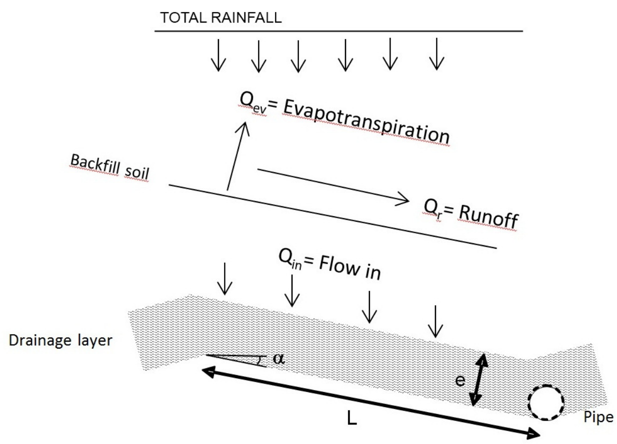

Figure 9. Schematic drawing of the hydraulic function of the drainage layer (ADEME 2001).

4 DISCUSSION

During design of a waste cover system, the ability of a geotextile to act as a capillary break should be taken into account when analyzing for veneer slope stability. In this case, the suction of evapotranspiration, and to a lesser extent, the roots of the vegetation stabilize the soil.

The cover system was designed to reduce the hydraulic head between the geocomposite tubes to equal to or less than 10 mm, and drain 3.2 x10^{-6} m/s of infiltration without increasing the pressure head in the tubes. The maximum rate of infiltration over a 5 minute period was 7.5 x10^{-7} m/s, which is only 23% of the design infiltration rate. Therefore, the design of the geocomposite and slope was satisfactory for the conditions encountered so far for this test pad.

It is therefore not known where the infiltration water originated from, because this study does not take into account the potential volume from water collected and drained from the top of the landfill cover. This means that the water collected from the geocomposite may or may not be water from within the test pad on the side slope.

5 SUMMARY

A drainage layer is necessary to drain a waste cover when there is a high volume of water to drain (i.e., high return period rain events, snow melt, no vegetation, etc). For this case study, the volume of water that reaches the geocomposite was significantly below its drainage capacity, even for a 12 hour, 10 year return period rainfall. In conclusion:

- Average annual infiltration to the geocomposite was 45% of precipitation
- Pore size and texture differences between the topsoil and the geotextile formed a capillary break that held water in the topsoil
- Evapotranspiration eliminated infiltration through the cover system from May to September
- The geocomposite performed as designed (calculated maximum rate of infiltration was 7.5 x10^{-7} m/s) when required to drain water from October to April, during periods when the cover system was not frozen

Although this test pad was a landfill cover, the same principle could be used for mine waste covers.

It is suggested that the local rate of evapotranspiration should be considered when designing a cover system to understand the volume and time periods when a drainage geocomposite is utilized. This would help to optimize costs and materials while designing the cover system.

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