GEUS

Nitrate and nitrate development in Danish drinking water

Birgitte Hansen, Senior Scientist, Ph.D.

Geological Survey of Denmark and Greenland
Danish Ministry of Climate, Energy and Building

MTTF WaterCap Taskforce meeting, 24th October 2014, Knowledge Centre for Agriculture

Outline

- Conceptual understanding
- Danish groundwater protection strategies
- Nitrate trends in groundwater
- Nitrate trends in drinking water

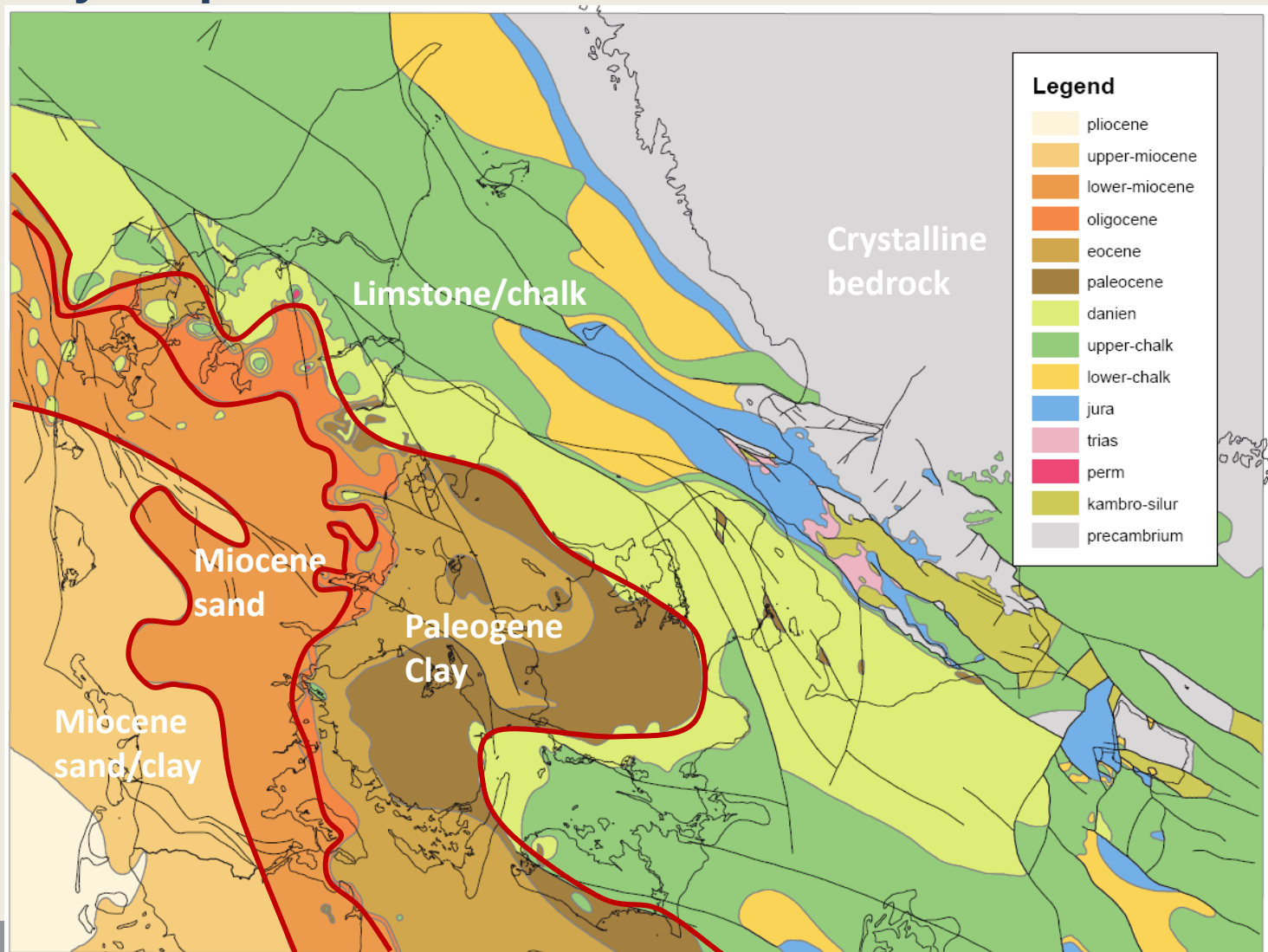
GEUS

Conceptual understanding

Geological setting: pre-quaternary map

Upper 300 m consists predominantly of sediment from Chalk, Paleogene, Neogene and Quaternary.

