Monitoring good water quality conditions: a comparative river and catchment analysis

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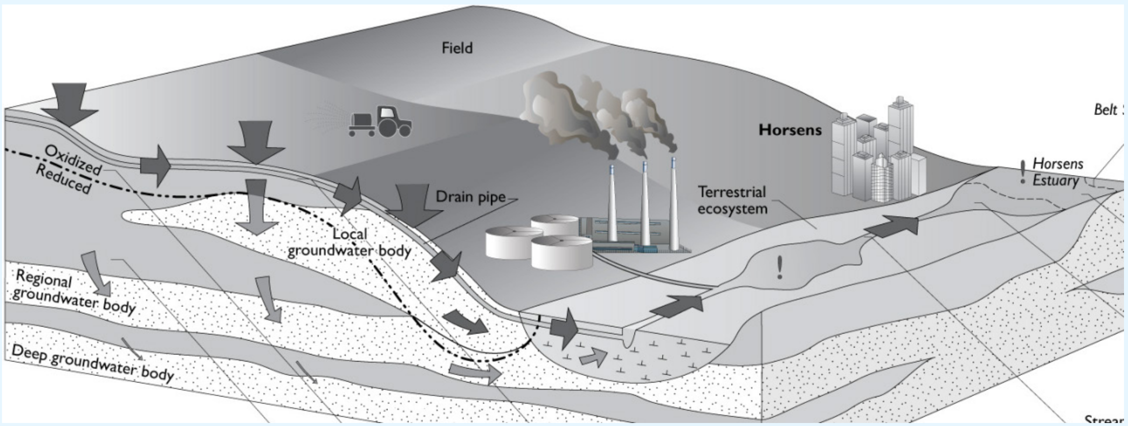
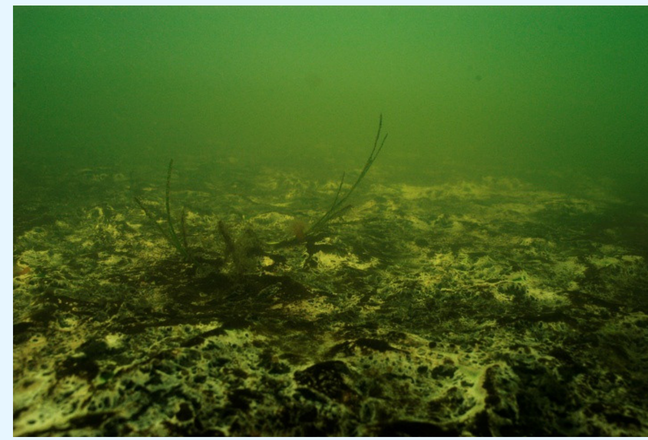
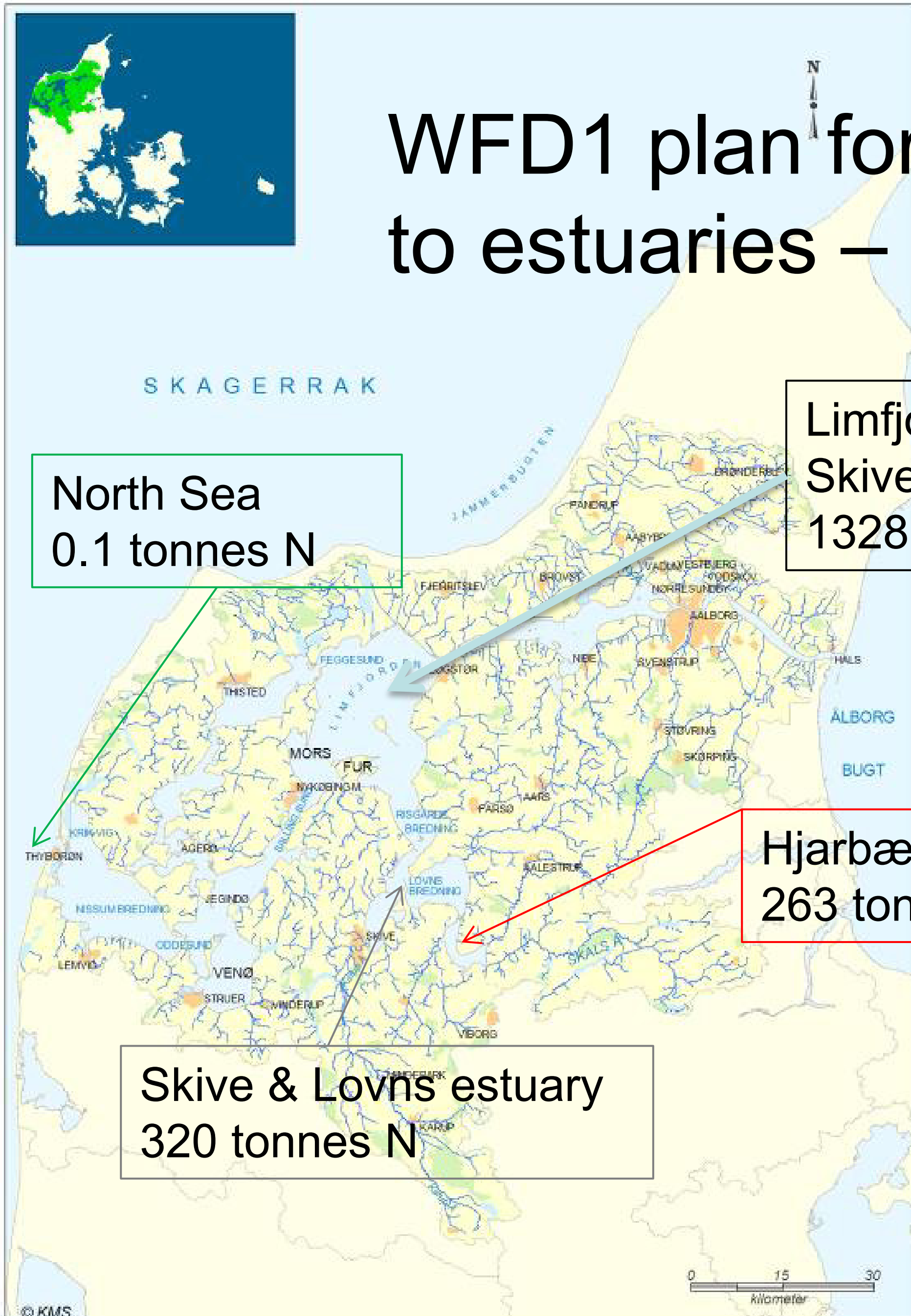
Introduction

Needs = to monitore pressures and water quality from catchment to catchment





WFD1 plan for nutrient reductions to estuaries – an example from DK



Very precise estimates for loading reductions – can such an effect be documented and how?

WFD1 plan for nutrient reductions to lakes – examples from Limfjordens catchment in Denmark

Again a very precise load reduction target is set !

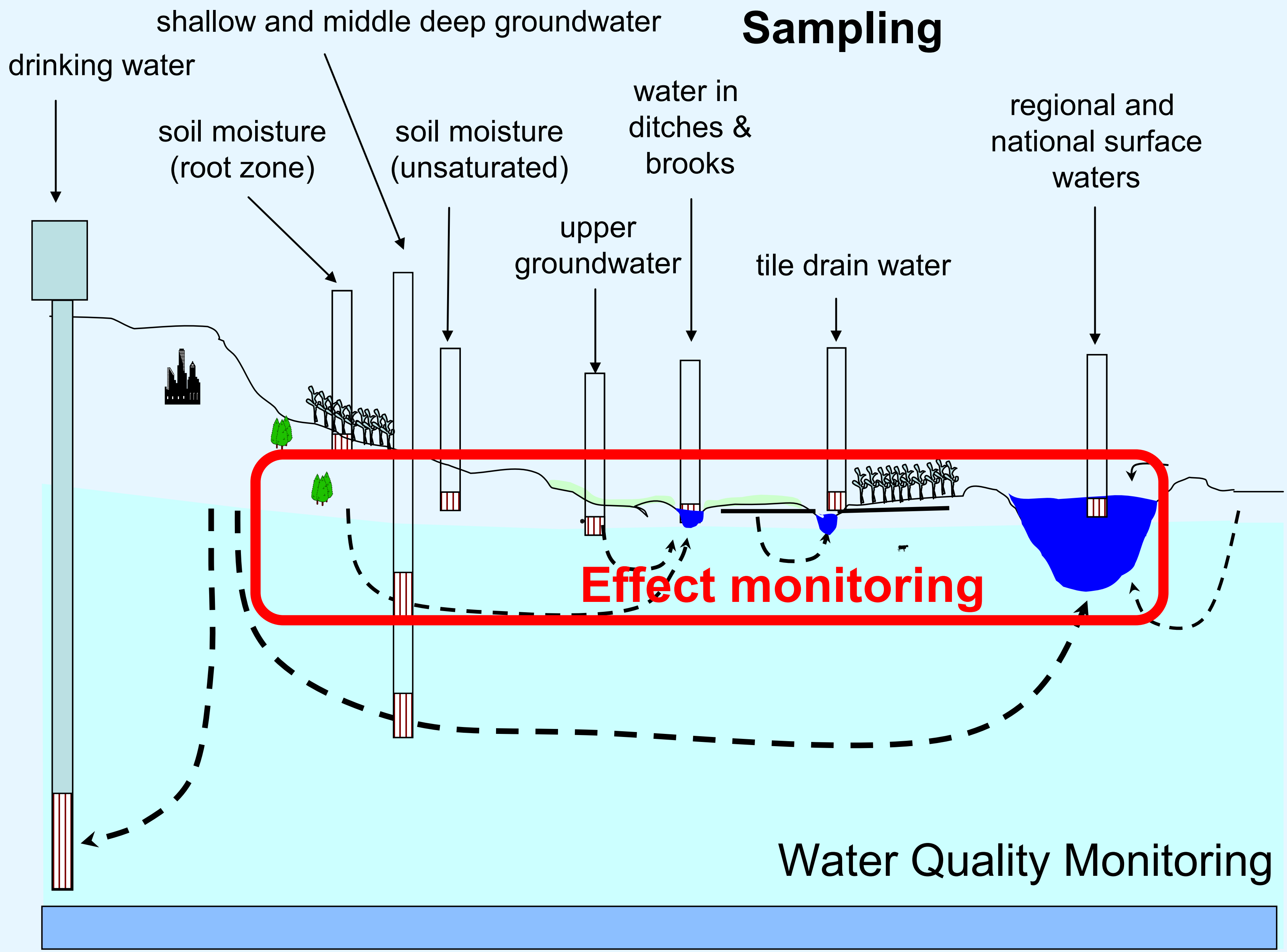
Lake name	Reduction in phosphorus loading during plan period I (2015)
Gjeller lake	1 kg P/yr
Hornum lake	16 kg P/yr
Suldrup lake	7 kg P/yr
Brokholm lake	382 kg P/yr
Flynder lake	1300 kg P/yr

influenced by its hydrogeology, land use and anthropogenic activities

The question is how, where and how often to monitore the water quality?

Monitoring of water quality

Sampling


shallow and middle deep groundwater
drinking water
soil moisture (root zone)
soil moisture (unsaturated)
water in ditches & brooks
regional and national surface waters
upper groundwater
tile drain water
Effect monitoring
Water Quality Monitoring

History of monitoring in Denmark

- 1970s to 1985 – at highest monthly sampling protocols
- 1987-1989: First intensive monitoring with automatic sampling in 2 years for two catchments – ca. 2100 samples per year in smaller catchment (11 km^2) and all water samples analysed for N-forms and four P fractions. Data used for a Monte Carlo assessment of uncertainties in load estimates and was baseline for guidance on sampling frequency and load estimation for the national monitoring programme launched in 1989 in Denmark.
- 1988: a mobile laboratory was bought in UK and tested in a small stream - testing failed mainly due to filtering problems and a high cost of technical assistance.

Continued

- 1989-1993: In situ meaurements of primary production in 5 agricultural streams
- Since then fortnightly sampling in streams draining smaller catchments (< 30 km2) and 18 times annually in streams draining larger catchments (> 30 km2).
- Due to high uncertainty in TP an intensive automatic sampling (weekly) time-proportional was launched in 1993-1997 and from 1998-2003 flow proportional (weekly basis) in 24 smaller catchments.
- Since 2003 only in 5 small catchments.

Data from intensive sampling

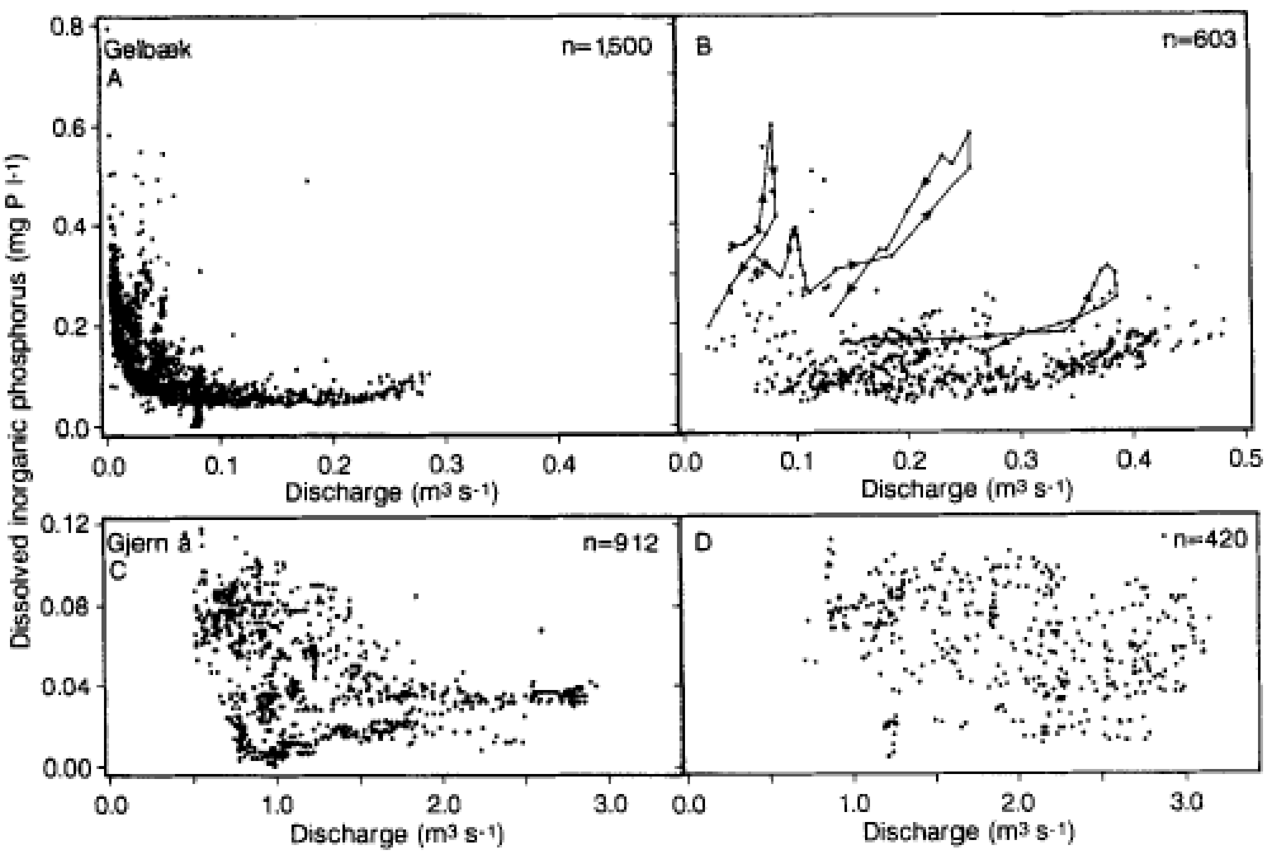


Figure 4. Relationship between measured concentration of dissolved inorganic phosphorus and discharge in the two test streams (Gelbæk: A and B; Gjern Å: C and D) during low-flow conditions (A and C) and storm-flow conditions (B and D). For the Gelbæk stream three examples of concentration loops during single storm events are shown (B)

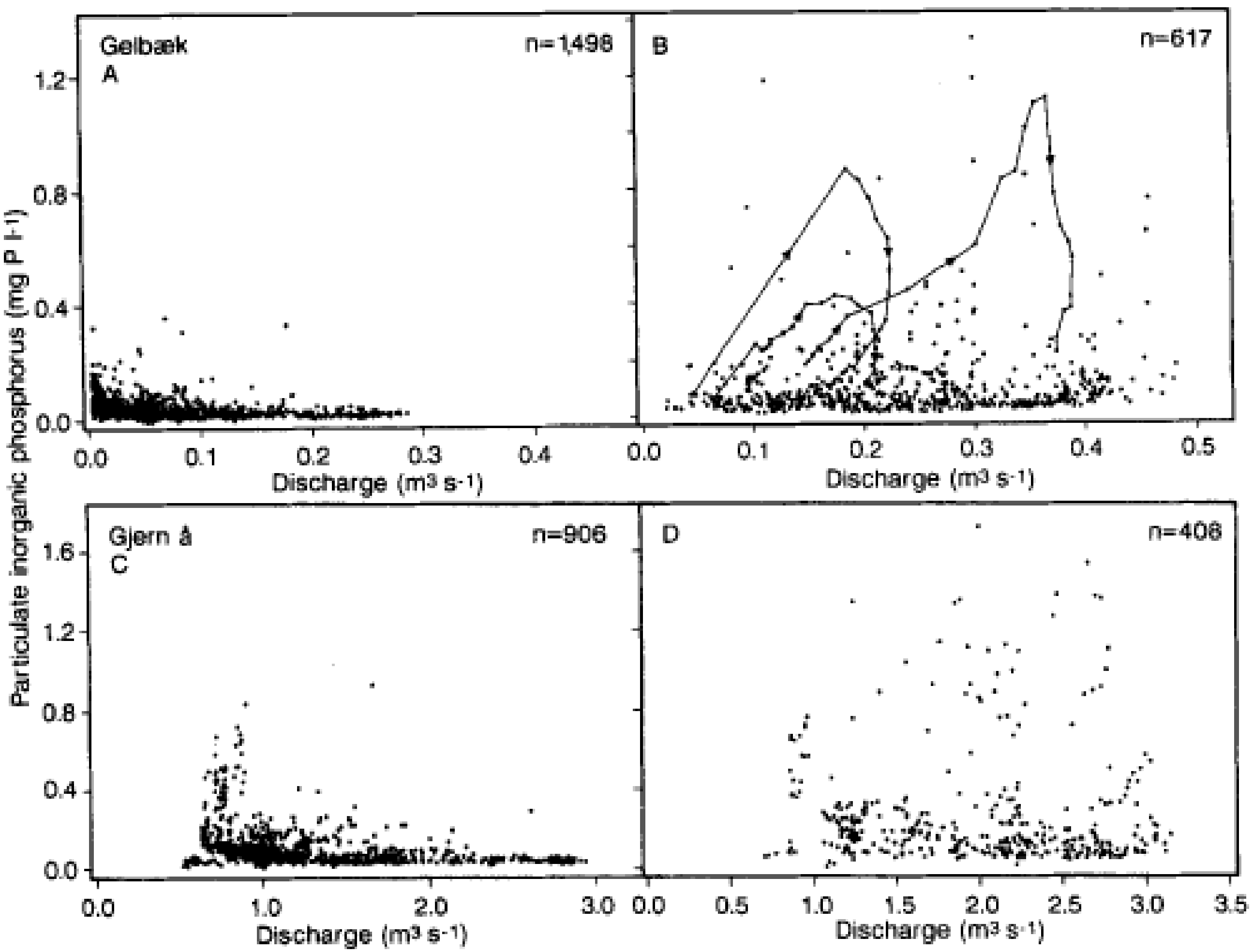


Figure 5. Relationship between measured concentration of particulate inorganic phosphorus and discharge in the two test streams (Gelbæk: A and B; Gjern Å: C and D) during low-flow conditions (A and C) and storm-flow conditions (B and D). For the Gelbæk stream three examples of concentration loops during single storm events are shown (B)

Three scales in river and catchment monitoring in Denmark

- Micro-catchment approach (5-15 km^2 since 1989-)

(5 agro-ecosystems with farmer surveys and 5x6 fields instrumented for monitoring soil water, groundwater, drainage water and stream water).

