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HYDROLOGY & SEDIMENT

REGIONAL MITIGATION ASSESSMENT WORKSHOP
Ho Chi Minh City
28-29 June 2010

MRC SEA OF HYDROPOWER ON THE MAINSTREAM MEKONG

Outline

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1. Overview of impacts assessment
2. Opportunities for avoidance
3. Opportunities for enhancement
4. Opportunities for mitigation
5. Critical gaps in understanding of the Mekong system
6. Institutional arrangements

Key strategic issues

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1. **Stream power:** rate at which energy is lost in moving over the bed of the river, and lost to turbulent flow dissipation (5-50MW/km)
2. **Water surface level changes:** rise and fall of water levels in the river in response to the 4 seasons (+/- 0.1 to 0.16m/day)
3. **Fate & transport of coarse sized sediment:** movement of large sediment primarily along the bed of the Mekong River. Important for:
   - Bank stability
   - In-channel seasonal habitats (deep pools, islands, sand bars, wetlands etc)
4. **Fate & transport of fine-sized sediment:** fine particles transported in suspension with attached nutrients:
   - Fertilisation of ~25,000km2 of agricultural land in the floodplains (Z5&6)
   - Channel and coastal stability of the Mekong delta
   - Primary source of nutrients for inland floodplain fisheries & delta coastal fisheries

Impacts: Stream power

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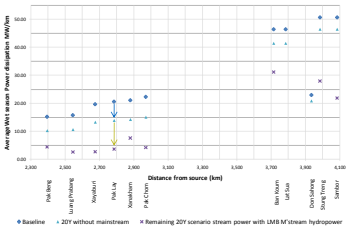
- **~55% of the total length of mainstream in the LMB will be converted to reservoir transforming the river from a live river to a series of impoundments with slow water movement**
  - i. concentrate energy dissipation at the dam sites for electricity generation.
  - ii. decrease in energy dissipated along the channel bed of the reservoirs and reaches sufficiently far downstream of the dam wall.
  - iii. During low and medium flows there is likely to be a complete reduction in available stream power, with a 50-80% reduction during the wet season



- **downstream stretches will experience rapidly changing flow in response to dam operations**

Impacts: Water level fluctuations

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- upper reaches of the LMB will **no longer experience the ecologically important transition seasons.**
- 7 of the projects will **experience inundation levels never yet observed in the history of data collection** affecting 5-10% of the river:
  - Irrigation infrastructure will need rebuilding, relocation & resizing
  - Loss of fertile river-bank growing area
  - Loss of the majority of Zone 2 & 3 floodplains & seasonal in-channel features
- Operational strategy: **peaking operation could exacerbate impacts to infrastructure & livelihoods:**
  - potential for hourly spikes in water level of up to 3-6m at towns and villages located 40-50 km downstream.
  - could translate this distance downstream in 1-2 hours giving very little time for notification
  - Under unplanned and emergency releases these peaking events could be larger

Impacts: Coarse-sized sediment

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- **change the mechanics of sediment transport:**
  - medium sized particles which moved in suspension will now move only partially in suspension
  - coarse sized particles which had moved partially in suspension and partially as bed load will now move as bed load or not at all causing greater retention rates in the impoundment of both medium and coarse sediment
- **Minor seasonal transport of coarse materials** in the reservoir (except in the immediate vicinity of the sluice gates)
- **formation of large deltaic-type deposits** at the head of each of the reservoirs

- Changes to the river thalweg & operability of many river gauging stations
- **increase down-cutting and channel bed and bank erosion** in alluvial reaches of the Mekong
- Without LMB mainstream there is an expected buffer period of ~1-2decades before erosion problems are felt in Cambodia: The LMB mainstream projects will reduce this compromising channel stability within a few water years

Impacts: Fine-sized sediment

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- Sediment load drop by ~50% for 2030 without LMB mainstream
- Sediment load will drop by 75% with LMB mainstream

SITE OF DEPOSITION	ANNUAL DEPOSITION VOLUME					
	BDP Baseline		Without LMB mainstream dams		With LMB mainstream	
	Sediment [Mt/yr]	Nutrient (Total P) [t/yr]	Sediment [Mt/yr]	Nutrient (Total P) [t/yr]	Sediment [Mt/yr]	Nutrient (Total P) [t/yr]
Kratie: annual sediment transport rate	***165***	***26,376***	***88***	***14,061***	***41***	***6,594***
Cambodian floodplain	25	*3,958*	13	*2,111*	6	*989*
Tonle Sap flood plain	9	*1,439*	5	*768*	2	*360*
Mekong Delta floodplain	26	*4,157*	14	*2,210*	7	*1,039*
Mekong river mouth	5	*800*	3	*427*	1	*200*
Ca Mau Peninsula	<1	*32*	<<1	*14*	~0	*8*
Offshore coastal shelf (<20km from the coast)	100	*15,990*	53	*8,533*	25	*3,998*

