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Observing social and environmental change in a large regulated river: the Rhône Valley Human-Environment Observatory

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Observing social and environmental change in a large regulated river: the Rhône Valley Human-Environment Observatory

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Abstract. Following the major floods of the early 2000s, the Rhône river has been the focus of an integrated management plan, the *Plan Rhône*. This plan advocates a new way of managing the river from a sustainable development perspective. The Rhône Valley Human-Environment Observatory (OHM VR) was set up in 2010 with sustainable development as a foundation applied to the scale of the river. The scientific objectives of the OHM VR have been to monitor the effects of this new management approach in a perspective of a highly anthropised socio-ecosystem, by studying the socio-environmental responses and adaptations in the Rhône corridor following a change in the mode of river management. Priority scientific themes were developed with the aim of covering most of the questions raised by this new mode of management: to achieve a better understanding of the geo-historical trajectory of the river to situate temporally the crisis events and their consequences; to provide insight into the new modes of management from a socio-political point of view and their reception by the local populations; to study the socio-economic processes in a context of ecological restoration actions; to analyse the environmental risks, in particular pollution; and to develop new tools to support the research works and the diffusion of scientific results. Interdisciplinarity and relations with local stakeholders provide the framework for these investigations. This article provides an overview of the activities of the OHM VR and their evolution since its creation, with a particular focus on two interdisciplinary case studies that have shaped collective scientific thinking in recent years.

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Keywords. Rhône river, Interdisciplinarity, Relation with local stakeholders, Human-Environment Observatory, Integrated management, Sustainable development.

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1. The Rhône: an anthropised river, partially restored

The Rhône River today is characteristic of a great European river subject to anthropic pressures for several centuries, to meet the needs of a wide range of human uses (Tockner et al., 2022). Connecting the French-Swiss Alps with the Mediterranean Sea, the Rhône River is 812 km long and the catchment area is 98 500 km^2, with 90 500 km^2 located in France (Olivier et al., 2022). The mean annual discharge is 1720 m^3·s^{-1} at the furthest downstream gauging station (Beaucaire), which makes the Rhône River the most important freshwater input into the northwestern Mediterranean Sea (Arnaud, Sehen Chanu, et al., 2021). The French course of the Rhône River exhibited two main phases of human intervention since the 19th century which fundamentally altered the hydromorphological and ecological functioning of the floodplain. First controlled to prevent floods and facilitate navigation, the river was subsequently regulated during the 20th century for the production of energy. Twenty-one hydroelectric dams and four nuclear power plants today make the Rhône River one of the main energy producers in France, supplying respectively a quarter of nuclear electrical production and a quarter of hydroelectricity (Comby, 2015) (Figure 1). Each year, 3.1 billion m^3 of water is extracted, including 48% for agricultural irrigation, 24% for hydroelectricity production, and 16% for the supply of drinking water (Agence de l'Eau bassin Rhône-Méditerranée Corse, 2023). The river is the recipient of domestic and industrial effluents, and has for several decades suffered from chronic pollution resulting in socio-political crises related to certain pollutants, such as PCBs (polychlorobiphenyls or Pyralene) (Gramaglia and Babut, 2014), or more recently the PFAS (per- and polyfluoroalkyl substances) (Le Naour and Thomas, 2022). Gravels from the Rhône channel and floodplain has been extensively exploited for infrastructure construction, especially since gravel extraction, by deepening the riverbed and locally limiting deposits, also facilitated navigation. Today, the Rhône River does not transport any bedload downstream of Lyon, and its geometry is largely fixed.

Overall, these anthropic pressures have radically transformed the socio-ecosystem dynamics of the Rhône River by altering hydrological, ecological and geomorphological processes, and also by causing a deterioration in water quality and biodiversity. From the early 1970s, and notably thanks to the French water act of 1964, France's first law to restore water quality and the creation of the *Agences de l'Eau* (French river basin water management agencies) (Bouleau, 2014), a wide-ranging water management policy has contributed to improving water quality and protecting rivers of ecological interest in France. At the end of the 1990s, a major hydraulic and ecological restoration scheme was launched by the stakeholders involved in the management of the Rhône following the publication of the first *Rhône Méditerranée Corse* SDAGE (river basin masterplan), which recommended the restoration of "a dynamic and free-flowing river". The planned restoration scheme consisted of increasing the minimum flows in bypassed channels downstream of dams, rehabilitating the *lônes*, i.e. former floodplain channels which host great biodiversity richness, and restoring the main pathways of fish migration (Lamouroux et al., 2015). Moreover, along the French Rhône and its main tributaries, several areas have protection status at a regional, national or European level, including Natura 2000 sites of Community importance (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) and special protection areas (Council Directive 79/409/CEE on the conservation of wild birds) (Olivier et al., 2022). The Rhône River corridor is therefore not only characteristic of a highly anthropised river, but is also a territory where there has been considerable investment in terms of measures for the management and the protection of nature. Current priorities, on both the use and the protection of water resources, are

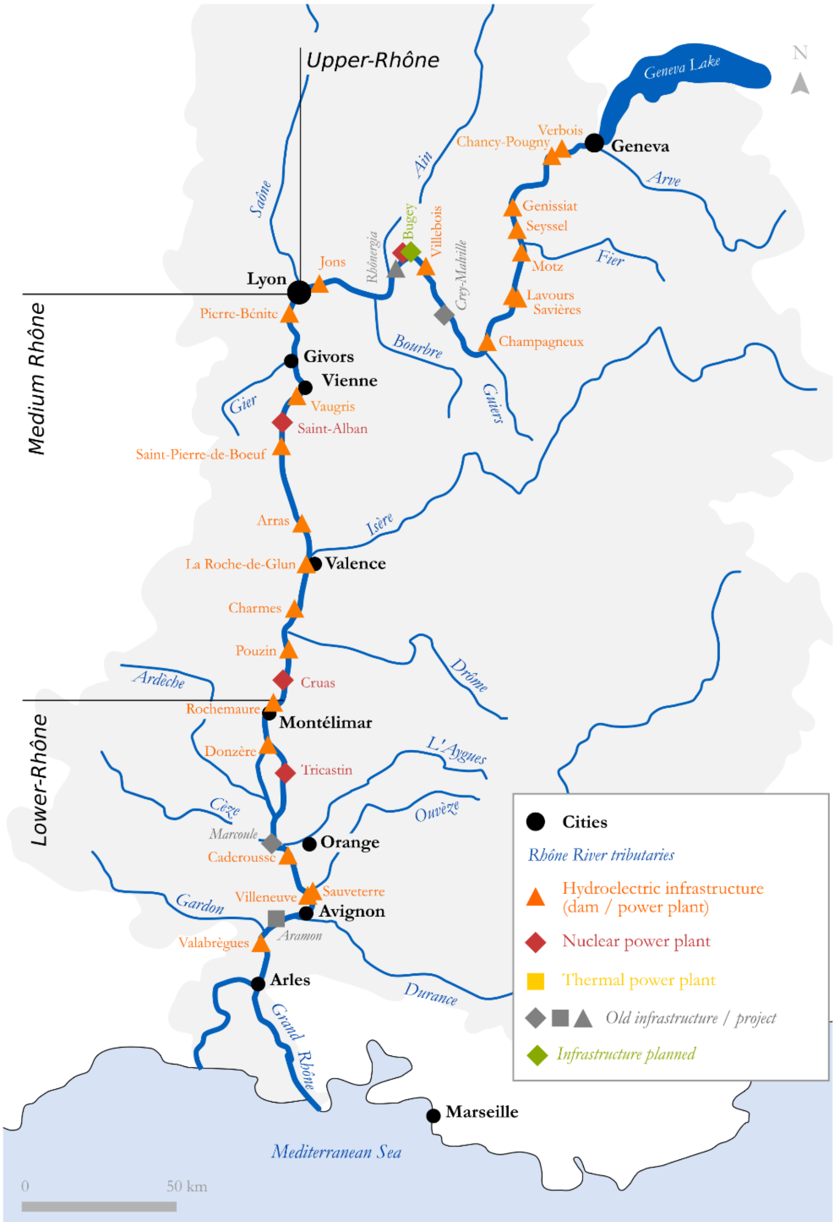


Figure 1. Energy production on the French Rhône river (past, present and planned infrastructures).

and will be impacted by climate change in progress, which results in changes in flood discharges, low-flow frequency and water temperature (Agence de l'Eau bassin Rhône-Méditerranée Corse, 2023). It is in this changing socio-environmental context that the Rhône Valley Human-Environment Observatory (*Observatoire Hommes-Milieux Vallée du Rhône*—OHM VR) is conducting its research.

