VULNERABILITY OF WATER QUALITY EXAMPLIFIED ON THE RIVER SEINE

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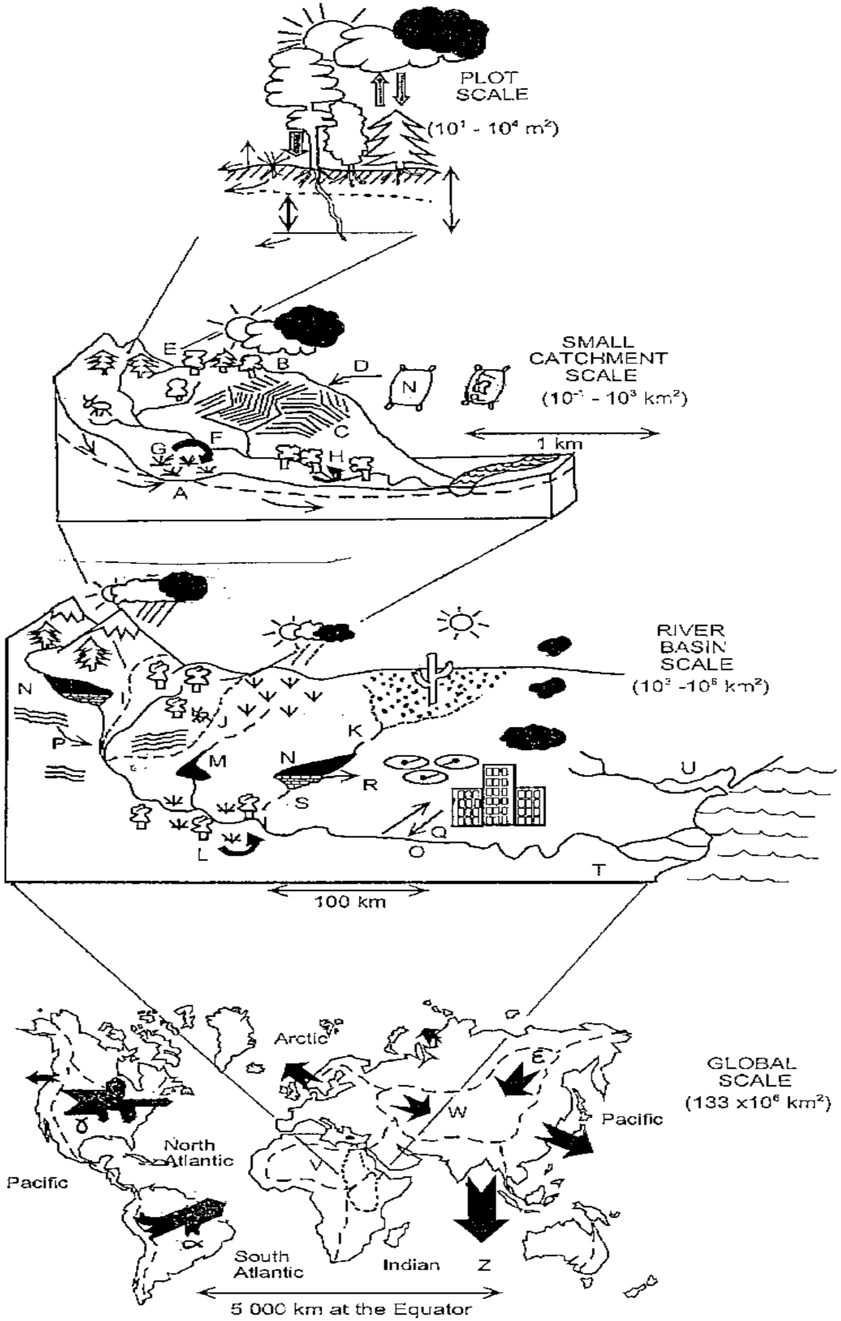
AVEC Conference, september 2005

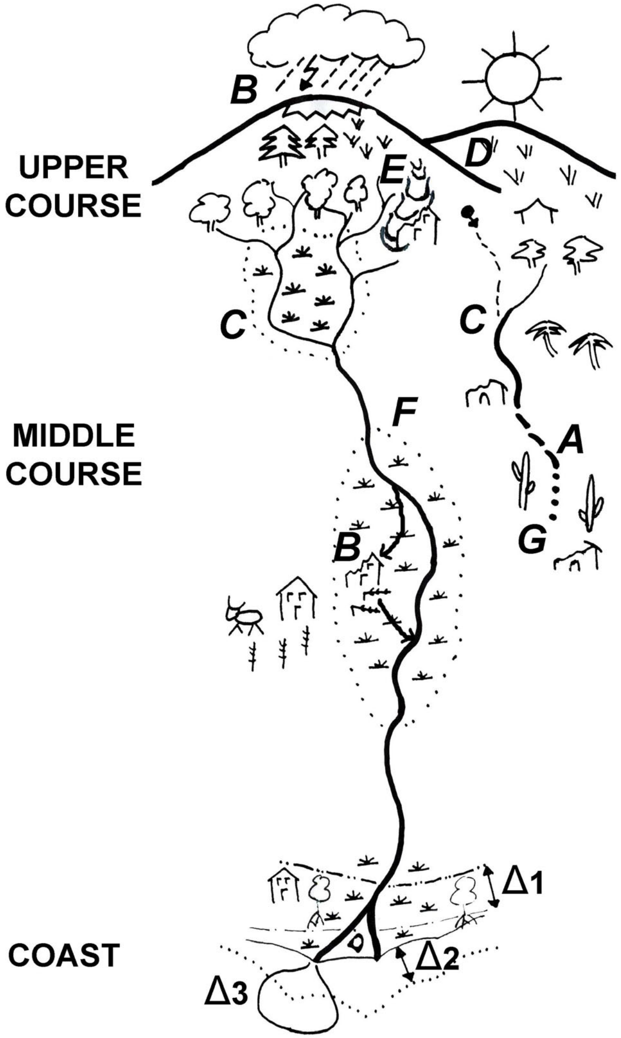
OUTLINE

- Local impacts vs. Earth System
- Issues and Pressures
- Time analysis
- Space analysis
- Budgets
- Scenarii: CC & HD

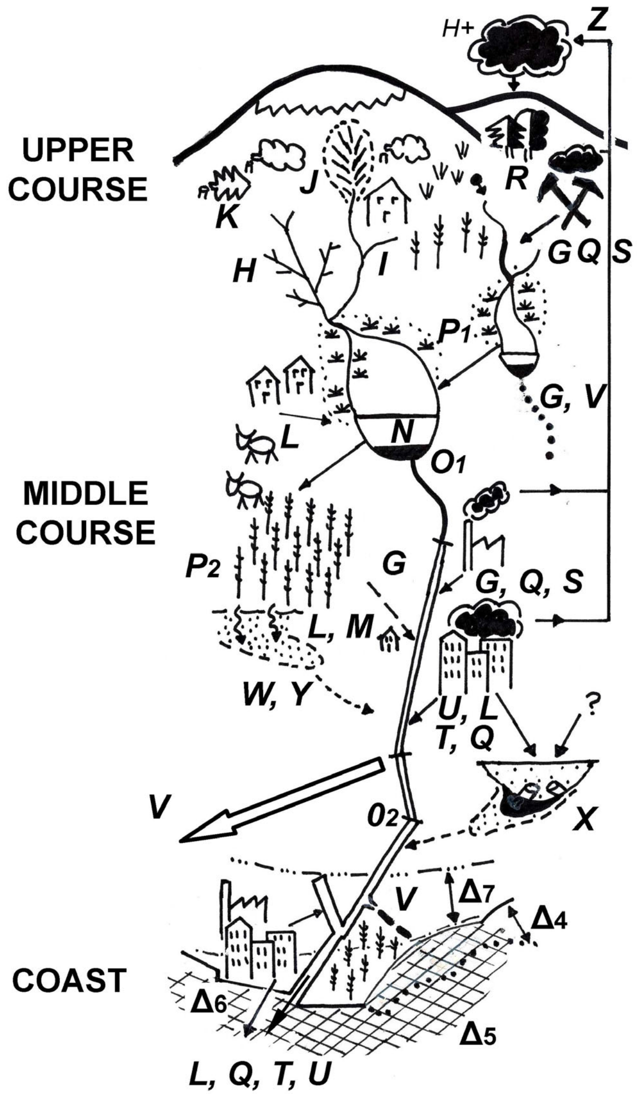


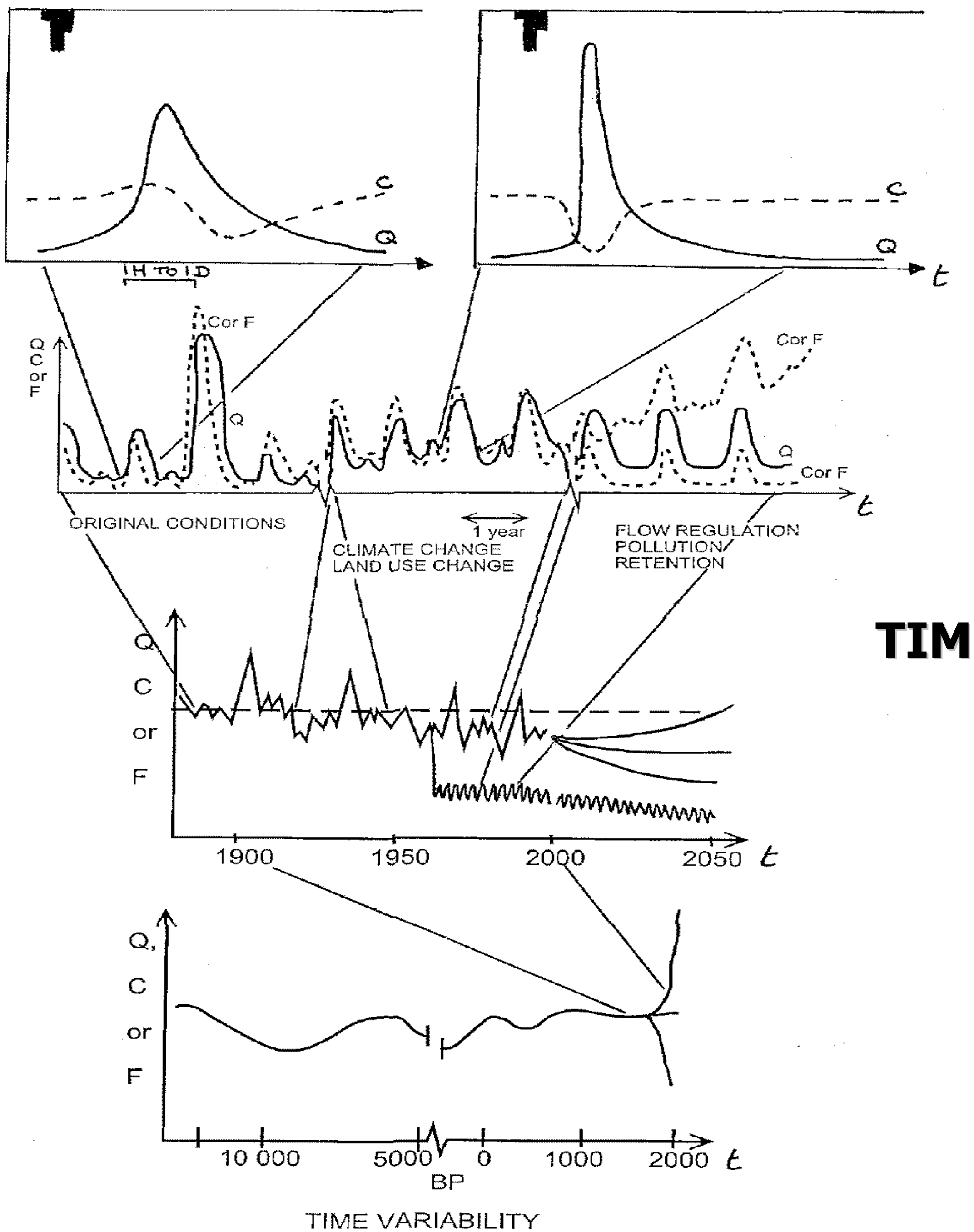
SPACE SCALES IN RIVER BASINS

River Systems impacted by Climate Change and Sea Level Rise



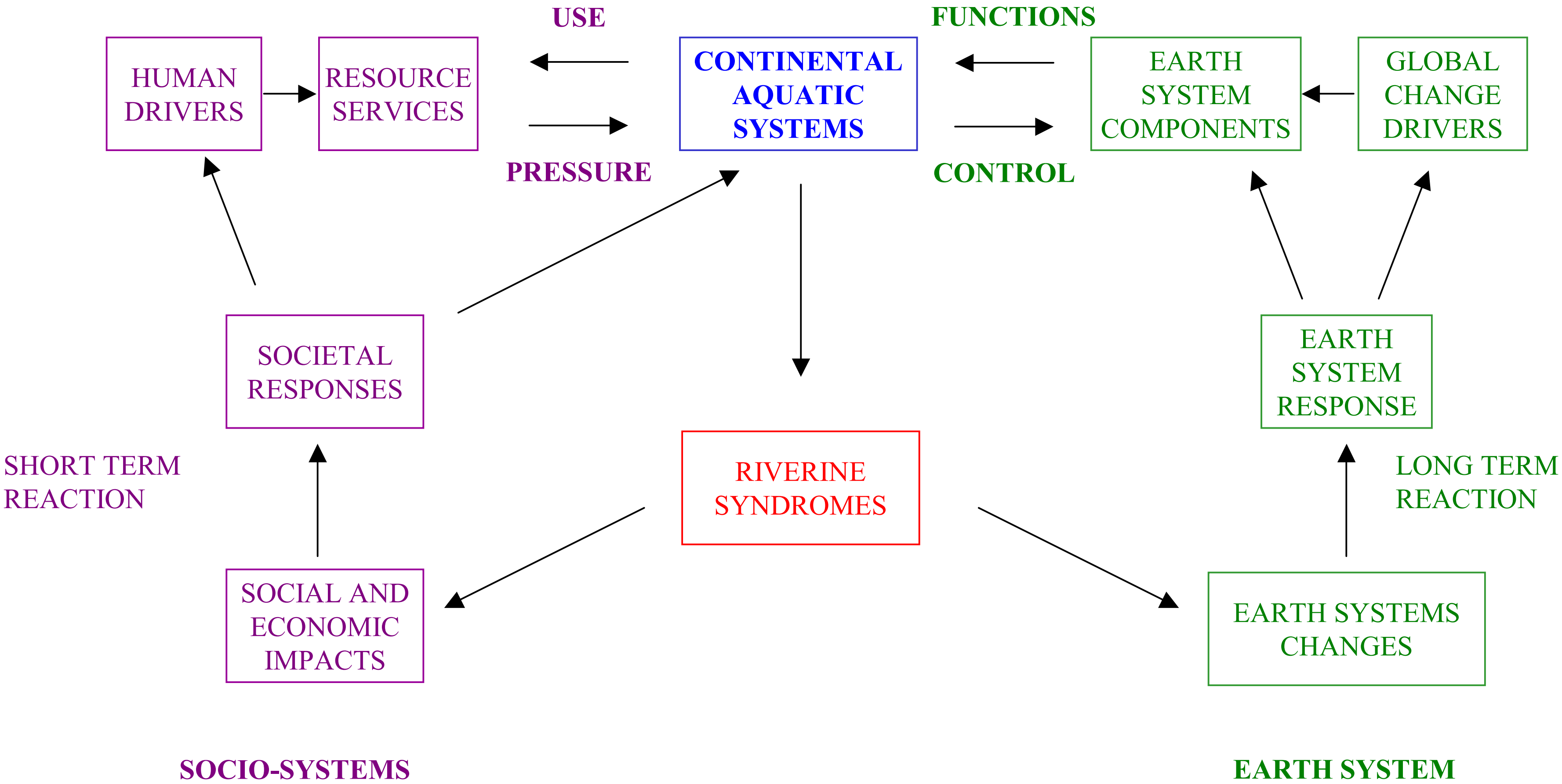
River Systems exposed to direct human impacts





TIME SCALES IN RIVER BASINS

SCHEMATIC POSITIONS OF CONTINENTAL AQUATIC SYSTEMS SHARED BY SOCIO-SYSTEMS AND EARTH SYSTEM



- The Driver-Pressure-State-Impact-Response cycle in socio-systems is generally observed at short to medium periods (10-50 y)
- The parallel Environmental impacts-Earth System response- Regional to Global Change is a long term reaction (100-1000 y) still poorly known

ISSUES IDENTIFIED ON THE SEINE

- 1830’s microbial pollution (cholera outbreak)
- 1960 organic pollution/O_2 balance
- 1976 eutrophication
- 1980’s metals, POPs
- 1980 nitrate
- 2000’s endocrine disruptors
- not identified as an issue: salinization
- not possible acidification
- not really addressed radionuclids
- 2000 possible thermal pollution

PROGRAMME "PIREN-SEINE"

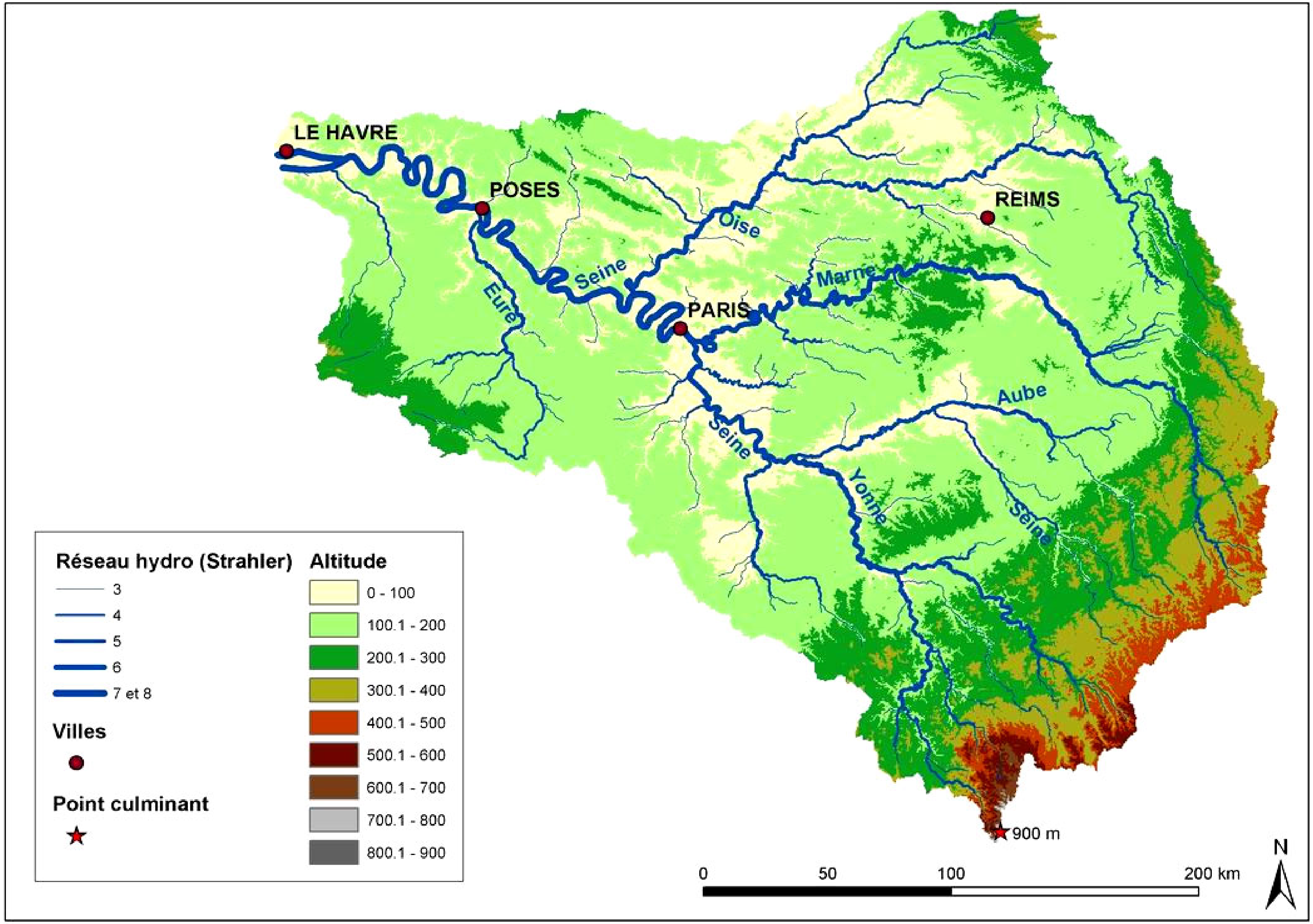
PIREN SEINE

- Multidisciplinary programme from historians to biogeochemists
- Long-term water quality records
- Long-term pressures and material reconstruction flow analysis
- Sedimentary archives
- Whole basin water quality models
- Scenarios

SEINE RIVER BASIN

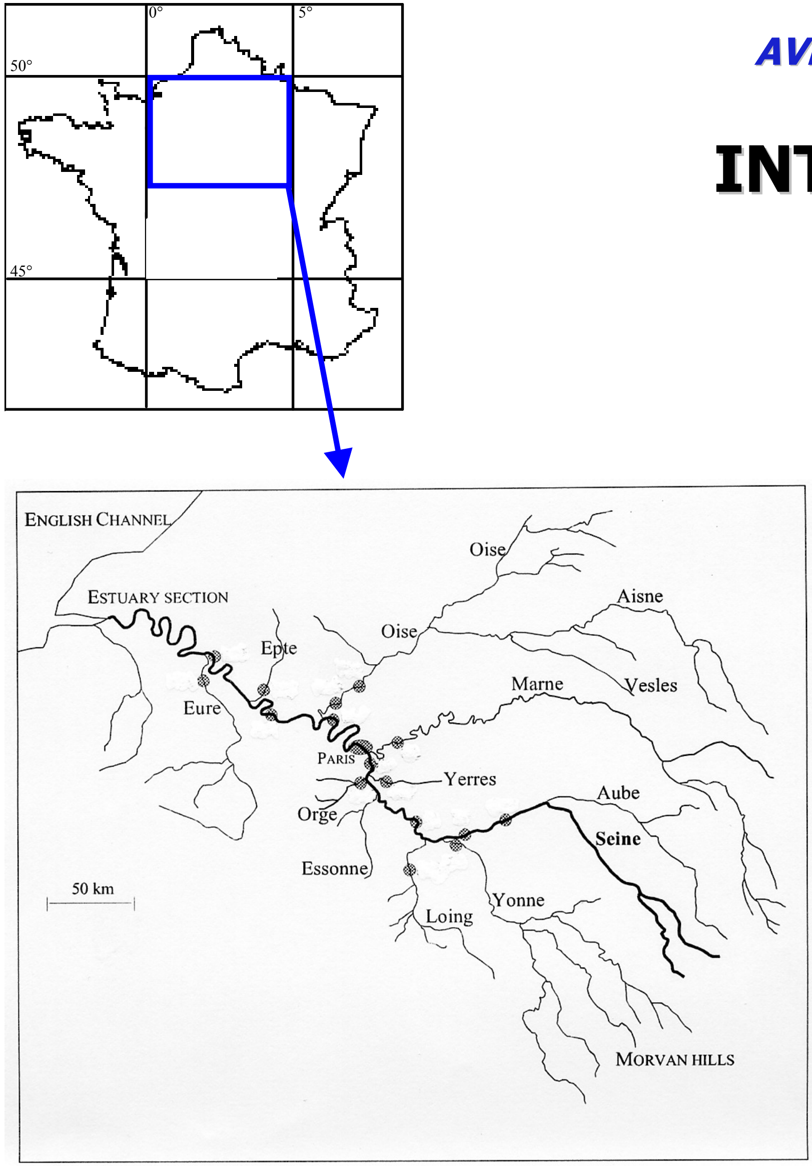
- 65 000 km² x 17 million people = **250 people/km²**
  vs. 50 p./km² for world average on exorheic
- Water dilution power moderate: runoff **8 l/s/km²**
  vs. 10 l/s/km² for WA
- Sediment dilution power very low: **10 t/km²/y** and **25 mg/L TSS**
  vs. 200 t/km²/y and 500 mg/L for WA

SEINE BASIN RELIEF



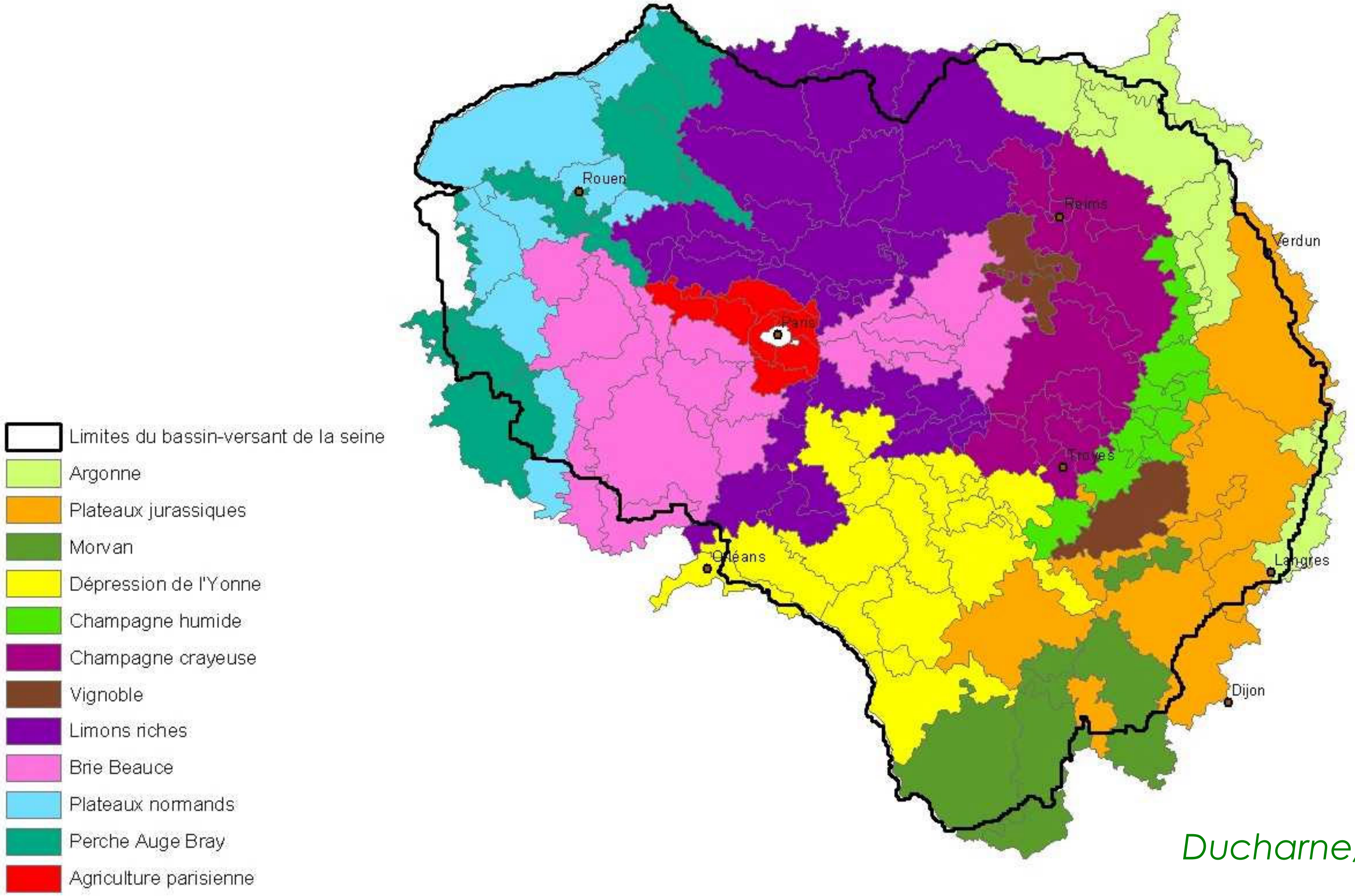
- 90 % of the basin is flat, climate and lithology are uniform

INTRODUCTION



- The Seine is naturally very vulnerable to most human pressures
- The Seine River is one of the most impacted fluvial system
- The Seine combines multiple syndromes of river change
- These trends can be reconstructed over 50 to 100 years
- Spatial complexity should also be carefully addressed
- Man and River relationships are begining to be deciphered
- Our perception and knowledge of environmental quality issues is evolving fast: is water quality a societal construction?