Quaternary sediments overlie the pre-quaternary deposits all over Denmark

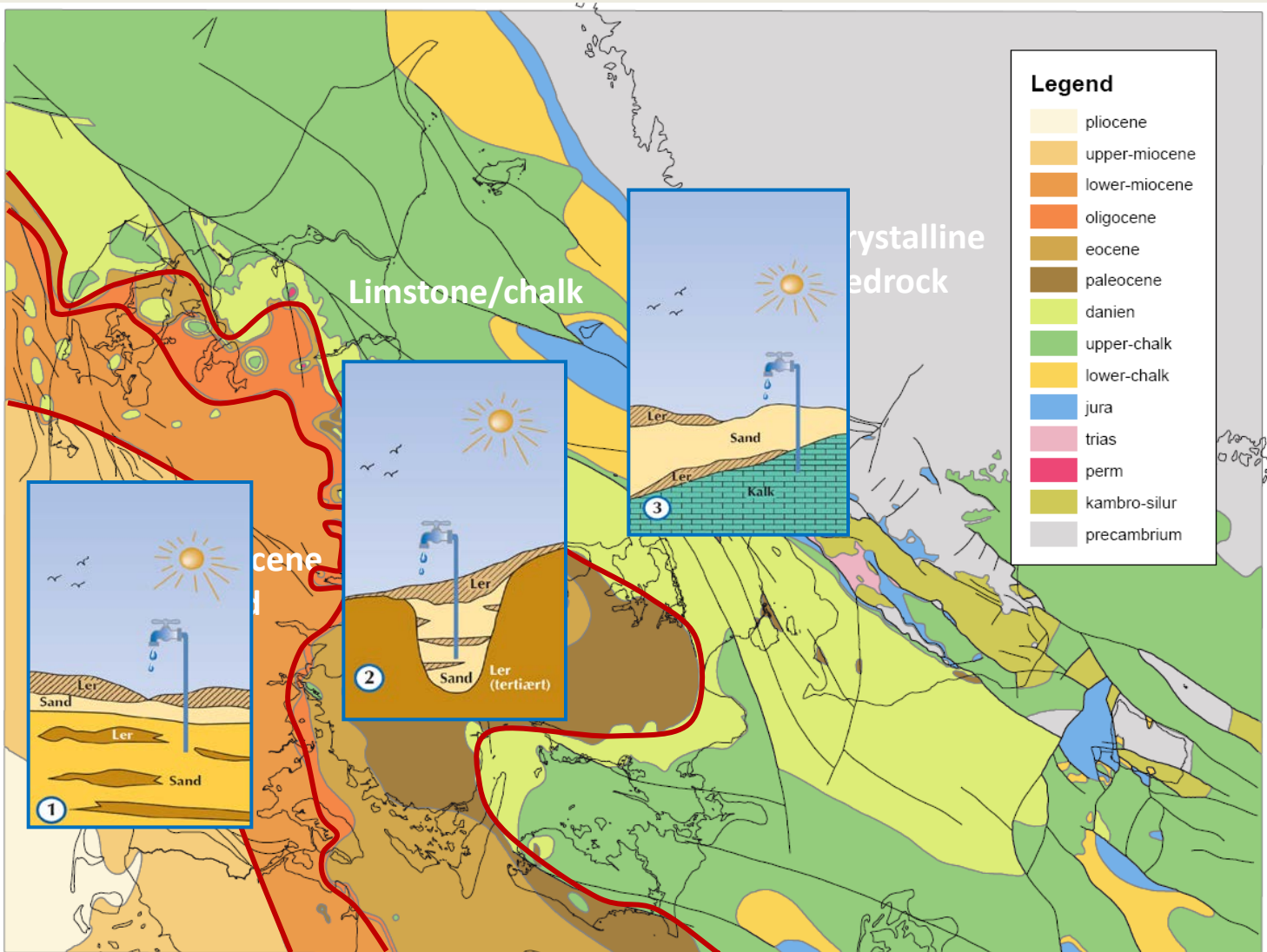


Geological setting: Aquifer types

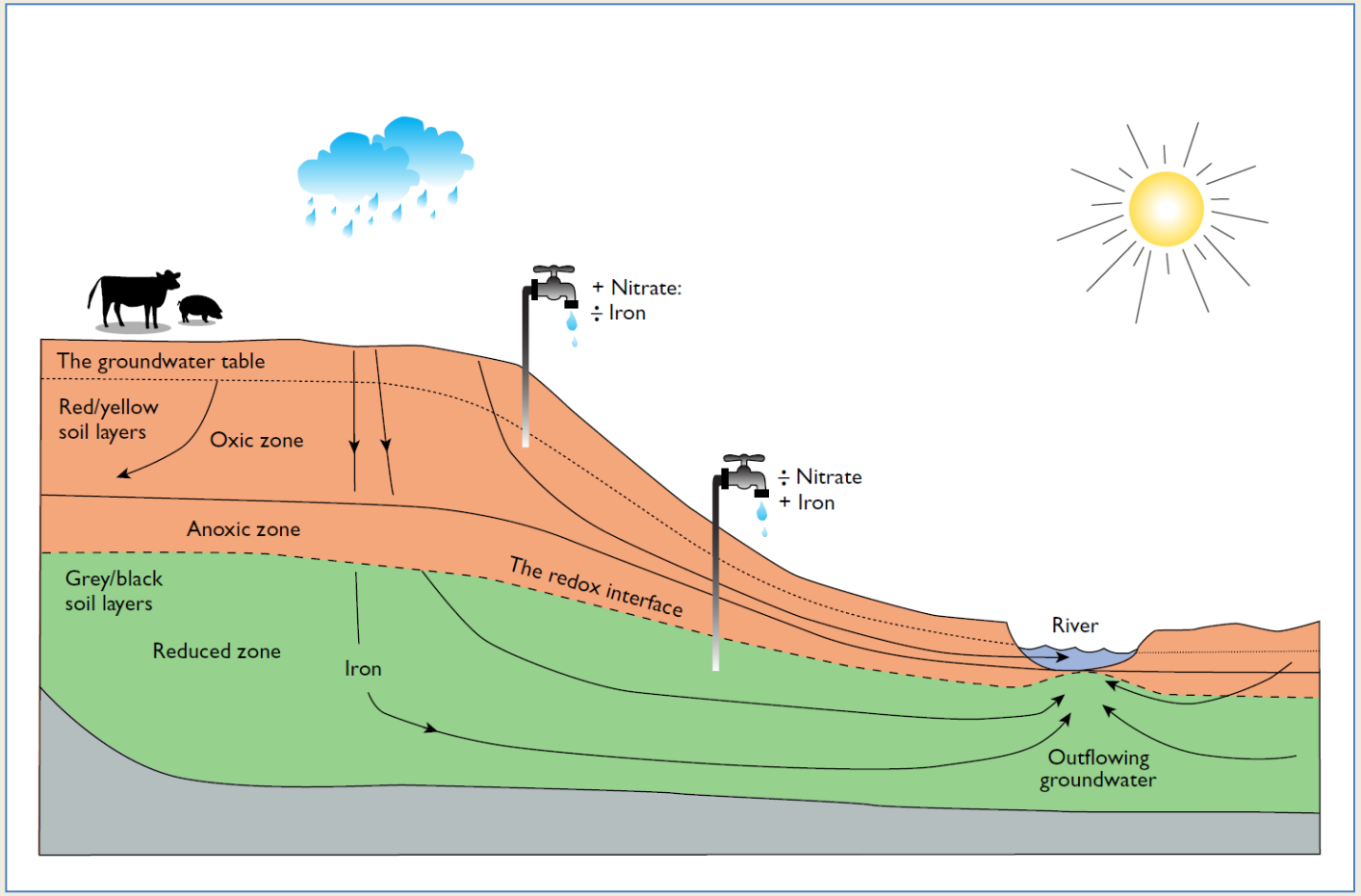
1: Extensive Quaternary and Miocene sand deposits

2: Quaternary sand deposits in quaternary valley structures eroded in Paleogene clay

3:Upper cretaceous and Danian limestone



The conceptual model for nitrate in groundwater



Nitrate reduction processes in the groundwater

Reduction with organic matter:

$$5CH_2O + 4NO_3^- \rightarrow 2N_2 + 4\,HCO_3^- + H_2CO_3 + 2H_2O$$

Reduction with pyrite:

$$FeS_2 + 3\,NO_3^- + H_2O \rightarrow {}^{3}/_{2}\,N_2 + 2\,SO_4^{2-} + FeOOH + H^+$$