2. The Rhône Valley Human-Environment Observatory: a geographic and interdisciplinary connection of the Rhône research

2.1. *The OHM VR conceptual framework*

The OHM VR was created in 2010. It was designed to connect communities of researchers working respectively on the southern and the northern reaches of the Rhône River. The observatory thus represented a way to consider the river over its entire course and to create a dialogue between research works that had previously been carried out in one or other part of the river, with no existing space for exchange. The geographical extent of the OHM VR covers the French river course from Lake Geneva to the Mediterranean Sea, i.e. a 534 km long reach. The space studied includes the channel, the banks, the floodplain and the delta. The creation of the OHM VR offered the means to develop exchanges between scientific disciplines. The aim was to find common research issues in order to develop a dialogue between all the environmental sciences, i.e. the "sciences of the Earth, life, humankind and societies" (Chenorkian, 2020) working on the Rhône River. To this end, the conceptual framework of the OHM VR was built on the basis of the ternary concept "structuring fact", "disrupting event" and "focal object" characteristic of OHM (Chenorkian, 2020; Chenorkian, 2023). The "structuring fact" is defined by the socio-ecological framework of a highly anthropised territory. In the case of the Rhône River, this means 175 years of hydraulic engineering which fundamentally altered the fluvial hydrosystem in response to the devastating floods of 1840 and 1856, the river was rectified along most of its course by means of embankments, from the Savoie department to the Mediterranean Sea. It was then regulated from the end of the 19th century with the construction of a complex system of longitudinal and transversal structures (*Casiers Girardon*) along the whole continuum downstream of Lyon, to achieve a shipping channel with constant depth (see Figure 10). The effects of these engineering works were to alter the river's geomorphology and sediment inputs in the delta and along the Mediterranean coasts. A second period, extending from the 1930s to the 1980s, consisted of the construction of twenty-one hydroelectric facilities including dams and canals. These also served to provide water for irrigation and to promote navigation. Other regulations along the Rhône River are dedicated to the water supply for industrial processes and for the cooling systems of nuclear power plants (Bugey, Saint-Alban, Cruas, Tricastin; see Figure 1). In the 1980s, the Rhône thus became a highly regulated river where all natural processes were disturbed. The "disrupting event", which is the second element of the conceptual framework of the OHMs, is defined by an event that disrupted the spatio-temporal trajectory of the socio-ecological framework. Floods that occurred in the Lower Rhône in the early 1990s and 2000s caused extensive damages that had a profound impact on local residents and all river stakeholders (Comby, 2015). The French State and the local authorities undertook a reform of the Rhône management, after examining the social, health, security and environmental consequences of the historical engineering works. As the first inter-regional development plan for the river, the *Plan Rhône* was signed in 2007 with the aim of introducing a "global" and "sustainable" management system, to replace the sectoral management system[1]. This paradigm shift in the Rhône River management constituted the disrupting event of the OHM VR. The "focal object", which is the last element of the ternary conceptual framework, is defined by the highly anthropised river corridor impacted by this new orientation in terms of public policy (Figure 2). This element is particularly well-suited for testing interdisciplinary research approaches to meet the socio-economic issues raised by the operational implementation of the sustainable management of the Rhône River.

The community of researchers brought together in the OHM VR device has set the objective of studying "the responses and socio-environmental adaptations in the Rhône River corridor following a change in the mode of river management" (Piégay and Barthélémy, 2014). Research was programmed with a view to exchange with operational stakeholders: the regional environmental management department (DREAL), the river basin water management agency (*Agence de l'Eau Rhône-Méditerranée-Corse*), the publicly-owned company to develop the Rhône River (*Compagnie Nationale du Rhône*—CNR), the national electricity company (EDF), river syndicates, nature reserves, etc. The research also aimed to include local residents, all of these providing scientific support to analyse the new *Plan Rhône* management system. More generally, the Rhône context and the conceptual framework of the OHMs have enabled to produce knowledge of the contemporary challenges regarding the integrated management of fluvial hydrosystems in a context of global change.

[1] https://www.plan-rhone.fr/.

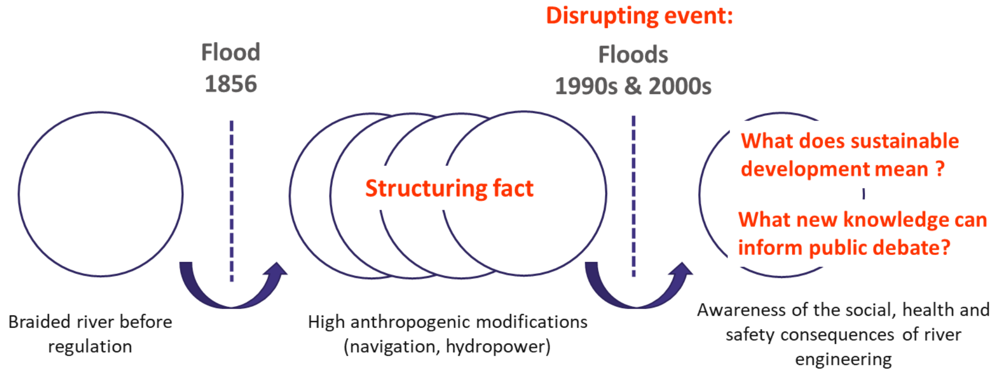


Figure 2. Conceptual framework of the OHM VR: radical change in the river management following floods of the 1990s and 2000s which gave rise to the implementation of a sustainable development policy and commitment by the actors to the *Plan Rhône* (Piégay and Barthélémy, 2014).

2.2. *The OHM VR research within the Rhône scientific ecosystem*

The research carried out by the OHM VR device is part of a particular institutional context, specific to the history of scientific production on the Rhône River. Its creation responded to the need to better interface major partnership research programs and scientific facilities working in the southern and the northern Rhône sectors, while broadening the thematic fields studied to better meet the challenge of integrated river management. This led us to mobilize the humanities and social sciences (SHS) in particular, given the complexity of the actors involved and the numerous environmental issues raised by researchers at the various sites and observatories in the Rhône Basin. This also enabled us to relaunch the site *Axe Rhône* of the existing *Zone Atelier Bassin du Rhône* (ZABR) for the Rhône River corridor, which had stalled due to a lack of collective projects. The OHM VR is now one of the nine sites and observatories in the *ZABR* (scientific platform from the Ecology & Environment Institute of the National Research Centre—CNRS; *Centre National de la Recherche Scientifique*). This structure makes it possible to collaborate with other researchers on the Rhône basin scale. The OHM VR incorporates three long-term research programs: (1) the RhônEco program[2], a unique ecological observatory that has been focused on the scientific monitoring of the hydraulic and ecological restoration of the Rhône since 1998, (2) the Rhône Sediment Observatory (*Observatoire des Sédiments du Rh*ône—OSR)[3], whose objective since 2009 has been to produce knowledge of the hydro-sedimentary functioning of the river and associated contaminant fluxes, and (3) the research platform of the Crépieux-Charmy water pumping field, labelled *Site d'Etude en Ecologie Globale—Milieux Anthropisés* (SEEG-MA; Research site in global ecology—anthropised environments) by the CNRS in 2019.

