RESERVOIR SEDIMENTATION: CHALLENGES AND MANAGEMENT STRATEGIES

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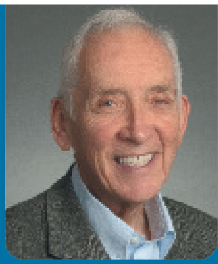
This is the third issue of Hydrolink on reservoir sedimentation. The decision to have three issues on this subject was in response to the great interest expressed by many IAHR members and others, which also led to the formation of working research group on reservoir sedimentation, sponsored by the Hydraulic Technical committee of IAHR which will be launched formally during the 38th IAHR World Congress in Panama, September 1-6, 2019. The current issue includes articles on the methods and strategies used in different countries for dealing with the problem of reservoir sedimentation.



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Reservoirs typically trap all the bedload and a percentage of the suspended load that depends on the ratio of the reservoir storage capacity to the river's mean annual flow. Assessing and understanding the risks associated with sediment trapping and management at hydropower facilities is an essential part of developing plans for the sustainable use of their reservoirs. As part of the hydroelectric production activities of Electricité de France (EDF), the risks generated by reservoir sedimentation and management at hydropower facilities have been assessed based on a classification by hazard, which is then broken down by the associated issues and /or sub-issues, and finally by the risks incurred. This methodology is described by Malavoi and El kadi Abderrezzak in the current issue.

The techniques to manage sediment in reservoirs include those that route sediment through or around the reservoir (*e.g*. flushing, sluicing, turbidity current venting, off-channel reservoir, bypass tunnels), those that remove sediment accumulated in the reservoir to regain capacity (*e.g*. mechanical excavation, hydraulic excavation), and those that minimize the sediment arriving to reservoirs from upstream (*e.g*. soil erosion control, check dams "*Sabo*", farm ponds, gully stabilization, revegetation). China has 98,795 reservoirs (as of 31 December 2017) with a total capacity of 941 billion m^3, but also an average annual rate of storage loss of 2.3%, the highest in the world. In this issue, Cao *et al*. describe sediment management strategies applied in China for recovering totally or partially the reservoir storage capacity, providing lessons to help guide planning and design of new dams. A mix of techniques, employed successfully, include check dams, afforestation, grass vegetation and terracing for soil and water conservation, application of the so-called reservoir operation method "store the clear and release the muddy" in many reservoirs, and hydraulic and mechanical desilting techniques to remove sediments, such as a pneumatic pump capable of handling very coarse deposits.

To understand how a reservoir behaves and how to manage it successfully, special investigations are needed to accurately determine the characteristics of sediments and their inflow rate. The sediment yield of the catchment draining in a reservoir depends on several factors, ranging from climate to geologic, topographic, and anthropogenic influences, and is subject to high degree of uncertainty. In the current issue, Francés discusses two methods used for this purpose: the Universal Soil Loss Equation, which calculates the soil erosion, and a spatially distributed, physically based mathematical model incorporating Land Use/Land Cover changes within the catchment. An example of a specific field case is presented in Zamora's article who proposes a simple method for computing the sediment yield of the Samalá river catchment in Guatemala, which has been affecting the El Canadá Hydropower plant. An off-stream regulation pond, which provides daily flow regulation for power peaking, has been losing half of its storage capacity annually due to sedimentation. Monitoring during dredging operations allowed the collection of daily data that were used to back-calculate the sediment yield.

Another specific case is the Camurí Grande basin, which was the theatre of the worst natural disaster in the history of Venezuela. The rainfall event of December 1991 triggered a huge soil mass movement (between 1.3 and 2.2 Mm^3 of sediments), causing thousands of casualties and heavy economic damage. In the current issue Sanchez and Courtel investigate numerically the adequacy of structural counter-measures (retention dams and channelization works) in reducing the consequences of debris flows on the lower parts of the Camurí Grande basin.

Dredging is a common but expensive technique for restoring reservoir storage capacity. The disposal of dredged material is an important issue. In some cases it is possible to discharge the dredged material to the river channel downstream of the dam, but in many cases this is not an option and there are constraints on land disposal. Therefore, it is important to find uses for the removed material. Potential uses of dredged fine sediments include habitat development, agriculture and construction. EDF is exploring different such options. Menu *et al*. describe past and ongoing work investigating the technical conditions and sediment properties required for pre-selected beneficial industrial reuses of the dredged material (*i.e.* roadway bed material; ceramic material, concrete or mortar; Portland cement clinker; agricultural amendment, soil construction and strip mines), without adverse impacts to the environment and public health.

The problems associated with reservoir sedimentation are the subject of ongoing research. For example, the Hydraulic Constructions Platform PL-LCH of the Ecole Polytechnique Fédérale de Lausanne is conducting experimental, numerical and in-situ research on innovative methods to cope with the accumulation of fine sediment in pumped-storage hydropower plants. PL-LCH is working on two solutions: operational reservoir stirring and forced stirring for maintaining fine sediment in suspension for subsequent routing downstream through the hydropower waterways. The first solution uses the inflow and outflow in the reservoir to maintain turbulence levels that prevent fine sediment settling. Forced stirring uses the specially developed SEDMIX water-jet device which has been tested in the laboratory and is now entering the phase of proof-of-concept at a prototype scale. PL-LCH has also proposed new design criteria for dam bottom outlet structures to optimize the efficiency of current turbidity venting operations, as described in the article by De Cesare *et al*.

Despite significant advances in understanding the physical processes, many questions remain. This includes questions on the mechanisms of flow and sediment transport within reservoirs, the migration of delta fronts, which may reach the dam, the formation and movement of turbidity currents, and the creation of dead-water regions, which are propitious areas for sediment deposition. Expanding data collection programs is essential for understanding reservoir sedimentation and assessing strategies for sustainable management. Improved measuring can contribute to developing more reliable estimates of sedimentation rates.

Morphodynamic numerical models are popular tools that are used to estimate sediment transport patterns in reservoirs and to solve related engineering problems. They can be used to simulate long-term reservoir sedimentation, to define operational rules for sediment downstream routing, to quantify the possible amounts of sluiced/flushed sediment under different conditions, and to determine the appropriate location and capacity of bottom outlets. However, still many processes (*e.g*. consolidation of cohesive sediments, mud-sand interactions) are not described well numerically, and are mostly accounted for using empirical relationships. One- or two-dimensional models cannot simulate the complex flow and sediment transport processes near bottom outlets during the initial stage of flushing, sluicing and turbidity current venting operations. This calls for the use of three-dimensional models. ■