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# Water History

## From asset to threat: trajectory of sediment on the Rhône River (France)

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Abstract:	<p>Sediment is physical matter and, as such, is usually studied in the physical and natural sciences, such as chemistry, geomorphology, or hydraulics and hydrology. However, sediment is also deeply embedded in society and politics. Sediment flows are affected by river transformation and, in turn, affect river management. This article highlights the changing ways in which society has considered sediment in the Rhône River (France). In the early-modern historical period (16e-18e c.) sediment was generally considered a blessing. However, the contemporary evolution of the Rhône's industrialisation, river engineering, and governance has challenged this perspective. Today sediment is more likely to be viewed as a threat. The concept of the hydrosocial cycle is a useful framework within which to describe the variety of ways societies have understood river sediment. The variation is caused by, and in turn affects, the meaning and representation of sediment, the structure of land and water governance, the nature of sedimentary and water resources, and the materiality of sediment and water, mediated by technology. This article aims to open the issue of sediment to the social sciences through a dialogue between history, human geography, and political science.</p>	
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## History and politics of sediment management on the Rhône River

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## From asset to threat: trajectory of sediment on the Rhône River

### Abstract

Sediment is physical matter and, as such, is usually studied in the physical and natural sciences, such as chemistry, geomorphology, or hydraulics and hydrology. However, sediment is also deeply embedded in society and politics. Sediment flows are affected by river transformation and, in turn, affect river management. This article highlights the changing ways in which society has considered sediment in the Rhône River (France). In the early-modern historical period (16e-18e c.) sediment was generally considered a blessing. However, the contemporary evolution of the Rhône's industrialisation, river engineering, and governance has challenged this perspective. Today sediment is more likely to be viewed as a threat. The concept of the hydrosocial cycle is a useful framework within which to describe the variety of ways societies have understood river sediment. The variation is caused by, and in turn affects, the meaning and representation of sediment, the structure of land and water governance, the nature of sedimentary and water resources, and the materiality of sediment and water, mediated by technology. This article aims to open the issue of sediment to the social sciences through a dialogue between history, human geography, and political science.

**Keywords:** Sediment; Rhône; Hydropolitics; Perception; Hydrosocial cycle.

## Introduction

Sediment is an essential part of rivers, and they are also important for the society living near rivers. On the Rhône River (France), if sediment is today rather considered as a threat regarding quality and quantity issues, this was not always the case. This article highlights the changing ways in which society has considered sediment in the Rhône River (France), comparing the early-modern historical period (16e-18e c.) and today.

The Rhône is a major river in France, rising in Switzerland and running towards south-eastern France, ending in the Mediterranean Sea by the Camargue delta (Figure 1). On many French maps the river appears to start at the French border. However, the issue of sediment transport does not stop at political boundaries. The Rhône drains a catchment area of 98,000 km<sup>2</sup> along its 718 km course through Switzerland and France. In France it has a 512 km main stem, flowing from Lake Geneva to the Mediterranean Sea. Several rivers contribute to the Rhône's considerable flow, including the Saône, Isère, Drôme and Durance. Representing a natural boundary, the river crosses three administrative regions and eleven departments. The Museum of Ancient Arles bears testimony to the rich history of human settlement on the banks of the Rhône and the use of the river for navigation and commercial exchanges in the Gallo-Roman period. The Rhône's particularly high flow played a crucial role in the reconstruction and modernisation of post-war France (Pritchard, 2011). Notoriously dangerous to navigate, the river was tamed through extensive modification over the course of the nineteenth and twentieth centuries, providing flood protection, easier navigation, hydropower and nuclear power. This altered the landscape significantly, as well as profoundly shifting the river's hydrology and sediment dynamics. The riparian inhabitants were also forced to adapt their relationship to the river. Today, the Rhône Valley is a major transit route (railway, motorway and waterway) and industrial axis in France, the riverbanks having been massively artificialised linking cities, industrial sites, and farmland.

*Figure 1: Map of the Rhône River valley (Comby, 2020)*

The Rhône River is about much more than water, as shown by a rich social science literature. Sara Pritchard's passionate history of the Rhône's post-war development shows how political and economic factors have been presented as 'natural' in terms of how the Rhône should flow. Indeed, 'masking the cultural and political work behind these "natural" changes has helped make their political implications invisible' (Pritchard, 2004, p.798). From a similar perspective of river development, other authors have shown how power relations have contributed historically to the shaping of the Rhône's riverscape (Comby et al., 2019). Political science has shown how floods were related to political factors, the risk being made alternately invisible through the Rhône development strategy and visible through sociopolitical crises (Guerrin, 2014). Sociologists have analysed the drivers and impediments to the implementation of restoration projects on the Rhône River and shown how local protests around

crises such as flooding and pollution could hamper or boost socio-natural changes along its banks (Barthélémy and Armani, 2015). Such examples testify to the diversity of socio-natural studies being carried out on the Rhône. Yet few specifically focus on the sediment itself, tending instead to focus on its connection to pollution. For example, Gramaglia and Babut (2014) deconstruct the sociopolitical crises that emerged on the Rhône with chemical pollution stored and dispersed by sediment. Comby et al. (2014) analysed the same crises through the media coverage. In this paper we focus on sediment to show how the idea of sediment and its role has evolved through history.

As Jamie Linton (2010) comprehensively explains, water is a lot more than H<sub>2</sub>O. Created by scientific discourse and developed by hydrology, this modern and abstract form has affected how we perceive water today. Linton differentiates H<sub>2</sub>O, water as a component we can scientifically know, with other ways of experiencing it, such as through our senses and beliefs. From this perspective, the works on the ‘hydrosocial cycle’ propose reintegrating water’s material nature (expressed by H<sub>2</sub>O) with theories, discourses, and representations of water, including the power relations and the role of technology and infrastructure within the construction of water (Linton and Budds, 2014). What has barely been proposed, however, is giving sediment back to water.

Recent works have advocated a reconsideration of one of the ‘foundational binaries’ of geography – ‘that of land and water’ (Lahiri-Dutt, 2014) – and a reintegration of land, and sediment, within the hydrosocial cycle (Lafaye de Micheaux et al., 2018). In the context of riverscapes, water has been separated from land and, therefore, from sediment through regulation and practices inherited from private land ownership and agriculture, as well as colonialism (Lahiri-Dutt, 2014). Interestingly, Lafaye de Micheaux et al. (2018) propose opening the hydrosocial cycle model to sediment through an analysis of: i) meanings and interpretations (including scientific and/or local knowledge) of land and water in so-called ‘muddyscapes’; ii) land and water governance and power relations; iii) resource (water and sediment) use and exchange patterns; and iv) physical and biological processes, partly mediated or affected by technology. This research agenda allows land to be brought back into the picture when looking at water, turning riverscapes into muddyscapes and reminding us that water and land are not so separate.

Sediment cannot be separated from water in riverscapes. It is deeply embedded in society and politics because it is not just physical matter. It has a social life. This paper shows that sediment is part of the Rhône’s hydrosocial cycle when extracted to repair dykes or produce cement, when it overflows (for better or worse), when fish are contaminated by chemical pollutants, or when sediment-charged water kills wildlife after dam flushing. However, sediment’s role has evolved over time. Until the 18<sup>th</sup> century, in early modern history, its management was part of the daily life of riparian Rhône inhabitants. Used in agriculture and construction, sediment was considered a valuable resource. Throughout the nineteenth and twentieth centuries the development of the river served to separate water from land through infrastructural changes related mainly to the hydropower and nuclear

industries. The riverscape was significantly modified, transforming its water and sediment regime. Yet, while sediment tended to be ignored and separated from water, we show that contemporary disputes have put it back on the Rhône's water agenda, albeit now cast in a negative role.

