ONEMA Meetings

Recap

Summary of the 29-30 June 2009 seminar, PARIS

# Climate change

## impacts on aquatic environments and consequences for management

LAURENT BASILICO, NATACHA MASSU, NIRMALA SEON-MASSIN

# Climate change, impacts on aquatic environments and consequences for management

*Summary of the 29-30 June 2009 seminar, Paris*

**Laurent Basilico, Natacha Massu, Nirmala Séon-Massin**

# Foreword


Arnaud Richard – Onema

*The "Climate change, impacts on aquatic environments and consequences for management" seminar was organised by the French National Agency for Water and Aquatic Environments (Onema) and the Management and Impacts of Climate Change programme (GICC) of the Ministry in charge of sustainable development, with the support of GIP Ecofor, on 29-30 June 2009 in Paris. It benefitted from the involvement of the French scientific council on water and aquatic environments.*

*This summary, the condensed version of it, the slides and interventions are available on line on the following websites:*
*Onema (www.onema.fr/IMG/EV/cat7a.htm)*
*GICC (www.gip-ecofor.org/gicc).*

The freshwater ecosystems of France, all along their more than 270,000 km of streams and rivers, are a priceless resource for society and the economy, teeming with remarkable ecological wealth as well as a unique cultural and human heritage. In this era of climate change, they are also increasingly an object for concern. What will the consequences of this change be on the quality and quantity of the waters in France? How will the aquatic ecosystems react to the new conditions? What do these new stakes means for the various human stakeholders in water: managers, service operators, farmers, fishermen?
The "Climate change, impacts on aquatic environments and consequences for management" seminar focussed on these issues. The seminar was co-organised by the French National Agency for Water and Aquatic Environments (Onema) and the Management and Impacts of Climate Change programme (GICC) of MEEDDM and was held in Paris on 29-30 June 2009. More than 120 scientists, experts, managers, and representatives of associations and companies attended. Based on a panorama of the available knowledge, the goal of the seminar, on a national scale, was to generate dialogue between scientists and water managers within the perspective of climate change. It then made it possible to suggest prospective elements to take the impacts of this change on aquatic environments into account from a political and economic standpoint.
The purpose of this document is to provide an overview of the data presented, the points of view that were expressed and the questions that were raised during these two days.

# Contents



# Contacts

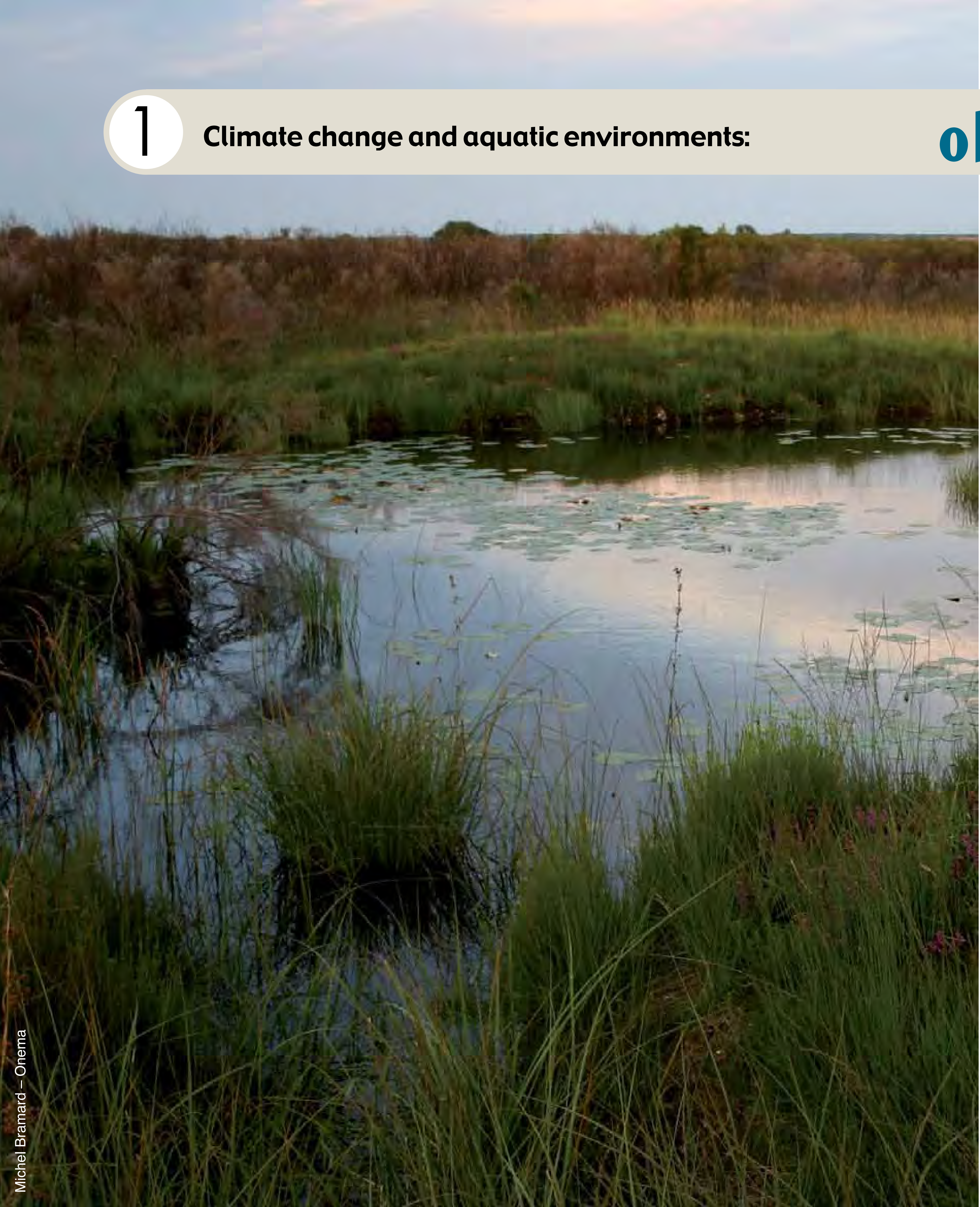

Natacha Massu
Climate change officer
GIP Ecofor
natacha.massu@gip-ecofor.org

Nirmala Séon-Massin
Global change and biodiversity officer
ONEMA
Research and development Department
nirmala.seon-massin@onema.fr

Véronique Barre
Scientific-council administrator/publications
ONEMA
Research and development Department
veronique.barre@onema.fr

Daniel Martin
Climate change officer
MEEDDM CGDD/DR/SR
daniel.martin@developpement-durablegouv.fr
Retired; please contact Maurice Imbard
maurice.imbard@developpement-durable.gouv.fr

Laurent Basilico
Journalist
lbasilico@free.fr



Michel Bramard – Onema

# 1 Climate change and aquatic environments: observed impacts and projections

The seminar in Paris on 28-29 June 2009 organised by Onema and the GICC programme (Paris Seminar 2009) opened with a session entitled “State of the situation on operational needs”, during which representatives of stakeholders in water – farmers, service operators, natural park managers – raised many questions as to the changes in their practices in the area of adaptation to climate change. This survey, covered in point 2.1 of this article, brought out expectations of a technical or socio-economic nature that are specific to each type of stakeholder. It also revealed a recurring need for scientific knowledge, which can be summarised as follows:

A clear vision concerning global changes
- ➡ climate scenarios under consideration
- ➡ models used
- ➡ associated uncertainties

Useable predictive data on the availability of water resources
- ➡ on the scale of the catchment area
- ➡ in the long term (2050, 2100) as well as on a shorter term (2020, 2030)

Knowledge on the impacts of CC on aquatic environments
- ➡ change in the distribution areas of species
- ➡ modification in the behaviour of species

Possible answers – and other issues raised – are provided in the rest of this document which summarises the scientific contributions that were presented during the seminar.

Published in 2007, the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) officially acknowledged the reality of climate change, and represented considerable progress in explaining the mechanisms that contribute to it. The report confirmed in particular that "*The warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.*" (IPCC, 2007)
It further specifies: "*Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.*" (IPCC, 2007)

**This first part** focuses on the consequences of climate change over metropolitan France, whether they have already been detected or been forecast by the models,. It presents data on their impact on the water cycle and on the hydrological network in terms of water quality, flow, temperature and seasonal variations. We will conclude with a state of the situation on the knowledge and the questions pertaining to the consequences of these changes on aquatic ecosystems, and especially on fish populations.


Hervé Jacquot – Onema

### Climate change, part of a global change

This development and the socio-economic analysis that follows have meaning only if climate change is shifted into the larger spectrum of anthropogenic pressures that aquatic ecosystems are subjected to. In just a few decades, industry and intensive farming have taken substantial volumes of water and have caused significant pollution. Accelerated urbanisation has led to an artificialisation of the river banks and a global degradation of natural environments. The globalisation of transport systems has allowed exotic and sometimes invasive species to arrive in ecosystems. The impact of these pressures on the environment is often combined with that of climate change. The latter will lead for example to conditions that are more favourable to the outbreak of certain species (furthermore, eutrophication of the environments would accelerate). Hydromorphological modifications of watercourses accentuate their warming, while the impact of pollution will be amplified by the drop in low-flow levels, through an increase in the concentration of chemical agents in the water.

Because of these multiple interactions, the primary challenge for the research conducted on adaptation to climate change is to decrease the vulnerability of the ecosystems to global change. Reciprocally, improving the adaptation capacity of environments means making concerted efforts in order to reduce local pressures. This notion of climate change as a component of a global change was largely agreed upon at the Paris Seminar 2009.



