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Monitoring, Modelling and Management of nitrogen – field to catchment scale

Learning aims

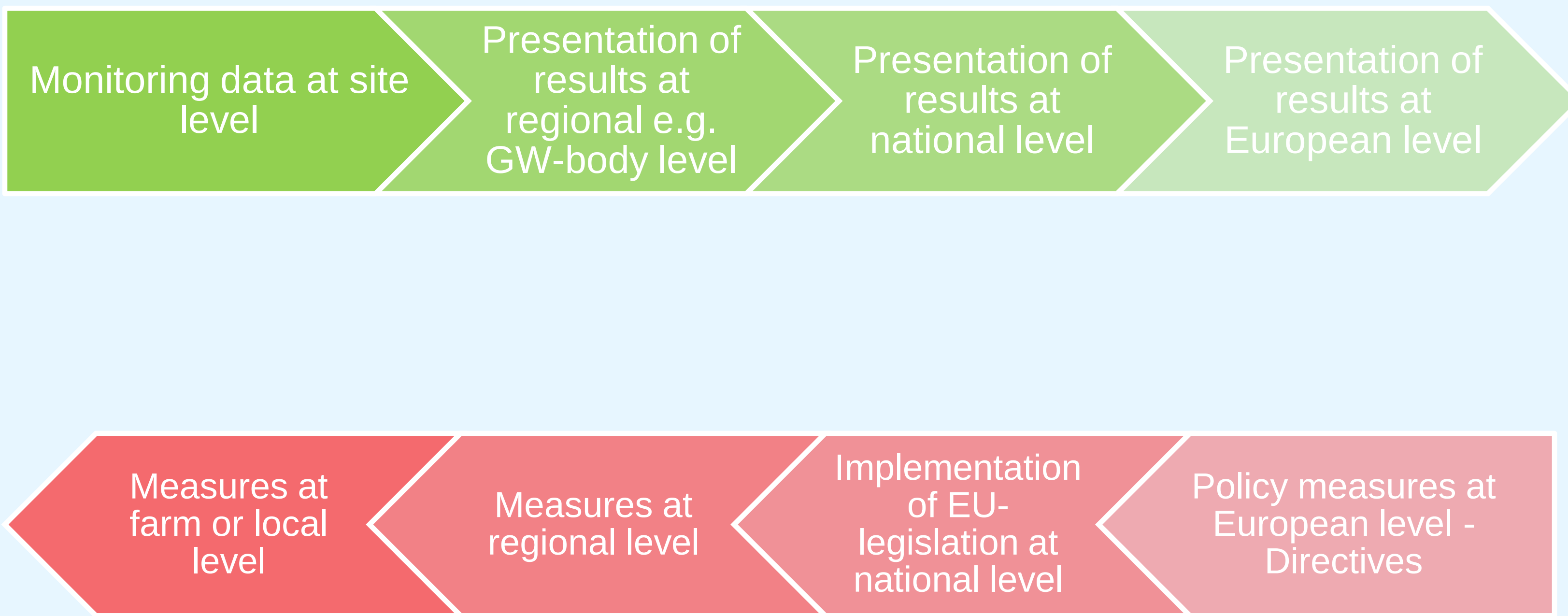
- **What is meant by the DPSIR concept used in management?**
- **What is meant my monitoring? and how and where should nutrients be monitored?**
- **What kind of models do we use in nutrient modelling?**
- **How can we mitigate nitrogen losses?**

Monitoring of water quality

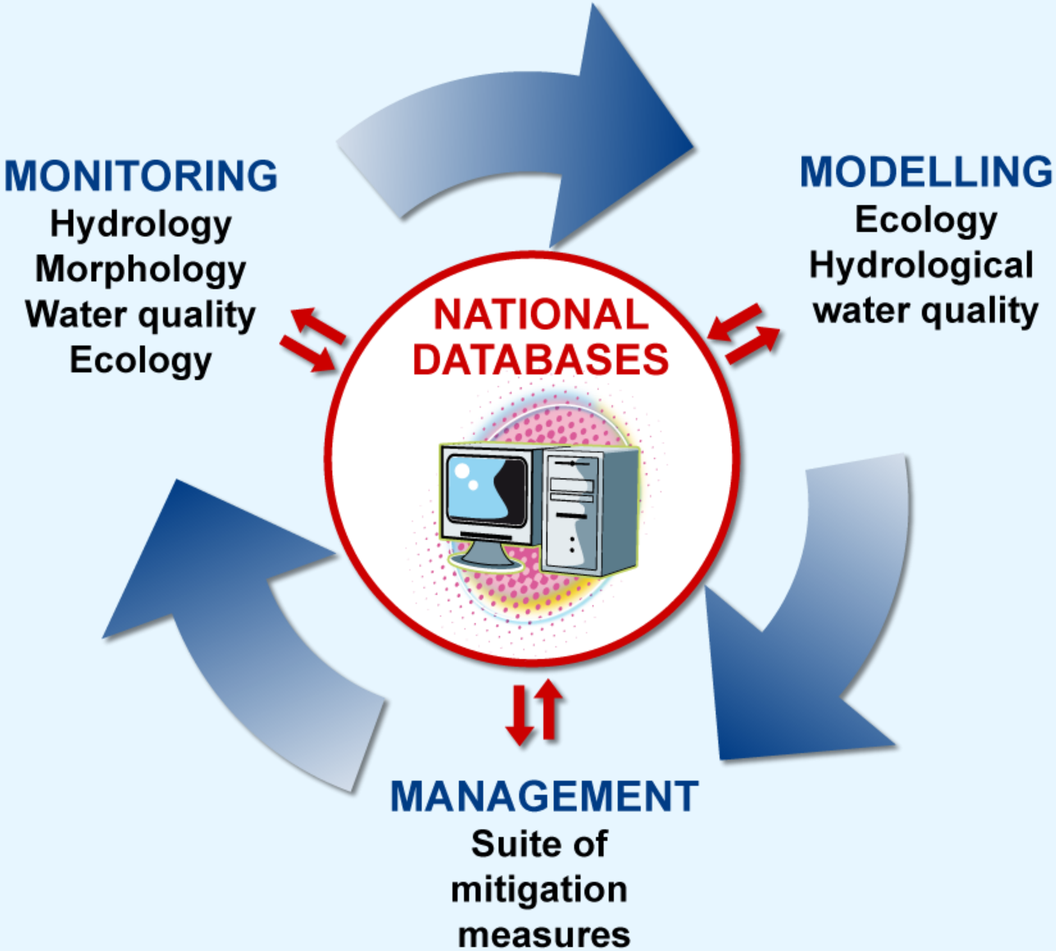
Quality standards

Environmental factors

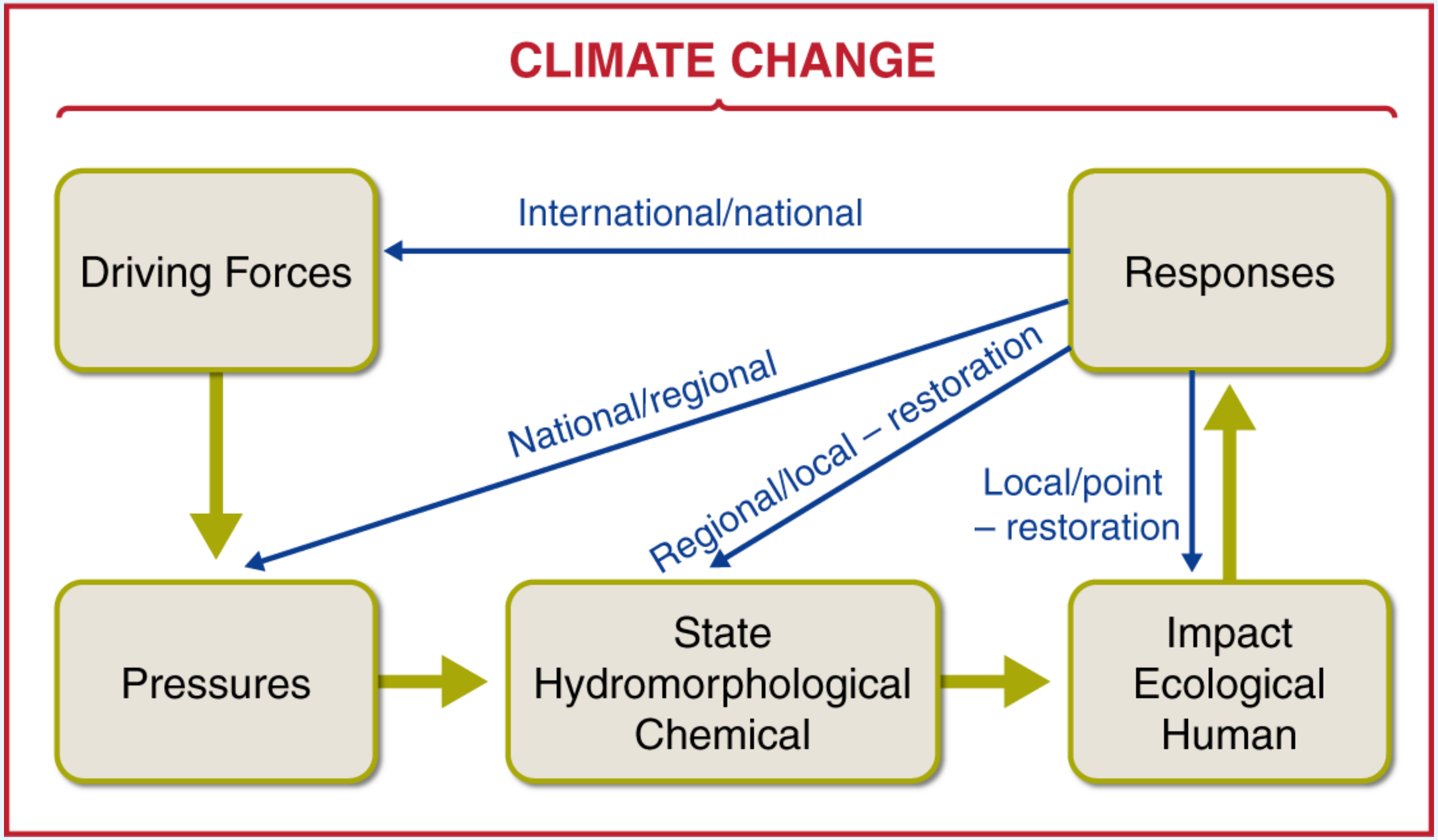
Monitoring and Policy Measures



Environmental information system: The Danish concept



River basin management – The DPSIR Concept



Example of use of DPSIR concept - agriculture

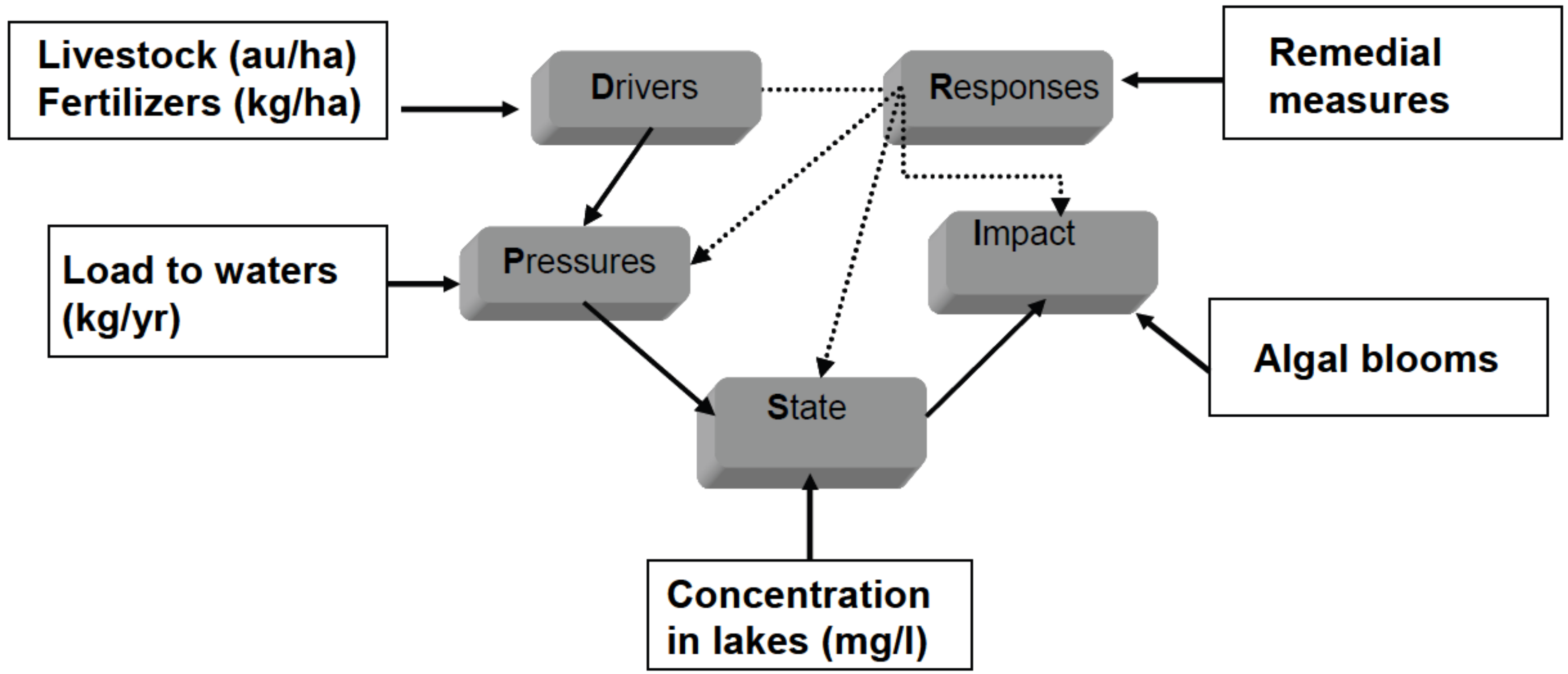
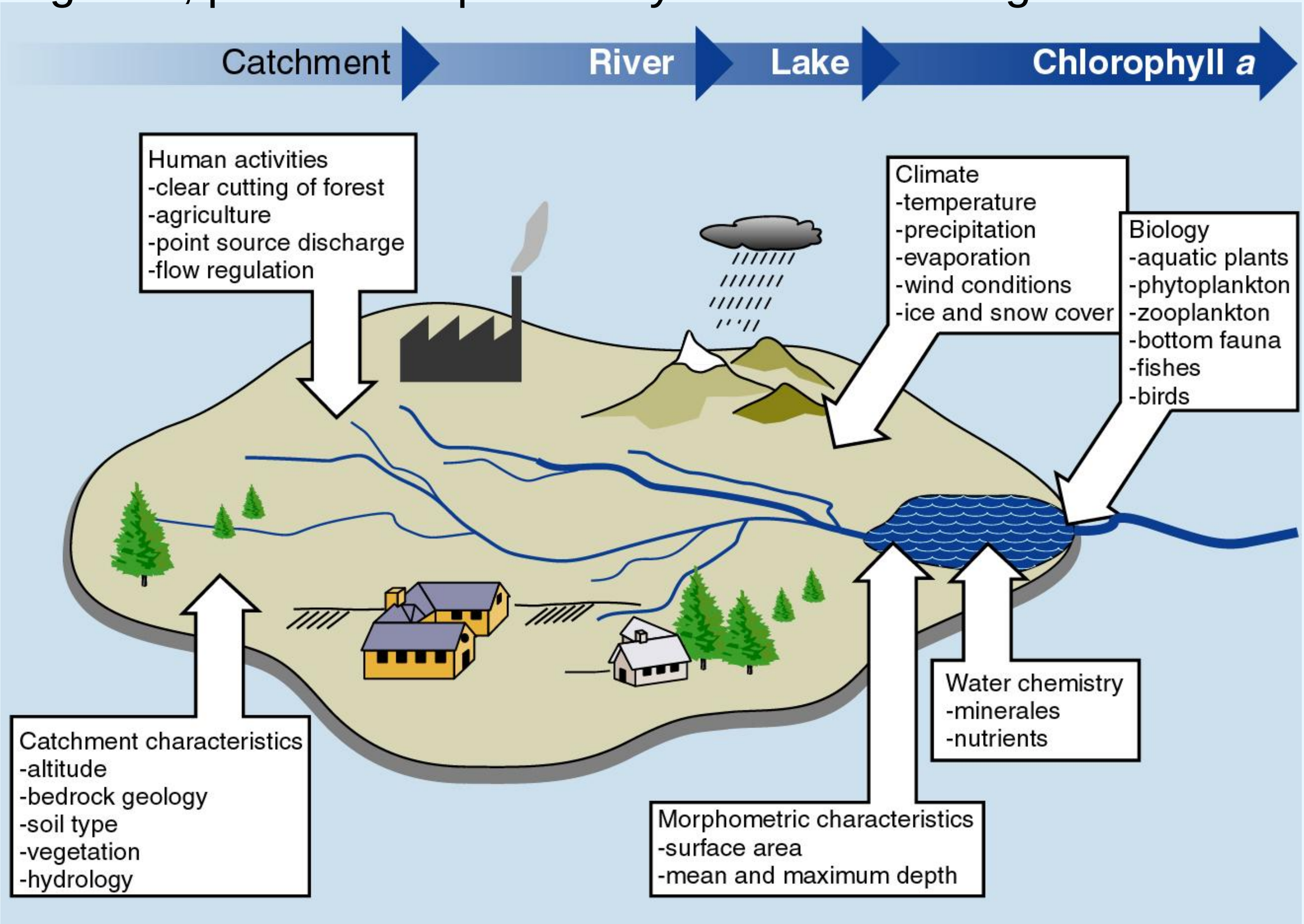


Figure 3.5

The DPSIR approach for a livestock based agricultural system. (after Rekolainen, 2006)

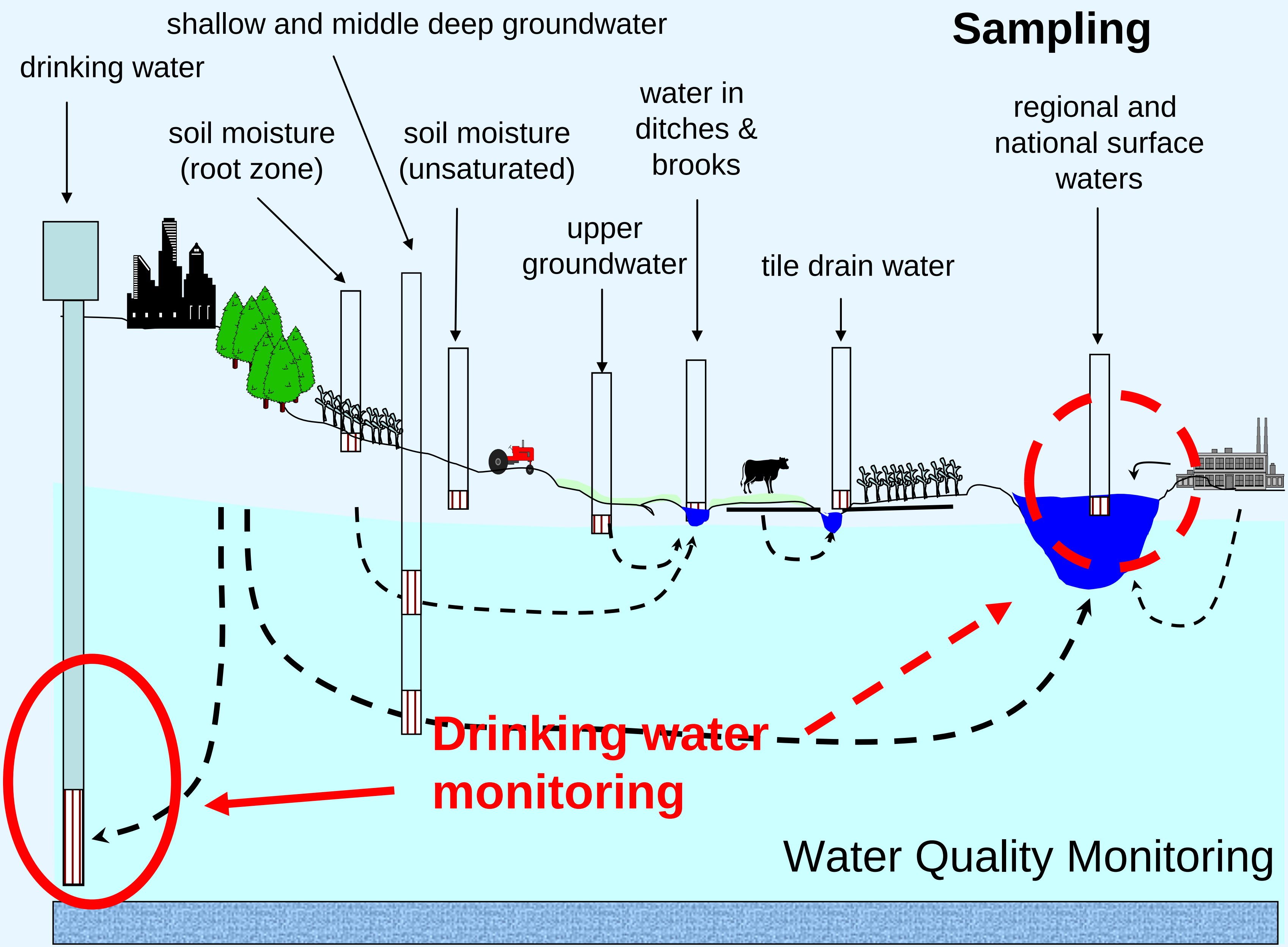
River Basin Management Plans have to be implemented based on monitoring data, pressure/impact analysis and modeling



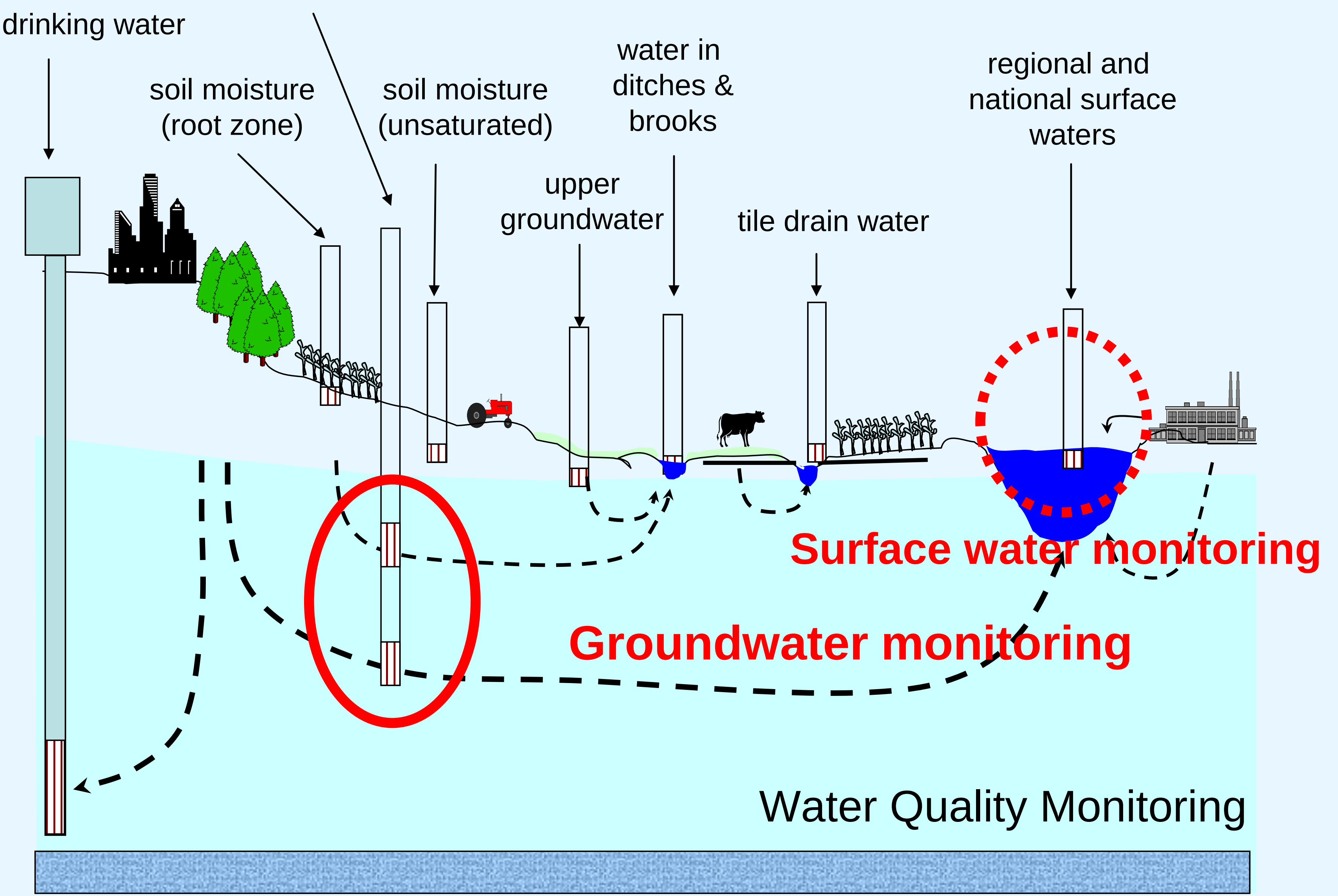
Questions to be addressed when deciding on monitoring approach

