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Science and the Water Framework Directive
20 years of research in hydrobiology for the good ecological status of aquatic environments

January 2021

In this dossier

prepared by Gisèle Parfait and Roxane Jupin (DAPP) and Christine Argillier (AQUA division)

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Acknowledgements

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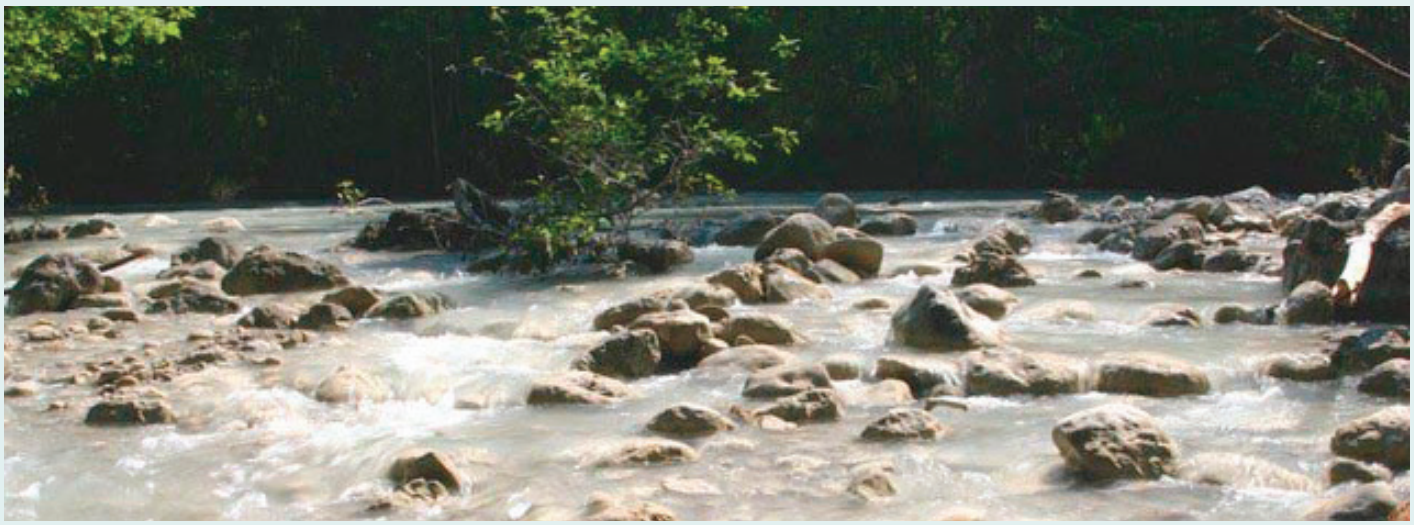

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The Water Framework Directive: twenty years to restore the good status of water bodies

Science and the Water Framework Directive 20 years of research in hydrobiology for the good ecological status of aquatic environments

The challenge set by the European Water Framework Directive (WFD) in 2000 for the Member States was to restore the good status of European water bodies within 20 years. Since knowledge for its implementation was lacking at the time, the Water and Biodiversity Directorate (DEB)of the French Ministry of Ecological Transition and the French National Office for Water and Aquatic Environments (Onema) entered into a large-scale collaboration with several research organisations in 2007. Given the research conducted in hydrology, biology and ecology, Cemagref/Irstea and INRA, now INRAE, were among the first partners. While efforts are ongoing to achieve the objective of good ecological status, the contributions of science to the implementation of this innovative and ambitious public environmental policy are already significant. A look back at 20 years of collaboration between French research and State services.

On 23 October 2000, the European Parliament and Council adopt the Water Framework Directive (WFD), an innovative public environmental policy in many ways. Its objective: to slow down the degradation of continental aquatic environments and restore the good status of water bodies. A major challenge that public operators could not have addressed without the help of scientists.

In 2006, the Law on Water and Aquatic Environments (Lema) transcribes the WFD on a national scale. As a result, the collaboration between the Ministry of Ecological Transition and research takes on a new dimension with the signing of a framework agreement and several agreements between the DEB, Onema, an operator of the Ministry of the Environment that became the AFB and subsequently the OFB, as well as Cemagref, which became Irstea in 2012 and INRAE in 2020. The same applies to INRAE. Other organisations, such as the BRGM, Ineris and Ifremer, also sign framework agreements on groundwater and coastal bodies. A long-term commitment that should contribute, on

the one hand, to the establishment of a monitoring system and, on the other, to the development of quality indicators. To this end, a number of disciplines are called upon, from hydrology to ecology, statistics and sociology, since science in support of public policy is also a human affair.
The water agencies, which manage the hydrosystems at the basin level, are key partners in the collaboration from the outset, given the data they collect and the technical planning documents (SDAGE) they draft. They establish the actions to be implemented in each river basin to achieve the objectives set by the WFD.