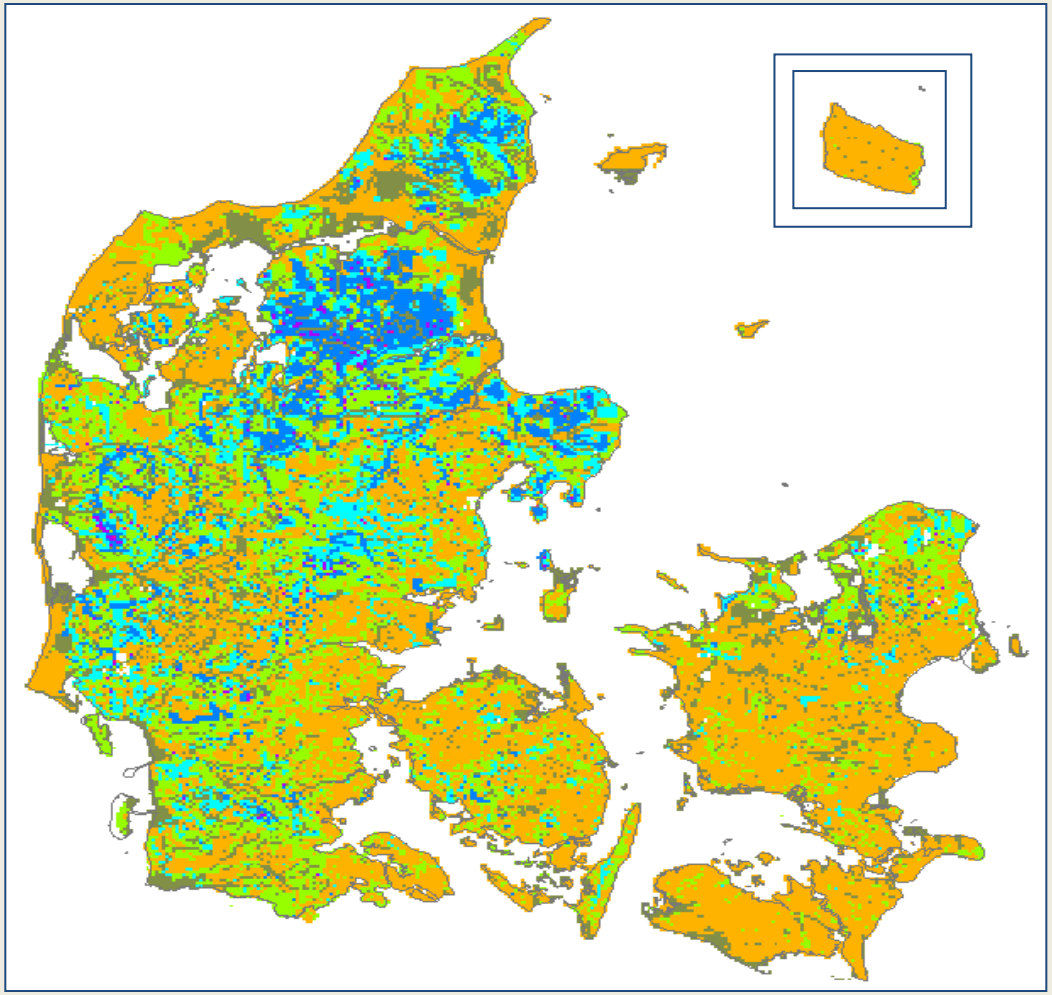
Reduction with ferro-ion and formation of free nitrogen:

$$5Fe^{2+} + NO_3^- + 7H_2O \rightarrow 5FeOOH + ½N_2 + 9\,H^+$$

The redox interface

Photo: Per Misser

The redox interface

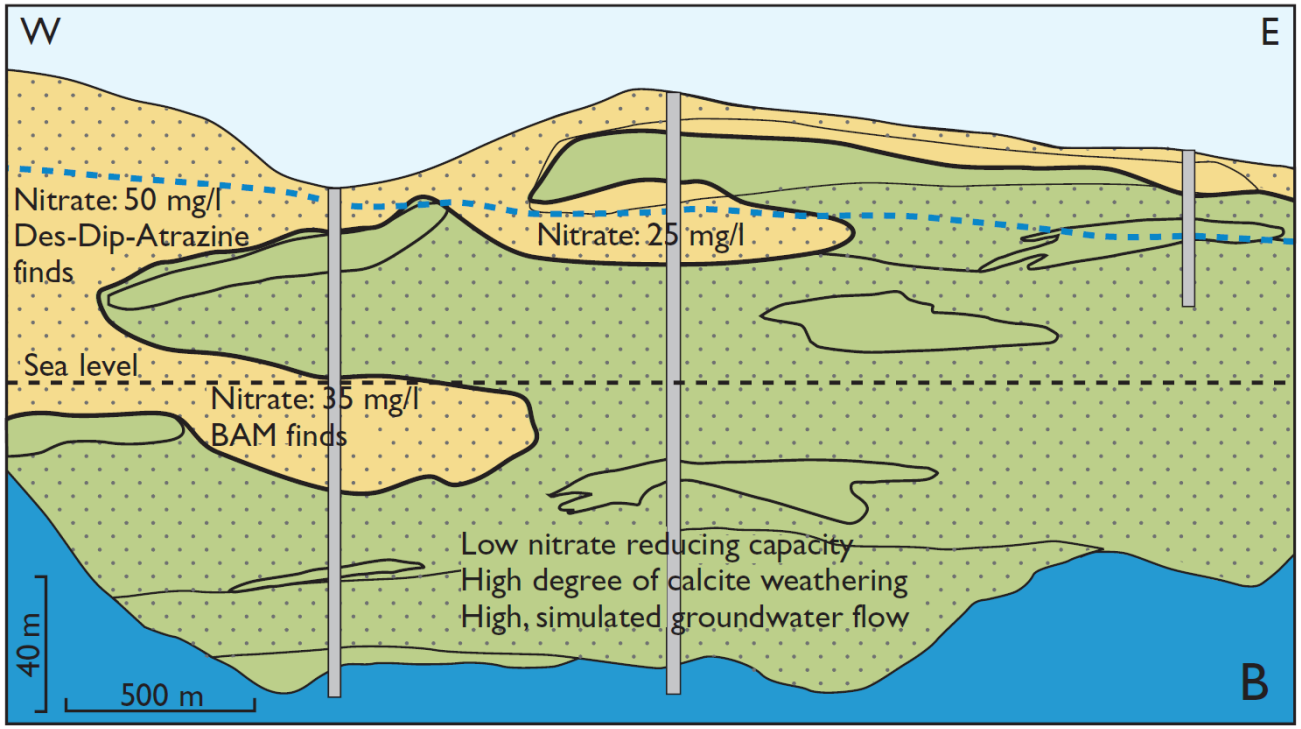


Depth (mbs)

< 1	1-5	5-10	10-15	15-30	30-50	50-100 m

Ernstsen et al., 2006

Variation in the redox interface



GEUS

Danish groundwater protection strategies

GEUS

The strategy

1. National environmental action plans with general N-regulation of agriculture
2. Local action plans based on detailed groundwater mapping
3. Extra protection around drinking water wells

1. Action plans and N measures

Year	Action plan	Important N measures
1985	"NPO-handlingsplanen"	Max. stock density. Mandatory slurry tank floating barriers. No runoff from silage clamps and manure heaps. Min. slurry capacity and ban on winter spreading of slurry for spring crops (including subsidies to invest in slurry tanks etc.).
1987	"Vandmiljøplan I"	Mandatory fertilizer and crop rotation plans. Min. proportion of area with winter crops.
1991	"Handlingsplan for et bæredygtigt landbrug"	Statutory norms for manure N utilization. Max N applied to crops equaling economic optimum.
1998	"Vandmiljøplan II"	Max. N applied 10% below economic optimum. 6% obligatory catch crops. Subsidies to e.g. organic farming and afforestation.
2004	"Vandmiljøplan III"	More catch crops.
2009	"Grønvækst"	Max. N applied ≈15% below economic optimum.

