Mekong River Commission
For Sustainable Development

THE MRC HYDROPOWER MITIGATION GUIDELINES

Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries

MRC TECHNICAL GUIDELINE SERIES
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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
BDP	Basin Development Plan
BP	Bank Procedure (World Bank)
CA	Concession Agreement
CIA	Cumulative Impact Assessment
CDP	Community Development Plan
ECAFE	United Nations Economic Commission for Asia
EMP	Environment Management Plan
ESMP	Environmental and Social Management Plan
ESIA	Environmental and Social Impact Assessment
IBRD	International Bank for Reconstruction and Development
IFC	International Finance Corporation
IHA	International Hydropower Association
ISH	Initiative on Sustainable Hydropower
IWRM	Integrated Water Resources Management
LMB	Lower Mekong Basin
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
MW	Megawatt
OD	Operational Directives
PDG	Preliminary Design Guidance
PES	Payment of Ecosystem Services
PNPCA	Procedures for Notification, Prior Consultation and Notification
PPA	Power Purchase Agreement
RAP	Resettlement Action Plan
SEA	Strategic Environmental Assessment
ToR	Terms of References
UMB	Upper Mekong Basin
WB	World Bank
WCD	World Commission of Dams

1. Introduction

Intensive hydropower development in the Mekong Basin has highlighted the substantial economic benefits of hydropower development for member countries towards their economic development goals. However, there are particular trade-offs with other sectors across economic, environmental and social spheres as highlighted in the MRC's recent Cumulative Impact Assessment (The Council Study). Basin scale and system scale planning is critical, and it's urgent to optimise across the energy and water sectors for efficient and sustainable development. These guidelines are aimed at providing mitigation guidance for planning, design and operation of hydropower facilities, focused on long term sustainability in the Mekong Basin, to support basin scale planning and management as well as immediate project development requirements.

This Guideline document gives an overview of the Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries (MRC Hydropower Mitigation Guidelines) developed by the MRC between 2015 and 2018.

The MRC Hydropower Mitigation Guidelines provide a clear process and detailed technical guidance to address a range of known risks and impacts in all phases of the Project Development Lifecycle.

The MRC Hydropower Mitigation Guidelines support the MRC's Preliminary Design Guidance (PDG, 2009), which may be used by developers during project preparation and then by the MRC to assess projects through its Procedure for Notification, Prior Consultation and Agreement (PNPCA). The guidelines detail the application of regional and global "good industry practice" for mitigation of hydropower impacts in the Mekong context and shall provide even better strategic and technical guidance as a supporting documents to the updated PDG in 2018.

1.1 Project Objectives, Thematic and Geographic Scope

The overall goal of the MRC Hydropower Mitigation Guidelines study is embedded in the Mekong Vision of an economically prosperous, socially just and environmentally sound Mekong River Basin. Overall the objective was:

"Development of relevant measures and guidelines for hydropower impact mitigation and risk management in the Lower Mekong mainstream and tributaries"

The specific objectives of the study has been to:

- Thoroughly document regionally relevant hydropower impact avoidance, minimisation and mitigation options for development of hydropower on the Mekong mainstream and tributaries;
- Scope and commission specific research to improve technical and scientific understanding towards improved mitigation options and the adaptation of existing methods to the region; and
- Document in consultation with regional agencies and developers engineering and scientific options, for the avoidance, minimization and mitigation of risks of mainstream hydropower dams.

The study's thematic scope was to:

- Understand the baseline natural resource processes in the Mekong Basin and the nature of hydro developments proposed;

- Describe the potential impacts of these developments as assessed by existing studies;
- Research regional and global experience on mitigation options for these Mekong hydropower developments;
- Undertake analysis and research into the effectiveness of these mitigation options;
- Make recommendations on improvements and approaches to impact mitigation;
- Commission further research to cover significant knowledge gaps;
- Provide mitigation guidelines and a substantial knowledge base on mitigation approach and solutions based on research and case studies. These will be made suitable for dissemination through the MRC web site or other media; and
- Build capacity in all areas of assessment avoidance, minimization and mitigation options within industry and line agencies.

The geographic scope has been twofold:

- The mitigation guidelines and recommendations has been developed to be generally applicable at basin level for the Lower Mekong mainstream and its tributaries.
- A more detailed assessment has been undertaken related to the applicability and operational implications of the mitigation guidelines for 5 mainstream cascade dams north of Vientiane (2nd Interim Phase) and all mainstream dams in the Final Phase.

The main output of the study is this Guidelines that builds especially on the principles of the 1995 Mekong Agreement (MA95), the related Procedures and MRC's Preliminary Design Guidance (PDG). The Guidelines also reference other important MRC initiatives especially the Council Study. The Guidelines and its supporting Manual include mitigation options and recommendations on hydrology and flows, geomorphology and sedimentation, water quality, fisheries and aquatic ecology, environmental flows, biodiversity and natural resources, ecosystem services as well as engineering response to environmental risks, impacts and vulnerabilities.

1.2 Risks and Impacts - Overview

The hydropower risks, impacts and vulnerabilities that are dealt with in the MRC Hydropower Mitigation Guidelines have been extensively researched in a number of Mekong Studies, most recently the MRC's Council Study and The Hydropower Mitigation Guidelines study itself. The latter therefore seek to address five major themes, namely:

1. River hydrology and downstream flows
2. Geomorphology and sediments
3. Water quality
4. Fisheries and aquatic ecology; and
5. Biodiversity, natural resources and ecosystem services

The MRC Hydropower Mitigation Guidelines address these thematic areas using a set of five key common overarching changes related to hydropower development:

I. Annual / inter-annual changes to flow (e.g. as a result of large storages in the basin)

II. Daily / short-time scale changes to flow and water level (e.g. due to hydro peaking)

III. Loss of river connectivity (e.g. due to high dams)

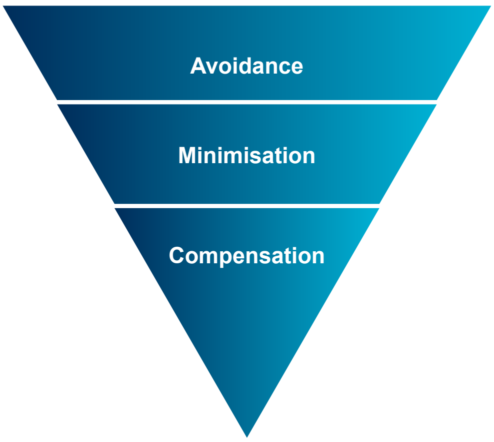
IV. Impoundments and pondages (i.e. converting rivers into lakes)

V. River Diversions and intra basin transfers (that may leave some reaches of the river dry)

Major basin studies over the past 10 years have identified and quantified the above impacts in some detail. The economic, social and environmental consequences of changes to these themes may lead to unsustainable and sub-optimal outcomes for communities within the basin. Difficult trade-offs must therefore be managed and the MRC Hydropower Mitigation Guidelines provide member countries and developers with good industry practice solutions to mitigate and minimise these risks as set out in Article 7 of the MA95, including the use of the Mitigation Hierarchy.

1.3 Mitigation Hierarchy

The commonly used "Mitigation Hierarchy" is employed in The Guidelines to prioritise the approach that is recommended in each step of the project lifecycle.



1. Impacts are firstly avoided through proper master planning, and siting and design of the hydropower projects.
2. If it is not possible to avoid these impacts then mitigation and minimisation approaches should be adopted. These mitigation and minimisation technologies are described in detail in these guidelines.
3. Lastly, the mitigation hierarchy recommends that, if impacts cannot be mitigated, then compensation of various forms should be considered. These compensation approaches may include options to "offset" the impact's; for example by providing alternative fish spawning habitats, or by leaving certain river reaches free of development to allow for fish migration. Benefit sharing options may also be considered, by use of enhancement measures and mechanisms.

1.4 Impact Mitigation across the Project Development Lifecycle

The mitigation hierarchy, when overlayed into the different steps in the project development lifecycle, portrays various grades of importance.

During master planning, siting and alternative design of hydropower projects it is important to consider ways to avoid the impacts in the first place. This may include alternative locations for projects, alternative project design scales (e.g., lower dams) and/or alternative energy sources.

Once projects are approved to go to the feasibility stage, avoidance of impacts remains a priority and mitigation and minimisation options become more relevant. At the feasibility stage of projects it is also critical to optimise the design for maximum economic efficiency together with concurrent minimisation of environmental and social impacts.

The full and detailed environmental and social impact assessment (ESIA) may indicate that certain impacts are not able to be mitigated. In which case, during the project design and operations phase, compensation measures must be considered.

The operational phase of a project may last 50 years or more. It is therefore important that ongoing monitoring of the effectiveness of mitigation measures is put in place. If agreed performance targets are not being met, adaptive management and revised operating rules may be devised to further mitigate the impacts.

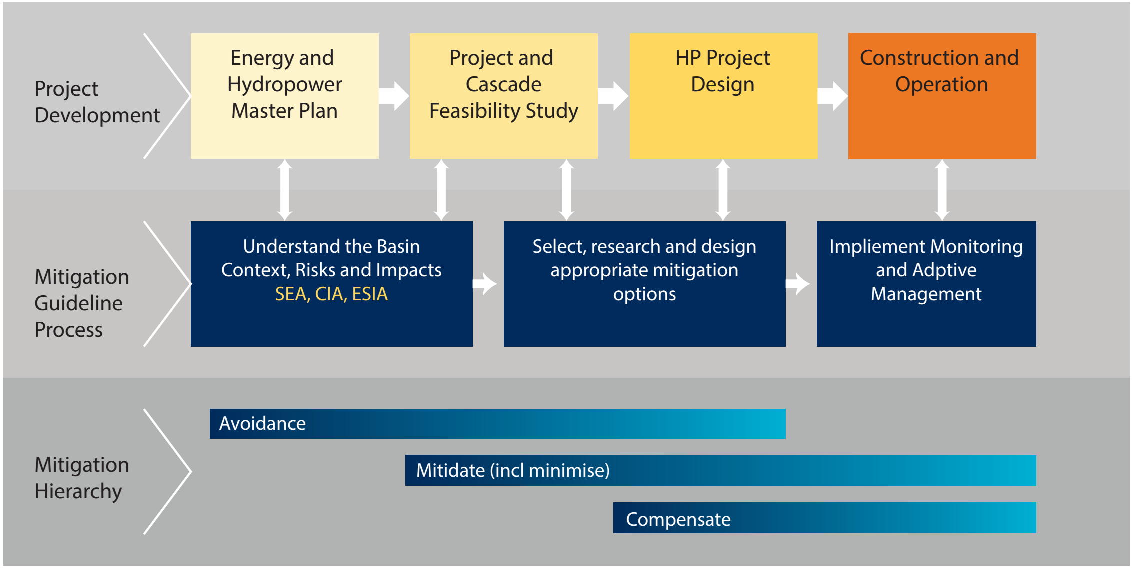


Figure 1.1: MRC Generic Practical Process for Risk and Impact Mitigation - Project Life Cycle.

2. Overall Guidelines Architecture

The MRC Hydropower Mitigation Guidelines are intended to support the overall MRC policy framework. Therefore, the Mekong Agreement of 1995 provides the overarching principles, procedures and governance structure for these major developments in the basin. The MRC's Preliminary Design Guidance of 2009, which is to be updated in 2018, is a key document used during the assessment of mainstream hydropower projects under the PNPCA. The MRC Hydropower Mitigation Guidelines provide a detailed technical support resource for users of the Preliminary Design Guidance and its subsequent update. The overall architecture is given in the figure below.

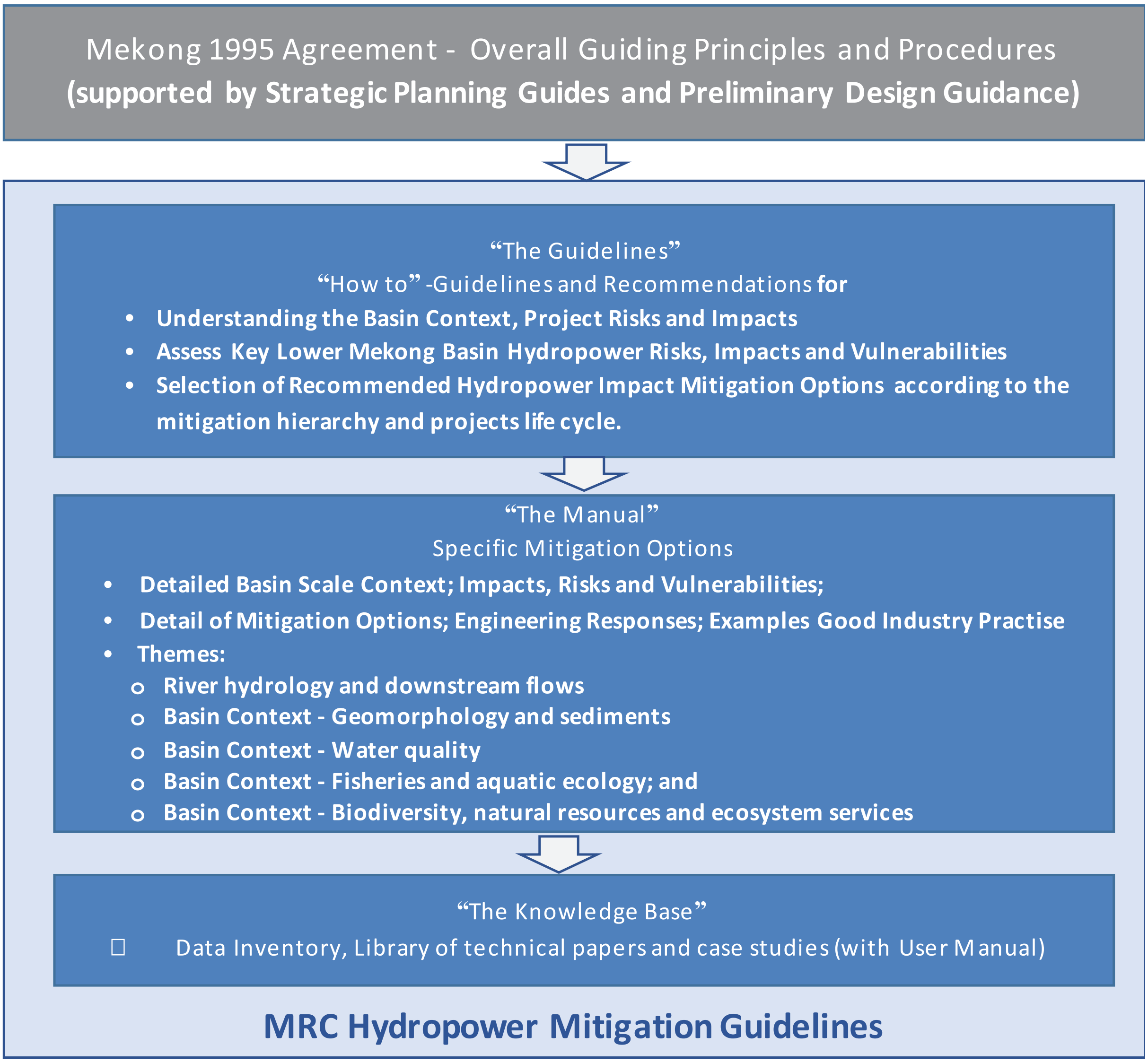


Figure 2.1: Overall Hydropower Mitigation Guidelines Architecture.

The MRC Hydropower Mitigation Guidelines consist of three technical volumes and one Case Study report:

- The Guidelines (this document) provide the method and process to assessing risks and considering appropriate mitigation options.
- The Manual is referenced in the Guidelines and describes risks, impacts and vulnerabilities

as well as specific mitigation options in more detail. The Manual also provides examples of good industry practise mitigation options sourced from international practice, from the Greater Mekong Sub-Region (GMS) and the Lower Mekong Basin (LMB).

- A Knowledge Base supports the Guidelines and Manual with a document inventory and an online library of relevant studies and technical papers.
- The Case Study Report: Promising mitigation options, described in The Guidelines and The Manual, have been applied to the cascade of five mainstream hydropower dams, upstream of Vientiane, Lao PDR. The effectiveness and economics of these mitigation options have then been modelled and analysed in detail. In association with the MRC's Council Study, mitigation on the remainder of the mainstream and some tributary dams have also been assessed. Conceptual level alternative schemes layouts have been proposed for mainstream and tributary dams. Research requirements have been scoped for further technical assessment of environmental risks and mitigation effectiveness.

All documents are available online at http://www.mrcmekong.org/about-mrc/completion-of-strategic-cycle-2011-2015/initiative-on-sustainable-hydropower/guidelines-for-hydropower-environmental-impact-mitigation-and-risk-management-in-the-lower-mekong-mainstream-and-tributaries-ish0306/

3. How to use the Guidelines, Manual and supporting Knowledge Base

The MRC Hydropower Mitigation Guidelines provide a systematic approach for a MRC member country interested in hydropower development, or a hydropower project proponent, once they have analysed their development risks and impacts, to design Mekong appropriate mitigation measures to cater for these impacts.

As portrayed in Chapter 1.4, the process recommended follows the steps shown in the figure below.

Figure 3.1: The Hydropower Mitigation Guideline Process.

