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Evaluation of the retention capacity of Pb and Cu in techno-soils of Sustainable Urban Drainage Systems (SUDs) in Bogota, Colombia

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BACKGROUND STUDY

- Bogotá is the capital of Colombia (8 M hab.) and its growth is fundamental for the development of its population. Therefore, the modern infrastructure not only allows it to cover its needs under a rapid growth, but also to take advantage of all its potential in order to be able to compete as a globalized city.

- Currently the Mayor's Office of Bogotá is developing important road infrastructure projects, which will allow to improve the internal connectivity of the city with works of high urban impact in areas of high residential development (Bogotá Mayor's Office, 2016).

- This resulted in surface sealing, heavy runoff and flooding. Thus many alternatives such as SUDs are being explored to mitigate these problems, with the counterpart of increasing the risk of groundwater contamination

MOTIVATION

The environmental pollution generated by economic development had caused a high emission of toxins into the environment such as heavy metals that affect the health of different natural environments with repercussions on the entire food chain (Rezania et al., 2016; B. Alloway,2013).

Some studies have identified the presence of several emerging pollutants in urban rainwater systems, such Pb and Cu, which are found in roadway sediments and affecting groundwater, and also significantly alter the biological system due to their high ecotoxicity (Zafra et al., 2013).

Heavy Metal Concentrations in Bogotá Roads	
Pb	1110 mg/kg
Cu	601 mg/kg
Zn	431 mg/kg
Fe	188010 mg/kg

Zafra et al. (2013)

Some research in Bogota

- Heavy metal accumulation in urban road sediments: factors of public health interesting (Zafra et al., 2013).
- Temporal assessment of heavy metal (Pb and Cu) concentrations associated with road sediment: Fontibón-Barrios Unidos (Bogotá D. C., Colombia) (Romero, 2015).

"In Colombia there is limited research associated with the monitoring, natural dynamics and follow-up of high concentrations of chemicals in the environment."

OBJECTIVES

GENERAL OBJECTIVE

- Evaluating the Pb and Cu retention capacity of a techno-soil used in Sustainable Urban Drainage Systems (SUDs) in Bogota, Colombia.

