Design and realisation of a pilot site for monitoring Infiltrated soil water under a real on-site treatment system; evaluation of soil functions

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Laboratoire Eau Environnement et Systèmes Urbains

WWW-YES workshop - June 2013-Paris

École des Ponts ParisTech

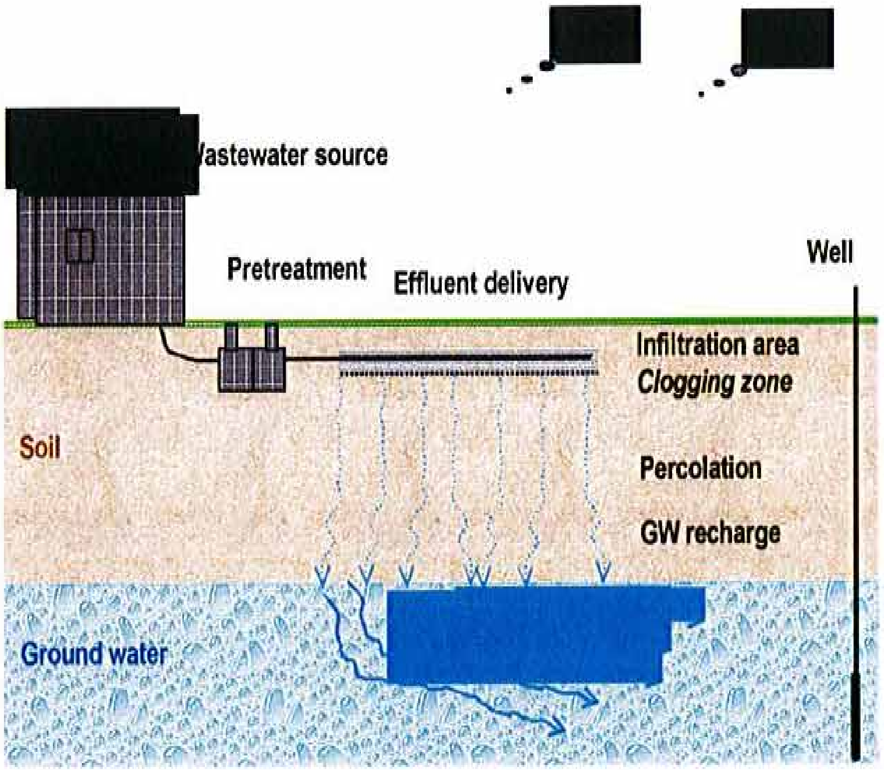
Plan of presentation

- Introduction
- Position of the problem
- Material and Methods
- Results and disccussion
- Conclusion

