Assessment of unfertilized field strip efficiency by analytical models for linking soil surface source zones to surface water receptor zones

Piet Groenendijk
Marius Heinen
Content

- Background
- Need for conceptual relations
- Examples of simple approaches
- Discussion
- Conclusions
National assessment using the STONE model chain

Hydrotypes

Climatic regions

Drainage groups

Soil physical units

Groundwater step groups

P fixation capacity

Drainage flux

Spatial distribution of STONE plots

Land use types
Regional approach

Calculation units: plots, HRU, Proxels, etc: combinations of:

- soil
- hydrology
- crops
- historical P-accumulation
- management
- fertilization
- relation with deep groundwater
Upscaling of field phenomena in a catchment model

Representation of 3D water flow to drains in a STONE plot

Upscaling to 1D vertical column

Diffuse abstraction of drainage flow in 1D vertical model

Drainage sink terms

Averaged phreatic surface
Need for conceptual relations

- Gaining insight in the key factors that control the processes or the effectiveness
- Quick scan (limited data availability) source areas
- Extrapolation of field specific processes to larger areas
- Bridging between scales (field <-> catchment)
- Spatial units in a catchment model larger than field size
Examples

- Source area for sub-surface phosphate transport
- Effectiveness of unfertilized field edges
- Vegetative filter strips (White & Arnold, 2009)
Source area for sub-surface phosphate transport

Stream

Highly P-saturated soil layer

Groundwater elevation during peak flow event

Soil surface

Saturated groundwater zone

Sub-surface flowpaths in highly P-saturated zone

Sub-surface flowpaths in both highly P-saturated and low P-saturated layers

Schematic description
Source area for sub-surface phosphate transport

Sub-surface flowpaths in highly P-saturated zone

Sub-surface flowpaths in both highly P-saturated and low P-saturated layers

Depth of highly P-saturated zone

Bounding streamline

Start point

Source area for subsurface transport defined by the position of starting point of the bounding streamline
Analytical expression can be derived for the width of a source area as function of:

- Field size
- Field slope
- Depth of P-saturated zone
- Depth of groundwater at critical discharge event
- Thickness of aquifer
- Soil hydraulic conductivity

Many assumptions !!!
Effectiveness of unfertilized field edges on nitrate loads

- Dry buffer strips: unfertilised buffer strips along ditches

\[ BSE = \frac{L_0 - L_{BS}}{L_0} \times 100\% \]

- \( BSE \) Buffer Strip Effectiveness \( \% \)
- \( L_0 \) Load in reference situation (without BS) \( \text{kg ha}^{-1} \)
- \( L_{BS} \) Load in situation with BS \( \text{kg ha}^{-1} \)
Hypothesis

- **Reduced fertilizer application: linear effect**
  - $y\%$ not fertilized $\rightarrow y\%$ less load towards ditch

- **Hydrology effect**
  - Streamlines within BS have shorter residence times: no N and P $\rightarrow$ less load towards ditch

- **Interception effect**
  - Streamlines starting outside BS may pass BS and N and P can be removed $\rightarrow$ less load towards ditch
Hypothesis

- Linear effect
- Hydrology + interception effect
Hypothesis: with background load

Background load: 40%
Steady-state analysis: perfect drain, $L/H > 4$

Rain

$\tau = \frac{1}{\int L dx}$

Seepage: $> 0$: inflow
$= 0$: no flow
$< 0$: outflow

$t_x = \tau \ln\left(\frac{1}{1 - x}\right)$

$c(t) = c_0 \exp(-kt)$

$c(x) = c_0 (1 - x)^{k\tau}$

$L = R \int c(x) \, dx$
Other conditions:

**Deep aquifer**

\[ t_1 = \tau_L x_0 \tan\left(\frac{1}{2} \pi x_0\right) \]

\[ \tau_L = \frac{\epsilon L}{4R} \]

**Monod**

\[ \frac{dc}{dt} = -k_0 \frac{c}{c_{1/2} + c} \]

\[ c = c_{1/2} W\left(\frac{c_0}{c_{1/2}} \exp\left(\frac{c_0}{c_{1/2}}\right) \exp\left(-\frac{k_0}{c_{1/2}} t\right)\right) \]
Steady-state analysis: perfect drain, $L/H > 4$

- Rain
  - $fL$: "high" decay: $k_1$
  - $(1-f)L$: "low" decay: $k_2$
- Seepage:
  - $> 0$: inflow
  - $= 0$: no flow
  - $< 0$: outflow

$H \downarrow c_0=0 \downarrow c_0=1$
Effectiveness

Regular agriculture

Unfertilized field edge

Regular agriculture

Distance

C₀

Distance

C₀
Example: thin aquifer

Thin aquifer; first order kinetics

Relative thickness of reactive zone \((d/H)\)

Effectiveness \((-\) \(\text{\textit{rel}}\))

Relative concentration \((-\) \(\text{\textit{rel}}\))

Relative distance or strip width \((-\) \(\text{\textit{rel}}\))
Elasticity: which parameters are most sensitive?

Thin aquifer, Monod kinetics

- Elasticity of effectiveness
- Relative distance or strip width
- Thin aquifer, Monod kinetics

- Parameters: tau_H, k1_top, c_half_1, c_half_2, (R+S)/R

Graph showing the elasticity of different parameters as a function of relative distance or strip width.
Example from literature

- Study by White & Arnold (2009)
- Vegetative filter strips (VFS)
- SWAT model (catchment scale)
- VFSs implemented at HRU level
- Two segment VFS is used
  - Section 1: filtered
  - Section 2: not filtered
Field phenomena in a catchment model (example 1)

- Three parameter submodel in SWAT to account for VFS

**Development of a simplistic vegetative filter strip model for sediment and nutrient retention at the field scale**

Michael J. White* and Jeff G. Arnold

*USDA-ARS Grassland, Soil, and Water Research Laboratory, Temple, Texas, USA
Discussion

- Extrapolation of field results: *meta-modelling*
  - Run the detailed process model for many combinations of inputs
  - Analyse the output
  - Find statistical relations between input and output
Approximation by statistical relations

\[ P - \text{load on surfacewater} = \]
\[ c_0 + c_1 \exp(\lambda MHW) + c_2 P_{\text{accumulated}} + c_3 P_{\text{surplus}} + \\
  c_4 [P]_{\text{background deep gr.w.}}^\mu + c_5 q_{\text{groundwater rech.}} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MHW )</td>
<td>Mean highest groundwater level</td>
</tr>
<tr>
<td>( \lambda, \mu )</td>
<td>Exponential constants</td>
</tr>
<tr>
<td>( c_0, c_1 )</td>
<td>Constants dependent on soiltype and crop</td>
</tr>
<tr>
<td>( c_2 )</td>
<td>Constant dependent on soiltype</td>
</tr>
<tr>
<td>( c_3, c_4, c_5 )</td>
<td>Constants</td>
</tr>
</tbody>
</table>
Meta-model: Approximation by statistical relations
Discussion

but for field specific phenomena:

- Source areas
- Effectiveness of buffer strips

Template for the expressions of the meta-model would be very helpful
Conclusions

There is a need for conceptual relations to account for field phenomena (effectiveness of buffer) in large scale models.

Some relations have been derived for sub-surface transport, making use of groundwater flow theory.

Can be extended to more complex situations.
Conclusions

Relations have a limited applicability, due to all the assumptions made.

But:

Give insight in the governing processes and parameters.

Can serve as a template for the statistical approximations of detailed models to be used for extrapolation.
Thank you