A 1-D hydro-sedimentary numerical model to improve the understanding of suspended particulate matters and contaminant fluxes in the Rhône River

Un modèle numérique hydro-sédimentaire 1-D pour aider à la compréhension des flux de matières en suspension et de contaminants dans le Rhône

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RÉSUMÉ

Dans le cadre de l'Observatoire des Sédiments du Rhône (OSR), un modèle hydro-sédimentaire 1-D du Rhône est développé entre le Lac Léman et la mer Méditerranée. Celui-ci prend en compte les apports des affluents majeurs ainsi que les consignes de réglage des aménagements hydroélectriques. Ce modèle a pour objectif d'améliorer la compréhension des processus hydro-sédimentaires dans le fleuve sur des échelles de temps allant de l'évènement hydrologique à des périodes couvrant plusieurs décennies. Une attention particulière est apportée à l'étude des flux de matières en suspension et de contaminants. La validation du modèle et l'intégration des consignes de réglage des aménagements ont été faites sur deux évènements hydro-sédimentaires majeurs : la crue Isère/Durance de mai-juin 2008 et la chasse des aménagements du Haut-Rhône en juin 2012. Les hydrogrammes ont pu être reproduits correctement par le modèle entre le Lac Léman et la mer. La décomposition des hydrogrammes en fonction de l'apport des affluents a également été réalisée par traçage numérique avec le modèle d'advection-dispersion Adis-TS et permet de connaître en tout point du réseau la quantité d'eau provenant des différents affluents.

ABSTRACT

As part of the Rhône Sediment Observatory (OSR), a 1-D hydro-sedimentary model has been developped to simulate the Rhône River from Lake Geneva onto the Mediterranean Sea. The model includes the outlets of major tributaries as well as the rules for hydropower schemes regulation. The model aims at improving the understanding of hydro-sedimentary processes including suspended particulate matters and contaminant fluxes throughout the river system at temporal scales ranging from hydrological events to multi-decadal periods. The validation of the model and the integration of hydropower schemes' rules have been performed using two major hydrological events : the May-June 2008 flood of the Isère and Durance rivers and the 2012 hydraulic dam flushes in the Upper-Rhône, upstream of Lyon. Hydrographs have been correctly reproduced by the model between Lake Geneva and the Mediterranean Sea. Decomposition of the streamflow according to the tributaries has also been performed with the advective-dispersive model Adis-TS based on numerical tracing. Results generate information on the composition of the streamflow at any location of the river network.

KEYWORDS

Hydrological event reconstruction, hydro-sedimentary model, suspended particulate matters, particulate contaminant fluxes, Rhône River.

1 INTRODUCTION

The Rhône River is characterized by a high transport of suspended particulate matters provided by its major alpine tributaries. From Lake Geneva to the Mediterranean Sea, 22 hydropower schemes, « run-of-river » type for most of them, have an impact on the sediment transport as they interrupt the river corridor continuity but also because they influence the water discharge / water level relation in the river. 19 of them are operated by the Compagnie Nationale du Rhône (CNR) (Grimaldi et al., 2012).

The objective of the present research project is to provide a 1-D numerical model from Lake Geneva to the Mediterranean Sea which is able to reproduce the transient flow of extreme events in the Rhône River with respect to hydropower schemes regulation and to simulate accurately the suspended sediment and pollutant fluxes with small time steps. As a valuable result, decomposition of the river flow according to the Rhône River's tributaries is also provided.

2 HYDRAULIC MODELING

The Rhône River system is modeled using the 1-D loop-meshed hydrodynamic model MAGE, coupled with an advection-dispersion resolution for pollutant and suspended sediment transport Adis-TS (Andries et al., 2011 ; Launay et al., 2014). The multi-reach network has been calibrated and validated over each reach using water longitudinal profiles provided by the CNR. As an indication, hydraulic numerical simulation of 16 days in a 170 km-long reach represents a computation time of approximately 3 minutes. Up to know, the model does not include floodplain and consequently can not be used to simulate overbank flow.

Bathymetries of the major tributaries, such as the Arve, Ain, Saône, Isère and Durance Rivers, are included from their confluence with the Rhône River to the closest monitoring stations. Other tributaries are only represented as local inputs.

For each hydropower scheme, two regulation rules are integrated to the model according to the theoretical ones applied by the CNR.

- The first one regulates the water discharge between the « old » natural Rhône and the bypass channel. It integrates the constant minimum compensation discharge in the natural Rhône as well as the maximum operating discharge of the hydropowerplant in the bypass channel.
- The second rule defines a fixed maximum water level in the reservoir as a function of the water discharge.

