MEKONG RIVER COMMISSION SECRETARIAT

Office of the Secretariat in Vientiane
184 Fa Ngoum Road, Ban Sithane Neua,
P.O. Box 6101, Vientiane, Lao PDR
Tel: (856-21) 263 263   Fax: (856-21) 263 264

Office of the Secretariat in Phnom Penh
576 National Road, no. 2, Chak Angre Krom,
P.O. Box 623, Phnom Penh, Cambodia
Tel: (855-23) 425 353 Fax: (855-23) 425 363

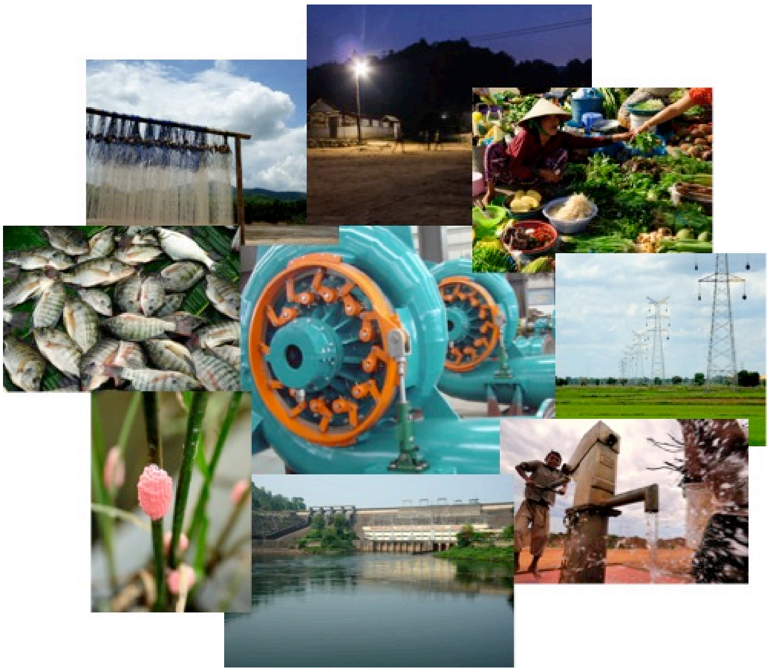
mrcs@mrcmekong.org

www.mrcmekong.org

MRC Initiative on Sustainable Hydropower (ISH)

GUIDING CONSIDERATIONS ON TRANSBOUNDARY MONITORING FOR LMB HYDROPOWER PLANNING AND MANAGEMENT

FINAL



16th December 2014

Produced by	MRC Initiative for Sustainable Hydropower
Produced for	MRC Member Countries
ISH11 Project Team authors	Dr Helen Locher, Team Leader, Sustainable Hydropower Specialist Dr Bruce Aylward, Economics Specialist Mr Kent Hortle, Fisheries Specialist Dr Lois Koehnken, Sediment, Water Quality & Hydrology Specialist Dr Jens Sjorslev, Social Specialist Dr Ilse Stubauer, Aquatic Ecologist
MRCS ISH Staff	Voradeth Phonekeo, ISH Programme Coordinator Simon Krohn, ISH Chief Technical Advisor

Document History

Document	Date	Authors	Status	Comment
Draft 1	26/08/2014	H Locher, B Aylward, K Hortle, L Koehnken, J Sjorslev, I Stubauer	Internal first draft for author review	Extracts from ISH11 Phase 2 Report
Draft 2	18/09/2014	As above	Internal second draft for author review	Minor refinements to Draft 1
Draft 3	26/11/2014	As above	Internal third draft for ISH review	Minor refinements to Draft 2
Final Draft	12/12/2014	As above	Submitted to MRC ISH	Minor refinements to Draft 3
Final	16/12/2014	As above	Final	Expanded information in Table 8 to present a more up-to-date view of the work on socio-economic indicators

Executive Summary

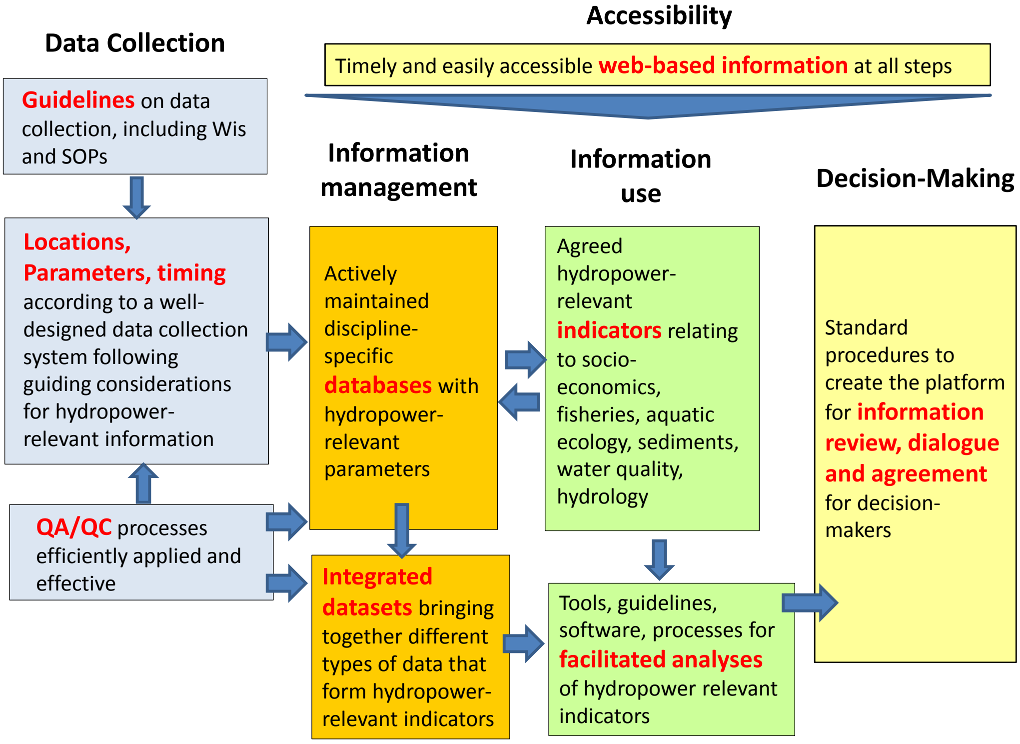
The lower Mekong River and surrounding basin are undergoing rapid development pressures, with hydropower a significant growth area. The Mekong River Commission (MRC) plays an important role in coordinating monitoring in the LMB, completing quality control checks and making information available that can support hydropower information needs, and subsequently enhance cooperation in development of the Mekong resources.

From a basin-scale perspective, hydropower information need include information about the availability and condition of the water resource and its linkages with environmental and socio-economic conditions in the basin, how these are changing over time, and how they may change under future hydropower developments. These inputs inform hydropower project siting and design, prediction of changes relating to the project, and development, application and evaluation of mitigation and management measures. This information provides a common basis for constructive discussions by communities and Member Countries on the implications of hydropower development.

Good environmental and socio-economic information can:

- document conditions before construction of hydropower (and other water resource developments);
- be used as a reference to assess potential and actual changes associated with these developments during their construction and operation;
- capture the current rate of change in the river, and highlight the existing and changing wider pressures on and variability within the basin's natural resources;
- provide alerts to sudden changes, and enables clarity should a rapid management response be required;
- allow more informed, effective and economic mitigation measures (e.g. fish passage, sediment flushing, environmental flows); and
- facilitate accurate and objective debate on the opportunities and impacts of any infrastructure development.

There is considerable potential to increase the value from existing monitoring programs to enhance their ability to satisfy hydropower information needs, by better identifying and understanding the hydropower information required at various temporal and spatial scales. To get the most value out of hydropower-related information, it is useful to think of the data as going through a value chain in which the value increases with each step that is able to be delivered.



The data value chain for hydropower-related information

This report provides a Guiding Framework for transboundary monitoring of key basin disciplines to assist hydropower decision-making and management. This framework is developed to support the MRC's Basin Indicator Framework.

Guiding Framework for Basin-Scale Information
for Hydropower Planning and Management

1. **<u>Locations of Data Collection</u>:**
   a) Cover all Mekong River hydro ecological zones
   b) Near proposed or operational hydropower project or group of projects
   c) Enable understanding of mainstream processes
   d) Facilitate understanding of changes occurring across national boundaries

2. **<u>Parameters Monitored</u>:**
   a) Provide inputs to indicators related to hydropower planning and management
   b) Able to be replicated across the basin
   c) Able to be measured and analysed at a low cost
   d) Able to help predict as well as explain cause and effect of changes

3. **<u>Timing of Data Collection</u>:**
   a) Length of record covers the cycles of natural variability (seasonal, annual, decadal)
   b) Frequency captures natural or operational system changes and migratory cycles

4. **<u>Information Management</u>:**
   a) Quality management systems are in place to ensure consistency across countries
   b) Systems allow information to be centrally archived and shared

5. **<u>Information Use</u>:**
   a) Information is readily available for users (e.g. Member Countries, developers, NMCs, Line Agencies)
   b) Links to tools are available for decision-support and analysis

The five main elements of this hydropower-monitoring framework address (1) locations, (2) parameters, (3) timing, (4) information management, and (5) information use. The key disciplines considered in this report are hydrology, sediments, water quality, aquatic ecology, fisheries and socio-economics. Whilst not fully inclusive of every form of information need, this covers critical areas, and which also provide information relevant to many other disciplines.

Locations:

Well-selected long-term monitoring locations provide an overall structure for a large-scale monitoring regime. Selection of monitoring locations needs to take into account continuity of long-term data sets, river hydro-morphology, proximity to significant developments, tributary and national boundary locations. With hydropower, the hydrological information network should provide the backbone to the overall monitoring programme, so that other disciplines can link their findings with hydrological patterns and changes. Exact sample collection sites for specific disciplines can be individually selected nearby the general monitoring location so that they are applicable to the methodology and characteristics of that data type for each discipline. For example fisheries data may be collected at several sites at one location, whereas hydrological and sediment data would be at a suitable cross-section. Within the overall structure provided by the lower Mekong long-term monitoring locations, more detailed data collection at individual locations can be undertaken to address questions of a more local nature.

The following considerations are important for locations of data collection:

1. Sites with good **long-term data** should be continued. Long-term sites may need to change over time due to localised alterations at a site (e.g. inundation due to reservoir development, reinforcement of local banks, etc). These changes need to be anticipated well in advance such that a ‘new’ site can be established and monitored for a sufficient time period to be able to interpret and ‘link’ the results from the two sites to retain the long-term usefulness of existing data sets.
2. Data from different disciplines should be collected at the **same monitoring locations** as far as practicable for maximum interpretation capabilities; environmental data should be supported by hydrological data (water level, flow, and hydraulic data) at monitoring locations.
3. Data from different disciplines may be collected at **different spatial densities** at a single location (e.g. fish may be collected from multiple sites at a general location; sediments from equidistant points in a cross-section; macro-invertebrates from the river bottom and the margins or at several cross section points) depending on the local morphology and processes influencing the data that is being targeted.
4. Locations should be **meaningful** with respect to the location of hydropower projects, hydro-ecological zones, the location of sites or assets of importance to key stakeholders that may have concerns about hydropower effects (these may include national borders), and the ability to distinguish cause-and-effect of changes due to hydropower versus other developments.
5. **Tributaries** that are important to understanding of processes in the river relied on or affected by the hydropower project(s) should be included in monitoring programmes. Consideration should be given to the allocation of resources to improve the monitoring of major tributaries and for the information to be on the central MRC archive.
6. In a transboundary river system, monitoring station **nomenclature** should consistently follow an agreed naming and location referencing convention. Typically this would include monitoring station name with consistent spelling, location (Northing and Easting), river name, station ID code, zero gauge of station (i.e. elevation above sea level), country name, and distance from the sea along the centre line of the relevant river(s).

Parameters:

To maximise efficiencies, monitoring parameters should be linked to indicators that inform management questions. Consistency in parameters and the methodologies for collection across all locations will ensure the most value can be derived from the data. Consistent parameters and methodologies facilitate comparisons in findings and quality control checks, and inter-disciplinary data integration on a basin wide basis.

The following considerations are important for monitoring parameters to ensure that they can support hydropower-relevant information:

1. Parameters should inform **indicators** meaningful to management, decision-making, and communication issues and requirements for hydropower;
2. Parameters **important** to hydropower information span across technical, financial, economic, social, environmental and governance areas and support all aspects of hydropower.
3. Parameters should support the understanding of environmental and socio-economic issues that might be anticipated to arise at **different times** through the hydropower project life cycle.
4. Ideally parameters should be able to be consistently and accurately measured using established methodologies by the responsible parties, and should be agreed and supported by stakeholders
5. Data collection and analysis **methods** should be consistent and comparable over time and between locations.
6. Consistency in **terminology** around parameters and indicators is helpful towards achieving a common understanding.

Timing

The frequency and timing of monitoring should capture timescales and events that provide the most insight for the type of data being collected. This ensures that resources are not wasted by collecting data that does not capture the important physical, biological and/or socio-economic processes. In the Mekong mainstream there are many examples of important timing considerations relating to specific data types; for example, more intensive data collection when the majority of sediment moves at the start of the wet season, or when fish migration is at a peak.

The following considerations are also important for <u>timing</u> of data collection and processing:

1. Data sets should be of **sufficient length and frequency** to reflect the types of and influences on the changes that are observed for each parameter, and should take into account changes that can occur at different times scales (decadal, annual, seasonal, daily, hourly).
2. **Interruptions in data sets should be avoided**; therefore monitoring programme design should take a long-term view so that the same location can provide before-and-after information when changes take place.
3. **Less frequent data collection** is sufficient to track some hydropower-relevant parameters (e.g. aerial photography, habitat assessment, bed material samples, and census data). Infrequent but regular data collection of selected variables on the scale of years to decades will provide a framework within which more frequently collected data can be interpreted, thus enhancing the usefulness of both scales of information.
4. Periodically undertaking **longitudinal surveys** (upstream → downstream) of a river system, in which a “parcel” of water is followed throughout the river system in a single monitoring exercise (i.e. a Lagrangian sampling approach), can greatly enhance the understanding and inter-

relationship of river system processes on a basin scale. This understanding provides a context for the interpretation of routine monitoring results, thus enhancing their usefulness.

5. Annual results provide information over short time scales that reflect the present condition, but over longer time scales this data will be used to **identify trends and variability**. It is the longer time scales that build confidence in the understanding of the system and how it responds to pressures or change.
6. Information needs relating to hydropower projects vary through the project life cycle (planning, construction, operation, decommissioning), which for hydropower can span decades up to a century, so **long-term data sets are of high importance** for the success of each stage.
7. **Timeliness** of data analysis and availability to users is as important as timeliness of data collection.

Information management:

Information management should be driven by the needs of information users and QAQC requirements. Systems and processes should ensure timely and complete data availability for the identified uses, with relevant meta data included such that the data set can be located and used well into the future.

The following considerations are important for information management when thinking about LMB hydropower-related information:

1. Data storage and retrieval of data sets relevant to water resource issues should be centralised and **readily accessible**;
2. Quality Assurance and Quality Control (**QA/QC**) procedures should be applied at multiple steps to ensure confidence in all data, including field and laboratory audits, capacity-building events, and inter-lab comparisons;
3. Implementation **responsibilities** for data collection, storage and management should be clear amongst all parties and documented, such as through the development of Standard Operating Procedures (SOP) and Work Instructions (WI);
4. International or regionally-accepted **standards** are useful to ensure common understanding of expectations (e.g. for specific sampling methods, and for quality management systems), and can be incorporated into SOPs or WIs; and
5. Monitoring programmes should be periodically **reviewed** to ensure efficiencies, value and contribution to objectives.

Information uses

Information uses may include trend analysis, prediction, forecasting, mitigation design, management planning, design of ongoing monitoring regimes, support for consultation processes, analysis of changes and attribution of influence and implications, integration with local scale information and considerations, and informing decisions to proceed or not with hydropower or other developments. Uses and users vary. Processes need to be in place to ensure that information gets to users in the appropriate formats and time periods to best inform management needs. Opportunities for information dissemination through MRC processes include the MRC data portal (www.mrcmekong.org) and through periodic discipline-specific technical reports and report cards. More inter-disciplinary collations of information put out on a regular (e.g. 5-yearly) basis include State of the Basin reports, the Planning Atlas, and the Assessment of Basin-wide Development

Scenarios, all of which inform the regularly updated IWRM-based Basin Development Strategy and MRC Strategic Plan.

The following considerations are important for information use:

1. Information end uses can **change over time** as contexts, developments, and management issues evolve; therefore information collected should be able to inform a variety of end-uses. This highlights the need for the collection of long-term basic data which can be used in a variety of ways over time.
2. Information collected and reported can be most meaningful to management, decision-making, and communication needs often through analysis and presentation in the form of agreed key **indicators**; these indicators can and will change over time as issues change and knowledge increases, so the parameters underpinning these indicators should be well-selected and consistently monitored.
3. Information should be accessible in **time-frames** relevant to awareness-raising and decision-making. It is very difficult to make good decisions if data is not provided to users until, for example, 3 years after it has been collected.
4. Information should be able to **explain variations** seen spatially and temporally so that decision-makers know whether they need to respond to the change being shown.
5. Information should assist in the analysis of **risks and impacts**, in combination with site-specific data.
6. Information should be available in **formats suitable for users** of the information, which can vary from technical officers, to planners and assessment specialists, to water resource managers and power system operators, to government and ministerial delegates.
7. Formats should enable information extraction or accessibility in **raw data** forms (e.g. easily downloadable raw datasets with metadata in consistent and clearly understood formats), **visual** forms (e.g. web-based visual presentations automatically updated) and **documentary** forms (e.g. technical reports, report cards, status reports, etc.).
8. **Technologies** for information storage, analysis and presentation change and evolve, and information management systems should closely follow trends so that users can get the benefits offered from technological improvements.

Linking basin-scale, national and project Information

Hydropower project developers and national governments alike can benefit from these guiding considerations for monitoring. Project developers can seek to apply the principles at a more local scale in their site specific monitoring. Developers and governments could link the design of their project or national monitoring network to the principal hydrological data locations used for basin scale assessment (to which other basin-scale discipline data collection is linked). Developers can also use basin-scale parameters and timing of data collection for their local data collection so that local data can be interpreted within a broader context allowing quality control assessments to be made. Similarly, national governments can link their requirements for data collection and analysis in project environmental and social impact assessments and in licenses/concession agreements during operation, to these same guiding principles so that regulators are able to analyse, interpret and respond to this information mindful of the broader context over long time frames.

Information for other basin uses and long term considerations

This document is designed to capture long-term guiding considerations that have value to diverse stakeholders when designing, reviewing or improving their information collection and management activities relating to hydropower.

These guiding considerations take into account that the monitoring programmes of the MRC were not set up solely to answer hydropower-related management questions. Additionally, institutional reforms such as the decentralisation process, which is being considered in the current time by the MRC, mean that the uptake up of some of these considerations may require time. A consistent and basin wide perspective, coordinated between Mekong River users, will greatly assist in improving the knowledge base for basin planning and decision making over time.

Abbreviations and Acronyms

3S	Sesan, Sre Pok and Sekong rivers
ADCP	Acoustic Doppler Current Profiler
AHNIP	Appropriate Hydrological Network Improvement Project
BDP	Basin Development Planning Programme (of the MRCS)
BoT	Balance of Trade
CO_2	Carbon dioxide
CPI	Consumer Price Index
CPUE	Catch per Unit Effort
DPSIR	Drivers, Pressures, States, Impacts, Responses
DSMP	Discharge and Sediment Monitoring Programme
EDI	Equal Discharge Increment
EHM	Ecological Health Monitoring
EP	Environment Programme (of the MRCS)
EWI	Equal Width Increment
FAO	Food and Agriculture Organisation (of the United Nations)
FMMP	Flood Management and Mitigation Programme (of the MRCS)
FP	Fisheries Programme (of the MRCS)
FSL	Full Supply Level
ftp	file transfer protocol
GDP	Gross Domestic Product
GIS	Geographic Information System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HH	Household
HPP	Hydropower Project
HYCOS	Hydrologic Cycle Observing Station
IBFM	Integrated Basin Flow Management
ID	Identification
IKMP	Information and Knowledge Management Programme (of the MRCS)
ISH	Initiative on Sustainable Hydropower (of the MRCS)
IWRM	Integrated Water Resource Management
LEK	Local Ecological Knowledge
LMB	Lower Mekong Basin
MA95	Mekong Agreement 1995
MHS	Multi-Habitat Sampling
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NMC	National Mekong Committee
NMCS	National Mekong Committee Secretariat
NPV	Net Present Value
OAA	Other Aquatic Animal

O/E	Observed/Expected
O&M	Operations and Maintenance
PDG	MRC Preliminary Design Guidance for Proposed LMB Mainstream Dams
PDIES	Procedures for Data and Information Exchange and Sharing
PMFM	Procedures for the Maintenance of Flows on the Mainstream
PNPCA	Procedures for Notification, Prior Consultation and Agreement
PPP	Power Purchasing Parity
PSIA	Poverty and Social Impact Assessment
PWUM	Procedures for Water Use Monitoring
PWQ	Procedures for Water Quality
QA/QC	Quality Assurance / Quality Control
QMS	Quality Management System
RAP	Rapid Assessment Protocol
RBM	River Basin Management
RSAT	Rapid basin-wide Sustainability Assessment Tool
SIMVA	Social Impact Monitoring and Vulnerability Assessment
SoB	State of the Basin
SOP	Standard Operating Procedure
TSS	Total Suspended Solids
USGS	United States Geological Survey
WHYCOS	World Hydrological Cycle Observing System
WI	Work Instruction
WMO	World Meteorological Organisation
WQMN	Water Quality Monitoring Network
WUA	Weighted Useable Area

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About this Document

This report provides a guidance document on monitoring that can best meet hydropower information needs at the basin and transboundary scale, focussed on the lower Mekong River mainstream. It is accompanied by a companion report "Information Sources to Support LMB Hydropower Information Needs".

This document is produced by the MRC's Initiative for Sustainable Hydropower (ISH). It is a product of the MRC 'ISH11' study "Improved Environmental and Socio-Economic Baseline Information for Hydropower Planning".

The ISH11 study addressed a fundamental aspect of the MRCS Basin Development Strategic Priority #3 to **"Improve the Sustainability of Hydropower Development".** Good information underpins all aspects of hydropower development and management, and is vital to maximise opportunities and reduce risks across economic, social and environmental dimensions for all stakeholders. The MRC has for many years taken up the role of gathering, storing and disseminating information important for basin planning for the benefit of all Member Countries.

The ISH11 study commenced in November 2012 with a multi-disciplinary team of experts, to review existing monitoring and information management systems at the MRC with respect to how they meet hydropower planning and management information needs. The team:

- reviewed information needs relevant to hydropower planning and management based on Mekong-specific issues and experiences elsewhere;
- established a Guiding Framework for hydropower information needs relevant to the MRC;
- completed a review of existing and presently-collected information for the Mekong;
- identified gaps and opportunities with respect to the Guiding Framework; and
- proposed improvements to address key gaps.

The ISH11 study focused primarily on disciplines that have been recognised as appropriate and relevant for centralised and shared information within the MRC information management systems: economics, social, fisheries, aquatic ecology, sediments, water quality, and hydrology. The geographic scope of this document is focussed on the LMB Mekong mainstream. Not considered in this document is information relating to geotechnical and engineering, terrestrial land-use and ecology, meteorology, off-river water bodies and wetlands. Information needs for these areas would need to be subject to their own analysis and guidance.

The ISH11 team produced a series of reports, as follows.

Inception Report, ***Jan 2013.*** A major report, with a mixture of technical content (for preliminary discussion with Member Countries) and non-technical content (study logistics to be agreed by ISH). This provided a confirmation of understanding of the study Terms of Reference, initial review of existing monitoring and data availability, preliminary findings and ideas. **The purpose of the Inception Report is to ensure all stakeholders are clear on the scope and timing of the study**.

Phase 1 Report, ***Mar 2013.*** A major report consisting of a Main Report plus seven separate discipline-specific Annexes (Socio-Economics; Fisheries; Aquatic Ecology; Sediments & Geomorphology; Water Quality; Hydrology; Data Management). The Main Report provides study overview information, relationships to other key MRC Programme initiatives, a proposed long-term monitoring framework for basin-scale information for hydropower planning and management, and summary information about the improvement proposals. Each Annex provides an outline of best practice monitoring, Mekong information sources (past and present), a brief overview of the state of knowledge, evaluation of hydropower information needs, forward MRCS monitoring programmes, and initial ideas on improvement proposals for consideration. **The purpose of the Phase 1 report is to**

stimulate and inform discussions during Phase 2 to help clarify background information, prioritise and refine improvement proposals, and detail resource requirements for trial implementation of selected improvement proposals in Phase 3.

Discussion Points, ***Aug 2013.*** A minor, non-technical report in the form of powerpoint slides and hand-outs. The content comprised the study objective and scope, basin scale information needs for hydropower planning and management, guiding framework and gap analysis of present monitoring, ISH11 Phase 3 design and implementation approach, and further Phase 2 timetable. **The purpose of the Discussion Points is to assist discussions within Member Countries relating to the ISH11 study**, so feedback can inform the Phase 2 Report.

Phase 2 Report, ***Aug 2014.*** Volume 1: Main Report plus Volume 2: Six discipline-specific Annexes (Socio-Economics; Fisheries; Aquatic Ecology; Sediment & Geomorphology; Water Quality; Hydrology). The **Main Report** contains information on hydropower information needs; a guiding framework for basin-scale monitoring information; present status, gaps and opportunities for improvement; and specific improvement proposals for ISH11 Phase 3 activities. The **Annexes** provide an update of the Phase 1 Report Annexes to include further information accessed, a more complete summary of information sources, discipline-specific comments and responses, and accompanying information to explain the context for the improvement proposals for Phase 3 activities. **The purpose of the Phase 2 report is to present an agreed set of improvement proposals.**

Guiding Considerations on Transboundary Monitoring for LMB Hydropower. ***Dec 2014.*** This is a major report that puts Phase 2 information into a simplified and accessible format. This report compiles elements of the Phase 2 Report into a guidance document on monitoring to best meet hydropower information needs at the basin and transboundary scale. **The purpose of the Guiding Considerations report is to guide commencement or review of data collection and analysis programmes that inform hydropower information needs in the LMB**.

Information Sources to Support LMB Hydropower Information Needs. ***Dec 2014***. This is a major report that accompanies the “Guiding Considerations” report. This report compiles key information sources in the LMB that can contribute to hydropower information needs. **The purpose of the Information Sources report is to provide an information foundation for those conducting studies that inform hydropower information needs in the LMB.**

1 Transboundary Information to Support Hydropower Decision-Making

1.1 Mainstream Hydropower in the Lower Mekong Basin

The countries of the Lower Mekong Basin (LMB) - Cambodia, Lao PDR, Thailand and Viet Nam (Figure 1) - are all experiencing rapid development. The growth in demand for electricity reflects this development, with sustained growth rates of over 10% a year across the region placing strain upon the power generation system and triggering investment in the construction of additional generating capacity.

The LMB countries regard hydropower as an important source of power generation, although each with a different perspective on this substantial development opportunity. Cambodia has limited generating capacity and rapid growth in power demand, and considers hydropower as a means to meet these demands whilst limiting dependence upon imported fossil fuels. Lao PDR has more limited internal demand but hydropower could be a major source of export earnings, and the country has aspirations to become the “battery of Asia”. Thailand already has a number of hydropower developments, and has a cautious approach to any further development but a growing demand for energy. Viet Nam also faces an increase in demand for power of over 15% per annum, and is seeking to maximize the development of hydropower potential although with reduced in-country opportunities. All countries are engaged in power sharing opportunities afforded by the potential for Greater Mekong Subregion power grid interconnection. The cross-border trade in electricity is likely to increase in the coming decades.

