Robust multi-scale strategies for increasing the resilience of the Mekong Delta

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Coastal areas and river deltas

- **By 2050, more than 1 billion people are expected to live in low-lying coastal areas and river deltas**
- **Deltas are hotspots of both agricultural production and urban industrial centers**
- **Worldwide, large deltas are shrinking and sinking, raising fundamental concerns about the future of delta livelihoods**

Drivers of land-loss and delta subsidence

Common drivers of land loss and reduced resilience of deltas

- Reservoirs and sand mining reduce sediment supply
- Global sea level rise and increasing extreme weather events
- Accelerated land subsidence from groundwater extraction

All of those drivers are highly uncertain, interconnected, and sometimes counteracting (e.g., land degradation increases sediment supply, sediment trapping in resrvoirs reduces sediment supply).

Delta subsidence is the result of human interference on different scales (delta, basin, global scales) and domains (water, energy, food).

Delta and basin processes form a natural continuum. But delta and basin management are not typically integrated.

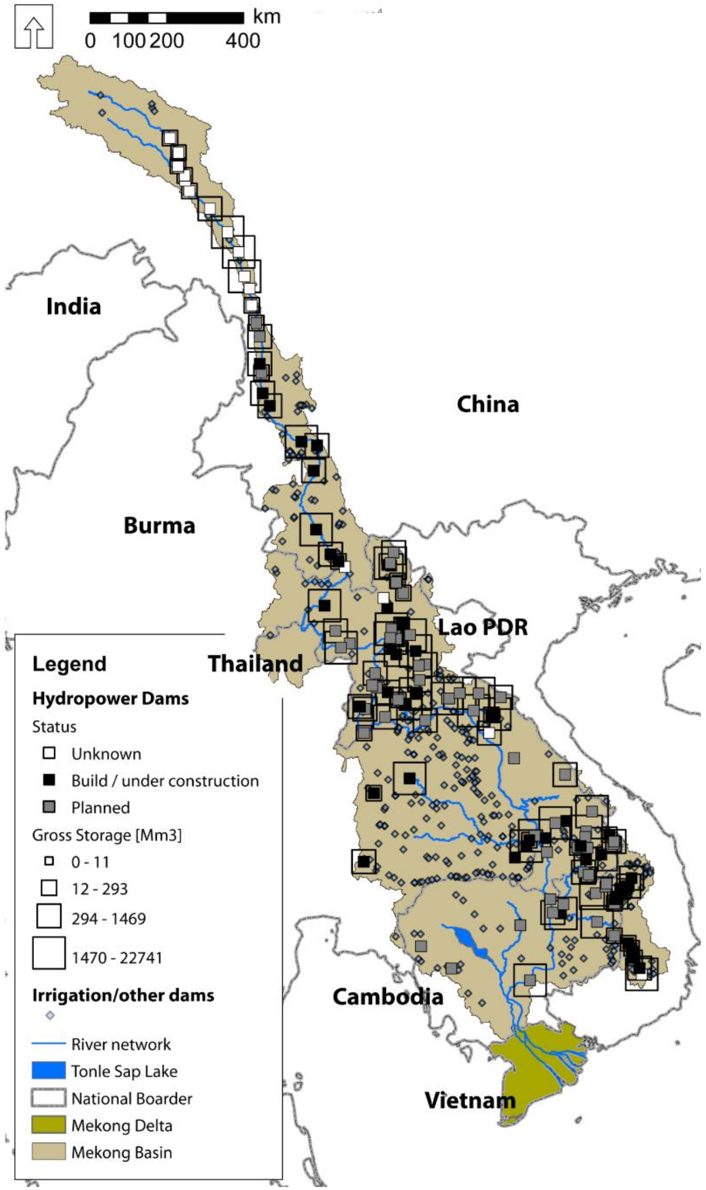
Case study – The Mekong Basin

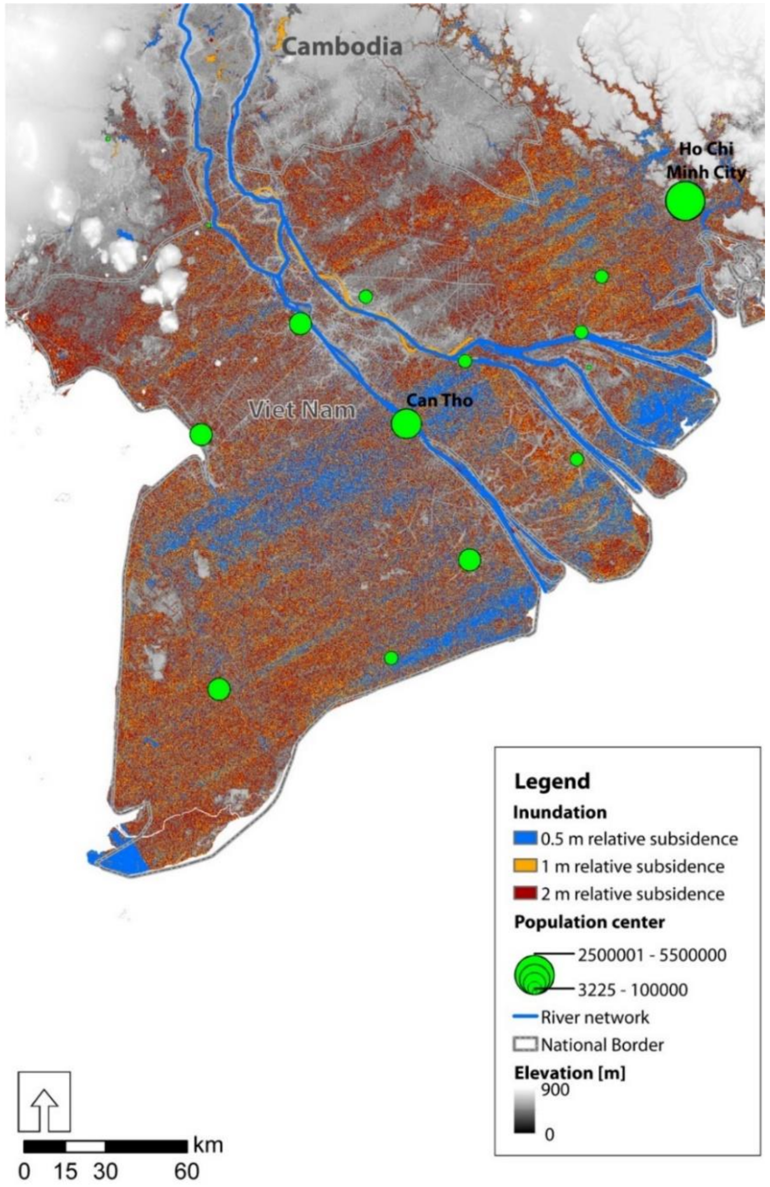
790,000 km^2 drainage area, shared between 6 riparian countries

100 – 160 Mt/yr of sediment supply built the Mekong delta over only around 8000 years

The 40,000 km^2 Mekong delta supports 17 million people and produces 16 Mt of rice per year. But most of the delta is less than 2 m above the sea level (Minderhoud et al., 2019)

The Mekong has a major potential for resource development, from hydropower to sand mining to agriculture and aquaculture expansion.





