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CNRS / University Pierre et Marie Curie (Paris VI)

TFIAM / COST 729 / NinE
Workshop on integrated modelling of nitrogen
28-30 November 2007, Laxenburg

Modelling the N cascade at the regional scale

The question asked ?

Anthropogenic Inputs of reactive N:

fertilizer application,
atmospheric deposition
crop N_2 fixation

Export as food/feed

Storage in landscape (soil, biomass)

Atmospheric emission (Denitrification, NH3 volatilization)

Transfer to hydrosystem

Storage in aquifers

Denitrification in river, ponds, lakes,…

Storage in reservoirs, sediments and the flood plain

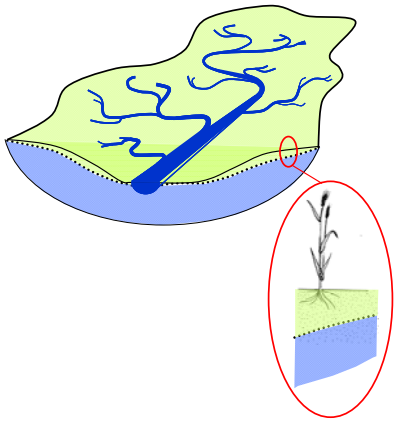
Transfer to estuarine & marine systems

Different scales:

Plot **Landscape** **regional territory** **continent** **whole globe**

The scale of management decision and policy assessment

Regional watershed (5 000 - 100 000 km²)



Regional territory structured by a drainage network

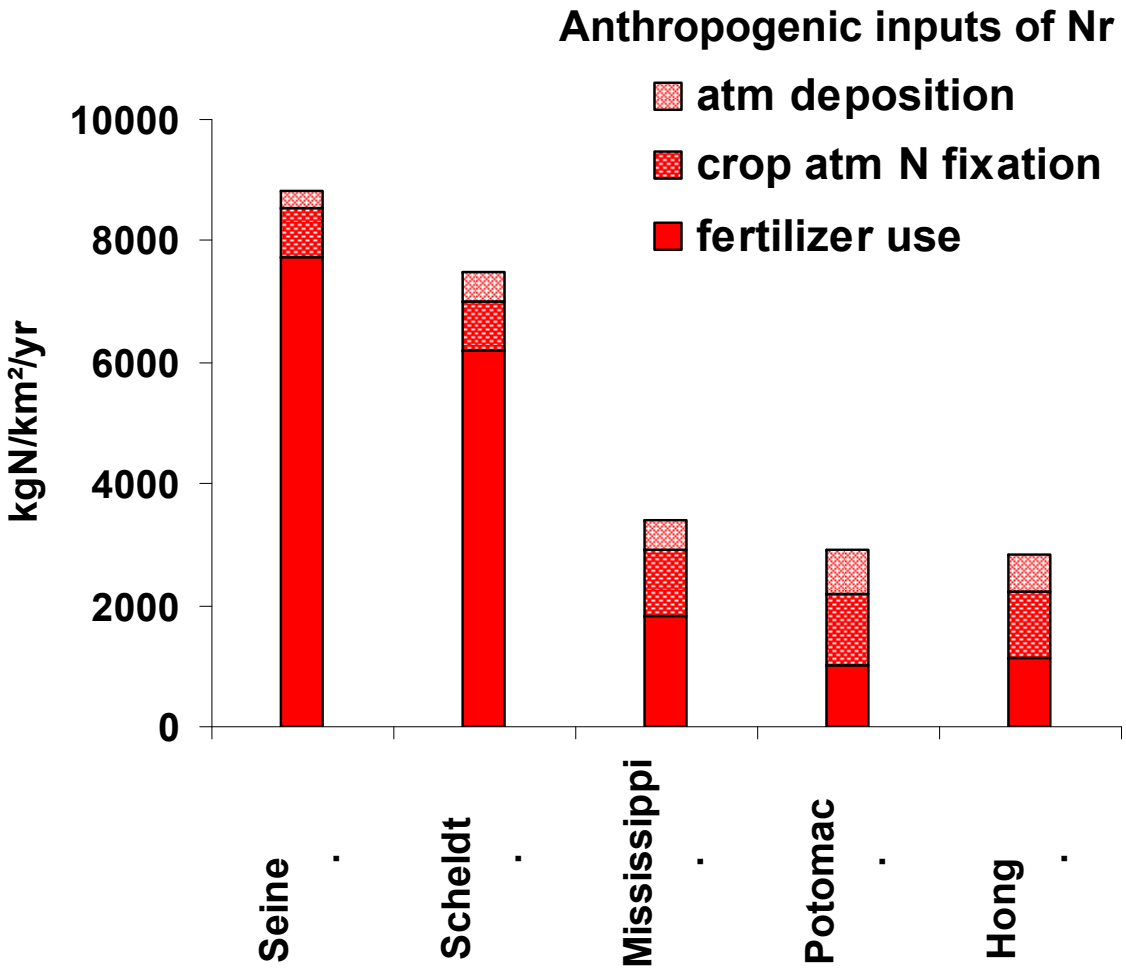
Different approaches:

Black-box **input-output budgets** → regression models

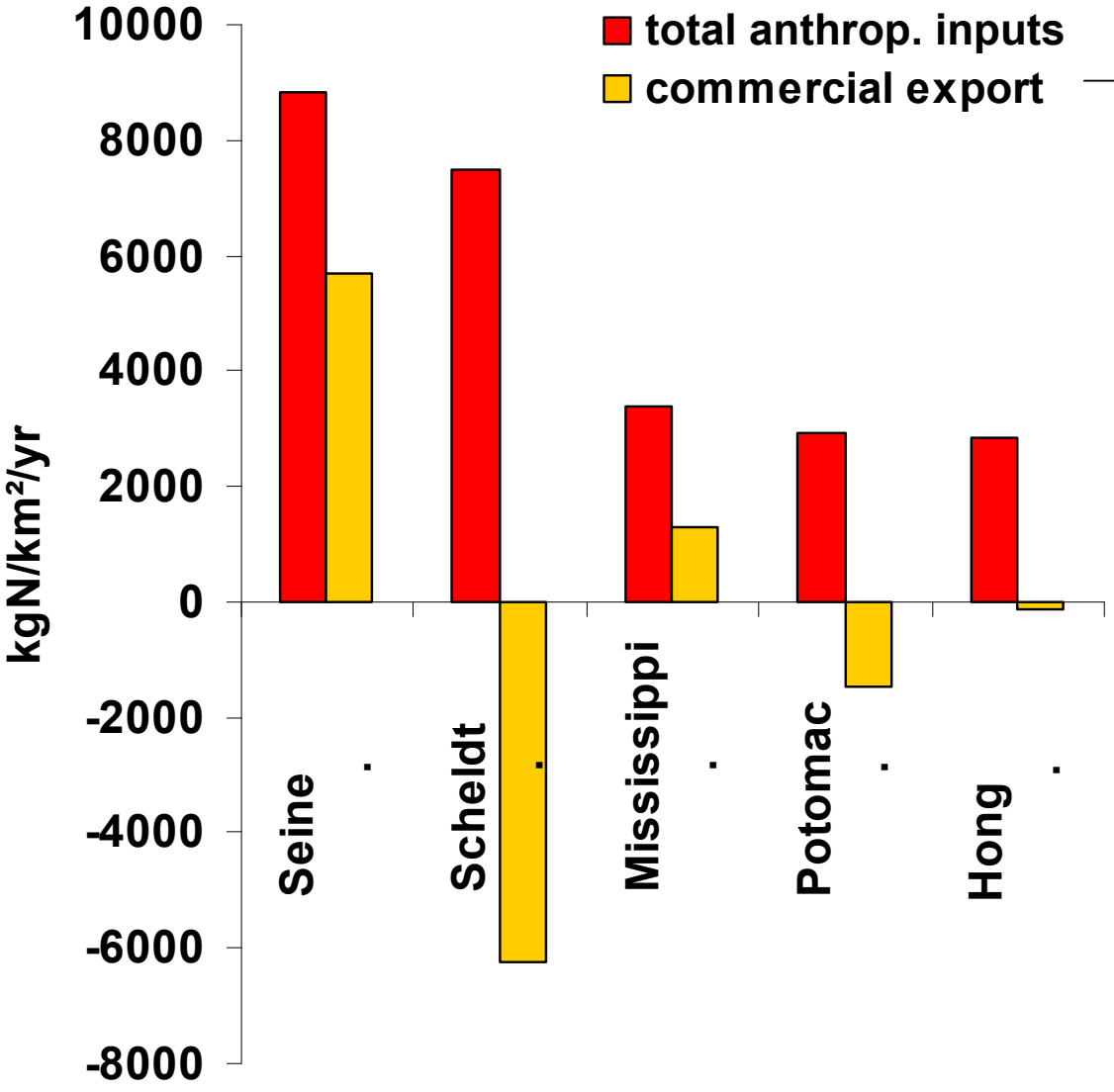
Process-based, spatially distributed models of N dynamics within regional systems.