1. **Purpose of monitoring**
2. **Representativeness of sampling points**
3. **Seasonal variation**
4. **Climatic variation**
5. **Trend analyses**
6. **Constructing cause/effect -relationships /effect modelling**
7. **Validation of results**

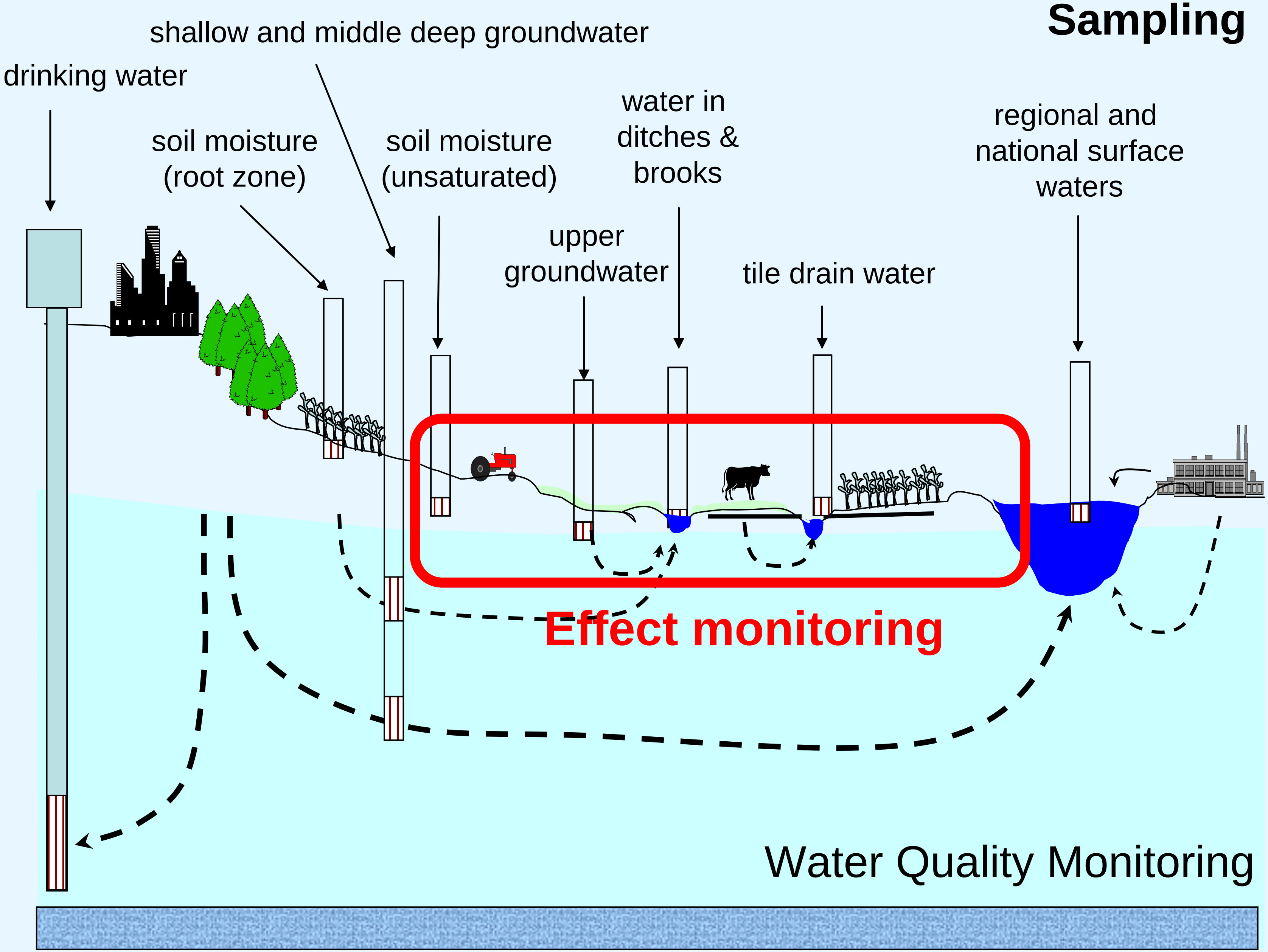
Sampling


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
Drinking water monitoring
Water Quality Monitoring

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
Surface water monitoring
Groundwater monitoring
Water Quality Monitoring

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 Danish monitoring programme

- **First Action Plan for the Aquatic Environment adopted in 1987, second plan in 1998 and third plan i 2003:**
  - **goal 1987: 49% reduction in N-leaching from rootzone**
  - **goal 2003: further 13% reduction in N-leaching from rootzone**

- **Comprehensive monitoring programme established in 1989 with the aim of following the effect the National Action Plans**
  - **agricultural catchment (5 ’study-catchments’)**
  - **surface water (63 agricultural catchments)**
  - **groundwater (1050 stations in younger groundwater)**
  - **coastal and marine waters**
  - **atmosphere**
  - **terrestial systems**

- **Revision of monitoring programme every 6 years**

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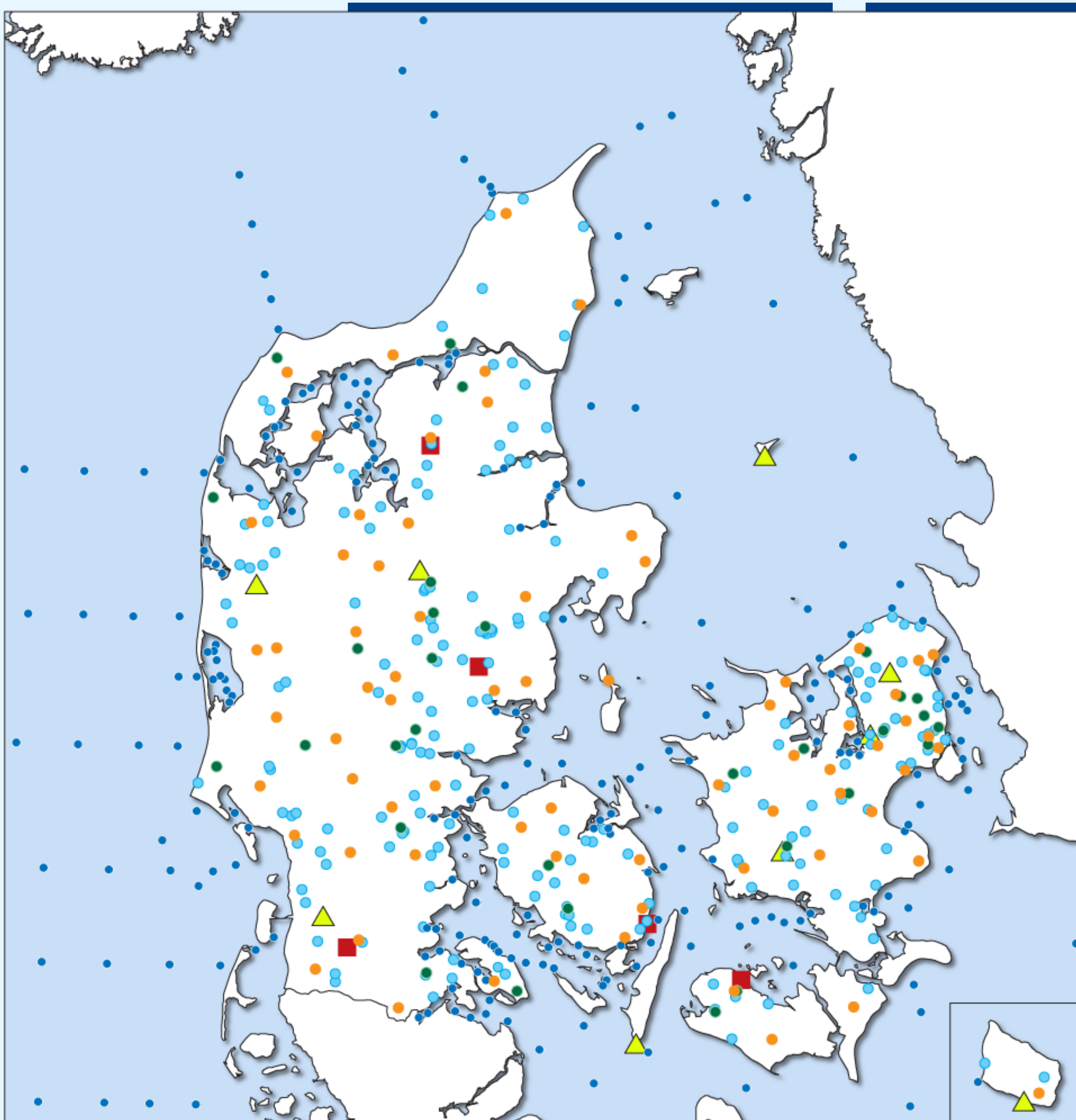
Monitoring stations in Denmark



- 9 Atmospheric deposition
- 5 Agricultural catchment monitoring
- 70 Groundwater
- 231 Watercourses
- 31 Lakes
- 157 Marine waters

Three scales in catchment nutrient 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

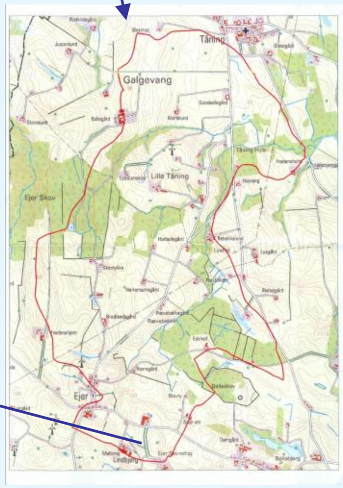
5 catchments (5-15 km²)

Measuring programme:

- **root zone water, 1 m (32 sites)**
- **drainage water (7 sites)**
- **upper-groundwater, 1.5-5 m (100 sites)**
- **streams (5 sites)**

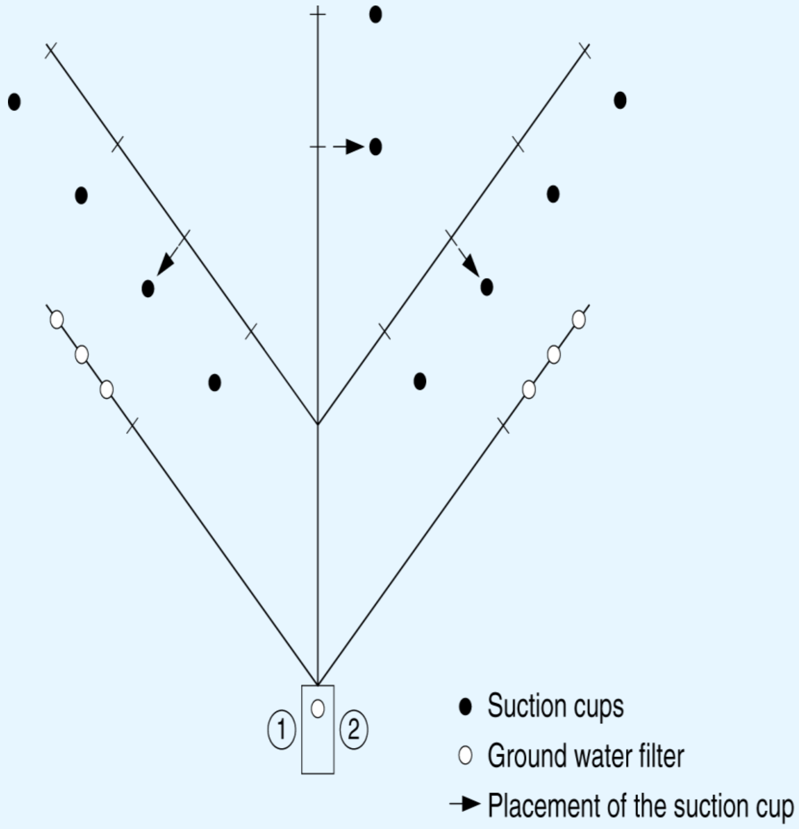
Annual interviews with farmers:

- **crops**
- **animals**
- **fertilizers**
- **manure**



Agricultural catchment monitoring

A soil water / ground water station

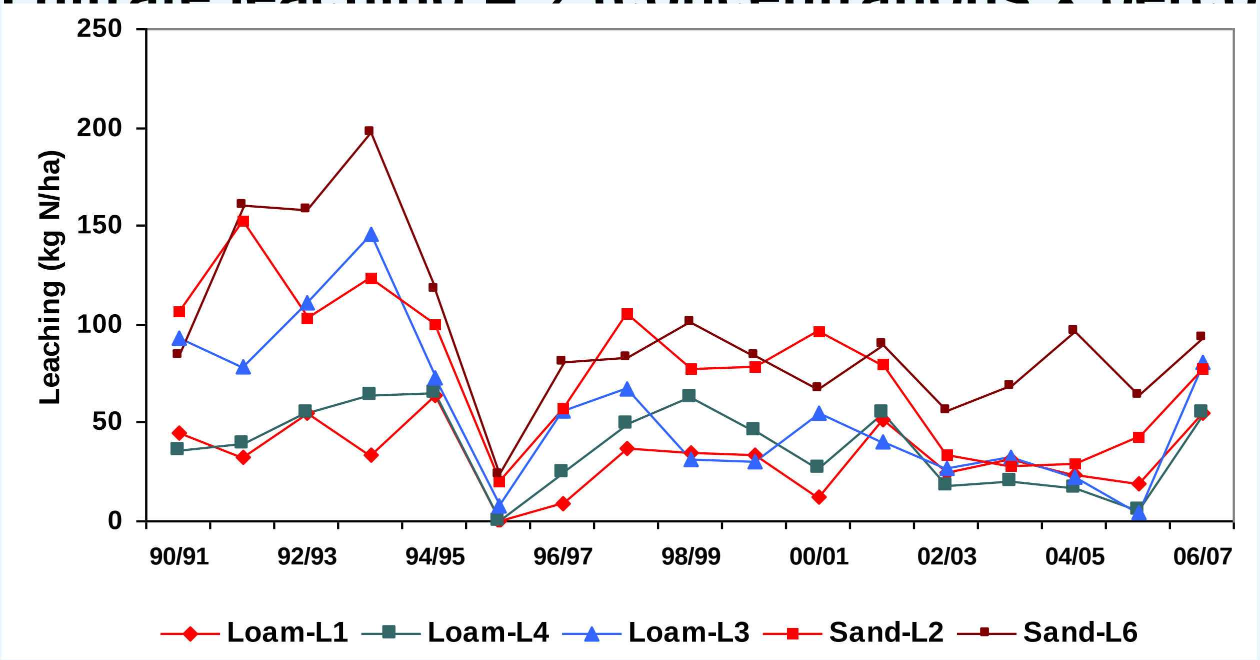


Monitored N-leaching

›**Soil water extracted continuously - weekly measurements**

›**Water percolation modelled (require detailed soil information)**

›**Annual nitrate leaching = Σ (concentrations x percolation)**



Pros and cons in relation to permanent monitoring sites

Problems to be dealt with:

› sites may not be representative

› wear of monitoring equipment

› farmers cooperation

Advantages

› takes account of seasonal variations -› annual flow weighted concentration

› detailed knowledge of the soil – water flow

› long-term time series – trend analyses

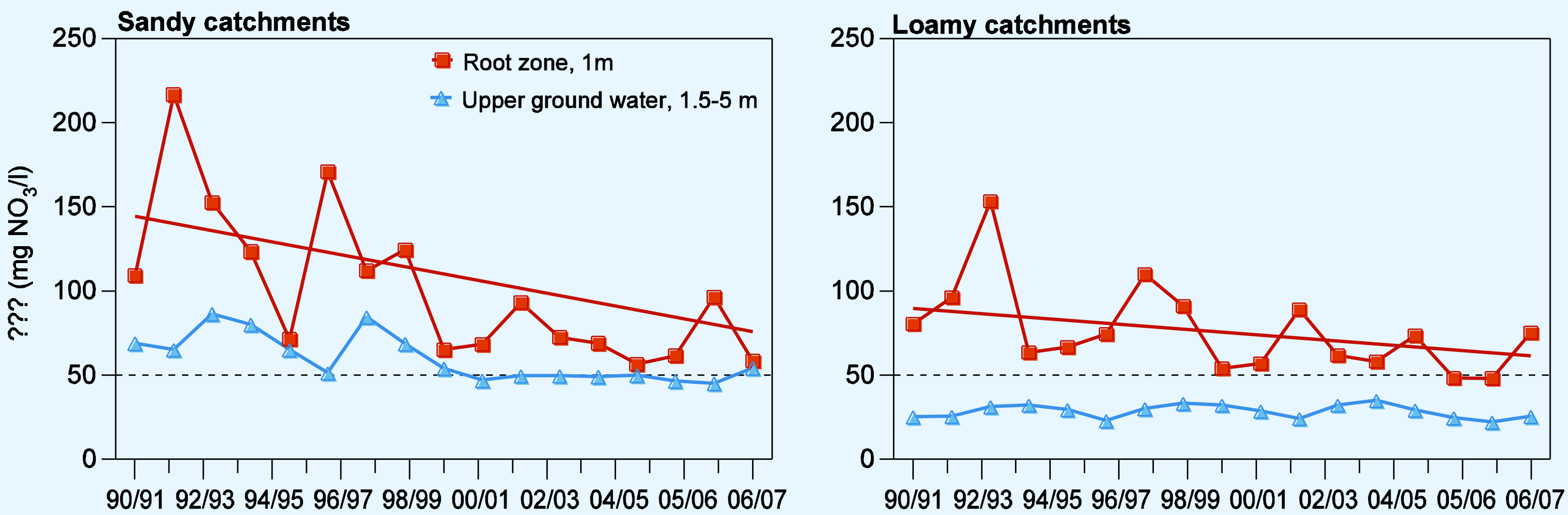
› cause-relationship analyses -› model development

Long-term time series of nitrate conc.

› **Long time series of annual flow-weighted nitrate-N concentrations**

› **Statisical trend analyses by seasonal Kendal test**

› **Reported to EU commission every year in relation to Danish derogation**



Time for an exercise ?

Different model approaches

Low

Level of complexity

High

Annual predictions based on export coefficient approach

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

Daily simulations of flow and solute concentrations

Load-oriented

Empirical

Model type

Conceptual

Process-based

Table 1 Models

No.	Name of the models and sub-models including key references	Nitrogen (N) and/or phosphorus (P) model
1	NL-CAT: ANIMO,[15] SWAP,[16] SWQN[17] and SWQL[18]	N, P
2	REALTA[14]	P
3	NLES-CAT[19]	N
4	MONERIS[20,21]	N, P
5	TRK: SOILNDB,[22] HBV,[23] HBV-N[24] and TRK[25,26]	N, P
6	SWAT[27–29]	N, P
7	EveNFlow[30–32]	N
8	NOPOLU[33]	N, P
9	Source apportionment (SA)[34]	N, P

Increasing level of complexity

Source Apportionment methodology

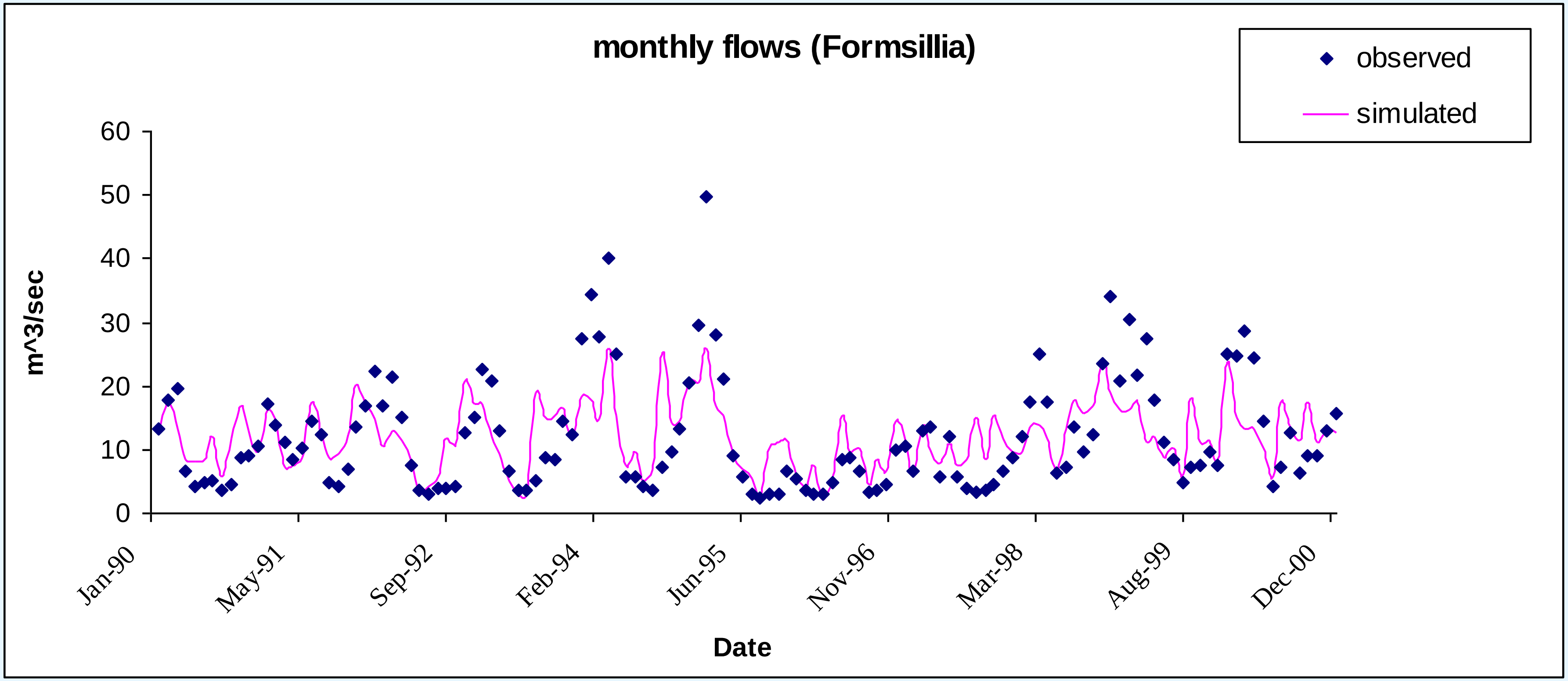
Level of complexity: LOW (Balance approach based on measurements)

$$A = L - P - S - B + R - D$$

A = Agricultural losses
L = Total measured losses
P = Losses from Point Sources
S = Losses from Scattered dwellings
B = Losses from Background/natural areas
R = Retention in lakes and rivers
D = atmospheric Deposition on freshwater

Total annual N and P losses (ton N or P per year)

Calibration and validation using split-sample technique



Calibration

(1990-1994)

Nash SuttCliff: 0,82

Validation

(1995-2000)

Nash Suttcliff: 0,65

Root mean squared error. The root mean squared error (RMSE) is a measure of accuracy and is given by:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}$$

where n is the number of data points, O_i is the average observation for year i and P_i is the average model prediction for year i. The lower limit for RMSE is zero. Lower values indicate greater accuracy.

Mean error. The mean error (ME) is a measure of systematic error or bias:

$$\mathrm{ME} = \frac{1}{n}\sum\nolimits_{i=1}^{n}(O_i - P_i)$$

ME < 0 denotes overestimation and ME > 0 underestimation. Its optimum value is zero.

Mean absolute error. The mean absolute error (MAE) is given by:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i|$$

Similar to the lower limit for the RMSE, the optimum value of the MAE is zero. However, the MAE is less susceptible to large errors since the errors are not squared.

