STATE of KNOWLEDGE

Mekong Sediment Basics

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What are sediments?

Sediments are inorganic materials produced by the weathering and erosion of rocks and soils. They are carried in rivers as either fine sediments carried by water (suspended load) or coarse 'bedload' (larger sediment fragments that generally move along the bottom of the riverbed) (Mekong River Commission, 2011:43). In a 'natural' river, habitat and species composition are strongly influenced by sediments (MRC, 2011:43; WCD, 2000:78). Between one- and two-thirds of a river's nitrogen and phosphorus content are attached to fine sediments (MRC, 2011: 43), and nitrogen and phosphorus are essential to ecosystem health and biodiversity.

The amount of sediment transported by a river (the sediment load) is lowest during the dry season and highest during the first months of the flood season, when loose sediments weathered during the dry season are washed into rivers (MRC, 2010). Sediment load is also influenced by population growth, land clearance, land-use change, reservoir construction and other infrastructural development (Walling, 2008). The two major sources of sediment in the Mekong River basin are the Lancang sub-basin and the '3S' area, which includes the Mekong tributary rivers Se Kong, Se San and Sre Pok. These two sources are thought to produce approximately 70 percent of the sediment found in the Mekong River (Kummu et al., 2010; Clift et al., 2004; MRC, 2010).

Sediment data for the Mekong is difficult to obtain and there is no definitive study on how much sediment is transported through the system (Kummu and Varis, 2007; Kummu et al., 2010). Sediment data down to Pakse is relatively good, and estimates range between 150 and170 million tons; but it is not well understood how much sediment is trapped by the floodplains downstream from Pakse (Kummu and Varis, 2007; Liu et al. 2013).

How does sedimentation affect dams and dam reservoirs?

A river's energy, and therefore its capacity to carry sediment, is determined by the flow and speed of the river. When a river slows down, such as when it enters a reservoir, it drops suspended sediment or loses its capacity to move heavier sediments. The physical barrier created by dams results in sediment 'trapping' behind dam walls (MRC, 2009; Morris and Fan, 1997; Thorne et al., 2011; Fu et al., 2008).

Sedimentation is a serious concern for dam planners and engineers, as it reduces reservoir storage capacity. If left unchecked, it will eventually cancel out the dam's capacity to regulate water flow and supply, thereby negating many of its intended benefits, be they for hydropower, irrigation, recreation or other purposes (Morris and Fan, 1997; Thorne et al., 2011; Vörösmarty et al., 1997).

Dam builders try to compensate for sediment trapping by ensuring that there is enough 'dead storage' in a reservoir for sediment deposits. This means that the reservoir only retains the full volume of water that it was designed for at the beginning of the dam's life. In spite of dead storage, as time goes by sediment accumulates and the dam continues to lose storage capacity until the impoundment area is filled with sediment (Morris and Fan, 1997; Thorne et al., 2011; Fu et al., 2008).

How much sediment will be blocked by Mekong dams?

Sediment loads are an important transboundary concern. A number of studies suggest that sediment delivery from the upper Mekong has decreased in recent years, although they differ on the extent of this change. Some suggest the figure could be as high as a 50 percent reduction at the dam site since the completion of the Manwan Dam on the Lancang Jiang River in 1993 (Lu and Siew, 2006; Fu and He, 2007; Kummu and Varis, 2007; Adamson, 2009; Wang, et al., 2011).

Dams are highly efficient at trapping sediments. The Manwan Dam lost 20 percent of its storage capacity to sediment deposits during the first ten years of operation, representing a loss of 20 million cubic meters of sediment to the mainstream Mekong. It is estimated that the completed Lancang cascade of dams will trap some 90 percent of the upper Mekong sediment contribution to the lower basin (Kummu and Varis, 2007; MRC, 2010:73).

When estimating the rates of sediment accumulation in reservoirs, it is important to account for 'trapping efficiency', how this may change over time, and how dams upstream of the reservoir in question might reduce sediment delivery to a downstream reservoir (MRC, 2009:16). Estimates suggest that as much as 50 percent of the Mekong sediment load will be removed by hydropower projects in China and the 3S rivers alone. Should all twelve Lower Mekong Basin (LMB) mainstream dams be constructed, the sediment load could be halved again (ICEM, 2010; MRC, 2011).