input-output budgets

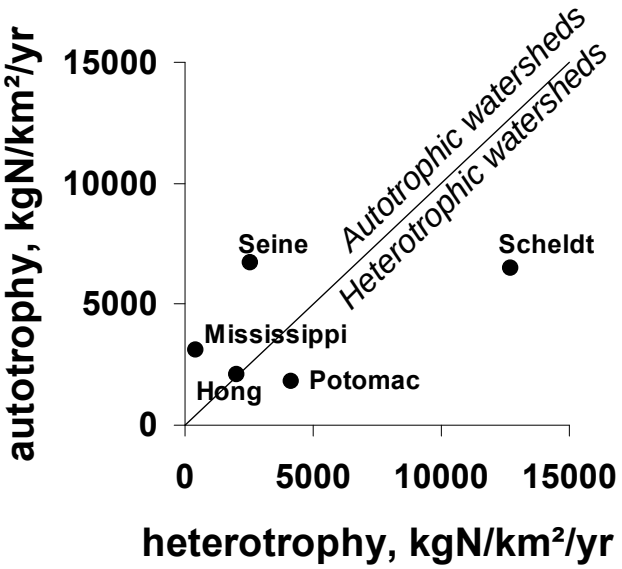
	km²	inhab/km²
Seine	65 000	190
Scheldt	19 900	520
Mississipi	3 230 000	20
Potomac	29 900	63
Hong (Vietnam)	156 500	200

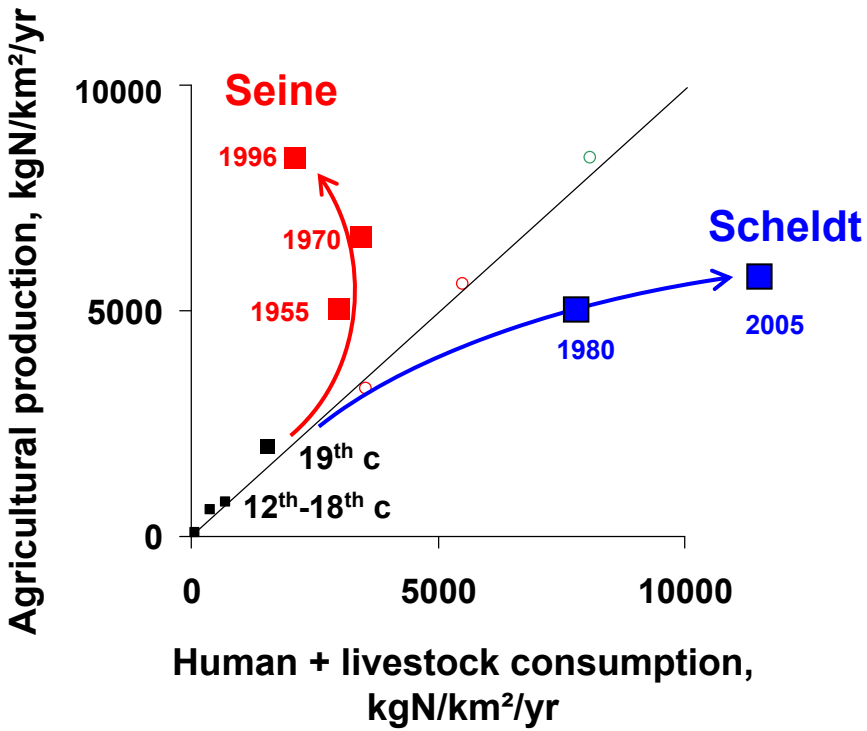


Export-Import balance of agricultural products across regional watershed limits



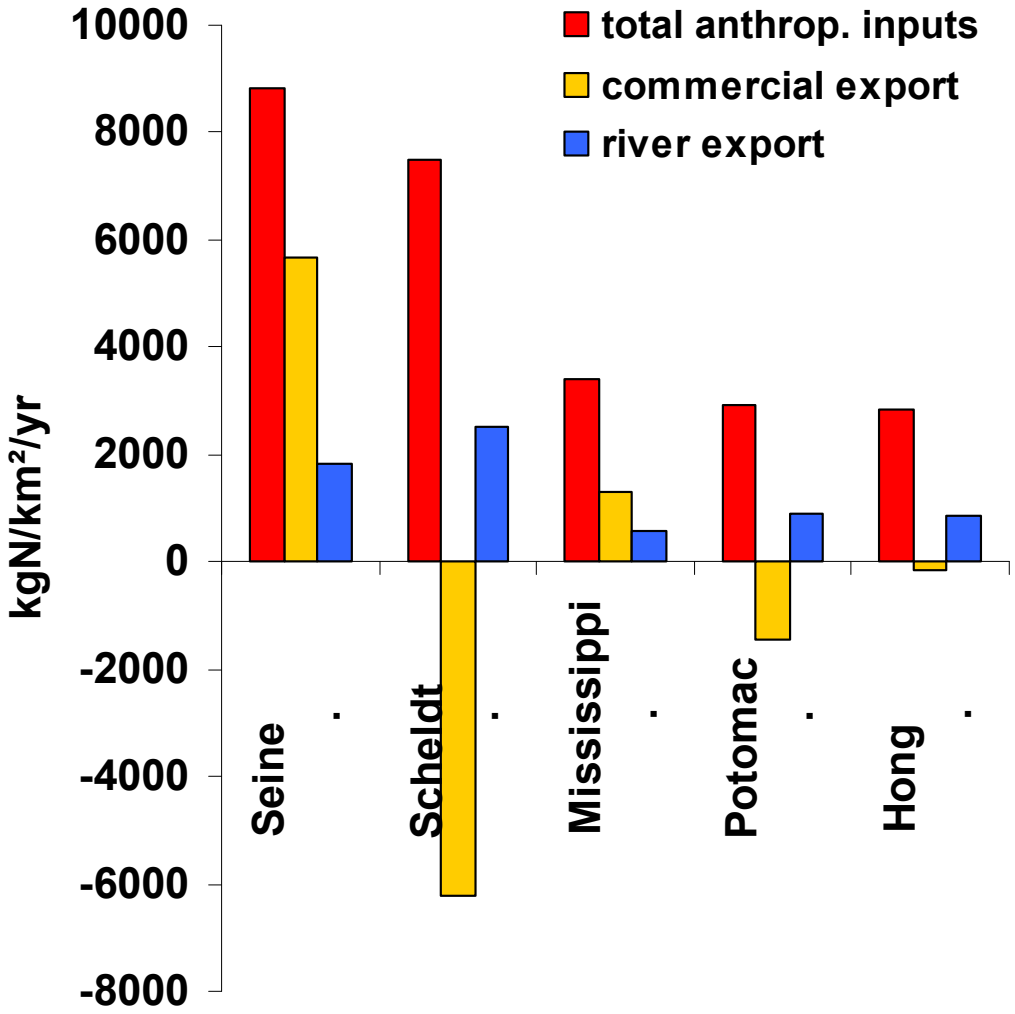
The balance between crop production (autotrophy) and consumption by human and livestock (heterotrophy)





The specialization of watersheds towards either autotrophy or heterotrophy is increasing since the last 50 years.

Riverine exports (N delivery to coastal marine systems)

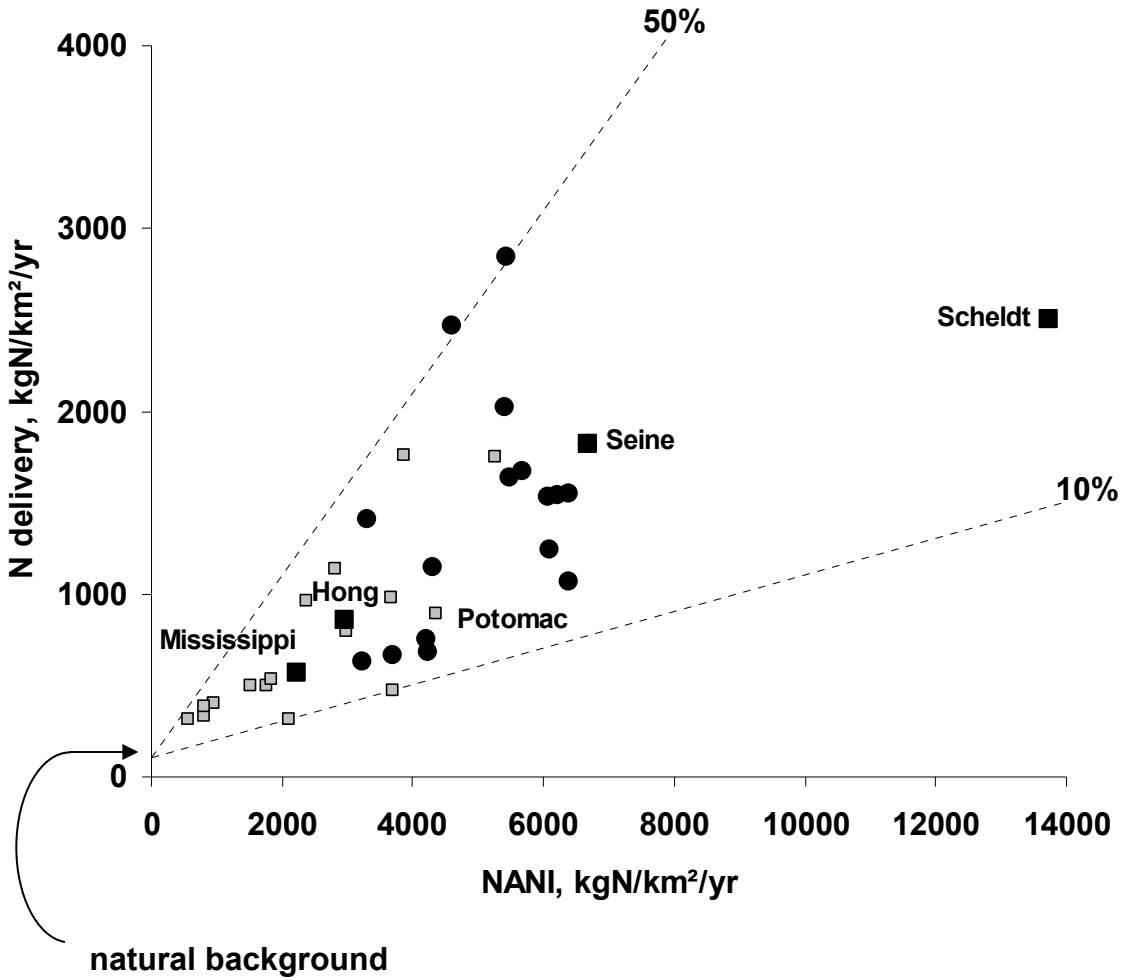


The 'NANI' models (Howarth et al., 1996; Boyer et al., 2002)