## 1.1 – What climate change?

### Climate change already observed

During the 20th century and more particularly since 1910, the average temperature of the Earth has increased by about 0.6°C. In France, the increase is of a magnitude of 1°C. In fact, the 1990s were the hottest in the 20th century with, as an average value and for the entire planet, a record for 1998. The current decade is keeping with the trend, which was already marked in Europe with an exceptional drought and heat wave in 2003, and the following years remained hot and dry. These modifications in the climate are the result of several causes, including the variation in solar activity and the increase in the atmospheric concentration in carbon dioxide and other greenhouse gases. The increase in these gases seems to be the primary reason for these climate modifications.

### Climate scenarios

Today, we know rather well what the future will hold in the next three or four decades on which it will be difficult to have any influence: the dice have been rolled for this period due to the high degree of inertia of the phenomena at play. However, much uncertainty remains for the rest of the 21st century and for later centuries. Many scenarios have been developed by the Intergovernmental Panel on Climate Change (IPCC), and two of these have received the most attention: a relatively optimistic scenario (called B2) which corresponds to a widespread and effective reduction in emissions, making it possible to slow down the increase in the atmospheric concentration of greenhouse gases and to limit the increase in the average temperature, in France, to about 3°C by 2100. A more pessimistic scenario (called A2), resulting from delayed or ineffective action of worldwide authorities, unable to avoid a tripling in the atmospheric content of carbon dioxide (compared to the beginning of the industrial era) by 2100, predicts an increase of 5°C in the average temperature in one century for France. Although this second scenario calls for alarm, the first is also of concern as it predicts an increase in the average temperature of the globe that goes beyond everything that the planet has experienced over the last 400,000 years.

### Climate models and uncertainties

These global climate scenarios are based on climate models (such as the Earth System Model developed by the Institut Pierre Simon Laplace) which attempt to model the concentrations of gases in the atmosphere and the complex phenomena that govern the climate as realistically as possible. Although these models are increasingly perfected, they however provide only an imperfect account of reality. Climate scenarios and projections therefore carry much uncertainty, and this must be taken into account in the scientific work and policies based upon them.

### *Necessary regionalisation*

Although they show the major trends, these global forecasts however are not suited for studying the consequences of these changes for aquatic environments, of which the most pertinent scale is the catchment area. Regionalising models is an indispensable step in taking the fine details of the topography into account, as topography has great influence on the local meteorology.

Several French and European research programmes have made it possible for example to develop regionalised climate models on the scale of the Mediterranean basin. This is in particular the case with three-dimensional variable mesh models developed by Météo France (Arpege) and IPSL (LMDz-Mediterranean). With an identical scenario, these models provide coherent results with the overall forecasts, while still providing much finer spatial resolution, and better rendering for extreme values in particular.

These changes toward model regionalisation, higher resolution, better consideration of influential parameters and transdisciplinarity form the current research trends. It is however foreseeable that taking these increasingly numerous and complex factors into account will not lead to a reduction in the uncertainties. A major challenge will therefore concern our ability to **define contrasted scenarios and to estimate their occurrence probability.**

## 1.2 – Consequences on hydrology

The transcription of variations on climate on the rivers, in terms of temperature or flow, is the result of a complex set of interactions. The heat exchanges between the river and the atmosphere are in particular governed by air temperature, wind, sunlight and the rate of humidity in the atmosphere. The physical characteristics of the river – depth, flow rate, topographical singularities – and anthropogenic pressures are also involved.
Selected observation data are however enough to notice a substantial change in the average temperatures in the watercourses over the last three decades. As such, the French Rhone River (Poirel, 2008) had an average temperature increase of 1 to 2°C over its entire course between 1978 and 2008. This increase is correlated with the change in air temperature. For the Meuse river, an increase in the annual average between 0.3 et 0.75°C was recorded between 1970 and 2005 (Laborelec – Univ. of Namur, 2008).
Over the middle course of the Loire River, the warming was from 1.5 to 2°C between 1977 and 2003, and was more marked in the spring and in the summer (Moatar, 2006). The heating of the river is more moderate (about 0.5°C) if the period from 1949 to 2003 is taken into consideration.

### *"Natural" temperature and local pressures*

In the case of the Loire River, a study attempted to evaluate the role of the climate on the changes in water temperature (Gosse *et al.*, 2008). It is based on comparing the change observed with that which would have occurred with the local «natural» temperature (Tnat), subjected only to the effects of the depth and of the local weather (Gras, 1970), reconstituted by deterministic models with a physical basis. This study showed that 85% of the warming observed in the summer on the middle course of the Loire River between 1980 and 2003 can be explained by the variations in the atmospheric conditions.

More generally (Gosse, Paris Seminar 2009), French rivers are at their Tnat over a good part of the year (middle-course and downstream portions of the Loire, Moselle, Saône, Seine, etc.) while others are at Tnat less frequently (the Garonne near Toulouse). For the French Rhine and Rhône rivers, Tnat occurrences are exceptional; the impact of the climate and anthropogenic pressures (planning, discharges, etc) must be taken into consideration over greater river distances.
A range of models with a physical basis makes it possible to simulate the future changes in river temperature. By applying six scenarios in which $CO_2$ emissions double (3rd assessment report of the IPCC) to the middle course of the Loire River, in a model that takes into account the effects of air temperature and precipitation, the average warming forecast is from 0.8 to 1.5°C around 2050, and can range up to +3°C for the hottest months. This result however needs to be put into perspective with regards to the limits of physical models (changes are not taken into account concerning cloud coverage, wind, humidity of the air, and the quantitative management of water resources) and with regards to the uncertainties concerning the scenario used.

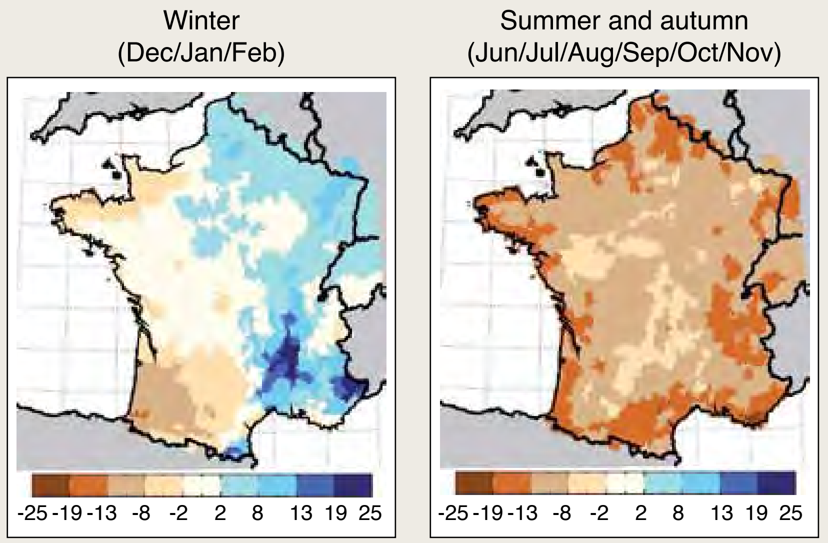
### *Flow projection: global change and special regimes*

An additional approach entails modelling the influence of climate change on river flow.

Michel Bramard – Onema

A recent thesis (Boé PhD thesis, 2007) has addressed this by using the so-called «weather type» method to regionalise the projections of 14 climate models of the 4th assessment report of the IPCC and by applying the results to a given hydrological model. This approach has made it possible to obtain detailed mapping of the changes in precipitation around 2050. Within the framework of an A1B climate scenario, marked drops in average rainfall are expected.

## Change in average precipitation

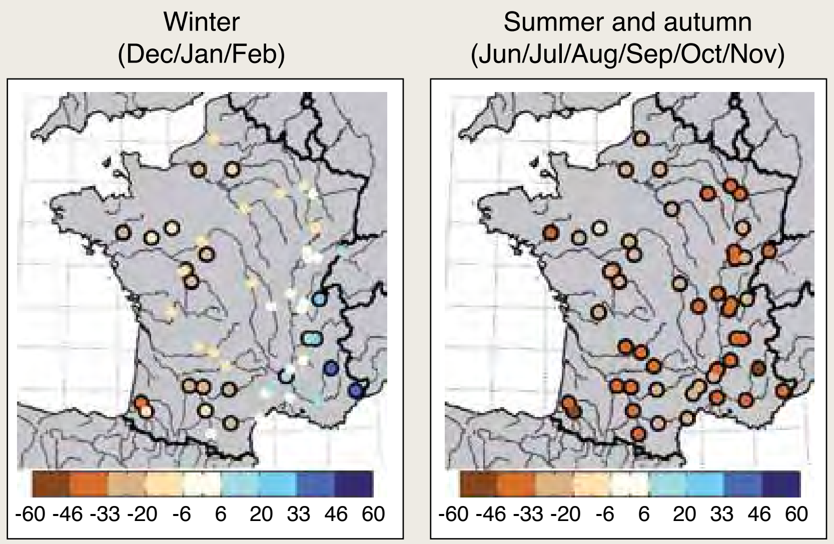



Multi-model relative change (in %), 2046/2065

Over the period 2046-2065, in summer and in autumn, precipitation levels are less than current levels everywhere, with the drop exceeding 10% in many regions.

*Source: J.Boé*

## Change in average flow rates




Multi-model relative change (in %), 2046/2065
Black points with circles: agreement of 85% of the models on the sign

The relative changes that would result on the summer and autumn average flow rates would be much higher, with the drop exceeding 30% of current values (even 50%!) for many catchment areas.

*Source: J.Boé*

Only a few Alpine rivers would have in increase in their flow in the winter. For extreme flows, simulations show rather low changes in flood flow rates, but **a general net increase in the frequency and in the severity of the low-flow periods**. These results still have the blemish of a high degree of uncertainty linked to the scenario in question and to the limits of the models used.