Such theoretical rules do not integrate real fluctuations due to hydropeaking and maintenance during normal operations.

3 RESULTS

Results illustrated in this section focus on the reach located between Lyon (km 0) and the monitoring station of Viviers (km 166,5) (Figure 1a). This reach includes 8 hydropower schemes and 12 tributaries. The 2008 flood on the Rhône River was simulated from May 25th to June 11th (16 days).

3.1 Hydraulic modeling

The hydraulic model was able to reproduce the hydrographs measured at several hydrometric stations along the Rhône River. In Figure 1b, the measurement made at Viviers (solid line) is compared with the simulated flood hydrograph (dashed line), calculated from the input discharges of the tributaries and the hydropower schemes regulation. The measured hydrograph was correctly reproduced by the model. Small variations between the two curves are mainly due to daily operations of each hydropower schemes which are not included in the model.

3.2 Streamflow decomposition

The 1-D model of the Rhône River coupled with Adis-TS can be used to decompose the flow hydrographs according to the water inputs from the different tributaries. This decomposition provides the origins of the water flowing at a downstream monitoring station. Combined with sediment concentration measurements, the suspended particulate matters (SPM) fluxes can be decomposed.

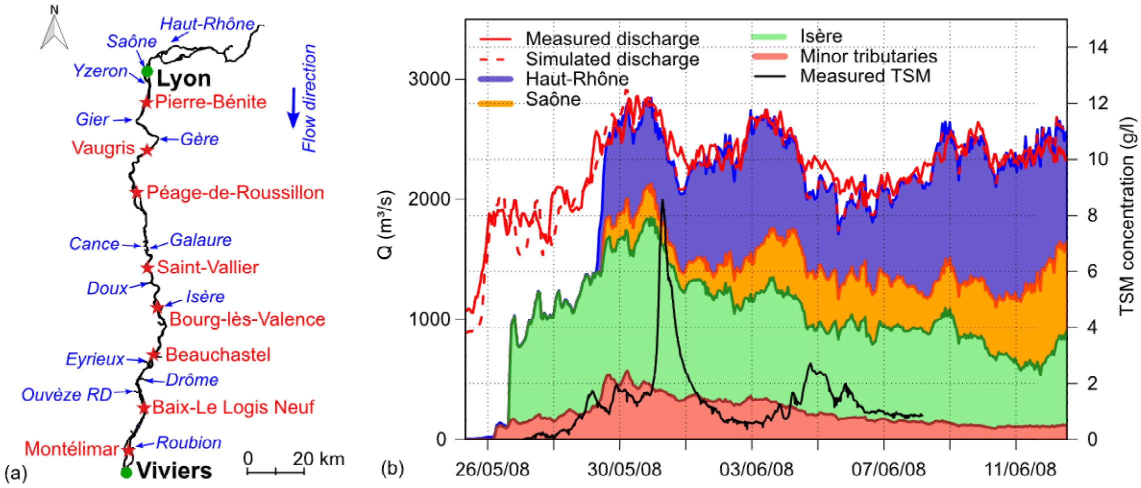

Figure 1 : (a) The Rhône River from Lyon to Viviers with tributaries (blue arrows) and hydropower schemes (red stars) ; (b) Results from hydraulic modeling and hydrograph decomposition according to tributaries

An example of this decomposition is provided in Figure 1b. In each of the 12 tributaries, a fictive tracer, called after the name of the corresponding tributary, is injected in the river system. From the resulting concentrations observed at the downstream monitoring station of Viviers, the proportion of water coming from each tributary can be determined which leads directly to the tributary hydrograph based on the relation, $C_i=Q_i/Q$, where Q_i and C_i are the water discharge and the concentration of tracer in the tributary i, respectively, and Q is the total water discharge. Comparison of the resulting hydrographs with TSM concentration measured in Viviers station shows that the peak of TSM coincides with the water discharge peak in the Isère River.

Such a decomposition can be performed at each point of the river system. It brings valuable additional information, especially for interpreting data of monitoring stations where measurements of pollutant or sediment concentration are performed.

4 CONCLUSION AND OUTLOOK

A 1-D model of the Rhône River has been constructed and validated between Lake Geneva and the Mediterranean Sea. This model includes the oulets of major tributaries as well as the hydropower schemes regulation and presents very low computation times which allow for simulating hydrological events as well as multidecadal periods with small time steps.

Calibration of suspended sediment transport on measurements performed during the 2008 flood and the 2012 flushing event is still under progress.

The model, which aims at improving the understanding of hydro-sedimentary processes including suspended particulate matters and contaminant fluxes throughout the river system, represents a valuable operation tool for planification and management of the river.

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