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Effect of geotextiles on the transfer of heavy metals in a calcareous soil underneath a stormwater infiltration basin at several concentrations.

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Abstract

Geotextiles are fibrous materials increasingly employed for the design of infiltration basins to separate different materials and for their hydraulic properties (drainage). Though currently used, their effect on the transfer of contaminants carried by stormwater has not been fully investigated. This study aims at showing that this effect depends upon contaminant load. Leaching column experiments were subjected to high metallic load and compared to previous leaching experiments at low load [1]. In the new columns, the metallic load was sufficient to allow SEM observations and provide useful information on their filtering contaminated particles.

Key words: *heavy metals, flow, columns experiments, calcareous deposit, infiltration basins, geotextiles, filtering, SEM.*

1-Introduction

Geotextiles are synthetic fibrous materials currently used in stormwater infiltration works such as infiltration trenches and ditches, infiltration basins and ponds. In these works, geotextiles are used to fulfil mechanical and hydraulic functions such as soil reinforcement, material separation, and water filtration. The influence of geotextiles on the transfer of contaminants transported by stormwater is seldom taken into account, yet some studies have shown that they can accumulate contaminants such as heavy metals in roads and in stormwater collection and infiltration systems [2,3].

And yet, the installation of geotextiles in the soil may result in a modification of the surrounding soils and in the formation of a new system soil – geotextile [4], with new hydraulic [5], chemical and even biological properties [6]. Recently Lassabatere et al. [1,7] studied the effect of geotextiles on heavy metal transfer in a real soil extracted from an infiltration basin, using leaching column experiments. Geotextiles were proved to significantly modify heavy metal transfer. This modification depended upon geotextile water contents, water flow rates, the type of geotextile and the configuration of the system soil – geotextile [1]. This modification was proved to be induced by their effect on flow [7]. For certain conditions (low water content and low flowrate), geotextiles homogenized the flow and then facilitated the contact between the contaminants transported by water and the reactive soil. This resulted in an increase in contaminant retention in the soil.

The aim of this paper was to complete these previous studies with the study of geotextiles effect on three metals (Zn, Pb and Cd) in the soil previously studied for several metallic loads. This aims at providing information relative to the following question: in case geotextiles are used to reduce contaminant transfer, can stormwater infiltrate in the basin, whatever its quality? Larger loads than the ones previously applied were applied to the system soil – geotextile, using columns experiments. The metallic load was then sufficient to allow observation of contaminated phases and the geotextiles with scanning electron microscope (SEM) to get further information at the microscopic scale.

2-Material and Methods

We tested the effect of geotextiles on flow and on the transfer of a certain metallic load with a first serial of experiments. The metals, i.e. Zinc (Zn), Cadmium (Cd) and Lead (Pb) were then injected at 10^{-3} mol/L. We then performed complementary serial to test the effect of geotextiles with a larger metallic load (same metals at concentrations 10^{-2} mol/L). This metallic load allowed SEM observations of contaminated phases.

2.1-Material

The soil corresponds to particle size fraction < 1 cm of the fluvio-glacial deposit that fills the "Django Reinhardt" infiltration basin in Lyon (France). The soil inherited the characteristics of the whole deposit, displaying heterogeneous and multi modal particle size distribution and a calcareous nature. Its high carbonate content (25%) results in a high pH (8.7) and a high reactivity relative to heavy metals (Plassard *et al.*, 2000). Two geotextiles currently used in civil and environmental engineering and in infiltration basins in particular, have been tested: a needlepunched geotextile with long fibers (GN), and a thermosealed geotextile (GT) (Table 1). Both are made of polypropylene. For the needlepunched geotextile, fiber cohesion is ensured by needlepunching (penetration of needles). Cohesion of the thermosealed geotextile is ensured by compression and heating. Before use, all the geotextiles were washed with sulfochromic acid to eliminate all production additives and then dried before use

Table 1. Geotextile characteristics.