While the net financial benefits of hydropower to project proponents are projected to be substantial, the relationship between hydropower development and social, environmental and economic issues is an issue of strategic concern to all governments and many other stakeholders in the region. Concerns include potential impacts on:

- water resources and associated ecosystems, including areas of high ecological value and sensitivity;
- poverty reduction and social equity (including benefit-sharing);
- maintenance of flows for ecosystems services;
- regional integration and transboundary relationships relating to both water and energy: and
- the distribution of benefits arising from hydropower development.

Impacts and benefits relating to hydropower development and operation are compounded with numerous other influences on regional development, including investments relating to improved socio-economic conditions, new infrastructure, and other resource use activities (e.g. mining, forestry, agriculture, aquaculture, and fisheries).

The LMB tributaries presently have approximately 26 existing or committed hydropower dams and are projected to have as many as 70 by 2030 (Figure 2). Of the 12 hydropower projects that have been proposed for the LMB Mekong River mainstream, 11 involve dams, and 11 have proponents and are at some stage of the development process from feasibility study onwards. Two (Xayaburi and Don Sahong) have been formally notified in accordance with the Procedures for Notification, Prior Consultation and Agreement (PNPCA).

Hydropower-relevant information has heightened importance to a multitude of stakeholders at this time of rapidly emerging developments. Both current and planned development of hydropower schemes in the Mekong mainstream and its tributaries have an important role in contributing to economic growth and welfare in the LMB, and many stakeholders hold interests in various aspects of these developments.

Mekong overview

GIS DATA SET	ORIGINAL SOURCE		LAST UPDATE	
	AGENCY	YEAR	MRCS	YEAR
Capital city	http://wikimapia.org/	2010	NONE	NONE
Major city	http://wikimapia.org/	2010	NONE	NONE
River LMB	Watershed Classification Project (WSCP), MRCS	Nov 2001	BDP	April 2009
River UMB	U.S. Geological Survey's (USGS) EROS Data Center	2001	IKMP	2003
Water body	Watershed Classification Project (WSCP), MRCS	2001	BDP	2008
Mekong boundary	Watershed Classification Project (WSCP), MRCS	Oct 2000	NONE	NONE
National boundary	1) Lower Basin: Watershed Classification Project (WSCP), MRCS 2) Upper Basin: U. S. Geological Survey	Oct 2001	IKMP	Nov 2004

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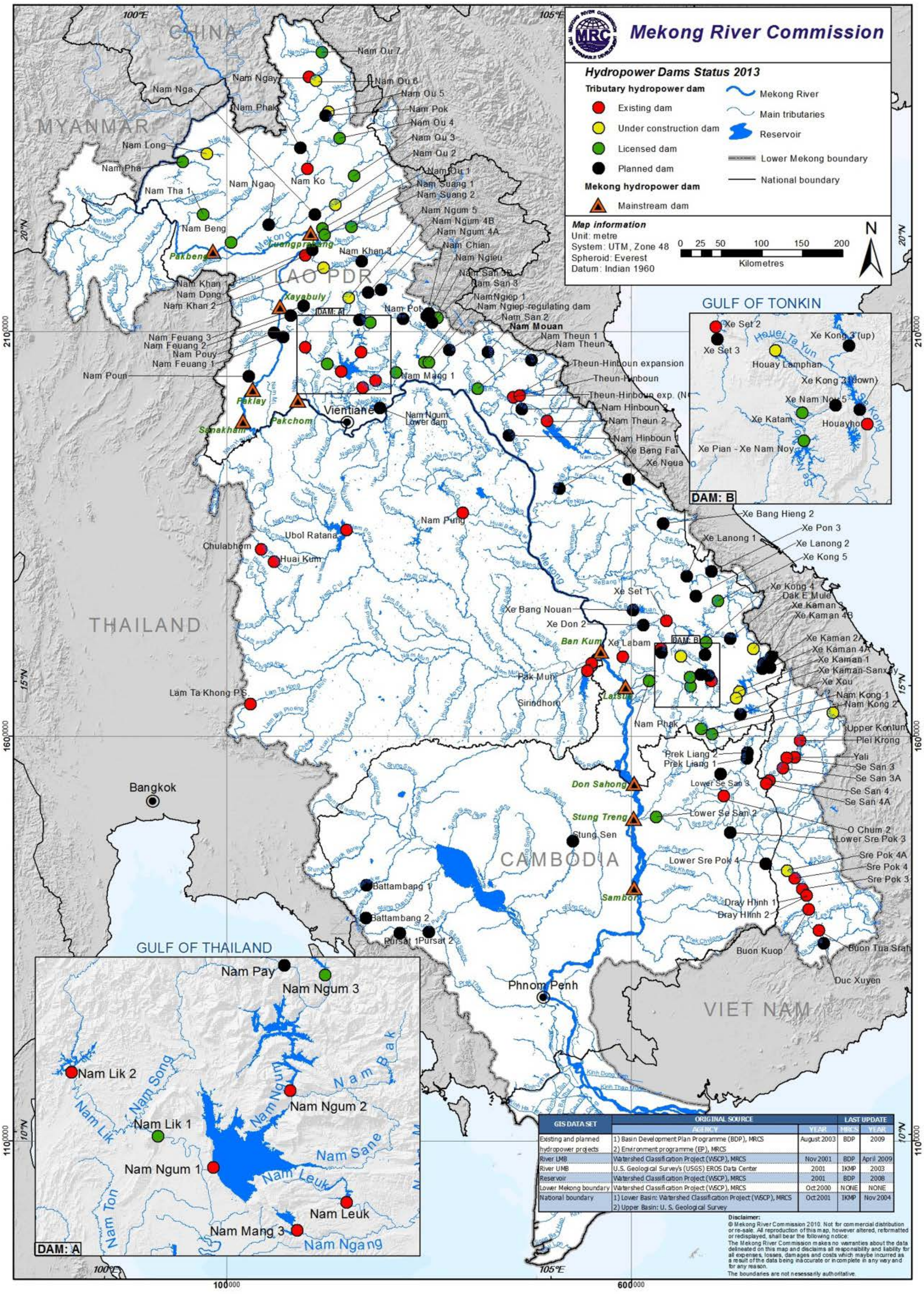
Figure 1 – Overview of the Mekong River Basin

Existing and planned hydropower projects



GIS DATA SET	ORIGINAL SOURCE		LAST UPDATE	
	AGENCY	YEAR	MRCS	YEAR
Existing and planned hydropower projects	1) Basin Development Plan Programme (BDP), MRCS 2) Environment programme (EP), MRCS	August 2003	BDP	2009
River LMB	Watershed Classification Project (WSCP), MRCS	Nov 2001	BDP	April 2009
River UMB	U.S. Geological Survey's (USGS) EROS Data Center	2001	IKMP	2003
Reservoir	Watershed Classification Project (WSCP), MRCS	2001	BDP	2008
Lower Mekong boundary	Watershed Classification Project (WSCP), MRCS	Oct 2000	NONE	NONE
National boundary	1) Lower Basin: Watershed Classification Project (WSCP), MRCS 2) Upper Basin: U. S. Geological Survey	Oct 2001	IKMP	Nov 2004

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Figure 2 – Existing and Planned Dams in the LMB

The 1995 Mekong Agreement provides a framework for communication and cooperation for the four countries of the LMB with respect to their shared water resource, the Mekong River. Through the MRC, the Member Countries have defined a common vision for the Mekong River Basin:

VISION for the Mekong River Basin:
An economically prosperous, socially just and environmentally sound Mekong River Basin

Good information underpins all aspects of hydropower development and management, and is vital to maximise opportunities and identify and reduce risks across economic, social and environmental dimensions for all stakeholders. The 1995 Mekong Agreement provides a compelling reason for the systematic, consistent and meaningful collection of good environmental and socio-economic information.

Parties to the 1995 Mekong Agreement need useable information on river basin condition that allows Member Countries to design hydropower projects to "avoid, minimise and mitigate" impacts. The Agreement requires determinations on whether impacts from water resource developments are "reasonable and equitable" when compared to all the other uses in the basin which are also having impacts.

The MRC has for many years been responsible for the gathering, storing and disseminating information important for basin planning for the benefit of all Member Countries. This document focuses on considerations important for the collection, management and distribution of shared information that can inform dialogue and decisions on hydropower developments and their transboundary implications.

1.2 Information Needs regarding Mainstream Hydropower Developments

1.2.1 Changes arising from hydropower developments

Box 1 provides an excerpt from the Basin Development Strategy about some of the anticipated changes arising from hydropower developments.

A number of important questions arise from the information in Box 1. Specific information is required to understand these aspects more clearly and to be able to manage these issues. Examples include:

- ***What are the net economic benefits to each Member Country of the current resource use and proposed basin wide infrastructure developments?*** This requires an understanding of the current macroeconomic conditions in each Member Country, and the distribution of benefits of current resource use, as well as the incremental benefits and distribution of planned infrastructure developments.
- ***Are incremental flow changes due to run-of-river operations insignificant?*** This requires an understanding of seasonal changes and daily fluctuations in water levels and flow, and the dependencies on flow timing, levels and duration for important ecological and socio-economic processes. Daily and hourly water level changes may cause issues for fisheries, aquatic ecology and riverbank stability with flow on socio-economic implications. Excellent, consistent and reliable hydrological information at meaningful monitoring locations is necessary to provide this understanding of potential issues, linked to data from other disciplines potentially affected, e.g.

fisheries and aquatic ecology. This includes tributary information, without which interpretation of data is very limited.

> The proposed 12 hydropower projects on the LMB mainstream are run-of-river, with little carry-over storage, so incremental flow changes at a transboundary scale will be insignificant. However, the total economic benefits are uncertain, due to the insufficient data and analysis of the complex Mekong Basin system. The projects could have very large benefits, with 11 mainstream dams (excluding the Thakho diversion project) generating US$ 15 billion NPV, 2.5 times the benefits of the planned 30 LMB tributary dams. About 400,000 new jobs would be created during the construction and operation phases. Greenhouse gas emissions could fall by 50 Mtonnes CO_2/year by 2030.
>
> However, the social and environmental costs could be very high: 60% of the biodiversity-rich river channel (including deep pools, rapids and sandbars) between Kratie and Houei Xai lost to a series of connected impoundments; 9 environmental hotspots highly impacted, mostly in Cambodia (Tonle Sap, 3S-Basin and the mainstream); 2 out of 4 flagship species at risk of extinction (giant catfish and Irrawaddy dolphin); and a near-total barrier to fish migration along most of the mainstream unless new, untested fish-passage facilities are provided. This will further reduce capture fisheries in the basin by 15%, bringing the overall decline of capture fisheries to 25% relative to the baseline.
>
> The dams will also trap sediments and nutrients. Impacts increase with increased number and downstream location of mainstream dams, due to increased pondage and backwater and barrier effects.
>
> ***Basin Development Strategy 2011**, pages 19-20*

Box 1 – Projected changes due to Mekong mainstream hydropower projects

- ***How well can we confidently identify transboundary changes?*** This requires an array of monitoring stations carefully sited so that information at national boundaries can be evaluated. In some cases this requires information upstream and downstream of a development; in other cases it requires left bank as well as right bank monitoring locations. Consistency in data collection parameters and methods is necessary to compare results between countries.

- ***What are the present socio-economic conditions against which benefits can be compared?*** This requires good and consistent information on socio-economic status and trends at a range of scales from national down to village or even household levels, with judgements to be made on spatial areas to be included in the data collection. It also requires being able to separate hydropower changes from other changes affecting the socio-economic conditions.

- ***How biodiversity-rich is the river channel, and will this change following hydropower developments?*** This requires an understanding of the present biota and in-channel habitat and life-cycle patterns. Choices need to be made on data collection relating to habitat quantity and quality, and species monitoring. Consistency, comprehensiveness and statistically-significant data sets are necessary to provide answers to these questions. More research may be required regarding species numbers, life cycle patterns of these species, ecological indications, and occurrence patterns.

- ***How confident are we to state a percentage change to capture fisheries due to hydropower developments?*** This requires good data on capture fisheries throughout the Mekong mainstream, and an understanding of how changes to flow and sediment movement affect fisheries. Basin-wide consistent methods for collection and analysis are required to enable a true understanding of changes to this important resource. The implication of any changes to capture fisheries for local communities requires integrating biological and socio-economic information.

- ***What are the issues when dams trap sediments and nutrients?*** This requires an understanding of basic sediment and water quality characteristics and cycles over the entire mainstream river, which in turn must be correlated with hydrological information so that meaningful interpretations can be made. Further, it is impossible to draw conclusions for the mainstream without understanding what is happening in tributaries. Changes to sediments have the potential to affect a range of other environmental and socio-economic aspects including aquatic habitats, riverbank stability, fisheries productivity, and local industry. Consequently, the monitoring programme needs to be designed so that these connections and attribution of cause and effect can be made.
- ***Over what time scale should changes, impacts and benefits be considered?*** Impacts and benefits can occur over short (e.g. seasonal), intermediate (e.g. annual to decadal) or long (e.g. inter-generational to geologic) timeframes, so parameters and methods must include an array capable of capturing changes at these different timescales.

1.2.2 How can good information help to answer these questions?

Information needs relating to hydropower require not only an understanding of where hydropower will be developed, but also the types of changes that can be expected from a hydropower development and the other influences on those changes.

Good environmental and socio-economic information can:

- document conditions before construction of hydropower (and other water resource developments);
- be used as a reference to assess potential and actual changes associated with these developments during their construction and operation;
- capture the current rate of change in the river, and highlight the existing and changing wider pressures on and variability within the basin’s natural resources;
- provide alerts to sudden changes, and enables clarity should a rapid management response be required;
- allow more informed, effective and economic mitigation measures (e.g. fish passage, sediment flushing, environmental flows); and
- facilitate accurate and objective debate on the opportunities and impacts of any infrastructure development.

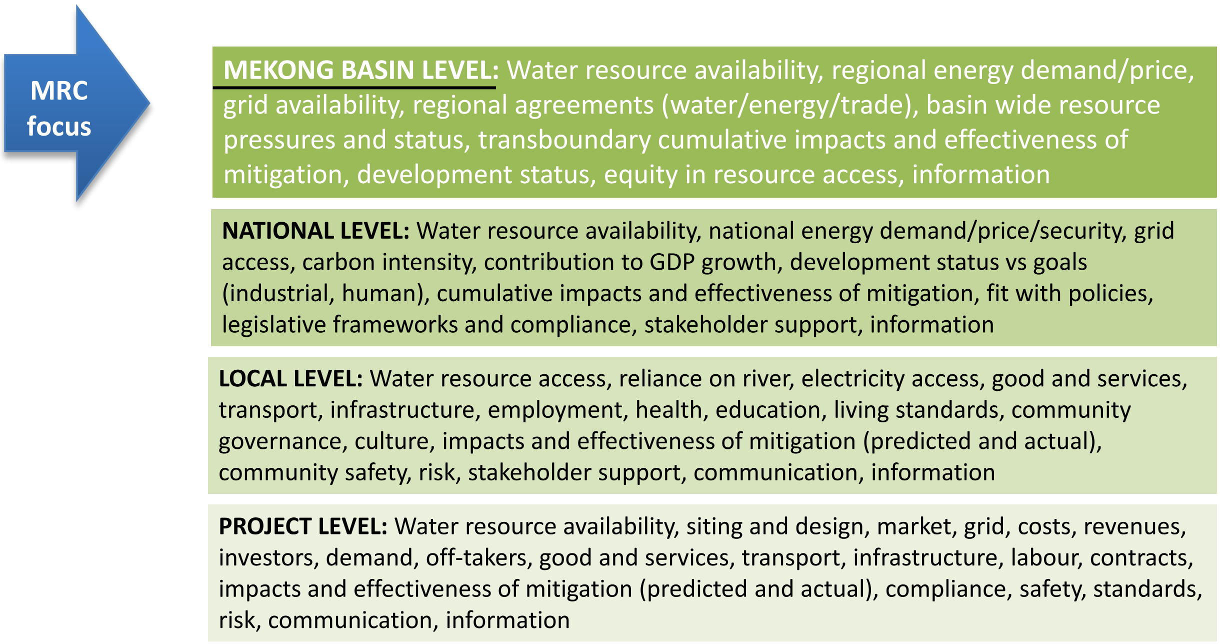
In summary, good information supports a transparent understanding of the environmental and socio-economic situation in the basin at any point in time, and provides an objective basis to assess transboundary issues and the status of the basin’s water resource over the long-term.

1.2.3 Linking basin, national and project level information

Large river systems like the Mekong are dynamic and have complex relationships amongst hydrology, sediments, aquatic ecology and socio-economic conditions. Local changes may be more easily detected immediately upstream and downstream of a development than changes further downstream, including transboundary changes, which may be influenced by other pressures on the measured parameters. In addition, primary impacts, such as changes to sediment flux and fisheries biomass, may have secondary effects on river- and floodplain-based ecosystems, livelihoods and food security.

There are many factors that influence the nature and degree of change due to hydropower, and influences from other catchment activities can compound or counteract the hydropower-related changes. The large variability amongst hydropower projects prevents generalisations being made about ‘hydropower’ changes, and highlights the need for accurate, site specific information.

The MRC is focussed on basin-level and transboundary considerations. Information needs to support hydropower planning in the LMB can be seen to vary depending on the spatial level. Examples of this are illustrated in Figure 3.



MEKONG BASIN LEVEL: Water resource availability, regional energy demand/price, grid availability, regional agreements (water/energy/trade), basin wide resource pressures and status, transboundary cumulative impacts and effectiveness of mitigation, development status, equity in resource access, information

NATIONAL LEVEL: Water resource availability, national energy demand/price/security, grid access, carbon intensity, contribution to GDP growth, development status vs goals (industrial, human), cumulative impacts and effectiveness of mitigation, fit with policies, legislative frameworks and compliance, stakeholder support, information

LOCAL LEVEL: Water resource access, reliance on river, electricity access, good and services, transport, infrastructure, employment, health, education, living standards, community governance, culture, impacts and effectiveness of mitigation (predicted and actual), community safety, risk, stakeholder support, communication, information

PROJECT LEVEL: Water resource availability, siting and design, market, grid, costs, revenues, investors, demand, off-takers, good and services, transport, infrastructure, labour, contracts, impacts and effectiveness of mitigation (predicted and actual), compliance, safety, standards, risk, communication, information

Figure 3 – Information Needs to Support Hydropower Planning in the LMB – Spatial Levels

There are benefits of the basin-level information for hydropower projects that can be seen at national, local and project levels, including some of the following.

- Countries and projects can use the same parameters and methods for more detailed information collection.
- Results of more detailed project-level information collection can be fit into the larger picture for interpretation purposes and can be verified against quality assured basin information.
- Information sharing, comparison between regions and scales, and transboundary evaluations is facilitated.
- Good information at all levels supports good decisions at all levels.

Project developers can seek to apply the Guiding Framework and associated considerations at a more local scale in their site specific monitoring. This can be achieved, for example, by designing an overall monitoring network underpinned by the hydrological data locations and linking other discipline data collation to these same locations. Developers can also look at the basin-scale parameters and timing of data collection, and seek to replicate these for their local data collection so that local data can be interpreted within a broader context and quality control assessments can be made.

National governments can seek to link requirements for data collection and analysis in project environmental and social impact assessments and in licenses/concession agreements during operation to these same guiding considerations so that regulators are able to analyse, interpret and respond to this information mindful of the broader context.

Consistency in the types of information that hydropower developers and operators are required to collect and provide to government has the potential to greatly contribute to the overall quality and depth of the basin-scale dataset, if and when the government feels it is appropriate to make this information more widely accessible.

1.3 Institutional Mechanisms for Transboundary Information Sharing

1.3.1 Agreements and procedures

A number of agreements, procedures and guidelines contribute to the MRC governance framework agreed to by the four Member Countries, including the following which have a strong bearing on transboundary information and sharing:

- 1995 Mekong Agreement and Procedures.
- Procedures for Data and Information Exchange and Sharing, 2001 (PDIES), plus guidelines for management of the hydro-meteorological network, 2005.
- Procedures for Notification, Prior Consultation and Agreement, 2003 (PNPCA), plus implementation guidelines, 2005.
- Procedures for Water Use Monitoring, 2003 (PWUM), plus implementation guidelines, 2006.
- Procedures for the Maintenance of Flows on the Mainstream, 2006 (PMFM), plus draft implementation guidelines, 2011.
- Procedures for Water Quality, 2011 (PWQ), plus draft implementation guidelines (chapter 1, 2009; chapter 2, 2010; chapters 3 and 4, in progress).

The Integrated Water Resources Management (IWRM) based Basin Development Strategy for the Mekong Basin (2009) included amongst its agreed strategic priorities:

3. *"to improve the sustainability of hydropower development";* and
4. *"to acquire essential knowledge to address uncertainty and minimize risks of identified development opportunities".*

Hydropower was considered one of the key development opportunities in the Mekong basin for which essential knowledge needed to be acquired. Studies of strategic importance to fill knowledge gaps identified in the Basin Development Strategy relate to sediments, water quality, fisheries, biodiversity and socio-economics. Similar essential knowledge needs have been identified through the Strategic Environmental Assessment process for mainstream dams, and the Prior Consultation Project Review, all of which inform the MRC Secretariat (MRCS) on their monitoring programmes. Strategic Priority 4 would ideally result in knowledge being managed within a long-term and sustainable framework, for use as future development opportunities arise.

The Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin, 2009 (the "PDG"), provides developers of proposed LMB mainstream dams with an overview of the issues considered by the MRC during prior consultation, such as navigation, fish passage, sediment transport and dam safety. Centralised and shared information by the MRCS supplements more specific and local information collected by developers about their developments.

1.3.2 MRCS monitoring programmes

An example of how these agreed approaches have been successfully implemented is the collaborative monitoring of water level and flow in the Mekong River. The hydrology of the Mekong River is a key driver of ecological processes and is fundamental to many socio-economic aspects of the region, including fisheries, irrigation, navigation, and energy production. Flooding, drought and saline intrusion in the basin pose significant economic and social risks, and require an understanding of the river's hydrology to develop appropriate forecasting models and identify management and mitigation options. In 2012, the MRC completed implementation of the Mekong-HYCOS system which expanded the existing AHNIP (Appropriate Hydrological Network Improvement Project) network. Collaborative monitoring of the sites by the MRC countries, combined with an efficient data transmission and dissemination system managed by the MRC has allowed real-time data to be used by MRC Programmes and member countries for flood forecasting and water resource management.

HYCOS monitoring is one of many information collection, management, analysis, reporting and sharing programmes managed by the MRCS. The MRCS has 12 programmes or initiatives organised within four divisions: Planning, Environment, Technical Support, and Operations, shown in Figure 4.

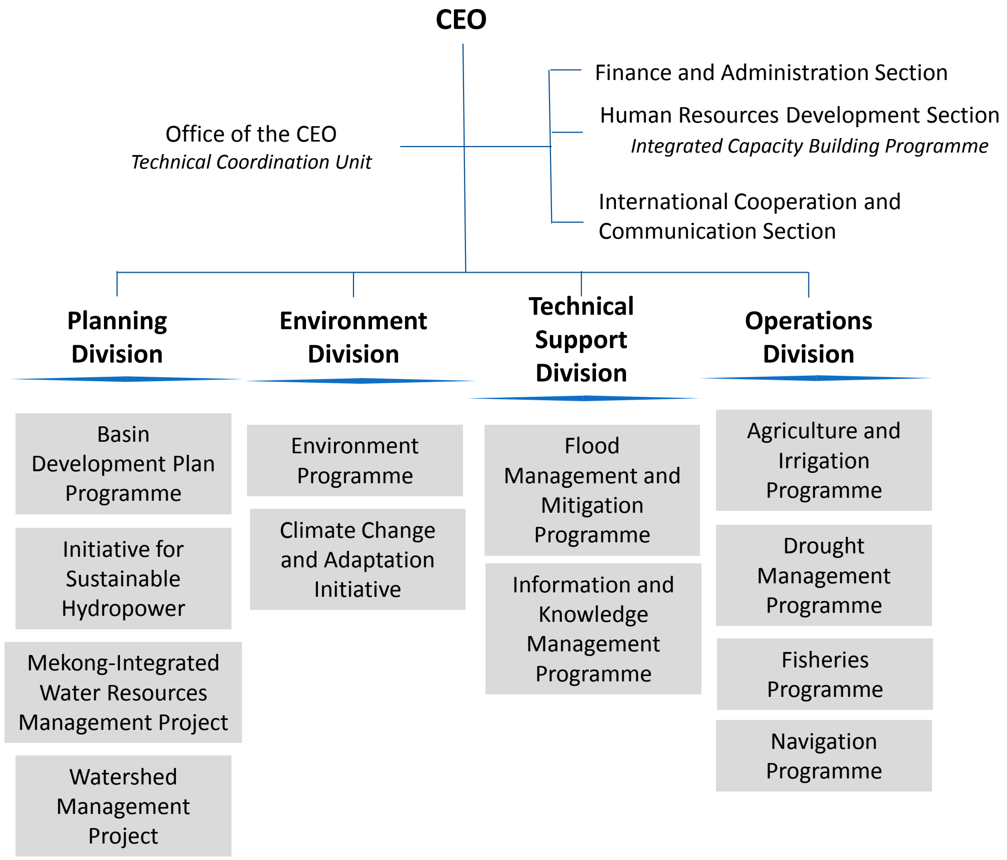


Figure 4 – MRCS Divisions and Programmes

The MRC Initiative for Sustainable Hydropower (ISH) sits within the Planning Division of the MRCS. It seeks to embed sustainable hydropower considerations into the regulatory frameworks and planning systems of the Member Countries and into hydropower project level planning, design, implementation and operational activities. The MRC ISH is a cross-cutting initiative in the MRC. It holds the responsibility for maintaining the MRC's hydropower project database for the LMB. Information to support hydropower decision-making needs requires a broad array of disciplines to be taken into account.

Figure 5 shows those MRC Programmes with primary responsibilities for data monitoring and management relevant to hydropower information needs (BDP, EP, FP, and IKMP). Other MRC Programmes may also have relevance to hydropower information needs (e.g. AIP, CCAI, DMP, FMMP, NP), depending on the types of questions that are of interest.