When it was set up, the OHM VR benefitted from the presence of two dynamic university sites, Lyon and Aix-Marseille, and an already structured and interdisciplinary community working on the Rhône River. While geography was one of the first disciplines to take an interest in the functioning of the river from the end of the 19th century, the 1960s saw the emergence of research in chemistry on water quality (following pollution accidents) (Bouleau, 2014). Ecology, particularly hydrobiology, and fluvial geomorphology have been mobilised since the 1980s within the framework of the *Programme Interdisciplinaire de Recherche sur l'ENvironnement* (PIREN) *du Haut-Rhône* (Interdisciplinary Research Program on the Environment of the Upper Rhône), launched by the CNRS and the French Ministry of the Environment to study the river's ecology in the context of hydroelectric development (Roux, 2014). His program notably saw the emergence of the four-dimensional

[2]https://www.rhoneco.fr/.

[3]https://observatoire-sediments-rhone.fr/.

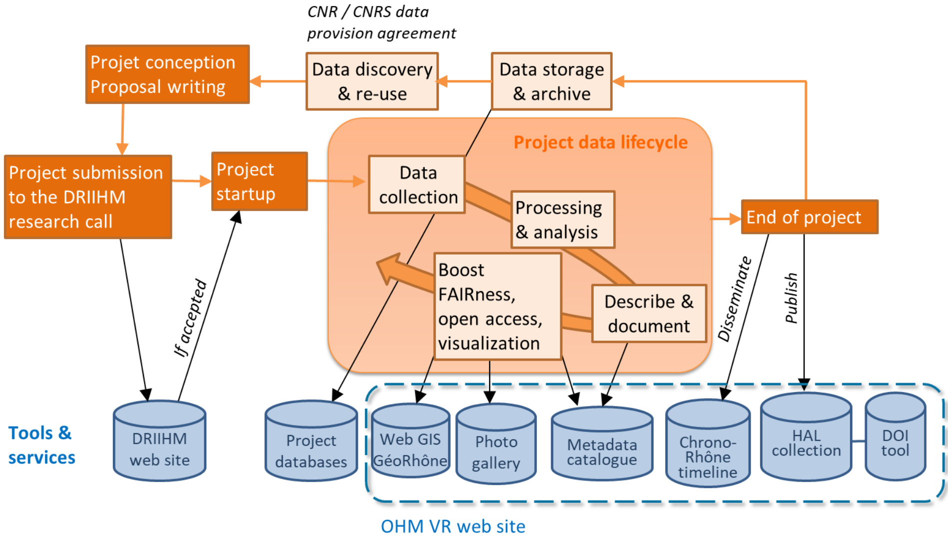


Figure 3. Scheme of the Research Data Infrastructure supporting the OHM VR (adapted from Arnaud, Lerigoleur, et al., 2020).

fluvial hydrosystem concept (Amoros and Petts, 1993), which was adopted by water actors on the national scale. The social sciences, in particular sociology and anthropology, became involved later in the Rhône scientific ecosystem (Chabenat, 1996; Barthélémy and Olivier, 2024). As the Lower Rhône, the Camargue delta and the Upper Rhône are the most studied parts of the river, the OHM VR community has been made up of these pools of researchers in order to share their knowledge at scientific seminars and explore new scientific questions developed in dialogue with the river stakeholders and funded mainly via the OHM VR call for projects.

2.3. *Numeric tools for sharing and promoting the Rhône research outputs*

A research observatory serves as an ideal setting for the long-term generation, exchange, and sharing of information and knowledge (Libourel et al., 2009). However, the multidisciplinary and complex nature of socio-ecosystems makes it challenging to develop tools to help research teams to work together effectively and to transfer scientific knowledge to decision makers and the general public. A Research Data Infrastructure (RDI) (Latif et al., 2019) has been developed over the years within the LabEx DRIIHM to provide tools and services for the storage, visualization, and dissemination of heterogeneous datasets produced by the OHMs (Arnaud, Lerigoleur, et al., 2020). The OHM VR early developed several tools to meet specific needs following the pioneer ZABR investment to inform, store and share data (Figure 3): metadata catalogue, webGIS GéoRhône, online and desktop databases (BDOH, ENS-Observatoires), photo gallery, and recently, the spatio-temporal interactive application (timeline) Chrono-Rhône that describes significant events in the socio-ecological trajectory of the Rhône River.

The challenge for an RDI such as this lies in maintaining technical skills (IT and geomatics engineers) over the long term, as well as offering permanent human assistance to help researchers in achieving a gradual cultural shift towards open science practices. However, if these numerical tools receive regular input, they can become powerful communication tools that can be used as quantitative indicators of the scientific production of the observatory. The documentary portal of the OHM VR currently contains 793 documents. A textometric analysis carried out on the metadata sheets published by the researchers running OHM VR projects between 2011 and 2024 (n = 95 metadata sheets; Figure 4) shows that the OHM VR produces data throughout the entire French Rhône and its tributaries. Some sectors are more investigated, e.g. the river downstream of Lyon and the

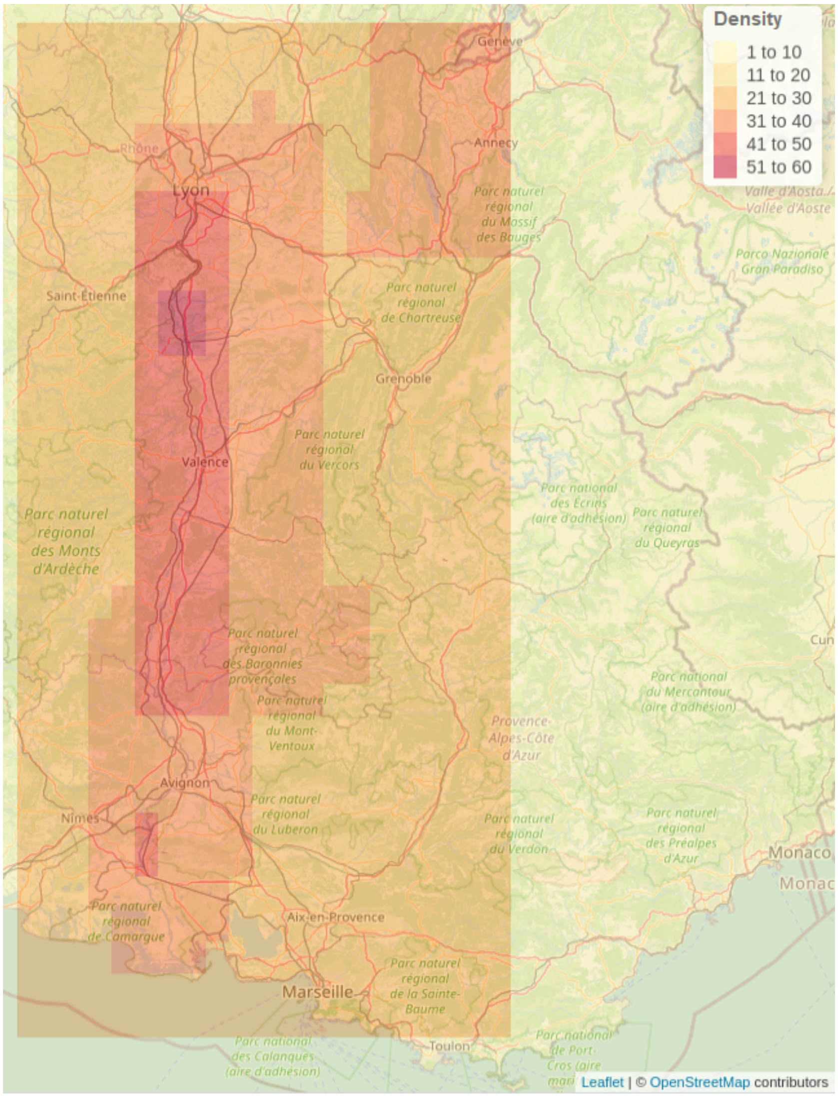


Figure 4. Geographical extent of the data produced and collected in the OHM VR between 2011 and 2024 ($n = 95$ metadata sheets).