- Catchment approach (10-100 km^2 since 1989)

(150 catchments with stream monitoring classified into types after dominating nutrient source being either diffuse agricultural, diffuse natural or point sources).

- National approach (43,100 km^2 since 1989)

(Combined monitoring and modelling of water and nutrient loadings and sources to Danish coastal waters).

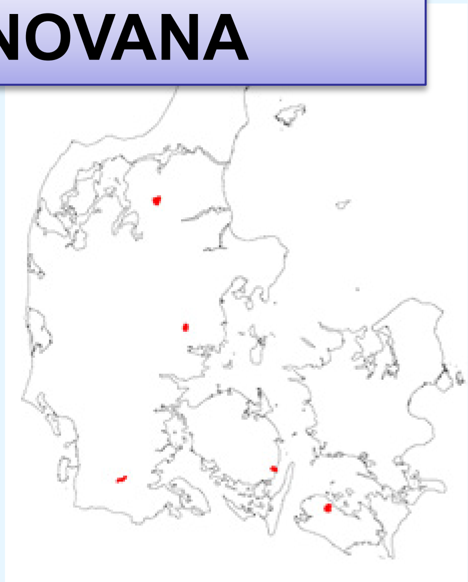
Agricultural catchment monitoring, NOVANA

25 years aniversary

5 catchments (5-15 km²)

Measuring programme:

- *root zone water, 1 m* — *(32 sites)*
- *drainage water* — *(7 sites)*
- *upper-groundwater, 1.5-5 m* — *es)*
- *streams* — *(5 sites)*



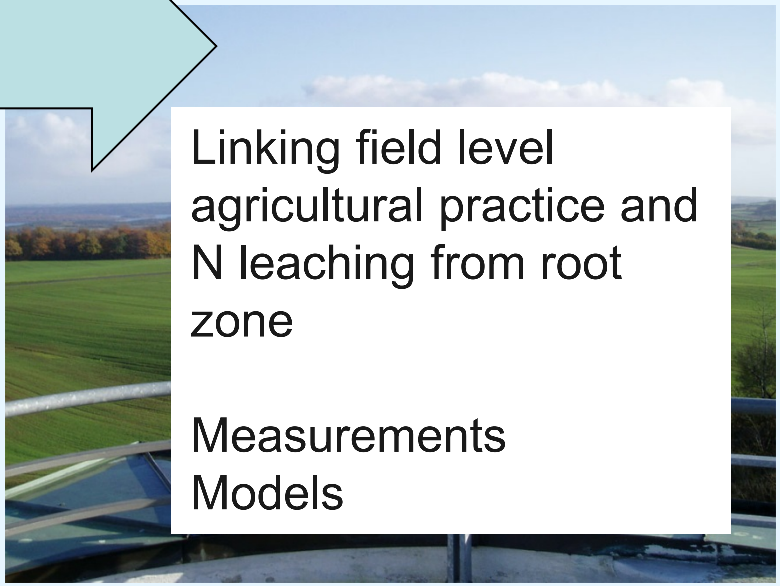
Annual interviews with farmers

crops

animals

Fertilizers

manure



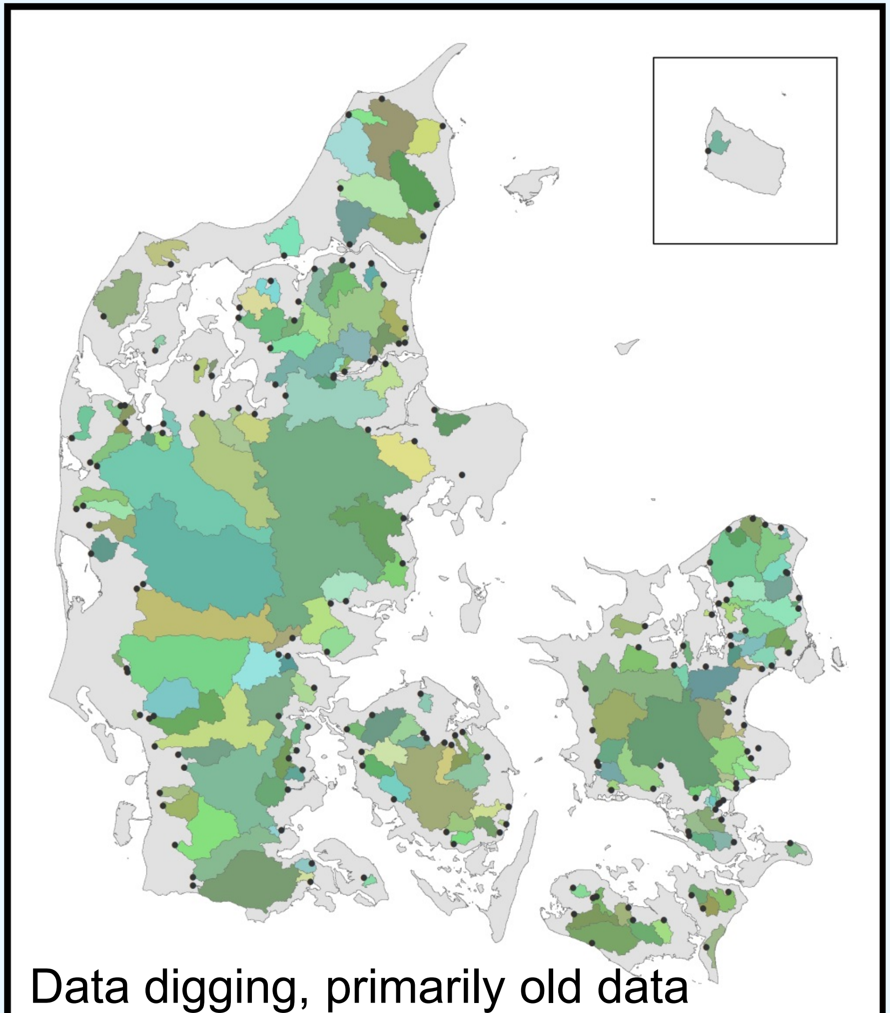
Linking field level agricultural practice and N leaching from root zone

Measurements
Models

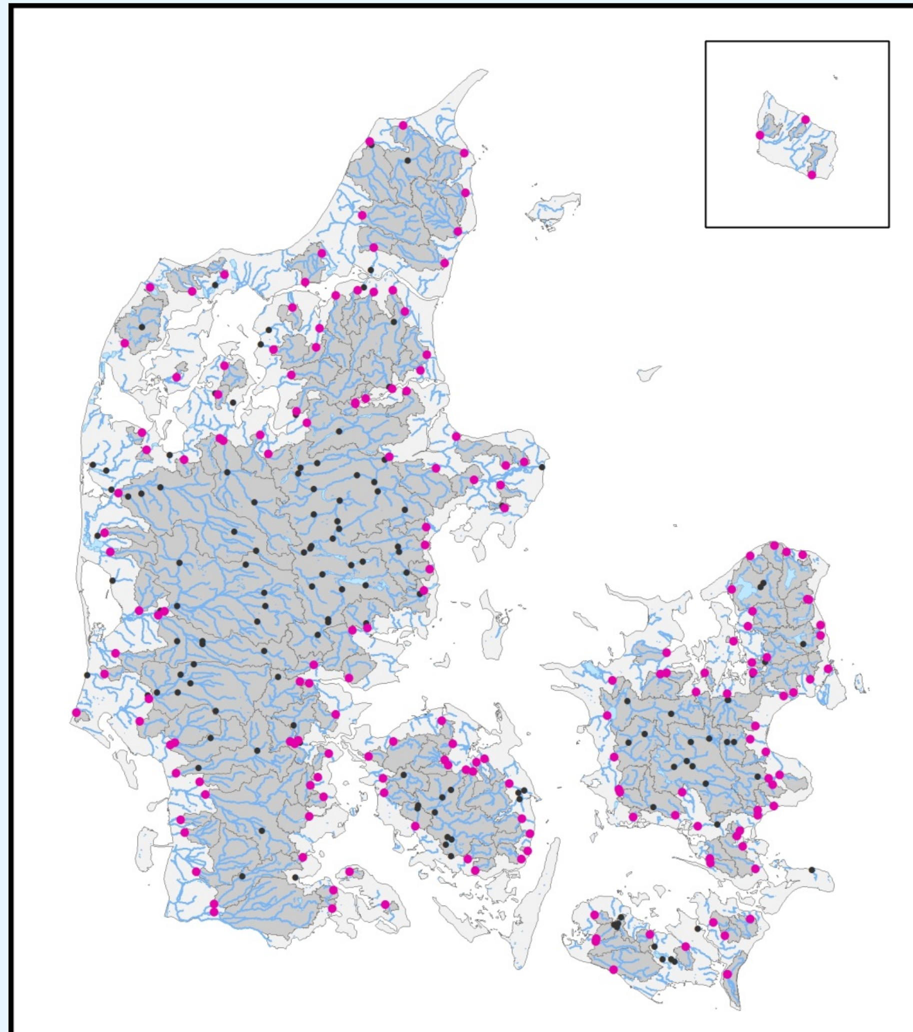
Nitrogen and Phosphorus in streams and the loading of coastal waters

1990…….

… increasing to 169 Gauging stations

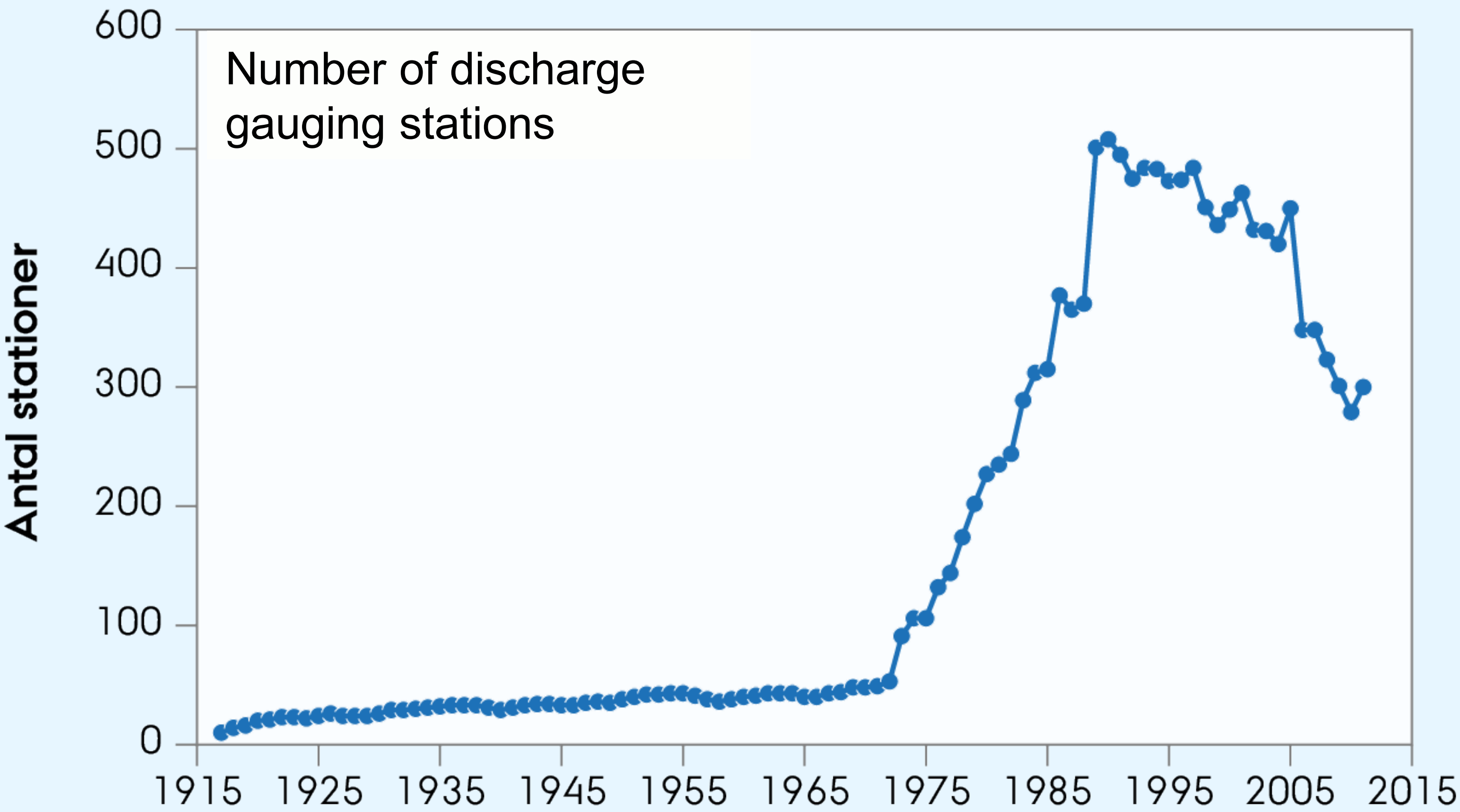


Gauging of fresh water discharge




Uncertainty in water quality monitoring

Huge reduction in monitoring activities during last 10 years in Denmark - what does it mean for uncertainties in loading calculations as ungauged areas increases?



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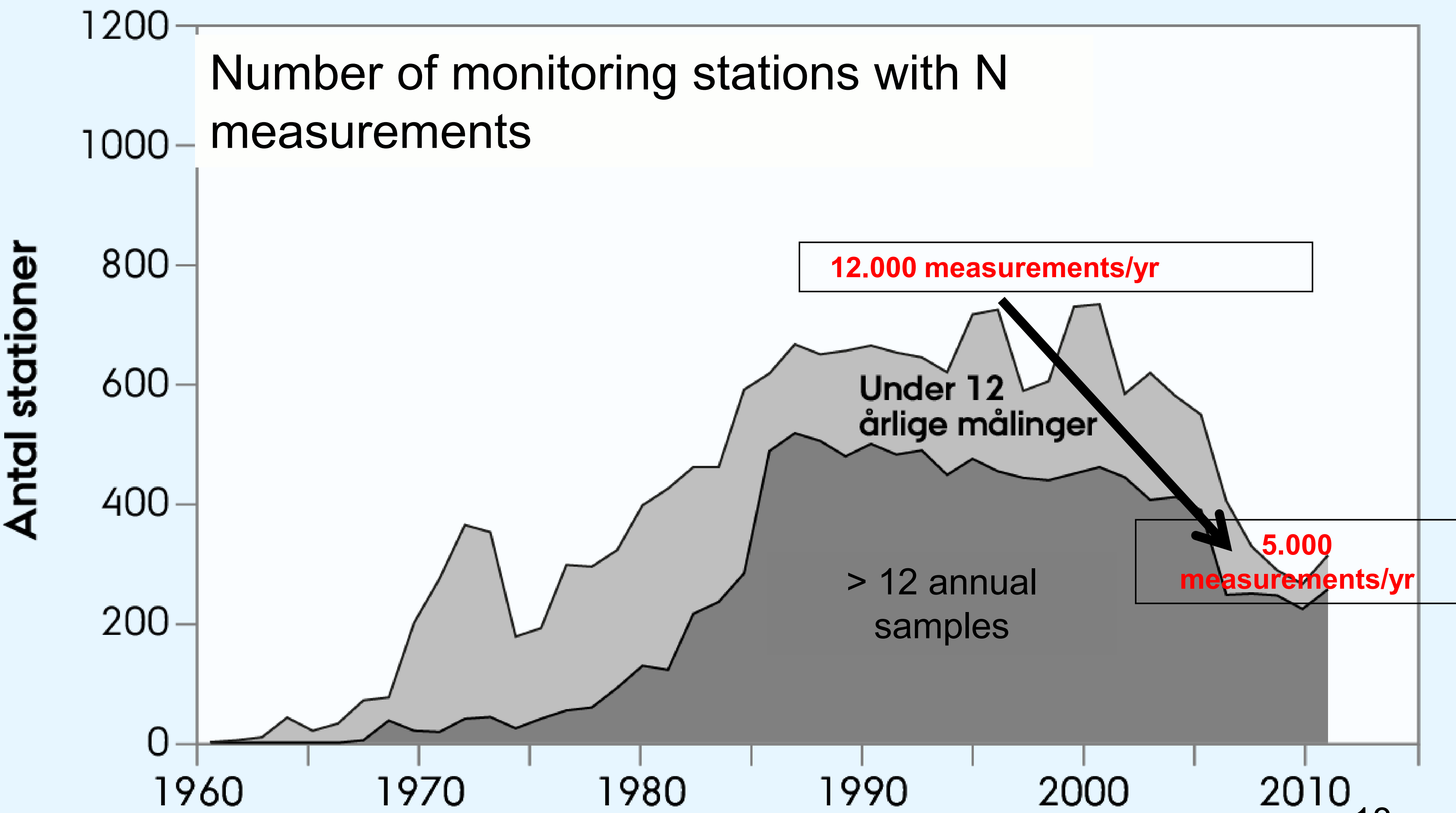
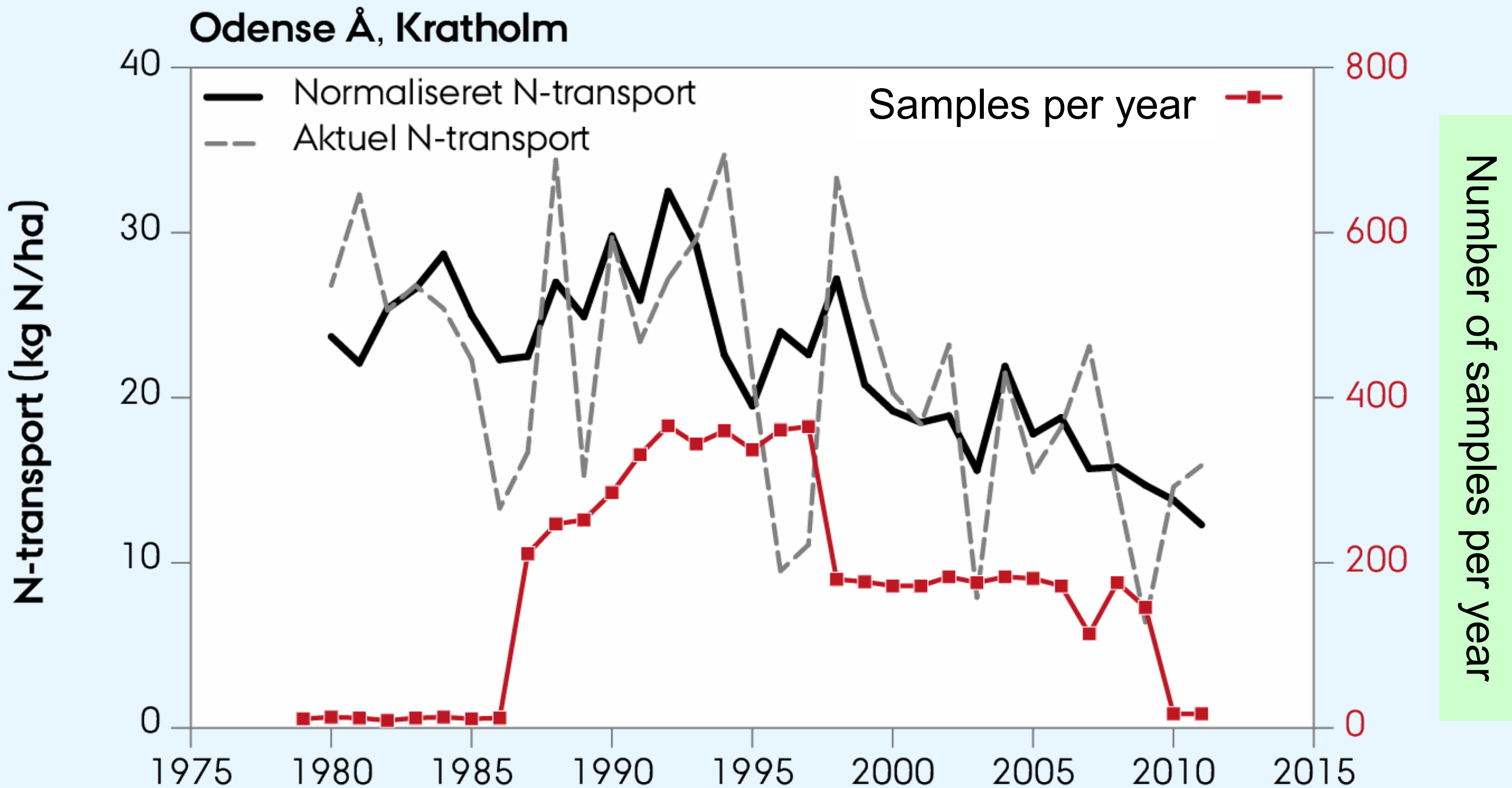


