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ISH0306 - GEOMORPHOLOGY, SEDIMENTS & WATER QUALITY

ISH0306 Final Regional Training Session

Geomorphology, Sediments & Water Quality

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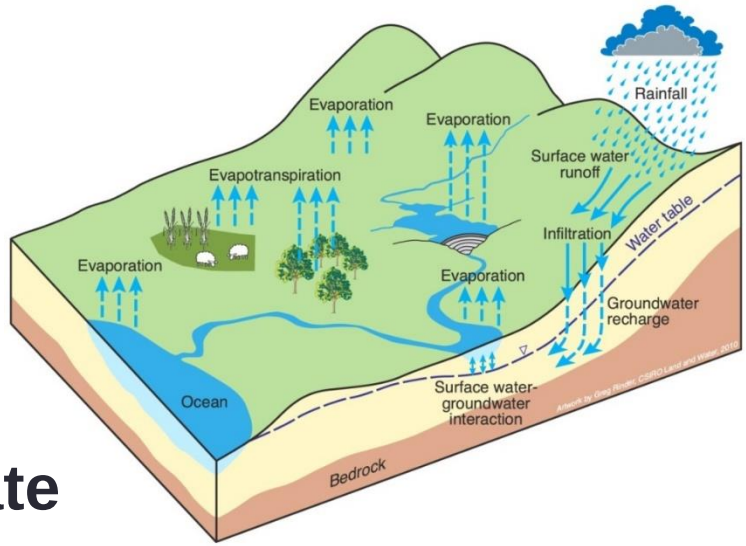
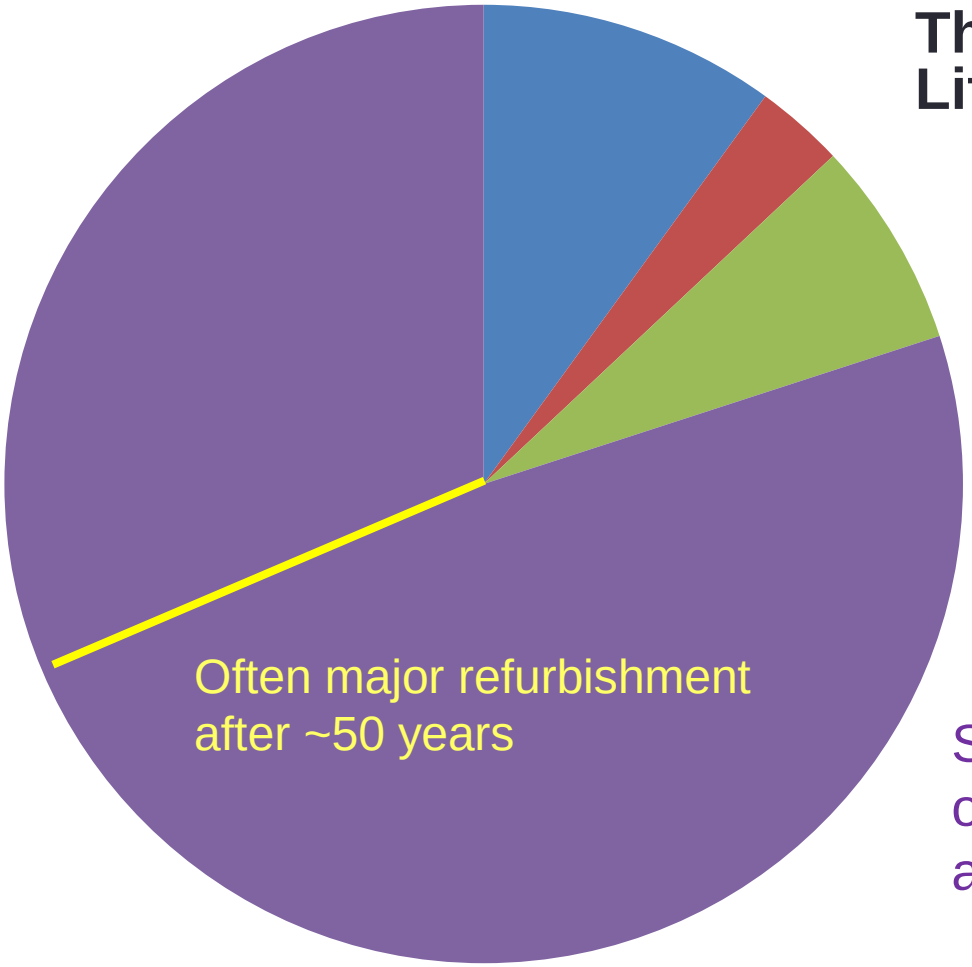
Introduction to Mitigation

- 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)

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

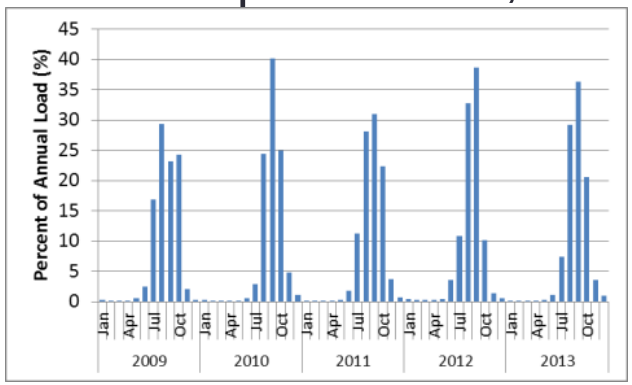
‘Someone's sitting in the shade today because someone planted a tree a long ***time ago’*** Warren Buffet