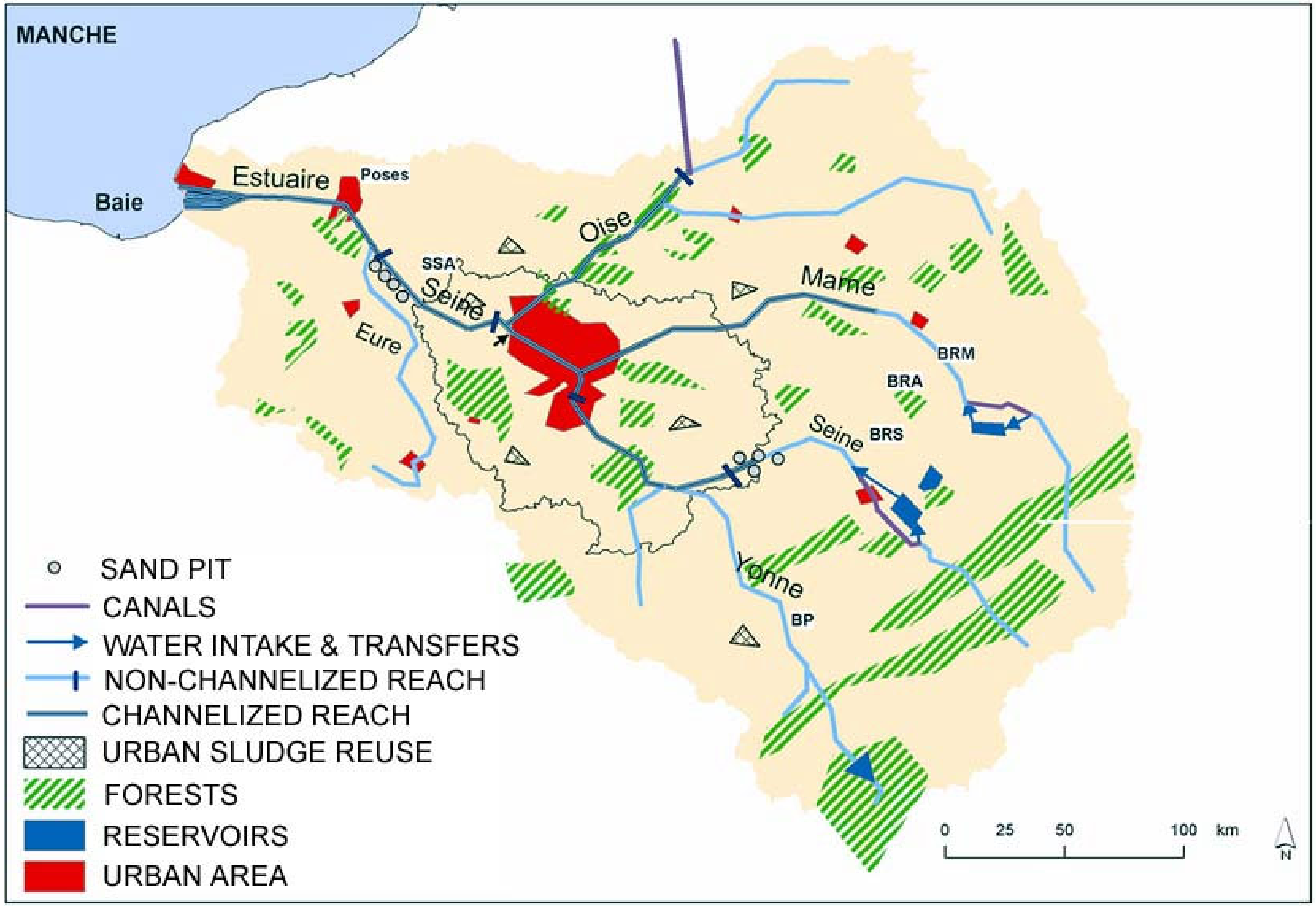
TYPOLOGY OF AGRICULTURE



Ducharne, 2005

- 12 main regions (20 soil types x 20 crop rotation x 20 farming practises)
- Used for scenarii analysis

SEINE RIVER BASIN



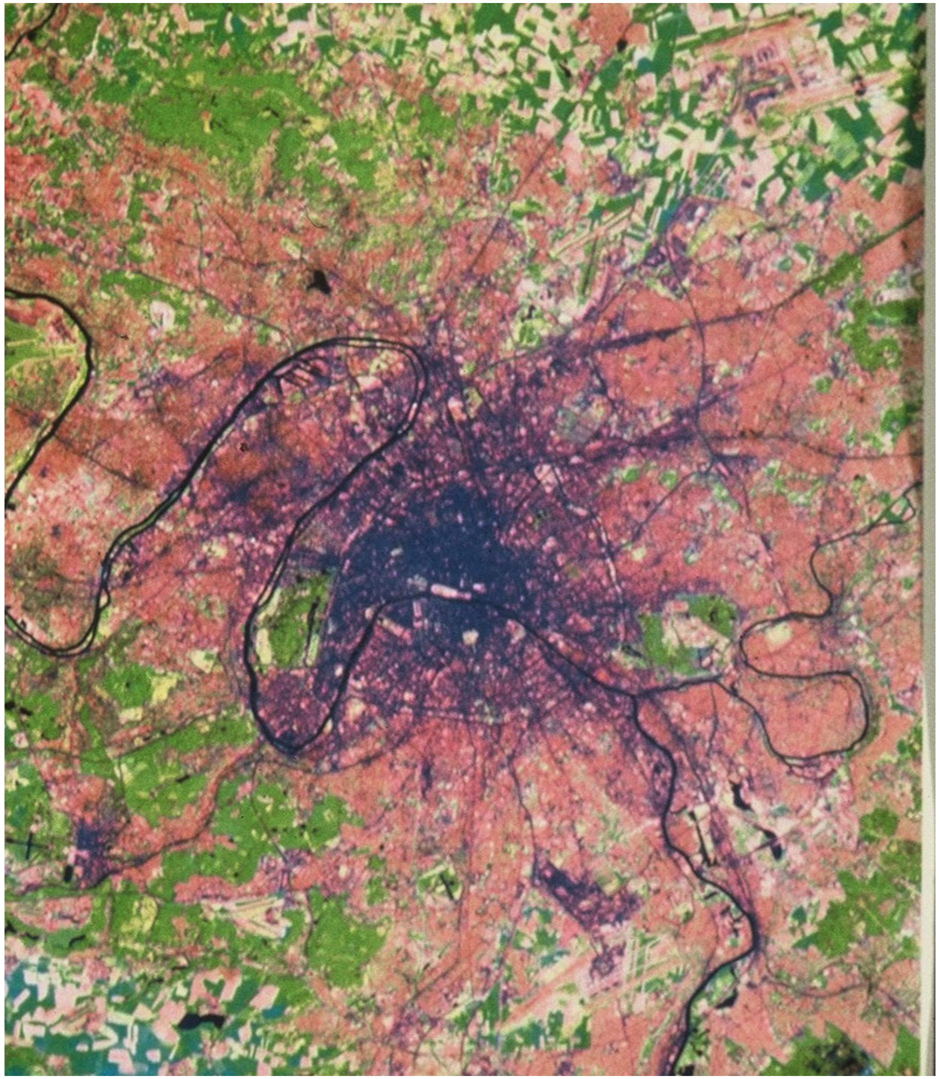
PIREN-Seine, 2004

- Most of the drained network is regulated
- Intensive agriculture is wide spread and single point sources: Paris megacity

PARIS MEGACITY

- Paris megacity (25 000 km^2): 10 Mpeople
  vs. Natural low flows in Paris 50 m^3/s
- About 1/3 of France industrial activity
  1/3 of France intensive agriculture (cropping)
- Highly regulated and navigated river → sluices; dredging
  → loss of habitat
- Old Human and agriculture occupation > 2000 years
- **No mining; 90 % carbonated rocks**
- **River basin authority since 1964 (effective in 1970)**

GREATED PARIS AND SEINE NETWORK SEEN BY SATELLITE



- Lutetia was settled here because the river was easy to cross
- Since 2000 y it has grown up to a megacity of 10 M people and 2500 km2 of built-up land
- Paris impact on its basin extend few 100 km upstream and downstream
- Natural fluxes of some material (nutrients, metals) have been multiplied by 10 to 100

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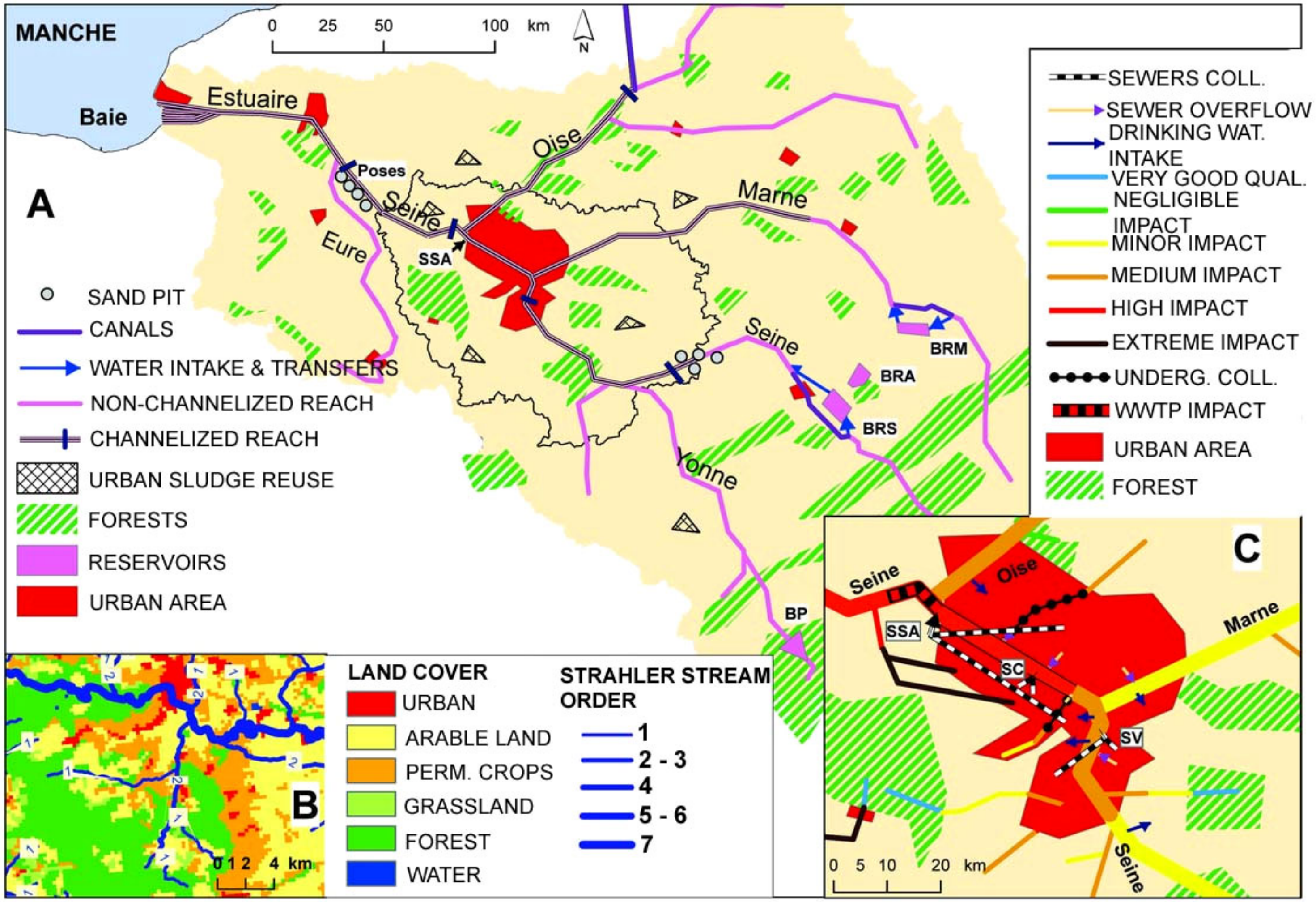
SEINE RIVER BASIN



PIREN-Seine, 2004

PARIS MEGACITY HISTORY

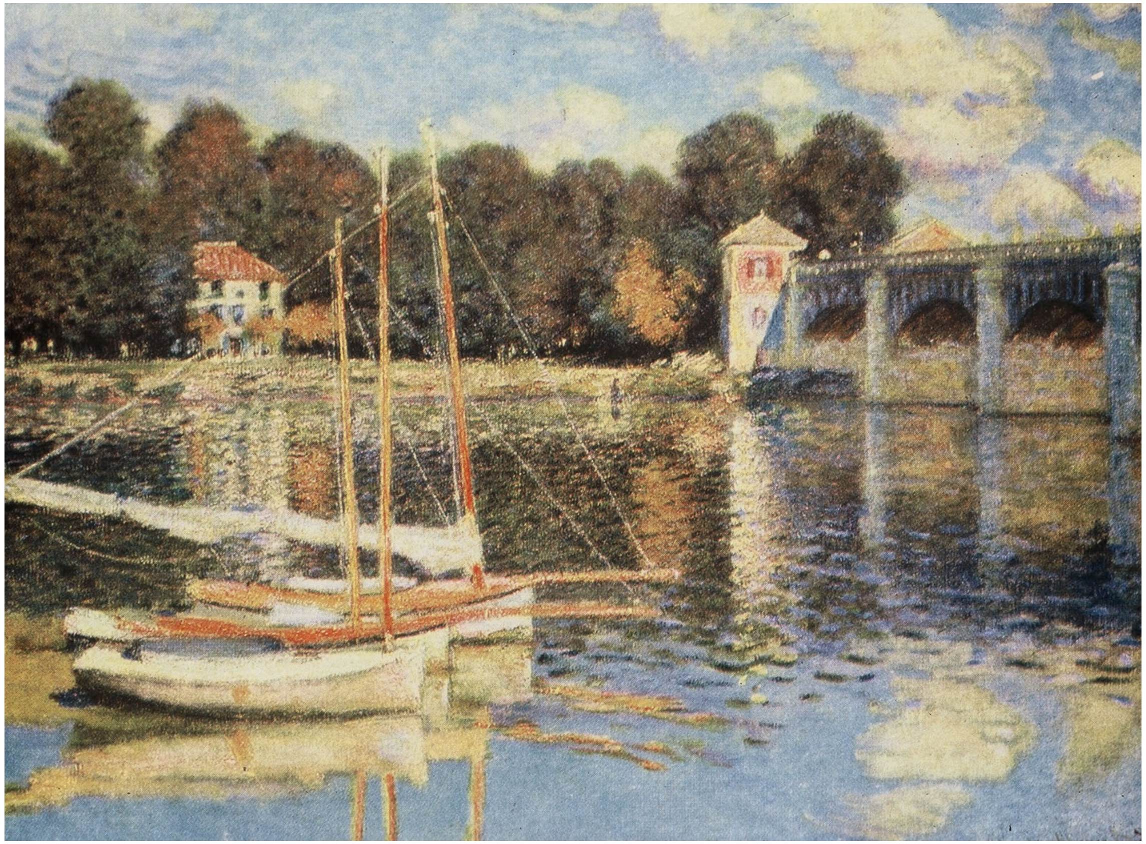
- In 1900's, about 2 Mpeople, now 10 Mpeople aggregated
- Sewer system started > 1850 (combined sewers than separated sewers)
- City very industrialized until 1960's

REGATA ON THE SEINE RIVER AT THE PONT NOTRE-DAME (1700'S)

DN5, Carnavalet Museum

- Notre Dame is typical of urban bridges of the late Middle Age
- Floating water mills were still in use at that time sharing the river with fluvial transportation
- Until 1900 the Seine river was used for multiple purposes including recreation

SEINE RIVER AT ARGENTEUIL (MONET) (1880's)



FH 14

- Personnal use of waterscape greatly favours the relation between citizens and water bodies
- Sailing is not allowed any more in the Seine

MAIN SEWAGE COLLECTOR IN PARIS, LATE 1800'S

FD 16 ; Paris Souterrain

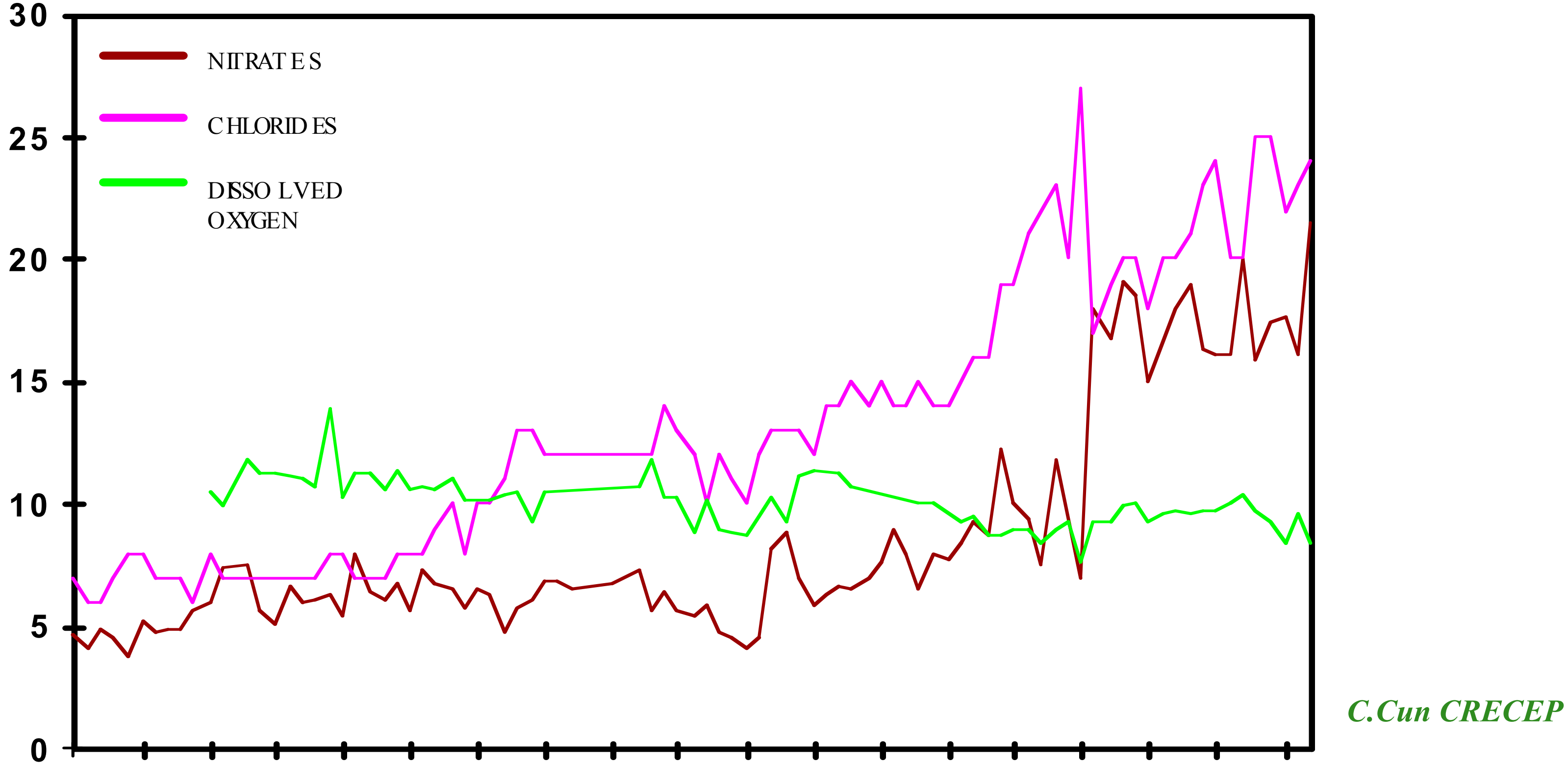
- The Paris sewage network has been conceived after the cholera outbreaks in the 1830's
- It took several decades to decide, plan and achieve this network, the waste waters being derived through siphons and tunnels some 50 km away
- Continuing the recycling of organic carbon and nutrients started in the Middle Age, waste waters were firts spread on agricultural land purchased by the city of Paris
- The modern waste water treatment was mostly developed in 1960-1990 in a giant facility (10 M people) ; the treated sludge is still reused as fertilizer

FLUVIAL TRANSPORT OF NEW CARS ACROSS GREATER PARIS

FE 25

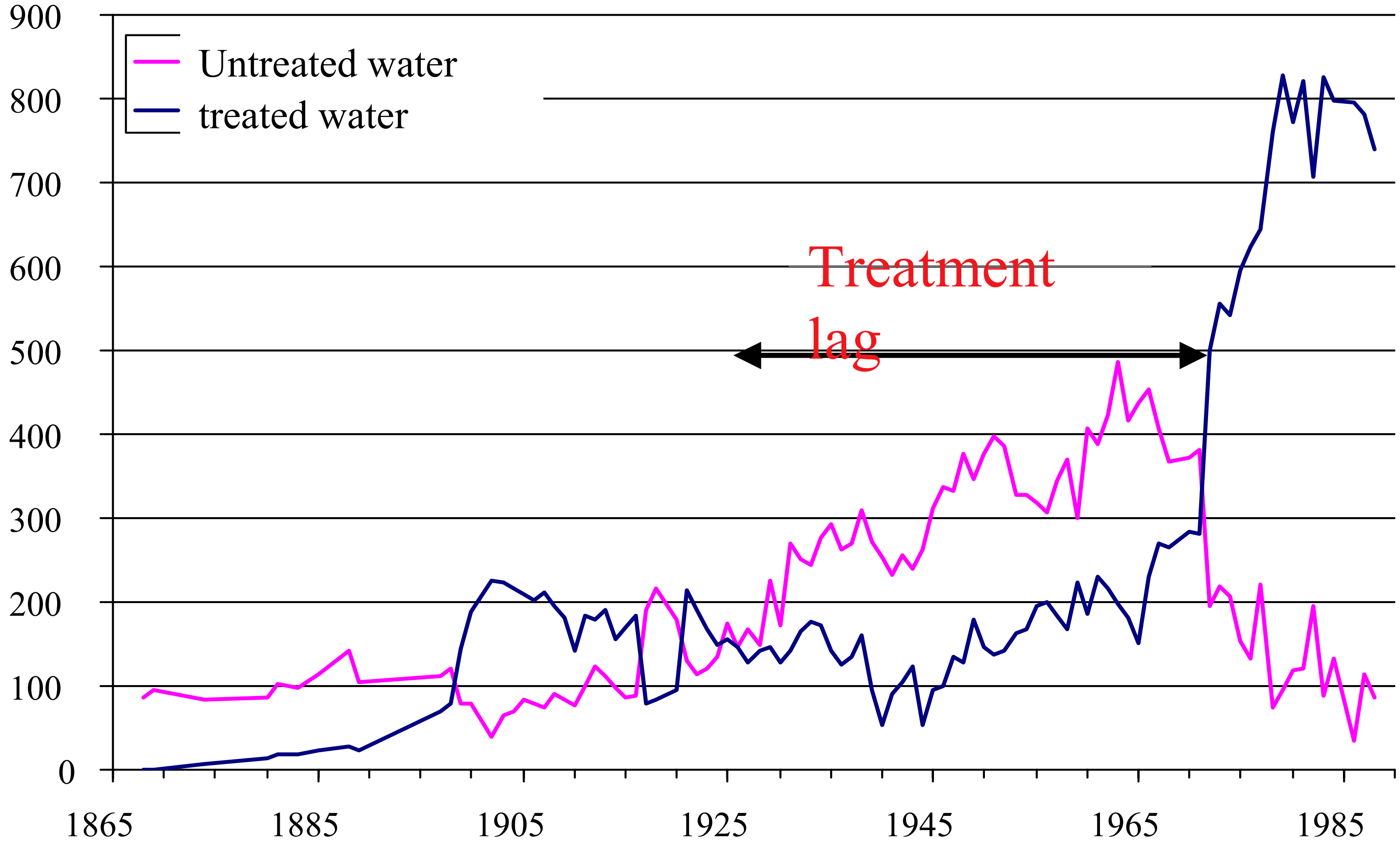
- Throughout the XXth centurry fluvial navigation has been a major driver of the river Seine management
- Other industrial drivers have been the Sewage works institution representing 10 M Parisians and the major water companies using the river as drinking water supply and Paris city using river banks as highways
- Since few years Paris river banks are now on UNESCO world's list of protected sites and common citizens are gradually beginning to reuse river amenities

SEINE WATER QUALITY TRENDS (1901-1991) UPSTREAM OF PARIS CITY (POP DENSITY ≈ 120p/km²)



- Nitrate levels have markedly increased due to industrial fertilisers use from 1950
- Dissolved oxygen is not affected by Greater Paris whose sewage water have been gradually collected, treated and released some 80 river km downstream
- Chloride levels have moderately increased from 1901 to 1971

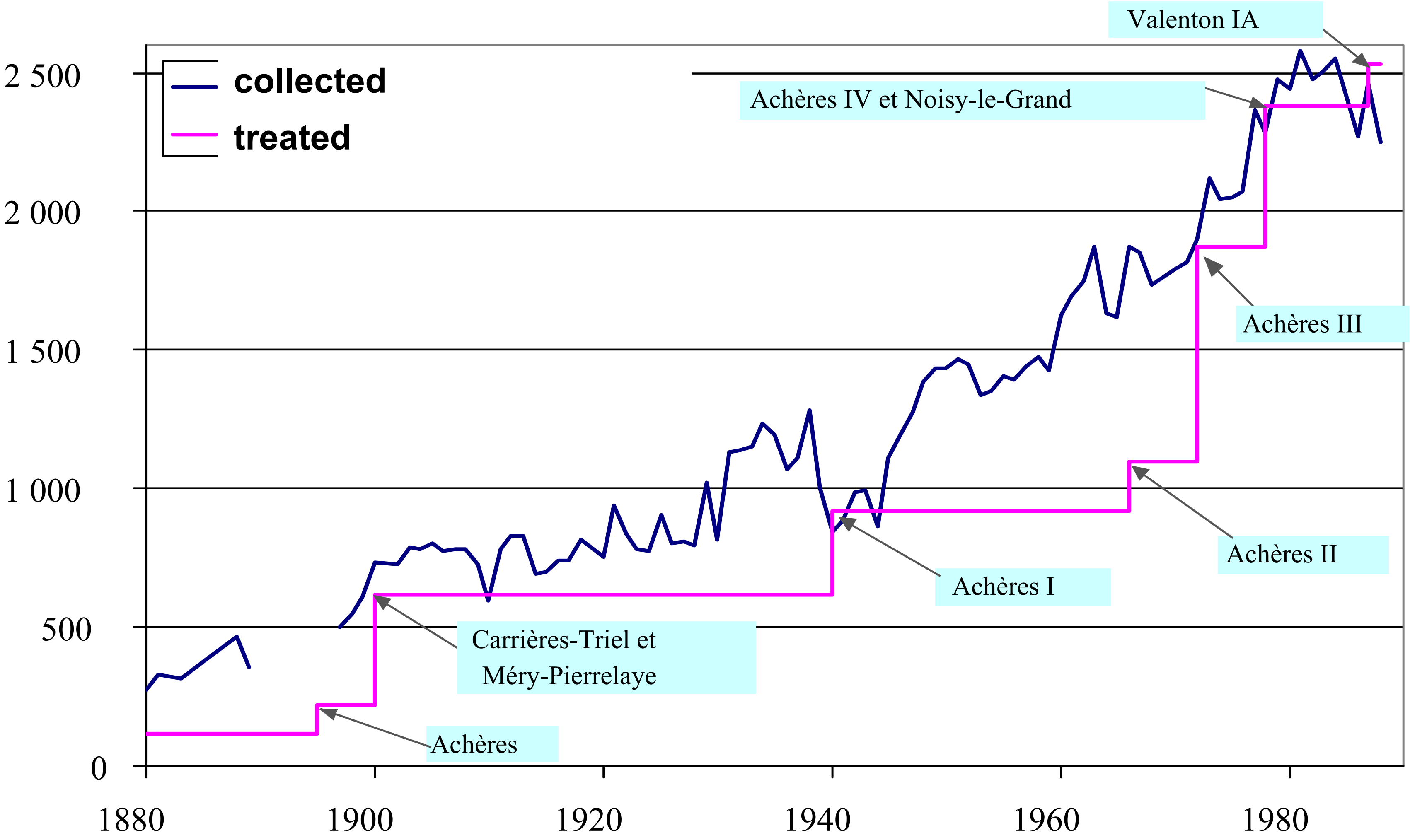
PARIS MEGACITY: VOLUME OF TREATED AND UNTREATED SEWAGE WATER (1865-1990) (10^6 m^3/y)



