Prognosis of Groundwater Nitrate Pollution in the Upper Rhine Valley Aquifer for Land Use Scenarios and Remedial Actions

19.05.2008
Waidhofen/Yppp
COST Action 869

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Background

- One of the largest ground water resources of Europe: 80 km³ (1.6 x Lake Constance)
- Significant parts exhibit high nitrate loads
- Despite actions to reduce pollution (EU-Nitrate Directive, German Fertilizer Directive, SchALVO etc.) only very gradual mitigation (D) or stagnation on a high level (F)
- Doubts about effectivity and efficiency of the protection measures (e.g. SchALVO)
- Decision support system (DSS) needed to predict future development of land use and to evaluate remedial actions

⇒ German-French-Swiss Projekt
EU-Interreg IIIA-Projekt MoNit „Modellierung der Grundwasserbelastung durch Nitrat im Oberrheingraben“
“Modelling groundwater contamination by nitrate in the Upper Rhine Valley”

Partners:

Project-coordination:
Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), Karlsruhe

Duration: 2003 – 2006

Budget: 3 Mio €
Goals of the project

Developing a **model system** to

a) reproduce magnitude and spatial distribution of the **current nitrate pollution** in the groundwater body

b) assess possible developments in agricultural practice due to **socio-economic changes** and to evaluate their effect on nitrate leaching and nitrate concentration in groundwater

c) evaluate **measures of cultivation** concerning their effect on nitrate leaching and nitrate concentration in groundwater.
Model-system MoNit

Different models were coupled:

Coordination:

Groundwater flow and transport of nitrate, Recharge from climatic data

N-Emission at large scale and at plot scale → measures of cultivation

Scenarios → changes in land use or cropping pattern

Different models were coupled:

LUBW

- GWN_BW
  - conversion of climatic data
  - contributions (surface water / ground water)
  - STREAM
    - surface water
  - MODFLOW
    - groundwater-flow model
  - hydrogeological model

LTZ

- STICS
  - nitrate leaching: process oriented simulation model
- STOFFBILANZ
  - nitrate balance
- Options for action
- Socio-economical model

BRGM

- Socio-economical model
- Scenarios
- CAP reform

Nitrate distribution in Upper Rhine Aquifer

LEGENDE
- data flow
- models directly coupled
Study area

internal project area (IPA):
- southern/middle part of Upper Rhine valley
- water volume: 80 km³ (1,6 x Lake Constance)
- area: 4’294 km²
  D: 1’700 km², F: 2’600 km²

→ 60% of internal project area (IPA) is agriculturally used

→ outer project area: 63% forest

Landnutzung / Utilisation des terres
STOFFBILANZ (Jahr / année 2000)

- Siedlung / colonie
- Acker / terre labourable
- Grünland / prairies
- Laubwald / forêt de feuillus
- Nadelwald / forêt de conifères
- Obstbau / production frutière
- Weinbau / vigne
- Gewässer / rivières, lacs
- sonstige / zone non classée
Cropping pattern of arable land, in %
Internal project area (IPA)

Frankreich

%
Cropping pattern of arable land, in %
Internal project area (IPA)

Deutschland

- D - 1980
- D - 1990
- D - 2000

Categories:
- W-Weizen
- W-Gerste
- W-Roggen
- S-Getreide
- K-Mais
- Silomais
- Raps
- sonst. Ölrüchte
- Kartoffeln
- Z-Rüben
- Futterleg.
- Gemüse
- Tabak (d)
- Tabak (h)
- Spargel
- Erdbeeren
- Stilllegung
Livestock 2000

Internal project area (IPA):
F: 0,4 cattle units/ha
D: 0,3 cattle units/ha

Data source:
D: Stat. Landesamt, BNHE 1999
F: SCEES
Conzept

1. Compiled list of remedial actions from the preceding project has been extended and evaluated by 20 agricultural authorities from Germany, France and Switzerland

   ➢ efficacy
   ➢ feasibility
   ➢ regional relevanz,
   ➢ model-technical feasibility

   8 options of action chosen for prediction ➔ "remedial actions"

2. Potential developments in agricultural economics have been estimated

   3 scenarios defined for prediction ➔ "Szenarios"
Estimation of future developments in agriculture

26 driving forces assorted and evaluated

- importance
- uncertainty
- feasibility

6 driving forces selected for defining "Scenarios"

  - corn rootworm proliferation
  - increase in energy price & costs for fertilizer (+ 40 bis + 200%)
  - expansion of acreage for bio fuels (rape, corn)
  - increasing costs and tax for water (France)
  - EU enlargement (costs of seasonal labor, Germany)
The three Scenarios