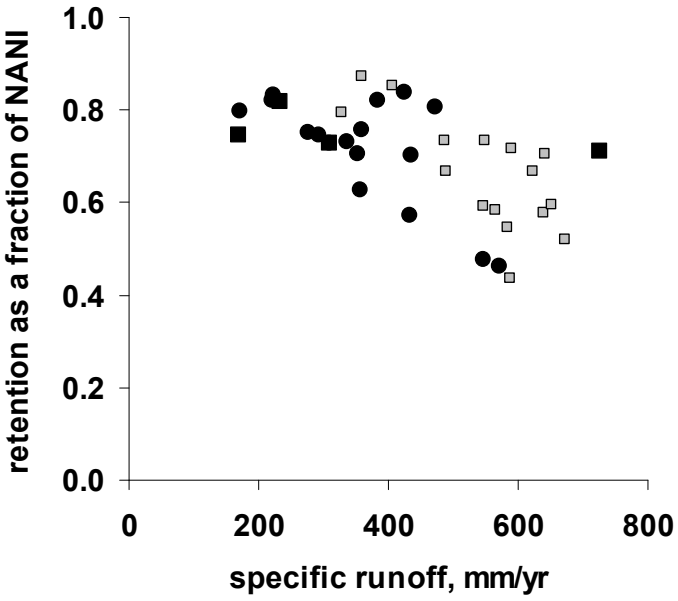
NANI (Net Anthropogenic N Inputs) = synth.Fertilizers + atm depos. + crop N_2 fix. **+ net food/feed imports**

Nexport = (1 – retention) . NANI + bckgrd natural export

Riverine delivery only accounts for 10-50% of NANI



'Retention' decreases with increasing runoff



Sparrow, Polflow, GlobNews Models (Smith, 1997; De Wit, 2000; Van Drecht, 2003; Dumont et al. 2005)

Introduce a distinction between

diffuse sources from the wshd to the hydrosystem

point inputs from urban wastewater

excess N inputs to soils over N uptake by crop production

+ atmospheric deposition
+ N_2 fixation
+ synth. fertilizer applic
+ animal manure
- harvesting & grazing

urban wastewater

Nexport = (1- river retention) . [((1- wshd retention) . diffuseInputs) + pointInputs]

'retention':

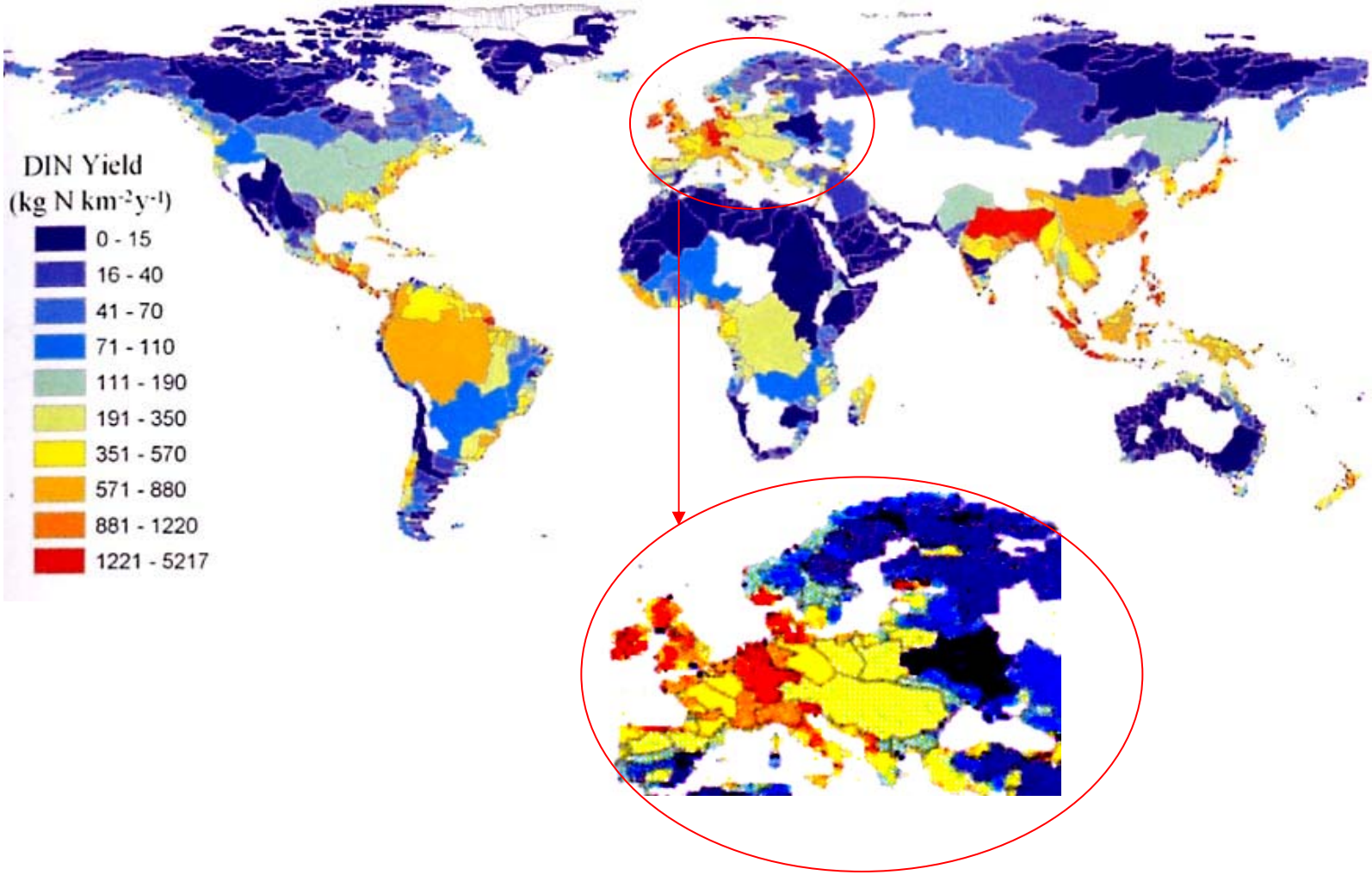
related to residence time in drainage network

(hence to damming)

Inversely related to runoff

A world wide estimate of river N export

e.g. Dumont et al, 2005



The possibility of testing future global scenarios (e.g. Millennium Ecosystem Assesment)

Questions left unanswered by the input-output regression models:

What is the exact nature of ‘retention’ ?

What is the fate of the missing N ?

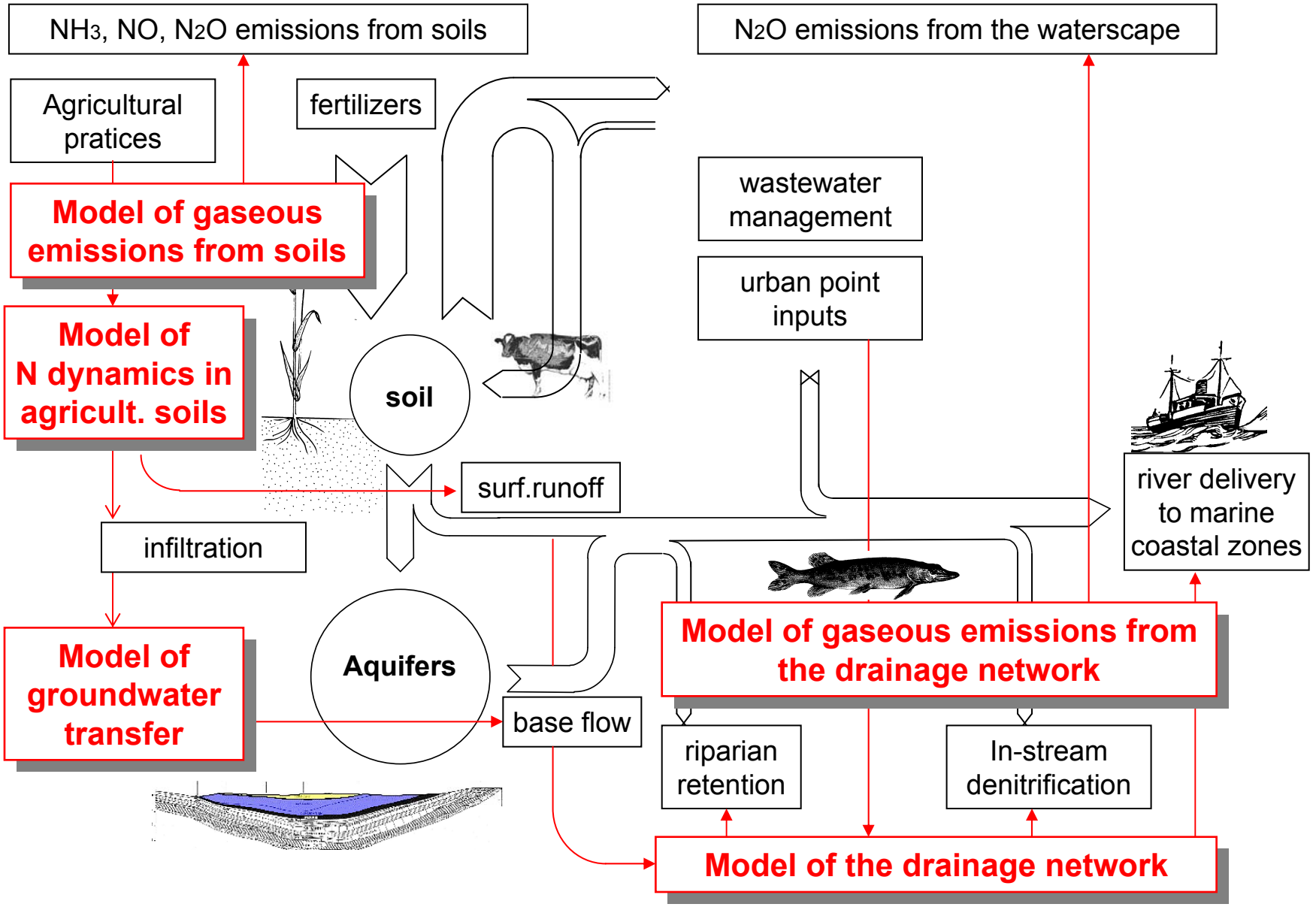
Where are the major retention processes localized in the watershed ?