Case study – The future of the Mekong Delta

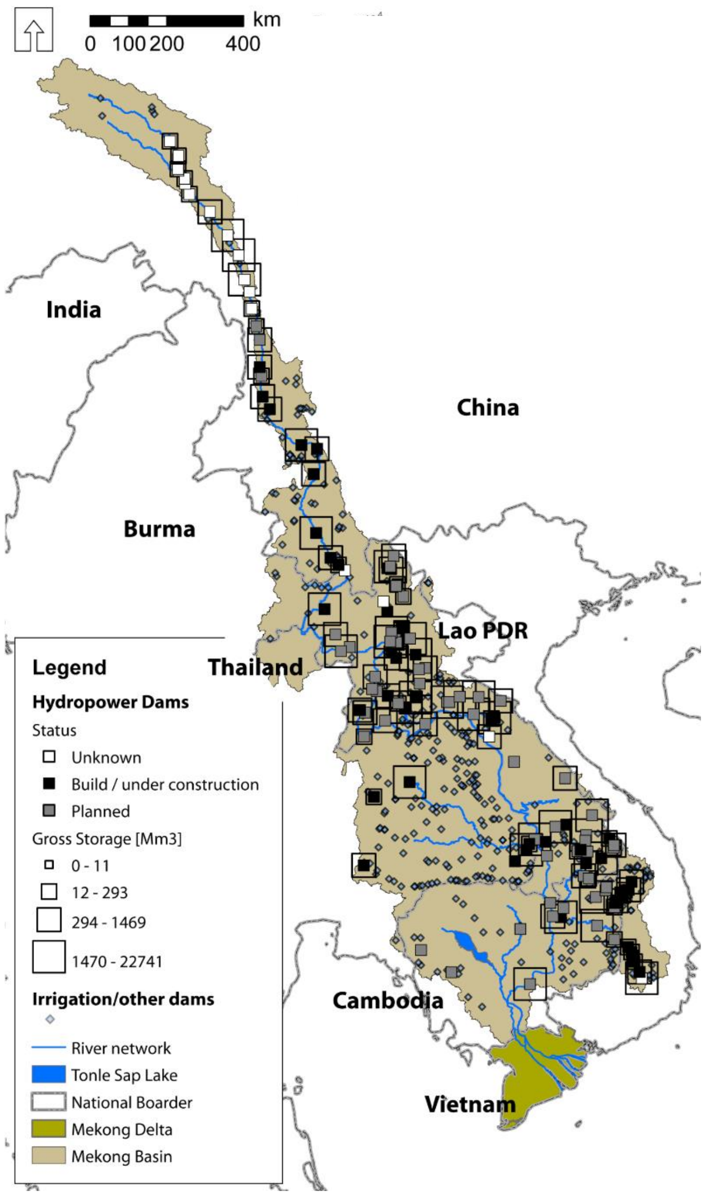
Hydropower development in the basin has already reduced sediment supply from 140 – 160 Mt/yr to 50 - 60Mt/yr.

Unsustainable groundwater use in the delta leads to centimeter-scale annual subsidence (Minderhoud 2020)

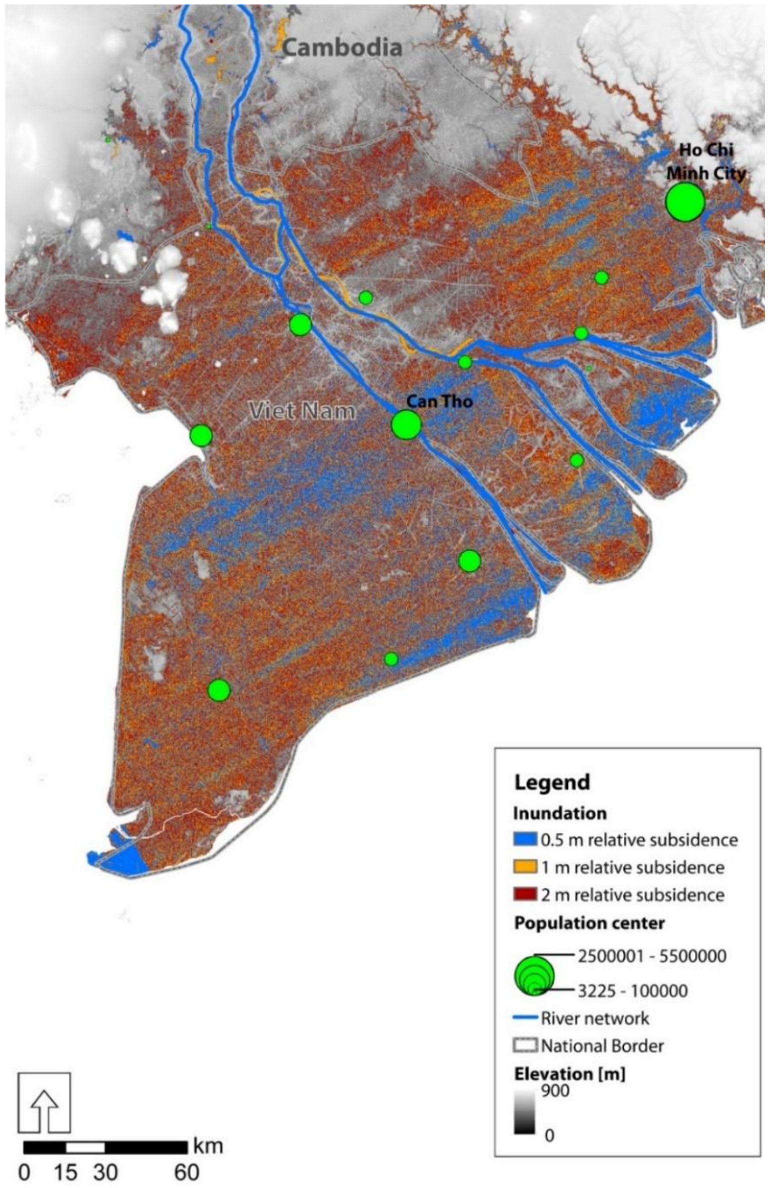
The future of sediment supply and accelerated subsidence is highly uncertain:

- Where are future dams going to be built?
- Will future and existing dams be upgraded, redesigned, re-operated for sediment passage?
- Could future landuse and climate change “mitigate” (or exacerbate) reduction in sediment supply?