Upper Rhône between Lake Geneva and Brégnier-Cordon.

The free keywords indicated by the researchers highlight the predominance of *casiers Girardon* and cartographical archives, and to a lesser extent, the datasets related to sedimentation, vegetation, floodplain, pollution, discourse, interviews and press (Figure 5). The OHM VR as a platform that federates research on the Rhône is also visible, with datasets that have been produced in shared works with the OSR or RhônEco programs.

3. An interdisciplinarity approach organized to question the implementation of sustainable development of the Rhône River

The political, social and economic crisis triggered by the floods of the 1990s and 2000s led to the creation, in 2004, of the "*Plan Rhône*" Interregional Project Contract, designed to provide local territories with the financial and other resources needed to implement what is known as global management or sustainable development. In the first *Plan Rhône*

Figure 5. Word cloud based on free keywords in metadata sheets (occurrence ≥ 2). The terms "Rhône" and "OHM VR" have been removed to avoid distorting the figure.

(2007–2013)[4], sustainable development is defined (p. 7) as "a project capable of making the most of the territory's potential, managing the constraints which it is subject and preserving its environmental assets and the quality of life of its inhabitants"[5]. While river development in the post-war years was mainly focused on using the resource for productive purposes, the 1970s–1980s were marked by environmentalist movements at national and local levels, which led to the initiation of research and policies related to nature protection (Barthélémy and Souchon, 2009). The "global sustainable development project for the river and its valley" advocated by the *Plan Rhône* (p. 3)[6] would then introduce a new phase, seeking to reconcile human uses and ecological issues. To respond to this disrupting event and to study the possible modalities of this sustainable development, the OHM VR has been structured with transversal research themes, potentially relevant to several scientific disciplines and enabling the interdisciplinary "cultural melting pot" specific to the OHMs device to function (Chenorkian, 2020).

3.1. *Structuring and evolutive research themes*

The lifetime of the OHM VR allows us to look back over almost 15 years of operation. This offers very clear evidence of the necessity of this long timeframe to establish both a community of researchers who are geographically and thematically distant, and common knowledge challenges. Between 2011 and 2014, the research themes rapidly increased from three to six (Figure 6).

The first three themes were focused on: (1) study and management of "constructed" alluvial margins, (2) stakeholders' perceptions and representations of the risks and challenges of the Rhône development, and (3) approaches to modeling and predicting change. A particular investment was made on the issue of dismantling "constructed" alluvial margins, i.e. the river banks inherited from the Girardon engineering works (Thorel et al., 2018). This issue is exemplary of the exchanges between researchers and river management stakeholders, as it is directly linked to concerns regarding to Rhône flood mitigation and river restoration issues (see Section 4). Three years after the creation of the OHM VR, it became clear that we needed to diversify our scientific perspectives in order to broaden the spectrum of the management paradigm shift, embracing a wider understanding of the socio-ecosystem and the main environmental issues associated with the river. Six priority themes were then identified (Figure 6):

(1) *Geo-historical trajectory and temporal disruption of 2003.* The aim of this theme is to resituate the change in the management paradigm within a longer time perspective, and to integrate the evolutions of the socio-ecosystem into its physical, biological, chemical and social dimensions. The OHM VR conceptual scheme (Figure 2) provides a simplified temporal image of the historical domestication of the river over a period of around 175 years. The aim is to specify this trajectory, and even to reveal whether earlier trajectories may have influenced current socio-environmental dynamics, such as the detailed establishment of infrastructures and their effects on sediment dynamics. An additional aim is to identify other temporal disruptions which might have contributed to the advent of the *Plan Rhône*

[4] https://www.planrhone.fr/fileadmin/medias/Publications/General/Contrat_Projets_Interregional_Plan_rhone_2007-1013.pdf.

[5] "Un projet à même de permettre tout à la fois d'exploiter au mieux les potentialités de ce territoire, de gérer les contraintes auxquelles il est soumis et de préserver ses richesses environnementales et le cadre de vie de ses habitants".

[6] "Projet global de développement durable pour le fleuve et sa vallée".

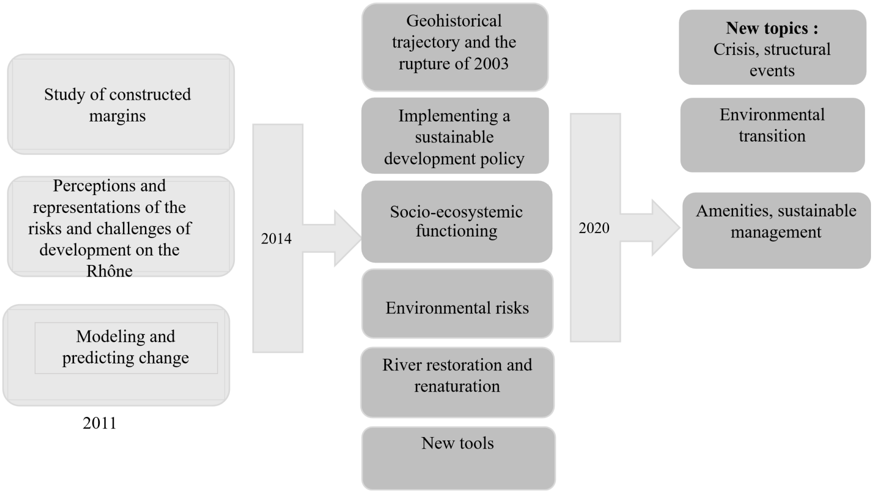


Figure 6. Evolution of OHM VR research themes between 2011 and 2020.

(heatwave of 2003, smaller-scale floods, historical or accidental pollution, etc.).

(2) *Implementing a sustainable development policy.* Presented as a sustainable development policy, the *Plan Rhône* was intended to renew actions related to the river, with a focus on transversality and shared governance. Has public action brought about changes in the way the river is managed, particularly in terms of environmental policies, economic development and social relations between stakeholders? What points of convergence or divergence can be detected in these interactions?

(3) *Socio-ecosystemic functioning.* The aim of this theme is to structure a collective, systemic and integrated approach around a shared, evolving and interdisciplinary conceptual scheme describing or representing the way in which the socio-ecosystem functions. In a sense, this is the core of the reflexive approach, which integrates ecological dimensions by considering the various compartments: fauna and flora, aquatic and riparian, hydromorphological, chemical and ecotoxicological, and socio-economic. The aim is also to produce methodological frameworks and, potentially, indicators (physical, biological and socio-economic) to diagnose the state of the river corridor, its natural or constructed alluvial margins and the services provided by the river.

(4) *Environmental risks.* Risk management is a major issue for the OHM VR. These include flooding, the development of invasive species, climate change and pollution. The aim is to quantify these risks by measuring their potential impact on the socio-ecosystem, and also to examine how they are perceived and represented by local residents, and the solutions envisaged by the various stakeholders.

(5) *Restoration and renaturation.* At the time this theme was defined, restoration objectives for the Rhône were evolving with the implementation of the river bed re-widening scheme (see Section 4), which led to a reconsideration of the restoration actions launched previously. These restoration actions no longer focused solely on increasing minimum flows or rehabilitating *lônes*, but also on removing bank protection structures, re-widening the riverbed and revitalizing sediment transport as a result of lateral erosion or artificial gravel supply.