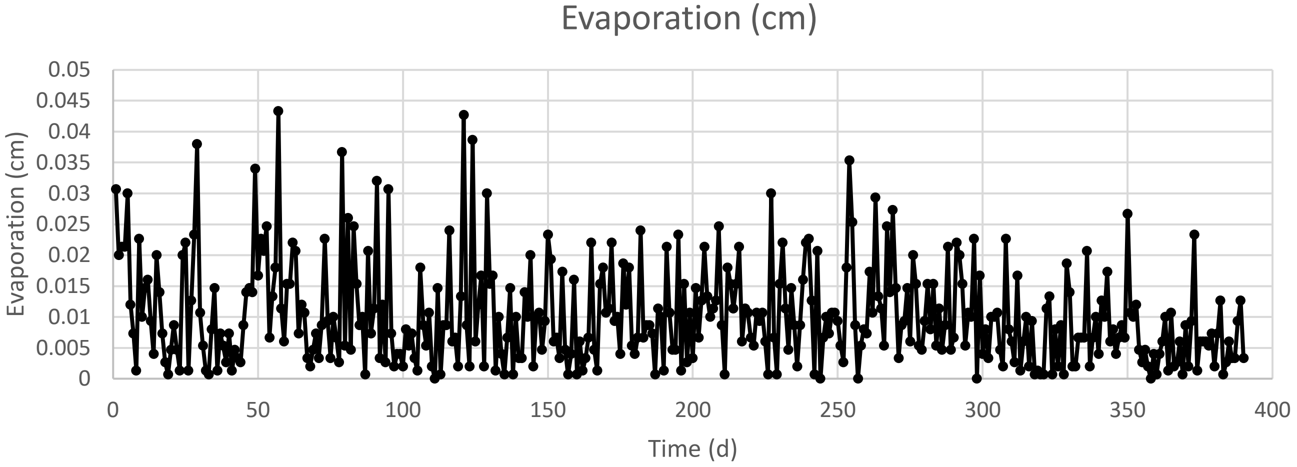
SPECIFIC RESEARCH OBJECTIVES

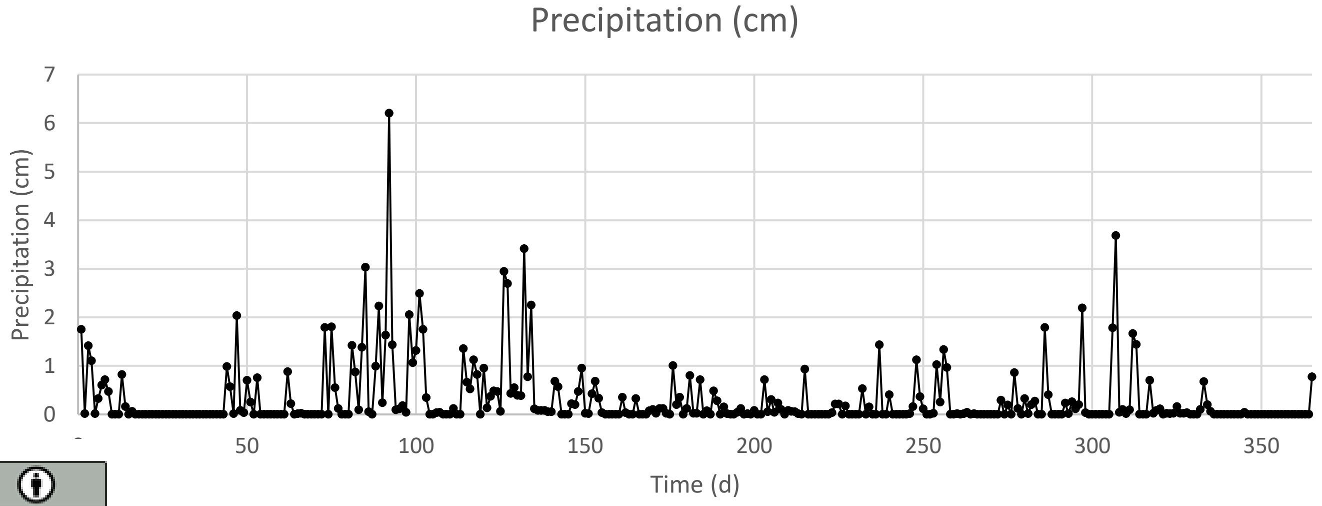
- Describe hydrodynamical flow parameters of the techno-soil using RETC model.
- Evaluate the metal solute transport model in the bioretention structure (SUDS), by comparing the one-dimensional flow model HYDRUS-1D and experimental data.
- Simulate the behaviour of the bio-retention structure in relation to the transport of solute together with the local climate conditions.

MATERIAL AND METHODS

Climate data (2019)

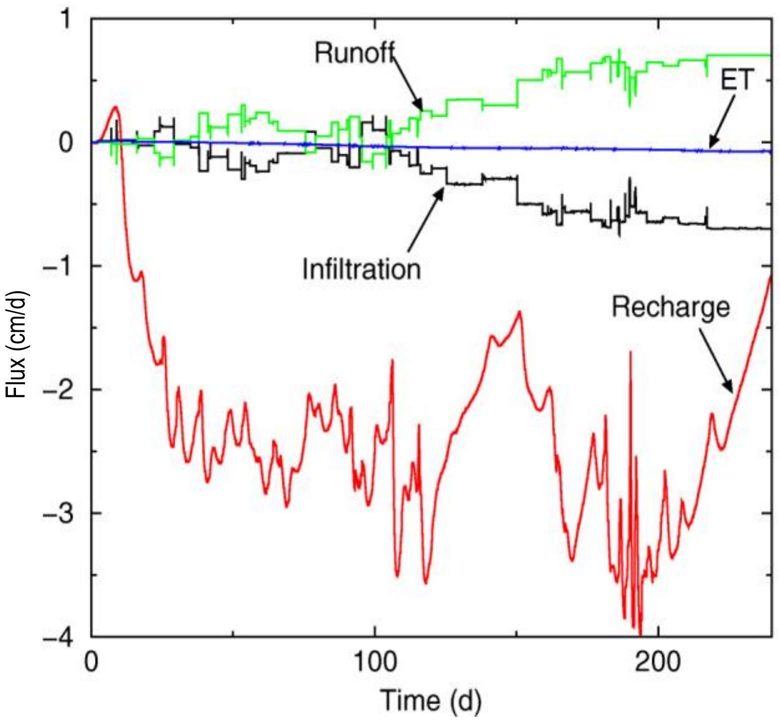
Climate data from a local meteorological station of the wheather and forecast administration.





Flow Boundary conditions for modelling

Boundary conditions to simulate SUDS structure water balance.