<u>The complexity and uncertainty of the system makes the Mekong a challenge for exploring links between sediment supply, delta management, and delta resilience</u>

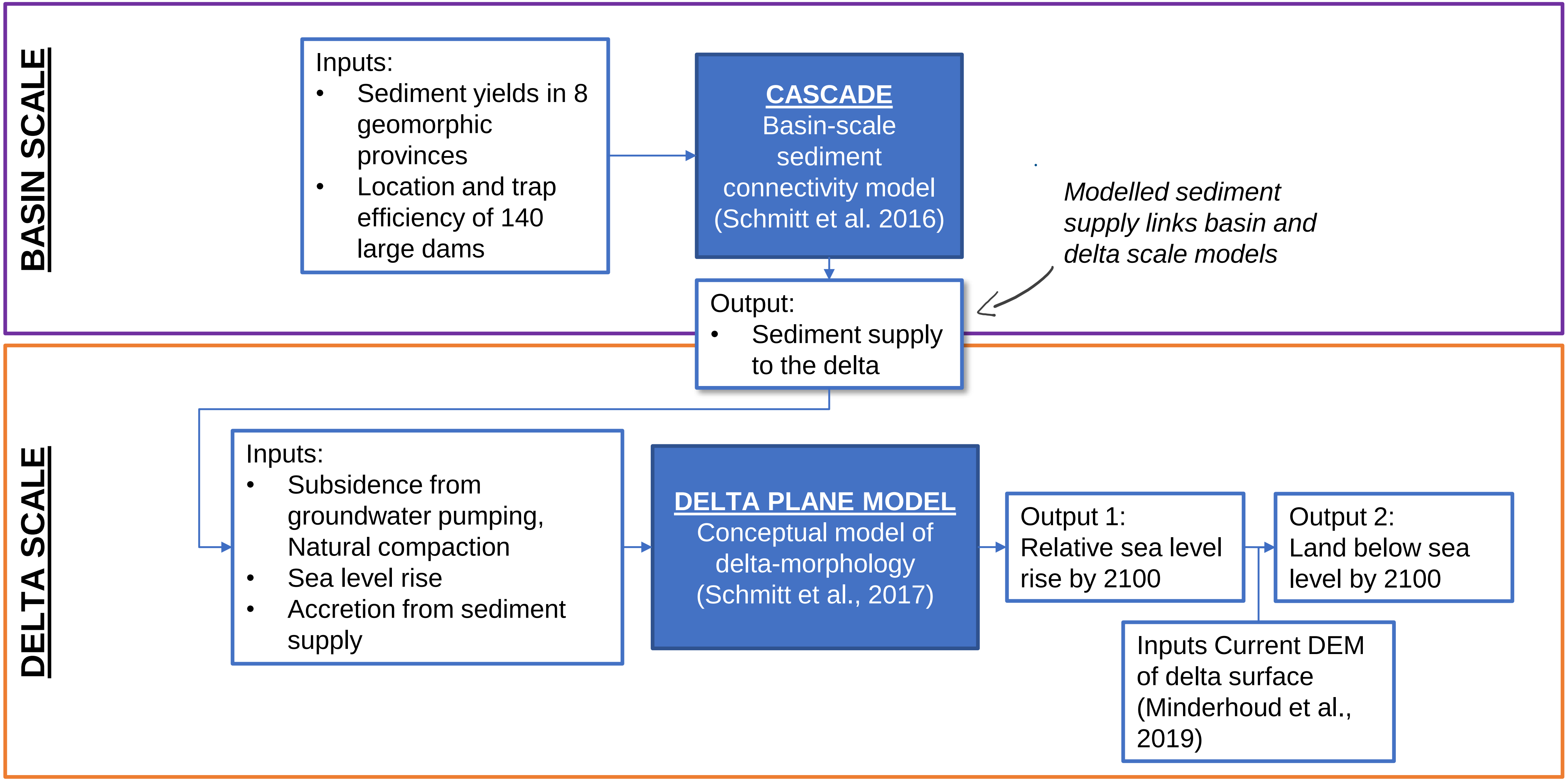


Kondolf et al., 2018



Identifying robust management strategies for a resilient Mekong Delta

1: Integrated modeling

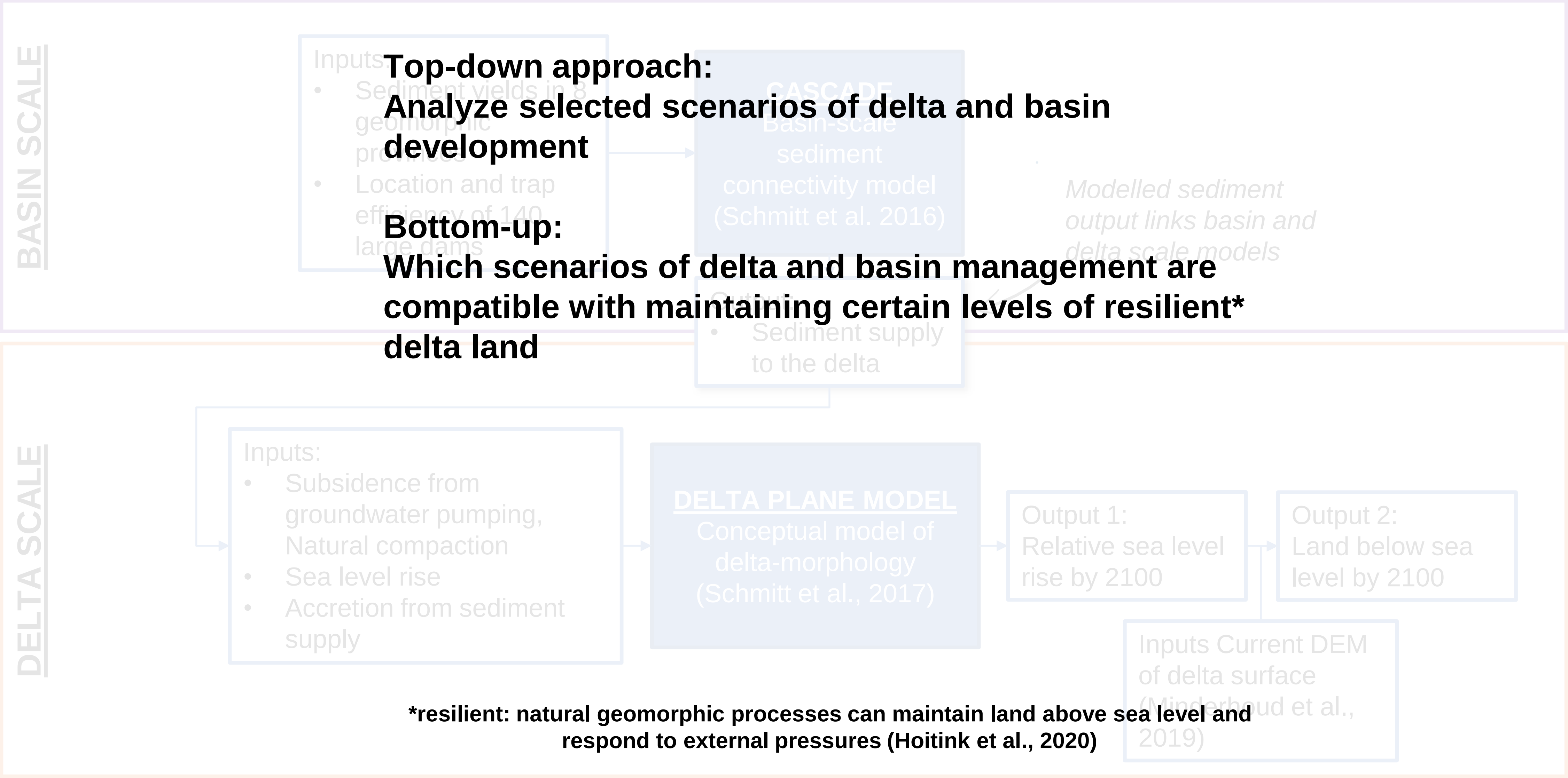


Identifying robust management strategies for a resilient Mekong Delta