When are they occurring ?

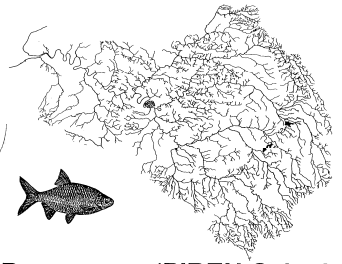
…

→ **Need for more ‘mechanistic’ models, with higher level of spatialization, and higher temporal resolution (seasonality)**

Process-based, distributed models of N transfers



The modelling chain of the PIREN-Seine



Programme 'PIREN-Seine'

The Seine watershed

Le Havre

Rouen

Reims

Paris

Troyes

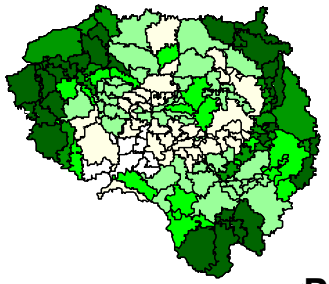
Urban areas

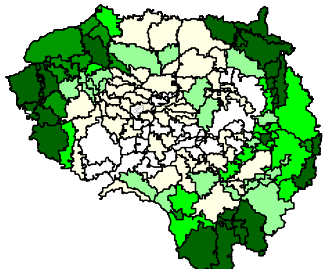
Arable land

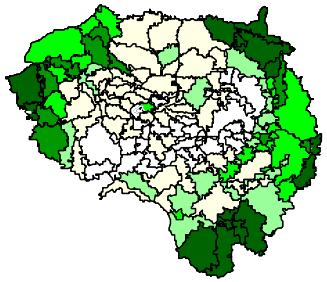
Grassland

Forest

Land use





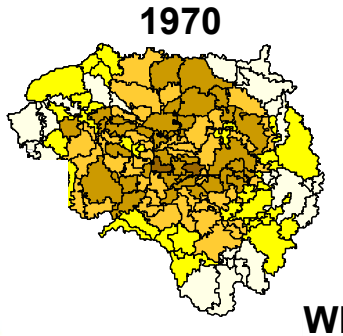


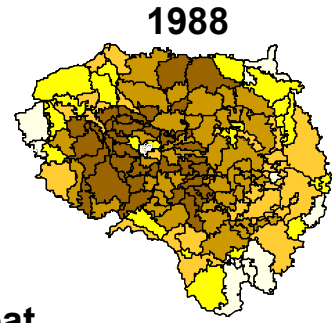
Permanent grassland

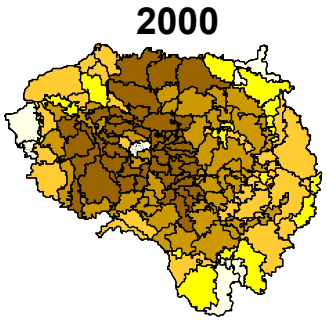
> 50%
35 - 50%
20 - 35%
10 - 20%
2 - 10%
< 2%

