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Evaluation of an improved modelling approach for the retention of heavy metals in SUDS soil

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KEYWORDS

Contamination profiles, Modelling, Runoff infiltration, Soil, Sustainable Urban Drainage Systems, Validation

SUMMARY

The ability of reactive transport models to accurately replicate the fate of contaminants in SUDS has been sparsely documented. The present work aims (*i*) to improve the description of the processes, including non-uniform fluxes at the surface, and (*ii*) to use extensive experimental data, collected in a stormwater infiltration basin, to evaluate the model's accuracy. Both the model and observations confirm that most infiltration occurs near the water inlet. Differences between the measured and predicted profiles are either attributable to the filtration of particle-bound metals, or to spatially variable sorption capacities of the soil – notably because of lower contents of organic matter.

INTRODUCTION

Source-control stormwater management appears as an efficient way to mitigate surface pollutant fluxes, but brings about some concerns regarding the fate of micropollutants in soil (Bressy *et al.*, 2012). Thereupon, experimental assessments of SUDS contamination may be valuably complemented by modelling approaches, so as to gain insight into, *e.g.*, potential downward fluxes of contaminants, or optimal designs towards pollutant retention (Quinn and Dussaillant, 2014). However, the current literature comprises few attempts at validating such models with field data from SUDS. Additionally, most existing models are one-dimensional, but recent investigations on surface soil contamination have evidenced that upper infiltration fluxes are highly non-uniform in such devices (Tedoldi *et al.*, 2017). Hence, the two main objectives of the present work are (*i*) to develop a new modelling framework to simulate the fate of metals in SUDS soil, and (*ii*) to compare the predicted distributions with experimental data.

MATERIALS & METHODS

Model description. So as to take into account non-uniform infiltration, the modelled facility is divided into n homogeneous zones starting from the inflow point (Fig. 1). The fraction of the flow rate exceeding the infiltration capacity of the domain k is routed towards the domain $k+1$ as an upper boundary condition; the potential excess of water from the domain n causes ponding in the whole device. Within each domain, the soil is described with a classical one-dimensional model, using (*i*) Richards equation to replicate hydrodynamics, (*ii*) an advection-dispersion equation to replicate solute transport, and (*iii*) a Langmuir sorption isotherm to replicate physical chemistry, associated with 1st order kinetics for a given part of the

sorption sites. The corresponding formulae are presented elsewhere (*e.g.* Simunek *et al.*, 2013). Each 1D problem is solved independently with the HYDRUS-1D software package.

Validation data. A thorough characterization of a stormwater infiltration basin was undertaken. The facility collects runoff water from a small residential area, where metals (and especially Zn) are expected to be mainly in dissolved form (Bressy *et al.*, 2012). The spatial distribution of Cu and Zn was determined both in the surface soil and along vertical profiles. Concurrently, hydrodynamic parameters were acquired *via* “BEST” infiltration tests (Lassabatère *et al.*, 2006) at several locations in the basin (Fig. 2a). The soil’s dispersivity was derived from inverse modelling of a conservative tracer experiment in a 50-cm-long soil column (Fig. 2b). Cu and Zn sorption characteristics were determined *via* batch tests (Fig. 2c-d), adjusting the initial concentrations so as to fit the isotherms in a typical range of runoff concentrations. All theoretical relationships satisfactorily fitted the data ($R^2 > 0.9$).

PRELIMINARY RESULTS & DISCUSSION

The last section of the inlet pipe has broken 3 years ago, so that the location of the inflow point has changed during the operation of the facility, as revealed by the spatial distribution of metals in the surface soil (Fig. 3a). The latter appears as an accurate signature of the cumulative infiltration fluxes, as replicated by the hydrologic model (Fig. 3b), which confirms that a significant part of the device is seldom reached by runoff contaminants.