Modified from Dalgaard et al., 2014

2. Local action plans and detailed groundwater mapping

Running from 1999-2015

Total cost: app. 360 million EUR (app. 2,7 billion DKK)

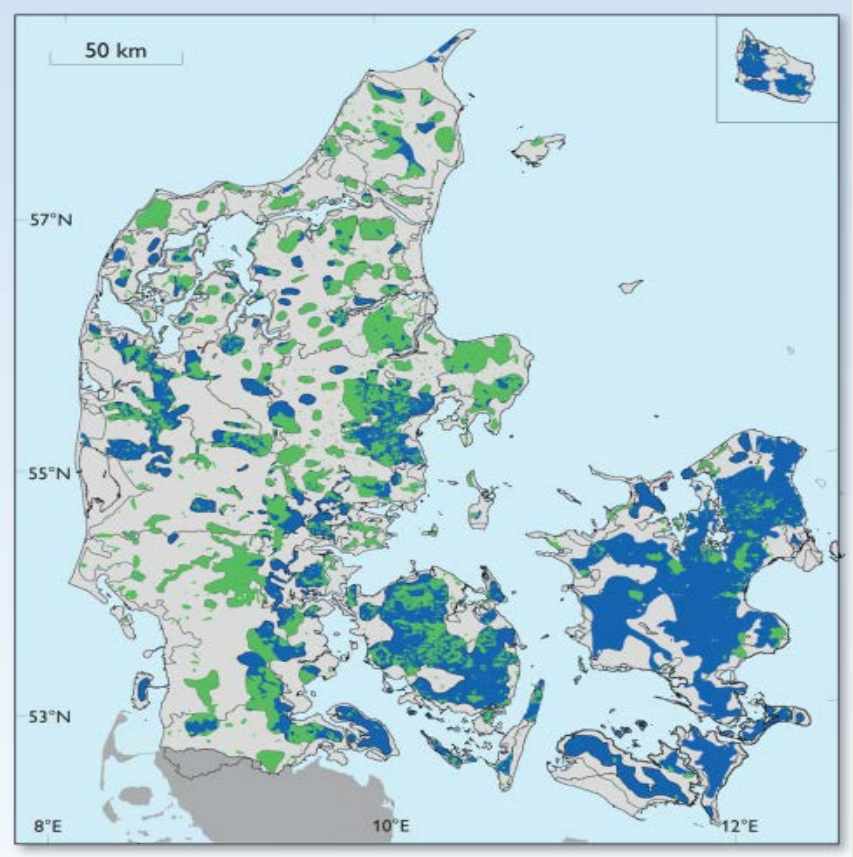
Conducted on 40% (~17.400 km^2) of the landmass of Denmark

Financed by water consumers paying extra 0.09 EUR (0.67 dkk) per m^3 of water.

The Danish Ministry of Environment is overall responsible

Local Municipalities are responsible for implementation of local action plans

Most of the practical work is carried out by private consulting companies

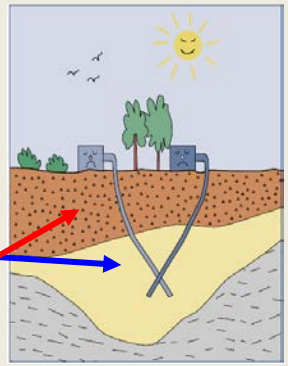


BLUE: Particularly valuable water abstraction areas (OSD), 40 % of DK

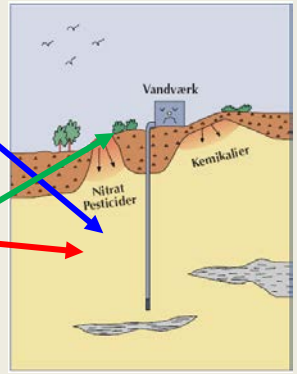
GREEN: Nitrate vulnerable abstraction areas (NFI), 15 % of the DK

The groundwater mapping concept

Detailed mapping of aquifers (size, location, interconnection)



Assessment of the nitrate vulnerability of aquifers



Local action plans for projection of groundwater

3. Extra protection around drinking water wells

- 25 meters zones around abstraction wells with ban of pesticides and fertilizers

- Larger additional protection areas around abstraction wells (BNBO)

GEUS

Nitrate trends in groundwater

Monitoring data!

Groundwater nitrate trends analyses

- Assessment of the general national nitrate trend in groundwater
- Aggregation of individual nitrate trends from groundwater monitoring wells

3 types of data

1. 20-year-timeseries from the Danish national groundwater monitoring programme:
   - app. 37.000 nitrate analyses from app. 1200 monitoring points

2. Yearly N surpluses in agriculture from Denmarks Statistics

3. CFC dating of groundwater once in the period 1997-2006

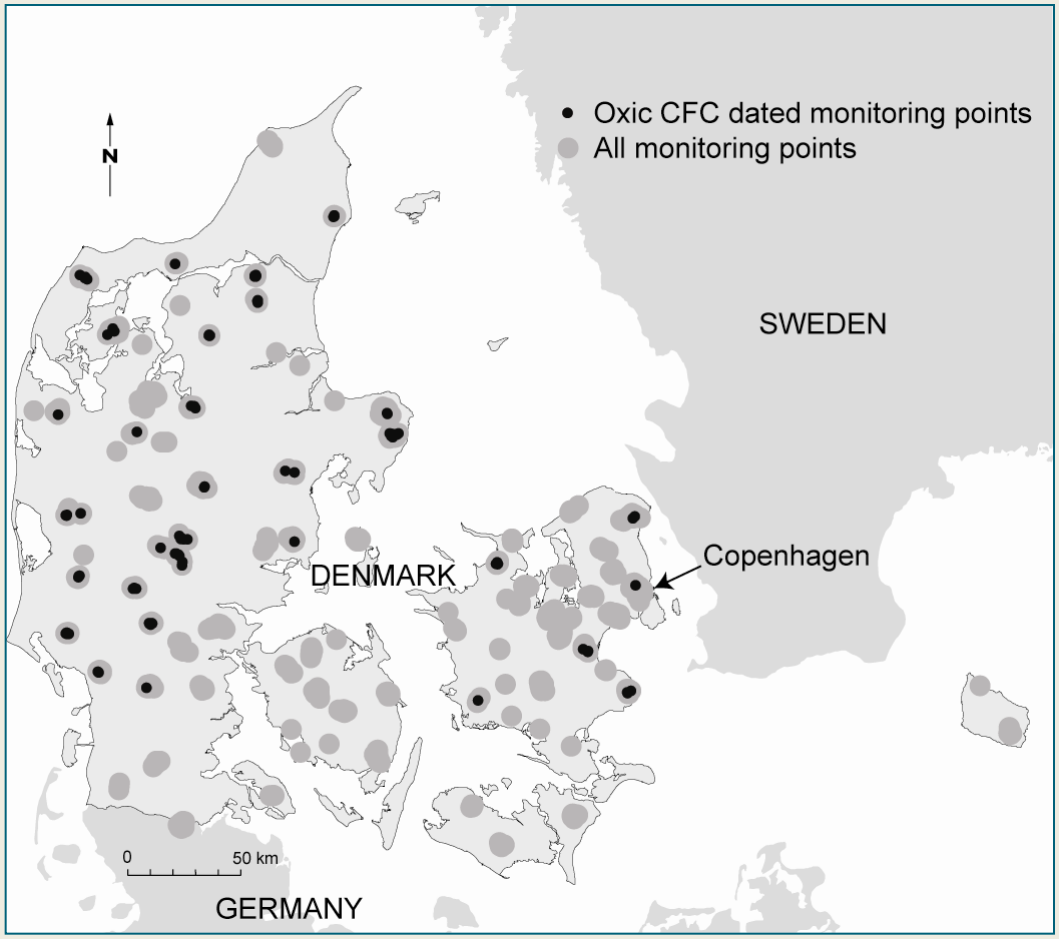
Statistical metods

SAS software programmes:

- **The national general nitrate trend:**
  - Two-section linear regression with one unknown change point fitted with ***PROC MCMC***

