Consequences of a dam flushing operation on concentration and fluxes of suspended sediment and associated contaminants in the Rhône River

Conséquences d'une opération de lâcher de barrage dans le Rhône sur la concentration et les flux de matières en suspension et de contaminants associés

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RÉSUMÉ

Les besoins croissants en énergie et en transport fluvial engendrés par le développement industriel du siècle dernier ont conduit à la construction de nombreux ouvrages sur les fleuves, comme les barrages ou les écluses. C'est le cas du Rhône où une vingtaine de barrages hydro-électriques sont installés depuis les années 1950. Pour optimiser la production d'énergie et éviter les problèmes liés au stockage de sédiments au niveau de ces ouvrages, des lâchers de barrages sont réalisés de manière périodique. Des travaux ont été menés en amont du Rhône pour évaluer l'impact d'un de ces lâchers sur les concentrations et les flux de sédiments et de contaminants adsorbés (métaux, polluants organiques, radionucléides). Les résultats montrent que les flux des matières en suspension sont fortement élevés à l'aval proche des barrages mais que ceux observés à plus de 100km en aval sont similaires à ceux mesurés en période de crue. Les teneurs de certains contaminants (Cu, Hg, PCB_{101}…) sont significativement inférieures à celles observées lors de crues. Cette différence s'explique en partie par la teneur en carbone organique particulaire qui est elle aussi inférieure et à la variation de la taille des particules. La concentration de ces mêmes éléments augmente en s'éloignant des barrages amont. Enfin, les flux de contaminant sont similaires à ceux observés lors des crues et représentent une fraction non négligeable du flux annuel.

ABSTRACT

The increasing need for energy and fluvial transport due to industrialization during the last century resulted in the construction of infrastructures along rivers, as dams or sluices. Thus, nineteen hydro-electrical dams have been built along the Rhône River since 1950. To improve the production of electricity and avoid problems due to sediment storage within these infrastructures, dam flushing operations are organized periodically. Investigations were conducted in the upper Rhône River to evaluate the impacts of dam flushing operations on suspended sediment and associated contaminants (metals, organic contaminants and radionuclides) concentrations and fluxes. Results demonstrated that suspended sediment fluxes were very high in the vicinity of the dam, but similar to fluxes registered during flood events at other stations (approx. 100km downstream). For several contaminants (Cu, Hg, PCB_{101}…), concentrations were lower during dam flushing periods than during flood events or normal flow condition. This difference could be explained by particulate organic carbon concentrations that were also lower and the variation of particle size. Concentration of these elements tends to increase with distance from upstream dams. Finally, dam flushing fluxes of contaminants were similar to flood-related fluxes and represent a non-negligible part of the annual fluxes.

MOTS CLES

Dam flushing, metals, organic contaminant, radionuclides, suspended sediment

1 INTRODUCTION

The need of electricity rose during the last century, following the growing industrialization. One of the solutions conducted was the construction of hydro-electrical dams on river systems, and in the Rhône River for example (France), 19 (+ 3 in Switzerland) dams were built from Lake Geneva to the Mediterranean Sea since 1950 to provide electricity. Along rivers, dam reservoirs are one of the main facilities that impact sediment transport, by reducing flow velocity and increasing sediment deposition. These impacts lead to a decrease in the reservoir storage capacity and trigger economic issues (White, 2001). To avoid such situation, dam releases are periodically organized, as it is the case for the upper Rhône River (Peteuil et al., 2013). It has been demonstrated by numerous studies that several contaminants (metals, organic contaminants, radionuclides…) are strongly fixed to suspended particulate matter (SPM), especially the finest, and may be dispersed during flushing operations (Lepage et al., 2015). Understanding suspended sediment behavior and associated contaminants during dam flushing operations is thus necessary to improve the environmental monitoring of rivers. In order to better constrain the impact of such operation and their characteristic in comparison with normal flood, SPM sampling was conducted during dam flushing in the Rhône River and associated contaminants were characterized within the framework of the Sediment Observatory of the Rhône River. Comparisons were done between these samples and the values measured during normal flow condition and flood events based on water discharge.

2 METHOD

Dam flushing events were investigated in the upper Rhône River in June 2012. Several dams were flushed during this month to prevent floods due to bed aggradation in Verbois reservoir, downstream the city of Geneva (Figure 1).