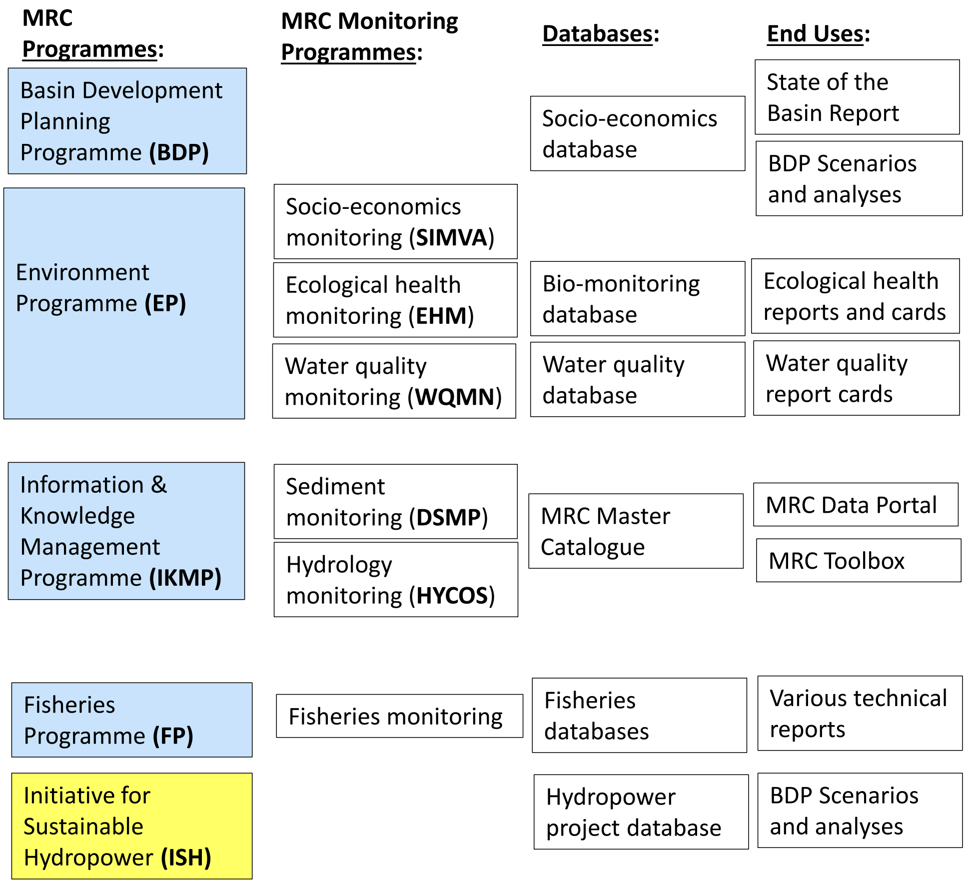


Figure 5 – MRC Programmes with key monitoring functions important for hydropower information needs

Figure 5 shows that four MRC Programmes (BDP, EP, FP, IKMP) are responsible for one or more monitoring programmes of key importance as sources of information that can inform hydropower information needs. In addition to data collection, there are a number of existing databases in the MRC managed by these programmes and serving various functions, and there are a range of existing end-uses for data. Some end-uses are unique to a particular programme and type of monitoring data (e.g. Ecological Health Monitoring Reports and EHM Report Cards, Fisheries Technical Reports); others are available to all programmes and draw on all types of monitoring data (e.g. MRC Data Portal; State of the Basin reporting; BDP scenario assessments).

1.3.3 Decision support frameworks, tools and processes

Essential to achieve the value of information collection, analysis and sharing programmes are mechanisms by which this information is quality assured, analysed and integrated to facilitate decision-making. These include:

- formalised MRC processes for collaborative analysis of and consultations on the five-yearly State of the Basin reports and the Assessment of Basin-wide Development Scenarios inform the regularly updated IWRM-based Basin Development Strategy and MRC Strategic Plan; and
- formalised MRC processes under the PNPCA process for evaluation of and consultations on information on proposed hydropower developments, supported by analyses by discipline-specific Expert Panels against the requirements of the PDG.

Over the years the MRC Programmes have worked on a variety of analytical tools to support decision-making, which form part of the Decision Support Framework. These include software used to analysis information with a diverse range of potential applications. More specific to hydropower decision-making, the MRC's Initiative for Sustainable Hydropower has several projects working on guidance and tools to support Member Country decision-making on hydropower. These include economic valuation and evaluation for hydropower project developments, and an evaluation framework for consideration of hydropower developments in ecologically sensitive sub-basins. BDP is working to develop a consistent, long-term, basin wide MRC indicator framework, to which the MRC ISH can contribute inputs regarding hydropower-relevant indicators. Development of useful and effective decision-support tools, frameworks and guidance to support hydropower decision-making benefits greatly from the inputs from Member Countries on what is useful and what would fit easily into their present information evaluation and decision-making processes.

1.3.4 Decentralisation of data collection activities

With the approval of the Strategic Plan 2011-2015, the MRC plans to move towards a new operational structure with a greater focus on sustaining the MRC through in-country resources. Accompanying this is the expectation that the MRC Secretariat (MRCS) will gradually shift from its current centralised programme-based approach to a leaner organisation built around the seven core river basin management (RBM) functions. This decentralisation of certain current MRC responsibilities to Member Countries will contribute to a greater alignment of the MRC activities with its mandate under the MA95. It will also assist in smoothing the transition towards increased ownership of the MRC by its Member Countries, and effective implementation and integration of MRC policies into national systems. The year 2030 has been set as a target for the MRC to be fully resourced by Member Countries.

Four categories of MRCS core functions have been defined to provide a framework for decentralisation. One of these, River Basin Management (RBM), includes the functions that will remain with the MRC and through which it routinely engages in water resources development and management issues at different scales in the Mekong River Basin. These functions include:

- data acquisition, exchange and monitoring
- analysis, modelling and assessment
- planning support
- forecasting, warning and emergency response
- implementing MRC Procedures
- promoting dialogue and communication
- reporting and dissemination

MRC programmes are at different stages of advancing implementation arrangements in which national agencies take increased responsibilities both in implementing and financing selected core functions. Guiding Considerations from this report that involve new monitoring sites and additional monitoring activities need to be taken into account in considering the long-term resource requirements and availability and their fit in the decentralisation discussions.

1.4 Information on Hydropower Projects

Figure 2 illustrates the challenge of keeping abreast of the status of hydropower development in the LMB with the large number of hydropower projects across the Mekong basin. The MRC has maintained a hydropower project database that provides input information for evaluation of basin development scenarios.

The following parameter groups are contained in the MRC's centralised hydropower database and are considered important for understanding hydropower development and management in the LMB:

- ***General Data Location and Characteristics**:* commissioning year, condition, status, owner, purpose, lay-out, dam type, specifications, spillway features, outlets, fish passage features, re-regulation storage
- ***Hydropower Operations:*** rated head, plant design discharge, installed capacity, peaking capacity, mean annual energy, firm annual energy, full supply level (FSL), low supply level, live storage, reservoir area at FSL, tailrace flow
- ***Project-related Hydrology:*** catchment area, production hydrology, project design flood, sediment load
- ***Construction, Resettlement, Migration:*** construction period, construction cost, reference year for budget, reference project budget, grid expansion, destination country for power, number of people resettled

Additionally, data on hydropower projects needs to reflect the life cycle-stage of each project, principally: development, construction and operation stages of projects. These stages can be lengthy, from years to decades depending on the project. Life cycle stages may not be neatly bounded, with preparation activities such as road and land clearing preceding on-site construction, and some turbines being commissioned while others are still to be installed.

The MRC's hydropower project database helps inform a number of regional and local scale analyses, and can underpin analyses of further development scenarios. Hydropower project general data and characteristics can inform analyses such as rate of development, and water resource and energy supply planning. Analyses can be undertaken to look at level of application of various mitigation features, use for multi-purpose objectives, and ownership/investment patterns. Information on hydropower operations can support analyses such as the degree of regulation of water flows, the degree of provision of base load versus peak load power, and reserve capacity. Evaluation of data on time periods and costs for various project development stages can help inform expectations for further developments. Understanding locations, size, project scale and operational characteristics of the hydropower projects is essential information in combination with analyses of environmental and socio-economic data to help understanding and interpret changes in basin condition.

Processes that can help maintain reliable and applicable information in this rapidly changing development context could include the annual provision of agreed data from Member Countries to the MRC for those data that vary and are quantified on an annual basis (e.g. power production, revenues, and operation and maintenance (O&M) costs) supplemented by a 3 or 5 yearly survey to Member Countries to ensure all information is relevant (e.g. installed capacity, types of turbines, etc.). The maintenance of an up-to-date hydropower project data base will require cooperation from all Member Countries, and will provide benefits at a basin, sub-catchment and local scale.

2 Guiding Framework for Transboundary Hydropower Monitoring

2.1 The Data Value Chain: Getting Useful Information out of Data

To get the most value out of hydropower-related information, it is useful to think of the data as going through a value chain in which the value increases with each step that is able to be delivered (see Figure 6).

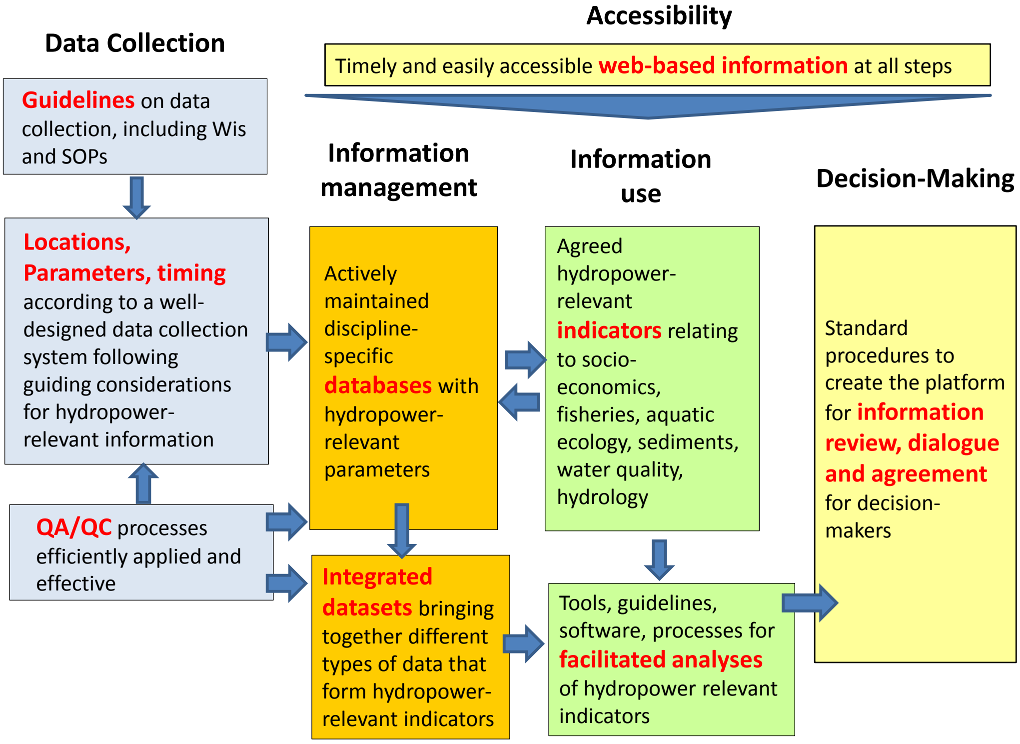


Figure 6 – The data value chain for hydropower-related information

Maximising the value of monitoring results begins with appropriate monitoring design. Important considerations include the identification of appropriate locations, parameters and monitoring timing and frequency. This design can be considerably enhanced for hydropower-related information needs by following the guiding considerations provided in this document. If these initial planning steps are not executed appropriately, the resulting data will have reduced value in the future.

Consistency in parameters and the methodologies for collection in all disciplines and across all locations will ensure the most value from the data, so that comparisons in findings and quality control checks can be made. Undertaking monitoring at times that provide the most insight for the type of data being collected ensures resources are not wasted by collecting data that misses the main story that is occurring in the river. In the Mekong mainstream there are many examples of important timing considerations relating to specific data types, for example ensuring high frequency monitoring is completed when the majority of sediment moves at the start of the wet season.

The value of the raw data collection is increased if guidelines are produced for data collection and storage to ensure standardisation and QA/QC. In the MRC these are commonly embedded into Standard Operating Procedures (SOPs) and Work Instructions (WIs). These SOPS and WIs are an important input to an overall quality assurance/quality control (QA/QC) program, but there must be additional QA/QC standard measures defined and applied at a number of steps in the data management process.

Active maintenance of well-designed databases is essential to ensure that data is stored and subsequently accessible in formats that are standardised and ensure quality. Within the MRC processes, there are a number of discipline-specific databases. Important for hydropower related information is to have supplementary databases that bring together different disciplines in a common platform (e.g. hydrology and water quality concentration data) so that the data can be collated and this collated information (in our example, water quality loads per unit time) itself forms a quality assured database that can be directly accessed.

Ensuring parameters are linked to indicators that inform management questions is important for efficiency purposes and maximising monitoring investments. Indicator development and agreement for hydropower-related management questions will help emphasise the value of particular data parameters that are collected. Indicators need to directly inform management questions, and standard analytical methods are ideally designed to easily generate and analyse these indicators.

To assist decision-makers, tools of various types are ideally developed to facilitate this analysis of hydropower-relevant indicators. These could be guidelines, software, standard reports, etc.

To maximise the value of the investment in a monitoring program for hydropower-relevant decision-making, platforms need to be developed and standardised that bring the information and the decision-maker together at the appropriate times. There are a number of these already that have been created by MRC procedures, for example the PNPCA process. Others would exist within governmental decision-making processes for each Member Country. The more that these can be standardised and well understood, the better the preceding steps are able to be set up and streamlined to feed into these processes.

Finally, the whole value proposition is lifted through ensuring information accessibility at all stages of the data value chain. In this day and age this is typically through web-based mechanisms, with differing levels of accessibility of the data according to type and user.

The following sections elaborate more on these components of the data value chain and provide guidance on approaches to each component that will help maximise value with respect to hydropower information needs.

2.2 A Long-Term Monitoring Program

Any system of centralised and shared information to support transboundary hydropower considerations should build on and complement existing data collection approaches of the MRC and Member Countries. An overall monitoring programme design should provide consistency, uniformity and comparability across the full basin, and be sustainable over the long-term, to best inform sustainable hydropower planning and decision-making. The objective of the information is to provide a clear and scientifically sound understanding of conditions, changes and trends in the LMB relevant to sustainable hydropower.

The over-arching design should include an annual data collection schedule of core data, with consistency over time with respect to locations, parameters and methods along the lower Mekong River. This annual cycle may involve monthly or seasonal sample collection on an ongoing basis. This would be supplemented by additional supplementary data collection on longer time-scales (e.g. every five years) oriented towards parameters that inform longer-term changes, e.g. aerial photography or channel cross-section surveying and habitat description. Establishment of the program on a sustainable basis will require some investigative studies to better understand ecological processes and linkages, which will assist in design and indicator determination.

Annual results provide information over short time scales that reflect the present condition, but over longer time scales this data will be used to identify trends and variability. It is the longer time scales that build confidence in the understanding of the system and its variability and how it responds to pressures or change. Being able to integrate different types of data from various disciplines at the same time and location on a consistent basis will assist in interpretation of cause and effect.

Presented in Box 2 is a **Guiding Framework for MRC Basin-Scale Information for Hydropower Planning & Management.**

The five categories cover the most basic considerations pertinent to information needs for hydropower planning and management. The criteria under each category concisely summarise key needs. Such a framework can provide a basis for a gap analysis, which in turn can lead to identification of areas for improvement to help address identified gaps.

It may be possible to transfer or adapt some of the principles or concepts to guide monitoring for hydropower at the project level.

Guiding Framework for Basin-Scale Information
for Hydropower Planning and Management

1. **Locations of Data Collection:**
    a. Cover all Mekong River hydro ecological zones
    b. Near proposed or operational hydropower project or group of projects
    c. Enable understanding of mainstream processes
    d. Facilitate understanding of changes occurring across national boundaries
2. **Parameters Monitored:**
    a. Provide inputs to indicators related to hydropower planning and management
    b. Able to be replicated across the basin
    c. Able to be measured and analysed at a low cost
    d. Able to help predict as well as explain cause and effect of changes
3. **Timing of Data Collection:**
    a. Length of record covers the cycles of natural variability (seasonal, annual, decadal)
    b. Frequency captures natural or operational system changes and migratory cycles
4. **Information Management:**
    a. Quality management systems are in place to ensure consistency across countries
    b. Systems allow information to be centrally archived and shared
5. **Information Use:**
    a. Information is readily available for users (e.g. Member Countries, developers, NMCs, Line Agencies)
    b. Links to tools are available for decision-support and analysis

Box 2 – Guiding Framework for Basin-Scale Information for Hydropower Planning and Management

2.3 Monitoring Locations

Locations of data collection provide the backbone of a basin-scale monitoring program for hydropower-relevant information.

Guiding Considerations:

The following considerations are important for locations of data collection:

1. Sites with good **long-term data** should be continued. Long-term sites may need to change over time due to localised alterations at a site (e.g. inundation due to reservoir development, reinforcement of local banks, etc.). These changes need to be anticipated well in advance such that a 'new' site can be established and monitored for a sufficient time period to be able to interpret and 'link' the results from the two sites to retain the long-term usefulness of existing data sets.

2. Data from different disciplines should be collected at the **same monitoring locations** as far as practicable for maximum interpretation capabilities; environmental data should be supported by hydrological data (water level, flow, and hydraulic data) at monitoring locations.
3. Data from different disciplines may be collected at **different spatial densities** at a single location (e.g. fish may be collected from multiple sites at a general location; sediments from equidistant points in a cross-section; macroinvertebrates from the river bottom and the margins or at several cross section points) depending on the local morphology and processes influencing the data that is being targeted.
4. Locations should be **meaningful** with respect to the location of hydropower projects, hydro-ecological zones, the location of sites or assets of importance to key stakeholders that may have concerns about hydropower effects (these may include national borders), and the ability to distinguish cause-and-effect of changes due to hydropower versus other developments.
5. **Tributaries** that are important to understanding of processes in the river relied on or affected by the hydropower project(s) should be included in monitoring programmes. Consideration should be given to the allocation of resources to improve the monitoring of major tributaries and for the information to be on the central MRC archive.
6. In a transboundary river system, monitoring station **nomenclature** should consistently follow an agreed naming and location referencing convention. Typically this would include monitoring station name with consistent spelling, location (Northing and Easting), river name, station ID code, zero gauge of station (i.e. elevation above sea level), country name, and distance from the sea along the centre line of the relevant river(s).

Application of the above guiding considerations means that locations of planned Mekong mainstream hydropower projects and reservoirs, national boundaries, hydro-ecological zones and population factors, and existing monitoring sites need to be taken into account in the identification of monitoring locations for Mekong River hydropower-relevant information. Additionally, integration of disciplines at each location will optimise interpretation abilities. From an institutional perspective, aspects of the MRC Procedures and Guidelines that address monitoring locations should be taken into account.

Application of the guiding considerations for monitoring locations for MRC basin-scale information for hydropower planning and management suggests that monitoring should be prioritised at the locations shown in Figure 7 and Table 1. These locations are strongly guided by the location of MRC HYCOS sites (the hydrological network) since good long-term hydrological data can greatly enhance interpretation of all other disciplines.

Figure 7 shows a total of 33 monitoring locations for MRC hydropower-relevant information needs. Of these, 30 are existing MRC or national monitoring sites on the Mekong mainstream and tributaries, and 3 are new proposals. 25 are on the Mekong mainstream and the Bassac River in the Mekong Delta, and 8 are in tributaries just upstream of their confluences with the Mekong River. These are considered to be a minimum set for the 2,300 km length of the lower Mekong River.

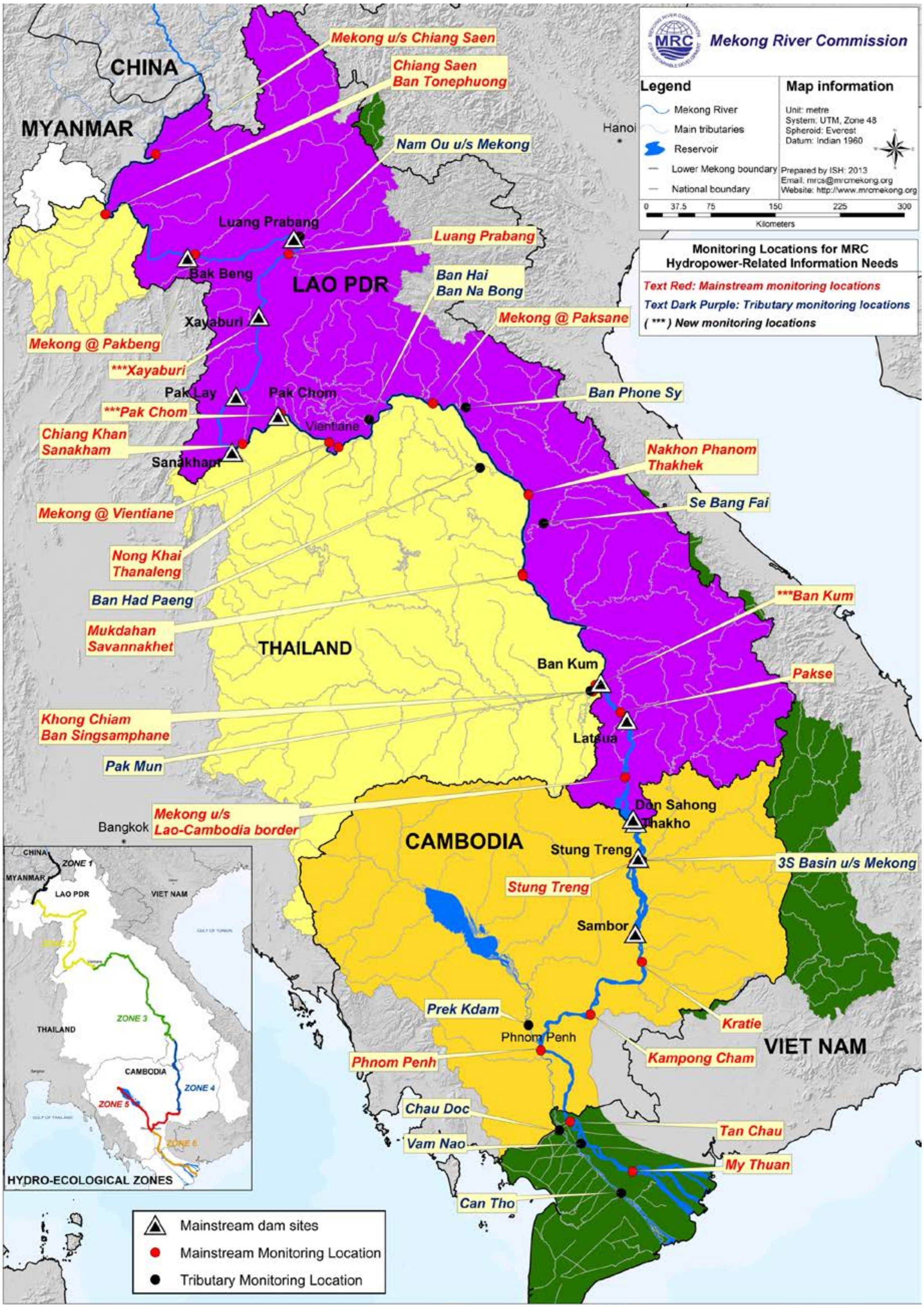


Figure 7 – Monitoring Locations for MRC Hydropower-Relevant Information Needs

Table 1 provides a list of these locations with country affiliations noted. Of the 33 locations, 10 of these are formally agreed to be monitored in the draft Technical Guidelines to the PMFM, shown as "PMFM location" in Table 1. An 11th PFMF location, Kampong Luong, does not appear in Table 1 as it is in the Tonle Sap.

Table 1 – Monitoring Locations for MRC Hydropower-Relevant Information Needs Showing Country Affiliations

🟨 Mekong u/s Chiang Saen
🟥 Mekong @ Chiang Saen/Ban Tonephuong **(PMFM)**
🟩 Mekong @ Pakbeng
🟩 Mekong @ Luang Prabang
🟩 Nam Ou u/s Mekong
🟩 Mekong @ Xayaburi
🟥 Mekong @ Chiang Khan / Sanakhan
🟥 Mekong @ Pak Chom
🟥 Mekong @ Vientiane **(PMFM)**
🟥 Mekong @ Nong Khai / Thanaleng
🟩 Nam Ngum @ Ban Hai/Ban Na Bong
🟥 Mekong @ Paksane
🟩 Nam Kading @ Ban Phone Sy
🟧 Nam Songkhram @ Ban Had Paeng/Ban Chai Buri
🟥 Mekong @ Nakhon Phanom/Thakhek
🟩 Se Bangfai u/s Mekong

🟥 Mekong @ Mukdahan / Savannakhet
🟥 Mekong @ Ban Kum
🟧 Pak Mun u/s Mekong
🟥 Mekong @ Khong Chiam / Ban Singsamphane **(PMFM)**
🟩 Mekong @ Pakse **(PMFM)**
🟩 Mekong u/s Lao-Cambodia border
🟪 3S Basin u/s Mekong
🟪 Mekong @ Stung Treng **(PMFM)**
🟪 Mekong @ Kratie **(PMFM)**
🟪 Mekong @ Kampong Cham
🟪 Tonle Sap @ Prek Kdam **(PMFM)**
🟪 Mekong @ Phnom Penh (Chaktomuk) **(PMFM)**
🟦 Mekong @ Tan Chau **(PMFM)**
🟦 Bassac @ Chau Doc **(PMFM)**
🟦 Mekong @ Vam Nao
🟦 Mekong @ My Thuan
🟦 Bassac @ Can Tho

🟨 - Lao-Myanmar (1)
🟥 - Thai-Lao (10)
🟩 - Lao PDR (9)
🟧 - Thai (2)
🟦 - Viet Nam (5)
🟪 - Cambodia (6)

Thirty-three locations for 2,300 km of the lower Mekong River is a relatively low number for a river of this length and diversity. These locations are not suggested as being representative of the whole river system, but they maximise and build upon existing data collection locations and long-term sites, and provide a structure to build on. Importantly, national and project-level monitoring should seek to fill in the gaps and to make use of the proposed basin-scale long-term sites to help in the more local data interpretation and quality control checks.

2.4 Monitoring Parameters

In addition to locations, the parameters for which data is collected are equally critical to the success of the program.

Guiding Considerations:

The following considerations are important for monitoring parameters to ensure that they can support hydropower-relevant information:

1. Parameters should inform **indicators** meaningful to management, decision-making, and communication issues and requirements for hydropower;
2. Parameters **important** to hydropower information span across technical, financial, economic, social, environmental and governance areas and support all aspects of hydropower.

3. Parameters should support the understanding of environmental and socio-economic issues that might be anticipated to arise at **different times** through the hydropower project life cycle.
4. Ideally parameters should be able to be consistently and accurately measured using established methodologies by the responsible parties, and should be agreed and supported by stakeholders
5. Data collection and analysis **methods** should be consistent and comparable over time and between locations.
6. Consistency in **terminology** around parameters and indicators is helpful towards achieving a common understanding.

To help ensure consistency in terminology, sustainability considerations relating to hydropower have been classified into five dimensions – economic, social, environmental, technical and governance – as shown in Figure 8. Major parameter groups can be identified under each dimension (often more commonly referred to as "disciplines", especially in the environmental dimension). The red circles in Figure 8 show the primary areas of focus in this document, as these have been shown important for basin-scale management questions through numerous MRC processes and are the focus of MRCS monitoring programme data collection, management, data sharing and reporting.

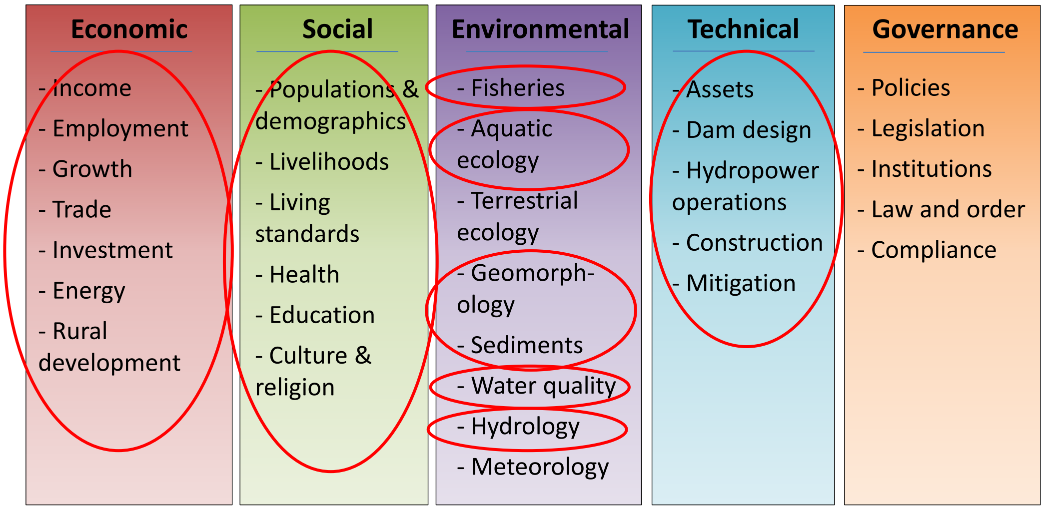


Figure 8 – Information Dimensions and Parameter Groups Relevant to Hydropower

This is not to say that the parameters that are uncircled are not relevant to hydropower information, but they are beyond the scope of this present document.