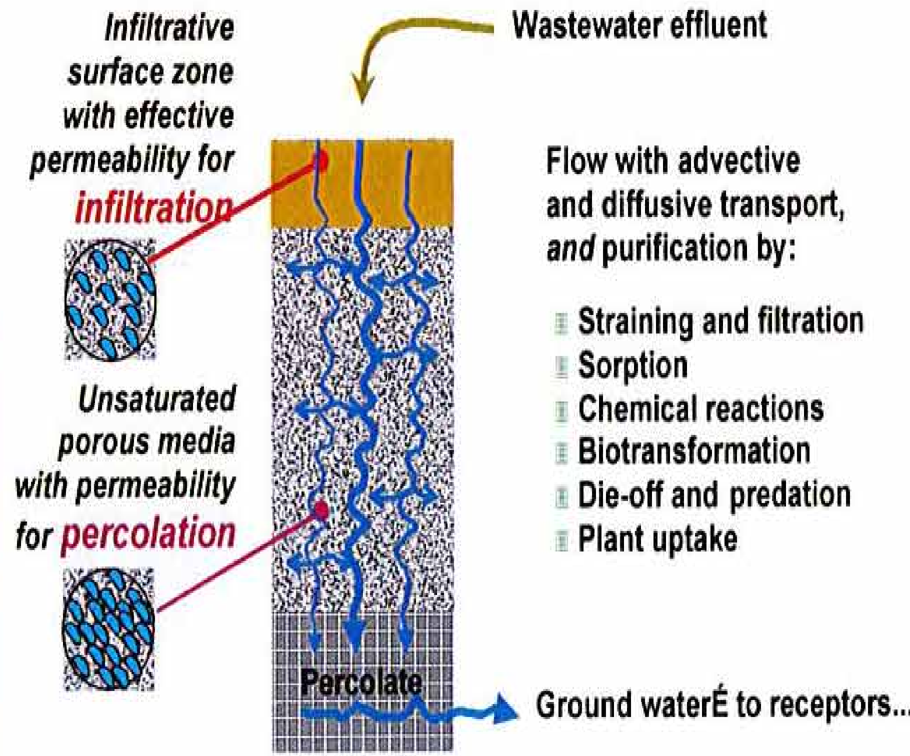
Introduction

- On-Site Treatment is a management way (in French, ANC: assainissement non collectif) which relies on a system to be chosen according to local conditions of each case among a series of standard agreed systems and ensures independently the collection, treatment and evacuation of domestic wastewater, near the house. This mode of wastewater purification concerns about 5.4 million homes, nearly 15% of the French population.
- In general, the OSTS shall be designed, installed and maintained so as to present no risk of soil contamination or water pollution, especially no risk to withdrawal waters which would be used for human alimentation or particular usages such as shellfish farming, fishing on foot or swimming (BRIGAND and LESIEUR, 2008).

Introduction



A typical onsite treatment system



Hydraulic and purification processes operative in a onsite treatment system

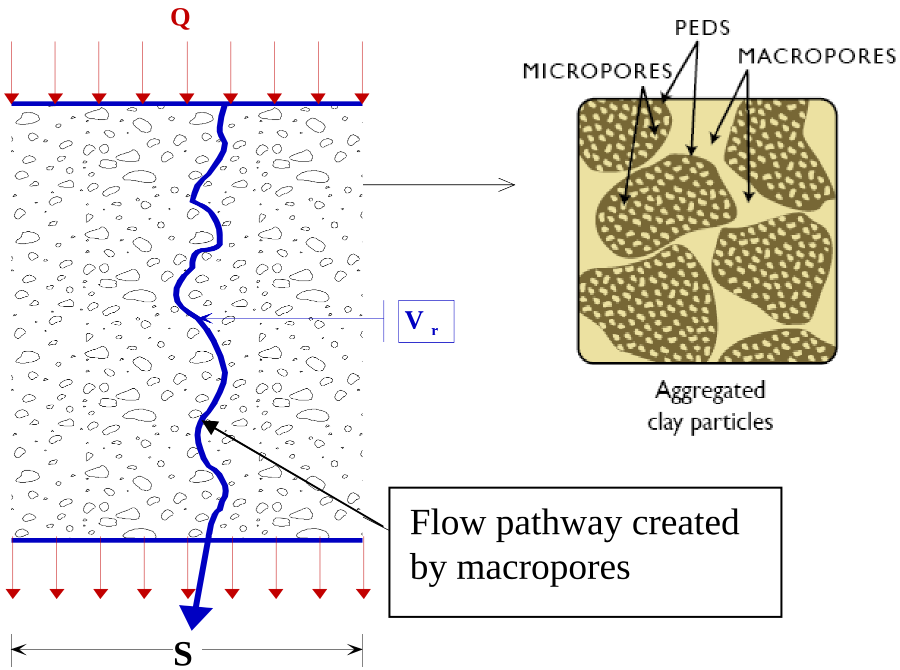
Introduction

- Pollutants in the vadose zone does not necessarily move at the same rate as water, but the transit time of water represents a lower limit for the transport time of certain pollutants. Otherwise, it is important to know and describe the terms of water flow in soil in order to characterize the soil's capacity as a vehicle for transport of dissolved and suspended substances (CALVET, 2003).
- When the structural pores are large in relation to those in the associated soil, the movement of water through the macropores, once initiated, may be much faster than equilibration of potentials in a respective volume of soil matrix. In heavy soils, channel drainage will in most cases precede general drainage; a portion of the water escaping by the open channels before the body of the soil has become saturated (LAWES et al., 1982).

Introduction

- The permeability of a soil during infiltration is mainly controlled by big pores, in which the water is not held under the influence of capillary forces (SCHMEACHER, 1864).

- Stony soils are soils containing over 35% or 40% in volume of soil particles larger than 2 mm .



Schematic picture of a vertical cross-section of a stony soil with fine clayey matrix. Two stages of macropores are observable a) macropores created by clayey aggregates (peds) (right), b) macropores created by the rock fragments (left).

Position of the problem

- Tthe effect of stones on the hydraulic properties of the soil is associated with arrangement and the amount of these particles. The stones in the soil add their own respective porosities in granular media (SHARMA et al., 1993).
- URBANEK and SHAKESBY (2009) argued that with large stone contents flow pathways develop along sand–stone interfaces and a continuous preferential flow path can form provided there are sufficient stone-to-stone connections.
- Verbist et al. (2008) demonstrated that stone fragment content correlated significantly with both saturated and unsaturated conductivities, probably due to a positive correlation between stone content and coarse lacunar pore space.
- COUSIN et al. (2003), in calcareous soils, found that the percolation was underestimated when the rock fragments were neglected and the soil was considered only as fine earth, while percolation was overestimated when the rock fragments were considered as non-porous stones.