	Fibers length	Thickness	Weight	Filtering opening size	Porosity	Hydraulic conductivity
		(mm)	($g;cm^{-2}$)	(μm)	(%)	($m.s^{-1}$)
GN	m	5.8	720	50	86.5	$3.5.10^{-3}$
GT	m	0.75	220	80	67.5	$4.5.10^{-4}$

2.2-Leaching column experiments performed at 10^{-3} mol/L

Leaching columns were made of high-density polyethylene of 10 cm width and 30 cm long. The soil was introduced at 8% massic water content, which led to an average dry density of 1.81 $g.cm^{-3}$. The geotextiles were installed at the center of the column. Before being fed with solutions, columns were saturated 24h using Mariotte bottles. The total water volume (V_0) averaged 600-650 cm^3, and the soil saturation degree averaged 75%. Water and solutes were injected upwards at a constant flow rate ($q = 7,5.10^{-2}$ $cm.min^{-1}$) by a peristaltic pump. Initially, 1 V_0 of neutral solution was injected to reach steady state flow. This neutral solution was made of sodium nitrate ($NaNO_3$) at 10^{-2} mol/L dissolved in deionized water. Columns were then fed with a tracer solution composed of potassium bromide (KBr) at 10^{-2} mol/L in deionized water in a pulse mode: 0.56 V_0 width pulse followed by 5.5 V_0 of neutral solution. The metals were then injected into the columns with 6.5 V_0 of metal solution (step mode) composed of Zinc ($Zn(NO_3)_2$), Lead ($Pb(NO_3)_2$), and Cadmium ($Cd(NO_3)_2$) nitrate at 10^{-3} mol/L in deionized water. Ionic strength was adjusted to 10^{-2} mol/L by adding sodium nitrate ($NaNO_3$). Each type of column was made as triplicate.

2.3-Column experiments performed at 10^{-2} mol/L

The columns were constructed as described above and presented similar characteristics. Three columns were realized, one filled with the soil, a second filled with the soil amended with the geotextile GN placed at the center and the last one amended with the geotextile GN placed at a quarter of the total length, closer to the inlet. The injection of the tracer was not performed. We considered that flow patterns should be similar as these observed for the columns described above. The metals were then injected into the columns with 6.5 V_0 of metal solution (step mode) composed of Zinc ($Zn(NO_3)_2$), Lead ($Pb(NO_3)_2$), and Cadmium ($Cd(NO_3)_2$) nitrate at 10^{-2} mol/L in deionized water. At the end of the experiments, the soil and the geotextiles were carefully extracted and air-dried prior SEM analysis.

2.4-Solute elution analysis

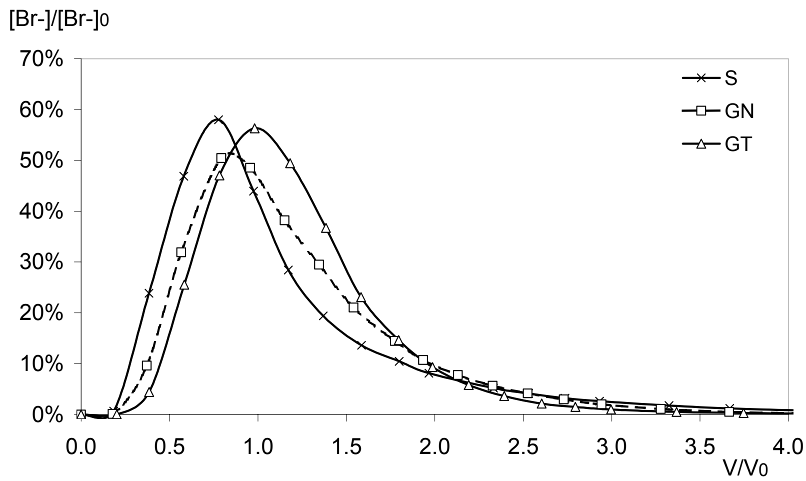
Bromide concentrations were measured by ionic chromatography. The heavy metal concentrations were measured with flame atomic adsorption spectroscopy (FAAS). Solute elutions were characterized by their breakthrough curves, by plotting the relative concentrations at the outlet ([Solute]/$[Solute]_0$) against the relative eluted volume (V/V_0). Metal elution was quantified by relative heavy metal concentrations at 6 V_0 ($C/C_0(6)$). Bromide mass balance and retardation factors were estimated by using the zero and the first order moments [8]. Bromide experimental elution was modeled with the MIM transport model (MIM for Mobile/Immobile water contents). This model assumes that water is fractionated into a mobile fraction active in mass transport (f_m), a stagnant immobile fraction (f_{im}) and an isolated fraction (f_{is}). The solutes are transported by convection and dispersion in mobile water and diffuse at the interface between the mobile and the immobile fractions with a first order rate [9]. Fitting experimental data with MIM provided estimations of the fractions (f_m, f_{im}, f_{is}) and the first order solute exchange rate (α), which facilitates the characterization of flow homogeneity. The model was developed on MathCad Professional by LTHE (Grenoble).