To take this analysis further on flow rates, it is however necessary to take into account the specifics of the various catchment areas, which for example are influenced by snow (mountain catchment areas) or by groundwater (case with the Seine River). The GICC-Rhône project has taken interest in the Alpine basins of the Durance and of the Ubaye Rivers. In every case, the results show higher winter flow rates, advanced nival floodwaters and lower summer flow rates (Ducharne, Paris Seminar 2009).

For the Seine River for example, the RExHySS project, based on ten regionalised scenarios and five hydrological models, is predicting a shift in the hydrogram first around 2050 and then around 2100, with delayed low-flow periods and floodwaters, and especially a global decrease in flow rates under the effect of the drop in annual precipitation and of the warming (Ducharne et al., 2009). In parallel, the annual recharge of groundwater, simulated by the MODCOU hydrological model according to the same scenarios, would record a 27% drop around 2050 (which is -2,200 million m3 per year), and a 33% drop around 2100. This substantial deficit – comparable to current annual sampling totals! – is by far greater than the uncertainties generated by the cascading use of several models, and moreover it ignores the foreseeable increase in the needs for irrigation.

UA study based on the changes in flow rates of six coastal rovers in Languedoc since 1965, with regards to the temperatures and precipitation recorded over the same period, provides the trends for a major portion of the


Mediterranean basin (Ludwig, Paris Seminar Paris 2009). It has in particular made it possible to confirm the beginnings of a drop in the flow, in response to the observed increase in temperatures in the spring and summer. The European project SESAME

(Ludwig, Paris Seminar 2009), based on a retrospective and prospective modelling of river inflows into the Mediterranean and the Black Sea, and based on four socio-economic scenarios of the Millennium Ecosystem Assessment, is also predicting a decrease in river inflows into the Mediterranean, even for the most optimistic scenarios, as well as an aggravation of the climate and anthropogenic pressures on water resources.

Generally, all recent research **indicate robust trends pertaining to the drop in low-flow periods and in piezometric** levels, and with regards to the reduction in the stocks of snow and ice – and of their buffer effect. A very likely increase in the risk of a summer default is therefore expected, and this can reach as far as breaking the continuity is certain watercourses.

Other changes – intense flooding in the Mediterranean regions, drop in flood flow rates in northern France – are also possible, but these hypotheses do not seem to be as robust due to the high degree of uncertainty with the projections concerning precipitation.

## 1.3 – Aquatic environments: impacts and adaptation

In addition to the changes in flow and temperature observed over the last few decades in the hydrological network in France, modifications concerning the operation of aquatic ecosystems can already be seen. According to the National French Fishing Federation (Breton, Paris Seminar 2009), strong development in the populations of certain fish (barb, nose fish, chub, dace), has been observed on the Seine downstream from Paris, to the detriment of other species such as bream and roach. Another example: recruitments of eels and shad have been showing an alarming regression for several years now. As such, in the case of shad populations in France, the annual restocking, which had increased from a few tens of thousands of individuals to several hundreds of thousands thanks to the efforts for protecting the species, fell sharply during the heat wave in 2003 and since then have stabilised to just a few thousand individuals every year (Monnier, Paris Seminar 2009). In parallel, an acceleration in the arrival and expansion of new species in the waters of France is observed. As such, in just 30 years, the sheatfish has settled in almost all of the watercourses in metropolitan France. The asp was reported for the first time in the Rhine River in 1988 and is now captured on a regular basis in the Moselle River and its tributaries. In 2007, the tubenose goby (*Protherorhinus semilunaris*), the Chinese mitten crab (*Eriocheir sinensis*) and the Red swamp crayfish (*Procambarus clarkii*) have been observed for the first time in the rivers of north-eastern France (Monnier, Paris Seminar 2009).

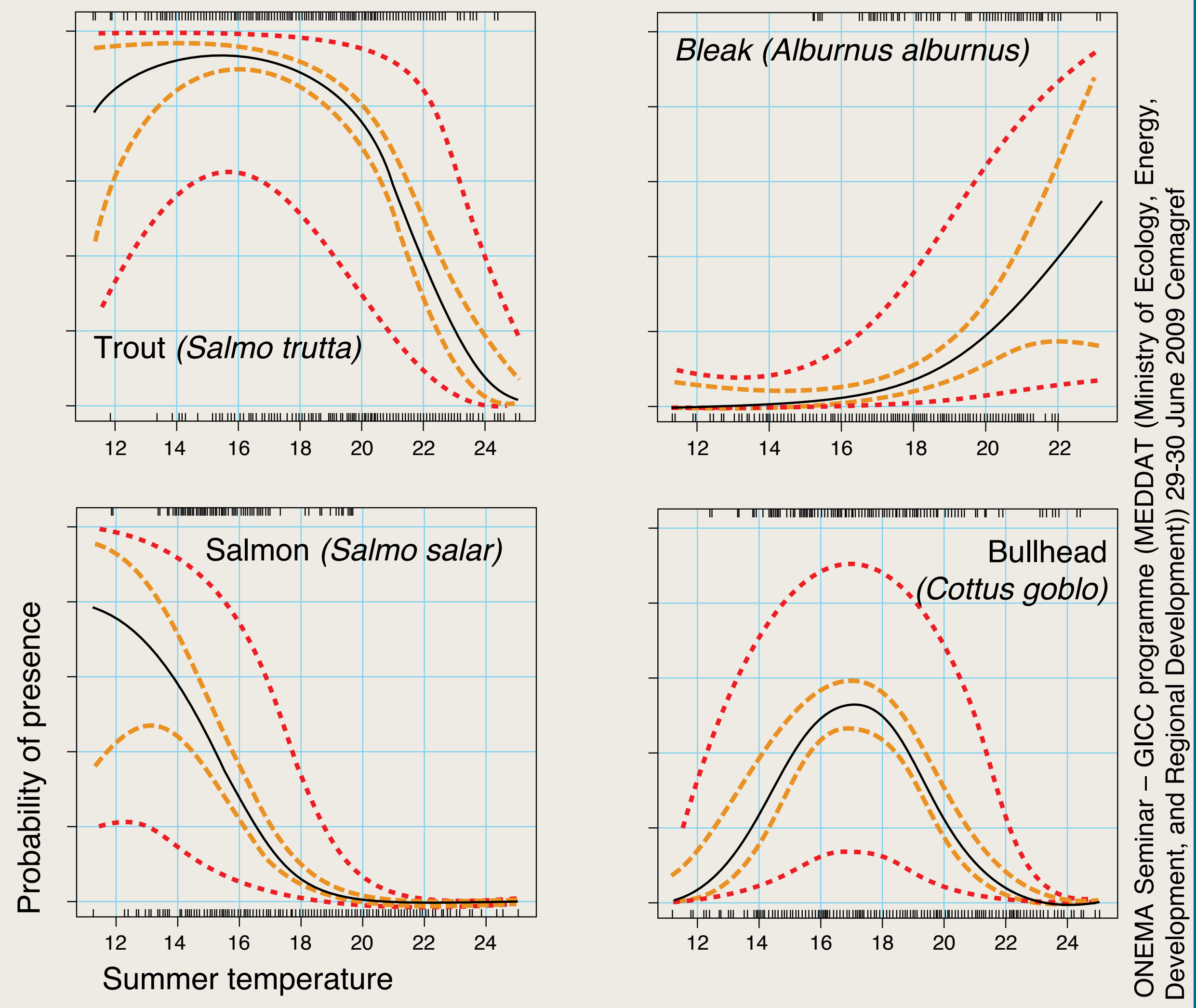


These changes cannot of course be imputed directly to climate change alone. The arrival of new species can be explained by the development of inland waterways (Rhine-Danube canal, for example) or through voluntary or accidental introductions. The regression in migratory species is to be linked to overfishing (eels), modification of watercourses and water quality. Climate change in fact is only just one of the elements of a global change.

### Temperature and distribution areas of species

It is acknowledged that the temperature of the water is one of the determinant factors in distribution areas for aquatic fauna and flora, especially fish.

**GLM models – Marginal profiles**




The marginal profiles of the probability of presence, for each species, according to the summer temperatures (Pont, Paris Seminar 2009) constitute a robust analysis tool.

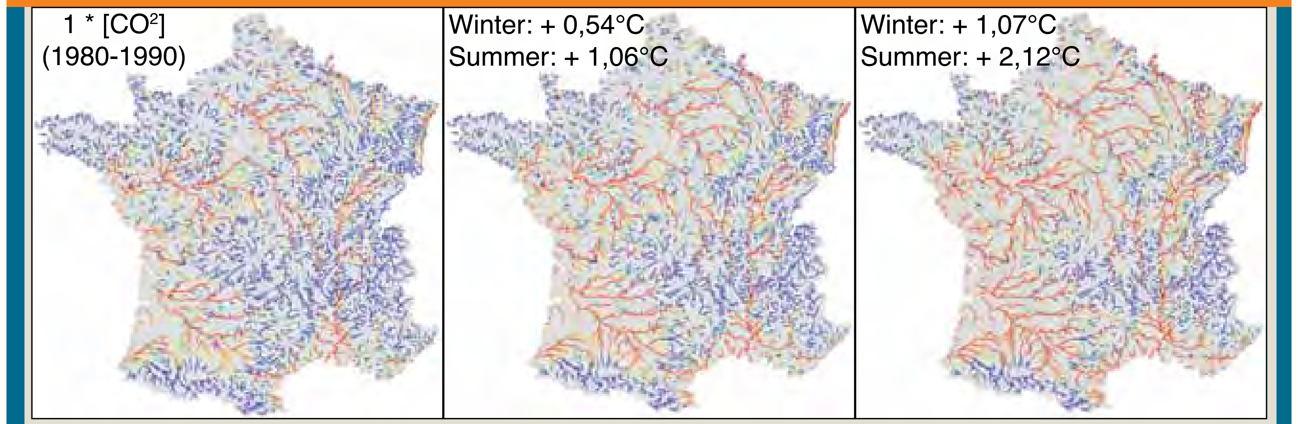
Didier Pont, ONEMA Seminar – GICC programme (MEDDAT (Ministry of Ecology, Energy, Sustainable Development, and Regional Development)) 29-30 June 2009 Cemagref

In a context of climate change marked by global warming, the consequences could be particularly marked in the case of cryophilic species (Atlantic salmon, smelt, Arctic char) or oligothermal thermophile species (common trout in particular).

