Identifying sustainable and robust trade-offs between hydropower and sediment trapping under uncertain sediment yields in the Mekong River Basin

Identifier des compromis durables et robustes entre l'hydroélectricité et le piégeage des sédiments dans des conditions incertaines de production de sédiments, dans le bassin du Mékong

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RÉSUMÉ

La planification stratégique des barrages à l'échelle de chaque bassin a été présentée comme une approche permettant des compromis durables entre la production hydroélectrique et les impacts environnementaux des barrages, tels que le piégeage des sédiments, sur les services d’écosystèmes fluviaux. Pour le piégeage des sédiments, la planification stratégique peut être compliquée par la méconnaissance de l’origine des sédiments dans un grand nombre de cours d’eau importants et par les changements futurs potentiellement graves dans l'utilisation des terres et l’évolution climatique, donc par les taux d'érosion et de sédimentation. Pour l'étude de cas du bassin du Mékong, nous montrons comment certaines estimations générales de la production de sédiments peuvent permettre une planification stratégique fiable compte tenu de la mauvaise connaissance des origines des sédiments dans le bassin et des changements futurs. Nous utilisons un modèle à l'échelle du réseau pour le routage et le piégeage des sédiments par le barrage avec une large délimitation du bassin dans neuf zones géomorphologiques avec des productions différentes de sédiments. Nous utilisons en outre un algorithme Multi Objective Evolutionary et une analyse de sensibilité formelle. Les résultats montrent que le bassin du Mékong connaît actuellement un tournant. La planification stratégique pourrait encore conduire à de meilleurs compromis entre la production d'hydroélectricité et le piégeage des sédiments. Suivre la trajectoire de développement prévue conduira au contraire à une réduction critique de la production de sédiments. Nos résultats sont fiables sur l’estimation de la production de sédiments, et indiquent donc que même des estimations larges peuvent être d'une grande valeur pour une meilleure prise de décision hydroélectrique dans les grands bassins fluviaux.

ABSTRACT

Strategic basin-scale planning of dam portfolios has been promoted as suitable approach to find sustainable trade-offs between hydropower production and dam environmental impacts, such as sediment trapping, on river ecosystem services. With regard to sediment trapping, strategic planning is potentially impeded by the poor knowledge of sediment origins in many large rivers and the potentially dramatic future changes in land use and climate change and hence erosion rates and sediment yields. For the case study of the Mekong River Basin, we herein show how some broad estimates of sediment yields can be used for strategic planning that is robust with regard to poor knowledge of sediment origins in the basin and future change. We feed a network scale model for sediment routing and dam sediment trapping with a broad delineation of the basin in nine geomorphic zones with different sediment yields. We couple that framework to a Multi Objective Evolutionary algorithm and a formal sensitivity analysis. Based on the results, we find that the Mekong basin is at a turning point. Strategic planning could still lead to better trade-offs between hydropower production and sediment trapping, following the planned development trajectory will instead lead to a critical reduction in sediment yield. Our results are robust with regard to estimated sediment yields, hence indicating that even broad estimates of sediment production can be of great value for better hydropower decision making in large river basins.

KEYWORDS

Strategic hydropower planning, sediment yield, land use change, Mekong

Dams and reservoirs are central infrastructures to fulfill human water needs in the face of changing climate and to provide carbon-free energy for socio-economic growth and development. Yet, dams disrupt the connected functioning of river systems, for example with regard to sediment transport and the associated bio-physical functioning of rivers. On the scale of a single dam, its impact and benefits on sediment transport are a function of its location in the river system and its technical layout. At the scale of an entire river network, both the location of dams in the network and the spatial pattern of different yields in a basin will control cumulative impacts of dams on river sediment transport.

Strategic basin-scale planning has been promoted as suitable approach to find dam portfolios that present a good trade-off between dam environmental impacts and their socio-economic benefits. With regard to sediment trapping, strategic planning is potentially impeded by two factors: 1) the poor knowledge of sediment origins in many large river basins that are currently hot-spots of dam development (such as the Amazon, Kongo, Mekong, and Irrawaddy) and 2) the potentially dramatic future changes in land use and climate that might make best estimates of status-quo sediment origins invalid in the near future.