2.5-SEM analysis.

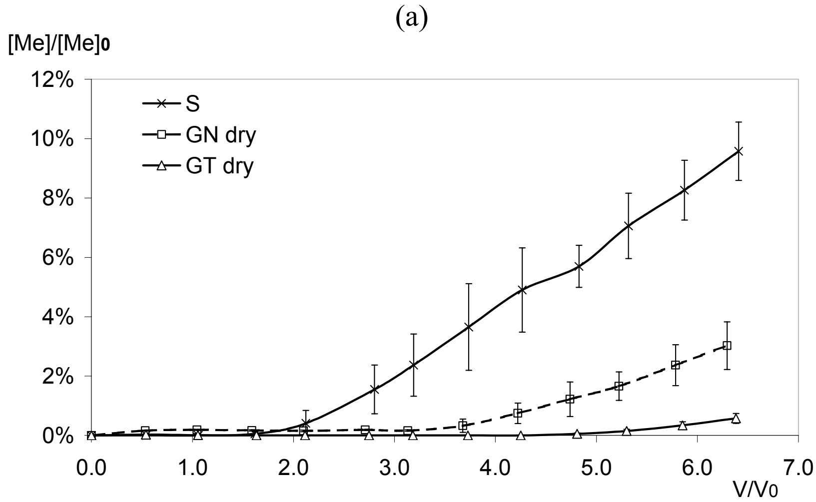
Some soil samples were observed directly. Others were fixed with epoxy glue and then cut into thin slices. The geotextiles were always observed directly. All the samples were then coated with a palladium/gold (Pd/Au) deposit before performing the SEM observations. The SEM apparatus was a JSM Jeol 840-A with an Energy Dispersive Spectrometer (EDS) Tracor Northern TN 8502\S at Laval University (Quebec, Canada). The SEM focuses an electron beam of several μm on samples at 15 KeV and captures backscattered electrons (BSE), secondary electrons (SE) and X-ray emissions. The analyses of the BSE, SE and X rays emissions give information on the density of phases, their structure and their atomic composition respectively [10].

3-Results

3.1-Effect of geotextiles on heavy metal elution at both 10^{-3} mol/L and 10^{-2} mol/L


[Br-]/[Br-]0
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
V/V0
S
GN
GT

(a)


[Me]/[Me]0
12%
10%
8%
6%
4%
2%
0%
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1.0
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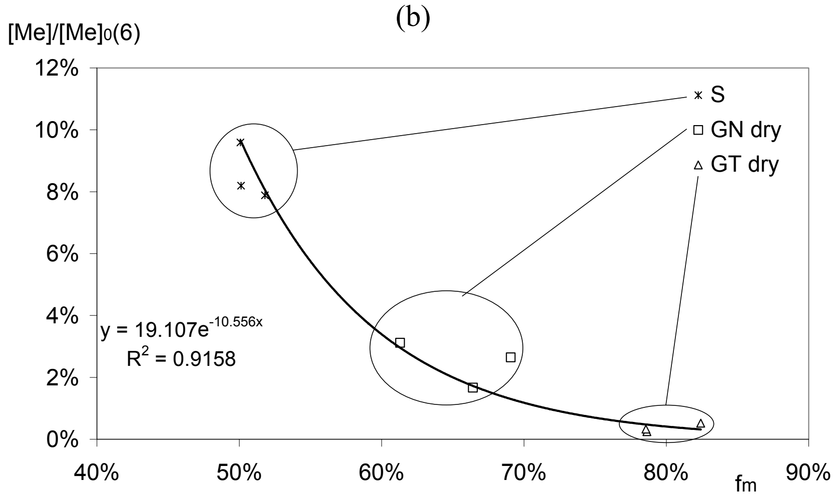
6.0
7.0
V/V0
S
GN dry
GT dry

(b)


[Me]/[Me]0(6)
12%
10%
8%
6%
4%
2%
0%
40%
50%
60%
70%
80%
90%
fm
S
GN dry
GT dry
y = 19.107e-10.556x
R2 = 0.9158

(c)

Figure 1. (a) Bromide experimental elution (b) heavy metal elution and (c) relative concentration versus mobile fraction.

