Interaction between land, sediments and surface water quality in different aquatic systems

Alterra, Wageningen University and Research Centre

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International Conference of Catchment Science, 14-16 September 2011, Dublin, Ireland
Outline

- Model approaches to quantify diffuse nutrient losses from land systems
- Results of studied aquatic systems (natural draining vs engineered systems)
- Conclusions & Challenges
Surface water quality measurements

Water Quality Indicators: often based on concentrations

Improvement of water quality:

- Information of driving forces are needed in terms of loads (and not concentrations) → Sources & pathways & actual load

- Effectiveness of mitigation options depend on the actual contribution of different (diffuse) sources

European Water Quality

<table>
<thead>
<tr>
<th>Countries (no. of stations)</th>
<th>Proportion of river stations in categories of OP (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO (46)</td>
<td>0-0.02 0.02-0.05 0.05-0.1 0.1-0.2 0.2-0.4 &gt;0.4</td>
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<tr>
<td>SE (105)</td>
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<table>
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<tr>
<th>Countries (no. of stations)</th>
<th>Proportion of lakes stations in categories of TP (mg/l)</th>
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</table>
1. Surface water quality measurements

Impossible to measure independently the contribution of all sources and pathways of losses from the land system

&

Often you don’t know what you measure; it needs to be interpreted

&

Data often insufficient (lack of data) or at the wrong place or even worse the data is wrong etc.
Interaction between land and surface waters complex
Model approaches to quantify diffuse losses

Nine different type of models

Low

Annual predictions based on export coefficient approach

Methods differ profoundly in their complexity, level of process representation and data requirements

High

Daily simulations of water flow and nutrient concentrations

Process oriented (deterministic)

Data oriented (empirical/statistical)

Location of EUROHARP
Study Catchments

EU-project EUROHARP
(Special issue JEM, 2009)
Lessons learned: Quantifying diffuse Losses

- Models are needed/useful to determine the fate of applied nutrients and explain the nutrient losses and pathways from land and dynamics in surface waters.

**But:**
- Modeller: There is an huge influence of the modeller’s choices in every modelling activity
- Models:
  - Empirical modelling often only valid for calibrated catchment; uncertainty scenario analysis
  - Deterministic models: *The results may be correct for the wrong reasons*; can have huge economic consequences (wrong decisions)
- There is no such thing as best model. Evaluate intermediate results (hydrological aspects, crop uptake, conc. in soil solution etc.). Discuss results with watershed manager / local experts.

- **Model result:** “25% model, 50% modeller, 25% good luck”

- Maybe better: use different models and modellers for the same catchment/river basin before you decide what to do!!! (Ensemble Modelling!!)
Dutch Surface water quality measurements

Dutch Surface water quality measurements

Legend
Meetpunten in de database naar herkomst:
- CNW
- LIMNO-database
- Eutrofieringsenquete

Distribution of the Dutch fresh water measurements

Losses from green area not covered by measurements
Balancing P losses

Log (nutrient discharge)

Log (Inp – Ret.)

Uncertainty increases

More detailed and accurate information is needed

Data: Which How much Where
Example: Standard measurements water quality (Drentse Aa)

Flow proportional
7-12 times a year each 3-5 years
Catchment characteristics

- Soil
- Groundwater
- Surface water system
- Discharge areas
- And a lot of other characteristics

Model

- Validated process oriented model

Measurements

- Meetpunt 2101
- Meetpunt 2204
1. H₂O, N, and P discharges
2. Relevant catchment data
3. Optimize gauging stations

**Challenge:** Set up Smart Monitoring Systems based on combination of Modelling and Measurements frequencies at the right place.
Outline

- Model approaches to quantify diffuse nutrient losses from land systems
- Results of studied aquatic systems (natural draining vs engineered systems; study of representative Dutch catchment in the period 2002 - 2011)
- Conclusion and Challenges
Representative Catchments (sandy, clay, peat)

- 2 natural aquatic systems (thick sandy soils)
- 2 engineered aquatic systems (clay and peat)
Surface water quality in natural drainage systems