The user may go to the following sections of the Guidelines to support the above process:

- Understand the Basin Context, Risk and Impacts
  a. Overall guiding principles (MA95, PDG etc.) and general principles for sustainable hydropower development (Section 6.1 – 6.3)
  b. Basin hydro-ecological zones (Section 4.4)
  c. Basin Context - River hydrology and downstream flows (Section 5, Table 5.1)
  d. Basin Context - Geomorphology and sediments (Section 5, Table 5.2)
  e. Basin Context - Water quality (Section 5, Table 5.3)
  f. Basin Context - Fisheries and aquatic ecology (Section 5, Table 5.4); and
  g. Basin Context - Biodiversity, natural resources and ecosystem services (Section 5, Table 5.5)

- Selection, Research and Design of mitigation options for the LMB (Section 6.4, Tables 6.1 - 6.5)
  a. Selection of Mitigation based on project life cycle and common overarching changes described in Section 5
  b. Details of Mitigation Options - River hydrology and downstream flows
  c. Details of Mitigation Options - Geomorphology and sediments
  d. Details of Mitigation Options - Water quality
  e. Details of Mitigation Options - Fisheries and aquatic ecology; and
  f. Details of Mitigation Options - Biodiversity, natural resources and ecosystem services
  g. Engineering responses to environmental risks and Dam Safety

Multi-Criteria Assessment, Indicator Framework and Monitoring (Section 7)

The mitigation guidelines, recommendations and options for the LMB builds also on the risks, impacts and vulnerabilities as described in The Manual, where these are treated more in detail, including examples of good industrial practise. Since many of the mitigation options, in The Guidelines, are integral across the above themes, they are organized according to the overarching changes related to hydropower as described above, in order to avoid repetition (see Tables 6.1 to 6.5 in Section 6.4).

4. Understanding the Mekong Context and Background

4.1 Overall Basin Development Context

The Mekong Basin is home to some 70 million people, from which this great river is a source of livelihoods, the basis of their ecosystems and a foundation for their economies (Matthews and Geheb, 2015). With its extensive wetlands and floodplains, the basin supports the largest inland fisheries in the world with an annual catch of 2.6 million tonnes and over 500 000 tonnes of other aquatic animals valued at between USD 3.9 – 7 million (Hortle, 2007).

MRC's "IWRM Strategic Directions" (2005)

Eight priority IWRM key result areas:

- Economic development & poverty alleviation
- Environmental protection
- Social development and equity
- Information based planning and management
- Reginal cooperation
- Governamce
- Intergration through basin planning

The Mekong is one of the world's largest rivers ranking 12th in terms of length at 4880 km (Gupta and Liew, 2007) and 8th in terms of mean annual discharge at the mouth, which is about 14 500 m^3/s (Meade, 1996; MRC, 2005). It has a catchment area of 795 000 km^2 within the six countries of China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam. The Mekong Basin has commonly been divided into Upper Mekong Basin (UMB-Lancang Jiang) and the Lower Mekong Basin (LMB). The UMB, in China, constitutes 24% of the total basin area whilst LMB the rest (MRC-Planning Atlas, 2011).

The UMB contributes to approximately 16% of the total flow in an average year, while 55% comes from the left bank tributaries in Lao PDR along with the Se Kong, Se San and Sre Pok (3S) River systems (Vietnam Central Highlands, Lao PDR and Cambodia). However, during the dry season, snowmelt from China leads to a contribution of 24.1 % of the total flows from the UMB (MRC, 2010; Pech, 2013).

Compared to other regions in the world, in terms of actual renewable water resources per capita, the Mekong basin is not water stressed. However, a number of locations currently faces a series of critical water issues, such as (MRC, 2010; Pech, 2013):

- Water shortages in Thailand coupled with increasing irrigation water demands
- Increasing salinity intrusion in the Mekong delta in Vietnam
- Threats and declines in basin fisheries and the degradation of natural habitats in many parts of the basin
- Recurring un-seasonal floods and droughts
- Reduced water quality, land-subsistence and morphological changes in the floodplains and delta areas; and
- Intensification of sectoral competition within and amongst the Mekong countries

Concurrently, hydropower dams development is happening on Mekong mainstream and tributaries and will intensify in the near future (see for example Winemiller et al., 2016). The critical water issues and hydropower dam developments cater for increased cooperation on the Mekong and its resources as well as joint basin scale planning. The overall context for hydropower development on the Mekong is described in Section 4.2, whilst a brief description of national initiatives with regard to the hydropower development on the Mekong is described in Section 4.3.

4.2 Overall Context for Hydropower Development on the Mekong

Situated within the water, food (fisheries, agriculture e.g.) and energy nexus hydropower can help meet the realities of climate change[1], and as a renewable energy it also contributes directly to a low carbon energy future. Hydropower's flexibility also supports the deployment of intermittent renewable energy sources such as wind and solar power. Multipurpose hydropower schemes can also support adaption to an increasingly difficult water resources situation by providing the means to regulate and store water to resist flood and drought shocks (WB, 2009). Thus, climate adaption and resilience in the Lower Mekong is essential for a safe, prosperous and sustainable future. Dealing with climate variability is also one of 8 priority areas in Mekong River Commission's (MRC) own "Integrated Water Resource Management Strategic Directions" (MRC, 2013).

Hydropower is recognized as an important development opportunity for the Mekong River Basin and the people living within it. As set out in the Mekong River Commission's Strategic Plan (2011 to 2015) and the Basin Development Plan (BDP, approved January 2011), the development of LMB should follow Integrated Water Resource Management (IWRM) principles. Within the IWRM context the need to improve the sustainability of the basin's hydropower developments is a key Strategic Priority. With the significantly increasing scale and prevalence of this energy option, all MRC member countries are taking steps to understand and employ sustainable hydropower considerations. The MRC Strategic Plan as well as the BDP has now been updated for the period 2016-2020 (MRC, 2016a and b). The new MRC Strategic Plan also includes a detailed roadmap for organisational reform of MRC and its functions currently under implementation.

Thus, for the LMB sustainable hydropower development incorporating Good Industrial Practise for environmental impact mitigation and risk management is of critical importance for the future. Further details on the scope and scale of hydropower proposed for the Mekong and Lancang basins is described in Annex 1.

As there is multiple cascade developments planned or in operation in the LMB, with resulting cumulative impacts, developing risks and mitigation guidelines and recommendations for these will be of high importance, including those of joint operation and flow releases, as this is currently lacking. Cumulative impacts will furthermore also be a combined result from incremental changes caused by other past, present or reasonably foreseeable actions together with the hydropower projects development (Walker et al. 1999).

1 E.g. changes in temperature, precipitation and runoff.

Figure 4.1: Overview over the Mekong and the LMB Study Area (Source: MRC, 2013 – ISH11).

4.3 National Initiatives

The planned hydropower schemes on the LMB mainstream and tributaries are subject to national EIA procedures and decisions. All the LMB countries have developed regulations for EIAs at project level and partly also for SEAs and CIAs. For example, the SEA is required by law in Vietnam (Keskinen & Kummu, 2010; Ke & Gao 2013). Additionally, Cambodia is drafting a new EIA law, the latest version of which also takes into account transboundary impacts (Ke & Gao 2013). Lao PDR, supported by the WB, has drafted its own Policy Guidelines for Implementation of Sustainable Hydropower Development in the country (MEM, 2015). The policy embarks primarily on sustainable planning principles from feasibility level and onwards in the project life cycle. However, embedded in the policy are some principles of Water Resource/Watershed Management and Conservation, including issues related to the mitigation hierarchy discussed in Section 1.3, i.e;

"Natural conserved habitat area losses due to hydropower development projects shall be avoided and mitigated as much as possible. Where avoidance is not possible, it must be compensated and restored by the project developers as well as provide funding to help manage and effectively conserve the watershed area as well as nearby watersheds and other important conservation areas. Must also develop a sustainable biodiversity management plan, consider compensation or help mitigate the impact on the local natural resources base"

As well as for those of revenue and benefit sharing, in accordance with international principles outlined in Annex 2;

"Project developer shall pay taxes, royalties and fees that is set-out in the regulations, laws and project specific agreements/contracts, as well as paying in cash or share benefits with the local communities through Community Funds for environmental protection and other Funds for watershed protection and development of basic socio-economic infrastructure within the project areas".

4.4 Overview of Mekong Hydro-ecological zones

How hydropower development in the Mekong mainstream or tributaries will affect the hydrology, ecology and geomorphology of the rivers will vary depending on the attributes of the area, and the operations of the hydropower schemes. The Lower Mekong has therefor been divided into Hydro-ecological zones, that are described more in detail in the Manual, Chapter 3.3, but given a brief overview here.

4.4.1 Zone 1 – Chiang Saen to upstream Vientiane

The characteristics of the Mekong in this zone include steep slope, a single channel, strong bed-rock control, with bedload consisting of a high proportion of gravels. The reach has recently experienced a large decrease in sediment supply and alterations to water levels due to development of the Lancang Cascade, and geomorphic changes are already occurring within the reach. The commissioning of the Xayabouri HP and tributary dams in the near future will further alter flows and sediment transport through the reach. Recent observations suggest that geomorphic changes associated with changes to water level in the dry season are already occurring, with the loss of vegetation, and erosion of banks.

4.4.2 Zone 2 – Upstream Vientiane to Kong Chiam

This zone that extends from upstream of Vientiane to Kong Chiam is characterized by lower slopes as compared to the upstream zone, and long alluvial reaches bordered by floodplains of varying width. Within the zone there is a large increase in flow and sediment load in the river owing to the inflow of the ‘left bank’ tributaries from Lao PDR, which have some of the highest runoff rates in the catchment. Several of these tributaries have already been developed for hydropower (Nam Theun, Nam Hinboun), and many other HP projects are under development. This zone is already experiencing flow changes associated with the Lancang Cascade and tributary developments. There are no mainstream dams planned here, but in the future the flow and sediment regime will continue to be modified due to the establishment of the cascade in upper Lao PDR, and the continued development of hydro-resources within the tributaries.

4.4.3 Zone 3 – Kong Chiam to Kratie

The zone encompassing Kong Chiam to Kratie is highly variable, and includes alluvial and bedrock controlled channel reaches. Slope within the zone varies, and is locally steep in the bedrock sections. The zone is also characterized by the inflow of the 3S River system (Sre Pok, Se San, Se Kong) which contributes a large percentage of water and sediment to the system. Floodplains are generally concentrated in the upper and lower reaches of the zone, with high flow accommodated within the broad, multi-channeled reach in the mid-zone.

4.4.4 Zone 4 – Kratie to Chaktomuk and Tonle Sap

The zone extending from Kratie to the Chaktomuk confluence, and the Tonle Sap River and Great Lake is characterized by alluvial reaches flowing through extensive floodplain deposits. The reach has low river slopes, and thick lateritic flood plains. The timing and magnitude of flow and sediment moving into and out of the Tonle Sap River and into the Great Lake are strongly influenced by water level in the Mekong mainstream, and the system provides water and sediment ‘buffering’ to the downstream delta.

4.4.5 Zone 5 – Delta

From the Chaktomuk confluence to the sea, the Mekong is characterized as a broad, flat alluvial delta system. The zone has a very low slope, and flow and sediment movement is affected by tidal influences. Flow and sediment dispersion in the delta has been modified through the development of an extensive canal system and other water management infrastructure.

5. Assess Key Lower Mekong Basin Hydropower Risks, Impacts and Vulnerabilities

This chapter summarizes the Key LMB Hydropower Risks, Impacts and Vulnerabilities related to the hydropower development proposed for the Mekong. It is treated in more detail in the Manual (), for each thematic area (hydrology and downstream flows, geomorphology and sediments etc.). Most of the key risks, impacts and vulnerabilities are also repeated in the tables in Chapter 6, the Hydropower Risk and Impact Mitigation Guidelines and Recommendations, with its associated mitigation options. For all the thematic areas below, a set of 5 key common potential overarching changes related to hydropower development has been identified, which are[2];

1. Annual / inter-annual changes to flow
2. Daily / short-time scale changes to flow and water level
3. Loss of river connectivity
4. Impoundments
5. Diversion or intra basin transfers

Within these major changes a set of sub-changes (left column) for each thematic area has also been identified. The identified risks, impacts and vulnerabilities are associated with these changes, and can be both cumulative and site specific.

Table 5.1: Hydrology and downstream flows – Key risks, impacts and vulnerabilities (see Chapter 2 in for details).

Change	Key Risks, Impacts & Vulnerabilities
Annual / inter-annual changes to flow	
Changes in seasonality & continuous uniform release	Change of timing & duration of floods and low flows, changes in flows Tonle Sap and changes in salt intrusion in the delta
Modification of flood intervals: Reduction in occurrence of minor floods & no change in large events	Peaks in flood and low flow change, smoother hydrograph
Daily / short-time period changes in flow	
Hydro-peaking	Safety and navigation related changes caused by sudden rise or drop of water levels

2 Some of these with its associated mitigation measures has also been studied in the Case Study (MRC, 2018)

Table 5.2: Geomorphology & sediments – Key risks, impacts and vulnerabilities (see Chapter 3 in for details).

Change	Key Risks, Impacts & Vulnerabilities
Annual / inter-annual changes to flow	
Changes in seasonality & continuous uniform release	Water logging & loss of vegetation leading to increased bank erosion Increased erosion due to increased scour (bed incision, bank erosion)
	Winnowing of smaller sediment leading to bed armouring & reduction in downstream sediment supply
	Bank scour focussed over limited range leading to increased bank erosion
Modification of flood intervals: Reduction in occurrence of minor floods & no change in large events	Channel narrowing through encroachment of vegetation Increased risk in upstream of flooding and floodplain stripping during large (>1:10 ARI) flood events
Change in relationship of flow & sediment transport	Decoupling of tributary & mainstream flows Erosion and / or deposition at tributary junctions due to tributary rejuvenation
Daily / short-time period changes in flow	
Hydro-peaking	Rapid water level fluctuations and wetting & drying of banks increases susceptibility to bank erosion and seepage erosion (piping) processes
	Increase in shear stress during flow changes increases erosion and bed incision
Loss of river connectivity	
Disconnect between flow and sediment delivery	Sediment availability not timed with periods of recession leading to decreased deposition and increased erosion
	Loss of seasonal sediment 'pulse'
Creation of impoundments	
Trapping of sediments	Reduction in sediment availability downstream of dam leading to increased erosion
	Changes to the grain-size distribution of sediment downstream contributing to channel armouring and alteration of habitat distribution and quality

Change	Key Risks, Impacts & Vulnerabilities
Water level changes within impoundment	Lake bank erosion, increased risk of landslips
Diversions or intra basin transfers	
Decreased flow in donor basin	Channel narrowing due to vegetation encroachment
	Armouring of beds and bars due to reduced sediment transport
	Decrease in frequency of high flow events increases impacts of extreme events (upstream flooding, floodplain stripping)
Increased flow in receiving basin	Increased bank erosion and bed incision to accommodate increased flow

Table 5.3: Water Quality – Key risks, impacts and vulnerabilities (see Chapter 4 in for details).

Change	Key Risks, Impacts & Vulnerabilities
Annual / inter-annual changes to flow	
Changes in seasonality & continuous uniform release	Changes / loss of seasonal temperature patterns downstream
Change in relationship between flow and sediment delivery	Increased water clarity increasing risk of algal growth Increased water clarity increasing water temperature Changes to magnitude and timing of nutrient delivery downstream
Daily / short-term changes in flow	
Hydro-peaking or fluctuating discharge	Fluctuating water quality including increase in variability of temperature and nutrients
	Altered concentrations of downstream discharges
Loss of river connectivity	
Changes to nutrient transfer	Trapping of nutrients within impoundment leading to change in downstream delivery
Creation of impoundments	
Conversion of river to lake	Lake stratification leading to low dissolved oxygen bearing water and release of nutrients, metals or pollutants from sediments
	Increased water clarity in lake increases risk of algal blooms

Change	Key Risks, Impacts & Vulnerabilities
	Temperature change in lake (warmer or cooler)
	DO and temperature of discharge affected by impoundment – Low DO or high gas supersaturation
Diversions or intra basin transfers	
Diversion of water from one catchment to another	Change in nutrient and other water quality parameters in both donor and receiving catchments

Table 5.4: Aquatic ecology and fisheries – Key risks, impacts and vulnerabilities (see Chapter 5 in for details).