So,

- rock fragment could increase the infiltration rate, by the creation of preferential flow (PF) pathways at the fine soil matrix-stone interface, the latter being active only at high water contents.

Position of the problem

The objective of this study was to evaluate infiltration imposed by an on-site treatment system in the heterogeneous stony soils of centre of France and to answer the following questions:

- Is it possible to clearly identify the effect of embedded stone fragments of soil on soil hydraulic conductivity?
- What variability in infiltration rates can be expected under an on-site treatment system which is characterized by heterogeneous, stony soils, but with a fine soil matrix between the rock fragments (identification of preferential flow)?
- What is the influence of the performance of the on-site treatment system on the spatial distribution of the infiltration rate in the soil?

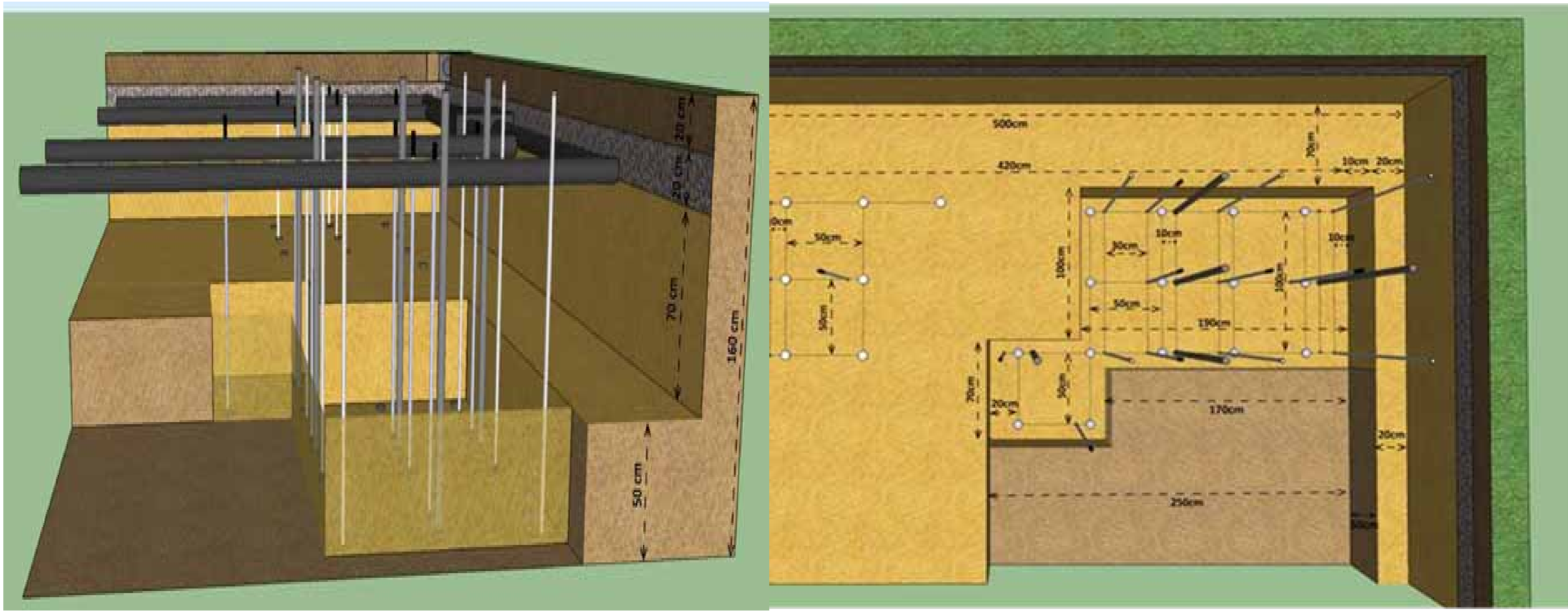
Material and Methods

- **Field site**:

The field site considered in this study is located in a valley in France and consist of a clay loam fine matrix of soil containing rock fragments (maximum size of 20 cm) which was developed on calcareous parent material.

The bottom of the excavation of a new undrained on-site treatment system (OSTS) in the yard of a house was considered to collect the soil samples, do the permeability tests and install the hydrodynamic monitoring probes.