Large reduction in sampling effort in this specific river – how does it impact the accuracy of a trend estimate?



Scale dependency of Accuracy and Precision of annual total Nitrogen Loads

Sampling frequency	Small scale ($10\ km^2$) Gelbæk stream	Medium scale ($100\ km^2$) Case: Gjern stream	Larger scale ($500\ km^2$) Case: Odense river
Accuracy (Bias)			
Monthly	**-3.2%**	**-3.3%**	**-1.0%**
Fortnightly	**-1.0%**	**-0.7%**	**~0%**
Precision (StDev)			
Monthly	**3.0%**	**4.0%**	**2%**
Fortnightly	**1.0%**	**1.5%**	**<<1%**

Kronvang et al., 1996: Hydrol. Proc. 10: 1483-1501

Scale dependency of Accuracy and Precision of Annual total phosphorus Loads

Sampling frequency	**Small scale (10 km^2) Gelbæk stream**	**Medium scale (100 km^2) Case: Gjern stream**	**Larger scale (500 km^2) Case: Odense river**
Accuracy (Bias)			
Monthly	**-18%**	**-6.1%**	**-3.0%**
Fortnightly	**-16%**	**-4.8%**	**-2.0%**
Precision (StDev)			
Monthly	**22%**	**16%**	**12%**
Fortnightly	**12%**	**9.3%**	**6.7%**

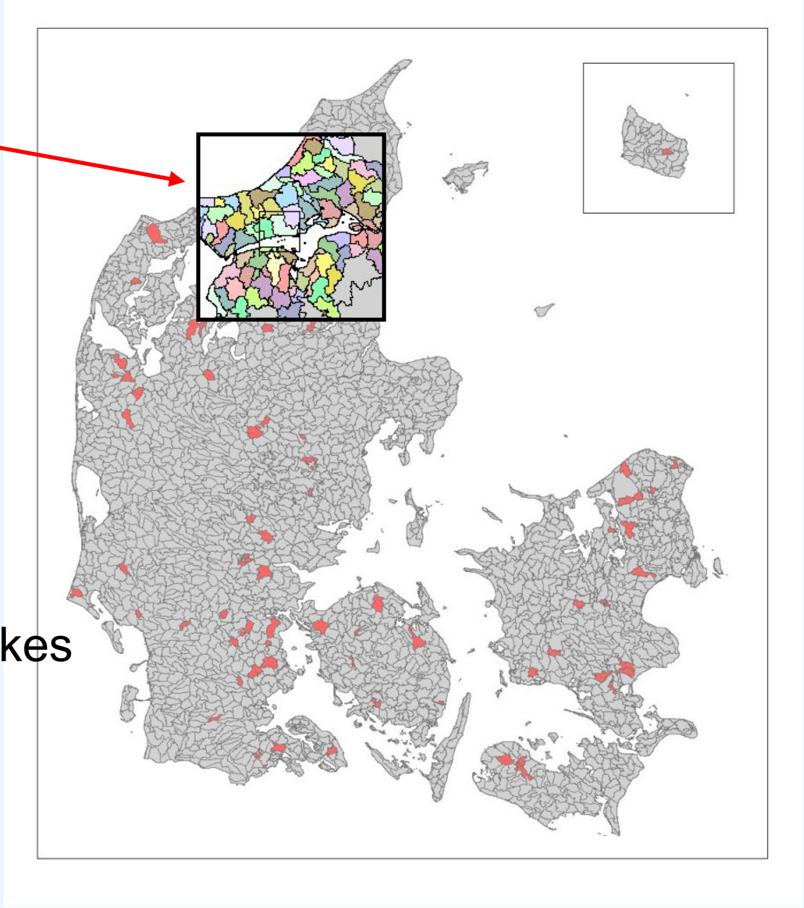
Kronvang et al., 1996: Hydrol. Proc. 10: 1483-1501

Ungauged areas

Denmark is divided into ca. 3000 Hydrological Units (10-20 km^2) covering the total land area (43.000 km^2)

.. in each HU Modelling monthly

- freshwater runoff
- **gross outlet** of N & P to surface waters
- **sinks and reduction** of N & P in surface waters
  - lakes, lake specific models for large lakes
  - in-stream reduction
  - inundated areas
  - restored wetlands

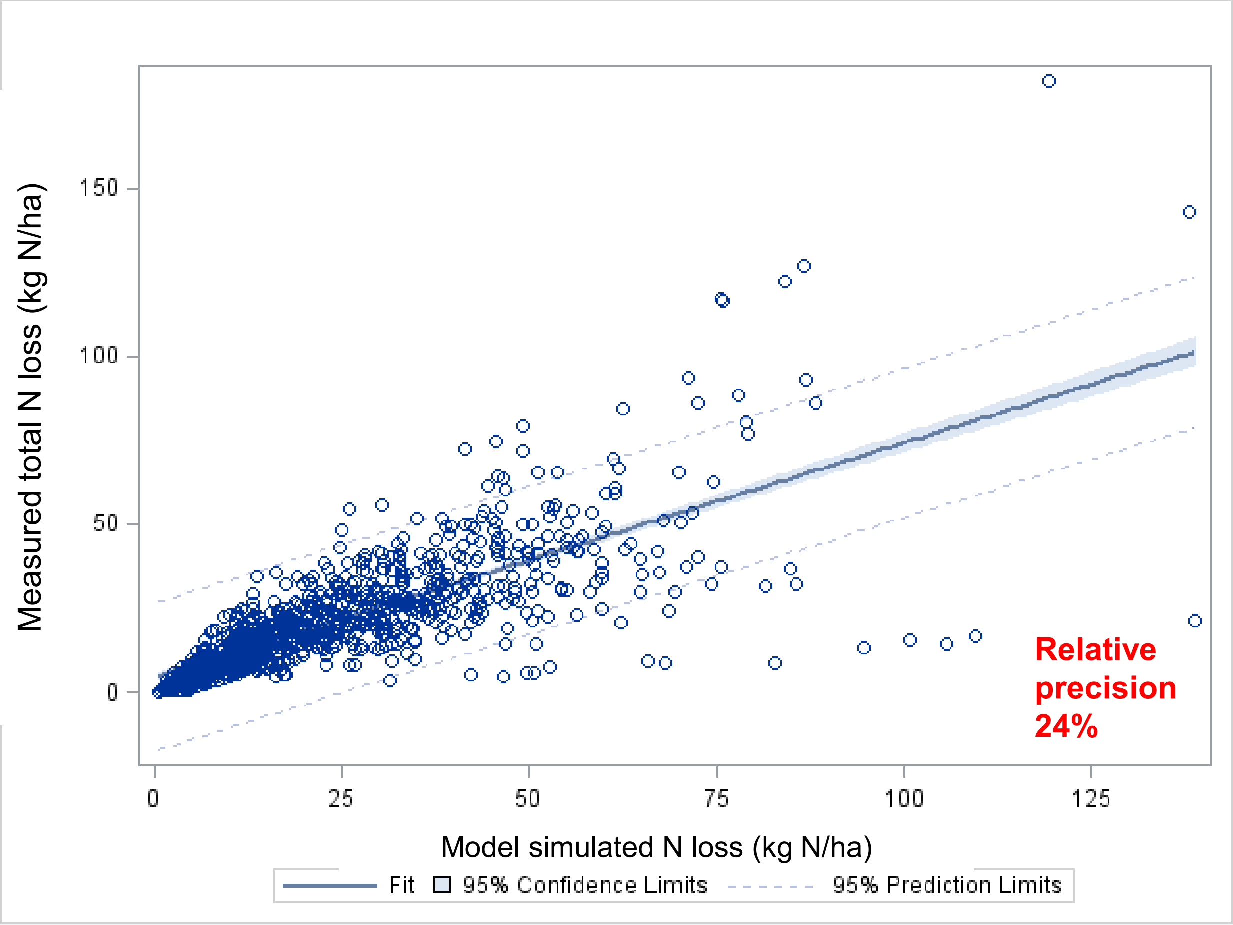


Aggregate to larger catchment to gauging stations (validation and bias correction) and to specific estuaries including ungauged subcatchments:

The DK-QNP model (Windolf et 2011, Journal of Environmental Monitoring)

Model predicted against measured total N loadings. Model is developed on data from ca. 80 catchments with dominantly diffuse sources (1989-2005).

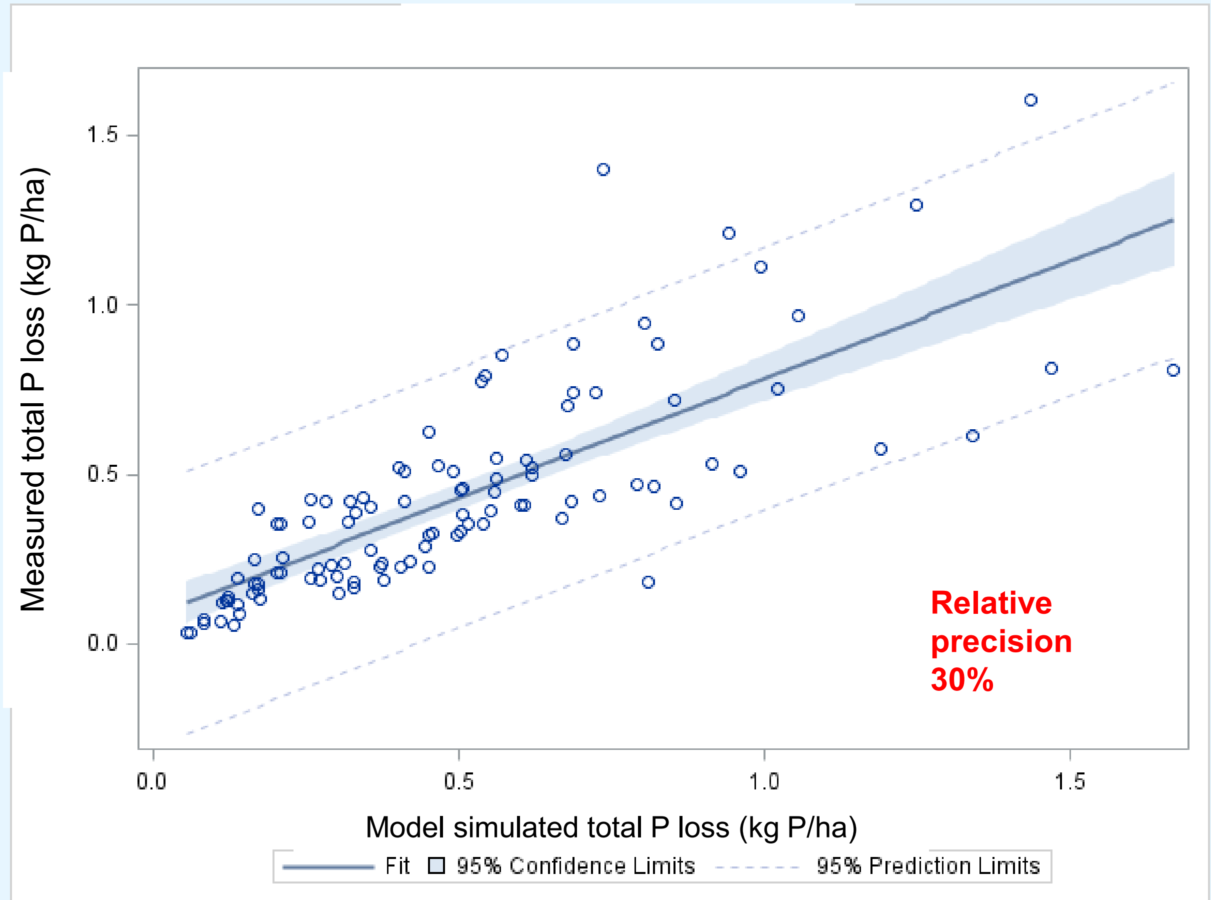
Model is applied in the Danish DK-QNP model for ungauged catchments (ID25)



Model predicted against measured total P loadings.

Model is developed on data from 24 intensively monitored dominantly agricultural catchment – 1993-2002.

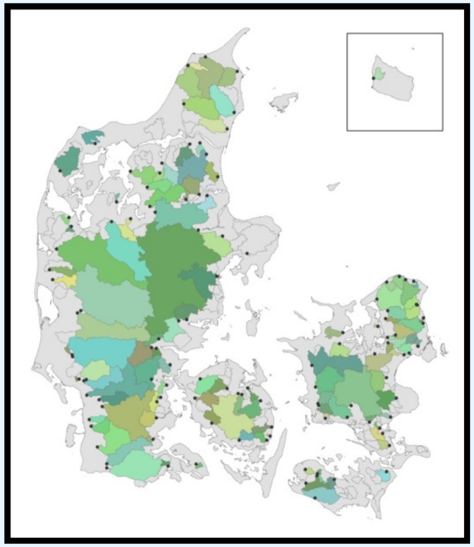
Model is applied in the Danish DK-QNP model for ungauged catchments (ID25)



Uncertainty: Example national scale – 50% ungauged

- Annual total nitrogen loading:
- Bias: -2.0%
- Precision: 0.5%

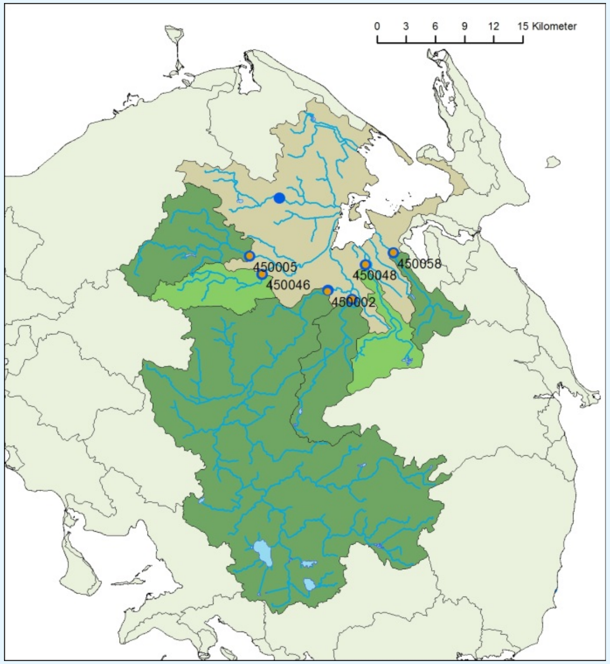
- Annual total phosphorus loading:
- Bias: -3.0%
- Precision: 1.6%



Uncertainty: Example regional scale (Catchment area:1000 km^2) – ungauged 50%

- Annual total nitrogen loading:
- Bias: -3.0%
- Precision: 2.7%

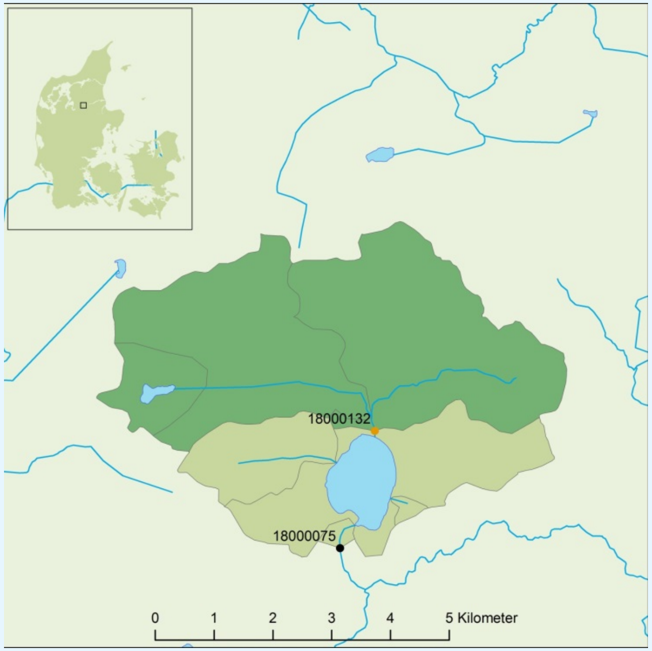
- Annual total phosphorus loading:
- Bias: -6.0%
- Precision: 6.1%



