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CAN FLOOD RISK MANAGEMENT RESTORE ECOGEOMORPHOLOGIC FUNCTIONING OF FLUVIAL MARGINS ALONG THE LOWER RHÔNE RIVER (FRANCE, SE)?

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ABSTRACT:

Over the last centuries, the Rhône River has been deeply modified by numerous uses and activities like navigation, irrigation, fight flooding, hydroelectricity production... Embankment, dams and groynes constructions, water diversion, and secondary channel artificial cut-off generated morphological changes such as channel degradation and narrowing, bank stabilization, and former channel terrestrialisation. These changes result in a fundamental modification of flowing conditions during floods and connections between channel and floodplain ecosystems.

Within the framework of compensatory measures, the CNR (Compagnie Nationale du Rhône, i.e. the Rhône River manager) wants to carry out a restoration project along the downstream reach of the Rhône River (southern France, 100 km length upstream from the mouth). The ambition is to combine both a decrease in local flood risk (by enlarging flood-carrying capacity) and an enhancement of geomorphological and ecological properties of the margins into the reach (sediment reworking, pioneer species regeneration...).

The Rhône River is a good case study for complex and deeply altered systems. Indeed, important issues have to be integrated: (i) flood risk for the major city along the reach (Arles), (ii) bank erosion control near cultivated areas, (iii) former channels loss of diversity due to terrestrialisation processes and floodplain forest disconnection because of the channel degradation, (iv) pollution risk if polluted sediments are reworked (contamination by metals, PCB and radionuclides), (v) navigation, and (vi) sediment deficit that impacts coastal evolution downstream the reach (Camargues delta).

We present a step-by-step strategy to reach an equilibrium between human activities and ecological purposes. All aspects are discussed: can historical state be considered as a reference-state? How can we choose sites to test the actions? How to design these actions? Which monitoring strategy has to be developed? Which kind of ecosystems can be expected under Mediterranean climate (composition, recovery rate, presence of exotic species...)?

Key words:

sedimentation, morphological adjustment, floodplain rehabilitation, flood management

1. INTRODUCTION: A RECENT CHANGE IN FLOODING CONDITIONS

Over the last decades the Rhône River has undergone significant morphological adjustment: stabilization, narrowing and deepening for several reaches (for the lower Rhône River see: Arnaud Fassetta, 1998; Antonelli, 2002; Raccasi, 2008). As a result of the floodplain evolution and channel configuration, we now observe significant changes in flooding conditions. For example, during the 2003 flood event (maximum discharge $11500 \text{ m}^3 \cdot \text{s}^{-1}$) some reaches underwent an higher waterlevel in the channel (for example +0.3 m upstream of Arles city, cf. figure 1) than during the 1856 flood (maximum $12500 \text{ m}^3 \cdot \text{s}^{-1}$). These observations led the Compagnie Nationale du Rhône (CNR, structure in charge of the Rhône River management) to set in motion some rehabilitation projects along the upper and middle Rhône River (Bravard *et al.*, 2008). Over the last decade, the CNR also initiated some rehabilitation actions in order to improve ecological functioning and diversity of Rhône's floodplain by former channel opening and excavation (Henry *et al.*, 2002; Amoros *et al.*, 2005).

The aim of this paper is to present the framework developed since 2007 for fluvial margins rehabilitation along the lower Rhône River reach. Because of this reach specificities (multiplicity of issues and stakeholders: inundation, bank erosion, pollution, navigation, riparian ecosystems, sediment transfer to coastal area), a particular framework has been developed.