Change	Key Risks, Impacts & Vulnerabilities
Annual / inter-annual changes to flow	
Changes in seasonality (e.g. delayed floods, increase of dry and decrease of wet season flows)	Habitat alteration / loss related to increased erosion (river bed incision, bed armouring, bank erosion etc.; see also Table 5.2)
	Habitat alteration / loss related to water quality changes (e.g. temperature, water clarity, salinity (relevant for the Delta), nutrient transport; see also Table 5.3.)
	Loss of ecological functions (e.g. migration/spawning triggers)
	Loss of productivity due to reduced flood pulse (increase in permanently flooded areas and decrease in seasonally flooded areas)
Daily / short-time period changes in flow	
Fast increase of flow	High drifting rate of fish and macroinvertebrates, loss of food sources, offset of migration triggers, stress for aquatic organisms
Fast decrease of flow	Stranding / loss of fish and macroinvertebrates, stress for aquatic organisms
Morphological alterations	Increased erosion and river bed incision causes habitat degradation (see also Table 5.3.)
Thermopeaking	Unnatural (fast changing) temperature regime, stress for aquatic organisms, offset of migration triggers
Barriers / loss of river connectivity	
Disconnection between flow, sediment and nutrient delivery	Habitat loss related to morphological alterations (see also Table 5.3.), offset of migration triggers, reduced productivity with regard to nutrient trapping and limited delivery downstream

Change	Key Risks, Impacts & Vulnerabilities
Habitat fragmentation	Blocked / reduced spawning and feeding migrations, potential isolation of sub-populations
Turbine passage	Stress, fish damage and kills
Spill flow passage	Stress, fish damage and kills
Creation of impoundments	
Trapping of sediments	Morphological alteration and habitat loss. *Upstream*: sedimentation, possibly filling up of deep pools, reduced vertical connectivity, change of choriotopes (fish, benthic invertebrates), degradation of shoreline habitats; *Downstream*: loss of habitat structures (e.g. sand bars), reduced habitat quality (e.g. change of choriotopes, river bed armouring), reduced connectivity to tributaries and floodplains (related to river bed incision)
Loss of free flowing river sections	Delay / deposition of drifting eggs & larvae
	Loss / reduction of fish species adapted to free flowing rivers
	Loss of orientation for upstream migrating fish
Increased visibility	Algae growth and changes in temperature, oxygen
Stratification & temperature changes	Stress due to water quality changes (temperature, oxygen)
Water level changes within impoundment	Stranding of fish and macroinvertebrates, degradation of shoreline habitats
Reservoir flushing	Flushing of benthic organisms and fish, potentially high losses related to high turbidity, destruction of habitats
Diversions or intra basin transfers	
Reduction of river dimension	Reduced productivity, species alteration (e.g. loss or large species), reduced depth may impact connectivity, water quality changes
Homogenisation of flows	Armouring of beds and bars due to reduced sediment transport, habitat loss
Increased flow in receiving basin	Increased bank erosion and bed incision to accommodate increased flow
Water quality changes	Stress

Change	Key Risks, Impacts & Vulnerabilities
Combined effects	Reduction of biomass and diversity of fish and other aquatic organisms

Table 5.5: Biodiversity, natural resources and ecosystem services- Key risks, impacts and vulnerabilities (see Chapter 6 in for details).

Change	Key Risks, Impacts & Vulnerabilities
Annual / inter-annual changes to flow	
Changes in seasonality to flow	Changes in timing of flow to wetlands and floodplain riparian habitats
Modification of flood recurrence intervals	Dispersal of species to and between floodplain habitats
Change in relationship between flow and sediment/nutrient delivery	Changes in wetlands functions, dynamics and ecosystem services due to timing of sediment and nutrient delivery
Change inundation/ exposure of downstream floodplains and wetlands	Loss of wetland / floodplain habitats
Daily / short-time period changes in flow	
Fast increase and decrease of flow velocity	Degradation of function, dynamics and ecosystem services of wetland and riparian habitats
Loss of river connectivity	
Change to sediment and nutrient transfer (amount)	Changes in wetland functions, dynamics and ecosystem services due to decrease in transfer of sediments and nutrients
Impoundments	
Change to/loss of riparian areas	Loss of riparian ecosystems, habitats and biodiversity
Diversion scheme / inter basin transfers	
Alternation of flow regime of contributing and receiving (sub) catchments	Flow changes to wetland and floodplain areas (decrease or increase) leading to changes in ecosystem- functions, dynamics and services as well as biodiversity

6. Recommended Hydropower Impact Mitigation Options

6.1 Good Industry Practice

The recommended hydropower impact mitigation options contained in these Guidelines are based on Good Industry Practise gathered from international and regional studies and research. Some of the relevant options have drawn on work by:

- the International Hydropower Association (IHA),
- The World Bank Group (WB), including International Finance Corporation (IFC).
- The Asian Development Bank Safeguards (ADB)
- Practice and Research arising from the World Commission on Dams
- MRC, WB and ADB experience in Benefit Sharing Mechanisms, and
- Regional and national experience on major hydropower projects on the Mekong and adjoining river basins.

In addition, global industry practice, from projects built in similar large tropical basins globally, have been gathered and a number of related research papers have been included in the Knowledge Base.

A more detailed description of the sourced documents are contained in Annex 2.

6.2 Overall Guiding Principles

The MRC cooperation is firmly based on the 1995 Agreement and during the last years the MRC has developed an applied its framework to address the issue of hydropower development in a holistic way. The following describes this framework to set the scene for the performance of the Guidelines and Recommendations.

6.2.1 The 1995 Mekong Agreement and the MRC Procedures

The Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin signed by Cambodia, Lao PDR, Thailand and Viet Nam on 5 April 1995 defines a set of principles and processes for pursuing a coherent strategy of integrated water resources management (IWRM) on the regional scale.

The 1995 Mekong Agreement encourages cooperation amongst the LMB countries to optimise the multiple use and mutual benefits of all riparian's while protecting the environmental and ecological balance in the basin.

The 1995 Agreement addresses different types of water use including proposed hydropower developments. In the latter respect, the following key chapters and articles are important guides to The Guidelines and The Manual:

- Chapter II: Definitions of Terms
- Article 1: Areas of cooperation

- Article 3: Protection of the Environment and Ecological Balance
- Article 4: Sovereign Equality and Territorial Integrity
- Article 5: Reasonable and Equitable Utilization
- Article 6: Maintenance of Flows on the mainstream
- Article 7: Prevention and Cessation of Damages of Harmful Effects
- Article 8: State Responsibility for Damages
- Article 26: Rules for Water Utilization and Inter-Basin Diversions
- Chapter V: Addressing Differences and Disputes

The Mekong River Commission (MRC) with its three bodies (Council, Joint Committee and Mekong River Commission Secretariat) serves as an international organization to ensure the implementation of the 1995 Mekong Agreement through its provisions and to adopt Procedures to facilitate and addressing such issues in a cooperative and amicable manner. The vision of the 1995 Mekong agreement is embedded within the following agreement between the member states; "..to cooperate in a constructive and mutually beneficial manner for sustainable development, utilization, conservation and management of the Mekong River Basin water and related resources.."

i. The five adopted Procedures for implementation within the MRC framework are the
ii. Procedures for Notification, Prior Consultation and Agreement (PNPCA; approved in 2003);
iii. Procedures for Data and Information Exchange and Sharing (PDIES; approved in 2001);
iv. Procedures for Water Use Monitoring (PWUM approved in 2003);
v. Procedures for Maintenance Flows on the Mainstream (PMFM approved in 2006);
vi. Procedures for Water Quality (PWQ approved in 2011).

According to the PNPCA, hydropower development on tributaries is subject to notification to the MRC Joint Committee and respective development on the mainstream requires prior consultation towards agreement between the countries.

The implementation of the PNPCA under the 1995 Mekong Agreement in case of a proposed hydropower dam, intends to benefit each MRC country and to facilitate the development of water and related resources in the LMB. Furthermore, the PNPCA commits the countries to notify their neighbours of proposed mainstream projects when they have sufficient information, then consult and reach agreement on whether or not to proceed, and if so, under what conditions.

The Mekong Agreement also requires the countries to "make every effort to avoid, minimize and mitigate harmful effects…", i.e. to adopt the mitigation hierarchy in the planning and implementation of hydropower and other infrastructure projects (see Section 1.3).

6.2.2 MRC Preliminary Design Guidance (PDG)

The most important safeguards for hydropower in the LMB are those in the Preliminary Design Guidance (PDG) for Mainstream Dams in the Lower Mekong Basin, which was issued by the MRC in 2009 (presently under review/updating).

The original PDG outlines the expectations of, and an approach to, mitigation of the major risks for hydropower dams in the Mekong mainstream. For example, the PDG requires all mainstream dams to incorporate both upstream and downstream fish passage facilities, which should ensure "effective" passage (i.e. safe passage for 95% of the target species under all flow conditions). The PDG criteria have served as the compliance benchmarks in the technical reviews of Xayaburi, Don Sahong, Pak Beng and Pak Lay hydropower projects, and currently is also used as part of the PNPCA process for Luang Prabang hydropower project..

This Guidelines with the supporting Manual seeks to enhance and expand the PDG and to provide more effective and detailed documentation of the options and methods that may be used to cover the mitigation of hydropower risks in the Mekong mainstream, as well as to expand the applicability of the PDG to the tributary developments. Hence the updated PDG will make reference The Guidelines and The Manual, with regard to details and solutions for general and specific mitigation approaches and options.

The Preliminary Design Guidance (PDG) for the Proposed Mainstream Dams in the Lower Mekong Basin provide developers with an overview of issues that the MRC will consider during the PNPCA process under the 1995 Mekong Agreement. With regard to the themes of this Guideline the PDG provides recommendations as follows. These will be further updated in the PDG to be issued in 2020.

Environmental Flow and Aquatic Ecology

The PDG stipulates to incorporate instream flow (environmental flow) considerations appropriately at different project stages (design, implementation, operation and monitoring). The Design Guidance states that the developers should systematically assess the effect of combination of flow releases from the dam to address downstream impacts at different times of the year, also taking into account the position of the dam in possible cascade series of dams. This should be done by introducing appropriate Environmental Flow Assessment (EFA) methodologies at the EIA and feasibility study stage, appropriate to the scale and significance of the flow changes, and referring to good practice techniques and methodologies. The prescribed documentations to refer are: IUCN Publication- 'Flow: The Essentials of Environmental Flows' and World Bank Publication- 'Environment Flows: Concepts and Methodologies'. MRC Environment Program (2011-2015) also highlights the requirement of further development of EFA approaches. In this guideline environmental flow mitigation is described in Section 6.4, and is also further described in the Manual under Chapter 5.3.2.3.

Sediment transport and geomorphology

The PDG provides an overview of potential sediment related impacts associated with the development of hydropower projects and approaches for mitigation and management. These impacts include reservoir deposition, changes to sediment transport from inflowing tributaries (both in the reservoir and downstream), downstream channel adjustments related to changes in hydrology and sediment loads and associated impacts on habitat distribution and quality. A summary of guiding principles for considering sediment related issues during the planning phase is provided for developers, which highlight the importance of:

- Understanding the relationships between hydraulics, river morphology and ecology;
- Assessing whether dam developments should be avoided in reaches susceptible to severe morphological change;
- Making dams transparent to sediment transport as much as possible;
- Considering sediment transport issues associated with tributary inputs.

The PDG discusses a range of sediment management options, including sediment routing, sediment bypass, sediment flushing, mechanical removal, sediment traps and sediment augmentation downstream of the reservoir. General guidance is provided with respect to site selection, modelling and monitoring of sediments into, within and downstream of the impoundment, and the inclusion of gates to enable sediment management options. Operational and ecological issues associated with the timing of sediment management are also highlighted, with an emphasis on continued monitoring over the life-cycle of the project to guide management strategies. Reactive measures, such as physical bank protection are indicated as a means of mitigating impacts which cannot be avoided through management of the project. In this guideline various sediments and geomorphology mitigation options is considered in Section 6.4 and is also further described in the Manual under Chapter 3.4.

Water Quality

The PDG focuses on water quality risks associated with a series of low-head dams as proposed for the mainstream Mekong in the LMB, emphasizing that larger deeper storages may promote greater changes. The water quality risks identified by the PDG include changes to physical and chemical water quality parameters which can impact on the downstream ecosystem, and geomorphology (as related to sediment concentrations).

The water quality parameters that are important to consider in hydropower developments include temperature, pH, dissolved oxygen, Biological Oxygen Demand, total nitrogen, total phosphorus and coliform bacteria. These parameters can be altered during storage within a reservoir and especially under conditions where thermal stratification can lead to the development of stagnant water at depth.

Guidance for maintaining water quality includes the design and management of reservoirs which will achieve the water quality guidelines as set out in the MRC Technical Guidelines for Procedures on Water Quality. The PDG state the necessity of site – specific water quality monitoring, with the results to be interpreted within larger scale trends provided by the Water Quality Monitoring Network and Ecological Health Monitoring Network. In this guideline various water quality mitigation options is considered in Section 6.4 and is also further described in the Manual under Chapter 4.3.

Fish passages on Mainstream Dams

The PDG gives an overview of the various fish guilds (10) on the Mekong and its tributaries and the likely impacts of mainstream dams. This is followed by guidance on fish passage design and operation. Important guiding principles are as follows:

- Fish passage facilities for both upstream and downstream passage must be incorporated into all dams;
- The developers should provide for effective fish passage bot upstream and downstream, defined as follows – “providing safe passage for 95% of the target species under all flow conditions”;
- Where fish passage rates are unlikely to be adequate to maintain viable populations other

mitigation options as part of compensation programs for lost fisheries resources must be developed;

- Fish passages and mitigation options should constitute multiple systems at each site to cater for the high number of species and high biomass.

The PDG details further biological, hydrological and hydraulic requirements for the fish passages during the various phases of the HPP project life cycle. In this guideline various fish passage mitigation options is considered in Section 6.4, and especially Table 6.3 and 6.4. It is also further described in detail the Manual in Chapter 5.3.3.

6.3 General Principles for Sustainable Hydropower Development

The general principles for sustainable hydropower development, along with the above MA95, guide the selection and design of mitigation in these Guidelines. For simplicity, these are taken from the International Hydropower Association's Hydropower Sustainability Assessment Protocol[3].

- Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
- Sustainable development embodies reducing poverty, respecting human rights, changing unsustainable patterns of production and consumption, long-term economic viability, protecting and managing the natural resource base, and responsible environmental management.
- Sustainable development calls for considering synergies and trade-offs amongst economic, social and environmental values. This balance should be achieved and ensured in a transparent and accountable manner, taking advantage of expanding knowledge, multiple perspectives, and innovation.
- Social responsibility, transparency, and accountability are core sustainability principles.
- Hydropower, developed and managed sustainably, can provide national, regional, and local benefits, and has the potential to play an important role in enabling communities to meet sustainable development objectives.

6.4 Selection of Mitigation Options for the LMB

The tables in the following pages (Tables 6.1 – 6.5) constitute a summary of the MRC Hydropower Mitigation Guidelines. The mitigation options are presented in detail by thematic area (hydrology, geomorphology & sediment, water quality, fisheries and aquatic ecology as well as biodiversity) in , the Manual. Each thematic area in includes examples of good international and regional industrial practice, available criteria for evaluating the applicability of mitigation measures, technical guidance and information about monitoring and indicators. also includes a chapter on engineering response to environmental risks.

The mitigation options are structured according to the 5 key common overarching changes related to hydropower development, as identified in Chapter 1.2 and 5. These are:

I. Annual / inter-annual changes to flow

II. Daily / short-time scale changes to flow and water level

III. Loss of river connectivity

IV. Impoundments

V. Diversion or intra basin transfers

Within these identified major changes a set of major risks and impacts (left column in the tables) for each thematic area has been identified. The identified mitigation options are then grouped into avoidance, mitigation (including minimization), compensation and adaption measures. The associated sub-sections define where in the project life cycle the various mitigation options are to be implemented. A succinct overview of how mitigation considerations should be incorporated into each stage of the hydropower life-cycle is presented following the Tables.

More details on the proposed mitigation measures can be found in as follows:

- Hydrology and flows (Vol 2, Chapter 2.3)
- Geomorphology and sediments (Vol 2, Chapter 3.4)
- Water quality (Vol 2, Chapter 4.3)
- Fisheries and Aquatic Ecology (Vol 2, Chapter 5.3)
- Biodiversity and Natural Resources (Vol 2, Chapter 6.3)
- Engineering Response to Environmental Risks (Vol 2, Chapter 7)
- Ecosystem Services (Vol 2, Chapter 8.4)

Some of the most promising mitigation options for hydrology and flows, geomorphology and sediments, water quality as well as fisheries and aquatic ecology has also been analysed and tested for the Case Study (see here for a detailed reporting on this).

