VULNERABILITY OF WATER QUALITY
EXAMPLIFIED ON THE RIVER SEINE

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OUTLINE

• Local impacts vs. Earth System
• Issues and Pressures
• Time analysis
• Space analysis
• Budgets
• Scenarii: CC & HD
SPACE SCALES IN RIVER BASINS

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• 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/O₂ 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
• 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
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SEINE BASIN RELIEF

• 90 % of the basin is flat, climate and lithology are uniform
• 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?
• 12 main regions (20 soil types x 20 crop rotation x 20 farming practices)
• Used for scenarii analysis
- Most of the drained network is regulated
- Intensive agriculture is wide spread and single point sources: Paris megacity

PIREN-Seine, 2004
PARIS MEGACITY

• Paris megacity (25 000 km²): 10 M people
  vs. Natural low flows in Paris 50 m³/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)
- 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.
PIREN-Seine, 2004
PARIS MEGACITY HISTORY

• In 1900’s, about 2 M people, now 10 M people 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)

• 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)

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

- Throughout the XXth century 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.
• 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 m³/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)

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S. Barles; Piren Seine, 2003
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

Conference

PIREN SEINE
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 abatement and NH$_4^+$ decrease.

- P-PO$_4^{3-}$ control then decrease was only achieved after the 1985 ban of P detergents and the dephosphatation in most treatment plants.
• From 1960 to 1990 nitrate has increased in most large rivers
• Maximum rates are observed in smaller catchments exposed to intensive fertilizer use
• Daily $O_2$ cycles may reach 9 mg/L!
• They are destroyed by river floods
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)
Treated solids of the sewage water plant of the parisian area (8 M people)

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

Copper

ASS

STD

EM

SPM

DS

BGR

FD

µg.g⁻¹

10000

1000

100

10

Pb contamination in the Seine basin

Lead

µg.g⁻¹

101000

10000

1000

100

10


ASS

STD

EM

SPM

DS

BGR

FD

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Hg contamination in the Seine basin

Mercury

µg.g⁻¹

EM

ASS

DS

SPM

STD

BGR

FD


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Hg contamination in the Seine basin
Ni contamination in the Seine basin

![Graph showing the concentration of nickel (µg.g⁻¹) from 1976 to 2003 in the Seine basin with different samples such as ASS, EM, SPM, DS, BGR, STD, and FD.](image)
Zn contamination in the Seine basin

[Graph showing the concentration of Zinc in different samples (ASS, EM, SPM, DS, STD) over the years 1976 to 2003.]
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)

- Leaded gasoline
- Accumulators
- Cables
- Metal
- Chemicals including oxides

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**CHEMICAL VARIABLES**
- $O_2$
- $NH_4^+$, $NO_3^-$
- $Cl^-$
- Major ions
- COD
- BOD
- POPs*
- Pesticides*

**PHYSICAL VARIABLES**
- $T^\circ$
- pH
- Cond.
- TSS
- Radionuclides*

**BIOLOGICAL VARIABLES**
- Microbial counts
- BOD
- Nutrients
- Biotic indices
- Pigments
- Sediment archives

- 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.

*Meybeck, 2004*
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
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)
90% of the basin is flat, climate and lithology are uniform.

PIREN-Seine, 2004
SCHEMATIC RANKING OF MEDIAN WATER QUALITY INDICATORS IN THE SEINE RIVER BY STREAM ORDERS FROM HEADWATERS TO RIVER MOUTH (500 KM)

**POINT SOURCES IMPACT**

- Hg, Ag
- NH₄⁺
- Pb, Zn
- Na⁺
- DOC, SO₄²⁻
- Mg, Ca, HCO₃⁻, Co

**DIFFUSE SOURCES IMPACT**

- Cd
- ALGAL POC
- NO₃⁻
- Cl⁻
- K, PP
- TSSₘᵟᵡ
- SiO₂

**XENOBOTICS**

- MAX. ATRAZINE
- PCBs

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

- AVEC CONFERENCE 2005
• The water quality assessment of a given basin is very dependant on the station location

Meybeck, 2004
1. Organic pollution
2. Sewer overflow
3. Estuarine nitrification
4. Metals
5. Habitat degradation
6. Atmospheric pollutants
7. Timber rafting (1500-1920)
The natural cycle of Nitrogen is generally very closed with limited export by rivers.

Impact of human activities has been reconstructed on the basis of monastic archives from Burgundy Abbeys (XIlth).
PHOSPHOROUS BUDGET, 1000 t N/YEAR

AGRICULTURAL SOURCES

- Fertilizers inputs: 95
- Agric. soils: 112
- Animal h usb: 27
- Accumulation: 7.5
- Export: 90
- Import: 5

URBAN AND INDUSTRIAL SOURCES

- Total urban sources: 7.1
- Megacity sewage
  - DOM: 1.5
  - IND: 4.5
  - EST: 0.1
  - Retention: 1

BIOGEOCHEMICAL CYCLING

- Forest soils: 0.1
- Erosion: 2.5
- Inputs to English channel: 8.5
- Retention: 0.3

PIREN-Seine, 2004
ZINC BUDGET, 1000 t N/YEAR

Inputs to English channel

PIRENS-Seine, 2004
• The percent drained area has dramatically increased since WW II
• The riparian denitrification has decreased by a factor 2

PIREN-Seine, 2004
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Ducharne, 2005
• 12 main regions (20 soil types x 20 crop rotation x 20 farming practices)
• Used for scenarii analysis
INCREASE OF NITRATE CONCENTRATIONS (%) DUE TO CLIMATE CHANGE ONLY IN SEINE AQUIFERS

Relative variations (%) of simulated NO$_3$- concentration

2050 (A$_2$ scenario) vs. reference period 2100

Ducharne, 2005
EXPLORING FUTURE BIOGEOCHEMISTRY AT MOUTH (Poses) WITH DIFFERENT SCENARIOS

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

Ducharne, 2005
SCENARIOS OF PHOSPHOROUS INPUT REDUCTION AND IMPACT ON CHLOROPHYL IN THE SEINE RIVER

- 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

Billen, Garnier, 2004

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

Billen, Garnier, 2004
LES Baigneurs (Ile de la Jatte) by Seurat

- 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 never happen due to the occurrence 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?
• 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
• 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 its own DPSIR trajectory, its own spatial development

• Issue perception depends on society consensus scientific knowledge etc..
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.
FLUVIAL SYSTEM FUNCTIONING IN THE ANTHROPOCENE
POLLUTED/REGULATED FLUVIAL SYSTEM

Artificial river network
Contaminated water
Regulated water flux
Pristine water

Socio economic systems
Impact/regulated environment
Transition environment
Sub pristine environment
Natural filters

Evaporation
Agrochemicals
Material, information and financial fluxes within anthroposphere
Impact detection, scientific consensus, societal inertia and polluters lobbying are responsible 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
Chaque critère peut être analysé selon une échelle d’impacts, ce qui permet la comparaison.


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

Metal Contamination Factor

1500 1000 500 0 500 1000 1500 1850 1900 1950 1980 2000

BP BRONZE ROMAN AD RENAISS. MODERN CONTEMP.