The variability of runoff concentrations was not considered; their mean value was derived from the sorption isotherms, assuming that soil-water equilibrium had been reached in the upper sample from the most contaminated region of the basin (*i.e.* near the former water inlet, referred to as “Zone 1”): the calculated Zn concentration is 150 µg/L, which is consistent with the land use.

The model appears to be rather accurate, but does not capture the sharp gradient of concentrations in the upper centimeters of soil, and slightly underestimates the migration depth of metals (Fig. 4a). This may be attributable to the mechanical filtration of particle-bound contaminants, and/or to the fact that the soil’s sorption capacities are actually variable with depth, as suggested by the vertical evolution of the volatile matter content (Fig. 4b), since organic matter is known to largely govern metal retention in soils.

CONCLUSIONS

Both the experimental results and the hydrologic model show that non-uniform processes should be taken into account, in order to improve the model’s accuracy. Uncertainties remain regarding the simulated contamination profiles, then further research will be dedicated (*i*) to incorporate mechanical filtration in the model, and (*ii*) to investigate the variability of the sorption isotherm with depth, and its consequences on the predicted soil concentrations.

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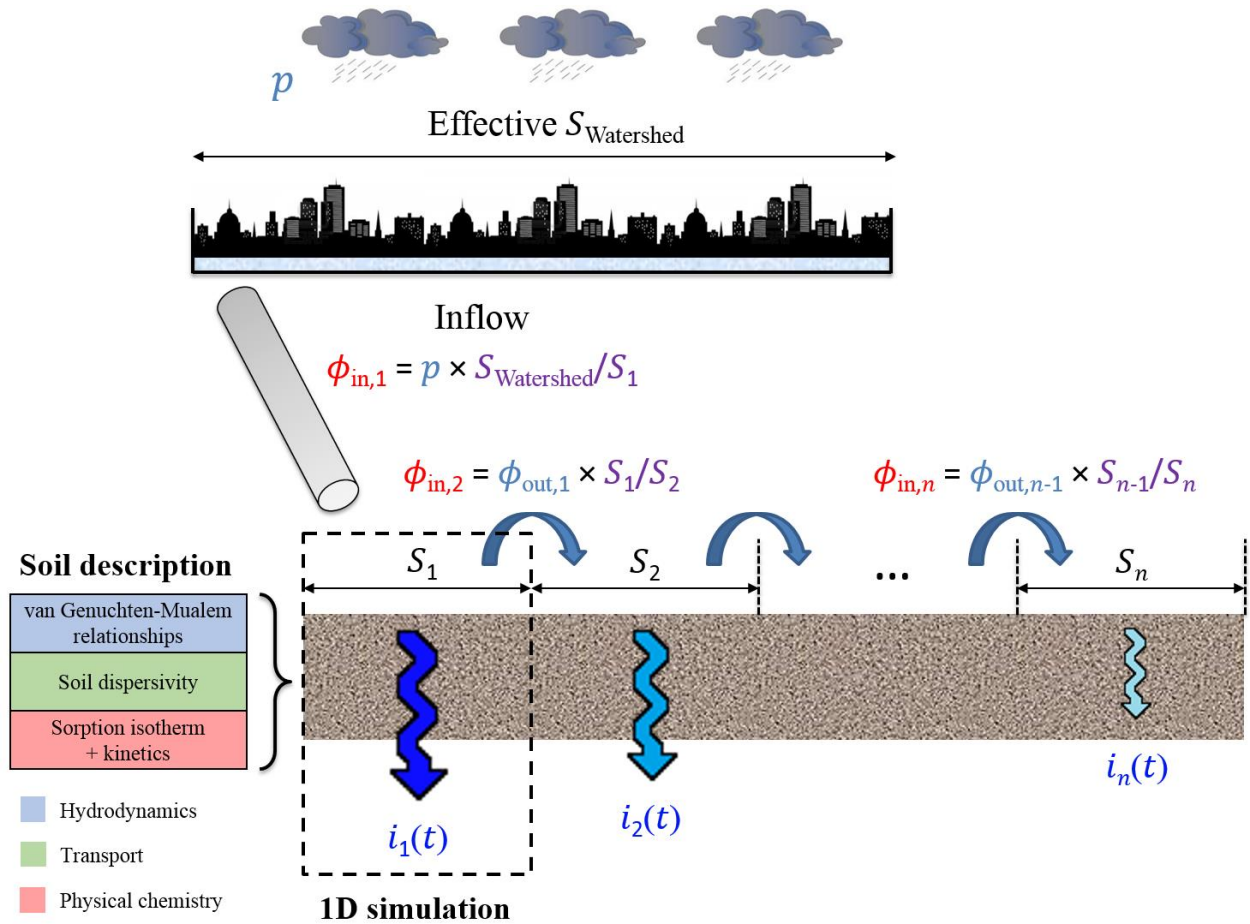


