PREFERENTIAL SOLUTE TRANSPORT MODELLING IN A SUB-IRRIGATED BUFFER ZONE

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A buffer zone can be defined as a transition area from one ecosystem to another, in this case from an agro-ecosystem to an aquatic ecosystem.

The EU ‘Nitrates Directive’ and the WFD introduced a series of measures designed to reduce water pollution caused by nitrates from agricultural sources. Therefore, there is an urgent requirement to control the nitrate concentration in freshwater.

Buffer zones can be used to accomplish this difficult task...but to correctly quantify their internal biogeochemical processes the retention time must be known and the flowpaths characterized.
SITE LOCATION

Location of the experimental area and drainage basin of Zero river
SITE REALIZATION STEPS

(Gumiero et al. 2011, Applied Ecology)
## SITE STRATIGRAPHY

Texture, total organic carbon (TOC), CaCO$_3$ content, and saturated hydraulic conductivity ($k_s$) in different soil horizons (data by ARPAV, 1999).

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>CaCO$_3$ (%)</th>
<th>$k_s$ (m/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap1</td>
<td>0-40</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td>Ap2</td>
<td>40-70</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td>Bw</td>
<td>70-90</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>Bk</td>
<td>90-120</td>
<td>15</td>
<td>0.002</td>
</tr>
<tr>
<td>Ckg</td>
<td>120-150</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>
Ground level (black line) and mean annual water table elevation measured in plot A from 2008 to 2010. These values are not significantly different to those from plot B. Vertical bars represent the standard error from three piezometers.

INFLOW MONITORING

- Irrigation
- Rainfall
- Piez. 1 IN
- Piez. 5 OUT

Legend:

- mm/day
- m s.l.m.
PIEZOMETERS MONITORING

Flowlines are mainly perpendicular to the ditches, but Cl⁻ distribution is highly heterogeneous within the piezometers grid, with values higher than in the input and output.

Stagnant zones characterize most of the piezometers, only B4 shows values similar to the ditches.
During slug tests within fully screened piezometers, changes of slope between displacement and time highlighted large $k_s$ heterogeneities. Thus, multi-level slug tests were performed to improve the conceptual model.

Summary of statistics for $k_s$ (m/d) obtained by slug tests:
- $k_s$ Mean stands for all the measurements,
- $k_s$ L1 stands for measurements from 0-0.5 m b.g.l.,
- $k_s$ L2 stands for measurements from 0.5-0.9 m b.g.l.,
- $k_s$ L3 stands for measurements from 0.9-1.5 m b.g.l.
R-WT CHARACTERIZATION

The R-WT injection have been monitored in the inflow and outflow ditches, with ISCO 6700 working at a sampling frequency of 30 min.
Assuming a uniform water content and steady-state flow conditions, the one-dimensional transport non-equilibrium advection–dispersion equation (ADE), including first-order degradation reaction, can be written as:

$$C(m - \frac{3}{3}) = \frac{D_m(L^2 - T)}{2} \frac{\partial^2 C}{\partial x^2} + J_w(L^T - 1) \frac{\partial C}{\partial t} + \alpha(T - 1) \frac{\partial C}{\partial t}$$

where $C$ denotes solute concentrations as a function of distance $x$ (L) and time $t$ (T). $D_m(L^2T^{-1})$ is the hydrodynamic dispersion coefficient for the mobile region, $J_w(LT^{-1})$ the volumetric water flux density, and the volumes $\theta(L^3L^{-3})$, $\theta_m(L^3L^{-3})$, and $\theta_{im}(L^3L^{-3})$ are the total, mobile and immobile water content. For $\theta_m = \theta$, Eq. 2 reduces to the single-domain ADE. The solute mass transfer between mobile and immobile regions is limited by the first-order rate coefficient $\alpha(T^{-1})$. 

**STANMOD for Windows, Version: 2.xx, December 2003**

STANMOD (STudio of ANalytical MODEls) is a public domain Windows-based computer software package for evaluating solute transport in porous media using analytical solutions of the convection-dispersion solute transport equation.

**Authors:**


**Reference:**

MODFLOW

Is a modular three-dimensional finite-difference groundwater flow model of the U.S. Geological Survey, to describe and predict the behavior of groundwater flow systems. MODFLOW was originally designed to simulate three-dimensional groundwater flow through a porous medium.

Spatial discretization scheme of an aquifer system with a mesh of cells and nodes at which hydraulic heads are calculated.
The model domain extents over an area of 0.7 ha and is discretized by a regularly spaced grid of 1 m × 1 m. and is vertically discretized into 3 layers. The CONSTANT HEAD BOUNDARY package was used to represent the inflow ditches present at the northern and southern boundaries, while the DRAIN package was used to simulate the outflow ditch in the centre of the model domain (Fig. 4). The automated inverse model PEST (Doherty, 2002) was used to assist model calibration.
Two dimensional plot of the calculated piezometric heads in the model domain (left side) and three dimensional plot of the calculated piezometric heads in the model domain (right side).
MT3DMS

MT3DMS is a transport model which uses a mixed Eulerian-Lagrangian approach to the solution of the three-dimensional advective-dispersive-reactive transport equation.

MT3DMS is based on the assumption that changes in the concentration field will not affect the flow field significantly. This allows the user to construct and calibrate a flow model independently.

MT3DMS can be used to simulate changes in concentration of single species miscible contaminants in groundwater considering advection, dispersion and some simple chemical reactions.
The transient simulation of the infiltration produces a R-WT plume that rapidly spreads downstream flowing towards the drainage ditch.
Observed (open circles) and calculated R-WT concentrations in the outflow ditch, calculated using CXTFIT (red line) and MT3DMS (black line).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CXTFIT</th>
<th>MT3DMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ν (m/d)</td>
<td>0.295</td>
<td>17.1</td>
</tr>
<tr>
<td>θ (%)</td>
<td>0.049</td>
<td>0.4</td>
</tr>
<tr>
<td>$\lambda_L$ (m)</td>
<td>25.4</td>
<td>1</td>
</tr>
<tr>
<td>$\theta_m$ (%)</td>
<td>7.0e-4</td>
<td>1.0e-2</td>
</tr>
<tr>
<td>α (d$^{-1}$)</td>
<td>8.5e-3</td>
<td>3.0e-3</td>
</tr>
<tr>
<td>$R^2$ (%)</td>
<td>97.9</td>
<td>98.2</td>
</tr>
</tbody>
</table>

Measured input concentration of R-WT in the inflow ditch (dashed line) and simulated (continuous line) in both CXTFIT and MT3DMS models, concentrations are expressed in mg/l.

(Mastrocicco et al. In Press, Ecohydrology)
CONCLUSIONS

This study addresses the flow and transport behaviour of a forested buffer zone, where preferential pathways lead to very short residence time of groundwater.

The three-dimensional flow and transport modelling captured the site’s complexity well, reproducing both observed piezometric heads, groundwater fluxes and tracer concentrations.

On the contrary, simpler one dimensional modelling captured the observed tracer concentrations but failed to reproduce reliable hydrological parameters.

This study shows that $k_s$ can increase more than one order of magnitude in a forested buffer area due to soil macropores created by the rooting system development. Thus, residence time can drastically decreases with respect to the one that can be expected looking at the hydraulic conductivities of the pristine soils.
THANK YOU FOR YOUR ATTENTION

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