2: Integrated, bottom-up approach

Top-down approach:
Analyze selected scenarios of delta and basin development

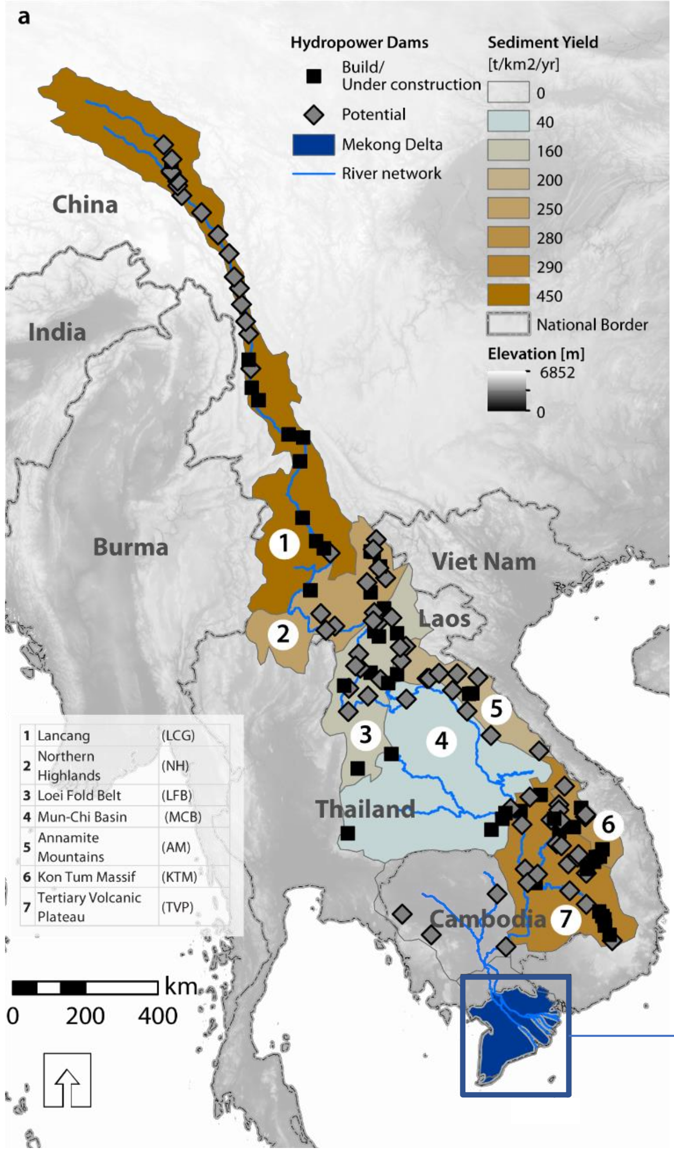
Bottom-up:
Which scenarios of delta and basin management are compatible with maintaining certain levels of resilient* delta land



***resilient: natural geomorphic processes can maintain land above sea level and respond to external pressures (Hoitink et al., 2020)**

