ISH0306 - GEOMORPHOLOGY, SEDIMENTS & WATER QUALITY

ISH0306 Final Regional Training Session

Geomorphology, Sediments & Water Quality

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Introduction to Mitigation

- HPPs have the potential to directly alter flow and sediment movement in river systems
- Rivers will respond to these changes, and these responses may have negative impacts with respect to:
  - The physical integrity of the river
  - The ecology of the river
  - The social uses of the river
- Ideally negative impacts are avoided but this is rarely possible
- When negative impacts cannot be avoided, need to minimise and **mitigate**
Hydropower projects operate for decades to centuries

The Hydropower Project Life Cycle (~100 years)

- Planning and pre-feasibility (~10 years)
- Design, feasibility, impact assessments (~3 years)
- Construction (~7 years)
- Operation (~80 years)

Often major refurbishment after ~50 years

Sometimes change of ownership, and/or relicensing, after some time period

‘Someone's sitting in the shade today because someone planted a tree a long time ago’ Warren Buffet
Mitigation Approach / Strategy

- Understand the river flow, geomorphology & sediments
- Identify values and risks
- Identify appropriate mitigation measures to
  - Avoid, minimise, mitigate
  - Maximise operational flexibility
- Model / trial / consult / revise
- ISH0306 ‘Manual’ follows this sequence
  - Manual contains some LMB site-specific information
    - Description of geomorphology by zones
    - Description of sediment delivery
    - Description of water quality
    - Based on MRCS monitoring programmes
  - Manual identifies some LMB specific ‘risks’
  - Mitigation measures appropriate to the LMB
ISH0306 Mitigation Approach – Geomorphology, Sediments & Water Quality

- **Understanding processes in the LMB**
- The better the understanding of the river system the more appropriate and cost effective the mitigation measures
  1. Need information about site, sub-basin, basin (transboundary)
  2. Channel characteristics – alluvial, bedrock, composite, slope
  3. Sediment sources, sediment loads, sediment characteristics & flow regime, seasonality of sediment delivery
  4. Water quality characteristics – temp, EC, turbidity / light penetration, nutrients

*Sediment loads & patterns*  
*Sediment grain-size*  
*WQ characteristics*
ISH0306 Mitigation Approach – Geomorph., seds & WQ

• Identifying values & risks-What needs protection?

• Geomorphic & sediment values – examples
  1. Physical: Channel, bank, infrastructure, delta and shoreline stability
  2. Ecological: Provision and maintenance of habitats
  3. Social: Construction materials, tourism, cultural sites

• Water quality values - examples
  1. Human uses: consumption, irrigation, industrial
  2. Maintenance of water quality conditions in river systems & Tonle Sap, e.g. water clarity, nutrient availability
  3. Delivery of nutrients to flood plains & flooded forests
  4. Delivery of nutrients to coastal zone
### Geomorphology – Values & Risks Examples

<table>
<thead>
<tr>
<th>Value</th>
<th>HP Risk</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance of river channel for stability and ecological habitats in sub-basin and basin</td>
<td>Alteration of flows leading to increased erosion / incision Reduction in sediment delivery &amp; change in grain-size</td>
<td>Maintain natural river seasonality Maintain natural range of daily water level changes Maintain sediment delivery on a seasonal basis</td>
</tr>
<tr>
<td>Floodplain and delta productivity &amp; stability</td>
<td>Reduction in sediment load &amp; change in grain-size distribution</td>
<td>Minimise sediment capture</td>
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<td></td>
<td>Change to timing of sediment delivery</td>
<td>Retain seasonality of sediment delivery to ensure floodplain deposition at high flow</td>
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<td>Retain high sediment loads during Tonle Sap reversal</td>
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<tr>
<td>Maintain habitats in local waterways</td>
<td>Sedimentation during construction</td>
<td>Minimise construction impacts</td>
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</table>
Example: HPP impacts on river geomorphology