- 1900: 85% treated
- 1940: 18% treated
- 1990 87% treated

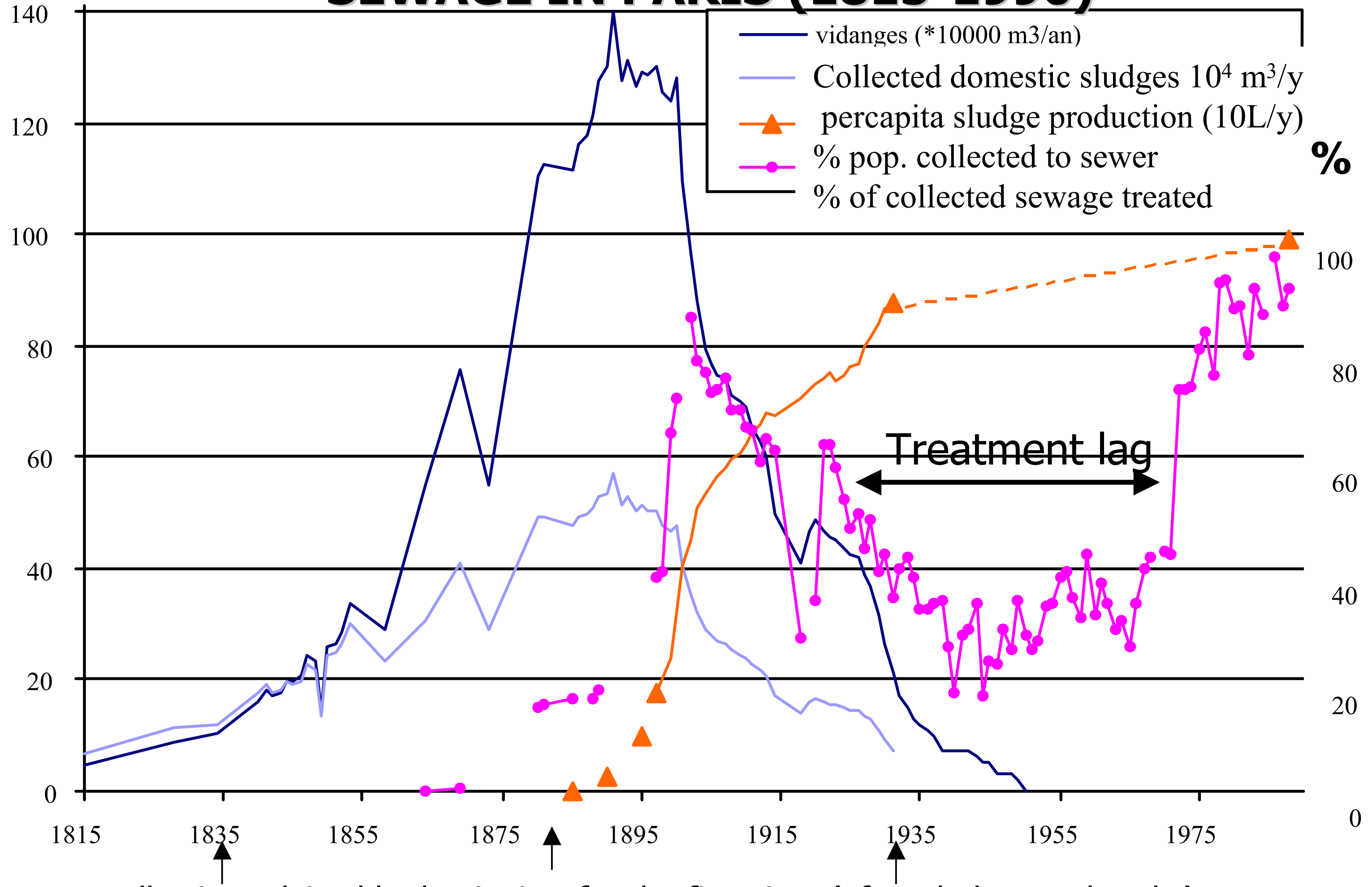
S. Barles ; Piren Seine, 2003

WASTE WATERS VOLUMES COLLECTED AND TREATED (103 m³/d) (1880-1990)



S. Barles ; Piren Seine, 2003

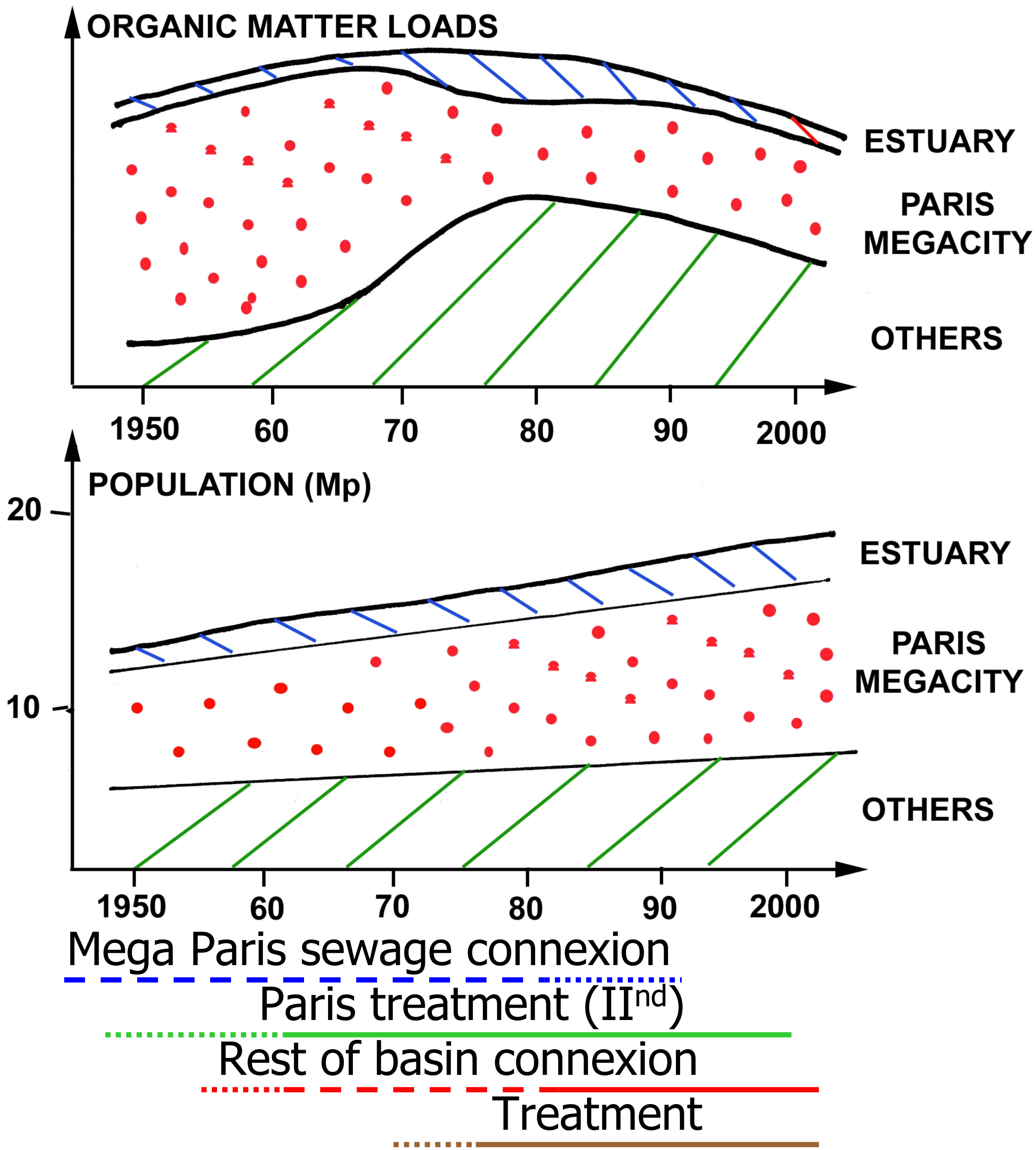
FROM DOMESTIC SLUDGE COLLECTION TO URBAN SEWAGE IN PARIS (1815-1990)



A. Sewage collection advised by hygienists for the first time (after cholera outbreaks)
B. 1885 Sewage collection recommended by city of Paris
1894 Sewage collection « obligatory within 3 years »
C. 1931 90 %collection achieved
From 1935 to 1970, the majority of population was collected but not treated

S. Barles
Piren Seine, 2003

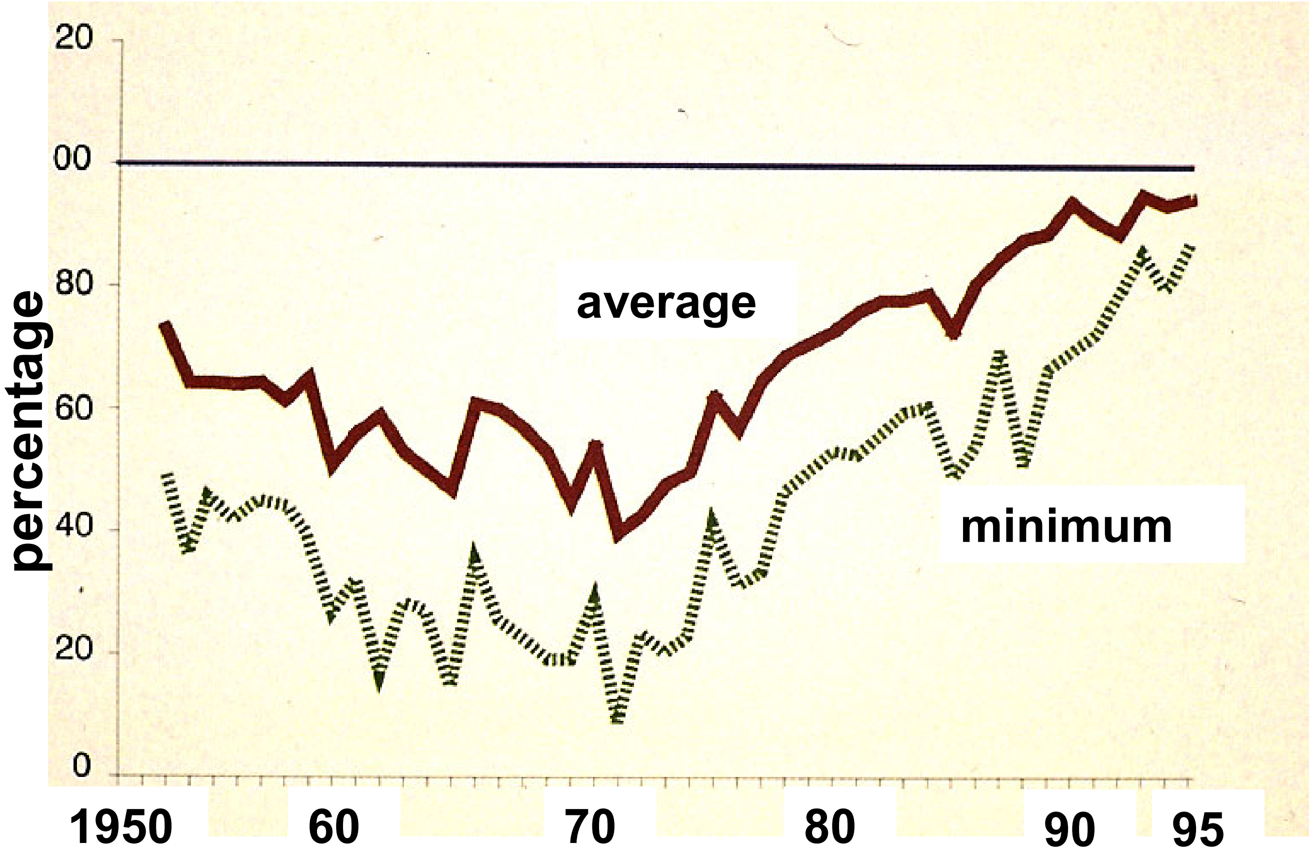
SCHEMATIC EVOLUTION OF ORGANIC (CARBONACEOUS) POLLUTION IN THE SEINE BASIN



PIREN SEINE

RHINE RIVER ASPHIXIATION (1960-1995)

River Rhine near Lobith, oxygen saturation

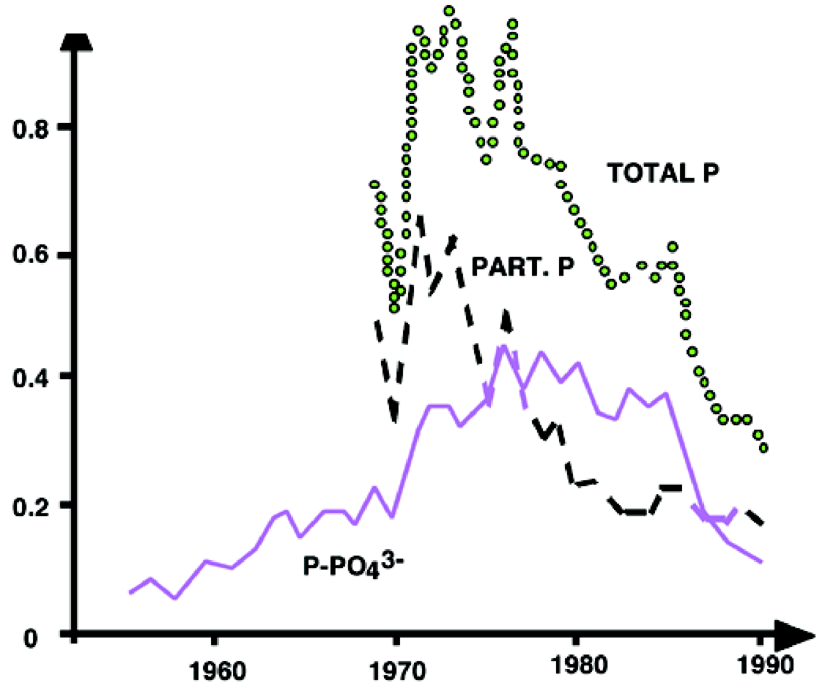


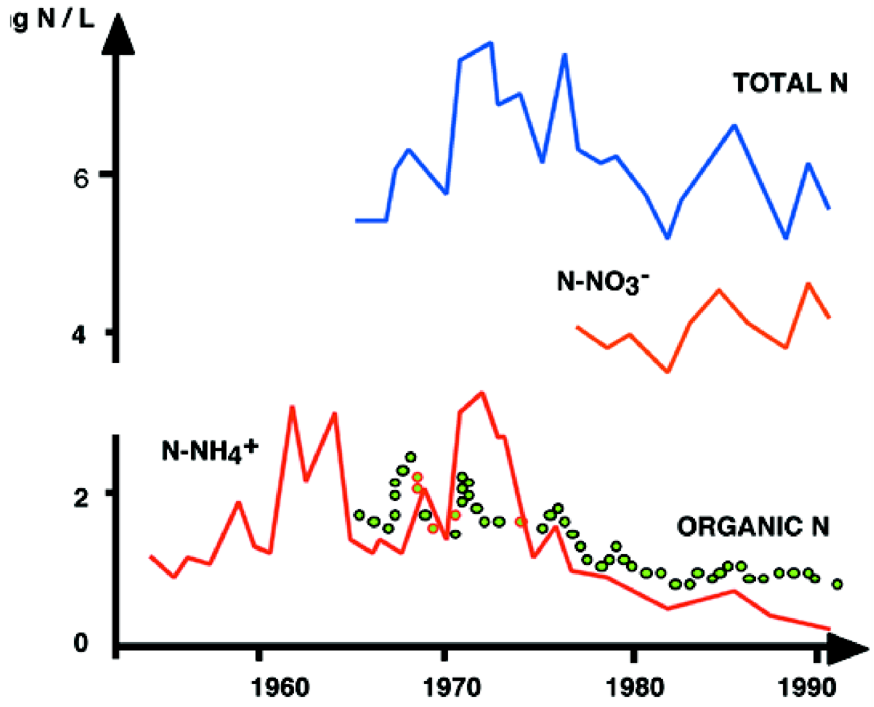
OG17

R. Breukel

The O_2 minimum period lasted 15 years until sewage collection and Oxygen Demand treatment was implemented (1960-1975)

A SUCCESS STORY : NUTRIENTS CONTROL IN THE RHINE R.

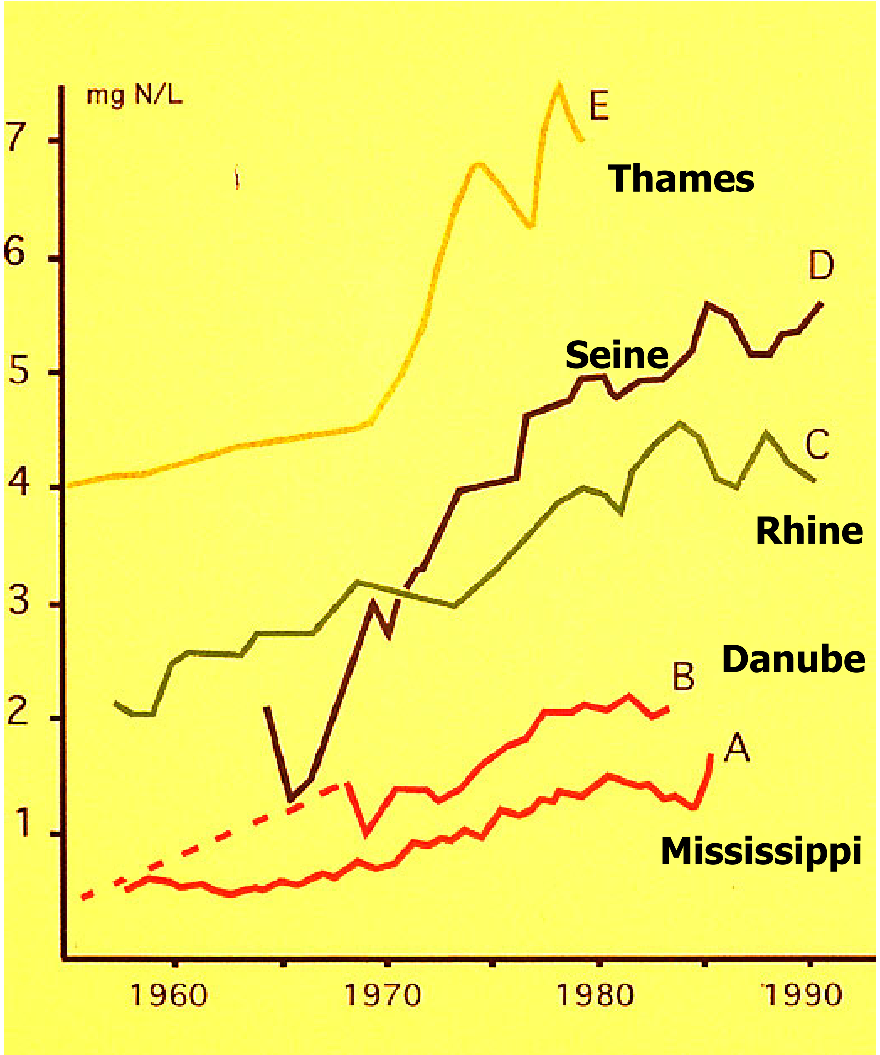




Van Dijk & Marteijn, 1993

- The major effort of sewage collection was between 1960 and 1975 : it resulted in particulate P abatment and NH_4^+ decrease
- $P\text{-}PO_4^{3-}$ control then decrease was only achieved after the 1985 ban of P detergents and the dephosphatation in most treatment plants

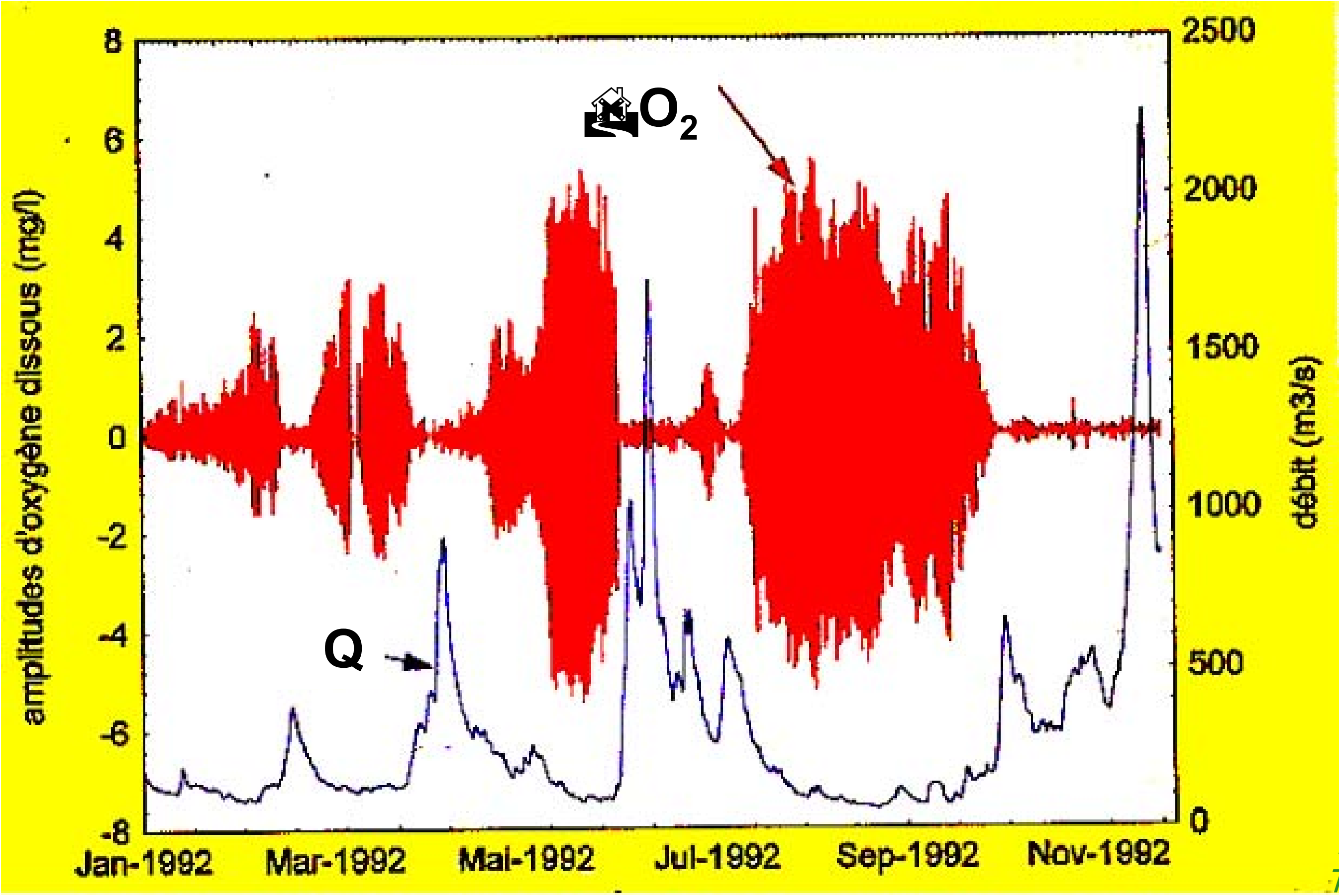
NITRATE TRENDS IN WORLD RIVERS



- From 1960 to 1990 nitrate has increased in most large rivers
- Maximum rates are observed in smaller catchments exposed to intensive fertilizer use

SD11

OXYGEN DAILY CYCLES AND RIVER DISCHARGE EUTROPHIED LOIRE RIVER (DAMPIERRE 1992)

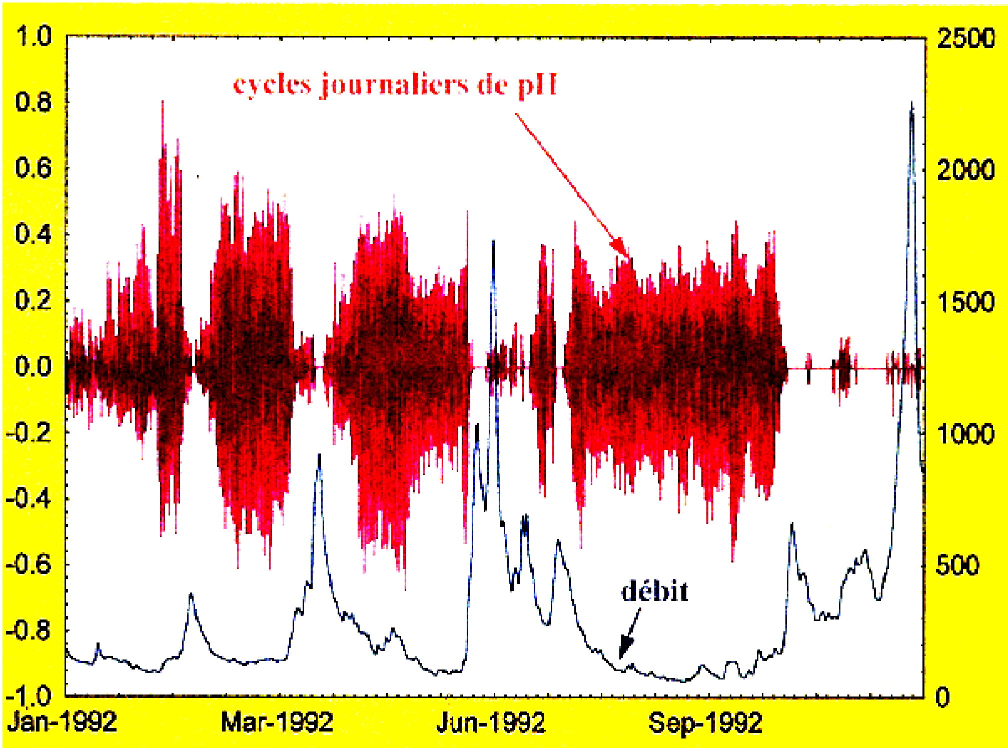


PA67

F. Moatar (Univ. Tours, 1999)

- Daily O_2 cycles may reach 9 mg/L !
- They are destroyed by river floods

RIVER EUTROPHICATION : DAILY pH CYCLES IN THE LOIRE RIVER (AT DAMPIERRE)