Society and public policy have been adapting to the evolving definition of sediment. The idea that the same matter can evolve from an asset to a threat – a resource to a hazard – is well documented in the literature of the sociology of risk (for a review of the French literature see Borraz et al., 2007). Risk is always defined in terms of specific social, political, and historical processes. This corresponds to a 'framing process' (Goffman, 1974) or 'schemata of interpretation that enable individuals to locate, perceive, identify and label occurrences within their life space and the world at large' (Snow et al., 1986 p.464). Framing refers to the understanding of issues in terms of specific contexts that can vary over time (e.g. floods can be framed as an environmental or a public security issue). This process is usually analysed through the role of actors (Cobb and Elder, 1972), social movements (Benford and Snow, 2000), or crises and political opportunities that open a 'policy window' (Kingdon, 1984), enabling something to be seen as a problem. Within a long-term perspective sediment in the Rhône has undergone a drastic evolution: framed as an asset in the past, it is now considered a threat. This trajectory is the core of our paper: what are the factors, actors, and effects of such an evolution?

The paper is organised into three main parts. First, we explore the role of sediment in early modern and modern history when it was seen primarily as a blessing. We then explore the infrastructural change on the Rhône in the nineteenth century, which intensified in the twentieth century, and the impact it had on sediment dynamics. In the third part we focus on the current construction of sediment as a threat through different aspects: pollution, flooding, and dam flush

## 1. Sediment as an asset in early modern times

The history of sediment is inherently linked to that of the Rhône's development. In medieval and early modern times the river largely maintained its natural course, evolving following major floods. Riparian communities used sediment dredged from the river to build dykes and protect themselves from floods. Nevertheless, given the magnitude and frequency of the flooding they could not prevent overflow into human settlements. Due to their agricultural value, however, overflows of water and sediment could be considered a blessing.

The profile of the Rhône River has changed greatly throughout history. Since Roman times, however, the Rhône has been a fundamental axis for inland navigation between Lyon and the Mediterranean Sea, and the river was an essential link within the Roman Empire, remaining so throughout the Middle Ages. In the Middle Ages the lower basin was formed of large wetlands, whose landscape evolved in accordance with the rhythm of the river (Rossiaud, 2007). From at least the twelfth century, cities located along the Rhône built levees both to protect against flooding and to ease navigation (Stouff, 1993). The form of their construction, in earth and wood, is well documented in



1 local archives. The levees in Arles (located at the delta of the Rhône, Figure 1) are the best known.  
2 *Levadiers*, city officials with responsibility for dykes, were documented from the mid twelfth century.  
3 Paid from landowners' taxes, they had the authority to order landowners to maintain or repair their  
4 dykes.  
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7 Despite the constant efforts to control it, the Rhône was still free to change its course and would  
8 regularly flood the surrounding land. In the fourteenth century, the surveyor Bertrand Boysset gave a  
9 detailed description of the lower Rhône area. Boysset's skills were essential to the social equilibrium  
10 of Arles (Portet, 2004): with flood after flood, property boundaries became less and less visible. Only  
11 the surveyor was able to delineate parcels of land and secure properties by fixing boundaries between  
12 land and water. Each flood event changed the waterways and could even create new arable areas due  
13 to sedimentation. Hence, medieval records describe the lower Rhône as a rich hunting and fishing area  
14 (Roucaute, 2004). The Romans cultivated the entire area, but during the Middle Ages wheat and other  
15 cereals were mostly grown in the upper areas, such as the Crau (a vast alluvial plain at the original  
16 confluence of the Durance and Rhône, Figure 1).  
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24 Practices had begun to change by the end of the fifteenth century when rural and urban elites  
25 invested in new land. Associations were established to oversee land drainage and agriculture, the first  
26 being officially registered in 1543 in the delta of the Rhône, the Camargue (Morera, 2016). Their role  
27 was to channel communal efforts to overcome the challenge of water management. They also installed  
28 hydraulic infrastructure, such as dykes and canals, as flood protection. Yet, as investors worked to  
29 separate land and water in order to develop arable land it remained important to maintain a link  
30 between the river and the cultivated soil, and at that time the link was fluvial sediment.  
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36 At the time, flooding was an ambiguous event. On one hand, a winter or spring flood was a disaster  
37 for the crops and promised a hard summer too: the loss of a harvest was terrible for the communities.  
38 But on the other hand, floods always enriched the land with sediment. It could wipe out a year's crops  
39 but at the same time ensure high yields in subsequent years. In the middle of the sixteenth century the  
40 Arles aristocrat Pierre Quiqueran de Beaujeu summarised this complex relationship between a  
41 community and its river, comparing the Rhône to the Nile because of sediment:  
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47 Then the Rhône returns to its bed, leaving behind very fertile silt similar to that of the  
48 Nile, apart from the monstrous animals. They are comparable because the Rhône's silt is  
49 also thick and sticky. When this mud settles in the summer not only does it burn those  
50 ears of wheat that are still standing, but when the heat dries it out it turns into sterile sand.  
51 These floods only occur in those areas of Arles where the fertile land is very low, forcing  
52 it to defend itself against this very dangerous river by building dykes, but this makes this  
53 area admirable. The flooding that the city of Arles undergoes every two or three years,  
54 and sometimes two or even three years in a row, takes with it seeds, the work of men and  
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1 oxen and the hopes of fathers. But the year the river does not overflow it provides them  
2 with such crops that it repays the damage and removes their fear of the future. (Quiqueran  
3 de Beaujeu, 1999 [1551]<sup>1</sup>)  
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5 It is clear that sediment so enriched the arable land that farmers could see the Rhône's floods as  
6 blessings. Sediment transport and deposition could offer valuable additional income to the community.  
7 At the time the Rhône's profile was not continuous and regular as it is today. Even in its lower part the  
8 riverbed was highly complex and shifting. Thanks to the sediment and the irregularities of the riverbed  
9 several islands divided the water flow. These offered very fertile land that benefited the community.  
10 Such was the case in Arles, where the city authorities leased the larger islands to farmers (Archives  
11 municipales d'Arles, DD 57 and 58) and thus obtained regular incomes. It was similar in the city of  
12 Avignon, the main part of which was built on islands that had been conceded by the king (Archives  
13 municipales d'Avignon, DD 106).  
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21 The relationship between the Rhône's riverside communities and its sediment became more  
22 complicated when property-related pressure intensified in the seventeenth century (Morera, 2011). The  
23 high level of sedimentation began to be seen as a problem. Draining projects were hampered by  
24 sediment build-up in the hydraulic infrastructure due to a lack of maintenance. Several surveys in the  
25 1630s described the lower Rhône valley as entirely under the influence of water. Filled in with  
26 sediment, canals were further obstructed by reeds and other tall grasses. Whether it came from the  
27 Rhône or not, sediment had taken possession of its main riverbed (Archives départementales des  
28 Bouches-du-Rhône, 108 E 97).  
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35 The major drainage projects of the 1640s were focused on the hydraulic infrastructure they had  
36 inherited. They were carried out in a relatively short period of time thanks to massive funding and land  
37 appropriation by investors in land drainage. The work mainly consisted of cleaning the drainage canals  
38 at great depths and removing the sediment and alluvium to ease the flow of water. But again sediment  
39 would create arable opportunities. Indeed, land was drained, and farmland was enriched by sediment.  
40 The agricultural results were rapid: yields on the newly cultivated land were high, thanks mainly to the  
41 richness of the alluvial deposits from the Rhône. The works led to a reoccupation of the land bordering  
42 the river. But now the benefits of the floods were less noticeable. Indeed, the risk they posed to  
43 infrastructure and crops was clearer than the benefit of sedimentary deposits. Capital expenditure had  
44 changed the environment and the relationship between the Rhône and those living alongside it.  
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52 Continuing to cultivate the land despite the challenges of the river meant local residents had to  
53 continuously maintain the hydraulic infrastructure, whether landowners or not. This entailed  
54 continuous renegotiation between the river and its sediment on one hand and social structures on the  
55 other. The eighteenth century was marked by a relative decline in the cultivation of the land in the  
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60 <sup>1</sup> Authors' translation.  
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Rhône Delta (Baehrel, 1988). With landowners' absenteeism and a consequent lack of interest in agriculture, the sediment reasserted itself and provoked constant flooding of the whole Lower Rhône with the loss of arable land. In 1733 Gaspard Bernardy, a royal engineer, produced a detailed study of this issue, according to which, from the Durance to Arles, the Rhône Valley was entirely submerged. This study laid the blame on a lack of maintenance and the filling in of canals. To bring the land back into cultivation Bernardy recommended restoring the slope of the canals and that, 'the land resulting from the dredging be used to thicken and raise the dykes to the necessary height to contain the highest waters so they do not overflow into the lowest lands' (Bernardy, 1733). Sediment needed to be taken out of the canals and could then be used to reinforce the existing dykes.

