

# Integrating structural changes in future research and modelling on the Seine River Basin

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**Abstract:** For years policy makers and researchers involved in the management of the Seine river basin have shared a common representation of the system's structure and behaviour: Paris, in the centre, divides the watershed into two very unequal parts, a "clean" upstream and the downstream where environmental problems occur due to Paris sewage. This representation resulted in both (1) a focus of the attention and the efforts of policy makers on the downstream area and (2) the structuring of scientific research on the Seine River in a very dissymmetric way, including the features of the models developed within the 12-year old and still ongoing research programme dedicated to the area. Hence, we were led to attempt studying the consequences of changing the watershed's spatial segmentation by considering a hypothetical future state of the river basin in which the city of Paris would be suffering from sewage discharged upstream. Exploring such "surprise-based scenario" using a "backcasting" approach raised both methodological issues of coupling structural changes in socio-economic scenarios with existing bio-geo-chemical models and some interesting lessons on the watershed behaviour: a strong resilience of the river basin, the weak feedback of water quality on the socio-economic dynamic (i.e. environmental considerations have little influence on the basin's evolution), and a new illustration of the absence of significant stakes related to the quantitative management of water.

**Keywords:** Seine River; Modelling; Backcasting; Prospective; Future Research

## 1. INTRODUCTION

In one of the 1980's most important contribution to environmental management, Clark and Munn [1986a] proposed a research programme aiming at improving our understanding of long-term interactions between environment and development [1986b]. Noticing that "most studies of the future are dominated by smooth projections that are free of significant discontinuities, or (...) surprises", the authors were emphasising two points that should contribute to the development of scientific research for sustainable development: (A) "Management is not the same as predictions", and (B) "Usable methodologies to deal with discontinuities" are to be developed.

However, today's diagnostic does not differ very much from Clark's: most studies on the future based on modelling are still based on some kind of evolutionary paradigm in a manner that can be described by surprise-free models. And there is still some lack of methodologies for introducing surprises into modelling. This paper is thus both a presentation of a specific modelling exercise, and

an attempted contribution to the methodological challenge of integrating structural change in modelling.

Detailing Clark's research programme, Brooks [1986] identifies three sources of surprises:

- "(1) Unexpected discrete events, such as oil shocks (...), revolutions, major natural catastrophes (...)
- (2) Discontinuities in long term trends (...)
- (3) The sudden emergence into political consciousness of new information"

Studying each of these groups of surprises requires specific approaches. In this paper, we will focus on the second kind of discontinuity. We will explore a Seine river basin scenario leading to a situation dramatically different from today's vision of the watershed, but mostly based on a continuation of present evolutions of socio-economic trends in the area. As the model used for this exercise only simulates the natural system, we had to develop a specific method for coupling the socio-economic scenarios and the simulation of the natural system. In this paper we will present (1) the model used for this exercise, (2) the methodology developed for

modelling the river basin's surprise-based scenario and (3) the result and learning from such approach.

## 2. THE "PIREN-SEINE" RESEARCH PROGRAMME AND ITS MODELS

### 2.1 The Seine River Basin

By French standards, the Seine river basin is highly populated: the watershed covers only 12% of the French territory but hosts 25% of its population. But the population isn't proportionally distributed within the basin: 10 of the 17 millions inhabitants are living on less than 4% of the watershed's territory (the Paris' urban area). As a result, population density along the river can vary from 3 to 5000 people per km<sup>2</sup>. Human pressure related to the river's flow is among the highest in Europe not only in Paris, but also near some mid-size cities (*Reims, Beauvais...*) [Meybeck *et al.*, 1998].

Paris in the centre of the river basin is thus dividing the watershed into two very unequal parts: a "clean" upstream area and a "dirty" downstream area where environmental problems occur due to Paris waste water. This representation of the system's structure and behaviour is reinforced by two key elements: (A) the presence 20 km downstream from the Eiffel Tower of the gigantic Achères' plant where wastewater from 8 millions people is treated and the impact of the discharge in the river's water quality can be perceived for kilometres. (B) The management of the four dams located in the head of the basin regulating the flows for the Seine River and 3 of its tributaries (*Marne, Yonne and Aube*). These dams are owned and managed by Paris' municipality and the three surrounding departments with two objectives: preventing major flooding and increasing water level during low-water period (restitution from the dams can correspond up to 75% of the flow during the driest months). As a result of this institutional arrangement, Paris and its suburbs are managing these works affecting the whole basin's hydraulics.