Mitigation Approach / Strategy

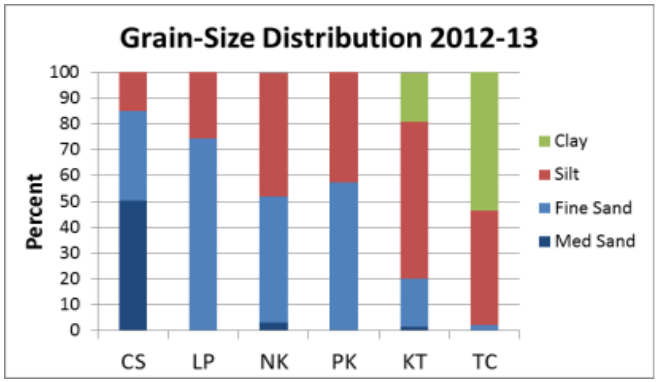
- Understand the river flow, geomorphology & sediments
- Identify values and risks
- Identify appropriate mitigation measures to
  - Avoid, minimise, mitigate
  - Maximise operational flexibility
- Model / trial / consult / revise
- ISH0306 ‘Manual’ follows this sequence
  - Manual contains some LMB 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

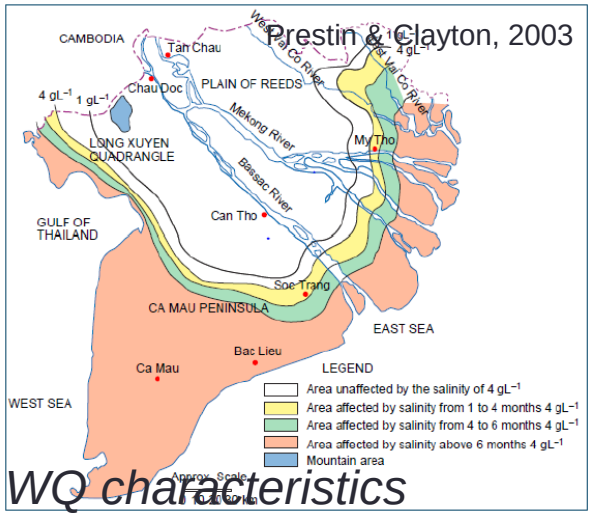
- **Understanding processes in the LMB**
- The better the understanding of the river system the more appropriate and cost effective the mitigation measures
  1. Need information about site, sub-basin, basin (transboundary)
  2. Channel characteristics – alluvial, bedrock, composite, slope
  3. Sediment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