Dynamics of diffuse losses from land system in sandy districts based on validated models.
Contribution from different pathways (sandy district)
Measuring 3 Farms (150 ha; blue line) and 3 km downstreams (1500 ha; red line)
Long term effect of % reduction in N and P input

Percentage reduction in loads form the land system
Surface water quality in engineered clay polder

Nutrient loading of surface water (yearly)

Winter

Summer

Atm. Dep.
Point Sources
Inlet Water
Land System
Surface water quality in engineered clay polder

Adapted monitoring program is necessary
Surface water quality in engineered peat polder

Nutrient loading of surface water (yearly)

Land system specified (yearly)

N

P

Atmosph. deposition
Manure/fertilizer (current)
Infiltrating surface water
Upward seepage
Manure/fertilizer (past)
Peat degradation

WAGENINGEN UNIVERSITEIT
Surface water quality in engineered peat polder

Due to pyrite oxidation in the land system sulphate leaching occurs. High $\text{SO}_4$ concentrations can not be explained by inlet water. $\text{SO}_4$ is reduced in surface water and determines the increase in $\text{P}$ concentration.
Conclusions

- In all catchment systems the influence of diffuse inland sources (N & P - application rates, deposition, peat degradation, upward seepage, background conditions and historical loading of the profile) on the water quality differ remarkably between catchments → important in relation to select measures and expectation what can be achieved if measures are applied at the right place.

- Especially in engineered aquatic systems, water inlet is important but doesn’t effect the whole surface water system → effect on location of gauging stations

- In peat areas: peat degradation and the dynamics of SO$_4$ production in land systems and SO$_4$ reduction in surface water have to be taken into account

- Better Monitoring Plan = combine and optimize Modelling and Measurements in an interactive way
River Basin Planning

Yes, we models/modellers can but verify (intermediate) results

Sources, pathways, loads info helps to decide...

Integrating surface & ground waters

Ecological objectives

Gaps: Effectiveness of measures
Needs: new monitoring approaches

Thank you for your attention
Thanks for your attention
Thanks for your attention
Mitigation Options for Nutrient Reduction in Surface Water and Groundwaters
at River Basin Scale in order to Reach Targets of the Water Framework Directive

Final International conference on
Realistic expectations for improving European waters
Keszthely, Hungary
12-14 October 2011

27 countries involved

Impact of mitigation options:

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<th>Category</th>
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<td>8</td>
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</table>

www.cost869.alterra.nl
Livestock densities (EU)

(JRC-atlas; Mulligan et al., 2006).
Water quality improvement: Phosphorus mainly due to treatment of point sources

(EEA, 2009)
Contribution from agricultural land

Source Apportionment method (balanced based approach):
\[ A = L - P - S - B - D + R \] (ton N or P per year)

- **A** = Agricultural losses
- **L** = Total “measured” nutrient discharges
- **P** = Losses from Point Sources
- **S** = Losses from Scattered dwellings
- **B** = Losses from Background/natural areas
- **D** = Atmospheric Deposition on freshwater
- **R** = Retention in lakes and rivers

EUROHARP (EU-project): Nine different methodologies were compared to assess independently the contribution from agriculture (land)

- High errors, location of hot spot areas unknown, pathways of the losses unknown, influence of different diffuse source unknown such as upward seepage, peat degradation, manure & fertilizer application, phosphorus accumulation in soils, etc.
Review of nutrient quantification tools

Criteria for \textit{a priori} assessments:

1) Model approach: underlying assumptions (original purpose / maturity)
2) dependencies on previous models (scientific evolution)
3) \textbf{processes and pathway considered}
4) scientific descriptions of major processes
5) spatial resolution and discretisation
6) temporal resolution
7) forms of nutrient losses modelled
8) data requirements
9) operational experience and skill requirement of users
10) results from previous model comparison studies
11) sub-models that can be independently checked
12) existing sensitivity analysis
13) cost indication (cost-effectiveness)
14) capability to evaluate nutrient and watershed management strategies
15) applicability within Europe (catchment typologies)
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Potential suitability of models for three types of scenario analysis