The WFD: a public policy exacting knowledge

With the entry into force of the directive, it is no longer enough for the physico-chemical quality of the water to be satisfactory in order to declare the "good status" of an aquatic environment. It is also necessary that all the living beings in this environment, the biocenoses, bear witness to this. By placing biology at the heart of the assessment of the ecological status of aquatic environments, the directive takes a new path for the field of bioindication in France.
By introducing a systemic approach, the WFD poses a number of scientific challenges: to better understand the ecology of species living in the same territory or their communities; to better understand the functioning of ecosystems subject to multiple pressures and their dynamics; to provide methods and tools capable of integrating the complexity of ecological systems. Some of these points still present a scientific challenge in the face of global change.

Stéphane Stroffek
Head of the Methods, Studies and Forecasting Department at the Rhone Mediterranean Corsica Agency

The water agencies are responsible for producing WFD data at the basin level, in partnership with the DREALs (French regional directorates for the environment, planning and housing) and the OFB. When the WFD arrived, we were almost ready, because since the 1964 law, water management in France has been structured by large basins. We already had monitoring programmes and planning missions, but it was necessary, for example, to integrate a much broader spectrum of indicators for all environments, with a result objective and a deadline. There was a sense of urgency. Scientists have provided us with a great deal of information in various fields: bioindication, delimitation of water bodies and alterations in the functioning and state of environments due to pressures from human activities. When setting up a research programme with scientists, it is very important to agree on the objectives. Even if the exploitation of the results is the responsibility of the manager, the co-construction of projects between managers and researchers guarantees the proper use of the scientific results. In the end, the WFD has boosted the restoration of aquatic environments, even if it will take a little more time to observe the effects of a more global restoration of environments on a larger scale.

CREATING A LINK BETWEEN STATE SERVICES AND RESEARCH

Already known in the United States, Canada, Australia and New Zealand, but never before used to consider the quality of the environment and aquatic environments in Europe, the bioindication principle adopted by the WFD raises new questions for science: what is meant by the «good ecological status» of water bodies? What is the reference state against which it should be assessed? How should organisms be sampled to construct bioindicators? Which bioindicators should be used to account for the impact of all pressures? How can the degree of uncertainty associated with each indicator be assessed? And many others…
To answer these questions, the State services, their public establishments and the scientists make a swift and long-term joint commitment.
The teams of Cemagref's Aquatic Environment Management Division thus draw on their knowledge of hydrology, biology and ecology from 2000 onwards and propose a collective research offer to the Water Directorate of the Ministry of Ecological Transition.

In 2001, the scientists join the national groups set up by the Ministry, such as the Continental Surface Water Assessment Group. In 2003, the Water Surfaces Scientific Interest Grouping is created, associating INRAE, the High Council for Fisheries (CSP), future Onema, and Cemagref.
At the same time, a unit dedicated to the WFD is created in Lyon. In 2008, it would become the joint cluster hydroecology of water courses, an original structure bringing together scientists from Cemagref and chargés de mission from Onema. In 2010, the cluster hydroecology of water surfaces is established in Aix-en-Provence based on the same model.
Lastly, the Aquaref consortium, comprising five scientific organisations (BRGM, Ineris, Cemagref, Ifremer, LNE and Onema) is established in 2007 with the support of Onema. Its objective: to coordinate methodological developments in hydrobiology and support operators.
Thus, this research programme has mobilised significant human resources to reach, at the peak of research activity, some 35 full-time equivalents per year (20 permanent and 15 contract researchers). All hydrobiology research units of the former Cemagref were mobilised (Aix-en-Provence, Antony,

Bordeaux, Lyon, Montpellier), as well as some units of the former INRA (Rennes and Thonon-les-Bains).

The financial investment was also substantial[2] and allowed the development of targeted research which to date totals almost 20 years of involvement of the teams in work at the interface between science and management.

Thanks to this human and financial investment, the operational tools for national coverage, harmonised at European level, were ultimately implemented in a timely manner, in accordance with the requirements of the European Commission.

2 Of the approximately 85 million euros that Irstea's research in support of the WFD has cost, nearly 30 correspond to subsidies provided by Onema

Jointly selected methodological bases for the path to bioindication

The systemic approach encouraged by the WFD and the urgency of its deadlines require a major collective effort for its implementation, based on a dynamic of consultation, an iterative process with relevant readjustment of actions in light of the results. A long-term consultation is therefore set up between scientists, services in charge of applying the directive and water agencies in charge of managing aquatic environments.

DATA BANKING: THE CORNERSTONE OF RESEARCH

Hydrobiological research for the WFD requires a large quantity of biological and environmental data on all water courses, water surfaces, transitional waters, coastal waters and groundwater. The banking of hydrobiological data already collected for several years by various operators, scientists, water agencies, federations and fishing associations is therefore necessary. To this must be added the data acquired in the new networks as they are set up, for all types of surface water bodies. Protocols for checking and validating some of these data have been developed, all of which are referenced in the National Framework for Water Data (SNDE).à la conformité et la stabilité des évaluations, sont quant à eux regroupés dans la bio-indication fonctionnelle, conçue

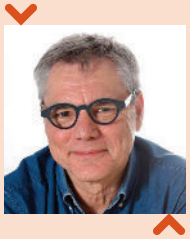
The European Water Framework Directive (WFD)