Concerning Bromide, experimental elution was well modeled and the fractions (f_m, f_{im} and f_{is}) and the solute exchange rate (α) could be estimated efficiently, for all the columns. Bromide elution revealed a heterogeneous flow in the columns of soil (S) with considerable immobile and isolated fractions at the expense of the mobile fraction (50.7%). For the columns amended with geotextiles, bromide elution revealed a more homogeneous flow with mobile fractions around 66% and 80%, respectively for GN and GT. Thus bromide elution analysis proved that geotextiles homogenized the flow in the columns.

Concerning the heavy metal transfer, we mainly focus on the global heavy metal load insofar as the heavy metal kept their specificity: Zinc and Cadmium eluted similarly, Lead never eluted (complete retention). We present the results with the averaged contents and relative concentrations. Geotextiles significantly reduced heavy metal elutions (Figure 1 (b)). At the end of the experiment, the relative concentrations dropped from 8% for the soil to 2.5% for geotextile GN and to 0.4% for geotextile, i.e. : GT: S << GN << GT for retention (Figure 1 (b)).

The plot of the relative concentration for the injection of 6 V_0 versus the mobile fraction (f_m) gives further information. The relation between relative concentration and mobile fraction can be accurately fitted with a strictly decreasing function (negative exponential function, R^2 = 0.914). That means that when the geotextiles homogenized the flow, they increased the retention of metals and reduced their elution. This is in fact a cause - effect relationship. When geotextiles homogenized the flow, they forced the water to pass through the whole matrix, which improved the contact between the contaminants transported by water and the reactive matrix. This improvement helped retention mechanisms and optimised the global retention. The value of correlation coefficient (R^2 = 0.914) indicates that no other factor may play any role, the effect on flow then being the main cause for their effect on heavy metal transfer.

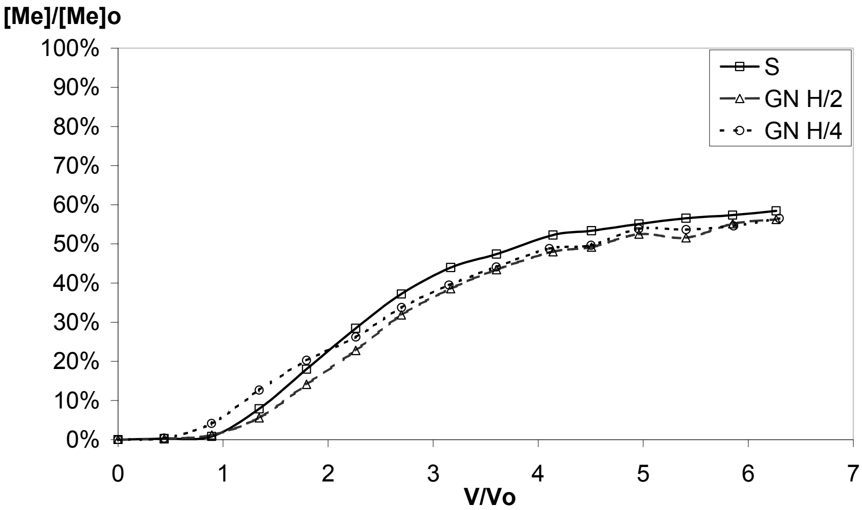


Figure 2. Elution of heavy metals for columns of soil (S), of soil / geotextile placed at the middle of the column (GN H/2) and of soil / geotextile placed at the quarter of the column (GN H/4) at 10^{-2} mol/L

Figure 2 presents metallic elution at 10^{-2} mol/L. The elution curves are quasi similar in all cases. All elution curves are characterized by a steady state at the end of the experiment, the relative concentrations reaching approximately 65%. This is due to the fact that Lead never eluted whereas Zinc and Cadmium elution were near 100% at the end of the experiment. If retention was complete for Lead, elution was complete for Zinc and Cadmium at the end of the experiment.