Fig. 1. Description of the model. The infiltration device is divided into n homogeneous zones starting from the inflow point, at the surface of which uniform infiltration occurs; surface runoff out of zone k is routed towards zone $k+1$. Water fluxes are expressed in mm.

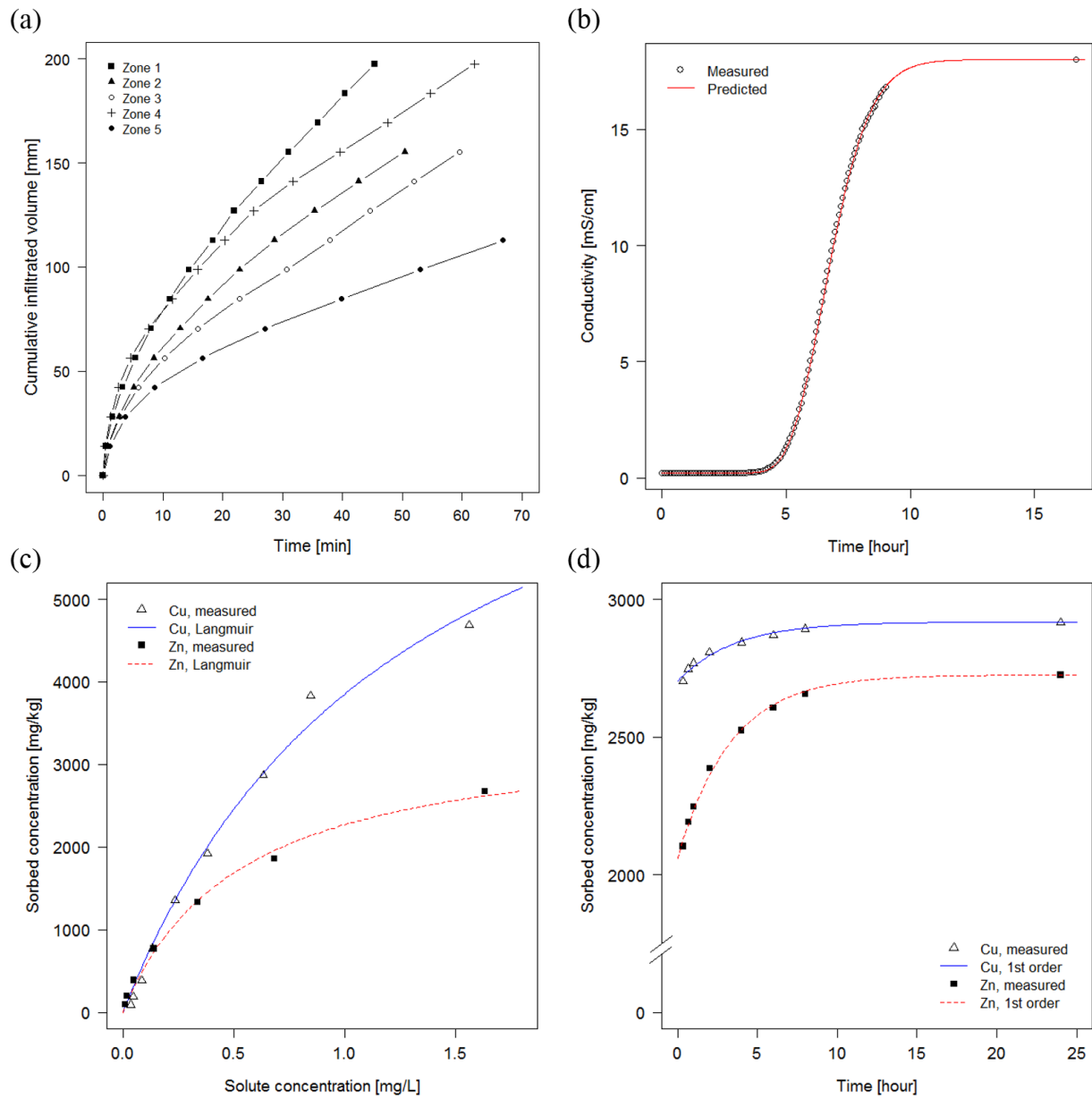


Fig. 2. Experimental assessment of the input data: (a) “BEST” infiltration tests at five locations in the basin, (b) breakthrough curve of NaCl at the bottom of a 50-cm-long column, (c) sorption isotherms for Cu and Zn, fitted with the Langmuir model, and (d) sorption kinetics, fitted with a pseudo 1st order model for a fraction of the sorption sites.