To achieve good ecological status of aquatic environments, the WFD is based on water management conducted at the scale of large European river basins. It introduces a dynamic «adaptive management» procedure consisting of assessing, diagnosing and prioritising the pressures on aquatic environments.
Good status objectives are set at the smallest scale, that of «water bodies», which correspond to homogeneous portions of water courses, water surfaces, transitional waters, coastal waters and groundwater.
A monitoring programme describes the system for tracking the state of the environment. The data collected as part of this programme are regularly reported to the European Commission.
The objective: to define on the one hand a management plan for each basin that sets the environmental objectives, and on the other hand a programme of measures that defines the actions to be implemented in order to achieve these objectives.
The management plan, programme of measures and monitoring programme are reviewed every six years. They are based on an array of tools and methods that are also necessary for setting up monitoring networks and a permanent reference network, the keystone of adaptive management. In France, the representatives of the stakeholders in the river basin take part in this process within consultation and decision-making bodies known as «basin committees».

This document, written by 6 INRAE scientists, summarises the actions carried out in support of the public authorities for the implementation of the European Water Framework Directive in France. Downloadable on HAL.

Olivier Monnier
Chargé de mission Aquatic Biodiversity overseas at the OFB

Applying the WFD overseas presented and still presents difficulties due to a lack of knowledge of the biology and ecology of overseas species and because the means to finance the water policy arrived later than in mainland France. From a scientific point of view, not all disciplines are present in the overseas departments. It was therefore necessary to combine the competencies of about twenty local and mainland establishments, such as the universities of the Réunion and the West Indies, the water offices, the IRD, the CNRS, INRAE, the MNHN, as well as research consultancies, in order to compensate for the knowledge gap and meet the need for indicators specific to tropical conditions. Indeed, some of the particularities of the field required the adaptation and others the complete rethink of existing tools, as is the case for coral reefs. In the end, we broadened the spectrum of data studied on a global scale to meet our French needs.



Yves Souchon
Emeritus research director, former head of the Quantitative Hydroecology Laboratory, INRAE

A multidisciplinary research-study cluster was set up in Lyon in 2008, bringing together ecologists, geomorphologists, geographers, statisticians, database managers and geographic information system operators. Within this type of group, which is not very common in academic research organisations, the basic rule was to share information and questions in real time between all members of the cluster. In the end, it was this collaborative system with a shared common ambition and non-hierarchical relationships that allowed us to establish a strong cohesion.

In order to place science in support of public policy, the role of the research institute is always paramount. It must display the activity as a mission in its own right, complementary and just as noble as fundamental research: playing the same note over and over again does not make a symphony. We must not forget the rest of the scale, nor that publication is not the sole object of the research activity. This system also allows for training that mobilises several skills, which is essential to accompany an innovative public policy. Secondly, for a collaboration with the contracting authorities to work well, it is essential that everyone respects the missions assigned to them in a climate of trust. The WFD mobilises a multiplicity of actors, the State and its decentralised services, the national office, water agencies, and scientists, each of whom must exercise their competences. The more complex, sensitive and new a method is, the more difficult it is to put it at the service of a public policy and to have it adopted. It is therefore necessary to find the right balance between scientific requirements and operational adhesion: the scientists are to propose tools and the managers to devise a strategy for their use and integration in relation to national issues and European reporting.

pour les différents bio-indicateurs à partir du modèle des taxons des macrophytes.
Since November 2016, the taxonomic references, which are essential for the conformity and stability of the assessments, have been grouped together in the functional bioindication, designed for the various bioindicators based on the model of the macrophyte taxa.

GRIDDING THE HYDROGRAPHIC NETWORK TO COLLECT DATA AND ASSESS THE WATER STATUS

Monitoring the ecological status of the entire French hydrographic network meant dividing it into «water bodies», homogeneous sections in terms of certain physical and environmental characteristics: relief, geology, climate or flow rate; all variables that govern the geographical distribution of biological organisms.
A total of 11,414 water bodies have been identified, including 10,706 for water courses alone.
Coastal and transitional water bodies have been defined following the same reasoning for a total of 179 coastal water bodies and 94 transitional water bodies.
For water surfaces covered by the WFD, most of which have a surface area of more than 50 hectares, the water body generally corresponds to the entire water surface. A total of 435 water surfaces have been established, including 6 in the overseas departments and regions[2].
These water bodies were then grouped into major types according to their ecological functioning. The 22 hydroecoregions identified by scientists before the year 2000 served as the basis for the development of the national typology of water courses and water surfaces. For estuaries, in addition to the region, size and salinity criteria were used.
In France, 124 types of water courses have thus been identified, 31 for water surfaces (12 natural and 19 man-made), 26 for coastal waters and 12 for transitional waters[3].
The main issue of this typology is the definition of the reference conditions from which the ecological states are established and their classification (deviations from the reference). This is particularly important for the biological references, since, independently of the problems of pollution or alterations to habitats, the geographical distribution of organisms (like invertebrates, fish, diatoms and macrophytes) is first of all linked to natural factors.