Impacts: Fine-sized sediment

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- **Delta stability:**
  - i. Greater instability and erosion of channels in the delta
  - ii. knock-on effects for irrigation works and inland water-way transport.
  - iii. In-channel islands & areas between channels, which are heavily populated and amongst the most fertile zones of the delta, are likely to experience greater erosion at the upstream end affecting communities and industries
  - iv. Increased coastal erosion and reduced delta-building along the eastern shoreline of the delta.
- **Loss of ~20,000t/yr of nutrient supply to:**
  - i. Cambodian & Vietnamese agriculture
  - ii. inland fisheries (including Tonle Sap)
  - iii. Delta coastal fishery (current production ~450,000t/yr)

Opportunities for avoidance

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Can we avoid the negative impacts the LMB mainstream dams will have on the hydro-sediment regime?

- *Both* opportunities *and* risks presented by the LMB mainstream projects arise from the concentration of energy dissipation to short reaches of the Mekong River at the turbines and gates of the proposed projects
- If energy is utilised in electricity generation it can not be used by the other hydro-ecological processes
- unavoidable trade-off for decision makers: **many of the knock-on impacts related to Mekong hydrology and sediment dynamics are unavoidable if the decision is taken to go ahead with the projects**
- Where opportunities for avoidance do exist, they would require reductions in electricity generation through alterations to the design, operations and management of the proposed projects

Opportunities for avoidance

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There are 3 types of potential avoidance activities:

1. **Excluding high impact projects:** Not all the projects have the same scale of impact on the hydro-sediment regime and the omission of some projects could avoid some impacts in localised areas of the basin
   - predicted reductions in the transport and arrival of medium and coarse-sized sediments to Zone 5 could be delayed by the order of decades if the Zone 3 and Zone 4 projects (Ban Koum, Latsua, Stung Treng, and Sambor) do not proceed
2. **Project operating strategies:** enforcement of continuous operating strategy for *all* mainstream projects would avoid rapid fluctuations in water surface levels (e.g. at the hourly, daily and weekly time-step).
   - This is most critical for projects with: (i) large communities downstream, and/or (ii) substantial downstream irrigation (Luang Prabang, Pak Lay, Pak Chom, Ban Koum, Lat Sua, Stung Treng, Kratie)

Opportunities for avoidance

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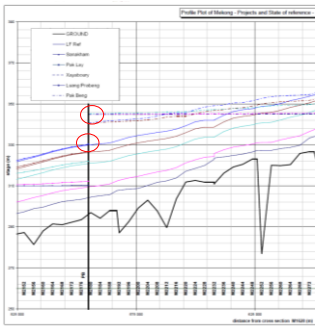
3. **Reduced operating water levels:** At present LMB mainstream projects maintain reservoir water levels 5-10m above the Q1000 level for significant stretches of the reservoir (10- 100km).
   - e.g. CNR Optimisation study has already reduced operating water levels & avoided: (i) transboundary disputes at Pak Beng, (ii) operator disputes within the Lao Cascade
   - redesign of some projects to reduce the water levels in the reservoir to remain below or comparable to a less extreme event (e.g. the Q20 flood event) would avoid the permanent inundation of some wetlands, floodplains and communities in Zone 2 and 3



Opportunities for enhancement

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Can we enhance the positive impacts the LMB mainstream dams will have on the hydro-sediment regime?

Benefits are focused on: (i) power generation & (ii) to a lesser extent irrigation.

- Enhancement opportunities are limited to these water users

1. **Enhancement of power production through peaking operations**
   - LMB mainstream projects could theoretically be brought on & off-line with very short ramping rates (order of minutes)
   - Profitability of the projects would increase substantially if electricity generation was timed to match peak demand times
2. **Enhancement of multipurpose water use through:**
   - Installation of new pumping infrastructure
   - Water licensing & allocation of quantities for irrigation and/or domestic use

- **Trade off** between power production and:
  - Multipurpose use
  - Avoiding/mitigating impacts on the natural system
  - If peaking operation is chosen then most negative impacts will be exacerbated and potential benefits for irrigation would be significantly reduced
- **The only feasible enhancement option which would improve the overall balance between opportunities and risks is development of reservoirs as multi-use projects**

Opportunities for mitigation

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Can we reduce the negative impacts the LMB mainstream dams will have on the hydro-sediment regime?