Material and Methods

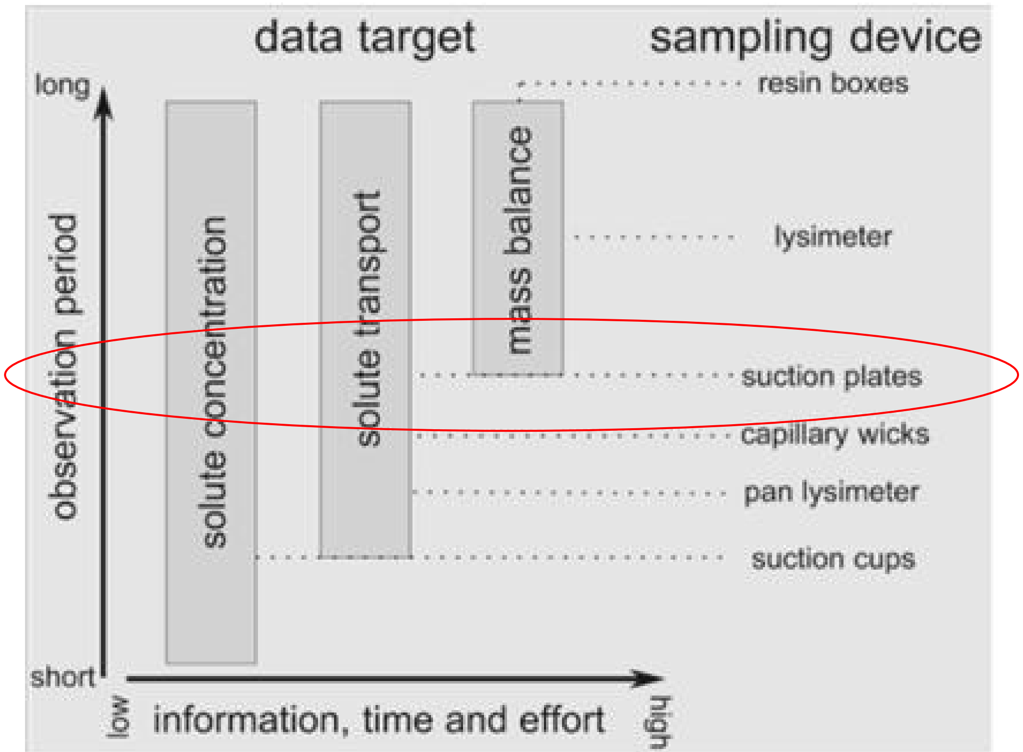


The cross section and plan of implantation of the instruments in the pilot UOSTS.

Material and Methods

• Selection and installation the soil water samplers

- Considering the objectives of the project and the method that was proposed by WEIHERMULLER et al. (2007), 25 devices of porous plates was chosen and were instaled in two different depthes (120 and 160 cm) under the gravel pack in the excavation.



Material and Methods

- **Field and laboratory measurements**:

- At the beginning of installing the undrained OSTS, the bottom of the excavation (120 cm depth) has been gridded into 25 square meshes of 1 m² and then 15 soil samples were collected from the first 15 m² (1 samples of averagely 10 kg for each m²). Simultaneously, in the middle of the each m², 15 permeability tests were done with a Guelph Permeameter (GP) device in order to measure the local saturated hydraulic conductivity of the soil.
- In the geotechnical laboratory of CNAM in Paris the 15 soil samples have been oven dried 105°C for 24 h. The fine earth fraction (soil matrix) was separated from the rock fragments by softly brushing and grinding. Soil matrix has been passed from the 0.08 mm sieve. For each of the samples, according to the French NORMES, the hydrometery tests have been done. Then, soil texture of the samples have determined by using the USDA soil texture triangle.

Material and Methods

- **Estimating the hydraulic conductivity due to soil fine matrix**:

- By using these textural data hydraulic conductivity of the soil matrix estimated by the pedotransfer equation developed by SAXTON et al. (1986):

$$K_s = 2.778 \times 10^{-6} \exp(X)$$

In which

$$X = 12.012 - 0.0755s + \frac{(-3.895 + 0.03671s - 0.1103c + 8.7546 \times 10^{-4} c^2)}{1 - (\rho_b / 2.65)}$$

where is the saturated hydraulic conductivity (m/s), s (%) and c (%) are percentages of sand and clay, and ρ_b is the bulk density of the soil (gr/m^3).