Such vision resulted both (1) in focusing the attention and efforts of policy makers on the downstream area and (2) in structuring in a very asymmetric way scientific research projects on the Seine River, including the features of the models developed within the "*PIREN-Seine*", a 12-year old and still ongoing research programme dedicated to the area.

### 2.2 The SENEQUE model

The *PIREN-Seine* research programme was

launched in 1989 aiming in particular at the development of an independent expertise on the watershed's management. In order to integrate and manage the diversity of results that came out of the programme a models "tool-box" has been developed [PIREN-Seine, 2000]. For the simulation described in this paper, we only used one of these tools: the SENEQUE model developed by G. Billen<sup>1</sup>.

SENEQUE includes three coupled modules:

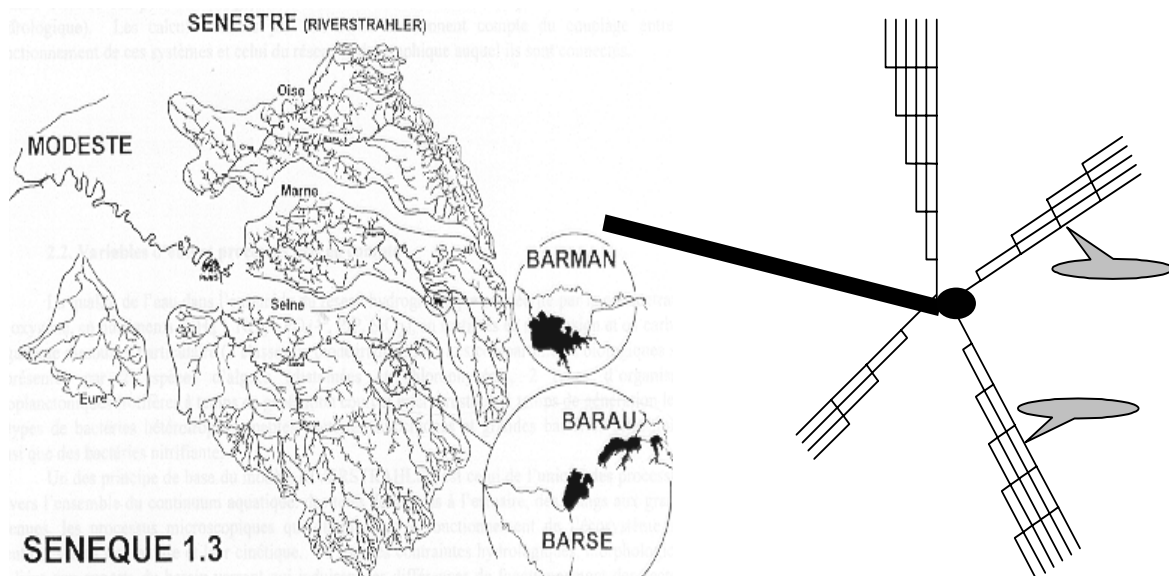
- (A) An application of the RIVERSTRAHLER approach to the Seine river [Billen and Garnier, 1998]. This module consists of an idealised hydrological model based on the concept of stream order. It describes the flow of water from the watershed in 4 sub-basins and the main branch of the Seine river
- (B) A kilometric description of the main branch of the Seine river downstream Paris which describes the flow of water
- (C) The RIVE module describing the kinetics of the various biological and physico-chemical processes affecting organic matter and nutrients [Billen and Garnier, 1997].

The dams are also simulated in a specific module treating both quantitative and qualitative aspects. As mentioned before, the model structure is reflecting the common representation of the river basin's functioning: the kilometric description of the Seine's main branch is much more detailed than the upstream statistical approach (cf. Fig. 1).