- Risks are focused on: (i) project impacts to the surrounding environment, and (ii) reduced performance/occurrence of unplanned events during project life

1. **Mitigation of temporal reductions in project performance:** Over time performance and efficiency of the proposed projects will reduce.
2. **Mitigation of impacts on the natural system and associated livelihoods,** based on the 4 strategic issues and their indicators

Opportunities for mitigation: project performance reservoir deposition

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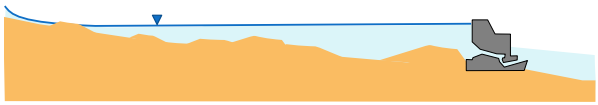
- **Impact:** Streampower reduction in the reservoirs causes deposition of sediment.
- **Mitigation:Sluicing** to remove sediment will be undertaken at the dams, but the effect of sluicing will influence only the reservoir bed within a short distance (100 to 200 m) upstream of the dams. The majority of the rest of the reservoir bottom will accumulate sediment.



Opportunities for mitigation: project performance permanent inundation

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- **Impact**: Permanent inundation of riverside areas associated with high water levels in reservoirs
- **Mitigation**:
  1. **Control project operating levels:** Re-design of projects so that proposed maximum reservoir levels are lower than high water levels that residents are accustomed to, e.g. <20 year return period flood levels. An energy generation penalty in the forecast electricity production will be a likely outcome.
     - This could even avoid some inundation impacts
  2. **Protect directly affected communities:** Local dykes with pumping facilities inside dykes to protect villages, tourist and cultural sites from inundation.
     - Clear arrangements for both responsibility and funding for maintaining and operating the dykes/pumps will be needed.

Opportunities for mitigation: project performance project operations

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- **Impact**: Hourly large changes in water surface level, associated with turbine operation to match peaks and troughs in daily loads

Mitigation:

- **Control mode of operation:** Projects to be operated in steady load mode, or in reduced peaking mode with only *minor* fluctuations from hour to hour. The magnitude of permissible fluctuations will need to be set and enforced by an independent authority
- Re-regulating dams?
  - Used to dampen dam-induced changes to hydrology (e.g. the Lancang cascade)
  - For LMB: Re-regulation dams are not suitable because of the very large daily water volumes involved in the mainstream projects.
  - Re-regulation dams would need to be in the order of half the reservoir length (~50+km) and would need to be placed downstream of a project or a cascade.
  - Re-regulation dams would multiply negative impacts from the dams
- Governments will have to regulate prior to project start-up, to ensure that satisfactory guidelines/rules are in place for operations, and then establish an independent technical authority which can enforce guidelines and monitor operations

Opportunities for mitigation: project performance
powerhouse, substation breakdowns & transmission line failures

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- **Impact**: Unexpected large changes in turbine flow, arising from unforeseen breakdowns in powerhouse plant, substations, or transmission facilities. Rapid load shedding causing water flow via turbines to cease, and rapid resumption of generation/flow.

- **Mitigation**: Early warning system for riverbank inhabitants, following shut downs and start-ups of powerhouse turbines. Governments will have to decide on guidelines for satisfactory rates of ramping, and on arrangements for early warning

Opportunities for mitigation:
flood & catastrophic releases

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- **Impact**: Flood releases and catastrophic damage to dam facilities, resulting from mechanical/electrical failure of spillway gate hoist mechanisms
- **Mitigation**:

1. Design of flood gate facilities with multiple back-up mechanical/electrical controls, to ensure operation of gates without fail when needed
2. Comprehensive dam safety reviews, undertaken regularly, by a team of independent international and local experts, with rapid follow-up on their recommendations
3. Early warning by rapid communications, betweendam operators in the proposed series of mainstream dams.
4. Early warning of problems to downstream riverside inhabitants

Opportunities for mitigation:
irrigation infrastructure

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- **Impact**: Irrigation pump station infrastructure rendered inoperable. Associated with:
  - a) very high water levels in the river associated with reservoir maximum operating levels and
  - b) changes to the deposition/scour areas for sediment

Mitigation:

- Pump station facilities to be raised to prevent inundation, or stations to be moved in the events of persistent siltation of intakes.
  - New infrastructure may be required, e.g. re-regulating ponds
- Pumps to be changed if needed, and replaced with pumps whose flow/head characteristics provide better matches to the water levels in the proposed reservoirs.
- Some floating pumps will need bank protection works or relocation to avoid being rendered inoperable

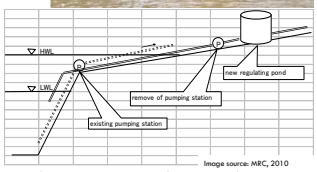

Image source: MRC, 2010

Opportunities for mitigation:
downstream erosion

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- **Impact**: Depletion of bed material deposits in reaches downstream of dams, with erosion of the banks and bed of the river

- **Mitigation**: Stabilisation of river banks and mid channel islands in localised areas by using bank protection such as rip-rap. Not feasible for erosion protection of extensive reaches, because of high cost for materials and construction.

Opportunities for mitigation: reservoir siltation

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Impact:

- Siltation (all sizes of sediment) at headwater reaches of reservoirs, associated with loss of energy in flowing waters.
- Difficulties with navigation, and instability of river channel

- **Mitigation:** Dredging and trucking of sediment deposits, particularly to ensure that a navigable channel is maintained

Opportunities for mitigation: loss of floodplain siltation & nutrient supply

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- **Impact:** Loss of annual silt deposition on the floodplain, resulting in loss of nutrients for soil fertility

Mitigation:

- enhanced fertiliser use, particularly in areas subject to large siltation rates, e.g. within about 1 km of the major channels
- ~25,000km2 in Cambodia & Vietnam

Opportunities for mitigation: Delta floodplain

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- **Impact:** Changes in extent of submerged Mekong delta, because of reduced sediment supply from the river.
  - Expected resulting loss of stability of banks of deltaic channels and main coastline.
  - Loss of fishpond and mangrove producing areas.

- **Mitigation:** Rip-rapping with or without dykes, but applicable in localised areas only because of high cost, and difficulty of maintenance.

Opportunities for mitigation: international conflict

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- **Impact:** River thalweg that presently defines international boundary will move in some locations. Loss of definition of river channel features with define international boundary line, e.g Thailand-Laos boundary.

- **Mitigation:** Negotiations if needed, to reach agreement and confirm latitude/longitude of break points in boundary line.

Opportunities for mitigation?

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- The majority of the impacts for the hydrological regime and Mekong sediment dynamics are un-mitigable
  - The Mekong River may be resilient enough to tolerate some of these, but
  - Most will fundamentally alter the movement or energy, flow and sediments along the Mekong
- **Decisions on whether or not to proceed with LMB mainstream projects should be made fully cognizant of the limitations of the potential for mitigation**

Unavoidable &unmitigable impacts: loss of sediment & nutrient supply to Tonle Sap

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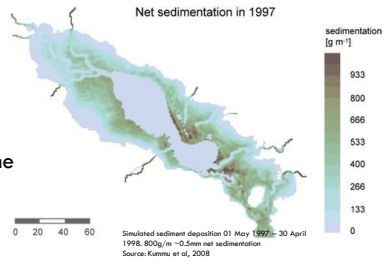
- **Impact:** Loss of annual silt/nutrient material entering and depositing in the Tonle Sap, with negative impacts on fisheries production and the flood forest
- **Mitigation:** None



Unavoidable &unmitigable impacts: loss of sediment & nutrient supply to coastal & estuary environments

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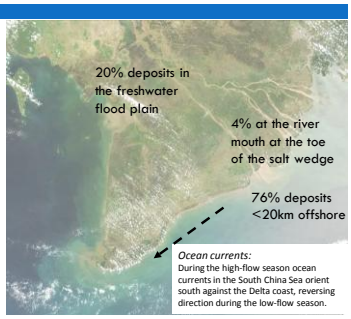
- **Impact:** Loss of 75% of silt/nutrients in the delta outflows and expected impact on estuarine and near-shore fishery
- Nutrients: ~16,000t/yr reduced to ~4,000t/yr
- **Mitigation:** None



Unavoidable &unmitigable impacts: deep pools

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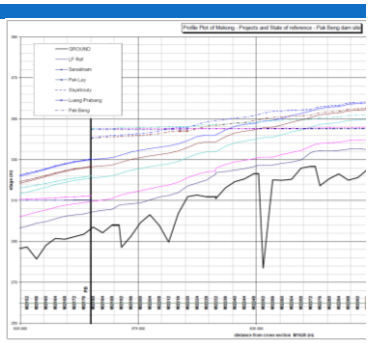
- **Impact:** Loss of deep pool river features in specific locations, particularly in sections of the proposed reservoirs
- **Mitigation:** None