• **trend tendency scenario T**: the most probable development

• Two more extreme scenarios following IPCC:
  – **scenario A1** “liberalized policy”
    • 100% decoupling financial subsidies from quantity of production also in France
    • less increase in energy prices (by state subsidies)
    • no problem with the corn rootworm (pesticides)
    • ....
  – **szenario B2** “energy-ecologically oriented policy”
    • high energy prices
    • taxes on water and fertilizer
    • acreage restriction for corn (rotation cropping to reduce corn rootworm)
    • ....
Remedial Actions

M1 fertilizing
a. fertilisation of grain maize according to legal requirements (ogD)
b. further 20% reduced fertilisation of grain maize (reD)
c. fertilisation of grain maize and wheat according to legal requirements (ogD)

M2 maximum amount of intercropping

M3 conversion of 20% of arable land into grassland
a. at "hot spots" (highest N surplus) within internal project area (IPA)
b. at "hot spots" per municipality
c. spots of unfavourable site characteristics (low denitrification, little dilution by surface water)

M4 Combination M1a, M2 und M3a

concerns:
crop management
land use pattern
crop management and land use pattern
Basis for Prognosis: Valid modeling of the status quo of nitrate in groundwater

Calculated for 2003 as a result of N immision since 1950

Measured in 2003

Essential features of spatial distribution and magnitude of nitrate concentration are reproduced satisfactorily
How did we model the N emission?

**Landsat:** 1975, 1991 and 2000

**Main categories of land use:**
Arable land, grassland, viticulture, fruit production, deciduous forest, coniferous forest, water bodies, urban area and degradation

**Allocation to**
- 500 m grid (inner project area)
- 1000 m grid (outer project area)

→ **N balance (annual balance)**

\[ = \text{N emission in kg N/ha} \]

spatially differentiated
Bilanzierungsansatz Ackerbau

1. kulturartspezifische N-Salden
2. gemäß Anbaustatistik flächengewichtet

Kulturartenverteilung der Gemeinde Sasbach (StaLa)

Raster: 500 m * 500 m

- Acker inkl. Gartenbau
- Laubwald
- Obstbau
- Siedlung
- Weinbau
- K-Mais
- W-Weizen
- Gemüse

Hauptnutzungsform
N emission 2000

Internal project area (IPA):
D = 17 kg N/ha
F = 17 kg N/ha
N emission 1990 and 1980

Internal project area (IPA):
D = 29 kg N/ha  
F = 26 kg N/ha

Internal project area (IPA):
D = 45 kg N/ha  
F = 38 kg N/ha
N emission [kg N/ha] from agricultural area (aa) Internal project area (IPA)
N emission from main land use categories
Internal project area (IPA)

**Deutschland**

- *Viticulture*: 60 kg N/ha (1980), 50 kg N/ha (1990), 20 kg N/ha (2000)
- *Arable land*: 60 kg N/ha (1980), 50 kg N/ha (1990), 20 kg N/ha (2000)
- *Grassland*: 10 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
- *Deciduous forest*: 5 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
- *Coferous forest*: 5 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
- *Urban area*: 10 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)

**Frankreich**

- *Viticulture*: 120 kg N/ha (1980), 100 kg N/ha (1990), 50 kg N/ha (2000)
- *Arable land*: 60 kg N/ha (1980), 50 kg N/ha (1990), 20 kg N/ha (2000)
- *Grassland*: 10 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
- *Deciduous forest*: 5 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
- *Coferous forest*: 5 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
- *Urban area*: 10 kg N/ha (1980), 5 kg N/ha (1990), 5 kg N/ha (2000)
Reasons for decreasing trend

1. Yield increases
2. Reduction of livestock
3. Improvement in fertilization practices (particularly with regard to viticulture)
4. Decline in atmospheric N deposition

Despite opposing effects

1. Increase of arable land from 34% to 49% in the inner study area, whereas the grassland percentage declined
2. Acreage of grain maize expanded and on the other hand winter wheat reduced
### N charge [t]
**Internal Project Area IPA**

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Germany</td>
<td>8.406</td>
<td>5.368</td>
<td>3.183</td>
<td>36</td>
<td>62</td>
</tr>
<tr>
<td>France</td>
<td>10.368</td>
<td>7.134</td>
<td>4.733</td>
<td>31</td>
<td>54</td>
</tr>
<tr>
<td>Switzerland</td>
<td>129</td>
<td>58</td>
<td>36</td>
<td>56</td>
<td>72</td>
</tr>
<tr>
<td>Total of internal project area (IPA)</td>
<td>18.903</td>
<td>12.559</td>
<td>7.952</td>
<td><strong>34</strong></td>
<td><strong>58</strong></td>
</tr>
</tbody>
</table>
Validation of modell system