The RIVERSTRAHLER module represents the complex network of tributaries of each sub-basin by a regular scheme of confluence rivers of increasing stream order based on mean morphological characteristics. Using a two-reservoir description of the rain-discharge relationship, it calculates the specific flow in each sub-basin from the seasonal variations of rainfall and evapotranspiration. The required hydrological parameters are calibrated using pluri-annual series of discharges values at the outlet of each sub-basin [Billen and Garnier, 1998]. The RIVE model summarises the results of about 20 years of microbial ecological research [Billen and Garnier, 1997]. It includes a detailed description of phytoplankton activities, zooplankton grazing, planktonic organic matter degradation, nitrification and benthic remineralisation. These processes are individually calculated by the module for all tributaries and along the main branch of the Seine River. Point sources of nutrients from wastewater works are taken into account using data

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<sup>1</sup> For this project, we used the 1998's version of the model : SENEQUE 1.3. Present version is 3.0  
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**Figure 1** - Comparison of the real network of contributors and the conceptual model of SENEQUE 1.3

communicated by the Seine river basin authority (*Agence de l'Eau Seine-Normandie*). For the sub-basins, the discharges from all wastewater works are distributed by stream order, while for the main branch they are taken individually into account at their exact kilometric position. In order to simulate diffuse pollution, land use and mean nitrate concentration in aquifers are used as the forcing functions for calculating the limit nitrogen concentration in (sub)surface and base flow respectively. The retention by the riparian zone is taken into account by a simple transfer coefficient [Billen and Garnier, 1998].

Hence, SENEQUE is (only) modelling the hydro-system. The socio-economic dimensions of the river basin can only be taken into account through their impact on forcing variables: diffuse pollution and point sources of nutrients. However, modelling significant structural change in the basin's global behaviour implies simulating the evolution of the socio-economical dynamics of the watershed. We had to develop a specific methodology for that purpose.

### 3. SIMULATING THE SEINE BEHAVIOUR FOR 2030

#### 3.1 Building a scenario using a backcasting approach

At the beginning of our research, we agreed on two objectives: (a) providing a vision of some possible future that would profoundly differ from today's situation and, (b) using the model developed by the research programme for analysing the hydrosystem's issues within such vision.

Since the common representation of the

watershed's structure is so strongly accepted in the actions taken by all Seine basin's stakeholders, we decided to study a situation in which the city of Paris is not only discharging massive pollution but also suffering from upstream sewage. This approach: first envisioning the final state of the system, and then studying a possible path that might lead the studied system to the final envisioned situation has been theorised in the "futures research" field, in particular by John B. Robinson [1988, 1991]. Unlike predictive forecasts, backcasts are not intended to indicate what the future is likely to be, but to indicate which development paths may lead to a specified state of the future at a given date.

The implementation of a backcasting methodology can be summarised in two steps: (1) defining the final objectives and (2) building a development path leading to a situation fitting target objectives. The SENEQUE model has been used at both stages. For the first step, we used SENEQUE as an "assessment tool" for identifying the key socio-economic variables that might cause Paris' upstream water quality degradation. In the second phase, we used the model as a "simulation tool" for refining the development path and ensuring its consistency regarding hydrosystem behaviour.

The first step of the process led to the final state's definition. In the scenario, the disruption is created by the tension resulting from a huge development of the area located between the cities of *Reims*, *Troyes* and *Chalons-sur-Marne* (RTC). This development is characterised by high population growth; the development of a new industrial area specialised in biotechnologies and GMO crops. Such developments result in a huge demand for irrigation water and, at the same time, for water quality in the RCT area. The disruption is thus

caused by both water and political conflicts.

The water conflict emerges from the different expectations on water management: the dams will not be sufficient both for maintaining a reasonable water level in Paris and furnishing the irrigation's demand. In the scenario, the reduction of both water quality and quantity might thus be sufficient to affect Paris' drinking water production through the increased occurrence of pollution peaks (until now, such temporary suspension of drinking water production already occurred but has not affected consumers, thanks to water storage).

This scenario also involves political conflict resulting from diverse trends: a demand for a more decentralised and democratic management of the dam (the 3 biggest reservoirs representing 725 of the 800 millions m<sup>3</sup> of the basin's water storage are located in the RCT area) and the contradiction between each area's risk management policy. Indeed Paris aims at preventing flooding, whereas RCT expects protecting the local economy against drought. In technical terms, Paris' strategy leads to reduce reservoir's filling in order to be able to reduce the impact of even late floods. On the contrary, RCT's industrial strategy implies maximising reservoir filling in order to avoid any situation in which the dams are not totally full at the end of the winter. This conflict is thus linked to the issue of finding an acceptable balance between diverging interests.

Having defined this general framework for the Seine river basin behaviour in 2030, we then needed (A) to explore a development path that might lead to such a situation and (B) to provide some quantitative assessment of the scenario's hypothesis that will confirm the plausibility of the rupture. Although the model is undoubtedly of great importance for introducing quantitative insights on the scenario, the studied rupture has many dimensions that can not be simulated by the SENEQUE model. Therefore, we had to define a specific methodology for modelling the interactions between human and natural systems.