Material and Methods

- **Installation of hydrodynamic detecting devices in the field site:**

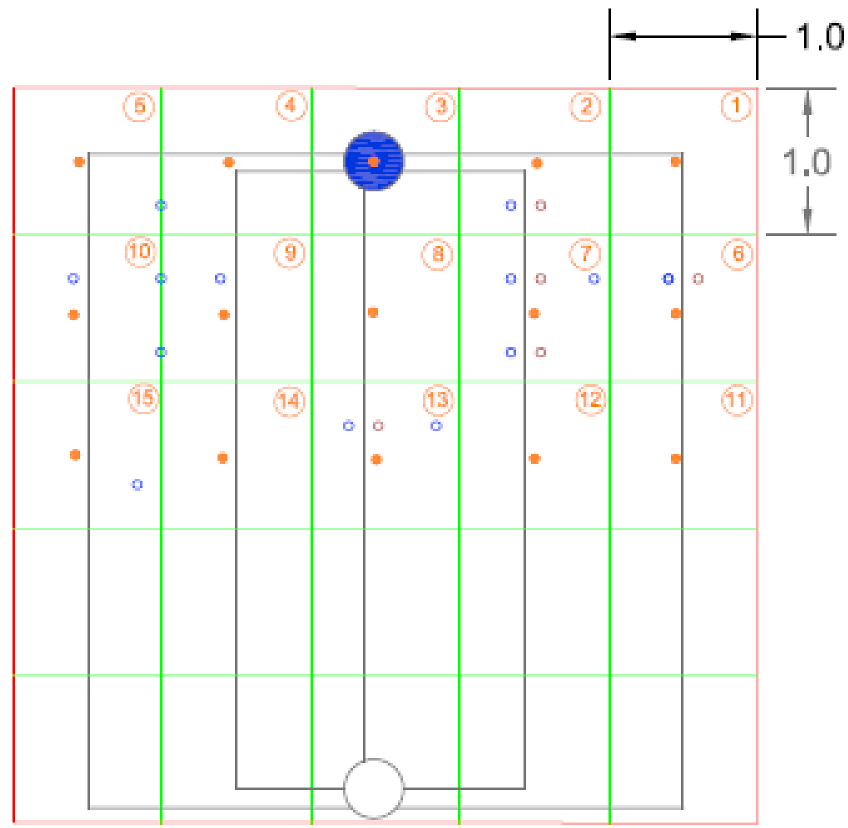
➢ In order to characterise the hydrodynamic evolution of soil, under the on-site treatment system due to infiltration the treated wastewater and rain water, the spatial distribution of water content and the matrix potential of the soil were monitored at the bottom of the excavation at two depths (120 and 160 cm). The system is composed of 12 electronic tensiometers (5 at 120 cm and 7 at 160 cm) (SDEC-France company; model: STCP 850) and 5 water content profiling probes which transmit an electromagnetic field extending about 100 mm into the soil as a ring in a definitive depth (Delta-T Devices Co; model PR2/6-FDR). Twelve electronic tensiometers provide longitudinal and transversal profiles across the soil. The probes give us the temporal and spatial distribution of volumetric water content of soil at 70, 80, 90, 100, 120 and 160 cm of depth from soil surface. A pressure sensor of free water table (Eijkelkamp company; model: Minidiver) was installed in a well downstream of the plot. This device is completed by a meteorological station (Watchdog 2900ET) implanted near the plot. The data are continuously recorded (time step of 30 min for rain, 10 min for soil tension and water content and 1 hour for the water table)

Material and Methods

Legend:

Site name	Plot (12)
Type	Non Drained Sand Pack

Object name	Symbol	Abreviation
Soil sample		ES
Repartition Box		RB
Guelph_Permeameter		Gl
PR2 probe		PR
Drain		Dr
plot limit		PL
Meshing line		Ml



- **Permeametery test and the implantation of the probes in the plot.**

Material and Methods

To infer the preferential flow three major techniques were used:

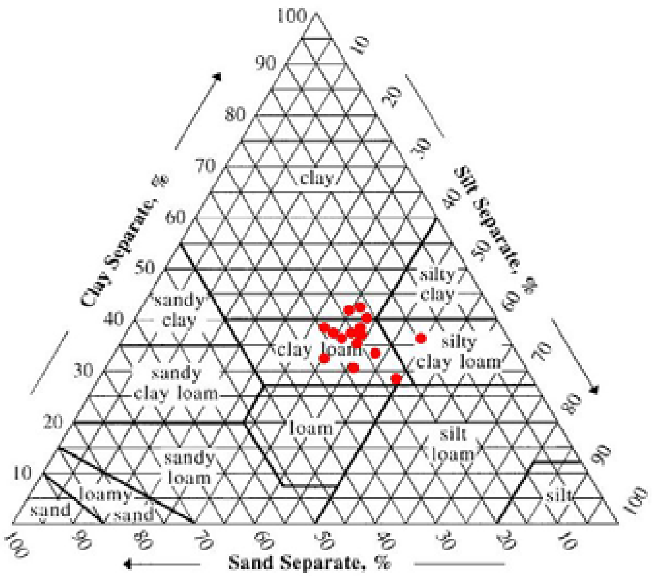
(i) Observation at the bottom of the excavation;

(ii) Field saturated hydraulic conductivity in multiple points.