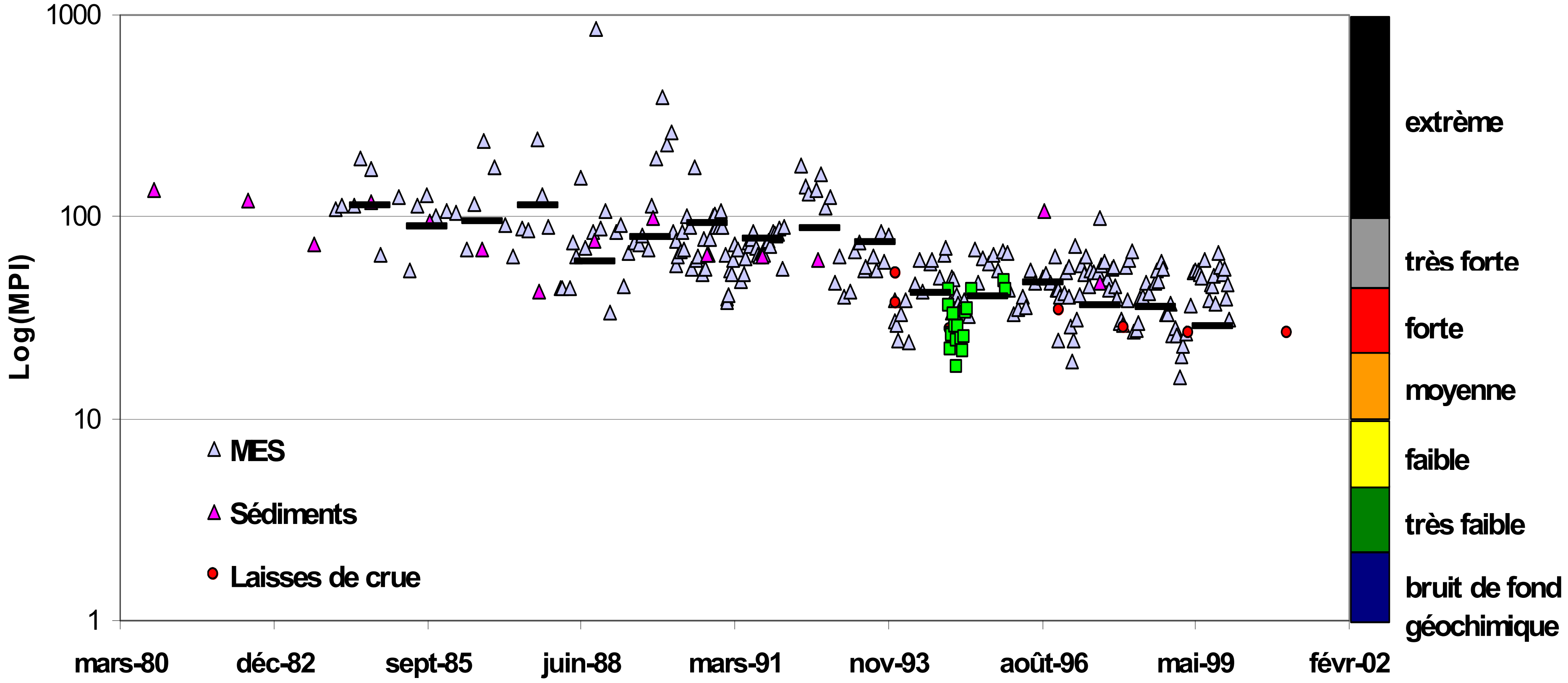


PA68

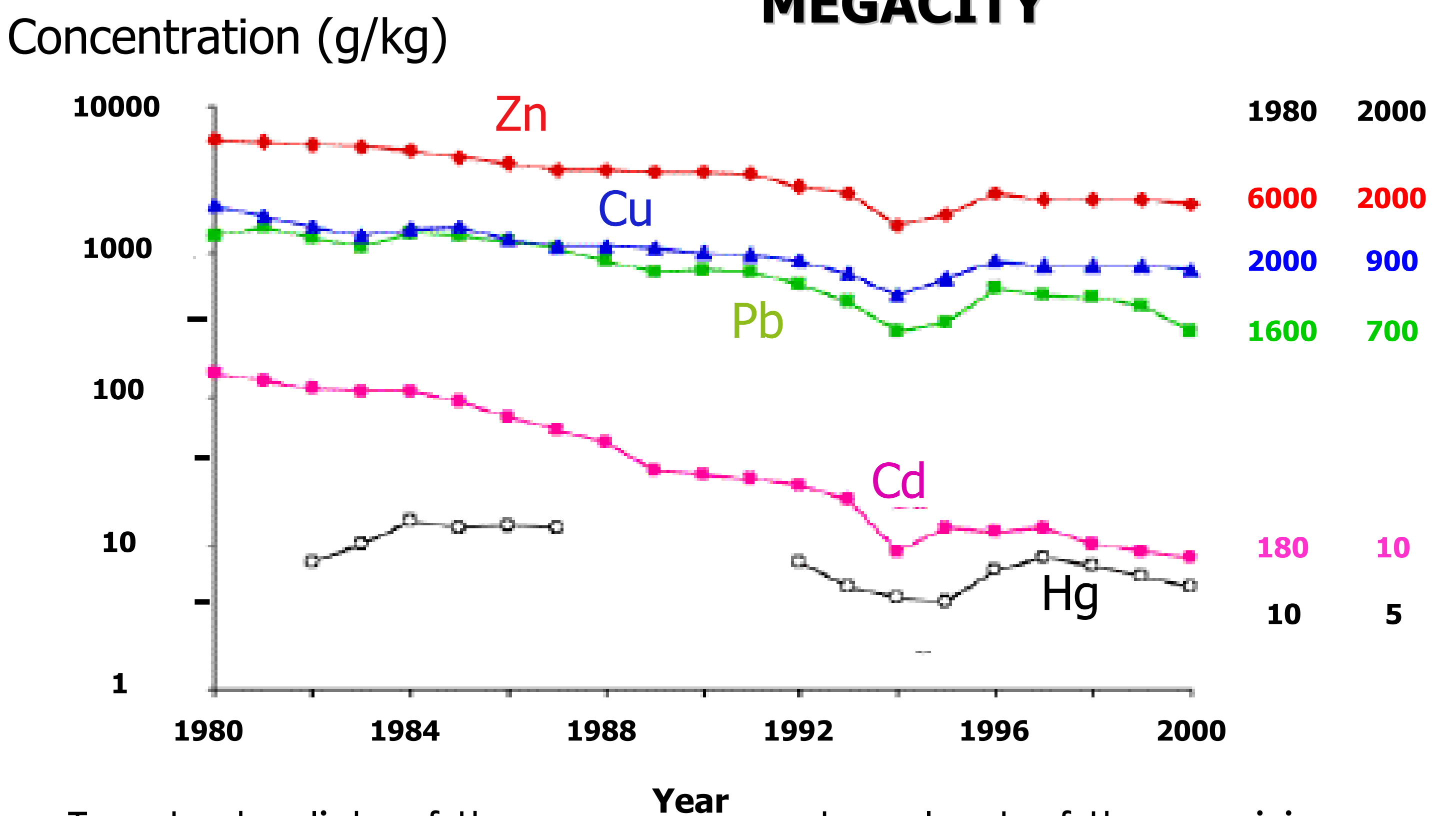
F. Moatar (1999, Univ. Tours)

- During spring and summer algal blooms (chloro A > 100 µg/L) the daily pH cycles may reach 1.2 pH units
- Such events can only be noted during stable low flows : they are destroyed by floods

Evolution of polymetallic contamination indicator in the Seine basin (Poses)

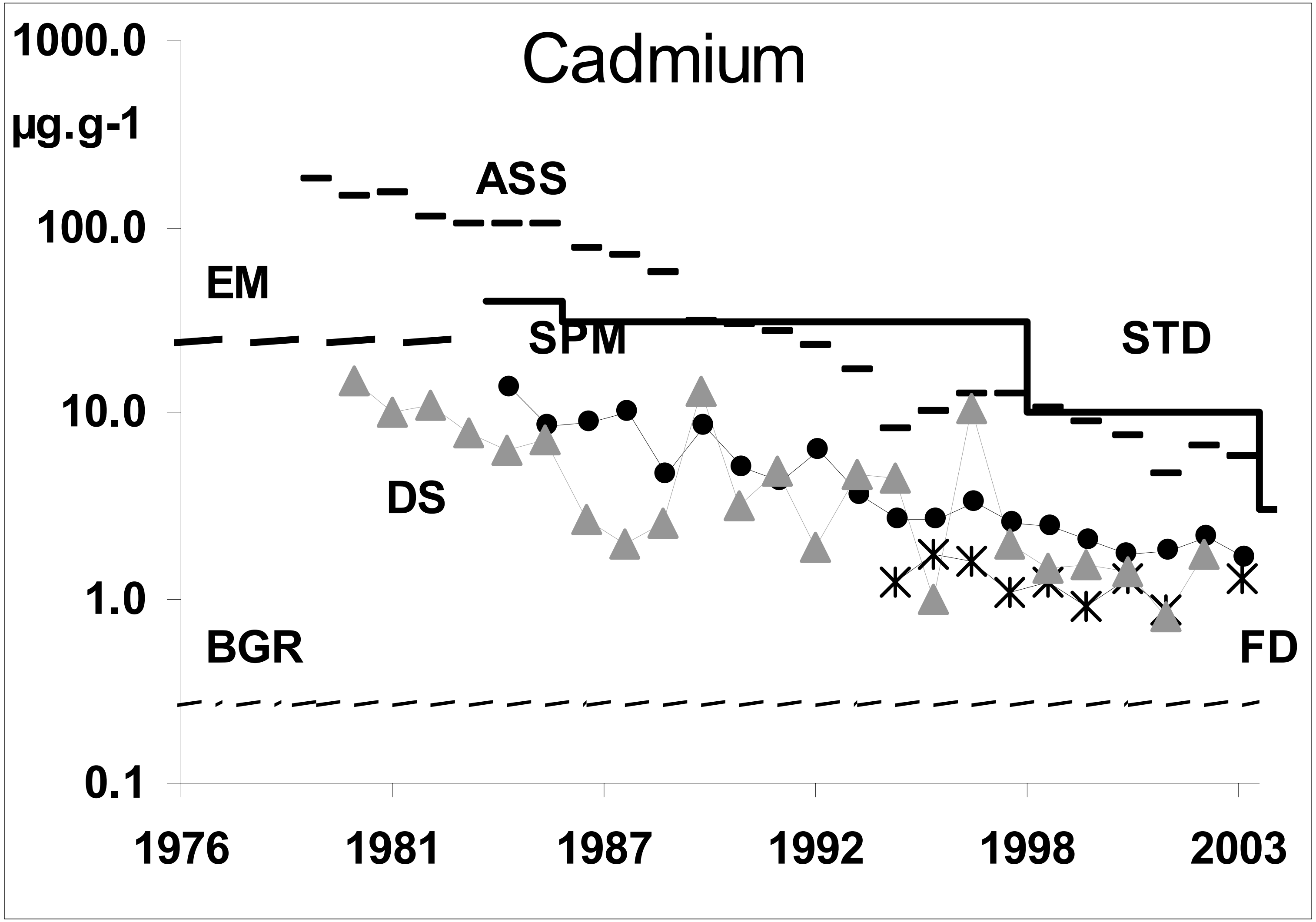


METAL CONTAMINATION: EXPONENTIAL DECREASE FOR PARIS MEGACITY

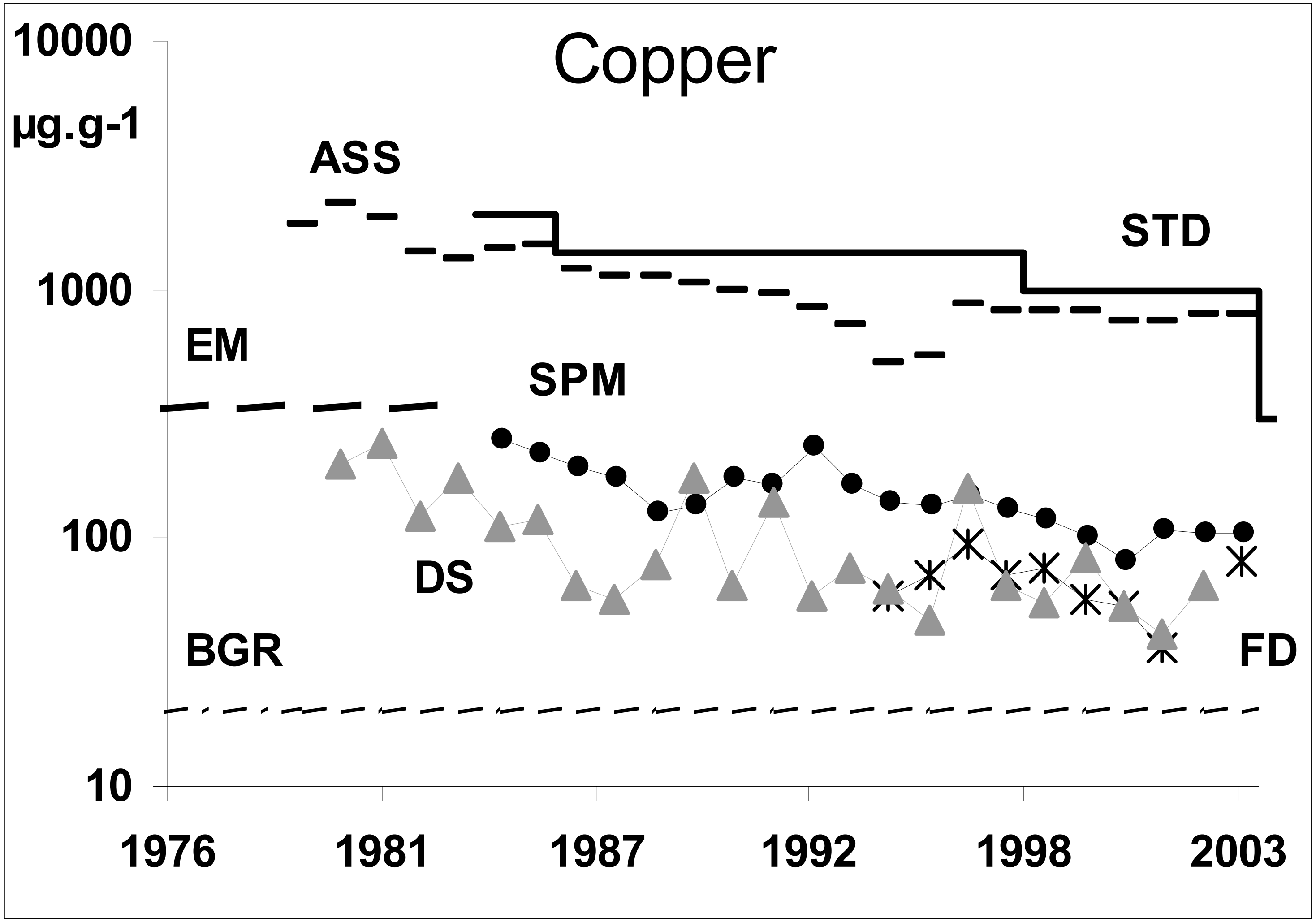


- Treated solids of the sewage water plant of the parisian area (8 Mpeople)
- Paris urban sewage sludge was extremely concentrated (70 to 700) in heavy metals in the early 1980 's
- Due to noted effort in industrial reuse of metals and raw water treatment the contamination decreased from 2 (Cu, Hg, Pb, Zn) to 18 (Cd) between 1980 and 2000
- Treated urban sludges are still high in metals for agricultural reuse (criteria have also been decreased by the EU over that period)