- **The individual nitrate trends:**
  - Probability plots of the residuals were checked for normality
  - Simple linear regression with ***PROC REG***
  - 3 age groups were compared in a regression model and fitted as a random coefficient model with ***PROC MIXED***

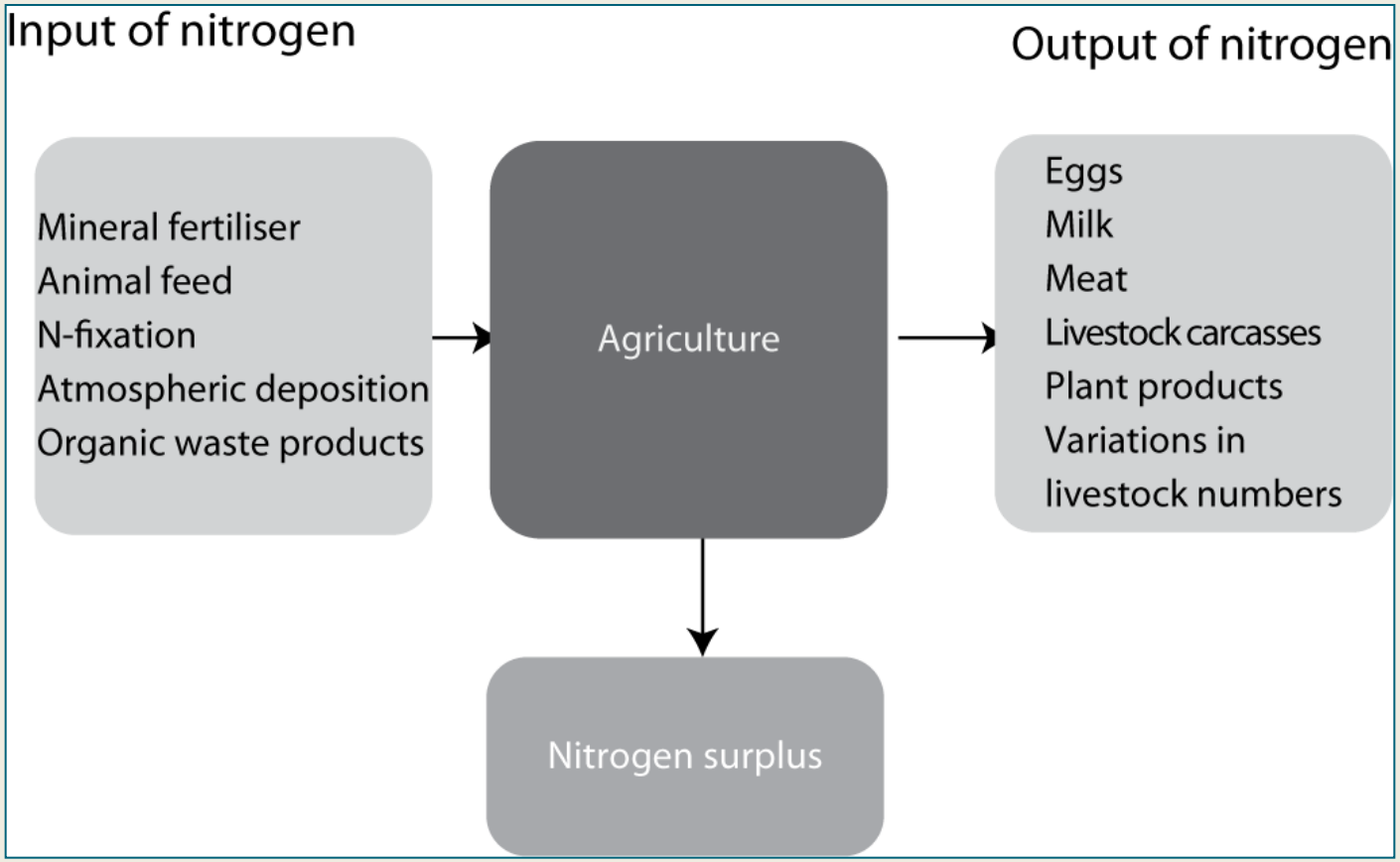
The groundwater monitoring points



ES&T, 45, 228-234:
Hansen et al. 2011

National N surplus in agriculture

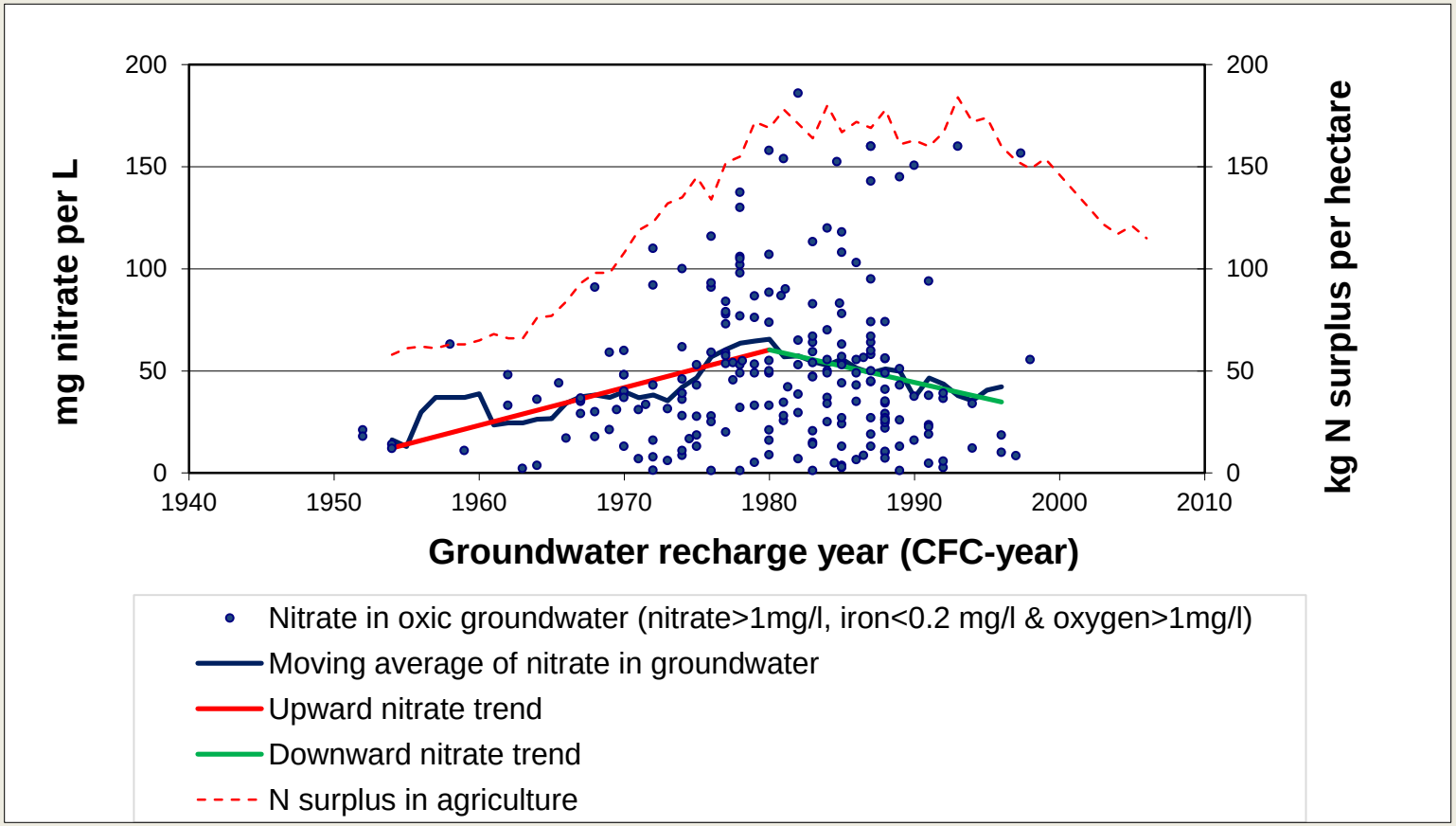
- An indicator of potential N leaching