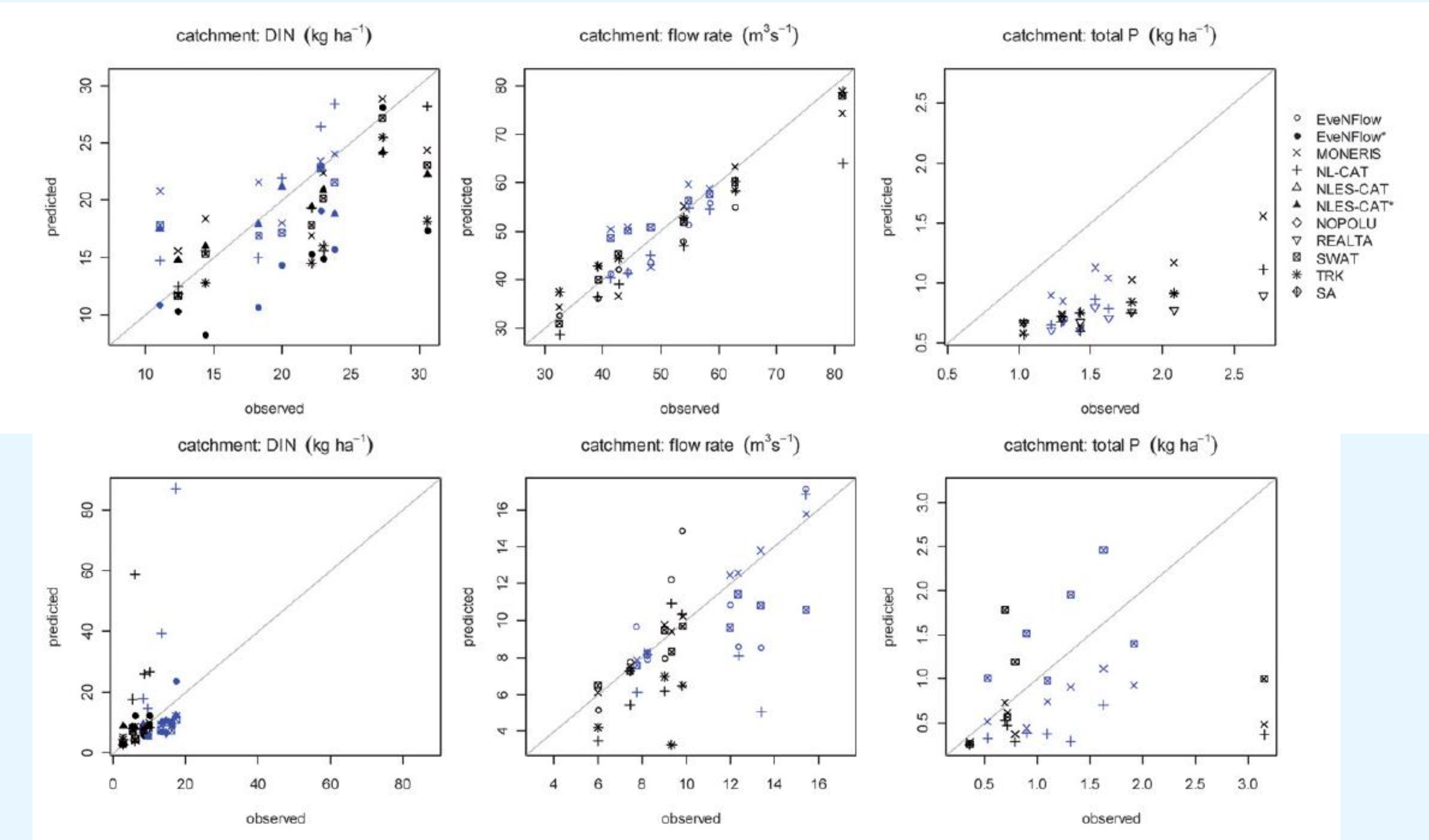
Nash–Suttcliffe's model efficiency. Nash–Suttcliffe's model efficiency (NS)[12] is

$$\mathrm{NS} = \frac{\sum_{i=1}^{n}(O_i - \bar{O})^2 - \sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

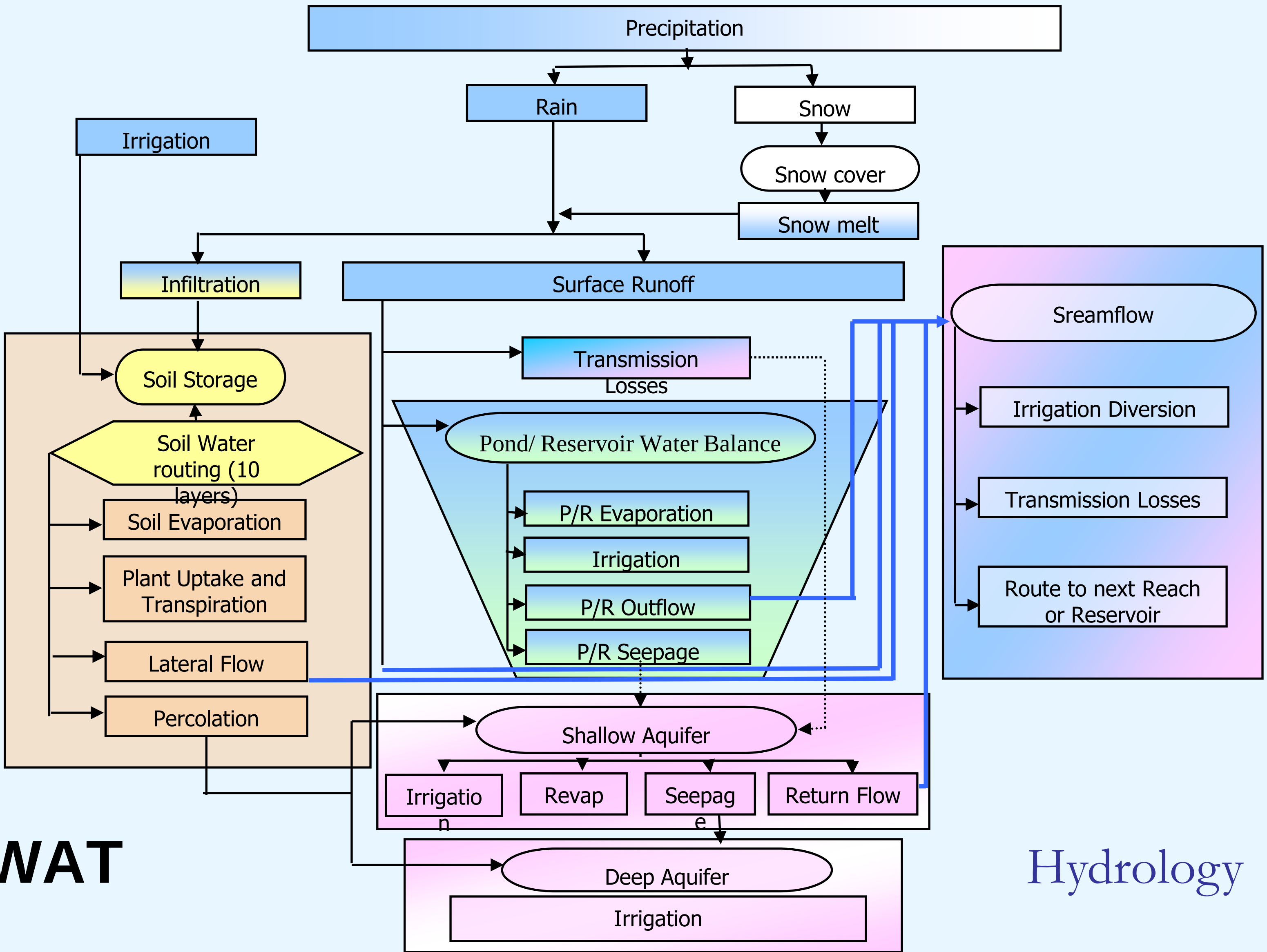
where $\bar{O}$ is given by:

$$\bar{O} = \frac{1}{n}\sum_{i=1}^{n} O_i$$

Predicted versus observed annual model results for a Norwegian and an English catchment modelled with different models



Level of complexity: High (SWAT)



SWAT

Hydrology

Table 3 Overview of the potential suitability of the models to assess the impact of nutrient losses from agricultural land to surface waters for different type of scenarios[a]

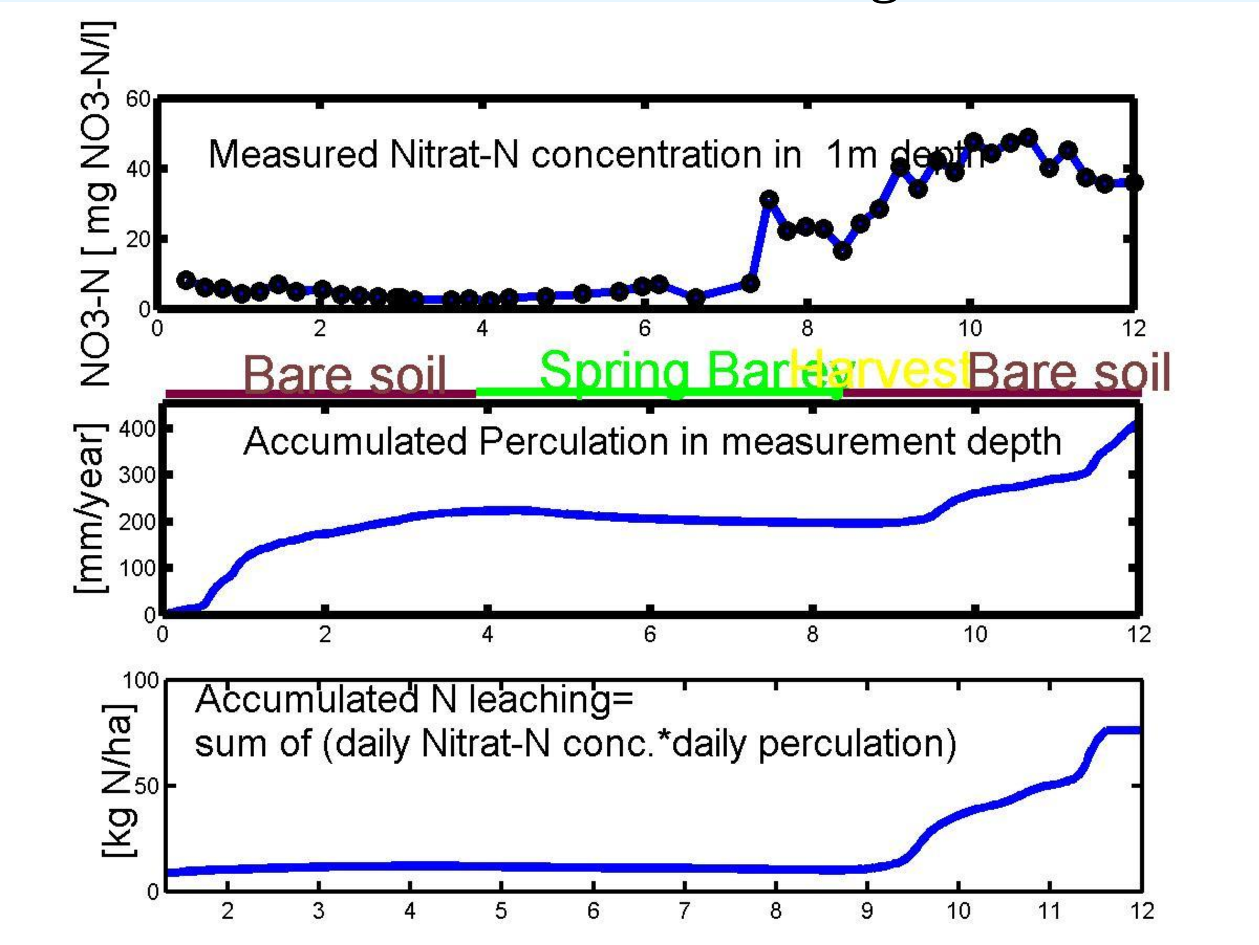
Model	Nutrient management	Land-use changes	Water measures
EveNFlow – N	o	+	+
MONERIS – N	+	+	+
MONERIS – P	+	+	+
NLCAT – N	++	++	++
NLCAT – P	++	+	++
NLES-CAT – N	+	o	–
NOPOLU – N	o	o	–
NOPOLU – P	–	–	–
REALTA – P	–	–	–
SA – N	–	–	–
SA – P	–	–	–
SWAT – N	++	++	++
SWAT – P	+	+	++
TRK – N	++	++	++
TRK – P	–	–	–

[a] ++ = highly capable (*e.g.* dynamic effects on turnover are modelled), + = capable (key processes are considered, at least in a lumped manner), o = partially capable (*e.g.* only long-term effects assessed without recalibration), – = not capable (model does not take account of management practices).

Data for NLES4 leaching model

Measured N leaching from field trials

Estimation of N leaching

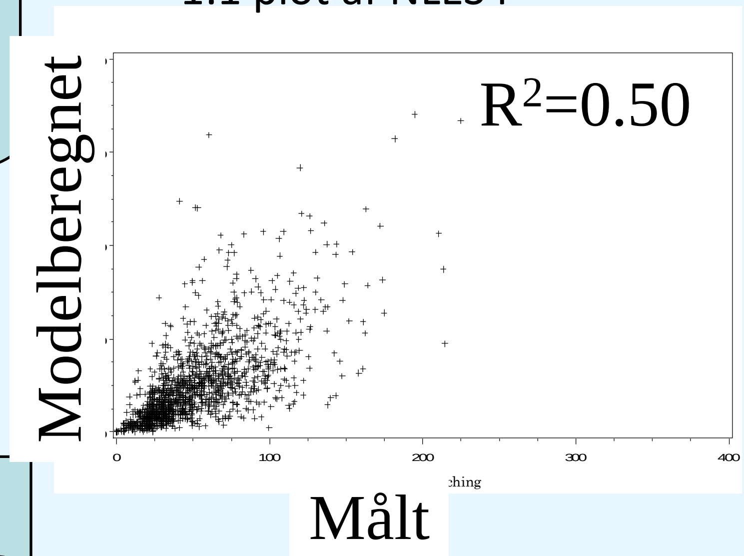


Empirical N leaching model NLES4

DJF og DMU data
1467 Obs.

Multiple regressions analyse NLES4

1:1 plot af NLES4



NLES4 parameters

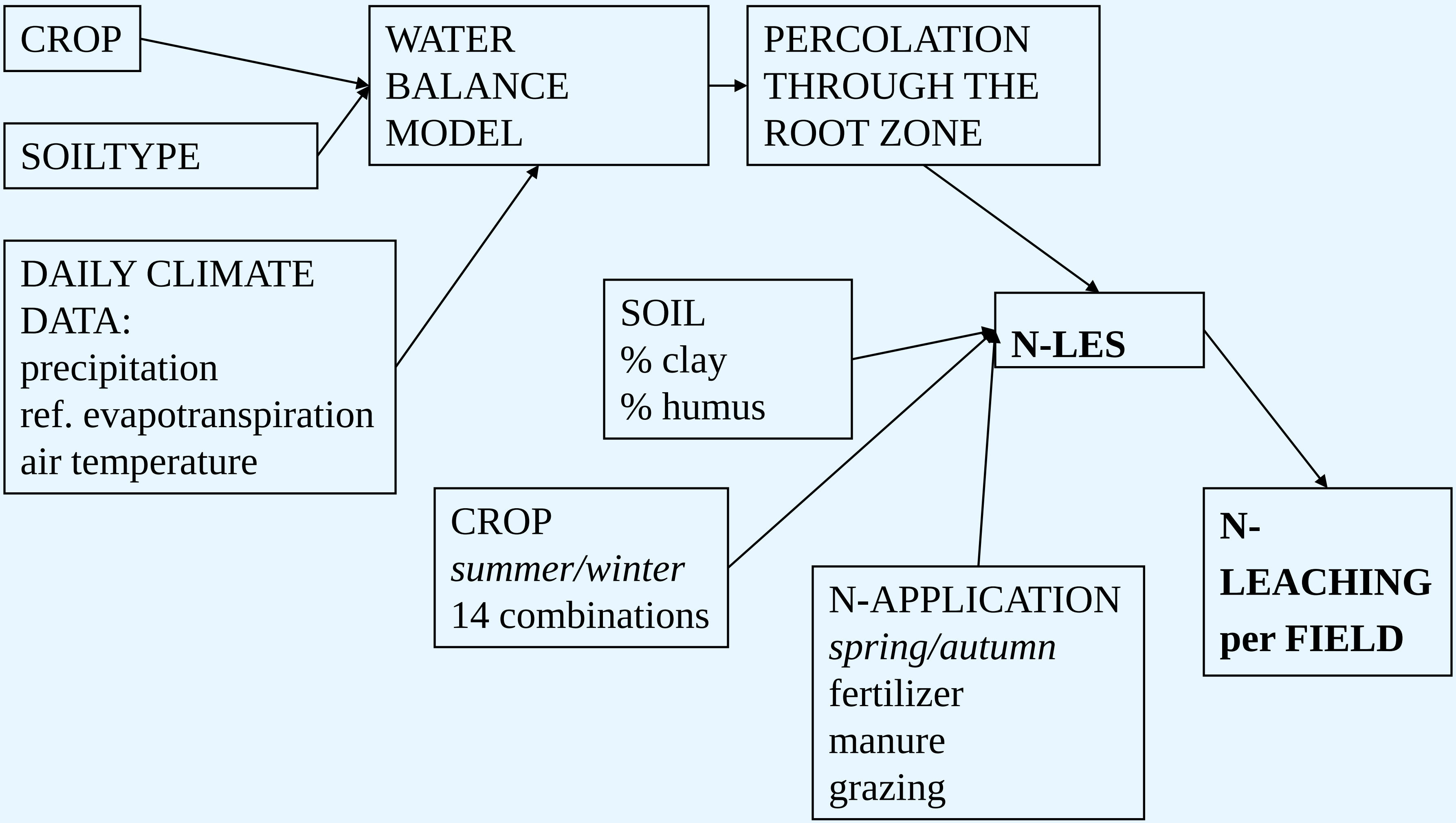
Percolation of water from root zone
Soil type(clay , organic C, C/N-ratio)
N input to field (animal manure-N & mineral-N, time of spreading)
Historical N inputs
Crop rotation
Technology

N-LES

$$Y = (80.2 + 0.00135*M^2 + 0.00051*S^2 + k_1*A + 1.0*F + k_2*P) * k_3 * (1-\exp(-Q*0.00473)) * \exp(-0.030*C) * \exp(-0.094*H) * 1.085$$

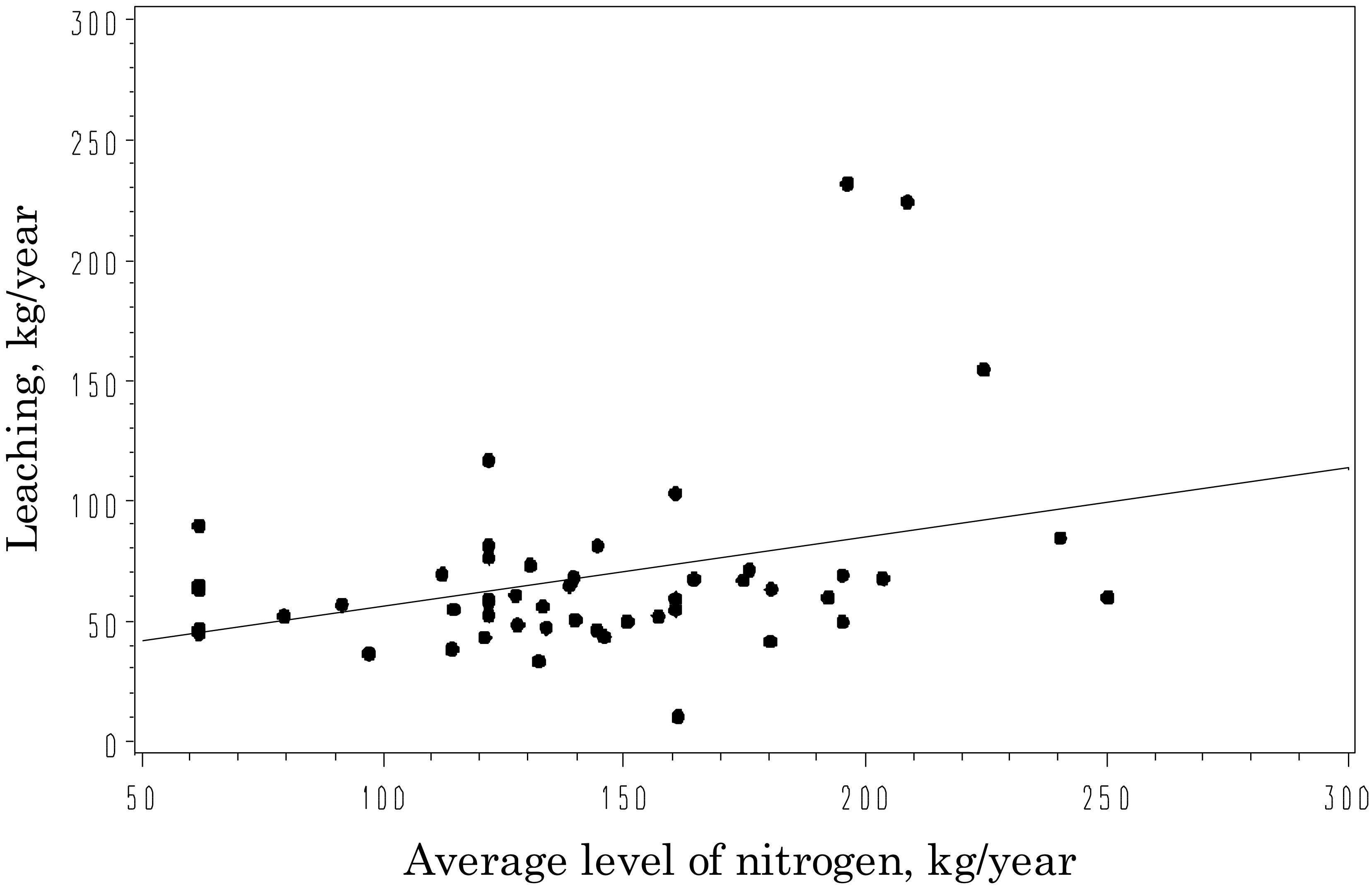
Y: leaching from root zone, kg N $ha^{-1}yr^{-1}$
M: level of total-N added in the crop rotation, kg N $ha^{-1}yr^{-1}$
S: spring fertilization, kg N $ha^{-1}yr^{-1}$
k_1: constant dependent on soil type
A: autumn fertilization, kg N $ha^{-1}yr^{-1}$
F: N left on the field by grazing animals, kg N $ha^{-1}yr^{-1}$
k_2: constant dependent on crop type
P: effect of ploughing. A function of crop, soil and time since ploughing
k_3: constant dependent on crop type
Q: water percolation through the root zone, mm yr^{-1}
C: percentage of clay in soil
H: percentage of humus in soil

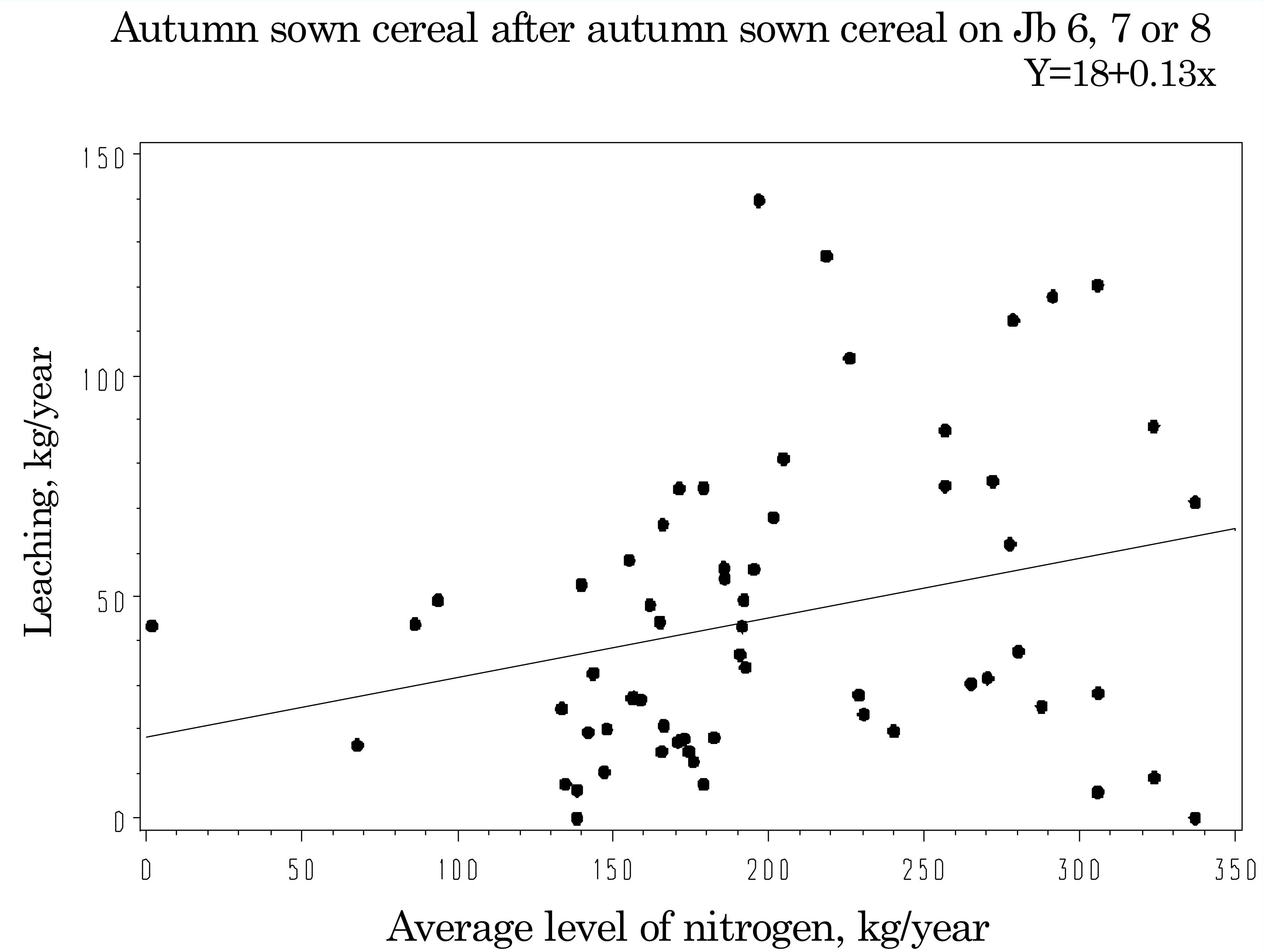
Model calculations with N-LES



Spring sown cereal after spring sown cereal on Jb 1

$Y=28+0.29x$




Autumn sown cereal after autumn sown cereal on Jb 6, 7 or 8
Y=18+0.13x
Leaching, kg/year
Average level of nitrogen, kg/year
0
50
100
150
0
50
100
150
200
250
300
350