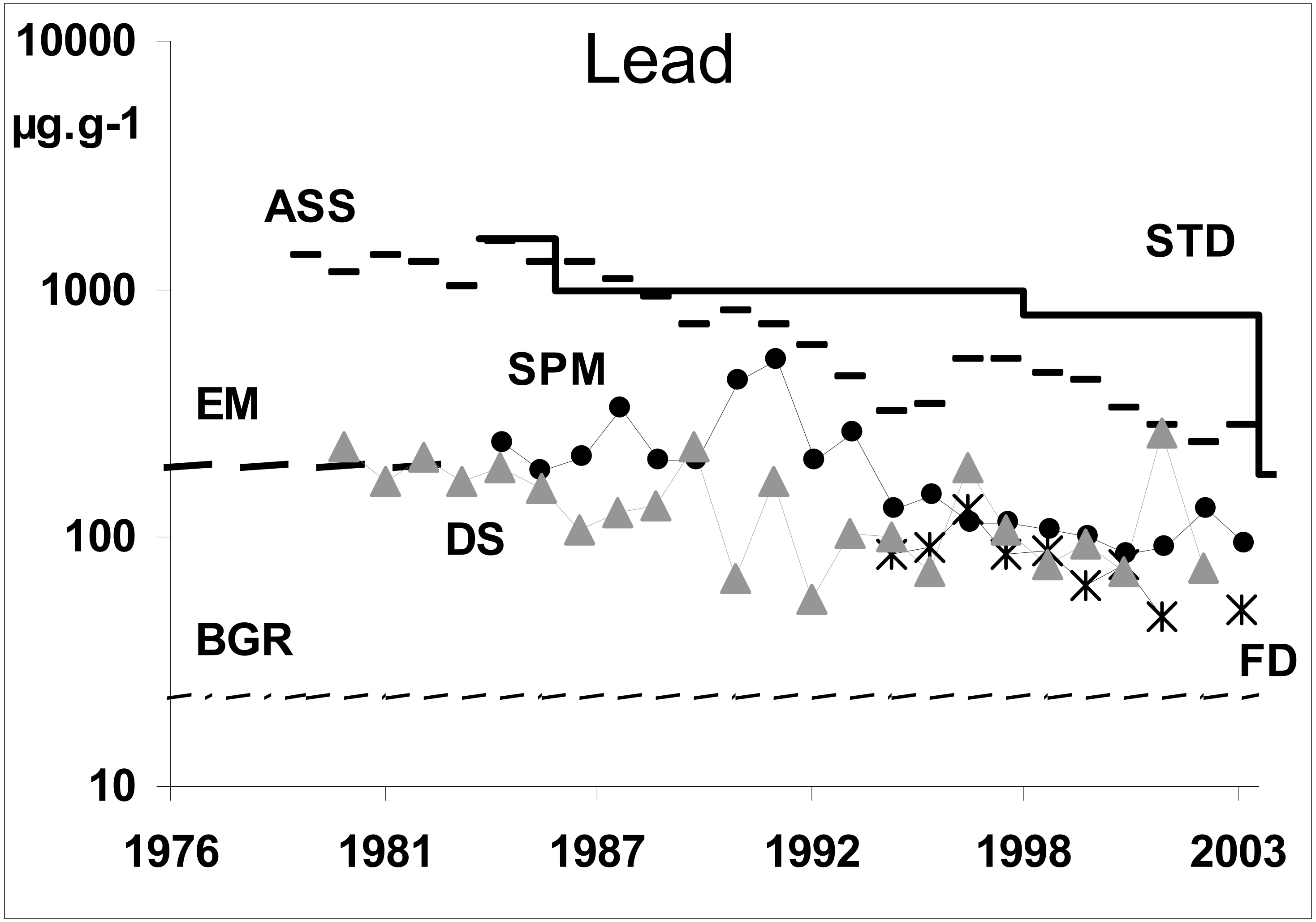
Cd contamination in the Seine basin



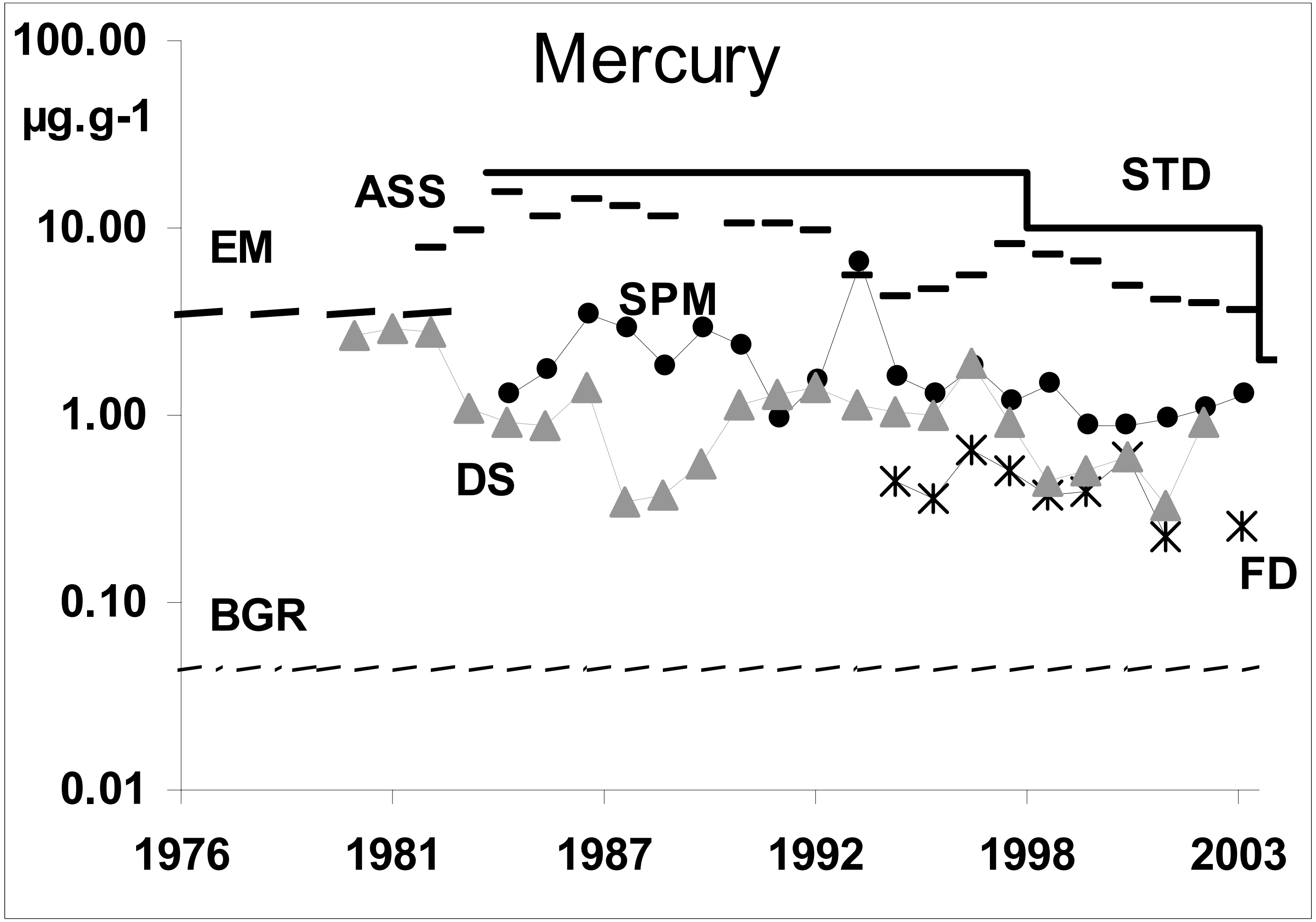
Cu contamination in the Seine basin



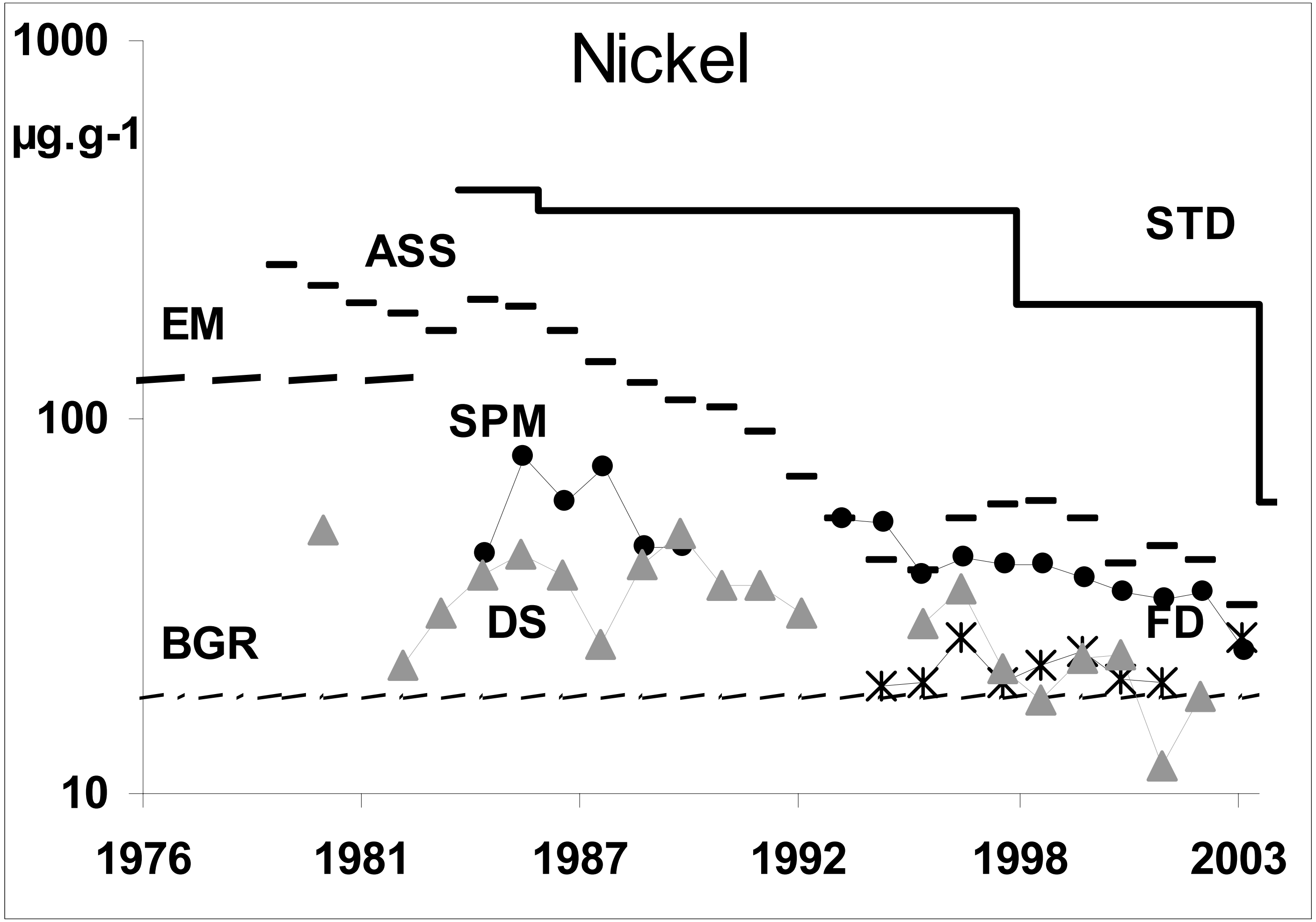
Pb contamination in the Seine basin



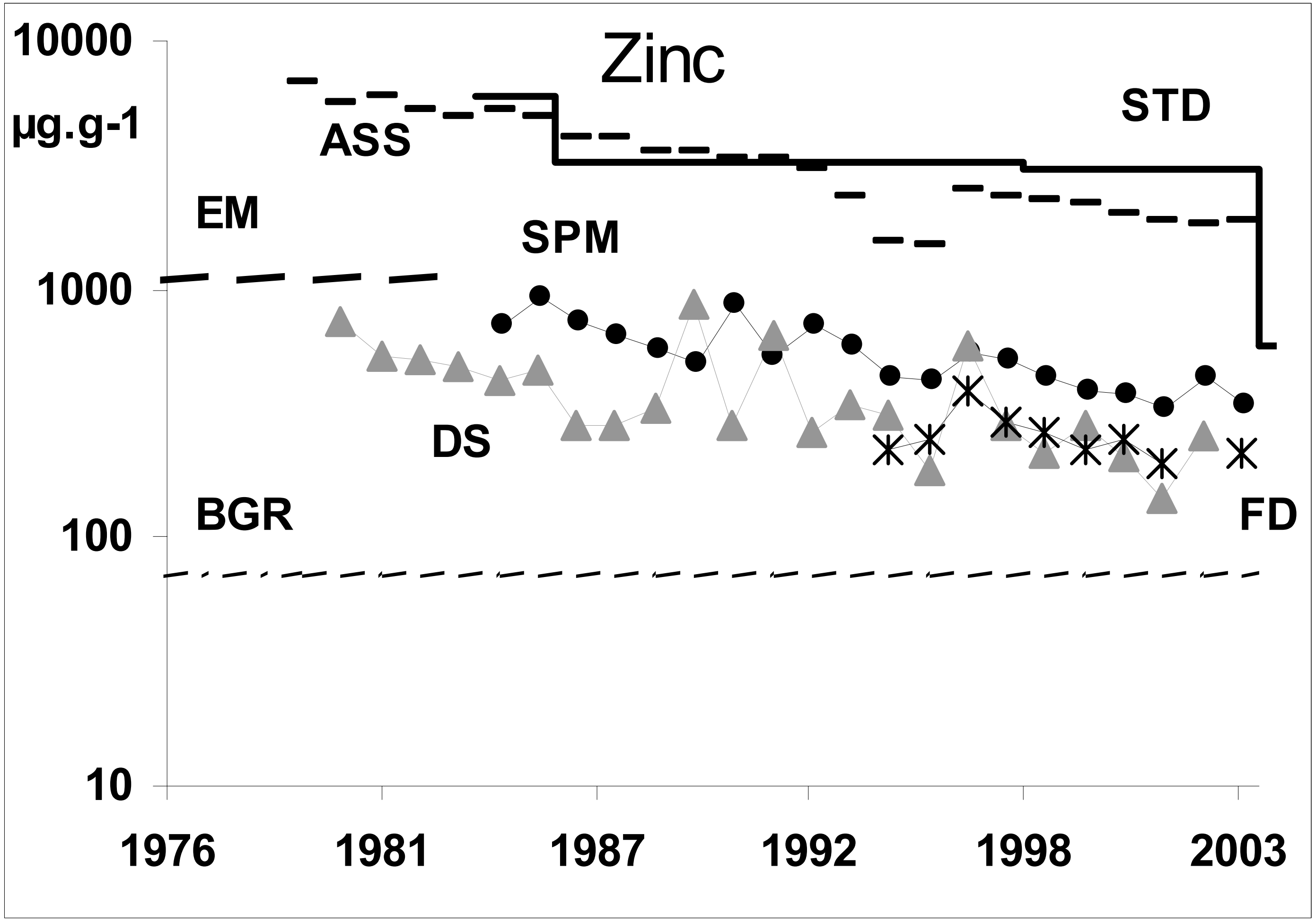
Hg contamination in the Seine basin



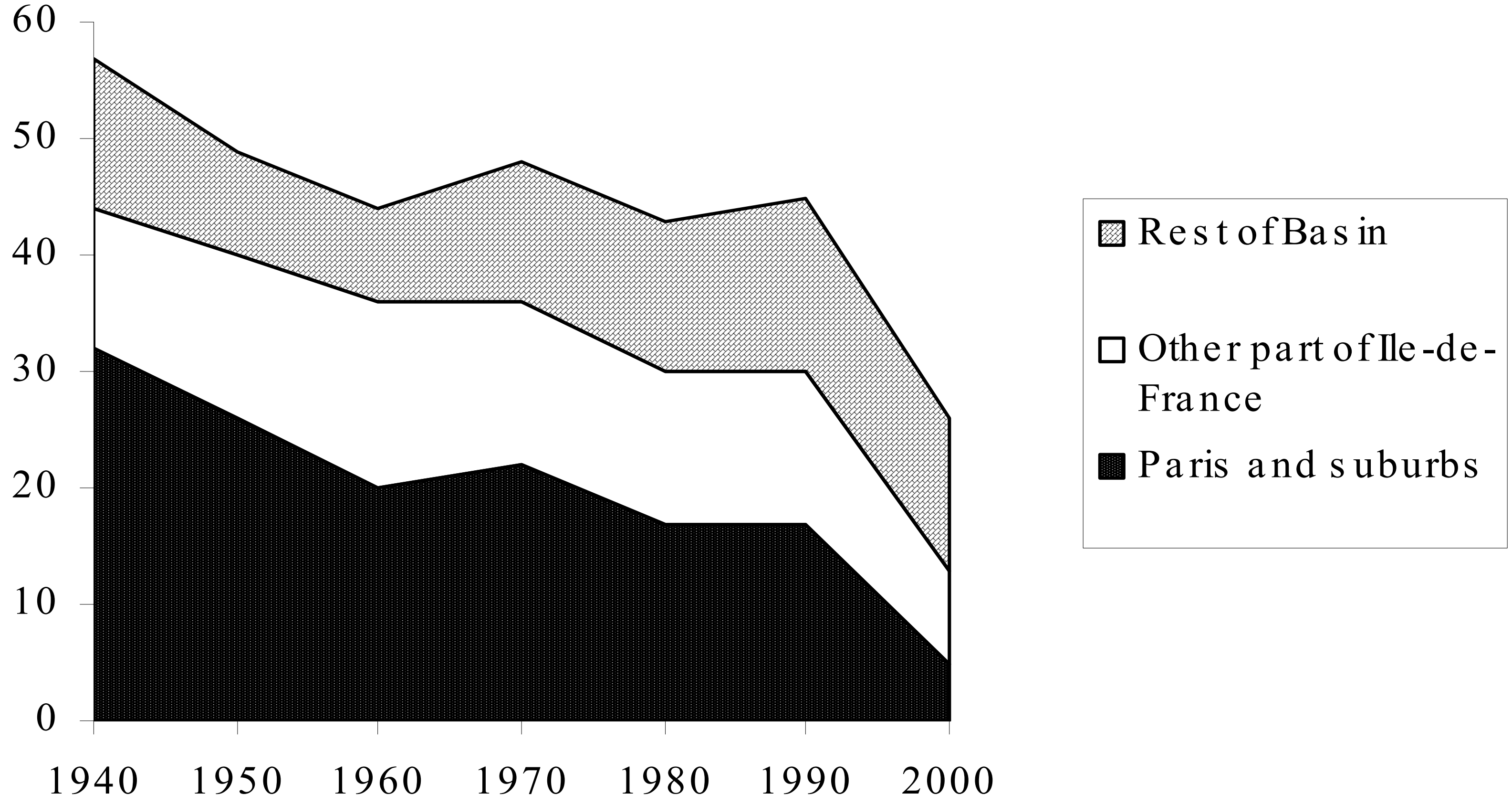
Ni contamination in the Seine basin



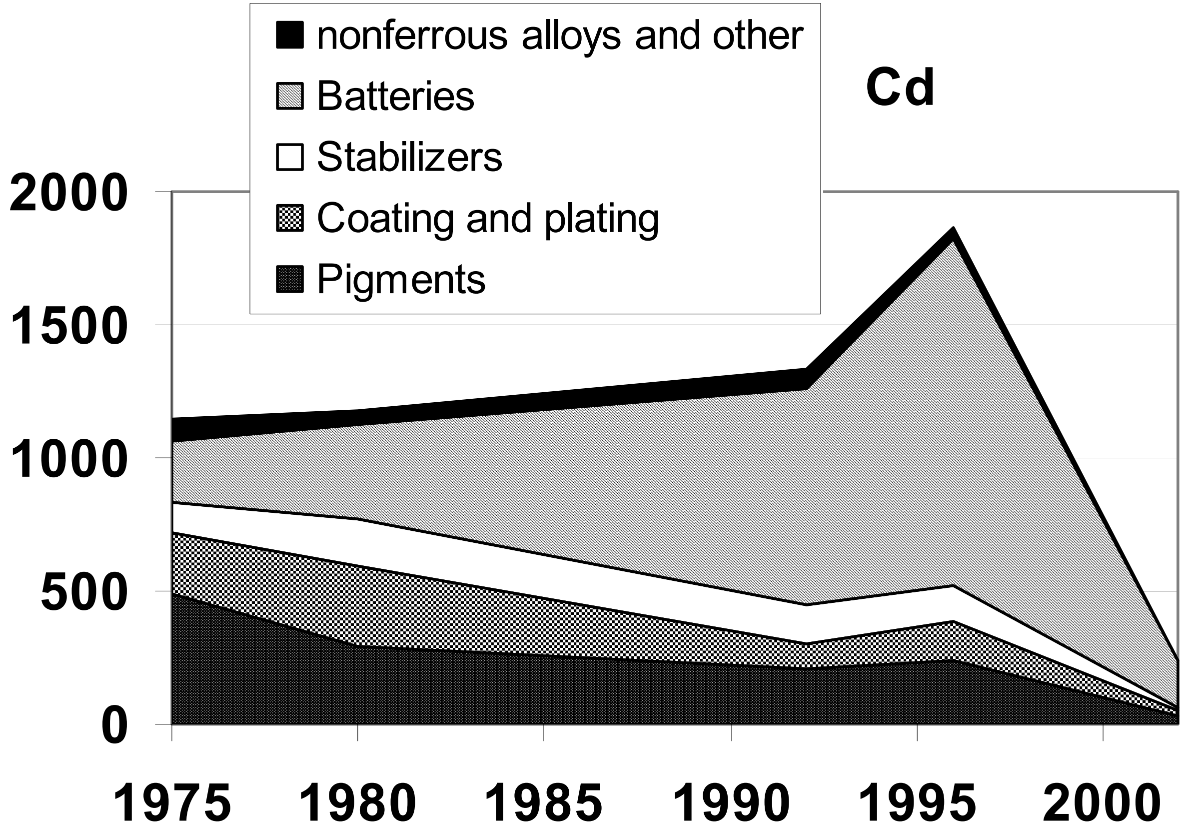
Zn contamination in the Seine basin



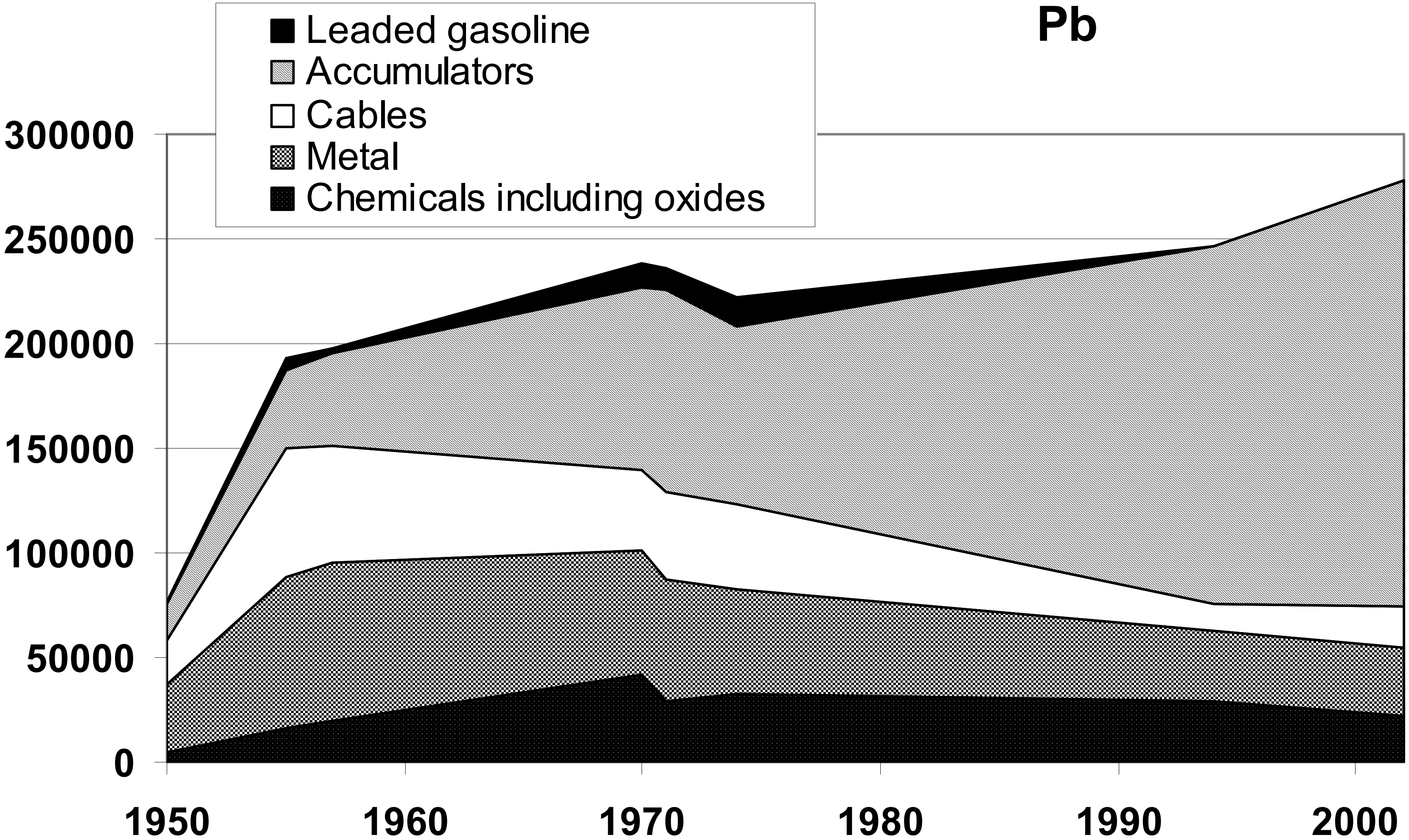
Decrease of the number of lead related industries in the Seine basin for Paris and suburbs, other part of Ile de France, and whole basin



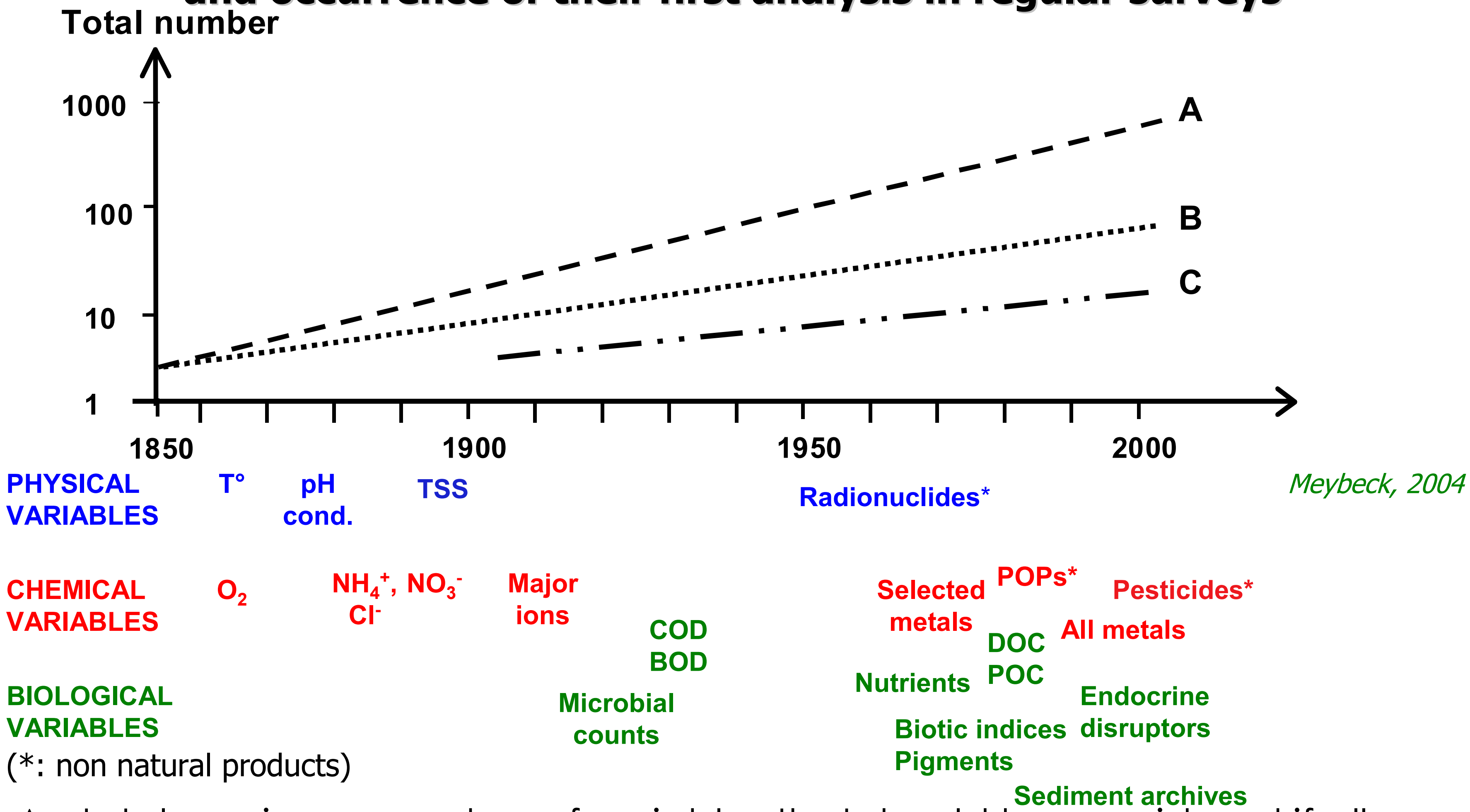
Cd consumption in France (1975-2000) (t per year)



Pb consumption in France (1950-2000) (t per year)

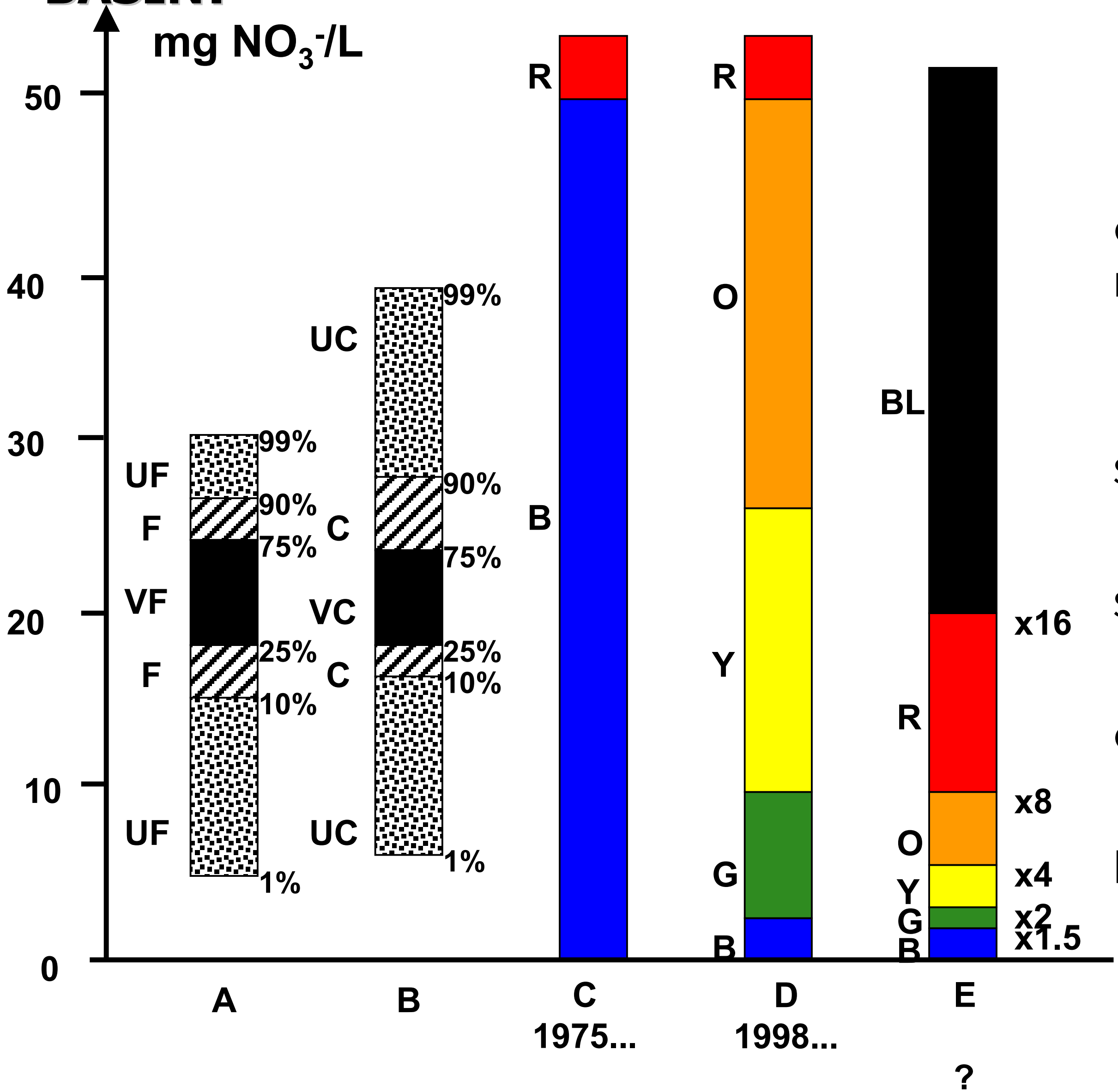


Exponential growth of water quality descriptors and occurrence of their first analysis in regular surveys



- A= total maximum number of variables that should be considered if all regulations were implemented
- B= number of variables actually routinely monitored in the first grade surveys
- C= monitoring capacities of Least Developed regions.

HOW TO ASSESS "NITRATE POLLUTION" ISSUE IN THE SEINE BASIN?

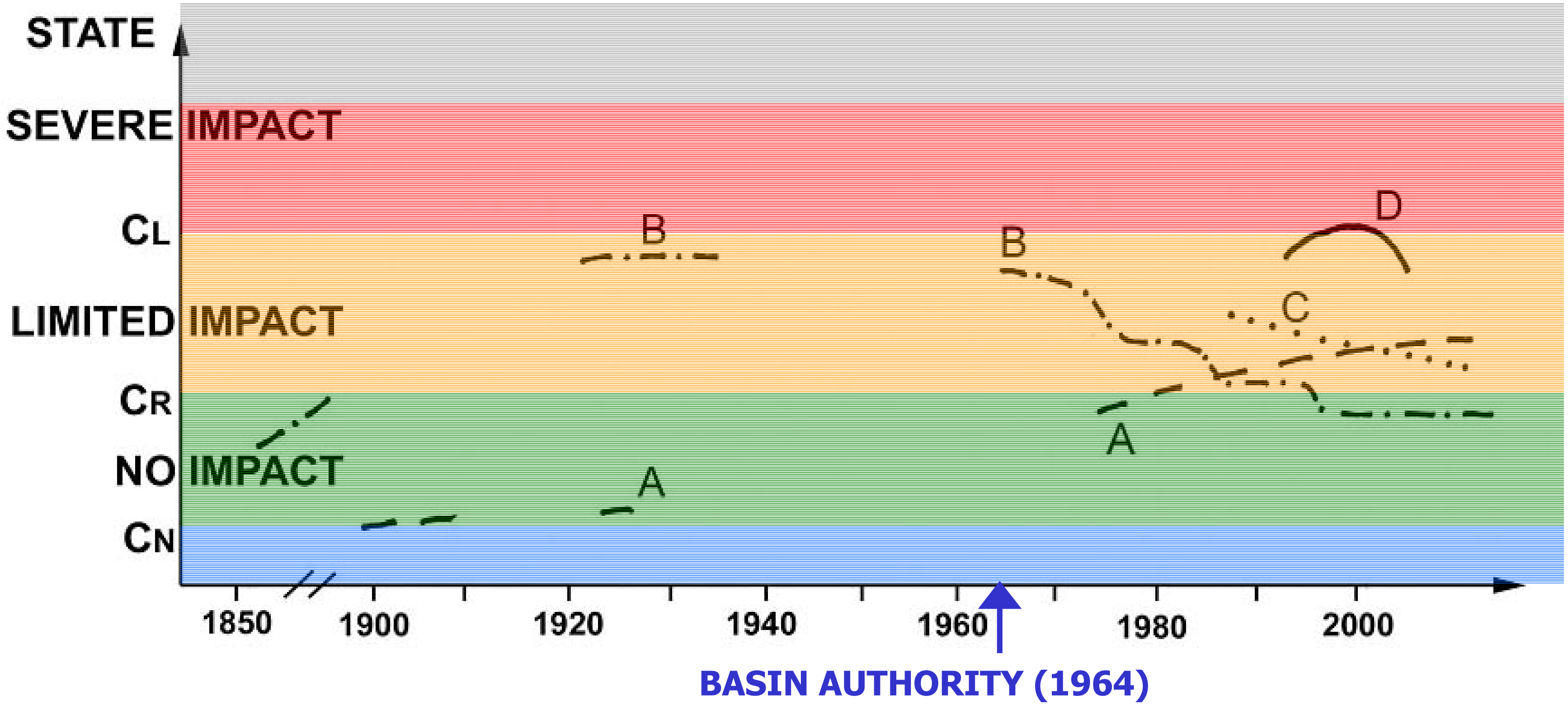


- A: Frequency distribution (1971-2002) of nitrate at river outlet
- B: Spatial distribution of 1971/02 medians (n≈200 stations)
- C: WHO drinking water standard
- D: new grid for river ecosystem management
- E: Grid based on natural background

Meybeck, 2004

EVOLUTION OF FOUR WATER QUALITY ISSUES IN THE LOWER SEINE (1850-2000)

I. Limited perception + optimistic criteria



A. Nitrate drinking water criteria; **B**. Organic pollution/oxygenation; **C**. Metals in Paris sewage sludge 1985 criteria; **D**. Atrazine

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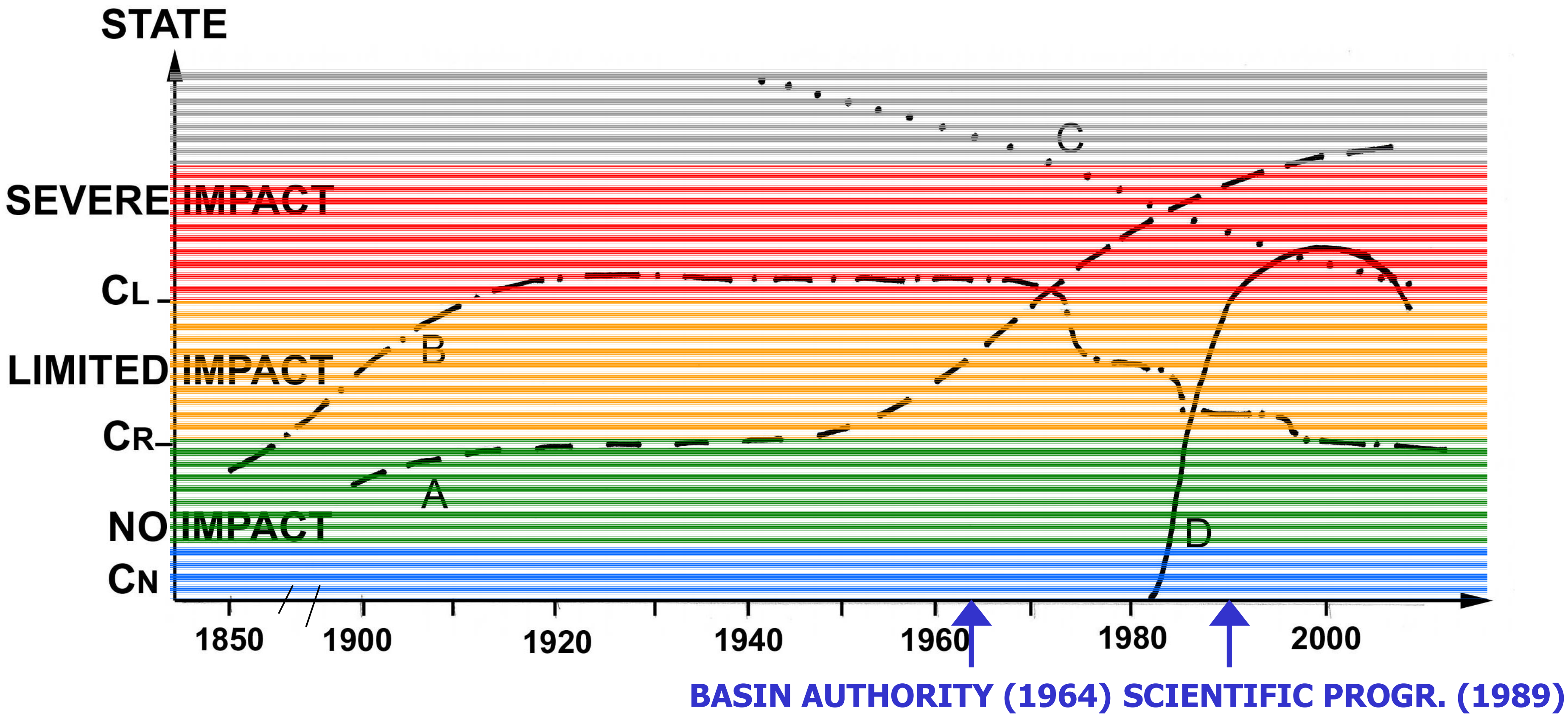
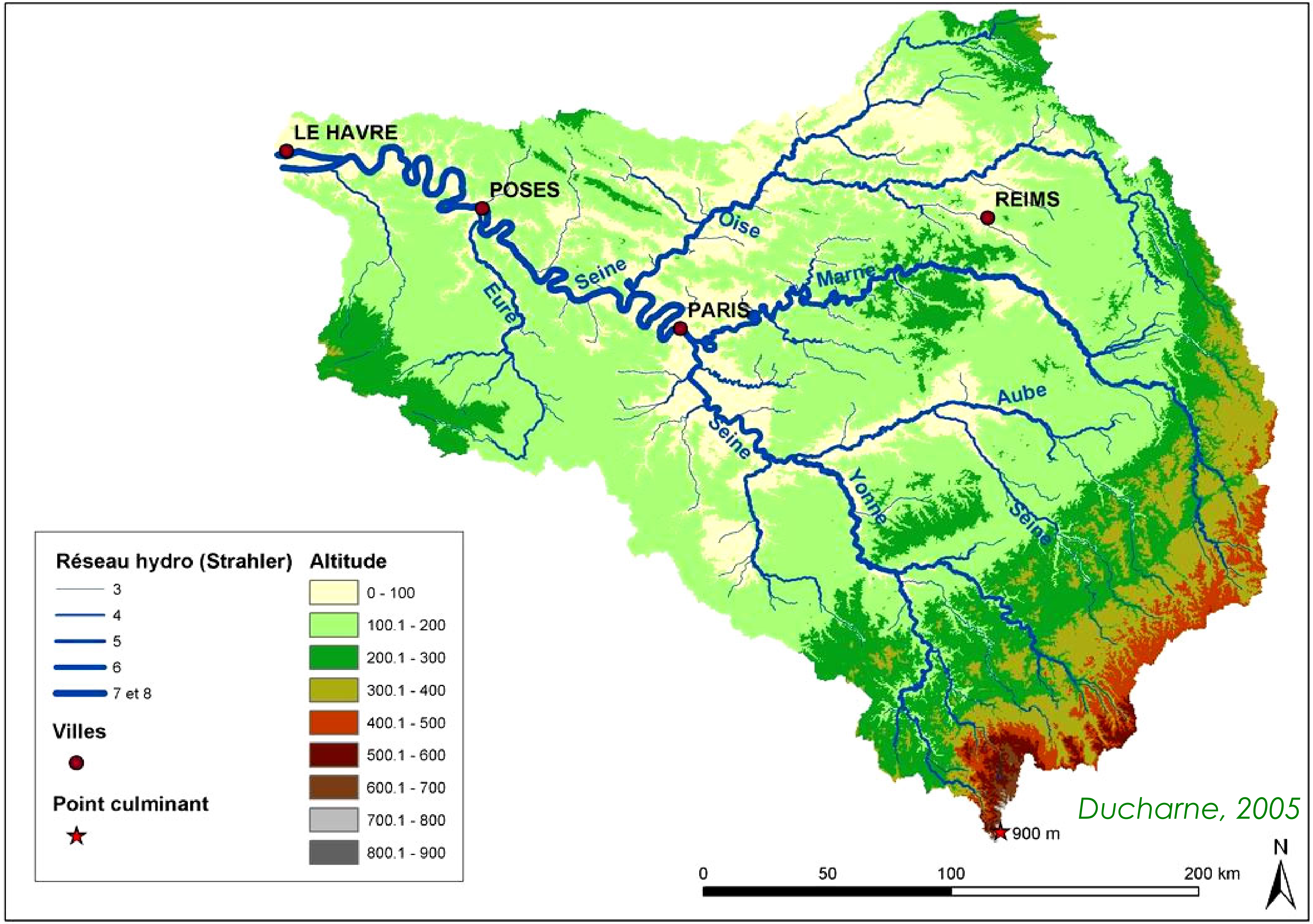
EVOLUTION OF FOUR WATER QUALITY ISSUES IN THE LOWER SEINE (1850-2000)