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<th>Phosphorus</th>
<th>Nutrient Management</th>
<th>Land use Changes</th>
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<td>NLCAT</td>
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<td>SWAT</td>
<td>+</td>
<td>+</td>
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</tr>
<tr>
<td>MONERIS</td>
<td>+</td>
<td>o</td>
<td>–</td>
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<tr>
<td>TRK</td>
<td>o</td>
<td>–</td>
<td>o</td>
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<tr>
<td>NOPOLU</td>
<td>o</td>
<td>–</td>
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<tr>
<td>REALTA</td>
<td>o</td>
<td>–</td>
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</tr>
<tr>
<td>SA</td>
<td>–</td>
<td>–</td>
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</tbody>
</table>

++ very suitable (e.g. dynamic effects on turnover are modelled)
+ suitable (key processes are considered, at least in a lumped manner)
o more or less suitable (e.g. only long-term effects assessed without major recalibration)
- not suitable (model does not take account of management practices)
# Measurement density

**Minimum and maximum measurement density (station/1000 km²)**

<table>
<thead>
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<th>Catchment name</th>
<th>flow</th>
<th>rain</th>
<th>NH₄</th>
<th>NO₃</th>
<th>TOTN</th>
<th>MRP</th>
<th>SRP</th>
<th>TOTP</th>
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<td>6- Vilaine (FR)</td>
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<td>8- Vechte (DE-NL)</td>
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<td>10- Rönne Å</td>
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<td>16- Kapos</td>
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<td>17- Pinios</td>
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<td>1.8</td>
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Example of overall model calibration (flow; Norway)
Comparison of annual observed and predicted Flow

Catchment: Vansjø-Hobøl
Model variable: Flow [m³/s]
QT: EveNFlow, MONERIS, NL-CAT, NLES-CAT, NOPOLU, SWAT, TRK
Impression of some results: Validation N

Mosselva (No)  TN (kg N/ha)

- Observed
- MONERIS
- NL-CAT
- NOPOLU
- SA
- SWAT

## Where do fertilizers go
### How does fertilizers flow: N

<table>
<thead>
<tr>
<th>Nitrogen (kg/ha)</th>
<th>Ouse</th>
<th>Zelivka</th>
<th>Vecht</th>
<th>Vansjo-Hobol</th>
<th>Enza</th>
<th>Odense</th>
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<tr>
<td>Nett input</td>
<td>113</td>
<td>29</td>
<td>150</td>
<td>66</td>
<td>112</td>
<td>55</td>
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<tr>
<td>Other N sources</td>
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<td>22</td>
<td>-1</td>
<td>30</td>
<td>44</td>
<td>5</td>
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<tr>
<td>Denitrification first meter</td>
<td>79</td>
<td>1</td>
<td>56</td>
<td>55</td>
<td>67</td>
<td>2</td>
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<tr>
<td>Denitrification below first meter</td>
<td>18</td>
<td>20</td>
<td>66</td>
<td>14</td>
<td>58</td>
<td>17</td>
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<tr>
<td><strong>Load on surface water</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Surface runoff</td>
<td>1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>3</td>
<td>2</td>
<td>&lt;1</td>
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<tr>
<td>-Subsurface runoff + deep groundwater</td>
<td>21</td>
<td>28</td>
<td>29</td>
<td>25</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>interflow and trenches</td>
<td>11</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>field drains and drain tubes</td>
<td>21</td>
<td>11</td>
<td>24</td>
<td>24</td>
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<td>streams and canals</td>
<td>10</td>
<td>6</td>
<td>3</td>
<td>29</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

* Already deducted from manure input
** For Zelivka, Vansjo-Hobol and Enza a minor amount of N erosion was simulated and added to the surface water model
*** Other Sources (mineralisation / depletion of organic N pools, N fixation, non registred N additions)
## Where do fertilizers go
### How does fertilizers flow: P