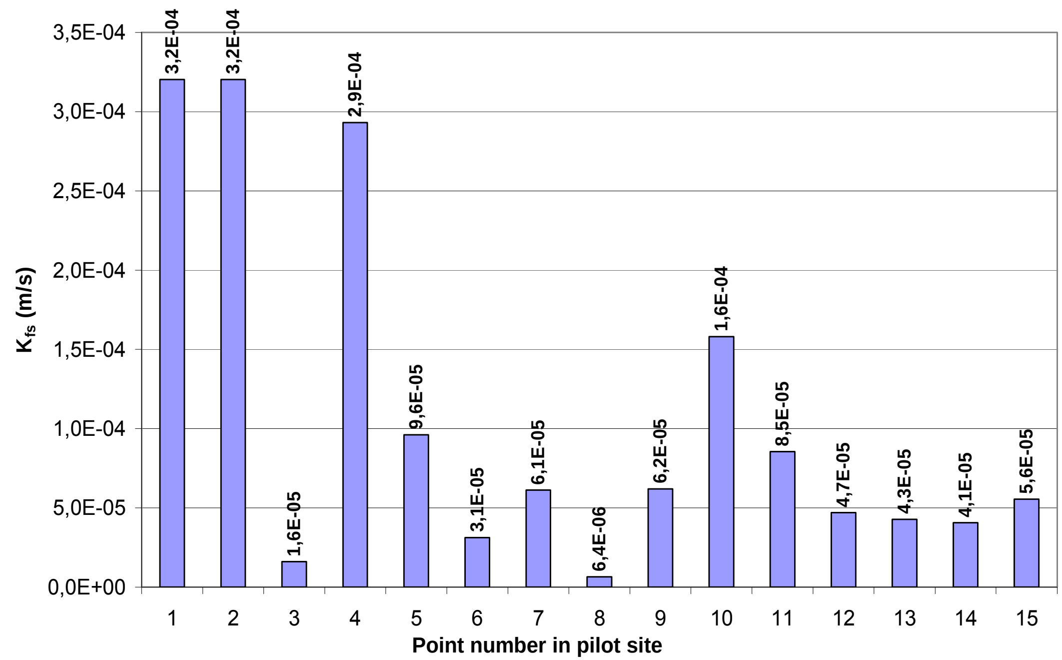
(iii) Water content and tension distribution.

Results and discussion

- **Soil texture and measured hydraulic conductivity:**



Variation in clay, silt, and sand contents at the 15 measurement points.