There are three types of biological responses to global change (Pont, Paris Seminar 2009): avoidance, which in particular results in modifications of the distribution area, adaptation, i.e. a change toward a stronger «tolerance», and biotic interactions, of which the density-dependent regulation mechanisms are an example. As such, the data available on the bullhead (Cottus gobio), a freshwater and territorial fish, with density-dependent regulation, show that an increase of 2 to 3°C in the temperature of the water would have many consequences on the biology of this species, participating in both adaptation and biotic interactions: increase in fertility and juvenile growth, early sexual maturity, slowdown on the growth of adults and decrease in longevity (from 7 to 5 years).

Changes in distribution areas were tackled by a predictive study over a large area within the framework of the Management and Impacts of Climate Change programme. Using correlative bioclimatic models, based on climate projections with Météo France ARPEGE global circulation model, the changes in the probabilities of presence of various fish species throughout the entire hydrological network in France were simulated. In the case of bullhead for example, for a forced global warming of +0.54°C in the winter and +1.06°C in the summer, then +1.07°C in the winter and +2.12°C in the summer, potential losses of habitat are expected to reach respectively 37% and 77%.

**Predictions for the entire French network (~ 65,000 km, 8,467 sections) *Salmo Trutta***




Presence: 49 900 km | Potential loss of habitat: 16% | Potential loss of habitat: 33%

Probability of presence

0 | 0,2 | 0,4 | 0,6 | 0,8 | 1

**CEM-type model (Climate Envelope Models)**
Climate projections : ARPEGE model (Météo-France)
Pont et al. 2006. MEEDDAT-GICC IFB

In the case of trout *(Salmo trutta)*, with the same hypotheses, these rates of loss are respectively at 16% and 33% - once again, to the nearest uncertainty (Pont, Paris Seminar 2009).

*Source: D. Pont*



Arnaud Richard – Onema

Fish are not the only aquatic organisms for which the geographical distribution is likely to change under the influence of climate change. Some cyanobacteria that synthesise toxins such as *Cylindrospermopsis raciborskii* for example have had their geographical distribution area change recently, especially under the influence of climate change (Gugger *et al*., 2005).

Likewise, some species of tropical diatoms (*Hydrosera triquetra* and *Diadesmis confervacea* for example) have been present on a permanent basis for a few years now in most of the rivers in the south of France. Contrary to cyanobacteria which can secrete toxins, no particular negative effect associated with the presence of these diatoms has been identified to date (Coste, 2006).

Moreover, the increase in the summer temperatures of aquatic environments makes it more likely for the appearance of cytobacteria blooms, due to its effect on the physiology of these organisms as well as on the stratification of reservoirs. Effects on other pathogenic organisms cannot be excluded (De Toni *et al*., 2009). With regards to macrophytes, the increase in the temperature of the water would also play a positive role on the expansion of proliferating species such as water primroses (*Ludwigia peploides, Ludwigia grandiflora*).

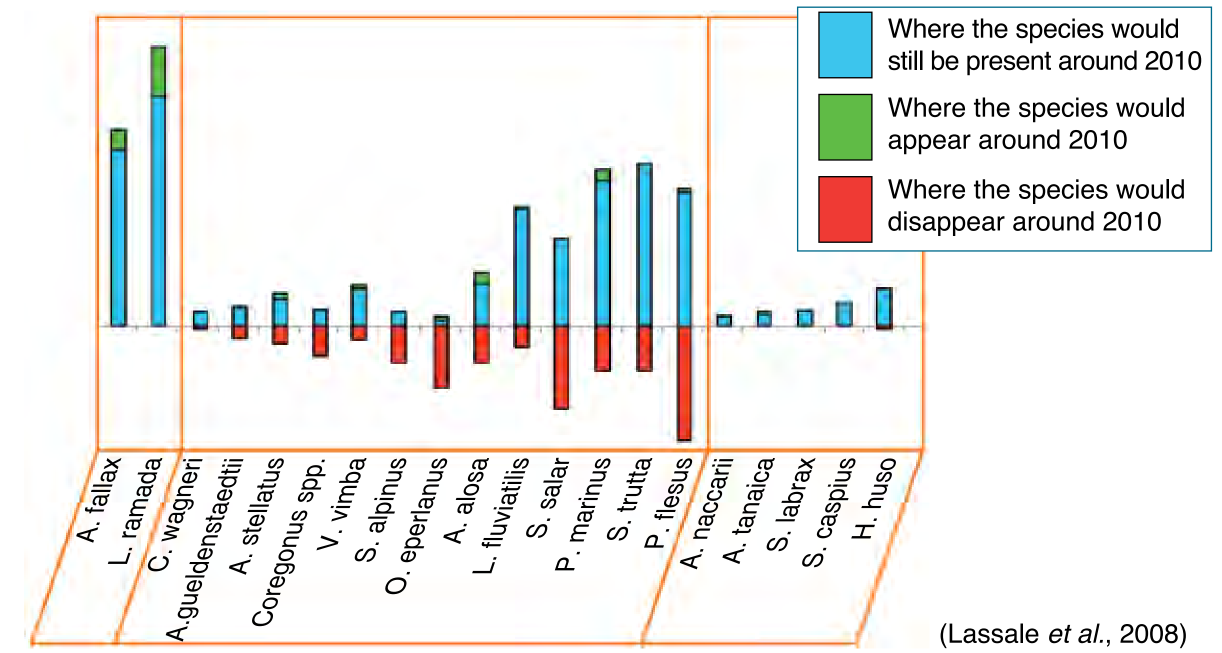
## Concerns for migratory species

The case of migratory fish has given rise to much literature. Often considered a heritage (eel, shad, lamprey, Atlantic salmon), for some of major economic importance (sturgeon), these travellers are cumulating worrisome signals, such as a reduction in the abundance (Johnson *et al*., 1999), or a contraction of the distribution areas (de Groot, 1992, 2002), despite specific protection measures.
A robust predictive approach (Rochard, Paris Seminar 2009) consists, based on the distribution

areas that existed at the beginning of the 20th century and in present times, in building distribution models (presence-absence, abundance classes) that take into account the characteristics of the catchment areas. The change in these geographical areas can then be projected according to various climate change scenarios. This method was used for 22 diadromous migratory species, of which 11 are present in France (eel, Atlantic salmon, sea trout, allis shad, twaite shad, sturgeon, sea and river lamprey, mullet, European flounder, smelt), with a wide scope of study encompassing 196 catchment areas in Europe, Northern Africa and the Near East (Lassalle, 2008) – *see diagram below.*

For Atlantic salmon, a comparison of the projections obtained with the four A1, A2, B1, B2 scenarios show rather clear disparities, scenarios B1 and B2, which are the most optimistic, are, not surprisingly, those with the lesser impact. However, the four scenarios predict the disappearance of salmon in the Iberian Peninsula, the catchment areas of the Baltics and, to various extents, in certain basins in south-western and western France. Finally, individual-based modelling methods, which incorporate demography and genetics, open a promising outlook for studying adaptation strategies of fish (Piou, Paris Seminar 2009). Currently under development, they could contribute to understanding the influences of climate change on the lifecycle of salmon.

### Using presence-absence models




(Lassale *et al.*, 2008)

Under the A2 scenario, net contractions in the distribution areas are predicted around 2100 for 14 of the species and a few gains (e.g. the arrival of the twaite shad in Icelandic rivers).



## *Exotic species and biodiversity: the debate is still open*

In parallel to the modifications in behaviour and in the distribution areas of autochthonous species, the arrival of so-called exotic species is accelerating rapidly: approximately ten species of naturalised allochtonous fish were numbered in 1950, there are now 23 in the freshwaters of metropolitan France, for 46 autochthonous species (Lévêque, Paris Seminar 2009). These introductions can be intentional (recreational fishing, food resource, aquaculture) or accidental («escaped» species, ballast tanks of ships, etc.). Their acceleration can be explained by the globalisation of world trade and advances with new navigable waterways, which provide many points of passage between catchment areas.

This change can form an additional factor in the **imbalance of aquatic environments**, with the proliferation of some species – e.g. the well-known cases of the zebra mussel (*Dreissena polymorpha*) and the pumpkinseed (*Lepomis gibbosus*), considered to be injurious in France.

This perception of exotic species as potentially injurious should however be nuanced by recalling that after the glaciations (20,000 B.C.) the restocking of the waters in Western Europe took place, step by step, via the Ponto-Caspian refuge (Lévêque, Paris Seminar 2009). The recent arrivals in our waters of fish such as the walleye, catfish, asp or Danube bream can therefore be viewed as an extension of this natural mechanism, facilitated by human activities. As for the genuine exotic species (originating from another continent), their presence in the environment is still often anecdotic.

In the end, the modification of ecosystems by anthropogenic pressures is often the source of an embrittlement of autochthonous populations. These new ecological conditions are in addition favourable to the installation of exotic species without there necessarily being competition amongst the species.