- Downstream bed erosion is common impact
- Erosion starts at dam toe and progresses downstream
  - Decades to centuries required for stabilisation
  - Halted by bedrock or armouring (coarse rock)
- Bed erosion leads to bank instability

Graph shows depth of bed erosion at the same point downstream of a dam over 30 years
Identify mitigation options appropriate to values and risks

- **Wide range of mitigation options:**
  - Designing HPPs that minimise impacts & maximise mitigation options
  - Implementing infrastructure to enable mitigation
  - Developing operating rules to achieve mitigation goals
  - Coordinating operations with other HPPs minimise impacts and maximise mitigation
  - Implementing catchment management to reduce overall impacts and maximise benefits

- **Mitigation approaches may change over life-cycle of project**
  - Construction / operations / decommissioning
Sediment Mitigation Approaches during Planning

- Planning, siting, design – VERY important for mitigation
  - Small volume reservoirs with inflow>>storage
    - Smaller impact on flow regime
    - Less sediment retention
  - Dam position wrt upstream tributaries
    - Unregulated tributaries enter downstream
    - Decreases percentage of flow & sediment regulated
  - Long downstream bedrock reach to limit impacts
    - Localised loss of sandy insets
    - River bed erosion controlled by bedrock
  - Infrastructure in place to maximise operational & mitigation options
    - Off-stream impoundments
    - Low level gates
    - Re-regulation weir to minimise water level fluctuations
    - By-pass channels, sedimentation ponds
    - Multiple intakes
  - Guided by site specific understanding

Dams A, B & C will have different impacts
Mitigation: Dam Design & Siting ‘tools’

Palmieri et al., 2003
Sediment Mitigation Approaches—Construction Stage

• Construction
  • Minimise sediment runoff
    • Sediment traps & cut-off drains
    • Protection of banks
    • Timing of works in dry season
  • Armouring of banks if erosion is identified as at risk
Sediment Mitigation Approaches-Operations

- Operations-sediment management
  - Majority of HP life-cycle
  - Minimise input / maximise throughput

- Minimise inputs
  - Catchment approaches
    - Management of sediment runoff in catchment to reduce sediment input to impoundments
    - Protects areas of high significance
      - Used in LMB
      - Protect biodiversity
    - Reforestation of degraded land
  - Bypass channels
    - Passes sediment around project during high flows
Sediment Mitigation Approaches - Operations

• Maximise throughput
  • Sediment sluicing - requires low level gates in dam
  • Draw down lake level at end of dry season
  • ‘Sluice’ initial sediment pulse
    • Low water level allows initial high flows to pass sediment through impoundment
    • High proportion of annual sediment load is discharged
    • Maintains seasonality of sediment pulse
  • Capture ‘lower’ sediment water later in flood pulse (if storage)
• Periodic sediment flushing
  • Lake level drawn down to river conditions to promote erosion of sediment
  • Ideally at start of wet season to maintain seasonality of sediment pulse
• Pass ‘turbidity currents’ through low-level gates
• Coordination of sediment flushing
  • Mainstream & tributary dams
Example Sediment Mitigation: Sediment Sluicing at Three Gorges Dam

- Flood season
  - 90% sediment
  - 60% flow
- Lake level reduced from ~175 m to 145 m
- Minimises sedimentation of fines in reservoir
- Does not pass bedload

- Similar approach could be achieved with by-pass channel

*From Wang*
Example Sediment Sluicing

- Sediment released from low level gates/intake
- Clear surface water released at same time
Sediment Mitigation Approaches

• Bedload management
  • Bedload not easily flushed until deposits reach toe of dam
  • Frequent flushing will increase rate of movement towards dam toe
  • Important for downstream habitats

• Dredging
  • Expensive but may be required to maintain shipping lane

• Sediment mining during drawdown
  • Reduce mining downstream of dam

• Upstream settling ponds
• Reintroduce material downstream

From Wang
Modelling to Evaluate Mitigation Options

- Modelling is a valuable tool for identifying and assessing mitigation options. Use models to:
  - Identify operating patterns to minimise sediment retention
  - Identify optimal conditions for sediment sluicing or flushing
    - Rates of draw down, minimum water levels, maximum discharge volume
  - Evaluate rates of daily water level changes on downstream impacts
- Investigate coordinated operations of mainstream HPs and tributary HPs
  - Flow interactions to minimise rates of water level in mainstream
  - Sediment management to maintain sediment delivery and prevent large plumes
Sediment Mitigation Challenges in the LMB

