Disturbed Sediment Continuum of the Mekong: Its Impacts and Proposed Mitigation Measures

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Rivers carry not only water, but also sediment. Essential to maintain channel form, beaches and deltas. Over geologic time, sediment is in motion. Temporary storage in bars, floodplains.

Dams & in-channel mining interrupt this natural continuity of sediment flux.

Source: Kondolf 1997 ‘Hungry Water’, Environmental Management
Many ways in which human activities alter the balance of flow (energy) and sediment load in river basins, inducing channel response.

Globally most rivers show decreasing sediment loads due to sediment trapping by dams.

Kondolf and Podolak 2013. ‘Space and time scales in human-landscape systems’. Environmental Management
The Mekong River Basin

- 15,060 m³/s average flow
- Sediment rich – many functions depend on sediment (nutrients, Tonle Sap productivity, floodplain fertility, delta landform)
- Upper Mekong (Lancang) contributed <20% flow, 50% sediment
- Strong seasonal differences in flow
- Important flow contributions from mountainous areas in Laos, Vietnam
- Over 70M people depend on the river (fisheries, agriculture)
Fish Migration in the Mekong
More than 850 fish species
2nd highest biodiversity after Amazon
Many fish migrate long distances
Migratory fish very important for riparian populations
Need to manage dams to reduce effects on fish migration
The Mekong Delta
The Delta built 250 km out from Phnom Penh over the last 7000 years from high sediment supply. Now retreating due to reduced sediment supply and accelerated subsidence. Population 17M, produces ~ 3% of world’s protein.
Dropping from 5000 m on the Tibetan Plateau, the Mekong has enormous potential to generate hydroelectricity. Dubbed the ‘battery of SE Asia’
In the Chinese section of the river (upstream), 7 dams have turned the river into a series of reservoirs, cutting off sediment supply from the upper basin, which formerly supplied 50% of the river’s sediment. More dams planned upstream.

Another >130 dam planned or being built on the lower Mekong River, in Laos, Cambodia, and Vietnam, 11 on the mainstem Mekong

What effect will all these dams have on channel and delta morphology?
We applied the 3W model to the ’full build’ scenario of ~140 dams.

Result: >90% of natural sediment load trapped along entire mainstem. Only 4% of the natural sediment load will reach the Delta.

**What will be effects of extreme reduction in sediment load?**

Kondolf et al 2014 ‘Dams on the Mekong: Cumulative Sediment Starvation’ *Water Resources Research*
Downstream effects on channel form?

Bedrock vs alluvial reaches:
- sand deposits flush from bedrock reaches
- incision, bank erosion in alluvial reaches

**What effect on delta of 96% decrease in sediment supply?**

Rubin et al., 2014 Anticipated geomorphic impacts from Mekong basin dam construction *Int Journal River Basin Mgmt*
96% reduction in sediment supply means the delta landform cannot maintain itself against rising seas and coastal erosion in the long run. But over what time scales and what other drivers?
- sand mining
- accelerated subsidence
- accelerated sea level rise
- channelizing distributaries

Much of the Delta is <1m above MSL (blue) or <2m above MSL (red)

2m subsidence affects 15M population

Bravard et al 2013 Geography of sand and gravel mining in the lower Mekong River, *EchoGéo*
Erban et al 2014 Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta *Environ Res Lett*
How to compile information on diverse drivers, expressed in different units?

We expressed all drivers in length scale, and our model evenly “spread out” sediment volumes over the area of the delta. We used average slope to convert elevation change into land loss.

• Undisturbed:
  • sediment inputs, compaction, and organic accumulation

• Net progradation as per holocene observations

Green means sediment inputs (positive balance)
Red means sediment sinks (negative balance)
Worst Case:
Continue ‘business as usual’
- Sand mining
- Sediment trapping
- Groundwater pumping

Under worst case scenario:
Central tendency = 2 m subsidence
Maximum = 3.3 m subsidence
However, management changes can reduce subsidence to ~ 60cm (by 2100), reduce delta loss land to only 10%

Sustainable management and strategic planning in dams
Reduce groundwater pumping,
Discontinue sand mining

Key strategies to sustainably manage sediment in regulated rivers

- Sluice incoming sediment and/or flush accumulated sediment
  (design with large, low-level outlets, periodically draw reservoir down)
- Vent density currents (open bottom outlets to pass currents)
- Pass sediment through bypass tunnels
- Reduce sediment yield from river basin upstream of reservoir

*These approaches work in many situations, but rarely implemented*

Annadale 2013. *Quenching the thirst*. Createspace
Kondolf et al 2014. Sustainable sediment management in reservoirs and regulated rivers: experiences from five continents. *Earth’s Future*
Strategic planning of dam site selection can reduce sediment impacts

Conventional project-by-project development in a river network without considering network scale cumulative impacts can result in high impacts for benefits provided.

Strategic portfolio planning aims to identify dam portfolios with a good trade-off between generation and cumulative sediment trapping.
For the largest downstream tributary, ‘3S’ (SrePok, SeSan, & SeSan river system):

**Actual built portfolio:**
15,000 GWh generation, trapping 90% of basin’s sediment

**Optimal portfolio:**
Same generation with < 20% trapping
Also more economically efficient

Relocating a dam to reduce impact: Sambor Dam, Cambodia

New site generates only 2/3 power of original proposal, but allows fish migration and sediment passing, thus sustainable over many decades in constrast to original.

Alternative site proposed by Natural Heritage Institute scientific team (one channel only)

Original site for Sambor Dam
A similar approach across the Laotian basin of the SeKong River

Substituting smaller dams in low-sediment yield headwaters for large mainstem dams allows important fish migrations to continue, and reduces sediment trapping by dams, while generating the same level of hydropower.
Strategic planning for hydropower to identify optimal dam portfolios and sustainable hydropower. (Hydropower only)

But important role for hydropower in facilitating transition to other renewables like solar

Source: Schmitt et al in review
Combine strategic hydropower planning with national/regional energy planning

Optimize benefits of hydropower as complement to solar, etc

Source: Schmitt et al in review
Conclusions
The Mekong River is experiencing a surge of dam construction. With intensive sand mining, this disrupts the sediment balance: Reservoirs fill with sediment, downstream river reaches and coasts become sediment starved.

Sustainable sediment management methods are rarely implemented in dams, thus we miss opportunities to pass sediment through and around dams.

Dams are usually planned and built on a site-by-site basis, without integrating strategic planning to select sites with lower impacts and to optimize tradeoffs between hydropower production and environmental impacts.

Strategic dam planning can be combined with energy planning to optimize hydropower contributions to the national energy grid.
Thank you!

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