Sediment loads & patterns



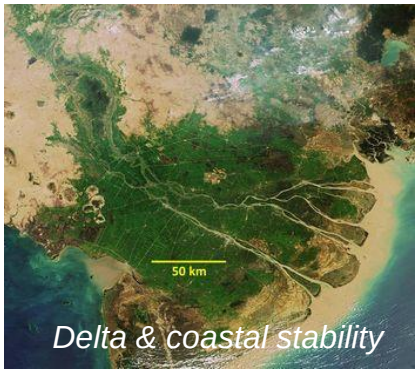
Sediment grain-size



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



Delta & coastal stability

- 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


Light penetration


Floodplain nourishment


Nutrients to ecosystems


Construction

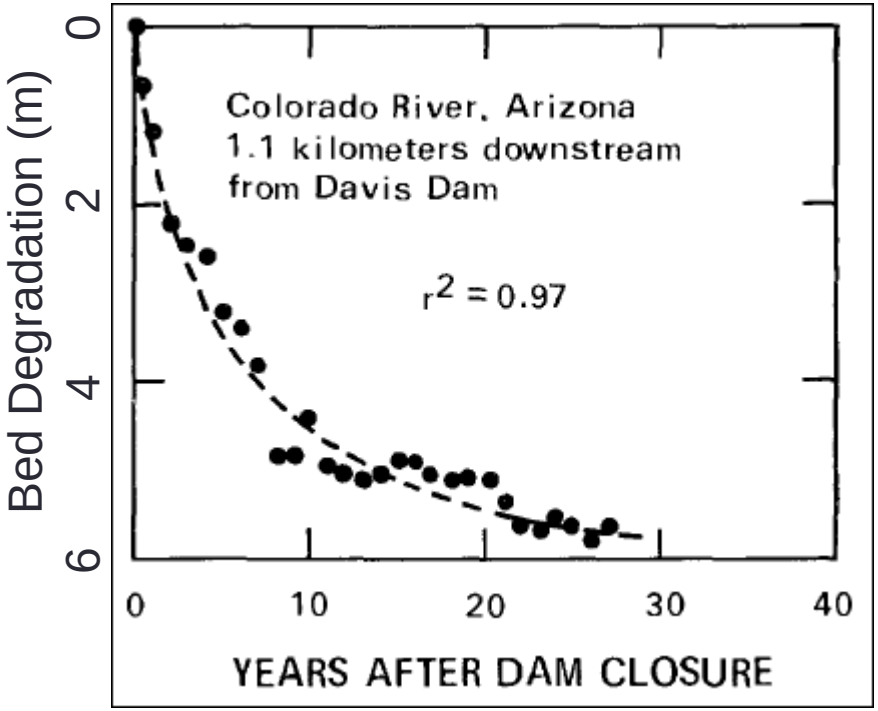

Habitats

Geomorphology – Values & Risks Examples

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

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



USGS, 1984

Graph shows depth of bed erosion at the same point downstream of a dam over 30 years

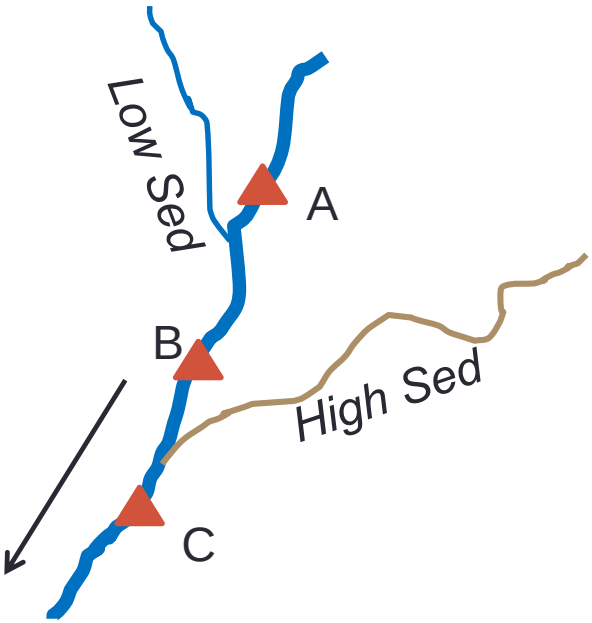
Identify mitigation options appropriate to values and risks

- 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

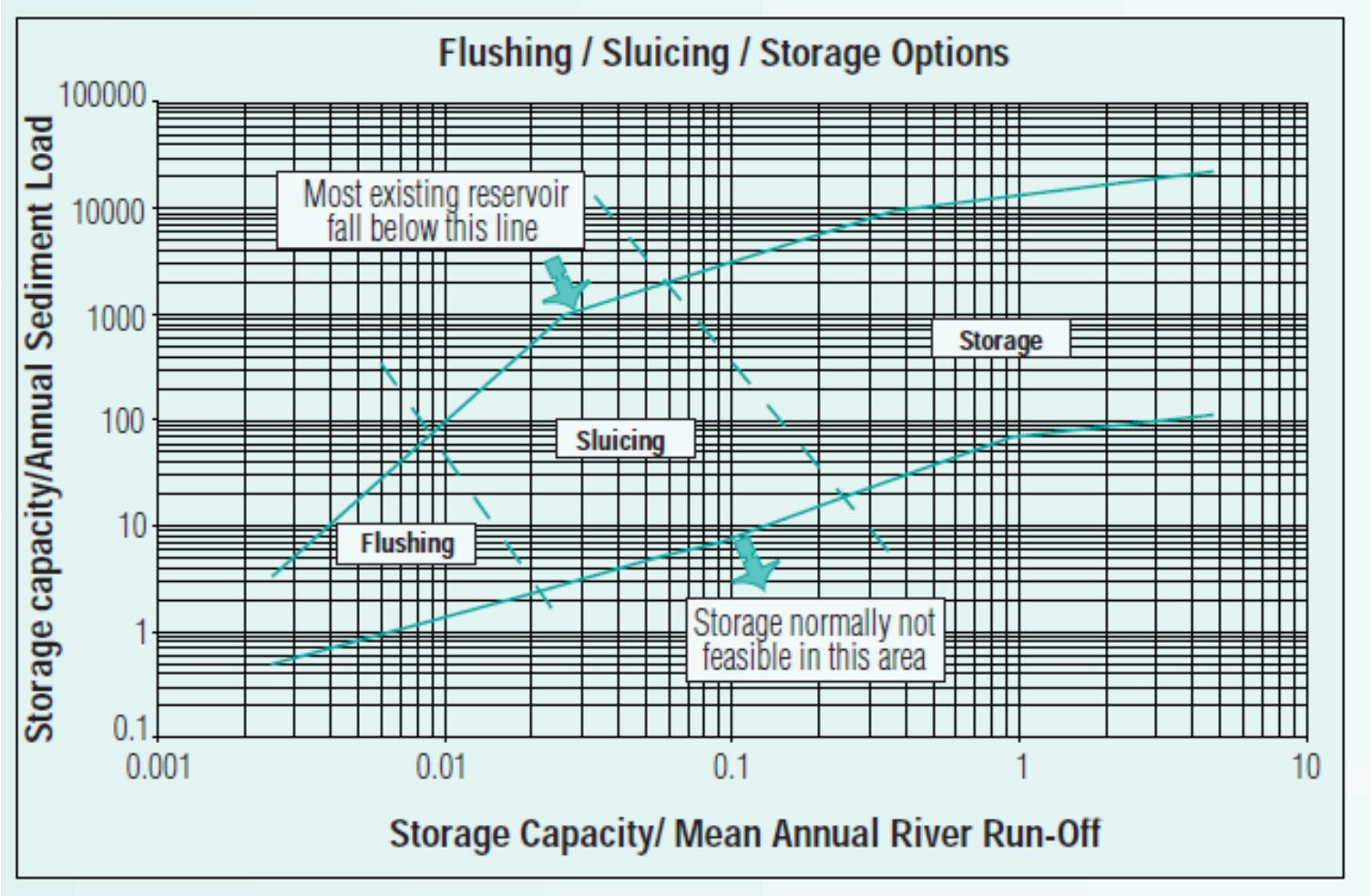
Sediment Mitigation Approaches during Planning

