GEUS

Nitrate reduction in a groundwater dominated catchment – how good are our models?

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Outline

- Problem to be addressed
- NICA – a new research project
- Research questions
- Methodology
- Policy implications

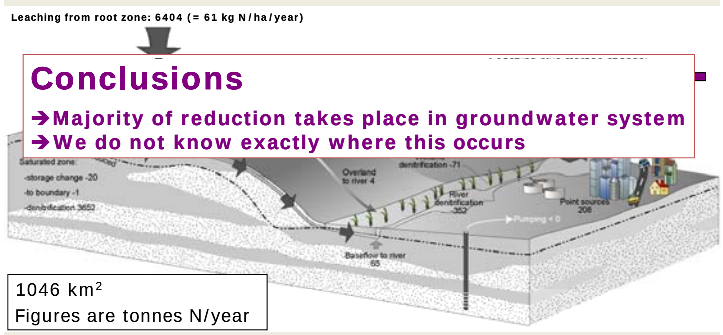
Problem to be addressed

- Nitrate load from Danish agriculture too high

- Nitrate load from agriculture a serious threat to the aquatic ecosystem in Denmark
  - 70% of Denmark agricultural land
  - Agricultural production very intensive
  - Complience with the ecological targets in the EU Water Framework Directive ➔ ~50% reduction of Nitrate load required
- Nitrate leaching from agriculture was reduced around 50% between 1980 and 2010, mainly by general regulation of agricultural practices
- A further ~50% reduction may have disasterous effects for the economy and competetiveness of the entire agricultural sector in Denmark ➔ politically very controversial issue

Odense Fjord catchment N balance

(Hansen et al., 2009)



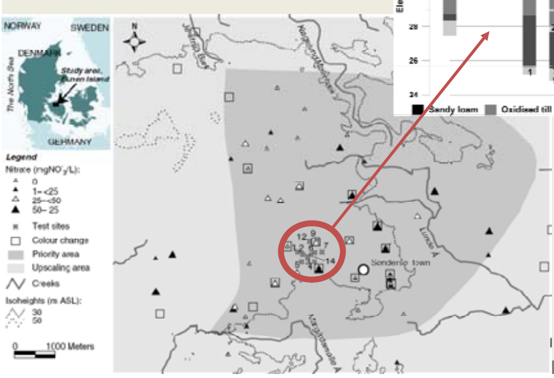
Conclusions

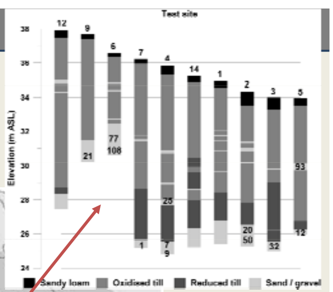
➔Majority of reduction takes place in groundwater system
➔We do not know exactly where this occurs

1046 km^2
Figures are tonnes N/year

N-reduction in subsurface varies spatially due to local scale geological heterogeneity

(Hansen et al., 2008)

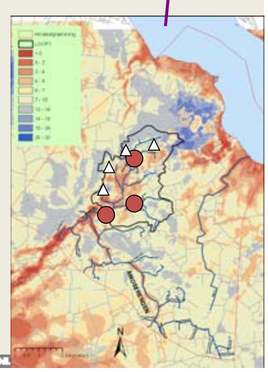




Our models cannot predict nitrate balance at small scales

- Example from national monitoring programme

- Experimental agricultural catchment – part of national monitoring
  - Catchment area: 10 km^2
  - 3 river stations (2 - 10 km^2) ●
  - 4 drainwater stations (2 – 6 ha) △
  - Lot of data
- Modelling work carried out by national research institutes and private consultants using state-of-the-art modelling methodologies
- Modelling strategy
  - Leaching from root zone: DAISY
  - Catchment transport, retention, reduction: MIKE SHE / MIKE 11