Parameters collected should inform management questions. An example of how this relationship can be seen is provided in Figure 9, for some management questions that are often associated with hydropower projects (HPPs).

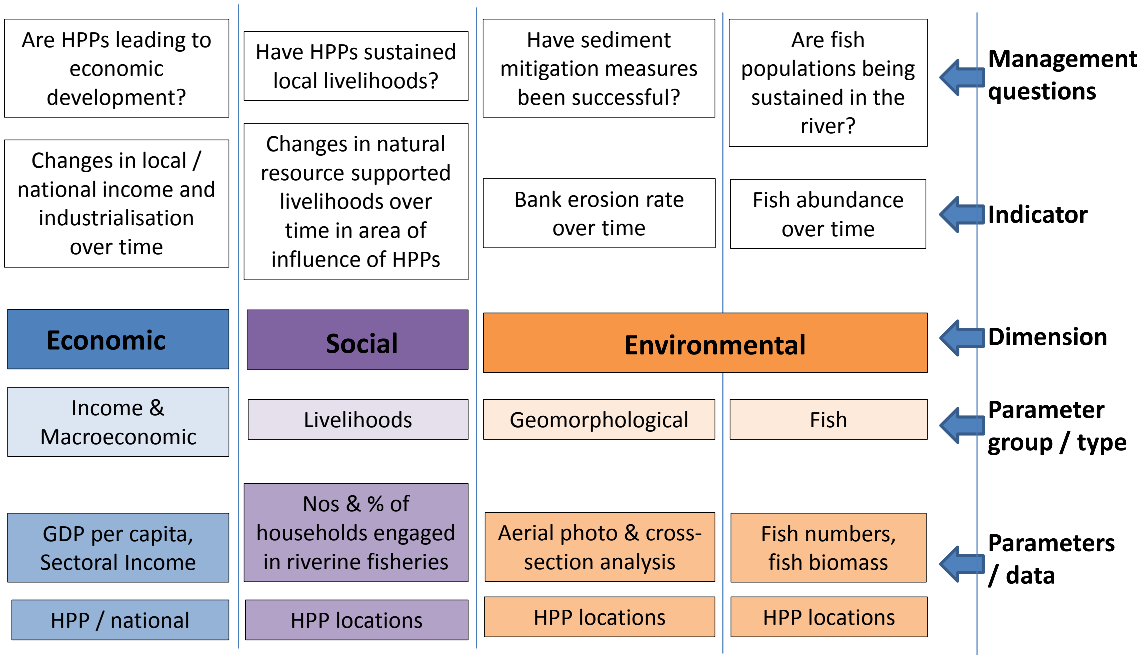


Figure 9 – An Example of How Parameters Support Management Questions Relevant to Hydropower

The MRC Basin Development Planning Programme's (BDP) project entitled 'Development of social, environmental and economic development and management indicators for the Mekong Basin' supports basin-wide scenario assessments as input into Basin Development Plans, as well as provides a structure for the five-yearly State of the Basin Reports. This is in keeping with the move towards a more results-based approach at MRC, which recognises the importance of development and management indicators to guide management, policy development and understanding by the public on conditions and trends in the Mekong Basin and the effectiveness of development and management interventions.

An agreed set of indicators, derived from parameters, will:

- provide continuity in different aspects and levels of MRC's work from routine monitoring to scenario assessments and State of the Basin reporting;
- allow tracking of a consistent set of indicators in the five-year State of the Basin Reports which will greatly improve the analysis of trends and the identification of the key issues that the Basin Development Plan and other MRC Programmes should address; and
- provide indicators to broaden the scenario assessment approach in order to ensure that all MRC sectors are effectively covered.

Indicators can be very simple (e.g. water quality concentrations compared to national standards, or plotted over time) or quite complex (e.g. the Human Development Index which is a composite of several types of socio-economic data). For some disciplines (e.g. aquatic ecology where knowledge of species' ecological indication is partly relatively low or not compiled ready for use) there is considerable ground work to be done to develop indicators, whereas for others they are quite well understood and transferable to many river systems (e.g. sediment transport). There are a number of indicators quite unique to the Mekong River system, e.g. the time period for the onset of the wet season, which can have strong linkages with many of the livelihood dependencies on the resources of the Mekong River.

Because some changes occur over long time scales, it is not always possible to see the changes in regularly collected data sets, so indicators that show trends over time is important. It is also important to recognise the signals that might indicate significant ecosystem process shifts (e.g. a change from a dominantly erosional to depositional sediment transport regimes, a change in the dominant aquatic ecology biological group linked to major hydromorphological change, a change in predator-prey dynamics leading to dominance of particular (sometimes introduced) species). When considering hydropower relevant information, it is necessary to understand the changes that have happened in other river systems and to be looking out for indicators of such changes occurring (or effectiveness of management measures that are trying to mitigate such a change).

Indicators that drawn on different discipline and highlight interlinkages can be of high value for hydropower-related questions, and increase the value of discipline-specific datasets. Examining interlinkages amongst data types is particularly useful for understanding influences on ecosystem processes, socio-economic conditions linked to natural resources, and seeking to interpret cause and effect of observed changes (i.e. are they caused by hydropower or by other influences?).Indicators can be defined that bridge the different disciplines, provided that the monitoring design – particularly locations and timing – have been set up to enable data integration.

Indicators are important contributors to understanding of cumulative impacts and any transboundary implications of changes. Cumulative impacts may arise from any number of combinations of resource development and use activities, both directly in the Mekong River and indirectly in the sub-basins, in the rivers and on land draining into the rivers. Cumulative impacts are often best revealed by seeing step changes in data trends following incremental development or resource use changes. Strategically chosen monitoring locations, well-selected parameters that link to indicators, and carefully considered timing of data collection, together should help understand the nature and implications of cumulative effects and what might be most influential in mitigating any negative impacts. Transboundary implications should be able to be identified and understood following the same principles, and most particularly with locations that are indicative of changes across national borders.

A number of potential indicators have been identified through the ISH11 study as meaningful to hydropower-related management considerations, but more work is required to sharpen those that will be tracked regularly in the long-term. A more concise research framework for hydropower information needs would be of benefit to develop and communicate, so that university- or other institution-based research initiatives can see where they can best orient their efforts.

2.5 Timing

Information needs to support hydropower planning need to take into account the range of time scales over which management questions will arise:

- ***Short-term*** could be considered to be any time period shorter than ten years. Short-term time scales would include at the hydropower project level many of the considerations at the beginning stages of a project life cycle (pre-feasibility, feasibility, construction, impoundment closure and filling, commissioning and early operation) during which a focus on prediction and detection of impacts and benefits are of high importance. Also in short-term time scales are incidents that might arise at any point in time (e.g. an oil spill or a disease outbreak), for which contextual information over large spatial and temporal scales assists interpretation of incident investigation data.
- ***Medium-term*** could be considered a decadal to generational time scale (~10-20 years), over which adjustments of economic, social and environmental systems take place in response to hydropower developments. Development status and plans, delivery of benefits, and evaluations of effectiveness of mitigation measures are important information needs at all levels.
- ***Long-term*** would be considered inter-generational time scales (>20 years), over which needs for information reflect changed conditions, values, objectives and expectations; adaptive

management requirements; and sustainability of benefits and the activities and systems that support these benefits into the long-term.

In addition to the necessity of informing long-term information needs within which there will be shorter-term management questions.

Guiding Considerations:

The following considerations are also important for timing of data collection and processing:

1. Data sets should be of **sufficient length and frequency** to reflect the types of and influences on the changes that are observed for each parameter, and should take into account changes that can occur at different times scales (decadal, annual, seasonal, daily, hourly).
2. **Interruptions in data sets should be avoided**; therefore monitoring programme design should take a long-term view so that the same location can provide before-and-after information when changes take place.
3. **Less frequent data collection** is sufficient to track some hydropower-relevant parameters (e.g. aerial photography, habitat assessment, bed material samples, and census data). Infrequent but regular data collection of selected variables on the scale of years to decades will provide a framework within which more frequently collected data can be interpreted, thus enhancing the usefulness of both scales of information.
4. Periodically undertaking **longitudinal surveys** (upstream → downstream) of a river system, in which a "parcel" of water is followed throughout the river system in a single monitoring exercise (i.e. a Lagrangian sampling approach), can greatly enhance the understanding and inter-relationship of river system processes on a basin scale. This understanding provides a context for the interpretation of routine monitoring results, thus enhancing their usefulness.
5. Annual results provide information over short time scales that reflect the present condition, but over longer time scales this data will be used to **identify trends and variability**. It is the longer time scales that build confidence in the understanding of the system and how it responds to pressures or change.
6. Information needs relating to hydropower projects vary through the project life cycle (planning, construction, operation, decommissioning), which for hydropower can span decades up to a century, so **long-term data sets are of high importance** for the success of each stage.
7. **Timeliness** of data analysis and availability to users is as important as timeliness of data collection.

From an institutional perspective, aspects of the MRC Procedures and Guidelines (Section 1.3) that address timing also need to be taken into account.

2.6 Information Management

The best data collection system will not have value to the end user unless good management systems are followed throughout the information management cycle.

Guiding Considerations:

The following considerations are important for information management when thinking about LMB hydropower-related information:

1. Data storage and retrieval of data sets relevant to water resource issues should be centralised and **readily accessible**;

2. Quality Assurance and Quality Control (**QA/QC**) procedures should be applied at multiple steps to ensure confidence in all data, including field and lab audits, capacity-building events, and inter-lab comparisons;
3. Implementation **responsibilities** for data collection, storage and management should be clear amongst all parties and documented, such as through the development of Standard Operating Procedures (SOP) and Work Instructions (WI);
4. International or regionally-accepted **standards** are useful to ensure common understanding of expectations (e.g. for specific sampling methods, and for quality management systems), and can be incorporated into SOPs or WIs; and
5. Monitoring programmes should be periodically **reviewed** to ensure efficiencies, value and contribution to objectives.

A **management systems** approach to long-term information collection and management is needed to ensure consistency, quality and value. The ideal system starts with clear objectives for the monitoring activities. Following agreement, programme implementation includes standard procedures, data collection, sample analysis, and data management and analysis. An important component is that results inform decision-making and management actions. If they do not, then refinements may need to be made to aspects of the overall management system.

Accompanying all of these steps are **capacity-building, QA/QC measures, and regular review** and refinement as needed. A schematic for such an approach is shown in Figure 10.

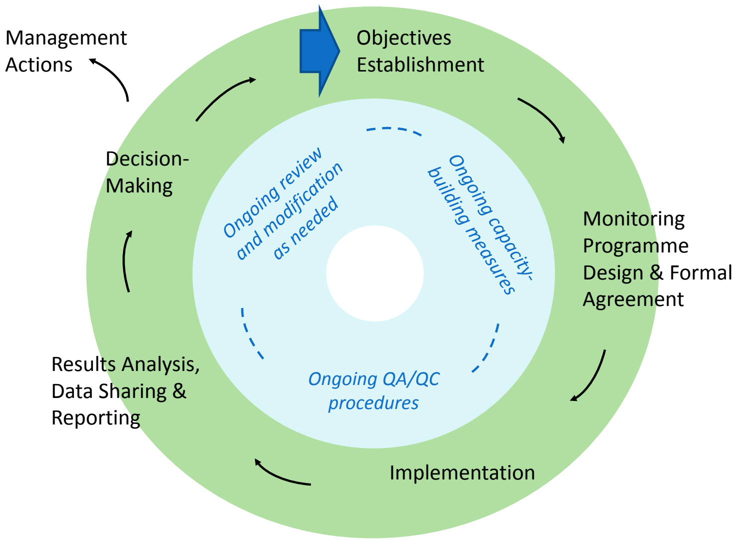


Figure 10 - A Management System Approach for Monitoring

2.7 Information End Uses

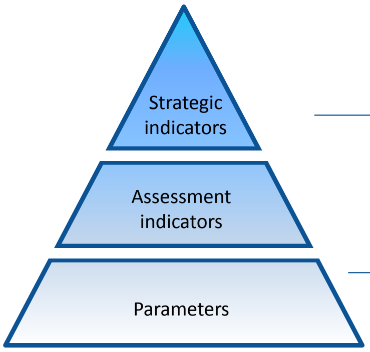
Finally, the ability of the information provided to serve the needs of the end users should be regularly evaluated.

The following considerations are important for information use:

1. Information end uses can **change over time** as contexts, developments, and management issues evolve; therefore information collected should be able to inform a variety of end-uses. This highlights the need for the collection of long-term basic data which can be used in a variety of ways over time.

2. Information collected and reported can be most meaningful to management, decision-making, and communication needs often through analysis and presentation in the form of agreed key **indicators**; these indicators can and will change over time as issues change and knowledge increases, so the parameters underpinning these indicators should be well-selected and consistently monitored.
3. Information should be accessible in **time-frames** relevant to awareness-raising and decision-making. It is very difficult to make good decisions if data is not provided to users until, for example, 3 years after it has been collected.
4. Information should be able to **explain variations** seen spatially and temporally so that decision-makers know whether they need to respond to the change being shown.
5. Information should assist in the analysis of **risks and impacts**, in combination with site-specific data.
6. Information should be available in **formats suitable for users** of the information, which can vary from technical officers, to planners and assessment specialists, to water resource managers and power system operators, to government and ministerial delegates.
7. Formats should enable information extraction or accessibility in **raw data** forms (e.g. easily downloadable raw datasets with metadata in consistent and clearly understood formats), **visual** forms (e.g. web-based visual presentations automatically updated) and **documentary** forms (e.g. technical reports, report cards, status reports, etc.).
8. **Technologies** for information storage, analysis and presentation change and evolve, and information management systems should closely follow trends so that users can get the benefits offered from technological improvements.

Close attention needs to be paid to the requirements of different information users and uses. Uses and users of information can vary widely, illustrated by Figure 11 showing tiers of users, uses and information formats in a structure relating these to the BDP indicator framework. Figure 11 shows that information uses by decision-makers and the formats that they require it in are quite different than those working with the technical data.



Information Users	***Role of the Information Users***	***Forms of information input and output***
Decision-Makers – Government Agency Heads, Ministers, Joint Council Members, Business Heads	*Receive recommendations and make decisions*	**Inputs** – Management papers for decision-making **Outputs** – Agreements, decisions, policies
Assessors and Planners – Consultants, Managers, Government Agency Staff	*Convert technical inputs into management reports for decision-makers*	**Inputs** – Technical reports, map-based condition info **Outputs** – Management papers for decision-making
Technical Users – Monitoring Teams, Monitoring, Database Managers, Modellers, Analysts	*Provide technical inputs to assessors and planners*	**Inputs** - Spreadsheets, databases, historical reports **Outputs** – Technical reports

Figure 11 – Users, Uses and Formats of Information

Further exploration of the Rapid basin-wide Sustainability Assessment Tool (RSAT) information needs would be insightful, as it highlights information needs from various users with key responsibilities (river basin planners and managers, energy and power sector planners and regulators, hydropower project developers and operators, and government policy-makers and regulators).

There are many ways that good basin-scale centralised information relevant to hydropower can be synthesised and used. Some of the uses include prediction, forecasting, mitigation, management, design of ongoing monitoring regimes, and translation to local uses. Forms of output for Member Country access and use of centralised MRCS information relating to hydropower as a minimum need to include:

- **easily extractable data** sets for information to inform hydropower planning and management accessible from the MRC Data Portal in a **timely and consistently formatted** manner, primarily of value to technical analysts who would then convert it into different outputs for consideration by assessors, planners and decision-makers;
- **map-based condition information** for hydropower-relevant parameters, periodically-updated and shown on the MRC website, useful for assessors, planners and decision-makers;
- **indicators and template figures or graphs** for future State of the Basin Reports relating to hydropower, useful to assessors, planners and decision-makers;
- **indicators** for future Basin Development Plans and Scenarios relating to hydropower, useful for decision-makers; and
- guidance or **guidelines** for Member Countries and developers/operators on priority parameters, methods for information collection, and indicators for hydropower-relevant information, useful for technical staff in designing and implementing monitoring programmes, and useful for assessors and planners in considering licensing requirements for monitoring programmes.

To best be available to inform management considerations and decision-making, it is necessary to have processes that ensure publication at predictable intervals. The MRC has a number of processes for regular public reporting that includes hydropower-relevant information, such as the following.

- The MRC website (***www.mrcmekong.org***) data portal to the Data and Information Services, which is a source of raw data that others can download to do their own analyses. Ideally raw data collected through MRC monitoring programmes would get onto that data portal as soon as QA/QC processes can be implemented.
- The MRC's **State of the Basin Reports** (MRC, 2010c; MRC, 2003) provide basic information on geology, geomorphology, hydrology, climate, biodiversity, economy, populations, social and economic indicators. They describe the status of fisheries, forestry, agriculture, hydropower, water quality, ecological health, wetlands, navigation and trade, climate change and flood management in the LMB. A good reference list accompanies each chapter. Data in the 2010 report is to the end of 2008. The next SoB Report is planned for 2015, and generally at five yearly intervals after that.
- The **Planning Atlas of the Lower Mekong River Basin** (MRC, 2011a) summarises and explains the key baseline data that supports development of the Basin Development Strategy, a process which is undertaken on a five-yearly basis. Data is grouped under the themes of: boundaries; social attributes; physical landforms and transport infrastructure; water resources; environment; and water uses. The final section shows the key monitoring stations used for meteorological, hydrological and water quality data collection. Data was assembled during 2008-2010 by the MRC BDP Programme.
- The **Assessment of Basin-wide Development Scenarios** (MRC, 2011b) covers a range of environmental, social, and economic criteria used for scenario assessments towards development of the Basin Development Strategy. Figure 6 in this 2011 MRC report provides a

conceptual model, and Table 4 a summary of indicators used. Section 5.3 addresses sufficiency of information and knowledge about impact processes; Section 6.5 addresses knowledge gaps and strategic issues; and Section 6.6 shows where monitoring and evaluation fit in the BDP planning cycle. The Main Report is accompanied by five additional volumes and supported by 13 Technical Notes, many of which are relevant to the disciplines to be incorporated in the ISH11 monitoring plan. Because updating of these scenarios is planned for every five years, it will become an important source document which examines agreed indicators and projects them into the future.

- The **IWRM-based Basin Development Strategy for the Lower Mekong Basin 2011-2015** (MRC, 2011c) sets out the MRC's strategic priorities for basin development and management along with an agreed Road Map for implementation during 2011-15. This would also be updated on a five-yearly basis, and would include important indicators for delivery of strategic objectives which would then be monitored and reported on through the MRC monitoring programmes.
- The **MRC Strategic Plan 2011-2015** (MRC, 2011d) describes the context within which the MRC functions, and outlines the basin vision, the MRC vision, the MRC mission and the MRC long-term goal. It outlined five specific MRC goals for the 2011-15 period, and defined outcomes for each goal. Indicators, targets and means of verification are defined. This will also be updated on a five-yearly basis.

Additional to these are reports more specific to individual disciplines, e.g. regular report cards for ecological health and for water quality and various technical reports such as for fisheries and for sediments.

A highly relevant information use is evaluating potential dam projects against the **Preliminary Design Guidance for Proposed Mainstream Dams** (MRC, 2009). The "PDG" provides design guidance to dam developers in the form of performance targets, design and operating principles for mitigation measures, taking into account potential transboundary impacts. The scope covers navigation, fish passage, sediment transport, river morphology, water quality, aquatic ecology and dam safety.

Examples of information uses that help inform decision-makers on important periodic assessment processes including the following.

- The **Strategic Environmental Assessment of Hydropower on the Mekong Mainstream** (ICEM, 2010), which sought to identify potential opportunities and risks, including the contribution to regional development, by assessing alternative mainstream Mekong hydropower development strategies.
- The **Prior Consultation Project Review Report for the Proposed Xayaburi Dam Project** (MRC, 2011e), which was a technical review of the proposed Xayaburi hydropower project in Lao PDR, the first mainstream project submitted for consideration by the MRC.
- The process for prior consultation for the proposed Don Sahong hydropower project, which is presently in progress.
- The Council Study and the Viet Nam Delta Study, both major cumulative and transboundary impact assessment studies, which are presently in progress.

Having identified these guiding considerations for hydropower-related information in the LMB at the basin scale, the following sections look more closely at the key disciplines identified as of primary importance to include in such a monitoring program.

3 Hydrology

3.1 Important Concepts

3.1.1 The role of hydrological information

Hydrology includes all components of the hydrologic cycle: rainfall, surface water flow, ground water movement and evaporation / evapotranspiration. Understanding the hydrology of a river basin is fundamental to water resource planning, management and development. Hydropower, irrigation, navigation, flood forecasting, drinking water supply, fisheries, etc., all require an understanding of water sources and movement in the catchment.

Sound hydrological information is also required for implementation of the MRC Procedures with respect to water usage and water quality.

Each element of the cycle must be considered with respect to monitoring design requirements (spatial extent and density, sampling intensity), monitoring techniques, and monitoring frequencies depending on the end use of the results.

Best practice hydrologic monitoring requires an integrated approach to ensure that the information collected is correct and is relevant to the questions needing to be addressed, the data is rapidly available to those requiring the information, such as flood forecasters, and the data from the various hydrologic components (e.g. rainfall, river discharge) can be integrated. One integrated approach to hydrologic monitoring has been summarised in a white paper by Aquatic Informatics (2012), and includes the following components:

- **Quality Management System (QMS)** - An overarching set of operating procedures that control the data production process to ensure the data are of consistent and known quality, and the data management process to ensure that data are maintained and available over long time periods.
- **Network design -** Identifying the sites and parameters required to address the needs of the data users. Network design a dynamic process, with sites and parameters added altered or eliminated based on information needs and funding.
- **Equipment / Technology** - Appropriate monitoring, logging and communications equipment needs to be identified which will collect the required data. Of critical importance is the on-going maintenance of the network to ensure continuity of information delivery. Issues to be considered include equipment reliability and applicability to setting, instrument sensitivity and precision, cost, site-specific conditions, and ease of use or familiarity by operators.
- **Training** - Monitoring and data management methodologies require a wide range of expertise, and there must be a consistent adherence to standards and protocols over long periods of time (inter-generational) to provide data consistency and reliability.

Within the LMB, IKMP has managed the development and implementation of an automated hydrologic monitoring network (HYCOS) which includes the measurement of rainfall and river levels, and appropriate data management processes through the World Meteorological Organisation (WMO) World Hydrological Cycle Observing System (WHYCOS) project. River discharge monitoring, completed through the Discharge Sediment Monitoring Project (DSMP) complements the automated information collected from HYCOS and allows the conversion of river level information to river discharge.

3.1.2 Information needs and uses

The development of sustainable hydropower requires a sound understanding of the water resource, the hydrologic processes governing flow rates, and how flow changes may propagate and affect the downstream environment. Hydrologic information is required at a range of spatial and temporal scales, as summarised in Figure 12.

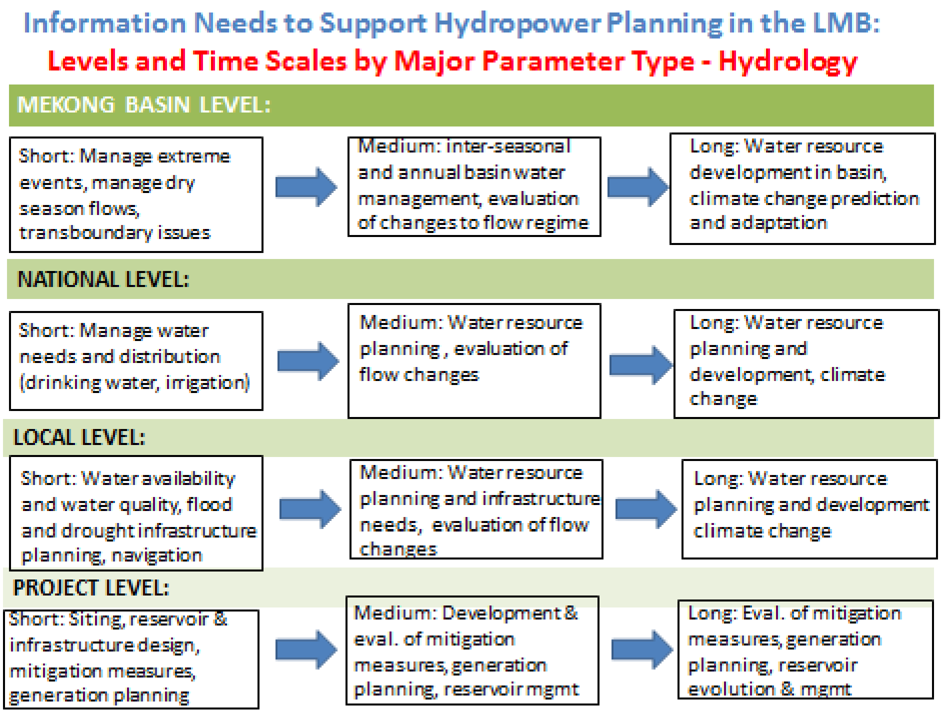


Figure 12 – Spatial and temporal information needs to support hydropower planning in the LMB

A basin-wide, large scale understanding of the sources and sinks of water is required for the transboundary management of extreme events, such as floods or droughts over short time frames, and for the sustainable development and management of water resources over longer time frames (hydropower, irrigation, industry, drinking water, and aquaculture).

At the national to local scale, hydrologic information is needed for the design and implementation of flood or drought management plans and infrastructure and water resource planning and management, over short to long time frames.

Sustainable hydropower requires hydrologic information at all project life cycle stages (pre-feasibility, feasibility, construction, operation) to guide design criteria, generation plans, mitigation measures, and management strategies regarding associated developments, such as water supply or aquaculture.

Rainfall and river flow data is required for siting, design and optimising generation from hydro power developments. Rainfall and inflows are analysed extensively to understand reliability and variability of the water resource, and hydrological/climatic risk. Flood magnitude and frequency analyses are essential to design appropriate spillway capacities and other dam safety features. Flood forecasting, and continuous monitoring of rainfall and inflows, informs operational decision-making over short- and long-time scales.

Hydrological data informs planning of hydropower operational releases including any requirements for environmental flow release measures. Flow data is analysed alongside other environmental and social data to evaluate effects of altered/regulated flow regimes on ecological processes and social conditions.

Groundwater saturation and river level data can be important to understand erosion risks in the downstream river system.

Tidal dynamics data helps understand if there are any implications of altered hydrological regimes on tidal variation and sea level change, which alongside other environmental and social data is important for analyses of impacts and their implications.

3.2 Locations

The HYCOS network provides good coverage of the Mekong mainstream and major tributaries at a catchment level. The present network provides large-scale information for hydrologic and climate modelling which is necessary for hydropower planning and management.