Critical gaps in understanding

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- Hydrology is one of the best studied features of the Mekong
- Sediment is one of the least understood components
- Recommendations for further studies cover:
  - i. Field work and monitoring
  - ii. Data management
  - iii. Information sharing (within LMB national monitoring programs & with China)
  - iv. technical studies
- MRC is well positioned to coordinate many of these activities and is already setting up a sediment program under IKMP

Required further studies
Mainstream dam operations

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1. **Reservoir sedimentation dynamics & flushing effectiveness:** Deposition and erosion of sediment in example reservoirs
2. **Downstream implications of peaking & continuous operation & ramping rates:**operational strategies, ramping rates & size of downstream wave propagation
3. **Seasonal reservoir simulation:** timing of water release ahead of the flood arrival & effects on timing of the downstream hydrograph.
4. **Sensitivity analysis of annual energy generation to operating water levels:** to understand the sensitivity of annual energy generation totals (GWh per year) at each site, to lowering the operating levels of the reservoirs
5. **Thermal plume:** explore the downstream changes to water temperature which could be induced by the Yunnan cascade
6. **Mekong River Cumulative Trapping Efficiency rule curves for mainstream projects:** sensitivity analysis to assess the implications of different groupings of the 11 LMB mainstream projects: (i) Northern Lao cascade (Chiang Saen - Vientiane), (ii) Lao-Thai projects (Vientiane – Khone Falls), (iii) Cambodian floodplain projects (Cambodian floodplain projects)
7. **Emergency management:** Time and motion study to simulate the operation of turbines and spillway gates following a breakdown of the electrical system, e.g. the transmission line or the transformers. Analysis of the speed of load shedding, and the ability of the spillway gates to open sufficiently quickly to keep reservoir levels at or below the design full pool level. Analysis of the resulting scenarios, and the propagation of a change of flow wave downstream, resulting from the breakdown
8. **UMB daily water level harmonics:** historic observed water levels before and after Manwan dam to statistically explore the fluctuations in water levels at daily and hourly time steps.

Required further studies
hydro-sediment regime

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9. **Marine sediment plume:** (i) map the changes to the extent and movement of the marine plume, and (ii) detailed hydrodynamic modelling of ocean processes with a focus on bio-geochemistry of fresh-saltwater interactions and sediment transport.
10. **Coastal erosion:** quantify the sites and rate of erosion in the context of the reduced sediment load predicted by the array of dams proposed for Lancang/Mekong and the Central Highlands.
11. **Groundwater recharge/connectivity**address the changes to groundwater connectivity in the Cambodian floodplains and the Mekong Delta with a focus on: (i) changes to the seasonal water table, (ii) impacts on arsenic levels, (ii) potential salinisation of groundwater through the elevation of the water table
12. **Morphological changes:** bed and bank erosion, lateral migration of the channel and changes to connectivity between the floodplains and the main stem. In the bed rock and confined reaches, the focus would be on sand bars and deep pools, as well as the fate and transport of bed load and non-cohesive sediments.
13. **Tonle Sap system:** explore the changes to the seasonal flooded area of the Tonle Sap (and implications for flooded forest), the change in the hydraulic gradient driving reversal in the Tonle Sap as well as revise the sediment balance for the system under a the 20Y scenario with reduced inputs.
14. **Consolidation of sediment data:** Resolution of why there is an apparent drop-out of the suspended sediment load at Nong Kai.

Required further studies
hydro-sediment regime

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15. **Profiling of the sediment grain size distribution:** (i) a comprehensive and ongoing monitoring program of suspended sediments, and (ii) for bed load, assessment should prioritise bed composition, size distribution of sediment and bed load transport, in the mainstream particularly in the Zone 3 reach, and in major tributaries. (iii) In addition, improved definition of time scale for projects causing serious bed erosion problems near Vientiane.
16. **Role of cohesive sediments:** (i) characterise the presence of cohesive sediments in all zones of the Mekong, (ii) assess their eco-morphological importance for processes of siltation, fertilisation, nutrient transport and aquatic productivity **Floodplain deposition:** The cumulative impacts of mainstream projects on floodplain deposition based on 3D hydrodynamic modeling of the floodplain with reduced sediment loads.
17. **Dynamics of fish migration:** Analysis of capability of migratory fish species to move upstream against an opposing river current, including the burst speed that fish are capable of sustaining. Design and hydraulic testing of a scale model fish ladder suitable for Mekong migratory fish, installation of a full scale fish ladder at a test site (e.g. at a dam somewhere on the lower Mekong tributary system), and observations to see the effectiveness of the ladder, and its limitations.
18. **Fate and transport of nutrients:** extend existing IKMP basin-scale sediment modeling undertaken to quantify the impacts on primary production and explore the longitudinal connectivity of the production cycle from the headwaters to the river mouth. With focus on: (i) floodplains, (ii) off shore delta, (iii) nutrient loading from major city sewage outfalls