We model nitrogen leaching at field level and

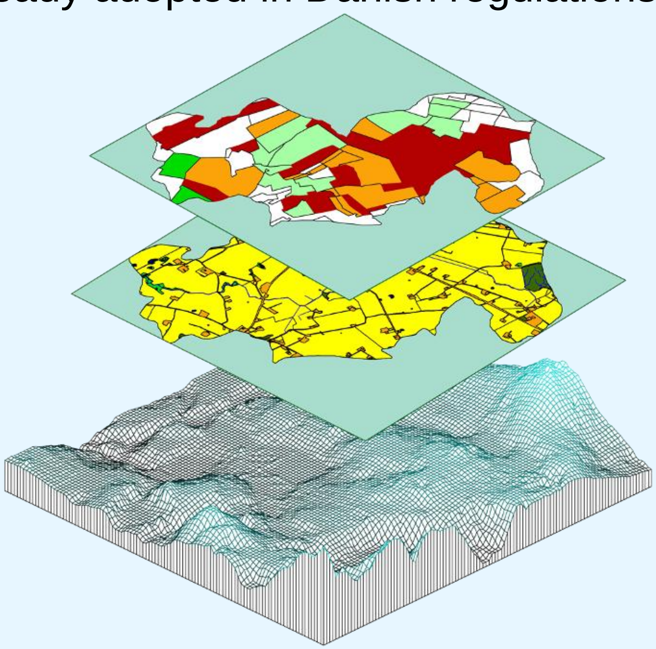
N-removal potential in freshwater

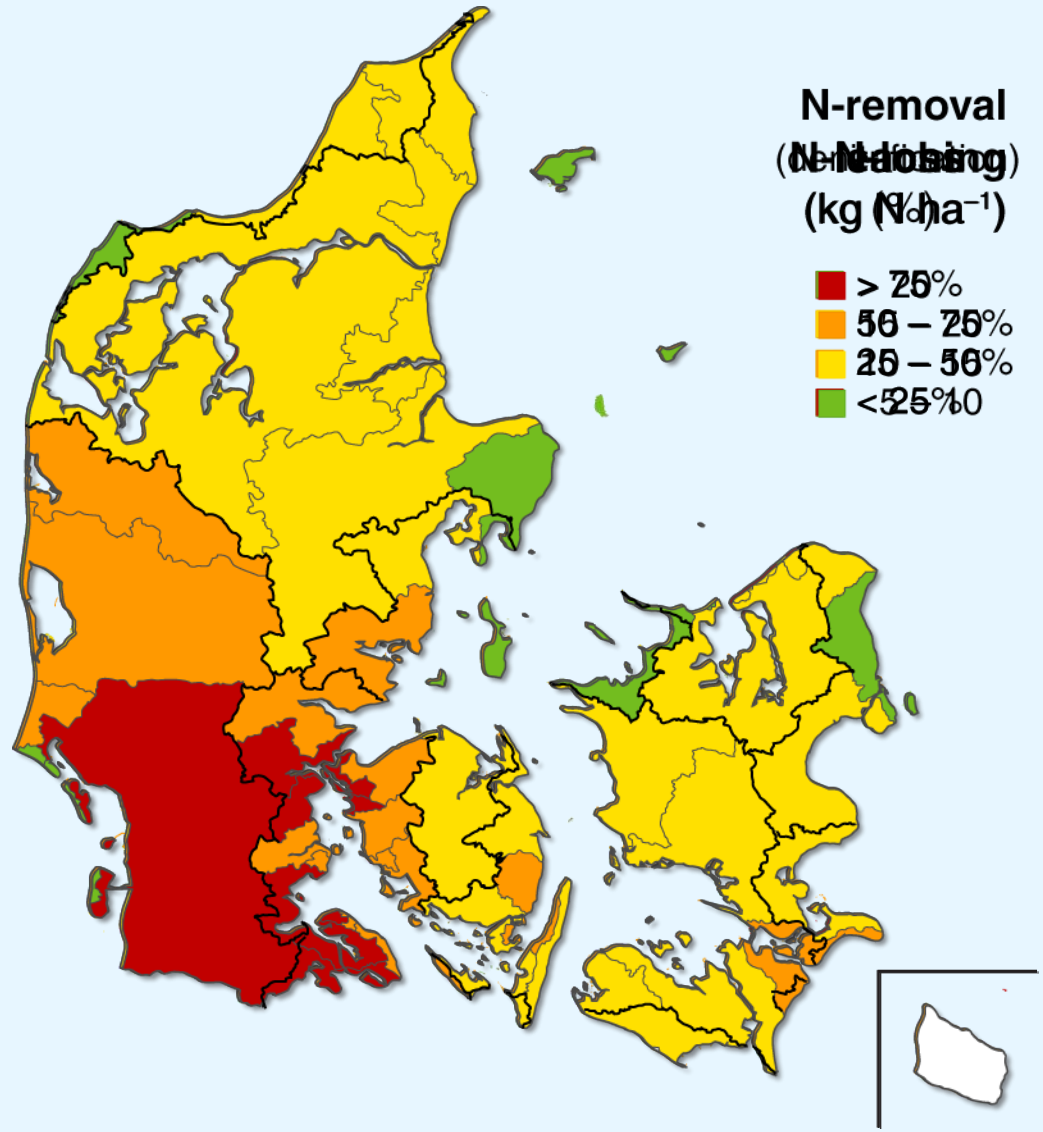
in a GIS-environment which combined

give us a mapping of high, medium and low

nitrogen risk areas for future farming

(already adopted in Danish regulations).





Nitrogen

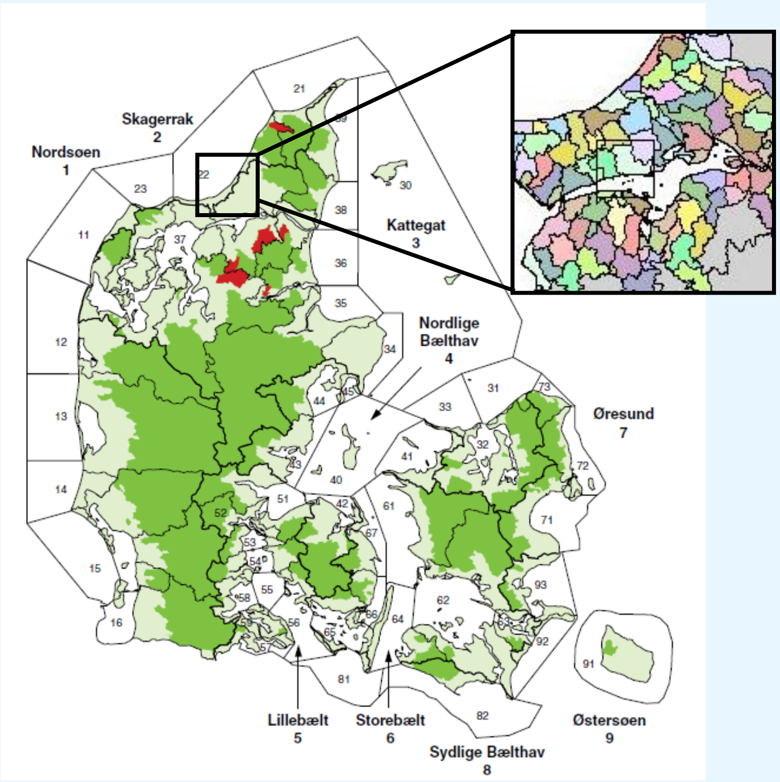
Land based nitrogen loading from a catchment to a coastal water:

Nnet-loading = Ngross outlet – Nretention

Modelled for small catchments (25 km^2) and then aggregating results for larger catchments

N retention can be permanent (i.e. denitrification) or temporal due to the residence time of N (and water) in the hydrological cycle.

Model for small sub-catchments

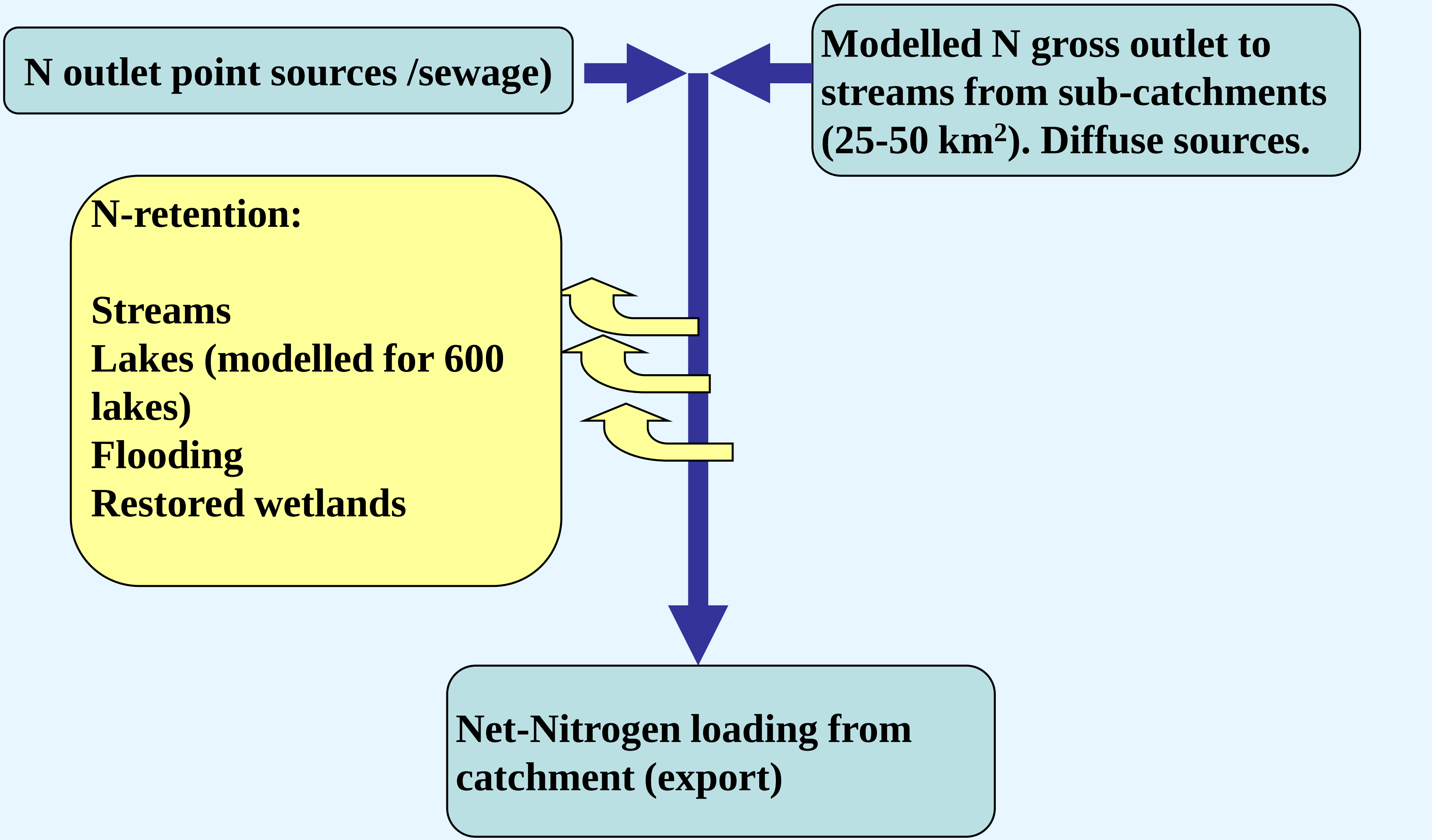


Model for small sub-catchments

2.663 sub-catchments

Aggregate results for larger catchments

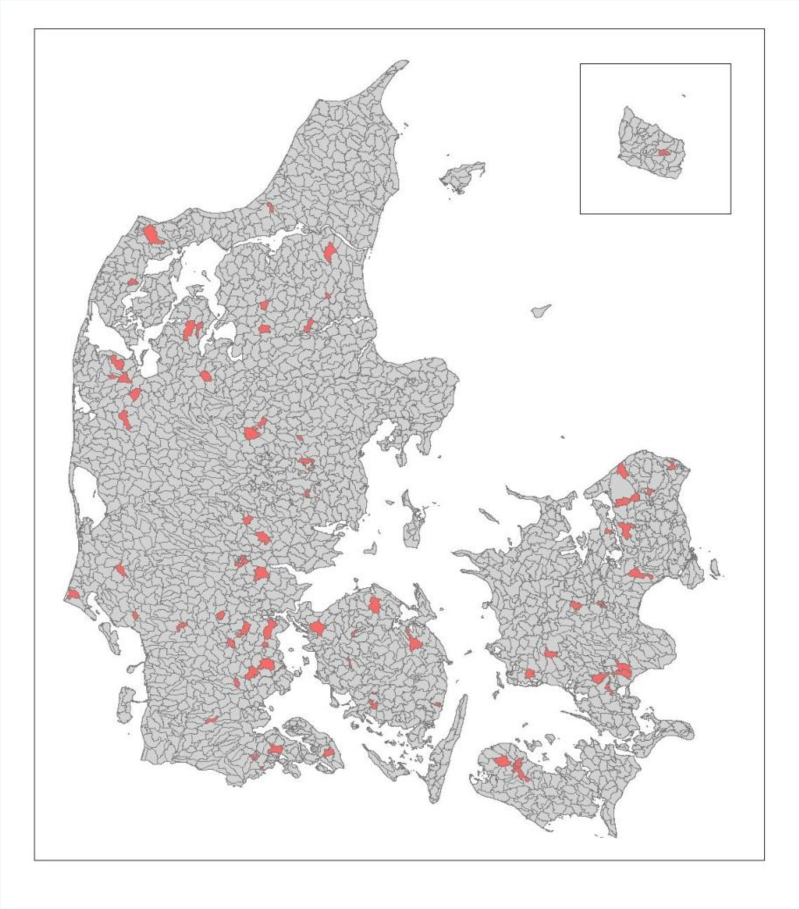
Nitrogen Loading NP-DK model



Modelled N gross outlet to streams from subcatchments (25-50 km^2). Diffuse sources.

Empirical Model (84 small catchments):

Nitrogen **concentration** (monthly)



Modelled N gross outlet to streams from subcatchments (25-50 km^2). Diffuse sources.

Empirical Model

(84 small catchments):

Nitrogen **concentration** (monthly) $R^2 = 0,43$

Variables

Farmed land (%)

Nitrogen surplus in agriculture (annual national figures)

Precipitation

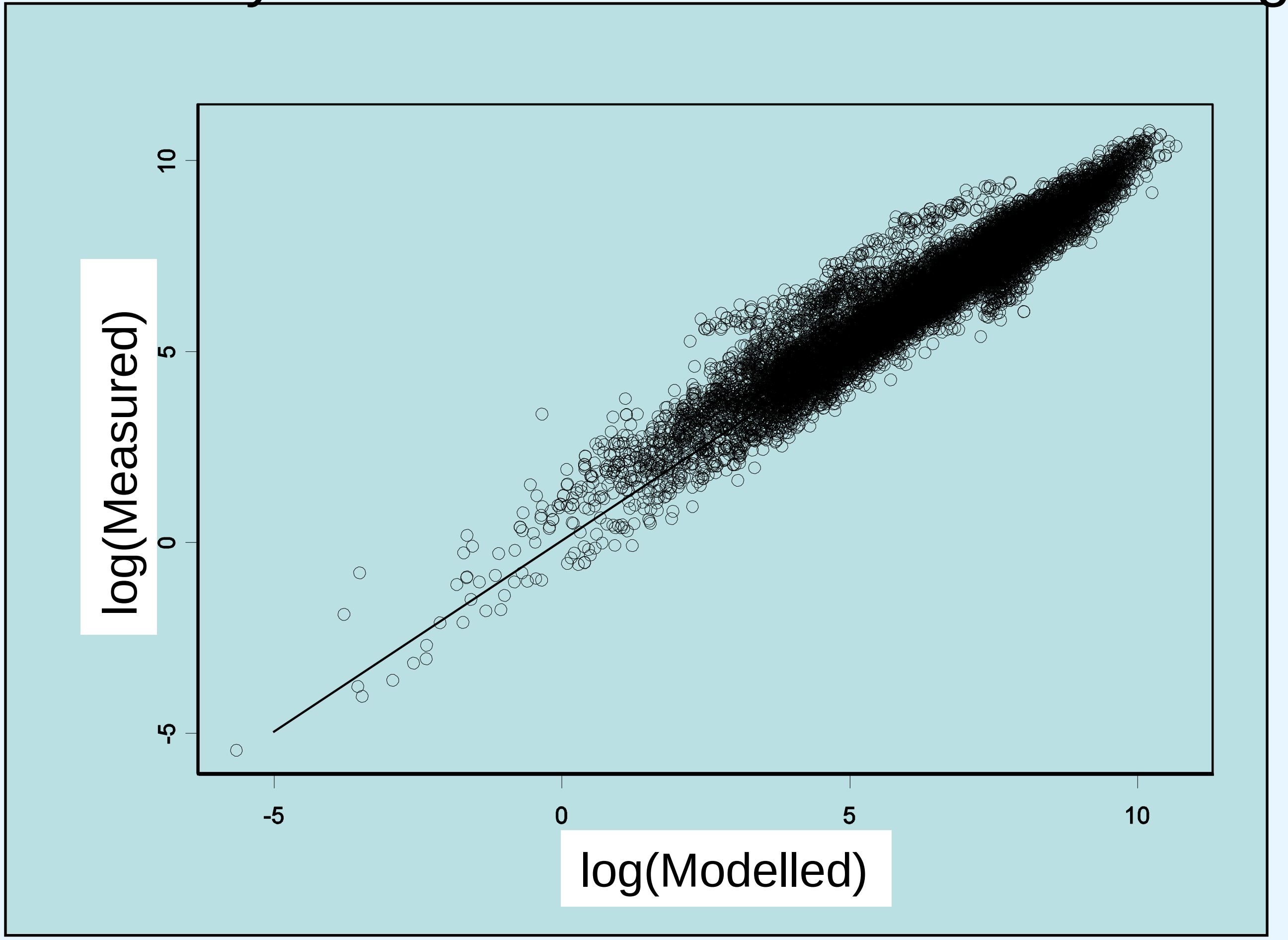
Potentiel tile drained areas (class)

Temperature (air)

Sandy soil (%)

Modelled and Measured Nitrogen Loading:

Monthly concentration * freshwater discharge



18144 observations

84 model catchments

General Results 1990-2008

Gross outlets of N to streams	1000 t N/y
Diffuse sources (modelled)	92*
Sewage from point sources **	10
Total outlet	**102**

Retention	
Small lakes	0,6
Large lakes (600)	7,8
Streams	15,1
Restored wet-lands (2)	0,1
Flooding	0,2
Total retention, 10^3 t N/år	**23,7**

N-loading coastal waters

78.000 t N/year

•Modelled estimates for 'measured' catchment adjusted to measured values….

•** including direct outlets to coastal waters

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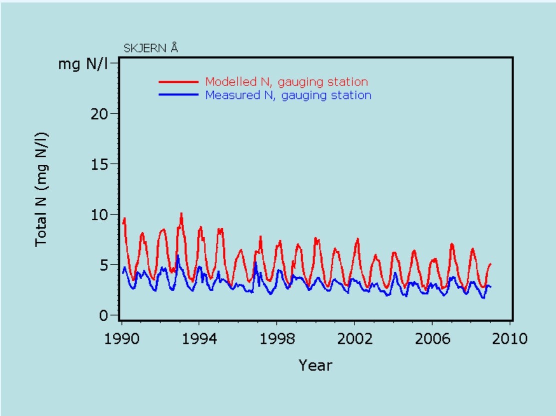
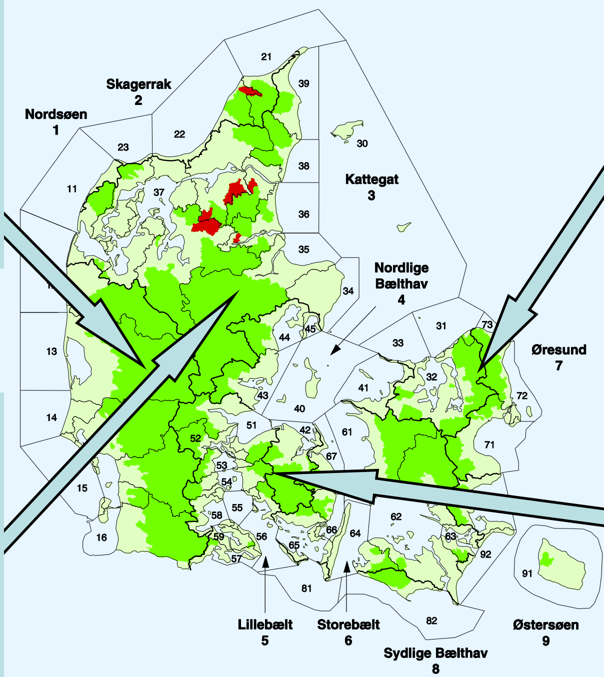
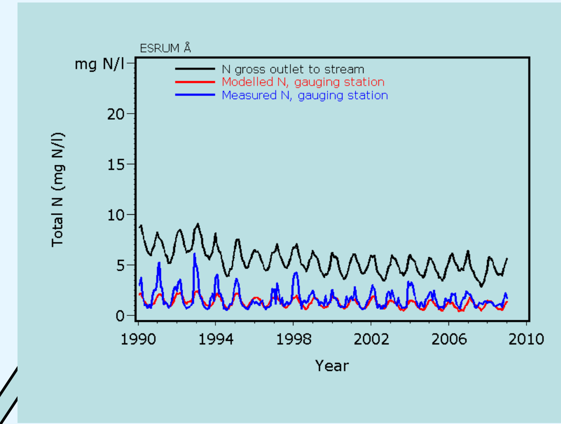
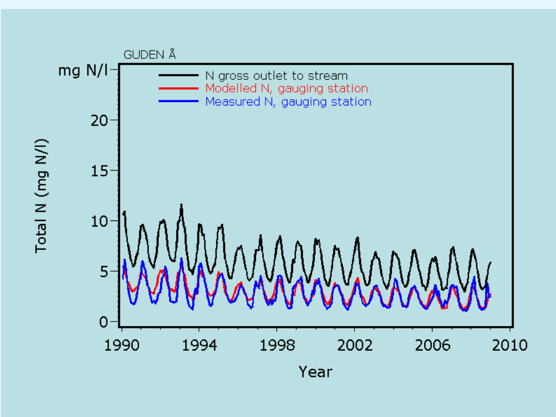
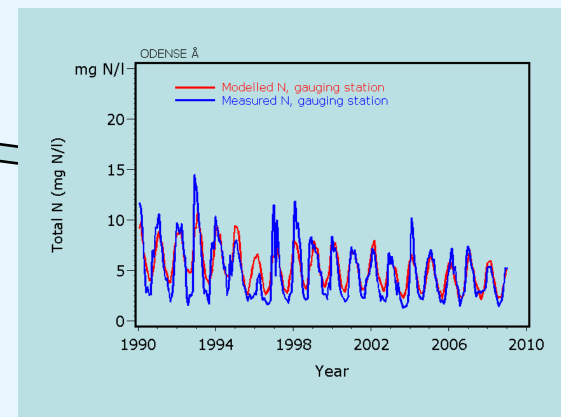
Model Performance:







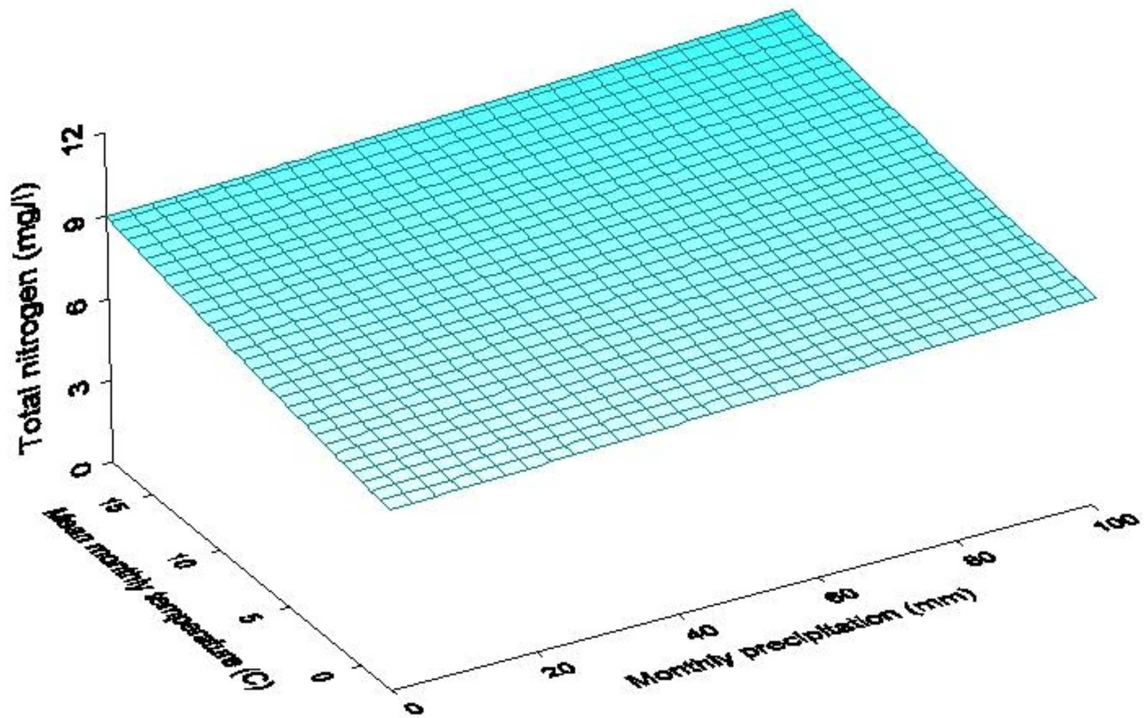




Nitrogen response surfaces for changes in precipitation and air temperature – the DK-QN model concept