Our models cannot predict nitrate balance at small scales

- Example from national monitoring programme

- Simulations of annual water balance – model deviations
  - River stations: 10 – 60% errors 😐
  - Drain stations: 40 – 400% errors ☹
- Simulations of annual N load
  - Downstream river station: OK 😐
  - Upstream river stations: Mixed ☹
  - Drain stations: Poor ☹ ☹
- Conclusions regarding capability of N modelling related to scale
  - A model can be tuned to fit observed data, also at small scale, through calibration of local scale parameters
  - Model performance deteriorates when you extract results from smaller scale than entire catchment where model calibration was performed

Summary of problem

- Nitrate load to surface water must be reduced by ~50%
- 2/3 of the nitrate leaching from the root zone is reduced (disappears) in the subsurface when flow lines cross below the redox interface
- Uniform regulations (identical for all agricultural fields) to reduce nitrate leaching ➔ efficiency of only 1/3
- If we knew the areas where subsurface reduction takes place we could design cost effective measures to reduce nitrate load
- **Due to unknown geological heterogeneity**
  - **we do not know where subsurface reduction occurs**
  - **we do not know at which spatial scale our models have the potential to provide reliable predictions (without calibration)**

Nitrate reduction in geologically heterogeneous catchments (NICA)

– a new research project

Supported by the Danish Strategic Research Council (DSF)

- 2010 – 2013
- Total budget: 20.2 MDKK (3.4 MUSD)
- DSF funding: 14.5 MDKK (2.4 MUSD)
- 3 PhDs + 3 PostDocs

Partners

- GEUS (Co-ordinator)
- Department of Earth Sciences, University of Aarhus
- Department of Geology and Geography, University of Copenhagen
- Institute of Food and Ressource Economics, University of Copenhagen
- Université Laval, Québec, Canada
- Aarhus Geophysics, Aps
- Danish Agricultural Advisory Services
- ALECTIA A/S
- SkyTEM Aps
- DHI
- Municipality of Aarhus
- Municipality of Odder

NICA – Research questions

- How can we improve the assessment of local scale geological heterogeneity?
- How can we identify the smallest potential scale (RES) at which a hydrological model can have predictive capability?
- What is the smallest possible scale at which nitrate reduction in the subsurface can be assessed with a specified uncertainty for Danish catchments?
- What are the potential economical benefits of more precise, local scale agricultural regulations?

Using (new) methodologies and tools that have the potential for operational use in Danish water resources management

NICA – Methodologies / Activities

- Field sites
  - Lillebæk, 5 km² experiemental agricultural catchment
  - Norsminde, 101 km² (moraine till)
- New geophysical instruments
  - MiniSkyTEM
  - MRS (Magnetic Resonance Sounding)
- Field work
  - Ground truth for geophysics
  - Geological heterogeneity
  - Depth to redox interface
  - N-measurements in stream – Norsminde only
- Geological modelling
  - Manual interpretation
  - Stochastic geology (e.g. TProGS)
- Hydrological modelling
  - MIKE SHE/Daisy
  - HydroGeoSphere
- Scale analysis – Representative Elementary Scale (RES)
- Water management
  - Involvement of farmers
  - Economis assessments

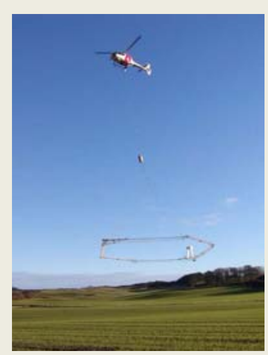
MiniSkyTEM – a new geophysical instrument

SkyTEM

- Transient Electromagnetic System (TEM)
- Airborne

MiniSkyTEM (further development in NICA)

- Smaller frame
- Larger flight speed
- Improved resolution of upper layers
  - Vertically: down to 1-2 m
  - Horisontally: down to 20-50 m