SAMPLING: A KEY STEP IN THE DEVELOPMENT OF BIOINDICATORS

Phytoplankton, macrophytes, diatoms, macroinvertebrates, fish and hydromorphology have been used to develop specific bioindicators for water courses, water surfaces and estuaries. In order to ensure the viability of the data, their collection follows a standardised method applicable on a national scale, adapted from classic methods. A compromise between the quality and accuracy of the information, reproducibility and the cost of implementation has been established. A laborious task, but one that pays off in the end.

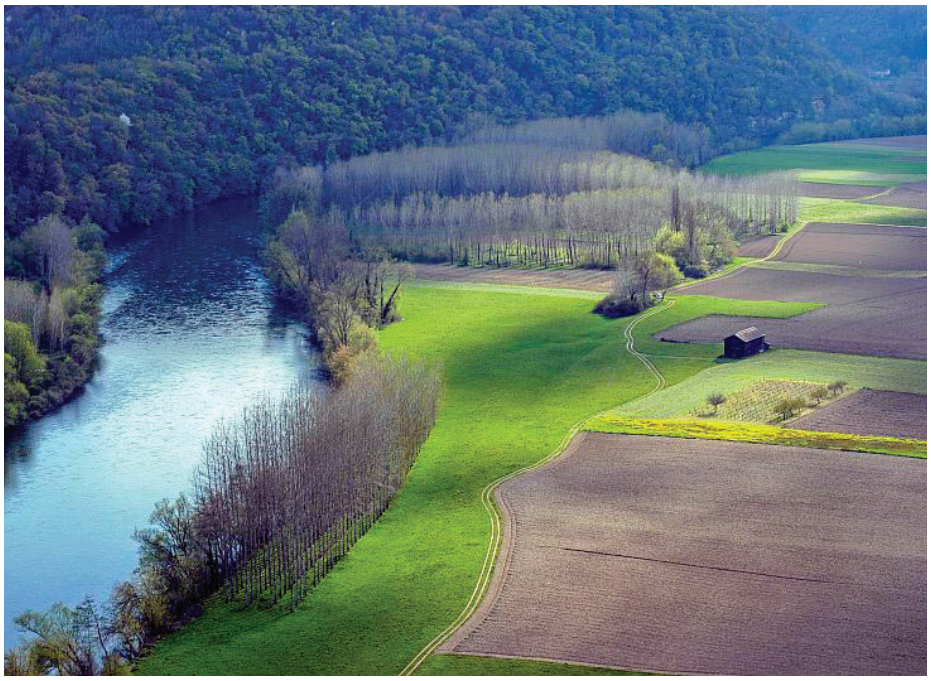
WHAT STATUS SHOULD BE USED TO ASSESS "GOOD ECOLOGICAL STATUS"?

In order to qualify the water status as «very good, good, average, mediocre or poor», it is necessary to be able to compare it to a reference status, the basis for assessing the ecological status and determining the good status objective. But how to define this status? Which reference should be chosen? Should one refer to historical references? Should one differentiate between natural environments and anthropized systems? In France, scientists have interpreted «good status» as the status observable in

2 Adeline Blard-Zakar (AFB) ; Janik Michon (AFB), Rapportage 2016 des données au titre de la DCE, 2018

3 Ministère de l'Écologie, Circulaire DCE 2005/11 relative à la typologie nationale des eaux de surface, 2005

«water bodies with little impact from anthropogenic pressures».
A network of approximately 300 reference sites for water courses was set up according to this approach and validated by the hydrobiological experts of the regional environment directorates (DIREN).
For water surfaces and estuaries, the selection of reference sites proved to be complex, as the environments selected were not very representative of the diversity of the types of water bodies. It was therefore often necessary to resort to modelling.
Once established, the network of sites provided the data needed to calculate the reference values of the bioindicators.
This approach was promoted and defended before the European authorities.



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The multiple pressures on water bodies require complex assessment tools.

Living organisms: a "thermometer" sensitive to the state of the environment

The development of bioindicators has greatly mobilised researchers, as attest the numerous publications and theses produced, as well as the necessary recruitments made.
Knowledge of the functioning of aquatic environments and their biocenoses has progressed considerably. It is not possible to report all the results here; for this we refer the reader to the scientific and technical literature.

TOWARDS ACCURATE AND SENSITIVE BIOINDICATORS

Prior to the 2000s, three indices were used in France to assess the state of water courses: the standardised global biological index (IBGN) based on macro-invertebrates, the biological diatom index (IBD) based on diatoms, and the fish river index (IPR). For the water surfaces, the phytoplankton index (IPL), the oligochaetes index (IOBL) and the mollusc index (IMOL) provided a quick account of the quality of the environments.

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Macroinvertebrates are one of the four biological quality elements used to assess the biological status of aquatic environments.

Three questions to

Bénédicte Augeard
Head of the Research, Development and Innovation Division
French Biodiversity Agency

Onema, which has now become the OFB, was created to accompany the implementation of the WFD with a great need for new knowledge. What were these needs?