- 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*

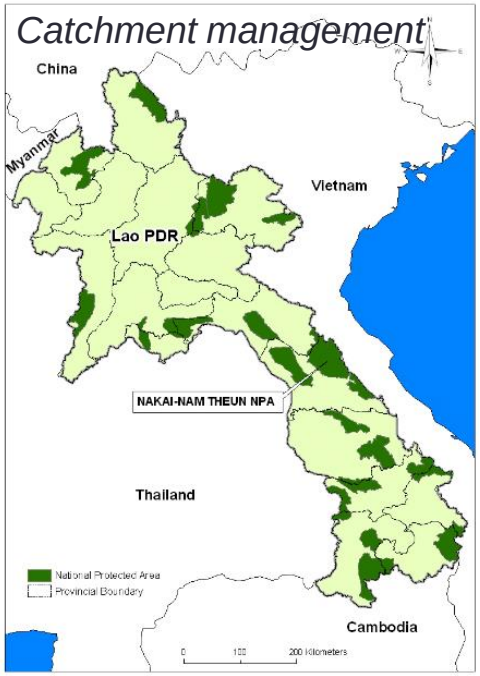
Sediment Mitigation Approaches-Construction Stage

- 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

Catchment management



Bypass channel

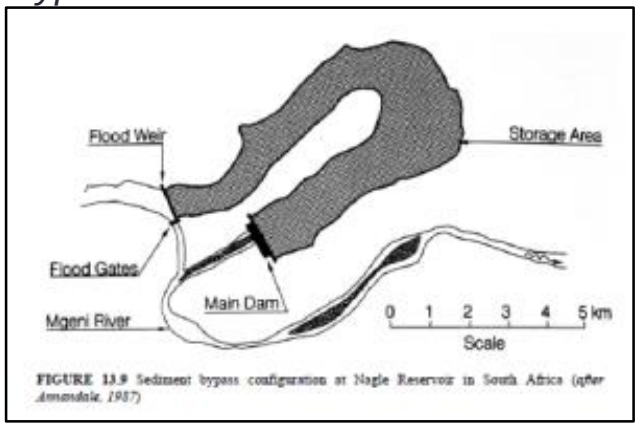
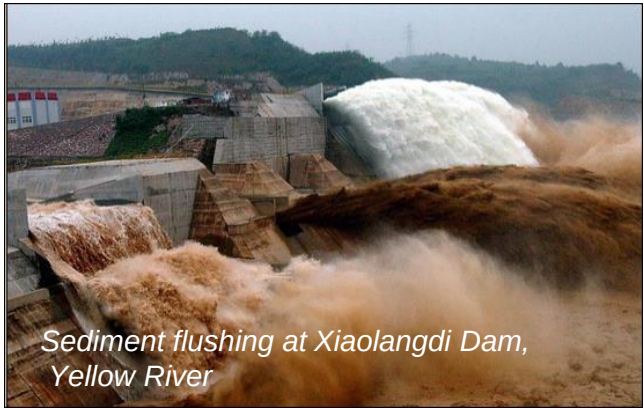


FIGURE 13.9 Sediment bypass configuration at Nagle Reservoir in South Africa (after Annandale, 1987)