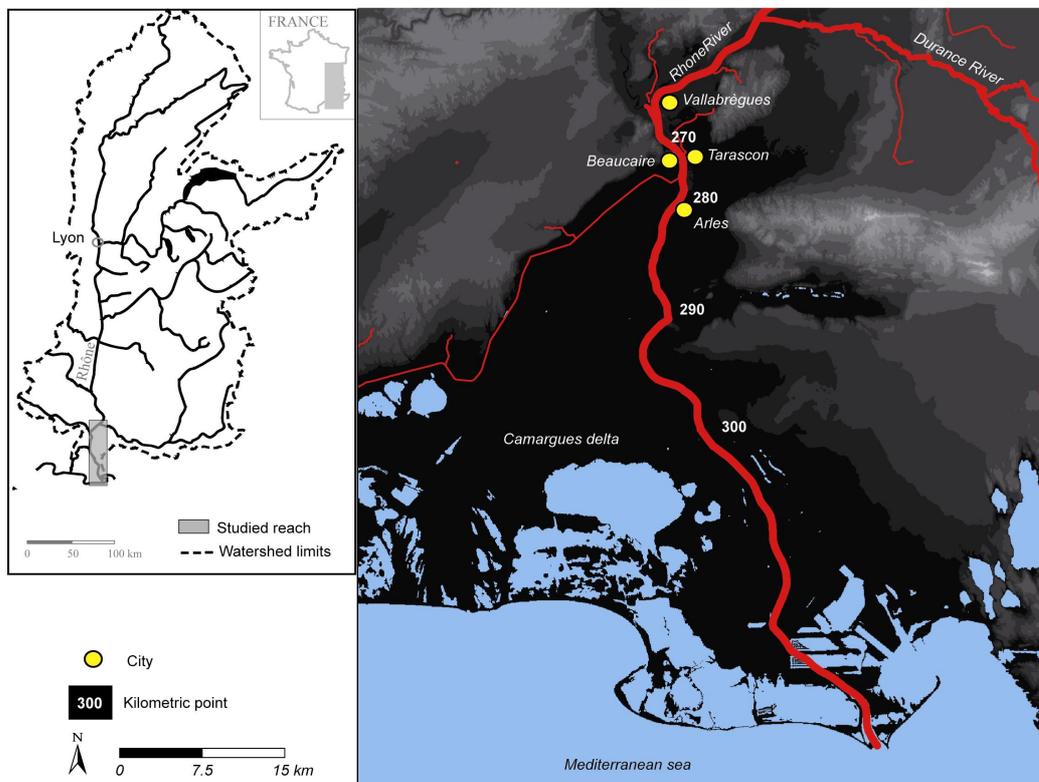


Figure 1: Location map.

2. REHABILITATION OF THE LOWER RHONE RIVER MARGINS: A GENERAL FRAMEWORK

The main goal of the rehabilitation project for the 70 km of lower Rhône River (from Vallabrègues to the sea) is to limit inundation during flood events, notably nearby the very sensitive areas such as Arles and Beaucaire-Tarascon (Figure 1). To tackle this question, we plan to increase channel capacity to evacuate floods by eroding fluvial margins that have been sedimented since the 19th century. Several strategies could be employed to initiate the eroding process: opening former channels, groynes removing, enhance bank erosion...

The project is made up of 2 steps. The first consist in testing the effect of rehabilitation upon a limited number of sites and the second in extending, if it is possible, actions to others sites along the

reach. The first step begun in 2007 and will be achieved in 2010. It can be divided in 7 successive steps (Table I). The first one is achieved; the second and third ones are still in progress.

Table I: framework for lower Rhône River rehabilitation project

Steps	Detail, intermediary steps	Goals
1. bibliographic analysis	Inventory of available data for the reach (hydrology, morphology, ecology)	To analyze the recent evolution of the reach To identify missing data and understudied sites within the reach
	Acquisition of additional information	To have homogeneous knowledge for the reach
2. selection of the sites	Identification of area filled by sediments during the 20 th century (notably former channels)	To identify all the sites that can be rehabilitated = potential sites (geomorphological criterion)
	From the potential sites list, identification of ownership constraint (exclusion of private sites)	To select sites on which the CNR can act quickly (legal criterion)
3. initial state	Implementation of the initial state: - historical evolution (from aerial photos, old plans) - current topography - sedimentation (thickness, grain size, associated pollutant) - hydraulic conditions (waterlevel during floods...) - vegetation (species, habitats)	To describe selected sites for rehabilitation before works
4. design of actions	- Description different potential methods (scenario, type of works and expected decrease in water level), - Identification of risks associated to each scenario - Financial estimation	To choose rehabilitation methods according to selected sites and locales constraint
5. implementation of actions	Implementation of works according to selected methods	To rehabilitate fluvial margins
6. monitoring	Monitoring implementation: - topography - sediment deposits - hydraulic conditions - vegetation (recovery cartography, communities characteristics)	To monitor the effectiveness of the selected methods
7. adjustment	Adaptation of the actions (depending of the results of the monitoring process)	To improve method effectiveness

3. DIAGNOSTIC: MORPHOLOGICAL CHANGES AND THEIR CAUSES (1876-2006).

To achieve the rehabilitation project a precise evaluation of both historical changes in floodplain topography and flood carrying capacities is needed.