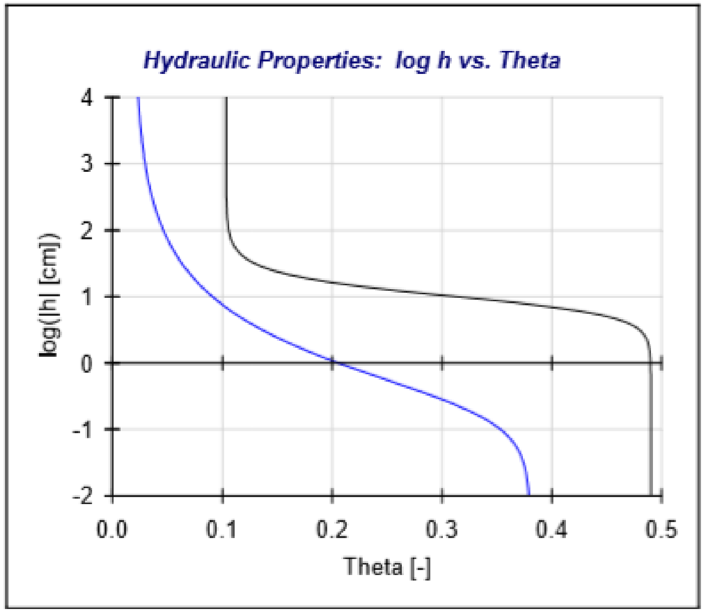
Simunek,2013

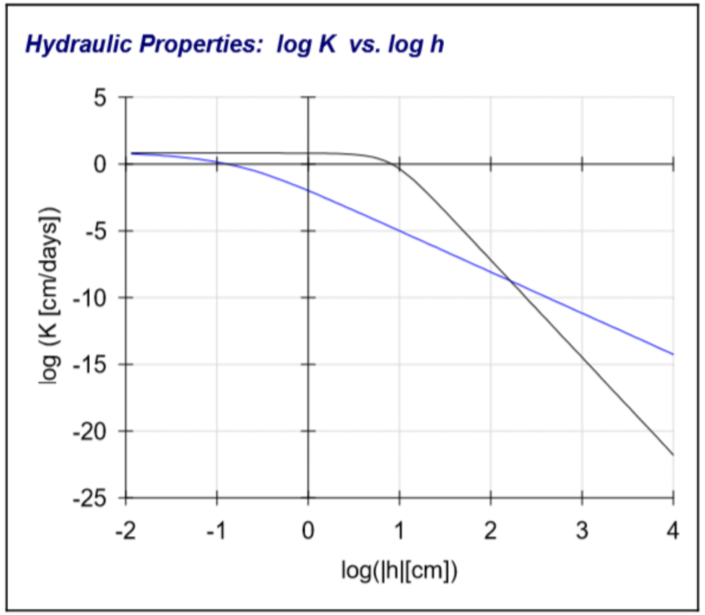
SUDs TECHNO-SOIL PROPERTIES
Measurement of hydraulic parameters

- The materials used in this research were selected based on the technical standards for the construction of urban drainage systems, in which the column consists of two layers
  - ✓ Layer 1: A mixture of sand and dried rice husk ash as a techno-soil (equivalent to a Sandy Loam), and
  - ✓ Layer 2: Sand acting as support and drainage layer.
- To determine the main hydraulic parameters required in the hydrodynamic model (water retention and hydraulic conductivity curves), we used pressure pots and hot air method (Richards method) (Angulo,2019). Laboratory results are presented in the graphs below:

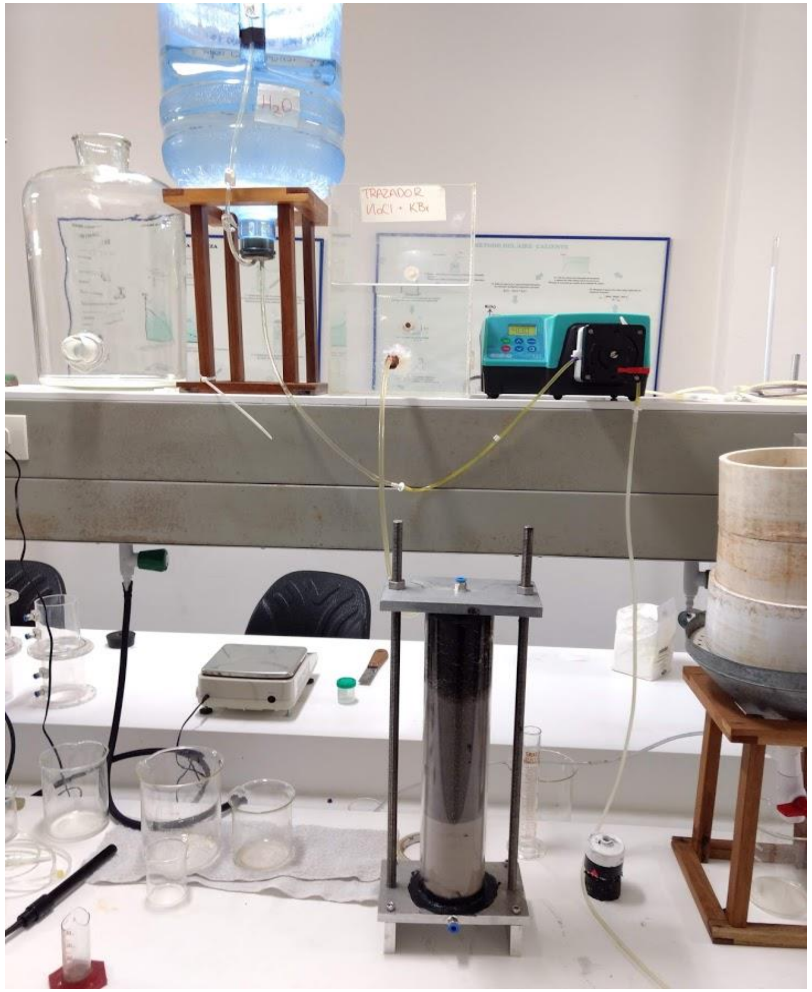
Conceptual Flow Model

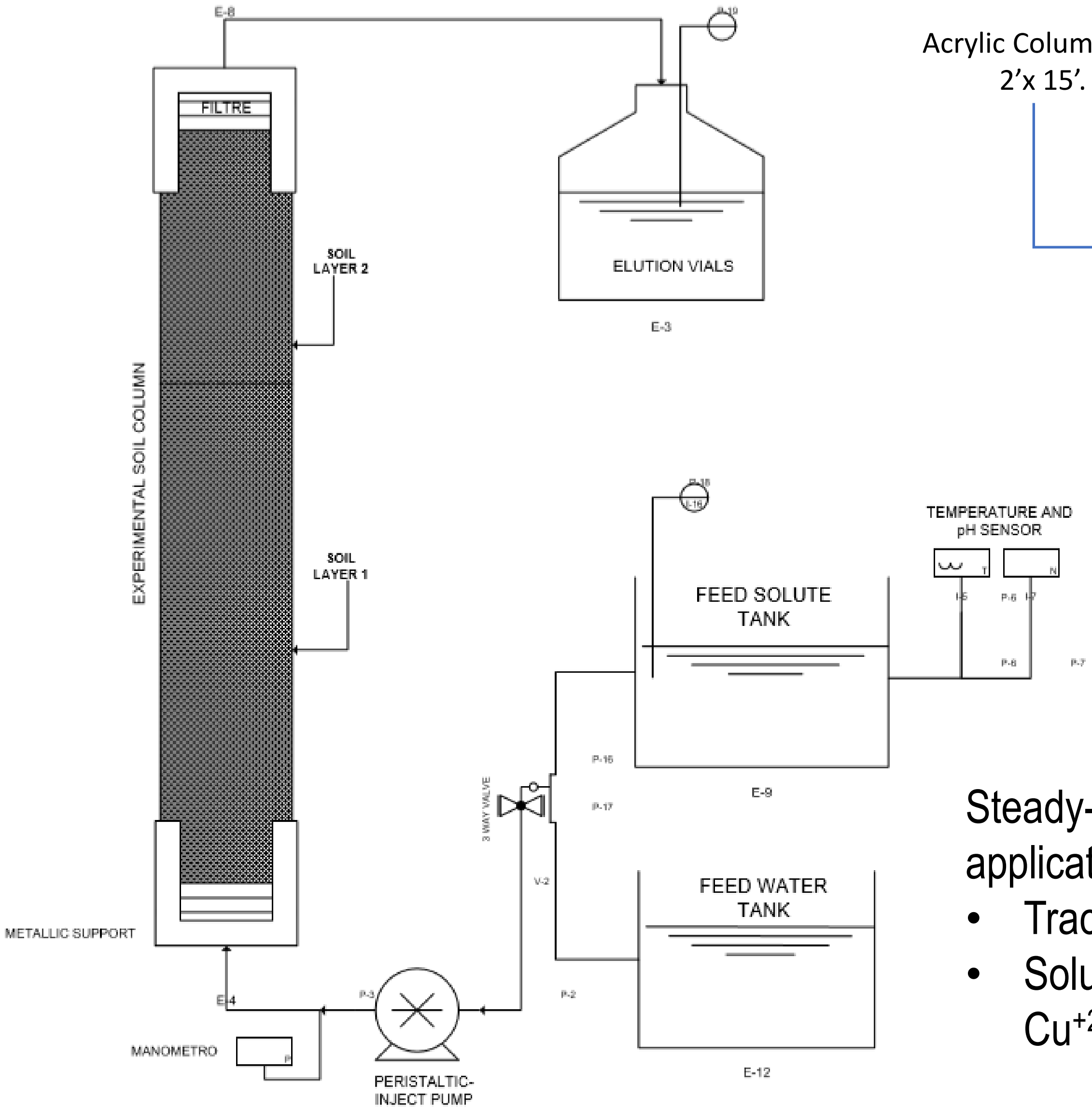
$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right].$$



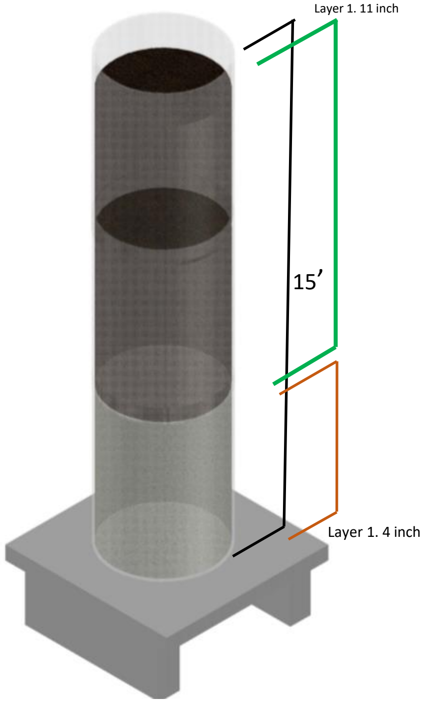


COLUMN BREAKTHROUG TESTS





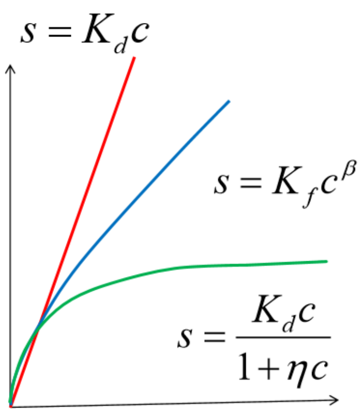
Acrylic Column size
2’x 15’.