Table 6.1: (I) Annual/Inter Annual Changes to Flow	
a. Risks / Impacts to be considered	
Hydrology and downstream flows 1) Change of timing & duration of floods and low flows 2) Peaks in flood and low flow change, smoother hydrograph 3) Changes in Tonle Sap flows and salt intrusion in the delta **Geomorphology and Sediments** 1) Water logging & loss of vegetation leading to increased bank erosion Increased erosion due to increased scour 2) Winnowing of smaller sediment leading to bed armouring & reduction in downstream sediment supply 3) Channel narrowing through encroachment of vegetation 4) Decoupling of tributary & mainstream flows. Erosion and / or deposition due to tributary rejuvenation 5) Backwater sedimentation causing flood-level increase upstream	**Water quality** 1) Changes / loss of seasonal temperature patterns downstream 2) Increased water clarity increasing water temperature and risk of algal growth **Fisheries and Aquatic Ecology** 1) Loss of migration/ spawning triggers; 2) Reduced flood pulse and related productivity loss; 3) Habitat loss due to morphological alterations **Biodiversity, Natural Resources and Ecosystem Services** 1) Changes in wetland functions and dynamics due to shifts in timing of sediment and nutrient delivery 2) Loss of wetland/floodplain habitats

Table 6.1: (I) Annual/Inter Annual Changes to Flow			
b. Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(I.1) Avoidance			
(I.1.1) Dam siting in Master Plans to avoid risks and impacts in themes hotspot areas (MP) (I.1.2) Selection of sites with less hydrological and sediment impact (MP)	River length affected; contribution to LMB flow and sediment loads		
(I.2.) Mitigation			
(I.2.1) Development of flow rules (MP and F) (I.2.2) Develop joint operation rules for releases (F) (I.2.3) Design multiple large gated spillways/outlets at multiple levels, and low level sediment outlets (D) (I.2.4) Design bypass channels (F and D)	Minimum flow, hydraulic parameters, magnitude, duration, timing of wet and dry season flows	(I.2.5) Mimic 'natural' flow regime (artificial releases, environmental flows) (I.2.6) Maintain seasonal patterns through HP operations (I.2.7) Annual sediment sluicing to maintain seasonal pulse (I.2.8) Monitoring of impacts	Minimum flow; onset of wet season; magnitude, duration of wet/ dry season flows (flow duration curve); changes to fish diversity/ biomass, sediment loads and timing of sediment delivery, extent and timing of salinity intrusion

<table>
<tr><th colspan="4">Table 6.1: (I) Annual/Inter Annual Changes to Flow</th></tr>
<tr><th colspan="4">b. Mitigation Options</th></tr>
<tr><th colspan="2">Planning / design / construction

MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction</th><th colspan="2">Operation</th></tr>
<tr><th>Options</th><th>Indicators</th><th>Options</th><th>Indicators</th></tr>
<tr><td colspan="4">(I.3) Compensation</td></tr>
<tr><td>Plan for and implement;

(I.3.1) Creation of offsets of residual impacted habitats and areas (F and D)
(I.3.2) Floodplain and wetland rehabilitation (F and D)</td><td>Area of offsets and improved floodplain and wetland habitats</td><td>(I.3.3) Monitor offsets and floodplain and wetland rehabilitation</td><td>Changes to diversity/ biomass of fish and other aquatic organisms</td></tr>
<tr><td colspan="4">(I.4) Adaptation</td></tr>
<tr><td colspan="4">Implementation of operating rules
Monitoring including stakeholder consultation to gauge effectiveness of mitigation actions
Adaptive management guided by monitoring
Catchment management activities to improve / maintain water quality, reduce sediment loads</td></tr>
</table>

Table 6.2: (II) Short-term flow fluctuations / Hydro-peaking	
a. Risks / Impacts to be considered	
Hydrology and downstream flows 1) Short term flow fluctuations 2) Safety and navigability **Geomorphology and Sediments** 1) Rapid wetting and drying of banks 2) Increase in shear stress on river channel **Water quality** 1) Fluctuating temperature and water quality 2) Altered concentrations of downstream WQ parameters	**Fisheries and Aquatic Ecology** 1) Degradation of riparian and instream habitats 2) Thermopeaking 3) Increased fish/ macroinvertebrate drift and stranding 4) Offset of migration triggers 5) Loss of food sources **Biodiversity, Natural Resources and Ecosystem Services** 1) Degradation of function, dynamics and ecosystem services of wetland and riparian habitats

Table 6.2: (II) Short-term flow fluctuations / Hydro-peaking			
b. Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(II.1) Avoidance			
(II.1.1) Dam siting in Master Plans to avoid risks and impacts in themes hotspot areas (MP) (II.1.2) Selection of sites where impacts are reduced by entering tributaries (MP)	River length affected; quickly dewatered area		
(II.2.) Mitigation			
(II.2.1) Development of flow rules (F and D) (II.2.2) Design of re-regulation weir (D) (II.2.3) Coordination of multiple hydropeaking HPP (II.2.4) Design of aeration weir (D) (II.2.5) Avoidance of flow fluctuations during construction (C) (II.2.6) Establish protected areas and evacuation paths for inundation zones (C) (II.2.7) Flexible mooring structures for ports (D and C) (II.2.8) River-bank stabilisation works (C)	Ramping frequency, amplitude, ramping rate, minimum flow temperature, dissolved oxygen, downstream damping of water-level fluctuations	(II.2.9) Re-regulation warning systems (II.2.10) Operating rules to minimise flow changes, management of re-regulation weir to provide appropriate downstream flow (II.2.11) Monitoring of impacts	Ramping frequency, ramping amplitude, ramping rate, minimum flow, changes to fish diversity/ biomass. Bank / bed erosion rates Downstream temperature, D.O. downstream damping of water-level fluctuations

<table>
<tr><th colspan="4">Table 6.2: (II) Short-term flow fluctuations / Hydro-peaking</th></tr>
<tr><th colspan="4">b. Mitigation Options</th></tr>
<tr><th colspan="2">Planning / design / construction
MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction</th><th colspan="2">Operation</th></tr>
<tr><th>Options</th><th>Indicators</th><th>Options</th><th>Indicators</th></tr>
<tr><td colspan="4">(II.3) Compensation</td></tr>
<tr><td>Plan for and implement;
(II.3.1) Habitat improvement (F and D)
(II.3.2) Floodplain and wetland rehabilitation (D and C)</td><td>Area of improved floodplain and wetland habitats</td><td>(II.3.3) Monitor habitat improvement and rehabilitation</td><td>Changes to fish diversity/ biomass</td></tr>
<tr><td colspan="4">(II.4) Adaptation</td></tr>
<tr><td colspan="4">Monitoring, adaptive management (based on monitoring data)
Catchment management to maximise water quality in and discharged from impoundment</td></tr>
</table>

Table 6.3: (III) Loss of river connectivity	
b. Risks / Impacts to be considered	
Geomorphology and Sediments 1) Sediment availability not timed with periods of recession 2) Loss of sediment 'pulse'	**Fisheries and Aquatic Ecology** 1) Blocked spawning/ feeding migrations 2) Habitat/ population fragmentation 3) Habitat loss due to morphological alterations 4) fish damage/ kills due to turbine/ spillflow passage
Water quality 1) Trapping of nutrients within impoundments (change in nutrient delivery downstream)	**Biodiversity, Natural Resources and Ecosystem Services** 1) Changes in wetland functions, dynamics and ecosystem services, due to decrease in sediment and nutrient transfer

Table 6.3: (III) Loss of river connectivity			
b. Recommended Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(III.1) Avoidance			
(III.1.1) Dam siting in Master Plans to avoid risks and impacts in themes hotspot areas (MP) (III.1.2.) Assessment of requirements and distribution of migratory species (MP and F) (III.1.3) Assessment of sections sensible to river fragmentation and important habitats (no-go areas) (MP) (III.1.4) Assessment of alternative hydropower designs, operations (MP and F) (III.1.5) Assessment of sediment budgets (F)	River length disconnected; number of migratory species; Proportion of sediment load affected Downstream bank erosion		

Table 6.3: (III) Loss of river connectivity			
b. Recommended Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(III.2.) Mitigation			
(III.2.1.) Consider alternative hydropower designs to minimize impacts on connectivity (MP and F) (III.2.2) Design multiple large gated spillways/outlets, and low level sediment outlets or bypass structures (D) (III.2.3) Design fish pass/ bypass channels (up- & downstream) (D) (III.2.4) Design measures for fish protection (i.e. suitable rakes; adapted turbines) (D) (III.2.5) Ensure connectivity during construction (C)	Number and type of migratory species, migratory behaviour; FP requirements, biomass peaks Sediment loads and seasonality	(III.2.6) Annual sediment sluicing to maintain seasonal pulse (III.2.7) Monitoring of sediment (III.2.7) Monitoring of fish pass functionality (III.2.8) Monitoring of fish kills (spill flow/ turbines) (III.2.9) Assessment of population functionality (life cycle)	Timing and concentration of sediment pulses Number of successfully passing migratory species; biomass peaks; population status
(III.3) Compensation			
Plan for and implement; (III.3.1) Introduction of additional sediment downstream of impoundment (C) (III.3.1) Reconnecting floodplains, ensure connectivity during construction (C)			

Table 6.3: (III) Loss of river connectivity			
b. Recommended Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(III.4) Adaptation			
Monitoring program to assess efficiency of measures , adaptive management; Adaptation of sediment management guided by monitoring results; Downstream bank protection works ; Adaptation of fish pass and fish protection on the basis of monitoring data			

Table 6.4: (IV) Impoundments	
a. Risks / Impacts to be considered	
Hydrology and downstream flows 1) Reservoir flow alternations superimposing impacts on the below **Geomorphology and Sediments** 1) Reduction in sediment availability downstream of dam leading to increased erosion 2) Changes to the grain-size distribution of sediment downstream contributing to channel armouring and alteration of habitats 3) Lake bank erosion, increased risk of landslips 4) Loss of volume of active storage **Water quality** 1) Lake stratification 2) Increased water clarity 3) Temperature change in lake and discharge 4) Low DO or high gas supersaturation 5) Changes in nutrient loads	**Fisheries and Aquatic Ecology** 1) Changes from fluvial to lake habitats (habitat & species loss) 2) Habitat loss due to sedimentation (upstream) and sediment deficit (downstream) 3) Deposition/ delay of drifting eggs/ larvae 4) Loss of orientation 5) Stranding due to water level fluctuations 6) Reservoir flushing leading to fish damage and kills and alteration of habitats **Biodiversity, Natural Resources and Ecosystem Services** 1) Change to / loss of riparian- ecosystems, habitats and biodiversity

Table 6.4: (IV) Impoundments			
b. Recommended Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(IV.1) Avoidance			
(IV.1.1) Dam siting in Master Plans to avoid risks and impacts in themes hotspot areas (MP)	River length affected Retention time, depth of potential impoundments		

Table 6.4: (IV) Impoundments			
b. Recommended Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(IV.2.) Mitigation			
(IV.2.1) Avoid high retention time, plan and implement large bypass-systems (F,D,C) (IV.2.2) Assess and implement suitable turbidity thresholds with regard to natural floods for aquatic species (F,D) Design multiple large gated spillways/outlets, and low level sediment outlets as well as bypass channels (D) (IV.2.3) Minimise sediment runoff through design of access roads & seasonal work schedules (D and C) (IV.2.4) Implement site-specific water quality standards (e.g. TSS, oxygen, temperature) (F,D)	TSS, grain-size distribution, retention time, flow velocity, temperature, oxygen saturation, bathymetry	(IV.2.5) Implement habitat improvements in head of impoundment (IV.2.6) Protection and armouring of downstream banks if required (IV.2.7) Catchment management to reduce sediment inputs (IV.2.8) Implement and apply suitable sediment management strategy (e.g. reservoir sluicing and/or occasional flushing) IV.2.9) Monitoring of abiotic parameters, species changes and passive drift rates (IV.2.10) Limit rate of water level drop to prevent slope and dam instability (IV.2.11) Use of high/low level outlets to mimic seasonal temperature and manage dissolved oxygen	TSS, retention time, flow velocity, temperature, oxygen saturation changes of fish community, biomass, fish drift, bathymetry

Table 6.4: (IV) Impoundments			
b. Recommended Mitigation Options			
Planning / design / construction MP=Master Plan; F=Feasibility Stage; D=Design; C=Construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(IV.3) Compensation			
Plan for and implement; (IV.3.1) Plan and provision for regeneration of vegetation and offset areas (D and C) (II.3.2) Catchment management to reduce sediment inputs and sustain ecosystem functions and services (F and D)		(IV.3.3) Maintain and monitor offset areas. (IV.3.4) Regulation of operation to maintain health of “new” riparian areas	
(IV.4) Adaptation			
Monitoring program to assess efficiency of measures , adaptive management Lake level fluctuation limits to manage lake bank erosion			

Table 6.5: (V) Diversions or Intra-basin Transfers	
a. Risks / Impacts to be considered	
Hydrology and downstream flows 1) Change of magnitude & dynamics of flows **Geomorphology and Sediments** 1) Channel narrowing due to vegetation encroachment 2) Armouring of beds and bars 3) Increased bank erosion and bed incision **Water quality** 1) Change in nutrient and other water quality parameters in both donor and receiving catchments	**Fisheries and Aquatic Ecology** 1) Reduced productivity due to reduced river dimension (flow, depth, width) and flow dynamics 2) Reduced connectivity 3) Stress due to water quality changes 4) Habitat loss due to morphological alterations 5) Possible loss of large species (due to river size reduction) **Biodiversity, Natural Resources and Ecosystem Services** 1) Flow changes to wetland and floodplain areas (decrease or increase) leading to changes in ecosystem- functions, dynamics and services as well as biodiversity

Table 6.5: (V) Diversions or Intra-basin Transfers			
b. Recommended Mitigation Options			
Planning / design / construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(V.1) Avoidance			
	River length affected, number of catchments affected, degree of flow alteration		
(V.2.) Mitigation			
(V.2.1) Minimise degree of transfer to minimise impacts in both catchments (F, D) (V.2.2) Development of environmental flow rules. i.e. minimum flow and dynamic flow (F and D) (V.2.3) Periodic flood releases to 'donor' river to maintain channel capacity (F and D)	Minimum flow, flow dynamics, seasonality of flow, flood frequency	(V.2.4) Application of environmental flows; monitoring of compliance and impacts; adaptive management (V.2.5) Operating rules to maintain geomorphic processes in both catchments (V.2.6) Protection and armouring of downstream banks in receiving catchment if required (V.2.7) Monitoring of flows and biological response	Flowrates, sediment loads and seasonality Downstream channel changes (erosion or constriction) fish diversity, fish biomass/ density

Table 6.5: (V) Diversions or Intra-basin Transfers			
b. Recommended Mitigation Options			
Planning / design / construction		**Operation**	
Options	**Indicators**	**Options**	**Indicators**
(V.3) Compensation			
(V.3.1) Restoration of impacted diversion stretch/channel (D and C)		(V.3.2) Maintain and monitor restored river/ channel/floodplain areas.	Same as under mitigation
(V.4) Adaptation			
Monitoring program to assess efficiency of measures, adaptive management Adaptation of environmental flow on the basis of monitoring data			

6.5 Mitigation Options and Engineering Response for the Different Project Phases

6.5.1 Approach of the guidelines

As demonstrated in Tables 6.1-6.5, the mitigation of hydropower risks and impacts requires a life-cycle approach to hydropower development and operation. The following sections provide a brief overview of the issues and approaches that should be considered during each phase of a hydropower project. These topics are discussed in detail by each thematic area in , which should be consulted for more detailed information. Figure 6.1 below transfer the general principles from the mitigation hierarchy (see Section 1.3) into the HP project life cycle and can be seen as an overarching generic practical process for risk and impact mitigation in LMB.

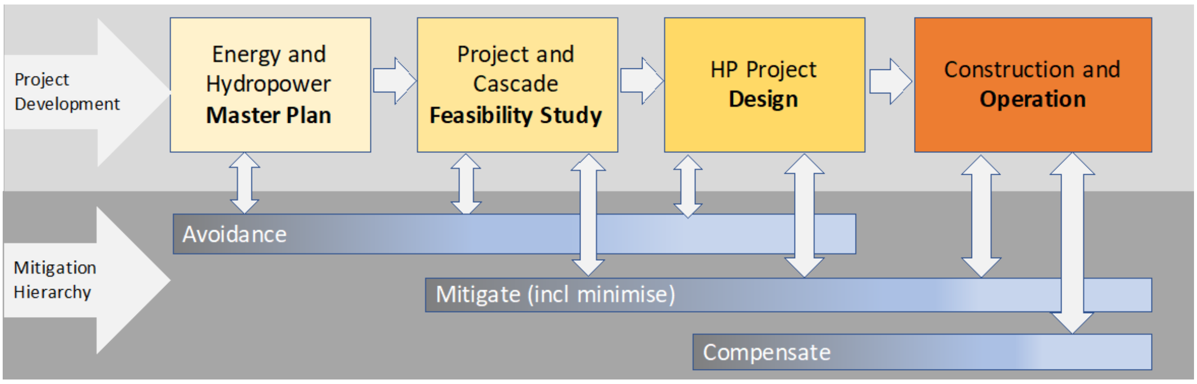


Figure 6.1: The MRC Generic Practical Process for Risk and Impact Mitigation - Project Life Cycle.

6.5.2 Integrated Planning at System/Basin Scale and Strategic Hydropower Portfolio Planning

Integrated hydropower planning at system/basin scale (spatial planning) is envisaged in the MRC's Strategic Plan 2016-2020 (MRC, 2016) as part of the overall Integrated Water Resources Management approach. Such an approach, at basin and catchment level, will cater for the incorporation of sustainable planning within a spatial and temporal context allowing for the application of the full mitigation hierarchy, from avoidance through minimization, mitigation and compensation/offsets. Integrated system planning will have the possibility to reduce cumulative impacts at a basin and catchment scale (Oppermann et al., 2013; Oppermann, 2017, Schmitt et al. 2017) making this approach highly relevant for the future hydropower planning of Mekong mainstream and its tributaries.

When mitigating within the spatial context at basin and catchment scale, and in line with the mitigation hierarchy, the status of the LMB ecosystems will benefit from early avoidance mitigation approaches, also addressing reduction of cumulative impacts. Examples might include maintenance of intact river routes and alternative dam designs. The latter has actually been studied for Sambor, and is amongst others reported in Wild and Loucks (2015). An illustration of the original proposed Sambor Dam and the smaller alternative is shown in Figure 6.2. The latter includes a natural sediment and fish bypass channel.