It was predominantly the towns of the Lower Rhône that had to deal with the issue of sediment accumulation, since that is where the alluvial material ended its journey. Yet, even in this area, society's relationship with the natural process of sedimentation was double-sided. On one hand the river enriched the soil for cultivation, but on the other it relentlessly weakened the infrastructure constructed to protect towns and land. Before being deposited, sediment must be gathered by the water. Communities feared the loss of sediment and the vanishing of profitable land. Moreover, along the Rhône, dykes and levees were made of alluvial sediment and stone (at certain points), and these had to be maintained to contain the river's greed. It was able to give with one hand and take with the other. Engineering surveys of eighteenth-century Avignon depict the erosion of hydraulic infrastructures. An example from 1747 shows a large section of the riverbank having collapsed. Those leading the survey urged the authorities to rebuild the levees of dykes in stone (Archives municipales d'Avignon, DD 105). In the face of this challenge, the city of Avignon, that was under the rule of the papacy, called on a large workforce to bring earth to renew the dykes, called *palières* (Archives municipales d'Avignon, DD 125). The city council allocated a substantial budget each year to prevent sediment loss.

Avignon's authorities saw the Rhône as a threat from which they needed to be protected. In a letter to the vice legate (the pope's representative) the engineer P. Thibaud defended his project to reinforce the town's hydraulic equipment by arguing that the Rhone was 'imperceptibly carrying away its land' (Archives municipales d'Avignon, DD 106, date unknown). Later, presumably in the late 1750s, another engineer urged the papacy to finance new dykes by stressing that, 'the water is often on the verge of taking land away' (Archives municipales d'Avignon, DD 106, date unknown). Thus, for the city of Avignon, sediment loss threatened the income from land cultivation and taxes.

Agricultural pressure on valley bottoms gave rise to highly ambiguous relationships with the water and sediment. The communities' interest in these areas arose from the arable value of sedimentation alongside the obstacle it posed to their use due to the risk of flooding from land loss. This contradiction was partly addressed by viewing sediment as raw material for large, technical infrastructure to raise watercourses, in particular building dykes along the Rhône and affluent canals

from sediment deposited on the riverbed. However, the fragility of this infrastructure and the unavoidable dyke breaches offered some flexibility to the socio-technical system that had been established. But it was an unstable equilibrium that lasted beyond the French Revolution only to be shaken by the agricultural crisis of the 1840s and state intervention during the Second Empire (Allard and Maurice Corsand, 2004). From the nineteenth century, floods became a public issue in France, and higher dykes were erected around major cities and the Camargue (Guerrin, 2014). Along with the transportation and energy advances of the twentieth century, this infrastructure caused significant change to the river and, consequently, sediment dynamics.

## 2. Industrialisation and river engineering from the nineteenth century onwards: affecting sediment quantity and quality

Until the nineteenth century, the Rhône was a meandering river with several channels. Sediment was part of the daily life of inhabitants. But in the nineteenth and twentieth centuries, industrial development and river engineering led to significant change in the river's landscape and in sediment dynamics. The creation of high and secure dykes durably separated land from water and limited the sedimentation of land. Sediment flux was reduced by the development of river engineering, as industrialisation created pollution that could reduce the sediment's quality.

Environmental and social transformations affect sediment flow. In terms of quantity, the amount of sediment flowing along the Rhône was drastically reduced from 18.8 mm<sup>3</sup> per year in the late nineteenth century to 6.1 mm<sup>3</sup> per year in 2010 (Provansal et al., 2014). Geomorphologists attribute this to climatic conditions, i.e. the natural decrease in the frequency of major floods at the end of the Little Ice Age (Bravard, 2010), as well as to anthropogenic factors (Provansal et al., 2014). Indeed, the nineteenth century saw a change in the flood regime of the Rhône River. Sediment flux was reduced by a combination of a rural exodus associated with a decline in mountain agriculture, catchment reforestation to prevent flood events, and the engineered stabilisation of feeder torrents (Provansal et al., 2014). The century also witnessed two major floods on the Rhône (1840 and 1856). For various sociopolitical reasons, the latter was to inspire France's first flood-protection legislation (Guerrin, 2014). Under Napoleon III the state invested in protection measures for the main cities along the Rhône River and the Camargue. Civil engineers from the Ponts et Chaussées corps supervised all dyke-building and maintenance on navigable rivers such as the Rhône. Major levees, termed 'unsinkable', were built around Lyon, Avignon and the Camargue to prevent flooding. The resulting decrease in the frequency of major and minor floods meant reduced sediment transfer and fewer sedimentary deposits on riparian forest (Provansal et al., 2014).

In the nineteenth century, navigation was the primary means of economic development and had geomorphological and ecological impacts that remain today (Comby, 2015). Sediment was cleared to improve navigation on the Rhône, and the river's fluvial pattern changed between 1860 and 1870

when the first levees were built (Bravard, 2010). At this time, structures known as *casiers Girardon*, submersible groynes resembling groyne fields, were built to narrow the Rhône's channel, concentrate its flow and ease navigation (Räpple, 2018). They consisted of a series of submerged dykes, perpendicular to the bank, to encourage sedimentation on the sides while the waterway became consequently deeper in the middle of the riverbed. The channelisation of the Rhône entailed the artificial disconnection of most of its secondary channels (Dépret et al., 2017) and a loss of connectivity between the floodplains and the channel (Vauclin et al., 2019). However, the infrastructure itself attracted sediment. By 1945, 42 per cent of the area it covered had become land, and today only 10 per cent remains aquatic (Thorel et al., 2018). The divisive *casiers Girardon* are now recognised as hosting interesting biodiversity but also as polluted sediment traps or for artificially separating the river from its bed.