## *Other interrogations*

In addition to the various aspects addressed during the Paris Seminar 2009, other issues should be brought forward concerning the proven or potential impacts of climate change on aquatic environments. This includes in particular potential interactions between climate change and the presence and the effects of **contaminants** in aquatic environments.

As has been mentioned previously, a modification in the hydrological regime will most likely be accompanied by changes in the exposure patterns to the toxic substances, by inducing for example an elevation in the concentration of the various contaminants during periods of low water due to a lesser dilution. In the event where the stress associated with a toxic substance would be added to the stress induced by the climate change, an exacerbation of the effects of the toxic substance could occur. Various laboratory studies on aquatic species have shown that, in general, sensitivity to toxic substances was higher for individuals placed in environmental

conditions that are close to their thermal tolerance threshold. Reciprocally, exposure to a toxic substance can reduce the tolerance interval of exposed organisms with regards to changes in their environment under the constraint of climate change.
Many hypotheses, sometimes contradictory, can be considered when evaluating the possible interactions (synergy, antagonism or additivity) between the increase in water temperature, such as predicted by the climate models, and the future and effects of toxic substances: acceleration in the (bio)degradation of organic molecules, higher toxicity for cold water stenothermal species, compensation of individual toxic effects on the populations through an increase in reproduction, growth or density, etc. Although the aggravating effects of an increase in temperature on the acute toxicity of various toxic substances in aquatic organisms and the associated mechanisms are relatively well known pertaining to the individual, the consequences of the interaction between an increase in temperature and the effects of toxic substances is not very well known at the population, community and ecosystem levels. Finally, outside of the aspects concerning the quantity of water and temperature, other effects associated with the increase in the atmospheric concentration of greenhouse gases on the dynamics of toxic substances in the environment and their effects cannot be excluded, in particular concerning the coastline environments (effect of water pH modifications on the dynamics of toxic substances and their impact, for example). □


Michel Bramard – Onema

In what was developed above, a panorama was compiled of the current knowledge on climate change and on the models used to assess its expected consequences on the freshwaters of France and their ecosystems, based on contributions to the Paris Seminar 2009. Here, the reader will have found a certain amount of well-established data, global trends, predictive ranges and magnitudes, as well as many remaining interrogations.
To the uncertainty that intrinsically characterises the socio-economic scenarios of greenhouse gas emissions is added, at each step of the analysis (global climate modelling, regionalisation, combining with hydrological models, combining with biological models, etc.) the uncertainties that are intrinsic to each model and to the incomplete nature of the observation data.
These recent scientific developments do however make it possible to affirm that climate change will have a significant impact on the water resources in France, resulting in an increase in global temperatures and a modification of the annual hydrograms characterised in most cases by a drop in the annual average flow and more specifically a net increase in the frequency and severity of summer low-flow periods. These changes will undoubtedly have consequences on aquatic environments, which will result in modifications that are sometimes major in the biology and distribution areas of species. The gravity of the expected impacts appears however to be highly dependent on greenhouse gas emissions scenarios, and more generally on the change, in the short and medium term, in anthropogenic pressures.

# in the era of climate change

Michel Bramard – Onema

Rich with a remarkable yet vulnerable biodiversity, aquatic environments also form a cultural, historical and touristic heritage as well as a vital resource for many human activities and needs. The total quantity of water taken in France was 32.6 billion m3 in 2006, among which 5.75 billion are consumed and do not return to the natural environment (Ministry in charge of sustainable development, 2007). This consumption can be attributed as follows: 49% for irrigation, 24% for drinking water, 23% for the production of energy and 4% for industry (excluding energy). The current socio-economic changes (demographic growth, improvement in the quality of life and land use modifications) should **lead to an overall increase in these takings**.

In order to understand and predict the impacts of climate change on aquatic environments, it is therefore necessary to analyse how it translates for each of the societal uses of water, which contribute to the local pressures on the ecosystems. Reciprocally, the consequences of global change on water resources, in terms of quantity and quality, will influence the practices and the strategies of the various human activities they sustain.

## 2.1 – A single resource, multiple needs

Entitled «State of the situation on operational needs», the opening session of the Paris Seminar 2009 made it possible for stakeholders to speak in **turn: farmers, service operators, managers of natural parks, fishermen, water agencies, associations**. This discussion, as well as the answers that were obtained from a questionnaire that was widely distributed beforehand to the stakeholders in the field, provided a preliminary inventory of the issues and needs that are specific to each type of stakeholder with the perspective of adaptation to climate change. Among these issues, the need for projections on the availability and the quality of the resource was prominent among the various parties. These questions were at least partly addressed by the various scientific statements of which a summary is provided in section 1 of this document. As to the issues that are specific to each use for water, they are calling for additional knowledge and a specific strategic response, which shall be detailed in this part.

### *Farming sector: from irrigated surface management to managing consumed volumes*

Among the changes in the climate observed, the increase in the frequency of droughts calls for concern as this is a particularly sensitive issue for the farming sector, which represents nearly half of the share of water consumed on a national level. Between 1976 and 2005, 13 spells of drought affecting a region of France have been listed, which is twice as frequent compared to the first half of the 20th century (Itier, 2008). The heat wave in 2003 represented a cost of 590 million euros for the nation. The climate projections for the upcoming decades, characterised by an increase in temperature and in the frequency of extreme events, with increased seasonal and regional (North/South) disparities, foretell a reduced availability of water resources as well as changes in precipitation distribution.

The impacts should be contrasted on the prairies and with large-scale farming (Kristell Astier-Cohu, Ministry of agriculture and fishing, Paris Seminar 2009). We can expect enhanced vulnerability for sectors such as arboriculture and vineyards, with possible changes in the production areas, as well as an increase in the risk of fodder shortage.

Finally and above all, the need of water for irrigation – especially for crops in the summer – should increase significantly under the effect of the increase in temperatures. Indeed, according to the «STICS» crop model under scenario A2, with the current irrigated surfaces and rotations, the irrigation needs in the Beauce region could increase by 60% by 2100 – this figure however is still to be regarded with a high degree of uncertainty (Ducharne, Paris Seminar 2009).

In order to adapt to a lesser availability of water resources, management of **consumed volumes will have to make irrigation a priority**. This necessity is already present within the framework of LEMA (Law on water and aquatic environments; see section 3.1), which defines the regulatory tools for the WARA (Water Attribution Regulation Areas). The measures call in particular for global management for all of the uses of water, the definition of withdrawal allowances and the collective organisation of all of the irrigators. The implementation for these tools remains however **penalised today by the lack of predictive data on the availability of the resource and the capacities for storing water on the scale of the catchment area** – this ties in with the already-mentioned need for regionalised models. The issue of the **prospective horizon** is also raised: most of the models focus on the trends for 2050 or 2100, yet the farming sector is looking for operational responses in the short term (2020 or 2030), in order to evaluate for example the change in withdrawal allowances in each WARA or anticipate the appearance of new WARA.


Michel Bramard – Onema

The second axis of adaptation of the sector is the reduction in its water needs. This could be done by favouring early varieties and those with a short cycle, or by reducing the aerial growth to the benefit of underground growth. From an agronomic standpoint, it seems necessary to rethink the technical itineraries in order to optimise the use of water and diversify the crops, especially by combining irrigated and non-irrigated crops, with a dual objective of both ecological interest and farmer protection. These measures require **an intensification in farming research** as well as the development of tools of accompaniment, guidance and training for a sustainable adaptation of farming practices.

Madeleine Carrouée – Onema

Finally, new needs are appearing in terms of **tools for assisting public decisions** in order to evaluate the socio-economic impacts of these alternatives, which involve a change in sector organisation and the development of new markets.

### *Service operators: water efficiency and funding method*

When a rarefaction of the resource is expected, a fundamental need such as the supply in drinking water for the population is a priority societal challenge. With about 24% of the share of the water consumed in France, it represents in quantity the second use of water after farming. Currently, the country has a relatively favourable situation for its supply of drinking water. Since 1976, many projects entailing interconnection or securing access to the resource have been carried out. Since 1987 in France, over 5.3 billion euros have been invested on «long-term imbalances» (260 million/year), of which 30% were funded by the water agencies (Impacts of climate change, adaptation and associated costs, DGEC-MEEDM 2009).

The projections nevertheless raise many questions for the upcoming decades. Climate change will result in more frequent shortages, even if there is no increase in demand. The degradation of the quality of the resource, accentuated by climate change (the increase in the temperature of the water could lead to the development of cyanobacteria, for example), would further reduce the freshwater supply that can be used for household purposes and would increase purification costs.

For service operators (Jaskulké, Paris Seminar 2009), the first necessity unsurprisingly is to have reliable and operational data available on the consequences of warming on the water cycle, i.e. having fine enough spatial resolution and based on scenarios that can be read in the middle and long term, but also in the short term.

It is based on these projections that the operator can effectively decide what measures to adopt in order to control water flows and gain in **water efficiency**. In this scope, it will be necessary to continue and intensify the actions initiated in searching for leaks and interconnection, and optimise the use of water for energy production. In certain local conditions of strong hydric stress, the supply in water would also result in balancing traditional resources (surface water and groundwater) with the interest in developing alternative resources (reusing or recycling wastewater at a suitable level, of rainwater, aquifer reloading, desalination, etc.).

These perspectives, which could result in conflicts of use and territorial planning, also raise the question of the funding **method for services and water efficiency**. It then appears desirable to consider incorporating the **value of water into the gross domestic product** (Jaskulké, Paris Seminar 2009).

More globally, making a decision would involve a prioritisation of **the socio-economic risks**, between a shortage of water, energy, risk of climatic unknowns, threats on biodiversity, etc. Reflection on these issues is only now emerging (Jaskulké, Paris Seminar 2009).