### 3.2 Modelling the interactions between human and natural systems

The scenario we studied aims at presenting the Seine river basin's evolution from 2000 to 2030, with an intermediary detailed image for the year 2015. In such a scenario, the hydrosystem's evolution is directly connected with the socio-economic dynamics, which are also largely dependent on the ecosystem's condition. Our methodology had to reflect such behaviour and to propose a modelling approach in which natural and socio-economic dynamics are effectively coupled.

Many approaches might be considered for this purpose. For example, the policy exercises attempt implementing hydrosystem models within a role-playing approach [Mermet, 1993]. The one we chose is largely inspired from structural analysis theory as developed in France by Michel Godet (see [Godet, 2001] for recent publication in English) or P-F. Teniere-Buchot (see [Teniere-Buchot, 1993] for an application to the Seine River). It is based on a ranking of the scenario's key variables using two criteria: their sensitivity to evolution of the ecosystem state, and their impact on the evolution on the ecosystem state. Such classification of course depends both on the state variables chosen to characterise the "state of the hydrosystem" and the studied area. However, it does not aim at being neither universal nor absolute, but only helps in building scenarios in a given situation. Using this typology, we simulated the system's evolution as follows:

- i. Propose an hypothesis for the evolution of the most "influential" socio-economic variables
- ii. Convert these hypothesis into quantitative data for the model
- iii. Simulate the response of the hydrosystem using these data
- iv. Given the simulated state of the hydrosystem, assess a plausible evolution for the most dependant socio-economic variables

At this stage, if significant discrepancies result from the independent evolution of the "influential" and "sensitive" variables, the whole cycle has to be run again until reaching a stable situation. Actually, the process converges quickly as the natural system's response time is very short compared to the inertia of the socio-economic variables. When no discrepancies remain, the last step consists in providing a plausible evolution for the neutral variables (which are neither "influential" nor "sensitive").

The whole process is summarised by the graph below. In our specific case, the "sensitive variables" are limited to Paris' drinking water, the "hot variables" correspond to the high added-value GMO cultures' irrigation and the "influential variables" were the upstream industry, sewage discharge from RTC's area, flooding, and dam management.

## 4. MAIN RESULTS

Since backcasts never intend to indicate what the future is likely to be, this scenario can not constitute any form of reference for the future. However, analysing this scenario offers interesting lessons on the watershed's behaviour.

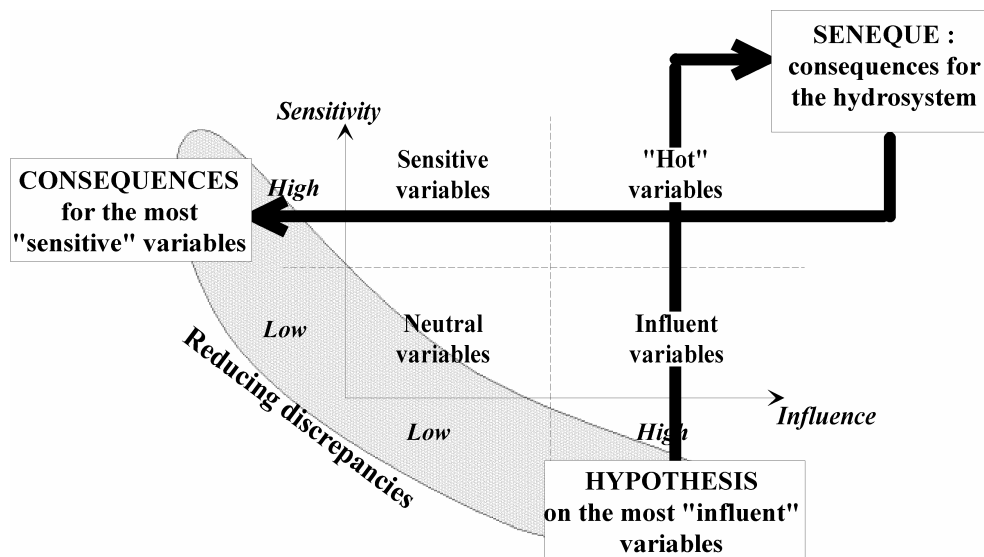


Figure 2 – Framework methodology for modelling the interactions between natural and human systems.