Variation of K_S values measured by Guelph permeameter at 120 cm depth

Results and discussion

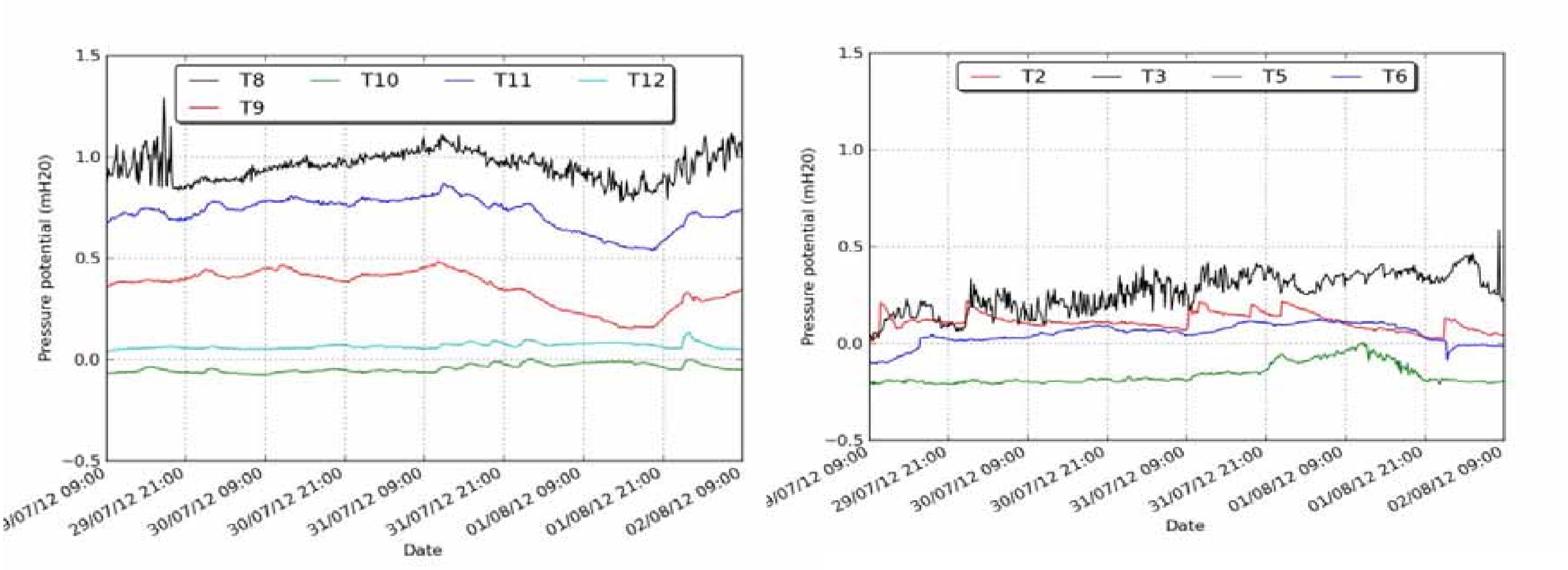
Measured and estimated hydraulic conductivity

Soil point number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
textural Class (USDA triangle)	Clay loam	Clay	Clay loam	Clay loam	Clay	Clay loam	Clay	Clay loam	Clay loam	Clay loam	Silty clay loam	Clay loam	Clay loam	Clay loam	Clay loam
Estimated Ks by Saxton's PTF m/s (KSE)	7,5E-07	6,7E-07	6,4E-07	8,6E-07	6,1E-07	9,4E-07	6,1E-07	8,1E-07	6,7E-07	7,2E-07	9,4E-07	1,4E-06	1,1E-06	7,2E-07	7,2E-07
Field measured Kfs (Guelph) m/s (KGP) (α*=12 m-1)	3,2E-04	3,2E-04	1,6E-05	2,9E-04	9,6E-05	3,1E-05	6,1E-05	6,4E-06	6,2E-05	1,6E-04	8,5E-05	4,7E-05	4,3E-05	4,1E-05	5,6E-05

- The average of the 15 Guelph measured hydraulic conductivities is 135 times higher than the average of matrix estimated ones. The variation of in measured hydraulic conductivities in the field follows no pattern and this is directly related to the amount of rock fragments and their alignment in the soil matrix.

Results and discussion

Monitoring the hydrodynamic parameters:



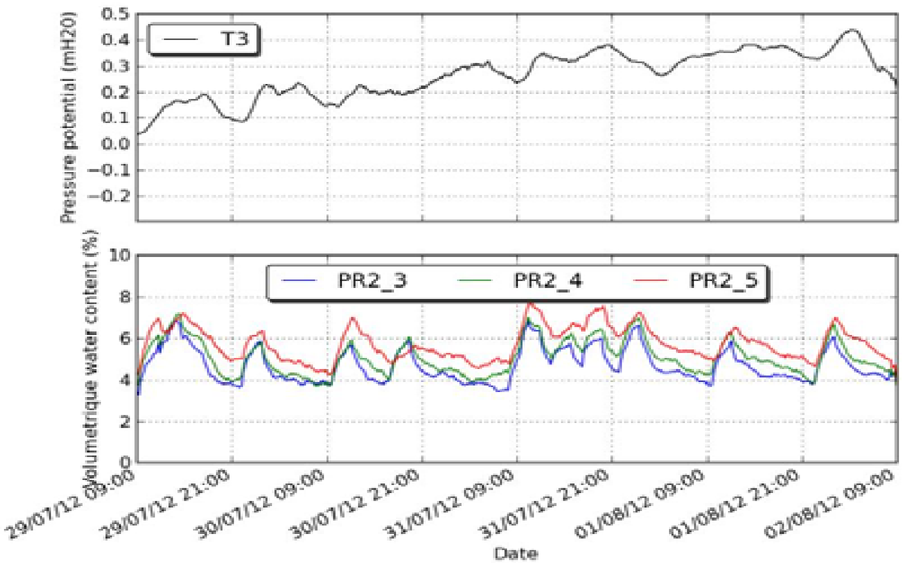
Left : pressure potential variation of tensiometers at 120 cm depth.
Right : pressure potential variation of tensiometers at 160 cm depth.