These estimates are considered conservative in light of the uncertainty surrounding i) our current understanding of fine sediment transport, and ii) our current understanding of the trapping efficiencies of lower Mekong mainstream dams and in-reservoir sediment dynamics (ICEM, 2010:77; Kummu et al., 2010:182; Roberts, 2004).

It is important to note that any attempt to predict future sediment loads in the Mekong basin is complicated by limited data availability, sediment model accuracy, uncertainty surrounding future land-use changes and global warming, as well as natural variability (Thorne et al., 2011; Adamson, 2009).

What are the impacts of reservoir sedimentation?

Dams alter the capacity of a river to transport sediment and also decrease the amount of sediment available for transport (Kummu and Varis, 2007). Substantial reductions in sediment supply can trigger widespread changes to the shape, course and structure of a river that will impact upon habitats, ecosystems and agricultural productivity (MRC, 2011). Downstream of the reservoir, impacts often include changes to basin ecology, water transparency, sediment balance, the amount of available nutrients and the river's course (Morris and Fan, 1997). Changes in sediment load and flow can be especially detrimental to coastal and offshore zones (ICEM, 2010; Fu et al., 2008; MRC, 2011; MRC, 2009).

How will dams impact on reservoir capacity and dam functioning?

An estimated one percent of existing reservoir storage volume in the world is lost to sedimentation each year. This loss of storage capacity is detrimental for hydropower dams as it reduces the volume of water that can be captured in a reservoir for energy generation (Morris and Fan, 1997; Fu et al., 2008).

The first sediments to deposit in a reservoir will be large, coarse sediment (small stones, grit and gravel). The first dams built on a river will generally accumulate more sediment because there are no upstream dams to trap it (ICEM, 2010). Sedimentation may affect a dam's mechanical equipment, including reservoir floodgates and turbine intakes, and compromise their structural integrity (MRC, 2009). Run-of-river hydropower dams do not suffer from such problems as much as reservoir dams, because they are not designed to create reservoirs. Run-of-river dams still slow a river's flow rate, causing sediment to be deposited, but at a potentially slower rate than in reservoir dams. Run-of-river dam designers must still be aware of potential damage to turbines and other mechanical equipment (Morris and Fan, 1997). Dam designers try to minimize sediment deposition to ensure the longevity of dam operations, as well as structural safety (MRC, 2009; Morris and Fan, 1997).

How will sedimentation impact on river basin habitats?

Dams that trap sediment will release water with a reduced sediment load and, therefore, excess capacity to transport materials (Kondolf, 2008). Known as 'sediment hungry' water, this water erodes riverbeds and banks until the water can no longer carry materials, at which point a new equilibrium will be reached. In the Mekong, it is expected that this process will result in coarsening of the streambed and widespread changes to river habitats, including the elimination of many fish spawning beds. This process could potentially have widespread impacts, reaching down to Vietnam's highly productive food producing delta (MRC, 2010; MRC, 2009; Kummu and Varis, 2007; Roberts, 2004; Thorne et al., 2011; WCD, 2000; Morris and Fan, 1997). Whether or not this will happen has yet to be seen.

Not all the potential impacts are entirely negative. For example, sediment trapping may prove beneficial to some aquatic ecosystems, such as coastal marine ecosystems, which might otherwise be harmed by excessively high levels of suspended sediment in water (Rogers, 1990; Morris and Fan, 1997).

How will reduced suspended sediment concentrations caused by dams impact on the Mekong basin?

Suspended sediments contain nutrients that are essential to maintaining river systems. A large proportion of the phosphorus and nitrogen found in a river are associated with sediments (Koponen et al., 2010; Lu and Siew, 2006; Thorne et al., 2011) Phosphorus is important because it controls primary production in freshwater ecosystems. Precise estimates of the amount of phosphorus and nitrogen attached to sediments in the Mekong are difficult to make due to a lack of data on nutrient binding and the size of particles involved. It is estimated, however, that about two-thirds of the phosphorus in the Mekong is associated with sediments (MRC, 2011; Thorne et al., 2011). Some estimates put the fine-sized suspended sediment load delivered to the Mekong floodplains and delta at 26,400 tonnes per year (ICEM, 2010).