- Flow regime & sediment timing already altered by Lancang Cascade
  - Delayed onset of flood
  - Altered timing of sediment delivery
  - Reduction in sediment load
- Flow regime & sediment timing of mainstream is also altered by tributary HPP developments
  - Sediment mitigation in mainstream dams only effective if sediment arrives from upstream and tributaries
  - Goal should be to re-align sediment delivery with start of flood pulse
  - Co-ordination of operations likely to provide best environmental outcome
    - Requires sediment mitigation in tributary projects
    - Coordination between tributary and mainstream
    - Coordination between UMB and LMB
Water Quality

- River(s) or P/S inflow
- Operating Range
- Wind Mixing
- Spillway or High Level Intake
- Warm Water
- Cold Water
- Increasing Density
- Decreasing Oxygen
- Redox Reactions
- Fe, Mn, Zn
- Low Level Intake or Gate
- Depends on duration of storage
- Depends on depth of impoundment

Aquatic Mercury Cycle

- Deposition
- Volatilization and Deposition
- Volatilization and Deposition
- CH₃Hg Deposition and Runoff
- Hg(II) Deposition and Runoff
- Reduction
- Hg(0)
- Demethylation
- CH₃Hg
- Outflow
- Methylation
- Diffusion/Sediment Resuspension
- Sedmentation
- Sedimentation
## Water Quality – Values & Risks

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<td>Maintenance of water quality in LMB</td>
<td>Decrease in quality of water during impoundment</td>
<td>Maintain good water quality within impoundments</td>
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<tr>
<td>Seasonal water quality cycles (e.g. temp, nutrients, turbidity)</td>
<td>Loss of seasonal changes due to storage and disconnect between sediment supply and flow</td>
<td>Maintain seasonal water quality signals</td>
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Water quality risks during storage

- Site and project specific – include:
  - Decreased DO from decay of organic matter
  - Increased light penetration due to sediment reduction
  - Altered temperature regime
  - Nutrient trapping
  - Stratification of water column
  - Potential low DO
  - Metal release from sediments
- Interaction between other activities and HPPs
  - Increased water availability can intensify agriculture & other development
  - Industrial discharges can alter WQ in impoundment
Water Quality Mitigation Approaches (1)

- Planning, siting, design:
  - Small volume reservoirs with inflow>>storage
    - Smaller impact on flow regime
    - Reduced storage period
    - Reduced risk of stratification
  - Steep reach for dam-site
    - Promotes turbulence and re-oxygenation downstream
  - Unregulated tributaries enter downstream
    - Decreases percentage of regulated flow
  - Removal of organic matter from inundation area
    - Retain some vegetation for future fish habitat?
  - Depth of intake affects stratification

(Dai et al, 2013)
Stratification in Reservoirs

Shallow Reservoir

Deep Reservoir

Henty Lake

Water Temperature (°C)

Depth (m)

9-Aug-11
27-Sep-11
22-Nov-11
11-Jan-12
27-Mar-12
18-May-12

Dissolved Oxygen (%Sat)

Depth (m)

9-Aug-11
27-Sep-11
22-Nov-11
11-Jan-12
27-Mar-12
18-May-12

L Mackintosh at Dam

Water Temperature (°C)

Depth (m)

8-Aug-11
28-Sep-11
24-Nov-11
11-Jan-12
26-Mar-12
16-May-12

Dissolved Oxygen (%Sat)

Depth (m)

8-Aug-11
28-Sep-11
24-Nov-11
11-Jan-12
26-Mar-12
16-May-12
HPP impacts on downstream water quality