### *Managers: the example of the Regional Natural Park of Camargue*

The approach initiated by the Regional Natural Park of Camargue provides a representative overview of the issues raised by managers of natural parks with an important aquatic dimension. Delimited by the Rhône River delta, this 121,300 hectare territory of which 86,300 is highly anthropized land is highly dependent on planning and management actions and shelters a remarkable biodiversity.
In addition to the changes observed on the temperature of the Rhône River (see section 1.2), the delta is confronted with the rise in the sea level, at an average rate of 2 mm a year. These changes, combined with the other local anthropogenic pressures, cause modifications in determinant parameters such as salinity or water level (Stéphane Marche, RNP of Camargue, Paris Seminar 2009). These phenomena result in the disappearance of habitats (dunes and backshore dunes). In parallel, new species (sacred ibis, purple swamphen) are appearing and changes in the behaviour of other species have been observed. As such, the flamingo seems to be increasingly present in the winter, which foreshadows a conflict with the rice growing sector, on which this species exerts substantial withdrawals.
This contexts leads (Marche, Paris Seminar 2009) to a rupture in the consensuses that historically existed between the various human stakeholders in the territory (farmers, fishermen, park managers). Consequently, the Park has initiated a strategic approach stemming from the local stakeholders: the 2011-2023 Charter, with the objective of incorporating climate change into a shared project for the territory.

The key factors for success in this approach, which can be generalised to other projects carried out elsewhere in France, are first based on a better identification and understanding of the phenomena at work, which implies having **available sustainable monitoring networks and regular exchanges with the world of research**. In order to be carried out, projects will have to be validated technically and politically, and provided with administrative and financial means. They must also make use of regular sharing of the diagnostic with the local stakeholders.

### *Fishermen: first-hand witnesses*

AAs stakeholders in water who are particular sensitive to the changes in hydrology and aquatic biodiversity, fishermen are first-hand witnesses of the effects of global change and often act as those who sound the alarm. The National French Fishing Federation (FNPF) is reporting (Bernard Breton, Paris Seminar 2009) modifications observed in the distribution areas of fish (see section 1.3) and increasingly severe low-flow periods, which require saving fish populations manually on a regular basis. The Federation shares the concerns expressed concerning the future of species with a reduced thermal spectrum (trout) and migratory species, as well as the change in time in exotic or prolific species – the cormorant is as such perceived as particularly injurious due to the substantial predation that it exerts on fish populations.
The question as to the beneficial or harmful nature of the **genetic mixing** caused by restocking allochthonous strains of fish (which cause a potential loss in biodiversity by «degenerating» the autochthonous strains), has long since fuelled a heated debate but comes up against **a persistent lack in solid scientific studies**.

From a regulatory standpoint, there is **difficulty observed in implementing the national texts**, due to limited control means and the subsistence of many special local situations – regulations in low-flow periods, for example.
Finally, the Federation is deploring a change in fishing practices deemed to be disastrous, with systematically releasing caught fish, substituting for real fish management.

**Needs expressed by stakeholders in water**

| Representative | Farming | Service operators | Regional natural parks | Fishermen |
|---|---|---|---|---|
| **Scientific knowledge** | • Reliable scenarios on the scale of the catchment area<br>• Prospective horizon 2020 - 2030<br>• Targeted research in agronomics | • Fine resolution flow predictions<br>• Prospective horizon 2020 - 2030 | • Understanding of the phenomena at work<br>• Change in the distribution areas and in the behaviour of species | • Change in the distribution areas and in the behaviour of fish species<br>• Impact of genetic mixing |
| **Technical needs** | • Data on the appearance of Water Attribution regulation areas (WARA) or the evolution in withdrawal allowances | • Development of alternative resources of water (recovering rainwater, etc.)<br>• Optimising the use of water for energy production | • Regular exchanges with researchers<br>• Sustainable monitoring networks | • Harmonised legislation |
| **Organisation** | • Support tools for farmers<br>• Advice and training | | • Integration of climate change into a territorial charter | |
| **Economic financing** | | • Method of financing for services and of water efficiency | • Economic and financial means | |
| **Socio-politics** | • Public decision-making tools<br>• Public awareness | • Incorporating the value of water into GDP<br>• Prioritising societal risks<br>• Public awareness | | |

## 2.2 – Aquatic environments, uses of water and society

Incomplete by nature, these responses from stakeholders in water form the basis of dialogue which should be continued further for each of the stakeholders. This however made it possible to show that all of the types of stakeholders in water, each observing climate change through their own viewing angles, have initiated an approach to adaptation, which allows a large number of needs and new questions to surface. The latter need two types of answers: scientific and technical on the one hand, and socio-economic on the other hand.
Among the needs for scientific knowledge is of course the concern for the pertinence of the scenarios used and the need for predictions that can be used in the short term, on a local level – change in the withdrawal and storage capacities for irrigation for example. This need entails supplementing the observation data by developing monitoring networks in particular. The Rhône-Mediterranean and Corsica water agency (Pelte, Paris Seminar 2009) also pinpoints the need to invest in data, and is calling for the creation of a national observatory.

Needs for specific knowledge are more over expressed: targeting research in farming, studies on the impact of genetic mixing, projections on the impact of flamingo wintering on rice growing, etc.
Questions of a socio-economic nature reflect three types of needs: a need for organisation, a need in terms of means and funding, a need to increase population awareness.

One observation that is shared by the various stakeholders and observers is that of the risk of the occurrence or aggravation of **conflict in water usage**, in the context of increased needs and lesser availability of the resource. A prioritisation of the socio-economic risks – shortage of water or energy, risk of climatic hazards, threats on biodiversity, etc is required (Jaskulké, Paris Seminar 2009). Conflicts could arise between the various uses of water on a global level (irrigation or the supply of drinking water) or in a local context (farmers and fishermen in Camargue).

In any case, the arbitrage generated in resolving these conflicts will have to address the concern for **preserving the ecosystems**. A thorough report from the Strategic Analysis Centre (CAS, April 2009), which focussed on an «Economic approach of biodiversity and services linked to the ecosystems», is geared on having this necessity taken into account from an economic standpoint. It recalls in particular (p. 36): «*The biodiversity and the ecosystems within which it expresses itself provide a large number of goods and services which support human life*».
In line with the conclusions of the *Millennium Ecosystem Assessment* of 2005, it distinguishes three types of services procured by ecosystems: withdrawal services (food, water, resources, etc.), regulation services (of the climate, of diseases, etc.), and cultural services (pedagogy, tourism, recreational fishing, etc.).

In this context of an increased risk of usage conflicts, preserving the aquatic environments appears to be the first condition for the quality of the available resource. The awareness of this imperative by stakeholders in the field and, beyond that, by the general public, forms a major stake in preparing a change in societal practices: change in farming production, economical attitude with regards to water and energy consumption, responsible practices in tourism and recreational fishing. This challenge in terms of awareness results in an increasing **need for dialogue between the scientific world and society** with the goal of breaking down the walls that close off knowledge and to objectively assess how the risk is perceived collectively. Information and scientific dissemination are already a part of the mission of organisations such as Onema and the Water agencies. Genuine problems in appropriating knowledge by the general public however continue to exist nationally, as shown by the very low return rate (1%) concerning the consultation for the Water Framework Directive (WFD). It therefore appears necessary to understand (Henri Décamps, member of the Academy of Sciences, Paris Seminar 2009), through the prism of human and social sciences, the mechanisms for this appropriation. □

Madeleine Carrouée – Onema

# 3 Which management strategies for adaptation?


Hervé Jacquot – Onema

Since the Earth Summit organised in Rio de Janeiro in 1992, followed by the summit on sustainable development in Johannesburg in 2002, biodiversity has imposed itself as an increasing concern for the international community which has manifested itself through the Convention on Biological Diversity. This concern resulted in 1995, on a European scale, with the defining of the Pan-European Biological and Landscape Diversity Strategy (updated in 2006), and in France with the French Strategy for Biodiversity (2004) and the Grenelle de l'Environnement (French Environmental forum) of 2007.

Moreover, several major laws have set down the basics for the water management system in France. The French Water Act of 1964, which initiated an approach via geographical catchment areas, is also at the origin of a decentralised institutional organisation with the creation of **water agencies**. The French Water Act of 1992, which defines water as a common heritage of the nation, rekindles decentralised planning by the setting up of two management tools: SDAGE (Water Management and Development Master Plan, RBMPs) for each major hydrographic basin, which can be broken down at the local level through the SAGE (Water Management and Development Schemes).
At the European scale, the European Water Framework Directive (WFD) of 23 October 2000 instituted the principles for a European water policy, getting its inspiration in particular from the French hydrographic basin approach. It was transposed into French legislation by the Law of 21 April 2004, which plans among other things a revision of the SDAGE.

In 2009, the European Commission published a white paper on adaptation to climate change, exposing the measures that are needed to reinforce the resilience ability of the Union facing climate change.

Taking into account the impact of climate change on water and introducing adaptation did not however occur in France until the Law on Water and Aquatic Environments (LEMA) of 30 December 2006.

After focusing on some of the existing systems (WFD and LEMA, Green and Blue Network project), this third part concentrated on providing prospective elements for a better inclusion in public policies of the impacts of climate change on aquatic environments, of adaptation and of the associated costs, based on contributions from the Paris Seminar 2009. It closes on a return to the scientific domain, attempting to provide recommendations for a science policy aimed at assisting decision-making.