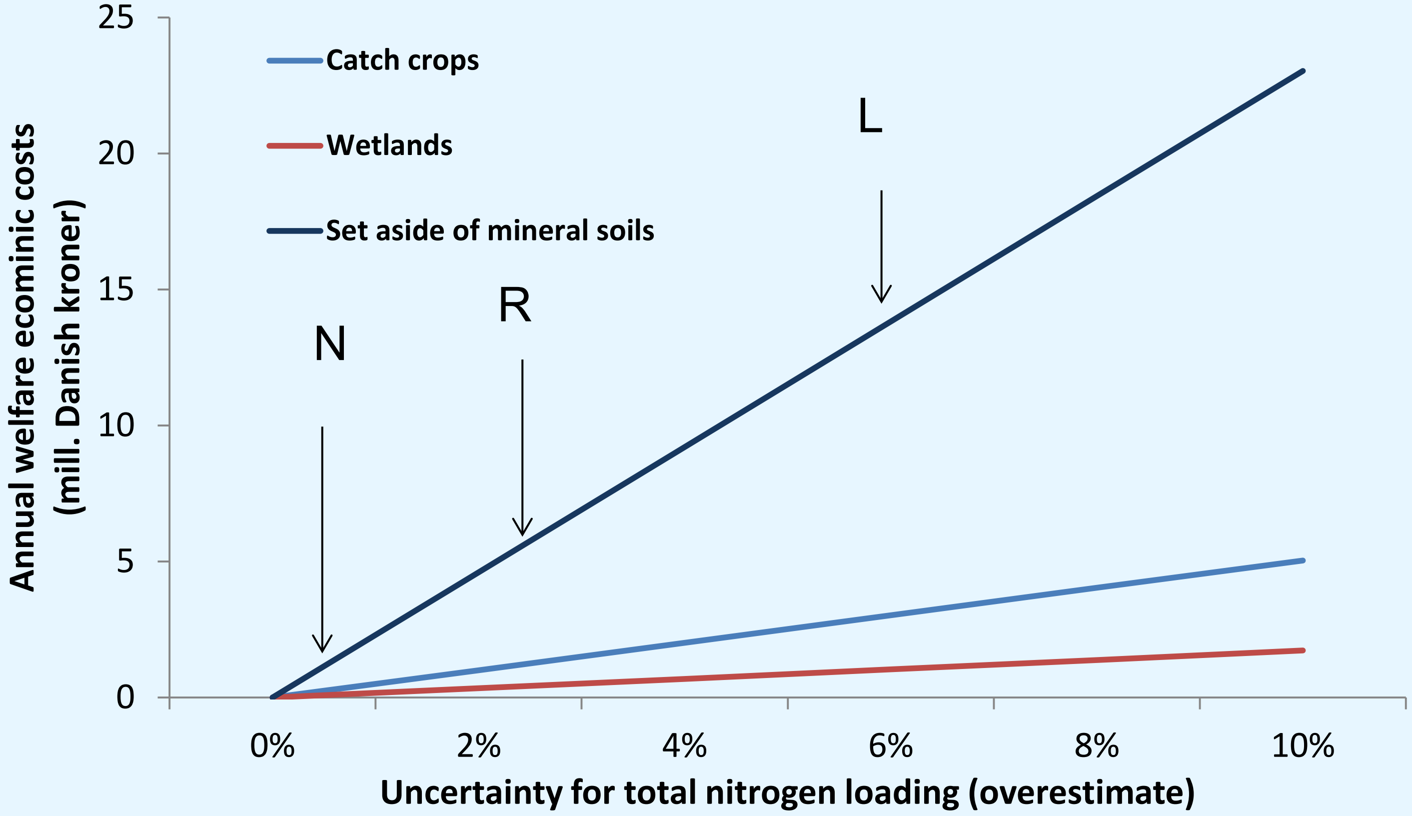
Uncertainty: Example local scale (Catchment area: 100 km^2) – ungauged 50%

› Annual total nitrogen loading:
› Bias: -3.0%
› Precision: 6.1%

› Annual total phosphorus loading:
› Bias: -12.0%
› Precision: 12.5%

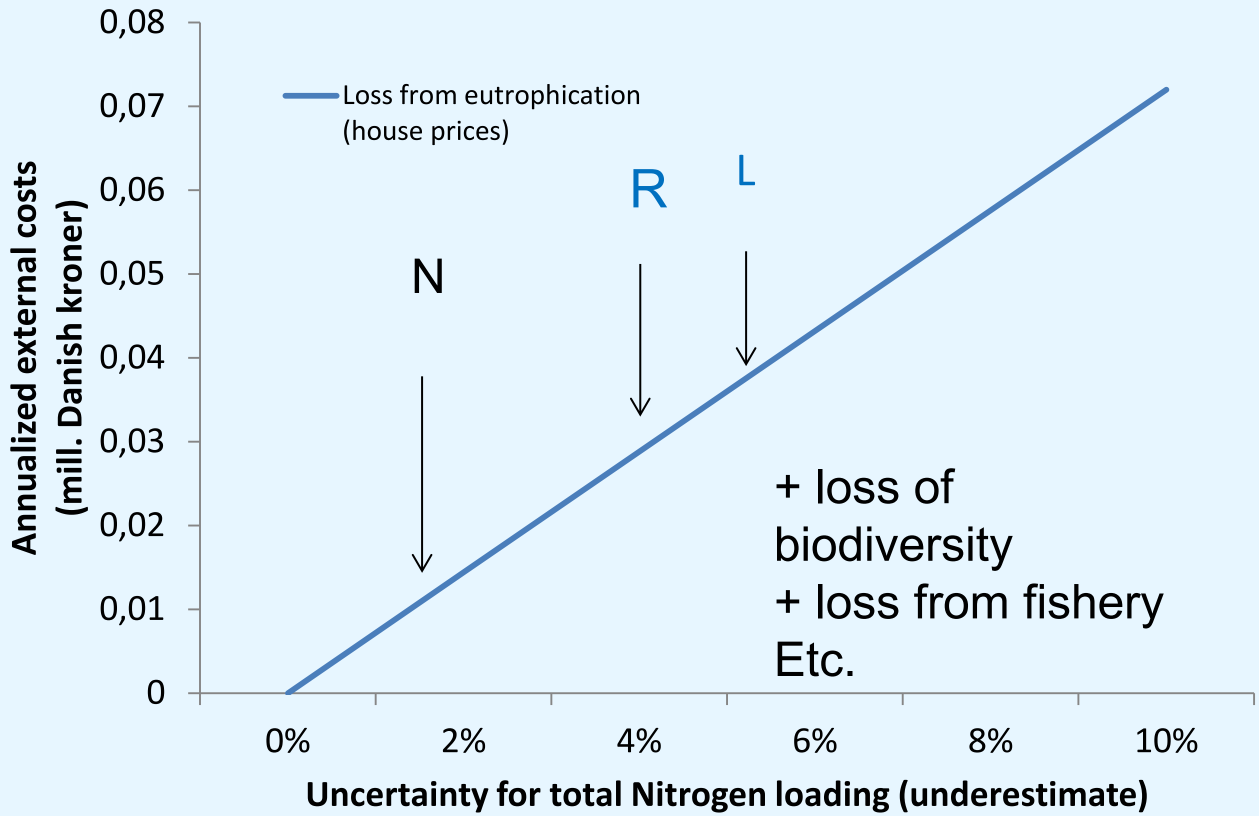


The costs of over implementation of mitigation measures due to overestimation of total N-loadings to estuaries



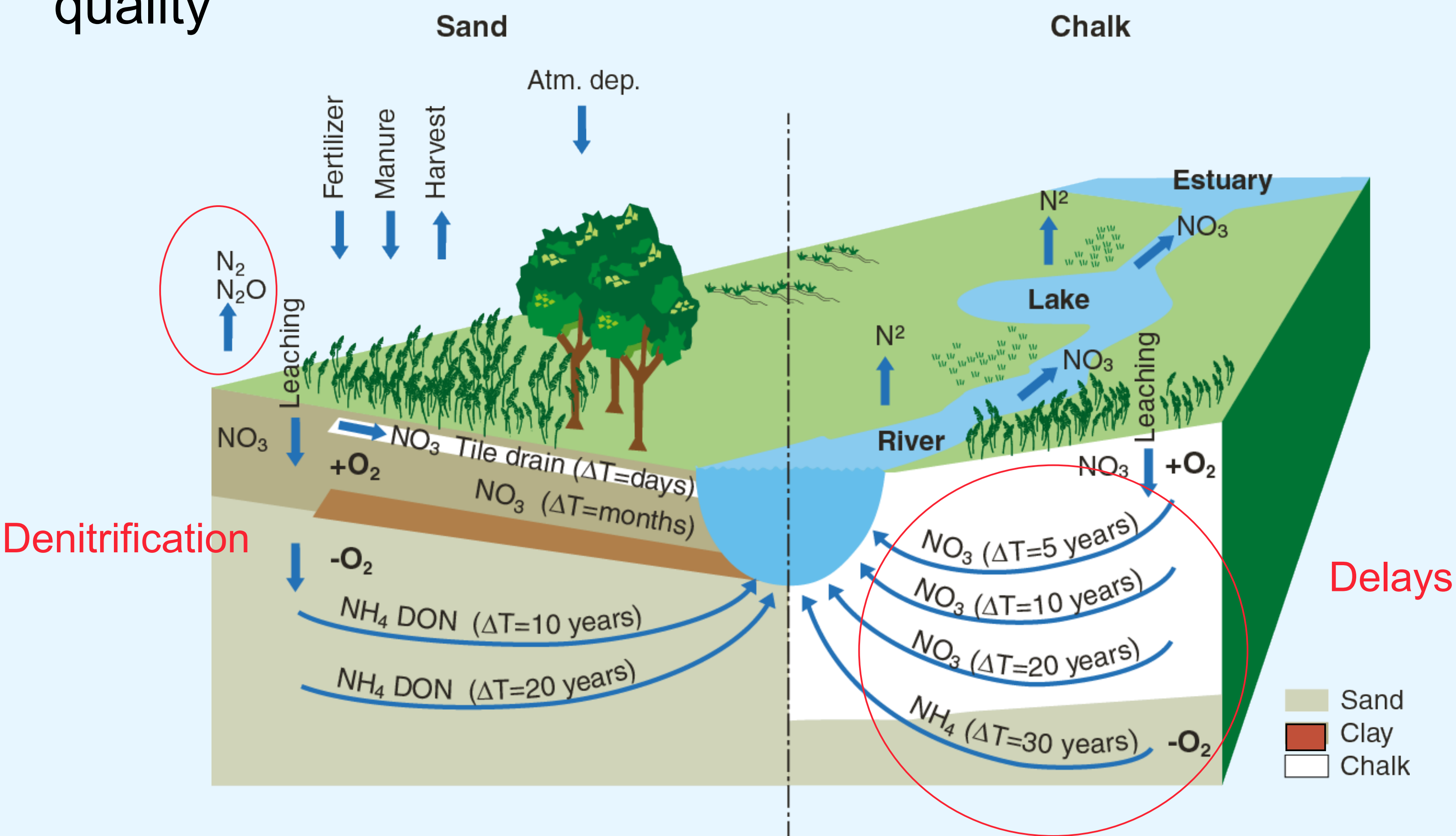
Schoue et al., 2007 NERI report No. 625.

Costs of under implementation of mitigation measures due to overestimation of N-loadings to estuaries

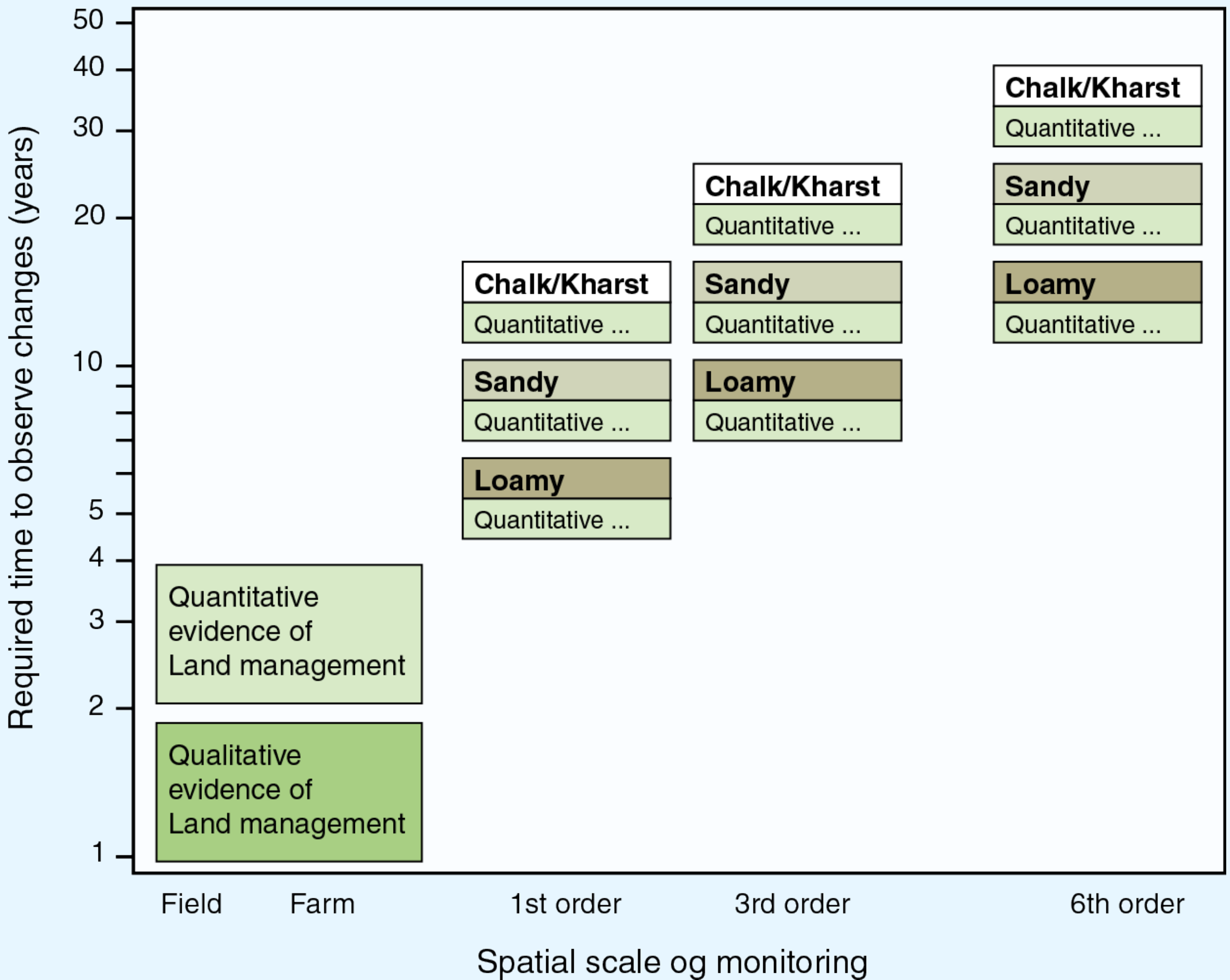


Andersen et al., 2011 International Review of Environmental and Resource Economics, 2011, 5: 1–46

Hydrological and biogeochemical processes in catchments influences nitrogen cycling (removal and inertia) – and also how large and when we expect to see an effect on water quality

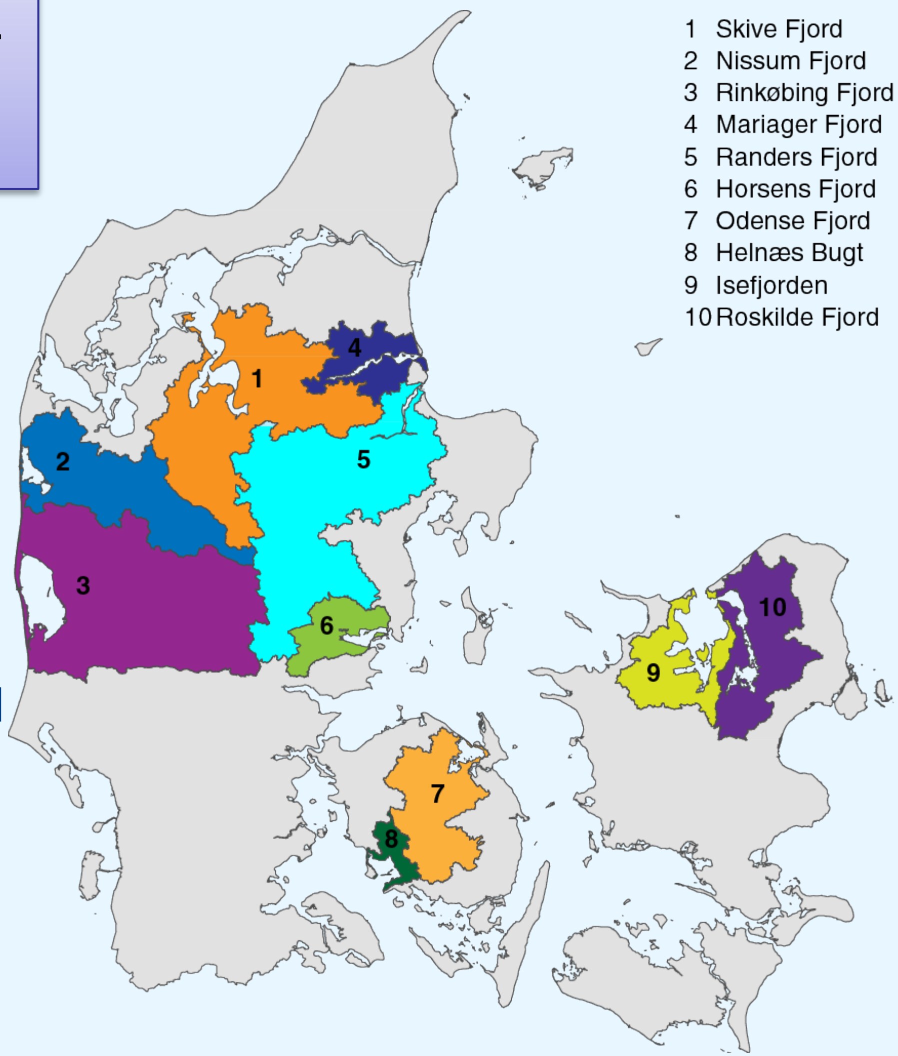


So, when can we expect to observe reductions in different water bodies as an outcome of NAP's ?