A detailed spatial data base of agricultural practices over the last 30 years

Mignolet et al, 2007



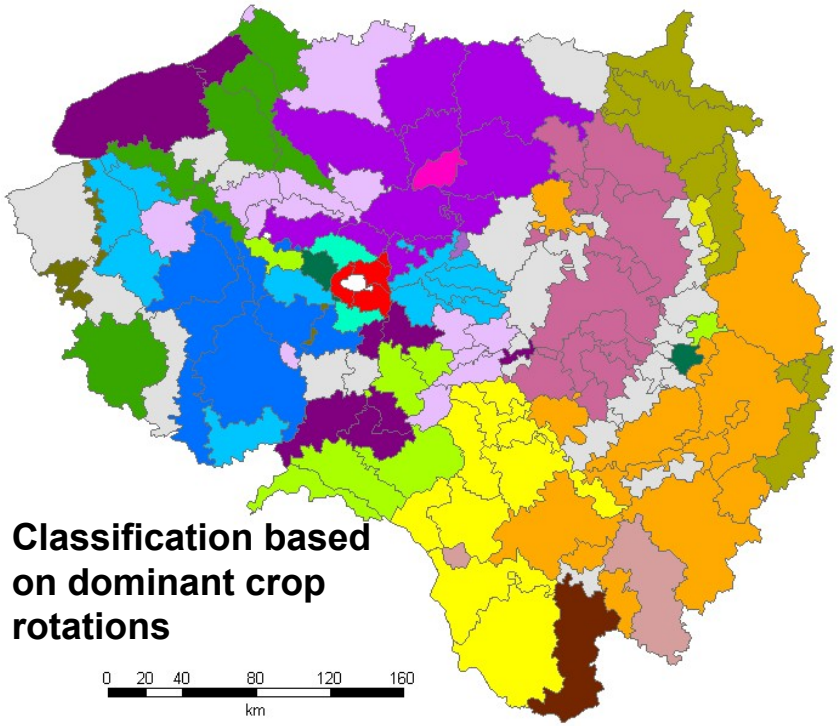




Wheat

> 40%
30 - 40%
20 - 30%
10 - 20%
< 10%

Crop successions

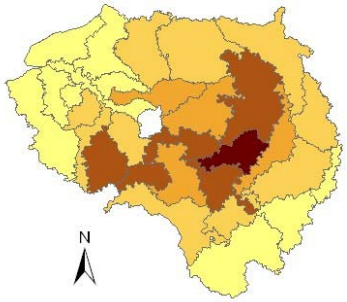


Classification based on dominant crop rotations

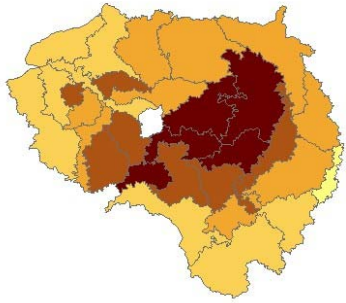
0 20 40 80 120 160
km

Fertilizer application

1994



2001



kgN/ha/yr

140,2 - 165,0
165,1 - 180,0
180,1 - 190,0
190,1 - 200,0
200,1 - 225,0

Agricultural pratices

Daily meteo data

STICS

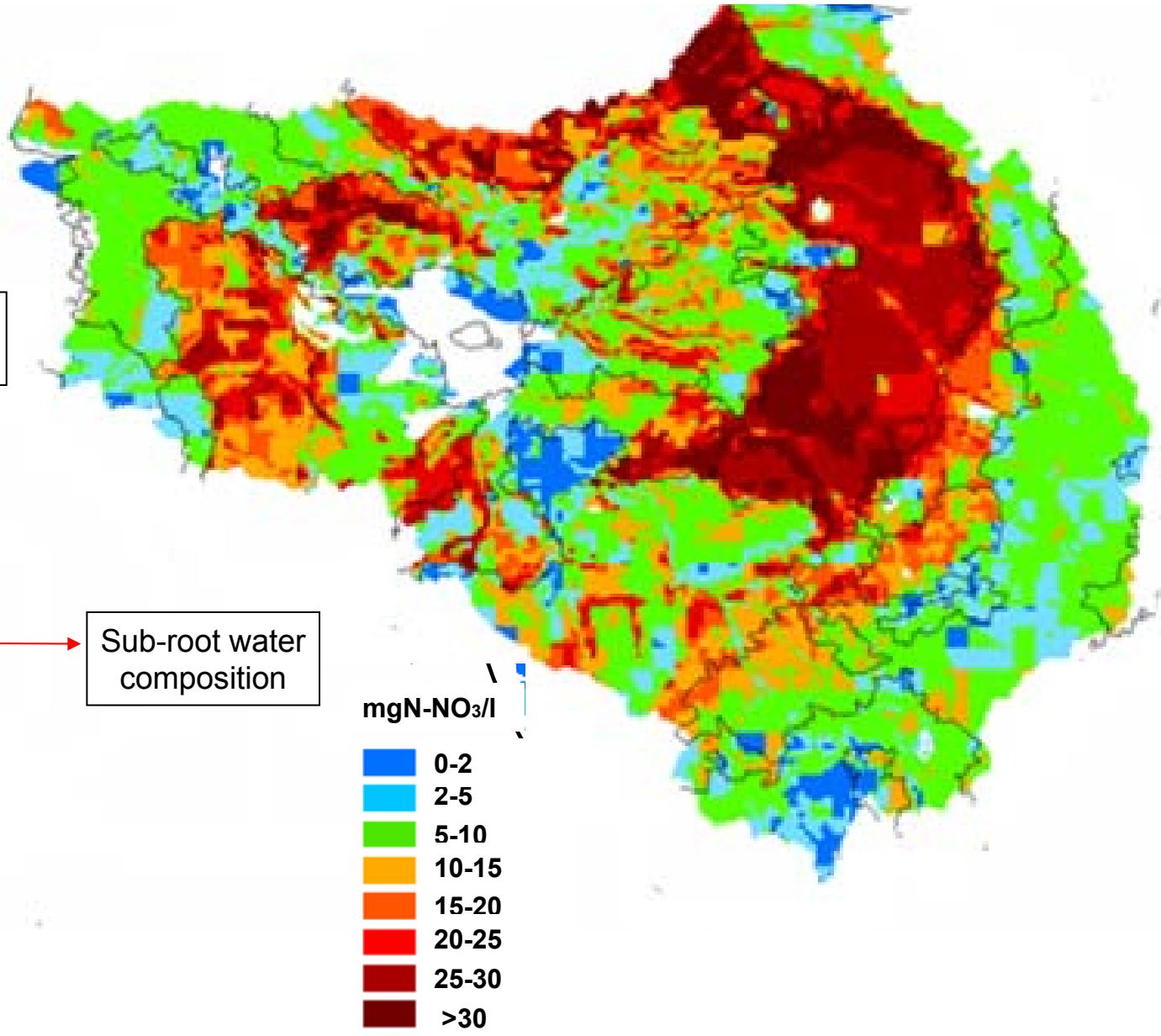
crop development, water balance, N dynamics in agricultural soils