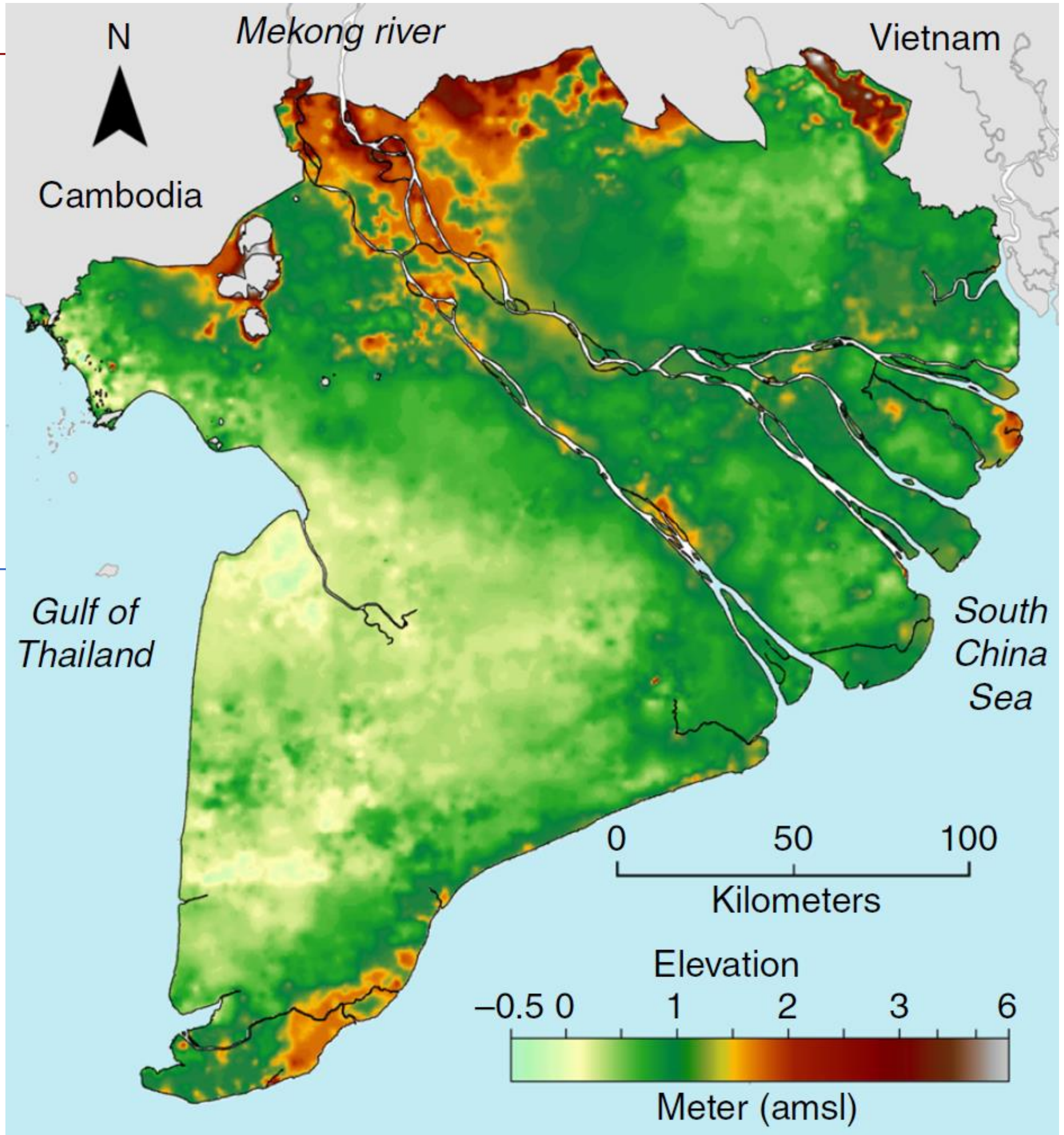
Identifying robust management strategies for a resilient Mekong Delta

1: Integrated modeling – Spatial representation



Setup of the CASCADE (Schmitt et al., 2016) model with river network, 7 geomorphic provinces, and existing and potential dam sites

Up-to-date DEM of the Mekong delta (Minderhoud et al., 2019), used to map land below sea level for different rates of relative se level rise.



Identifying robust management strategies for a resilient Mekong Delta

2: Exploratory, bottom-up approach: key inputs

Step 1| <u>Delta response to changing drivers</u>
Model relative sea level rise for 5 scenarios of sediment supply, and 3 different scenarios of delta-scale drivers

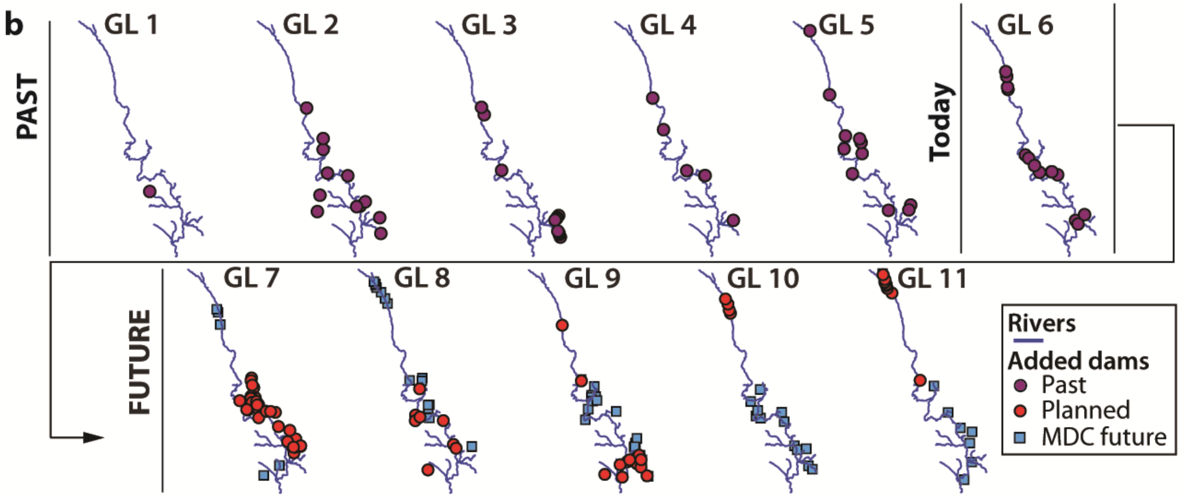
Step 2| <u>Hydropower development</u>
Identify 12 different future scenarios for the siting of future dams

Step 3| <u>Uncertainty in sediment supply</u>
Run each hydropower scenario for 80,000 different sets of basin parameters (sediment yield and sediment trapping in dams)

Step 4| <u>Bottom up analysis</u>
Sobol' analysis points to most sensitive parameters. Identify which combinations of sensitive basin parameters result in a sediment supply maintainining a partially resilient delta

Driver	Unit	DELTA-SCALE SCENARIOS: Best case	Central estimate	Worst estimate
Sea level rise	[mm/yr]	3	7	12
Groundwater pumping	[mm/yr]	9	16	23
Natural compaction	[mm/yr]	1.9	2.2	2.4
Sand Mining	[Mt/yr]		50	
Management rate factor	[-]		0.9	

Step 1: Worst, central, and best-case estimates for delta-scale drivers



Step 2: Different simulated hydropower portfolios starting from the status quo (GL 6). "planned" (red) is the business-as-usual development. "MDC futures" (blue) are dam scenarios maximized for sediment passage (Schmitt et al., 2019). Increasing GL (generation levels) numbers indicate more hydropower generation and thus more dams.