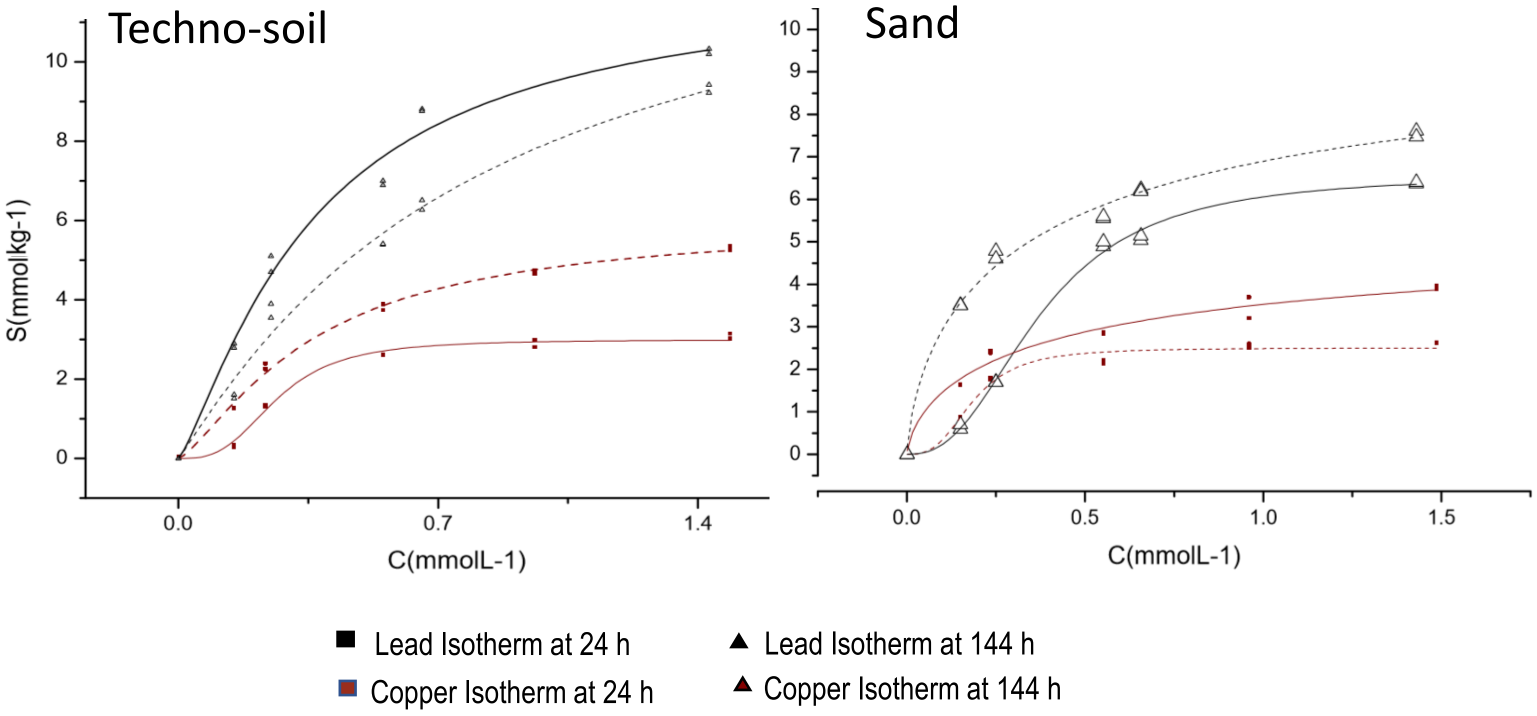
Steady-state unsaturated flow and application of a step of solute

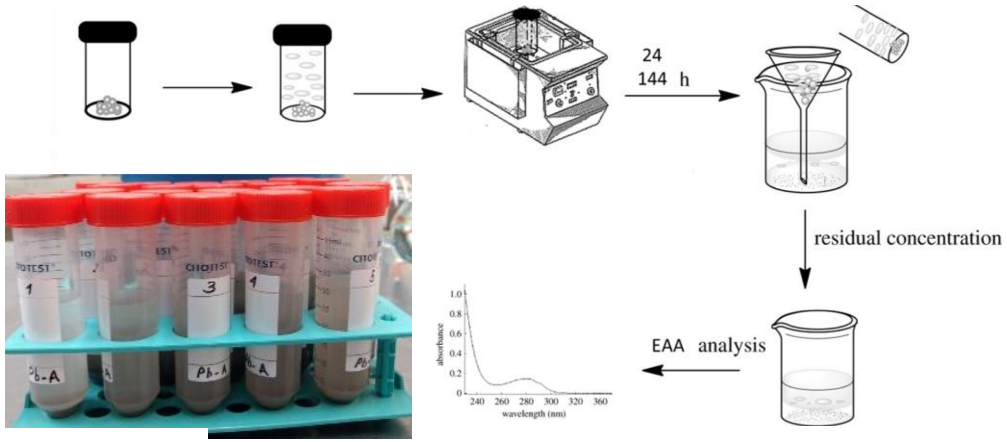
- Tracer solution: NaCl
- Solutions: Pb^{+2}, Cu^{+2} and Pb^{+2} + Cu^{+2}

BATCH tests: measurement of kinetic adsorption isotherms



Adsorption Isotherms Models (Simunek, 2013)





Experimental data was fitted both to Langmuir and Freundlich adsorption isotherm models using nonlinear optimization kinetics parameters.

The solution pH is an important parameter in controlling metal sorption in soil profile.

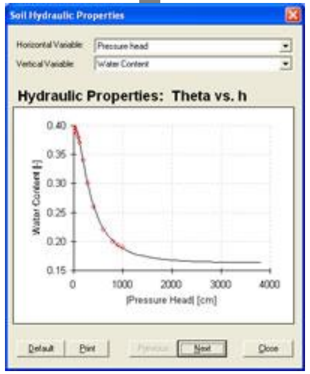
The maximum adsorption and the sorption affinity of the metals follows the order

$Pb^{2+} > Cu^{2+}$

possibly related to the inverse of ionic radio.

