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Viewpoint

River Damming Impacts on Carbon Emissions Should Be Revisited in the Context of the Aquatic Continuum Concept

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The growing demand for water and energy has driven a global increase in river damming and impoundment. By 2015, reservoirs supplied around 17% of global electricity and 30−40% of irrigation water.[1] River damming introduces physical barriers that fragment rivers and disrupt the natural flow of matter and energy. Consequently, the physical, biological, and biogeochemical effects of river damming have become the central research areas.[1] Notably, the emissions of carbon-based greenhouse gas (methane: CH_4 and carbon dioxide: CO_2) from reservoirs have become a major focus of biogeochemical research under the context of climate change, challenging the previous perception of hydropower as a clean and green energy. It is estimated that hydroelectric reservoirs alone emit about 48 Tg CO_2 and 3 Tg CH_4 annually, accounting for 4% of carbon emissions from global inland waters, thus representing a non-negligible component of global carbon emissions.[2] Over the past three decades, the diverse pathways and significant spatiotemporal variability of carbon emissions have been well recognized and captured, which is essential for reducing the uncertainty in reservoir carbon emission estimates. Currently, detailed exploration and clear definition of the impacts of river damming on carbon emissions are demanded, as a thorough and scientific evaluation of these effects is a crucial prerequisite for future dam constructions.

A CLEAR DEFINITION DOES MATTER

Alterations in river carbon cycle processes affecting CH_4 and CO_2 emissions are not solely caused by river damming, but these processes also occur naturally, for instance, organic carbon burial and decomposition can occur elsewhere in the absence of river damming. Therefore, a clear definition of how river damming affects carbon emissions does matter. Synthesizing previous studies, Prairie et al.[3] proposed an insight into identify which changes in carbon emissions are directly attributed to river damming and which are merely displaced. One of the key components is to quantify the differences in carbon emissions before and after river damming and impoundment.[3] A handful studies, such as Bertassoli et al.[4] indicates that carbon emissions after the impoundment of Belo Monte Reservoir are 2- to 3-fold higher than those before impoundment. However, this work still poses challenges due to the scarcity of continuous and direct field measurements on carbon emissions from rivers and inundated areas before and after reservoir impoundment. With the clear definition and connotation of how river damming affect carbon emissions, it becomes evident that previous studies were confined to a relative narrow area within and around the reservoir itself, such as the reservoir-water interface, the drawdown area, turbine degassing, and downstream emissions from oversaturated released water with limited distance.

RIVER DAMMING IMPACT ON CARBON CYCLE: BROADER THAN THOUGHT

The operation of reservoirs under specific hydrological management strategies profoundly affects downstream hydrological and nutrient regimes (Figure 1). Strategies like peak shaving and valley filling significantly modify the hydrological and hydrodynamic conditions of downstream rivers. The retention of biogenic elements such as carbon, nitrogen, phosphorus, and silicon by reservoirs can drastically alter downstream nutrient regimes and may even lead to imbalances in nitrogen-to-phosphorus ratios at estuaries, e.g., increase the TN (total nitrogen) and RP (reactive phosphorus) ratio by 24% in the East China Sea.[1] These disruptions in hydrology and nutrient regimes directly and indirectly affect carbon cycling processes in downstream aquatic ecosystems, including primary productivity, ecosystem metabolism, wetland vegetation growth and organic matter burial, and thereby influencing CH_4 and CO_2 emissions (Figure 1).

Recent studies have offered new insights on how reservoir impoundment and operation impact on downstream carbon emissions. It was reported that CH_4 and CO_2 emissions from downstream river dropped 18% and 55%, respectively, since

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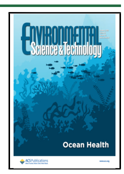