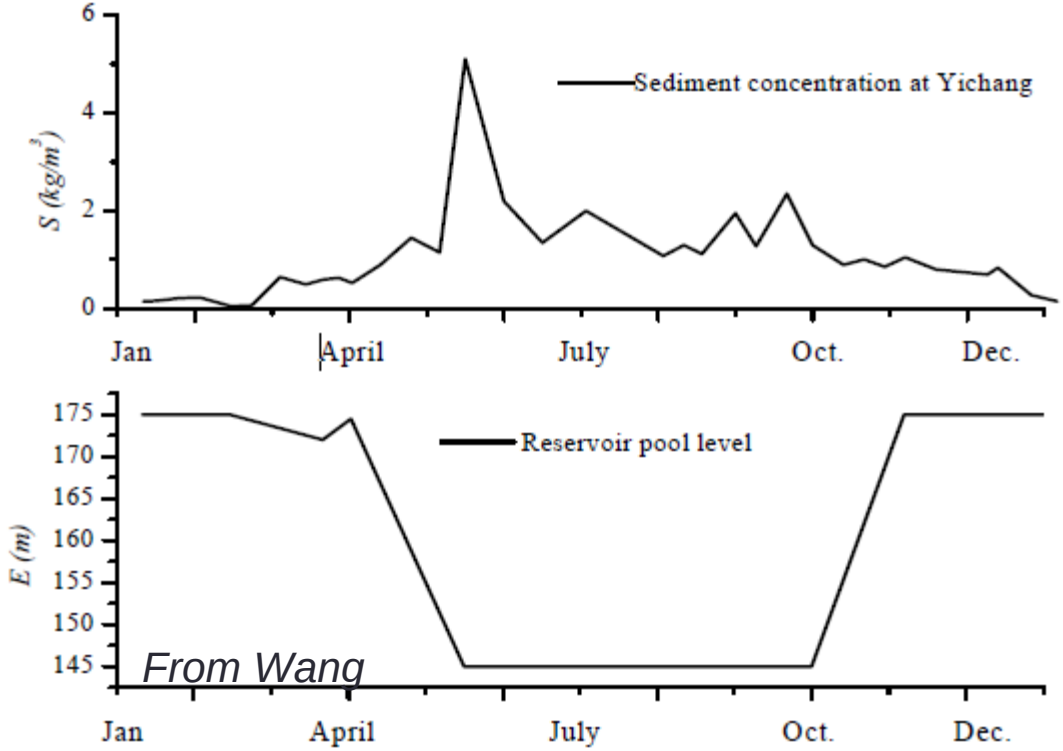
Sediment Mitigation Approaches - Operations

- 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



Sediment flushing at Xiaolangdi Dam, Yellow River

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

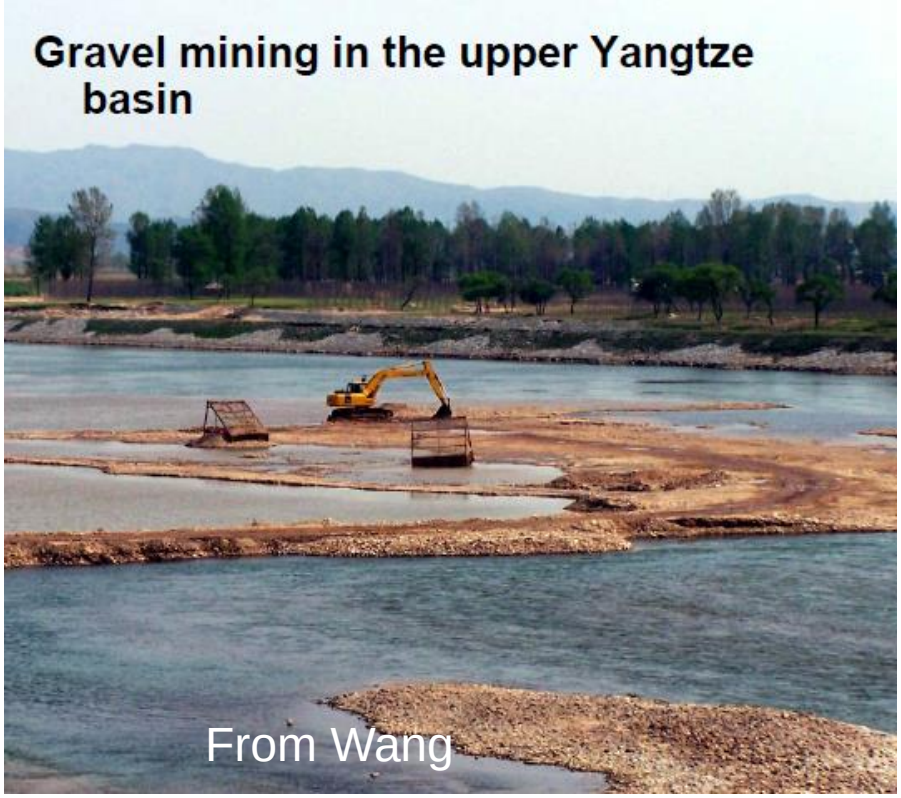
- Similar approach could be achieved with by-pass channel