Structure of numerical model for solute transport in SUDS structure

Parameter estimation using RETC and laboratory data



Van Genucthen, 1991

HYDRUS MODEL

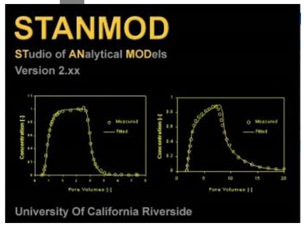
FLOW MODEL

- BOUNDARY CONDITIONS
- WATER RETENTION AND HYDRAULIC CONDUCTIVITY CURVE

SOLUTE TRANSPORT

- EQUILIBRIUM MODEL
- NON EQUILIBRIUM MODEL

Parameter estimation using STANMOD and BTC in columns

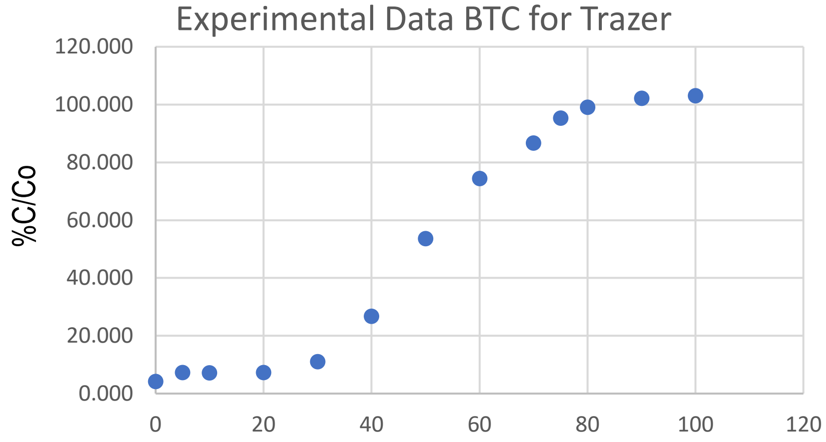


Toride, Leij, & van Genuchten, 1999

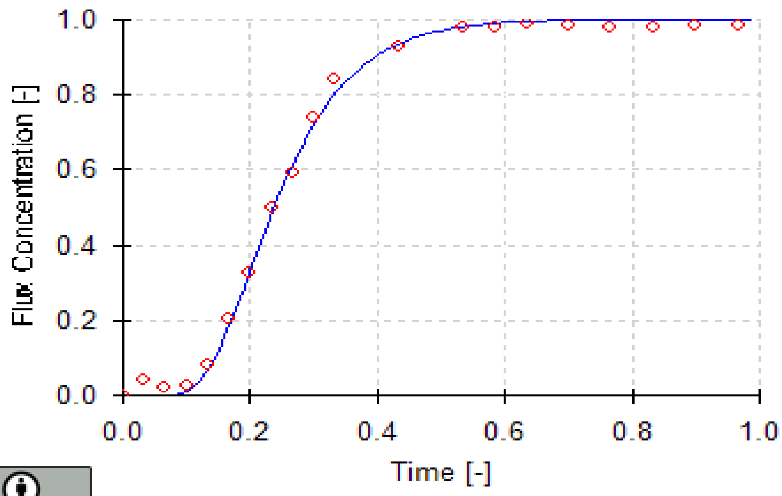
SOLUTE TRANSPORT MODELLING

RESULTS

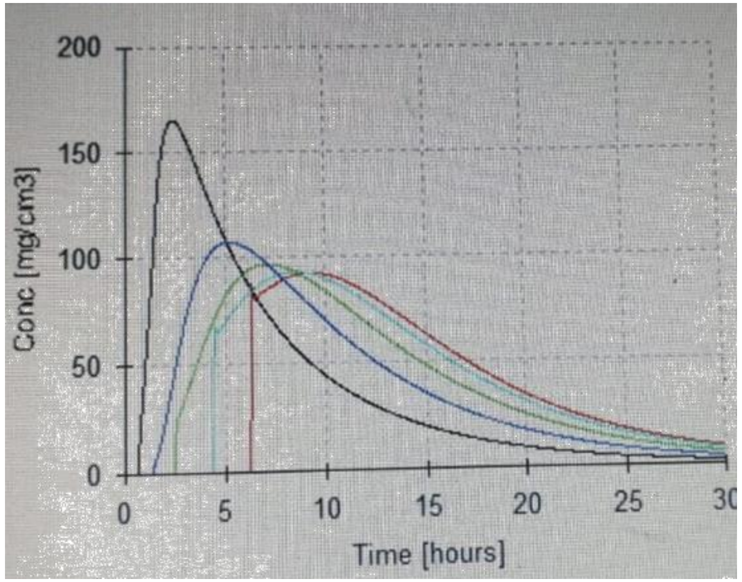
Solute Transport Models in STANMOD (CXTFIT) and HYDRUS Model