July

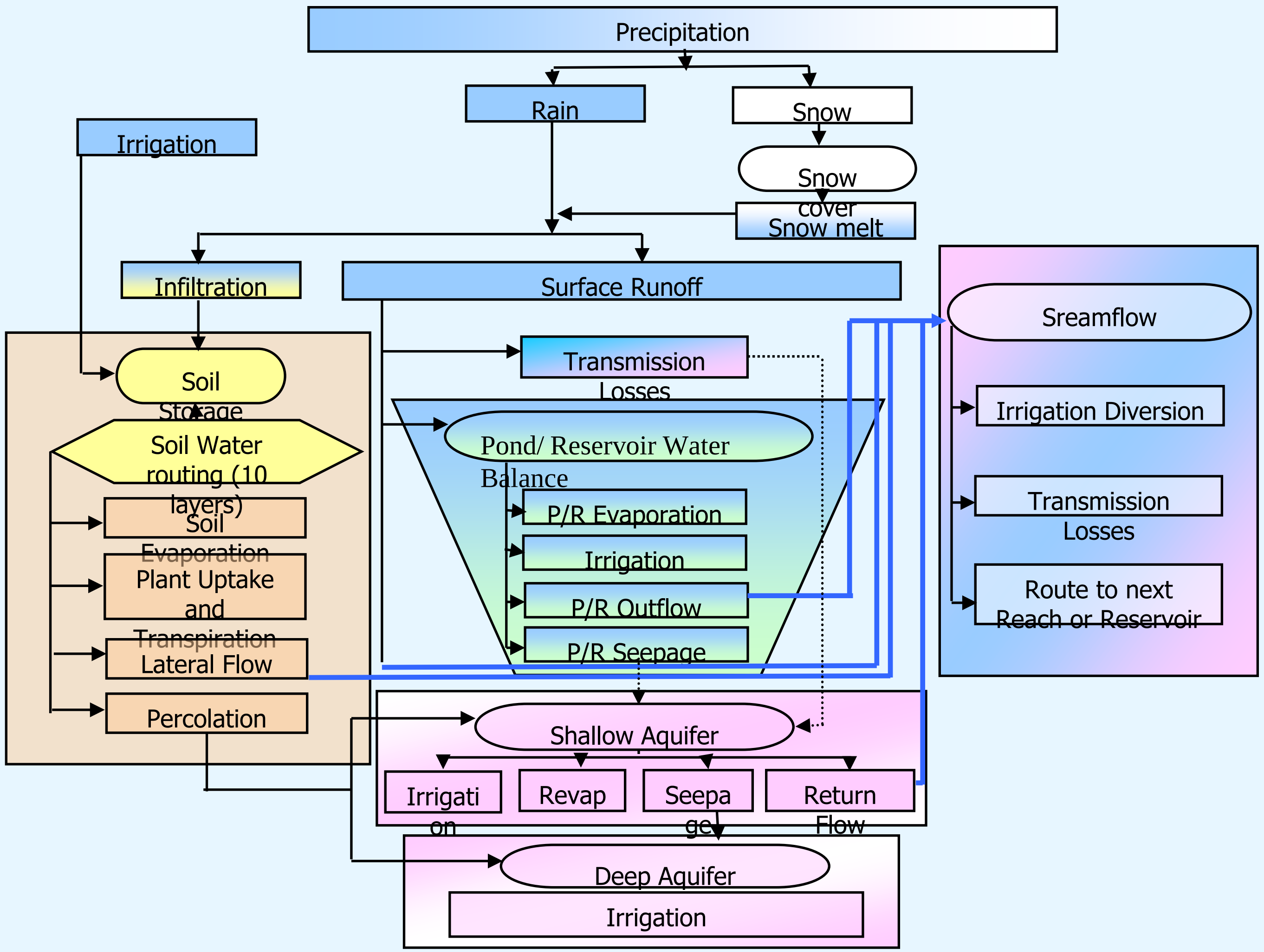
January



Windolf et al., 2011. J. Environ. Mon.


Time for a break ?
MAC

More complex models SWAT, NL-CAT, MIKE are data hungry for modelling



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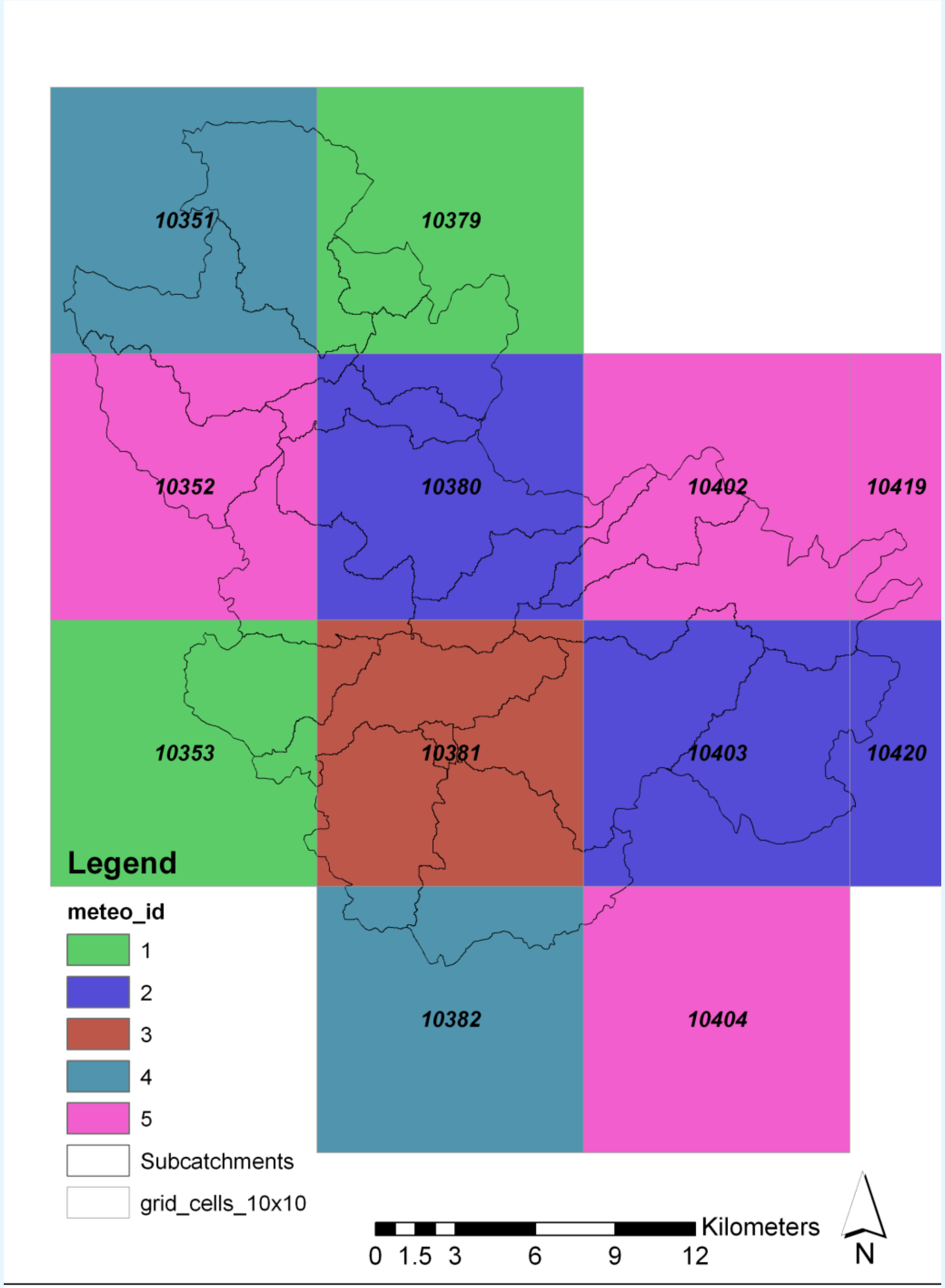
Odense-catchment

Meteo

districts



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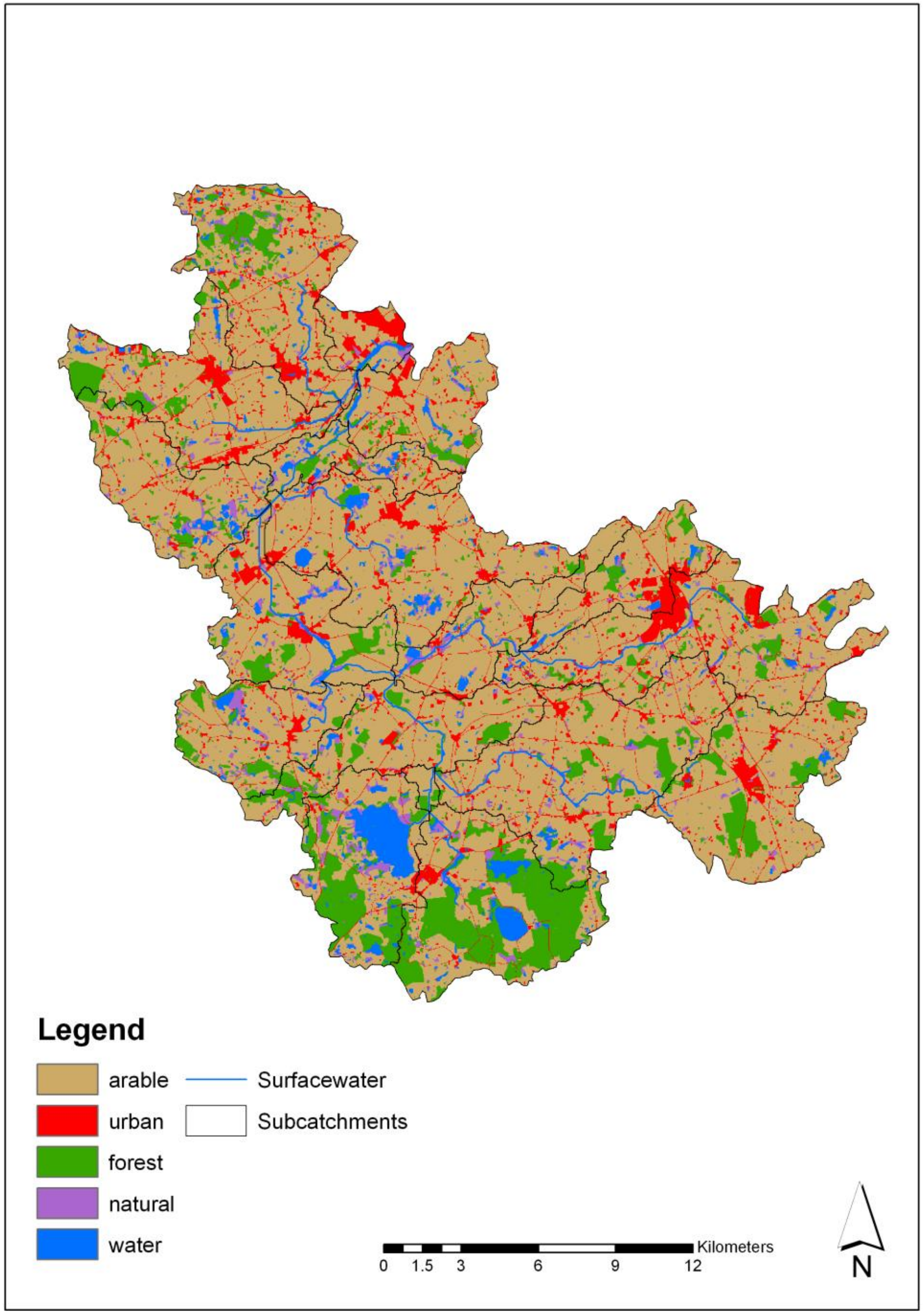
Odense-catchment

Land use



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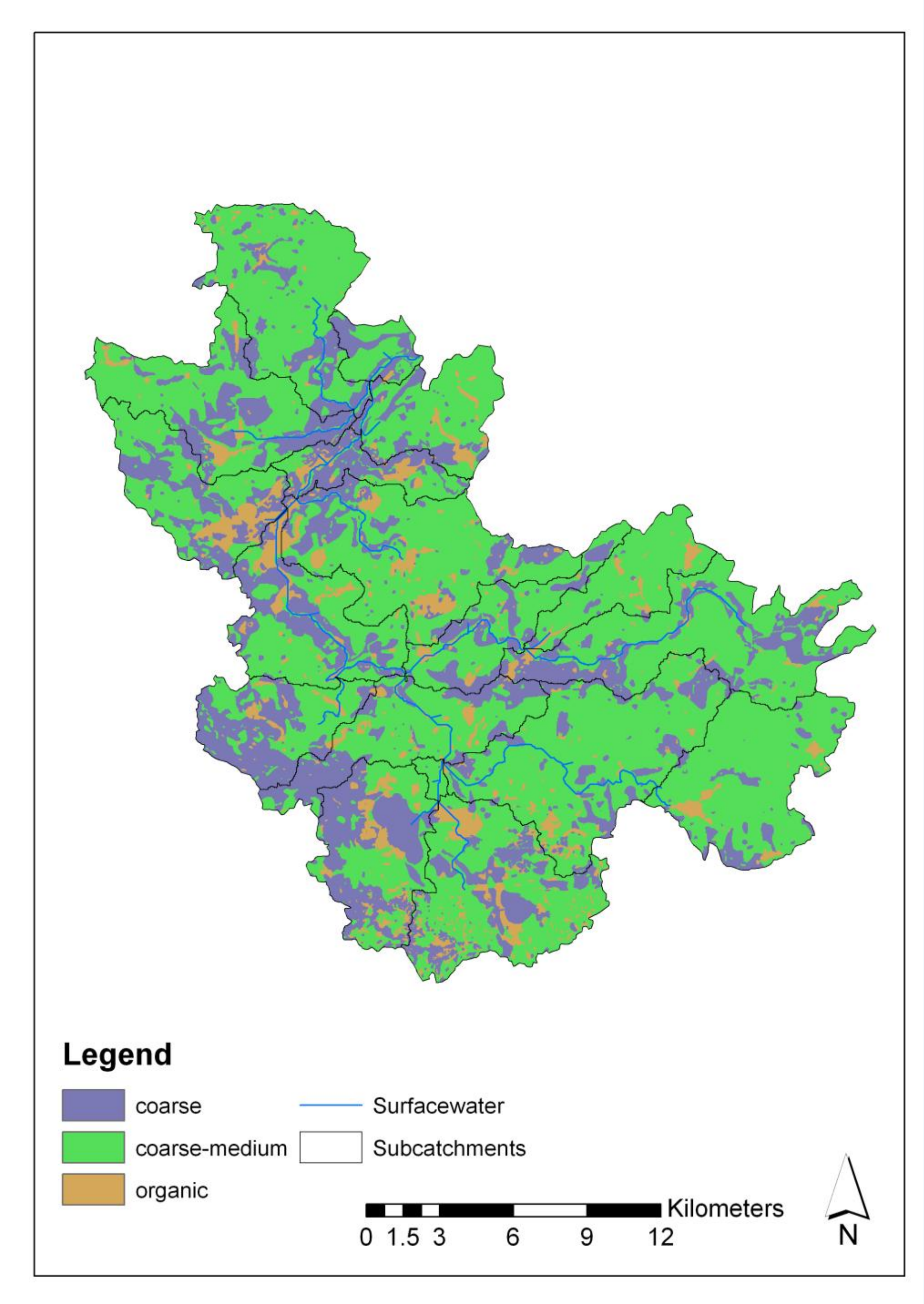
Odense-catchment

Soil data



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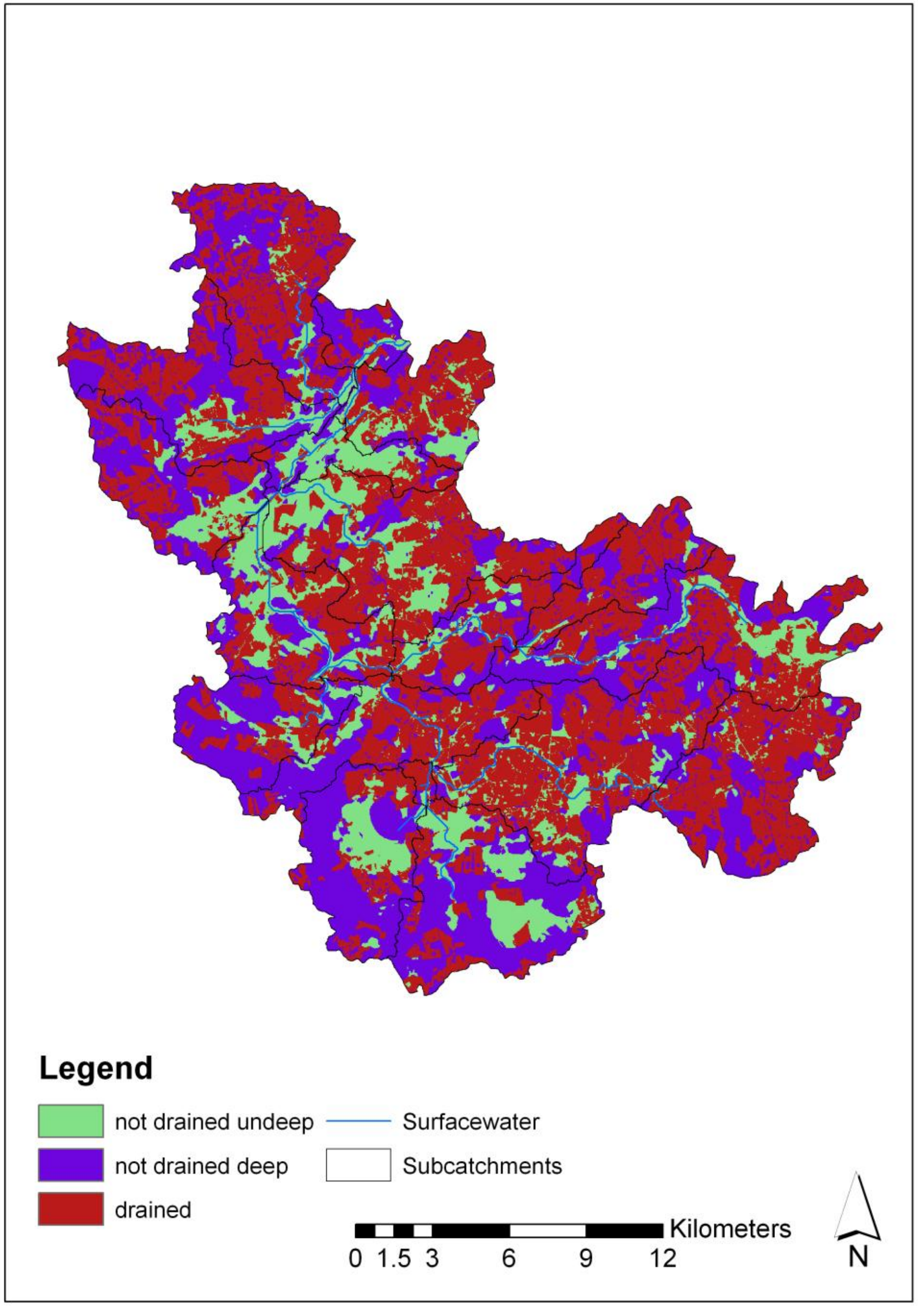
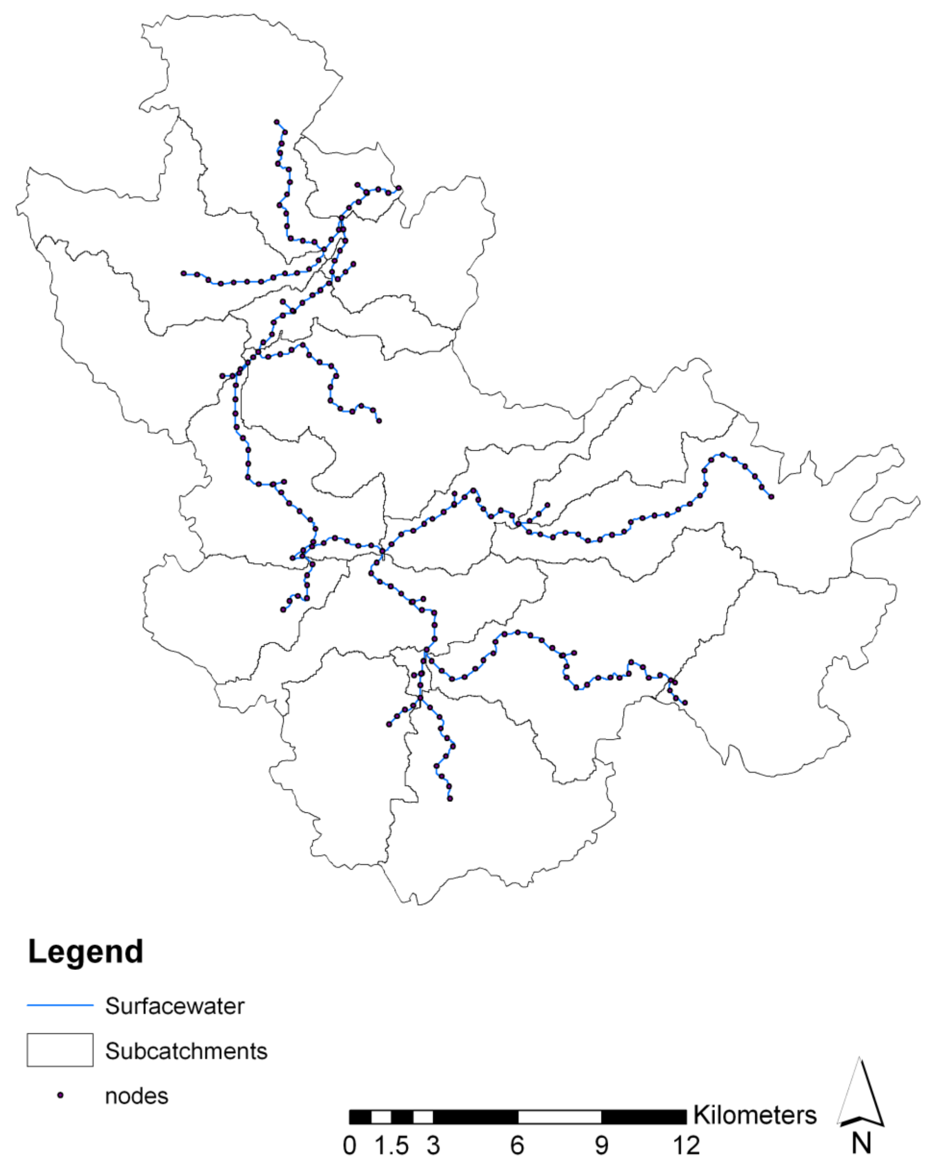
Odense-catchment