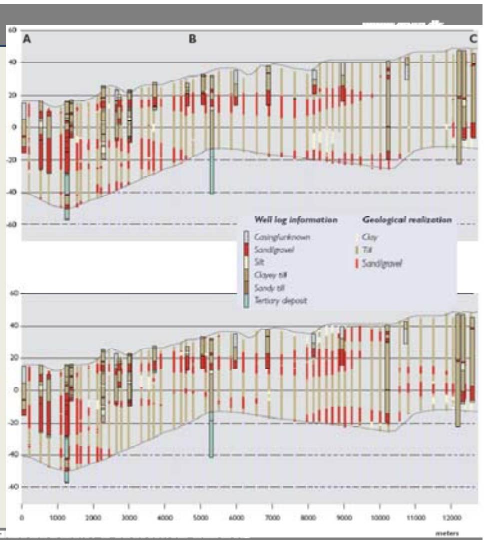
Stochastic geology

Function

Generation of local scale heterogeneity conditioned by available data

Example

Two alternative, equally probable geological interpolations between boreholes



Scale analysis

- Representative Elementary Scale (RES)

RES = The smallest spatial scale at which a model potentially has predictive capability

- Catchment characteristics exhibit local scale heterogeneity
- We will never get sufficient data to describe local scale heterogeneity deterministically
- But we can describe local scale heterogeneity geostatistically by use of probability density functions and semi-variograms
- Many plausible realisations of local scale characteristics exist
  - Generate 5-10 geological models
  - Calculate the effects of the differences between the 5-10 models with respect to subsurface nitrate reduction for different size sub-catchments

Representative Elementary Scale (RES) - principle of calculation

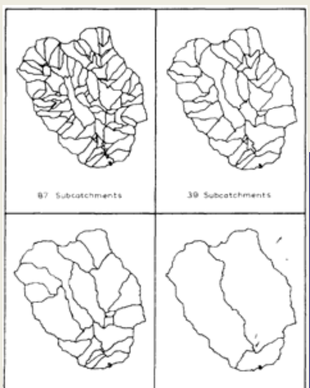
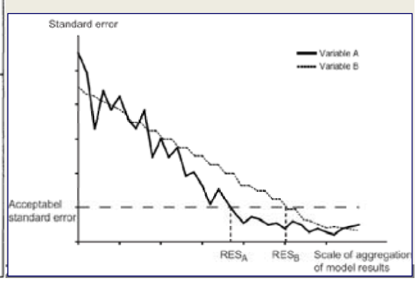


Figure from Wood et al. (1988)

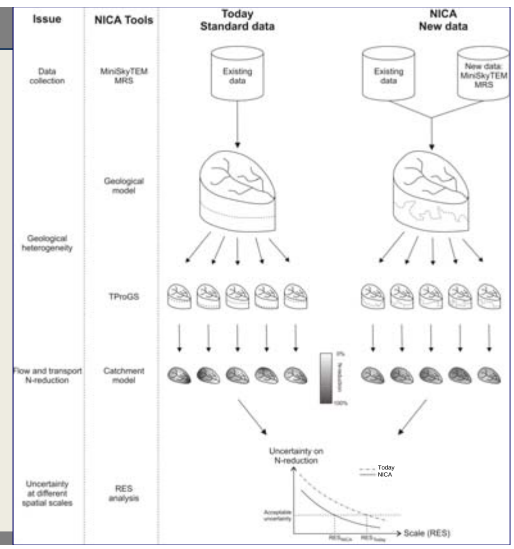
Heterogeneity – stochastic generation

- Geology
- Depth to redox interface
- Net precipitation / N-leaching
- Etc.



General approach

See figure in book of abstracts



Conclusions - policy implications

Policy problem

- Differentiated regulation of agricultural practise is more cost-effective than universal regulations
- Differentiated regulation requires scientifically based evidence to document that regulations are imposed on the right areas

NICA will contribute to

- provide the scientific basis for a differential management based on hydrogeological knowledge

Further information

Website to be operational soon

www.nitrat.dk