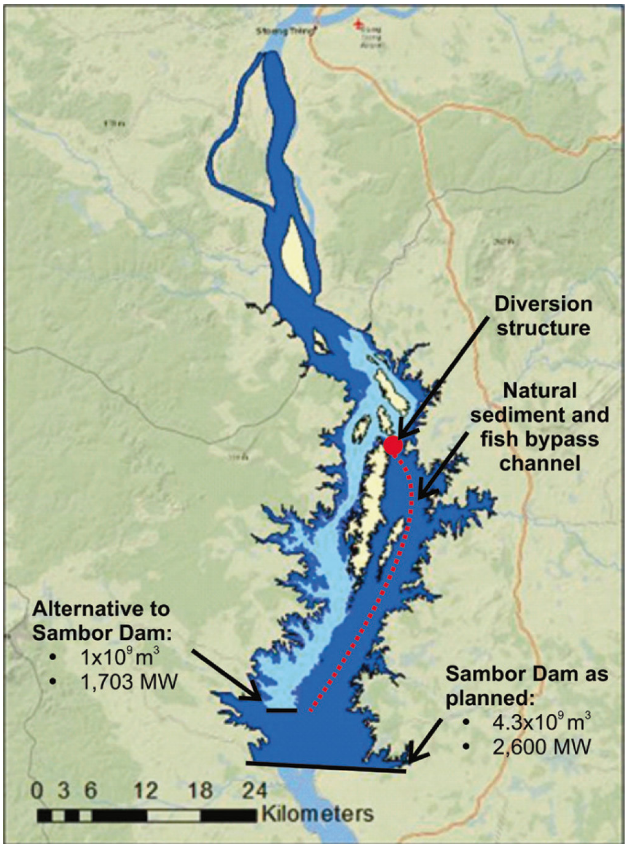


Figure 6.2: Map of the original proposed Sambor Dam and the smaller alternative (Source: Wild and Loucks, 2015).

Another spatial context approach to balance environmental, social and economic trade-offs is strategic hydropower portfolio planning. This approach compares different spatially configured portfolios of hydropower project and their trade-offs as mentioned above. This has been studied, by Schmitt et al. (2017), for the 3S basins with regard to balancing trade-offs by sediment transport and hydropower production, indicating that spatial hydropower portfolio planning can yield higher overall benefits between sediment transport or ecosystem value and hydropower production compared to traditional project by project planning. These approaches can be parts of Master Plans (Section 6.5.3) or Basin Plans.

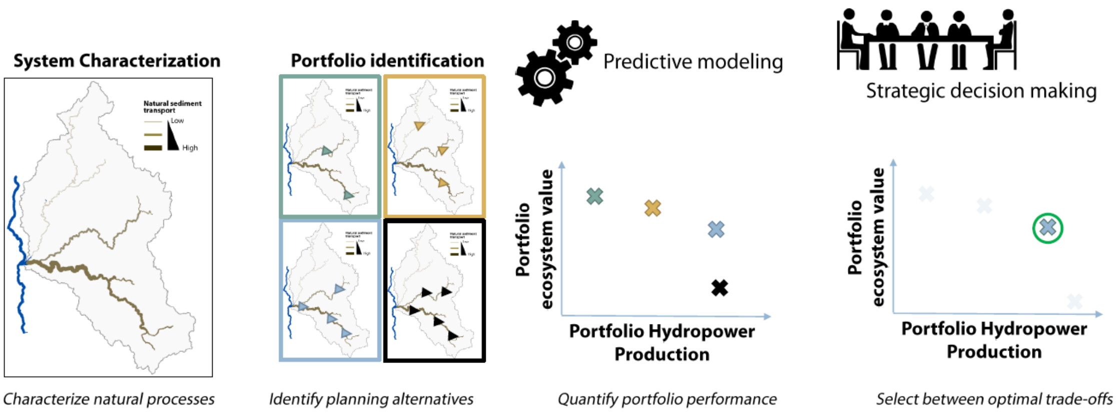


Figure 6.3: Illustration of benefits from spatial scale portfolio planning in the 3S system of Mekong (from Schmitt et al. 2017).

6.5.3 Master Plans

The development of Master Plans can be critical to the development of sustainable hydropower. Master Plans need to be based on a sound knowledge of the conditions within the catchment (flow regimes, sediment budgets, fisheries and aquatic ecological systems) and how hydropower development could potentially alter these systems. Hence, Master Plans typically should include a SEA and/or CIA (see Section 1.4). The identification and feasibility of potential mitigation measures should be an integral part of Master Planning and included at the earliest stages of planning. The siting and scale of hydropower projects are critical factors in determining the long-term impacts of developments, and environmental factors as well as power production potential need to be considered and evaluated during the development of Master Plans. Attributes of hydropower projects that need to be considered at the Master Planning phase include:

- Location of project relative to upstream and downstream tributaries: Typically, having larger unregulated tributaries entering downstream can assist with the mitigation of impacts by providing seasonally appropriate flow and sediment input, and maintaining catchment connectivity for migratory fish species;
- Height of dam and size of impoundment. Generally lower dams and smaller developments have lower levels of impact (for example the smaller Sambor alternative in relation to the original);
- Relationship to other hydropower or water resource developments.

Master planning should consider the impact of individual hydropower developments, as well as the cumulative impacts of hydropower development (and other water resource developments) within and between catchments. Master Planning provides the opportunity to develop integrated and complementary hydropower projects that can be operationally coordinated to meet power demands whilst limiting environmental and social impacts to acceptable levels.

Master Planning also provides the opportunity to establish basin and catchment specific requirements and targets for hydropower developments (as integrated planning at system/basin scale). These types of overarching criteria might include inter alia:

- Environmental flow requirements (minimum flows, seasonal releases, irrigation releases, etc.)
- Limits on ramping rates
- Water quality targets, such as dissolved oxygen levels and seasonal temperature ranges
- Sediment concentration limits or targets associated with sediment flushing operations
- Limits to lake level operating ranges (e.g. to facilitate other water uses)
- Identification and protection of ecosystem, biodiversity and wetland hotspots
- Identification of potential intact river-routes for fish migration and other water uses

6.5.4 Feasibility

The key objective of the feasibility stage is to optimise the installed capacity and layout of a project within the constraints imposed by the associated ESIA. Furthermore, during the feasibility stage of a development, a more detailed understanding of the environmental conditions within the catchment is required to guide the general project layout and preliminary design, including the identification of appropriate mitigation measures. Detailed investigations into the physical and ecological characteristics of the catchment should be initiated during this phase, and continue through the design phase, providing as long a record as practical to guide project development. The final siting and design specifications of a project needs to be decided taking into account power generation and environmental mitigation issues.

At this stage, mitigation measures to address known issues, such as the provision of an acceptable downstream flow regime and / or fish passage should be incorporated into the project, but mitigation strategies that provide for unforeseen future changes also need to be considered. Future changes might be associated with future water resource of other developments upstream or downstream of the project that could impose operating constraints on the HP operation, or changes associated with the energy market or societal expectations. The feasibility study provides the basis on which investment decisions are made, so all issues need to be identified and catered for in the proposed design and operation, including flexibility for any future changes. This includes the identification, selection and costing of appropriate infrastructure, operating rules, and potential offsets. The development and implementation of site-specific monitoring regimes that can provide additional information for the design, construction and long-term operation of the project should also be developed and implemented during the feasibility stage.

The feasibility stage should also be guided by the results of site-specific investigations and detailed modelling at the project and catchment scale to arrive at the best environmental outcome in the most cost effective manner, too also back up the drafting of the CA and the PPA.

Stakeholder consultation during this phase is essential for refining the understanding of potential environmental issues and impacts identified in the Master Plan, and to guide the direction of the feasibility study.

6.5.5 Detailed Design

The detailed design phase of Hydropower developments progresses and refines, and developers in detail, the mitigation concepts and approaches identified during the feasibility phase to arrive at the final design of the project. This includes the detailing of mitigation infrastructure, which might include:

- High and low level outlets to facilitate the discharge of water from different levels within the impoundment and the potential to pass sediments through the dam;
- Re-regulations weirs to dampen downstream water level fluctuations;
- Aeration weirs to increase oxygen levels in the tail water;
- Fish passage addressing both upstream and downstream migration;
- Sediment bypass channels or tunnels, or infrastructure to promote the deposition of sediment at the upstream end of reservoirs where it can be periodically harvested;

The detailed design phase also typically involves the drafting of an Environmental Monitoring and Management Plan (EMMP), to be implemented during the Construction and Operation phases.

6.5.6 Construction

Environmental mitigation measures should be incorporated into the construction process by analysing the potential impacts of access, working areas, sources of materials, equipment and materials management and construction methodologies and defining actions to eliminate or mitigate these impacts. To this end, it is standard good industrial practice to require the contractor to finalize, submit and implement the Environmental Monitoring and Management Plan (EMMP) drafted during the detailed design phase. This plan should be required to include specific sub-plans which would typically include the following:

- Erosion and Sediment Control Plan
- Spoil Disposal Plan
- Quarry Management Plan
- Water Quality Monitoring Plan
- Chemical Waste/Spillage Management Plan
- Emergency Plan for Hazardous Materials
- Emissions and Dust Control Plan
- Noise Control Plan
- Physical Cultural Resources
- Landscaping and Revegetation Plan
- Vegetation Clearing Plan
- Waste Management Plan
- Reservoir Impoundment Management Plan
- Environmental Training for Construction Workers Plan
- On-site Traffic and Access Management Plan
- Explosive Ordnance Survey and Disposal Plan
- Constructions Work Camps and Spontaneous Settlement Areas Plan

In addition, a Manual of Best Practice in Site Management of Environmental Matters and a Project Staff Health Program should be drafted and reviewed by an independent expert. To achieve a consistent approach such standards should be imposed by Government through the Concession Agreement.

6.5.7 Operations

The operational phase of a hydropower project is the longest period of the project life-cycle, and can last from decades to centuries. Operations should be based on the principle of adaptive management, underpinned by appropriate monitoring. Operating rules need to be continually evaluated and modified as warranted. The range of potential mitigation responses and measures incorporated during the feasibility and design stages (and as part of the EMMP) will determine the range of responses available during the operational phase of a project.

During operations, the hydropower operator needs to be actively involved in catchment management activities. Catchment management goals should include the minimisation of upstream or downstream changes that might affect HP operations. The operator needs to be aware of risks associated with new developments that might be linked to the creation of the impoundment, such as water quality risks associated with increased runoff from agricultural or industrial discharges or in situ activities such as aquaculture. Catchment management also needs to include the development and maintenance of communication systems to alert communities regarding the potential for extreme flows or other unusual events (e.g. sediment flushing).

Over the decades, operations will need to adapt to changing conditions associated with climate change, and changes to electrical transmission systems or energy markets. The development of upstream, downstream or tributary hydropower projects can also lead to the need for altering operations. These future ‘unknowns’ highlight the need for ongoing monitoring flexibility with respect to environmental mitigation measures.

Effective environmental mitigation and management of power system requirements cannot be undertaken on a project by project basis. It requires a co-ordinated basin wide approach. Once multiple hydropower projects are developed on a cascade, or within a single river basin, there will be an inter relationship governing overall energy output and environmental impact. To obtain optimal results an integrated, joint operating strategy must be developed and centrally directed. This integrated strategy will most probably deliver better overall energy output than the current approach of incentivising individual project owners to optimise the performance of their projects. A conjunctive operation approach will also permit better management of grid stability and system requirements.

The mitigation of impacts on sediment transport, fish passage, water quality and variations in short term and long term discharge also require a co-ordinated approach between projects on the same river system. This approach will need to be revised and adapted as new projects are developed and catchment conditions change. A conjunctive operating strategy will be required based on a programme of continuous monitoring and revisions to scheme operation to achieve overall environmental targets.

The longevity of hydropower operations provides unique challenges to the hydropower sector, and successional planning and inter-generational information management is required for sustainable operations. Monitoring and reporting should be based on a systems approach to ensure that information and knowledge is efficiently stored and available for future generations.

7. Multi-Criteria Assessment, Indicator Framework and Monitoring

When considering multi-criteria assessment, indicators and monitoring requirements for the various themes in this guideline, it is important to implement monitoring regimes that will provide adequate information at the required scales. For example, short term sediment transport information is required to understand the timing, seasonality and variability of sediment inputs, whilst the same information over years and decades is needed to assess how long-term sediment yields respond to upstream flow alterations, catchment land use changes or climate change. Similar considerations are also relevant for the other issues.

The multi-criteria assessment and indicator framework developed for the study comprises four large scale criteria that address the potential economic, physical, ecological and biodiversity dimensions associated with development, and identifies desired outcomes with respect to hydropower mitigation measures. Each of the desired outcomes is characterised by one or more sub-criteria that can be linked to quantitative and qualitative indicators. Some hydropower mitigation measures has been studied for the mainstream Lao Cascade, and their effectiveness has been tested by use of the indicator framework in Table 7.1 below. The result of this is reported in the Case Study Report (MRC, 2018). Wherever possible, indicators have been identified that can be quantitatively assessed using the modelling results with recent or historic monitoring or modelling results (BDP, Council Study, DSF) providing a context or reference for evaluation, if applicable. Where indicators cannot be directly measured, a qualitative assessment of the indicator has been made based on known relationships and responses of indicators, using Mekong specific information wherever possible.

The indicators coincide well with indicators previously identified by the BDP and other MRC initiatives (ISH Baseline study, Council Study etc.).

Table 7.1: Multi-criteria indicator framework for ranking for mitigation measures in the Case Study.

Desired generic outcomes	Sub-Criteria	Indicator
Net economic benefit	Energy revenue	* USD
	Investment in mitigation	* USD
	Value of fishery products	* USD
	Value of sand & gravel downstream	* Million USD Sand & gravel
	Value of silt & clay downstream	* Million USD silt & clay
Maintain flows (flood pulse)	Near natural river flows	* flow volume of the wet season (Mio m³)
		* duration of the wet season (days)
		* onset of wet seasons (date)

Desired generic outcomes	Sub-Criteria	Indicator
Maintain existing river channel habitats	Sandbanks, riparian zone	* hourly dewatered area for quick down-ramping operations (ha/hr)
		* length of downstream river section impacted by peaking
		*Changes to channel volume over 1st 7 years (Mm^3/yr): + = deposition, - = erosion
	Deep pools, rapids	* quality/quantity of deep pools
		* quality/quantity of rapids
	River dimension	* mean water depth in the cascade
		* mean water surface of the cascade compared to historic condition
Maintain river connectivity	Sediment transfer	* sediment transport - medium sand and larger (*103 ton)
		* sediment transport - fine sand (*103 ton)
		* sediment transport - silt and clay (103 ton)
		* seasonal timing of sediment delivery (% Sed Load during Aug'-Dec)
		* median sediment grain'-size being transported
	Connectivity for fish	* $DCI_{Strahler}$
		* DCI_{Migr}
		* cumulative upstream passage efficiency in cascade
		* cumulative downstream mortality (large species)
		* cumulative downstream mortality (small species)
		* months with flow velocities <0.2 m/s within the cascade
		* delay of larvae drift in days (for months with velocities <0.2m/s in the cascade)

Desired generic outcomes	Sub-Criteria	Indicator
Maintain water quality	Water Quality	* residence time impoundment during Dry Season (days)
		* turbidity/water clarity (% of time suspended solids <50 mg/L)
		* percent of time with vel <0.4 m3/s
		* turbidity during flushing events
		* nutrient transport (Silt & clay used as surrogate)
Maintain fish production	Overall fish biomass	* overall fish biomass

For the multi-criteria assessment, a common assessment schema was developed, for uniform ranking across the indicators and constitutes as follows:

Table 7.2: Common assessment schema for indicators.

Scoring by indicators based on measures	Level of significance
+3	Most of the risks are mitigated
+2	There is a significant and substantial increase, some of the risks are mitigated
+1	There is a significant increase, but the increase is still weak
0	No significant effect of mitigation measures (no increase or decrease) compared with base case (no risks are mitigated)
-1	There is a significant decrease, but the decrease is still weak, worse than the base case
-2	There is a significant and substantial decrease
-3	There is a significant and severe decrease
--	Not relevant (indicator not targeted by mitigation measure)

The range set in Table 7.2, indicated positive to negative impact of implementing various mitigation measures and hence their effectiveness, as tested for the Case Study. For the latter a set of the most promising indicators were then cumulatively added (summed up based on their individual scores based on the range portrayed in Table 7.2), for each of the scenarios that were tested, indicating the range of benefits and impacts from implementing the chosen mitigation measures.

Indicators and monitoring is dealt with in detail for each theme in , the Manual. This exercise can be used also in future assessments of mitigation measures or even expanded on to cater also for livelihoods and social issues as in the ISH11 project.

The ISH11 project (Improved Environmental and Socio-Economic Baseline Information for Hydropower Planning) identified information needs for hydropower projects over the project-life-cycle. Table 7.3 contains a summary of the range of indicators from the ISH11 project.

Table. 7.3: Indicators relevant to Hydropower developed by ISH11.