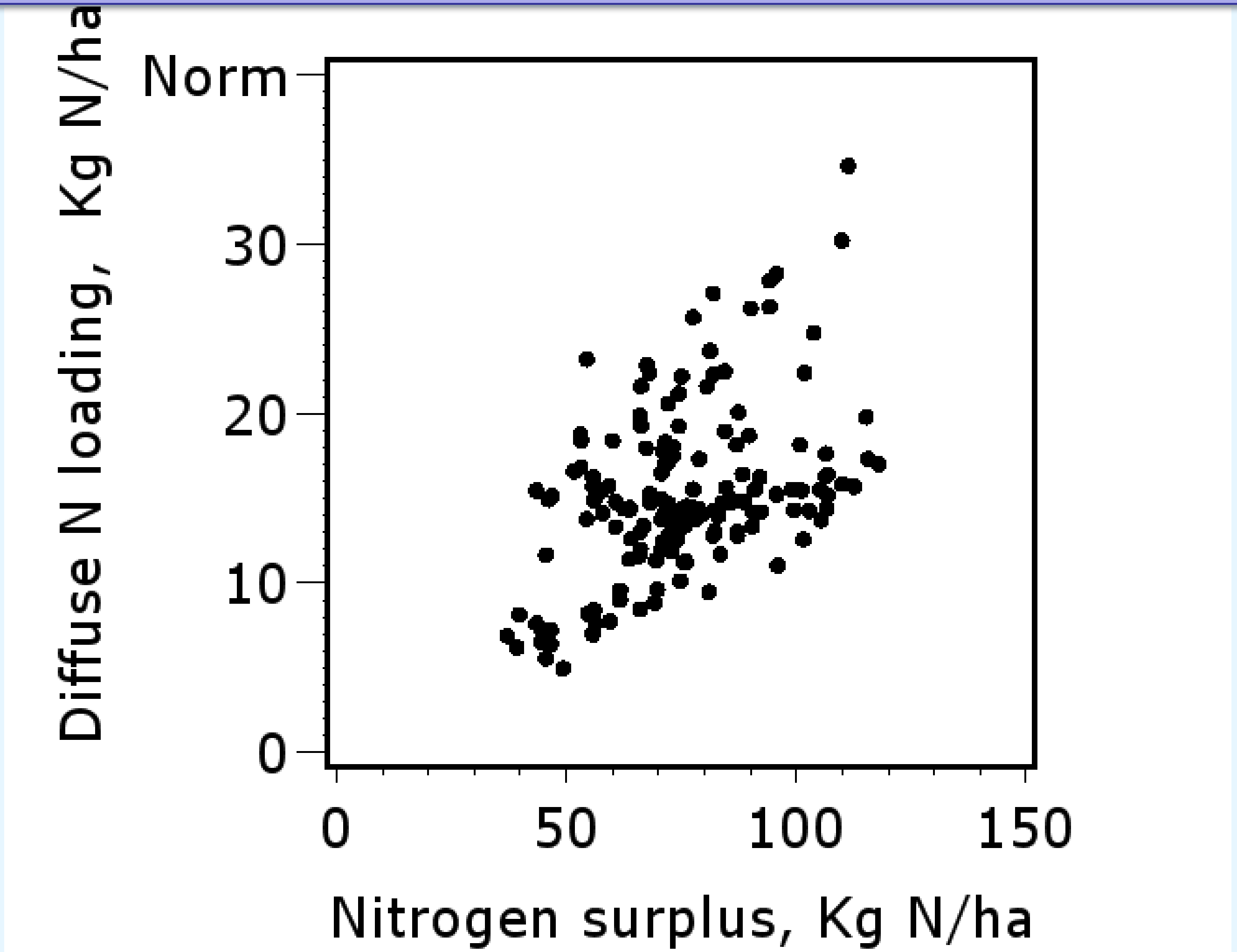


An evample:
Examining 10 Danish linked catchments and estuaries

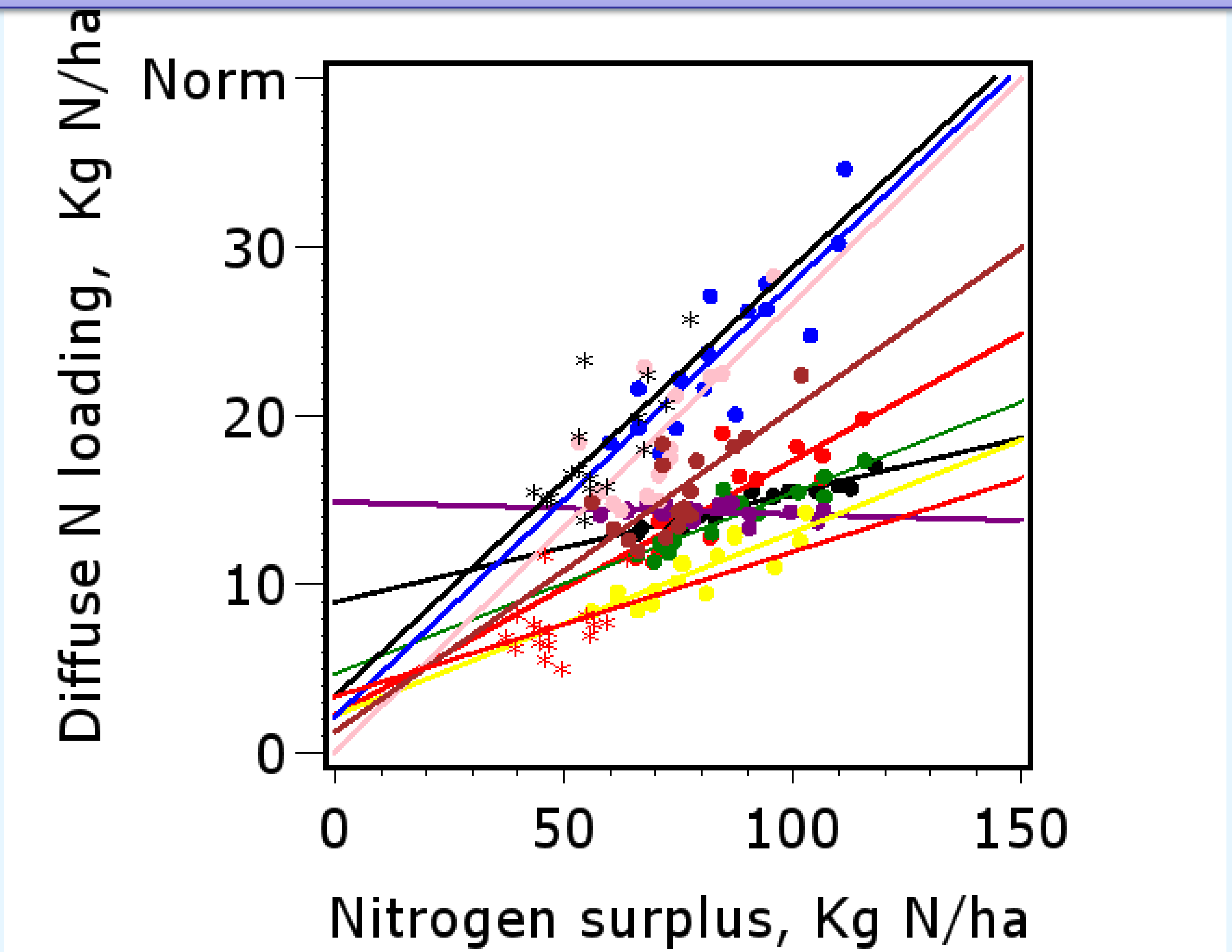
- Monitoring programme 1990-…
- Freshwater runoff
- N- loading
- N- sources and sinks
- Mitigation measures reducing N pressure
- Results achieved…
- Cost’s



Annual N surplus and annual N loading from diffuse sources (normalised) from 10 catchment



Annual N surplus and annual N loading from diffuse sources (normalized) from 10 catchment catchment specific relations



Catchment specific relations:

r^2 = 0.66

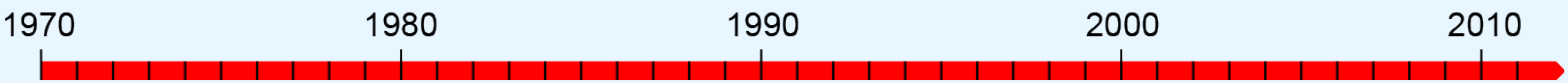
(mean for n=9)

Nitrogen fluxes, mean values 2005-2009,

10 estuary catchments

Nitrogen surplus ……………………….(index=100)	Min	Mean	Max
Exported to estuary waters	15%	21%	29%

Management of nutrients in Denmark



Action Plans in Denmark

Mid-1970s: Regional Action Plans

- Organic matter and nutrients from Urban WWTP's

1987 National Action Plan I

- 80% P reduction from UWWTP's
- 50% N reduction from agriculture and point sources
- 9 month slurry storage capacity

1991 Action Plan for Sustainable Agriculture

- Ban on slurry spreading in winter (harvest to 1st February)
- Obligatory fertilizer budgets

Strict national rules, negotiated and with a consensus between agricultural and environmental ministry

1998 National Action Plan II

- Subsidies to establish 16,000 ha of wetlands
- Livestock density of maximum 1.7 Livestock Units
- Plant available N to crops 10% below economic optimum

2004 National Action Plan III

- 50% reduction of P surplus in agriculture
- 13% further reduction of N from agriculture
- 10 m wide buffer strips along all watercourses and lakes (> 10 ha) (voluntary)

2011 Green Growth/WFD River Basin Management Plans

- Subsidies to establish N-wetlands
- Subsidies to establish P-wetlands
- Subsidies to establish 10 m buffer zones along all watercourses and lakes (> 10 ha) (compulsory)
- Demand for more catch crops in catchments to vulnerable estuaries (10-14%)

Department of Bioscience
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NITROGEN

..NATIONAL FIGURES FROM MONITORING TO PROVE THAT MANAGEMENT HAS WORKED

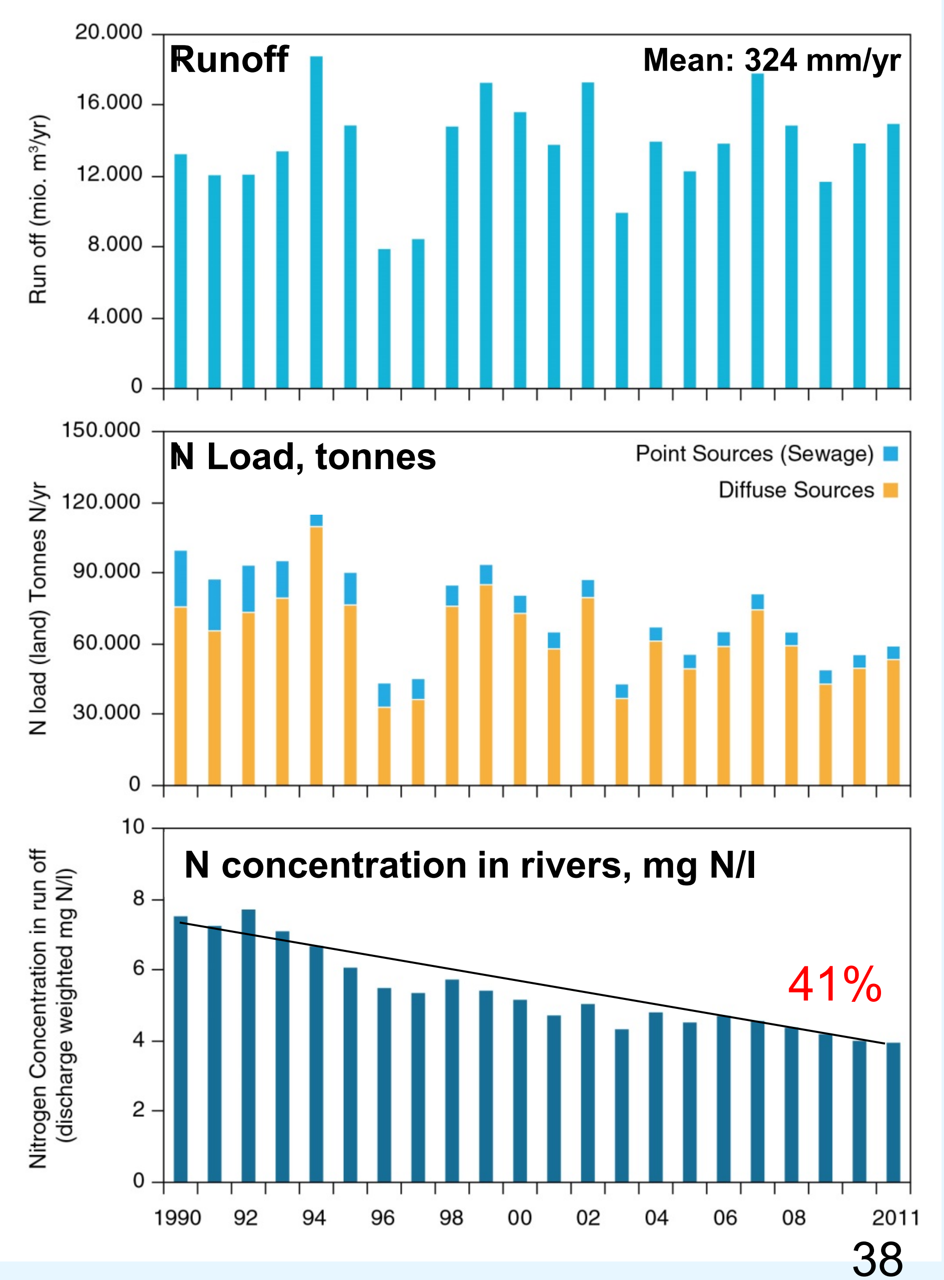
INTER-ANNUAL VARIATION IN NITROGEN LOAD FROM DIFFUSE SOURCES

MARKED DECREASE IN LOAD AND IN NITROGEN CONCENTRATION IN RIVERS

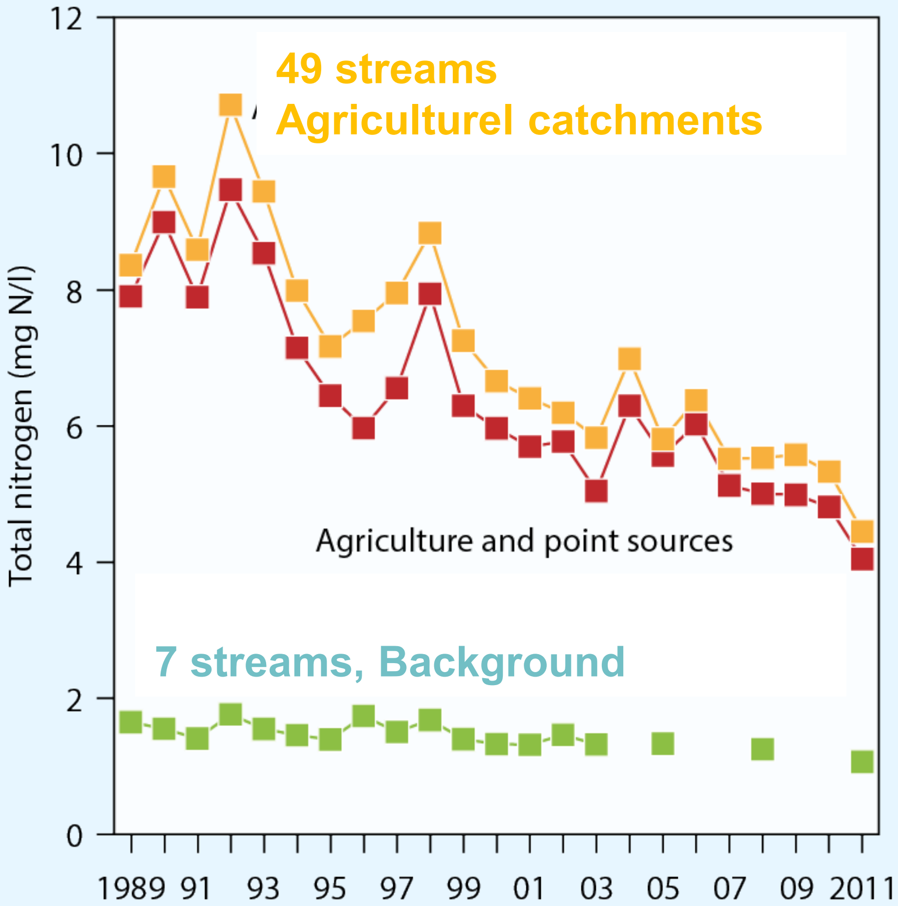
DUE TO:

BETTER SEWAGE TREATMENT

REDUCED NO3 EMMISSIONS FROM FARMED LAND



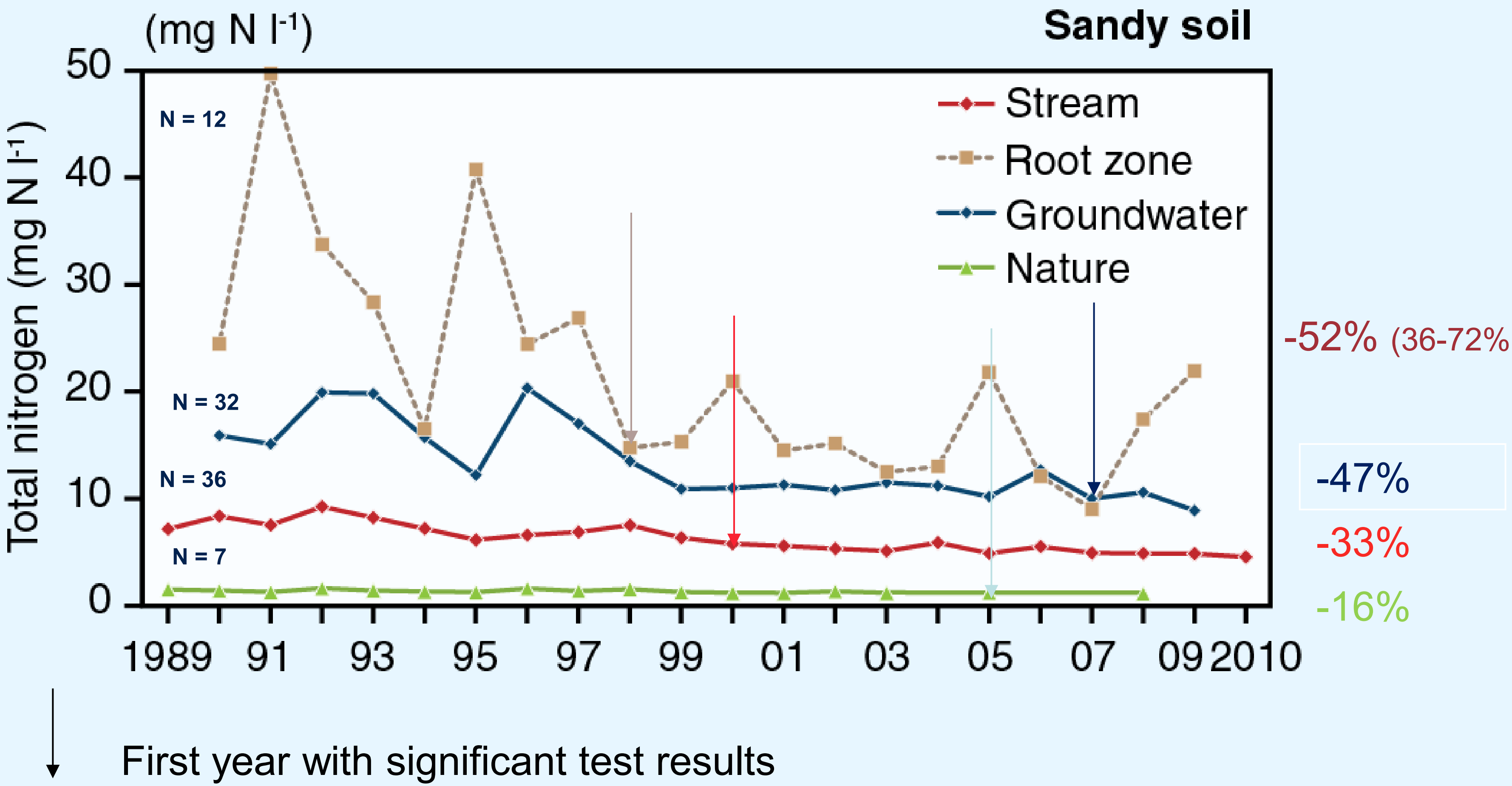
Trends in Nitrogen concentrations in 3 different Danish catchment pressure types