- Maximum/model: a bit early, (at least for F) possibly too low compared with measured values.
- Later and higher maximum of concentration could point to a later (1985?) and higher (45 kg N/(ha a)?) maximum of N input.
- Coherent dimension of N immission and calculated concentrations.
- Trend/model: similar to measured values. The model can be used for prognosis.
Simulated vs. measured: Concentration time series 1986-2003

Local Deviations
N-input since 1990 possibly underestimated?

-- measured
-- simulated
Prognosis

1. Agroeconomic Scenarios
2. Remedial actions
Socio-economic modelling with SEM (SÖM)

Identification of homogeneous small agricultural regions (PRA)

Development of a farm typology

Sample farm case studies (interviews)

Development of micro-economic farm models

Definition of scenarios

Identification of instruments for agricultural diffuse pollution management

Simulation runs

Extrapolation of the results on regional level

Linkage with the N-Emission Modell STOFFBILANZ
13 Small agricultural regions (PRA)

Types de Petites Régions Agricoles
- Hardt
- Plaine du Rhin
- Ried
- Montagne et piémonts sous-Vosgien

Plateau Lorrain
Région sous-Vosgienne
Montagne Vosgienne
Ochsenfeld
Plateaux moyens du Jura
Plaine du Rhin
Hardt
Offenburger-Bühler Vorberge piémont de la forêt Noire
Ried
Lahr Emmendingen Vorberge piémont de la forêt Noire
Kaiserstuhl
Freiburger Bucht
Marktgräftler Hügelland

limité de l’aquifère-Grundw. Grenze délimitation de la zone d’étude; Abgrenzung der Projektzone (les surfaces prises en compte sont supérieures! die berücksichtigten Flächen sind größer!)
Scenarios: Changes in cropping pattern until 2015

Calculated by the socio-economic model SEM (SÖM)

COST Action 869, Waidhofen 19.05.2008
Changes in land use cause changes in N emission

Change in N-emission 2015 vs. reference 2003 in % according to STOFFBILANZ

13 small agricultural regions

Germany

France

Differences between small agricultural regions (PRA) and F - G

T – Tendency scenario
Scenario A1
Scenario B2
Groundwater: prognosis for scenarios

Indicator **ÜF_50**: Total area, in which $c_{NO3} = 50$ mg/l is exceeded

Indicator **Mw**: Average of $c_{NO3}$ for inner project area (IPA)

**Zero-Input-Run (N0)**: Any N input stops directly and completely from 2006 on (fictitious)

**Reference run (Rs)**: N-Emission of 2000 (aggregated for the small agricultural areas) remains constant until 2050 ("No action")

**Tendency scenario T** and scenario **A1**: Improvement relative to the actual state, similar curves

**Scenario B2**: Corresponding to the higher N Input degradation in relation to reference run Rs
Prognosis of change of nitrate concentration for 2050, layer 0 – 10 m, in mg NO₃/l - Compared to reference run (Rs)
Implementation of remedial actions

At the present time some of the options for action concerning fertilization and intercropping are already practiced partially

But: regional differences and missing data

The N emission for year 2000, where no remedial actions are considered, is the reference

Changes in N leaching due to changes in the amount of fertilizer or due to intercropping depend largely on site characteristics and climate

Process-orientated plant-soil-model: STICS (INRA, Avignon)

Regionalization: Simulations were made for 43 soil-precipitation areas = 85% of the arable land of the IPA. In the remaining area average values were used

94 % of the arable land is considered in forecasting
Reduction in yield and N leaching for grain maize in the German project area (Model STICS)

Variability: Simulation over 17 years (climate data 1985 – 2002)

8 soil-precipitation-units

Calculated reduction of N-emission expressed as percentages is transferred to STOFFBILANZ
M1 option for action fertilization:

Reduction of N emission compared to the Referenz (N emission 2000) in kg N/ha

M 1a = fertilization of grain maize according to legal requirements

M 1b = further 20% reduced fertilization of grain maize

M 1c = fertilization of grain maize and winter wheat according to legal requirements
Groundwater: Option fertilization

R: N-immission from 2000 remains constant until 2050

N: N-immission stops directly and completely from 2006 on
Option for action M3: Conversion of arable land into grassland