Dams decrease the concentration of suspended solids in rivers, thereby reducing the amount of nutrients available downstream (Koponen et al., 2010; Lu and Siew, 2006; Thorne et al., 2011; MRC, 2011; Rosenberg et al., 1997; Nikula, 2005). It is estimated that if Cambodia, Laos, Thailand and Vietnam were to proceed with the construction of 11 mainstream and 71 tributary dams (in addition to the six existing mainstream Chinese dams), the fine-sized suspended sediment load of the Mekong would be reduced by 75% (to approximately 6,600 tonnes per year). Approximately 25% of this reduction would be a result of mainstream dam construction (ICEM, 2010). Alternatively, during periods when water is released, areas downstream of dams will experience unnaturally high concentrations of sediment and associated nutrients (MRC, 2011).

Reduced sediment loads will impact on both natural and human environments. In the following sections we examine some of these impacts in depth.

Fisheries and aquatic species

Trapping of sediments may decrease the biological productivity of rivers. Upstream of dams, increased sediment loads will alter reservoir ecology, affecting the quantity and type of fish present (Kummu and Varis, 2007; Morris and Fan, 1997; WCD, 2000). Most Mekong fish species lay eggs that attach to the riverbed, so increased sediment and silt may bury or damage eggs (MRC, 2011; MRC, 2010; ICEM, 2010; Roberts, 2004).

Downstream of dams, sediment trapping could lead to a decline in both biodiversity and productivity of fish and other aquatic species. Adapted to the sediment-rich conditions of the Mekong basin, fish and other aquatic species may not be able to adjust to changes to their feeding and spawning grounds (Kummu and Varis, 2007; Morris and Fan, 1997; WCD, 2000). Reduced nutrient availability will affect aquatic plant growth, a major source of food for Mekong fish and an important component of fishery food chains (MRC, 2011, 2010; ICEM, 2010; Roberts, 2004). Negative impacts on marine fisheries are also a possibility (MRC, 2011; Hai et al., 2009).

Downstream of Vietnam's Yali Falls dams, Cambodian communities have reported dramatic declines in fish catches since the dam's construction. The fisheries decline has been linked to increased turbidity and sediment loads (a result of sediment hungry waters eroding riverbanks), which has smothered algal growth. High sediment loads have resulted in sediment deposition and in-filling of important fish habitats: there has also been a negative impact on fish species that cannot tolerate high sediment loads (Wyatt and Baird, 2007).

Agriculture

When rivers flood they deposit sediments on floodplains. Floodplains are highly fertile and play an important role in agricultural productivity. Reductions in suspended sediment load and associated nutrients will also impact on the region's agricultural productivity (ICEM, 2010; MRC, 2011). Immediate impacts on regional rice production are expected to be 'modest', but long-term impacts may be more serious. Reduced sediment loads will also result in the loss of agricultural land in inundated areas, riverbank gardens and floodplains. The poor will be most affected by these losses of agricultural land (ICEM, 2010; Hai et al., 2009).

Navigation

Commercial and recreational navigation will be impacted by sediment accumulation at locks, delta areas, marinas and boat ramps during periods when sediment-laden water is released from dams (Morris and Fan, 1997). During periods of water storage, when dam gates are closed, it is likely that destabilization of riverbanks and bed erosion by sediment hungry waters downstream of dams will have a detrimental impact on navigation in the Mekong Delta, an area of high river transport use (ICEM, 2010).

However, it is possible that sediment trapping will have a positive impact on navigation by reducing the amount of sediment deposited into channels that serve as navigation routes (Hori, 2000).

Cambodian floodplains and Tonle Sap system

The seasonal flooding of the Cambodian floodplains, including the Tonle Sap Lake, is the basis of the Mekong's high productivity. Every year, approximately 80 percent of the sediment and nutrients entering the lake system are retained after flood waters recede. This natural fertilization contributes greatly to agricultural and fisheries productivity (MRC, 2005; Sarkkula et al., 2003; Kummu et al., 2008; Nikula 2005; Zalinge et al., 2003; Sarkkula et al., 2003; Zalinge et al., 2003).

Decreased suspended sediment concentrations pose a serious risk to nutrient balance in the lake, and therefore to the system's productivity (ICEM, 2010; Sarkkula et al., 2003; Koponen et al., 2010). A decrease in the fertility of the flooded forests that serve as important habitats and breeding grounds for fish will reduce the size of fish landings (Kummu et al., 2008). If all planned mainstream and tributary dams are built, it is estimated that productivity in large areas of the Cambodian floodplains will be halved (Koponen et al., 2010).