Discipline Area	Type of Parameter or Indicator	Parameter and Indicator Examples
Hydrology	Rainfall	Level, variability, extreme events
	Water level	fluctuations, attenuation
	Discharge	Patterns (frequency, magnitude, rate of change), seasonality
	Tidal flow dynamics	Current directions, velocities, timing
Water Quality	Physical	temperature, pH, electrical conductivity, dissolved oxygen, turbidity, total suspended solids (TSS)
	Chemical	ions, metals, nutrients, chemical oxygen demand
	Biological	Chlorophyll-a, Faecal coliforms
Sediments and Geomorph-ology	Sediment loads	Suspended sediment load, bedload
	Sediment characteristics	Grain size, organic content, nutrient content
	Morphology	Cross-section profiles, longitudinal channel profiles, planform features (e.g. channel sinuosity or braiding), changes in rate of channel migration, bank stability
	Habitat quantity & quality	e.g. coefficient in variability of depth; heterogeneity of current velocities; presence of large woody debris; land cover
	Tidal sediment dynamics	Rates of change and locations for transport, deposition, erosion
Aquatic Ecology	Macroinvertebrates	Abundance, richness, biomass, proportions, diversity of species or groups
	Selected taxa	e.g. mayflies, snails, bivalves, flagship species – abundance, condition

Discipline Area	Type of Parameter or Indicator	Parameter and Indicator Examples
Fisheries	Fish and OOAs populations & biology	Species diversity, composition, abundance, biomass, size, condition
	Fishing activities	Number of fishers, boats, gear; catches as CPUE or consumption (kg/hh/yr)
Socio-economic	Economic development	Population growth rate; national income/expenses from/to hydropower; GDP; income level and distribution (including poverty); taxes and subsidies (related to hydropower); employment statistics; number and types of industries; electricity demand; urbanisation - migration/urban growth; extent and production of irrigated areas; tourism; income mix.
	Livelihoods	Full-time and part-time fishers; access to riverbank gardens; number of HHs resettled; scale of river transport; scale of sand mining.
	Dependency on water-resources	% people fishing in river and connected wetlands; % of fish and OAA/P based diet
	Vulnerability and resilience	Poverty incidence; mobility (migration); education level; household size, dependency rate (household age structure); percent of households with non-aquatic sources of income.
	Community living conditions	Access to affordable electricity; access to services (health, education, water supply); employment; road types and density; investment levels; resettlements; culturally sensitive areas affected.
	Food security	Level of food security, including nutrition; freshwater/ aquaculture/ marine fish and OAA/Ps in diet; CPUE.
	Benefit sharing	Access to and price of electricity for communities affected by hydropower; existence and levels of cash transfers to those.
	Capacity building	Reservoir stocking; cage aquaculture; resettlement; reservoir leisure and tourism activities.
	Climate change	National CO_2 emissions from power production; level of CDM funding of hydropower
	Hydropower plants	Numbers, location, size of hydropower plants of different types

Further development of the multi-criteria evaluation could be based on a combined economic and financial analysis together with an assessment of non-monetized environmental benefits, shortly described below and to be developed further during the Final Phase. The economic assessment of alternative designs and operations, due to recommended mitigation options, could be through a comparison of indicators (net present value – NPV, economic internal rate of return – EIRR, benefit-cost ratio – B/C, etc.) calculated on the basis of net benefits (benefits minus costs valued in economic terms (alternative value)) over a time period of say 25 years of operation. This calculation will be net of all taxes, duties and subsidies. The financial assessment of alternative designs and operations, due to recommended mitigation guidelines, could be through a comparison of indicators (net present value – NPV, financial internal rate of return – FIRR, levelled power tariff, etc.) calculated on the basis of net cash flow (revenues minus costs) over a time period.

The economic and financial indicators above could then be weighed against a ranking of selected monetized and non-monetized environmental benefits and risks. Assessment of environmental benefits from proposed mitigation options can be undertaken by use of some of the most promising indicators described in Table 7.1. These indicators can be ranked to the scale outlined in Table 7.2 (or alternatively a +/- 5 scale range). The indicators can them be pooled to come up with and overall ranking of monetized and non-monetized environmental benefits from the proposed mitigation measures. Lastly the ranking of the non-monetized benefits can be weighed against the economic and financial assessment to come up with a final pooled multi-criteria evaluation of the mitigation recommendations. This approach is also embedded in the Portfolio Planning Concept of ISH02 as portrayed below.

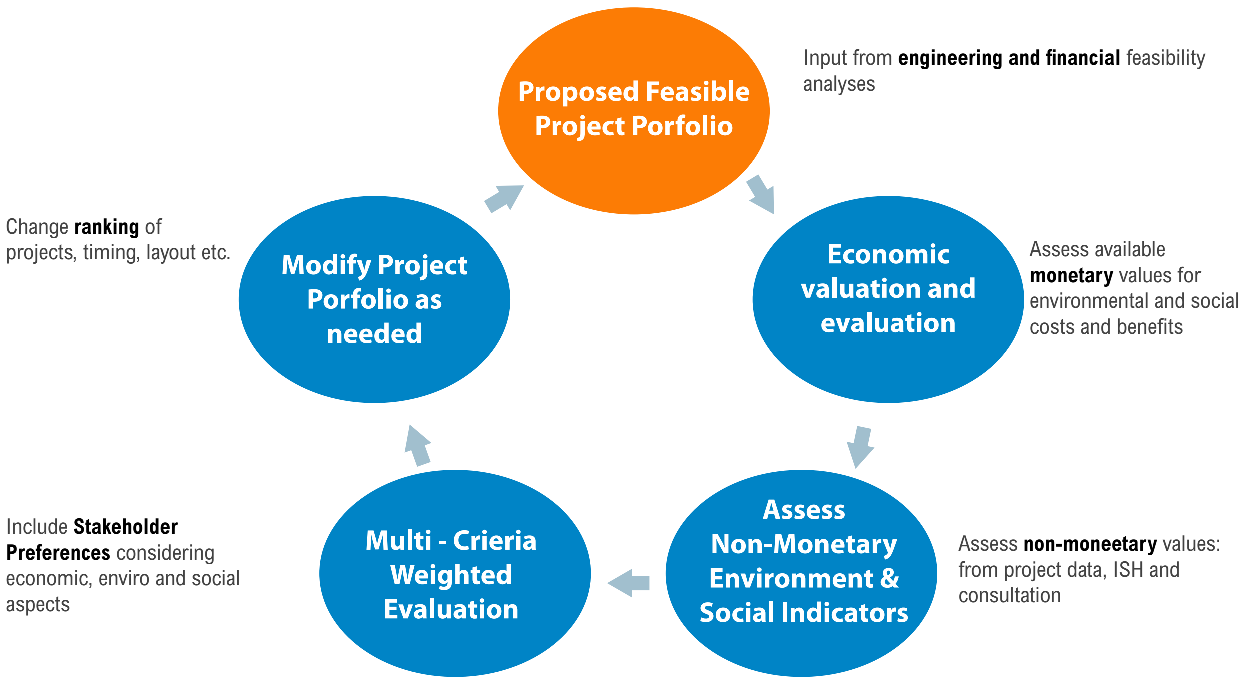


Figure 7.1: The Portfolio Planning Concept for evaluation of hydropower and multipurpose planning portfolios (Source: MRC, 2015).

References

The full set of references is provided at the end of the Manual. Further documentation is also available in the Knowledge Base..

ANNEXES

Annex 1. Hydropower Development on the Mekong

Overview

Hydropower's potential contribution to energy and water management goes beyond domestic and national electricity generation. As both power and water issues spill over national boundaries, as is the case of LMB, hydropower offers potential benefits to regional development. From the energy perspective it can help stabilize the regional electricity grid systems through unique services such as storage and regulating capacity and load following and reduce costs through coordination with solar, wind and thermal plants. Good practise in managing hydropower and water resources demands a river basin approach, regardless of national borders. Ensuring effective development and management of water infrastructure can help balance upstream and downstream interest and transform a potential source of conflict into a tool for regional cooperation and development (WB, 2009). As such MRC's initiatives in developing design and mitigation guidelines is an integral tool for this regional cooperation and development, given the vast plans for hydropower development on Mekong mainstream and the tributaries. Hydropower will also likely play a key role in climate resilience and adaptation as a renewable source of energy which can contribute to the reduction of GHG and to adaptation to changes from the foreseen increase in hydrological variability, e.g. help mitigate drought and floods. Furthermore, from the lessons learned of the past decade or so, hydropower is increasingly recognized as providing multiple opportunities to significantly enhance community, regional, national and transboundary development if planned, designed and implemented in a sustainable manner, including implementation of good industrial practise mitigation guidelines and options.

Lancang River

Introduction

The upper reach of the Mekong River rises as the Zaqu River on the Tibetan Plateau in Qinghai province, China and flows through the Tibetan Autonomous Region and then through the Yunnan Province as the Lancang River until it arrives at the meeting point of the borders of Myanmar, Laos and China.

Lancang River is divided into the Yunnan catchment, Tibet catchment and Qinghai catchment, respectively. The Yunnan catchment is further divided into the upper and lower Yunnan. Most of the large hydropower projects under construction and operation are in the Yunnan catcment.

Figure A.1.1 identifies the majority of locations of existing and planned hydropower projects on the mainstream of the Lancang (Zaqu) River. The approximate number of hydropower projects under construction, planned and in operation on the Lancang River in China are summarised in Table A.1.1 and are listed in greater detail in Table A.1.2.

Table A.1.1: Existing, under construction and planned hydropower schemes per province.

Province	Existing, Under Construction & Planned Hydropower Schemes (No.)
Qinghai, China	10
Tibet Autonomous Region	13
Yunnan, China	14
Total	**37**

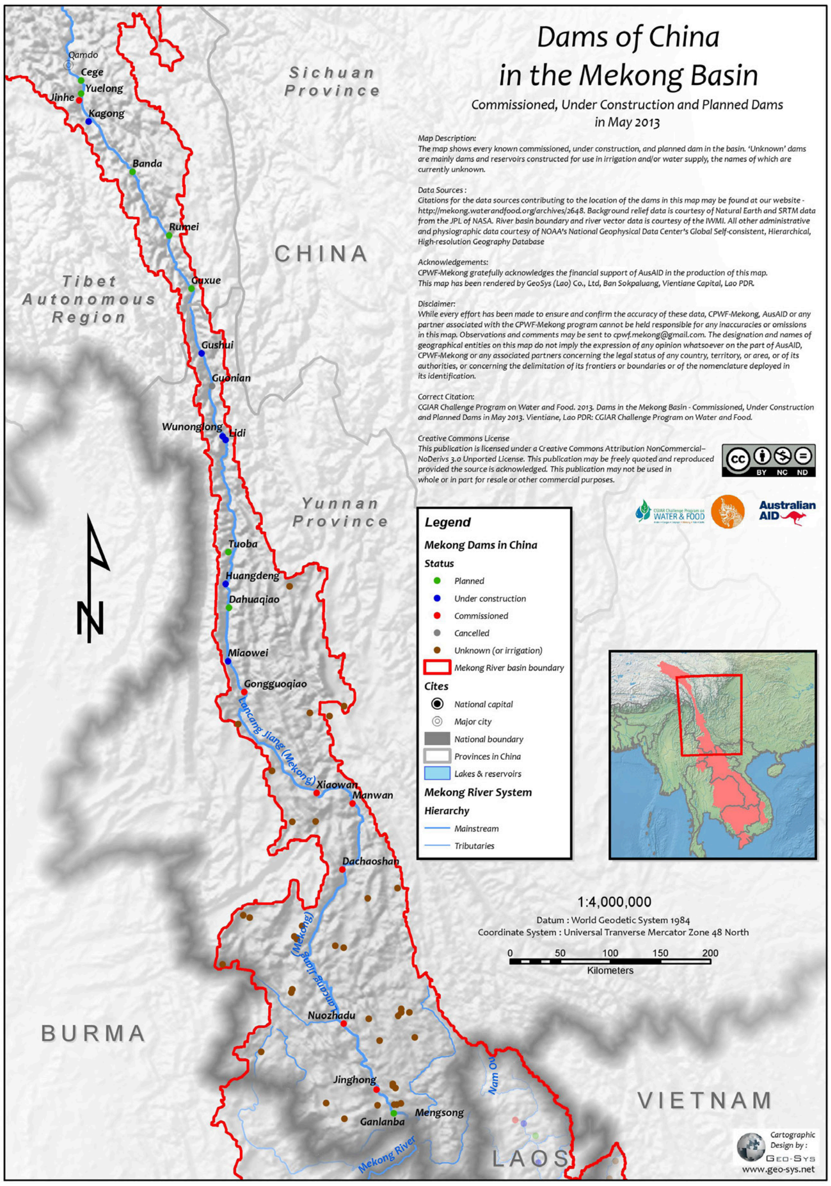


Figure A.1.1: Hydropower Projects Planned, under Construction or in Operation on the Lancang River in 2013.

Lancang River Hydropower Schemes

A summary of the hydropower projects that are planned, under construction or in operation is presented in Table A.1.2. (Ref: Major Dams in China, International Rivers, November 2014, combined with information from the same document dated 2012; 2013 Update: Dams on the Drichu (Yangtze), Zachu (Mekong) and Gyalmo Ngulchu (Salween) rivers on the Tibetan Plateau; Dams and Development in China: The Moral Economy of Water and Power and Yunnan's Fast-Paced Large Hydropower Development, MDPI Water, October 2016).

Table A.1.2: Planned or constructed hydropower schemes on Lancang River, China and Tibet Autonomous Region.

Name of Project	Province, Country	Status	Installed Capacity (MW)
Ganlanba	Yunnan, China	Operational	155
Jinghong	Yunnan, China	Operational	1750
Nuozhadu	Yunnan, China	Operational	5850
Dachaoshan	Yunnan, China	Operational	1350
Manwan	Yunnan, China	Operational	1550
Xiaowan	Yunnan, China	Operational	4200
Gongguoqiao	Yunnan, China	Operational	900
Miaowei	Yunnan, China	Under Construction	1400
Dahuaqiao	Yunnan, China	Under Construction	920
Huangdeng	Yunnan, China	Under Construction	1900
Tuoba	Yunnan, China	Planned	1400
Lidi	Yunnan, China	Under Construction	420
Wunonglong	Yunnan, China	Under Construction	990
Gushui	Yunnan, China	Planned	1800
Baita	Tibet Autonomous Region	Planned	Unknown
Guxue	Tibet Autonomous Region	Site Preparation	2400
Bangduo	Tibet Autonomous Region	Under Active Consideration	Unknown
Rumei	Tibet Autonomous Region	Site Preparation	2400
Banda	Tibet Autonomous Region	Site Preparation	1000
Kagong	Tibet Autonomous Region	Site Preparation	240
Yuelong	Tibet Autonomous Region	Planned	100
Cege	Tibet Autonomous Region	Planned	160

Name of Project	Province, Country	Status	Installed Capacity (MW)
Linchang	Tibet Autonomous Region	Planned	72
Ruyi	Tibet Autonomous Region	Planned	114
Xiangda	Tibet Autonomous Region	Planned	66
Guoduo	Tibet Autonomous Region	Operational	165
Dongzhong	Tibet Autonomous Region	Planned	108
Niangla	Qinghai, China	Unknown	Unknown
Zhaqu	Qinghai, China	Operational	Unknown
Gongdou	Qinghai, China	Unknown	Unknown
Dariaka	Qinghai, China	Unknown	Unknown
Atong	Qinghai, China	Unknown	Unknown
Angsai	Qinghai, China	Planned	55
Saiqing	Qinghai, China	Unknown	Unknown
Longqingxia	Qinghai, China	Operational	2.5
Aduo	Qinghai, China	Unknown	Unknown
Shuiasai	Qinghai, China	Unknown	Unknown
		Total	**31517.5**

The scale and pace of the exploitation of Lancang River for its hydropower potential has gained momentum since the 1980's. As noted from Table A.1.2, there are nine operational schemes with combined installed capacity of 15,757.5 MW, and a further six schemes with a combined installed capacity of 5,795 MW under construction. In addition there are four schemes where site preparation has commenced with a combined installed capacity of 6,040 MW.

There are approximately eight hydropower projects in the Qinghai province of China currently planned. Two further hydropower projects, Zhaqu and Longqingxia, are operational. In Tibet Autonomous Region, there are approximately 12 hydropower projects, of which one is currently under construction. The 165 MW Guoduo hydropower project was completed in 2015 and the 240 MW Kagong hydropower project is reported to be commencing site preparation.

Reliable information concerning hydropower development in the upstream reach of the Lancang River, both in Tibet Autonomous Region, and Qinghai province of China, is difficult to obtain. There are approximately seven projects with an unknown status and installed capacity.

In China, hydropower is promoted as the best possible alternative to coal-fired power stations. It is intended that hydropower development will significantly contribute to the target of 15 % of renewable energy by 2020.

The main operational hydropower schemes on the Lancang River are reported from various sources to be as follows:

Jinghong Dam

The Jinghong Dam hydropower project is located in the southern part of Yunnan Province, China. The project is designed for power generation but also for flood control and navigation purposes. The construction of the scheme started in 2005, with the first unit entering commercial operation in 2008. The project was reported to be fully operational in 2009.

The scheme has an installed capacity of 1,750 MW, and comprises the following main structures:

Figure A.1.2: *Jinghong Dam (Source www.flickr.com).*

- Main Dam (RCC gravity dam, 704.5 m long and 108 m high).
- Power house containing 5 x 350 MW Francis turbine generator units
- Spillway structure
- Ship lock

Nuozhadu Hydropower Project

The Nuozhadu hydropower project is located in the Yunnan Province of China. The project is designed mainly for power generation but also fulfils multifunctional purposes such as flood control and improvement of downstream navigation. The scheme has an installed capacity of 5,850 MW, which is reported to be the largest hydropower station along the Lancang River and in Yunnan Province. The project comprises the following main structures:

- Main Dam (central core rockfill dam, 608 m long and 261.5 m high).
- Power house containing 9 x 650 MW turbine generator units
- Gated side channel spillway.

The scheme has been operational since 2012, with the last unit commissioned in 2014. The reservoir created by the dam allows for major seasonal regulation.

Figure A.1.3. *Nuozhadu Hydropower Project (Source www.flickr.com).*

Dachaoshan Hydropower Project

The Dachaoshan hydropower project, located on Lancang River, Yunnan province, is a single purpose project for power production. The project has an installed capacity of 1,350 MW and commenced commercial operation in 2003. The project comprises the following main structures:

- Main Dam (RCC gravity dam, 460 m long and 111 m high).
- Power house containing 6 x 225 MW Francis turbine generator units
- Crest overflow gated spillways

Figure A.1.4: *Dachaoshan Hydropower Project (Source www.flickr.com).*

Manwan Hydropower Project

The Manwan hydropower project, located on Lancang River, has an installed capacity of 1,550 MW and comprises the following main structures:

Figure A.1.5: *Manwan Hydropower Project.(Source: www.flickr.com).*

- Main Dam (concrete gravity dam, 418 m long and 132 m high).
- Power house containing 5 x 250 + 1 x 300 MW Francis turbine generator units
- Crest gated spillway and a tunnel spillway

The Manwan Hydropower Station began operation in 1996 and has been subject of extensive studies as the first large scale hydropower station on the Lancang River.