<table>
<thead>
<tr>
<th></th>
<th>Ouse</th>
<th>Zelivka</th>
<th>Vecht</th>
<th>Vansjo-Hobol</th>
<th>Enza</th>
<th>Odense</th>
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</thead>
<tbody>
<tr>
<td><strong>Phosphorus (kg/ha)</strong></td>
<td></td>
<td></td>
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<tr>
<td>Application</td>
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<tr>
<td>- manure</td>
<td>4.8</td>
<td>3.7</td>
<td>12.0</td>
<td>1.4</td>
<td>11.5</td>
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<td>- fertilizer</td>
<td>29.7</td>
<td>21.1</td>
<td>44.7</td>
<td>23.7</td>
<td>30.5</td>
<td>32.3</td>
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<tr>
<td>- deposition</td>
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<td>0.7</td>
<td>0.0</td>
<td>0.2</td>
<td>0.9</td>
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<td>Harvest</td>
<td>23.1</td>
<td>15.6</td>
<td>35.9</td>
<td>17.3</td>
<td>24.0</td>
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<tr>
<td>Nett input</td>
<td>12.4</td>
<td>9.9</td>
<td>20.7</td>
<td>8.0</td>
<td>18.9</td>
<td>7.9</td>
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<tr>
<td>Nett accumulation (organic / mineral)</td>
<td>12.1</td>
<td>9.6</td>
<td>20.5</td>
<td>8.1</td>
<td>18.6</td>
<td>7.1</td>
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<td><strong>Load on surface water</strong></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>- Erosion (total catchment)</td>
<td>0.01</td>
<td>0.09</td>
<td>&lt;0.01</td>
<td>0.36</td>
<td>0.07</td>
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<tr>
<td>- Surface</td>
<td>0.06</td>
<td>0.07</td>
<td>0.03</td>
<td>0.20</td>
<td>0.10</td>
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<tr>
<td>- Subsurface + deep groundwater</td>
<td>0.38</td>
<td>0.15</td>
<td>1.18</td>
<td>0.73</td>
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<td>0.50</td>
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<td>0.22</td>
<td>0.01</td>
<td>0.96</td>
<td>0.03</td>
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<td>0.70</td>
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<td>0.16</td>
<td>0.04</td>
<td>0.06</td>
<td></td>
<td>0.21</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Modelling: integrating land & surface water

**Quantity**
- Precipitation
- Evapotranspiration
- Drainage
- Seepage
- Downward seepage

**Quality**
- Fertilisation
- Crop uptake
- Surface runoff + erosion
- Wet+dry atmospheric input
- Infiltration
- Evapotranspiration
- Surface runoff
- Infiltration
- Drainage
- Seepage
- Leaching

**Models**
- SWAP
- SWQN
- SWQL
- ANIMO

**Processes**
- Quantity: integrating land & surface water
Measuring 3 Farms (150 ha; blue line) and 3 km downstreams (1500 ha; red line)
Nutrient loading from land system

N loading (kg/ha/yr)
- < 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- 30 - 50
- > 50

P loading (kg/ha/yr)
- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- > 5
Model for months of April-July 2004-2008

Peatland & water = 1 ha

Peat soil:
85% of area

Peat water courses:
water depth: 0.4 m
water volume $V$: 600 m$^3$

Mathematical models: linear reservoir model

\[
\frac{dc}{dt} = \frac{q_m}{fV} c_{in} + \frac{q_{dr}}{fV} c_{dr} - \frac{q_{inf}}{fV} c - \frac{q_{out}}{fV} c - k_t(t) c
\]

\[
\frac{dc}{dt} = \frac{q_m}{fV} c_{in} + \frac{q_{dr}}{fV} c_{dr} - \frac{q_{inf}}{fV} c - \frac{q_{out}}{fV} c - k_b(t) c + k_m(t) c
\]
Surface water quality in engineered peat polder

Due to pyrite oxidation in the land system sulphate leaching occurs. High $SO_4$ concentrations can not be explained by inlet water. $SO_4$ is reduced surface water and determines the increase in $P$ concentration.

$k_r(t) = 0.0128 + 0.021 \cdot \left(\frac{t}{122}\right)^{1.5}$