Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California

J. Toby Minear[1] and G. Matt Kondolf[1]

Received 27 November 2007; revised 8 June 2009; accepted 27 July 2009; published 25 December 2009.

[1] Previous reservoir sedimentation models have ignored two key factors for large spatial and temporal modeling of multiple reservoirs: trapping by upstream dams and decreasing sediment trapping as reservoirs fill. We developed a spreadsheet-based model that incorporates both factors. Using California as a case study, we used measured sedimentation rates to estimate sediment yields for distinct geomorphic regions and applied those rates to unmeasured reservoirs by region. Statewide reservoirs have likely filled with 2.1 billion m^3 of sediment to date, decreasing total reservoir capacity by 4.5%. About 200 reservoirs have likely lost more than half their initial capacity to sedimentation.

Citation: Minear, J. T., and G. M. Kondolf (2009), Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California, *Water Resour. Res.*, *45*, W12502, doi:10.1029/2007WR006703.

1. Introduction

[2] Reservoir sedimentation is a serious problem in many regions with high sediment yield, particularly in, geologically active regions such as California. Small-capacity reservoirs in rapidly eroding mountain regions are most vulnerable to sedimentation problems. The costs of dealing with accumulated sediments can be prohibitively expensive and, for some dam removals, have been the greatest component of dam decommissioning costs [e.g., *U.S. Bureau of Reclamation*, 2006]. Even before reservoirs fill completely with sediment, sediment within the reservoir can reduce usable capacity, interfere with outlet works, damage turbines, and cause backwater flooding upstream [*Morris and Fan*, 1998]. Reservoirs filled with sediment may be at greater risk during earthquakes because accumulated sediment deposits are denser than water and may exert greater force against the dam during seismic shaking [*Chen and Hung*, 1993]. Reservoir sediments are also a significant global sink for carbon and other important nutrients [*Vorosmarty et al.*, 2003; *Stallard*, 1998]. In addition, the trapped sediment is not available for downstream economic and ecological benefits, such as beach replenishment [*Willis and Griggs*, 2003] or salmonid habitat, and release of sediment-starved water commonly causes bed incision in the downstream channel, which can result in downstream stream bank erosion, infrastructure damage, and drawdown of the alluvial water table [*Williams and Wolman*, 1984; *Kondolf*, 1997].

[3] In the design and maintenance of most reservoirs, little thought has been given to sustaining reservoir functions as capacity is progressively lost to sedimentation. Loss of reservoir capacity from sedimentation is difficult to offset with construction of new reservoirs because reservoirs have already been constructed at most viable sites in the developed world [*Morris and Fan*, 1998]. Maintaining reservoir capacity into the future will require that we address capacity losses from sedimentation, which requires tools to predict sedimentation rates and to identify reservoirs vulnerable to rapid sedimentation.

[4] Existing reservoir sedimentation models are not able to model large temporal or spatial scale patterns of sedimentation, primarily due to the extensive data requirements of the models. Current sedimentation models include process-based models that operate at small temporal and spatial scales and require data such as yearly or daily hydrologic records, detailed reservoir bathymetry, and sediment grain size distributions [e.g., *Ackers and Thompson*, 1987; *Sundborg*, 1992; *Lajczak*, 1996; *Tarela and Menendez*, 1999; *Rowan et al.*, 2000]. Similarly, geographic information system (GIS) based large spatial scale models estimate sedimentation on the basis of land use and/or hydrologic data [*Verstraeten et al.*, 2003; *Vorosmarty et al.*, 2003], which are lacking for most areas, particularly for historical periods. In addition, applying these process-based models without calibration can result in modeled sediment yields diverging from measured sediment yield rates by orders of magnitude [*Trimble*, 1999].

[5] Most importantly, existing reservoir sedimentation models do not account for two important factors: the effects of trapping by upstream reservoirs and changes in the rate of sediment retention, known as the trap efficiency, over time as reservoirs fill. As upstream reservoirs are built, they can reduce sediment yield to downstream reservoirs. This effect is particularly important in areas with numerous reservoirs within the same watershed, as exemplified by the 57 reservoirs on the American River and tributaries upstream of Folsom Reservoir, California (California Division of Safety of Dams (CDSD), Electronic database of dams and reservoirs in California, 2005, available at http://www.water.ca.gov/damsafety/).

[6] Temporally variable trap efficiency, the percentage of the incoming sediment trapped by a reservoir, is an important factor to include in sedimentation models when the time

[1]Department of Landscape Architecture and Environmental Planning, University of California, Berkeley, California, USA.

0043-1397/09/2007WR006703