Improved coverage with respect to hydropower needs could be achieved by increasing river level and discharge monitoring sites in: 1) areas where large or numerous tributary inputs occur over short distances, to better define inputs to the system; and 2) areas where hydropower is planned and HYCOS sites are lacking. Examples of 1) include the confluence of the Nam Ou, Pak Mun or 3S Rivers which in the future are likely to be entering the Mekong in river reaches strongly affected by hydropower operations. Examples of 2) include sites in northern Lao PDR where multiple hydropower projects are proposed between Luang Prabang and Chiang Kong.

The expansion of the HYCOS network is not the sole approach available for increasing the locations where hydrological information is collected. There are several alternative approaches for increasing hydrologic information as follows.

- Hydrologic modelling may be able to provide information relative to hydropower planning and management, although this is contingent on there being sufficient information to provide adequate input data for the model. Input information includes rainfall, river flow and river channel characteristics (in the case of hydraulic modelling). Modelling short-term flow responses associated with power station operations, or the interaction between power station discharges and downstream tributaries, requires detailed, site-specific information. The applicability of hydrologic models will need to be assessed on a project-by-project basis.
- Proponents of hydropower projects generally establish site-specific hydrologic monitoring sites at key locations associated with proposed hydropower developments. The sharing of this information between developers and the MRC would be an efficient way to obtain more detailed hydrologic information, and would provide a common ground for the developers and other countries in the basin for understanding, predicting and potentially managing flow changes associated with hydropower developments.
- Temporary hydrologic sites, consisting of gauge boards, could be established at locations where more information about river flow is required. These can be manually read or logged locally without connecting to the HYCOS network, with discharge measured using ADCP or current meters during other monitoring activities (e.g. sediment monitoring). This is a cost effective approach to obtaining additional information over short-time frames, and is especially applicable where additional hydrologic information is required to develop hydrologic models, or interpret the results from other monitoring projects, such as sediment, fisheries or aquatic ecology.

3.3 Parameters

Sustainable hydropower development requires an understanding of all aspects of the water cycle. The monitoring of rainfall related parameters (quantity, intensity) throughout the catchment is required to quantify the water resource for hydro (or other water resource) development. Rainfall patterns and intensity are required for the design of appropriate dams, spillways and the efficient management of power generation. Monitoring and understanding rainfall is also necessary for the successful implementation of mitigation measures linked to reservoir draw-downs, or high flow spill events.

River flows, and their relationship to rainfall patterns and catchment runoff, need to be understood to accurately predict inflow rates to impoundments, and for power station (turbine type, number, capacity), and spillway and sluice gate design.

Groundwater information may be relevant to hydropower development for identifying losses from storages. Locally, water levels will increase around impoundments, and can affect slope stability and vegetation viability. Changes to groundwater levels can also affect groundwater quality which can affect groundwater uses. Downstream of power stations, the rate of change of released flows can affect bank saturation and stability, and understanding the linkages between river level changes and groundwater fluctuations can assist in designing appropriate operating procedures, such as ramp-down rules.

The hydrodynamics of the tidal delta are complex, and a detailed understanding of the surface, and sub-surface hydrology is required to predict potential changes which might be associated with hydropower. Importantly, there are many other activities (irrigation, diversions, water extraction for drinking water or industrial supply, land use change, aquaculture, etc.) that can affect the hydrodynamics of the delta, so a good understanding of the hydrology of the delta is critical for separating potential hydropower impacts from other catchment developments and activities.

Table 2 provides a summary of those parameter groups needed for hydropower-relevant MRC hydrology information.

Table 2 – Parameter Needs for MRC Hydropower-Relevant Hydrology Information

MRC-Centralised Parameter Groups	Hydropower Relevance	Example Basin-Scale Indicators
***Rainfall**:* hourly, daily, monthly, annual total, intensity, seasonality	➢ Required for the siting, design and optimising generation from hydro power developments; ➢ Planning of hydropower operations to manage alterations to d/s flow and the effect on ecological processes and to minimise social impacts; ➢ Maintaining flows on mainstream (per PMFM).	✓ Changes in hourly, daily and seasonal river flow levels and patterns ✓ Tidal variation and sea level change ✓ Groundwater levels
River Flow: Magnitude, duration, seasonality, rate of change, frequency,		
Groundwater: Level, direction of movement, linkage to river level		
Tidal dynamics: flow direction, flow magnitude, inland extent, linkage to ground water		

3.4 Timing

MRC information to support hydropower planning and management should take into account the following timing needs and considerations important to hydrology.

- Hydrologic data is required at a number of time-scales for hydropower planning. Hydrologic information at the continuous, hourly, daily, weekly, monthly, seasonal, annual and inter-annual scale is all required to address the range of planning and management issues.

- Over short time scales (hours to days), **continuous recording rainfall and river flow data** is needed for the planning, siting, and operation of hydropower projects, as it provides information about the timing and magnitude of river flows. Short-term information is also required to manage extreme (high and low) flow events, and manage transboundary water supply issues. This information is also required for hydrologic modelling, navigation, and the interpretation of water quality, sediment, fisheries and ecological health monitoring results. The 'continuous' monitoring of rainfall and river level at HYCOS sites is appropriate for hydropower planning, as data can be aggregated to longer time scales as required.
- **Longer-term records** are needed for **assessment of the potential hydrologic resource**, inter-seasonal and inter-annual operational management, and developing and evaluating mitigation measures.
- **Ground water** data are needed on a **short-term to seasonal basis** to understand potential hydrologic changes associated with hydropower operations.
- An understanding of the **short-term to seasonal** interaction between **tidal forces** and river flow is required to understand potential changes to sediment movement and ecological processes associated with hydropower operation.
- **Long-term (years to decades)** hydrological data is needed to understand long-term, basin wide characteristics such as changes to water availability due to land use changes, water use development (irrigation, ground water extractions, industrial extractions) and climate change. This long-term information is also needed for long-term hydropower planning and other large scale water development projects. Long-term hydrologic data provides an understanding of the variability of the system and changes which occur beyond the LMB (e.g. dams in China) which is needed for the development of accurate hydrologic models to underpin basin development planning.
- An important consideration with respect to timing and continuity of monitoring is the on-going maintenance and calibration of HYCOS sites. Ensuring the on-going, accurate functioning of the network is fundamental to long-term basin wide planning and management. The checking and calibration of instrumentation, rapid availability of spare parts, implementation of the established HYCOS SOPs, training, implementation of appropriate QA/QC measures and successional planning all need to be considered for the long-term reliable operation of the network. The adherence to the established data management procedures and long-term maintenance of the data base is also critical to long term water resource development in the LMB.

3.5 Methodological Considerations

3.5.1 River level monitoring

River level monitoring at each of the HYCOS sites is completed following best practice international standards, appropriate for the local conditions. River level is measured using either a shaft encoder, bubble level recorder, or a radar level sensor (Figure 15). Manual checks of the logged river level against the gauge board level are made on a regular basis and any offsets are noted and corrected.

River level data collected at the telemetered sites are convertible to river flows using rating curves based on discharge measurements collected and reported to the IKMP by hydrologic teams in each MRC country, under collaborative arrangements managed by the MRC.

3.5.2 Conversion of river levels to river discharge

In order to convert river levels to river flow, a discharge rating curve needs to be developed which relates stage height to flow volumes. To obtain a reliable rating curve, the physical channel at the monitoring site must remain constant, such that any changes to river level are attributable to flow changes only, rather than channel modifications. Cross-sectional survey measurements, and discharge measurements are co-operatively completed by each country under the Discharge Sediment Monitoring Project, which is coordinated by the IKMP. The National monitoring teams regularly complete surveyed cross-sections of the monitoring sites to document any changes which may occur. River discharge measurements are completed using either current meters or Acoustic Doppler Current Profilers (ADCPs) at various river stages periodically through the year with this information added to the existing data set. As the underlying data set grows, rating curves become more accurate, and the on-going updating and checking of rating curves is an important component of data management. Rating curves have been recently updated in an MRC Technical Report (Someth, *et al.,* 2013).

3.5.3 Data management and information uses

The HYCOS monitoring data is telemetered using a GPRS system on a GSM network to an internet server, and then retrieved by the IKMP via an ftp site. The IKMP is responsible for the quality control of the information and distribution of the data to third party users, and final publication on the internet. The system also has the capacity to generate automatic warnings, generate alarms, activate warning signs and send text messages to cell phones to alert staff in case of key events or exceedance of pre-set thresholds.

This integrated approach to monitoring is being extended into data management, with the IKMP in having procured the *Aquarius software* package which will enable enhanced management and interpretation of the available information, ensure QA/QC measures are implemented, and facilitate the integration of different data streams (e.g. hydrology, water quality, sediment).

Figure 13 – Top Left: Radar water level sensor used at HYCOS stations; Top Right: Bubble river level sensor; Bottom Left: Shaft encoder and logging box; Bottom Right: Tipping bucket rain gauge. All photos from MRC (2012)

4 Sediments & Geomorphology

4.1 Important Concepts

4.1.1 Understanding sediment transport and geomorphology

The movement of sediment in rivers is governed by the supply of sediment and the flow regime. How sediment moves through a river is dependent on sediment supply, size and shape of the sediments, flow velocity, and channel morphology. The total sediment load can be divided into the suspended sediment load, which is carried by the river without interacting with the river bed, and the bedload which moves via traction or saltation on or near the river bed. Fine sediments (<63µm), which rarely interact with the bed, are frequently termed the ‘wash-load’. Coarser material can travel either as suspended load or bedload, depending on the flow velocity of the river. The variability of sediment transport in a natural river is demonstrated in Figure 14 where the distribution with depth of different sediment classes is shown for the Missouri River in the U.S.A. (from Federal Interagency Project Reports, 1963). Fine-sand and larger material is preferentially transported in the lower water column near the bed, where silts and clays are transported more uniformly over the entire water column. It is for this reason that Total Suspended Solid (TSS) measurements completed on ‘surface grabs’ tend to under estimate suspended sediment concentrations due to sand being under represented in the sample.

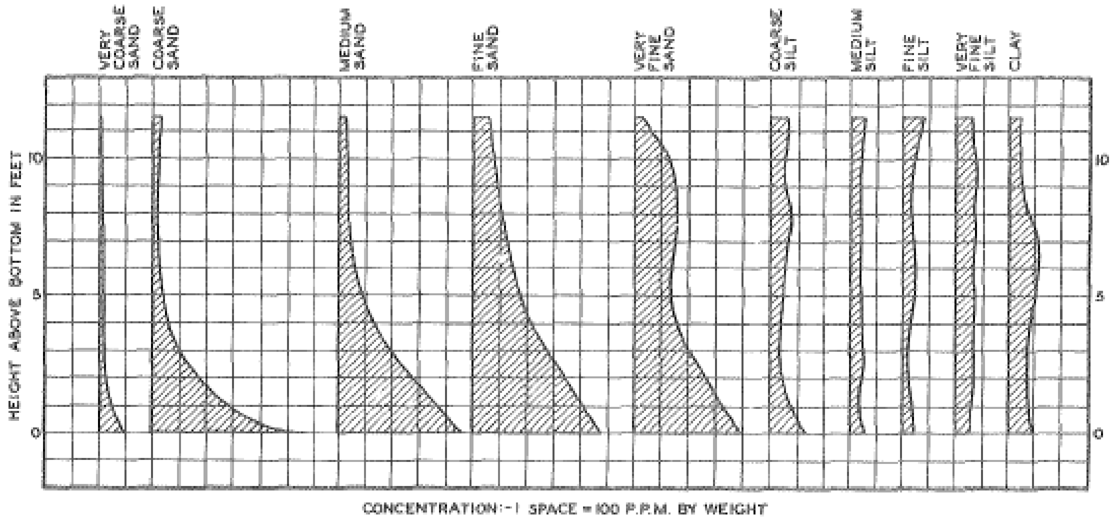


Figure 14 – Distribution with depth of different sediment classes in the Missouri River, Kansas City Missouri

Sediments, geomorphology and sediment transport processes are important considerations relating to hydropower, as they can both impact hydropower developments and be impacted by developments over a range of spatial and temporal scales. This is an issue of high importance to Mekong River stakeholders, especially those whose livelihoods are closely dependent on existing sediment related processes.

Accurately predicting inflows and the movement of sediment through reservoirs over decades requires hydrologic and sediment transport models, which must be based on appropriate and accurate information. Sediment characteristics and how they behave during passage through or storage in a reservoir will also have direct impacts on water quality and aquatic habitat condition. For example, organic-rich sediments can affect oxygen and nutrient concentrations in impoundments, which in turn can affect the downstream environment once the water is released from the dam.

The disruption or alteration of sediment flow patterns in a river can alter habitat distribution and affect habitat quality in the downstream river system. The capture of coarse grained material and large woody debris within a dam combined with the alteration of the relationship between flow and sediment delivery can reduce habitat heterogeneity, and alter seasonal cycles of erosion and deposition in the channel and on floodplains. Flow and sediment regulation can also alter the interactions between tributary inflows and the mainstream, leading to increased deposition or erosion at and downstream of tributary confluences.

Erosion of alluvial material is commonly observed downstream of dams or weirs, with the extent of impact related to the characteristics of the downstream river, such as the slope and sediment size of material within alluvial reaches, and the number, size and location of downstream tributaries which introduce additional sediment to the system. Channel widening through bank erosion can occur where sediment supply is reduced, but channel narrowing through vegetation encroachment can also occur if flow regulation reduces median and / or peak flow rates. To accurately predict impacts and identify appropriate mitigation measures requires a site-specific understanding of the local geomorphic processes and pre-dam flow rates in the river reach, and the role these processes play in the context of the basin.

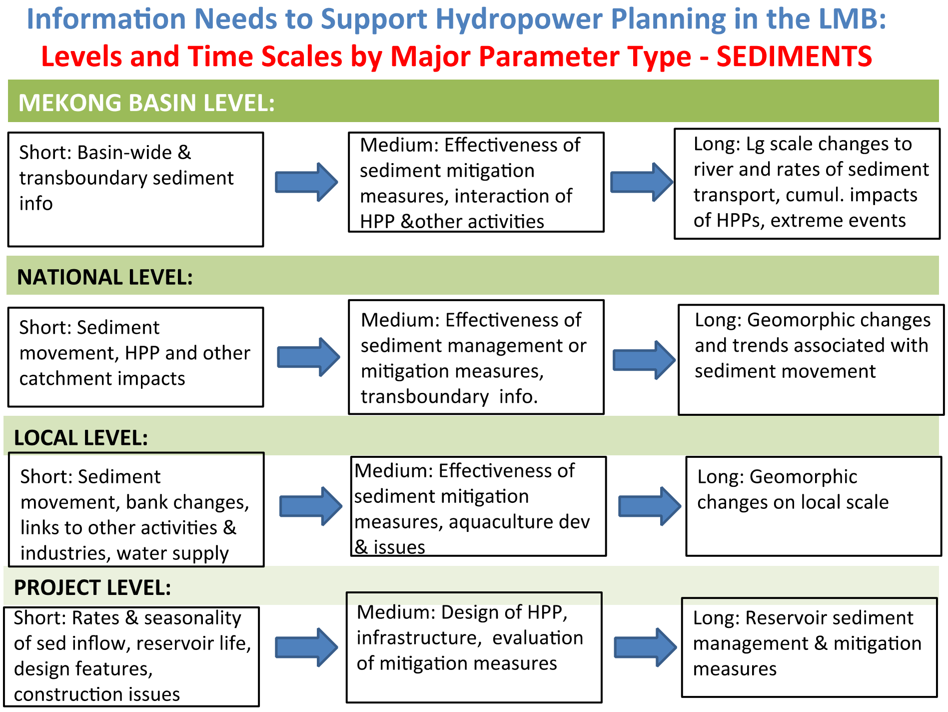
Important linkages with other disciplines include:

- sediment transport and sediment characteristics are critical to the distribution and condition of aquatic habitats which is linked to the distribution of aquatic organisms and to biological productivity;
- the movement and availability of sediment associated nutrients is important for water quality and aquatic ecology, including floodplain processes and productivity; and,
- sediment movement is of social relevance, in that it directly affects bank stability, river navigation, sand mining, floodplain aquaculture, and the potential longevity and economic viability of irrigation and hydropower impoundments and infrastructure.

Hydropower is not the only type of development that can alter and affect sediment transport and geomorphic processes in a river system. Other activities which can affect sediment budgets and geomorphic processes include: land clearing and land use practices, flow extractions and runoff associated with irrigation developments, extractive gravel and sand mining, and hard rock mining which can increase sediment inflows through runoff and discharges. Separating ‘cause’ and ‘effect’ associated with hydro developments from these other impacts is a challenge, and requires a detailed understanding of the sediment transport and geomorphic processes and rates operating in the catchment.

4.1.2 Information needs and uses

Sediment-related information requirements for hydropower planning vary over short-, medium and long time scales, as illustrated in Figure 15.



Information Needs to Support Hydropower Planning in the LMB:
Levels and Time Scales by Major Parameter Type - SEDIMENTS

MEKONG BASIN LEVEL:

Short: Basin-wide & transboundary sediment info

Medium: Effectiveness of sediment mitigation measures, interaction of HPP &other activities

Long: Lg scale changes to river and rates of sediment transport, cumul. impacts of HPPs, extreme events

NATIONAL LEVEL:

Short: Sediment movement, HPP and other catchment impacts

Medium: Effectiveness of sediment management or mitigation measures, transboundary info.

Long: Geomorphic changes and trends associated with sediment movement

LOCAL LEVEL:

Short: Sediment movement, bank changes, links to other activities & industries, water supply

Medium: Effectiveness of sediment mitigation measures, aquaculture dev & issues

Long: Geomorphic changes on local scale

PROJECT LEVEL:

Short: Rates & seasonality of sed inflow, reservoir life, design features, construction issues

Medium: Design of HPP, infrastructure, evaluation of mitigation measures

Long: Reservoir sediment management & mitigation measures

Figure 15 – Information needs to support hydropower planning in the LMB

An understanding of how sediments move through the basin, including rates, seasonality and variability, is critical for predicting, evaluating and mitigating large scale and transboundary impacts. A 'big-picture' understanding of the river at short time frames will assist in understanding how alterations or events at one site will propagate downstream, and over a longer-time frame provides an understanding of large scale river trajectories (e.g. channel widening, changes to river slope, river planform). At smaller spatial scales, information is needed to evaluate the effectiveness of mitigation measures, understand links between hydropower and the immediate downstream environment, and understand and manage the interaction between hydropower and associated developments and opportunities (e.g. water supply, aquaculture).

At the hydropower project level, sediment information serves a number of roles with respect to hydropower planning, management and decision-making needs.

The influx of sediments to impoundments is critical to understand for the siting and design of hydro schemes. This includes grain size and characteristics, to be able to predict if it will fill the impoundment or pass through the turbines and over spillways. Mitigation measures may need to be built into the hydropower project design if expected sediment trends look to be problematic. Understanding seasonality of sediment movement can help ensure that mitigation measures are addressing the time of year when sediment movement is at its peak. Understanding sources and sinks of sediments, and how these might change into the future, helps understand and plan for future changes.

Changes to sediment loads downstream of dams and power stations can be important to understand, in relation to riverbank stability, floodplain processes, aquatic animal habitats, and other ecosystem and community issues and needs. Good data on geomorphic characteristics over time (e.g. river cross-sections, channel planform features) forms part of this analysis of long-term changes and their influences downstream of a power station.

Land-use data of a variety of forms is also an important input to these analyses. Attribution of cause-and-effect to observed changes can be very difficult in practice, and good documentation of land-use changes and activities can assist.

4.2 Locations

Suspended sediment, bedload, bed material and channel geomorphology samples and measurements ideally need to be collected at the same time and locations as the hydrological and water quality data, to maximise the ability to interpret existing conditions, trends and changes. As discussed previously, monitoring locations need to reflect tributary inputs, hydropower locations, important and hydrologic locations (e.g. all arms of the Chaktomuk bifurcation), and areas affected by human activities, such as intensive sand-mining.

Additionally, an understanding of the surrounding landscapes at a large scale is required to better understand sub-basin processes and their contributions to basin scale landscape evolution.

4.3 Parameters

Sediment transport and geomorphic monitoring parameters for hydropower needs requires capturing parameters that reflect processes ranging from the daily transport of sediment through the river, to large scale channel changes occurring in the river on time-scales of decades to centuries.

Table 3 provides a summary of those parameter groups needed for hydropower-relevant MRC sediments information.

Table 3 – Parameter Needs for MRC Hydropower-Relevant Sediments Information

MRC-Centralised Parameter Groups	Hydropower Relevance	Example Basin-Scale Indicators
Sediment characteristics: suspended and bedload concentrations and fluxes, seasonality, grain-size distribution, organic content, mineralogy, lithology	➢ Influx of sediments to impoundments is critical for siting and design of hydro schemes; understanding sources and sinks and how these might change into the future helps plan for future trends ➢ Need to understand sediment and geomorphic processes to design and implement effective mitigation measures ➢ Changes to sediment fluxes downstream of power stations can affect geomorphological and ecological processes and have social impacts ➢ Separating changes due to hydropower from the effects of other basin developments/actions at transboundary locations.	✓ Changes in sediment budget and sediment characteristics (grain size distribution) at locations over time ✓ Changes in river morphology, habitat ✓ Coastal erosion rates
Geomorphic characteristics and habitat quantity & quality: channel cross-sections, channel characteristics (depth, roughness, hydraulic radius, etc.) longitudinal channel profiles, planform features (e.g. width, number of channels, sinuosity, braiding), composition of channel (bedrock controlled, alluvial, combination, presence of woody debris)		
Geomorphic rates: rate of channel migration, rates of channel infilling or incision, bank stability		
Land-use characteristics & linkages to sediment availability: land cover, vegetation cover, vegetation types, catchment elevation and slopes, landforms, susceptibility to erosion		
River dynamics: flow regime, coefficient in variability of depth, heterogeneity of current velocities floodplain connectivity, Tonle Sap reversal		
Tidal sediment dynamics: rates of change and locations for transport, deposition, erosion		

The priority parameters relevant to hydropower information needs include sediment characteristics, river morphology, and river and tidal dynamics.

Sediment characteristics include the mass, seasonal patterns, grain-size distribution and composition (organic matter, mineralogy, and lithology) of suspended, bedload and bed sediments. The quantity and variability of sediment transport is determined through the routine measurement of suspended and bed load sediments. The sediments collected during monitoring can then be analysed for an array of additional parameters that provide information about the source of the material, nutrient and organic content, and likely fate, e.g., fine sediment is generally maintained as wash load and transported to the sea whereas coarser material is more likely to be, at least temporarily, stored in the channel, controlling channel morphology and contributing to habitat maintenance.

The morphology of the river can be documented and investigated using bathymetric survey methods (ADCP, echo sounder), remote sensing (aerial or satellite photos), mapping (e.g. distribution of woody debris or land slips), or repeat photo monitoring of small scale features such as individual banks or bars. This information is relevant to understanding the geomorphic processes operating in the river, which determine the distribution and quality of habitats in the river.

Understanding river and tidal dynamics is important for linking the flow regime to sediment transport and aquatic habitats. The heterogeneity of flow rates within a cross-section and through a reach is directly linked to the variability of habitats found within rivers. For example, the deep-pools present in the Mekong are due to the local hydraulics of the reaches which result in peak flows having sufficient erosive power to maintain the pools. River dynamics can be directly investigated through the interpretation of ADCP profiles and long-sections, hydraulic and sediment transport modelling, or interpretation of sediment characteristics (e.g. Bravard, 2013).

4.4 Timing

MRC information to support hydropower planning and management should take into account the following timing needs and considerations important to sediments and geomorphology.

- **Continuous** recording river level measurements are needed to understand the relationship between power station operations and river flow rates and bank saturation. Flow rates will directly affect downstream sediment transport rates; while a rapid decrease in river level when banks are saturated can induce bank erosion, which will affect channel characteristics.
- High frequency monitoring (**weekly to monthly**) is needed to understand the linkage between sediment transport processes and hydrology, and to accurately quantify concentrations and derive budgets.
- **Episodic events**, such as extreme floods, can result in large changes over short periods of time, and surveys designs should include sufficient flexibility to capture changes caused by these events.
- **Long periods of record** (i.e. decades) at key locations is needed to understand the variability of sediment transport in the basin, and how it is responding to present development and land use activities.
- Longer-term, **large scale geomorphic monitoring**, including aerial photos, channel cross-sections, longitudinal bathymetric sections, mapping of bank features (slope, shape, woody debris, vegetation etc.) is needed at **the year to decade time scale** to understand rates and trends associated with geomorphic processes operation at longer time scales. River morphology generally changes on time-scales of years to decades, so annual or 5-yearly repeat surveys are useful for documenting channel changes and can be used to estimate rates of change. This information is important as it provides a context for the interpretation of more frequent monitoring, and underpins an understanding of how the river is likely to respond to hydropower

or other basin development projects. Both short- and long-term sediment and geomorphic monitoring are essential for the development, implementation and evaluation of mitigation measures associated with sediment movement through impoundments.

- The **continuity of data** collection is also important. Monitoring programs should be designed to ensure the long-term collection of monitoring results and with special consideration given to ensure data collection during the onset of the wet season, when sediment transport tends to be at a maximum, and throughout the flood season.

4.5 Methodological Considerations

Best Practice sediment monitoring collects samples which accurately reflect the distribution of sediments across the river cross-section and with depth in the water column, at a frequency which captures the flow variability. To achieve this, both suspended and bedload-materials need to be collected at multiple points across the cross-section. Methods need to capture the sediment variability with depth over a range of flow conditions.

Comprehensive reviews on suspended sediment monitoring are available (*e.g.* Diplas, *et al.,* 2008; Federal Interagency Project Reports, 1963; USGS, 2005) and should be consulted for detailed discussions. This section presents an overview of the best practice method for suspended and bedload sediment collection which has been implemented by the IKMP for the Discharge Sediment Monitoring Project (DSMP), based on the recommendations in the Project Proposal prepared by Conlan (2009), and recently reviewed by Koehnken (2012, 2014).

4.5.1 Suspended sediment sampling

The best practice approach to suspended sediment sampling revolves around collected depth integrated, flow proportional samples at multiple points across a river transect. These samples can then be analysed individually, to provide detailed information about sediment concentrations in the cross-section, or composited and split (or analysed in total) to provide one representative sample of suspended sediment transport at the river cross-section.

Prior to sampling for suspended sediments, the discharge of the river at the cross-section to be sampled is typically measured using best practice techniques. This generally involves measuring the water velocity at numerous points across the cross section using a current meter, or more typically obtaining a discharge measurement using an ADCP (Acoustic Doppler Current Profiler). The ADCP results provide a bathymetric profile of the cross-section and a detailed output of flow velocity with respect to depth and distance across the river.

A representative suspended sediment sample can be collected at a point using a depth integrated, flow-proportional sampler (Figure 16). The sampler consists of an outer chamber with fins which maintains the sampler orientated into the current during sampling, and a nozzle attached to a plastic bag which fits slides into the outer unit. The sampler weighs about 60 kg which allows it to be deployed vertically in the river at flow velocities up to ~3.5 m/s.

From a stationary boat, the sampler is lowered by a winch at a fixed speed from the surface of the river, to just above the river bed, and then raised back to the surface at the same rate. As it moves through the water column, the nozzle is positioned horizontally and pointed upstream into the oncoming flow. Water enters the nozzle at a rate which is proportional to the rate at which the river is flowing, that is, more water enters the sampler where the flow velocity is high as compared to where the velocity is low. The maximum depth of the cross-section combined with the average velocity of the river are used to determine the winch velocity for deploying the sampler such that an adequate sample volume can be obtained at each monitoring point, but the sampler is not over filled, which can lead to an errors in the suspended sediment concentration and composition.