II. 2005's knowledge + most constraining criteria



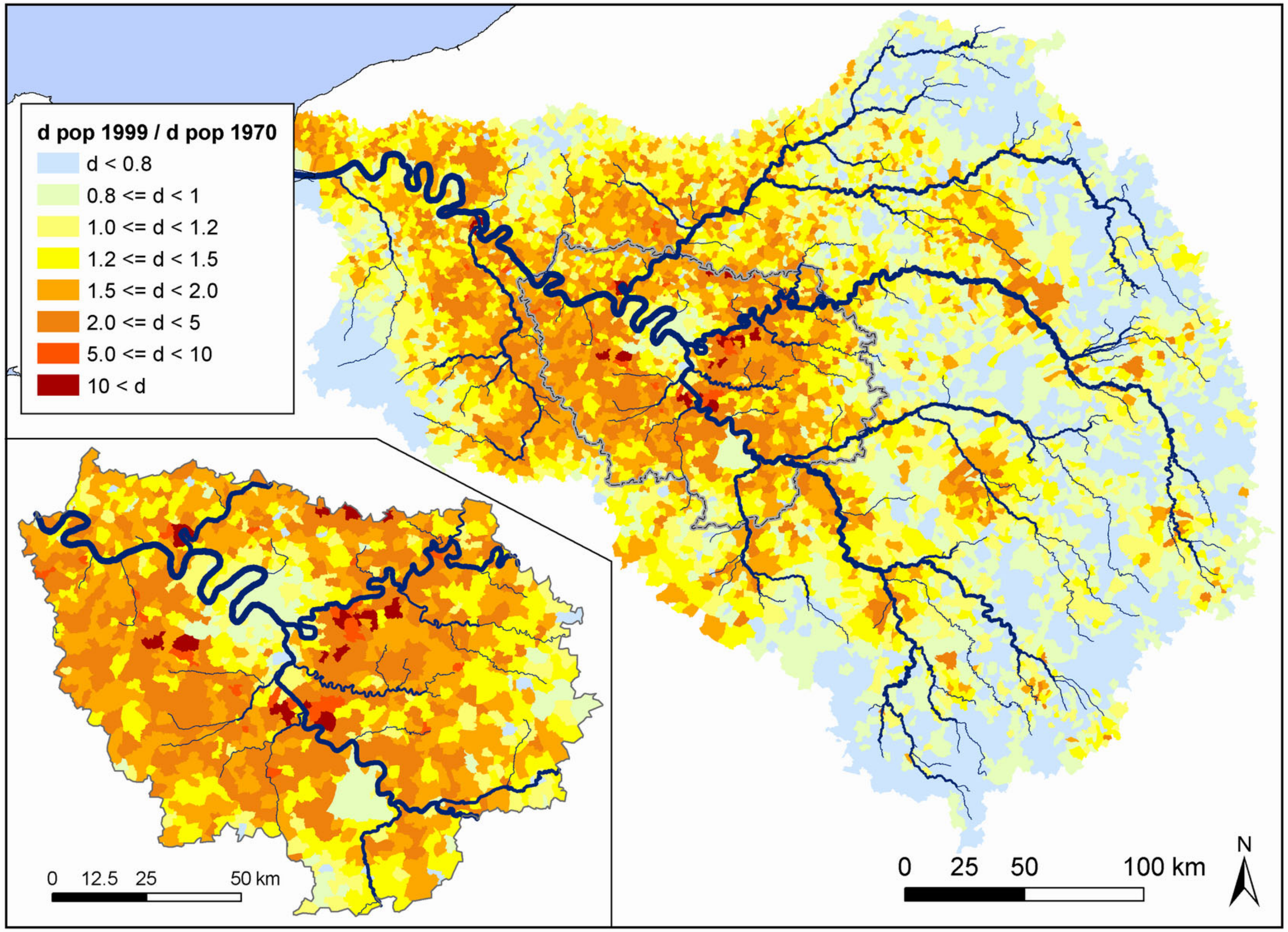
A. Nitrate: eutrophication criteria; **B**. Organic pollution/oxygenation; **C**. Metals in Paris sewage sludge (2005 criteria; sedimentary archives); **D**. Atrazine (estimated)

SEINE BASIN RELIEF



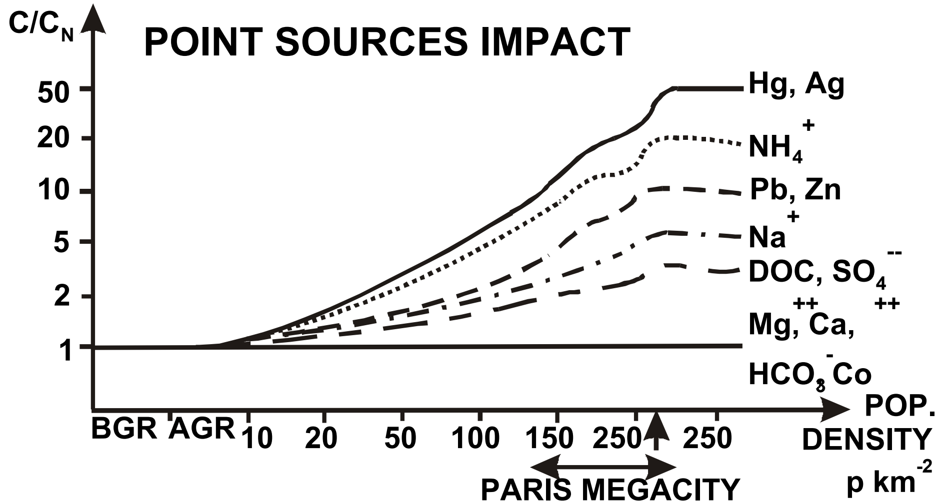
- 90 % of the basin is flat, climate and lithology are uniform

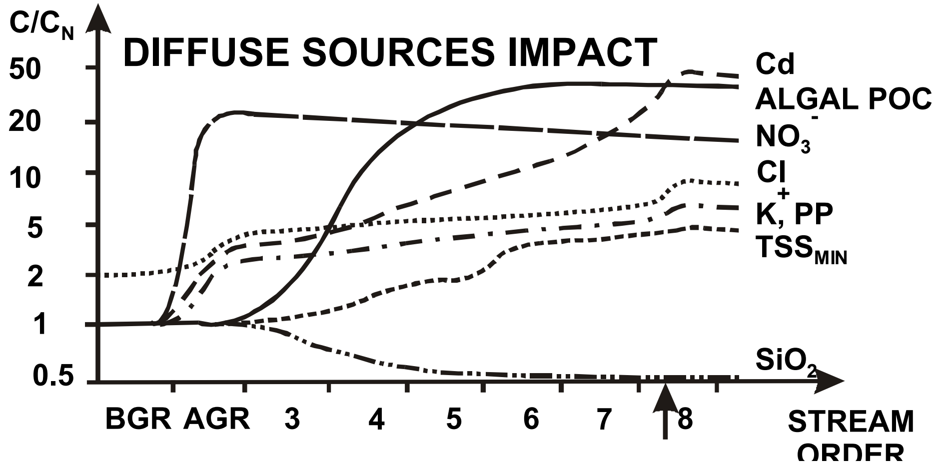
POPULATION DENSITY TREND IN THE SEINE BASIN (1970-2000)

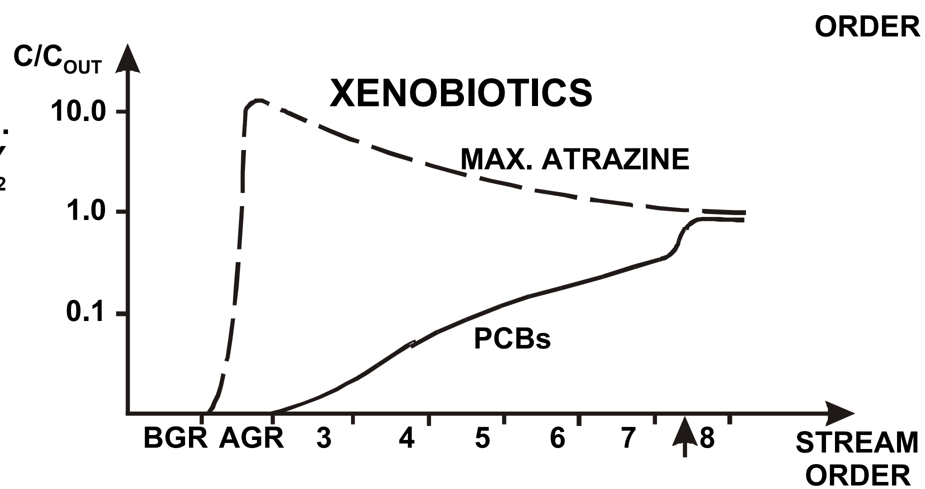


PIREN-Seine, 2004

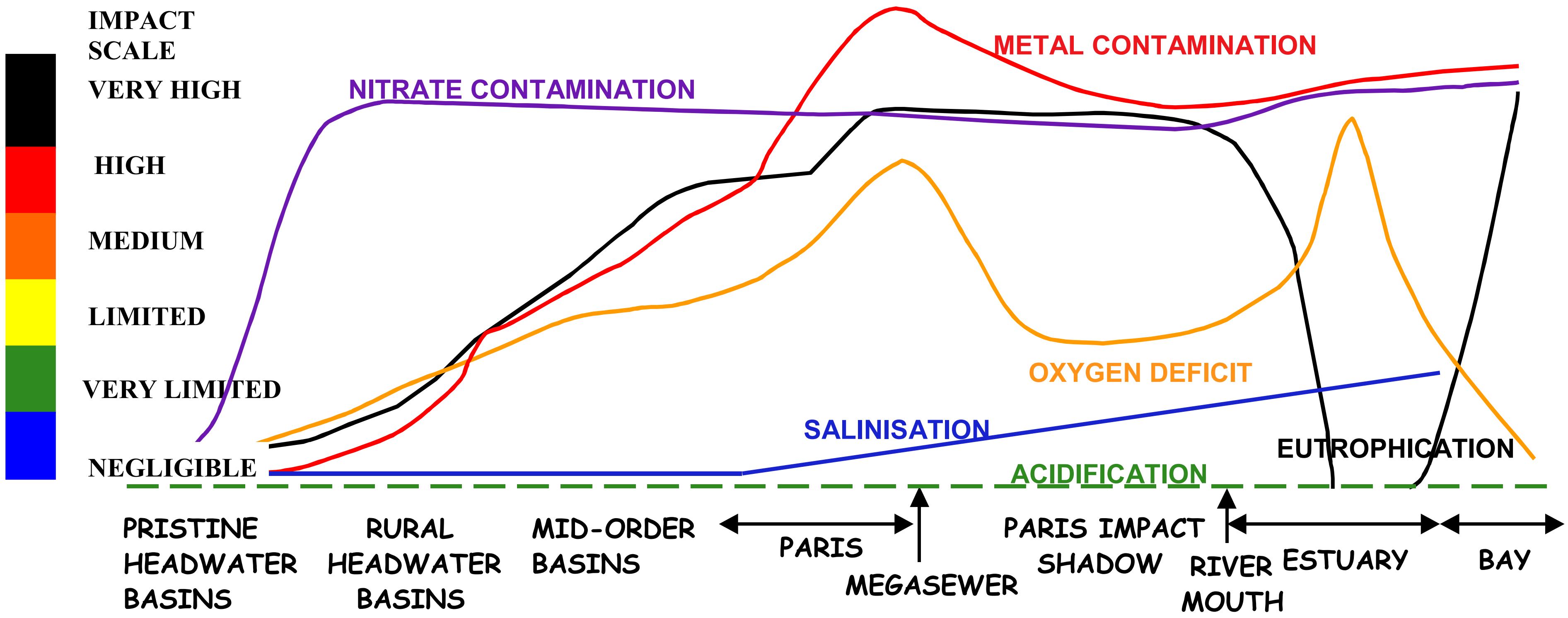
SCHEMATIC RANKING OF MEDIAN WATER QUALITY INDICATORS IN THE SEINE RIVER BY STREAM ORDERS FROM HEADWATERS TO RIVER MOUTH (500 KM)







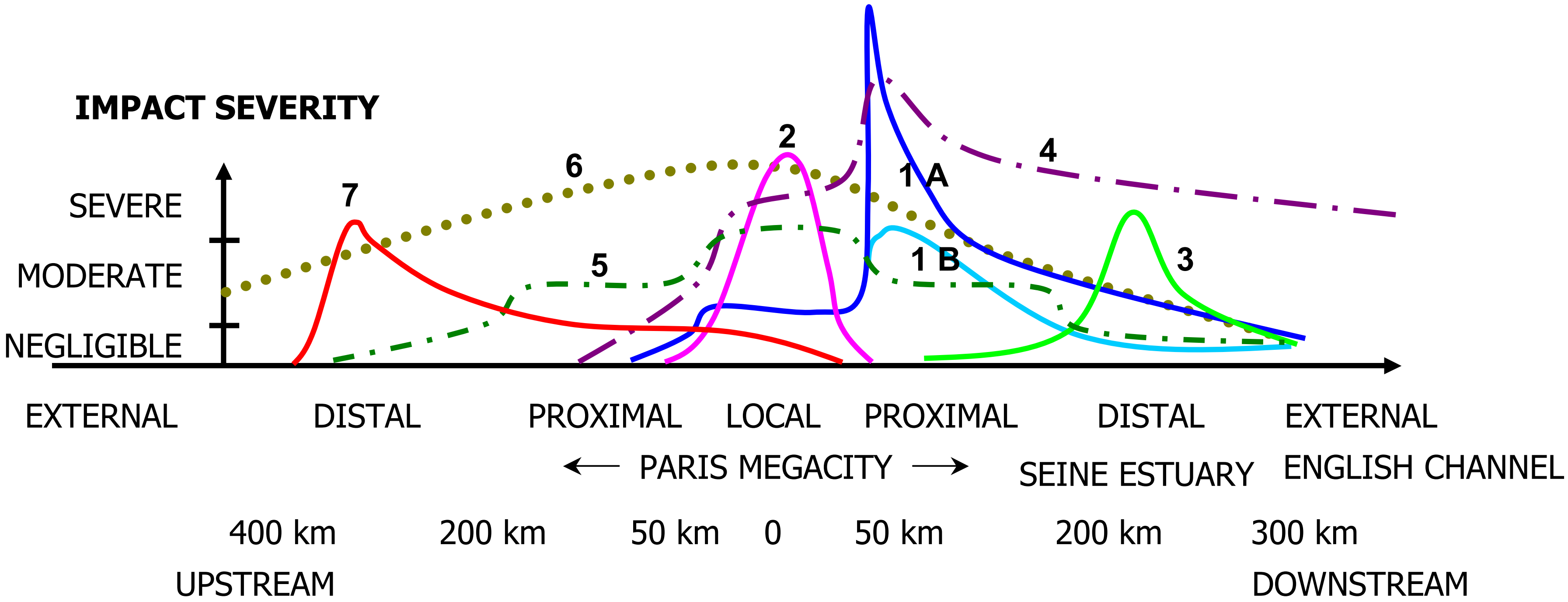
WATER QUALITY ISSUES IN THE SEINE BASIN (2000): SCHEMATIC LONGITUDINAL PROFILE FROM HEADWATERS TO ESTUARIES



Meybeck, 2004

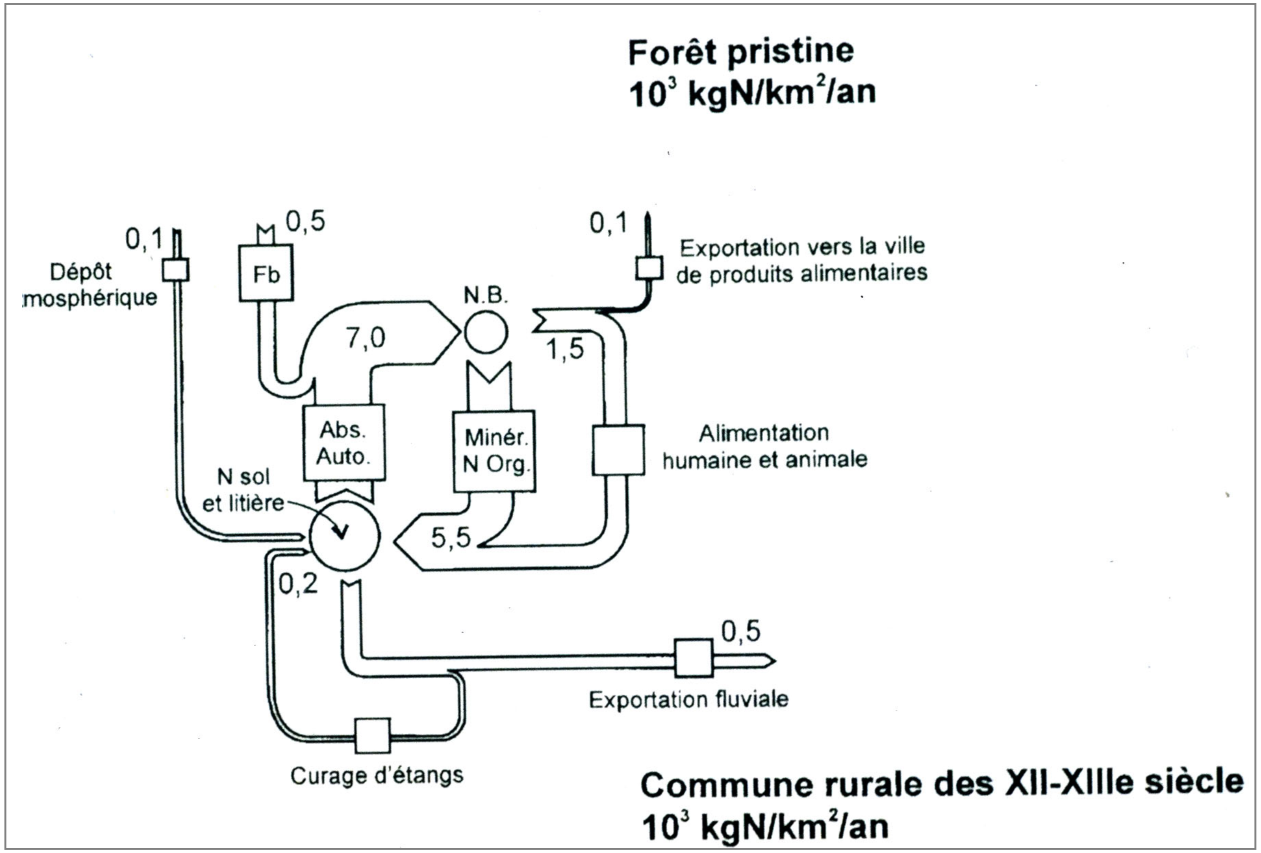
- The water quality assessment of a given basin is very dependant on the station location

IMPACT PROFILES OF PARIS MEGACITY ON THE SEINE R.



1. Organic pollution
2. Sewer overflow
3. Estuarine nitrification
4. Metals
5. Habitat degradation
6. Atmospheric pollutants
7. Timber rafting (1500-1920)

MIDDLE AGE NITROGEN CYCLE IN SEINE BASIN



OH 23

G. BILLEN

- The natural cycle of Nitrogen is generally very closed with limited export by rivers
- Impact of human activities has been reconstructed on the bassis of monastic arcjives from Burgundy Abbeys (XIIth)

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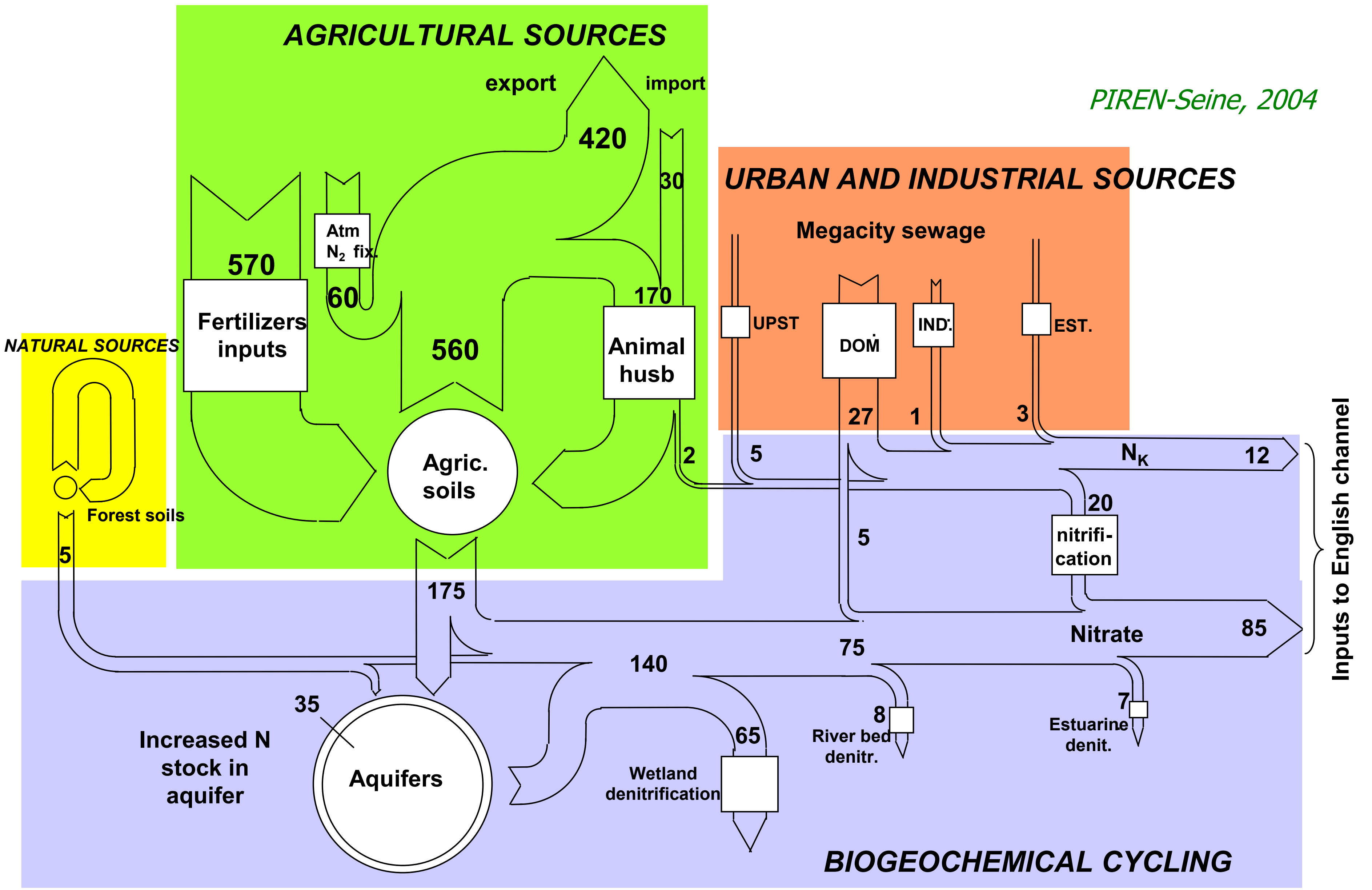
NITROGEN BUDGET, 1000 t N/YEAR



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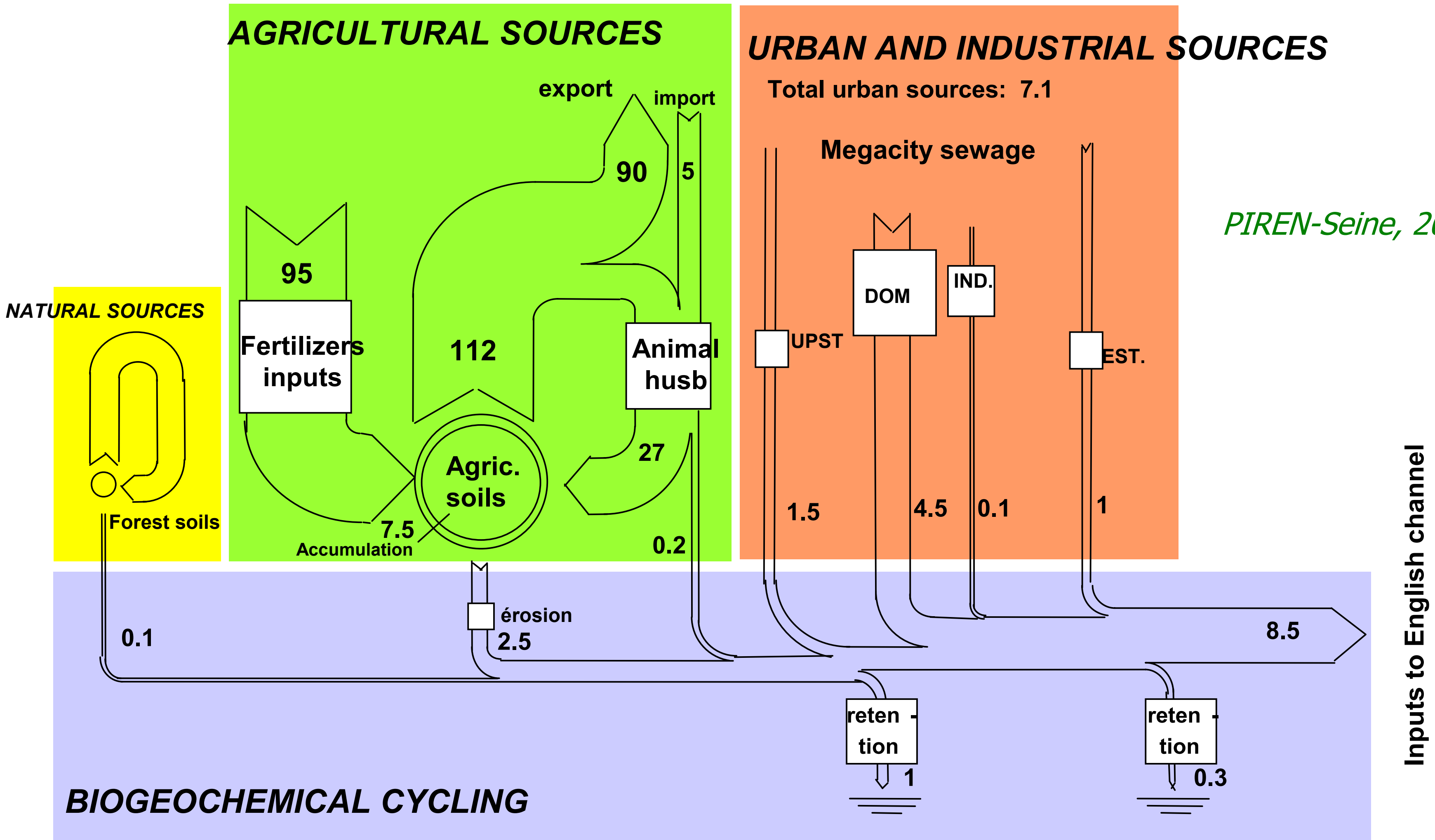
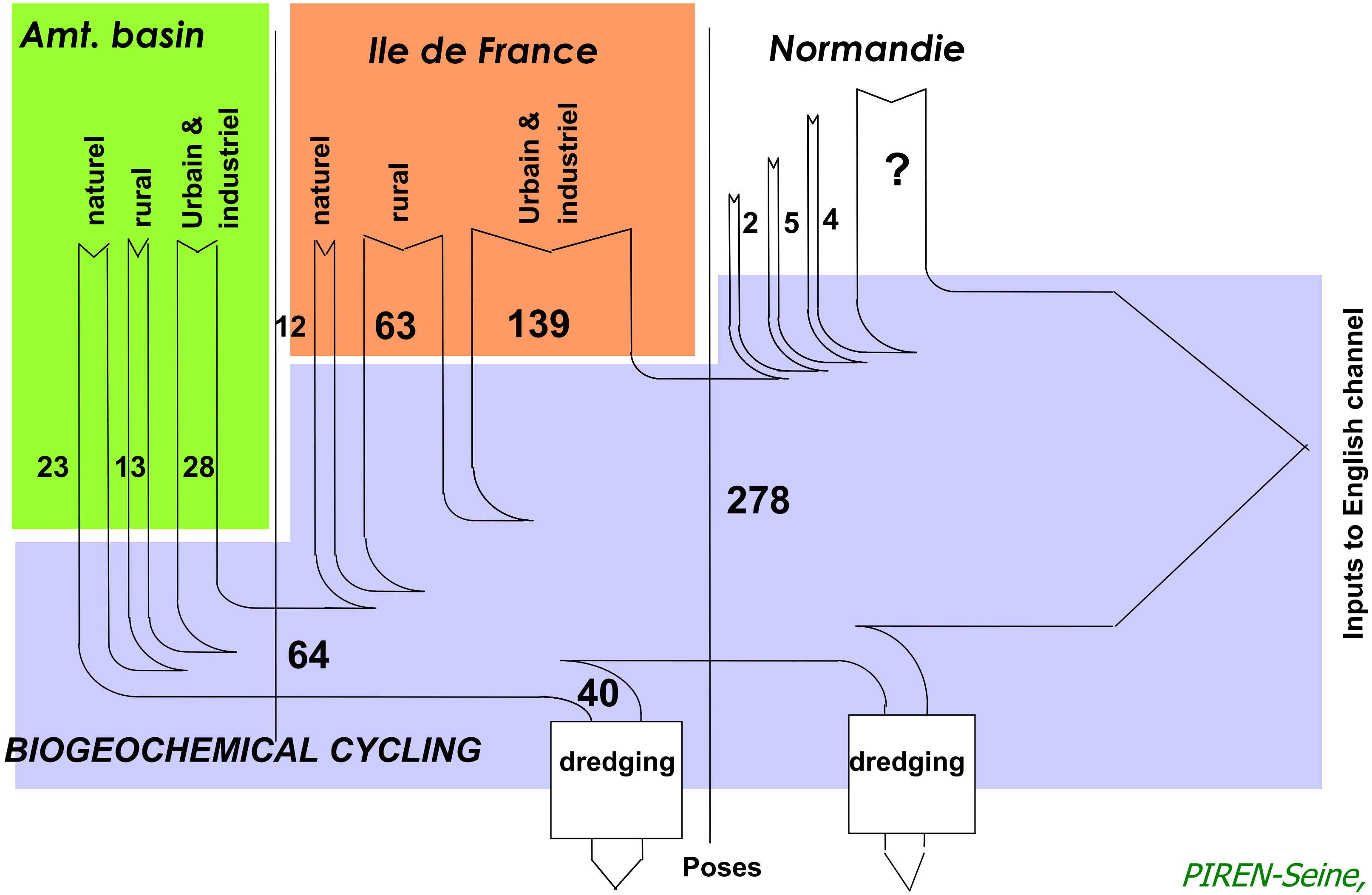
PHOSPHOROUS BUDGET, 1000 t N/YEAR