#### 4.1 Learning on watershed behaviour

At the end of the process, the state of the hydrosystem simulated by SENEQUE for the year 2030 was in concordance with the objectives of our backcasting approach: water quality in the area located between RTC and Paris has largely decreased compared to the present situation. The most significant degradation has been observed for ammonium (the concentration increases up to 300%) and, to a lesser extent, for dissolved oxygen and organic pollution. The impact of this situation on algal blooms is more difficult to assess, as it will vary, depending on precipitation and hydraulics. However, we concluded in a probable degradation for the *chlorophyceae*. All these parameters actually affect Paris' drinking water production by increasing the frequency of production suspension caused by pollution peaks.

Although we have been able to produce a scenario in which Paris is suffering from upstream water quality degradation, this pollution has no real impact on the area downstream Paris. Seine River's quality is still mainly influenced by Acheres works' discharge. The present vision on the Seine river basin is thus semi-confirmed: the downstream impact of Paris city is definitely determining.

These conclusions highlight the strong resilience of the river basin. Even with such a major rupture as the one in our scenario, there is few and weak direct feedback from water quality on the socio-economic dynamic: environmental considerations *per se* have little influence on the socio-ecosystem's evolution. Conflicts on water quality indeed essentially reflect diverging economic interests.

The same conclusions can be drawn on water

supply issue. No significant stakes related to the quantitative management of water in the Seine river basin appear in this work: even with the high levels of water consumption for irrigation simulated, no real supply issue have been detected. Again, water quantity conflicts are indeed economics ones.

#### 4.2 Learning on institutional arrangements

Analysing the results also revealed interesting learning on the basin's institutional arrangement's behaviour. As detailed above, qualitative and quantitative issue *per se* have little influence on socio-economic dynamics of the basin, which are more significantly influenced by economical conflicts and interests. However, although there are no significant problems in the basin, our work also revealed that current political and institutional arrangements for water management might lead to strong crises if diverging interests appear.

Present arrangement for dam management are indeed mainly oriented to preserve Paris drinking water supply against severe low water periods in summer and the dam management committee is today monopolised by the city of Paris. If competing interests – like high water demand for irrigation purpose in our scenario – appear in the watershed, tensions might occur in the basin. If these competing interests are located in the district area hosting the dam but not represented in the dam management committee, such tension might lead to strong institutional crises in the watershed.

This issue might also become of importance in a context such as climate change in which supply issue should become problematic, but might force negotiations between the watershed's stakeholders

to take place.

### 4.3 Methodological results

The specificity of our approach has two sides. It provides a framework for both integrating socio-economic issues into the modelling process and, simulating the socio-ecosystem evolution in a way that enable qualitative dimensions to be taken into account. This approach proves to be successful for studying a plausible future that can not be directly assessed through existing models, such as introducing a rupture within present trends.

One of the key success factors of this project has been the relatively short response time of the natural system compared to the inertia of the society. The framework should thus be revised to include natural dynamics having a high inertia (such as ground water nitrates concentration) or to simulate the co-evolution of natural and socio-economic dynamics having both important inertia (such as the regional impact of climate change).

## 5. CONCLUSIONS

The starting point of this exercise was an attempt to study a plausible rupture with the present commonly shared vision of the Seine river basin structure and functioning. For this purpose, we developed a backcasting approach integrating both scenario building and modelling approaches. Since the implemented model is only simulating the behaviour of the hydrosystem but the hypothetical rupture studied was mostly determined by socio-economic factors, we developed a new modelling method that attempts simulating the interactions between human and natural systems.

We thus simulated a scenario in which the city of Paris is significantly affected by upstream water management, and the institutional framework for water management faces a huge crisis. Simulation results' analysis led to the identification of the following watershed's behaviour:

- i. A strong resilience for the river basin: environmental issues *per se* have little influence on the socio-ecosystem's evolution.
- ii. A new illustration of the absence of significant quantitative stakes in the basin.
- iii. A confirmation that downstream water quality is mostly determined by Paris' discharge.
- iv. The identification of present institutional arrangements' potential weakness.

Limits of the proposed framework have also been identified. We will therefore pursue developing such methodological framework for modelling long term interactions between natural and social

systems, in particular through a recently initiated project on the impact of climate change on the Seine river basin.

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