Whereas geotextile GN had significant effect on heavy metal elution at 10^{-3} mol/L, the same geotextile has no longer effect for larger metallic load (Figure 2). As a result, whether geotextiles are placed in the soil or not, elution and retention are no longer significantly changed. This may be explained by the fact that the metallic load is very important and thus may be far higher than retention in the soil even maximum retention (obtained with homogenized flow with geotextiles). Whatever the homogeneity of the flow, i.e. whatever metallic retention, even maximum, retention is too poor to prevent metals from passing through the soil.

3.2-SEM observations

SEM observations of the soil helped in characterizing contaminated particles and thus heavy metal retention. When observing samples with SEM with backscattered electrons (BSE), contaminated phases that are denser appear in bright. This facilitates searching for contaminated particles.

Figure 3 presents four micrographs. The first micrograph corresponds to the direct observation with secondary electrons (SE) of sticks accumulated on a particle.

Secondary electrons are more appropriate for direct observation of samples. The other micrographs correspond to observations of soil with backscattered electrons (BSE). The black corresponds to voids, the gray to uncontaminated particles and the white to denser particles or parts of them that were contaminated with metals.

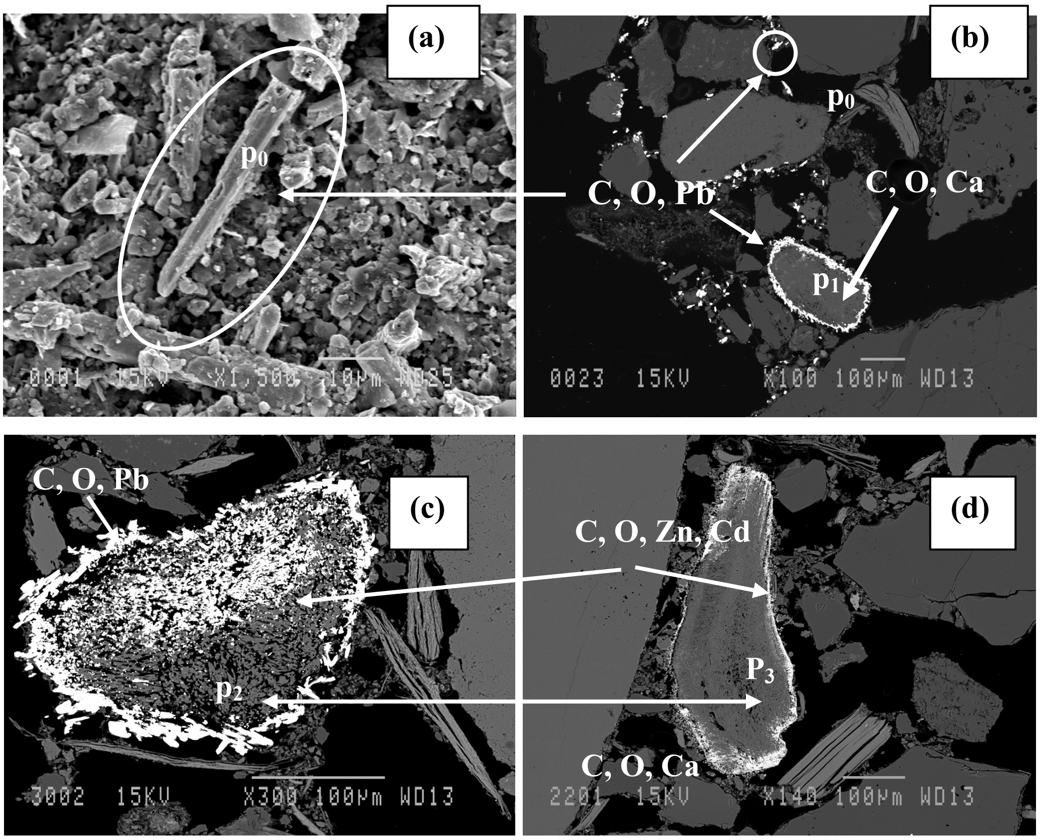


Figure 3. (a) Lead carbonate sticks, (b) calcareous particle contaminated with Lead, (c) calcareous particle contaminated with Lead, Zinc and Cadmium, (d) calcareous particle contaminated with Zinc and Cadmium.