Groundwater classes



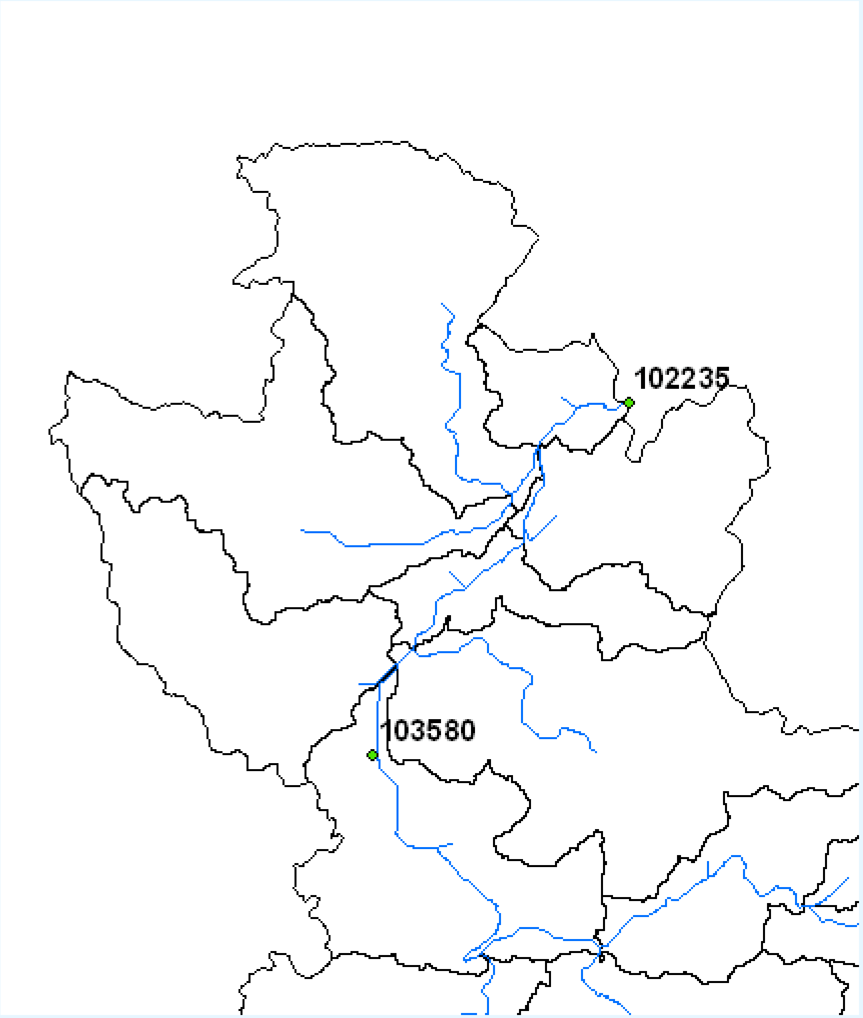
Odense-catchment

Surface water network

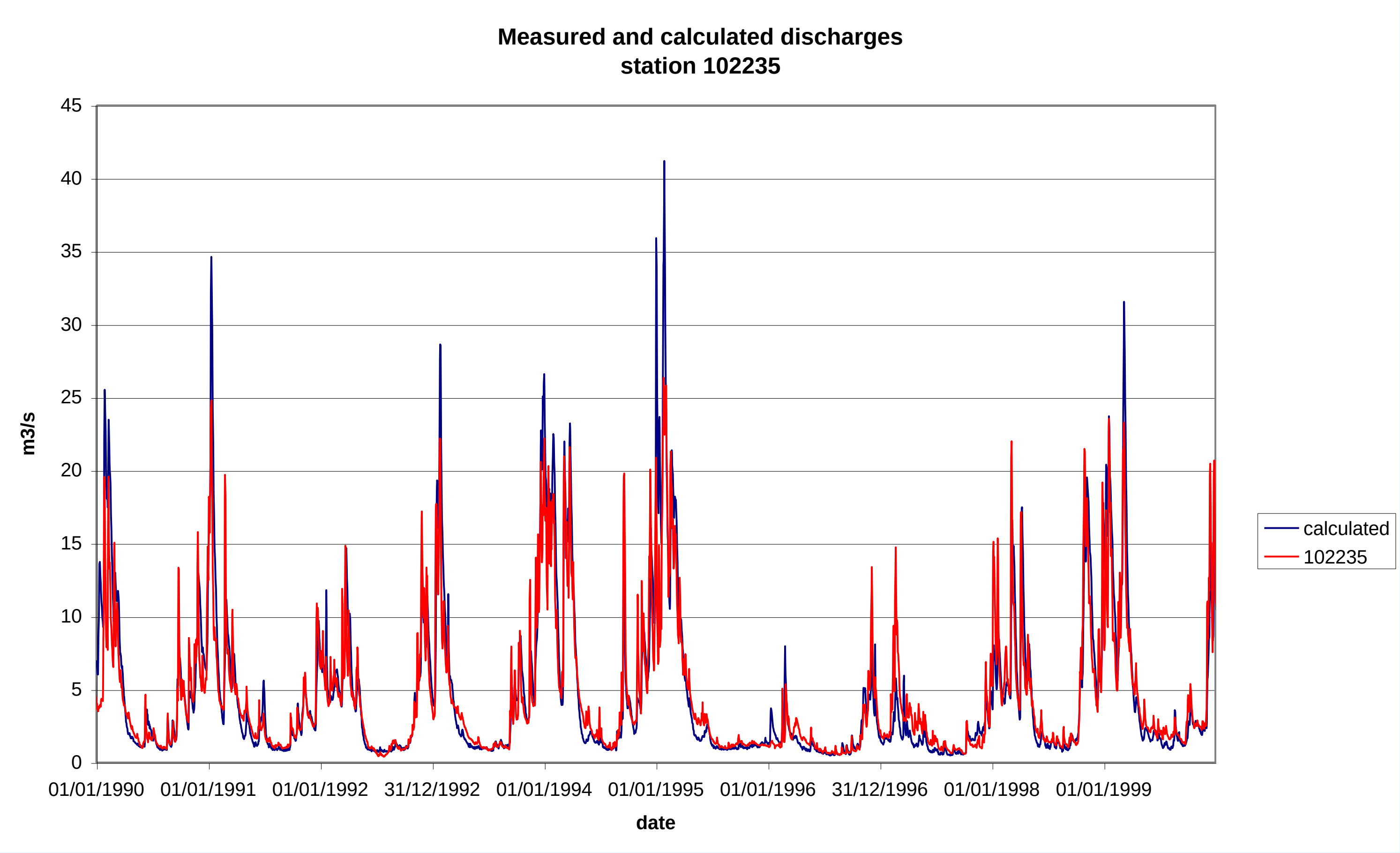


Odense-catchment

Selected surface water stations



Odense-catchment



daily flows at outlet

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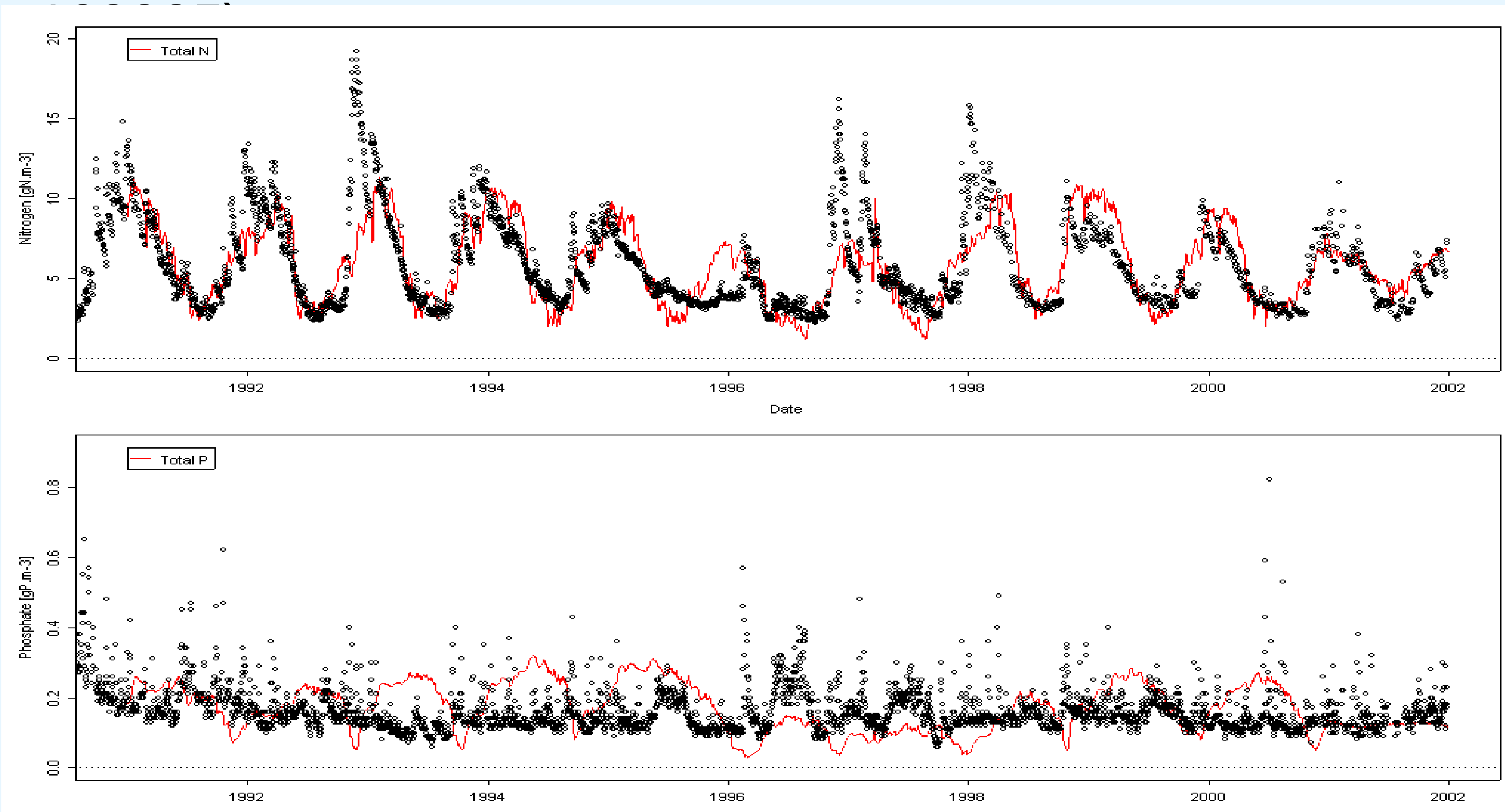
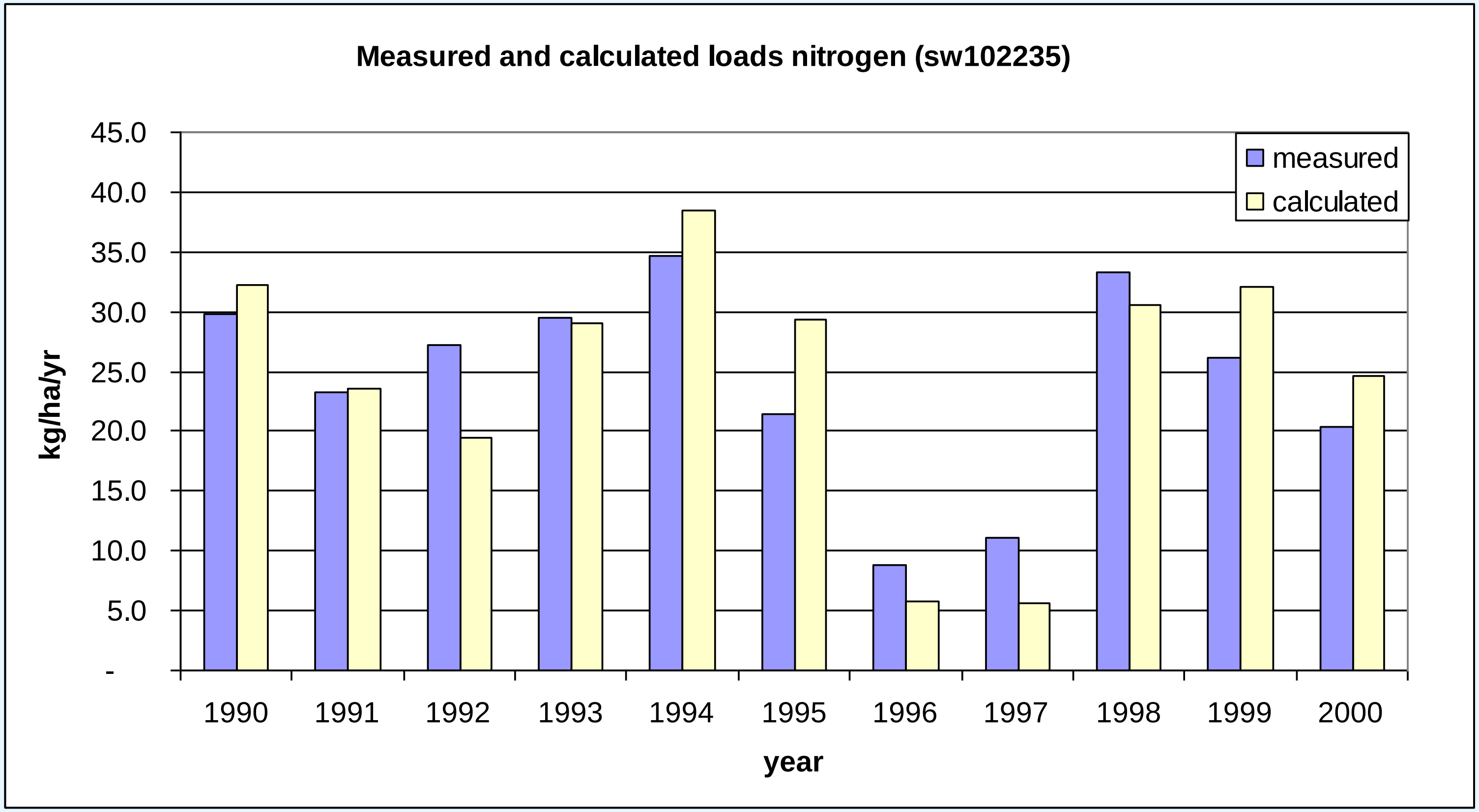
Odense-catchment

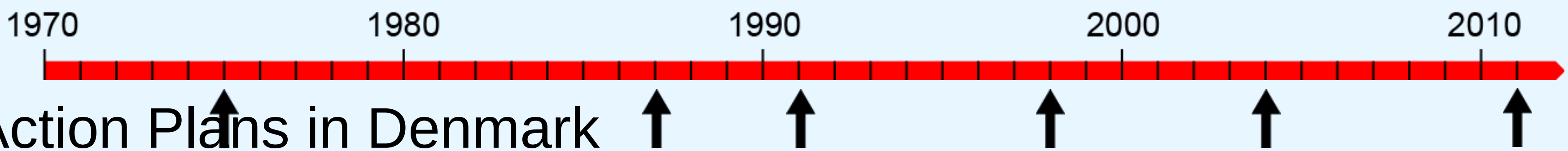
daily concentrations at outlet (station



Odense-catchment

Yearly loads N at outlet





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**

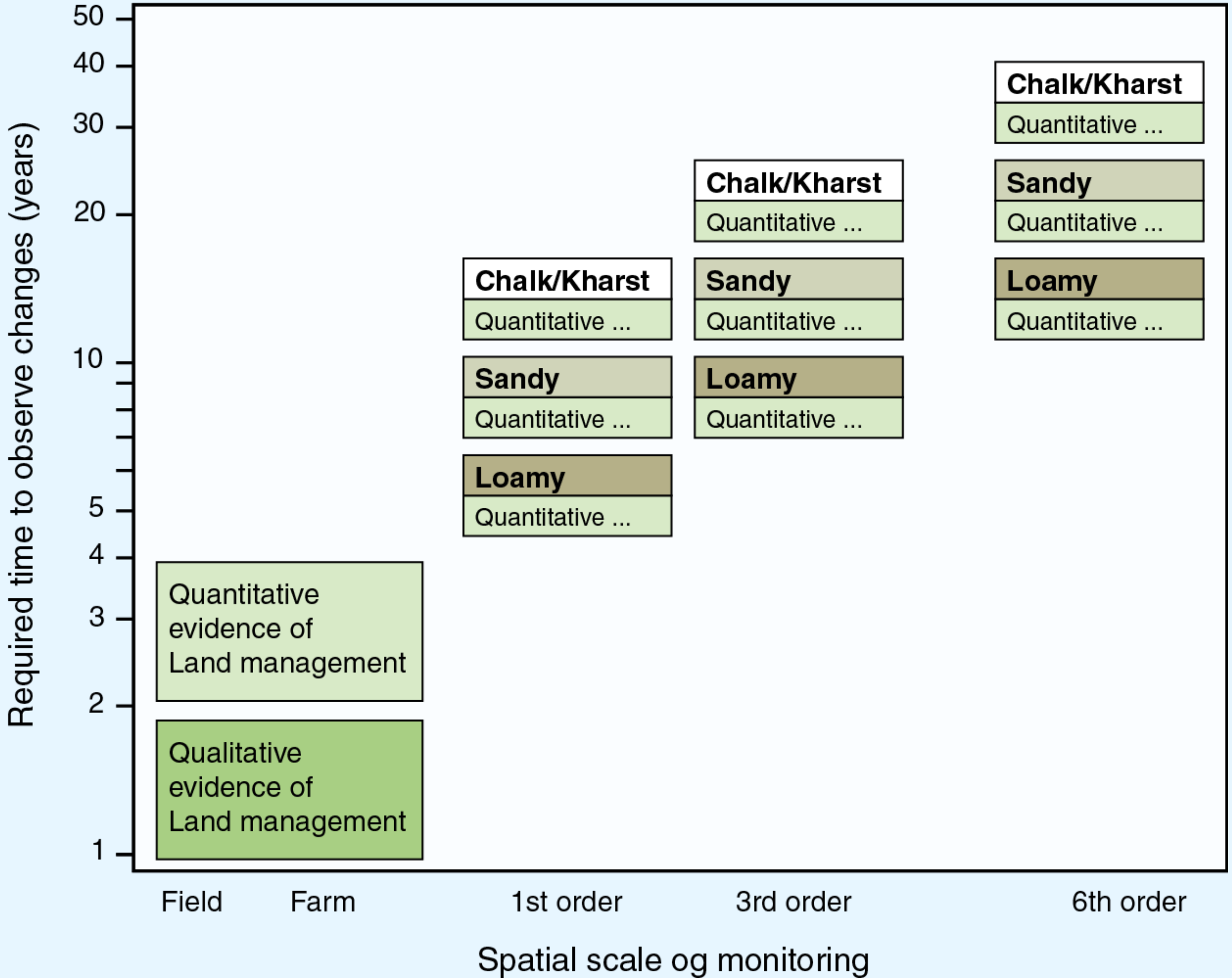
1998 National Action Plan II
- **Subsidies to establish 16,000 ha of wetlands**
- **Livestock density of maximum 1.7 Livestock Units**
- **Plant available N to crops 10% below economic optimum**

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%)**

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

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



Management of nutrients in catchments: Suite of mitigation options

List of mitigation options for nutrients

› 1. Nutrient management
› 2. Crop management
› 3. Livestock management
› 4. Soil management
› 5. Water management within agricultural land
› 6. Land use change
› 7. Landscape management
› 8. Surface water management

Livestock management – harmoni between land area and livestock density

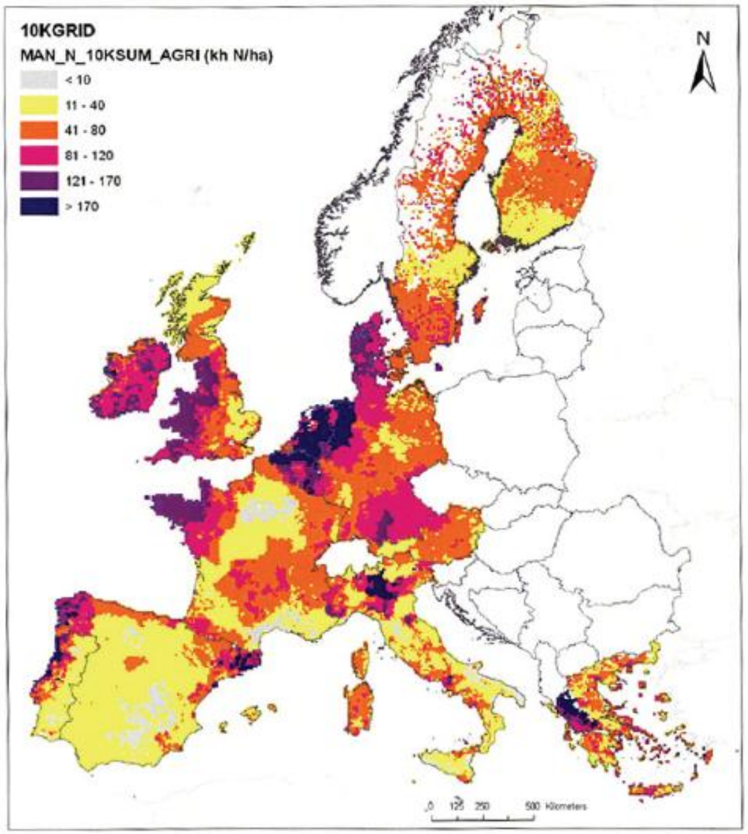


Figure 4.25 European map of nitrogen manure input per agricultural area in EU15, average on 10 km^2 area. (In Sweden and Finland the white colour indicates the absence of agricultural land within the 10 km^2 area).

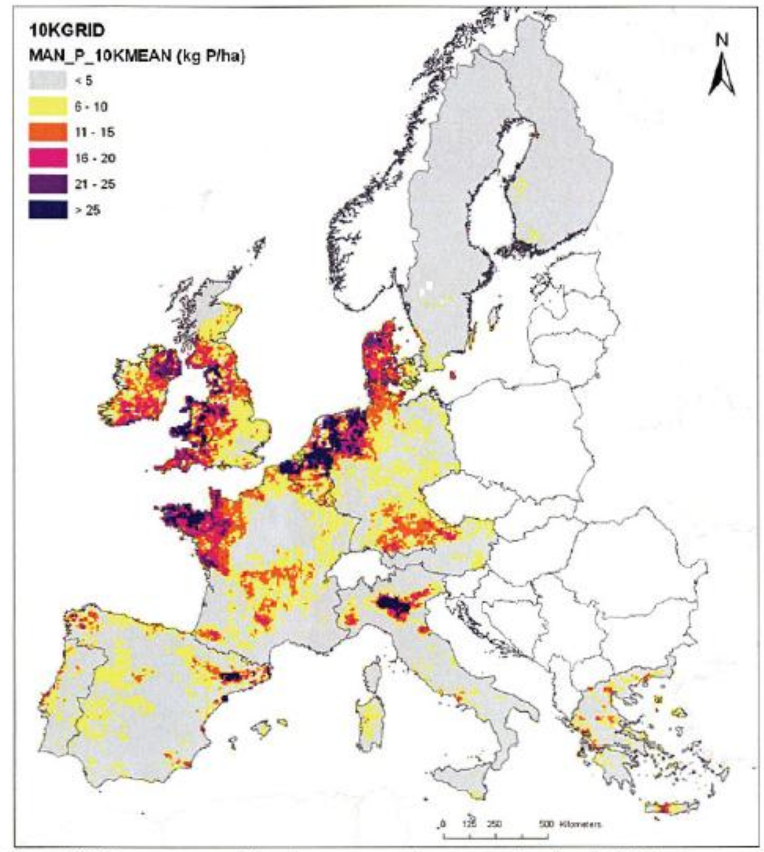


Figure 4.26 European map of phosphorus manure input per total surface in EU15, average on 10 km^2 area.