From the nineteenth century onwards the landscape of the Rhône changed rapidly with Napoleon III dykes and the *casiers Girardon*. A river with braided channels in the eighteenth century, it was transformed into a simple channel, disconnected from its former meanders (Figure 2), as we can see from these two historical maps showing the landscape's evolution between 1832 and 1907.

*Figure 2: Historical maps and changing riverscape at Pont-Saint-Esprit (Gard department, France)*

While engineering projects had been affecting the landscape since the nineteenth century, works progressed even more rapidly after World War II, with the construction of nineteen dams and five nuclear power plants. In 1945 the Rhône's riverscapes served the political purpose of reinforcing the authority of the central government over the regions, to promote economic development and to ensure national independence (Pritchard, 2011). In 1933 the Compagnie Nationale du Rhône (National Rhone Company, CNR) was created and was given the concession for managing the Rhône with three objectives: hydropower, navigation, and irrigation. From 1945 to 1986, CNR built 19 hydropower dams along the river (Figure 1), between the Swiss border and the upstream part of the delta, associated with major dykes to channel the river. Press reports of the time compared the CNR's projects to those of the Tennessee Valley Authority in the US (Comby et al., 2019). In the 1970s and 1980s five nuclear plants were built near the Rhône (four are still in operation), drawing water from the Rhône to cool their reactors.

These major infrastructural changes in the landscape of the Rhône had impacts on sediment flux. Dams reduced sediment transport within the river, and, in its catchment, major Alpine dams retain much of the sediment. The large Serre Ponçon dam, for example, was estimated to have been retaining around 200 mm<sup>3</sup> of sediment, or 4 mm<sup>3</sup> per year since the 1950s (Provansal et al., 2014), creating riverbed incision downstream of the reservoirs. Although CNR hydropower plants (mostly run-of-the-river dams) retain less water and therefore less sediment, some coarser sediment is unable to travel

through the bypassed channel as the usual managed discharge is insufficient. Therefore, much of the sediment is conveyed during large floods (Provansal et al., 2014).

Gravel mining further reduced sediment transport in the Rhône River. The amount of gravel dredged from the river's main channel between Lyon and Arles was estimated at 13.5 mm<sup>3</sup> (0.83 mm<sup>3</sup>/y) between 1970 and 1990 and around 84 mm<sup>3</sup> for the entire basin, according to Provansal et al. (2014). Mining also took place in the tributaries, resulting in less available bedload flux and exacerbating riverbed incision (Provansal et al., 2014).

The significant transformation of the Rhône's riverscape in the nineteenth and twentieth centuries was illustrated by the use of the term 'river highway' in the national press in reference to the straightening of the river (Comby et al., 2019). In the space of 150 years the river formerly described as a 'furious bull' by the French historian Michelet in 1840 was tamed and transformed into a source of many utilities (nuclear power, hydraulic power, water for irrigation, navigation route), becoming a channelised river between two large banks for the majority of its course, flanked by a motorway and a high-speed railway. The development continued as part of a post-war modernisation project that sought national independence through hydraulic and nuclear power as well as strong trade links through navigation. These strategic goals, along with riparian interests and local authorities looking to develop irrigated agriculture, defined how the Rhône's water and sediment currently flow. According to geomorphologists, the principal threats to large rivers, especially the Rhône, are artificial modifications to their discharge and channel and floodplain morphology (Lamouroux et al., 2015). Indeed, gravel mining, dyke and dam construction and channelisation for navigation have simplified the lateral pattern of the channel and incised and paved the riverbed (Parrot, 2015). This has separated land and water and deeply impacted sediment flux in the Rhône.

In the same period of time industrialisation took hold in the Rhône Valley. A 25 km stretch from Lyon harbour to Loire-sur-Rhône was called 'chemical valley' (Duchêne and Marchand, 2015). In the second half of the nineteenth century various factories were established in the south of Lyon, and for almost a century companies grew up along the Rhône, particularly in connection with Lyon's textile and photographic industries. For example, Rhône-Poulenc produced dyes for the silk industry. Various economic crises led these businesses to be joined by other economic sectors, such as the pharmaceutical industry and petrochemicals, with the installation of a refinery in Feyzin and a pipeline between Fos (France) and Karlsruhe (Germany), which has run along the valley since 1962. The industrialisation extends downstream, beyond Lyon's urban area. Among the companies present in the Rhône Valley, Lafarge operates quarries, notably at Le Teil in Ardèche. In the 1960s and 1970s the Rhône was polluted by industrial and domestic waste, as the press reported: 'The Rhône flows, depending on the day, with nothing but masses of red or blue moss, waste from riverside factories' (*Le Monde*, 16 June 1972); 'Upstream from Lyon, the river is practically free of pollution. It is not the same downstream' (*Le Monde*, 14 May 1966). Indeed, the Rhône was considered a convenient sewer.

But industrial accidents (e.g. Pierre-Bénite in 1976) highlighted the problem of pollution and had a lasting impact on its perception.

The pollution of the Rhône was due to the valley's industrialisation and urbanisation, as well as industrialisation around tributaries that increased the contaminated discharge. For example, the current presence of PCBs (polychlorinated biphenyl) in the river is partly linked to industrialisation along its course. PCBs were produced in large quantities from the 1930s, mainly for use in capacitors<sup>2</sup> and transformers sold in France through the firm General Electrics. The production of PCBs in France was estimated at between 130,000 and 180,000 tons for domestic use (Gramaglia and Babut, 2014). In particular, two industrial sites near Grenoble produced the majority of PCBs used in France from the 1950s until 1984 (Gramaglia and Babut, 2014). In Saint-Vulbas, along the Rhône River, a company (Tredi) treats PCB waste (Comby et al., 2014). The pollution arising from such intense industrialisation ultimately affected the quality of sediment.

Major anthropogenic and technological changes had a huge impact on sediment flux and quality and therefore on the relationships that the Rhône's communities had with the river. There was a significant reduction in sediment import from the upstream catchment and tributaries. Moreover, sediment transported within the river was blocked by the many dams and levees, even creating artificial banks, particularly at the *casiers Girardon*. Today, bed mobility remains very low, and it is mainly fine sediment that is transported (Vázquez-Tarrió et al., 2019). Since 1999 various reaches of the Rhône have been restored as part of a programme to regain lateral connectivity by removing dykes, installing migratory fish passages, increasing minimum flow, and regenerating floodplain channels and habitats that are no longer maintained or created by fluvial processes by dredging alluviums (Riquier et al., 2015). However, the implementation of this programme was hampered by the politicisation of sediment through the issues of flooding and pollution. We will see more closely how sediment came to be pushed into politics.

### 3. The contemporary politics of sediment

Sediment is subject to politics. It becomes political when policies are devised to address specific problems framed around sediment (i.e. quantity or quality) or when actors use sediment to defend their interests. The concept of politicisation can be defined as the 'requalification of any social activity that comes from an agreement between social agents to question or transgress the existing separation of activities'<sup>3</sup> (Lagroye, 2003, pp.360-361). According to Lagroye, politicising an activity or matter would mean changing, or intending to change, the category (social, political) it belonged to. The process of politicisation is not limited to qualifying an activity or matter as political but extends to the

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<sup>2</sup> A capacitor is an electrical component that stores energy.