Brisson et al, 2003
Ledoux et al, 2007

Sub-root water composition

infiltration

Crop yield



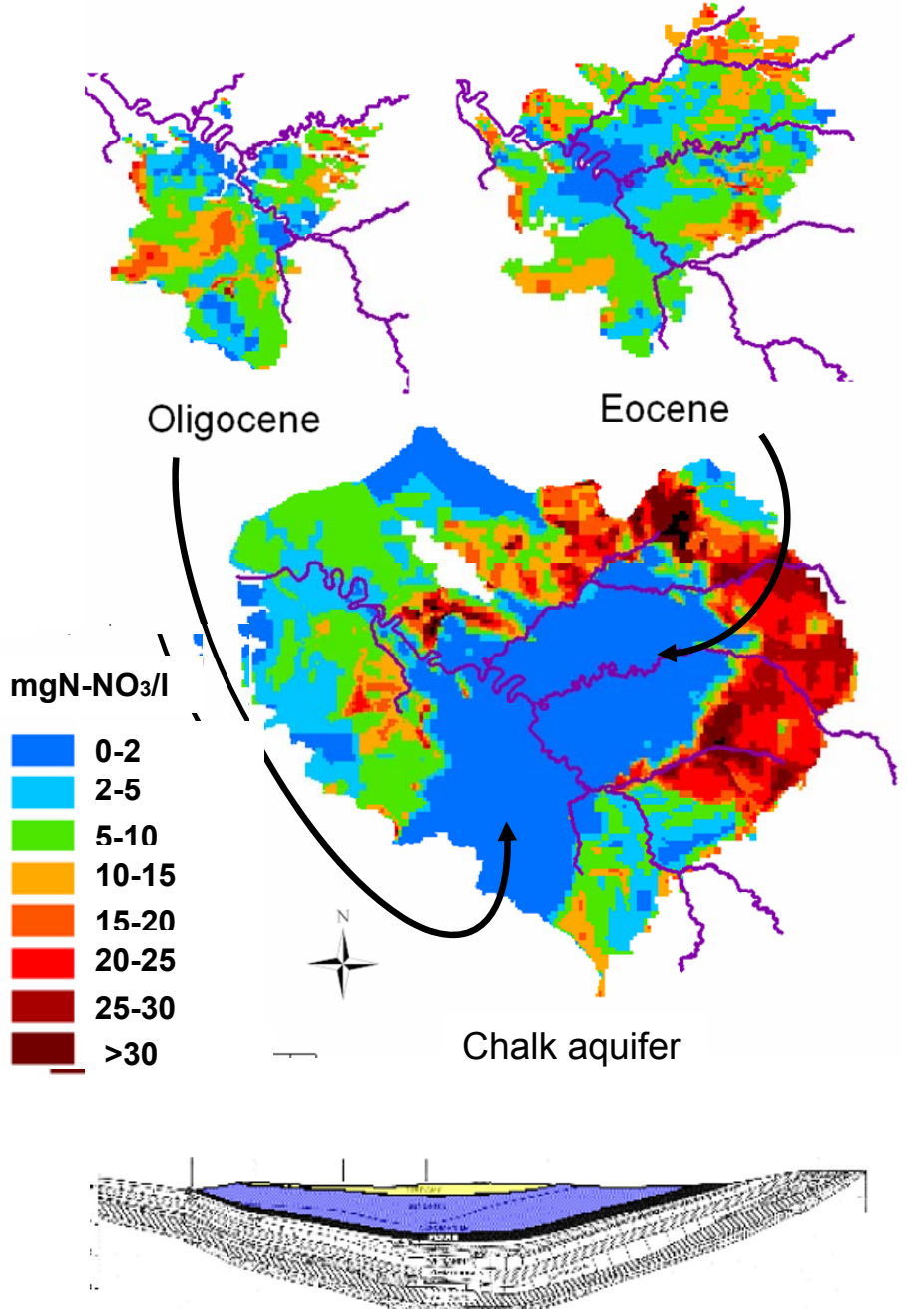
Agricultural pratices

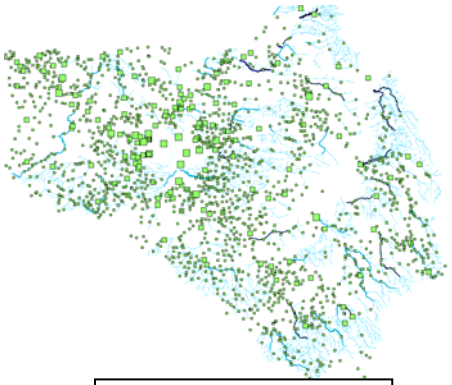
STICS
N dynamics in agricult. soils

infiltration

MODCOU
groundwater transfer
Ledoux et al, 2007

nitrate conc in aquifers





Agricultural pratices

wastewater management

urban point inputs

Model of N dynamics in agricult. soils

surf.runoff

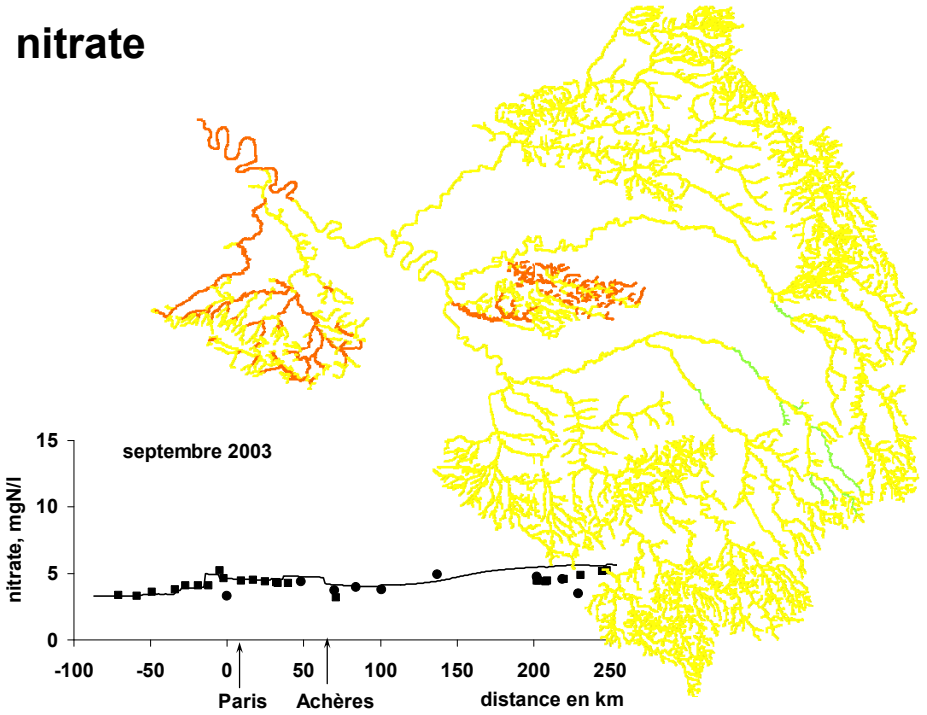
infiltration

Model of groundwater transfer

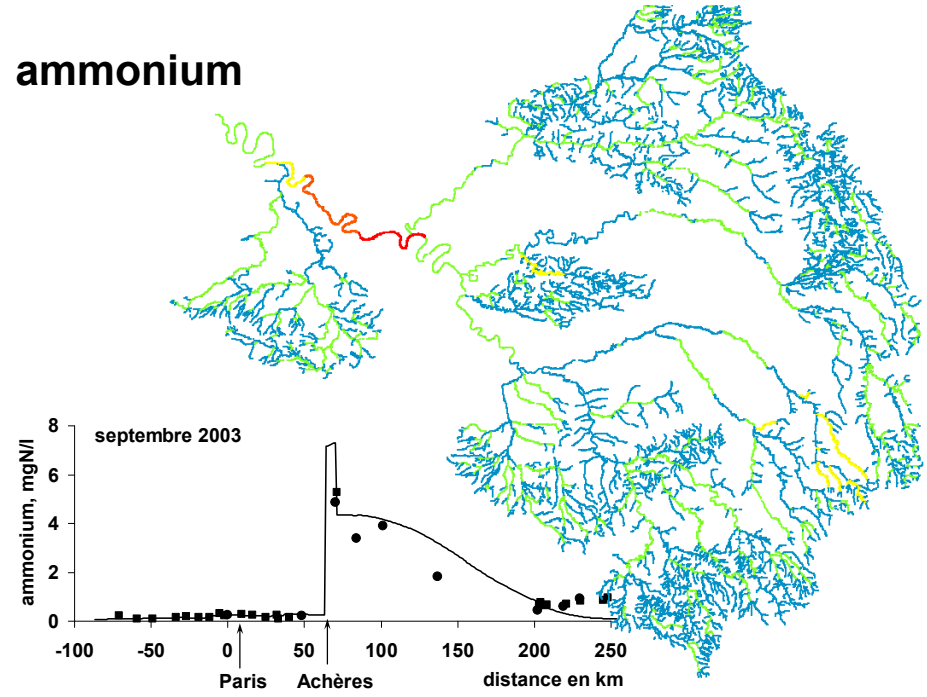
base flow

SENEQUE/Riverstrahler model of nutrient dynamics in the drainage network
(Billen et al., 2000; Ruelland et al, 2007)