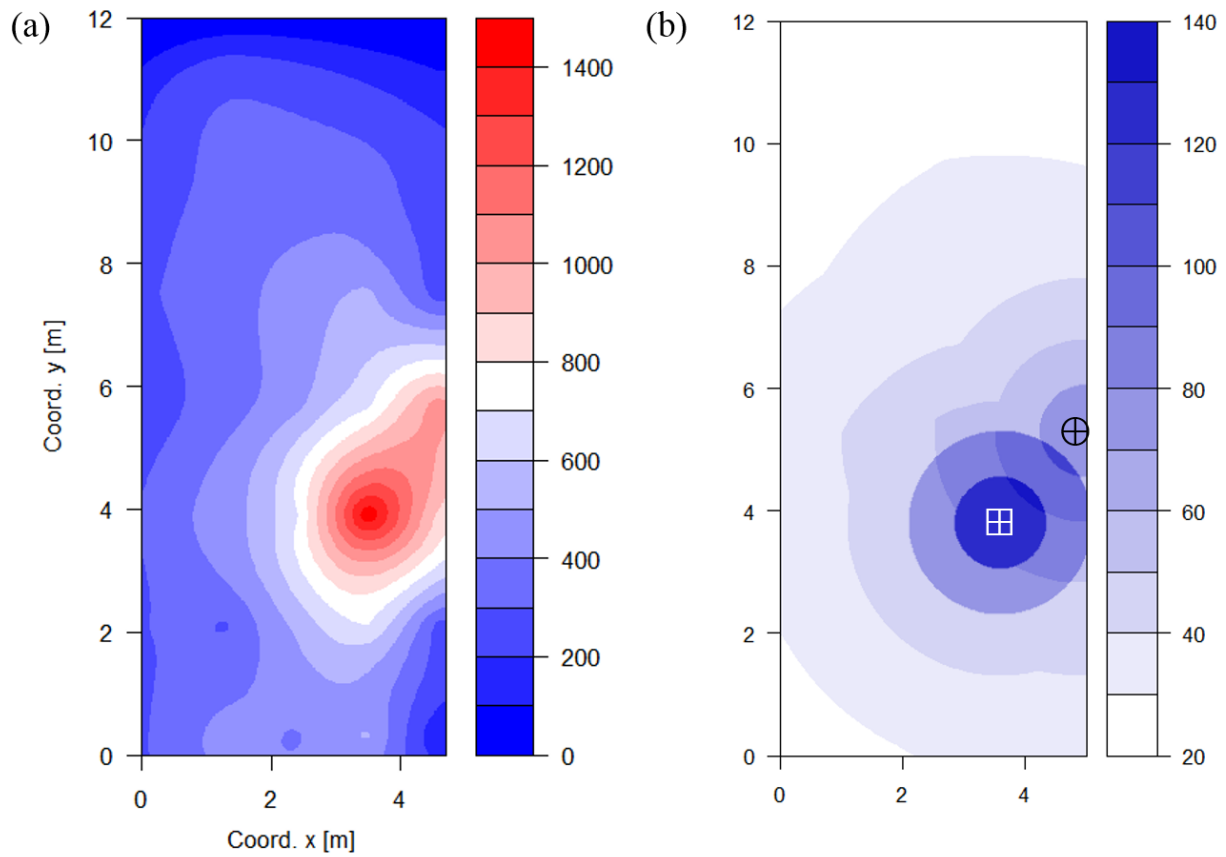


Fig. 3. Spatial distribution of (a) zinc [mg/kg], and (b) modelled ratio between cumulative infiltration fluxes and cumulative rainfall [-], at the surface of the investigated basin (plan view). The symbols \boxplus and \oplus