Xiaowan Hydropower Project

The Xiaowan hydropower project is a significant component of the Lancang River cascade. Its main purpose is electricity generation. It is one of the world's highest arch dams at 292 m and it creates a large reservoir which is acting as a sediment retention buffer for the Manwan and Dachaoshan hydropower projects. The Xiaowan hydropower project has an installed capacity of 4,200 MW, and comprises the following main structures:

- Main Dam (double curvature arch dam, 902 m long and 292 m high).
- Power house containing 6 x 700 MW Francis turbine generator units
- Crest gated spillway and a tunnel spillway

The construction of the scheme commenced in 2002. The first unit entered commercial operation in 2009 and last unit was commissioned in 2010. The size of the reservoir created by the dam allows for major seasonal regulation.

Figure A.1.6: *Xiaowan Hydropower Project. (Source: Mekong River Commission).*

Gongguoqiao Dam

The 900 MW Gongguoqiao hydropower project comprises the following main structures:

Figure A.1.7: *Gongguoqiao Dam (Source: www.flickr.com).*

- Main Dam (gravity, roller compacted concrete dam, 356 m long and 105 m high).
- Power house containing 4 x 225 MW Francis turbine generator units
- Crest gated spillway and a tunnel spillway

The construction of the project started in 2008 and the scheme commenced commercial operation in 2011. The last unit was commissioned in 2012.

Implications of Hydropower Development on the Lancang River

The development of hydropower projects on the Lancang River has implications for the Mekong River downstream. However, the impact on average flow diminishes gradually downstream as the overall contribution of the Lancang to the Mekong at the delta is only approximately 16%, albeit the Case Study assessment (MRC, 2018) indicates that flow impacts of the Lancang major storage dams is noticeable in the upper parts of LMB, and especially during extreme events.

Changes in flow due to the Lancang cascade may include:

- Peak flows decreased and lower annual flood volumes,
- Early flood season flows lower and later flood season flows higher,
- Later start and end of flood season conditions, and
- Increased dry season flows.

As an example, estimates for the change of flows for Chiang Saen (Northern Thailand), downstream of Lancang cascade, are 17-22% decrease in flow in June – November, and 60 – 90% increase in flow in December – May. The estimates for Kratie (Cambodia) are 8 – 11% decrease in flow in June – November, and 28 – 71 % increase in flow in December – May (Source: Mekong River Commission).

Although the annual average flows may not vary substantially, at least further downstream LMB, monthly and shorter time-frame changes in flow have an impact on fisheries and sediment transport. There are concerns about sediment transport and possible impacts of the dams due to sediment trapping for the Lower Mekong Basin, and a decrease has actually been reported in the Case Study assessment (MRC, 2018). The river channel is responding to reduced sediment input, altered timing of flows and altered timing of sediment delivery, including increased bank erosion or channel incision, loss of riparian vegetation, increased exposure of bedrock or armouring of riverbed.

Furthermore, the water quality risks due to hydropower development on the Lancang River include nutrient growth in impoundments due to increased nutrients and light, low dissolved oxygen in impoundments and increased water temperature downstream. Water quality in Lancang reservoirs is further affected by land use as run off from rubber plantations, mining and possible increase of agricultural opportunities due to the access to water for irrigation purposes.

As an example of sedimentation on Lancang cascade, a bathymetric survey was conducted for the Manwan dam in 1996 (3 years after the closure of the dam), which showed that the elevation of the bottom of the reservoir was 30 m higher compared to when the dam was constructed. Since then, the Xiaowan dam, impounding a large reservoir upstream of Manwan, has been constructed, and the sediment load incoming to the Manwan reservoir has been greatly reduced. It is noted, however, that water quality has improved through co-operative operation of Manwan and Dachaoshan Dams.

The reduction in sediment load, altered timing of sediment delivery and delayed onset of flood are representing challenges for mitigation in the Lower Mekong Basin (see also MRC, 2017c). The flow regime and sediment timing of mainstream are going to be further altered by tributary hydropower developments.

The impacts of Lancang development on fisheries and aquatic ecology are mainly due to connectivity interruptions, impoundments, sedimentation, hydrological and water quality alterations and associated cumulative effects.

Lower Mekong Basin

Introduction

The lower Mekong Basin downstream of the Chinese border comprises the majority of the land area of Lao PDR and Cambodia, the northern and northeast regions of Thailand and the Mekong Delta and Central Highland regions of Viet Nam.

Figure A.1.8 identifies the majority of locations of existing and planned hydropower projects on the mainstream of the lower Mekong Basin and its tributaries. With reference to Figure A.1.8 and data obtained from the Lao PDR Ministry of Energy and Mines, the approximate number of existing and planned hydropower projects per country is presented in Table A.1.3. It is evident from Table A.1.3 that the majority of hydropower projects in the lower Mekong Basin are located in Lao PDR.

Existing and planned hydropower projects

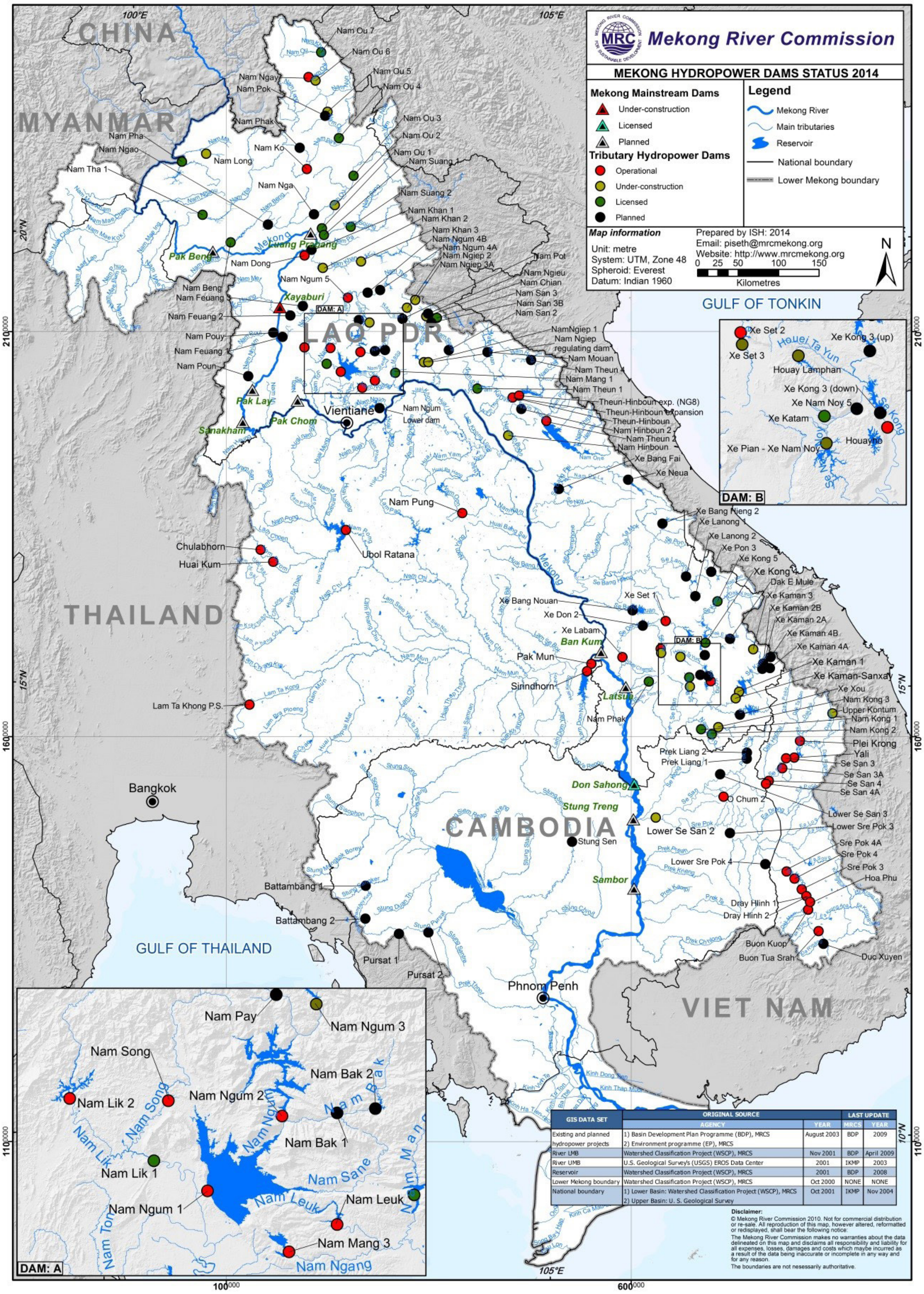


Figure A.1.8: Hydropower Dams (operational, under construction, licensed and planned) on the Lower Mekong mainstream and tributaries in 2014 (Source: Mekong River Commission ISH).

Table A.1.3: Lower Mekong Basin Existing and Planned Hydropower Schemes.

Country	Existing & Planned Hydropower Schemes (No.)
Lao PDR	135
Viet Nam	16
Thailand	7
Cambodia	6
Total	164

Lower Mekong Basin – Mainstream

Proposed dams on the Lower Mekong mainstream are listed in Table A.1.4 and identified in Figure A.1.8. Of these, ten would involve construction of dams across the entire river channel, eight within Lao PDR and two in Cambodia. The Don Sahong project within Lao PDR will involve commanding only the Hou Sahong Channel leaving the other channels of the Mekong at Khone Falls uninterrupted. The Sambor project included in the table is the smaller alternative dam that will include a natural sediment and bypass channel.

Table A.1.4: Mainstream Hydropower Schemes.

Name of Project	Country	Status	Installed Capacity (MW)
Pak Beng	Lao PDR	Planned	912
Luang Prabang	Lao PDR	Planned	1,460
Xayaburi	Lao PDR	Under construction	1,285
Pak Lay	Lao PDR	Planned	770
Sanakham	Lao PDR	Planned	660
Pak Chom	Lao PDR	Planned	1,079
Ban Khoum	Lao PDR	Planned	2,000
Pou Ngoy (Lat Sua)	Lao PDR	Planned	651
Don Sahong	Lao PDR	Under construction	260
Stung Treng	Cambodia	Planned	980
Sambor[4]	Cambodia	Planned	1,703
		Total	11,760

(Ref DEB July 2015, updated 2019)

4 Alternative to the original Sambor that was 2600 MW (Wild and Loucks, 2015).

Lower Mekong Basin – Tributaries

Hydropower schemes on the tributaries of the lower Mekong have been identified in relation to the catchments within which they are located and for clarity Figure A.1.9 shows the many catchments that make up the lower Mekong basin.

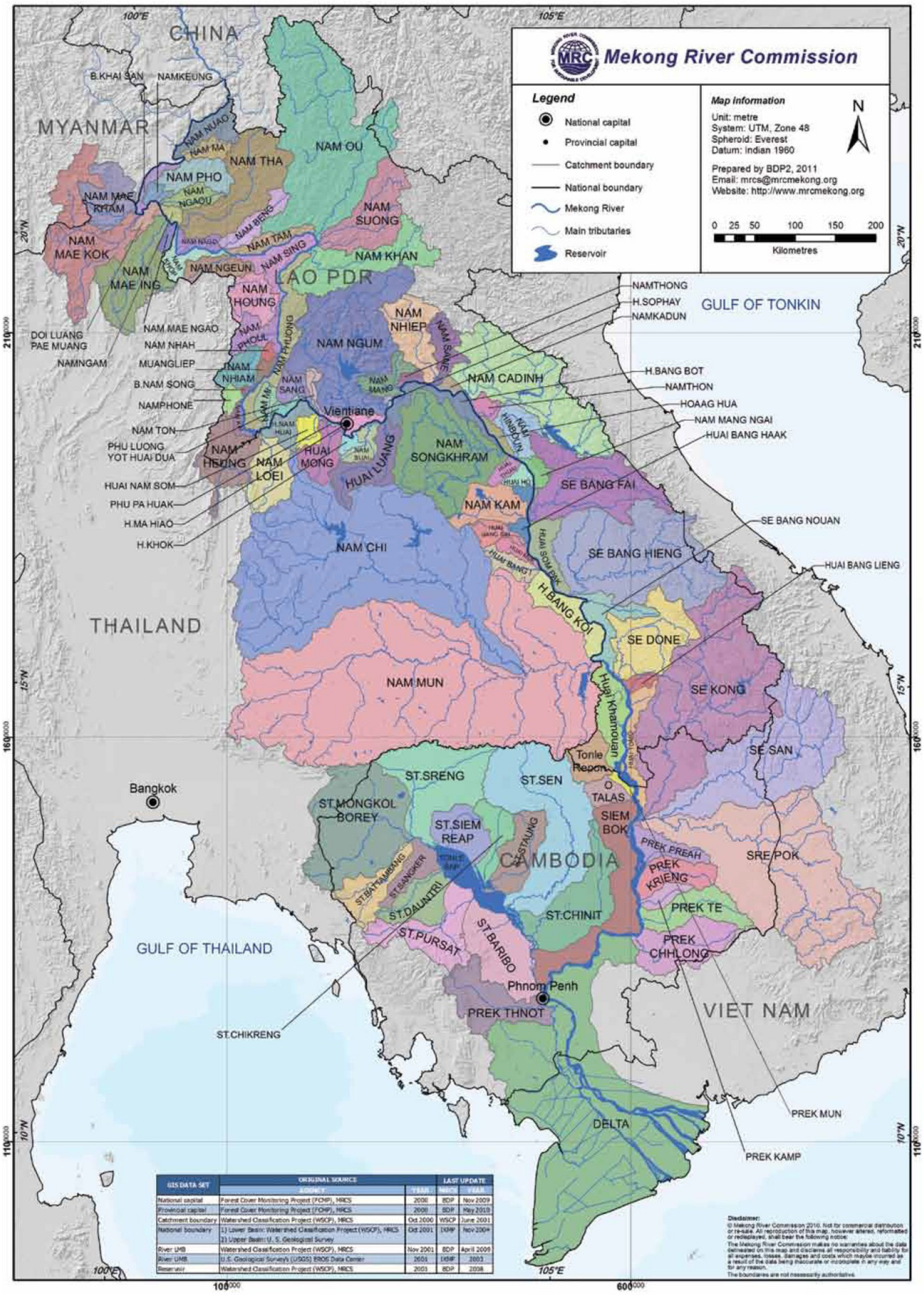


Figure A.1.9: Catchments of the Lower Mekong Basin (Source: Mekong River Commission Planning Atlas).

Tributary hydropower schemes have been classified as either operational, under construction or licensed/planned. Tables A.1.5 and A.1.6 present schemes that are classified as operational or under construction. These have been arranged by catchment. Data has been sourced from Lao PDR Ministry of Energy; Update of the Status of Mekong Mainstream Dams, International Rivers, June 2017; Study of Independent Power Producers in Lao PDR, Ministry of Economy, Trade and Industry, February 2017 and Figure A.1.8.

Table A.1.5: Operational Hydropower Projects on Mekong Tributaries (2017).

Catchment	Name of Project	Country	Installed Capacity (MW)
Nam Ma	Nam Long	Lao PDR	5
Nam Tha	Nam Nhone	Lao PDR	3
Nam Beng	Nam Beng	Lao PDR	34
Nam Ou	Nam Ko	Lao PDR	2
	Nam Ngay	Lao PDR	1
	Nam Ou 2	Lao PDR	120
	Nam Ou 5	Lao PDR	240
	Nam Ou 6	Lao PDR	180
Nam Khan	Nam Mong	Lao PDR	1
	Nam Dong	Lao PDR	1
	Nam Khan 2	Lao PDR	130
Nam Ngiep	Nam Ngiep 3A	Lao PDR	44
	Nam Ngiep 2	Lao PDR	180
Nam Mang	Nam Mang 3	Lao PDR	40
	Nam Mang 1	Lao PDR	64
	Nam Leuk	Lao PDR	60
Nam Ngum	Nam Ngum 1	Lao PDR	155
	Nam Ngum 2	Lao PDR	615
	Nam Ngum 5	Lao PDR	120
	Nam Lik 1-2	Lao PDR	100
	Nam Song	Lao PDR	6
Nam San	Nam San 3A	Lao PDR	69
	Nam San 3B	Lao PDR	45

Catchment	Name of Project	Country	Installed Capacity (MW)
Nam Kading	Nam Theun 2	Lao PDR	1,080
	Theun-Hinboun	Lao PDR	220
	Theun-Hinboun Expansion	Lao PDR	280
Xe Bang Hieng	Tad Salen	Lao PDR	3
Xe Done	Xe Set 1	Lao PDR	45
	Xe Set 2	Lao PDR	76
	Xe Labam	Lao PDR	5
Xe Kong	Houay Ho	Lao PDR	152
	Xe Kaman 3	Lao PDR	250
Se San	O Chum 2	Cambodia	1
	Plei Krong	Viet Nam	100
	Yali	Viet Nam	720
	Se San 3	Viet Nam	260
	Se San 3A	Viet Nam	96
	Se San 4	Viet Nam	360
	Se San 4A	Viet Nam	63
Sre Pok	Sre Pok 3	Viet Nam	220
	Sre Pok 4	Viet Nam	80
	Sre Pok 4A	Viet Nam	64
	Hoa Phu	Viet Nam	29
	Dray Hinh 1	Viet Nam	12
	Dray Hinh 2	Viet Nam	16
	Buon Kuop	Viet Nam	280
	Buon Tua Srah	Viet Nam	86
Nam Kan	Nam Pung	Thailand	6

Catchment	Name of Project	Country	Installed Capacity (MW)
Nam Mun	Pak Mun	Thailand	136
	Iam Ta Khong P.S.	Thailand	500
	Sirindhorn	Thailand	36
Nam Chi	Chulabhorn	Thailand	40
	Huai Kum	Thailand	1
	Ubol Ratana	Thailand	25
Unknown	Nam Ken	Lao PDR	3
		Total	**7,461**

Table A.1.6: Hydropower Projects Under Construction on Mekong Tributaries (2017).