## 3.1 – Existing systems

Called to play a strategic role and lay the bases for water policy, the WFD defines a framework for managing and protecting water by major hydrographic basin on a European scale. It sets ambitious goals for preserving and restoring the status of surface (freshwaters and coastal waters) and groundwater.
In particular, it calls for ensuring the non-degradation of water quality and **to reach, by 2015, good status** for groundwater as well as for surface water, including coastal waters. An adapted objective (good ecological potential) has furthermore been retained for artificial or highly-modified water bodies, in particular due to economic activities. Taking the impacts of climate change into account however is not provided for in any way in the current version of the WFD. This is the case, on the contrary, within the framework of the **Law on water and aquatic environments** (LEMA), which responds to a triple ambition: set up the tools needed to reach the objectives of the WFD, improve the public service for water and treatment within the scope of access to water for all, and finally modernise the organisation of freshwater fishing. The result of several years of preparation and containing 102 articles, it strongly confirms the desire to protect aquatic environments and their biodiversity. It results in **a revamping of governance for water** by instituting, in particular, the creation of ONEMA and of the FNPF (National French Fishing Federation).

The WFD institutes several major principles, among which:

- **Management via catchment areas**, on the French model, by ensuring coherency of the delimitations for international river basins.
- **An economic analysis**: the directive calls for assessing the methods for water pricing and the application of the principle of recovering the costs of water services, including environmental costs, in light of the application of the “polluter pays” principle.
- **Consultation of the public**: In the desire for transparency, the directive calls for ensuring active participation of the stakeholders in water and of the public in developing the management plans, by planning consultations of the public in particular.

### *Green and blue network: a major project for the ecological continuity in France*

The concept of a green network has existed in France since the 1980s, designating a set of networks of green areas that are more or less connected, often structured around walking or hiking paths. It has taken a real ecological leap with the Grenelle I and II laws, which provide for the creation of a Green and Blue Network by the end of 2012 over the French territory.
Taking into account the observation that natural environment is fragmented in metropolitan France due to anthropisation (land use planning, transport network), the project’s end goal is to preserve and restore ecological continuity. This ambition can be broken down into several objectives:

- Identify and connect the areas that are important in **preserving the biodiversity** via ecological corridors;
- Reach or maintain the good ecological status or the good potential of surface waters;
- Take the biology of migratory species into account;
- Facilitate the genetic exchanges that are needed for the survival of wild species;
- Improve the quality and the diversity of landscapes;
- Allow for the displacement of distribution areas of wild species and natural habitats within the **context of climate change**.

This as such forms an operational tool that participates in implementing the provisions of WFD and LEMA concerning the protection of natural environments.

The Green and Blue Network project is based on the complementarity between a green component, comprised of areas under permanent environmental coverage connected by ecological corridors, and a blue component comprised of watercourses, canals and wetlands that are important in protecting biodiversity. In the context of climate change, the development of the project aims to **favour the adaptation of species** (Salles, Paris Seminar 2009), in particular by preparing a spatial reorganisation of their distribution areas, while still maintaining the diversity and the balance of the ecosystems, which will then show increased resilience.
Transposing the project to the field is based on the principle of co-construction between the projects of the local authorities, regional plans for ecological coherency developed in a logic of participatory democracy, and finally with national orientations. This method of concerted development satisfies the **will to closely associate the stakeholders in the territory** (expressed in section 2.2) in the decision on the adaptation to climate change, and comprises as such a means for **increasing public awareness**. In the same scope, the Green and Blue Network operational committee, which met at the end of 2009, will in particular have the mission of communicating and informing, in liaison with other strategies carried out in France, such as the «nature in town» plan.

## 3.2 – Moving toward taking climate change into account in water public policies

On a European scale (Davy, Paris Seminar 2009), taking the impacts of climate change into account in water management has completed a first key step with the creation of a working group in charge of producing **a guide «WFD and climate change»**, submitted for approval to the European water directors in November 20091.

Using the work of existing groups – in particular on the topics of drought, flooding and ecological status – in order to specify the impacts of climate change on the WFD, the working group is striving to anticipate the changes on the scale of water bodies; understand the importance and the causes of the change on the reference sites; evaluate the direct and indirect influences of climate change on the pressures; specify **the changes in the reference state and in the associated bioindicators**, and finally organise monitoring for zones identified as the most sensitive to climate change. For each of these objectives, the guide suggests **guideline principles intended for river basin managers**.

Implementing the provisions is planned in coherence with the steps for implementing the WFD. Except where genuine justification is provided, climate change cannot be used as a derogation to the objectives of the WFD.

The document received comments from the Member States and from the other groups in the Common implementation strategy (CIS) of the WFD until this past August. A European seminar on the topic «WFD and climate change» was organised at the end of October 2009 in Paris.

## *Estimate of the associated costs: limits within current knowledge*

In France, an Inter-ministry Group worked from the beginning of 2007 to October 2009 on the ambitious theme «Impacts of climate change, adaptation and associated costs in France». Stemming from the National adaptation strategy, this group is using the A2 and B2 scenarios of the IPCC as a base and is considering three prospective horizons: 2030, 2050 and 2100. In the scope of the National **adaptation plan** of 2011, it addressed with a sector approach the impacts of climate change on various fields, including farming, forestry, health, energy, transport infrastructure, and tourism, with a transversal view of the impacts on biodiversity, water and territories.

Available on the ONERC website (http://www.onerc.gouv.fr), the reports from this group form a considerable amount of observation data, statistics, analyses and questions. Within the scope of making decisions on adaptation to climate change, they form (Berthault, Paris Seminar 2009) a precious tool for increasing awareness of decision-makers, argumentation and arbitrage.

However, we see that due to the fact that the interest given to these questions is still rather recent, the socio-political recommendations coming out of this work is often of a general nature and not very operational, with the notable exception in the field of forestry.

The literature, especially in cases concerning water, remains directed more on the scientific aspects than on social and policy adaptation measures. In particular, the problem of the costs of adaptation appears difficult to address today. This difficulty, which **reflects the lack of a quantitative approach of the services provided by aquatic ecosystems,** comes from the multi-factor nature of the impacts and other components of climate change. These observations lead to a consensus with regards to **the need to reinforce governance** on questions linked to climate change.

## *Adaptation and economics: What is the role of the private sector?*

The Organisation for Economic Cooperation and Development (OECD), of which the work on adaptation began in 2002, is suggesting several pathways (Macher-Poitras, Paris Seminar 2009) for the economic approach of adaptation to climate change in the water sector. Defining adaptation as «all of the deliberate actions undertaken to reduce the adverse consequences, as well as to harness any beneficial opportunities of climate change», the OECD takes stock of the situation by sector of the estimates of the costs and benefits of adaptation. It observes that the latter are limited for the time being, in the water sector, to studies of particular cases – although they are rather complete for example in cases concerning farming and especially in coastal areas where available studies almost cover the entire coastline.

The prospective conducted by the OECD on the adaptation of water management in France is calling for additional **action from the public authorities and from the private sector.** In this vision (Macher-Poitras, Paris Seminar 2009), the public authorities, considering adaptation as a public good (via a dedicated infrastructure) should focus on creating measures that encourage adaptation. The private sector would commit its financial and operational capacities as well as its resources for research and development. In the case of France, this role would be facilitated via the long tradition of the private sector in water distribution and the municipal services, committing first-rate stakeholders such as Suez, Veolia or Saur. In 2006, investment in the area of water and treatment stood at 5.6 billion euros, of which 713 million through the private sector.

**Private-Public Partnerships** could within this scope form a useful economic instrument, available to the public authorities (Macher-Poitras, Paris Seminar 2009). This possibility however appears to be subjected to the ability of the private partners in financing this at a reasonable cost in a context of increased risk, in increasing efficiency (by a reduction in maintenance costs, for example), and in taking full advantage of technological innovations.

## *Strategy for adaptation or adaptive strategy?*

The measures initiated to take adaptation through management into account, still in progress for the most part, bear witness however to a **recent but powerful awakening as to the impacts of climate change** concerning public policies. Let's wager that their contributions

1 – The guide was adopted by the European water directors at their meeting in Sweden on 30 November and 1 December 2009.

(«WFD and climate change» guide, Reports from the French inter-ministry group) will make it possible to enlighten the decision at the next milestones – starting with the National adaptation plan of 2011.

The limits observed with crucial points such as estimating the costs associated with adaptation or monetisation of water services seem however to be inherent to the very notion of adaptation, which suggests linking the time for the decision – comprised of one-off events – with the time of climate change, which is based on the continual development of complex phenomena. For example, should we implement everything possible today in order to maintain the presence of a fish species (or of a crop) for a particular catchment area for 2050, although most of the scenarios show its disappearance as inevitable locally?
This difficulty leads to questioning, from a semantic standpoint (Millier, Paris Seminar 2009) the pertinence of the notion of «**adaptation strategy**». Several participants (Astier-Cohu, Berthault) have as such made reference to the concept of «adaptive strategy». This expression seems pertinent in realising the necessarily iterative nature, based on a constant refining of the predictions with regards to the changes observed and of the policy treatment of climate change.

Franck Cichy – Onema



## 3.3 – Which scientific outlooks can feed the decision?

The operational measures presented in the previous section (taking climate change into account in the WFD on a European scale, National adaptation plan in France) must be supported by adapted research efforts, making it possible to supplement the knowledge that is available. The expectations of the stakeholders from a technical standpoint and the needs expressed during the seminar (listed all throughout this document) participate in specifying the outline for this scientific policy.

Among the global objectives is the objective of progressively **refining the scope of climate scenarios and improving the physical pertinence of the models**. This point entails the increasingly-complete taking into account of the **cross-mechanisms** that have an influence on climate, and also the **regionalisation** of models within the scope of an operational use for the results. In the same logic, the **prospective horizons** being considered will have to allow for anticipating changes in the medium and long term, and also localised forecasts in the short term (2020 or 2030). These projections will furthermore need to be **based on extended and adapted observational data**.
Finally, in the context of global change, the adaptive strategy of the various stakeholders in water will have to be **based on** specific research in **varied fields – agronomics, genetics, energy, and also human sciences**.

