Modelling Water Flow and Transport in Real Soils and Catchments

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Why is it important?

Understanding the processes by which water flows and transports solutes in catchments is central to:

- predicting streamflow and flooding
- assessing the movement of nutrients and pollutants
- predicting water quality and availability

All of which have important environmental and social impacts.

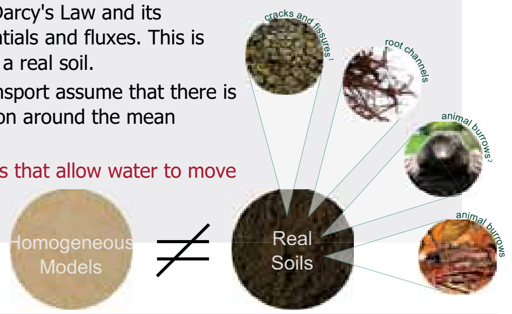
What's wrong with current models?

Subsurface flow processes form a vital component of run-off.

Most models of subsurface flows rely on Darcy's Law and its assumptions of local equilibration of potentials and fluxes. This is more appropriate to a porous matrix than a real soil.

And most models that describe solute transport assume that there is a symmetric pore water velocity distribution around the mean Darcian velocity.

However, real soils contain heterogeneities that allow water to move much faster than in the matrix pores, and cause dynamic mixing of water volumes.



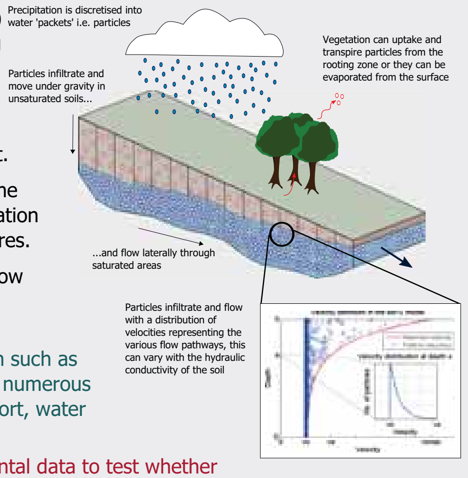
A new approach: the Multiple Interacting Pathways model

The Multiple Interacting Pathways (MIPs) model is a novel modelling concept being developed at Lancaster University.
It has 3 main components:

Random particle tracking is used to represent the water in the catchment.

Velocity distributions are applied to the particles, which allows the representation of flow through heterogeneous features.

Transition probabilities then define how particles move from one pathway to another.

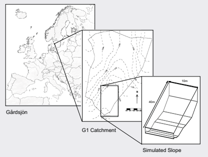


Each particle can carry with it information such as age, origin and chemistry. This opens up numerous possibilities for exploring chemical transport, water sources and catchment residence times.

The model has been applied to experimental data to test whether process understanding matches the real system behaviour.

Slope scale experiment

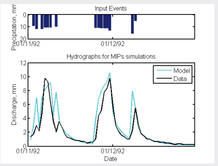
The model was applied to a slope scale experiment that was conducted in Gårdsjön, Sweden.



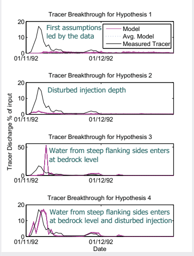
Tritiated water was applied as a tracer at the top of a 40m slope, and monitored in a trench at the outlet (Nyberg 1995 & Nyberg et al 1999).

The MIPs model was used as a hypothesis testing tool to explore which flow processes may be have been in action.

The mass flow of water was well reproduced by the model...



... however, several hypotheses were tested before a result was found that approximates the measured tracer.



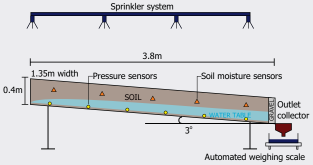
This highlights the importance of combining models with multiple measurements to test our understanding of flow processes.

Laboratory scale experiment

A laboratory experiment is in its final stages in which the influence of worm burrows on water travel times is explored.

Tracer experiments have been made using Bromide on an indoor slope in a rainfall simulation laboratory. Experiments were conducted using a slope:

- evenly packed with soil.
- with added worms, to introduce soil structure.

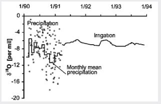


Results are under analysis, however, they suggest that the vertical burrows allow faster infiltration, but do not increase drainage, and that the tracer travel times were reduced.

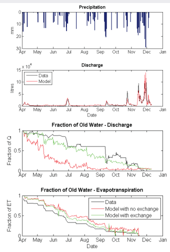
Catchment scale experiment

A roof was constructed over a small catchment in Gårdsjön Sweden, which interecepted the natural precipitation. Below the roof, the catchment was sprinkled with lake water.

Isotopic content of the lake water is enriched compared to rainfall, creating a step-change in the isotope of input waters. This was monitored to estimate the amount of 'new' (post-roof) and 'old' (pre-roof) water was in the run-off (Rodhe et al 1996).



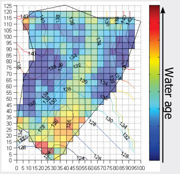
Isotope content of rainfall and lake water (irrigation).



A catchment-wide 3D MIPs model was created to reproduce this experiment. Water particles in the model can be easily marked old and new.

The model performs well at reproducing the discharge.

The proportions of old/new water in the evapo-transpiration is well reproduced in the MIPs model. This is largely controlled by rooting depth.



The MIPs model allows analysis of water age both temporally and spatially.

The old/new water proportion is less well simulated for the discharge under the assumption that water remains in one pathway for it's lifetime in the catchment. However, if exchange between pathways is assumed, then a better result is obtained. Other hypotheses and exchange scenarios are currently being investigated.

Conclusions

Flow and transport of water in catchments has many vital environmental and social implications.

The MIPs model is a new methodology for exploring these processes, which directly acknowledges the structural complexities of real soils in a scalable framework.

The model has been successfully applied to a plot-scale and catchment-scale experiment, and will soon be applied to a laboratory experiment.

There are many exciting further applications for the model such as water chemistry, sediment transport processes and contaminant modelling.

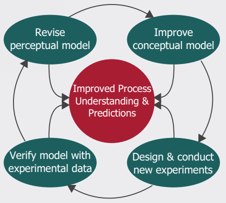


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Photo Acknowledgements

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