Here, we report a new approach to make strategic system-scale planning of dam portfolios more robust with regard to these two factors. We develop that approach for the Mekong River Basin, where sediment plays a key role for maintaining the morphologic integrity of the Mekong Delta, the lower Mekong floodplains, and the ecosystems and livelihoods that these landforms support. The Mekong Basin's pristine sediment load of around 160 Mt/yr is already reduced through sediment trapping many major dams in the basin (Kondolf et al., 2014). However, besides dam impacts, there is also a major uncertainty regarding how sediment yields from various parts of the basin will change in the near future, for example because of deforestation and construction of infrastructures, especially roads. For sediment trapping in the Mekong, we identify three research questions: (1) is there still an opportunity to find better trade-offs between cumulative sediment trapping and hydropower production? (2) how sensitive are modelled sediment transport rates at various levels of dam development to poor knowledge and future changes of sediment yield? (3) might future changes in sediment yield partially balance dam impacts on the sediment budget of the Mekong?

To address these research questions, we combine a delineation of the Mekong Basin into nine geomorphic provinces with different sediment yields (Kondolf et al., 2014) with a network scale model for sediment routing and dam sediment trapping (Schmitt et al., 2016). We couple that modeling framework to a Multi Objective Evolutionary algorithm to find dam portfolios that present an optimal trade-off between sediment trapping and hydropower production. We then generate an ensemble of 80000 random permutations of sediment yield, covering the range from an 80 % reduction to a 200 % increase in sediment yield from each geomorphic province (Hadka and Reed, 2012). Based on the results, we analyze the sensitivity of computed total load in the Mekong to the estimated yield from each province. Finally, we discuss if any future change in sediment yield, e.g., because of land-use changes, has the potential to balance dam sediment trapping and hence to maintain at some residual sediment transport to the lower Mekong and the Mekong Delta.

First, we find that the Mekong basin is at a turning point for reducing dam sediment trapping in the Mekong through strategic planning. The dams that are currently build and under construction will trap approximately 60 % of the basins sediment load. Under the currently planned development trajectory, the construction of major mainstem dams will soon increase sediment trapping to >90 %, while expanding hydropower production by only around 10 %. With strategic planning, in contrast, a major increase in hydropower production (~ 50 %) could be reached with little added impact on sediment delivery. Such a co-benefit could be created by prioritizing major dams in the upper Mekong and hence upstream of already existing dams. We find that the calculated sediment load in the Mekong both in a pristine state and under the status-quo of dam development is sensitive to yield estimates in two geomorphic provinces, only. Specifically, total load is sensitive to the sediment yield from the upper Mekong (Lancang) and few lower Mekong tributaries. Uncertainty or future changes in sediment yield from the other geomorphic provinces have instead no major impact on the estimated total load. Under the current status-quo of dams in the basin, total sediment load in the Mekong is mainly sensitive to sediment yields from the lower Mekong tributaries and to a lesser extend from the Lancang. This is because the Lancang is already disconnected from the lower Mekong by existing dams. However, for the planned development strategy, even an unlikely two-fold increase in sediment yield from the lower Mekong tributaries would not have a major impact on sediment loads to the lower Mekong as most additional sediment would be trapped in major mainstem dams. If an optimal dam development strategy would be adopted, a moderate increase in sediment yield in the Lancang and the lower Mekong tributaries would potentially maintain total load above 80 Mt/yr, and hence around

50 % of the pristine value.

To conclude, it has often been proposed that basin development and the associated increase in erosion rates and sediment yields could balance sediment trapping in dams. Here, we show how both processes can be analyzed in a common framework. We then demonstrate how the resulting information can be used for strategic hydropower decision making that is robust with regard to future changes in sediment yields. If dam construction continues as planned in the Mekong a critical reduction of sediment load to the delta (> 90 % compared to the pristine state) is unavoidable even under most extreme changes in basin sediment yield. If future hydropower would be sited strategically, there is some chance that future changes in sediment yield will partially balance dam sediment trapping and maintain at least half of the natural sediment transport to the delta. Hence, strategic planning together with a robust analysis of uncertainty in sediment yields (and potentially other eco-system services) could be of great value for finding better trade-offs with regard to hydropower and dam sediment trapping. The proposed strategy implements such a strategic planning under full consideration of the great uncertainty in current and future sediment yields in the large river basins that will be the hotspots of dam development in the near future.

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