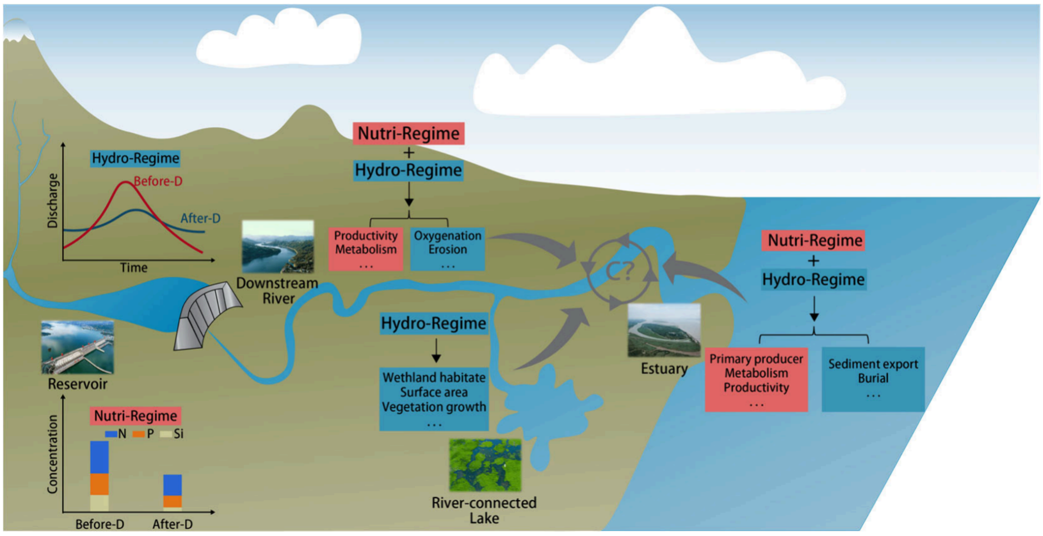

Figure 1. A conceptual schematic illustrating the effects of river damming on downstream hydrological and nutrient regimes, and how these changes further impact carbon cycling processes in downstream aquatic ecosystems, including rivers, connected lakes, and estuarine ecosystems. Before-D and After-D denote conditions before and after river damming.

the operation of the Three Gorges Reservoir (TGR). This reduction is attributed to the alterations in the physical, chemical, and biological environments of downstream rivers.[5] The hydrological regulation of TGR affects the habitat, surface area, and thus the development of plants in downstream connected wetlands in Poyang Lake, shifting it from being a CO_2 source to a sink.[6] Moreover, reservoir impoundment and operation can cause intermittent downstream flows, with alternating wet and dry conditions in riverbeds, which can significantly impact carbon emissions. It was indicated that CO_2 emissions from exposed and dry sediments were nearly double than that from lotic waters.[7] These findings suggest that the impact of reservoirs on downstream carbon cycling may far exceed our previous understanding. However, key scientific questions persist regarding whether, how, and to what extent river damming affects carbon cycle processes (Figure 1).

RECOMMENDATION AND OUTLOOK

Rivers act as essential pathways linking terrestrial land and ocean, playing a disproportionate role in carbon emissions. The aquatic continuum concept describes the longitudinal gradient of physical conditions in undisturbed waters and highlights the interconnectedness of upstream and downstream aquatic ecosystems.[8] This framework provides crucial insights for understanding how carbon is transported and transformed from land to ocean within inland aquatic ecosystems, especially under human-induced disturbances like river damming. Although extensive monitoring networks have been established nationally, providing crucial database, they are insufficient for fully comprehending river damming's impact on the carbon cycle. The advancement of sophisticated process-based biogeochemical models focused on the cycles of carbon and other biogenic elements has become an invaluable tool for investigating carbon transport and transformations along the aquatic continuum, especially through integrated estuarine modeling. Therefore, this viewpoint emphasizes the urgent necessity to explore the impact of river damming on carbon emissions within the aquatic continuum framework (Figure 1), particularly given the current surge in dam construction. Such research will enhance our understanding on how river damming affects downstream aquatic ecosystems, including carbon cycling processes in rivers, river-connected lakes, and estuaries (Figure 1). This effort requires intensive interdisciplinary collaboration. Based on our current but scattered knowledge, we strongly emphasize that scientists in related fields should revisit the impacts of river damming on carbon emissions within the framework of the aquatic continuum to enrich our understanding of these impacts.

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Notes

The authors declare no competing financial interest.

Biographies

Dr. Xingcheng Yan earned his PhD in Geosciences, Natural Resources, and Environment from Sorbonne University, Paris, in 2022. He currently serves as a senior engineer in the Eco-Environmental Research Department at the Nanjing Hydraulic Research Institute. He leads the Young Scientist Project under the National Key Research and Development Program, as well as the Young Foundation Project of the National Natural Science Foundation of China. His research primarily focuses on the eco-environmental impacts of river damming, with particular attention to the biogeochemical cycling of carbon, nitrogen, phosphorus, and silicon.

Dr. Qiuwen Chen is currently the head of Eco-Environmental Research Department of Nanjing Hydraulic Research Institute (NHRI). He received Ph.D. degree from Delft University of Technology in 2004. Then, he worked in RCEES Chinese Academy of Science from 2004 to 2013, and joined NHRI in 2014. He has been long engaged in Eco-environmental conservation for hydraulic engineering and hydropower development. He has published more than 400 international peer-reviewed papers. He was awarded the 20th Arthur Thomas Ippen Award from the International Association for Hydro-Environment Engineering (IAHR) and the Xplore Prize. He is now the chairman of Global Water Security of IHAR, and an associate editor of 2 international journals.

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