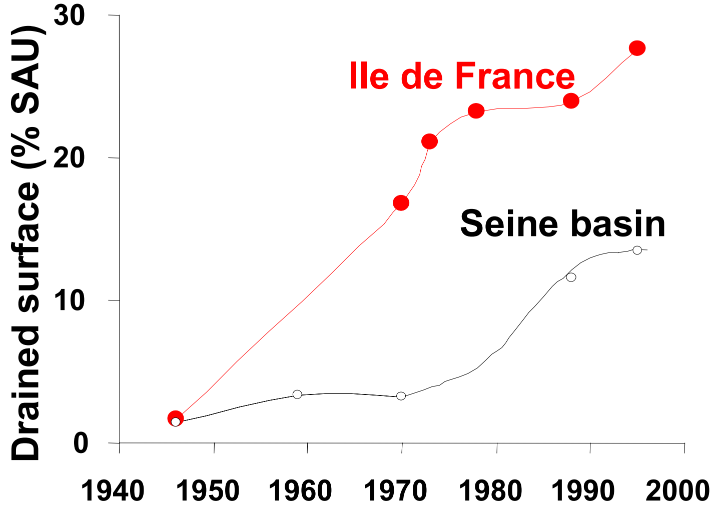


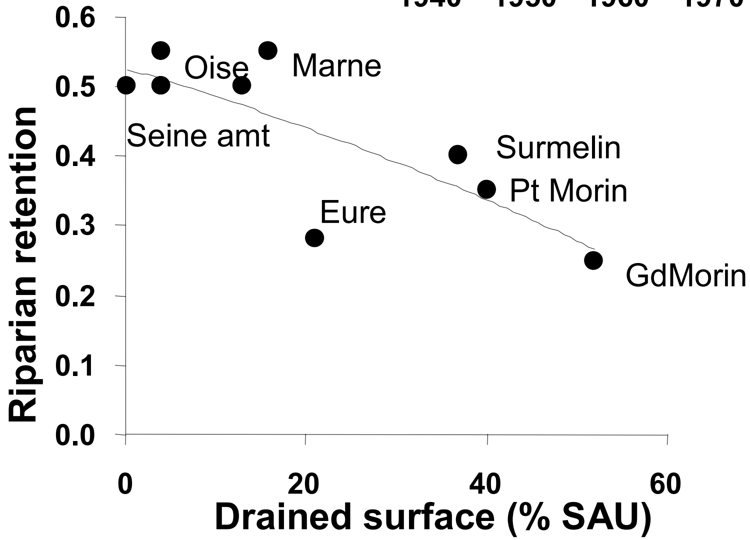
ZINC BUDGET, 1000 t N/YEAR



PIREN-Seine, 2004

SEINE RIVER BASIN





PIREN-Seine, 2004

- The percent drained area has dramatically increased since WW II
- The riparian denitrifcation has decreased by a factor 2

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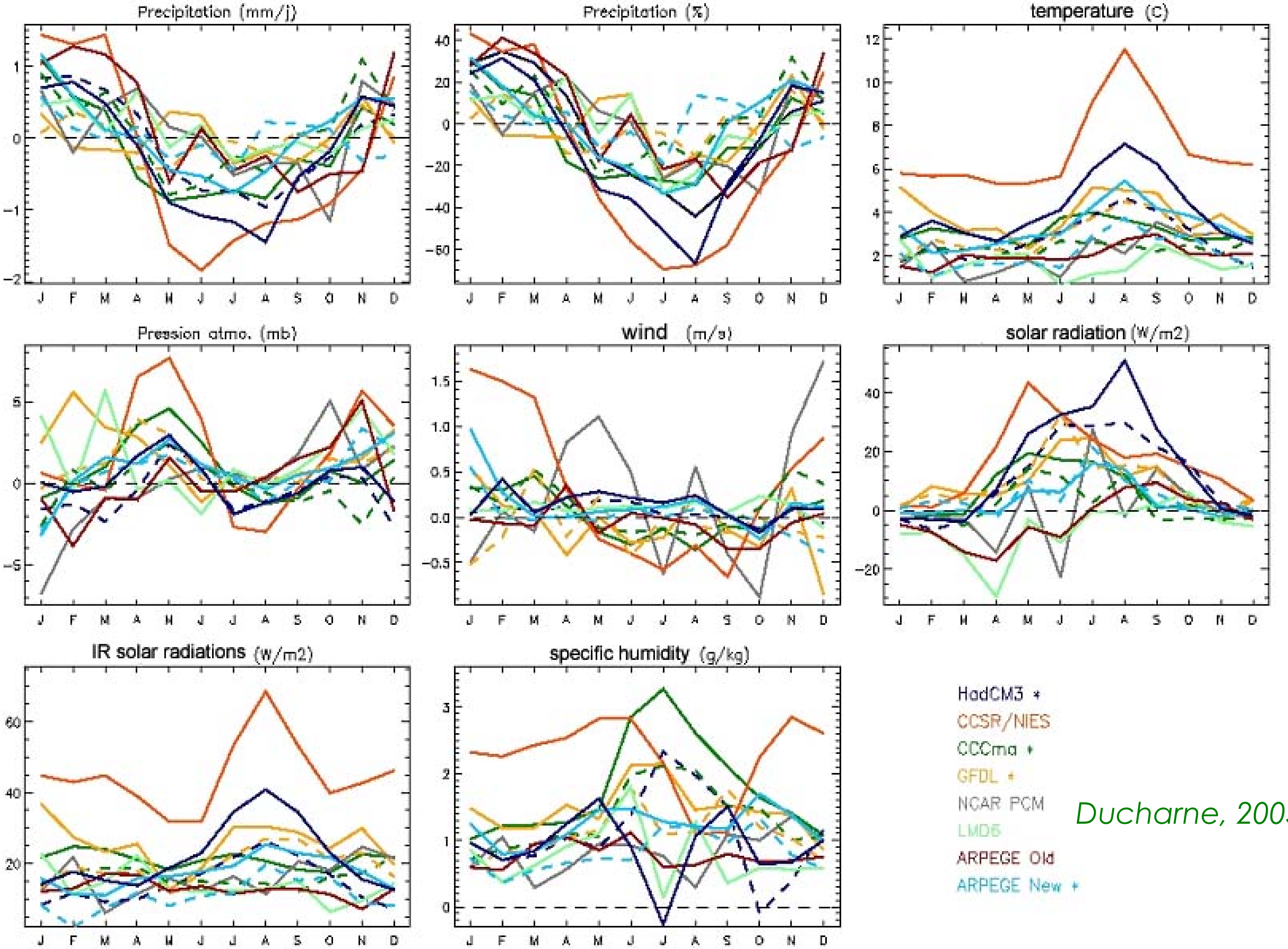
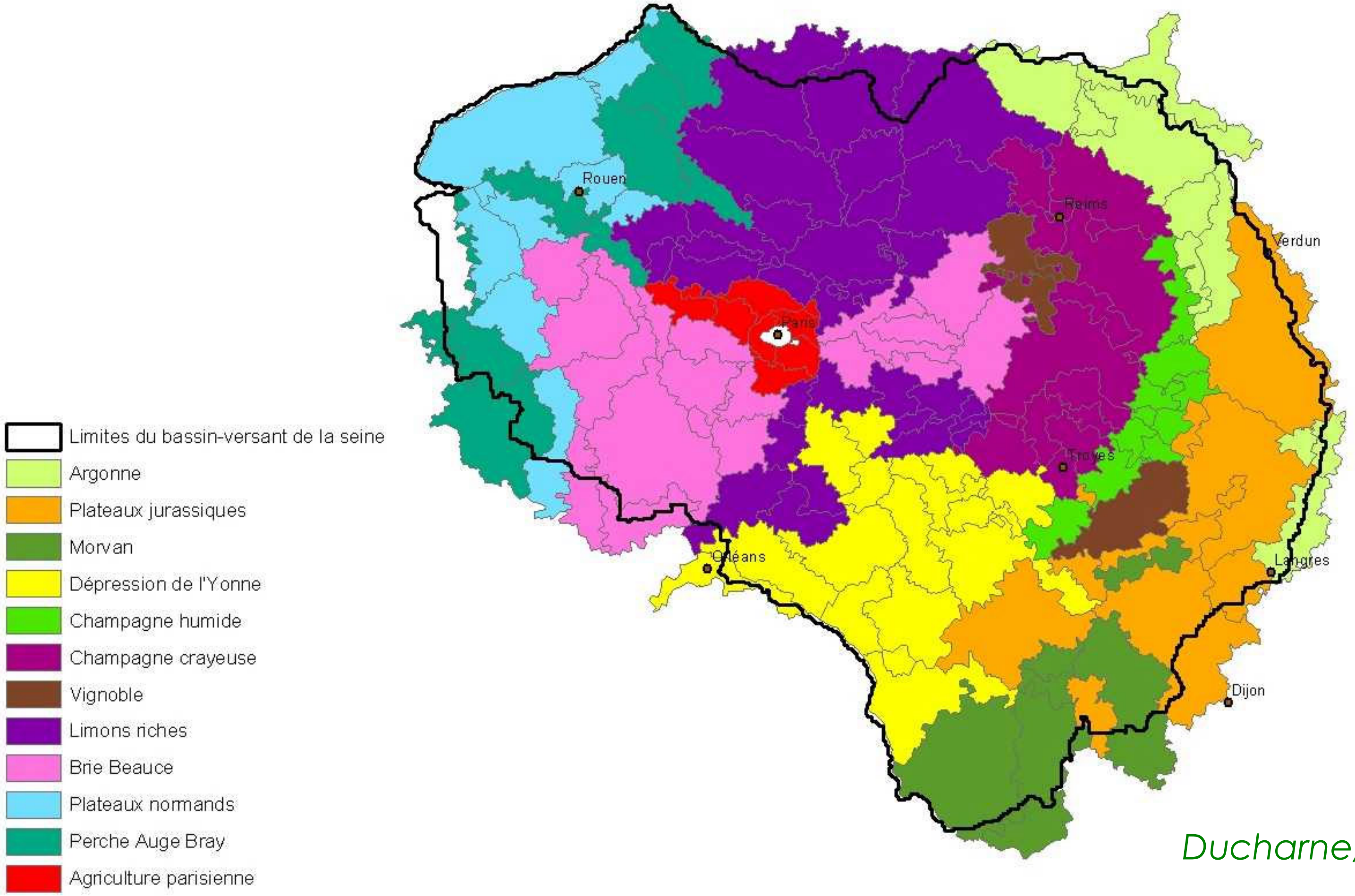


Ducharne, 2005

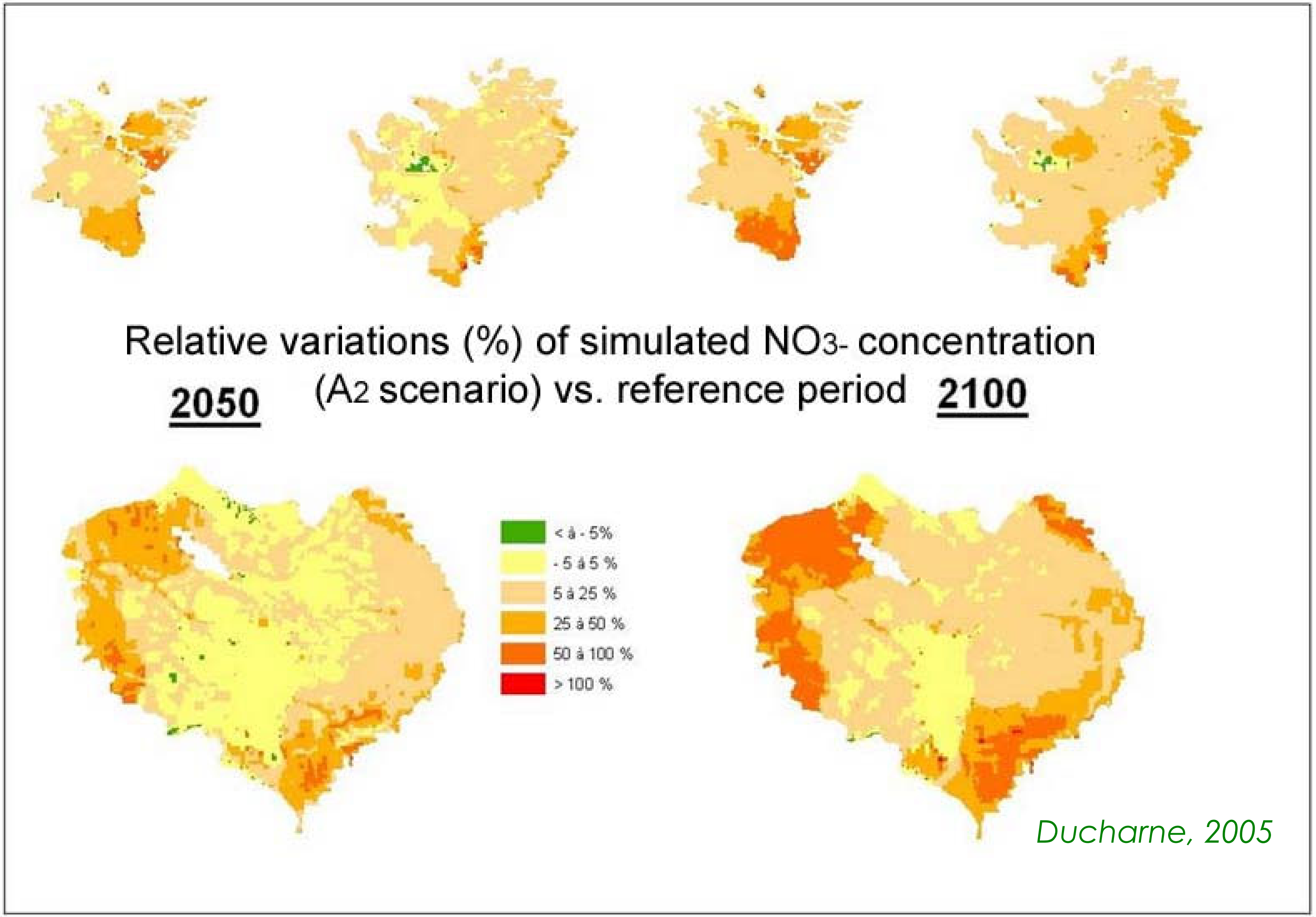
TYPOLOGY OF AGRICULTURE



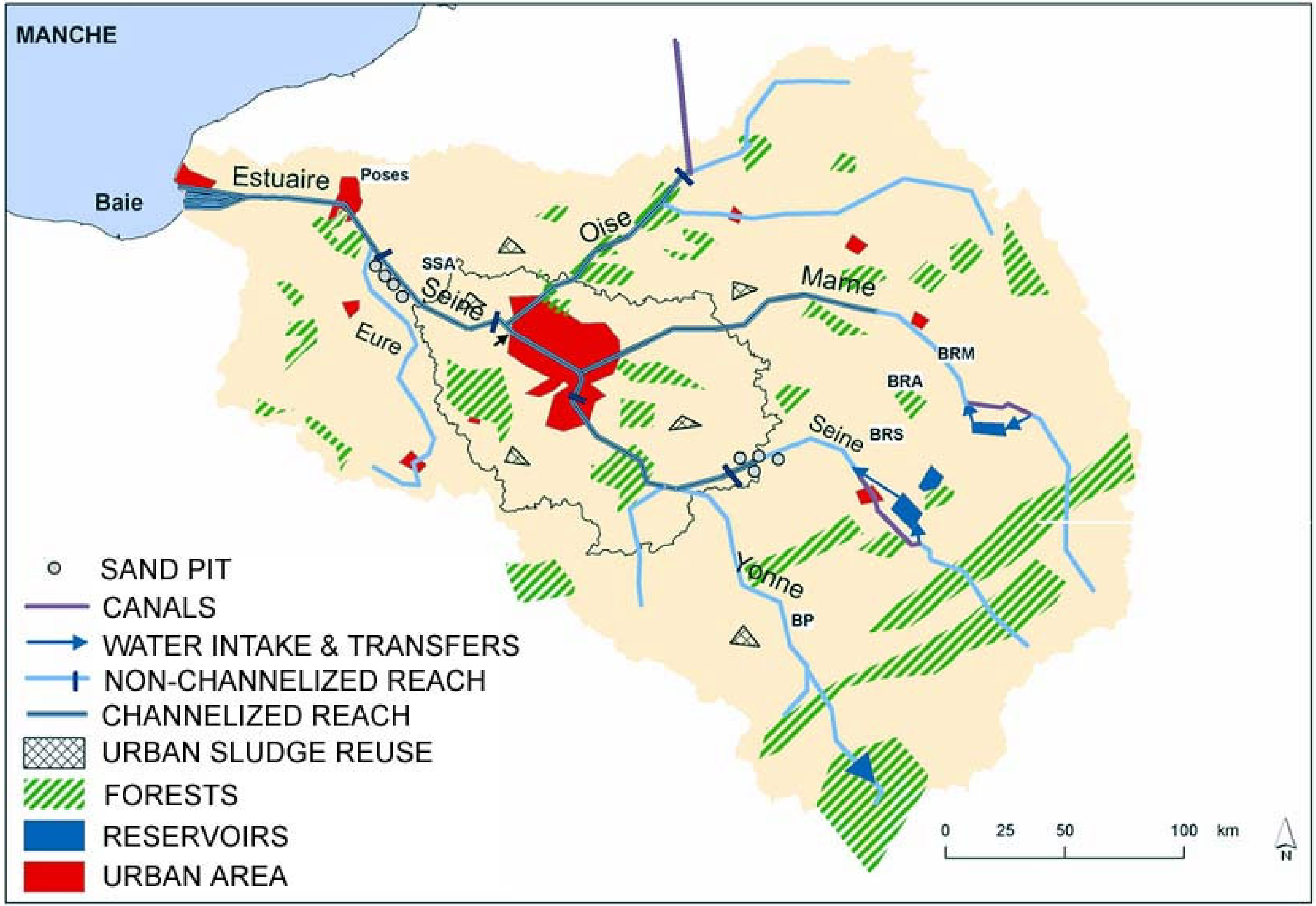
Ducharne, 2005

- 12 main regions (20 soil types x 20 crop rotation x 20 farming practises)
- Used for scenarii analysis

INCREASE OF NITRATE CONCENTRATIONS (%) DUE TO CLIMATE CHANGE ONLY IN SEINE AQUIFERS

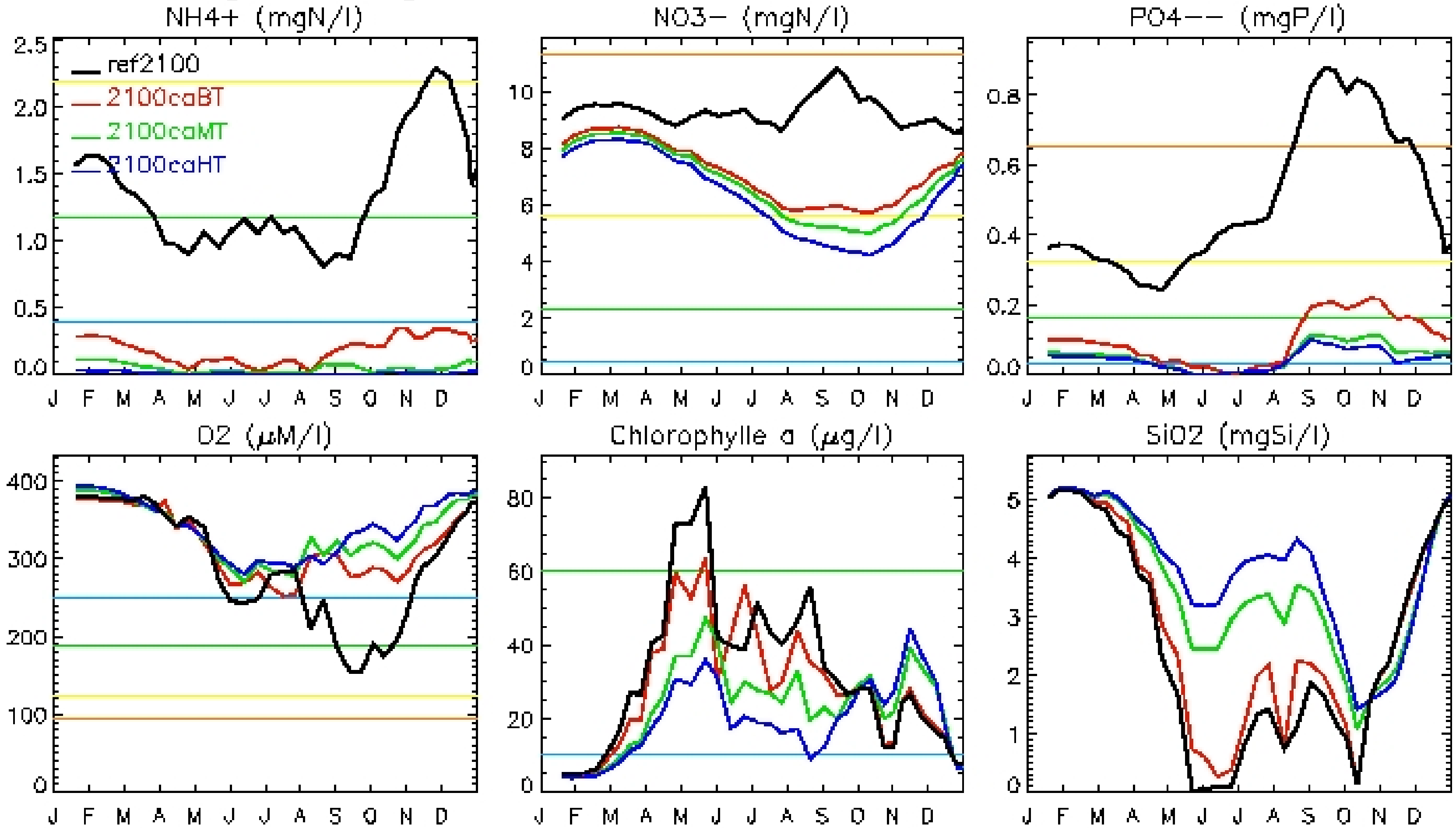


SEINE RIVER BASIN



PIREN-Seine, 2004

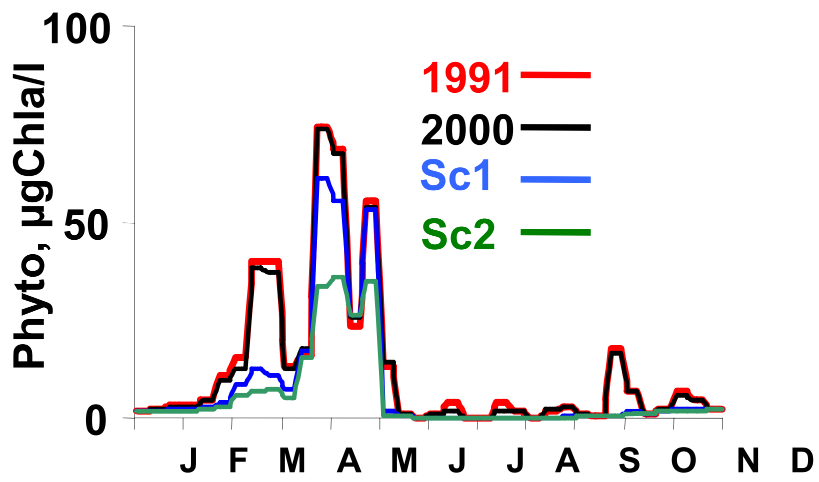
EXPLORING FUTURE BIOGEOCHEMISTRY AT MOUTH (Poses) WITH DIFFERENT SCENARIOS

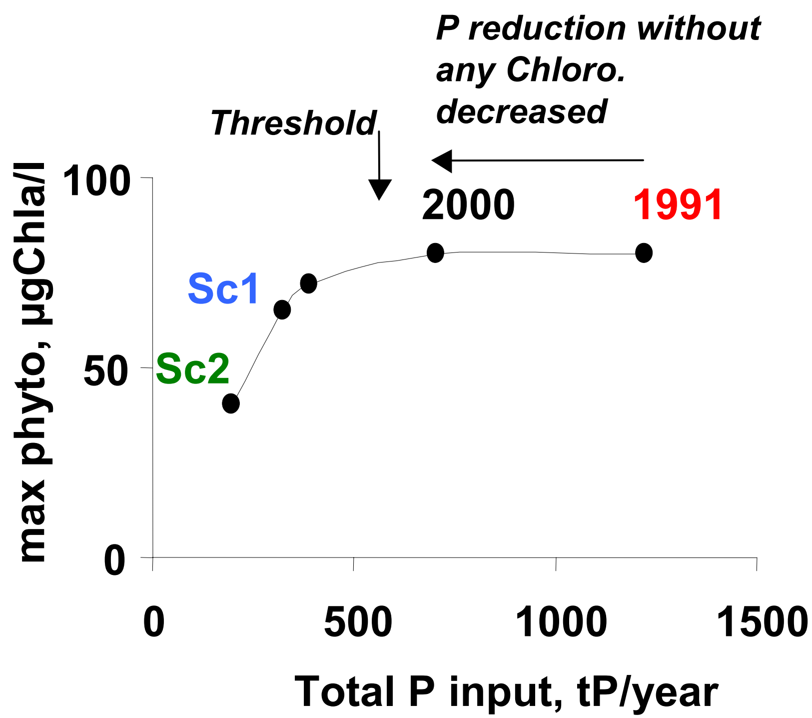


Ducharne, 2005

- Average monthly water quality is highly variable and depends on HD x CC scenarii
- Water quality criteria are those establish for 2000