Vietnam Delta

Some studies estimate that 79 million metric tonnes of sediments reach Vietnam's Mekong Delta each year, of which 9 to 13 million tonnes are deposited on floodplains and the rest contributes to the enlargement of the delta and fertilizing coastal fisheries (Huang and Tamai, 1999; Fox and Sneddon, 2005). Sediment deposited in shallow coastal waters protects the coast from wave-induced erosion. Reduced sediment supply will increase coastal erosion (Wolanski et al., 1996), a process that is likely to be made worse by sea level rise due to climate change. Bank erosion downstream of reservoirs as a result of sediment hungry water will only partially compensate for sediments that become trapped in reservoirs (MRC, 2010:73). An estimated one million people will be directly affected by coastal erosion and land loss in the Mekong Delta by 2050 (IPCC, 2007).

Vietnamese agriculture and marine capture fisheries are dependent on sediment for nutrient transport (Wild and Loucks, 2012; ICEM, 2010). A reduction in sediment load is likely to imply significant costs for both agriculture and marine fisheries. Agricultural development and urbanization may provide alternative sources of nutrients, but the precise impacts of these on the delta are not well understood (ICEM, 2010).

Can reservoir capacity be sustained?

While the sedimentation of reservoirs is often considered an irreversible process, water supplies and electricity generated from dam projects cannot be considered sustainable unless the sedimentation process is controlled (Morris and Fan, 1997).

Ideally, dams will be built in a way that minimizes their tendency to retain sediment, thereby reducing impacts on the environment and agricultural productivity, as well as reducing potential liability for compensation payments to downstream stakeholders (MRC, 2011). Sustainable sediment management will take into account the watershed, river, reservoir and dam in question and the cumulative impacts of dam cascades. The process would include a sedimentation assessment (Morris and Fan, 1997), consideration of appropriate site selection and dam design, and an operation strategy and consistent monitoring and management (MRC, 2009).

To avoid sedimentation, and preserve relatively normal nutrient transport patterns to downstream areas and limiting morphological impacts, dams must be cleared of sediment regularly (Thorne et al., 2011). Removing and disposing of sediments that have accumulated in reservoirs is an expensive and difficult process (Morris and Fan, 1997). There are several options for sediment removal, including sediment routing, sediment bypass, sediment flushing (or sluicing), mechanical removal and sediment traps (MRC, 2009). Dams can significantly reduce sediment problems by building flushing gates into the dam wall. These are located at the base of the wall, and are opened periodically to let sediments out of the reservoir. This will also, to some extent, help ensure that beneficial uses of sediment downstream can be maintained. Virtually no dams on the Mekong, however, have flushing gates, in part because it increases dam construction costs, and because that would mean that some portion of the reservoir water would be used for flushing and not for electricity generation.

Dam planners must determine which method is appropriate for each dam. Managing sediment in a cascade of dams will require coordination between government authorities, dam planners and operators and the many agencies advocating on behalf of environmental health as well as the livelihoods of people who derive a living from the river and its ecosystems (MRC, 2009).

Can reductions in sediment loads be mitigated through other processes?

One idea in circulation is that increased fertilizer use could compensate for reductions in nutrients due to decreased suspended sediment concentrations. This has yet to be tested. It is possible that the majority of nutrient rich sediment originates in the mountains (particularly in China), in which case fertilizer would not compensate for the extent of nutrient losses. More data is necessary to better understand the nutrient cycle of the Mekong (Koponen et al., 2010).

Another proposed solution is 'sediment augmentation', or the deliberate addition of sediment downstream of a dam. Sediment augmentation must account for the volume of sediment trapped in reservoirs as well as the downstream river's decreased velocity, and therefore, decreased capacity to move sediment. The ecological effects of sediment augmentation must also be considered (MRC, 2009).

Conclusions

The potential impacts of dam development on sediment and therefore on nutrients, river and marine ecosystems and livelihoods are considerable. Comprehensive data and assessments of the dynamics of sediment and nutrient transport in the Mekong are limited, particularly those that account for the combined effects of cascades of mainstream and tributary dams. While more studies are needed to better understand better the complex interactions of sediment in the Mekong, it should also be recognized that uncertainty will never be completely removed by models and theoretical predictions. Dam planners, managers and policy makers are advised to proceed with caution, even when building dams that take into account adaptive sediment management and which account adequately for uncertainty (Thorne et al., 2011). Given the complexity of interactions between sediment, nutrients, ecosystems and numerous other variables, "experiments in real life" should be closely monitored.

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