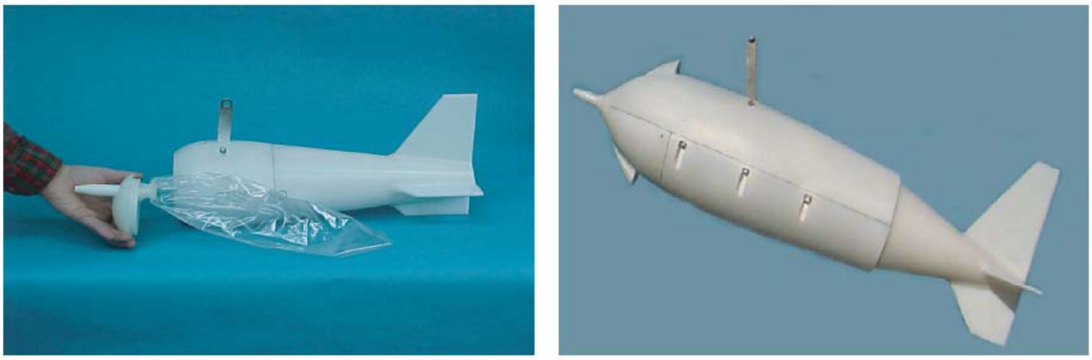


Figure 16 – Depth-integrating suspended sediment sampler (model D-96). Photos from USGS, 2005

A representative suspended sediment sample can be collected at a cross-section by repeating the depth-integrated sampling at multiple points across the cross section. There are two design methods for establishing where the point samples should be collected in the cross-section. The Equal Width Increment (EWI) is based on collected samples at uniform fixed increments across the cross section, using the same transit rate (rate of lowering and raising the suspended sediment sampler) at each vertical sampling point. This method will result in variable volumes of water being collected at each monitoring point reflecting the varying flow velocities across the cross-section. Typically 10 or more monitoring points are recommended for a representative EWI cross-section sample.

The Equal Discharge Increment (EDI) involves dividing the discharge volume of the river by the number of vertical point samples to be collected, and identifying where in the cross-section each of these divisions is located (e.g., if river discharge is 500 m^3/s and 5 points are to be sampled, then starting from the bank, the location where the discharge is 100 m^3/s, 200 m^3/s, 300 m^3/s, etc. is identified), and then sampling the mid-point of each interval. The output data from the ADCP discharge measurement can be used to calculate the appropriate sampling locations using the USGS developed *ed.exe* software package. Using the EDI method, 5 or more monitoring points in a cross-section are recommended, with each sampling reflecting 20% of the total flow in the river.

The EDI method has been adopted by the IKMP DSMP project, and each point sample is filtered and weighed. The sediment load for the cross section is derived by averaging the 5 point samples and using this value with the river discharge to derive the sediment load.

An alternative methodology, which greatly reduces the number of samples requiring analysis, is the compositing and ‘splitting of samples with the use of a churn-splitter (Figure 17). The advantage of this method is that one representative sample can be obtained from a cross-section for sediment or water quality analyses which greatly reduces analytical costs. The disadvantage is that it is difficult to identify a poor or unrepresentative point sample, which may lead to an erroneous result for the entire cross-section.

The composited samples are ‘churned’ and re-suspended in the bucket such that a representative sub-sample can be drawn from the tap. The churn splitter has been demonstrated to accurately re-suspend material <63µm in size, but not larger material. Therefore, prior to compositing, samples must be passed through a 63µm sieve with the volume of the sample recorded. All of the >63µm sediment sample is retained and dried and weighed in the laboratory with the >63µm sediment fraction added back to the <63µm sediment fraction post analysis.

Figure 17 – Suspended sediment and water quality churn splitter used to accurately subsample composited suspended sediment samples

Total suspended sediment concentrations are generally expressed as mass/volume (e.g. mg/l, g/m^3). Following collection, the samples can be analysed for mass, particle size distribution, mineralogy, and chemical composition (metals, nutrients, extractable metals or nutrients, organic content).

4.5.2 Bedload sampling

The depth integrated sediment samples are capable of collecting a representative sample within a few centimetres of the river bed. A bedload sampler is used to collect the material which is suspended, rolling or saltating (bouncing) within the bottom few centimetres of the water column.

Several styles of bottom samplers have been developed (basket samplers, tray samples, pressure difference samplers), with the BL-84 pressure sampler commonly used and adopted for use in the Mekong DSMP (Figure 18).

For an accurate bedload measurement, the sampler must sit firmly on the bed of the river, be oriented such that the opening is perpendicular to the flow direction, and remain stationary for the duration of the measurement. The sampler is lowered to the river bed where water and associated sediments flow into the mouth and through the sample bag, which typically has a 250 µm mesh size. The mouth and chamber of the BL-84 is designed such that there is no pressure decrease through the sampler, resulting in the collection of a representative sample. The length of deployment varies depending on the flow velocity, with deployment generally in the range of 30 -60 seconds.

For a successful deployment, the alignment of the sampler must be correct, the mesh bag must remain free of clogging, and the sampler needs to be recovered without disturbing the material in the bag. Ideally the sampler is deployed from a stationary platform, such as a bridge, and stay-lines are used to ensure alignment of the sampler and prevent movement during sampling. For application in large rivers such as the Mekong this is not feasible, and the unit is deployed using a winch from a boat, which is held stationary either through the use of an anchor or the engine.

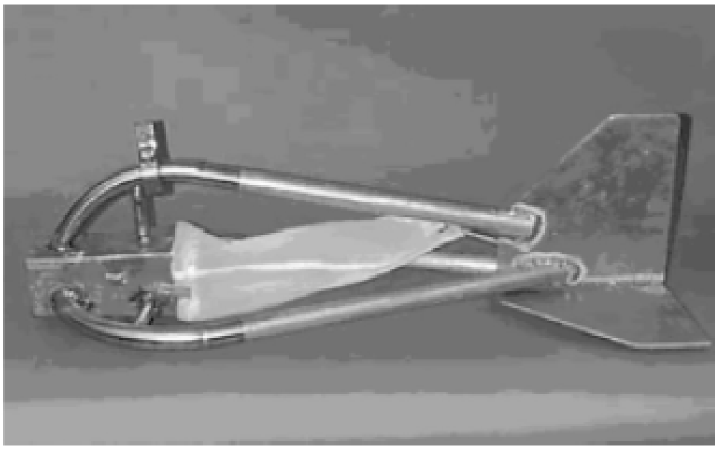


Figure 18 – U.S. BL-84 bedload sediment sampler

Bedload samplers have been found to have sampling efficiencies of 80% to 180% based on calibration tests (Diplas, *et al,* 2008). The difficulties associated with deploying the sampler combined with the natural variability of bedload movement generally yields highly variable results. For these reasons, a large number of bedload samples are generally collected from any cross-section, with samples either collected at short intervals across the section, or multiple samples collected from vertical points positioned at larger intervals.

ADCP results may also be used to estimate bedload movement, by determination of the ‘average bed velocity’ through the execution of a ‘Loop-test’. This test is executed using the ADCP in bottom-tracking mode. If the bed is actively moving downstream, ADCP results will show a downstream movement of the boat when a cross-stream ‘loop’ is completed (boat completes a round trip across the river returning to the starting location). The apparent downstream movement is directly proportional to the average bed velocity and can be used to estimate bed movement.

Bedload monitoring results are typically expressed as mass per unit length per unit time. Following collection, the samples can be analysed for mass, particle size distribution, mineralogy, and chemical composition (metals, nutrients, extractable metals or nutrients, organic content).

4.5.3 Bed material sampling

The material present on the bed of the river is frequently sampled at the time of bedload sampling to provide an indication of the nature (habitat) of the cross-section, and information as to what material is available for bedload or suspended transport. Bed materials can vary through time at a cross-section depending on preceding flow conditions and sediment availability.

The collection of bed material is typically completed using a coring instrument, grab sampler, pipe dredge, or spring loaded bucket sampler (Figure 19). Different samplers provide different depths of samples. In the Mekong River, the spring loaded bucket sampler has been used which provides a representative sample to a depth of approximately 5 cm.

Bed materials are typically collected at multiple points across a river transect to capture the variability of materials due to velocity differences. Following collection, material is typically sieved to determine the particle size distribution. Additional analyses may characterise the material properties (density, roundness, mineralogy, lithology) or chemical composition (metals, nutrients, extractable metals or nutrients).

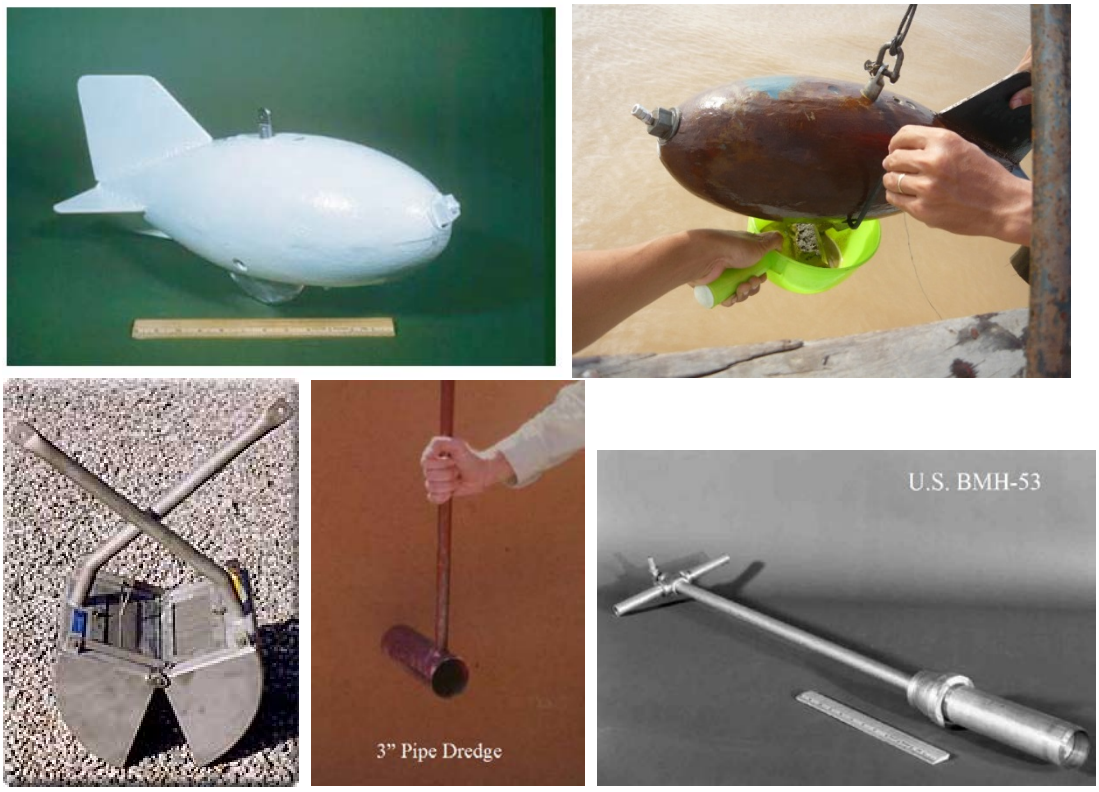


Figure 19 – Top: BM-54 spring loaded bed material sampler, and material being removed from sampler after collection, bottom: bed material grab sampler, pipe dredge sampler and piston corer.

The photos in Figure 19 are taken from USGS manuals and publications, except for the top right (author's photo) and the grab sampler (from www.duncanandassociates.co.uk.com).

4.5.4 Geomorphology monitoring

Best Practice geomorphology monitoring as applied to rivers is based on understanding the geomorphic processes operating in the catchment over the spatial and temporal time-scales of relevance to the objectives of the investigation. To achieve this, a range of approaches and techniques are generally required, each of which targets a different aspect of the spatial or temporal dimension of the catchment.

Gaining a large-scale understanding of the geomorphic setting of a river basin is a first step to understanding fluvial geomorphology. This includes identifying the geology, climate and basin-scale developments or alternations (water diversions, impoundments, etc.) that will drive changes in the catchment over long time-scales. Geologic, topographic, climatological and hydrological information is generally integrated to identify large-scale geomorphic provenances, which have similar characteristics. GIS tools are typically used for this scale of analysis. An example of geomorphic provenances identified by Kondolf *et al.,* 2012 for the Mekong basin is shown in Figure 20.

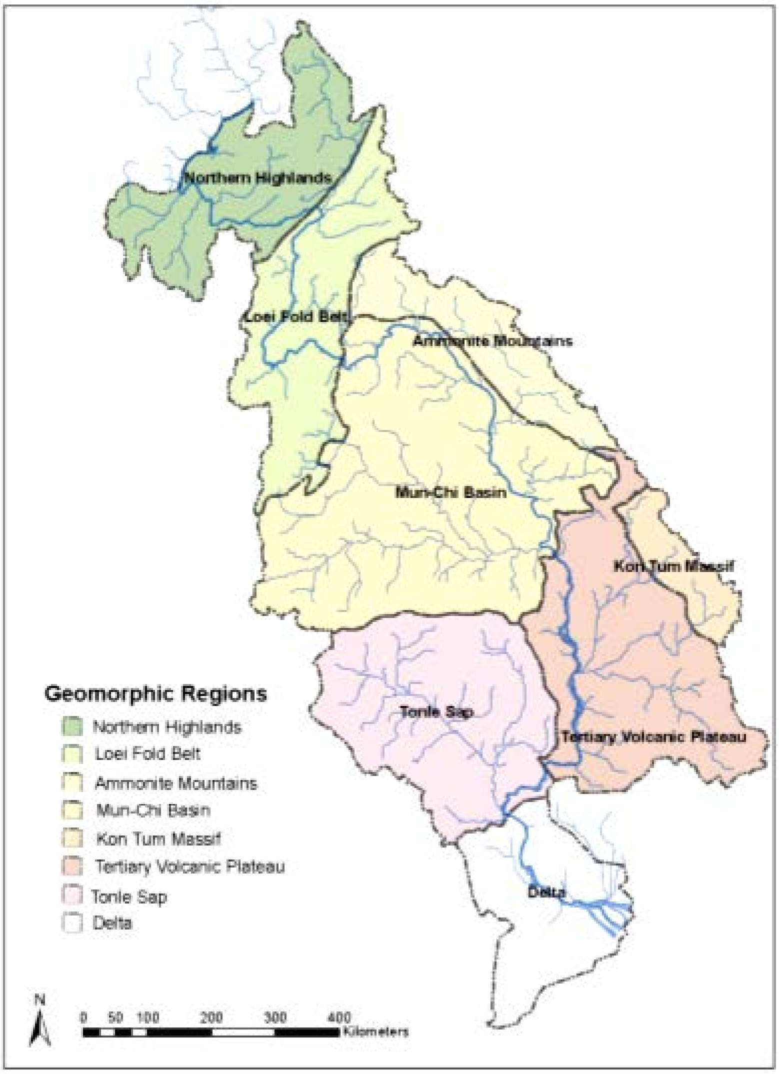


Figure 20 – Geomorphic regions in the Mekong River based on tectonic history, current relief and rock type

At a regional to river reach scale, an understanding of how the larger scale drivers combine to control river characteristics such as slope, river planform (shape of river as viewed from above), channel morphology (cross-sectional characteristics), sediment characteristics and availability and bank characteristics needs to be gained. Investigative methods include:

- field mapping (distribution of bank materials, bank height, bank slope, size of sediment on bars and banks);
- surveying (channel cross-sections, bathymetric transects); and
- remote sensing and GIS techniques.

At this scale, understanding and linking seasonal / annual / decadal or longer river flow and sea level patterns and trends to geomorphic characteristics is important, such as identifying annual and greater flood or low-flow levels, estimating the duration of bank or bar inundation or exposure, recognising previous sea level stands and identifying local hydraulic features which will affect geomorphic processes at the river reach scale (gorges, pools, availability of flood plain, etc.). Integrating this meso-scale level of information can assist in defining geomorphic 'zones' within rivers which have similar characteristics, and are likely to behave similarly. An example of a long-section of the Mekong showing the variability of river slope in the river and previous sea levels is shown in Figure 21 (used courtesy of Tim Burnhill in Kondolf *et al*., 2012), and is useful for predicting the hydraulic characteristics of different river reaches.

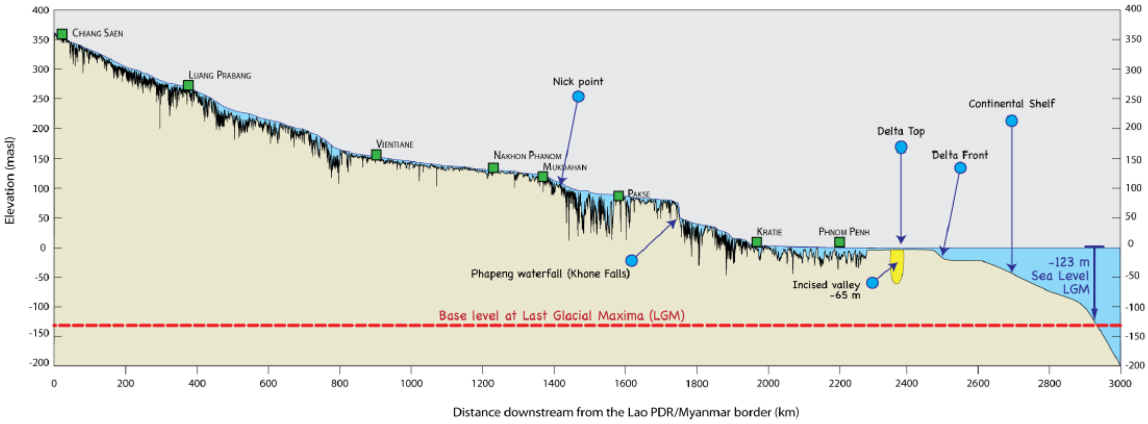


Figure 21 – Long-section of the Mekong River from Chiang Saen to the sea

Once an understanding of the large and regional / reach scale geomorphic setting is gained, investigations need to be undertaken to identify and quantify the major geomorphic processes operating within the catchment. Understanding geomorphic processes requires investigative techniques which measure geomorphic changes at appropriate time-scales. To measure rates of changes in rivers over years to decades, aerial or satellite photo analysis is generally used. The determination of channel migration rates is an example of this application. Ground based techniques to determine rates of change include repeat photo surveys, repeat cross-sectional surveys, or the repeat measurement of erosion pins in banks. Geomorphic rates can also be captured through the monitoring of the sediment flux of a river, which provides an integrated measure of catchment erosion rates. Geomorphic rates are typically highly variable due to the episodic nature of events, and hydrologic variability, so derived geomorphic rates are usually considered as broad estimates of landscape change.

Interpreting the measured rates of geomorphic change in river zones with respect to the hydrology of the river can provide an understanding of how individual components of the flow regime (e.g. magnitude, seasonality, frequency, or rates of flow level change) contribute to geomorphic change. Based on this understanding, conceptual models can be developed which link river flow components to geomorphic processes, and can be used to predict the response of a river to potential changes in flow and / or sediment dynamics.

5 Water Quality

5.1 Important Concepts

5.1.1 The role of water quality information

Good water quality is critical for human and ecological health. Riverine water quality is affected by inflows and inputs, as well as instream and groundwater processes. In the context of sustainable hydropower planning, implementation and management, water quality can have a direct effect on hydropower infrastructure and operations, and hydropower operations can affect water quality, especially during storage in reservoirs. The establishment of hydropower schemes can also lead to the parallel development of new water based industries (e.g. aquaculture) or social benefits (potable water supply) which have water quality requirements or impacts that need to be understood. Water quality is also a transboundary issue, with the potential for cumulative impacts.

Water quality issues encompass a wide range of parameters and processes. Best Practice water quality monitoring uses a management system approach to produce accurate and reliable information relevant to the objectives of the water quality monitoring programme. A Best Practice water quality monitoring system includes: identifying the objectives of monitoring, sampling design, sampling methods, analytical methods for sample analysis, and data management. Each of these components is discussed in the following sections.

5.1.2 Needs for and uses of information

The information needs for hydropower development span over a range of spatial and temporal scales and are linked to a wide range of social, economic and ecological issues. Basin wide, medium to long-term planning for hydropower and other water resource developments require an understanding of the linkages between water quality, human health and ecological issues over a range of time-scales (Figure 22). Shorter-term, local water considerations include management responses to ‘spills’ or water quality incidents, whilst long-term information is required for water resource planning, including power generation planning, and evaluating management and mitigation measures and transboundary impacts.

Water quality can affect hydropower infrastructure, for example through causing coatings on surfaces, nuisance algal blooms, etc.

An understanding of influent water quality to a reservoir helps prediction and management of potential changes during water storage, and ideally to avoid any associated problems. An example of a practical reservoir water quality problem can be reservoir stratification and release of anoxic water to the downstream environment for deep water storages, or high turbidity levels for shallow wind-blown water storages, or elevated nutrients in storages with long water retention times and high nutrient loads due to surrounding land-uses. Suitable water quality information is required to evaluate the risks of these situations arising and / or develop appropriate mitigation measures.

Similarly, good water quality data downstream of a hydropower project, at well-chosen locations, can be important to distinguish cause-and-effect of any emerging water quality issues. Relating water quality data to hydrological data is important so that the relationship can be understood and used to guide management and mitigation measures.

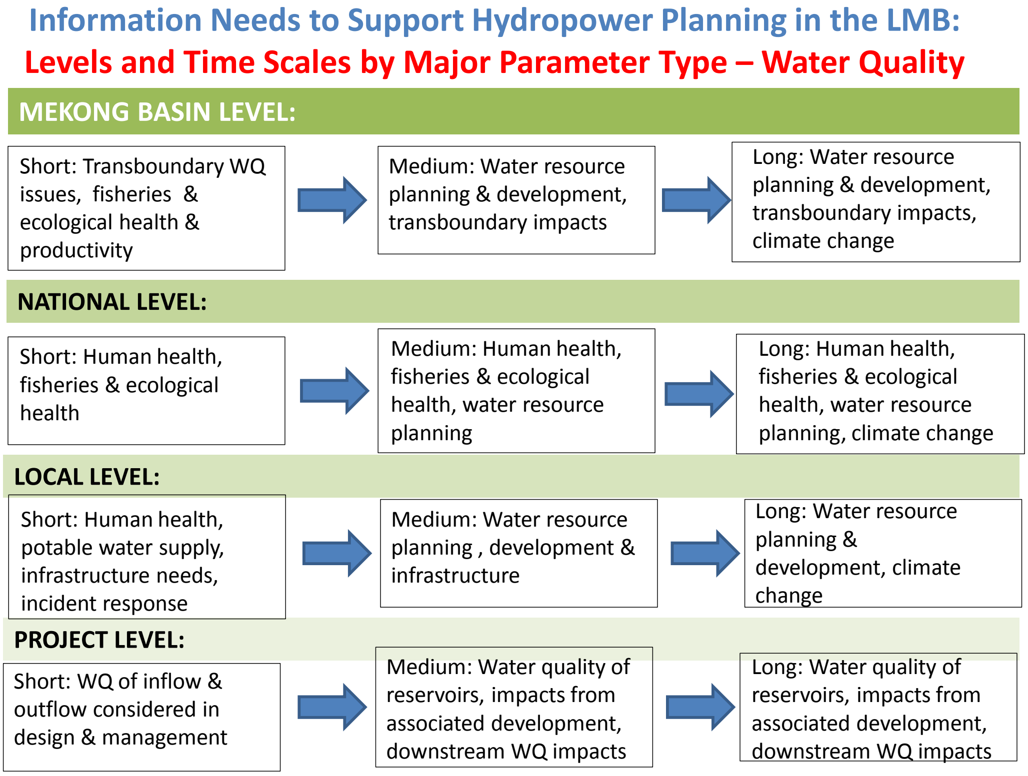


Figure 22 – Water quality information needs to support sustainable hydropower planning in the LMB

5.1.3 Monitoring objectives

Clearly identifying the objectives of a monitoring program is necessary to guide development of the entire project. The objectives will dictate sampling design, monitoring frequency and the field or laboratory methods required for sample analysis. Generally, in order to identify the water quality objectives, the processes and factors affecting water quality, and linkages to other parts of the riverine environment need to be understood. Ideally, a conceptual model is developed based on this understanding.

As an example, in the case of hydropower planning, a water quality monitoring objective might be to understand how the water quality will change during storage in a reservoir. Water quality changes are commonly experienced in reservoirs and in some cases can cause problems for the power station operations, for other reservoir or downstream water users, and/or for the ecology (e.g. due to turbidity, algal blooms, anoxic conditions). The processes associated with this change could include: changes to the oxygen content of water during storage, changes to nutrient concentrations due to algal growth, release from decaying vegetation or catchment runoff; changes to the water temperature during storage and the potential for stratification within the impoundment; changes to suspended sediment and associated nutrients due to deposition in the reservoir. Understanding processes enables identification of potential problems, as well as avoidance, minimisation and management actions that can be taken.

When designing long-term, catchment wide water quality monitoring programmes, it must be recognised that monitoring objectives are likely to change over time. During the life-cycle of a hydropower project, water quality objectives during the investigative and design phases are likely to include establishing baseline information and collecting data for reservoir modelling and design of any necessary water quality mitigation measures (e.g. intake location and specifications). During the construction phase, information to enable effective management of water quality issues associated with run-off from the site would be a priority, whereas after dam closure, monitoring the evolution of the impoundment and water quality in the downstream environment would be necessary to support the key objectives of avoiding and managing water quality issues.

5.1.4 Data management

The documentation and preservation of information about all aspects of water quality monitoring programmes is required if the data is to be useful over long time frames. This includes:

- Exact geographical information regarding sampling collection sites;
- The names and affiliations of field party members;
- Dates and times of sampling (with time zone specified)
- Comments concerning field conditions, especially if samples were not collected due to unusual conditions;
- Field monitoring techniques, including calibration information for field instruments;
- Sample treatments prior to analysis (e.g. filtration, acidification);
- Analytical methods used, and any alteration to standard method;
- QA/QC results for field and laboratory methods; and
- Water quality results.

The data management requirements for a water quality database are the same as for any other environmental database, and extra value can frequently be gained from the water quality monitoring programmes through the integration of results with other disciplines.

5.2 Locations

Water quality data collection for transboundary hydropower-relevant information should align with the same locations as the hydrological, sediment and ecological data collection to provide an understanding of linkages and allow integration of data sets. Additional considerations relate to the ability to ascertain cause-and-effect of various influences on water quality. If there are notable activities that may be able to significantly influence Mekong River water quality it could be advisable to have monitoring locations upstream and downstream of these so that it can be clear if the changes observed do or do not relate to hydropower-related causes.

5.3 Parameters

Water quality parameters relevant to hydropower can be divided into those which could have a direct effect on hydropower infrastructure or efficiency, and those which have the potential to be altered due to the implementation and operation of hydropower developments. The latter are most relevant to basin-scale information needs, but interpretation and understanding is maximised with the former.

Table 4 provides a summary of those parameter groups needed for hydropower-relevant MRC water quality information. Examples of parameters that have the potential to directly affect hydropower operations include:

- suspended solids which can degrade turbines or if deposited in the tailrace affect the efficiency of the station;

- nutrient concentrations which can promote bio-fouling of hydropower infrastructure, including trash racks, intake structures, or penstocks;

- metals such as iron or manganese which under certain conditions can be deposited and cause fouling of penstocks or other infrastructure; and

- acidity, whether natural or due to poor water quality, which can affect the plating on turbines and other infrastructure.

