The Importance of Sand

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Overview

- Why is sediment important & how rivers respond to changes
- Sand mining trends & impacts
- Hydropower trends & impacts
- Mitigation & management approaches to reduce impacts from river developments
Why is Sediment Continuity Important? Rivers Carve Landscapes and Transport Sediments
Importance of Hydrologic & Sediment Transport Processes

- Distribution and quality of habitats
  - Geomorphology & vegetation are closely linked
  - Vegetation responds to flow & sediment changes, which alters bank stability
- Stability of the river channel & deltas
- Social dependence on river systems
  - Flood plains agriculture
  - Navigation
  - Water availability
  - Energy production
- Need to be understand how rivers will change when developed
  - *Rivers will ‘adjust’ to any change to hydrology or sediment processes*
Fine-grained Sediment
Coarse-grained sediment – sand, gravel, cobbles
Channel shape respond to flow, sediment & slope changes

- Channel is stable if:
- Sediment load & size is in balance with flow & river slope
- If sediment load decreases, bed will erode
- If sediment size decreases, bed will erode
- If flow increases, bed will erode
- Hydropower changes flow & sediment load & sediment grain-size
- Sand mining reduces sediment load and changes sediment size
Sand mining: consumption trends

- Sand mining is a ubiquitous activity
  - Global construction industry is based on cheap sand
  - Local activity – cost linked to transportation
  - Local governance frequently poor
  - Illegal extraction reported in over 70 countries

- Estimated up to 50 billion tonnes of aggregate is extracted annually
  - 30 billion tonnes used in construction
  - Road bases and land reclamation other major uses
    - 1 km requires 30,000 tonnes of aggregate
Structured literature review of sand mining impacts

- Papers link sand mining with geomorphic change, but few establish direct link to ecosystem changes
  - Spatially & temporally complex
- An increasing number of investigations about sand mining are being published
- The vast majority of the sand is being extracted for construction
- Most investigations are from North America and Europe
  - May reflect exclusion of papers not in English

(Koehnken, et al., 2020)
Summary of Physical Impacts

Physical changes to the environment are widely documented, affecting channel morphology, sediment budgets, instream habitat, the flow regime, and water quality.

- Channel incision is the most widely reported impact.

(Koehnken, et al., 2020)

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<thead>
<tr>
<th>Channel Changes</th>
<th>Morphological Changes</th>
<th>Flow Changes</th>
<th>Water Quality Changes</th>
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<td>Bed coarsening</td>
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<td>Increase in bed load</td>
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<td>Sediment reduction</td>
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<td>Creation of deep pools</td>
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<td>Consolidation of islands</td>
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<td>Destruction of aquatic/riparian habitat</td>
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<td>Afforestation</td>
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<td>Increased flow velocity</td>
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<td>Improved flood control</td>
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<td>Decrease in flood control</td>
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<td>Increased turbidity</td>
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<td>Increase in metals</td>
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Ecosystem impacts by sand mining

- **Demonstrated impacts include:**
  - Fish kills
  - Reduction in diversity and abundance of fish in mined areas
  - Change from lentic to lotic populations due to removal of riffle sequences
  - Increase in invasive species in disturbed areas
  - High mortality during embryonic stage due to suction dredging
  - Temporary and reversible change to abundance and diversity of invertebrates in **small scale** mining
  - Change in food web dynamics in mined areas
  - Impacts on larval drift due to increased turbidity
  - Changes to riparian vegetation

- **Inferred impacts include:**
  - Loss of gravel substrate impacting fish spawning
  - Channel alterations affecting migratory patterns
  - Decline in native fisheries
  - Water quality changes affecting biota
  - Decline in deltaic ecosystems and coastal fisheries

*Habitat loss & destruction is #1 stressor on IUCN Redlist*

*(Pham, 2017)*
Examples of changing river profiles from mining

- Examples from India due to sand mining
- As channels deepen, banks become unstable
  - Bank erosion
  - Risk to infrastructure
  - Loss of channel & riparian habitats