(6) *New tools for assessing human-environment interactions.* The aim of this sixth theme is to promote research on innovative tools for characterizing, assessing and predicting socio-ecosystem trajectories, as well as for compiling and sharing information with various stakeholders, thus enriching the observatory's research data infrastructure (Figure 3).

The six themes defined here cover the full range of issues involved in the new management of the river. This structure of six themes has persisted until today, however, their content has changed over time, in particular following the re-editions of the *Plan Rhône*:

whereas the first edition of the plan (2007–2013) emphasized the issues of "global project" and "sustainable development", the second edition (2015–2020)[7] rather highlighted the notion of "integrated management", notably through a new axis entitled "Multifunctional management of the waters and environments of the Rhône and Saône rivers". The notion of "transition" (ecological, energy) also made its appearance in the second *Plan Rhône*. The third current plan, now called the *Plan Rhône-Saône* (2021–2027)[8], confirms this evolution by displaying a "new ambition": "the ecological and climatic transition of activities and territories". These semantic shifts thus led the OHM VR community to revise its research themes in 2020 (Figure 6) in order to better follow and question the changing concerns of river managers.

From a scientific point of view, the creation of the OHM VR has enabled the emergence and refinement of certain research questions specific to the observatory: how to go beyond the segmented legacies of previous management and envisage a "human-environment" co-evolution based on the knowledge and indicators defined in the OHM VR? How does the socio-ecosystem function and react to new management practices and certain environmental conditions? How do public and private action support these changes? What about the relationship with the river and the expectations of local residents?

3.2. *Thematic analysis of the OHM VR research projects*

Figure 7 shows the research themes addressed in the projects selected during the first period of operation of the OHM VR (between 2010 and 2016, the year of its first scientific evaluation), and during the second period, from 2017 to 2024. This corresponds respectively to 36 and 44 projects funded during each period, including 13 inter-OHM projects. The number of projects increased overall for all research themes, with the exception of the most widely covered theme on the socio-ecosystemic functioning, which decreased slightly during the second period. Projects on environmental risks and geo-historical trajectory occupy second place in terms of funded projects. Depending on the project, the risk theme is addressed from the angle of flooding, climate change, water resources, water or sediment pollution, and ecotoxicological risks, with some projects also considering risks to human health. Projects on integrated river management (theme 2), with a focus more specifically on the shift in management paradigm at the core of the OHM VR, and concerning in priority the field of SHS, were strengthened during the second period.

An analysis of specificities conducted on the project titles confirms this thematic division and its evolution. Figure 8 highlights the importance of projects funded in the first period in the *casiers of Girardon*, and also the socio-ecosystemic functioning and the risks through climatic processes. The second period exhibited more research on the geo-historical trajectory ("19th century", "Little Ice Age"), as well as on restoration and management issues.

3.3. *The success of the interdisciplinary dialogue*

Over the 15 years of operation of the OHM VR, the consolidation of finalised research questions, more related to the river stakeholders, was also highlighted by an analysis of the publications on the Rhône River carried out by Poirier et al. (2023). This involved a content analysis of 97 peer-reviewed scientific articles (71 were written in English and 26 in French) written by ZABR and OHM VR researchers working on the river and published between 2006 and 2016. The authors show that the appearance of articles related to certain societal concerns is concomitant to the advent of the OHM VR in 2010, suggesting that the OHM VR acted as a catalyser to consolidate and develop this type of research. Fairly symmetrically with the research themes most investigated by the OHM VR (Figure 7), the articles studied by Poirier et al. (ibid.) are mostly divided between physico-chemical aspects (53% of articles), biological aspects (32%) and societal aspects (11%). On the other hand, Poirier et al. (ibid.) show that the development of research works focused on societal issues was also supported by the ZABR and the

[7] https://www.plan-rhone.fr/fileadmin/medias/Publications/General/CPIER_2015_2020_SIGNE_VDEF_BD.pdf.

[8] https://www.plan-rhone.fr/fileadmin/medias/Publications/General/CPIER_Sept23_enPages.pdf.

Figure 7. Number of research projects funded by the OHM VR, by theme and by period (a project can be part of several themes).

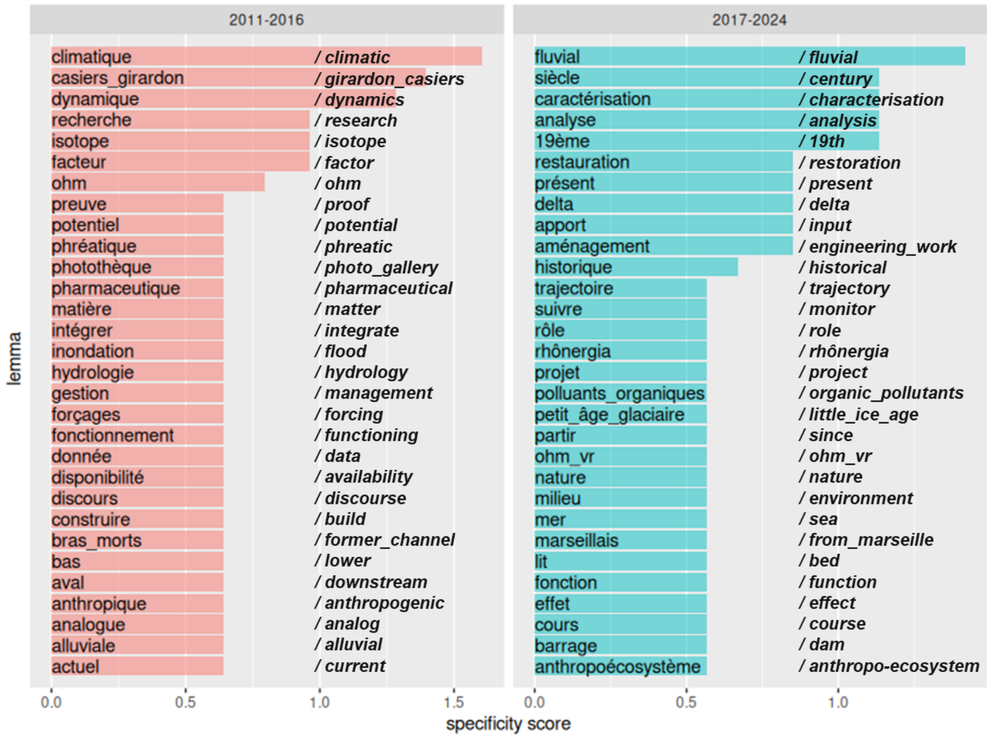


Figure 8. Analysis of specificities from the titles of 81 projects funded by the OHM VR: (A) between 2010 and 2016; (B) between 2017 and 2024.

co-construction of projects with the *Agence de l'Eau Rhône-Méditerranée-Corse* (e.g., the RhonAVel'Eau project).

In order to encourage interdisciplinarity, the OHM VR has from its creation requested that projects submitted to the APR be interdisciplinary, while remaining open to disciplinary proposals with the aim of encouraging the emergence of unexplored research fields. Thus, all projects funded by the OHM VR between 2010 and 2024 involve at least two disciplines,

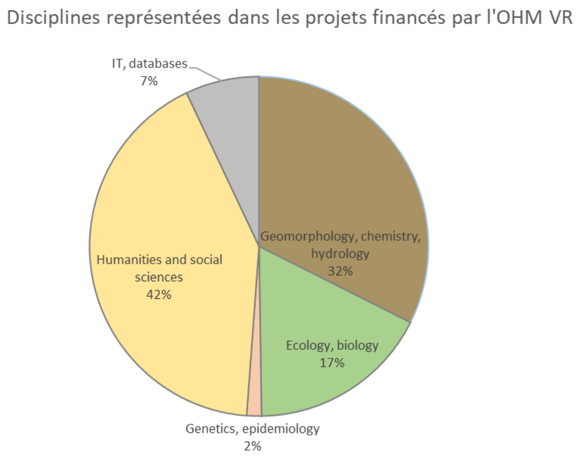


Figure 9. Disciplines involved in projects funded by the OHM VR.

within the same domain (e.g., geography and sociology within the SHS) or between distinct domains (e.g., chemistry and history) (Figure 9). In this context, we can reasonably hypothesize that interdisciplinary projects combining SHS, Engineering Sciences and Natural Sciences emerge after a few years of operation of the OHM device, the latter playing the role of catalyser as conceptualised by Chenorkian (2020).

