Predicting Infiltration and Pollutant Retention in Sustainable Drainage Systems: Experiments, Modelling and Design

Ruth Quinn, Alejandro Dussaillant,
University of Greenwich

Research Importance

Problem

•**Diffuse pollution** caused by urban drainage systems is increasing e.g. **11%** of all Scottish waterways polluted predominately because of it [1].

SuDS

•**Sustainable drainage systems** are designed to receive water runoff from impervious surfaces which reduces the volume going through conventional drainage systems. This **decreases diffuse pollution**.

Research

•Previously: developed models for hydrologic design, based on Richards equation [2,3] and Green-Ampt [4], and for pollutant retention [5]

•Now:
1. Develop a computer **model which predicts heavy metal retention in SuDS**, such as rain garden.
2. Conduct experiments which investigate the **impact of macropore flow on heavy metal retention in a rain garden (no studies** examining the effect of macropores on pollutant retention in SuDS)

•**Macropores** are **preferential pathways** in soils which **increase pollutant transfer** to subsoil (Fig. 1).

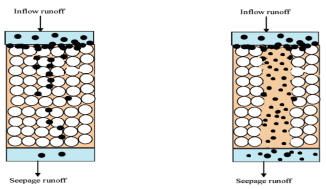

Figure 1. Heavy Metal Retention in Soil

Background

- A **rain garden is a vegetated layered facility** that has been specifically designed to collect and infiltrate the storm water runoff from impervious areas such as car parks, roofs and pavements (Fig. 2).
- **Heavy metals** were chosen as the initial focus of this model as they pose the **greatest health hazard.**
- **Column Experiments** were completed in the hydraulics laboratory at the University of Greenwich.

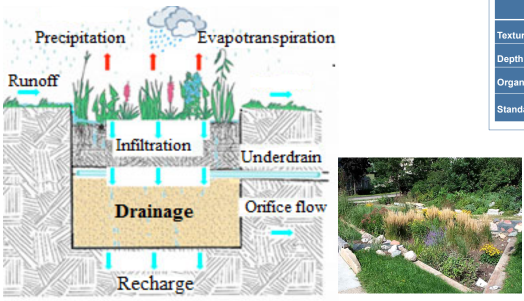

Figure 2. Rain Garden diagram (left) and example (right).
Adapted from [3,6]

Methods – Experimental Columns

Experimental Layout (Fig. 3)
• 3 Non-Macropore (Matrix) Columns
• 2 Macropore Columns (one vertical 1mm macropore)

Table 1. Experimental Parameters

Parameter	Value
Column Length	1.2m
Upper layer substrate: Lower layer substrate:	Sand/Compost Mix (60cm) Coarse Sand (30cm)
Flowrate	12 cm/h
No. of Runs	4
Length of Run	300min
Heavy Metal Concentration	Cu, Pb: 10mg/L. Zn: 30mg/L.

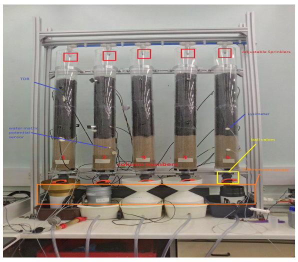

Figure 3. Experimental Layout

Methods – Model & Application

Water Modelling Approach

A dual-permeability model is used which models both:
- Matrix Flow
- Macropore Flow

Both modelled with the **Kinematic Wave Equation** [7].

Pollutant Retention Modelling Approach

Modelled with **Advection-Diffusion-Retardation Equation** and **Linear, Langmuir and Freundlich Isotherm** [8].

Case Study

Proposed bioretention system in a roundabout in Thanet, Kent [9]: simulated over a 10 year period.
The effects of two factors (Soil Type & Area Ratio - between contributing area to bioretention area) are examined regarding:
- Accumulation of Lead (Pb)
- Transfer of Copper (Cu) through the system

Table 2. Parameters used for Thanet roundabout bioretention system

Soil Characteristic	Root Zone	Storage Zone Layer
Texture	Loam	Sand
Depth (cm)	30	30
Organic-enriched (O-E) Soil Pb Retention (L/kg)	171214	1295
Standard Topsoil Pb Retention (Stan.) (L/kg)	500	1295

Acknowledgements

This work was funded by the University of Greenwich RAE-11 grant and School of Engineering funding for Ph.D. studentship and laboratory studies. We would also like to thank technicians from the Department of Civil Engineering for their critical help, Bronwyn Buntine, SuDS Manager from Kent County Council, and colleagues Roger Smith and John Norman for their always generous support.

