

Save the Mekong Delta from Drowning

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Abstract

A few decades of environmental degradation have sufficed to reverse a 7000 year trajectory of progradation in Mekong Delta to retreat. With the current trends, the Mekong Delta, amongst the world's most productive deltas, likely will not exist in its current form by the end of the century. Dams and sand mining reduce its sediment supply, groundwater pumping accelerates subsidence, and dikes prevent sediment-charged floodwaters from spreading out over the delta surface to build land. However, national and international planning and investments still mostly respond only to local symptoms of a drowning delta, and are slow to adopt systemic approaches to maintain geomorphic processes that build new delta land. Rather than mitigate local symptoms, we urge six actions to restore fundamental processes sustaining the delta. Such an approach is challenging and will need to draw on technological innovation, basin-scale coordination, trade-offs with existing vested interests, and rethinking the

political landscape of delta management beyond national boundaries. However, it is the only way to maintain a resilient Mekong Delta for future generations.

Keywords

Deltas, Vietnam, sediment budget, sediment starvation, dam effects, sand mining, subsidence, erosion, groundwater pumping, saltwater intrusion, delta management.

Introduction: Threats to a tenuous landform

The Mekong Delta's dense population and its importance for regional economy and food security belie its recent origin and fragility. When the Giza Pyramids were built 4500 years ago, the Mekong Delta covered only 35 % of its current 40,000 km² extent. Only 7000 years ago, the delta landform was non-existent. The Mekong Delta's recent origins also holds a warning for its future, as land that was built rapidly might quickly disappear. Already now, owing to only a few decades of human influence and unsustainable management of the Mekong basin's natural resources, the Mekong Delta is receding, and we project that most of the delta landform and associated livelihoods could slip below sea level by the end of the century(1).

Avoiding such a catastrophic impact on the Mekong Delta will require concerted actions that acknowledge root causes for land loss and the global importance of the delta landform. Deltas persist and grow if sediment supply from an upstream river basin builds delta land at the same or greater rates than land is submerged by relative sea-level rise and erosion. As sea levels continue to rise, more and more of those natural water and sediment resources would be required to maintain the current extent of the Mekong Delta. However, uncoordinated basin-wide development depletes the delta of those critical resources.

The Delta, which lies mostly in Vietnam, ranks second among the world's mega-deltas in terms of its size. The delta has seen notable development in past century, transforming it into a human-made landscape, or "Delta Machine" (2) with a population of over 17 million, and which produces 7-10% of all rice traded internationally. The Mekong Delta averages less than 1 m above sea level making it very vulnerable to subsidence and coastal erosion. Yet, many initiatives to protect its residents' livelihoods have supported local adaptation measures to address symptoms of a sinking delta. While important, these do not address underlying anthropogenic drivers of subsidence at both the delta and catchment scales, nor do they necessarily take into account the international nature of the basin.

Figure 1. a. Location map of the Mekong River basin, showing the Mekong Delta. b. The Mekong Delta, showing progressive progradation since 7000BP, population density (red tones), and value of agricultural production (green tones). c. Resources at stake in the Delta, and projected loss of human habitat and agriculture with relative sea level rises of 1, 2, and 3 m.

Originally, the delta received 140 – 160 million tons of sediment annually from the Mekong River basin, of which more than half is now being trapped in reservoirs. In the upper Mekong basin in China (the Lancang), eight large hydropower dams have been completed, with another 20 under construction or planned. In the lower Mekong, another 133 dams are either built or planned, of which 11 are on the mainstem. If built as planned, these dams will trap 96% of the sediment formerly reaching the delta (3). Additionally, sediment supply from the basin has been halved since 1981 as runoff from tropical cyclones, which deliver about 32% of the suspended sediment load reaching the delta, is reducing as cyclone tracks shift north (4).

The remaining sediment load is further reduced by in-channel mining, as an estimated 54 Mt/y of sand from the Mekong River, mostly in Cambodia and Vietnam are used in construction and land reclamation (5), resulting in downstream sediment starvation and contributing to recent coastal erosion and channel incision (6), tidal amplification and salinity intrusion.

