# Management and Impacts of Climate Change
# Programme GICC
## CRP 2001

# 8/01 – Influence of climate change on the hydrological and biogeochemical processes of the Seine watershed

## Summary of Final Report


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The objective of the GICC-Seine project is to study the influence of climate change, in relation with changes in direct anthropogenic constraints, on the water resource of the Seine watershed. This project aims beyond the hydrological implications of climate change; it also seeks to analyse the direct and indirect effects of climate change on the biogeochemical quality of the hydrosystem (nutrients, including nitrates; oxygen, eutrophication, etc.).

The research is based on an analytical approach, which begins with the disconnection of the various components of the system and then proceeds with the analysis of their superimposed responses. The only element involving an explicit modelling is the Seine hydrosystem itself. We used a series of four models, designed and linked up in the course of the last decade, within the framework of the PIREN-Seine Programme, to simulate the hydrological and biogeochemical processes of the Seine hydrosystem (the surface hydrographic network, including its associated reservoirs, aquifers, and cultivated catchment area). These models allowed us to explore and quantify the superimposed impact of three sets of scenarios concerning forcings of the hydrosystem:

- Climate change scenarios based on 12 climate change simulations for the 21st century using general circulation models, in order to encompass a wide range of the uncertainties linked to these simulations;
- Scenarios concerning the trends followed by the cultivated catchment area and the point releases (point pollutions) in water courses, to 2050-2100, using the prospective method of scenarios. We chose to design contrasting scenarios likely to induce large effects on the hydrosystem. Comparing them with the climate change scenarios allowed us to better assess the importance of the latter in the future modifications of the watershed.

We started by assessing the direct impacts of climate change. Concerning the watershed's hydrology, we have highlighted an intensification of the seasonal variations of the Seine discharge, and in particular a severe decline in low water discharges. The trend in flood discharges is less clear, however. Moisture levels in the root zone decrease systematically, but fluctuations in the standing level of aquifers generally remain low. We also showed that the direct impacts of climate change on the agricultural production of the Seine watershed are positive

overall (shortened crop cycles, which facilitates the complete maturing of the crops; higher yields). Climate changes also enhance the mineralization of soil nitrogen. This is followed by (i) an increased flux of soil nitrates into the aquifers, and (ii) an increased nitrate concentration in these same aquifers, to exceed by 2100 the maximum accepted levels for drinking water in a large proportion of the aquifers.

The integrated agriculture scenario makes it possible, in contrast, to substantially reduce the mean nitric concentration of infiltrated water and aquifers in 2100. The impacts of integrated farming and climate change are similar in magnitude but opposed, and their superimposed impact results in climate change offsetting most of the positive effects of integrated farming on the nitrate pollution of the watershed's aquifers.

We also simulated the impact of the three categories of hydrosystem constraint scenarios (climate change, agriculture, point releases) on the biogeochemical quality of the Seine. The most striking effect is the drastic improvement of the quality of the water courses with the general reduction of point releases by 2050 in the three constructed scenarios. Through its effect on the diffuse inflow of nitrates from aquifers and cultivated catchment areas, climate change produces a significant increase of the nitrate concentration in water courses. This impact is of the same order of magnitude (approximately 10 mg $NO_3$/l) as that of integrated farming, but in the other direction. As regards the other biogeochemical quality variables, the impact of climate change is widely overridden by that of the rise in water temperature on the spatial and temporal dynamics of biological populations. As long as point releases are limited, this impact comes out more positive than negative. With the notable exception of nitrates, the impact of climate change is of the same order of magnitude as the differences between the three point release scenarios, and is thus very marginal in comparison with the effect of the general abatement of releases according to these three scenarios.

In brief, the impact of climate change on the Seine watershed, outlined up to 2100 on the basis of the above findings, seems far from catastrophic. Obviously, this picture does not claim to be a projection of the state of the watershed, since it disregards many factors of change - related or not to climate change - that can be seen as many new perspectives of research.

**Key words**: climate change, Seine watershed, hydrology, aquifers, agriculture, water quality, nitrates, point pollutions, water management, prospective, scenarios.