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



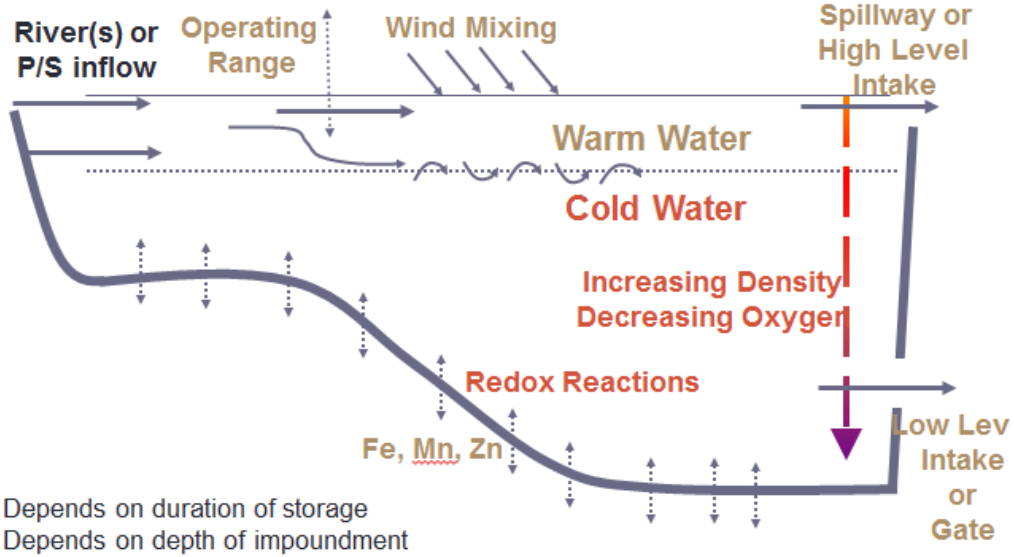
Modelling to Evaluate Mitigation Options

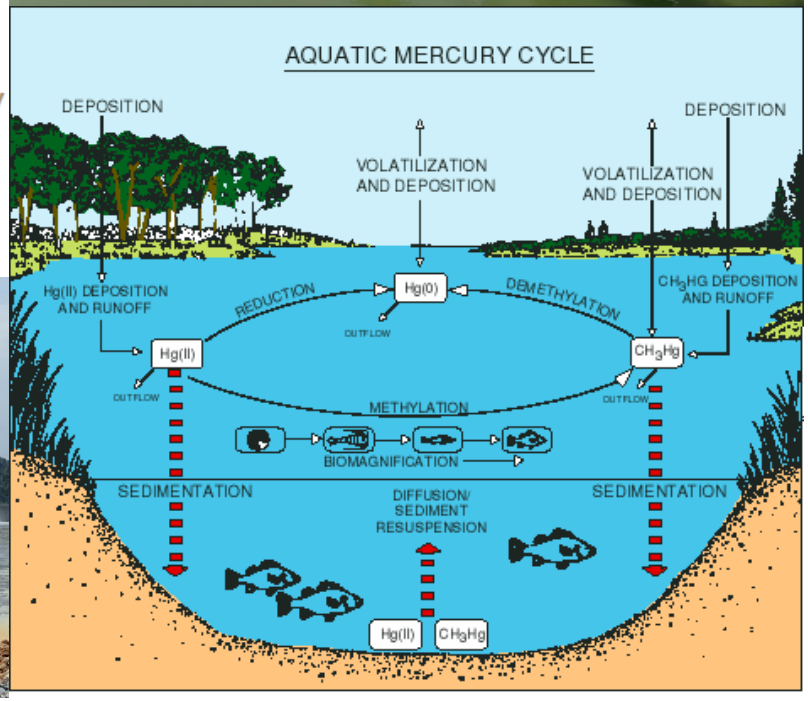
- Modelling is a valuable tool for identifying and assessing mitigation options. Use models to:
  - Identify operating patterns to minimise sediment retention
  - Identify optimal conditions for sediment sluicing or flushing
    - Rates of draw down, minimum water levels, maximum discharge volume
  - 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



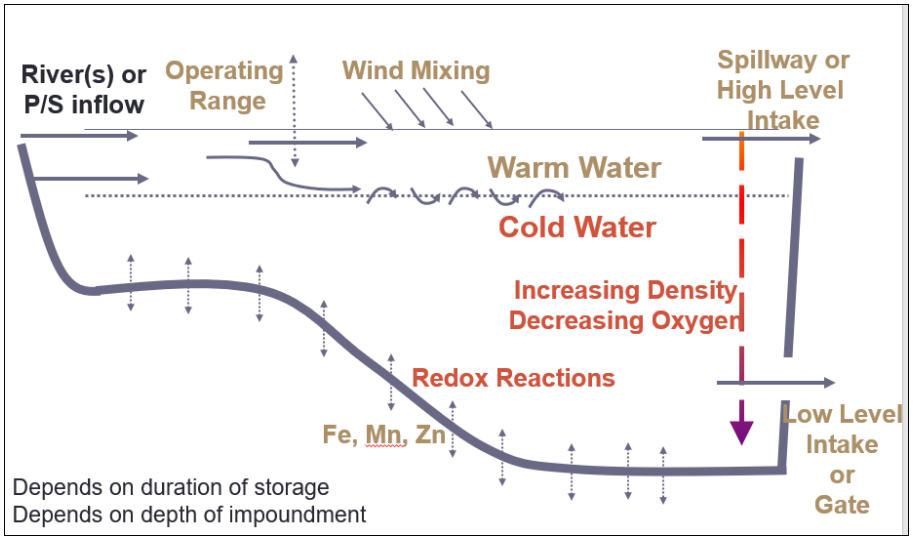


Water Quality – Values & Risks

Value	HP Risk	Goal
Maintenance of water quality in LMB	Decrease in quality of water during impoundment	Maintain good water quality within impoundments
		Release good water quality from impoundments
		Maintain ecosystems in LMB
Seasonal water quality cycles (e.g. temp, nutrients, turbidity)	Loss of seasonal changes due to storage and disconnect between sediment supply and flow	Maintain seasonal water quality signals