Source: http://www.indiaenvironmentportal.org.in/files/images/20040531/33-graph.jpg
Hydropower developments increasing

- **Hydropower installed capacity** also increasing rapidly
- **Same regions developing** HPPs where demand for sand is increasing
- **Dam construction large consumer of sand**
  - 13Mm$^3$ sand and gravel in Three Gorges

Where hydropower increased in 2017

- HPPs capture sediments
- Change grain-size distribution downstream
- Alter downstream flow patterns
  - Affects channel morphology

Source: International Hydropower Association
Example of sediment changes from HPP cascade

- Hydropower cascade is reducing sediment load & changing grain-size distribution of the sediment load
- Results in channel erosion downstream
- Big impact to ecology even if channel is bedrock controlled

MRC, 2020
HPP & mining mitigation measures – Manage where sediment deposits

- Check dams or sedimentation ponds to promote sediment deposition at head of impoundment
  - Sediment available for mining
  - Reduction in sedimentation in active volume of impoundment
- Does not address downstream impacts from hydropower
  - Prevents additional impacts from sand mining
HPP & mining mitigation approaches – Extract deposited material from HPPs

- **Sediment mining during draw down of impoundment**
  - Reduce pressure in upstream and downstream river channel by mining sand captured by impoundments
  - Requires lake level management
    - Draw down during dry season
  - Can be used in combination with check dams or sediment settling basins

- **Dredging can also be used**
Sediment flushing from HPPs

- Maintains sediment supply to downstream channel
- Ecological risks if sediment concentration too high
  - Timing and frequency are important
- Managed using
  - Rate of water level raw down
  - Duration of flushing
  - Release of ‘clean’ water
  - Set maximum sediment concentration limit for downstream
  - Monitoring & modelling
- Mitigation needs to be considered during dam design

Sediment flushing in Shihmen Reservoir, Taiwan
Sustainable sand mining?

- Some evidence mining can be sustainable if volume extracted is small compared to sediment load
  - Within range of natural variability
- River will ‘adjust’ to any change, aim is to maintain change within acceptable limits
  - Need to consider entire river
- To establish sustainable volume requires extensive research and on-going monitoring / modelling expertise
  - No examples in literature of long-term sustainable extraction
  - More research required

**Flow-chart for sustainable sediment volume**

1. Start
2. River Survey
3. Sediment Sampling
4. Replenishment Rate Determination
5. High Flow Period Determination
6. Extraction Volume Determination
7. Management Plan
8. End

- The cross-section survey should cover a minimum distance of 1.0 km upstream and 1.0 km downstream of the potential reach for extraction (Refer Chapter 4).
- The sediment sampling should include the bed material and bed material load before, during and after extraction period.
- Develop a sediment rating curve at the upstream end of the potential reach using the surveyed cross-section. Use both Yano or Engelund-Hansen equations and the measured bed material parameter.
- Using the historical or gauged flow rating curve, determine the suitable period of high flow that can replenish the extracted volume.
- Calculate the extraction volume based on the sediment rating curve and high flow period after determining the allowable mining depth.
- The cross-section survey should be made before, during and after extraction period to determine the exact volume of extraction and effects of extraction (Refer Chapter 4).

(DID, 2009)
Synthesis / Final comments

- Sand / sediment is a fundamental & critical component of river systems
- Dam development and sand mining impact sediment budgets
- Both sand mining and HPP development are increasing – most rapidly in developing economies
- Any river development needs to be based on sound understanding of river
  - Rivers are a continuum
    - Sediment budget - upstream, at development & downstream
    - Ecosystem characteristics and values throughout river system
- Sediment mitigation / management needs to be included at earliest design stage of HPPs
  - Strategic development of HPPs can minimise sediment disruption
  - Flexibility of infrastructure to respond to changing conditions & issues
  - Operating procedures to mimic natural flow and sediment patterns
- Sand mining requires ongoing monitoring and evaluation
  - Identification of off stream sources should be priority
Thank you