44-48% Reduction

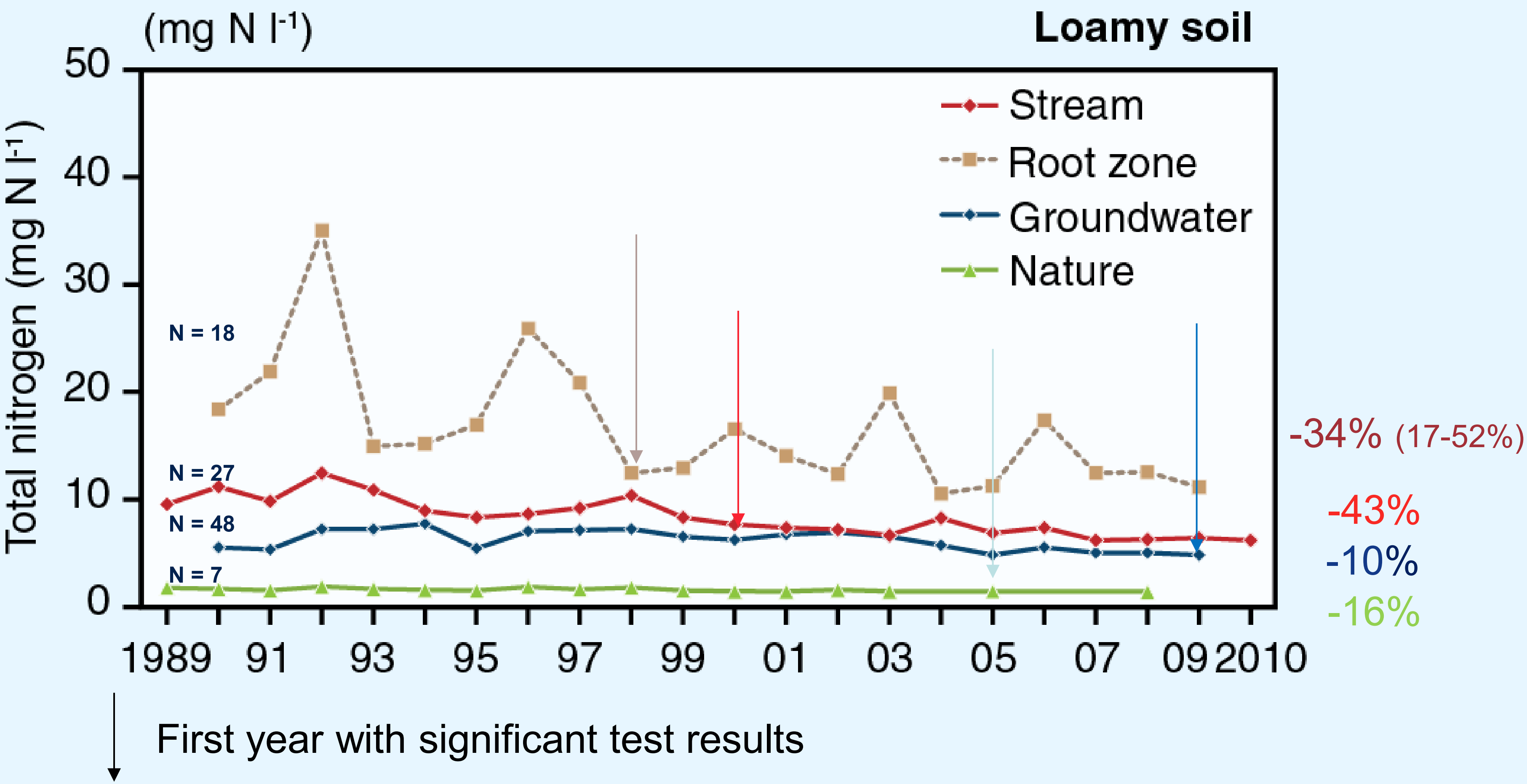
In 5 of 7 streams in catchments with no agriculture and no sewage is N significantly reduced
Mean reduction: 20%
Equals the reduction in atmospheric N-deposition?

Flow weighted nitrogen concentrations in soil water, groundwater and streams draining arable and natural catchments – what is going on ?

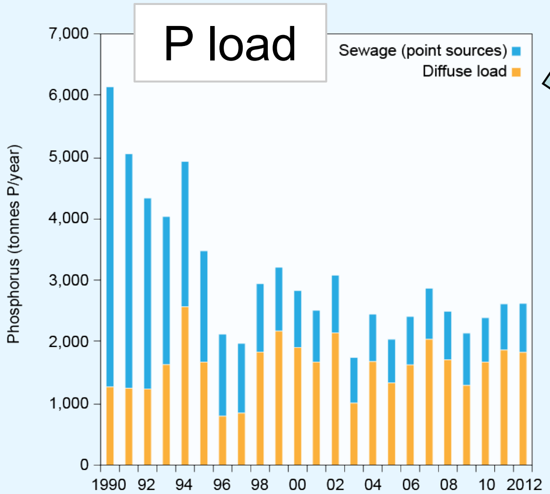


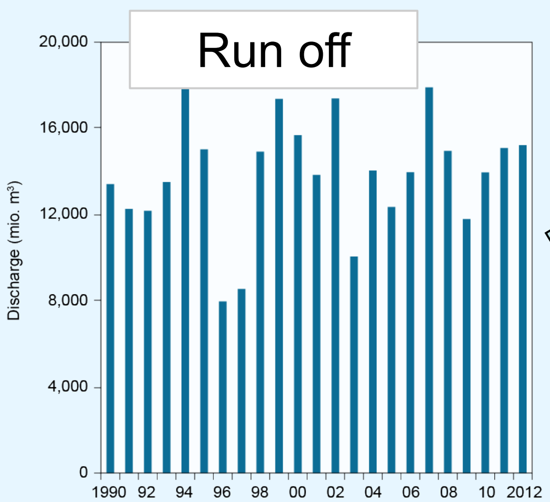
First year with significant test results

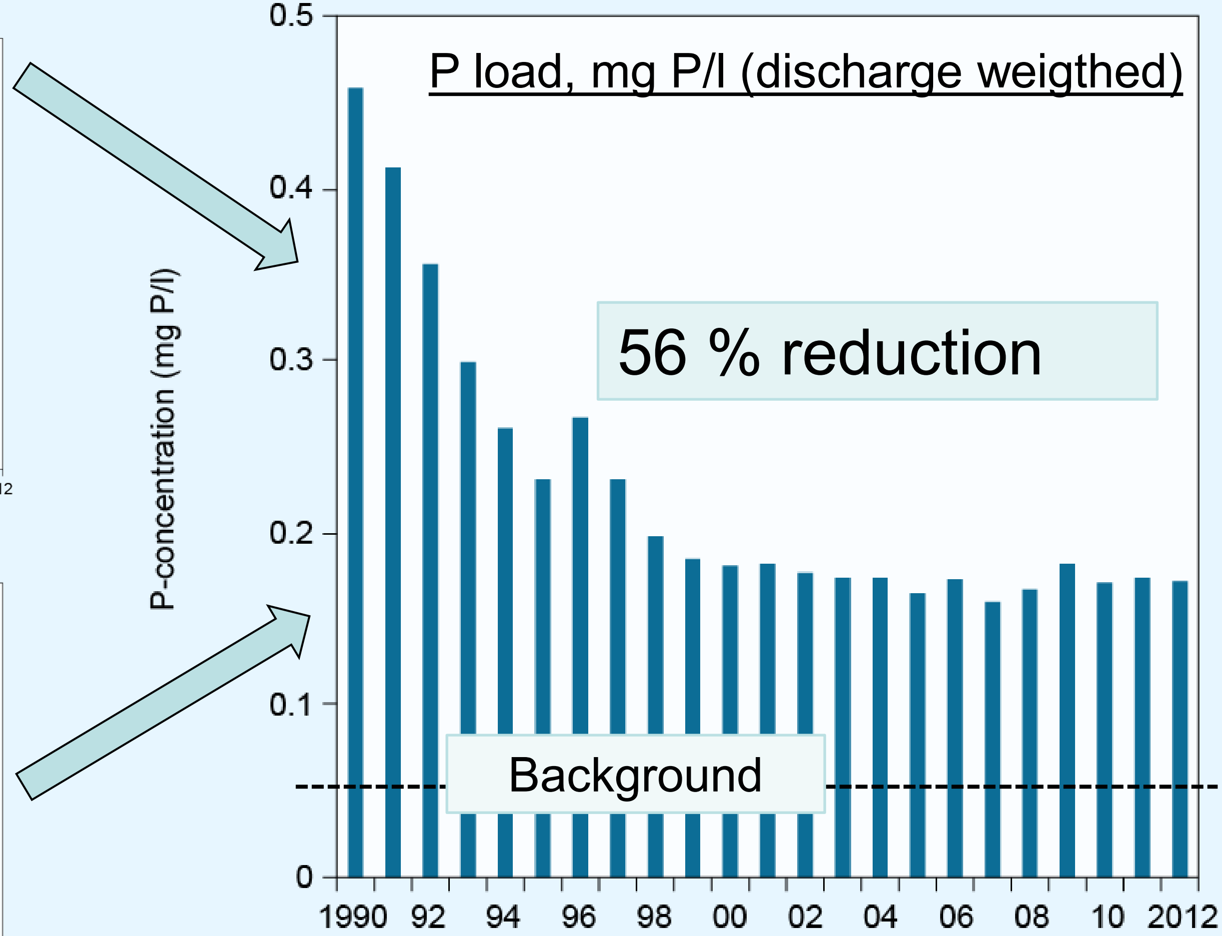
Flow weighted nitrogen concentrations in soil water, groundwater and streams draining arable and natural catchments



First year with significant test results


P load
Sewage (point sources)
Diffuse load
Phosphorus (tonnes P/year)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1990 92 94 96 98 00 02 04 06 08 10 2012


Run off
Discharge (mio. m³)
20,000
16,000
12,000
8,000
4,000
0
1990 92 94 96 98 00 02 04 06 08 10 2012


P load, mg P/l (discharge weigthed)
56 % reduction
Background
P-concentration (mg P/l)
0.5
0.4
0.3
0.2
0.1
0
1990 92 94 96 98 00 02 04 06 08 10 2012

P sources: Sewage

(tonnes P/year)

Sewage from…	1990	2012	Reduction (%)
Seawage treatment plants	3700	500	86%
Industry	650	20	97%
Scattered dwellings	420	180	57%
Storm water outlets	260	180	31%
Fishfarm	250	90	64%
Total	5300	970	82%