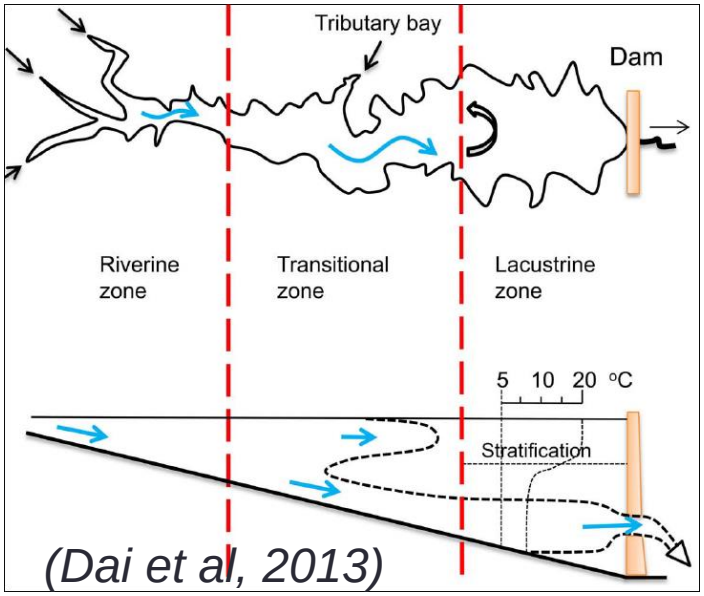
Water quality risks during storage

- 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)

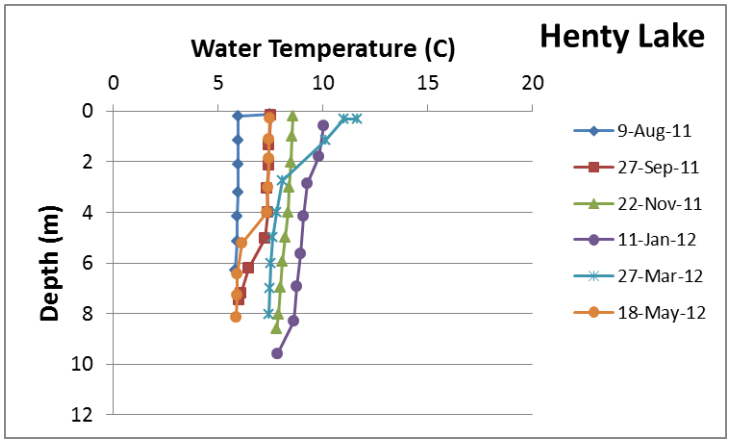
- Planning, siting, design:
  - Small volume reservoirs with inflow>>storage
    - Smaller impact on flow regime
    - Reduced storage period
    - Reduced risk of stratification
  - Steep reach for dam-site
    - Promotes turbulence and re-oxygenation downstream
  - Unregulated tributaries enter downstream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

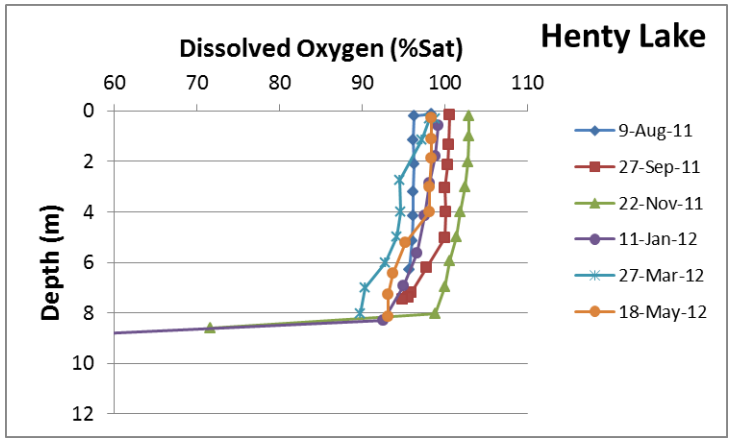


(Dai et al, 2013)