While the Mekong's sediment supply from the basin has been depleted dramatically, management actions within the delta such as sand mining further reduce sediment and the ability of the remaining sediment to maintain delta land. Management of the delta has historically focused on controlling the waters to enable agricultural intensification and flood regulation, and to prevent saline water intrusion. While successful in this regard, this management approach has fundamentally affected the natural processes that maintain the delta land itself. Where distributary channels and coastal currents formerly distributed sediment-laden flood flows across the delta plain and along its coastlines, dikes now restrict water and sediment to the main channels and deprive the delta plain of deposition during floods. Natural mangrove vegetation traps sediment to build up delta land, absorbs wave energy, and reduces coastal erosion. However, the Delta's mangroves largely have been replaced by agriculture and aquaculture, and the remaining mangroves are now starved of sediment to trap (7).

All deltas naturally subside, as recently deposited sediment compacts. For the Mekong Delta, this natural subsidence is exacerbated by the effects of groundwater pumping for agriculture and urban use, presently the single greatest driver of subsidence in the Delta (8). By 2100, a 'business as usual' scenario results in average relative subsidence of up to 1.8m, while a best-case scenario (strongly curtailed pumping, mining, and dam construction) results in subsidence of 0.15m. The Mekong Delta is so flat and low-lying that subsidence of 1.8m under the 'business as usual' case would result in submergence of over 90% of the delta, while the best case scenario of 0.15m subsidence inundates about 10% of the delta.

Many of the above-mentioned drivers create vicious circles. For example, as salt water further intrudes into the delta, farmers may turn to greater use of groundwater, or migrate to urban centers that are already foci of subsidence. As subsidence accelerates, building dikes that lock out floods becomes more attractive to local interests, but these dikes in turn prevent sediment from spreading over the delta surface and building elevation.

Causal solutions for a subsiding landform.

The very existence of the Mekong Delta as we know it today is due to massive human-made modifications –canals, dikes, saltwater dams and other hydraulic interventions– that has led to major

ecological and economic transformations (9). While the colonial-era interventions of the 19th Century and early 20th Century aimed to open up the delta for the flow of water, goods and people, later interventions have focused on large scale infrastructure aiming to control the delta's water and lands (10). Since the Vietnamese reunification in 1975, the delta has seen a number of studies and master plans, most of them with international support, that promote centralized, integrated planning with focus on short-term socio-economic development (11). While highly successful in turning the delta into an agricultural and economic powerhouse, this has increasingly locked the delta's management into an unsustainable path with weak adaptation capacity, siloed governance, weak horizontal and vertical integration between the key institutions, and lack of coordination with actions in upstream countries

We argue that the focus on socio-economic development and strong belief in human mastery over nature also explain why the current policies fail to properly acknowledge that most of the delta might fall below mean sea level within a human lifetime. The key Viet Nam government document guiding the delta's development, Resolution 120 (enacted in 2017) takes steps in the right direction, emphasizing the need for more nature-based development and encouraging integrated planning across different sectors and spatial scales, and aiming to “develop an integrated plan for sustainable and climate resilience development of the Mekong Delta” (12). Yet, the Resolution and the related “Mekong Delta Plan” (13) treat flooding, salinity, and coastal erosion more as isolated engineering challenges, proposing solutions on local scales, rather explicitly seeing them as symptoms of underlying causes spanning multiple scales. While the Plan reports ongoing subsidence rates, the existential threat to the delta is not addressed by the limited proposals to minimize subsidence, re-establish sediment connectivity, and increase delta resilience. This gap in management is also not overcome in more recent plans, such as “The Mekong Delta Integrated Regional Plan” proposed to the Vietnamese Ministry of Planning and Investment in July 2020 or the government report reviewing the first three years of the implementation of Resolution 120 (14).