Figure 7.1

European map of input via manure of N (left) and P (right) per total surface in EU 15, average on 10 km^2 area (Grizzetti et al., 2007)

Soil management

Figure 8.1

Water quality in surface runoff from field lysimeters with winter wheat sown with shallow cultivation (1), direct drilling (2) and ploughing (3) (Grønsten et al., 2007)

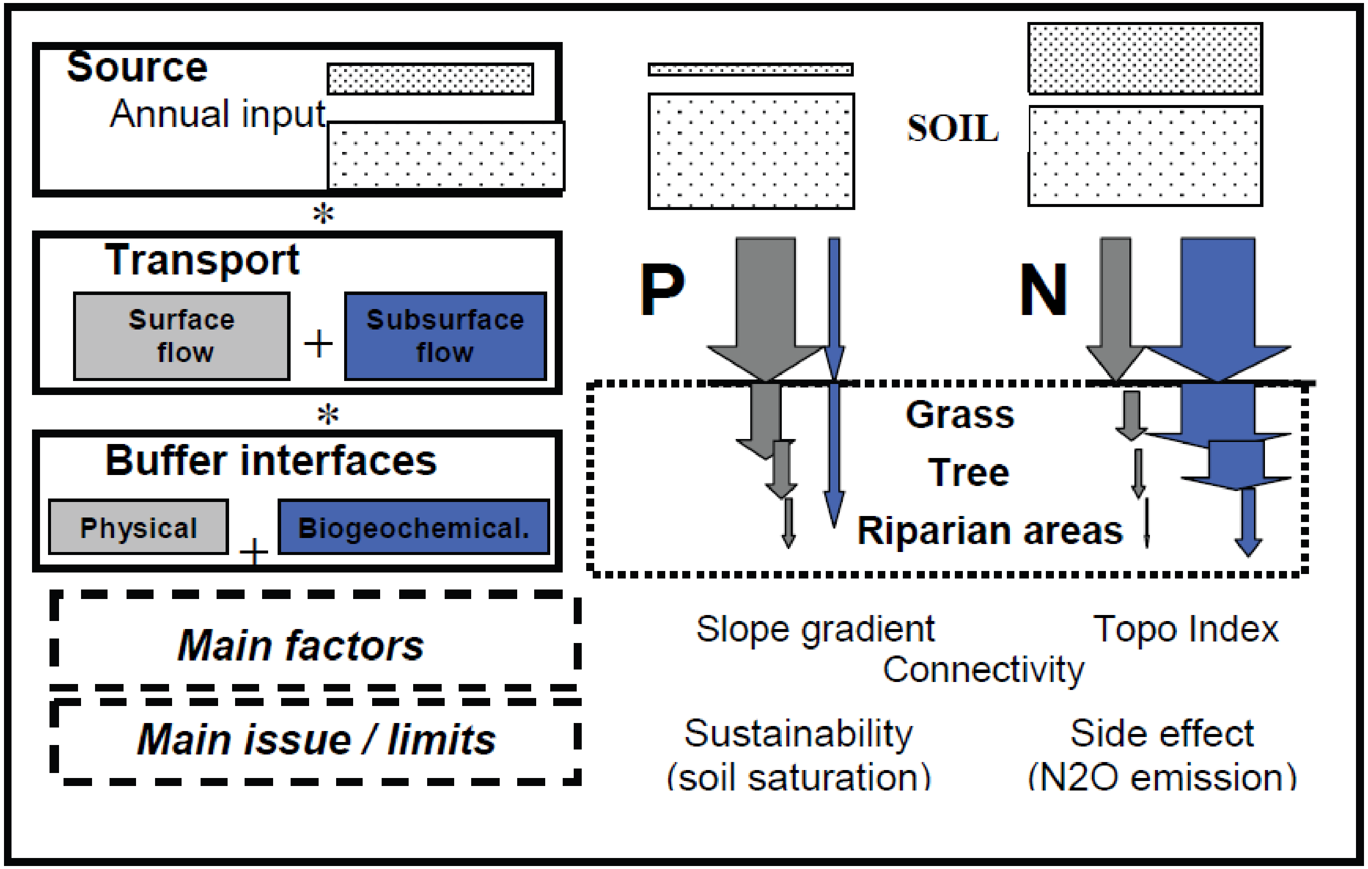


Figure 11.1

Main stages of nutrients dynamics at the landscape scale: comparison between P and N, regarding soil stocks (squares), fluxes according to flow paths (arrows) and effect of main landscape interface on fluxes

Riparian buffer functioning

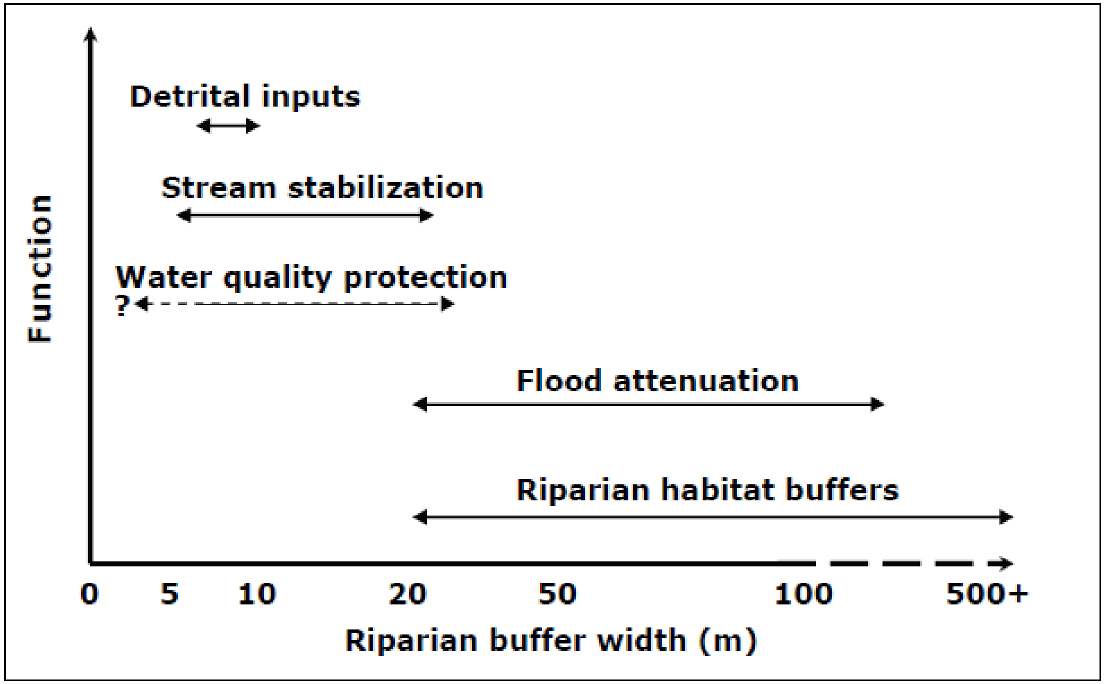


Figure 11.3

The functions that can be expected of riparian buffers according to their widths

Table 12.2

Nitrogen removal in the restored wetland and reduction in nitrogen leaching from changed land use estimated from a one year monitoring and mass-balance of restored wetland sites in Denmark. (After Hoffmann and Baattrup-Pedersen7)

Wetland project area	Measured N-removal	Reduction in N-leaching due to changed land use	Total change in nitrogen loss
		(kg N ha/yr)	
Egebjerg enge	53	-	53
Kappel	14	25	39
Geddebækken	90	35	125
Horne Mølleå	220	35	255
Karlsmosen	337	35	372
Lindkær	191	35	226
Snaremose ”Sø”	256	35	291
Ulleruplund	133	37	170
Gammelby Bæk	83	22	105
Nagbøl Å	163	24	187
Hjarup Bæk	170	30	200

Table 12.3

Outcome of phosphorus mass-balances for restored wetlands in Denmark after the first post-restoration year (After Hoffmann and Baattrup-Pedersen, 2007)

Measures to reduce N-leaching from root zone on agricultural land

- **Closed application periods for fertilizer and manure in rainy season and season with frozen ground.**
- **Plant catch crops after harvest**
- **Reduction of N application rate**
- **Change the crop rotation system**
- **Organic dairy farms**
- **Establish wetlands**
- **Grow forest on arable land**
- **Fallow - set aside land**

Closed periods for bringing out manure and fertilizers on fields in Europe

Table 5.6

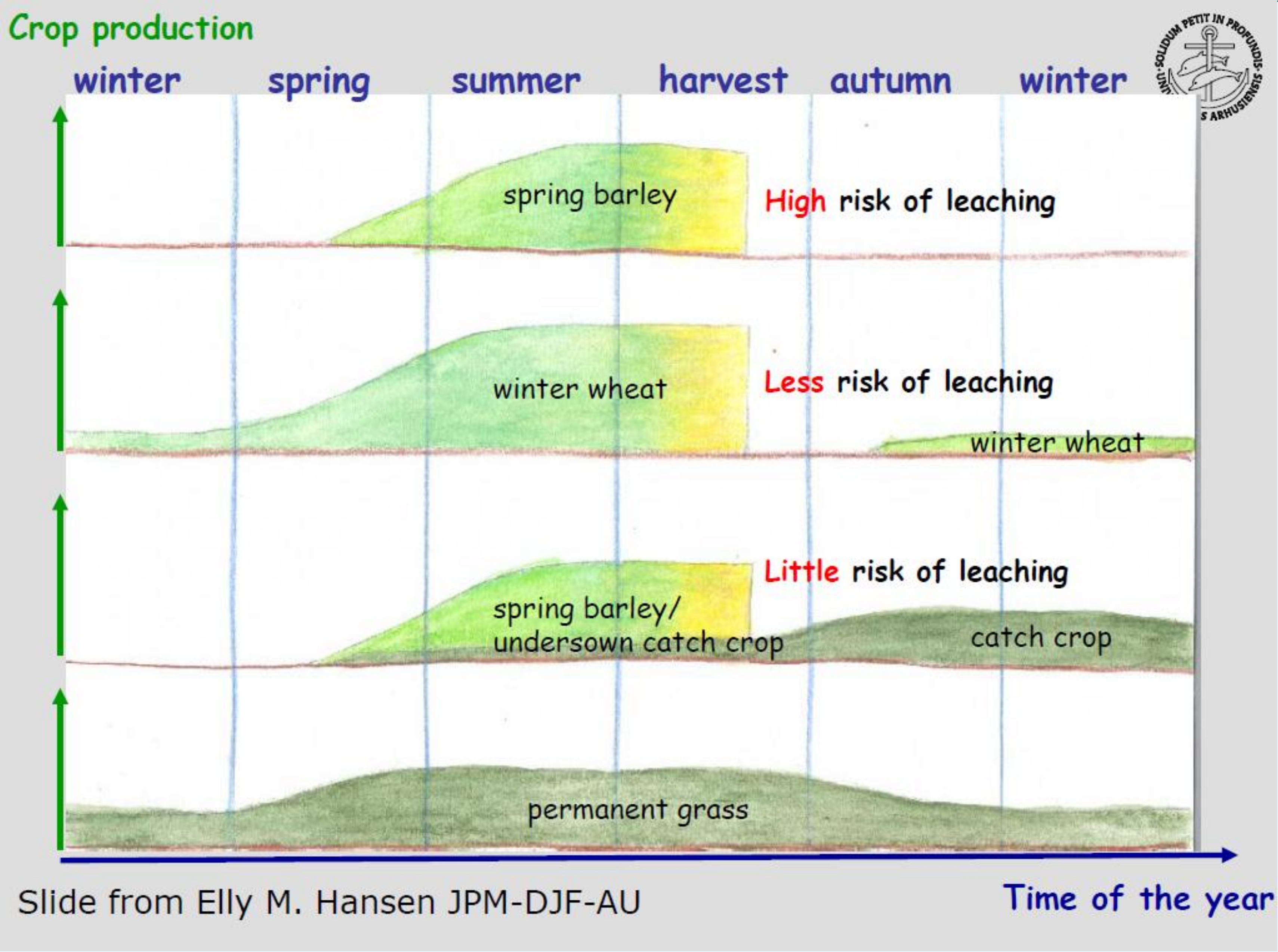
Closed periods of some of the EC-member states

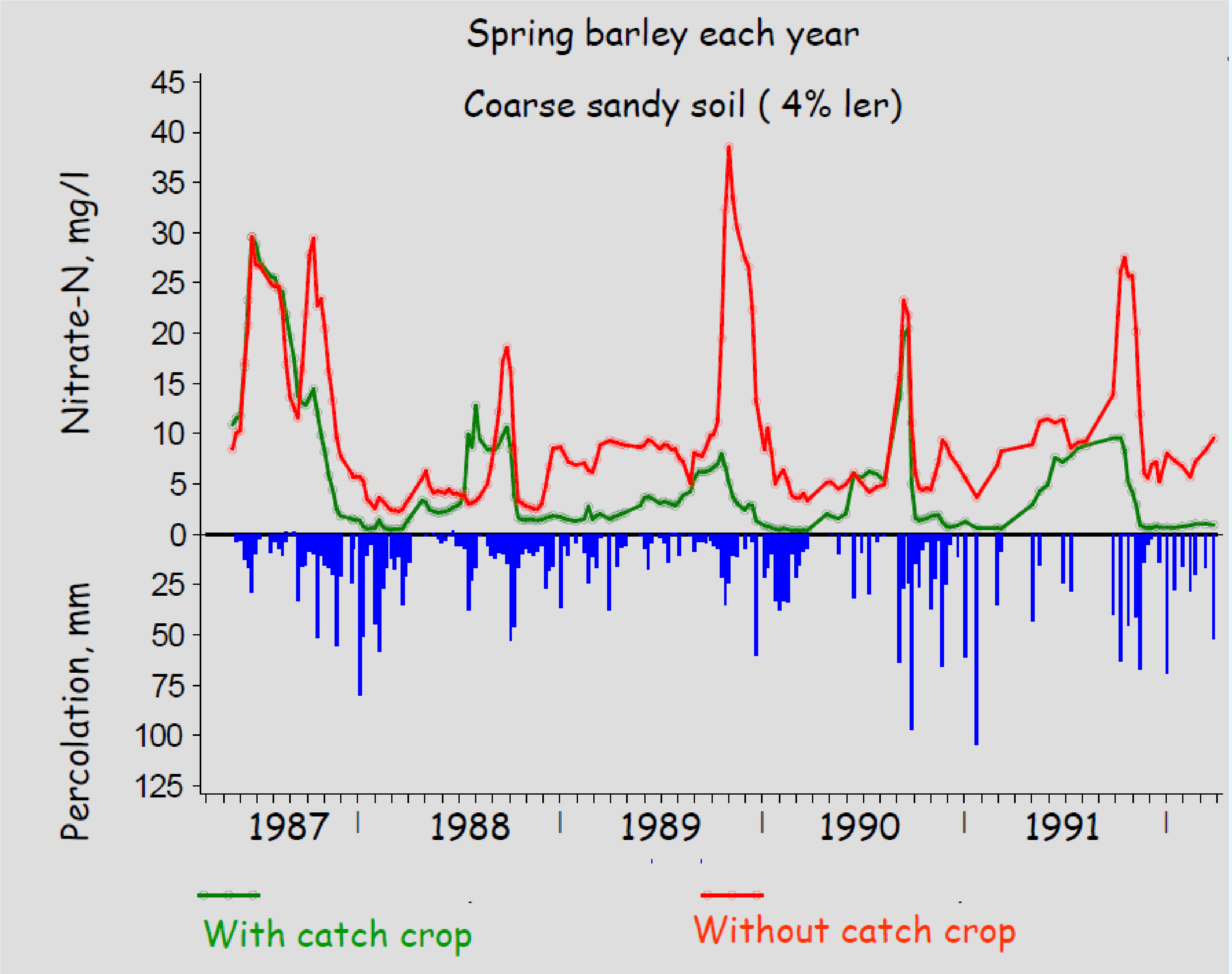
Country	Remarks[*)]	harvest	1-sep	15-sep	1-okt	15-okt	1-nov	15-nov	1-dec	15-dec	1-jan	15-jan	1-feb	15-feb	28-feb
Be (Flanders)	other		■	■	■	■	■	■	■	■	■	■	■	■	
	clay soils					■	■	■	■	■	■	■	■	■	
	farmyard manure & compost							■	■	■	■				
Netherlands	grassland sand and loss		■	■	■	■	■	■	■	■	■	■			
	grassland clay and peat soils			■	■	■	■	■	■	■	■	■			
Denmark	other	■	■	■	■	■	■	■	■	■	■	■			
	grassland and winterrape				■	■	■	■	■	■	■	■			
Norway							■	■	■	■	■	■	■	■	
Ireland	based on regional rainfall (South end 12/1)			■	■	■	■	■	■	■	■				
North Ireland				■	■	■	■	■	■	■	■	■			
Italy	NVZ: mineral fertilizers; organic fertilizer., farmyard manure (FYM)						■	■	■	■	■	■	■		
	NVZ: poultry manure						■	■	■	■	■	■	■	■	■
	NVZ: liquid manure on grass, winter cereals, horticult., fruit trees						■	■	■	■	■	■	■		
	NVZ: liquid manure other crops						■	■	■	■	■	■	■	■	■

*) *closed also in other periods for frozen and snow covered soil*

Catch Crops

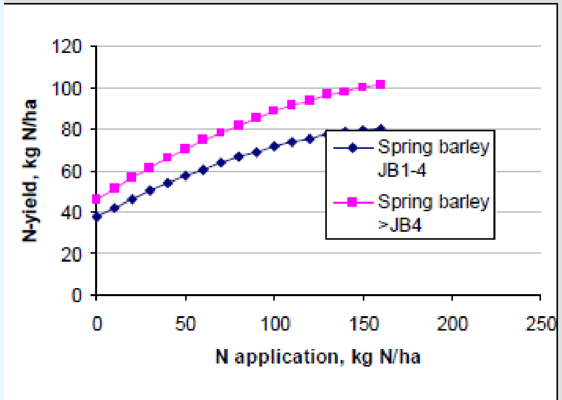
- N uptake of a crop between a harvested crop and a spring sown crop.
- Reduce the inorganic N content (Nitrate and ammonium) in soil and thereby reduce the N leaching during autumn and winter period.
- After incorporating the catch crop in the soil (Late autumn or spring before sowing) the N-mineralization of the added organic crop residuals can be taken up by the following crop or stored in the organic N pool and mineralized later.
- The field can not be grown with a winter crop.
- Reduce N leaching to a lower level (Reduction estimated to be between 16-46 kg N/ha depending on soil types and number of livestock units per hectare).

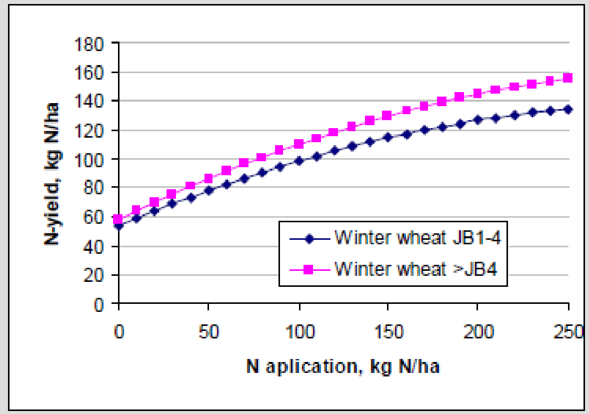

Crop production
winter
spring
summer
harvest
autumn
winter
spring barley
High risk of leaching
winter wheat
Less risk of leaching
winter wheat
Little risk of leaching
spring barley/
undersown catch crop
catch crop
permanent grass
Slide from Elly M. Hansen JPM-DJF-AU
Time of the year

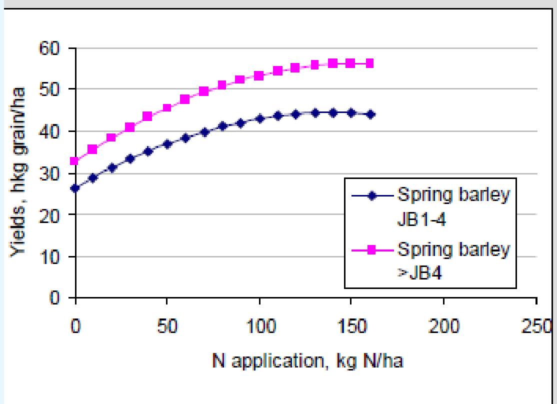

Spring barley each year
Coarse sandy soil (4% ler)
Nitrate-N, mg/l
Percolation, mm
45
40
35
30
25
20
15
10
5
0
25
50
75
100
125
1987
1988
1989
1990
1991
With catch crop
Without catch crop

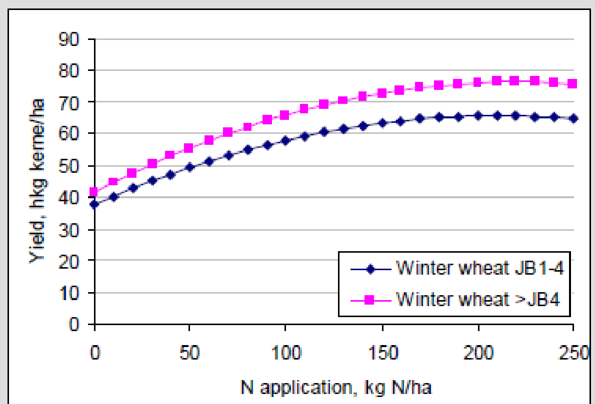
Reduced N application to reduce Nitrate leaching

Yields response to N application rates



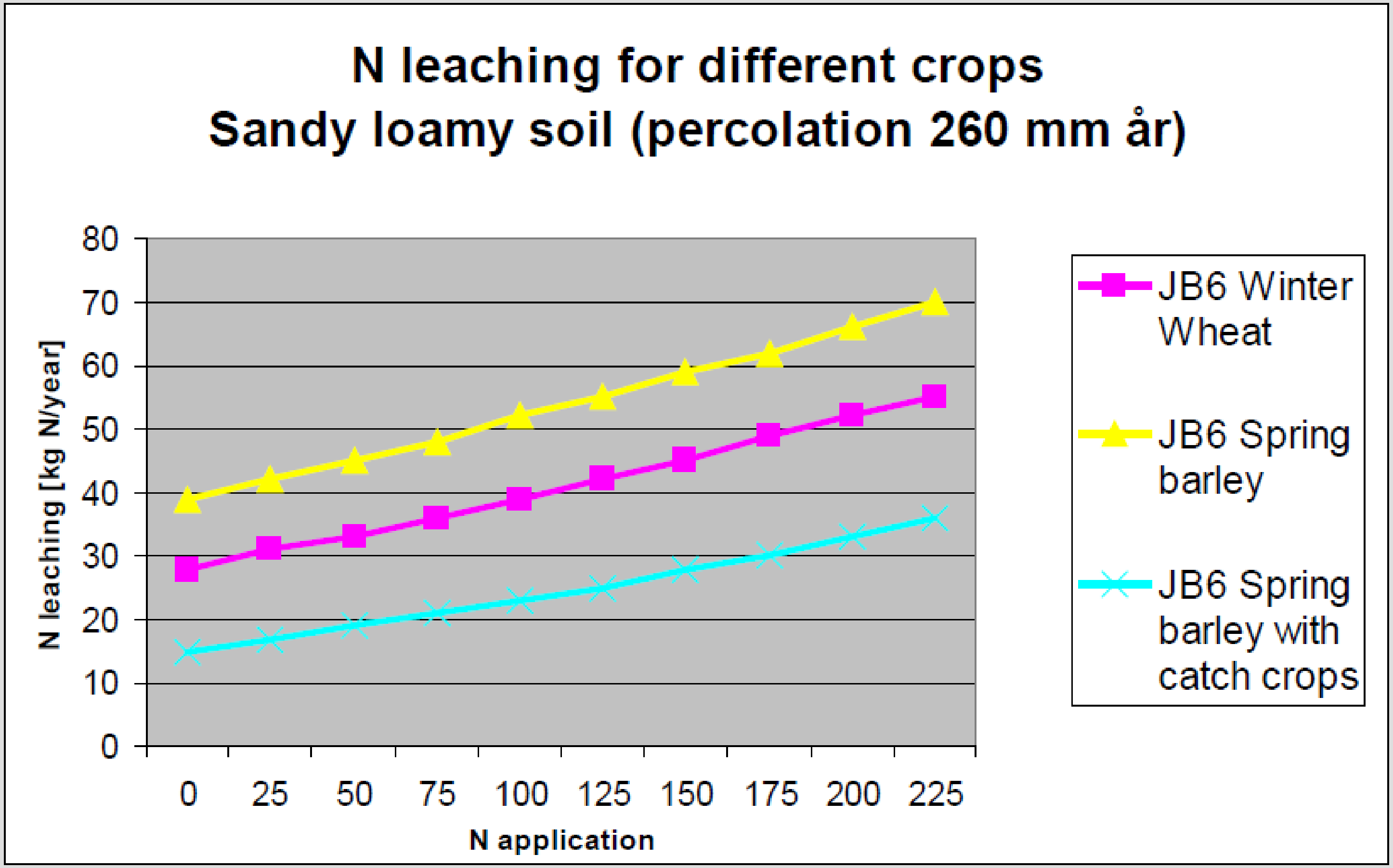






Reduced N application to reduce nitrate leaching

Nitrogen Leaching response to N application rates



Change in land use from arable land to Fellow/natural vegetation reduce N leaching

- Reduce N leaching to a level of 10-20 kg N/ha
- Effects the harmony area
- Concentrate of the slurry application on the remaining arable land => higher N slurry rates per ha.
- Can introduce competition between farmers on arable land for harmony area => raise in prices of land.
- Higher biodiversity

Planting of new forest to reduce N leaching

- Reduce N leaching to a lover level after many years to 10-15 kg N/ha.
- After 1 –2 years the leaching is app. 50-100 kg N/ha
- Concentrate of the slurry application on the remaining arable land => higher N slurry rates per ha.
- Can introduce competition between farmers on arable land for harmony area => raise in prices of land.
- Higher biodiversity

Crop production for energy use

› Reduce the N leaching to a lower level 15 –30 kg N/ha.
› N rate (75-120 kg N/ha)
› Reduction in productions of cereals (Pig farms or dairy farms)
› Harmony area is not effected
› Effects are the visual impression in the landscape.
› Nature effect
› Low pesticide use
› Higher biodiversity.

Change in farm type from conventional to Organic dairy farm

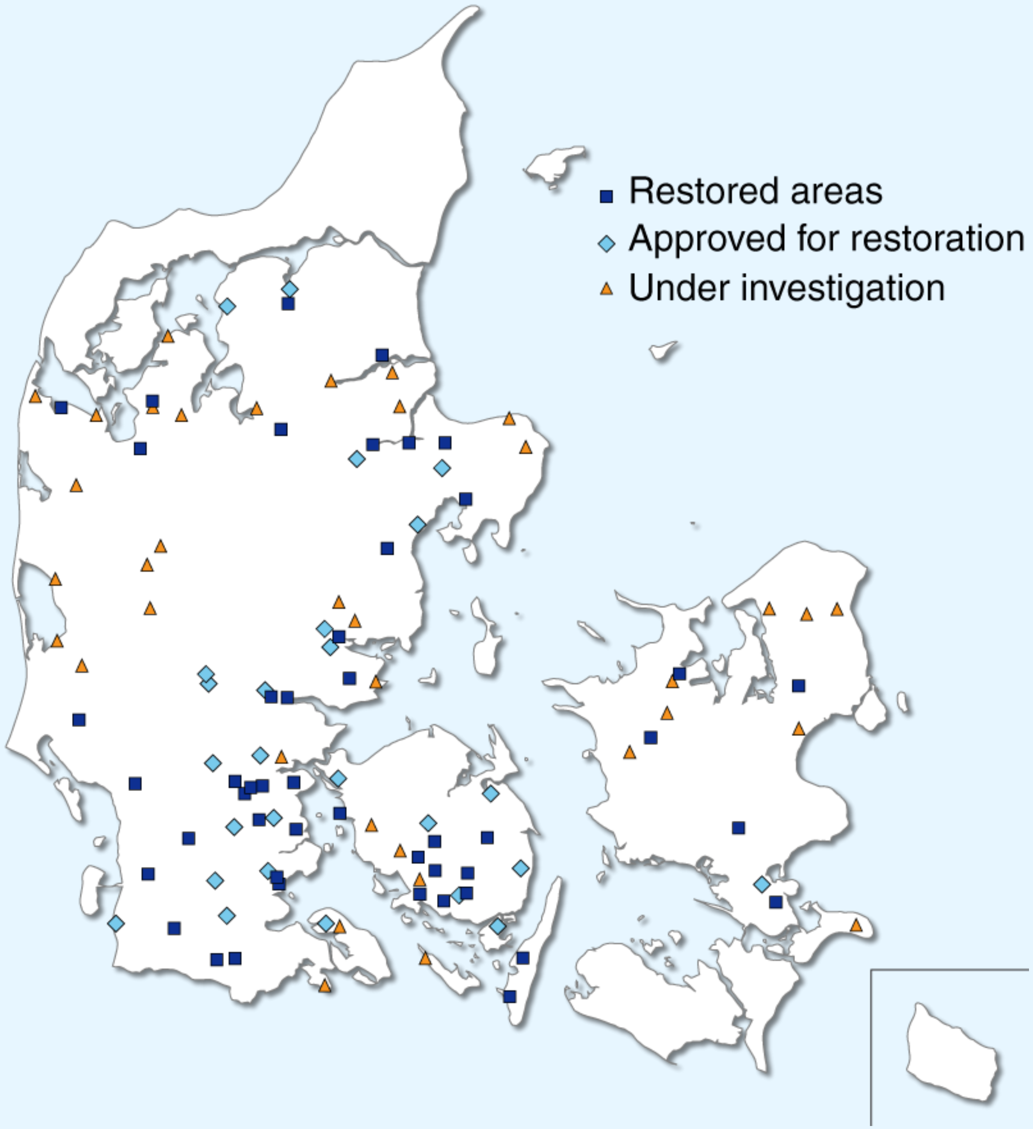
- Reduce N leaching to a lower level (Reduction estimated to be between 20-40 kg N/ha depending on soil types).
- Harmony area not effected.
- Maximum 1.4 live stock units per hectare.
- Effects are the visual impression in the landscape, more fields with grazing animals.
- No pesticide use
- Higher biodiversity by lower intensive management .