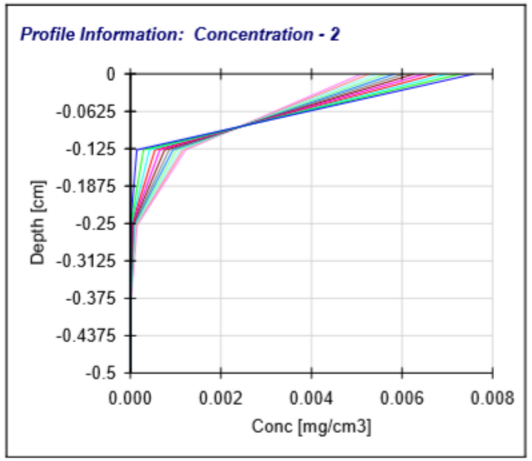
Calibration Transport Parameters



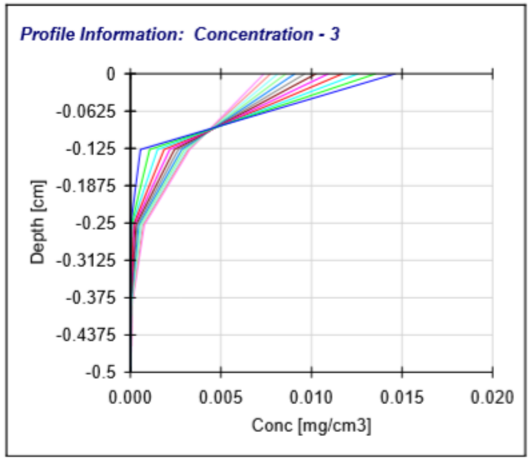
Validation of experimental experiences to inverse model (STANMOD)



HYDRUS Heavy metal transport (2019)



Lead

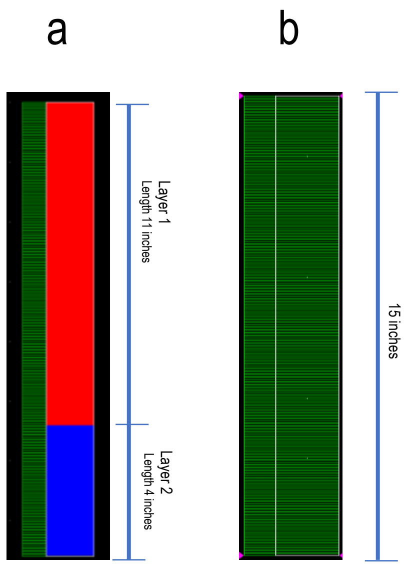


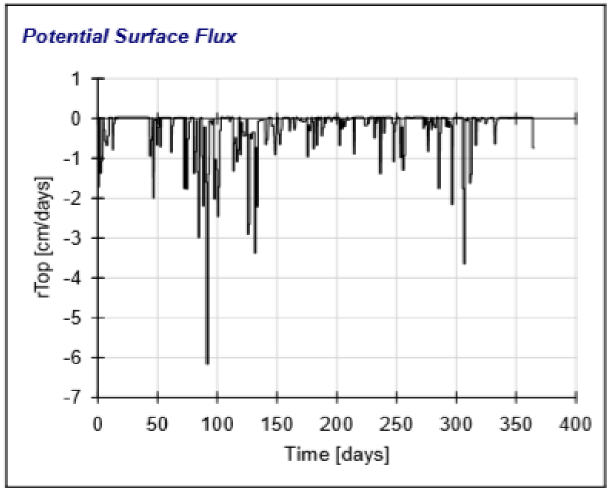
Copper

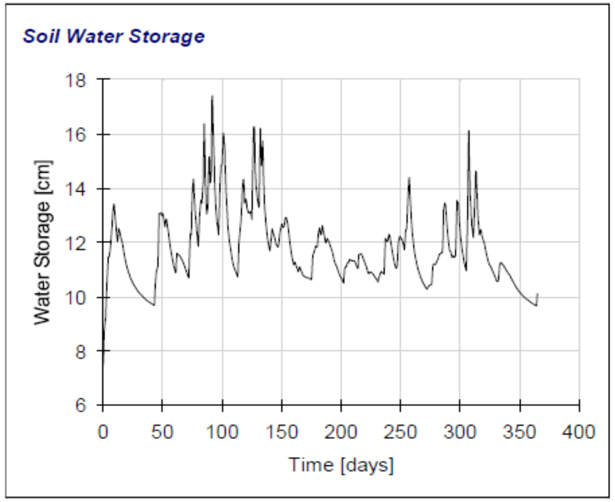
Hydrological modelling*

RESULTS

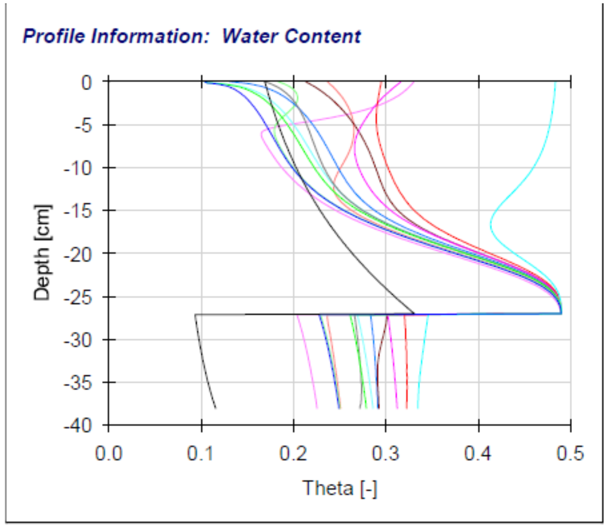
Domain Mesh Discretisation in HYDRUS 1D (2 materials)







Water content profiles of the SUD structure based on 2019 hydrological data using a single porosity model (one profile per month for the calculation of the monthly mass balance).