<sup>3</sup> Authors' translation.

questioning of an institutionalised category. Hence, studying the politicisation of sediment means questioning the apparently natural origin of the existing view of sediment – as a blessing, for example.

The politicisation of the Rhône's sediment arose from various sectors, such as professional fishing and flood and dam management, each of which defines the issue in its own way. Having been viewed as a blessing or valuable resource in the past, over time sediment came to be seen as a natural hazard. It can now be considered a threat for reasons of quantity, such as when it is blamed for exacerbating floods or destroying biodiversity during dam flushing, or quality, such as when it contaminates fish and ultimately humans through the bioaccumulation of pollutants or spoils agricultural soil due to its adverse quality. Focusing on the politicisation leads to a questioning of the legitimacy of a particular order. The politics of sediment, which involve new ways of viewing it or making it (in)visible, or even a new framing of the issue, usually arise at times of dispute. Indeed, modifying the existing order implies a transgression of accepted categories, but one that can be legitimised by a specific crisis. Three forms of the politicisation of sediment on the Rhône arose during sociopolitical crises connected to pollution, flooding and dam flushing.

#### Sediment and pollution

Rivers receive many different persistent organic pollutants, including PCBs, that are released into the environment by improper disposal, leakage, incineration and volatilisation (Mourier et al., 2014). PCBs attach to sediment, which is ingested by fish that are then unsuitable for human consumption. Indeed, PCBs have an impact on aquatic biota and, ultimately, human health through bioaccumulation (Lopes et al., 2012). The production, use, and sale of PCBs were prohibited in the 1980s; however, river dynamics, such as floods and dam flushes, have been contributing to the dissemination of PCBs in the environment (Mourier et al., 2014).

In the 1980s local scientists and NGOs highlighted the issue of the Rhône's fish being contaminated with chemicals such as PCBs, but the authorities did not allow the warnings to reach the public. With two European Directives, in 1976 and 1985, the use of PCBs was prohibited in France in 1987, giving the impression that the problem had been dealt with (Gramaglia and Babut, 2014). In 1996 the Council of the European Union planned PCB decontamination in several countries, but by 2002 France was criticised for having done too little too late to confront the issue (Comby et al. 2014). As a result, the problem came to light again in 2005 locally in the Lyon urban area, in 2007 along the Rhône Valley and then nationally through sediment. In 2005, in order to reassure his clients of the safety of Rhône fish, a professional angler submitted two sample breams to the local veterinary services for analysis. A high concentration of PCBs was discovered in them. As a result, the prefect of the Rhône department imposed a ban on the sale and consumption of fish from the area where the first two had been caught (Meunier, 2008). Following the initial discoveries, several surveys were conducted within the valley, at certain points along the Rhône River up to the delta. These led to further department-wide bans on fish from almost every point on the river. This raised the issue of



1 public authority jurisdictions with regard to rivers. The ban on fish consumption was imposed by the  
2 prefect, meaning the measure was taken at the departmental level. As the Rhône marks the boundary  
3 between departments, a fish could not be eaten on the left bank (the Prefecture of Rhône and Isère  
4 prohibited the sale and consumption of fish in February 2007), yet the same ban did not come into  
5 force until several months later, in June 2007, in the Loire Department on the right bank. Many  
6 anglers criticised these measures, pointing out that fish and sediment do not recognise departmental  
7 boundaries.  
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11 The pollution crisis made sediment a political object, notably through the actions of a few local  
12 elected representatives upstream of Lyon where the first two contaminated breams had been fished.  
13 They maintained pressure on the authorities to act on the problem and helped to frame the issue as  
14 affecting the entire river rather than just their local area, thereby highlighting the disseminating role of  
15 sediment (Vionnet, 2011). Prior to 2007 the main stakeholders had been the prefects, a few mayors  
16 and an environmental NGO, but by the end of 2007 the role of the state and the presidential majority  
17 had become prominent (Comby et al., 2014). Thus, on 10 October 2007 the Minister of Ecology  
18 Nathalie Kosciusko-Morizet appeared beside the Rhône River to announce a national response (a  
19 commission and research programme) to the pollution of French rivers by PCBs. A National  
20 Assembly commission ordered a parliamentary report, which was produced in 2008, entitled 'The  
21 Rhône and PCBs: long-term pollution' (Meunier, 2008). The member of parliament responsible for the  
22 report belonged to the same party as the president and represented the area where the first two  
23 contaminated breams had been caught. At the same time the association of professional anglers on the  
24 Rhône filed a complaint, demonstrating the degree of concern from those in the private sector who  
25 were dependent upon fish production (Meunier, 2008). Similarly, environmental NGOs highlighted  
26 the unwitting actions of the dam operators (EDF and CNR) during river dredging that would be  
27 spreading contaminated sediment (Vionnet, 2011). The local and national media broadcast alarming  
28 information about the dangerous nature of PCBs and the fact that a public health crisis had been  
29 allowed to happen despite the authorities having been aware of the dangers twenty years earlier. The  
30 term 'French Chernobyl' was used several times by bloggers and NGOs (Meunier, 2008).  
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46 The broadening of the PCB debate to the full length of the river had the effect of widening the  
47 administrative responsibility from the prefect of the Rhône Department to the river basin prefect in  
48 2007 (Gramaglia and Babut, 2014) and then to the national level. As a result of this local crisis, a  
49 national action plan was adopted in 2008 to improve scientific knowledge on the dissemination of  
50 PCBs through sediment and to introduce the widespread monitoring of fish intended for human  
51 consumption (Gramaglia and Babut, 2014). From 2005 to 2007 studies concentrated primarily on  
52 sediment and fish. Since 2008, however, in addition to examining more and more species of fish and  
53 types of sediment, researchers have also examined invertebrates and sediment cores (Comby et al.,  
54 2014). Scientists are working to establish the broader role of sediment pollution throughout the  
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hydrologic cycle. According to scientists, it will be at least another decade before PCB concentrations meet the regulatory level for fish consumption (Mourier et al., 2014). Fluvial dynamics mean that PCB concentrations in sediment increase exponentially in a downstream direction, and that they are unlikely to diminish in the short term (Mourier et al., 2014). The significance of contaminated sediment to local actors was illustrated by the nexus that was discovered between floods, dam flushes, and contaminated sediment. Since 2007, however, the Plan Rhône (a development contract linking riverbasin stakeholders, the state, and the EU) brought local actors into river management, encouraging studies on PCBs and the tackling of the issue at the basin level. Sediment spread PCBs, and PCBs in turn framed sediment as a threat, due to its contamination, via the human consumption of fish. This pollution crisis impacted the treatment of another major public concern along the Rhône: flood risk.

### The nexus of sediment and flood

Subsequent events were to reactivate the issues of sediment quantity and quality, including floods and the restoration of the Rhône's meanders. Sediment was placed on the political agenda by flooding on the Rhône and its tributaries between 1990 and 2003. Severe events occurred in 1993, 1994, 2002 and 2003, around the Rhône and/or its tributaries that caused extreme damage. In 1993 dyke breaches caused severe damage in the delta; the events of 1994 claimed 10 lives; in 2002 flooding on Rhône tributaries caused 23 deaths in the Gard department; and in 2003 the Rhône and its tributaries flooded a large area, causing 1 billion euros of damage (Guerrin, 2014).