Onema, which became the French Biodiversity Agency in 2017, then the French Biodiversity Agency (OFB) in 2020, was a public institution created by the 2006 law on water and aquatic environments to support the Water and Biodiversity Directorate of the Ministry in charge of the Environment, particularly in the implementation of the 2000 European Water Framework Directive (WFD).

The implementation of the WFD in France has given rise to a great many research questions. The WFD provided a fairly precise framework for monitoring, assessing and acting to improve water status: defining types of water bodies (water courses, lakes and estuaries, coastal waters, groundwater) as a working scale, identifying hydroecoregions, reference conditions, developing indicators to qualify ecological status on the basis of, for example, fish, invertebrates and algae. In this context, many questions arose: how to construct a bioindicator from these targeted biological compartments? What measurements should be taken? In order to assess the impacts of which human activities? What references and thresholds should be used for these indicators? How to prioritise the specific actions to be taken and assess their effects?

The main research needs for the implementation of the WFD concerned not only the qualification of the ecological status of environments, but also the chemical water status. On the one hand, this qualification involved metrology and evaluation of the ecotoxicology of substances, and on the other the establishment of a relationship between pressures, human activities and their impacts on organisms. In addition, public policies on quantitative water management also needed insight into drought and low water levels. The human and social sciences have been useful to accompany the reflection on the adopted measures, the economic and social aspects, the participation of the stakeholders and more.

In these different fields, the objective was to develop robust national tools, some of which have in fact been integrated into the regulations.

In the overseas departments, the need for knowledge was even greater than in mainland France. Research resources were weaker and more scattered. Very little data were available and had to be acquired in the field.

On behalf of the ministry, Onema devoted significant resources to supporting research aimed at public policy. With regard to continental surface water, Cemagref, which became Irstea, then INRAE today, played a central role due to its history in this field, even if other research institutes also contributed,

in particular the former INRA and the University of Lorraine.

Did the scientific results meet the needs of the action?

Overall, yes. The researchers were deeply involved in gathering existing data, understanding the framework of the directive, exchanging with water managers (Onema, Ministry, DREALs and water agencies) and developing the evaluation methods or tools expected. Once the tools were operational, they also got involved in providing support through guides, seminars, training courses or even mechanisms such as Aquaref. These researcher-manager exchanges throughout the projects are a real asset for guaranteeing the operationality of research results.

This work has enabled many researchers to progress in their understanding of ecological processes and to valorise the results in academic publications. Bioindication is a complex issue that requires a good knowledge of the ecology of environments, of the sensitivity of species to pollution and habitats, of interactions between species, and also requires to investigate the evolutionary trajectories of ecosystems. Work on the vast amounts of data from WFD monitoring can bring out relationships that subsequently need to be well characterised.

Other advances have been made with INRA, INRAE today, on the link between agricultural practices and nonpoint water pollution, on quantitative approaches to water use, and on new monitoring methods with the use of environmental DNA, which allows for more rapid assessments.

However, not all tools developed could be used. As the monitoring network was set up and the knowledge produced by research increased, we had increasingly accurate tools, but they degraded the overall rating of the status of the water bodies, masking the efforts made to restore good status, and thereby creating a risk of despondency for the managers. Thus, the historical fish river index, the IPR, had been improved in its IPR+ version, becoming a powerful diagnostic tool. However, it was not included in the regulations, as its sensitivity was such that it downgraded the status of the water bodies too much. It was complicated for water managers to show such a significant deterioration in the ecological status of water bodies without an increase in the explanatory factors. This indicator is therefore rather used more for selective diagnoses.

Do public policies need science?

Of course, the work discussed above illustrates this for the WFD. Similar questions arise today for the implementation of the European Marine Strategy Framework Directive (MSFD): how to set up a monitoring system, develop descriptors of the ecological status of the marine environment, define management objectives and measures, and so forth. Research is very much needed here too and this requires an awareness of what is known and what is not yet known, as well as the ability to explain uncertainties...

However, a clear distinction must be made between the scientific approach, its results and the use that will be made of it for action by the stakeholders. Thus, working with researchers in ecology or water sciences enriches the regulations, but they are not based solely on scientific knowledge and integrate many other societal issues to ensure their applicability.

Beyond the needs of public policies, scientists also have a role to play in providing information to other stakeholders in society, companies, NGOs and citizens, who are also concerned by water and environmental management issues. Dialogue with society must be encouraged to raise awareness of the issues at stake and move the yardsticks.

Three questions to

Laurent Roy

Director General of the RMC (Rhone Mediterranean Corsica) Water Agency
Former Director of Water and Biodiversity at the MTE (Ministry of Ecological Transition) from 2012 to 2015
Former DREAL of the Provence-Alpes-Côte d'Azur (PACA) region

At the time of the WFD's implementation in the 2000s, you directed three public structures of the Ministry of Ecological Transition: the DREAL PACA, the DEB and today the RMC water agency. What were the knowledge needs, particularly in terms of bioindication?