*This study is creating a daily pollutant concentrations data series to include in hydrological modelling (HYDRUS model) for having a major approach of capability of heavy metal retention in real conditions.

Conclusions and Perspectives

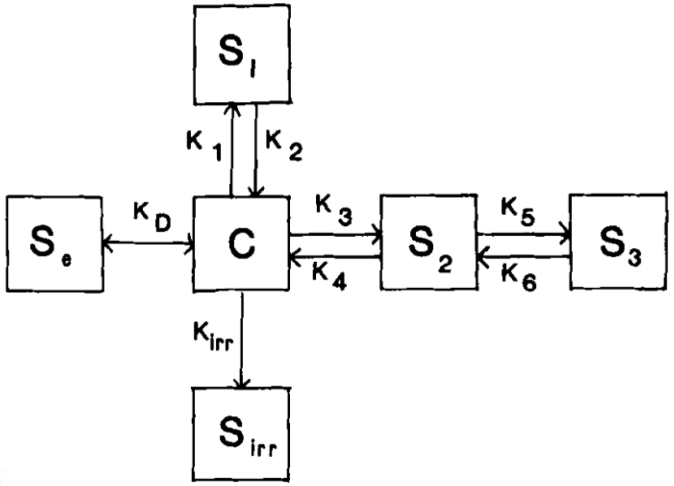
- Techno soil samples were used to investigate Pb and Cu adsorption and their mobility in urban bio-retention structure SUD. Sorption isotherms shown nonlinear behaviour and exhibited strong sorption of Pb than Cu.
- Pb is adsorbed in the first 2 cm of the techno-soil layer allowing the Cu to move to a greater depth.
- Column experiments with a tracer solution showed a good correlation between experimental and simulated data validating STANMOD and inverse modeling as a good transport parameter estimation tool for techno-soil.
- Heavy metal breakthrough curve results indicated high absorption capabilities to remove pollutant flows.
- Simulations using conventional model had shown good results in representing solute transport. However, Some interactions between solute and soil matrix cannot be include in CDE* model, for that reason it’s necessary to try changing absorption models that it can describe chemical transfer with more complex model multi reactive model (MRM)

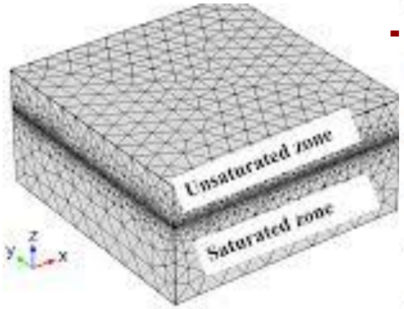
* Convection Dispersion Equation

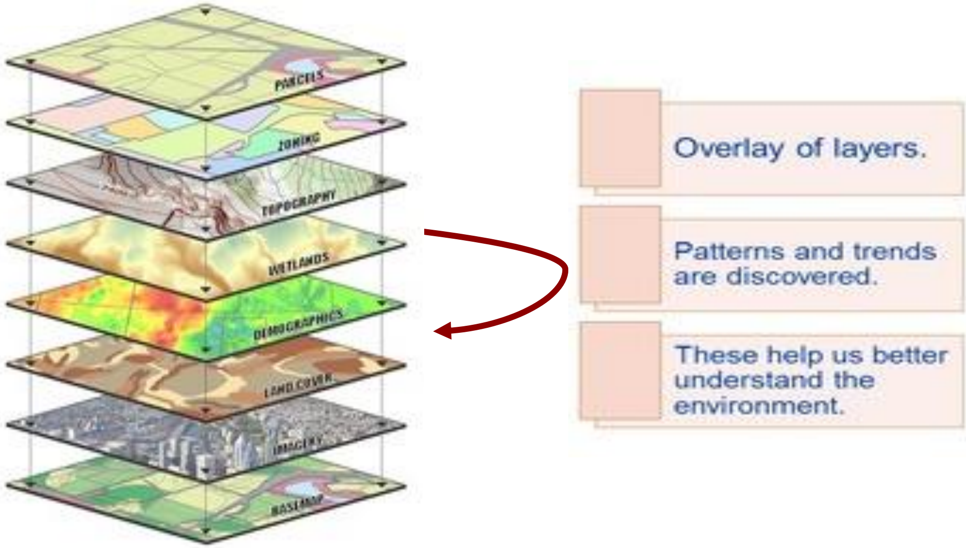
FUTURE WORK

To evaluate the transport model of metallic solutes in the bioretention structure (SUDS), by comparing the experimental and one dimensional model using techniques based on **data driven modelling** (i.e., Machine Learning).

Coupling models to describe chemical and hydrodispersive dispersion of pollutants like multi reactive model MRM, multi reactive transport model MRTM. (Tamer E., 2013)







Using spatial and temporal modelling to identify the vulnerability zones with high pollution risk and monitoring diffusive pollution.

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THANKS