Sediment was accused of aggravating the impact of flooding by lowering river margins and narrowing riverbeds. Dredging the river and removing sediment, in particular from the meanders of the 'former Rhône', became a regular demand from flood victim associations and local representatives in order to improve flood protection (Barthélémy and Souchon, 2009; Guerrin, 2014). Debates organised after a flood on the Rhône River in 2003 revealed that those affected by the flooding who were in attendance tended to believe that the river was becoming filled up with sediment and that the answer, therefore, was to dredge the river. According to Barthélémy and Souchon (2009), these impressions are based on what locals can see, such as bridge piers and *casiers Girardon* filled with sediment. Others suggest that such observations would be reinforced by a sceptical view of the CNR, whose programme of river containment had been understood by locals to include levees that would protect them from flooding (Guerrin, 2014). Indeed, they had been encouraged in this view by the CNR's communication strategy while developing hydropower. Following the floods of the 1990s and 2000s the CNR, along with the state, was regularly held responsible for what was seen as the failure of the levee and dam system. As a consequence, the CNR was also blamed for the issue of sediment, which was seen as having been exacerbated by dams (Guerrin, 2014).

The demand for sediment to be removed from the river was then incorporated into the ecological agenda of environmentalists calling for the restoration of the Girardon infrastructure and the meanders

1 of the former Rhône. In 1999, when the environmentalist Dominique Voynet entered government, a  
2 10-year programme for the Rhône was launched. It aimed to restore a ‘fast and flowing river’. State  
3 authorities and scientists understood this as increased river flows to benefit specific migratory fishes,  
4 but for urban planners and riverside municipalities it meant more life in former meanders, more  
5 amenable landscapes and more space for water during flooding (Barthélémy and Souchon, 2009).  
6 They requested that sediment be excavated in order to store floodwater and reduce damage. However,  
7 the PCB crisis raised concerns over the practice of putting sediment back into the water (Bouleau et  
8 al., 2018), and the project to remove the *casiers Girardon* was blocked from 2005 to 2010 (Thorel et  
9 al., 2018).

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11 Sediment quality was also used as political leverage to oppose a floodplain restoration project on  
12 the downstream Rhône. The 1990s saw changes to state flood policy in France, and more broadly in  
13 Europe and the United States (Guerrin and Bouleau, 2014). The public savings ideology proponents  
14 questioned the public expense of dyke building and flood damage compensation, and Western  
15 governments became less and less willing to fund them. This new approach opened an avenue for  
16 environmentalists who had long criticised the impact of dykes on freshwater ecosystems. They  
17 successfully claimed that flooding was beneficial for the managing of sediment, land fertility, and  
18 groundwater recharge, and thereby gained public support for the restoration of the Rhône (Bouleau et  
19 al., 2018).

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21 However, not everyone was ready to celebrate the benefit of sediment brought by flooding. The  
22 mayors of two municipalities located on the downstream Rhône, Piolenc and Mornas, overcame their  
23 former political rivalry and came together to oppose the project that had earmarked their areas for  
24 floodplain restoration (Guerrin, 2015). To counter the environmentalist narrative of the benefits of  
25 sediment, these elected officials drew the public’s attention to the pollution of the Rhône’s sediment  
26 (particularly with PCBs) and its potential effect on agriculture and drinking water. They pointed out  
27 that contaminated sediment would be transferred, and contrasted this with the high quality of the land  
28 along the river thanks to the long-standing separation of agricultural land from (contaminated) water  
29 by the CNR dykes. Indeed, the dispersal of PCBs is exacerbated by sediment flushing operations and  
30 flooding, since floods cause bank erosion, which results in ‘inputs of less-contaminated sediment in  
31 some cases, or in inputs of more contaminated sediment in others’ (Mourier et al., 2014). The  
32 politicisation of Rhône pollution was expressed by the media with a familiar dramatic reference:  
33 ‘Chernobyl risk in Provence’ (*La Provence*, 6 July 2008). Alongside other concerns and obstacles, the  
34 opposition led by Piolenc and Mornas saw the cancellation of the floodplain restoration project  
35 (Guerrin, 2014).

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37 Sediment is therefore seen as a flood-related problem in two ways. Following the recurrent,  
38 devastating floods of the 1990s and 2000s, flood victim associations blamed the *quantity* of sediment  
39 for increasing the degree of overflow at times of flooding. But when a former floodplain was  
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identified for potential restoration to store floodwater again, sediment came back as an issue but with regard to its *quality*, in terms of pollution. Land and water had been separate for so long that people were no longer used to living with floods. Rather, they had come to see the Rhône as polluted due to the contamination of sediment with PCBs. Those who opposed the floodplain restoration programme used the new evidence and the media coverage generated by the PCB crisis to support their cause. They even recycled the image of Chernobyl that had been used locally during the initial crisis. A plan to store water within a former floodplain, framed as an issue of water quantity, came to be reframed as one of quality by its opponents. Hence, the Rhône's hydrosocial cycle created a link between flooding and the quantity and quality of sediment that was to prevent state action. The question of dam flushes further highlighted the controversial nature of the river's sediment.

### Sediment becomes transnational through the issue of dam flushing

Dams control the flow of sediment in the Rhône. Over time, sediment accumulates behind dams, lowering their water storage capacity and hence their power production. Flushing operations are carried out to mitigate this phenomenon. On the Rhône, dam flushing is managed by the Verbois dam in Switzerland, which has a large reservoir, produces electricity, and prevents flooding in the Geneva urban area. However, it also traps solid material which it must regularly discharge in a process taking place about every three years. Between World War II and 2016, 22 flushing operations were carried out on the Rhône. A flushing event is a temporary and planned disruption of the functioning of water and sediment flows. This dam-water-sediment interaction affects ecosystems and potential uses of the river. Flushing on the Rhône necessitates international cooperation between Switzerland and France, and sees collaboration between the Swiss dam operator (SIG – Geneva Industrial Services) and the CNR in France.

From the 1950s to the 1970s French mayors believed that flushing was an effective way to remove pollutants. Yet, in the 1970s the procedure became a political issue as fishers raised objections locally. Initially these concerned the flushing itself, which visibly changed the water by suddenly filling it with sediment. At the time, dam operators carried out the operations in summer, when the water level is low and electricity production less profitable. However, the low water level made the impact of the flushing more obvious (by the sight and smell), potentially affecting tourism and leisure activities (e.g. fishing). Therefore, from the mid-1970s flushing operations were moved from July or August to May to appease the locals.