Table 4 – Parameter Needs for MRC Hydropower-Relevant Water Quality Information

MRC-Centralised Parameter Groups	Hydropower Relevance	Example Basin-Scale Indicators
Suspended sediment characteristics: size and composition of material	➢ Water quality can affect hydropower infrastructure	✓ Water quality standards for human health, drinking water, water for aquatic ecosystems, water for domestic uses, water for agricultural and industrial uses ✓ Aquatic biota indicators linked to EHM and Aquatic Biological Indicators (e.g. impact of oxygen or nutrient changes)
Physico-chemical water quality characteristics: temperature, pH, electrical conductivity, acidity, clarity, alkalinity, dissolved oxygen in surface and sub-surface water	➢ Need to understand influent water quality to predict and manage potential changes during storage, and to assess whether inflowing water is changing over time	
Metals: total and dissolved iron, manganese, zinc, mercury, arsenic	➢ Need to understand changes to water quality during storage so can differentiate between hydropower development impacts and other impacts (such as aquaculture or land run-off)	
Nutrients & carbon: concentration, speciation, seasonal variability, changes during storage	➢ Need to understand any downstream impact on water quality due to hydropower operations, and to distinguish between hydropower impacts and other land use impacts	

Water quality parameters that have the <u>potential to be altered due to the implementation of hydropower developments</u> include:

- suspended solids content of river water can decrease during storage in a reservoir due to settlement of silt and sand sized materials, leading to increased light penetration in the water column;
- water temperature can increase or decrease during storage in a reservoir relative to the inflowing river temperature. Elevated surface water temperatures can promote thermal stratification in reservoirs;
- dissolved oxygen concentrations can decrease at depth in reservoirs due to the degradation of organic matter. Depending on the depth of the power station intake, this low dissolved oxygen water can be discharged to the downstream environment;
- low dissolved oxygen levels in reservoirs can lead to the release of metals from sediments or submerged soils;
- bacterial activity in low oxygen environments can alter the speciation of metals, e.g. mercury methylation;
- dissolved oxygen concentrations can be greatly increased downstream of power stations due to turbulence occurring within intake structures, via spillways, or through air injection during power generation;

- nutrients in reservoirs can promote higher levels of algal growth as compared to the riverine environment due to the lower flow rates, and greater water clarity following sediment settling; and
- oil or other chemical spills (e.g. transformer oil) from hydropower plants can directly impact water quality.

These water quality changes can also have flow on effects for the ecology in a reservoir, or in the downstream environment. For example, increased oxygen concentrations can occur downstream of power stations if excessive turbulence occurs during passage through the power station. In Tasmania, Australia, this situation led to a substantial fish-kill in 1990 that was attributable to gas-bubble-disease (Koehnken, 1992). For these reasons, it is important that influent water quality to a reservoir, potential water quality changes during storage, and the water quality of power station releases to the downstream environment all be considered and monitored during the planning, implementation and management phases of hydropower projects.

5.4 Timing

MRC information to support hydropower planning and management should take into account the following timing needs and considerations important to water quality.

- Water quality parameters such as **temperature, nutrients and dissolved oxygen** can be altered during storage in impoundments, so downstream water quality may need to be monitored on an **hourly or more frequent basis** to capture alterations associated with power station release patterns.
- Within an impoundment, water quality will vary as a function of inflows, surrounding land use, depth of impoundment and duration of storage, so reservoir monitoring frequency will need to reflect these site specific requirements, capturing the **variability between wet and dry season** inflows.
- **Long-term water quality monitoring** of inflows and outflows is needed for guiding hydropower management and assessing mitigation measures.

The timing of water quality monitoring with respect to hydropower information needs ranges from long-term, low-frequency catchment-wide monitoring, to short-term, high frequency associated with power station operating patterns.

Understanding the long-term trends associated with inflowing water to hydropower impoundments is important for predicting and managing water quality changes which can affect hydropower operations over time. For example, increasing nutrient loads over time due to land use practices would increase the risk of algal blooms and oxygen depletion in reservoirs. At the other end of the scale, hydropower stations operating in a ‘peaking’ mode (high frequency short-duration discharges) could lead to numerous and rapid changes in water temperature and dissolved oxygen levels downstream which might affect fish and other aquatic organisms. Water quality monitoring also needs to be flexible, and able to target specific operating scenarios, such as reservoir draw down for maintenance reasons, releases associated with periodic valve or gate testing or sediment flushing, or water quality changes associated with reservoir creation.

5.5 Methodological Considerations

5.5.1 Sampling design & sampling methods

Sampling strategies need to capture the spatial and temporal variability of the processes being targeted for investigation. Key issues to be considered include:

- The size of the catchment, distribution of tributary inflows and extent of tidal influence. The number and distribution of monitoring sites needs to capture this spatial variability at a scale applicable to the monitoring objectives;
- The variability of the flow regime, with respect to seasonal, monthly and shorter-term flow patterns. Water quality frequently changes with flow in a river, both over short periods (e.g. ‘first flushes ‘associated with rising limbs of hydrographs, or in association with hydropower ‘peaking operations’) and over longer time frames (e.g. during prolonged dry seasons when groundwater contribution to water quality is at a maximum);
- The locations and timing of ecological processes and cycles, such as fish migration, wetland inundation or draining or algal blooms, which are dependent on, or have the potential to affect water quality;
- The location of existing or planned developments or activities which have the potential to affect water quality, which might include irrigation or industrial off-takes, aquaculture, hydropower, or industrial or municipal discharges; and
- Logistical and safety issues associated with accessing sites over the range of flow conditions to be monitored.

Sampling design also includes the identification of appropriate water quality monitoring techniques. Water quality within rivers can be highly variable. The distribution of dissolved water quality constituents can vary across a river cross-section, and / or with depth, depending on upstream inflows. Thorough mixing within rivers can require very long distances (many kilometres), so it is often difficult to obtain a representative ‘grab’ sample. Water quality parameters associated with sediment, such as total nutrients or metals, will vary as sediment concentrations change in the river cross-section. To obtain a representative sample, collection of depth-integrated, flow proportional samples is required (Figure 23[1]).

Figure 23- Left: Depth integrating water quality sampler. Right: Autosampler that can be set to sample at fixed time intervals, or flow levels

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[1] Fig.23 left hand figure is from http://ga.water.usgs.gov/edu/qwsampler.html; Fig.23 right hand figure is from http://ga.water.usgs.gov/edu/autosampler.html

Sampling may be completed at a discrete point in time, or over longer periods using remotely deployed continuous recording instruments and integrating samplers. Water quality probes that can continuously measure temperature, pH, electrical conductivity, dissolved oxygen, turbidity or nutrients are useful for deployment at fixed locations and can provide a long time-series of water quality characteristics. Automatic water samples (Figure 23) can be remotely deployed, and set to collect samples at fixed time intervals, or pre-determined river levels.The samplers can also be used to collect composited samples over a range of conditions (e.g., a daily or weekly composite). Short-term more intensive sampling (e.g. through use of autosamplers or detailed cross-sectional sampling) can be a strategic approach to aid understanding of longer-term less intensive datasets. The placement of both continuous recording probes and autosamplers must be carefully considered to provide the most representative information possible about the river cross section.

Sample collection in the field requires appropriate techniques to preserve the integrity of the sample. ‘Clean’ techniques are required for many parameters, which require appropriate sample container selection, preparation, and sample handling in the field. All field monitoring programs also require the collection of duplicate samples and processing of field blanks for appropriate QA/QC procedures.

5.5.2 Analytical methods

The methods adopted for analysing water samples need to be guided by the characteristics of the samples (pH, salinity, oxygen content, and composition), and precision of the required result. There are recognised and validated techniques for water analysis, with the most common reference being *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, WEF, 2012). The analysis of waters generally also includes analytical standards, internal standards, duplicate samples and blanks for QA/QC purposes, and inter-laboratory comparisons.

6 Aquatic Ecology

6.1 Important Concepts

6.1.1 Understanding aquatic ecology information

For defining appropriate aquatic ecology data to support hydropower planning and management, effects on the different aquatic ecology groups have to be considered. Worldwide, rivers suffer from multiple pressures (e.g. Wong et al. 2007); this is also valid for the Mekong River (e.g. ICEM 2010). Cause-effect chains concerning biology and ecosystem functions and processes in (large) rivers are not easy to understand, and will be subject to research in the next years/decades worldwide (Vienna Declaration 2011). The goal should always be to maintain or achieve overall good ecological status of waterbodies as a basis for ensuring provision of aquatic ecosystem services.

Biological data are worthwhile for detecting environmental degradation and determining the ecological status of rivers. The value of the manifold services that healthy aquatic ecological systems provide to society must not be underestimated, and the importance of bio-monitoring has to be highlighted. Ecosystem services such as self-purification capacity of rivers and its relation to clean drinking water are often taken for granted. Unimpaired interaction between river, groundwater and floodplain is another vital aspect regarding healthy ecosystems. Maintaining robust, self-sustaining aquatic ecosystems provides several other services, such as habitat for fisheries and food production, and spawning grounds for fish or habitats for indigenous species to support biodiversity. Societal benefits for humans such as traditional ways of life, recreational areas etc. are also part of ecosystem services (Barbour & Paul 2010).

Figure 24 (from Schmutz 2012, pers. comm.) gives an overview on issues to be considered in context with impoundments. The figure focuses on temperate rivers and may not directly be transferable to tropical rivers, but the principle interactions are shown.

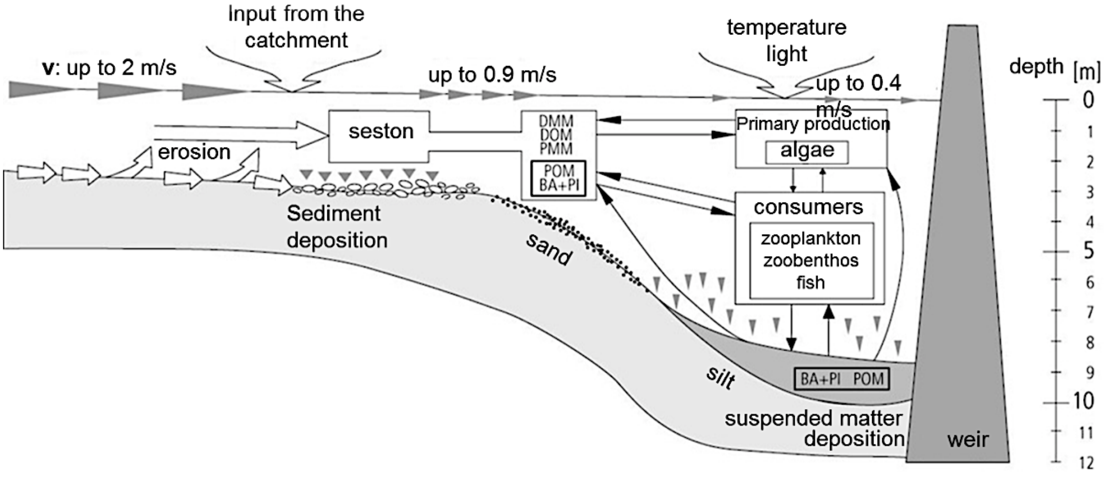


Figure 24 - Interactions of aquatic ecology and physico-chemical parameters

In aquatic ecology the focus lays on data sampled for different biological groups. These data are evaluated in context with possible pressures, such as those arising from hydropower effects. The main needs are to choose relevant sampling sites, collect standardised samples, to have standard approaches for laboratory sorting including Q/QC and to identify biota to the best level possible.

Based on Figure 24, biological groups relevant to hydropower that should be monitored include:

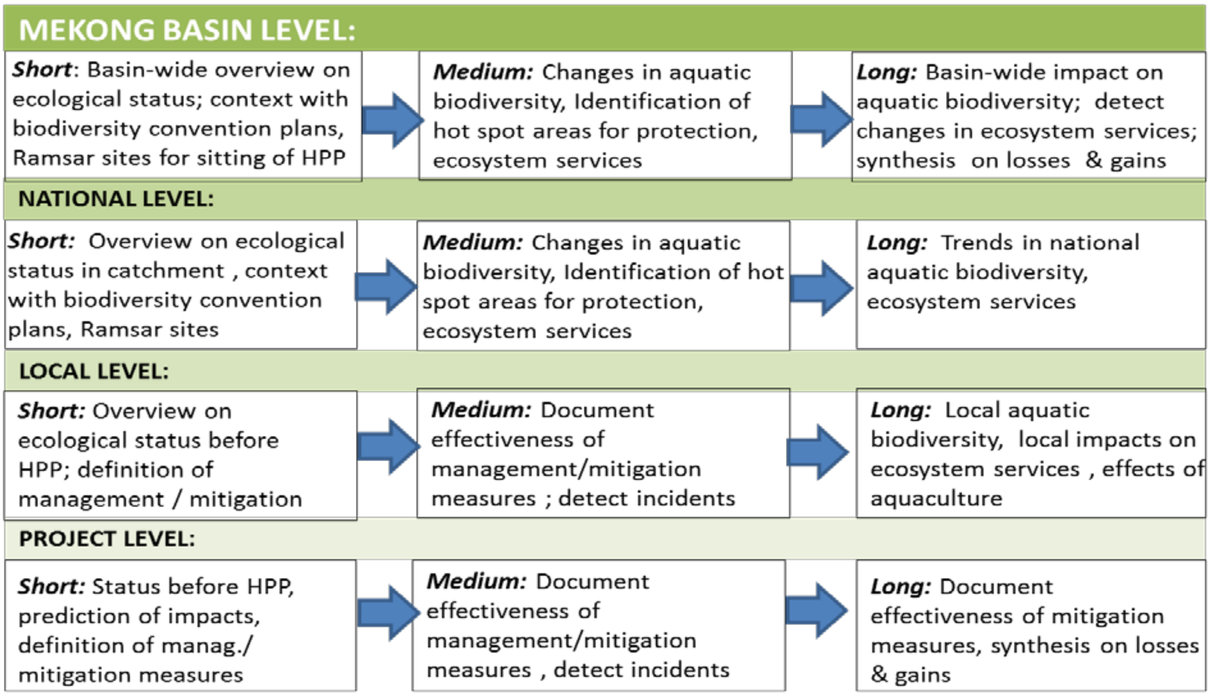
- primary producers (phytoplankton, diatoms),
- primary consumers (zooplankton, zoobenthos i.e. macroinvertebrates), and
- secondary consumers (fish, zoobenthos i.e. macroinvertebrates).

Many best practice approaches in aquatic ecology monitoring use biological groups indicating mid- to long-term interactions with environmental conditions and reacting predictably to pressures along a gradient. Sound approaches monitor two or more biological groups to address different levels in the food web.

Routine monitoring of aquatic ecology is not too costly, compared for example to assessing toxic pollutants chemically or with toxicity tests. Aquatic ecology monitoring is used worldwide as a complement to (chemical) water quality monitoring, providing information over longer time spans based on the life cycles of biota.

6.1.2 Information needs and uses

Some aquatic ecology information required in context with hydropower is summarised in Figure 25, with consideration of a range of spatial and temporal scales.



MEKONG BASIN LEVEL:		
Short: Basin-wide overview on ecological status; context with biodiversity convention plans, Ramsar sites for sitting of HPP	***Medium:*** Changes in aquatic biodiversity, Identification of hot spot areas for protection, ecosystem services	***Long:*** Basin-wide impact on aquatic biodiversity; detect changes in ecosystem services; synthesis on losses & gains
NATIONAL LEVEL:		
Short: Overview on ecological status in catchment , context with biodiversity convention plans, Ramsar sites	***Medium:*** Changes in aquatic biodiversity, Identification of hot spot areas for protection, ecosystem services	***Long:*** Trends in national aquatic biodiversity, ecosystem services
LOCAL LEVEL:		
Short: Overview on ecological status before HPP; definition of management / mitigation	***Medium:*** Document effectiveness of management/mitigation measures ; detect incidents	***Long:*** Local aquatic biodiversity, local impacts on ecosystem services , effects of aquaculture
PROJECT LEVEL:		
Short: Status before HPP, prediction of impacts, definition of manag./ mitigation measures	***Medium:*** Document effectiveness of management/mitigation measures , detect incidents	***Long:*** Document effectiveness of mitigation measures, synthesis on losses & gains

Figure 25 – Information needs to support hydropower planning

The most useful aquatic ecology data with respect to hydropower management information needs are benthic and littoral macroinvertebrates. Typically one would use data describing abundance and diversity per sample and per sampling site, and would look at the proportions of different species that are known to prefer certain habitat, depth, current velocity and light conditions. This data supports an understanding of the effects of hydropower on the downstream environment, including the implications of flow and habitat changes on this component of the aquatic food chain. Macroinvertebrate abundance and health can be closely linked to key fisheries and sediment parameters, which in turn can have strong linkages with socio-economic factors.

Plankton data can also be insightful with respect to understanding changes in biodiversity at locations over time and longitudinal distance along the Mekong mainstream. Plankton is an important component of fish diet in the Mekong River, and is particularly relevant for reservoirs with low flow velocities and high transparency. Data on plankton can help understand the implications of hydropower projects for fish populations.

To best inform hydropower planning and management, reactions of aquatic ecology to changes in and along the river need to be understood. This may be challenging, due to lack of scientific background knowledge for certain regions in general, and also due to multiple pressures especially on large rivers. Some findings may not be easy to interpret given present levels of knowledge. Data collection on aquatic ecology should start well before hydropower plants are built and operating, in order to provide good datasets of the un-impounded Mekong mainstream that can serve as reference data sets and support future indicator development.

6.2 Locations

Aquatic ecology monitoring is often hydropower project related, but a monitoring programme for aquatic ecology should ideally give a picture of the whole basin. Biota do not “adhere to sharp borders” and both longitudinal and lateral information is essential. A basin-wide program allows understanding of the association of different groups and species to different ecosystems and conditions, which may then enable interpretation of changes over time at any point in the river system.

6.3 Parameters

Some issues to take into consideration when using biological groups in aquatic ecology monitoring are outlined below.

- *Planktonic organisms* are not well-integrated in routine monitoring. On the one hand this is because they are considered to indicate more the water quality in the water column; on the other hand monitoring approaches have mainly been developed in temperate rivers where occurrence of plankton is limited. In the Mekong context these groups would benefit from further evaluation, particularly in the context of hydropower information, as local issues can arise with algal (phytoplankton) blooms and both phytoplankton and zooplankton are a critical food resource for fish larvae.

- *Microalgae* (diatoms) are known to reflect short-term changes (e.g. nutrient level, physical changes), to have high reproduction rates and short life cycles. Being dependent on light, their use in large rivers with high suspended solids is a challenge.

- *Macrophytes* play an important role e.g. in the wetlands, in the delta and the inundation area. They are not integrated in routine bio-monitoring in the LMB, as far as known to date.

- *Macroinvertebrates* are the main group used in bio-monitoring worldwide due to long-term use in many countries. They are key components in food webs, linking nutrient resources with higher trophic levels. They have comparably long-life spans and life-stages of different sensitivities. Macroinvertebrate species differ in their response to alterations in hydraulic, habitat and water quality, and so with the benefit of research can be used at a species-level to indicate particular ecosystem changes with anticipated follow-on effects in the food chain. Invertebrates respond to habitat alterations on a larger scale when the size and distribution of patches of habitat change, which allows them to be linked to habitat and sediment distribution. They can also partly be used as flow indicators, as already proposed in the Integrated Basin Flow Management (IBFM) project.

- *Fish* are long-lived, mobile, indicate various habitat conditions, and are on top of the aquatic food web. They are mainly used to monitor mid-term to long-term effects. Being of major importance for the LMB, fish are considered separately (Section 7).

Table 5 identifies those parameter groups most recommended for hydropower-relevant MRC aquatic ecology information.

Table 5 – Parameter Needs for MRC Hydropower-Relevant Aquatic Ecology Information

MRC-Centralised Parameter Groups, Parameters	Hydropower Relevance	Example Basin-Scale Indicators
Benthic and littoral macroinvertebrates: abundance and diversity per sample and per sampling site	➢ Support understanding of effects of hydropower relating to impoundment, hydro-peaking and channel dewatering. ➢ Can be closely linked to key fisheries and sediment parameters.	✓ Changes in biological health of the river concerned at a location over time ✓ Changes in biodiversity at locations over time and longitudinal along Mekong mainstream
Plankton	➢ Important component of fish diet in the Mekong River ➢ Particularly relevant for impoundments / reservoirs with low flow velocities and high transparency	

Diatoms are not prioritised for hydropower relevance because, being dependent on light, their use and interpretation of results in large rivers with high suspended solids (such as the Mekong) is challenging and may need more research input. Macrophytes are important e.g. in wetlands, floodplains and the delta, which are beyond the scope of this report and are thus not highlighted in the parameter needs in this report.

During field work, site and habitat characteristics as well as physical and basic chemical parameters (e.g. conductivity, oxygen content) should be recorded to be able to link biological indicators to influencing changes e.g. in hydromorphology or water quality. Field and lab work need to be done in a consistent way (use of same methods) and personnel capacity needs to be high, especially for taxonomic identification for reliable data quality.

Each biological group may provide information on the status of the environment via indicators. These can be calculated from biological data sampled. Examples for indicators are composition of taxa, richness, diversity, tolerance metrics, or presence or absence of certain biota compared to reference sites. Indicator development depends on the monitoring and assessment approach followed (standardised sampling) and state of ecological knowledge for the biological groups.

For aquatic invertebrates (benthic and littoral) more specific indicator examples could include:

- changes in aquatic invertebrate biodiversity expressed as “observed over expected (O/E) values”
- invertebrate species composition (site specific, in hydro-ecological zones, longitudinal)
- ratios in invertebrate taxa groups (indicating e.g. changes in sediment composition, biological responses to habitat quantity and distribution)
- flow indicators (e.g. as in IBFM report)
- number of sensitive organisms within the whole catchment, and percentage of loss of sensitive organisms
- ratios of rheophilic to stagnophilic organisms

- grazers/filter feeders to collector dominated assemblages
- organisms indicating little organic amount (oligosaprobic) to organisms indicating higher organic amount (e.g. alpha-mesosaprobic) (link to water quality)
- changes in biomass of macroinvertebrates (link to fisheries indicators)

The relevance for and questions occurring in context with hydropower planning and management are exemplified in detail for the parameter group aquatic invertebrates. Several aspects are also true for the other parameter groups diatoms, zoo- and phytoplankton, whereby these are more bound to water velocity and depth, water chemistry e.g. oxygen content, and nutrient content / mobilisation.

6.4 Timing

MRC information to support hydropower planning and management should take into account the following timing needs and considerations important to aquatic ecology.

- Aquatic **biological groups** (invertebrates, diatoms, plankton…) show seasonal variations, and their life cycles are often connected with the hydrological regime of a river.
- For scientific study purposes and aquatic biodiversity overviews, **several seasons are sampled** to show within-year variations.
- At hydropower-related locations, **samples are needed at least once a year at a defined season** to reflect inter-annual conditions. This data can detect environmental changes over longer time periods against agreed criteria, for example through use of "observed over expected" ratios.
- The **dry season** is technically easier to sample than the flood season given the relatively stable conditions. Biota, mainly benthic invertebrates, experience the greatest stress during the dry season due to high temperatures and low dilution, so this may reflect "worst case" conditions.
- Plankton is a relatively short-term indicator that may show different densities in different seasons; needs for sampling time and number of occasions would need to be developed based on the experience of **trials** for Mekong mainstream.
- **Event-based sampling** may at times be needed, e.g. with reservoir flushing during which losses in invertebrate biomass and biodiversity could be significant.
- **Hydro-peaking** operations need targeted downstream surveys to capture fluctuating water level effects on biota, as such effects could continue for some distance downstream depending on attenuation distances and magnitude of water level changes. This would need more research for the Mekong region.

6.5 Methodological Considerations

6.5.1 Field and laboratory work

This section does not focus on describing methods for all aquatic ecology groups in detail, but aims on highlighting general aspects and providing examples for good-practice field and lab work. Examples for field work procedures in aquatic ecology, which are based on international approaches, are described in the MRC "biomonitoring handbook" (MRC 2010a).

Field and laboratory methods as well as data analysis for aquatic ecology are mostly tailored to river systems where they are applied. Thus there is no singular worldwide best practice approach available. Methods in use must be appropriate for the river system under study. Some general issues to be considered are mentioned below:

- Existence of standardised methods in field work and correct application, including QA/QC procedures
- Existence of standardised methods in lab work and correct application, including QA/QC procedures
- A specific issue is taxonomic identification, which needs ongoing capacity-building and training to maintain competencies

For large, turbid rivers especially field methods are a challenge. Sampling needs to give a realistic picture of the biology of such rivers, but it is evident that it has to be targeted to certain parts of the rivers. A standardised sampling approach allows collecting representative data for reliable assessment.

The Ecological Health Monitoring (EHM) – applied in the Mekong River basin - includes standardised approaches for all biological groups and provides a valuable basis for all further activities. It also takes into account the difficulties that occur in large rivers, e.g. by sampling invertebrates in littoral areas and mid-channel with different methods. Littoral sampling is done in wade-able areas with a hand-net (Figure 26, photo from MRC). Deeper sections are sampled by boat and with a grab (Figure 27, photo from BOKU), which is good practice in aquatic ecology monitoring for large rivers.

Figure 26 – Littoral sampling in EHM

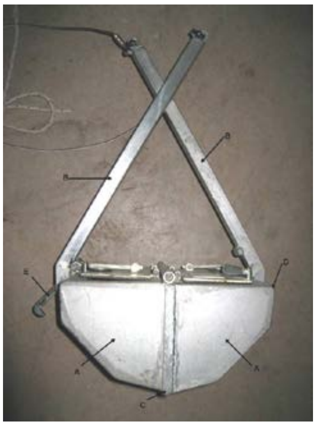


Figure 27 – Grab for sampling invertebrates in deeper-water areas

Besides the already mentioned methods in the MRC “biomonitoring handbook”, a further example is the so-called Multi Habitat Sampling (MHS) (Figure 28, photo from BOKU), which is widely used in Europe, the US to collect invertebrates. The MHS has been adapted and applied in several Asian countries and is also used in the LMB (Getwongsa & Sangpradub 2008, Uttaruk et al. 2011). The MHS method is applicable for wade-able sections of a river. For a large river like the Mekong mainstream, such a method provides data for only a part of the river - comparable to littoral sampling in EHM. The littoral zone represents the wade-able near-shore areas. Biota collected there are indicative for human influences to those parts of the river. The MHS method is very similar to the littoral sampling approach in EHM. It includes a higher degree of standardisation via habitat specific sampling and provides possibilities to link invertebrate data to substrate (categories). More detail is provided in the ISH11 Phase 2 Report Aquatic Ecology Annex.

Figure 28 – MHS-net and MHS-sampling

For invertebrates, sampling both littoral and benthic (deeper-water) areas is a very good approach. Using a grab is a simple, effective approach, when applied correctly. It is good for sampling fine substrates, but needs to assure that stones do not get stuck between the two halves of the grab. This would cause a leakage of the substrate without knowing how much is left in the grab.

Lab work for invertebrates needs highly trained personnel, both for sorting and identification. A QA/QC procedure which is not only designed but strictly implemented and followed is essential.

For benthic diatoms, again mostly the wade-able section of the river is sampled (as in EHM). As diatoms are plants, they need light and are thus not abundant or even not occurring in deep parts of turbid rivers. Field methods do not need much equipment (bottles, brushes). Lab work is time consuming and identification needs highly skilled personnel. Again QA/QC is needful.

Zooplankton sampling is also not costly and is quite easy, but lab work needs highly skilled personnel. Phytoplankton sampling (Figure 29) is time consuming in the field, but if only productivity is measured, not much lab work is needed. For plankton sampling, turbidity of rivers is a challenging factor regarding presence of plankton and application of nets (clogging by suspended solids).