Column Hydraulic Results: There was no significant difference between Matrix and Macropore Columns with regard to Hydraulic Properties.

Copper Retention Results

Cu Concentration Mean Values

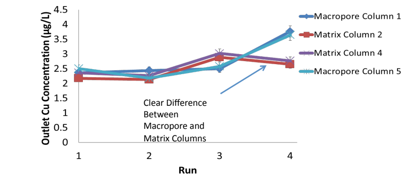

Figure 4. Plot of Means for Cu Outflow Concentration

There is very high retention of Cu, supported by other work [4]

Comparing Matrix-Macropore Columns (p-values)

Table 3. p-values on Cu outflow on pairs of matrix-macropore columns

Run	Columns 1-2	Columns 1-4	Columns 5-2	Columns 5-4
1	0.532	1	0.052	0.335
2	0.475	0.720	0.834	0.815
3	0.490	0.378	0.496	0.365
4	0.071	0.062	**0.023**	**0.004**

There is a significant difference between matrix (2, 4) and macropore (1, 5) columns that increases with successive runs.

Model Application Results

Accumulation of Pb in Soil Profile

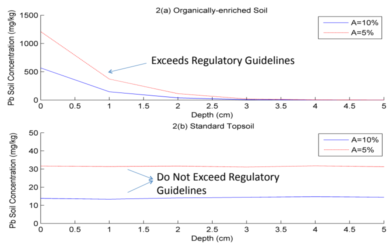

Figure 5. Pb in rain garden soil with highly retentive (organically-enriched) soil (above) and lower retentive (standard) topsoil (below) for two area ratios (contributing to bioret area).

Conclusions

Model Application:
• Pb in soil: for **O-E soil** with **5% area ratio** after **6 years, maintenance** is needed. **None** required **for the other cases** in the time period considered.
• Cu in water: **in all cases no Cu was transferred** through the system. When **retention in the upper layer is reduced**, the majority of the **capture shifts to the storage zone**.
• Model available for water & pollutant retention design [10]

Column Experiments:
- There is **excellent retention of metals.**
- **Macropore flow: not significant** hydraulically but **significant for pollutant (Cu) retention.**

Next: extend model (hydrocarbons, ET) & experiments (pollutants & substrates for rain gardens & green roofs)

Contact

Ruth Quinn
R.Quinn@greenwich.ac.uk

Alejandro Dussaillant
A.DussaillantJones@greenwich.ac.uk

References

1. D'Arcy, B., Rosenqvist, T., Mitchell, G., Kellagher, R., & Billett, S. 2005 Restoration challenges for urban rivers. *Water Sci. Technol.* **55**, *1-7.*
2. **Dussaillant, A R**, K W Potter and C. Wu 2004. Richards Equation Model of a Rain Garden. J. Hydrologic Engineering 9 (3): 219-225.
3. Aravena, J.* & **A. Dussaillant** 2009 Stormwater infiltration and focused recharge modeling with finite-volume two-dimensional Richards equation: application to an experimental rain garden. Journal of Hydraulic Engineering 135 (12): 1073-1080
4. **Dussaillant, A** R, A Cuevas* & K W Potter 2005. Raingardens for Stormwater Infiltration and Focused Groundwater Recharge: Simulations for Different World Climates. Water Science & Technology: Water Supply 5 (3-4): 173-179. 2005. http://dnr.wi.gov/topic/stormwater/standards/recarga.html
5. ***Quinn R, Dussaillant A****, 2014. Predicting infiltration and pollutant retention in bioretention sustainable drainage systems: model development and validation, Hydrology Research, doi:10.2166/nh.2014.146*
6. Flint Creek Watershed Partnership. (2009). *Rain Garden Initiative: A natural solution to water pollution*. Retrieved April 1, 2012, from Flint Creek Watershed Partnership Website: http://www.flintcreekwatershed.org/rain_garden.html
7. Smith, R. E. 1983 Approximate soil water movement by kinematic characteristics. *Soil Sci. Soc. Am . J.* **47**, 3-8.
8. Li, H., & Davis, A. P. 2008a Heavy Metal Capture and Accumulation in Bioretention Media. *Environ. Sci. Technol.* **42**, 5247-5253
9. Pam Brown Associates. 2012 Phase 1 desk study and phase 2 geoenvironmental investigation: town centre consolidation, Westwood Cross, Thanet., *Pam Brown Associates*, Burton on Trent.
10. ***Quinn R, Dussaillant A****, 2014. Modeling heavy metal behavior in Sustainable Drainage Systems: a case study, CLEAN Soil Air Water, 42 (2): 160-168.*

UNIVERSITY of GREENWICH