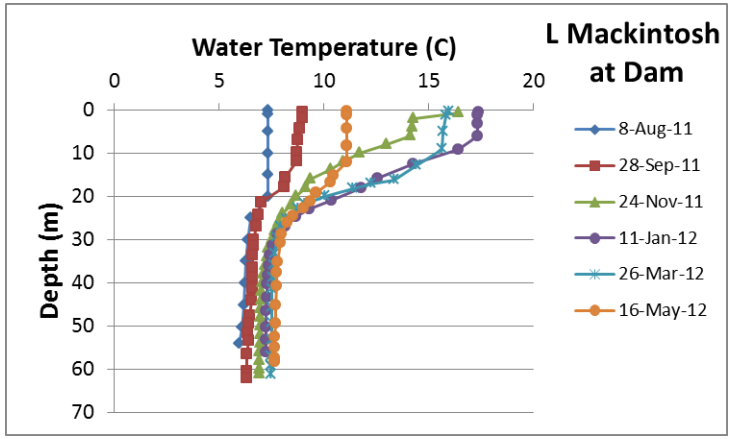
Stratification in Reservoirs

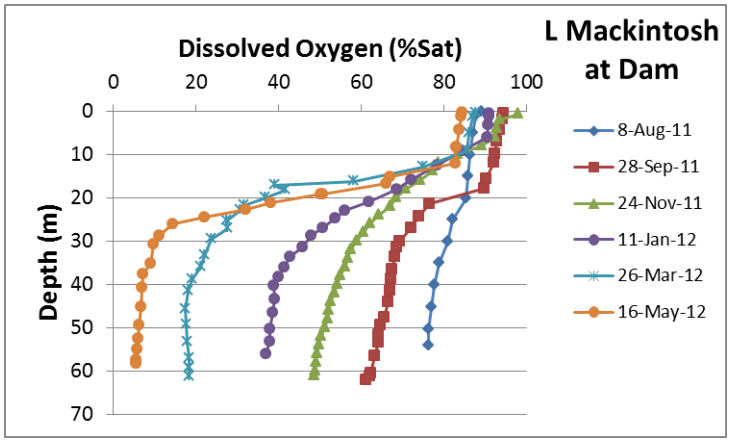
Shallow Reservoir



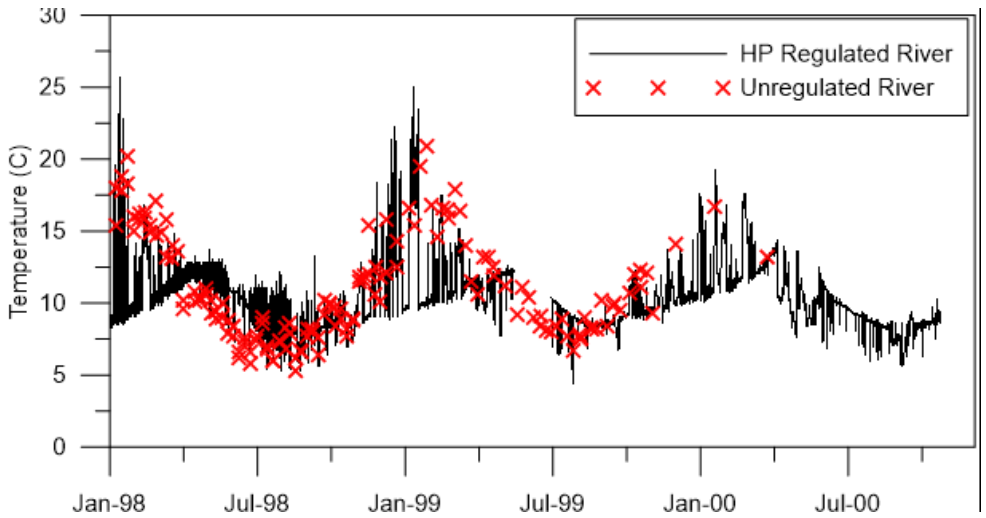


Deep Reservoir





HPP impacts on downstream water quality



Temperature in discharge from HPP compared to temperature in unregulated river
***'X'** = unregulated river*

- 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

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

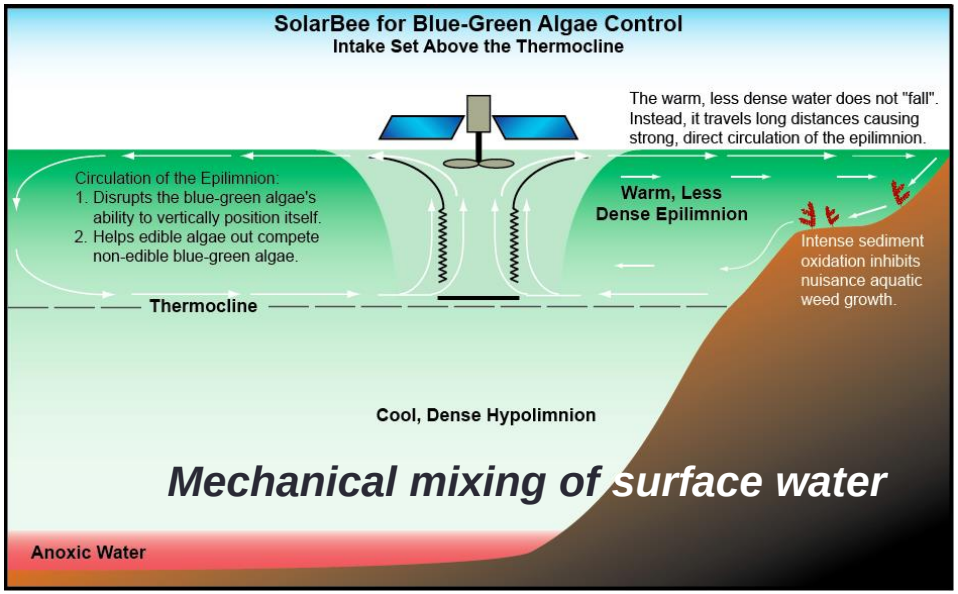
Secure waste disposal Site at Nam Ngiep

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 managenet
  - 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