- **Effectivity** considered as high, **feasibility** considered as low
- So far only realized in a few options for action (F: CAD (Contrat d'Agriculture Durable))
  Mostly the area is bought by water supply companies
- Since 2005: Duty to keep the amount of grassland constant in the scope of the **cross-compliance obligations**
Option for action M3: Conversion arable land into grassland

Reduction of N-emission in comparison to reference run (N emission 2000) in kg N/ha

M 3a = 20% of the arable land with the highest N emission in the IPA

M 3b = 20% of the arable land with the highest N emission per municipality

M 3c = 20% of the arable land with unfavorable site characteristics
Groundwater: arable land → grassland

<table>
<thead>
<tr>
<th>Reduction of N-input_{A+G}</th>
<th>R</th>
<th>M3a</th>
<th>M3b</th>
<th>M3c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averages [kg N/(ha a)], (%)</td>
<td>25,4</td>
<td>19,1 (-25%)</td>
<td>19,9 (-22%)</td>
<td>22,0 (-13%)</td>
</tr>
</tbody>
</table>

\[\text{M3c: lowest N reduction (approx. = "effort"), but nearly the same effect as M3a and M3b => preferably use of this option!}\]
Further options of action

**M2:** Maximum amount of intercropping
- is demanded by the EU Nitrates-Directive
- is less practiced: e.g. in Alsace in the winter wheat cultivation only 9,000 from 40,000 ha
- problem: intercropping is not possible with grain maize cultivation; undersown crops instead (governmental aid in Germany: MEKA; in France: AdERM) only accessed for 2% of the acreage (2,300 ha)
- model-technical implementation: On the basis of surveys with STICS (Poitou-Charentes) the N surplus of the preceding crop was reduced by 70%.

**M4:** Combination of arrangements
- M1a - fertilization according to the legal requirements (grain maize) + M2 - maximum intercropping + M3a - conversion from 20% of the arable land into grassland in the IPA
Options for action M2 and M4

Reduction of N emission compared to the Referenz (N emission 2000) in kg N/ha

M2: Maximum amount of intercropping

M4 = Combination of M1a, M2 and M3a
4 remedial actions
Indicators exceeding area (ÜF50) and average (Mw)
Criteria to compare the options of action

- **Effectivity [%]**: Relative difference (in the year 2050) between the reference run and the run of a specific option of action regarding, for example, the indicator ÜF_50

- **Acceleration [years]**: Time period in which a specific option of action reaches the corresponding value faster than the value of the reference run in the year 2050

Example zero run:
- **Acceleration**: 38 years
- **Effectivity**: 100%
Overall evaluation of the remedial actions

Relative diminuation of ÜF_50 versus Referenz R

TM2 = Maximum intercropping with cropping pattern as in the trend scenario
Concluding remark

The developed model system MoNit works

a) Magnitude and spatial distribution of the current nitrate load in the groundwater as well as the trend show a satisfactory agreement.

   The model can be used for prognosis.

b) Agri-economic scenarios have been worked out and their impact on nitrate leaching and nitrate concentration in the groundwater has been evaluated

c) Mitigation options have been evaluated by local experts. On this basis 8 cultivation measures, relevant for the project area, have been modelled and the impact on nitrate leaching and nitrate concentration in the groundwater comparatively evaluated

The models are run by staff of the institutions LUBW, LTZ and BRGM in order to be able to model current issues.
Publications


Projektberichte:

• MoNit: Entwicklung von Prognosewerkzeugen (Zwischenpräsentation) / MoNit: Développement des outils de prévision (présentation intermédiaire), 2005
• Hydrogeologischer Bau und hydraulische Eigenschaften / Structure hydrogéologique et caractéristiques hydrauliques, 2006
• Grundwasserströmung und Nitrattransport / Modélisation hydrodynamique et transport des nitrates, 2006
• Fluss-Grundwasser-Interaktion / Interactions nappe-riviè re, 2006
• Nitratherkunft im Bodenwasser und Grundwasser / Origine des nitrates dans l'eau du sol et les eaux souterraines, 2006
• Prognosen zur Entwicklung der Nitratbelastung / Perspectives d'evolution de la pollution par les nitrates, 2006

Edited by Landesanstalt für Umwelt, Messungen und Naturschutz (LUBW), Postfach 10 01 63, 76231 www.lubw.baden-wuerttemberg.de
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- APRONA Colmar: F. Toulet
- Contractors: GIT Hydros Consult Freiburg (St. Schrempp), Univ. Dresden (M. Gebel, M. Kaiser), kup Stuttgart (U. Lang, A. Maier) et al.

Thanks a lot for your attention!