SCENARIOS OF PHOSPHOROUS INPUT REDUCTION AND IMPACT ON CHLOROPHYL IN THE SEINE RIVER

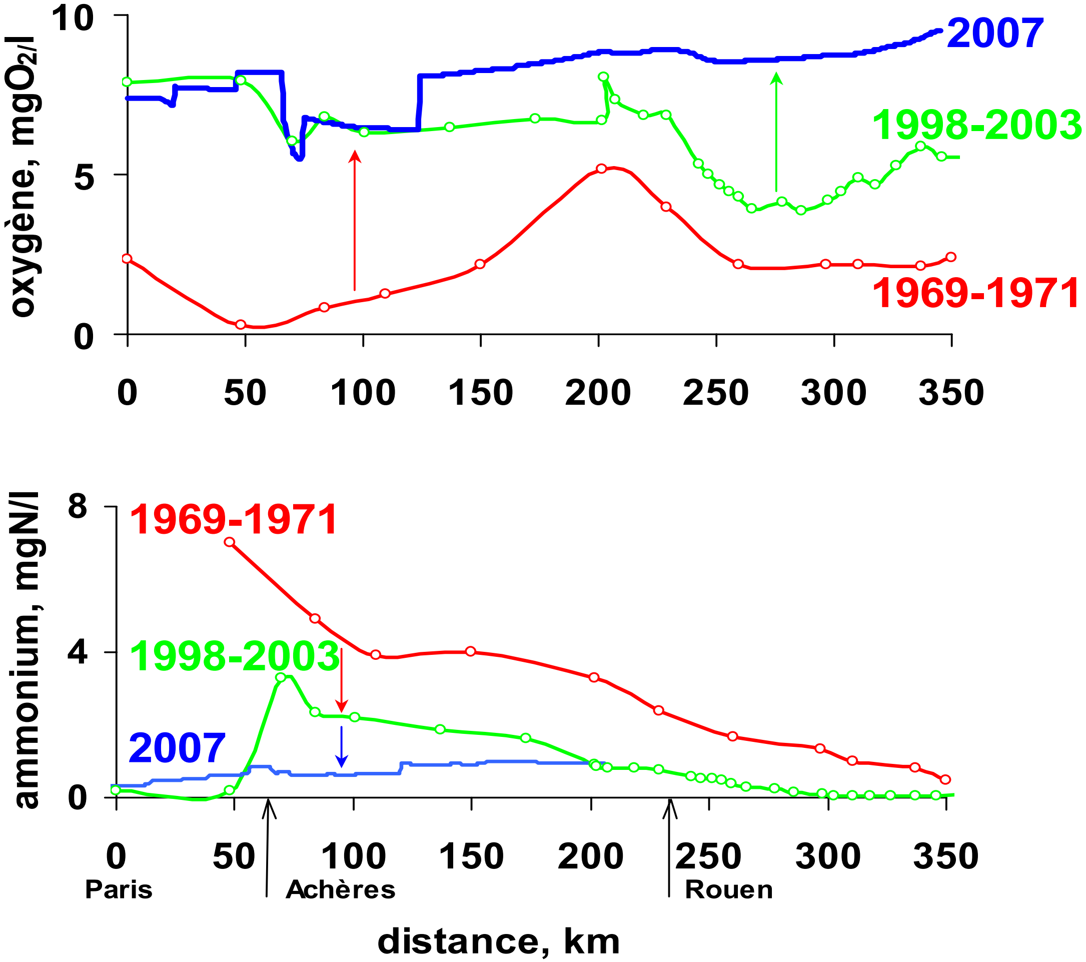




Billen, Garnier, 2004

- Scenario 2000: P reduction in city sewage (> 10 000)
- Scenario 1: P reduction in village sewage (> 2000)
- Scenario 2: 50% P reduction from diffuse sources

SUMMER OXYGEN AND AMMONIUM PROFILES IN THE SEINE (1970-2003) AND SCENARIO FOR 2007



Billen, Garnier, 2004

- The explored scenario concerns nitrifcation/denitrification processes at Paris sewage treatment plant (8 Meq people)

LES BAIGNEURS (ILE DE LA JATTE) BY SEURAT

HD 15

- Due to sewage collection of Paris city, one could bath downstream of Paris center in the late 1800's
- Despite continuous efforts since 1970 the water quality of the Seine does not allow such recreational use in 2000
- It may neverhappen due to the occurence of the combined sewers overflow system in Paris center, aged 100y

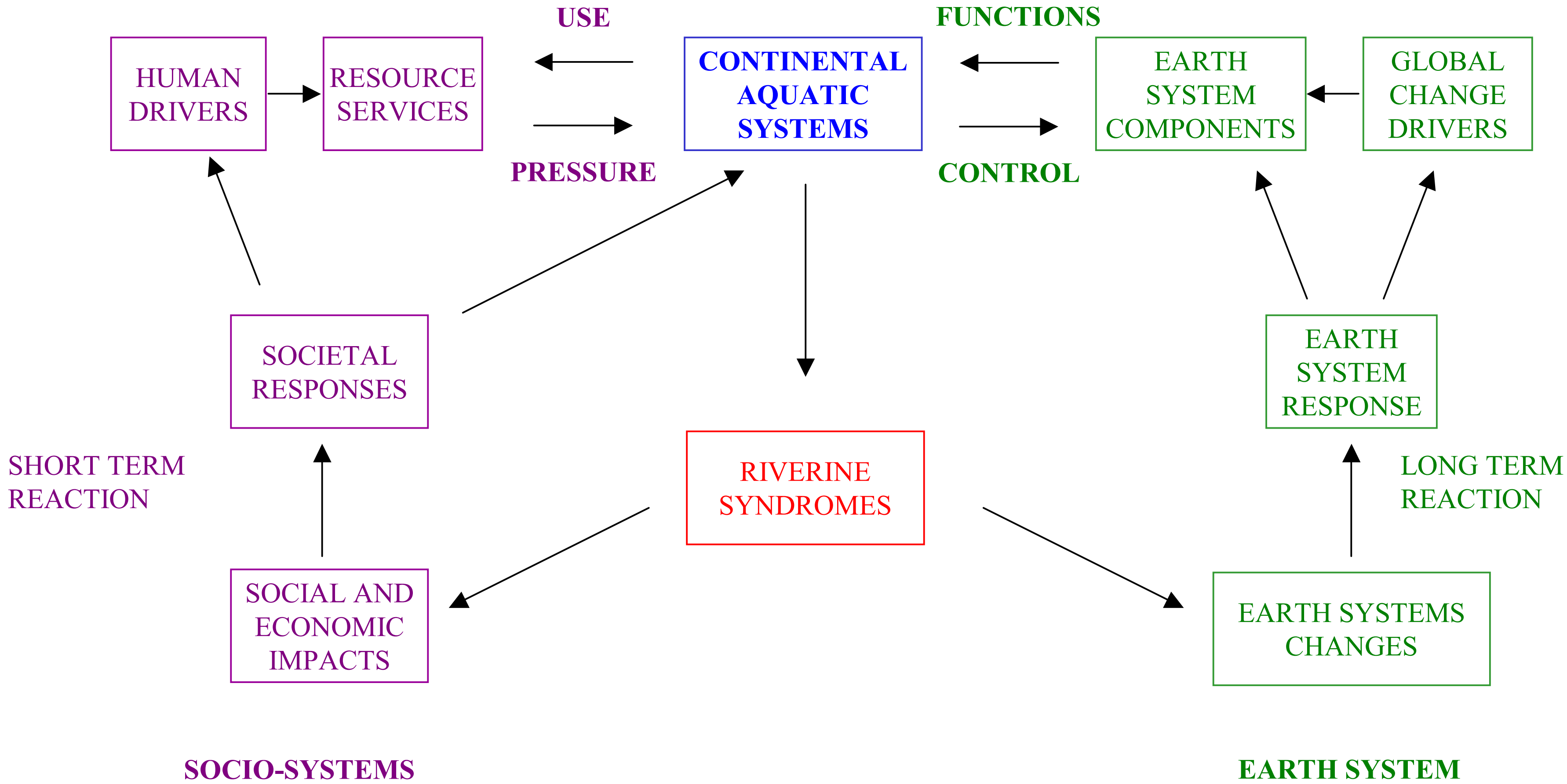
SOME RESPONSES FAILURES

- Issue not identified (e.g. Redfield Ratio change; metal contamination)
- Lack of scientific tools (riverine eutrophication; coastal eutrophication)
- Controversial issue (e.g. P limitation)
- Intensive lobbying (metal; nitrates)
- Lack of early warning (atrazine; endocrine disruptors)

ISSUE IDENTIFICATION

- What is happening? Natural processes / social-societal processes
- Which water body?
- When has it happened? State trajectory reconstruction
- Why does it occur ? Pressures
- How did it happened ? Drivers
- Who is responsible ? Pressures/drivers analysis
- Who is suffering ? Impact analysis
- Who is controlling ? Regulation/envir. survey analysis
- Where are the drivers?
- Where are the pressures ?
- Where are the change of state?
- Where are the impact ?
- Where are the responses ?

SCHEMATIC POSITIONS OF CONTINENTAL AQUATIC SYSTEMS SHARED BY SOCIO-SYSTEMS AND EARTH SYSTEM



- The Driver-Pressure-State-Impact-Response cycle in socio-systems is generally observed at short to medium periods (10-50 y)
- The parallel Environmental impacts-Earth System response- Regional to Global Change is a long term reaction (100-1000 y) still poorly known

CONCLUSIONS

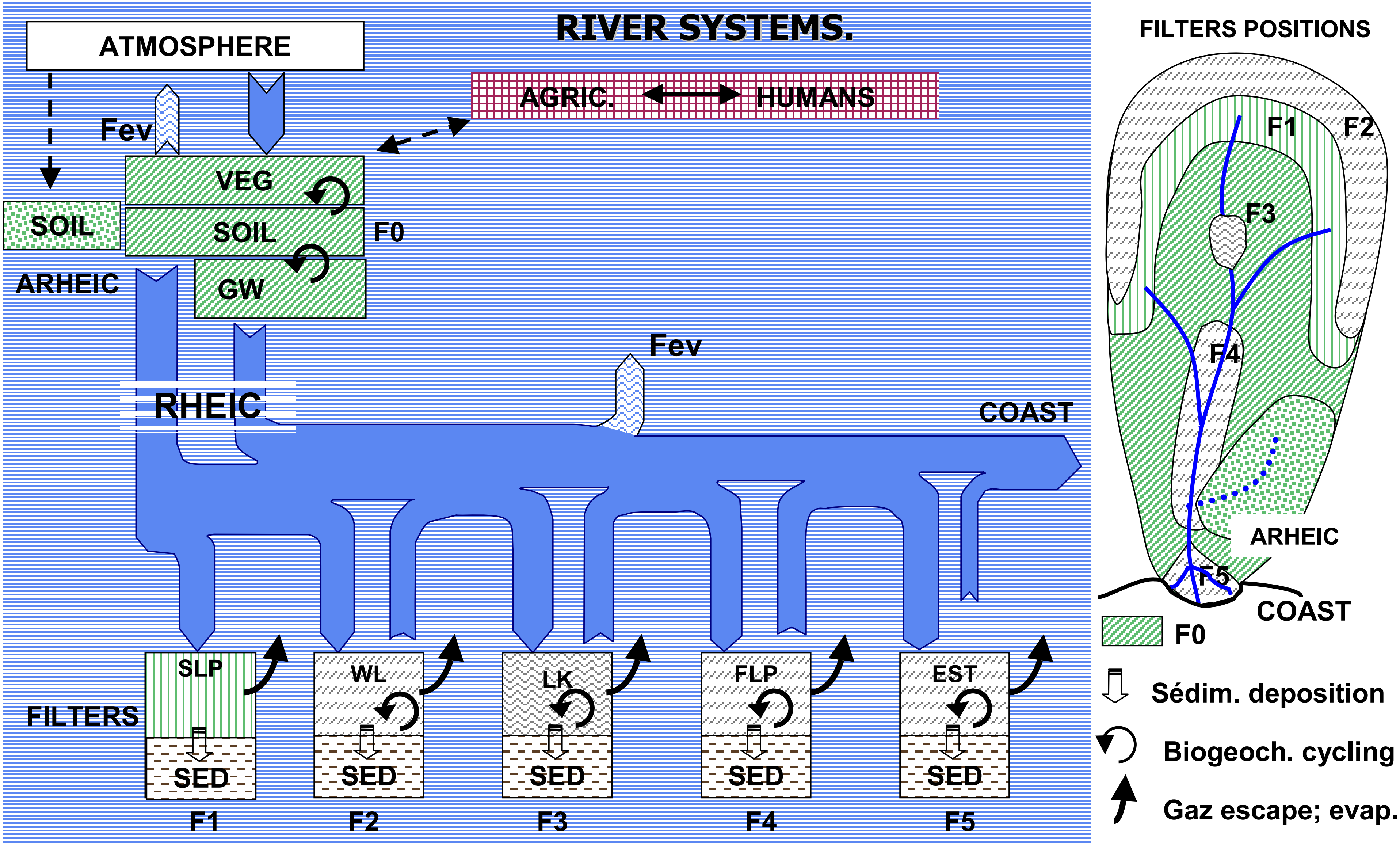
- Managers need tools as scenarios exploration based on models

- Models need a lot of process understanding, socio-economic data, field data for validation

- Each issue has it own DPSIR trajectory, its own spatial development

- Issue perception depends on society consensus scientific knowledge etc..

SCHEMATIC POSITION OF RIVER MATERIAL FILTERS WITHIN PRISTINE RIVER SYSTEMS.



In addition to the soil/plant filter (F0), different types of filters control the pathways and transfers of river borne material: slopes and piedmonts (F1), headwaters wetlands (F2), lakes (F3), inundated floodplain (F4) and estuaries (F5). Human impacts are very limited.

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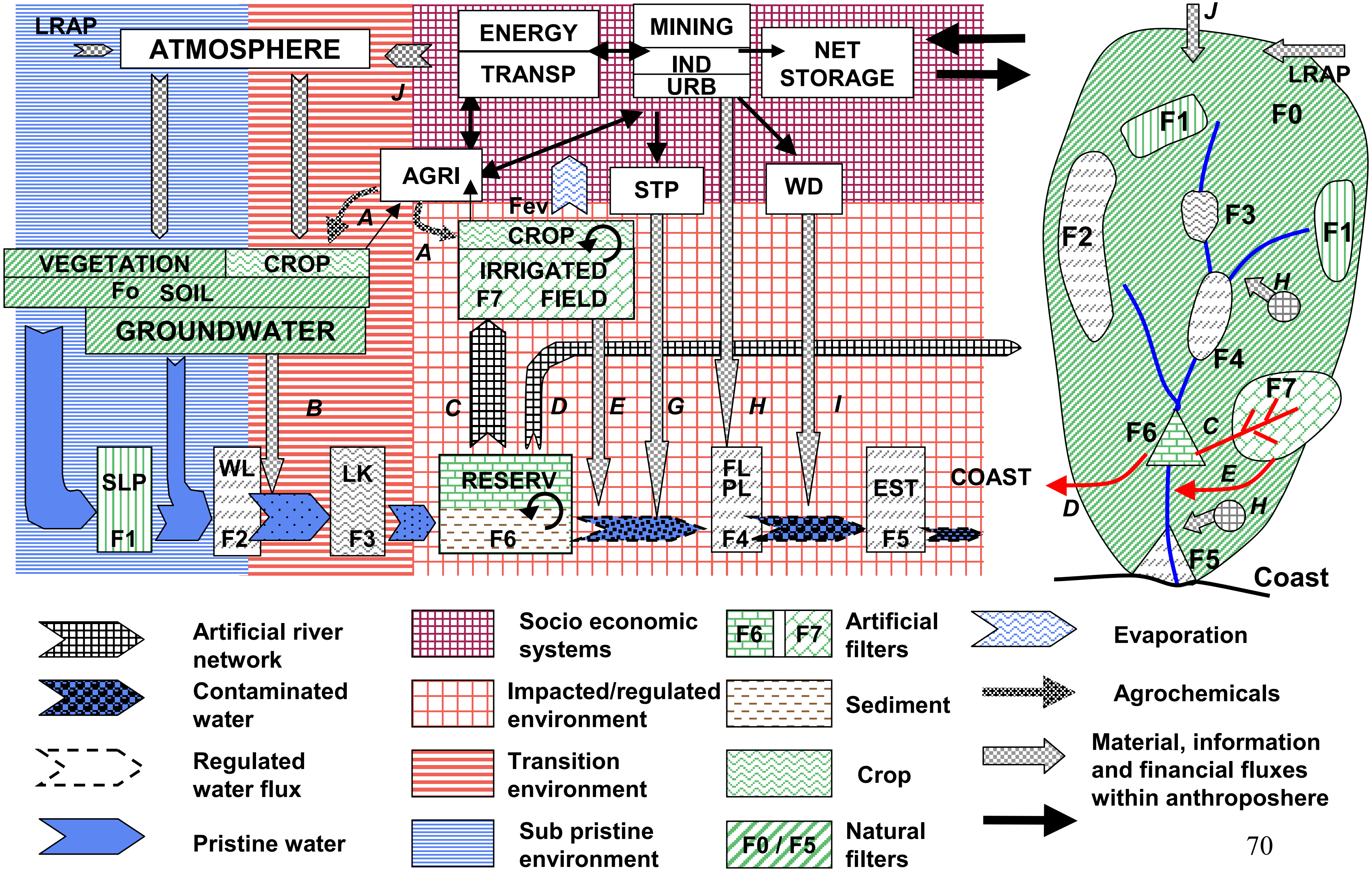
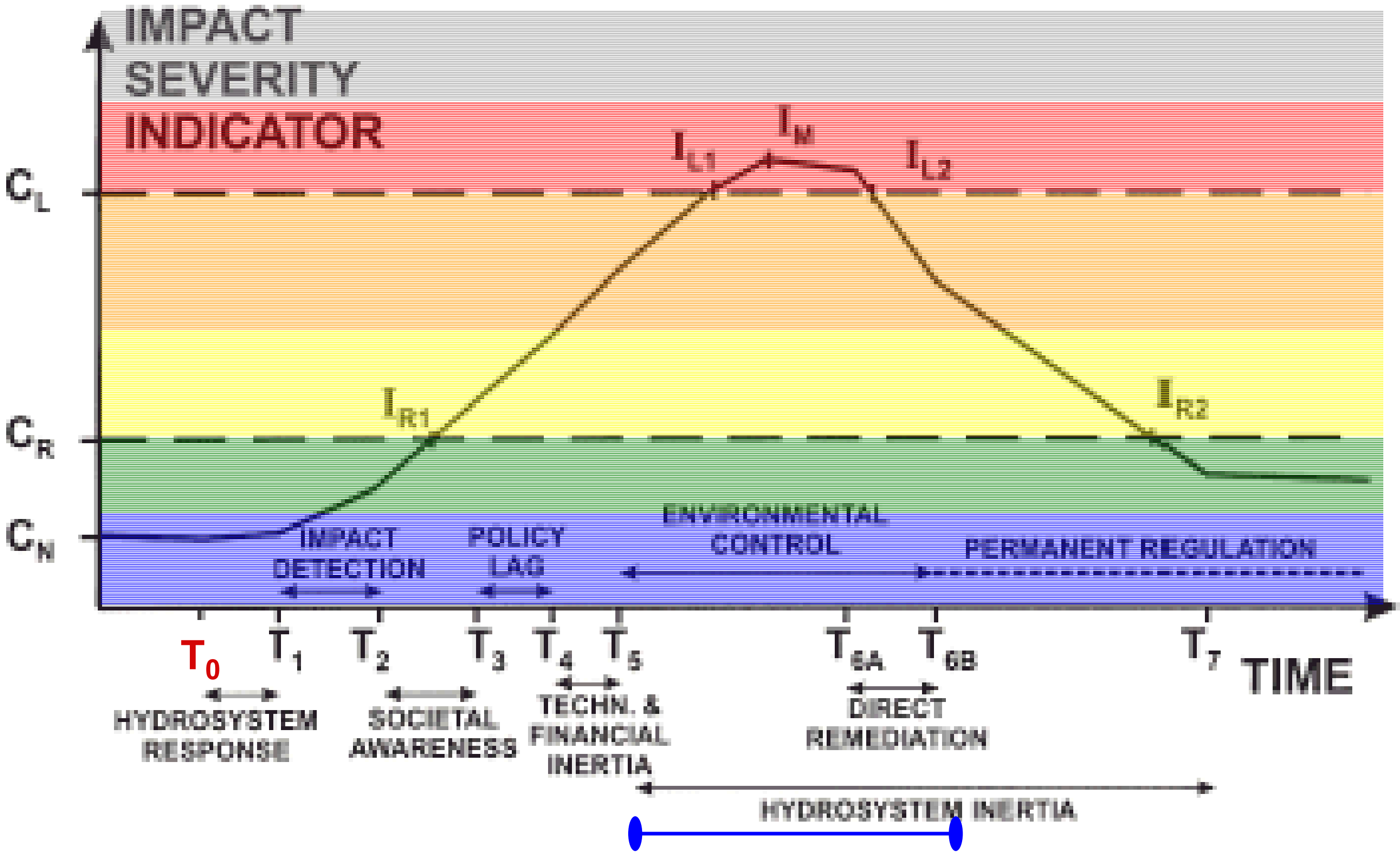
FLUVIAL SYSTEM FUNCTIONING IN THE ANTHROPOCENE

POLLUTED/REGULATED FLUVIAL SYSTEM



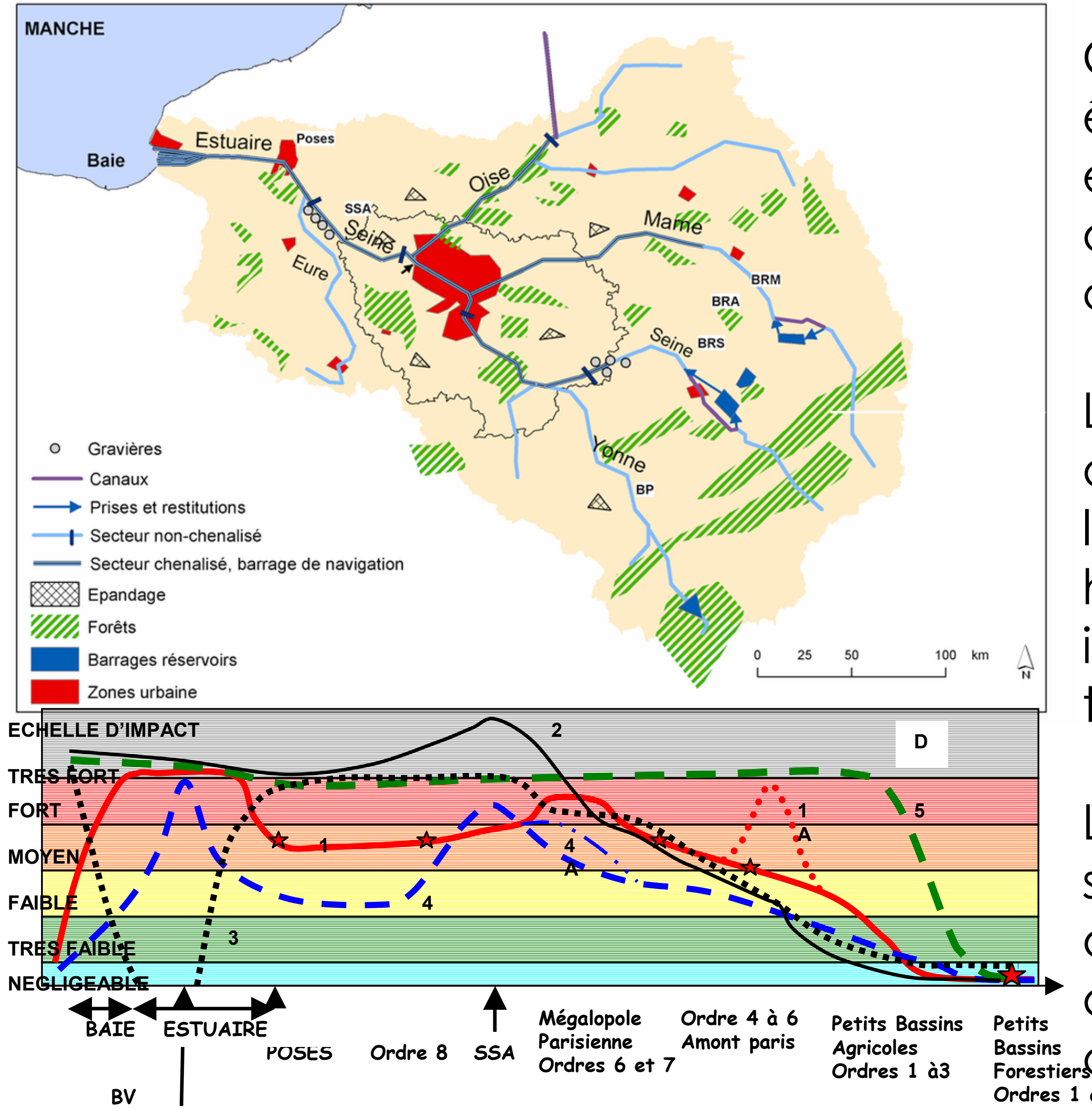
SUCCESSFUL RESTOARTION CYCLE OF WATER QUALITY: CUMULATED ECOSYSTEM AND SOCIOSYSTEMS INERTIA



Impact detection, scientific consensus, societal inertia and polluters lobbying are reponsible for delayed or partial responses. As a result critical environmental conditions are reached with severe ecological, economic or health impacts. Pressure-Response-Remediation cycles take decades.

Meybeck et al., EUROCAT WP5, 2004

RELATIVE QUALITY OF AQUATIC SYSTEM (SEINE RIVER)



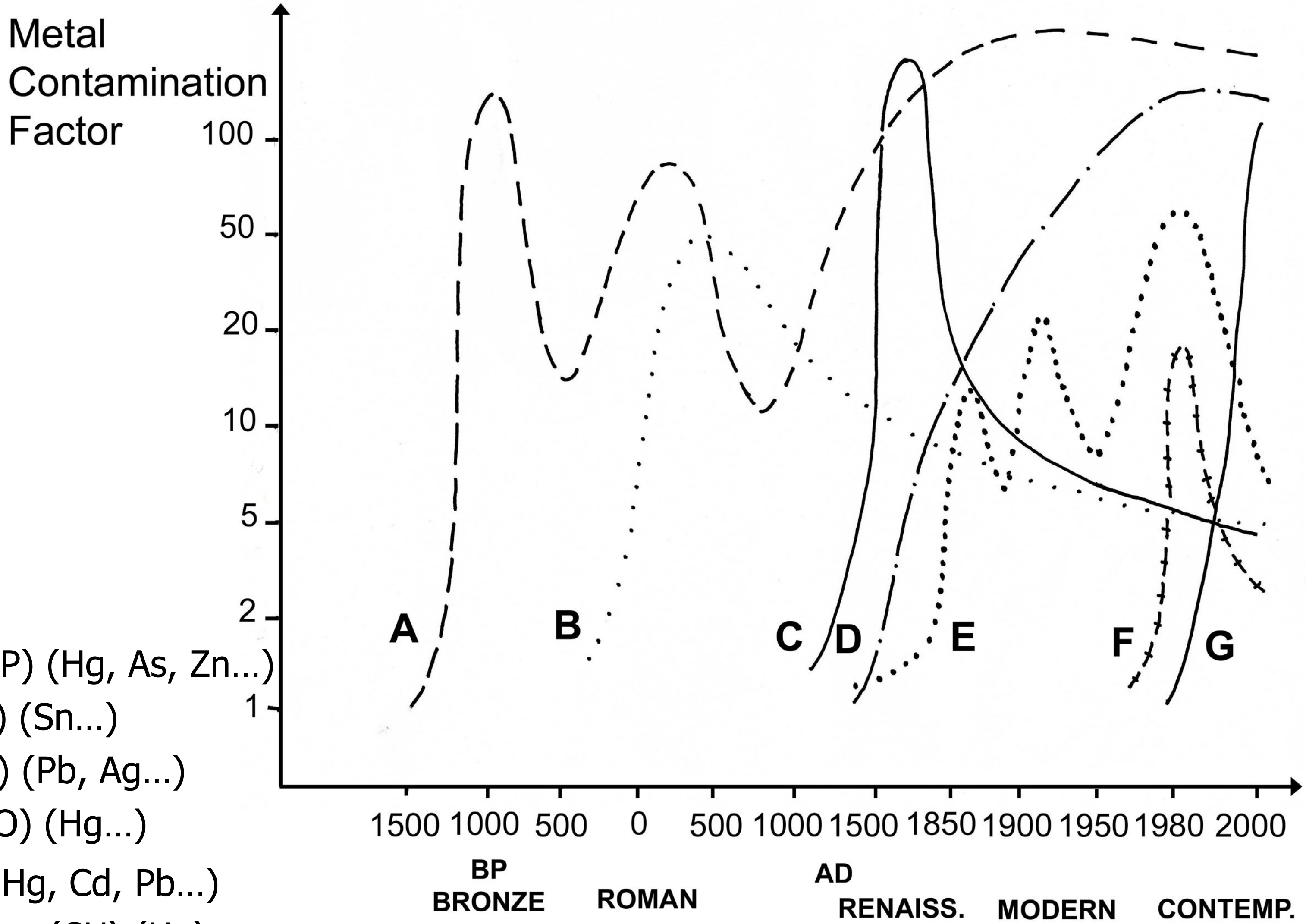
Chaque critère peut être analysé selon une échelle d'impacts, ce qui permet la comparaison.

Les profils moyens d'impact combinent les ordres hydrologiques et l' impact de Paris: ils sont tous différents.

Les impacts de Paris s'exercent sur l'amont du bassin et très en aval (Baie de Seine), après le filtre estuarien.

Meybeck et al., 2004. Cahiers IAURIF

SCHEMATIC METAL CONTAMINATION IN RIVERS



- **A**: R. Tinto (SP) (Hg, As, Zn…)
- **B**: Wales (UK) (Sn…)
- **C**: Brittany (F) (Pb, Ag…)
- **D**: Idrija (ISLO) (Hg…)
- **E**: Rhine (As, Hg, Cd, Pb…)
- **F**: Alpine Rhone (CH) (Hg)
- **G**: Sepik (PNG) (Cu…)