Since 1976 the hydrobiology laboratory at the University of Lyon 1 has been studying the impact of dams on invertebrate fauna. In 1978 a technical company conducted a survey in Brégnier-Cordon (Ain department, Figure 1) and observed that massive amounts of fish would die during flushing due to the anoxic flow (Bravard, 1987). The findings drew the attention of anglers, environmental NGOs and scientists. Indeed, it turned out that the flushing operation of 1978 had been an ecological disaster. The decline in river flow at the Chancy-Pougny dam caused a high concentration of coarse and fine

1 material downstream, notably at the Génissiat dam. Fish mortality was very high up to 100 km  
2 downstream of the dam. The event shed light on the flow of suspended material, emphasising the roles  
3 of geomorphology and physical geography in understanding the hydrosystem. In June 1978 an  
4 association of anglers filed a complaint in court. Environmentalists, anglers and scientists called for  
5 new bilateral management between Switzerland and France of flushing operations and the sediment  
6 issue. The CNR adopted specific measures, for example monitoring the minimum flow and  
7 sedimentary material during the operation and the creation of a nature reserve. Further, as a result of  
8 this issue a specific quantity of suspended material was established with regard to any financial  
9 compensation (Comby, 2015). Regulatory standards were set that the French and Swiss dam operators  
10 could use to negotiate and establish agreements. While the immediate controversy waned, stakeholders  
11 continued to pay greater attention to the issue of sediment.  
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18 Although flushing is usually carried out every three years on the Rhône, none took place between  
19 2003 and 2012, in part due to a public inquiry that required bilateral authorisation for each operation  
20 (Bréthaut and Pflieger, 2013). The delay was also affected by protests mounted by anglers in  
21 Switzerland in 2006 and France in 2010. All were calling for greater transparency in terms of sediment  
22 flow through dams, and this created many challenges for flood management in the Geneva area,  
23 questioning a usually technical subject: 'The anglers have played a decisive role. It was unimaginable  
24 to question Verbois flushing,' stated Robert Cramer, a councillor in the canton of Geneva (*Le Progrès*,  
25 19 June 2006). The protestors focused not only on the quantity of suspended material but also on flow  
26 rates and river ecology. During the French public inquiry organised across 47 communes, mayors  
27 expressed concern about, or even openly opposed, flushing. In an interview with a regional  
28 newspaper, the mayor of Aoste explained: 'We are going to see our Rhône loaded with mud and many  
29 other things. We have been Switzerland's dump for years and it is still going on' (*Le Progrès*, 27 May  
30 2012). In the same article the mayor of Creys-Mépieu said, 'we voted against the operation because of  
31 the nature reserve. It is a scandal for flora and fauna to flush at this time of year. The results are less  
32 harsh in winter'. An environmental group declared they 'would prefer that flushing operations take  
33 place in autumn because of breeding periods. It could be done another way; for example, by removing  
34 the sediment more gradually. Yet one must understand that the Swiss do as they want. They have the  
35 Lake Geneva tap that allows them to work on the river'. The Swiss stakeholders are perceived to be  
36 more powerful because they generate the Rhône's flow by controlling Lake Geneva. The issue of  
37 flushing, therefore, embodies the unbalanced relationship between upstream and downstream  
38 stretches. Because of local resistance on the Swiss and French sides, the dam operators had to  
39 postpone the operation that was scheduled for spring 2010.  
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56 The flushing operation eventually took place in June 2012 and garnered huge media coverage. The  
57 level of the Chancy-Pougny dam was lower than expected. There was a lot of rain. Facing very high  
58 concentrations of suspended material, the Swiss dam operator decided to stop the flushing operation  
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1 before it was complete. A few months later the Swiss operator explained that it had not been 2.6 mm<sup>3</sup>  
2 of sediment that had transited from Switzerland to France as expected but 4.3 mm<sup>3</sup> (*Le Progrès*, 5  
3 March 2013). An environmental group suspected that the SIG had done it on purpose. Rumours  
4 fuelled the tension. The events had economic as well as ecological consequences: the CNR announced  
5 an 8 million-euro loss due to the pause in hydroelectric production, having to pay staff in the field to  
6 ensure people's safety, save fish, and monitor the flushing operation, and running an awareness  
7 campaign to forewarn river users. The object of people's anger was thus twofold, namely the  
8 ecological and economic impact of having failed to comply with the legal level of suspended material,  
9 which had been central to the balance of the system of actors since the event of 1978.  
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11 As has been seen, flushing can fuel a negative perception of sediment due to the change in the  
12 colour of the water during the operation, the size of the sediment (Le Lay et al., 2013), the quantity of  
13 dead fish, and the issue of pollutants. The event of 2012 led some environmental groups to blame  
14 sediment, even calling it 'shit' (*Le Progrès*, 5 March 2013). Flushing operations disturb riverscapes.  
15 They remind inhabitants and users that the river is made of water and sediment. Views of sediment are  
16 built both from residents' experiences of it and detailed scientific monitoring by geomorphologists,  
17 hydrologists, and ecologists. One feature of the Rhône River is the transnational character of its  
18 flushing operations, where sediment flows from Switzerland to France, and the multilevel governance  
19 of this flow has been crucial in minimising disputes.  
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## 21 Conclusion