The analysis of all the samples proved that the heavy metals behaved differently. Lead tends to form little sticks (particle p_0 in Figure 3 (a) or in Figure 3 (b)), only few tenth micrometer in length, that always accumulated near calcareous particles (particle p_1 in Figure 3 (b)). These sticks are made of Lead (Pb), carbon (C) and oxygen (traces), and are supposed to be Lead carbonate. Lead accumulated also directly on the contours of calcareous particles (particle p_1 in Figure 3 (b) or particle p_2 in Figure 3 (c)). Zinc and Cadmium contaminated either the center of these particles (particle p_2 in Figure 3(c)) or their contours (particle p_3 in Figure 3(d)) depending upon the presence of Lead. As a result, these metals were always linked to particles about several hundreds of micrometers, which may prevent their remove by water. On the contrary, one could wonder if Lead sticks could not be removed and transported by water in case of high flow rates?

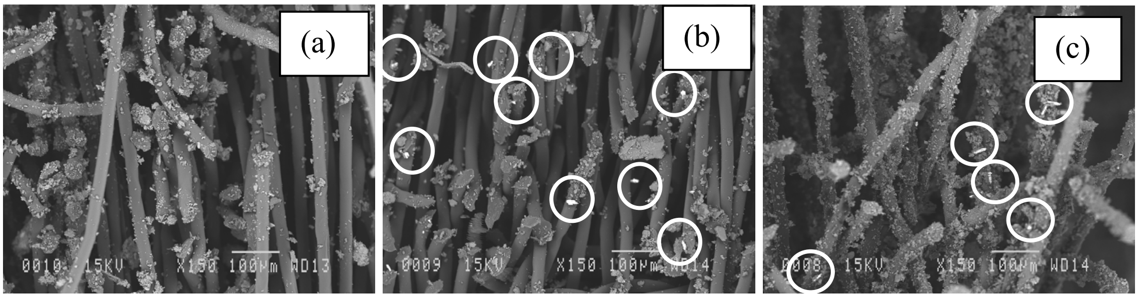


Figure 4. uncontaminated particles and contaminated particles (white circles) in (a) the upper part, (b) middle part and (c) bottom part of the geotextile.

Figure 4 illustrates SEM observations in three parts of the geotextile placed at a quarter of the column: in the upper part, the middle and the bottom part (i.e. the closest to the inlet). The other geotextile did not present any trace of contamination. All observations were performed directly on samples of geotextiles and using secondary electrons (SE). Uncontaminated particles did not accumulated in the middle of the geotextile. Geotextile GN filtering opening size around is 50 µm (Table 1), which means that larger particles may not enter the geotextile.

Concerning the heavy metals, several Lead sticks were found inside geotextiles and in the bottom part of them, i.e. closer to heavy metal entrance. The hypothesis of formation of these sticks in the geotextile may appear inconsistent. Lead sticks always formed near calcareous particles in the soil, and there are none inside the geotextiles. On the contrary, Lead sticks may have formed in the soil, been transported by water before being filtered by the geotextile. This may explain the presence of the sticks mostly in the bottom part, and some in the middle part of the geotextiles, and none in the upper part. In that case, the geotextile would have played the role of filter for contaminants; even this may have been insufficient to decrease significantly metallic elution through the columns (Figure 2).

4-Conclusion

This study shows, at first, that geotextiles can improve contaminant retention in soils through homogenizing the flow and thus optimizing the contact between contaminants and reactive particles. This is of importance to reduce the vertical transfer of contaminants and then to preserve the quality of both the underground and the groundwater. It also proved that geotextiles effect depends on the contaminant loads and that they effect can be completely reduced for too high contaminant loads. It must be borne in mind that geotextiles do not change anything in the soil reactivity insofar as they present any reactivity [11]. That means that when the contaminant load greatly overtakes soil retention capability, the geotextiles play no longer any role. From a technical point of view, this implies that stormwater quality must be controlled before its infiltration to ensure that contaminant load is lower that global retention capability of the soil. Another solution consists in improving soil capability by adding reactive media.

Microanalysis with SEM observations proved that geotextiles could filter some contaminated phases (above several micrometer length). This was the case for the higher load, when Lead formed little sticks that could be transported by water and then be filtered by the geotextile. This information is also interesting for the optimization of the design of infiltration basins. Geotextiles could then be used to stabilize and filter contaminated particles. This kind of use could be planned in infiltration basins but also under roads, where contaminants take the form of particles [2].

5-Acknowledgements

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