## 1. Participants

This project derives from the PIREN-Seine Programme, co-funded by CNRS and the main water management actors of the Seine watershed. As such, it benefited from the achievements of 10 years' worth of research and collaborations, most notably in terms of modelling and prospective reflection. It also benefited from the feedback of the GICC-Rhône project, with which participants to CIG/ENSMP also collaborate.

Seven research teams involved in the PIREN-Seine Programme participated in the project in close collaboration:

| | Teams | Researchers | Status | % time | Months |
|---|---|---|---|---|---|
| 1 | UMR Sisyphe : UPMC | A. Ducharne | Chargée de recherche | 70% / 2 years | 17 |
| | | G. Billen | Directeur de recherche | 20% / 2 years | 5 |
| | | J. Garnier | Directrice de recherche | 10% / 2 years | 2.5 |

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|---|---|---|---|---|---|
| | | S. Théry<br>J.E. Sicart<br>F. Curie<br>C. Lavaud | Ingénieur d'étude CDD<br>Post-doctorant CDD<br>Stagiaire DEA<br>Stagiaire EPF (4ème année) | 60% / 1 year<br>100%/ 5 months<br>30% / 6 months<br>100%/ 2 months | 8<br>5<br>2<br>2 |
| 2 | UMR Sisyphe: CIG/ENSMP (ARMINES) | E. Ledoux<br>P. Viennot<br>E. Gomez<br>C. Baubion | Directeur de recherche<br>Ingénieur de recherche<br>Post-doctorant CDD<br>Stagiaire DEA | 10% / 2 years<br>40% / 2 years<br>85% / 1 year<br>100%/ 6 months | 2.5<br>10<br>10<br>6 |
| 3 | INRA Laon: Unité d'Agronomie | B. Mary<br>N. Beaudoin<br>S. Lebonvallet<br>E. Souboua | Directeur de recherche<br>Ingénieur de recherche<br>Ingénieur CDD<br>Post-doctorante CDD | 5% / 2 years<br>20% / 2 years<br>100%/ 8 months<br>100%/ 4 months | 1<br>5<br>8<br>4 |
| 4 | INRA Avignon | N. Brisson | Directrice de recherche | 15% / 2 years | 3.5 |
| 5 | INRA Mirecourt: UR Systèmes Agraires et Développement | M. Benoit<br>C. Mignolet<br>C. Schott | Directeur de recherche<br>Ingénieur de recherche<br>Post-doctorante CDD | 15% / 2 years<br>20% / 2 years<br>100% / 1 year | 3.5<br>5<br>12 |
| 6 | ENGREF: Equipe RGTE | L. Mermet<br>H. Kieken<br>A. Aboualkhair | Professeur<br>Thésitif<br>Stagiaire DEA | 5% / 2 years<br>60% / 1 year<br>100%/ 6 months | 1<br>8<br>6 |
| 7 | AScA | X. Poux<br>G. Olive<br>G. Ducos | Chef de projet<br>Stagiaire DEA<br>Stagiaire DEA | 50% / 2 years<br>100% / 6months<br>100% / 6months | 12<br>6<br>6 |
| | 7 teams | | 12 statutory researchers<br>6 fixed-term contract researchers<br>7 university students | | 68<br>46<br>28 |
| | | | 24 people | | 143 |

The participants are also involved in several international programmes or networks on the functioning of hydrosystems and agrosystems, among which the 'Integrated Approaches to Drainage Basins Nutrient Inputs and Coastal Eutrophication' of the Nordic Network for Research and Education, the Si-WEBS European network, and the 'Biospheric Aspects of the Hydrological Cycle' (BAHC) and 'Land-Ocean Interactions in the Coastal Zone' (LOICZ) programmes of IGBP.

Finally, our research also benefited from several outside collaborations:

- Météo-France;
- Three pairs of climate change simulations with the ARPEGE model from Michel Déqué;
- Meteorological data from SAFRAN-CROCUS;
- Output from one pair of climate change simulations with the LMD6 model, from the GICC-BD project ('Climate Change Simulations Database for Impact Studies') coordinated by Jan Polcher (LMD).