$$N_{surplus} = N_{emission} + N_{accumulation} + N_{leaching}$$

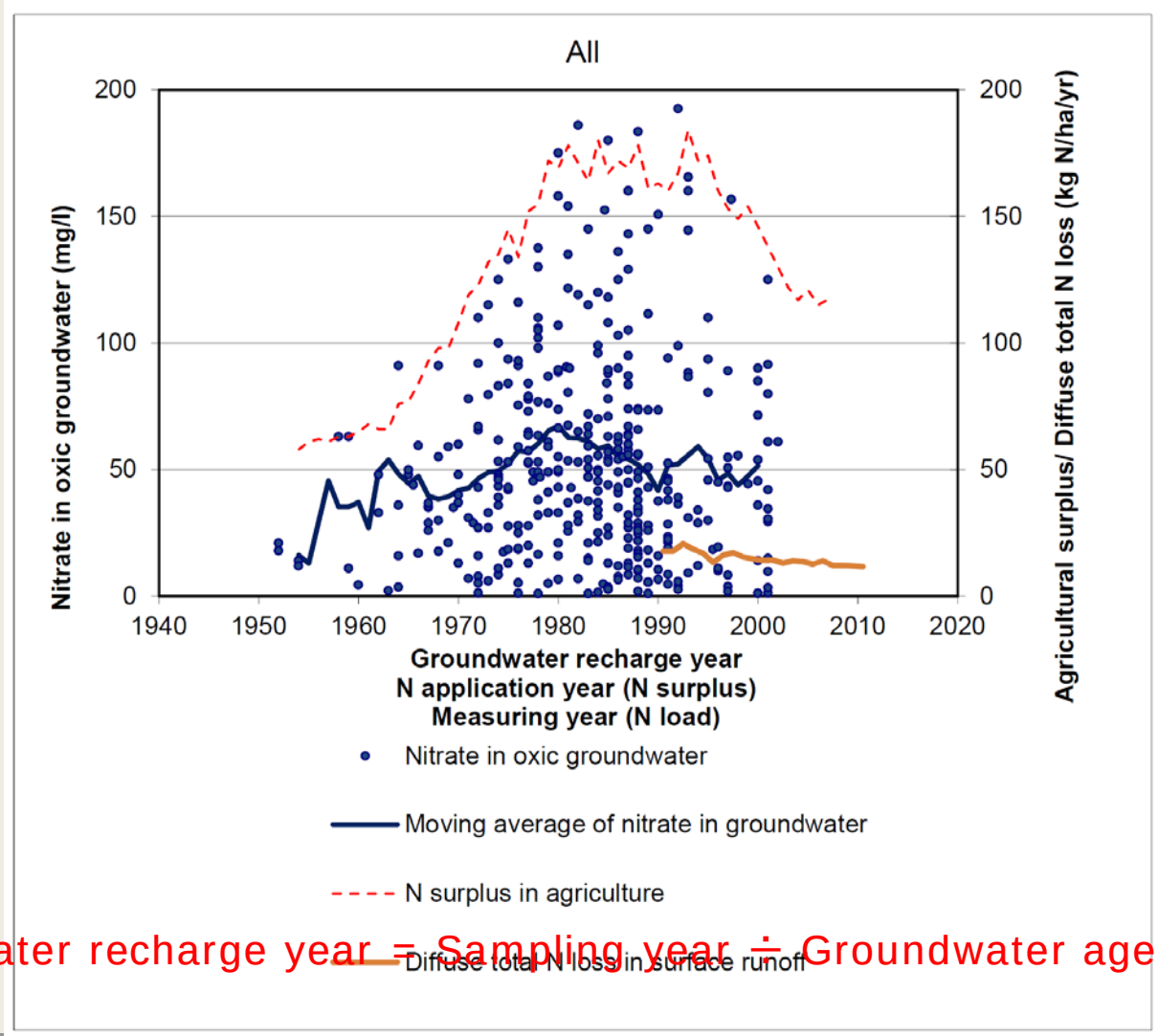
ES&T, 45, 228-234: Hansen et al. 2011

The national general nitrate trend - 194 oxic groundwater monitoring points



ES&T, 45, 228-234:
Hansen et al. 2011

National N trends in Denmark
In groundwater and surface water

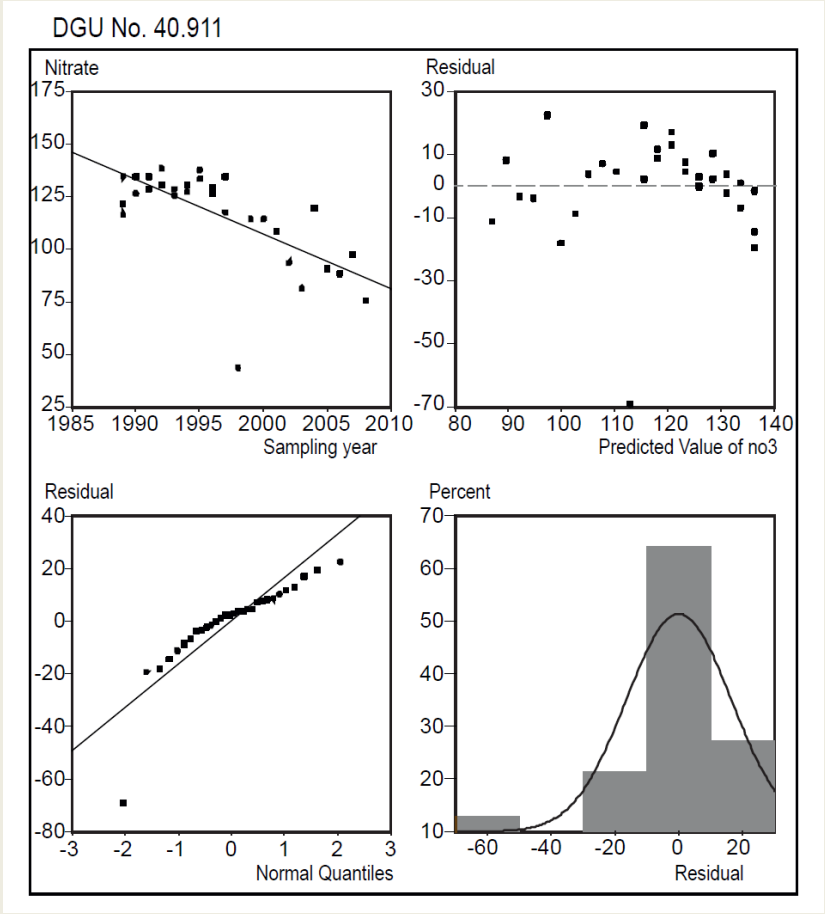


Groundwater recharge year = Sampling year – Groundwater age

Trend reversal of nitrate in Danish groundwater in 1980 (±3.4 years)