3.1. Morphological changes (1876-2006)

Historical data analysis (old maps and surveys) clearly demonstrate that the lower Rhône River underwent several changes in channel geometry and bank position over the last 150 years (channel incision and narrowing, former channel sedimentation, bank accretion). For example, at the kilometric point (kp) 275.5, the channel has undergone a bed degradation of 2 m as well as a 500 m active channel narrowing between 2006 and 1876 (Figure 2). For the same discharge ($5800 \text{ m}^3 \cdot \text{s}^{-1}$; 2 years return period), increase in water level at this point is close to 0.5 m.

The comparison of two DEMs (1876 and 2006) gives an accurate quantification and localization of the sedimentation. Between Beaucaire and Arles (9 km), $9 \times 10^6 \text{ m}^3$ of sediment have been accumulated over the last 130 years. These modifications occur mainly in the channel and nearby, whereas the external part of the floodplain was quite stable over the period.

3.2. Causes

The current channel geometry results from the evolution of external controls and local constraints. Both flood event (Pichard, 1995) frequency and sediment supply from tributaries decreased since the 19th century. because of natural and artificial afforestation and dams' construction (Vallauri, 1997; Landon, 1999; Bravard, 2002; Kondolf *et al.*, 2002; Marston *et al.*, 2003; Piegay *et al.*, 2004). Consequently sediment transport decreased from $900\,000 \text{ m}^3 \cdot \text{y}^{-1}$ to $200\,000 \text{ m}^3 \cdot \text{y}^{-1}$ during the 20th century (BCEOM, 2003), whereas during the same period, mean discharge was constant (Pardé, 1925; François, 1937; Anselmo *et al.*, 2005).

The regulation works (dikes, groynes...) built downstream of Beaucaire between 1870 and 1938, to improve navigation, also greatly participated to the observed adjustments. For example, some groynes and submersible dikes from kp 293 to kp 297 have been built since 1867 (figure 3) to limit lateral mo-

bility in concavities and to close the side channels. They resulted in a very fast channel narrowing of 80 m from 1867 to 1869.

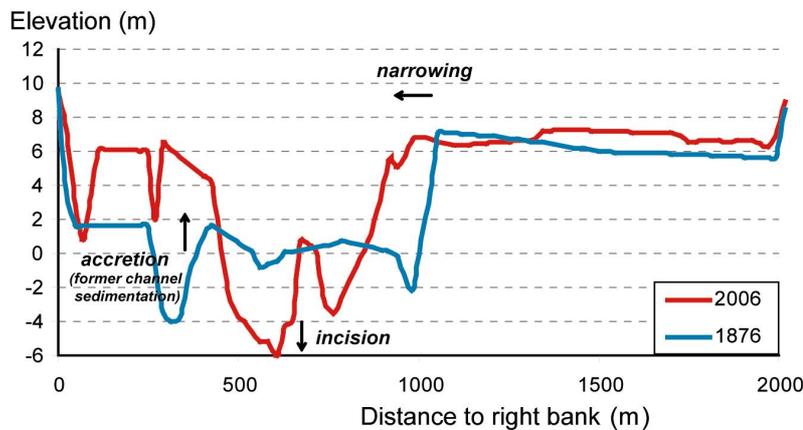


Figure 2: Channel cross sections at the kilometric point (kp) 275.5 in 1876 and 2006. Main changes are illustrated here: channel degradation and narrowing, sedimentation in former channels.