At the same time, large-scale investments keep on pouring into the delta, with a mixture of instruments to advance development and respond to the threat posed by climate change. For example, the World Bank alone has committed to loans and bilateral funding of nearly US\$2 Billion from 2007 to 2022. While this level of funding is small compared to private investment (in the hundreds of billion USD annually), funding decisions of international financial institutions have tremendous influence in setting standards for other investors, and could help push investments generally towards more sustainable solutions. Much of the current World Bank funding aims to address the impacts that a sinking delta creates on the livelihoods of its inhabitants. Those investments are needed to protect against local flooding and coastal erosion, deal with salinized water supplies and provide support for adaptation planning. However, many of the investment proposals we reviewed did not explicitly acknowledge the long-term existential risks to both livelihoods and investments, nor emphasize opportunities to reverse those trends through concerted larger-scale actions, a finding that applies similarly to other international actors.

Responding to the Threats

It is encouraging that the delta's management and related investments have evolved in a positive direction, with increasing focus on adaptive and integrative measures to address long-term challenges as well as short. Yet, the current plans alone will not be sufficient to make the Delta resilient to extreme environmental stress because they address internal issues only, but not the root causes of the deprivation

of the sediment supply from upstream. The persistent governance challenges that the top-down, hierarchical system and institutional rivalries maintain may hinder the continued positive evolution described above. For the delta landform to persist in the longer term, two fundamental changes are required. Firstly, to ensure that all future investments in the delta across key economic sectors (agriculture, aquaculture, transport, energy, construction) register and address the challenge of sediment management, both basin wide and within the delta, and address how each investment impacts and potentially depends on sediment-related ecosystem services. Secondly, to adapt policies and management tools so that they explicitly assess and monitor all future investments in the delta and the basin for their effects on and resilience to land subsidence and erosion.

To respond to the fundamental threat that delta is facing, future projects should not contribute to increased subsidence and land loss and should be resilient to future subsidence up to 2100 and beyond. To achieve this, we recommend that future measures explicitly account for the scales at which the drivers operate, and that management efforts be undertaken at appropriate scales.

While some drivers of subsidence can be influenced by local actions, others will require interventions that are coordinated on different scales, e.g., among the provinces of the Vietnamese Mekong Delta, between Cambodia and Vietnam, which share the lower-most Mekong and its delta, and through the entire basin, from which the essential water and sediment resources are derived. Planning on larger scales might seem unlikely given current political realities, but changing those realities towards a whole basin dialogue is needed to open a larger solution space where all riparian countries have rights and obligations (15). At the same time, longer-term strategies to manage the basin more sustainably should not divert attention from local degradation and resulting impacts. For example, channel incision caused by local sand mining in the delta has been recently identified as a key driver behind salinity intrusion.

Also actors are changing. Private sector investors, whose combined investments in the delta far surpass investment by international donors, are increasingly acknowledging systemic risks from a sinking delta and have committed to investments with systemic benefits, e.g., to aquaculture with improved water, sediment, and nutrient dynamics.

In this context, we propose six measures, to prolong the life of the Mekong Delta. Implementing those measures can safeguard the livelihoods and infrastructure in the Mekong Delta, and be a positive example for managing deltas and coasts globally, which are projected to support 1 billion people by the end of the century:

- *Avoid high-impact dams.* Do not build dams at sites with highest sediment trapping potential. Use network-scale portfolio analysis to identify optimal dam placement to minimize impacts while maintaining hydropower production. The benefits and impacts of alternative energy sources should be considered along with hydropower, as some planned hydropower projects are no longer competitive with alternatives, such as solar photovoltaic.

- *Maximize sediment passage through/around dams.* Sustainable sediment management strategies such as sluicing, flushing, and bypasses can allow some sediment to move from upstream to downstream. These approaches could apply to many dams and are already included in the Mekong River Commission (MRC)'s mainstem dam guidance. Additionally, studies are needed to evaluate the retrofit potential of dams currently not equipped for sediment management.

- *Control and phase-out riverbed sand mining.* Impacts of sand mining can be reduced through better enforcement of mining regulations, limiting extraction rates to a sustainable fraction of the river's sand and gravel load, and encouraging alternative sources of aggregate for construction, such as crushed aggregates, floodplain sand quarries and recycling of concrete rubble, as increasingly required by policies worldwide.