- Leveling out of the N surplus after a period of strong increase
- Before the first environment action plan in 1985
- Due to better handling of animal manure
- Due to reduction of N-losses from point sources
- Due to economical drivers

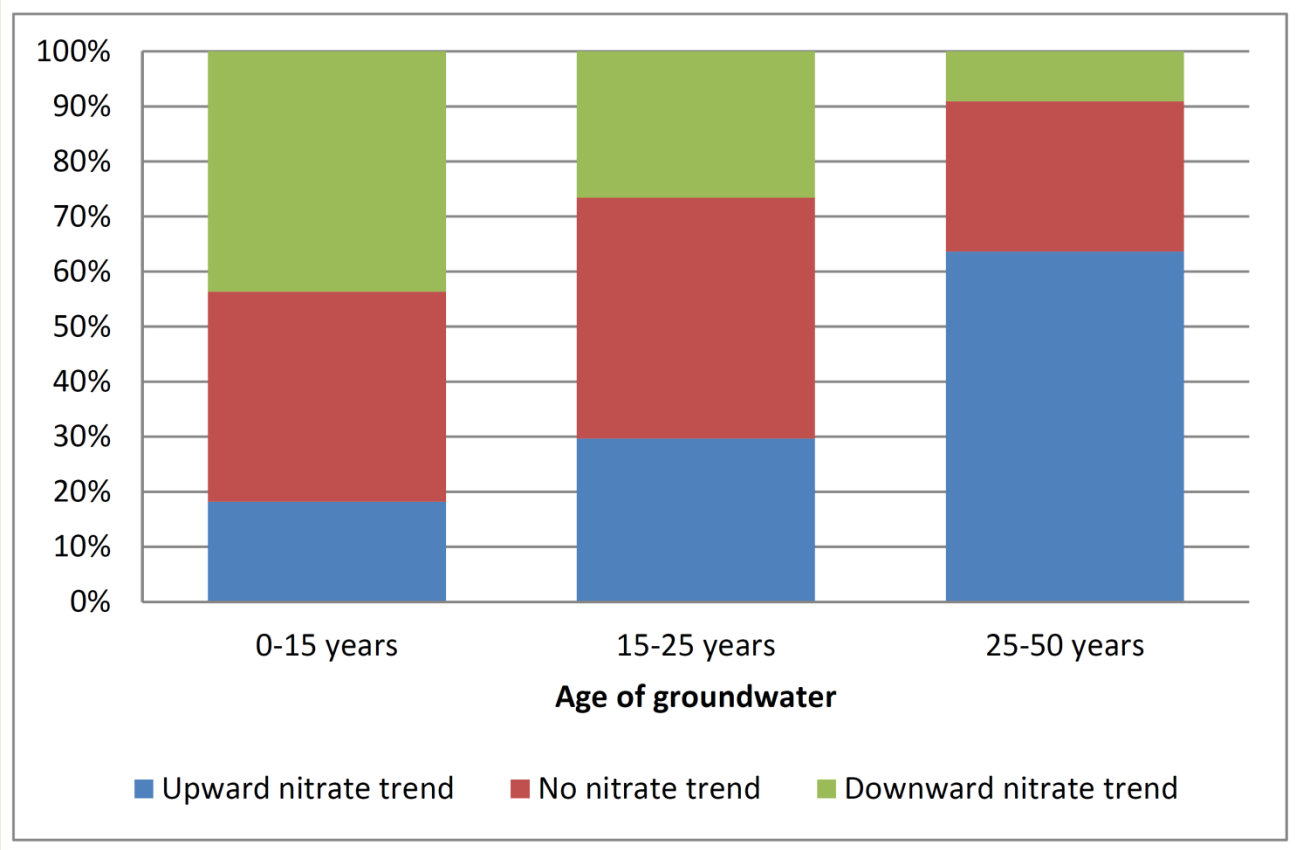
Example of an individual nitrate trend - check for normality