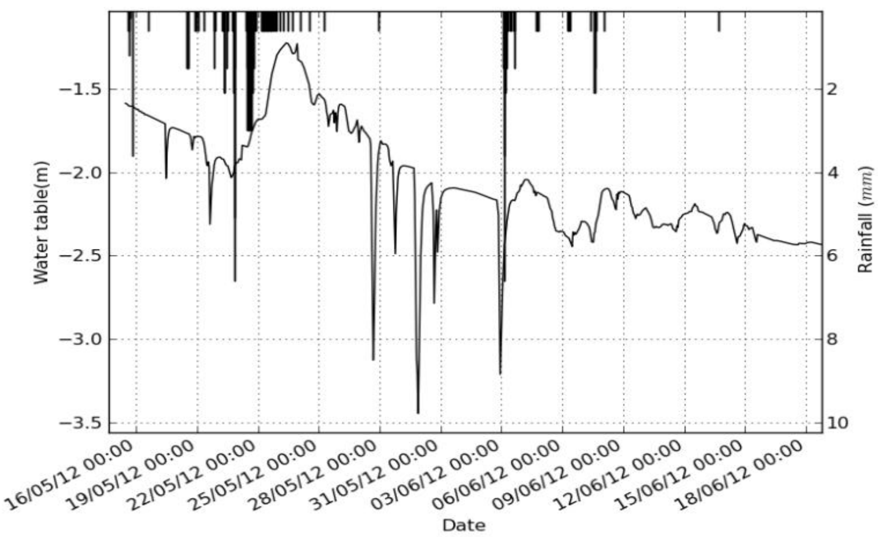
Results and discussion

For all the tensiometers there is a daily cycle with 2 principles peaks at 13:00 and 23:00 which are compatible with the peak time consummation of water at home by the inhabitants. As well the identical temporal behaviour of T10 and T12 together and T8, T9 and T12 indicates that they receive the same sequences of water with different amounts. The spatial variation of the pressure in this part is due to, the non-equilibrium repartition of treated wastewater in the drains but the spatial distribution is complicated and it can be because of the heterogeneous rock fragment repartition in the soil. The range of variation of pressure, among the tensiometers, is averagely between 0 and 1 m-water.

Results and discussion

Monitoring the hydrodynamic parameters:





Left: Temporal evolution of soil tension (T3) and water content (PR2) at mesh number 2.
Right: Variation of the water table and rainfall for a period of one month.

Results and discussion

The 2 daily peaks of water content due to infiltration of treated wastewater are observable in the PR2 curve which correspond the variation of water tension of the soil recorded by T3 for the same time period. According to the three curves of water content variation, the vertical gradient in 3 depths shows that water content varies between 4 and 7.5 present each day and water content increase in the depth.

By using the water table variation data and the rainfall data for a pluvial period which has been illustrated in figure 10. We can see a clear reaction of water table to the rain with a progressive rise of water table and a delay which is due to the time that water needs to flux in the soil and arrive in water table from the surface.

Conclusion

- The variability of hydraulic conductivities measured in 15 points proved to be significantly related to differences in the stone fragment content.

- The influence of the stoniness on hydraulic conductivity is positive.

- The observations of 2 trickles of water flow at the bottom of the excavation before filling with the sand and the remarkable difference between the in situ measured hydraulic conductivity and which derived from soil texture approves the existence of preferential pathways in the soil.

- The non-uniform distribution of water content and matrix potentiel of the soil under the system approve this heterogeneity in the soil.

- The results be extended to stony soils of calcareous regions and beyond, to heterogeneous urban soils more or less anthropogenic. This implies that stone fragment content should be taken into account when hydrologic processes are evaluated and when developing pedotransfer functions to predict hydraulic properties.

Conclusion

- The use of Guelph permameter to estimate the Ks of the soil and at the same time characterising the soil physical properties is a useful method to evaluate and improve the soil capacity in relation to infiltrating water in the areas where there is a lock of place and the soil is not pertinent to evacuate the wastewater.
- Comparison the quality of the soil water samples, collected in different levels, helps at first to evaluated the operation of the Gravel Pack and then the impact of this percolated pre-treated wastewater on the soil.

Hydraulic conductivity tests by Guelph permeameter at the bottom of the excavation

Installation the porous disks and the electronic probes at two different depths

Pre-treated wastewater drains and the probes

Thanks for your attention