- *Transform agriculture in the Vietnamese Mekong Delta to produce less quantity but higher quality, and as part of this transition adapt agricultural practices to minimize groundwater extraction and reconnect distributaries to the delta plain.* As recommended by Resolution 120, reduce groundwater pumping through shift to less-water-intensive crops, improve access to alternative surface water supplies and maintain their quality, regulate water demand and reuse water.

- *Maintain connectivity of delta floodplains.* Adapt water infrastructure in the Delta to allow sediment-charged flows to spread over the delta surface at least one year in three, and acknowledge socio-economic benefits of floods and sediment. Prevent dikes from cutting off channels from floodplains and allow natural sediment deposition and water infiltration on the floodplains.

- *Leverage nature-based solutions for coastal protection.* At low cost, mangroves and natural wetlands are a proven solution to coastal erosion with benefits for biodiversity and livelihoods, but for those ecosystems to build land there must be a supply of sediment for them to trap.

In a large and transboundary basin, those measures are ambitious and will require actors to significantly rethink governance and investments in the basin. Yet they are not unprecedented globally, and they can build on lessons from successful examples from other geographies (Table 1, Supplemental Table 1).

Table 1. Six measures to prolong the life of the Mekong Delta. See Supplemental material for further details and references to original studies.

Core measure	Scale	Techno-economic-social enablers	Global precedence	Key roadblocks in the Mekong
Avoid high-impact dams	<p>WHOLE BASIN</p> 	Non-hydropower renewables and regional power grids enable foregoing high impact dams while reaching ambitious climate goals	Moratorium on mainstem hydropower, canceling of high impact dams, national strategic planning processes throughout the region e.g., in Cambodia, Malaysia, Myanmar	Ambitious plans for hydropower exports in the basin's countries and lack of incentives and compensation for developers to forgo dams.
Increase sediment passage through existing dams		Non-hydropower renewables increase operational flexibility of dams.	Sediment passage through dams can be achieved through well-tested operational and structural measures	Sediment passage can reduce generation by 10-15%. High sediment releases can have negative impacts on water users & ecosystems; retrofits & reoperation costly.
Control and phase-out riverbed sand mining		Alternative sourcing. Circular sand economy and less concrete-heavy building designs	Riverbed mining has been phased out in many countries or limited to sustainable rates, being replaced with aggregate from alternative terrestrial sources	Lack of business case, cost-benefit analyses, & policy incentives for economically competitive alternatives; revenues from sand export and land reclamation
Adapt agricultural practices to minimize groundwater extraction		Precise and locally adopted agri- and aquaculture to significantly increase the 'crop per drop'	Sustainable Groundwater Management Act (California) increases regional regulatory oversight while providing resources for better practices to agriculture and domestic users	The Delta's long legacy of high intensity rice cropping and freshwater aquaculture requires systemic shifts in agricultural production
Maintain connectivity of delta floodplains		Certification of 'delta friendly' agriculture increases incentives for better sectoral sediment management	Artificial sediment splays and controlled flooding now applied, e.g., in the Mississippi and Ganges Brahmaputra Deltas to increase sedimentation.	Increasing infrastructure in floodplains and promotion of three season rice create a legacy of disconnected floodplains
Leverage nature-based solutions for coastal protection		DELTA AND COASTAL	International donors and local planners increasingly shift priorities from grey to green infrastructure	Successful coastal protection with nature based solutions (Vietnam, Florida, New York) and adaptation of shrimp farming-forestry enterprises (SFFEs) in Vietnam

Conclusions

By virtue of its national, regional and global importance, the Mekong Delta has attracted extensive interest from the national government as well as researchers, international development partners, and multinational corporations. However, the severity and urgency of its existential and cumulative threats, at both delta and basin scales, has not previously been analyzed by combining such a wide range of drivers, nor has it been sufficiently considered in key policies and investment plans. That the Delta faces an existential crisis is increasingly recognized by the government, as reflected in Deputy Prime Minister Dung's May 2020 call for an "emergency" response to climate change, recognizing that rising seas, coastal erosion and subsidence could occur earlier than previously understood. However, the prospect of the delta falling below sea level has not been explicitly mainstreamed into investment plans nor an urgent ad hoc multi-lateral response formulated.