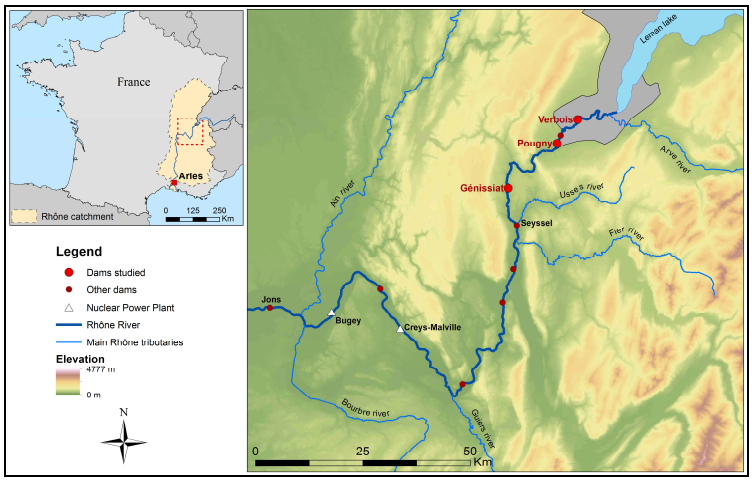

Figure 1 – Study area in the upper Rhône River

The release took about three weeks, and almost fifty samples were collected at six stations along the upper Rhône River. SPM were collected using sediment traps and continuous-flow centrifugation. SPM concentrations were determined using turbidimeters and manual samplings. Polychlorobiphenyls (PCB) and Polycyclic Aromatic Hydrocarbons (PAH) were analyzed according to the XP X33-012 Standard. Total Hg was determined according to the USEPA Method 7473 (USEPA, 2007) by thermal decomposition, amalgamation and atomic absorption spectrophotometry. Metals concentrations were measured by ICP-MS. Finally, three radionuclides were also characterized: Cesium-137 by gamma spectrometry, Tritiated Hydrogen (HTO) by liquid scintillation counting and Organically Bound Tritium (OBT) by noble gas mass spectrometry, measuring He-3, the decay product of tritium. The flux of SPM and associated contaminants were calculated by using discharge measurement (provided by National Company of Rhône River – CNR) and SPM concentrations.

3 RESULTS

Most of the sediments have deposited in the vicinity of the upstream dams. From 9th to 18th June, approx. 2.60 Mt of sediments transited by Pougny station, but only 0.22 Mt were measured at Jons. Most of the sediments were stored in the Génissiat dam (almost 2.0 Mt), which had been emptied a week before Verbois dam flushing (from 4th to 12th).

Three different trends were observed at Jons when comparing contaminant concentrations during the dam flushing event with values from normal flow conditions and flood events periods (Figure 2):

- concentrations remained similar (Cd, Nonylphénol and DEHP),
- concentrations were significantly (approx. 25% lower, $p < 0.05$) lower (POC, Cu, Hg, Pb, PCB_{101}, Zn and ^{137}Cs),
- only Benzo[a]Pyrene had concentrations significantly (approx. 50% higher, $p > 0.05$) higher.

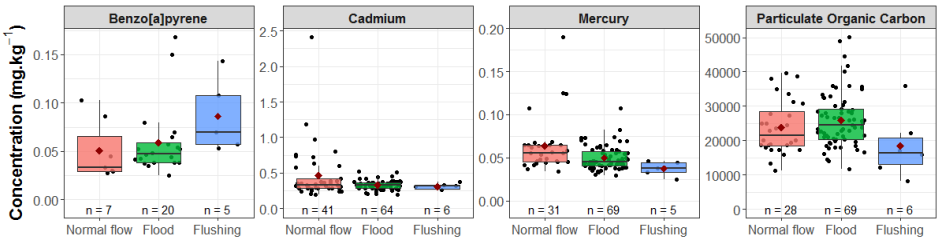

Figure 3 – Concentration box plots of Benzo[a]Pyrene, Cd, Hg and COP for three hydrological conditions at Jons.

The second trend, which is the most common, may be explained by the variation of particulate organic carbon (POC) content, which also shows a decrease from flood to flushing (Figure 3). It is well recognized that Cu, Zn and Hg have a particular affinity for particulate organic matter, in relation with our observations. Variations of particle size are also related to these observations.

For all parameters except PCB_{101}, the concentrations increased with distance from Pougny up to Creys-Malville (figure 1), where they reached the highest values (Table 1). Then these concentrations remained similar between Creys-Malville and Jons (only ^{137}Cs showed an increase). Variation observed may be related to POC, particle size, or additional source of contaminants (Nuclear Power Plant, tributaries…) but additional investigation will be conducted.

Table 1 – Spatial variation of parameter concentrations during the dam flushing. "=": concentrations similar to the closest upstream station, "↗": concentrations increases.

Stations =>	Seyssel	Creys-Malville	Jons
Benzo[a]Pyrene, ^{137}Cs, Cd, Hg	↗	↗	=
POC, Cu, Pb, Zn, OBT,	=	↗	=
PCB_{101}	=	=	=

Finally, fluxes were estimated especially at Jons were annual fluxes are recorded since 2011. Results demonstrated that this flushing event represented approx. 36% of the annual flux of suspended sediment transported during this period. This proportion is similar for most of the fluxes of contaminants. For example, 38% to 46% of annual ^{137}Cs flux was transported in 18 days. This is directly due to the fact that the variation is entirely associated due to that of SPM and not to contaminant concentrations.

4 CONCLUSION

Variation of contaminant concentrations and fluxes were investigated during dam flushing operations. It was demonstrated that only one contaminant concentration (Benzo[a]Pyrene) increased during this dam flushing operation. Thus, this operation had no impact on contaminant concentrations, and the fluxes were similar to fluxes measured during flood events. Additional investigation is needed to identify the reasons of the observed variations. First results demonstrated that they could be related to POC and particle size but further investigation on sources of contaminants may be necessary.

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