Measures to be used to reduce N leaching , Effects and costs.

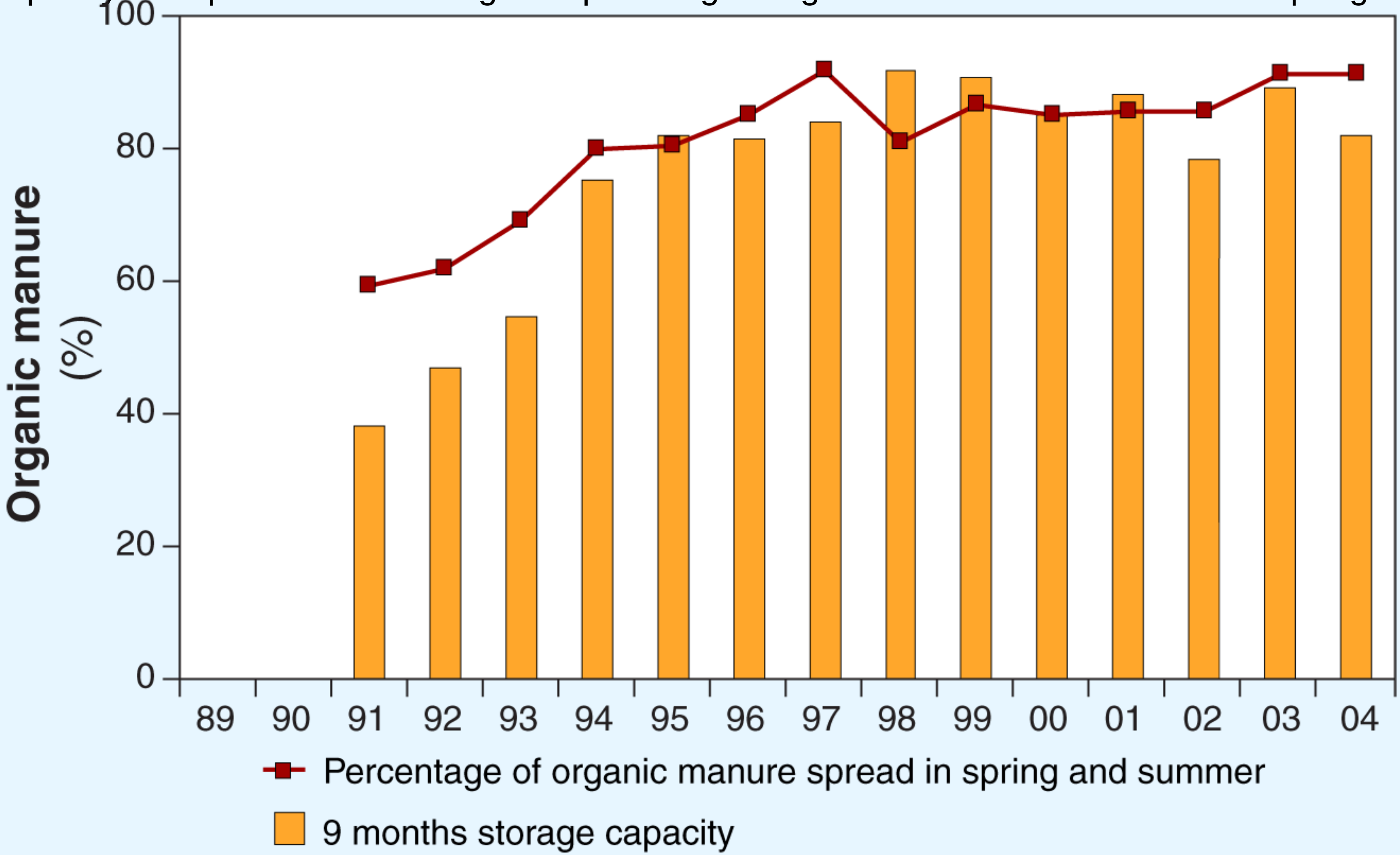
Measures to reduce N leaching	Reduced N leaching (kg N/ha)		Socio economic costs (kr./ha)	
	Sandy loamy JB5-7	Sandy (JB1-4)	Sandy loamy JB5-7	Sandy (JB1-4)
Measure				
Catch crops, farms with less than 0,8 AU/ha*	16	34	610	385
Catch crops, farms with more than 0,8 AU/ha*	28	46	610	385
10% reduced N-rate.	(N-rate*0,1)*0,25	(N-rate*0,1)*0,35	280	280
Change to organic dairy farm	20	40	680	680
Change arable land to natural vegetation	leaching - 10		6.100	3.800
Grow forest on arable land	leaching - 12		6.200	3.900
Energy crops	leaching - 23		2.000	-
Constructed wetlands	100 kg N/ha		4.679	3.663

Wetland restoration is a key mitigation option - Denmark is in the forefront having restored more than 40 wetlands in the period 1998-2007

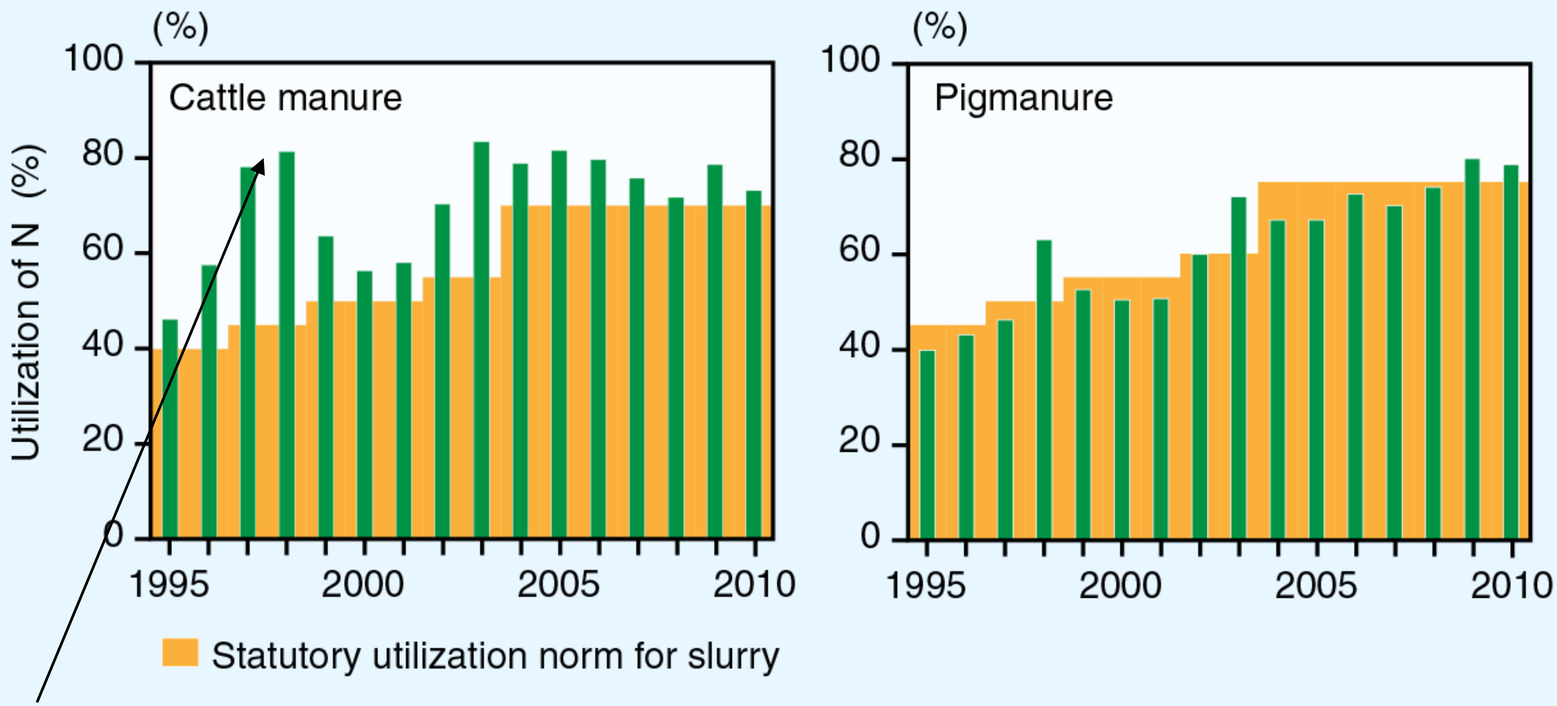
Project type	Hectares restored	Nitrogen retention (kg N ha^{-1} yr^{-1})
Restored wetlands	2,985	264
Restored lakes	3,844	251
Total	6,829	259



Observations at farm level from interviews show early and large improvement met for storage capacity for liquid manure change in spreading of organic manure from autumn to spring

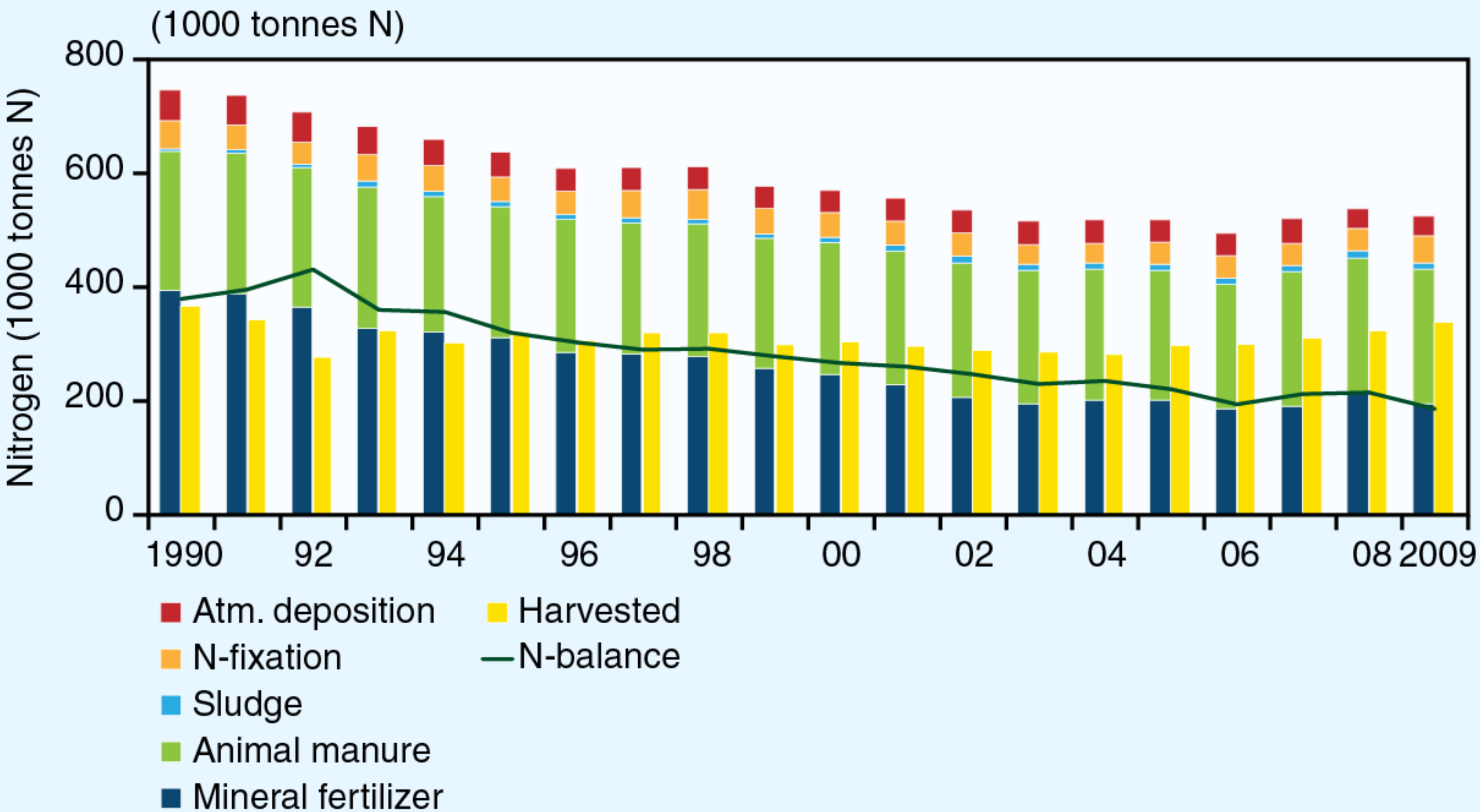


N-budgets at farm level also show that Danish farmers have improved the utilization of animal manure as required in AP's statutory norms for slurry – from agricultural micro-catchments



N-norms set for grassland were unrealistic high and therefore lowered

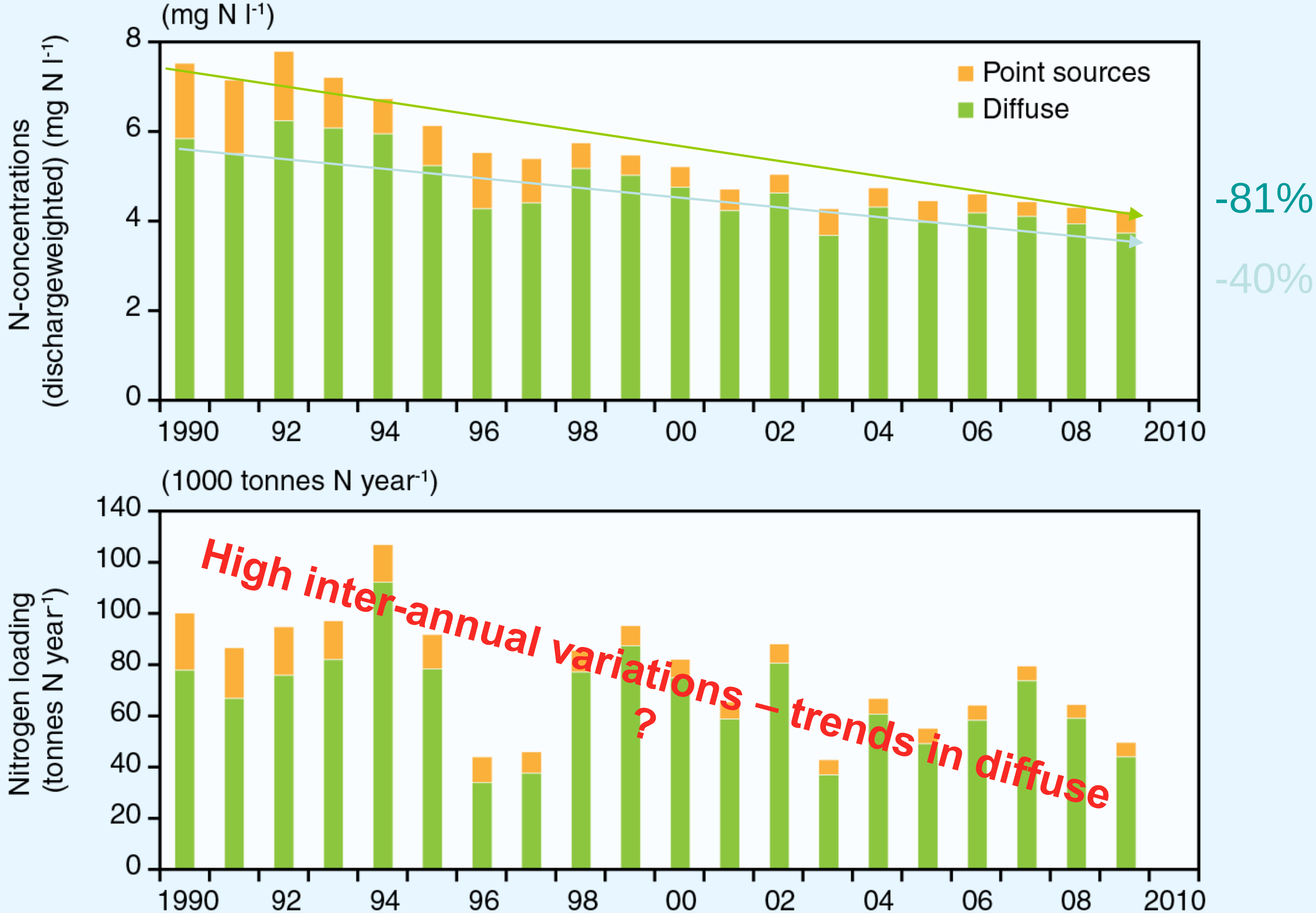
The improved handling and utilization of animal manure can be seen in the national field nitrogen balances



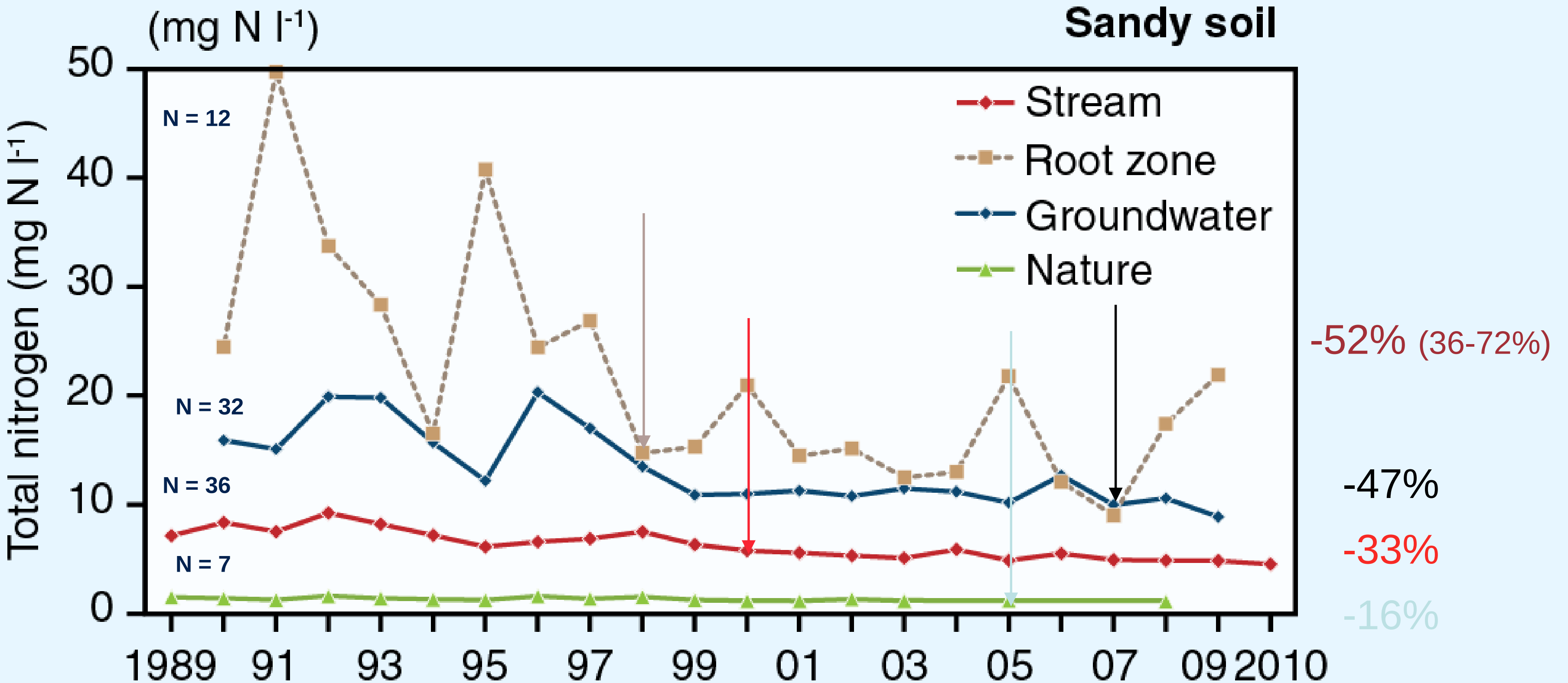
N-surplus

-50%

Trends in measured and modelled national diffuse nitrogen loadings to coastal waters can only be seen when normalizing the loading according to runoff



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

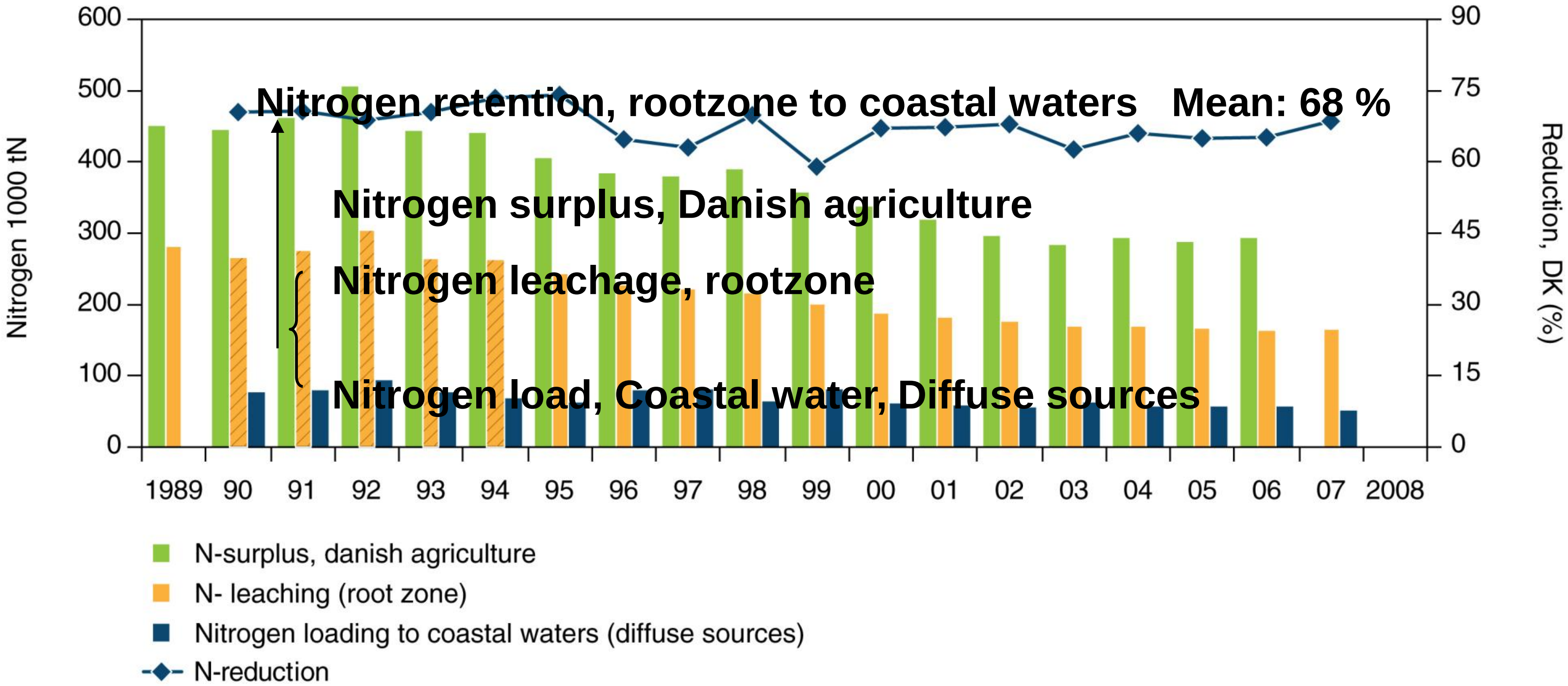


↓ First year with significant test results

Trend in Key Nitrogen loading figures

N surplus agriculture, N-leaching root zone, N load of coastal waters from diffuse sources and N retention of N leached.

Data normalised to mean climatic condition




Time for an exercise ?
MAC