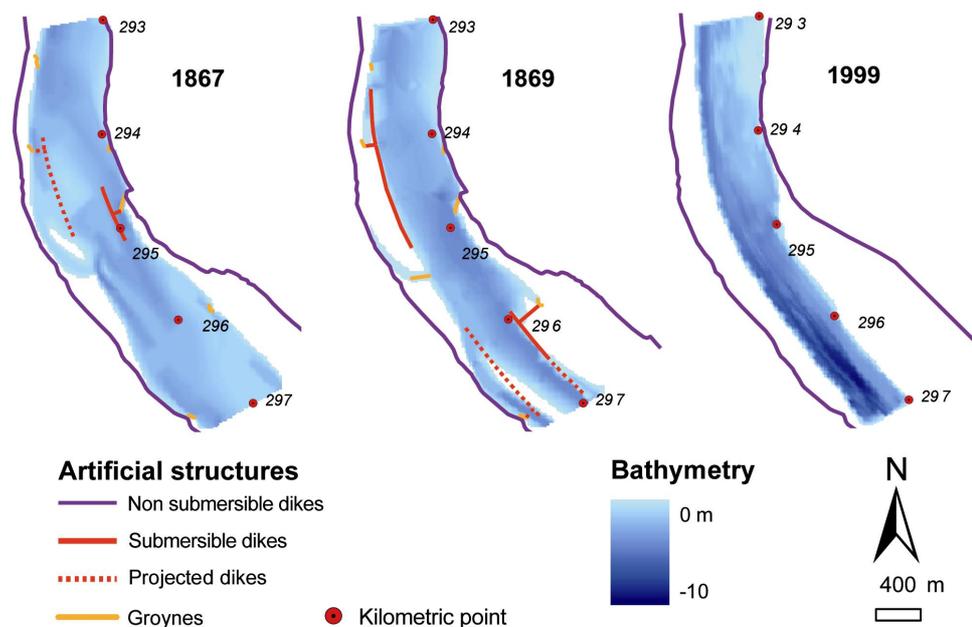


Figure 3: An example of regulation impact on channel geometry (incision and narrowing)

4. SITES SELECTION AND MULTIPLE ISSUES MANAGEMENT

The rehabilitation project of the lower Rhône River concerns a 70 km length reach where several issues are overlaid (Table II). On one hand, the instream introduction of sediments stored in the floodplain could cause negative consequences to others aspects such as private land erosion, navigation, and polluted sediments introduction. On the other hand, this action could benefit sediment supply to coastal area or ecological functioning of the floodplain. Moreover, all the length is not favourable to implement actions. Indeed, the vulnerability to inundation is concentrated only in the first kilometres of the reach and not in the Camargues delta. To increase erosion, channel gradient is also more favourable upstream from Arles. As a result, few sites appear to be potentially rehabilitated (2 to 4 sites along 70 km).

Table II: summary of issues to take into account in the rehabilitation project

Issue	Positive consequences of the rehabilitation	Potential negative consequences or constraints
Sediment transfer	Sediment reworking can increase sediment supply to coastal area (in deficit)	Current deficit is higher than potential available sediment During flood events a large part of the sediments move to the sea and do not participate to the coastal alimentation
Ecology	Improve ecological functioning of the floodplain and increase biodiversity by former channel rehabilitation	Expected habitats are not known because of a deeply and formerly impacted system with very few reference sites Increase in exotic species frequency (<i>Amorpha fruticosa</i> L., <i>Ludwigia</i> spp.)
Pollution		Sediment reworking can re-introduce pollutants in the systems (PCBs, mineral pollutants: metals and radionuclides)
Navigation		Actions must be limited to preserve the navigability of the reach: conserve a water level high enough and no change in channel position
Bank erosion		Rehabilitation actions have to generate not any problem of bank erosion of private area

5. CONCLUSION: IS THE REHABILITATION OF THE MARGINS A DURABLE SOLUTION FOR THE LOWER RHÔNE RIVER?

Along rivers that have recorded narrowing process over the last decades, sediment remobilisation could be used to decrease water level during flood events. From a theoretical point of view, this is particularly efficient for floodplains which present a high accretion rate. But, as for many rehabilitation projects, the technical limitation were not the biggest. Along the lower Rhône River, taking into account all the issues led to a drastic reduction of experimental sites number (and the area). So we expect a limited effect of actions upon flooding conditions (evaluation in progress). A negative feedback could be generated and make harder the extension of these actions to other sites or reaches.

To conciliate flooding management and eco-morphological several questions must be solved; the first is fundamental and complex: which kind of ecosystem we may expect? In our situation, human impact is ancient and strong and reference can't be a "natural" one. We clearly assume the impossibility to go back to the situation of the 19 or early 20th century, and that the past is not a better reference. A new reference must be identified, but how?

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