nitrate



ammonium



Agricultural pratices

wastewater management

urban point inputs

Model of N dynamics in agricult. soils

surf.runoff

infiltration

Model of groundwater transfer

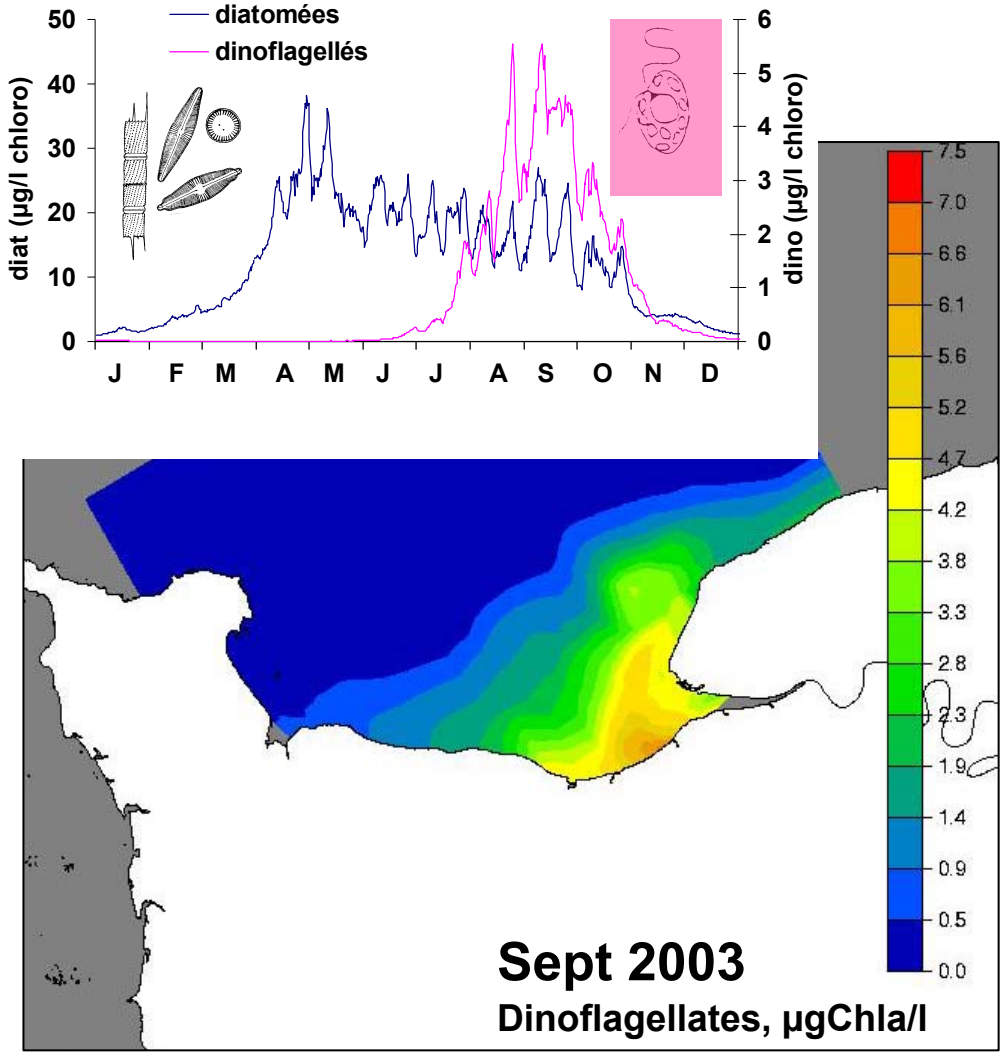
base flow

SENEQUE/Riverstrahler model of the drainage network

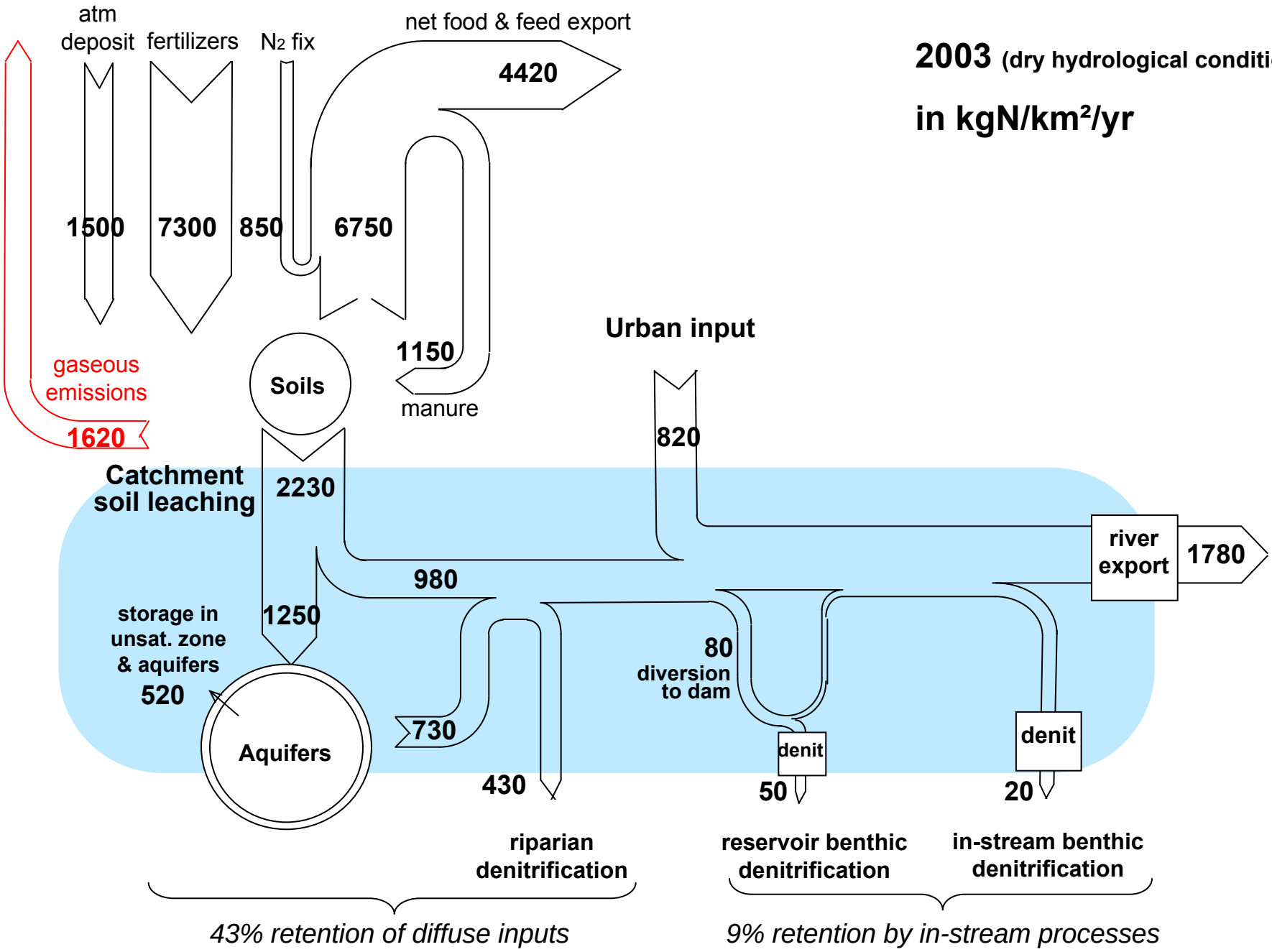
river delivery to marine coastal zones

SiAM 3D/ELISE model of algal development in the coastal zone

Cugier et al., 2005



a detailed budget of N transfer and retention in the Seine watershed



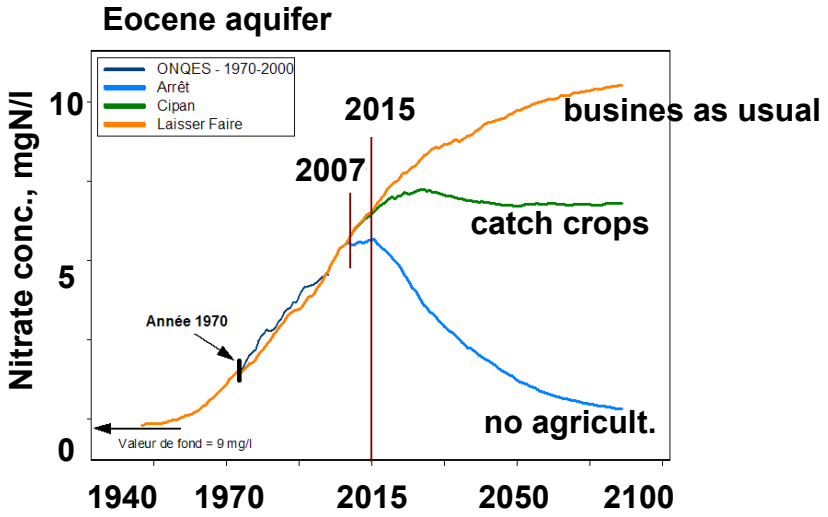
2003 (dry hydrological conditions)

in kgN/km²/yr

Testing detailed future scenarios

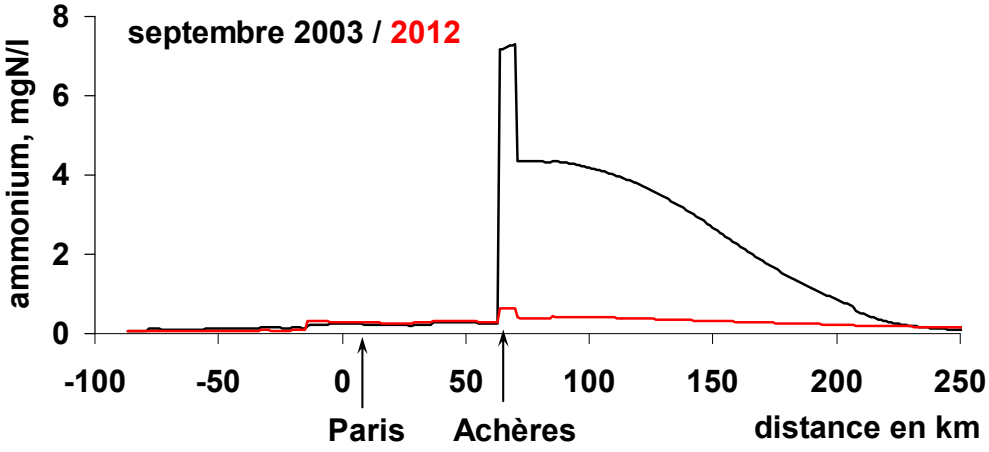
Agro-environmental measures

Systematic introduction of catch crops in culture rotation could stabilize nitrate contamination of aquifers by 2020

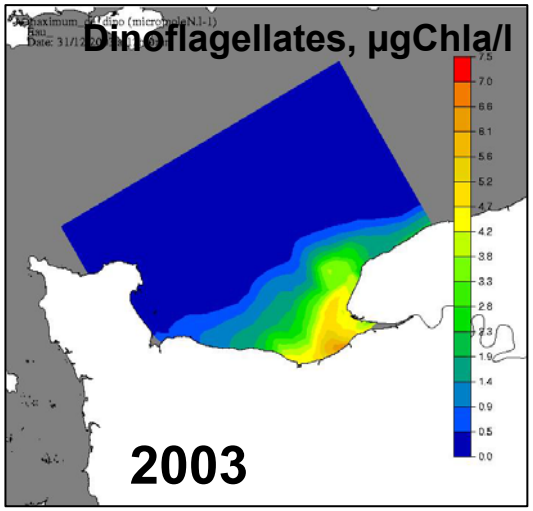


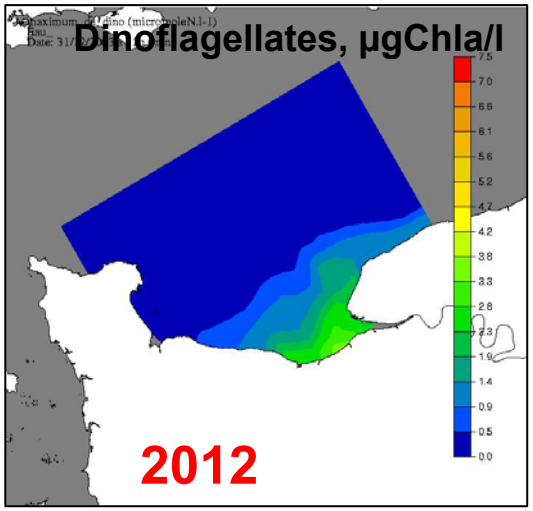
Improvement of wastewater treatment

Introduction of a nitrification step in the treatment line of the biggest Paris wastewater purification plant at Achères considerably reduces ammonium contamination of the river Seine



Although the nitrogen delivery by the Seine river into the sea is predicted to further increase in the next 10 years, the risk of harmfull algal blooms will decrease owing to to the ongoing reduction of phosphorus loading





Conclusion

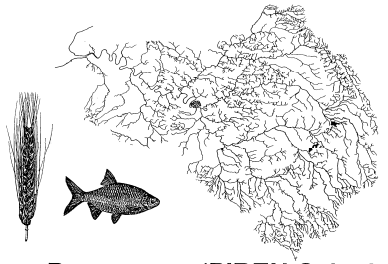
Considerable progress has been achieved in modeling the nitrogen cascade at the scale of regional watersheds.

Input-output budgets and regression models are able to quantify the major routes of transfer and retention of anthropogenic Nr.

Chain of process oriented, spatially distributed models are able to reliably predict nitrogen transfer and retention along its cascade from agricultural soils to aquifers, surface water and coastal sea, with a spatial resolution and a degree of details in the description of the process suitable for management scenario analysis.

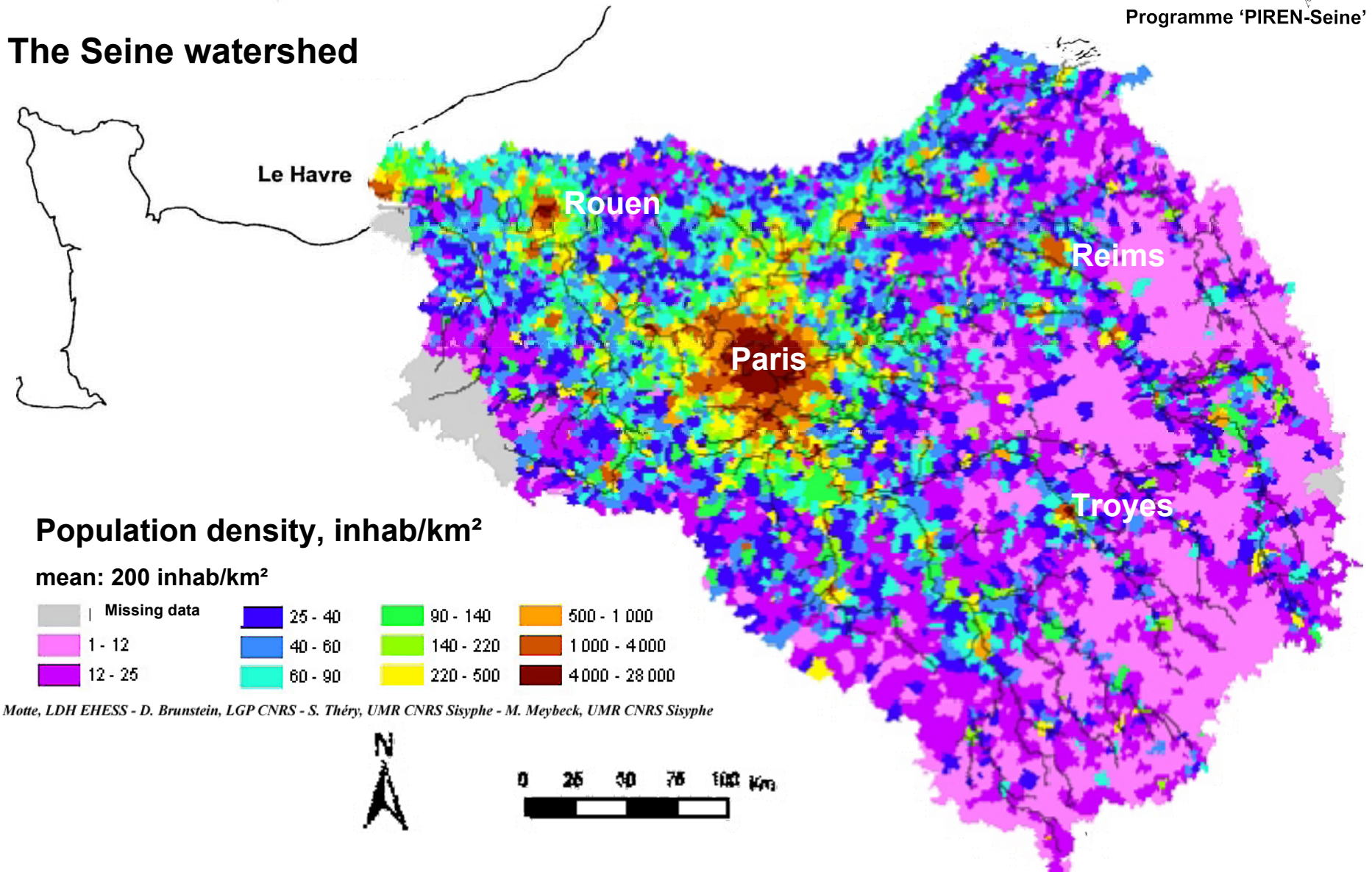
The description of gaseous emission processes, in agricultural soils, wetland and aquatic systems, requires further research efforts.