Regional Scale

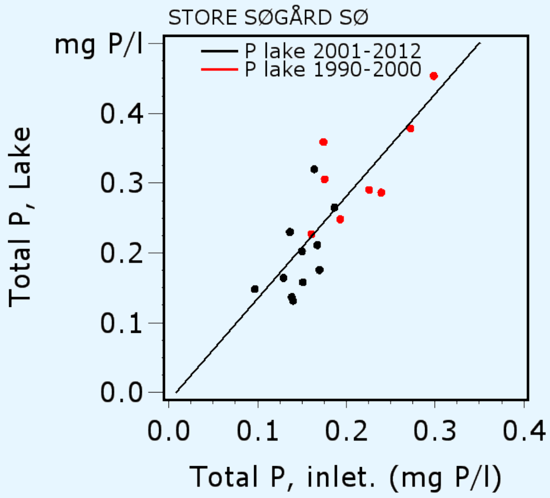
10 estuaries, …..17 lakes

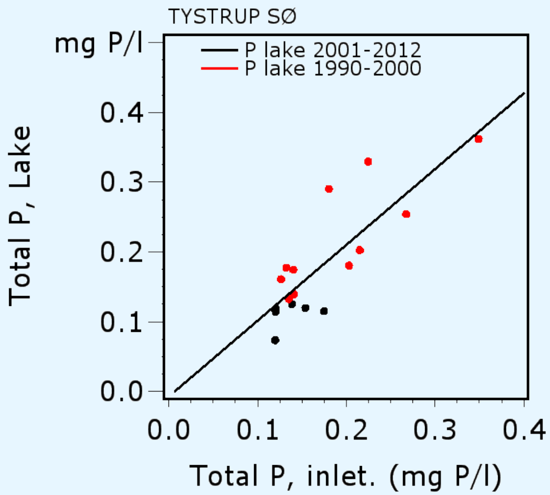
P load, land based

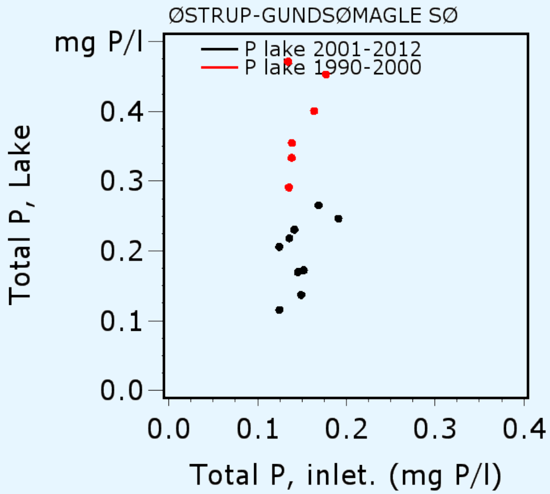
P concentration in lake and

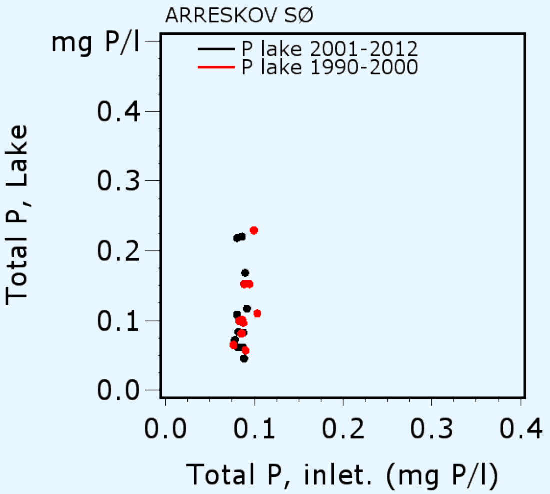
coastal waters

4 Danish lakes, annual values, 1990-2012. P concentrations: Inlet water and lake water



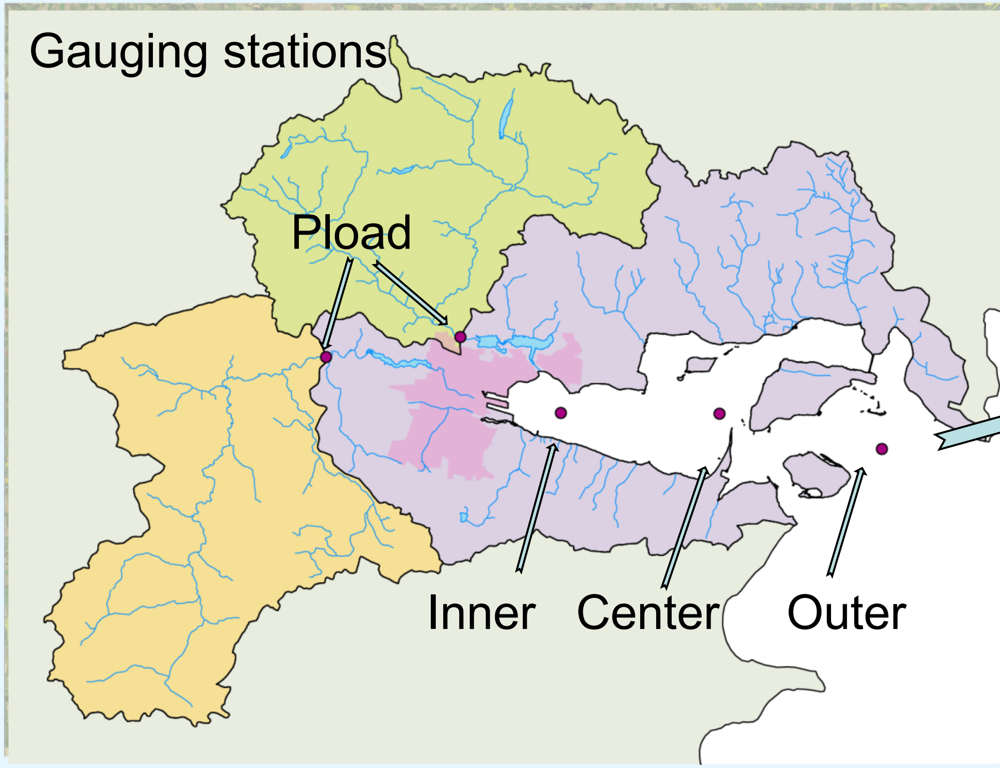


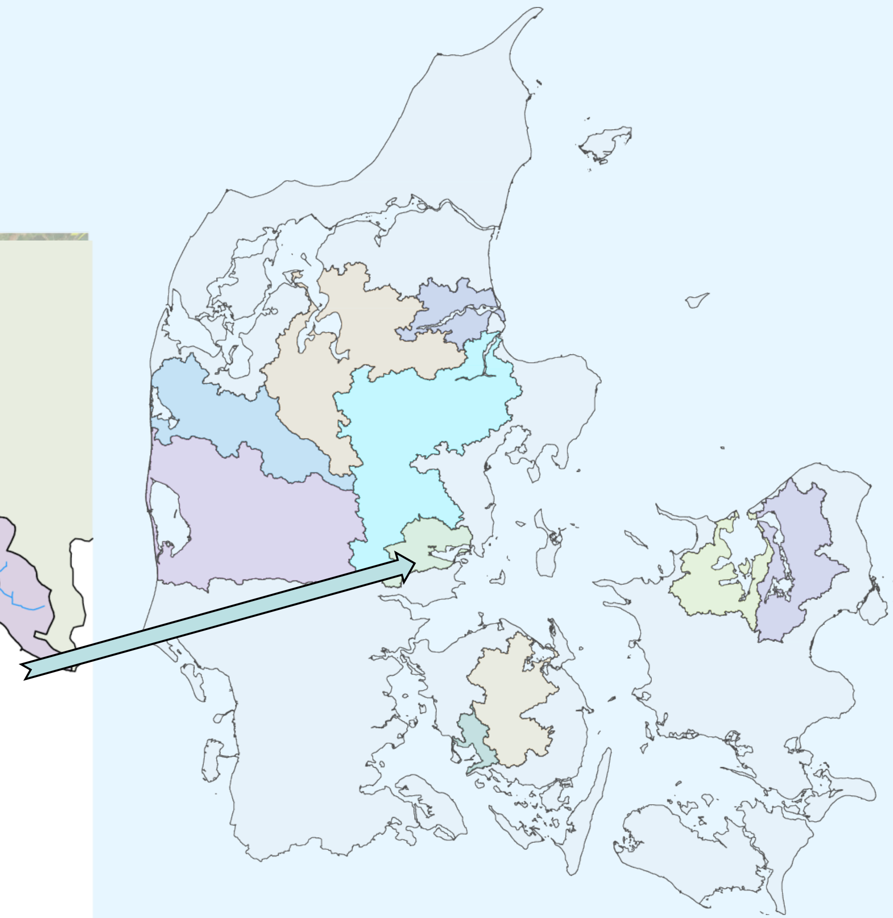




Regional Scale

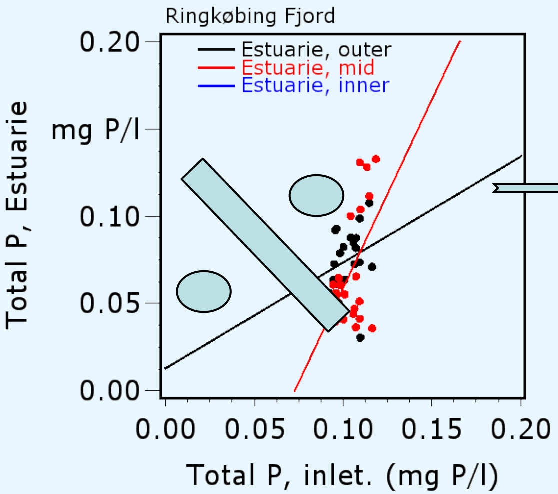
10 estuaries

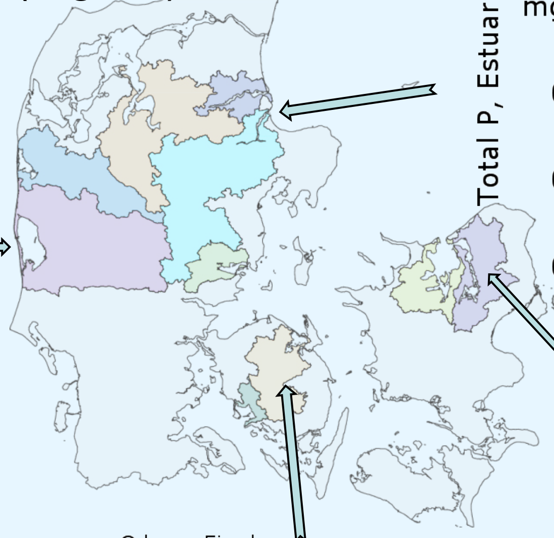


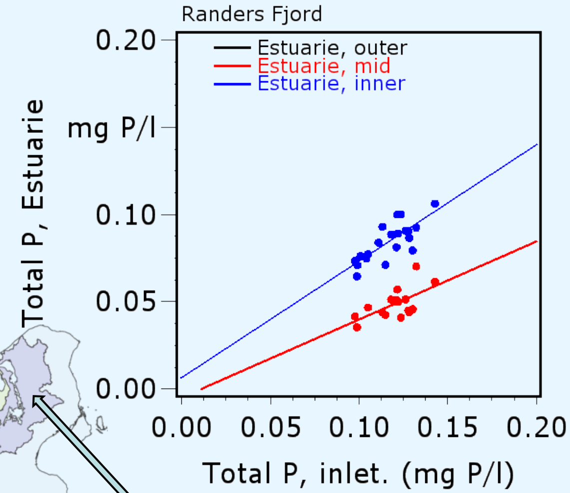


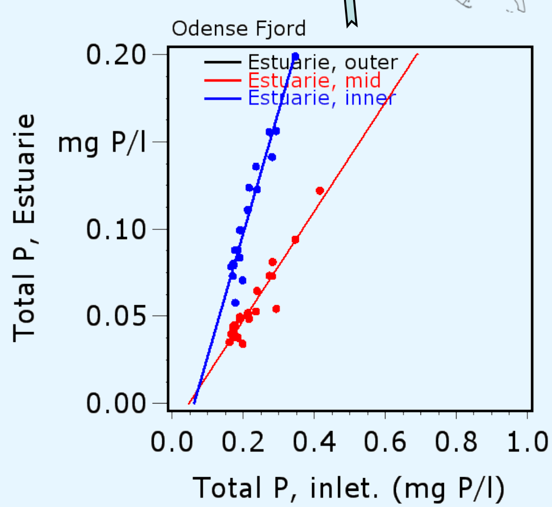
Estuaries (1990-2012:

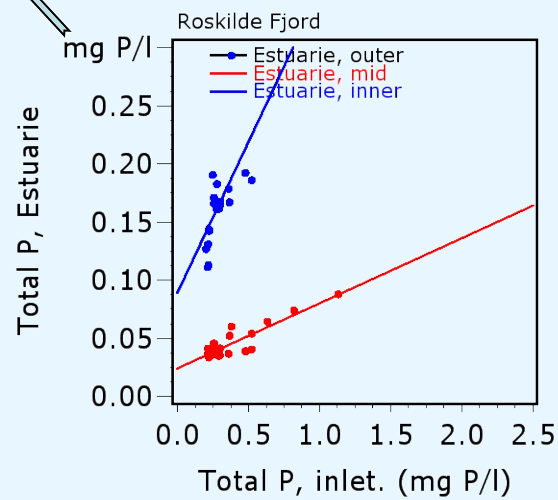
P inlet and estuarie waters (mg P/l):











Local Scale

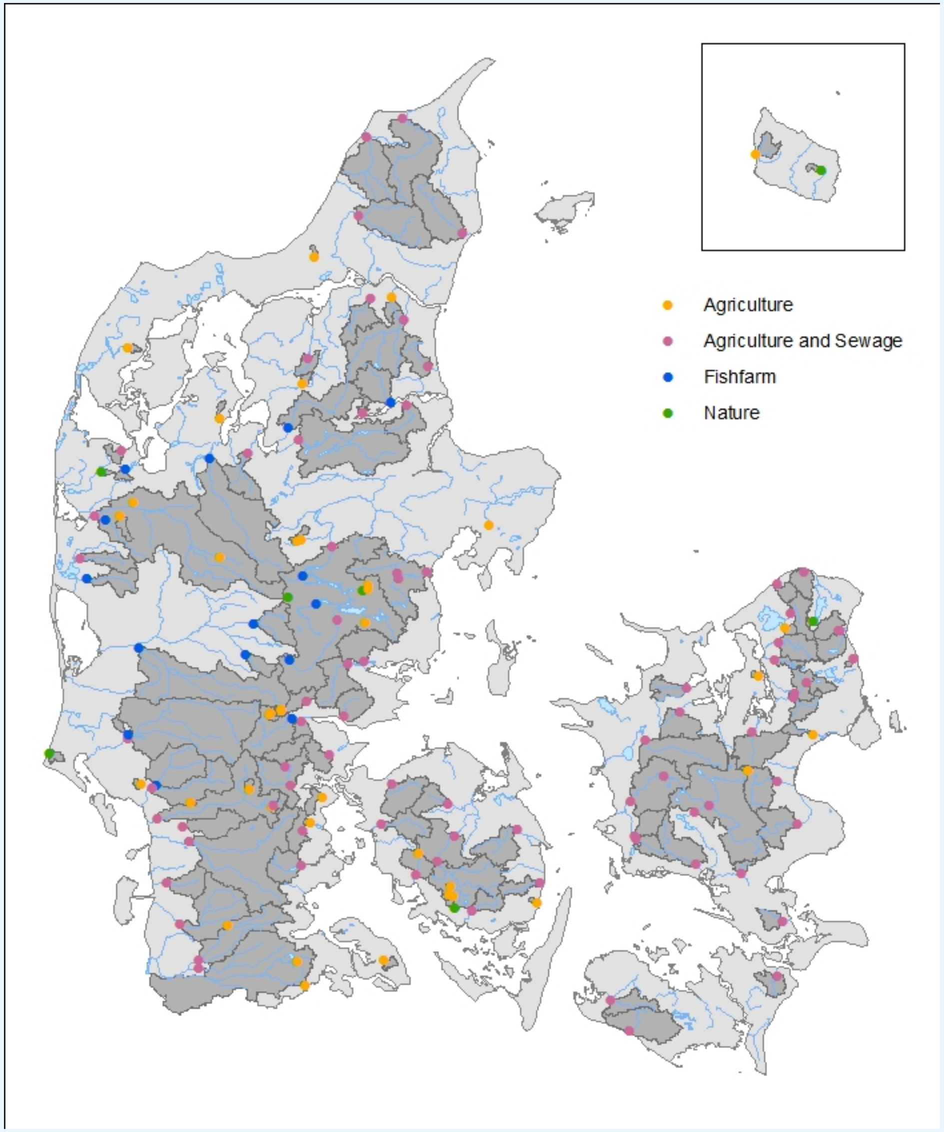
MONITORING OF P

Streams draining catchments with varying human impact on Pload

Including **31 agricultural catchments**

(no sewage from larger point sources
…but some sewage
from scattered dwellings)

Median catchment area: **13 km^2**



Mitigation measures implemented for reduction of diffuse P-emissions since late 1980'ies:……………………………………………………

Mid 1980s: Stop for effluents from farms and farm yards – building slurry tanks, etc.

Late 1980s: Phosphate free detergents.

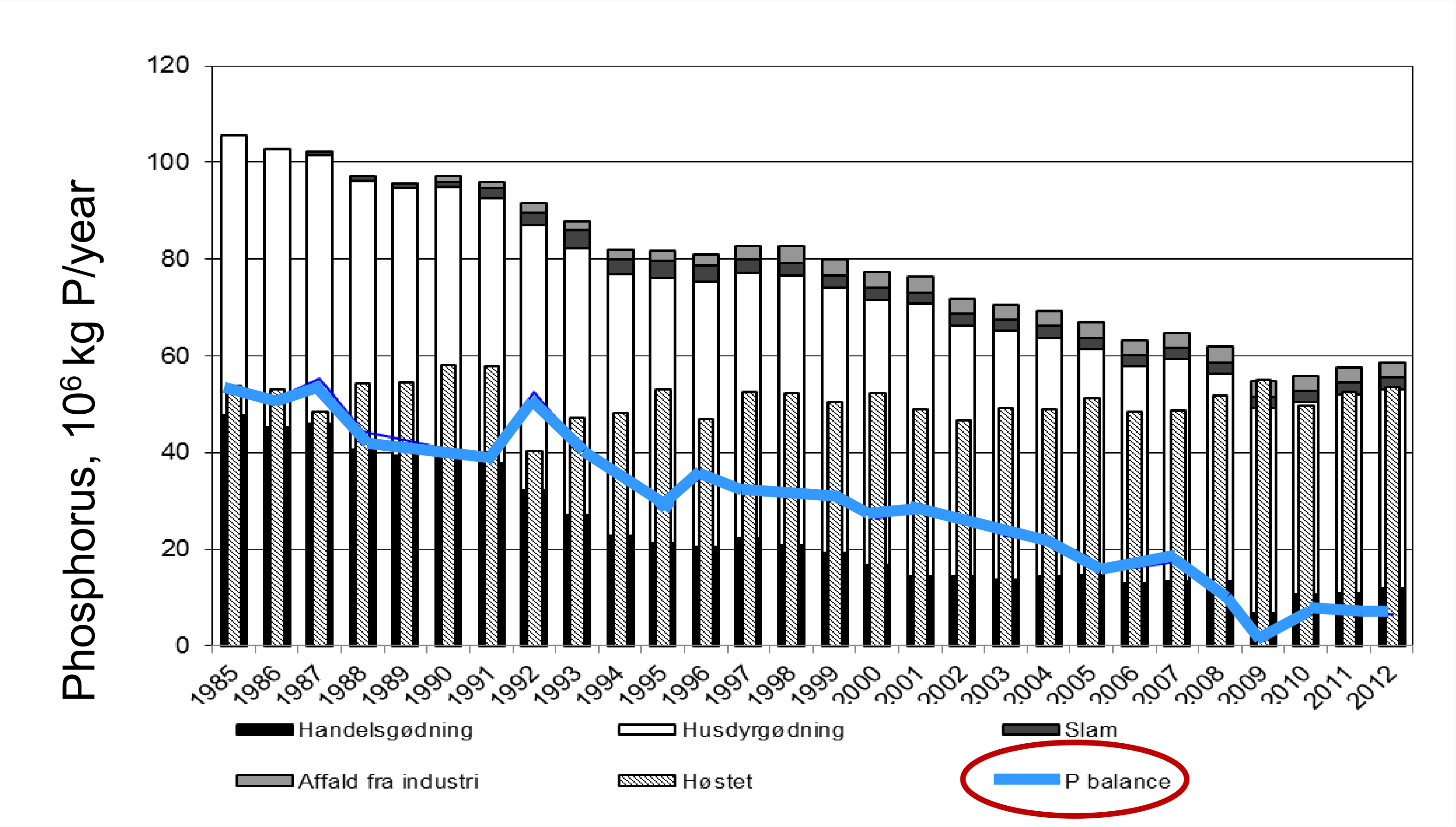
1992: Mandatory 2 m buffer strip along all natural watercourses and watercourses with a high environmental objective.

1998 -: Mitigation effluents from scattered dwellings in ecological sensitive waters.

2003: Action Plan III in Denmark with the goal of halving P-surplus before 2015.

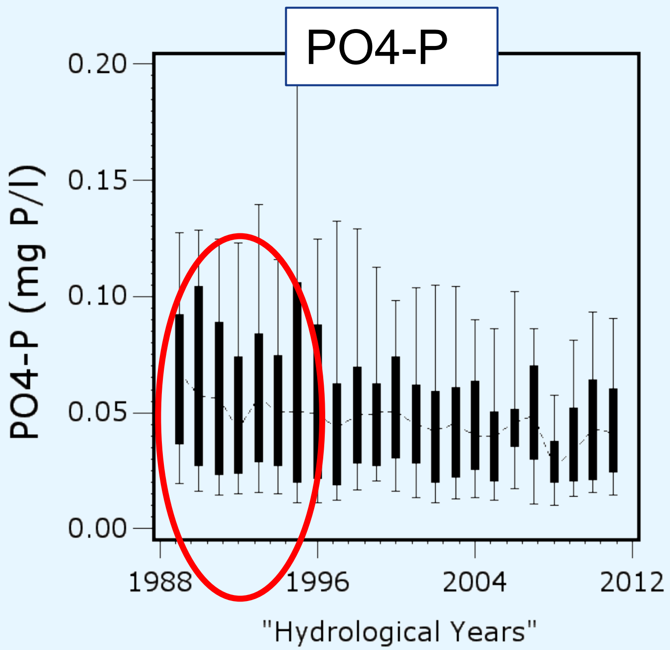
2012: Mandatory 10 m wide buffer strips along all watercourses – no farming activities.

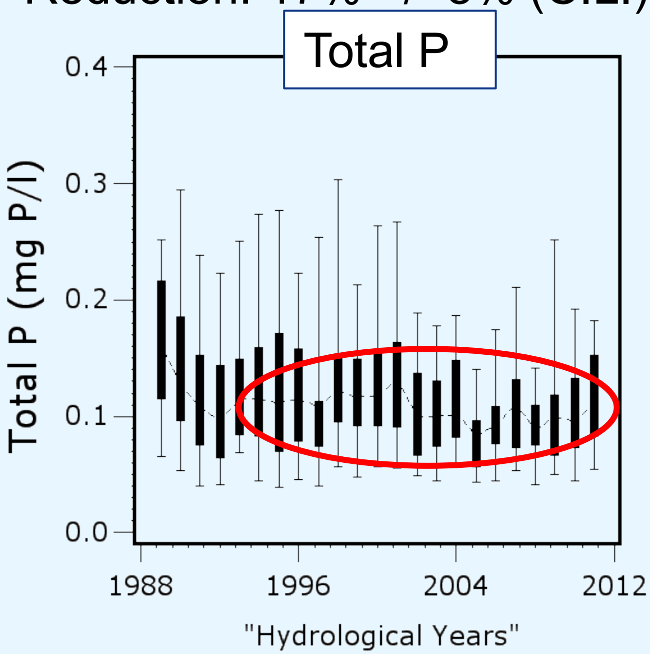
Phosphorus Balance (surplus fields)



31 catchments: Agriculture, - no larger point sources (>30 P.E.)

14 out of 31 streams reduced P
Reduction: 17% +/- 8% (C.L.)