ES&T, 45, 228-234:
Hansen et al. 2011

Individual nitrate trends

152 oxic groudwater monitoring points
94 with significant trends

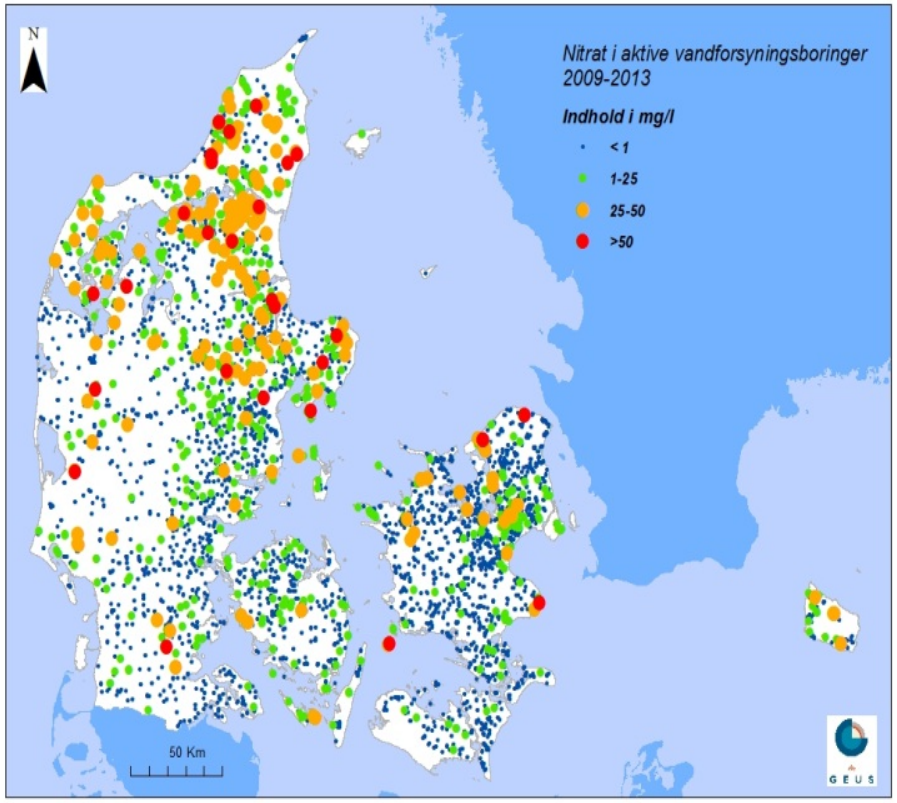


Nitrate trends in oxic groundwater Status 2013

GEUS

Nitrate trends in drinking water

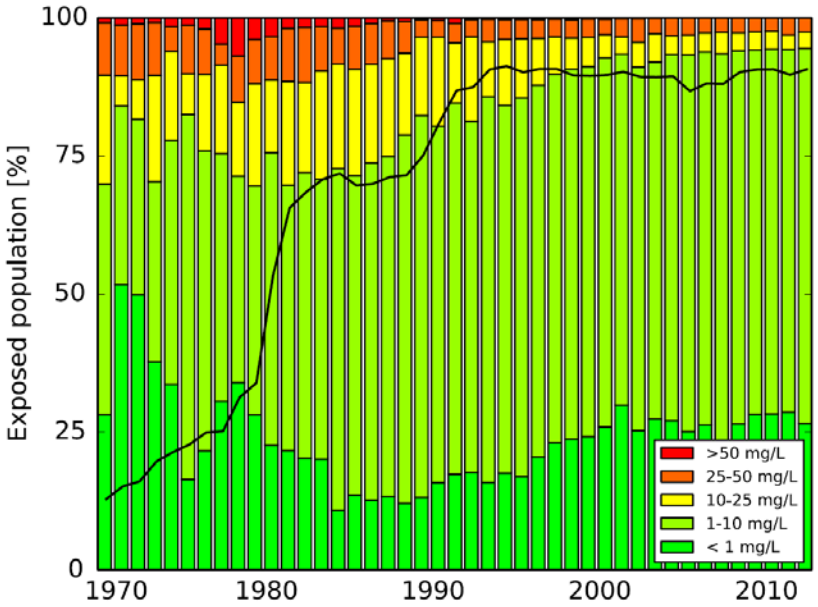
Nitrate in groundwater from abstractions wells

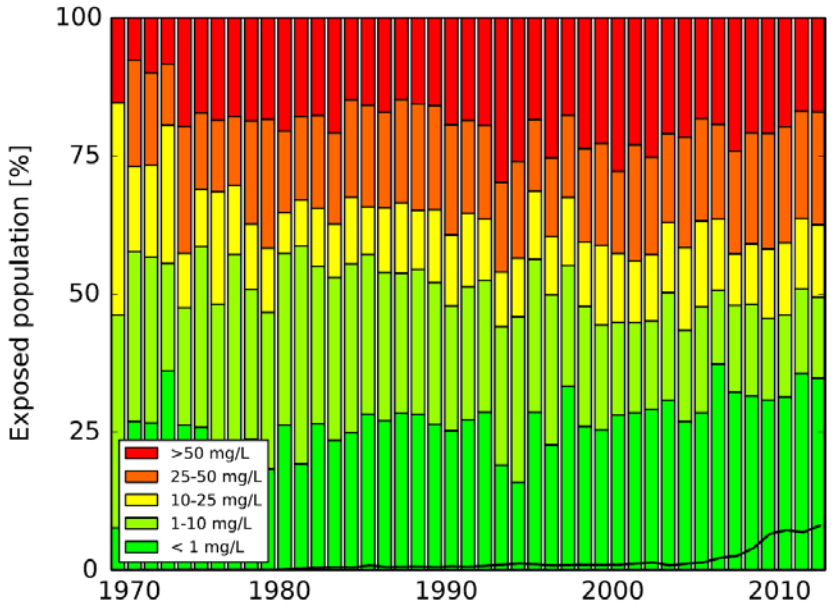


Exposed Danish population to nitrate in drinking water

PUBLIC WATERWORKS **PRIVATE WELLS**

Solid line is the percentage of classified consumers





J. Schullehner & B. Hansen, 2014, ERL: http://iopscience.iop.org/1748-9326/9/9/095001

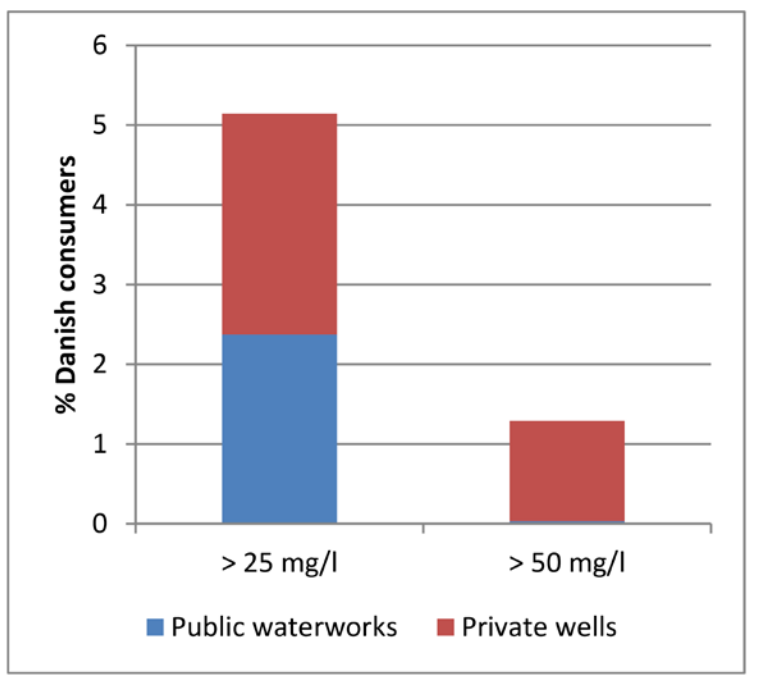
Exposed Danish population to nitrate in drinking water in 2012

Public waterworks:

- ≥ 10 households
- 2800 waterworks
- 5 mill. consumers

Private wells:

- < 10 households
- 70.000 wells
- 400.000 consumers



J. Schullehner & B. Hansen, 2014, ERL: http://iopscience.iop.org/1748-9326/9/9/095001

GEUS

Conclusions

- Overall nitrate trend reversal in Danish oxic groundwater in about 1980
- The youngest oxic groundwater has the most downward nitrate trends
- But 40 % of the oxic groundwater has > 50 mg nitrate/l
- But 9 % of the youngest groundwater has both > 50 mg nitrate/l and upward trends
- Nitrate concentrations in drinking water from public waterworks have been decreasing since 1970
- While the nitrate concentrations in drinking water from private wells are estimated to be increasing

Challenges

- Stricter regulation and more measures are necessary in order to meet the demand of WFD (to reverse trends and comply with standards)

- Future integration of N-targets for nature and environment including groundwater

- Does nitrate in drinking water affect human health?
  Ph.D. project in: dNmark research alliance http://www.dnmark.org

Publications

- Thorling, L., Brüsch, W, Hansen, B., Langtofte, C., Mielby, S., Troldborg, L. & Sørensen, B., 2013. Grundvandsovervågning 2013. Technical report, in Danish, GEUS 2013. http://www.geus.dk/DK/publications/groundwater_monitoring/Sider/1989_2012.aspx

- Hansen, B., Thorling, L., Dalgaard, T. & Erlandsen, M., 2011. Trend Reversal of Nitrate in Danish Groundwater – a Reflection of Agricultural Practices and Nitrogen Surpluses since 1950. Environmental Science & Technology, 45, 228-234. http://pubs.acs.org/doi/abs/10.1021/es102334u

- Hansen, B., Dalgaard, T., Thorling, L., Sørensen, B. & Erlandsen, M., 2012. Regional analysis of groundwater nitrate concentrations and trends in Denmark in regard to agricultural influence. Biogeosciences, 9, 3277-3286. http://www.biogeosciences.net/9/3277/2012/bg-9-3277-2012.html

- Schullehner & Hansen 2014, Nitrate exposure from drinking water in Denmark over the last 35 years. Environmental Research Letters: http://iopscience.iop.org/1748-9326/9/9/095001

- Dalgaard et al., 2014: Policies for agricultural nitrogen management – trends, challenges and prospects for improved efficiency in Denmark. Environmental Research Letters. In press.

Birgitte Hansen
bgh@geus.dk