The modelling chain of the PIREN-Seine

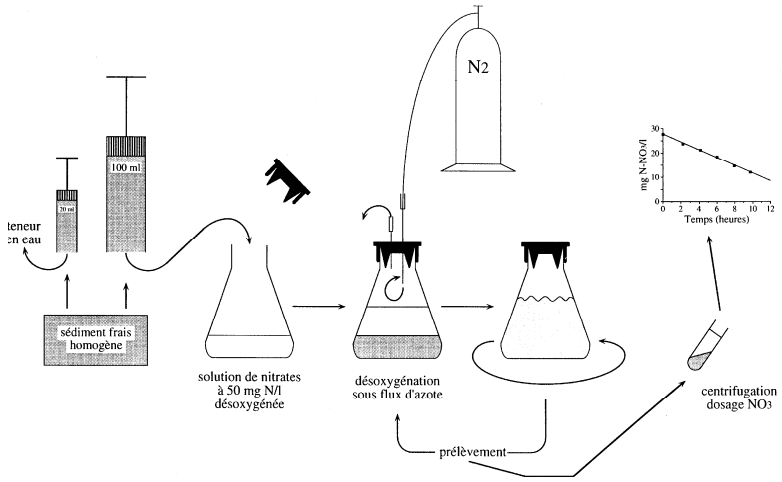


Programme 'PIREN-Seine'

The Seine watershed

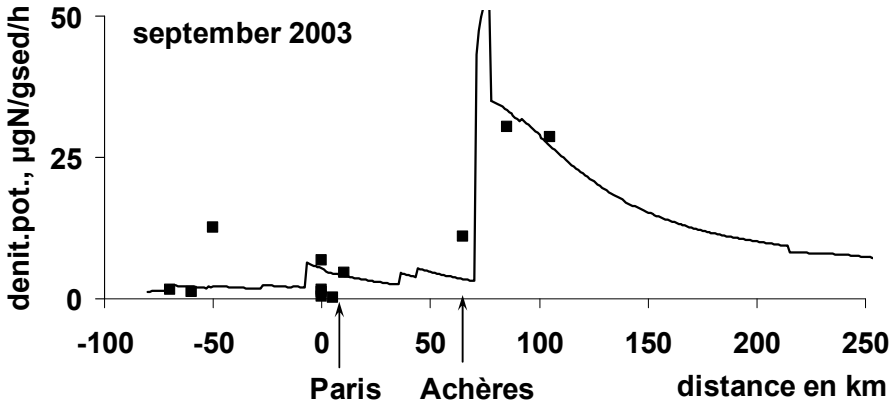


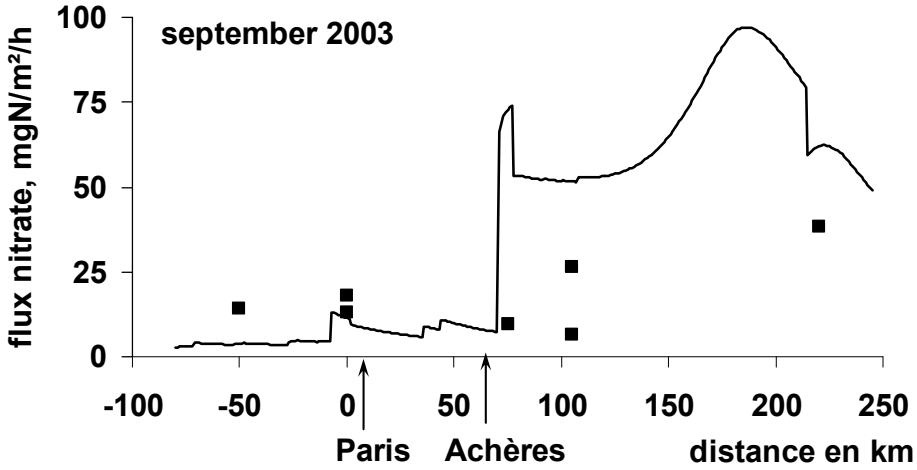
Allows a detailed evaluation of the sites of nitrogen ‘retention’ in the drainage network



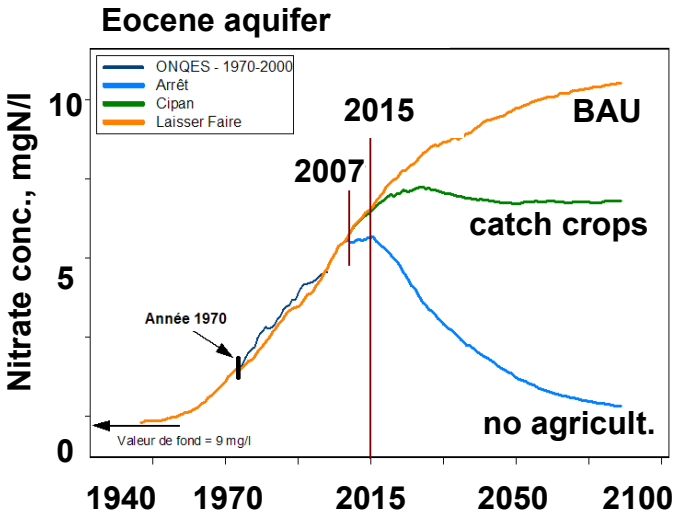
Measurement of potential denitrification (Sanchez, 1996)

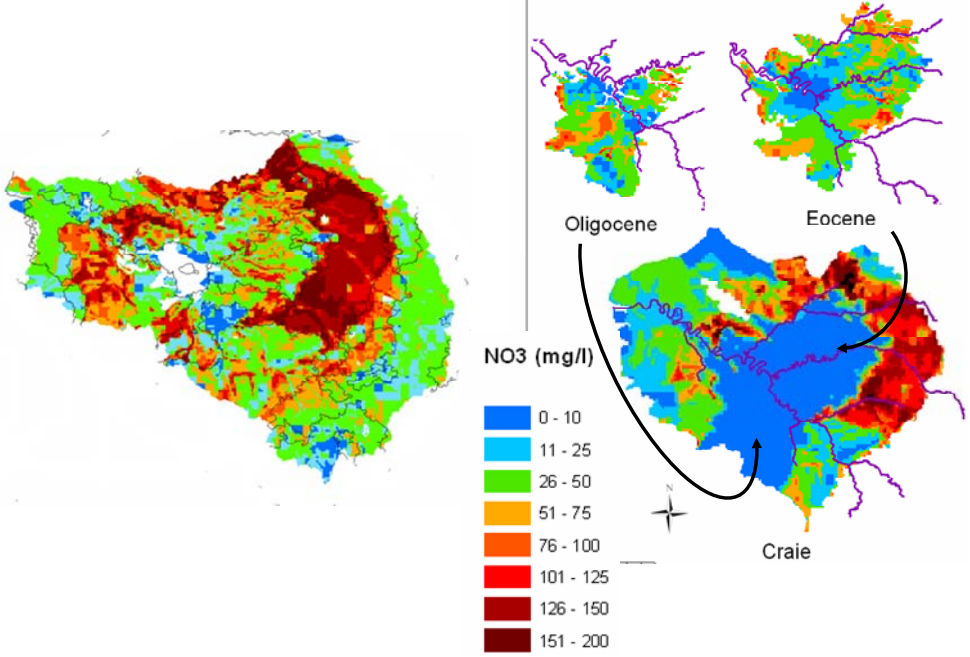
Seine River system, 2003





Thouvenot et al., in prep.


Eocene aquifer
ONQES - 1970-2000
Arrêt
Cipan
Laisser Faire
Nitrate conc., mgN/l
10
5
0
2015
BAU
2007
catch crops
Année 1970
no agricult.
Valeur de fond = 9 mg/l
1940
1970
2015
2050
2100


Oligocene
Eocene
Craie
NO3 (mg/l)
0 - 10
11 - 25
26 - 50
51 - 75
76 - 100
101 - 125
126 - 150
151 - 200