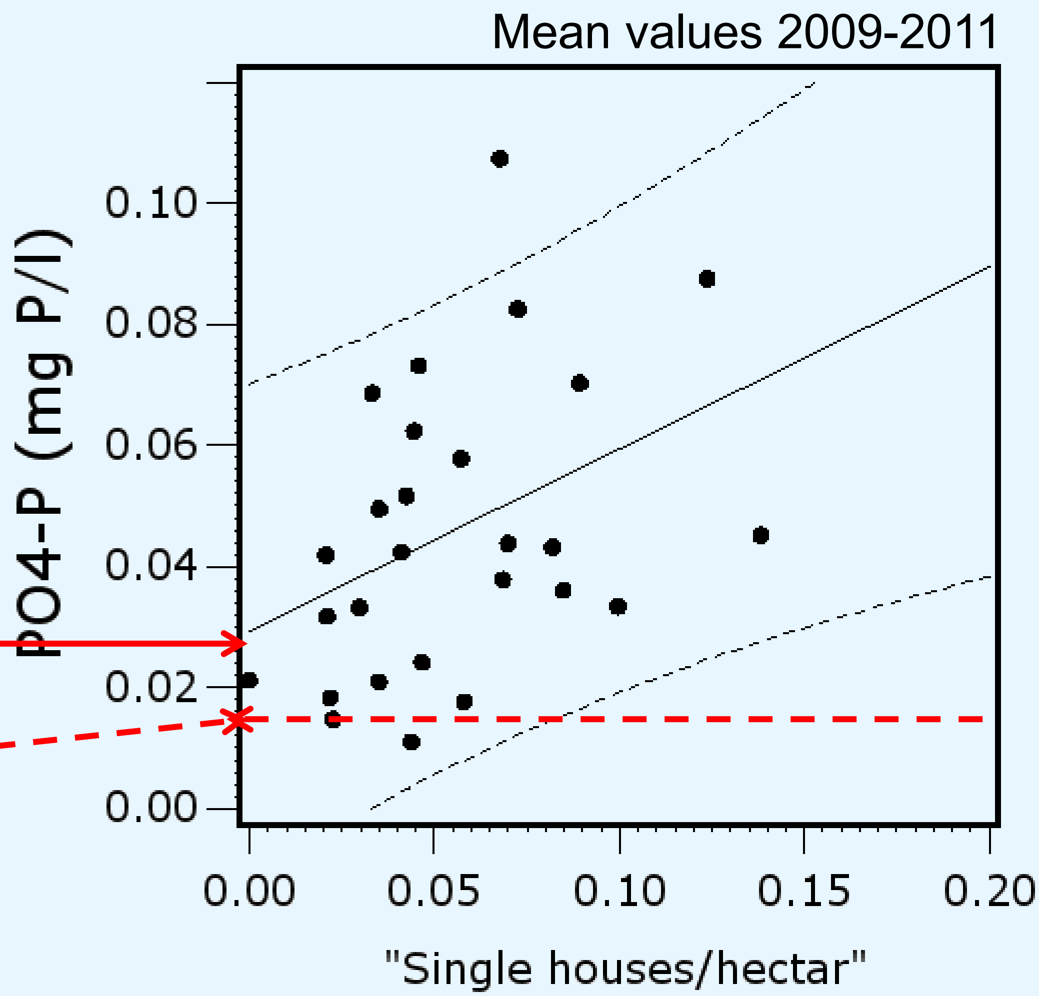
Reduced outlets from single houses… but no visible effect of reduced P field surplus

Indications:

Impact on dissolved P in streams from scattered dwellings

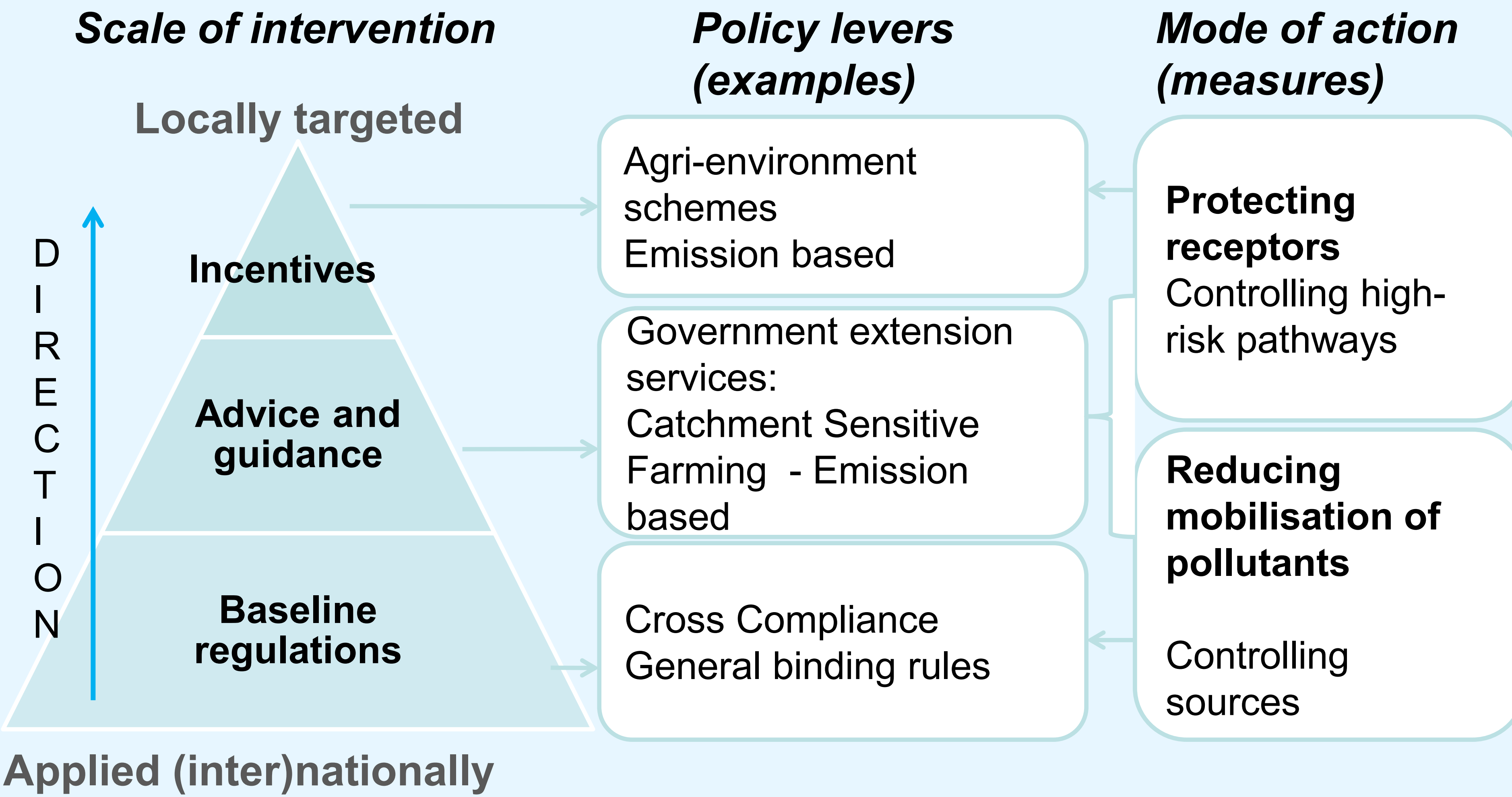
Y = 0.30 * X +**0.029**
(r2=0.16; p<0.05)

Background **0.017***



* From streams draining catchments with no agriculture (<10%) and no sewage

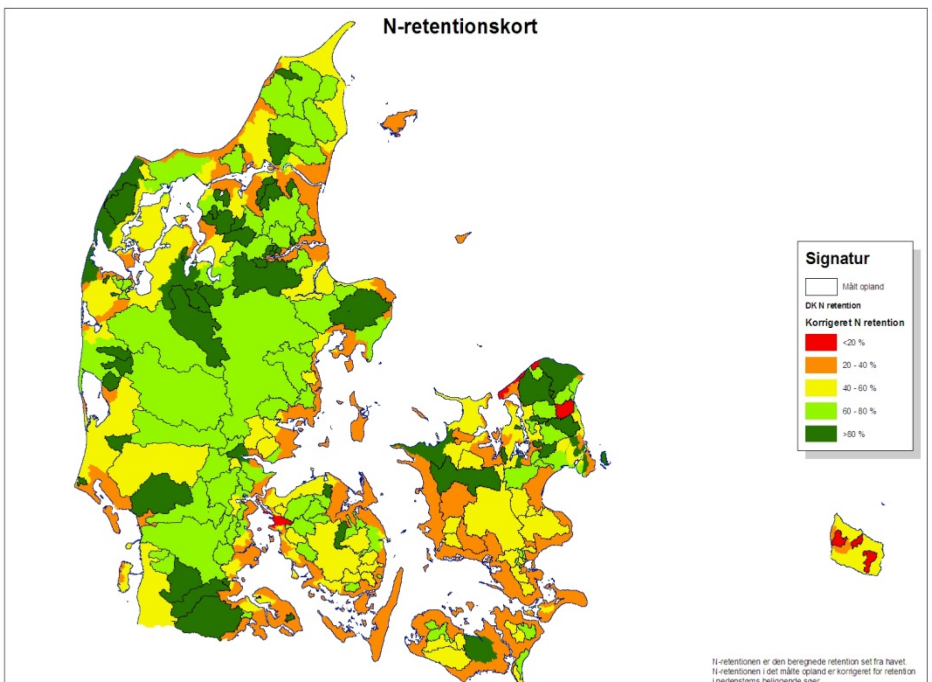
Policy interventions – new research requirements



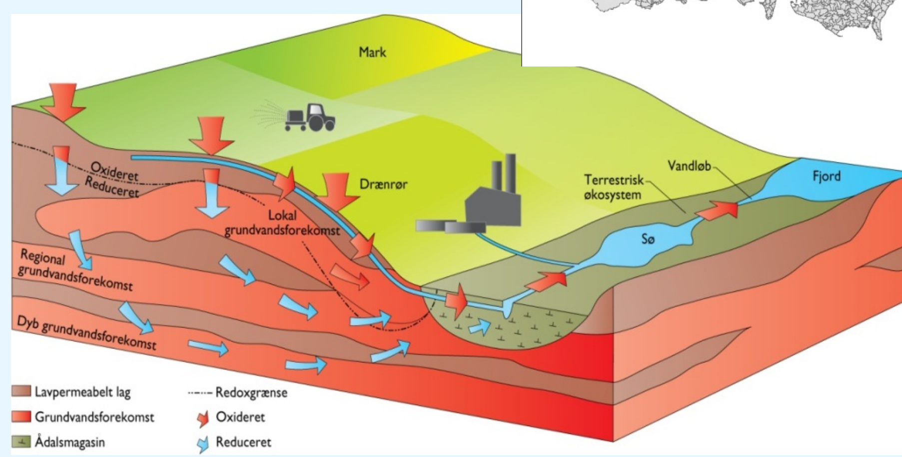
New research horizons: A new reduction map for nitrogen is being developed this year in a project between GEUS and AU.

Moreover, we are starting a new GUDP reseach project on how to perform emission based regulation of nitrogen in DK agriculture

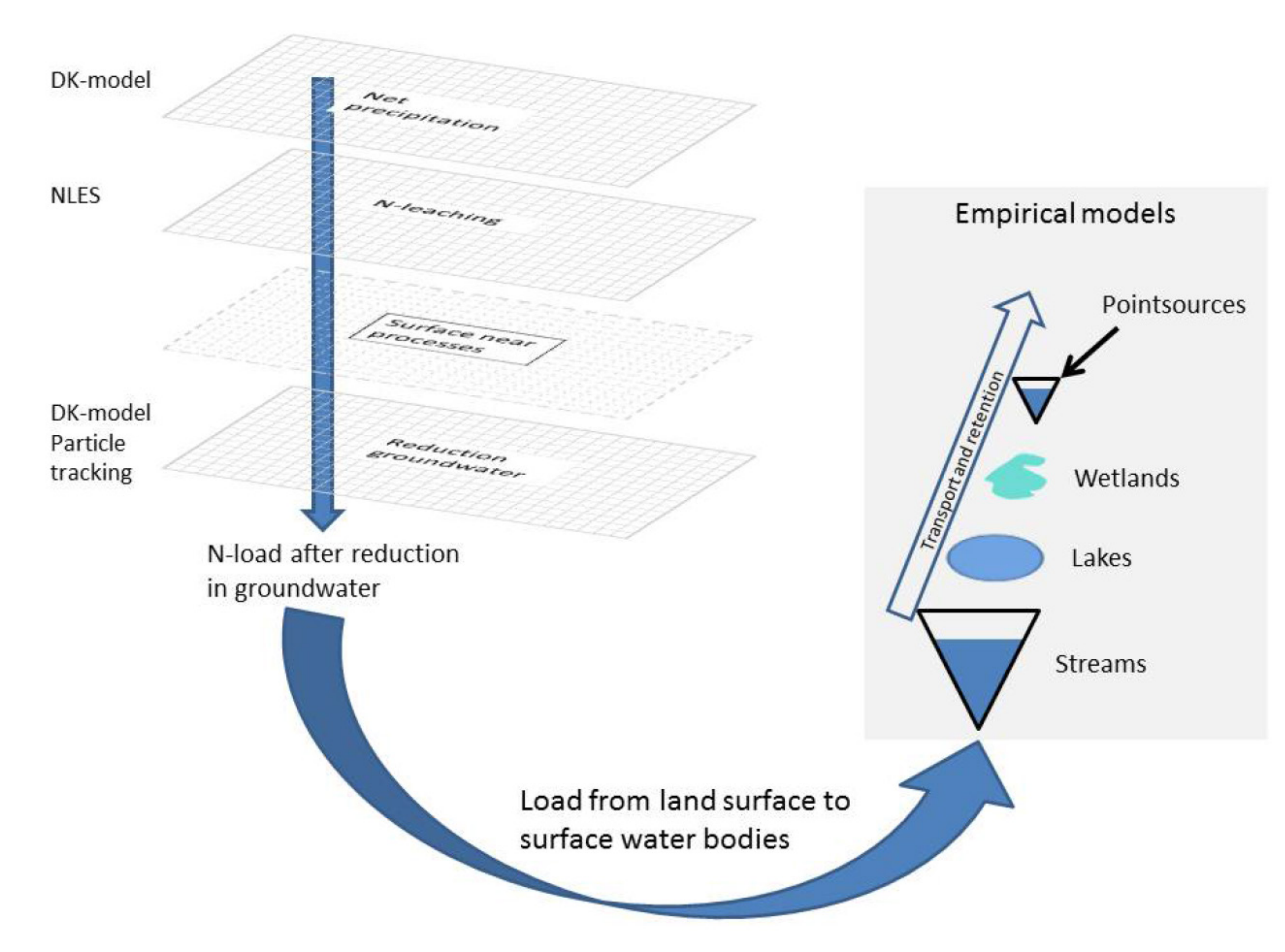
2nd Generation map – from 2008



3rd generation map – in 2014 from new concensus DK-model based on ID15 polygons – ca. 3500

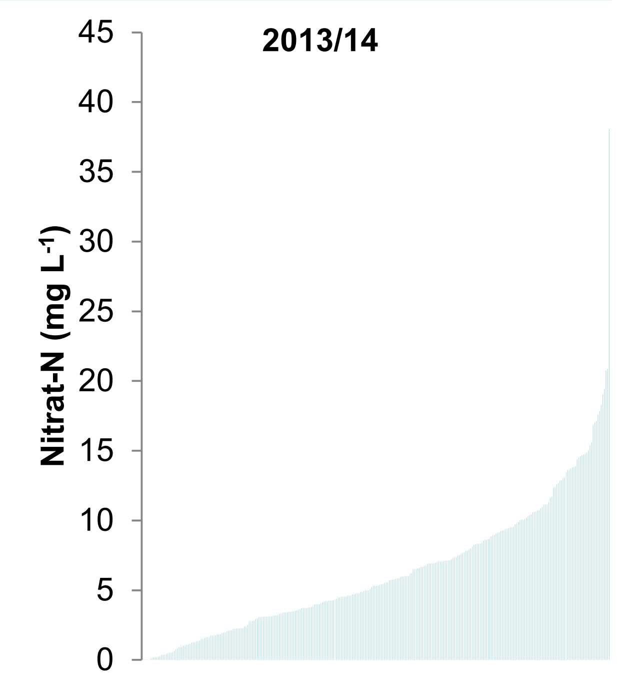


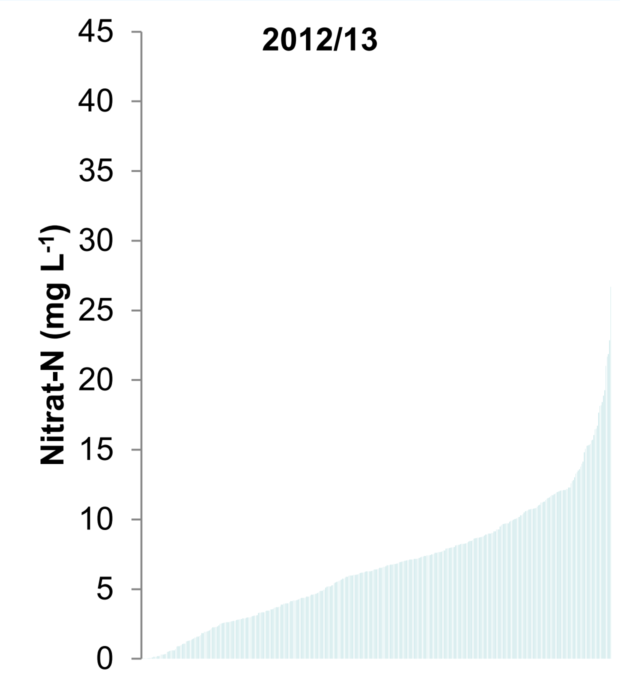
Water and nitrogen cycling: New national concensus model under development in DK – operating at 500x500 m grid level

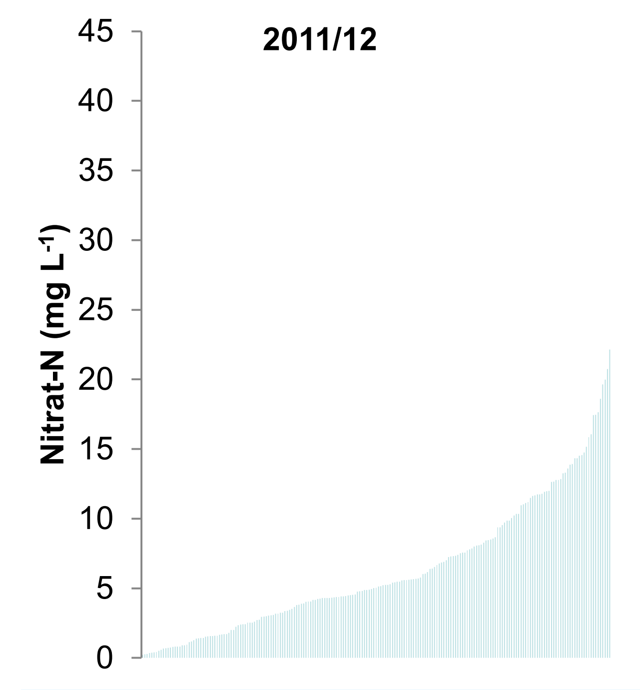


The national drainage water survey

Total nitrogen (TN)
Nitrate (NO_3^-)
Ortho-P







Conclusions and Future Challenges

- More efforts should be devoted to give an 'error estimate' together with water quality monitoring data as many countries and regions presently are cutting down on threir sampling efforts.
- Intensive data from different types of catchment across Europe can assist in developing an error catalogue for catchment types.
- The costs of under or over implementation of mitigation options may in many cases be much higher than the cost of running appropriate monitoring programmes.
- Denmark is a nice example that general binding rules targeting N and P pollution helps for improving water quality in both surface and groundwaters.
- But effects may in some water bodies take a long time to be seen.
- A new more targeted management of agricutural pollution is on the way in Denmark – including own monitoring of emissions


Thank you for your attention !