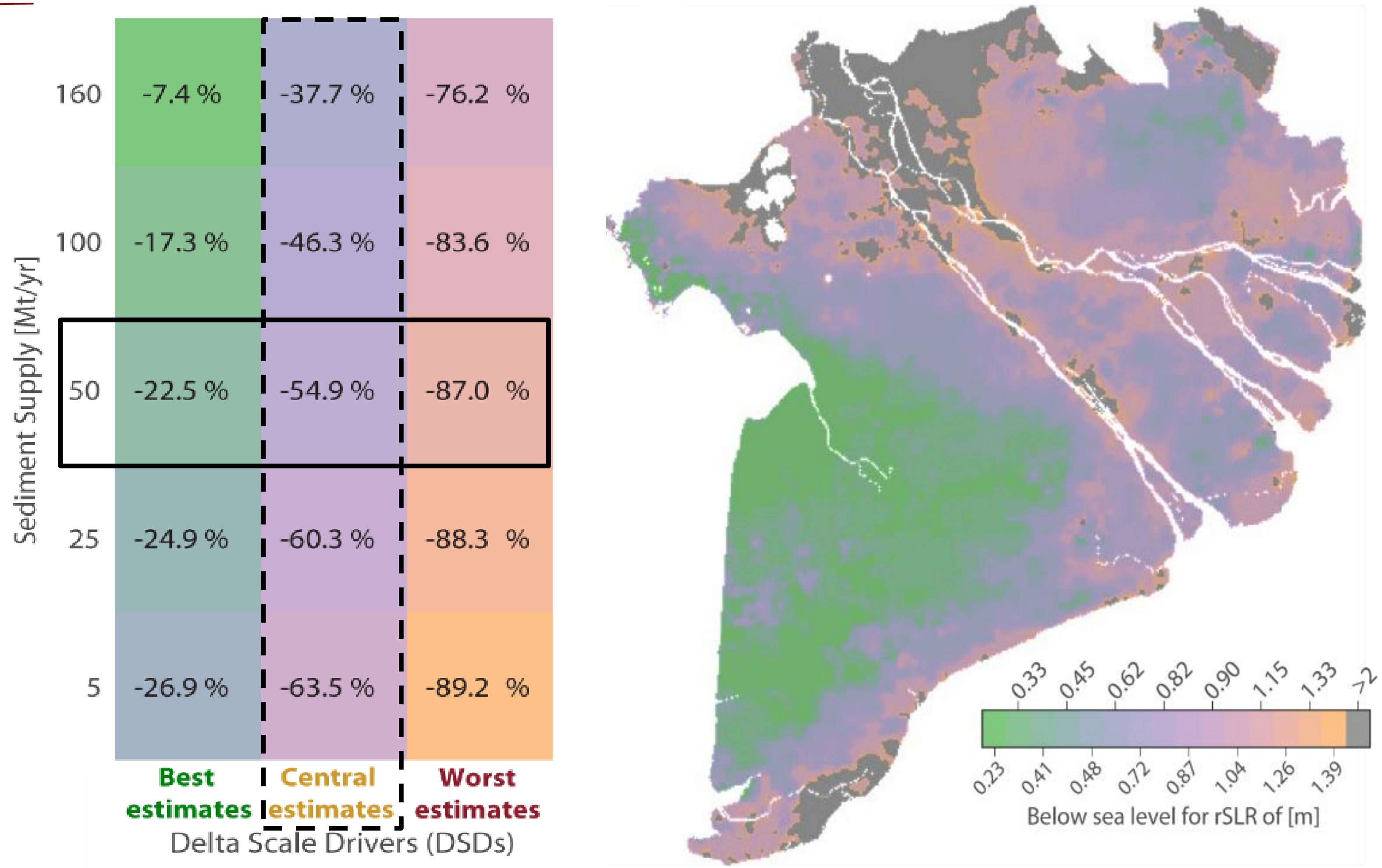
Results

1: Delta response to changing drivers

With the current level of sediment supply (50 – 60 Mt/yr, solid black box), 22.5 % (best estimate) – 87 % (worst estimates) of the delta falls below sea level by 2100

For central estimates of delta scale driver (dashed black box) 37.7 to 63.5 % of the delta falls below sea level by 2100.

The area of land falling below sea level is more sensitive to delta scale drivers than to sediment supply. However, varying sediment supply between 5 and 160 Mt/yr has still a major impact on how much land falls below sea level.



Relative sea level rise (colors) and resulting decrease in area above sea level (percent) for different combinations of sediment supply (y-axis) and delta scale drivers (x-axis) by 2100. The map, based on recent topo data (Minderhoud et al., 2019) indicates which areas fall below sea level for different levels of rSLR (colors correspond between map and table).