The size of the Delta and its thriving economy makes it difficult to conceive of the immediacy of the threat and the precariousness of this vital human asset. However, after 7,000 years of progradation, the delta is now rapidly subsiding and eroding from the combined effects of human-induced reduction in sediment supply, accelerated subsidence, and sea level rise. 'Business as usual' practices will result in about 90% of the delta landform being below sea level by 2100 (1). The six changes to management practices we propose at both the delta and basin-wide scales could slow subsidence and erosion, thereby extending the life of the delta significantly.


Each of the proposed measures engenders financial costs, political engagement, and technological innovation in the near-term. We are under no illusions that these changes will be easy to implement. Yet, the cost of not addressing such key threats needs also to be considered in the current policies and investments plans emphasizing adaptive and integrated planning in the delta. We should recognize signals from the private sector that indicate many of the solutions we recommend are in fact bankable, thus would open new business opportunities. Large private investments could provide a major support to the public sector effort to implement the transformative change needed. To confront the existential threat facing the delta will require unprecedented intersectoral coordination and cooperation at sub-national, national and regional scales. We need a new frame with which to screen investments for systemic impacts and benefits. With these steps, solutions are available to ensure the Mekong Delta does not drown by the century's end.

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Supplemental Information

Core measure	Scale	Techno-economic-social enablers	Global precedence	Key roadblocks in the Mekong
Avoid high-impact dams	WHOLE BASIN 	Non-hydropower renewables and regional power grids enable foregoing high impact dams while reaching ambitious climate goals (1–4).	Moratorium on mainstem hydropower, canceling of high impact dams, national strategic planning processes throughout the region e.g., in Cambodia, Malaysia, Myanmar (3, 5–7).	Ambitious plans for hydropower exports in the basin’s countries and lack of incentives and compensation for developers to forgo dams.
Increase sediment passage through existing dams		Non-hydropower renewables increase operational flexibility of dams (8)	Sediment passage through dams can be achieved through well-tested operational (9, 10) and structural measures (11–13)	Sediment passage can reduce generation by 10–15%. High sediment releases at baseflow can have negative impacts on water users & ecosystems (14, 15); retrofits and reoperation costly (11).
Control and phase-out riverbed sand mining		Alternative sourcing. Circular sand economy, less concrete-heavy building designs (16, 17).	Riverbed mining has been phased out in many countries or limited to sustainable rates (18, 19), being replaced with aggregate from alternative terrestrial sources (20–22).	Lack of business case, cost-benefit analyses, & policy incentives for economically competitive alternatives; revenues from sand export and land reclamation (23–25)
Adapt agricultural practices to minimize groundwater extraction		Precise and locally adopted agri- and aquaculture (26) to significantly increase the ‘crop per drop’	Sustainable Groundwater Management Act (California) increases regional regulatory oversight while providing resources for better practices to agriculture and domestic users (27)	The Delta’s long legacy of high intensity rice cropping and freshwater aquaculture requires systemic shifts in agricultural production (28)
Maintain connectivity of delta floodplains		Certification of ‘delta friendly’ agriculture increases incentives for better sectoral sediment management (29).	Artificial sediment splays and controlled flooding now applied, e.g., in the Mississippi (30, 31) and Ganges Brahmaputra (32) Deltas to increase sedimentation.	Increasing infrastructure in floodplains and promotion of three season rice create a legacy of disconnected floodplains (28, 33, 34).
Leverage nature-based solutions for coastal protection	DELTA AND COASTAL	International donors and local planners increasingly shift their priorities from grey to green infrastructure.	Successful coastal protection with nature based solutions (Vietnam, Florida, New York) and adaptation of shrimp farming-forestry enterprises (SFFEs) in Vietnam (35–37).	Existing wetland and mangrove forests are destroyed or degraded for other uses. Lack of sediment decreases effectiveness of nature-based solutions, e.g., Mangroves, to protect coastlines and build land (38–41).

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