Another fundamental aspect of the OHM device is exchanges with local stakeholders. This is particularly well-developed on the Rhône River, due to the history of scientific work and its close links with operational actors. According to Tress et al. (2005), the research carried out in the OHM VR is part of partnership between researchers and non-academic actors in the co-production of knowledge. This is illustrated by the RhônEco and OSR programs, which for over fifteen years have been co-constructed by researchers from different disciplines, CNR engineers, the *Agence de l'Eau Rhône-Méditerranée-Corse* and other stakeholders to produce knowledge to meet the challenges of integrated river management, thus constituting unique programs of their kind on an international scale. These collaborations are also visible in the projects funded by the OHM VR, which in recent years has accounted for several projects involving both scientists and river managers.

In the following section, we have chosen to develop two case studies that are representative of the implementation of interdisciplinarity on the Rhône River, the first involving dialogues between researchers from different disciplines, and the second involving exchanges between researchers and river managers.

4. Two interdisciplinary case studies: the analysis of the PCB crisis and the dismantling of the Rhône's constructed margins

4.1. *Examine pollutant crises over the long term: from PCBs to PFAS*

Most of the research carried out on the theme of pollution in the OHM VR has been done on an interdisciplinary basis, involving the environmental sciences in the broadest sense of the term. This research associates disciplines from the life and earth sciences (sedimentology and geochemistry, for example), or results from a dialogue with the SHS (sociology, social geography). Publications, in particular that of Gramaglia and Babut (2014) on PCB pollution of the Rhône, have contributed to highlight the close and complex links that exist between the often toxic chemical substances resulting from our modes of industrial production and consumption patterns, and the social, political and economic frameworks that consider them differently according to the periods and social groups concerned.

Annual scientific seminars are an important part of the OHM device, providing an opportunity for researchers to exchange ideas. It was at the OHM VR annual scientific seminar in 2020 that the issue of PCB pollution in the Rhône was debated again, some ten years after the crisis of 2008. While surveys of users and local residents show the permanence, since the first PCB alert in the 1980s, of concerns about the presence of these pollutants in the sediments and fish of the Rhône (ibid.), measurements carried out as part of the OSR program converge, on the contrary, towards a decrease in their concentration since the 2000s (Mourier, Barthélémy, et al., 2025). This exchange between experts in sociology, sedimentology and geochemistry highlighted the discrepancies between certain apprehensions of non-scientists and scientific measurements of pollution in the environment. Among riverside residents of the Rhône, the issue of pollution, and in particular PCBs, occupies a special place in social representations. It is a stabilized representation, forming part of what Jean-Claude Abric calls "the hard core" of representations (1987), stemming from a long history of pollution on the Rhône, exacerbated by the period of rediscovery and management of the PCB crisis in the 2000s. Indeed, the accidental rediscovery of the presence of this pollutant in two fish upstream of the Lyon conurbation generated, from 2005 onwards, a large-scale process of publicization, controversy and regulation which went beyond the Rhône basin, since it notably led the French State to set up a national PCB action plan in 2008 (Comby et al., 2014). Thus, as is often the case with pollution issues, knowledge needs far exceed monitoring capacities, and the managers invested in this type of crisis are often different from those managing the *Plan Rhône*.

Ongoing concerns about PCBs can still be observed today, for example during the consultations organized between December 2023 and February 2024 by the *Commission Nationale du Débat Public*, concerning a new hydroelectric dam project upstream of Lyon[9], which has since been abandoned. Local residents and users expressed their concerns about the presence of PCBs in old sediments in the area affected by the dam, which is geographically close to the plant responsible for PCB production, and their possible release into the environment. However, since 1997, concentrations have been in decline throughout the river continuum, including upstream of Lyon, and are even below regulatory thresholds (norms established for benthic invertebrates) (Mourier, Desmet, et al., 2014; Dendievel et al., 2020).

The discussions that took place during the OHM VR seminar in 2020 continued and led an interdisciplinary group of researchers to write a chapter in the collective work "*Contaminations, contaminants, contaminer*" (Contamination, contaminants, contaminate), coordinated by the LabEx DRIIHM (Mourier, Barthélémy, et al., 2025). The cross-disciplinary approach between SHS, sedimentology and geochemistry firstly highlighted the need to work on a long time scale in order to compare environmental and socio-political trajectories. Indeed, the detection of PCBs in sediment cores makes it possible to track their presence in the environment over several decades. However, this temporality does not correspond to their socio-political acceptance: the toxicity of PCBs on the environment and human health was debated for "only" fifteen years or so (out of a period of 80 years since they were first marketed in 1930), in the 1980s, 1990s and, above all, between 2005 and 2011. This result underlines the time lag between the "materialization" of pollution (measurements and monitoring) and society's assumption of responsibility for this materiality when it becomes problematic in terms of public health and environmental protection, and breaks away from the simple commercial use of the substance in question.

For Gramaglia and Babut (2014), even if the PCB crisis of the 2000s had moved some lines in the public handling of pollution, there were still many administrative, scientific and political obstacles to overcome before we could imagine other ways of managing current and future industrial pollution, other than in a short period of socio-environmental crisis. History may well be proving them right, with the advent of a new crisis around the Rhône, regarding PFAS. These "eternal pollutants" include over 4000 chemical compounds with anti-adhesive, waterproofing and heat-resistant properties, used in many industrial fields and in everyday consumer products (Paul et al., 2009). In May 2022, a *France Télévisions* documentary revealed the abnormal presence of these pollutants in the vicinity of a PFAS-producing industrial complex in Pierre-Bénite, with measurements carried out in the air, soil, drinking water and breast milk of local residents. Since then, this media scandal has generated a movement of mobilization on the part of local residents and nature protection associations, as well as State services and local authorities (Le Naour and Thomas, 2022). It has also brought to light scientific work in ecotoxicology and geochemistry carried out by Rhône researchers in the 2010s, which already showed major contamination of all compartments of the fluvial hydrosystem over several tens of kilometres downstream of the industrial complex (Babut et al., 2016; Mourier, Labadie, et al., 2019), but which had not been followed by any action on the part of the public authorities.

In this context, the interdisciplinary research carried out at the OHM VR and its and its openness to new research fronts may enable the observatory to take on a "whistle-blower" role, or at least to reveal

[9] Field notes, Carole Barthélémy.

the mechanisms of socio-environmental crises that risk being repeated in time and space (Le Naour and Thomas, 2023; Mourier and Arnaud, 2023).

Last, the topic of pollution has led to joint projects with other OHM: two in the south of France: Bassin Minier de Provence and Littoral Méditerranéen, and an International OHM, Estarreja (Portugal). Six inter-OHM projects focused on two perspectives. The first was to compare measures of pollution in different industrial pollution contexts between the Rhône and Estarreja sectors[10]. The second analytical perspective involved questioning lay people's relationships to pollution, by bringing together scientific experts and activists from associations committed to gaining recognition for pollution and the associated risks[11]. These projects between OHMs enable comparisons to be extended, for a better understanding of pollution-related "crises".