Results

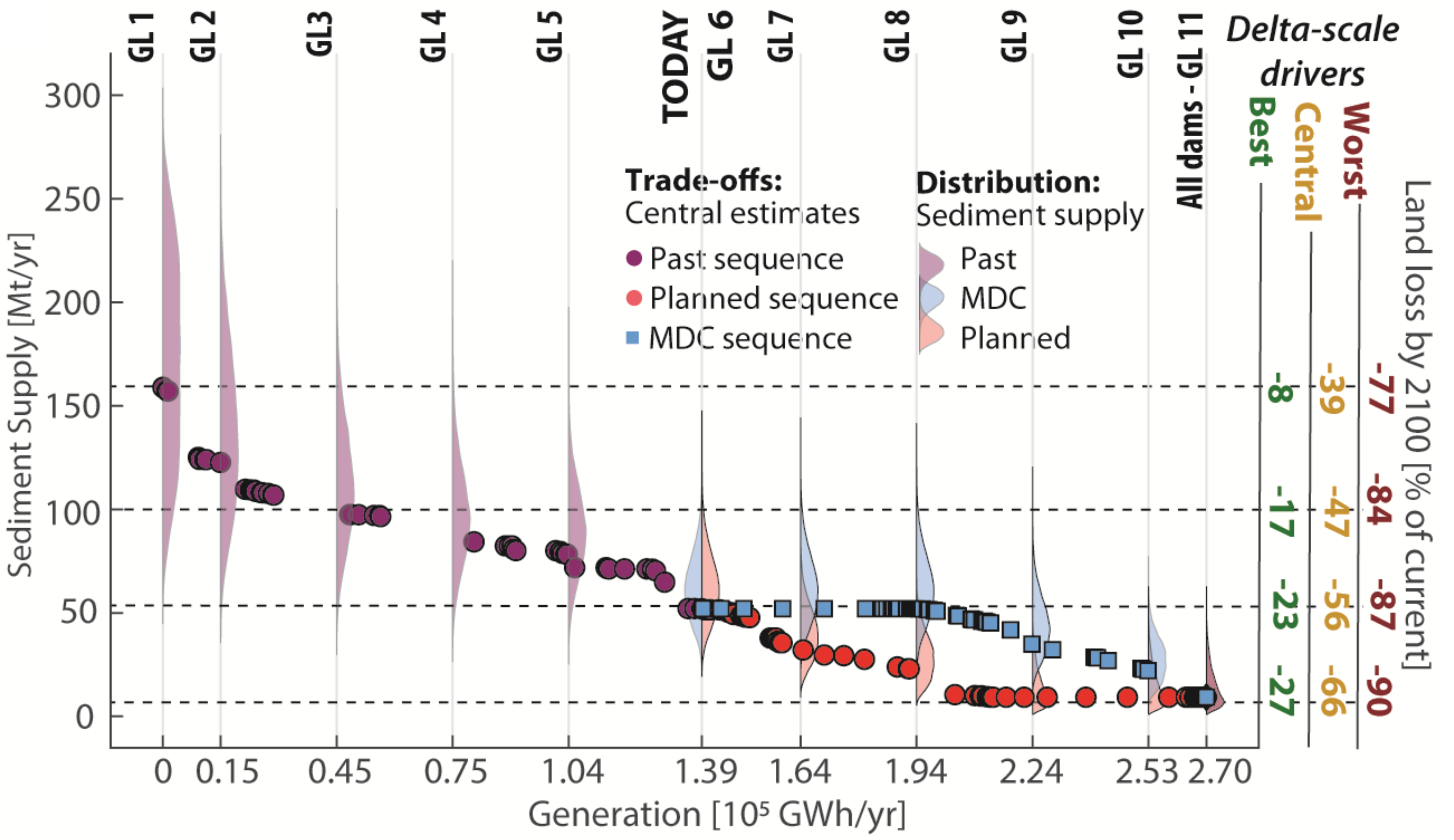
2: Uncertainty in sediment supply from hydropower and landuse

Sediment supply is an important factor to keep delta land above sea level

The more dams are built in the basin, the more sediment supply to the delta is decreased (markers).

With more dams being built in the basin, sediment supply becomes less and less sensitive to uncertainty in basin scale drivers (see shrinking ranges of sediment supply)

Business as usual development in would soon lead to a further reduction in sediment delivery (red dots). Up to a point, this can be avoided by optimized dam siting (blue dots).



Sediment delivery to the delta has already decrease strongly. More and more dams have increased hydropower generation (x-axis) in the past, but at the cost of decreasing sediment supply (left y-axis). The right y-axis translates rates of sediment supply into land above the sea level by 2100. Violin plots indicate the statistical distribution of sediment supply, resulting from 80000 model runs for each level of hydropower generation.

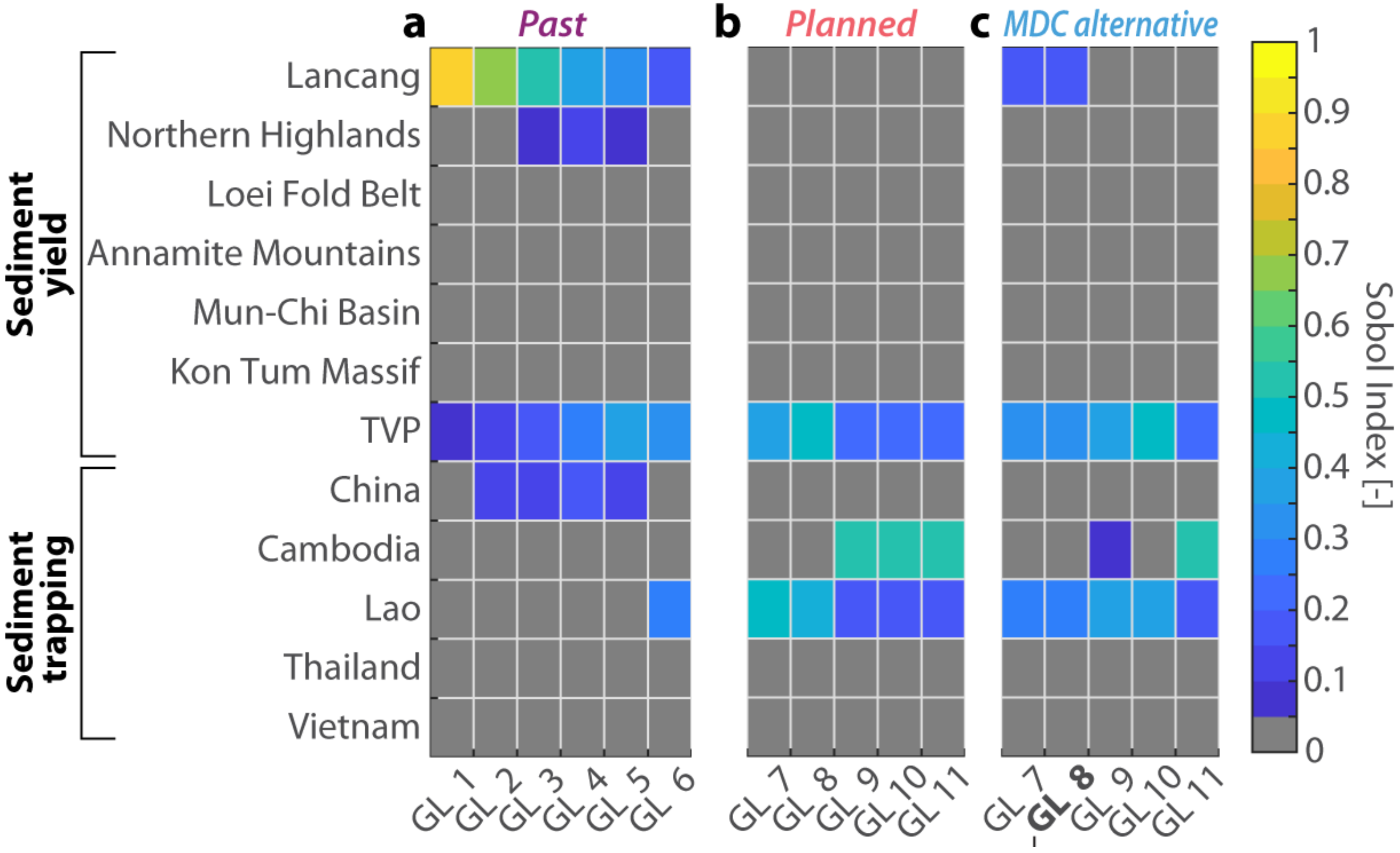
Results

3: Sensitivity of sediment supply to basin scale drivers

The sensitivity of sediment supply to the basin is altered by where dams are placed in the basin.