22 Sediment has a social and political life. Once welcomed as a valuable resource, sediment has come  
23 to be criticised for its quality by impacting biodiversity and also fishing and its quantity, being blamed  
24 for exacerbating flood damage. Sediment is subject to evolving interpretations, meanings, uses, and  
25 means of knowledge production, depending on historical, socio-natural and technical factors. The  
26 changing governance structure within which the Rhône falls has also affected whether sediment has  
27 been viewed as a blessing or a curse. Indeed, the state engineers' monopoly of expertise and the  
28 modernist approach to the Rhône's development nullified the role of sediment, which only came back  
29 onto the agenda thanks to local residents and elected representatives through sociopolitical crises,  
30 conflicts and disputes, which altered the pre-existing power relations. The Rhône's sediment, once a  
31 blessing, is now seen largely as a threat, hampering any state action to remove it and implement  
32 floodplain restoration projects.  
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34 The Rhône is indeed about more than water. As historical and contemporaneous politics remind us,  
35 sediment is part of water, and their combination affects sociopolitical processes that have a dialectical  
36 impact on biological and physical sediment dynamics. Indeed, sediment is deeply embedded within  
37 the Rhône's hydrosocial cycle. The management of the Rhône's water as a resource affected sediment  
38 dynamics, highlighting the fact that water is not only about H<sub>2</sub>O but also about sediment transport.  
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1 Sediment dynamics on the Rhône were deeply affected by technological developments in terms of  
2 their quantity and quality. Today, technology is in turn affected by the social and political life of  
3 sediment, when dam flushing is the subject of dispute and local opposition. The Rhône may not look  
4 like a muddyscape, since water and land seem clearly separated, but conceptually it is. Sediment – a  
5 natural feature – now confronts hydraulic infrastructure, and the societies it supports, head on. The  
6 mud that engineers had hoped to hide has dramatically re-emerged as a critical issue.  
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10 Sediment is involved in socio-natural processes and is, therefore, an object of natural as well as  
11 social science. In 2009 the Rhône Sediment Observatory (OSR) was established. Its research teams,  
12 spread along the river, gather data on the quantity and quality of sediment, as well as the levels of  
13 contamination. There are currently no social scientists at the OSR. Yet it has enormous potential as a  
14 forum for the comprehensive exchange of ideas between those in the social and natural sciences about  
15 socio-natural sediment dynamics. The social sciences have a role to play in highlighting the effects of  
16 sediment dynamics on societies and of social dynamics on sediment.  
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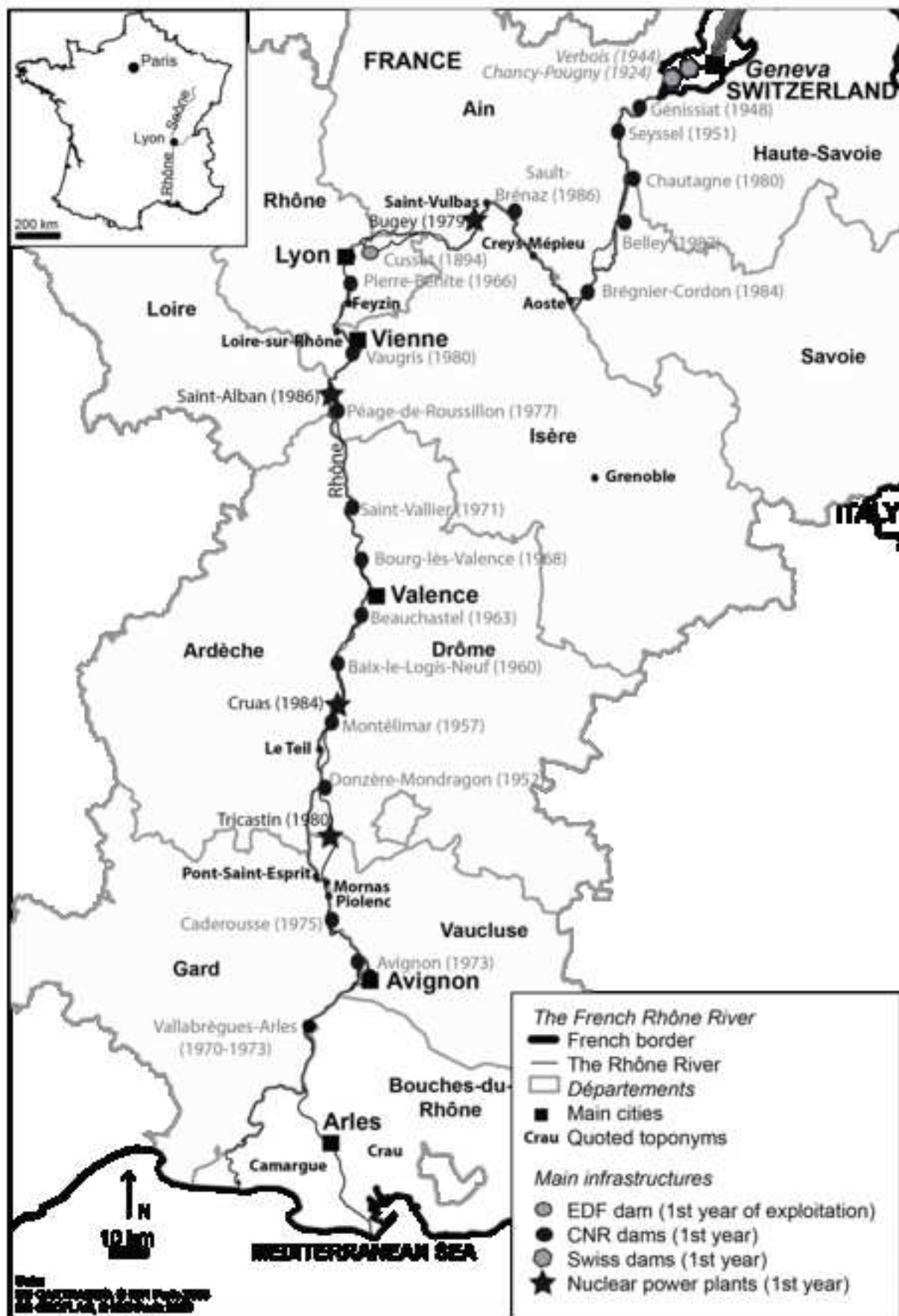
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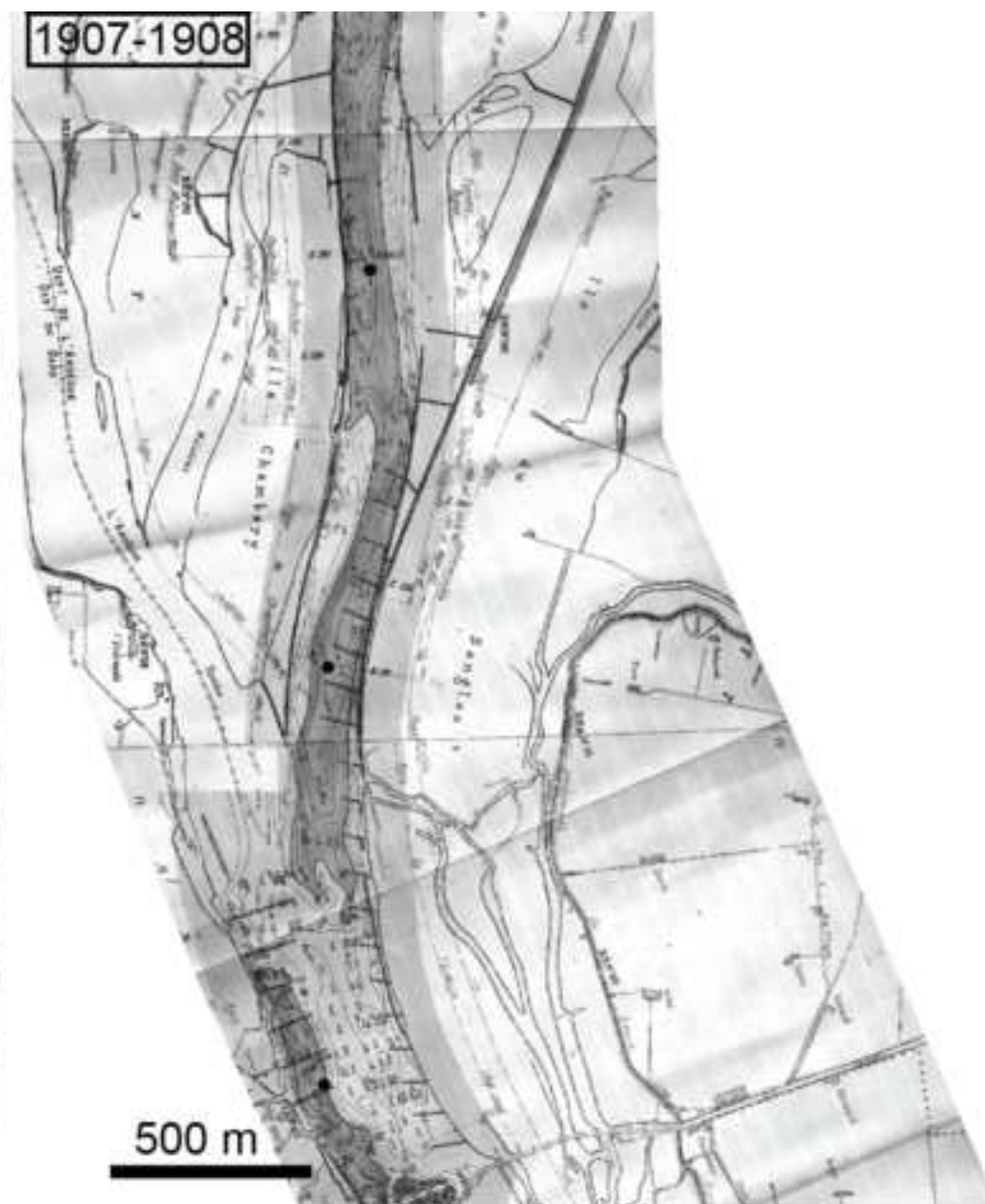
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**Cadastral map**  
(Archives départementales du Vaucluse)



**Bathymetric chart**  
(Compagnie nationale du Rhône)