indicate respectively the former and current locations of the inlet point.

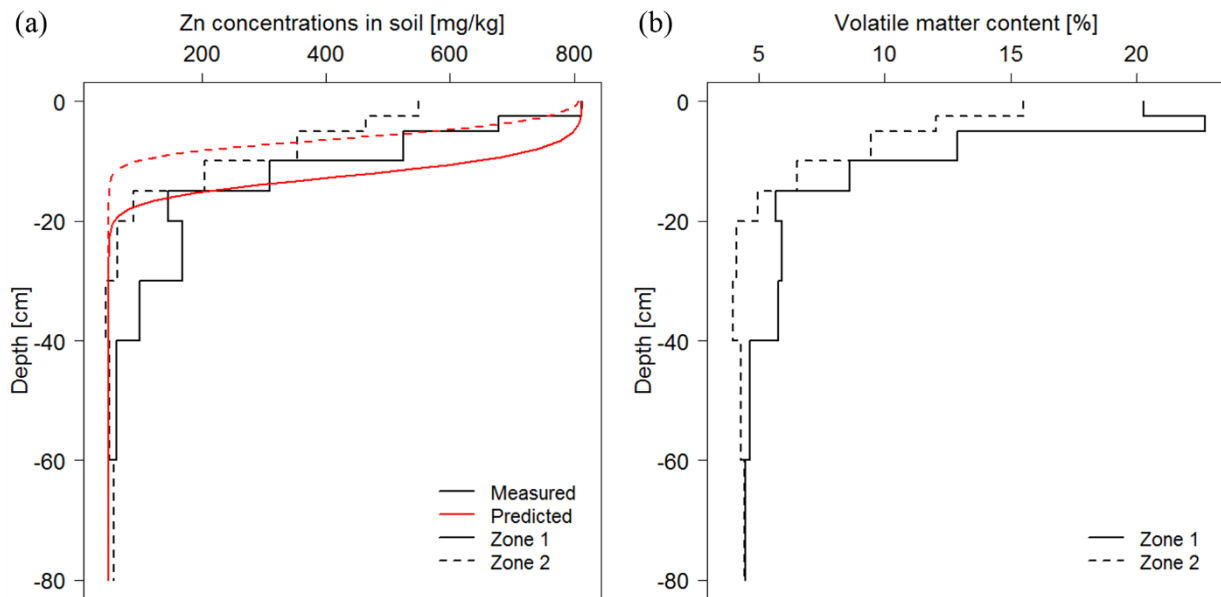


Fig. 4. (a) Measured (black lines) and predicted (red lines) Zn profiles in two homogeneous zones of the device. (b) Volatile matter profiles in the same zones.