With more dams, sediment supply is less and less sensitive to sediment yields in the upper parts of the basin (Lancang, Norther Laotian Highlands) and more and more sensitive to sediment yields in the lower parts of the basin (TVP area).

Above current generation level (GL 6), sediment supply is mostly sensitive to sediment trapping in dams in the countries of the lower Mekong basin (Laos, Cambodia)



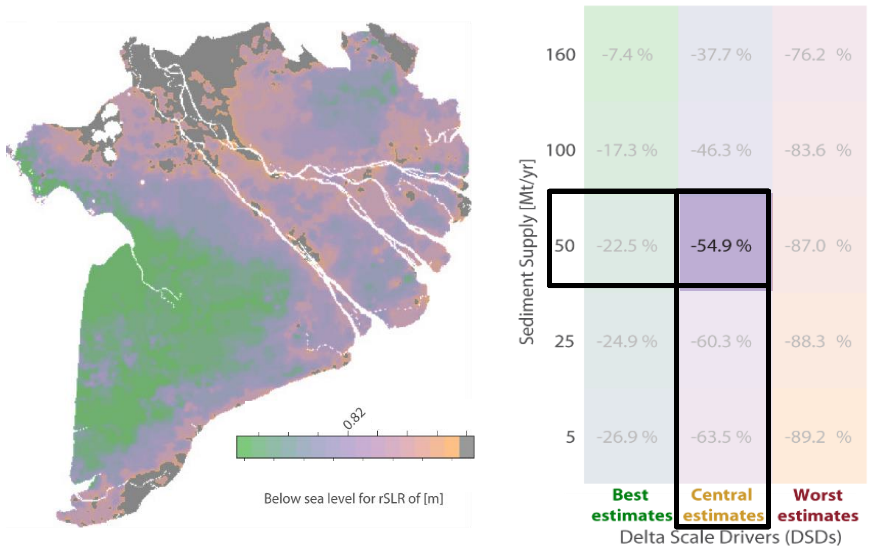
Sensitivity of sediment supply to the delta to sediment yields and sediment trapping in dams. Sensitivity is measured as Sobol Index (colors). Notably, sensitivity changes for increasing hydropower scenarios/generation levels (GLs).

Results

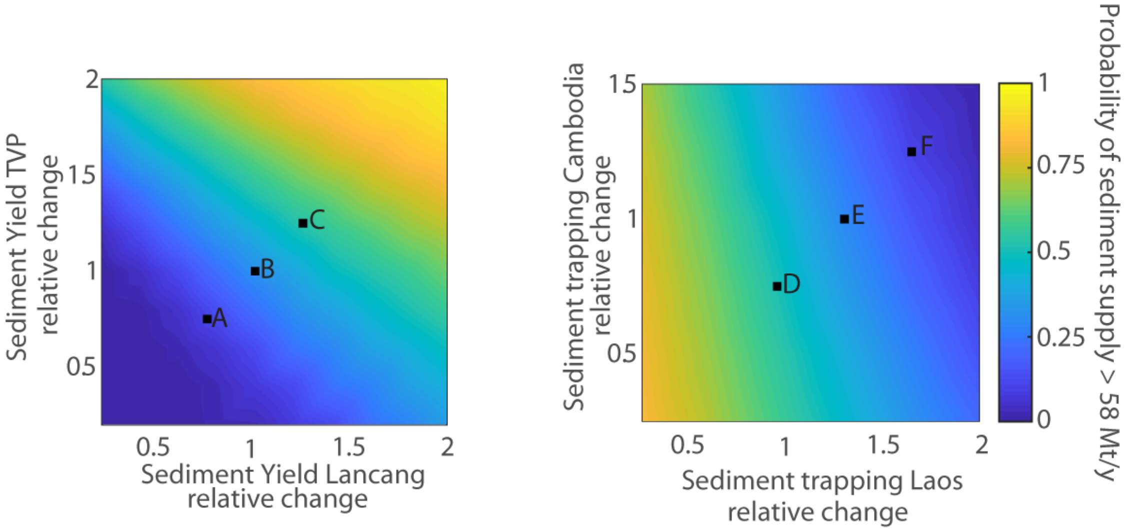
4: Bringing it together: Increasing hydropower without further impacts on sediment yields?

For current levels of sediment supply (ca 58 Mt/yr) and central estimates of delta-scale drivers, rSLR is around 0.8 m, and around 50 % of the delta will fall below sea level.

A slight increase in hydropower using a strategically planned expansion in hydropower has an around 40 % chance of not reducing the sediment supply to less than the current central estimate of 58 Mt/yr.



Half of the delta would be below sea level by 2100 with central estimates of delta scale drivers and current levels of sediment supply. How likely is it that future hydropower development is compatible with at least not further reducing sediment supply?



For central estimates of sediment yield and sediment trapping in most relevant countries / geomorphic provinces (points B and C), a slight expansion of hydropower would, with a 40 % probability, lead to maintaining or exceeding the current sediment supply (color scheme). If, for example, sediment yields were 25 % higher (Point C), that probability would increase to around 60 %.

Conclusion & Future directions

Sediment supply is crucial for maintaining resilient delta land (Hoitink et al., 2020, Loucks, 2020).

We propose an exploratory, bottom up approach, which integrates basin and delta processes to study the role of sediment supply for a resilient Mekong delta

The Mekong delta as a whole would not be resilient to rSLR, even with a pristine sediment load. Managing delta-scale drivers of accelerated subsidence is key to minimize land falling below sea level

Sediment supply from the basin is still key to continue land building on a reduced sub-aerial delta surface

Dam placement controls sediment supply to the delta. Optimized dam portfolios are a robust option to maximize the resilience of the delta

Future research should deploy higher fidelity delta models and integrate the delta model in the stochastic bottom-up modeling

Contact and references

Looking forward to your questions: rschmitt@stanford.edu

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