The WFD sets an obligation to achieve good status for water bodies by 2027 at the latest. The European Commission's Directorate-General for Environment asked the Member States to set up in particular a system for assessing the status of continental surface waters. To this end, we needed tools to link pressures and the state of the environment, all documented, robust, and recorded at least every 6 years during each assessment cycle.

When the WFD was implemented in the 2000s, we were not starting from scratch in France: the system of water management by large river basins was already in place, we had benefited from an environmentally demanding water law since 1992, and research in aquatic ecology by several teams was already well underway. At the time, a bioindicator for macro-invertebrates, the global biological index (IBGN), a fish river index (IPR) and an index based on diatoms (IBD), which are microscopic algae, were used in France.

The DREALs played an important role in assessing the state of the water through their hydrobiology laboratories.

However, all these tools and know-how had to be further developed in order to meet the objectives of the WFD, in particular to have biological indicators sensitive to pressures in order to prioritise and target actions as well as possible. There was still a great lack of knowledge on this point.

The DEB and Onema, its operator created in 2007 by the water law (Lema), the DREALs, the research community and the water agencies combined their efforts to produce the knowledge needed for action.
With substantial resources and the technical and financial support of the water agencies, Onema set up and financed research agreements covering all needs, including surface water, groundwater and risks, together with targeted research organisations, including Cemagref, which had been involved in hydrobiology and hydroecoregions for years. Thus provided with substantial financial resources, research on bioindication could be intensified.

What are the constraints of producing knowledge for the application of a public policy such as the WFD ?

The tools must be efficient and sensitive to pressures. As research has progressed, they have improved, but the system for assessing water status set by the WFD is problematic: it is enough for a single factor to be in less than «good» status for the status of the water body to be

downgraded («one out all out» principle). This approach masks the progress made and leads to great inertia in status assessment.

Tensions therefore emerged between the search for the most relevant indicators possible and the operational requirements to measure and show the progress made as a result of involving the stakeholders in the water sector.

The DEB was therefore caught between the scientific production of Onema, then Irstea, the European Commission and its demands for an evaluation system that covered all fields in the best possible way, and the operational services of the State (including the DREAL) and the water agencies, the system's exclusive financiers. It became then a question of finding a compromise that would meet the various requirements.

Today, as director of a water agency, I would say that a good number of parameters have unquestionably improved, even if the integrating tools for evaluating good status mask this genuine progress. For example, we find 20 times less ammonium, the indicator of "domestic" pollution, in the rivers of the Rhône-Mediterranean basin today compared to 1990. The average toxicity of metals, markers of industrial pollution, has been divided by 6.

Monitoring of water status has also improved considerably, with many more analyses carried out, parameters monitored and constant progress in estimating the link between pressures and the functioning of environments. The improvement in the biology of water courses has thus begun to be felt over the last 5 to 6 years, when considering the I2M2 invertebrate indicator.

Science has made an enormous contribution to the establishment of all these indicators and to understanding the links between human activities and the state of the environment. The functional ecology of water courses and water surfaces is essential in order to progress in the understanding and the choice of measures to be taken

Is there still a need for research?

We have at least three new challenges ahead of us: 1/ the question of quantity, with climate change which will increasingly put pressure on water resources, 2/ the question of nonpoint pollution by a multitude of chemical substances, the "cocktail" effects of which are poorly understood, and 3/ the pressures on the morphology of water courses and their artificialisation, which is very damaging to their good status. The effects of the measures in this field are gradual, the managers are impatient and our basin committee is asking us for returns on investment.

I note a strong «appetite» among our basin authorities for knowledge and science, a desire to know more, to understand. We have set up several meeting places that allow mutual acculturation and facilitate mutual understanding. The next stage, to which the recent experience of Covid-19 invites us, will be to bring the general public closer, as it has discovered science with its doubts and controversies, its unknowns, destabilising for it, but a reality.

Decision-makers and legislators need scientists to act and scientists must contribute to public decision-making, without taking the place of decision-makers.

However, these bioindicators only partially met the environmental requirements of the WFD. Indeed, some of them did not cover all the required criteria like density, diversity and abundance of sensitive taxa. Others did not allow the assessment of all types of water bodies, or did not really measure a deviation from undisturbed or slightly disturbed reference conditions.

The development of new bioindicators for all biological compartments and all water bodies was therefore necessary. It mobilised skills in biology and ecology, statistics, data analysis and modelling.

The methods implemented varied from one bioindicator to another depending on the data available, the teams' experience and the constraints inherent to the contexts. The challenge was in particular to prove the capacity of biological indicators to qualify aquatic ecosystems in greater detail than physico-chemistry and toxicology, and to establish a strong and statistically significant relationship between physico-chemical, hydrological pressures or pressures linked to the degradation of the physical habitat and the various characteristics of the communities.

Assessment methods were thus developed for the three types of continental surface water bodies and an indicator was constructed for each of them based on the plant or animal groups required by the WFD: phytoplankton (IPLAC), macrophytes (IBMR and IBML), diatoms (IBD), invertebrates (I2M2) and fish fauna (IPR+, IIL, IIR and ELFI). In addition to the development of these bioindicators revealing the ecological status, a degree of uncertainty relating, for example, to the acquisition of field data or the calculation of pressures was associated with them.