Catchment	Name of Project	Country	Installed Capacity (MW)
Nam Pho	Nam Pha	Lao PDR	130
Nam Tha	Nam Tha 1	Lao PDR	168
Nam Ou	Nam Phak	Lao PDR	45
	Nam Ou 1	Lao PDR	180
	Nam Ou 3	Lao PDR	210
	Nam Ou 4	Lao PDR	132
	Nam Ou 7	Lao PDR	210
	Nam Khan 3	Lao PDR	60
Nam Ngiep	Nam Ngiep regulating dam	Lao PDR	18
	Nam Ngiep 1	Lao PDR	272
		Lao PDR	180
Nam Ngum	Nam Bak 1	Lao PDR	163
		Lao PDR	61
	Nam Phay	Lao PDR	86
	Nam Ngum 3	Lao PDR	480
	Nam Chien	Lao PDR	104
Nam Kading	Nam Theun 1	Lao PDR	670

Catchment	Name of Project	Country	Installed Capacity (MW)
Nam Hinboun	Nam Hinboun	Lao PDR	30
Nam Sam	Nam Sam 3	Lao PDR	156
Nam Mo	Nam Mo 2	Lao PDR	120
Se Kong	Xe Pian & Xe Namnoy	Lao PDR	390
	Xe Kaman 1	Lao PDR	322
	Se Set 3	Lao PDR	23
	Nam Kong 1	Lao PDR	150
	Nam Kong 2	Lao PDR	66
	Nam Kong 3	Lao PDR	45
Se San	Lower Se San 2	Cambodia	400
	Upper Kontum	Viet Nam	220
Unknown	Nam Sim	Lao PDR	8
		Total	**5,099**

In addition to schemes that are operational or under construction, there are in excess of 70 schemes planned for development on the tributaries of the Mekong. Seven planned schemes are known to be licensed with the largest, Nam Theun 1, having a planned installed capacity of 670MW.

Annex 2. International Practise, Policy and Safeguards on Mitigating Hydropower Risks and Impacts

This section describes Good Industrial Practise internationally related to mitigation of risks, impacts and vulnerabilities from hydropower development (as summarized for LMB in Chapter 6). Henceforth, it is not part of the guidelines and recommendations as such but meant to support the latter. In the following is the most relevant practises, policy's and safeguards from important agencies, organisations and initiatives internationally.

Asian Development Bank (ADB) Safeguard Policies

The Safeguard Policy Statement approved in June 2009 comprises the safeguard requirements for lending and project financing by the Asian Development Bank (ADB). ADB's safeguard policy framework is composed of three operational policies on the environment, Indigenous Peoples and involuntary resettlement. The operational policies are further elaborated in operational manuals on environmental considerations in ADB operations. Finally, ADB has issued two handbooks on Resettlement (1998) and Environmental Assessment (2003) that are providing information on good practise approaches to implementing safeguards.

In Appendix 1 of the safeguard requirements regarding environmental impacts are set out. The requirements do not specifically address hydropower deployment but lists Environmental Assessment and preparation of an Environmental Management Plan as the basic requirements associated with developments. As a part of the Environmental Assessment project impacts and risks on biodiversity and natural resources shall be assessed. The aspects most relevant for hydropower development in general, and Mekong mainstream and tributary hydropower development projects in particular, are the requirements regarding natural habitats. The main requirement is that a project shall not adversely affect and significantly convert or degrade natural habitats unless alternatives are available or it is demonstrated through a comprehensive analysis that the overall benefits from the project will substantially outweigh the project costs, including environmental costs. In addition any conversion or degradation shall be appropriately mitigated and the mitigation measures shall aim at achieving at least no net loss of biodiversity.

World Bank Safeguard Policies

The World Bank's (IBRD) Set of Safeguard Policies consist of a number of Operational Policies (OPs) Operational Directives (ODs) and Bank Procedures (BPs). The Environmental Assessment (EA) Policy (OP/BP 4.01) is the Bank's umbrella safeguard policy which sets out a number of specific requirements for environmental and social investigations that shall be carried out for major infrastructure projects, including hydropower projects, before a support in terms of guarantees and loans can be considered.

The EA Policy does not deal with or mention hydropower development projects specifically but states in general terms that the Environmental Management Plan (EMP) identifies feasible and cost-effective measures that may reduce potentially significant adverse environmental impacts to acceptable levels. It is furthermore required that the EMP describes each mitigation measure in detail including technical designs, equipment descriptions and operating procedures.

Of the Banks other safeguard policies Natural Habitats (OP/BP 4.04), Safety of Dams (OP/BP

4.37) and International Waterways (OP/BP 7.50) also have important implications for hydropower projects. Regarding Natural Habitats it is stated that the Bank does not support projects that, in the Bank's opinion, involve the significant conversion or degradation of critical natural habitats.

The Safety of Dams Policy requires that experienced and competent professionals design and supervise construction, and that the dam safety measures are implemented throughout the project cycle.

The International waterways Policy seeks to ensure that all concerned and affected riparian countries on an international waterway are notified about hydropower development and other water-use projects are invited to express their views on the project.

International Finance Corporation (IFC)

IFC is one of the five organizations that forms the World Bank Group. While the World Bank (IBRD) provides loans and guarantees for governments and public sector projects IFC caters to private sector clients in developing countries.

IFC has developed a Sustainability Framework aimed at promoting sound environmental and social practices as well as transparency and accountability. IFC's Environmental and Social Performance Standards, that constitute a vital part of the Sustainability Framework, were first launched in 2006 while the latest revision was carried out in 2012. Today the IFC Performance standards have been recognized across the world as the benchmark for environmental and social risk management in the private sector.

There are eight separate Performance Standards dealing with the main sustainability aspects of a project. The first Performance Standard, Assessment and Management of Environmental and Social Risks and Impacts, requires borrowers to carry out an integrated assessment to identify the environmental and social impacts as well as risks, and opportunities related to their projects. The establishment of an environmental management system to manage environmental and social performance throughout the life of the project is also demanded.

The other Performance Standards set out objectives and requirements to avoid, minimize and compensate for impacts to workers, affected communities and the environment.

In the context of environmental impacts related to hydropower development Performance Standard 6, Biodiversity Conservation and Sustainable Management of Living Natural Resources, is one of the most important. Natural Habitats are here defined as intact geographical areas composed of plant and animal species of largely native origin. The main requirement is that a project shall not significantly convert or degrade natural habitats, unless no other viable alternatives exist or, where feasible, all impacts on the habitat will be mitigated so that no net loss of biodiversity occurs.

The Performance Standards are complemented by the separate Guidance Notes providing more details of the requirements under each Standard.

In addition to the Performance Standards IFC has developed Environmental Health and Safety (EHS) Guidelines which are technical reference documents with general and specific examples of Good International Industry Practices. They consist of the cross cutting General EHS guidelines applicable to all sectors plus eight industry specific guidelines whereof the power sector is one. However, so far guidelines have been made only for wind energy, geothermal power generation, thermal power plants and transmission lines while guidelines for hydropower are yet to be developed.

The IFC has also published a Good Practise Handbook for Rapid Cumulative Impact Assessment (IFC, 2013) amongst other with focus on required steps in the process and involvement of stakeholders. The Handbook is meant to be a Guidance for the private sector in emerging markets. This handbook is relevant for cumulative impact assessments on the Mekong and its tributaries.

The World Commission of Dams

The World Commission on Dams issued their report, Dams and Development in 2000. Part I of the report reviews the worldwide experience with large dams with regard to a number of aspects, among them the environmental performance which is dealt with in Chapter 2 of the Report. Part II of the report proposes a framework for decision making related to water and energy resources development and puts forward a set of criteria and guidelines for planning, constructing and operating large dams.

Chapter 8 of the WCD report presents seven broad strategic priorities for guiding the decision making regarding large dams and hydropower projects, including public acceptance, alternative options assessment, sustaining rivers and livelihoods and entitlements and benefit sharing.

Chapter 9 presents a set of guidelines for good practices for each of the Strategic Priorities. The most relevant regarding environmental impacts of hydropower development are probably Strategic Priority no. 14, 15 and 16 presented under Strategic Priority 4: Sustaining Rivers and Livelihoods

Guideline no 14 – Baseline Ecosystem Surveys - states that surveys are necessary to establish the link between the hydrological regime of a river and its associated ecosystems and that relevant information on the following should be collected:

- the biology of important fish species (especially migratory species);
- habitats for threatened or endangered species;
- important areas for biodiversity; and
- important natural resources for downstream communities.

Guideline no 15 – Environmental Flow Assessments - recommends that an environmental flow should be released to sustain downstream ecosystems and livelihoods. Finally, Guideline no. 16 – Maintaining Productive Fisheries - recommends that proposed fish passes should be tested hydraulically and shown to be efficient mitigation tools for facilitating and enabling migration of the target species. Regarding reservoir fisheries its potential and productivity should be rigorously assessed, based on regional experience from similar reservoir fisheries. The guideline further recommends that reservoir fisheries to be properly managed to:

- prevent the loss of endangered and/or commercially important fish species;
- maintain the fish stock;
- ensure the long-term sustainability of the fish populations; and
- produce fish for local consumption and export.

Although various stakeholders have expressed their concerns about the implementation of the policy principles and detailed guidelines in the Report a number of international banks, including the World Bank, have adapted many of the recommendations of the World Commission of Dams in their safeguards.

International Hydropower Association (IHA)

After a comprehensive consultation and review process involving the World Commission on Dams recommendations, the Equator Principles, the World Bank Safe Guard Policies and the IFC Performance Standards, the international Hydropower Association published their last version of their Hydropower Sustainability Assessment Protocol in 2010. The Protocol is intended to be a tool that promotes and guides development of more sustainable hydropower through offering a sustainability assessment framework for development of hydropower projects and operation of hydropower plants. In order to reflect the different stages of hydropower development, the Protocol includes four standalone sections covering four phases, Early Stage (project identification), Preparation, Implementation and Operation. The sustainability of a project is assessed on the basis of objective evidence to establish a score which is compared to statements of basic good practice and proven best practice within each sustainability topic. There are five scoring levels with Level 3 and 5 providing benchmark performance levels against which the other scoring levels are calibrated. Level 3 describes basic good practise while Level 5 describes proven best practise.

Relevant sustainability topics for evaluating environmental performance of hydropower projects in the Implementation phase are:

- Biodiversity and Invasive Species (I-15);
- Erosion and Sedimentation (I-16);
- Water Quality (I-17);
- Waste, Noise and Air Quality (I-18)
- Reservoir Preparation and Filling (I-19);
- Downstream Flow Regimes (I-20)

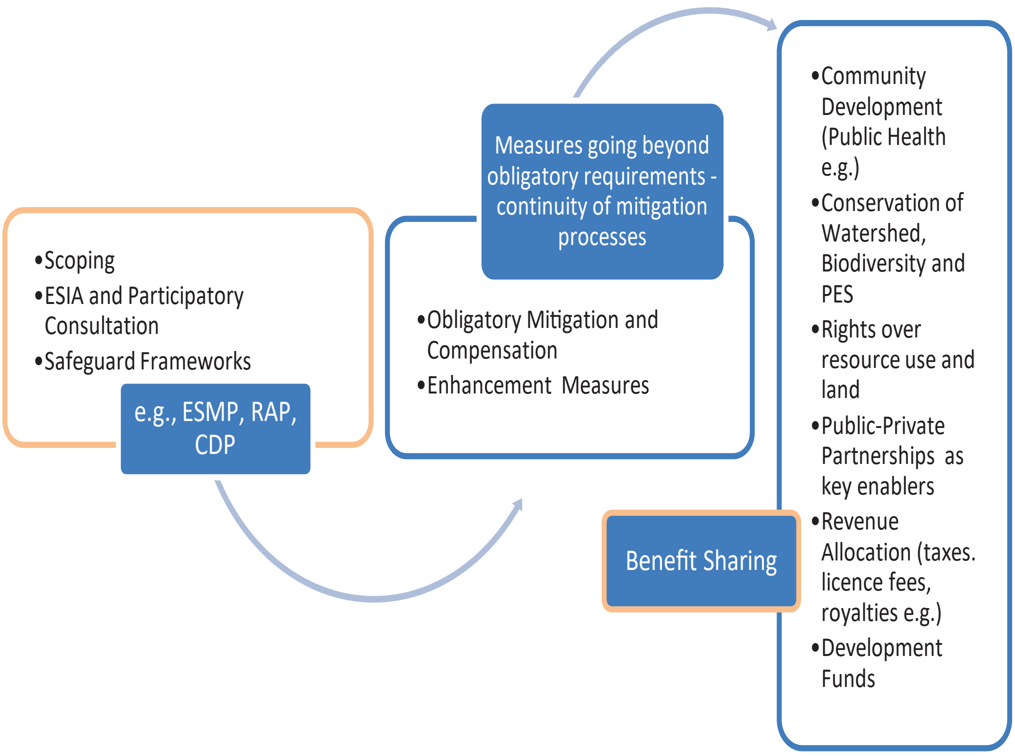
For a project to score 3 and be judged to apply basic good practice it is required that impacts within the sustainability topics during project implementation are avoided, minimised and mitigated with no significant gaps. To score 5 it is in addition required that enhancements to pre-project conditions or contribution to addressing impacts beyond those caused by the project are achieved or are on track to be achieved.

The IHA Assessment Protocol does not go into detail and describe what constitutes basic good practise and proven best practise for mitigating impacts within the more than 20 sustainability topics that it covers.

Benefit Sharing (MRC, WB and ADB)

Benefit sharing is a promising concept in sustainably implementing hydropower and water infrastructure projects, and is emerging as a supplement to the standard requirements of compensation and mitigation. It has been championed by MRC, WB and ADB in various fora's, initiatives and projects. For MRC it was implemented by Initiative for Sustainable Hydropower, through ISH13 (see for example MRC, 2014). Benefit sharing is being driven by a societal responsibility to ensure that local communities end up with something better than pre-project economic conditions. For benefit sharing to work, certain core mechanisms must be in place: policies and the regulatory framework (government), corporate social responsibility policies (project proponent), and community acceptance of the project. Cooperation among these three parties enables tripartite partnerships (Lillehammer, Martin, and Dhillion 2011).

Mitigation measures are normally anchored in commitments related to the environmental impact assessment and licensing processes, either in international guidelines or more specifically in national legislation and regulatory processes. Benefit sharing goes beyond these commitments and focuses on enhancing community development related to opportunities created by the projects instead of only mitigating impacts (WB, ASTAE, 2014). Figure 4.1 illustrates the relationship and differences between traditional compensation and mitigation measures compared with benefit sharing. Note the relevance of conservation of watershed and biodiversity through either Payment for Ecosystem Services (PES) or Develoment Funds, for this guideline.



(PES = Payment for Ecosystem Services, ESMP = Environmental and Social Management Plans, RAP = Resettlement Action Plan and CDP = Community Development Plan)

Figure A.2.1: Flow chart showing measures which go beyond their expected obligatory limits in quality and time (Source: Lillehammer, Martin and Dhillion, 2011).

Vietnam has been developing and piloting benefit sharing for local communities affected by hydropower projects since 2006. The A'Vuong hydropower project was selected as a pilot study for benefit sharing in Vietnam, where the government of Vietnam and the Asian Development Bank were involved. As part of the technical assistance, a draft decree on benefit sharing was prepared in 2008, for pilot testing for the A'Vuong project. The pilot was completed in 2010 and implemented by the Electricity Regulatory Authority of Vietnam in close cooperation with the Provincial People's

Committee of Quang Nam Province. The pilot included a wide range of actions such as direct involvement of communities and payments for ecological services.

Benefit Sharing might also be considered at transboundary level, through Joint Action, between the LMB member countries and beyond (see Case Study report for details. Joint Action can include opportunities for joint development and Benefit Sharing as considered by the recent MRC Benefit Sharing initiative (MRC, 2014 and 2015). This comprehensive review of good industry practice was undertaken with the MRC Member Countries and provides a supporting framework to guide the process. Joint Action represent the greatest level of coordination and cooperation at Basin Scale and is normally formalized in treaties and strong institutions, where benefit sharing arrangements such as joint ownership and management of assets can form the basis (Sadoff et al., 2008 and Lillehammer et al., 2011). The Lesotho Highlands Water Project (LHWP) with its Treaty (LHWC, 1986) is an example of Joint Transboundary Action (Lesotho and South Africa). The LHWP Treaty explicitly states how benefits from cooperative development will be shared (royalties from water, electricity from HPP, other ancillary benefits etc.).

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