These objectives come together in the short term, over several **concrete efforts** for France. Note in particular the prospective workshop ADAGE (ADaptation to climate change of Farming and human-influenced Ecosystems), launched in February 2009 by the French National Agency for Research, of which the objective is to identify the research that is needed in order to adapt farming and ecosystems that are managed by man, such as forests, prairies and aquatic environments, to climate change.

The Scientific Board animated by the French National Agency for Water and Aquatic Environments (ONEMA) is moreover setting up a working group on climate change, aimed at directing research to operational needs, especially based on the work presented at the Paris Seminar 2009. This work also benefitted from the GICC programme's scientific board, in preparing its 2010 call for research projects.

# Bibliography


AEE, 2006. *The changing faces of Europe's coastal areas (Évolutions des zones côtières de l'Europe)*. Rapport de l'AEE n° 6/2006.

AEE, 2008. *Impacts of Europe's changing climate — 2008 indicator-based assessment (Impacts du changement climatique en Europe : l'évaluation 2008 basée sur des indicateurs)*. Rapport de l'AEE n° 4/2008.

AEE, 2009. *Water resources across Europe - Confronting water scarcity and drought*. Report 2/2009, 60 pp., European Environment Agency, Coppenhaguen.

AEE, 2008, *Rapport 2008 énergie et environnement*. Rapport de l'AEE, n° 6/2008.

Amigues J. P., Ebaeke D. P., Itier B., Lemaire G., Seguin B., Tardieu F., Thomas A., 2006. *Sécheresse et agriculture. Adapter l'agriculture à un risque accru de manque d'eau*. Rapport de l'expertise scientifique collective, INRA, Paris.

Boé J., Terray L., Habets F., Martin E., 2006. A simple statistical-dynamical downscaling scheme based on weather types and conditional resampling, *J. Geophys. Res.*, 111, D23106.

Boé J., 2007. *Changement global et cycle hydrologique : une étude de régionalisation sur la France*, Thèse de doctorat de l'Université Toulouse III – Paul Sabatier, 256 pp + annexes.

Boé J., Terray L., Habets F., Martin, E., 2007. Statistical and dynamical downscaling of the Seine basin climate for hydro-meteorological studies. *International Journal of Climatology*, 7 (12), 1643–1655. URL http://dx.doi.org/10.1002/joc.1602.

Boé J., Terray L., 2008. Uncertainties in summer evapotranspiration changes over Europe and implications for regional climate change. *Geophys. Res. Lett.*

Centre d'analyse statégique, 2009. Approche économique de la biodiversité et des services liés aux écosystèmes : contributions à la décision publique. *La documentation française* - Paris, juin 2009. ISBN : 978-2-11-007791-2.

Coste M., Ector L., 2006. Diatomées invasives exotiques ou rares en France: principales observations. *Systematics and Geography of Plants*. Pt 70 : 373-400.

De Groot R.S., 1992. Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making. *Wolters-Noordhoff*, Groningen.

De Groot R.S., Wilson M. and Boumans R., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* Volume 41, Issue 3, 393-408.

De Toni A., Touron-Bodilis A., Wallet F., 2009. Effet du changement climatique sur les micro-organismes aquatiques pathogènes : quelques exemples. *Environnement, Risques & Santé*. Volume 8, Numéro 4, 311-21. DOI : 10.1684/ers.2009.0274.

Ducharne A., Habets F., Déqué M., Evaux L., Hachour A., Lepaillier A., Lepelletier T., Martin E., Oudin L., Pagé C., Ribstein P., Sauquet E., Thiéry D., Terray L., Viennot P., Boé J., Bourqui M., Crespi O., Gascoin S., Rieu J., 2008. *Impact du changement climatique sur les Ressources en eau et les Extrêmes Hydrologiques dans les bassins de la Seine et la Somme*. Rapport final du projet Rexhyss financé dans le cadre du programme GICC.

Ducharne A., Gascoin S., Ribstein P., Carli M., Habets F., 2009. Adaptation of a catchment-based land surface model to the hydrogeological setting of the Somme River basin (France). *Journal of Hydrology* Volume 368, Issues 1-4, 105-116.

Ducharne A., Baubion C., Beaudoin N., Benoit M., Billen G., Brisson N., Garnier J., Kieken H., Lebonvallet S., Ledoux E., Mary B., Mignolet C., Poux X., Sauboua E., Schott C., Théry S. and Viennot P., 2007. Long term prospective of the Seine river system: Confronting climatic and direct anthropogenic changes. *Science of the Total Environment*, 375, 292-311, DOI : 10.1016/j.scitotenv.2006.12.011.

GIEC, 2001 : *Third Assessment Report - Climate Change 2001*, GIEC, Genève, Suisse.

GIEC, 2007 : *Bilan 2007 des changements climatiques*. Contribution des Groupes de travail I, II et III au quatrième rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), Genève, Suisse, 103 pages.

Gosse Ph., Gailhard J., Hendrickx F., 2008. Analyse de la température de la Loire moyenne en été sur la période 1949 à 2003. Analysis of the mid-Loire temperature in summer (1949-2003) *Hydroécol. Appl.* 16 233-274. DOI : 10.1051/hydro/2009009.

Gras R., 1969. Simulation du comportement thermique d'une rivière à partir des données fournies par un réseau classique d'observations météorologiques. *IAHR Congress*, Kyoto. Article A53, Vol. 1, 491-502.

Gras R., 1970. *Estimation des éléments du bilan radiatif pour le calcul des températures naturelles d'un secteur de cours d'eau.* Rapport EDF HF/041/70/n° 26, Électricité de France, Paris.

Gugger M., Lenoir S., Berger C., Ledreux A., Druart J. C., Humbert J. F., Guette C., Bernard C., 2005. First report in a river in France of the benthic cyanobacterium Phormidium favosum producing anatoxin-a associated with dog neurotoxicosis. *Toxicon* Volume 45, Issue 7, 919-928.

Itier B., Seguin B., 2007 - La sécheresse : caractérisation et occurrence, en lien avec le climat et l'hydrologie. *Fourrages* (Versailles) - cat.inist.fr.

Itier B., 2008. Agriculture et sécheresse : le contexte et les enjeux. *Innovations Agronomiques* 2, 1-8.

Johnston N. M., Clarke A, 1999. Scaling of metabolic rate with body mass and temperature in teleost fish. *Journal of Animal Ecology*, 68: 893-905.

Khalanski M. *et al.*, 2008 Étude thermique globale du Rhône - Impacts hydrobiologiques des échauffements cumulés. *Hydroécol. Appl.* Tome 16, 53-108.

Lassalle G., Béguer M., Beaulaton L., Rochard E., 2008. Diadromous fish conservation plans need to consider global warming issues: An approach using biogeographical models. *Biological Conservation* Volume 141, Issue 4, 1105-1118.

MEEDDM – ONERC, 2009. *Rapport Changement climatique, adaptation et coûts associés*, DGEC-MEEDM.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being : Synthesis*. Island Press, Washington, DC.

Moatar F., Meybeck M., Poirel A., 2009. Variabilité journalière de la qualité des rivières et son incidence sur la surveillance a long terme : exemple de la Loire moyenne. *La Houille Blanche* (4) 91-99. DOI : 10.1051/lhb/2009050.

Oberdorff T., Pont D., Hugueny B., Porcher J.P., 2002. Development and validation of a fish-based index (FBI) for the assessment of river health in France. *Freshwater Biology* 47, 1720–1734.

Poirel A., Lauters F., Desaint B., 2008. 1977-2006 : Trente années de mesures des températures de l'eau dans le Bassin du Rhône. *Hydroécol. Appl.* 16 191-213 (2008), DOI : 10.1051/hydro/2009002.

Pont D., Hugueny B., Rogers C., 2009. Development of a fish-based index for the assessment of river health in Europe: the European Fish Index. *Fisheries Management and Ecology*, Volume 14 Issue 6, 427-439.

Pont D., Hugueny B., Beier U., Goffaux D., Melcher A., Noble R., Rogers C., Roset N., Schmutz S., 2006. Assessing river biotic condition at the continental scale : a European approach using functional metrics and fish assemblages. *Journal of Applied Ecology* 43, 70–80.

Pont D., 2010. *Changement global et stratégies démographiques des populations piscicoles.* Rapport final en cours de rédaction dans le cadre du programme GICC.

# Webography

IPSL: http://www.ipsl.fr/fr/Organisation/Les-structures-federatives/Les-poles-scientifiques/Pole-de-modelisation-du-climat

AEE: http://www.eea.europa.eu/fr

IPCC / GIEC: http://www.ipcc.ch

CNRM - MétéoFrance: http://www.cnrm.meteo.fr

MEEDDM: http://www.developpement-durable.gouv.fr

Office International de l'Eau OIEAU: http://www.oieau.fr

The EauFrance portal: http://www.eaufrance.fr/spip.php?rubrique187&id_article=449

En savoir plus sur la Loi sur l'Eau et les Milieux Aquatiques Lema :

Full texte on legifrance.gouv.fr: http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000649171&dateTexte=

ISBN 979-10-91047-03-6

Translation: Tradutours
Layout design: Inzemoon (06 75 24 19 30)
Production: Bluelife (04 67 91 33 55)

Printed in December 2011 on paper from sustainably managed forests by:
IME – Imprimerie Moderne de l'Est
3, rue de l'industrie – B.P. 32017
25112 BAUME-LES-DAMES CEDEX

*Printed in France*