Their translation into regulations and into the implementation of the directive at the basin level has been gradual. Similarly, the bioindicators have been integrated into a water status evaluation system (SEEE) which continues to be implemented today.

EUROPEAN HARMONISATION: THE CHALLENGE OF INTERCALIBRATION

As each Member State developed its own methods for assessing the status of aquatic environments, a harmonisation phase, called intercalibration, was imperative. For example, it was necessary to be able to compare the results obtained by neighbouring countries for Alpine or Mediterranean aquatic environments. Thus, the best «compromise» was sought for each bioindicator in order to ensure a harmonised assessment of the ecological status of environmentally and physically comparable water bodies belonging to the same geographical area.

This intercalibration period was intense in terms of consultation, on the one hand because the bioindicators and stress factors measured differed greatly from one country to another, and on the other hand because the calibration of the intercalibration method was itself a "work in progress". Incidentally, the exercise is not yet complete.

Intercalibration on a European scale helps to make the data comparable. After comparing several techniques, the beam trawl was chosen for sampling fish in estuaries.

From physico-chemical and hydro-morphological to ecological status

"SUPPORTING BIOLOGY", A NEW CONCEPT

While physico-chemical criteria were for a long time considered as the only indicators of the state of an environment, they are now considered as «in support of biology» in the WFD's ecological status assessment system. The aim was therefore to gain a better understanding of the links between physico-chemistry and biology and to set new physico-chemical quality thresholds for each type of water body, taking into account the characteristics of the biological compartments.
Similarly, hydromorphological characteristics «in support of biology» were introduced into the assessment of the ecological status of water bodies. Significant scientific and technical investment was devoted to the hydromorphological characterisation of ecosystems by developing observation methods, some of them highly innovative (acoustic echo sounding and remote sensing, for example). Subsequently, modelling made it possible to specify the link between the hydrological and morphological characteristics of water bodies and aquatic life.

THE RISK OF NOT ACHIEVING GOOD ECOLOGICAL STATUS: THE EXAMPLE OF WATER COURSE HYDROMORPHOLOGY

The relational system of water course hydromorphology auditing (SYRAH-CE) was initiated in 2006. It combines different characteristics of the river basin, major and minor riverbeds and riparian forests to calculate a risk of alteration of their structure and physical functioning for each water body.
Without going into detail here, the SYRAH-CE system is a good example of research-action built on the basis of continuous exchanges and validation of each step with the direct users, i.e. the water agencies, the French regional directorates for the environment, planning and housing (DREAL) and Onema.
Since the overview reported in 2013, this system has been the basis for assessing hydromorphological pressures in order to draw up the French Water Development and Management Plans (SDAGE). The body of data made available makes it thus possible to define priorities for the management of watercourses. They enable the ecological data to be better contextualised and interpreted, and to anticipate future alterations.
For transitional waters and water surfaces, the first overview in 2004 was carried out entirely on the basis of expert opinion; very little hydromorphological data were available at the time. The methods subsequently developed to describe lake hydro-morphology and its alteration indirectly make it possible to approach the risks of dysfunction, and therefore of failure to achieve good status of the environment. They are used to develop models linking biology and hydromorphology and thus to establish the evaluation of the ecological status.

LIFE SIZE APPLIED RESEARCH

By setting an objective of improving the ecological status of aquatic environments with an obligation to achieve results, the Water Framework Directive automatically implies the widespread implementation of operations to restore altered environments. Since the end of the 1990s, hydromorphological restoration operations have multiplied. However, the effects must also be measured. To do so, the French Biodiversity Agency (formerly Onema, now OFB) has initiated a monitoring process for restoration operations in which scientists are involved. The scientific and operational objectives are to evaluate the efficiency of restoration work, to make the most of feedback on restoration and to produce recommendations for managers.
This approach should make it possible to greatly improve the understanding of the resilience of ecosystems in the context of global change.

Mario Lepage
Senior Fish Biologist, Research engineer in estuarine Ecology at INRAE

As far as estuaries are concerned, we were starting from a very low base: there was no reference state or "typology" of estuaries. We had nothing on pressures or on how to assess their level. We only knew the Gironde estuary well, as we had been working there at Cemagref for nearly twenty years. As part of the research on bioindication, I led a group of 25 European experts in the development of a fish indicator in estuaries and lagoons: we saw the tensions between purists and pragmatists, but the question was above all to remain operational. Improving an indicator can make it more sensitive and thus make it a better diagnostic tool, which is its initial raison d'être. The question is to know how far the scientist goes in the decision-making of managers. Our work on the uncertainty of assessments is very much along these lines.

We were able to recruit researchers and capitalise on knowledge, skills and expertise. Understanding in order to act is truly the adventure that I have experienced and shared during these years of research for the WFD. In addition to the satisfaction of feeling a bit like a "player" in the improvement of very degraded environments, there is also a great deal of recognition from partners. I often receive proposals for collaboration with European researchers to participate in international consortia. It is also important to have this activity recognised by peers and evaluators..