- Temperature fluctuations affect fish and OAOs
- Peaking operations can alter temperature over short time periods
  - When operating, Temp is higher / lower than ambient due to changes during storage
- Storage projects can alter temperatures continuously
  - Remove seasonal cues for migration, spawning, etc

Temperature in discharge from HPP compared to temperature in unregulated river

‘X’ = unregulated river
Water Quality Mitigation Approaches (2)

- Infrastructure to reduce WQ impacts
  - Low dams & shallow impoundments
    - Reduce risk of stratification
  - Multiple outlets, including high level
    - Avoid discharge of poor quality water
    - Potential to ‘mix’ water discharged
    - Potential to release water during sediment flushing to reduce SS in downstream
  - Infrastructure in place to maximise operational & mitigation options
    - Aeration weir or ponds
    - Multiple intakes
- Guided by site specific monitoring
WQ Mitigation Approaches - Construction

- Minimise runoff of contaminated water
  - Oils, fuels, drilling fluids
- Management of sanitation & waste water at work sites & camps
  - Large influx of workers needs to be managed
- Management of solid wastes to avoid leaching
- Minimise sediment runoff

Secure waste disposal
Site at Nam Ngiep
WQ Mitigation Approaches-Operations

- Water quality management
  - Majority of HP life-cycle
  - Challenges will change over time
- Maximise quality of inflowing water to impoundment
  - Catchment approaches
    - Land use management to minimise sediment, fertilizer, herbicide, pesticide runoff
    - Protected areas or buffers around impoundments
- Minimise residence time
  - Reduce risk of stratification and low DO
  - Reduce risk of algal growth of sediment flushing
- Use infrastructure to increase DO
WQ Mitigation Approaches

- Maximise quality of discharge from impoundment
  - High level intakes / gates
    - Passive aeration
  - Aeration channels / weirs
  - Air pumping into sub-surface waters
- Air injection in power station
- Algal bloom management
  - Physical mixing of surface waters
  - Harvesting of algae
Multi-approach mitigation of DO

- Low dissolved oxygen in discharge from Tennessee Valley Authority schemes
- Implemented a range of measures
  - Limited power production in summer months
  - Aerating turbines
  - Water surface pumps
  - Oxygen injection & air blowers
  - Aeration weirs
- Live monitoring
- Improved downstream environment
- Increased operational flexibility
Water Quality Mitigation Challenges in the LMB

• Trend is towards increasing nutrient and COD concentrations in LMB
  • Whole of LMB issue

• Water quality of influent water will be affected by upstream mainstream and tributary HP projects
  • Many projects coming on line soon
  • High risk of low DO water from each project during early years
    • Potential for large cumulative impact on downstream HPs

• Can’t predict how future developments will affect WQ

• Decoupling of sediment from flow will alter nutrient delivery in LMB
  • Goal should be to retain water quality annual cycles

• Co-ordination and communication with other mainstream and tributary operations likely to provide best environmental outcome
Modelling to Evaluate Mitigation Options

• Goal: Maintain good water quality within impoundments
  • Modelling to provide information about residence times
    • Likelihood of water temperature increase
    • Risk of stratification and discharge of low DO water
  • Circulation within impoundments
    • Deposition patterns for sediments & assoc. nutrients
    • Long-term trends as impoundment ‘evolves’

• Goal: Good discharge water quality
  • Modelling and local experience to guide mitigation
  • What is presently working in LMB
    • Use of aeration weirs & re-regulation ponds
Summary of Mitigation Approaches

• Mitigation needs to be based on site-specific monitoring and understanding of ecosystem processes in the local downstream environment

• Whole of catchment approach required which recognises interaction between HPs and other activities
  • Land use changes / run off
  • Sediment extraction

• Mitigation measures likely to be most successful if based on communication and coordination between developers/operators
  • Coordinated sediment sluicing
  • Maintenance of seasonal flow patterns (e.g. T1, T2, etc.)

• Mitigation in LMB challenging due to:
  • Evolving impacts from existing UMB dams
  • Large number of tributary HPs projects being developed at same time
THANK YOU