4.2. *When the OHM VR responds to public action on flood management*

Built between 1884 and 1938, the so-called *casiers Girardon* (named after the engineer who supervised the works) aimed to improve the navigability of the Rhône River between Lyon and the Mediterranean Sea. Their main function was to stabilize a navigation channel both laterally and vertically, by promoting the movement of sediments that "clogged up" the channel and their deposition within *casiers* constructed along the riverbanks (Figure 10).

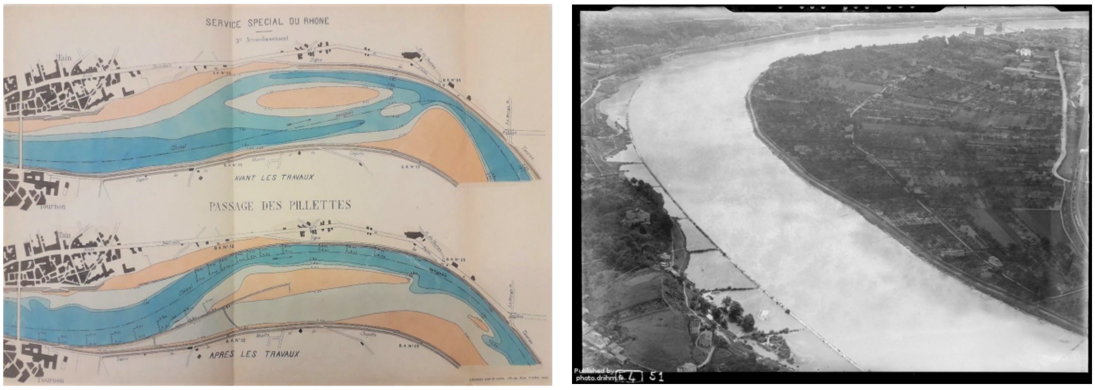
The Girardon works fulfilled their function, as over time they led to channel incision, a reduction in channel width, and the infilling of aquatic *casiers* with coarse and fine sediments (Tena et al., 2020; Vauclin, Mourier, Tena, et al., 2020; Seignemartin et al., 2023). These sediments, particularly after the reduction of flows downstream of diversion dams, provided fertile surfaces that were rapidly colonised by the alluvial forest (Janssen et al., 2021). These impacts, which resulted in an increased disconnection between the river and its floodplain, had been demonstrated by researchers, especially geomorphologists, since the 1990s. The Pierre-Bénite reach, located south of Lyon, is a site particularly affected by the hydromorphological impacts of the Girardon and damming works. It serves as a pioneering site for ecological restoration, with actions initiated by the CNR as early as 1999–2000, including a tenfold increase in the minimum flow downstream of the dam and the rehabilitation of disconnected *lônes* (Collectif RhônEco, 2016).

This body of knowledge was to be solicited following the catastrophic floods that affected the Lower Rhône from December 1 to 5, 2003. The tributaries, impacted by heavy rainfall at that time of year, contributed to a flow of 11 500 m^3/s measured at Beaucaire (a 100-year return period). The damage in the affected areas was estimated at one billion euros. The implementation of a global flood prevention strategy was then partly based on consultations jointly organized by the State authorities and the three Regions bordering the Rhône between 2004 and 2006, to respond to the outcry and the anger of local residents (Barthélémy and Souchon, 2009; Comby, 2015; Guerrin, 2014). These consultations gathered several hundred people. Representatives of associations formed in reaction to the floods, as well as individuals, initially expressed themselves with strong emotion. A common theme in their remarks was criticism of the CNR for not having sufficiently "dredged" the river and for allowing it to "fill up" (Barthélémy and Souchon, 2009).

These two terms refer to an argument that was once widely shared, linking the sedimentation process in the riverbed to the acceleration and amplification of flooding. This argument was based on empirical knowledge held by local elected representatives and residents, stemming from their observations, such as a damaged bridge pile, a *lône* that had filled up, or a transformation in the course of the river observed during previous floods. Local memory was thus mobilized, generating criticism of the French State, via the CNR, for allegedly neglecting the management of the Rhône and its tributaries, a feeling intensified by the occurrence of the flood. Observations made during the consultations showed that the anger was gradually attenuated when representatives from the State services and the CNR provided explanations. The regulatory framework

[10] Project « Évaluation des risques écotoxicologiques et pour la santé humaine de contaminants organiques dans la zone d'Estarreja et dans des friches industrielles de la vallée du Rhône », JP Bedell, 2016.

[11] Project « Pollutions, mobilisations environnementales et territoires industrialisés : les cas de Fos sur Mer, de Gardanne et du littoral sud marseillais », J. Rouchier, I. Laffont-Schwob, 2019.



(A) (B)

Figure 10. (A) Map of the *Passage des Pillettes* at Tain-l'Hermitage before and after the Girardon works, presented at the *Exposition Universelle* of 1889. Source: Rhône Department Archives (Souquet, 2022). (B) Aerial view from July 1920 showing the Girardon aquatic *casiers* on the left bank of the Rhône at Vienne. Source: IGN, *Remonter le temps*.

was clarified, including the prohibition of gravel extraction from the riverbed since the 1992 Water Act, as well as the administrative responsibilities of the CNR, which is tasked with ensuring that its facilities do not "worsen the waterline". Scientists, particularly geomorphologists, who have been working for several years in the field of river restoration, were also solicited and they spoke publicly. They explained why dredging coarse sediments was unnecessary, as small or medium-scale floods could take could do it (Provansal and Bravard, 2009). However, they debated the issue of fine sediments, which are present on the constructed margins inherited from the Girardon works and which could indeed be removed (Bravard et al., 2005). This argument, expressed by a scientist, gained consensus as it partly addressed the representations and expectations of local residents, who wished to "dredge" the river (Thorel et al., 2018). The CNR supported the proposal to "reactivate" the alluvial margins, which fell within its mission of global river management. It can also be assumed that proposing a concrete action, which seemed achievable within a reasonable timeframe, acted as a common value in the post-flood Rhône context (Guerrin, 2014). For the OHM VR, these discussions helped identify the need for fundamental knowledge and the necessity of defining indicators, which led to the production of numerous doctoral theses and research projects on this topic. These research efforts thus allowed for questioning and redefining what initially seemed self-evident during the flooding crisis.

Proposed by the scientists, a master plan for reactivating the fluvial dynamics of the Rhône's margins was developed between 2009 and 2013. The aim was to improve knowledge of the impacts of the Girardon engineering works through the study of changes in fluvial dynamics, land use, topography, sediment dynamics, flooding, and the landscape over the past 150 years. The document identifies elements of vulnerability, ecological and patrimonial issues, and initiates reflections on the hydraulic feasibility of sediment remobilization through the widening of the Rhône's margins. This would involve, in by-passed sections, mobilize sediments stored on the margins to restore fluvial dynamics and increase the flow conveyance of the former river channel (Gaydou and Bravard, 2013).