Recommended institutional arrangements

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Establishment of a River Authority to take responsibility for the satisfactory design and operation of the hydro electric facilities, and of navigation and fisheries issues

Potential for increasing the mandate of the MRC

- Experience can be drawn from organizations such as Central African Power Corporation (operating the Kariba project, Zambia/Zimbabwe) and from the background and contents of the Columbia River Treaty.
- The Authority must:
  - be independent (politically & financially),
  - Have a mandate for enforcement
  - Strong engineering capacity
- A formula for assigning a mil rate to the electrical energy production at the proposed projects would provide part of the annual funding, and this would be paid annually to the River Authority for supporting its work

Recommended institutional arrangements

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- **Design guidance:** ensuring uniformity of design, with particular reference to dam safety and safe operating procedures. Assuring uniformity of guidelines for construction, construction management, and work/environmental safety during construction.
- **Coordination of dam operations:** ensuring good communications between completed projects, to coordinate electricity supply to national grids, and in the way that water is released from one project to the next one downstream
- **Emergency management protocols:** organizing water releases that are coordinated between projects in emergency situations, e.g. resulting from major floods or from equipment failure/breakdowns
- **Navigation:** ensuring that navigation is coordinated, to facilitate the best possible transit times through each of the dams, with the arrival of boats from upstream or downstream, and the coordination of dredging of the navigation channel to ensure minimal disturbance to boat traffic.
- **Stakeholder notification and consultation:** provide effective communication of dam operation activities and events to directly affected communities and ongoing consultation with these communities in relation to livelihood implications of dam operations
- **Coordinated reservoir flushing & maintenance schedule:** Co-ordinate reservoir flushing activities so that downstream residents are minimally disturbed, and to fit in with navigation channel dredging activities.

Recommended institutional arrangements

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- **Dam safety reviews & enforcement:** Ensuring that comprehensive dam safety reviews are carried out in a sufficiently thorough way, and at sufficient repeat periods to ensure that the very best advice is provided to the dam owners in a timely way. Ensure that the advice given to the dam owners is acted upon.
- **Independent turbine efficiency testing:** Providing a standardised service for turbine efficiency testing, to assess periodically whether the power delivered for given water flows measures up to the manufacturers specified efficiency. This will be important, as the turbines will be operating in a highly abrasive environment (large ingestion of sand load), and rapid deterioration of efficiency should be anticipated.
- **Standardised water licensing & enforcement:** Developing a standardized structure for water licenses/agreements, specifying the limits of storage (full pool level, flood level, volume stored), the maximum diversion flow amounts through the turbines, the required fisheries/environmental flow diversion (in m3/s), and navigation requirements, if applicable.
- **Independent control & enforcement of environmental flows:** Providing an independent assessment of the magnitude of the environmental and fisheries flow releases, checked from time to time to ensure that the flows are no smaller than the values agreed to when the government(s) issued the storage and diversion flow license.
- **Turbine control guidelines:** Providing guidelines for ramping rates for the turbines and the spillway gates at each of the projects, computed to provide sufficiency slow rates of change of the water surface at key downstream locations. Making sure that there is future compliance with these guideline values
- **Ongoing hydrological monitoring:** Providing funding and technical input to MRCS to recalibrate, relocate and rebuild gauging stations that were seriously impacted by the proposed projects, either by inundation, or by very significant deposition or erosion of bed material/bed level

Conclusions

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- There is a trade-off between the benefits of extracting energy from the Mekong for electricity production & the impacts of this reduced stream power for the natural system
- Few of the negative impacts can be avoided and only some can be mitigated
- For the hydro-sediment regime: the only reasonable enhancement option is for multi-purpose use of the reservoirs
- Good existing foundation of scientific understanding – especially for hydrology, but a significant amount of study is needed to fully understand the implications of mainstream hydropower development
- A River basin authority is needed for the whole basin with the mandate to design and enforce management of reservoir operations