From research to support for public policies: between scientific rigour and pragmatism of action

Christine Argillier
Research director and ecologist of aquatic environments, INRAE

Those who embarked on this adventure believed in it. Setting up a system for assessing the state of aquatic environments, based on biology, at a national level, and harmonised at European level, was engaging and motivating. We had to be prepared to take risks, as well as have a management to back us, which we were lucky enough to have. The initial motivation for getting involved in public policy support is undeniably the wish to do targeted research. It is not always easy and often takes us out of our comfort zone, but it allows us to be at the heart of the action, to exchange points of view and to move the yardstick, even if only slightly. Here, everything had to be built, so it was incredibly exciting.

More than 50 scientists from various disciplines have been involved for some 20 years in supporting the implementation of the WFD, most of the time in a challenging scientific environment: lack of hydrobiological data, methods, time, heterogeneous data and so forth.

The considerable efforts made to collect national and even international data and information have made it possible to build a solid foundation for further macro-ecological and trophic ecology studies. In this respect, they are fully valued.

All these assessment processes based on biology are complex and their appropriation by users is sometimes difficult. Indeed, biological responses to the environment are the result of processes that operate on different spatial and temporal scales. Their understanding is less easy than a chemical response that is conventionally measured to account for disturbances in the river basin or at the scale of the station. Their transfer can therefore not be done without support.

Thus, in addition to the research activity dedicated to the development of environmental status monitoring, many other actions in support of public policies have been carried out in order to facilitate the appropriation of research work by stakeholders: training for operators, various expert assessments, notably for laboratory accreditation, standardisation (CEN and AFNOR), contribution to the work of various bodies and steering groups, opinions and advice, as well as contributions to regulatory texts. INRAE scientists also continue to be involved in the Aquaref consortium, which is now recognised by national and European players.

The importance of research needs for the implementation of the WFD is at the origin of the creation of consortia of scientists. With financial support from Europe, they have made a major contribution to advancing knowledge, with teams recognised in the context of European research projects.

The mobilisation of a large scientific community has enabled a considerable gain in knowledge useful for the restoration of aquatic environments.

Assessment and prospects for 2027: the journey continues

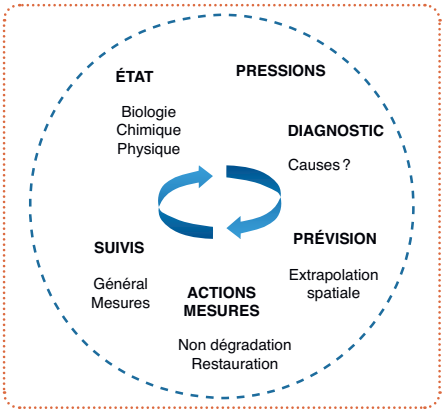
Continental aquatic ecosystems are essential to human societies through the many vital services they provide: drinking water, water for industry, energy and agriculture, bathing, landscapes, biomass production, fishing, biodiversity, recycling and storage of nutrients and carbon. They are very complex systems, hierarchically structured from the upper catchment to the sea, interconnected with each other and with the surrounding terrestrial systems. They are the seat of numerous physical, chemical and biological interactions. Research in hydroecology contributes to a better understanding of these systems.

The knowledge acquired since the 1980s has enabled scientists to respond positively and rapidly to the various challenges posed by the operational translation of the major environmental public policy that is the Water Framework Directive. Owing to the substantial investments and partnerships implemented for this research, the results are there for all to see.

The first common factor of these achievements was the change of scale necessary in order to be from the outset positioned at a national level with all its geographical and sociological complexity. The second was the appropriation of the new knowledge and methods by the users. And thirdly, meeting the requirements of reproducibility, accuracy and cost for network use is also a key factor of success.

Knowledge of continental aquatic environments and the communities they host, both from a biological and ecological point of view, has therefore progressed considerably during the implementation of the WFD, as have the methodologies, sampling and measurements of characteristics of environments, modelling and bioindication.

Although France now has reliable, accurate, rigorous and comparable means of assessing and restoring the good ecological status of its water bodies, this has not yet been fully achieved. The pressures on the environments remain very strong. In parallel with the efforts of managers, research work is being continued in order to improve the quality of assessments and to propose efficient restoration tools that integrate the problems associated with climate change, nonpoint pollution and the pressures exerted on the morphology of water bodies ■



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In the adaptive management process of the WFD, knowledge of the state of a system makes it possible to adjust the action owing to the mastery of indicators and the advancement of knowledge of anthropic pressures.

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The Dortmann's cardinalflower is included in the IUCN red list. The continuous improvement of water quality assessment is a major challenge to achieve the protection and restoration objectives set by the WFD by 2027

4 sites to find out more (in French)

- The French national reference laboratory for monitoring aquatic environments: https://www.aquaref.fr/
- The technical portal of the French Biodiversity Agency: https://professionnels.ofb.fr/
- Practical information and tools on bioindication: https://hydrobio-dce.inrae.fr/
- The reports on water of and to the European Commission: https://rapportage.eaufrance.fr/

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