However, before dismantling structures dating from the 19th century, the scientific community aimed to assess their potential effects in terms of sediment transport, as well as the impacts on existing biodiversity. In 2005, the (re)discovery of the Rhône pollution by PCBs added a degree of complexity to the project, as the potential remobilization of contaminated sediments stored on alluvial margins posed environmental and health risks. The studies revealed that pollutant stocks were generally higher in the sediments of secondary channels and in certain floodplain compartments compared to pre-engineering sediments. This can be attributed to a matrix effect linked to their finer grain size and the industrial era during which they were deposited (Vauclin, Mourier, Dendievel, et al., 2021). Indeed, the most concentrated pollutant stocks were found in sedimentation zones formed after the construction of dams (post-1970), along the river continuum downstream of Lyon to the confluence with the Isère. Although the quantified PCB stocks in certain areas are relatively modest compared to the industrial quantities rejected in the environment and transported by the river, they nevertheless represent a complex legacy to consider. Within the OHM VR, the funding of several doctoral theses (Räpple, 2018; Seignemartin, 2020), a postdoctoral project (Thorel et al., 2018), and around fifteen research projects have provided interdisciplinary insights into the functioning of constructed alluvial margins. The first major finding was the identification that the majority of the *casiers of Girardon* were terrestrialized (ibid.): 90% of the Girardon groyne fields exhibit aging and homogeneous riparian forest. The remaining 10% of structures that have maintained their aquatic features constitute *a contrario* "novel ecosystems". These functional ecosystems can serve as feeding sites for fish, carbon or nitrogen sinks (denitrification), and contribute to the diversity of riverine habitats along with their associated fauna and flora. The second major finding, published in 2018 (Thorel et al.), does not advocate for a single management approach for the Rhône's constructed margins. Instead, it emphasizes the integration of results from several disciplines: hydrology, geomorphology, ecology, chemistry, sociology, and geography. This interdisciplinary synthesis led to a conceptual model designed to support decision-making based on the full set of data acquired. As a result, Thorel et al. (ibid.) proposed four alternative trajectories for restoring the Rhône's river margins: (i) dismantling terrestrialized *casiers* with large volumes of potentially mobile bedload gravel and low levels of sediment pollution; (ii) dismantling terrestrialized *casiers* in cases with fewer benefits (mobile gravel) and higher risks (polluted sediment), but which would enhance riparian habitat diversity and decrease flood risks from the point of view of residents; (iii) reconnecting isolated aquatic *casiers*; and (iv) preserving aquatic *casiers* with suitable water quality and hydraulic connectivity to foster a more heterogeneous habitat mosaic.

It is noteworthy that flood risk was primarily considered in the public debate through the lens of perceptions held by residents and local elected representatives. The measured hydraulic effects of the Girardon works on water levels and peak flows, as well as the expected response of the restored channel, were not investigated by Gaydou and Bravard (2013), as no explicit feedback on this aspect had yet been identified (Thorel et al., 2018). This highlights that an integrated management approach for a socio-ecosystem must emerge from a consensus balancing biophysical processes and with societal expectations.

The master plan for reactivating the fluvial dynamics of the Rhône's margins was integrated into the SDAGE *Rhône Méditerranée Corse*. Dismantling work was first tested in 2016–2017 at the Péage-de-Roussillon Nature Reserve. In 2021, the first operational implementation was carried out on the Baix-Logis-Neuf reach, consisting of the removal of 880 meters of dikes and seven *casier Girardon*, the rehabilitation of a *lône*, and the artificial supply of 12 000 m^3 of gravel into the Rhône channel. Several reaches are currently in the planning stages (Pierre-Bénite, Saint-Vallier, Donzère). These works are accompanied by monitoring efforts co-designed and coordinated between the CNR and research teams from OSR and RhônEco programs.

The OHM VR, by facilitating dialogue across multiple disciplines, has contributed to producing not only knowledge but also a research approach that takes into account the inherent complexity of the Rhône River functioning. The management of the Rhône's constructed margins serves as a prime example of complex science for anthropo-ecosystems that can only be studied and managed from this perspective. This type of integrated approach is a key element of the interdisciplinarity practice demonstrated within the OHM. Through this example, we can also observe how and why research themes emerge and develop in the OHM, and how, depending on their degree of maturity, they are addressed in other research platforms of the Rhône scientific ecosystem, and/or integrated into new river management strategies, translated and adopted by managers. These research efforts have notably led to a revision of the Rhône restoration policy, initially proposed in the 1990s, by emphasizing a restoration approach more based on river processes.

5. Conclusion and perspectives: from one disruption to another …

The Rhône is the paradigmatic example of an anthropized river, whose physical, ecological, and social trajectories have been conditioned since the 19th century by human use, resource exploitation, and the perceptions held about the river. The Rhône has been marked by successive ruptures and crises that question not only the modes of river management but also the various impacts it has been subjected to, which in turn affect the sustainability of this socio-ecosystem. The disrupting event of the OHM VR raises questions about the socio-environmental significance of a management approach that prioritizes sustainability and the integration of key issues. Twenty years have passed since the catastrophic floods of 2003, revealing several conclusive elements.

A first key element relates to the capacity of the OHM VR to consistently address pollution issues and socio-ecological dynamics across multiple disciplinary fields. The research notably revealed a temporal gap between the production and use of industrial substances and the concentrations measured in the environment, alongside the socio-political crises that emerge. These findings highlight the complexity of risk interpretation by local populations and the necessity of taking control of these crises, beyond action plans, by the relevant State services. For both PCBs and PFAS, the persistence of long-chains compounds in sediments presents an additional challenge: their accumulation poses long-term risks and could undermine certain ecological restoration efforts that might remobilize these old stocks. This situation also puts pressure on drinking water production systems, confronted with the challenge of eliminating these persistent substances from water extracted from the Rhône's alluvial aquifers. Looking ahead, the work of the OHM VR opens the possibility of re-examining the conceptual framework of OHMs in order to better integrate the recurrent pollution-related crises and the stakeholders involved in their management.

A second key element of the OHM VR is related to the proposal and support for a new approach to ecological restoration that promotes fluvial dynamics based on processes without increasing flood risk. This evolution benefited from interdisciplinary research, intended to demonstrate the complex interdependencies characteristic of this type of project, to better assess induced risks, morphological adjustments and potential ecological responses of the restored river, while leaving space for managers to engage with these findings. The hydraulic and ecological restoration issues addressed in the specific RhônEco and OSR research programs have benefitted from the interdisciplinary environment of the OHM VR, particularly through insights from the social sciences. The participation of local residents and the uncertainties that may accompany restoration projects have become a more recent focus in the OHM VR (Cottet, 2022). Research and exchanges between disciplines find support in the call for projects of the LabEx DRIIHM, which offers smaller-scale projects that make it easier to take risks and explore new pioneering research fronts.

Approaches in the humanities and social sciences conducted in the OHM VR have provided an analytical perspective on the implementation of the *Plan Rhône*, particularly in terms of its shared governance objectives. The long-term period of observation reveals some achievements in the inter-region and inter-services modes of functioning, such as the effective technical and social management of flood risks, particularly in the Lower Rhône, and restoration efforts along the entire river. However, monitoring also highlights a political exhaustion, leading to a technical and administrative routinization of the *Plan Rhône-Saône* (Barthélémy and Comby, 2019).

Will the experience acquired from integrated management be able to address what are now the major challenges shaping the future of the Rhône River? The first challenge concerns a government decision in favour of reindustrialization and energy independency, within the context of meeting European greenhouse gas emission reduction targets. Therefore, the Rhône upstream of Lyon has been targeted by two major energy production projects, something that had not happened for forty years: a hydroelectric dam upstream of the confluence with the Ain (subsequently abandoned), and two new reactors at the Bugey nuclear site. How might these projects, announced in the name of the energy transition, impact the existing socio-environmental dynamics?

The second challenge, which the OHM VR is already working on, concerns the effects of climate change. While projections and models are beginning to clearly outline its potential impacts (Explore 2, 2024), what about the response of ecosystems, the sharing of water resource with cross-border issues, transformations in agricultural needs (ongoing discussions about extending the Aqua Domitia infrastructure, water intake towards Occitania to supply the *Pyrénées Orientales* (Barthélémy, Arnaud, et al., 2024)), and the growing desire to develop cooling spaces or even swimming areas in the cities [ARCO ANR project, 2024–2027]? The sustainable management of the Rhône River is therefore facing considerable challenges, and it will be essential to continue monitoring and supporting it within the OHM VR in this context of transition.

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