For lab work in general, best practice is aiming on receiving high quality taxa lists for all biological groups investigated. This starts with quality assurance in e.g. sample preservation, allocation of unique sampling codes, correct sample storage etc. Sorting processes need to follow standardised approaches. Species identification needs to be done to the best level possible and taxonomic identification keys need to be up-to date and applicable for the area under study. All this will support data evaluation, interpretation of results and management decision.

Figure 29 – Plankton net. Photo from MRC

6.5.2 Data analysis

For analysing data with respect to hydropower there is no defined common approach available in aquatic ecology that could be followed.

The approaches used in aquatic ecology are e.g. use of Diversity or Biotic Indices, Multimetric or Multivariate Approaches or Functional Approaches. Examples are e.g. the European Water Framework Directive (2000), the ANZECC guidelines (2000) and the Australian River Assessment System (AUSRIVAS) or several US EPA guidelines (e.g. Barbour *et al*, 1999).

Multimetric systems (e.g. Multimetric index, Index of Biotic Integrity; Karr 1993, Karr & Chu 1999) are very much used for evaluating reaction to stressors, including a reference site based approach (benchmark against which investigated sites can be compared, "observed over expected ratios").

Such best practice approaches need to be developed tailor-made for freshwater ecosystems. Most methods include the following:

- Typology, based on e.g. freshwater ecoregions; catchment size classes, altitude classes and main geology (classes),
- A set of reference sites per "river type"
- A set of impaired sites (pre-classified via environmental variables along a gradient) per "river type"
- Sampling with standardised methods for all sites, including measuring physico-chemical and environmental variable at the respective sampling sites
- Developing stressor-specific assessment methods including benchmarks against which investigated sites can be compared.

Multimetric approaches represent a means to integrate a set of metrics ("indicators"), which represent structural and functional attributes of an ecosystem (such as taxa richness, abundance, dominance, and functional feeding groups) (Li Li et. al 2010). An issue in data analysis is the interpretation of cause and effects. Indicators that are able to discriminate effects of hydropower need to be developed specific to the river system under study. For the Mekong region, first attempts regarding Multimetric Index development and application have been made in Thailand. A research outline and programme – including seeking of financial support – is recommended.

6.5.3 Data management

The data collected for aquatic ecology parameter groups should not be stored only for project-specific or for short-term use. Data should not be stored in a software programme or format that makes data storage and use error prone. A user-friendly database including good metadata information is state-of-the-art and enables data availability for long-term use.

Biological data storage also requires up-to-date taxonomic information, i.e. valid taxa names, correct spelling, correct taxonomic hierarchy, synonyms etc. Taxa catalogues that lie in the background of a database can be kept up-to-date without losing data.

A biomonitoring database may serve as central aquatic ecology database to support all kinds of information needs, including for hydropower planning and management.

7 Fisheries

7.1 Important Concepts

7.1.1 Fisheries as complex systems

Fisheries are complex systems involving biological production, harvest (catches), processing, distribution and consumption, supported by various industries, producing various wastes, and at the receiving end of all kinds of impacts from human activities and natural events. Each of the main elements of fisheries may be studied or monitored, each requiring particular approaches and producing various kinds of information. The main elements that can be monitored are as shown in Figure 30.

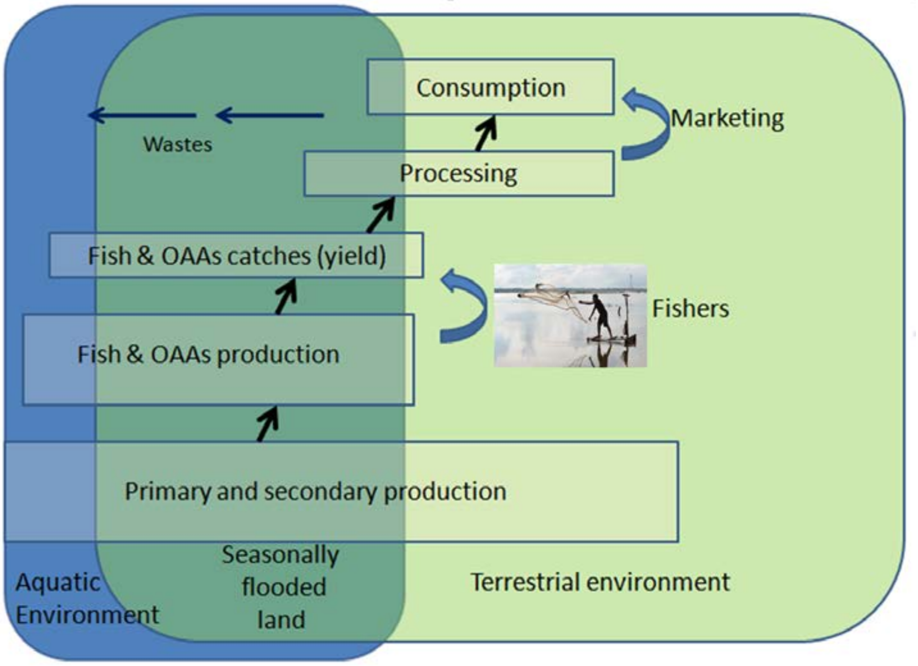


Figure 30 – Diagram of a fishery's main elements, each of which can be monitored

Seasonally flooded land is particularly important in the Mekong basin, and terrestrial processes all affect fisheries. Supporting industries are omitted from Figure 30 for clarity.

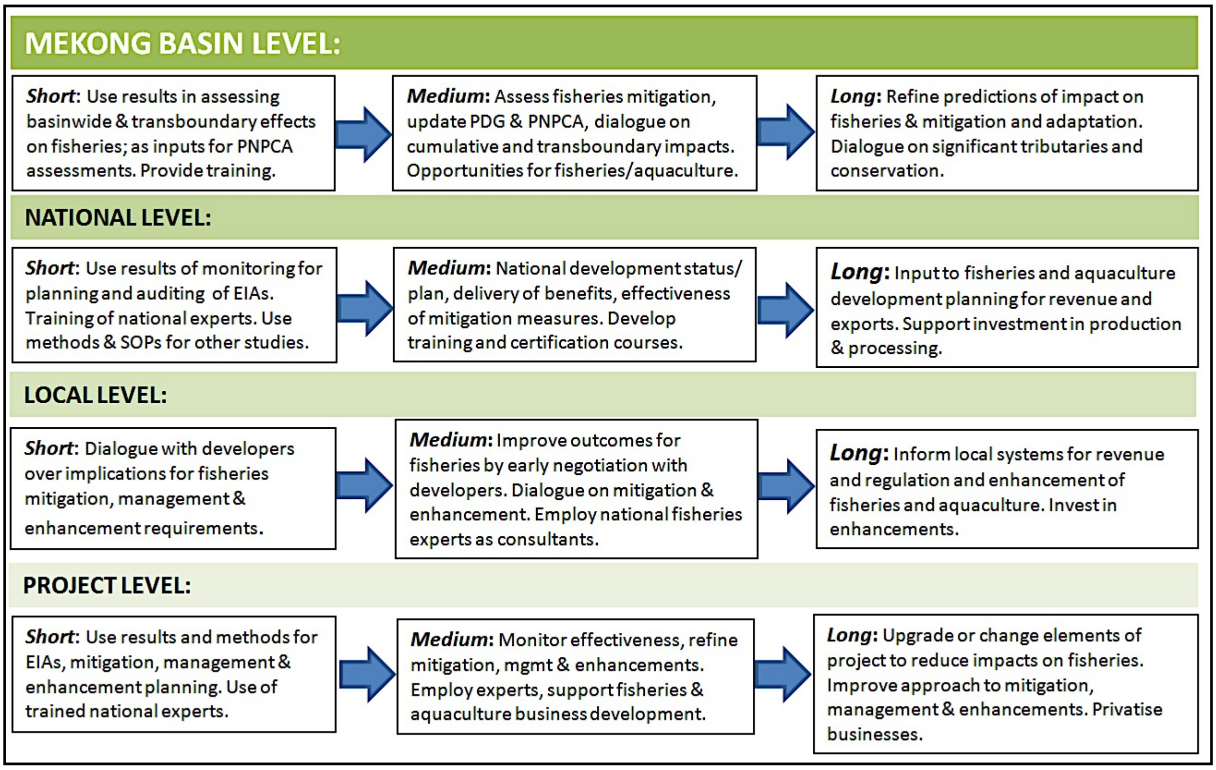
A fishery may be monitored for two broad purposes:

1. to describe changes in the fishery itself, or
2. to use fish or fisheries as a way of monitoring the ecological status or health of the aquatic environment.

LMB fisheries are of great importance for livelihoods and nutrition. The main objective of MRC-sponsored monitoring is to describe and understand changes in fisheries in their own right (1), and this objective is the focus of the monitoring proposed and consistent with the objectives of the MRC Fisheries Programme (FP). However, some of the activities recommended will support (2) as changes in fisheries in the Mekong are likely to be a result of natural environmental variation (e.g. in water and nutrient availability), environmental changes caused by development in other sectors, and fishing pressure. Hence interpretation of data from monitoring of inland fisheries requires ancillary supporting environmental data as well as data from other sectors that cause stress or pressure on fisheries. Interpretation of fisheries monitoring data also requires information on fishing pressure, to discriminate the causes of changes. As well as monitoring the quantities and value of fish and other aquatic organisms (OAAs) caught – the emphasis of the FP to date - the condition and quality of fisheries species must receive more attention.

7.1.2 Information needs and uses

Data on fisheries and aquaculture are needed for information to inform hydropower development at various levels and time scales, as exemplified in Figure 31. Fisheries are addressed through several processes in the MRC and each of these can be progressively improved as more focused fisheries monitoring information becomes available. National governments can also benefit by reference to MRC monitoring data which will show the relative importance, size and value of fisheries in hydropower-affected areas. At local and project level, fisheries monitoring data are useful in EIA processes and development of fisheries and aquaculture opportunities.



MEKONG BASIN LEVEL:

Short: Use results in assessing basinwide & transboundary effects on fisheries; as inputs for PNPCA assessments. Provide training.

Medium: Assess fisheries mitigation, update PDG & PNPCA, dialogue on cumulative and transboundary impacts. Opportunities for fisheries/aquaculture.

Long: Refine predictions of impact on fisheries & mitigation and adaptation. Dialogue on significant tributaries and conservation.

NATIONAL LEVEL:

Short: Use results of monitoring for planning and auditing of EIAs. Training of national experts. Use methods & SOPs for other studies.

Medium: National development status/ plan, delivery of benefits, effectiveness of mitigation measures. Develop training and certification courses.

Long: Input to fisheries and aquaculture development planning for revenue and exports. Support investment in production & processing.

LOCAL LEVEL:

Short: Dialogue with developers over implications for fisheries mitigation, management & enhancement requirements.

Medium: Improve outcomes for fisheries by early negotiation with developers. Dialogue on mitigation & enhancement. Employ national fisheries experts as consultants.

Long: Inform local systems for revenue and regulation and enhancement of fisheries and aquaculture. Invest in enhancements.

PROJECT LEVEL:

Short: Use results and methods for EIAs, mitigation, management & enhancement planning. Use of trained national experts.

Medium: Monitor effectiveness, refine mitigation, mgmt & enhancements. Employ experts, support fisheries & aquaculture business development.

Long: Upgrade or change elements of project to reduce impacts on fisheries. Improve approach to mitigation, management & enhancements. Privatise businesses.

Figure 31 – Information needs to support hydropower planning

The many different aspects of fisheries that can be monitored can inform many questions that arise about the implications of hydropower for fisheries.

Basic data on the current status and changes in fish stocks and species diversity, and total biomass that may need to be passed through dams at locations and change over time, is important to predicting implications of a hydropower project on fish communities and planning mitigation measures.

Associated data is required such as on habitat, water quality, aquatic ecology and land-uses so that cause-and-effect of changes to fish populations and condition over time can be analysed and causal factors could be mitigated if any problems arise.

Participation in fisheries may change after hydropower development, which requires planning, management and mitigation. Data on participation in fisheries and fishing effort is important to monitor pre- and post-conditions and effectiveness of management measures. Important indicators may include reliance of the river communities on the fish resource, and reservoir fisheries as proportion of total consumption.

As fisheries are at the receiving end of many impacts, it will be difficult to categorically identify hydropower dams as the cause of any particular changes. However, large dams are known to cause various changes that are likely to be distinctive and greater close to a dam. These include changes to the environment which include barrier effects, and others which can be grouped under hydrology, water quality or habitat. These can lead to changes to the fish populations and changes to the behaviour and condition of individual fish, all of which lead to changes in fishing activities and the composition, abundance and biomass in catches or samples, which further affect marketing and the industries that support fisheries. Aquaculture tends to expand in hydropower reservoirs and downstream.

Indicators can be readily defined based upon these well-established effects.

There will usually be alternative explanations for any observed changes, so interpretation must rely upon likelihoods and weight-of-evidence approaches, and supporting environmental and pressure data will be necessary for interpretation.

7.1.3 Quality principles and practices

Best practice monitoring of fisheries follows basic quality principles and generally established practices, suitably adjusted to take account of local conditions. Some best-practice approaches specific to fisheries include:

- following a documented process to select gears;
- consistent design of gears;
- consistent setting or use of gears by habitat and time;
- understanding and taking account of gear biases;
- accurate recording of sampling or fishing effort;
- accurate identification of fish and OAAs;
- accurately measuring lengths and weights; and
- reducing operator errors in large-scale surveys with many participants.

Best practice approaches can be defined for monitoring of each of the fisheries main elements shown in Figure 22. For all existing monitoring there needs to be good documentation of methods and use of Standard Operating Procedures (SOPs), and where relevant chain-of-custody for samples, and a systematic and documented approach to data handling.

7.2 Locations

Fisheries data collection for transboundary hydropower-relevant information should follow the same general principles as outlined in Section 2.2 and Box 2. Fisheries monitoring locations should align with the locations where data is collected on hydrology, sediments, water quality and aquatic ecology to facilitate interpretation of the causes of variation in fisheries parameters. Given the large spatial scale of fish migrations and likely distribution of fish assemblages, fish sampling sites can be selected within a few kilometres of target locations, to be general representative of conditions over a river reach and to avoid places of heavy traffic or fishing activity or local impacts such as pollution.

7.3 Parameters

Table 6 identifies those parameter groups most recommended for hydropower-relevant MRC fisheries information.

Table 6 – Parameter Needs for MRC Hydropower-Relevant Fisheries Information

MRC-Centralised Parameter Groups, Parameters	Hydropower Relevance	Example Basin-Scale Indicators
Participation in fisheries and fishing effort: Number of fishers full-time, part-time, occasional, fishing effort by fisher, time and gear type.	Participation in fisheries changes under hydropower development, which requires planning, management and mitigation.	✓ Current status and changes in fish stocks and species diversity ✓ Total biomass that may need to be passed through dams at locations and change over time ✓ Reliance of the river communities on the fish resource ✓ Reservoir fisheries as proportion of total consumption ✓ Aquaculture as proportion of total
Abundance and diversity of fish in catches or samples: CPUE (numbers and biomass) by species can be used directly and to generate various indicators.	Fisheries are affected in many ways by hydropower development, which should be planned and managed and mitigate impacts.	
Habitat: River width, depth, current speed, substrata, in-stream and riparian vegetation.	Hydropower development will change habitats, leading to a range of flow-on effects which require management and mitigation.	
Biological characteristics of fish: Migration patterns, fish health, diet, reproduction, condition, and value as food.	Fish biology may change as a result of hydropower development; monitoring allows adjustments to mitigate and manage impacts.	
Fish migration and behaviours: Species-specific information on distances travelled, timing, start/end/resting places for migrations	Fish migration mitigation measures are often built into hydropower projects at the design stage and should provide the most cost-effective solutions	
Aquaculture and Reservoir Fisheries: Species, production quantity and value, inputs and costs, profitability.	Aquaculture may be favoured in reservoirs and downstream of HP plants if flows are stabilized.	

Fisheries monitoring as a minimum typically reports abundance (numbers and biomass) of each species in catches or in samples, expressed as CPUE (catch per unit effort), which is assumed to be correlated with underlying changes in fish populations. CPUE data need to be supplemented with information on total effort, because more fishers or greater effort also reduce average CPUE. CPUE by species is likely to change in response to many factors, but can also be used to derive indicators which are likely to be affected specifically by hydropower dams; such indicators could include proportion of large migratory species (likely decrease), planktivorous species (likely increase) and exotic species (likely increase).

These are appropriate best-practice ways of summarising and reporting such data and can be used directly or with some refinement as indicators of hydropower effects; e.g. proportions of highly migratory fishes (likely decrease) and planktivorous species (likely increase). Classification of fish into guilds is a way to reduce the complexity of reporting where many species are present. Guilds are groupings of fish judged as ecologically similar, e.g. in terms of size, breeding characteristics, trophic level and migratory behaviour. Fish within guilds are likely to respond in similar ways to hydropower impacts, simplifying analyses, as there are typically 200-300 species recorded at any site and about 850 recorded from the Mekong Basin (Hortle 2009).

As well as abundance-related indicators, the biological status of fish may change as a result of hydropower dams. Fish diet, growth rate, condition, reproductive output and mercury content are all indicators that could be reported if biological analyses are implemented. Migration patterns and behaviours for fish is also an area of information important to hydropower planning and management.

Hydropower development will also cause changes in habitat types and quality. Data on river and floodplain dimensions, flows and substrata are needed, as well as information on the habitat preferences or tolerances of fish. Weighted useable area (WUA) is a common derived indicator reported downstream of hydropower dams, and identifies the hydraulic conditions most suited for particular fish species. Methods for mapping aquatic habitats have developed since the 1970s and are well-described by Bain and Stevenson (1999), DEP (2006) and Zale *et al.* (2013). Habitat mapping at sampling locations will generally include in-stream measurements of wetted width, slope, stream depth, turbulence, water velocity and substrate, as well as cover, which includes wood debris and aquatic vegetation. Other out-of-stream habitat measurements include stream-bank and shoreline condition, riparian vegetation extent and density, and barriers to fish movement. At the time of sampling, supplementary water quality data may be collected to relate to fisheries sampling efficiency (e.g. Secchi disc transparency or conductivity) or to understand 24-hour patterns (especially oxygen concentration) which are not evident from routine (2-monthly) data collection. Methods are well-described in standard texts, but will require testing and development for the Mekong. A high level of precision may not be required where measurements are used only to classify sites or part of the river into broad categories, as is likely to be the case. General elements of best practice should be followed during development of methods.

Aquaculture is heavily promoted in LMB countries, where all national fisheries agencies collect detailed data on aquaculture. Reservoir fisheries are also monitored by LMB fisheries agencies and hydropower developers generally monitor fisheries of the reservoirs formed by their dams.

Indicators of hydropower impacts would be generated from parameters based on well-established patterns from hydropower dams elsewhere, for example:

- changes in habitat types and extent, for example loss of pools, reduction in flooded area;
- changes in habitat quality, for example loss of snags as trees are trapped by dams;
- changes in the food chain, from a diversity of riverine and terrestrial food, especially insects, to a simplified food chain based on the zooplankton growing in reservoirs, with consequent changes in the fish community;
- declines in large migratory fish species;
- increases in generalist species;
- increases in planktivorous or filter-feeding fishes and OAAs such as clams;
- increases in some predatory species in reservoirs and immediately downstream of dams, including some fishes and predatory birds;
- increased mercury content in fish as a result of biomethylation in anoxic sediments in dams;
- other biological effects on fish, such as reduced condition and fecundity (egg production);
- changes in the fishery, such as increasing commercial fishing;
- flow-on effects to increased aquaculture production; and
- the habitat of particular species.

7.4 Timing

MRC information to support hydropower planning and management should take into account the following timing needs and considerations important to fisheries.

- Cycles of **fish migration** need to be captured by data collection processes, but migration periods can differ by species and also by season and river. It is not always possible to predict when these will occur, and accompanying data (e.g. lunar cycle, hydrology, water quality, plankton) can help understand triggers and cues for the onset of migratory periods. Many studies in the LMB show migration peaks can be over very short periods, when daily monitoring may be necessary, with relatively low catches at other times, when sampling can be less frequent with little loss of information.
- Other seasonal activities such as **breeding** need to be recorded by species.
- Timing aspects of regulatory and socio-economic factors affecting **fish capture** may influence fisheries data.
- **Multi-year intervals** are appropriate for monitoring trends in participation, fishing pressure and household catches and consumption over large scales.
- Supplementary information collection methods are needed to document and record **event-based** information such as effects on fisheries of droughts and floods.
- Daily data collection by fishers may promote consistency and continuity, but is too much to process; strategies are needed to enable **fast data processing** by selecting from the daily collected data.
- MRC data need to be publically available and **up-to-date** to provide their full value to users.
- Fisheries monitoring needs to take into account **fishing regulations and socio-economic factors** which may affecting fishing effort at certain times and thereby the results from catches or samples.

Daily fisher catch monitoring is considered excessive in terms of covering natural cycles, fish migrations and operational system changes, as well as being far more frequent than in typical monitoring programmes elsewhere, where data are collected at intervals varying from 5-6 times per month to annual, depending upon specific objectives and environmental characteristics (FAO 1999). Or, where catches are high over relatively short periods (e.g. at the beginning and end of the wet season), sampling may be stratified, with data recorded more frequently in the high-catch period and less frequently at other times. Reducing the frequency of MRC fisheries monitoring would allow for faster data processing, analyses and reporting, and would also free-up capacity for standard sampling, biological analyses and habitat assessment. Any changes to monitoring frequency should however be justified fully based on statistical principles and after reviewing existing data and taking into account objectives and the particular features of the Mekong's fisheries. For example, where there are highly skewed catch distributions (as is typical in the Mekong), monitoring should be stratified between high-catch periods (short duration, high sampling frequency required) and low-catch periods (longer duration, much less frequent sampling) periods. It may also be desirable to collect field data daily (as at present) but process the data at a reduced frequency, which would significantly reduce cost and time delays as well as eliminating any risk of lost data.

Proposed standard sampling should be at the same frequency as fish catch assessment, but preceded by training, trials and calibration during intensive sampling exercises at key locations. Proposed biological analyses should be carried out at least monthly as is typical to cover the range of seasonal variation. Frequency of habitat assessments would vary depending upon scale – over large scales assessments could be made at intervals up to 5 years which would suit State of the Basin reporting.

More frequent assessments – monthly or quarterly – are typical over smaller scales, such as for sampling locations or sites.

7.5 Methodological Considerations

7.5.1 Interviews for collecting fisheries information

To establish the range of variation and trends in fisheries parameters of interest may require many measurements to be taken over years or even decades. As a result, "best practice" monitoring has increasing emphasis on accessing local ecological knowledge (LEK) by interviews of fishers (e.g. Haggan *et al*. 2007, Bao *et al.* 2001, Friend 2009) on the assumption that LEK integrates many years of prior observations by many people. At a minimum, such interviews can provide considerable background information that is useful for design of more conventional sampling as is proposed for this ISH11 study, and ideally provide more quantitative data on catches and/or consumption. Socio-economic surveys using standardised interviews have provided a great deal of fisheries information and are the only feasible way to assess the characteristics and size of inland fisheries over large scales for inland fisheries such as in the LMB (see discussion in Hortle 2009). Some surveys in the LMB are discussed by Hortle (2007), MRC (2010b) and Bouapao *et al.* (2012). Best practice in this context is not fisheries-specific, but includes survey design, the science of asking questions and correctly formulating questionnaires (e.g. Schaeffer and Presser 2003), as well as reducing 'operator error' (differences between observers). Operator error should be covered by the piloting and training processes set up, for example under the SIMVA process.

An important aspect that requires attention is calibration of interview results against monitoring data so that biases are understood. Elsewhere, there is a considerable literature on dietary monitoring (daily food records) compared with interviews based on recall, with both methods having some inherent biases, and improvements continue to be made (e.g. Fiedler *et al.* 2012, Lazarte *et al.* 2012).

7.5.2 Fisher catch monitoring

Fisher catch monitoring is a common practice worldwide that may be carried out at various scales and with more or less involvement of experts as data recorders. At one extreme, fishers enter data in logbooks themselves (e.g. Cooke *et al.* 2000), as this is may be the only practical way to record data from many fishers; at the other, experts may systematically record representative data on major elements of fisheries (e.g. FAO 1999). Both approaches are used in the Mekong by the FP – fisher catch monitoring using logbooks, and expert monitoring of the dai fishery and the large lee trap and gill net fisheries at Khone Falls.

Fisher catch monitoring can only cover a small proportion of the many gears and habitats; interviews are necessary to get broad coverage. The photo in Figure 32 is on a tributary, Huai Mong, in northeast Thailand.

Figure 32 – Lift nets are a common small-scale gear in the Mekong basin

7.5.3 Standardised sampling of fish

Many background documents on fisheries sampling methods were consulted in developing the following information on best practice fish sampling, including Backiel and Welcomme (1980), Bonar *et al.* (2009), CEN (2005), Deap *et al.* (2003), DEP (2006), FAO (1999), Potter and Pawson (1991), USGS (2002), TVA (2010) and Zale *et al.* (2013).

Non-capture methods: Fish and OAAs may in some situations be directly observed, identified and counted, a common practice where rivers or lakes are clear, but one that could not generally be applied in the Mekong, which is too large and often turbid. Indirect counting measures use mechanical, electrical or hydro-acoustic instruments. Of these, hydro-acoustics is becoming commonly used in large open water-bodies such as lakes, where there are few interferences and where the method can be calibrated against other removal-based methods. This method has been trialled in the Mekong (Viravong *et al.* 2006) and has some application to certain habitats such as deep pools or reservoirs at certain times, but cannot be used across a range of sites and habitats throughout the year. It is also complex and requires specialised and ongoing maintenance and operator training.

Capture methods: Sampling of fish by capture using various standard methods is common in developed countries as one element in monitoring fisheries or as a way of characterising ecological health of inland waters. Generally such sampling seeks to provide information on the number and biomass of fish in a water-body. Standard sampling produces statistics on either absolute or relative abundance. Absolute abundance (e.g. kg or number of fish per hectare) may be estimated by pumping out a water-body, by depletion sampling or by mark recapture; all are problematic in large open systems like the Mekong. In this situation, the best practice approach would aim to produce relative estimates of abundance as catch per unit effort, which are assumed to be related to underlying population abundance and biomass.

To develop appropriate sampling methods, it is usual to compare various gears to understand their limitations and biases, with long-term monitoring usually employing one or a few gears and methods.

The FAO defines 11 main types of gear, of which there are hundreds of variants in use in the Mekong system:

- Surrounding nets (including purse seines)
- Seine nets (including beach seines and Boat, Scottish/Danish seines)

- Trawl nets (including Bottom: beam, otter and pair trawls, and Midwater: otter and pair trawls)
- Dredges
- Lift nets (Figure 32)
- Falling gears (including cast nets)
- Gill-nets and entangling nets (including set and drifting gillnets; trammel nets)
- Traps (including pots, stow or bag nets, fixed traps)
- Hooks and lines (including hand-lines, pole and lines, set or drifting longlines, trolling lines)
- Grappling and wounding gears (including harpoons, spears, arrows, etc.)
- Stupefying devices (such as electro-fishers or poisons).

Gears commonly used for sampling in inland rivers include electro-fishers and rotenone (a poison) but these are not likely to be widely applicable in the Mekong, because (1) they are illegal, so permitting may not be possible or may cause copycatting by others; (2) as 'active' methods, they depend greatly upon operator skill and application; and (3) environmental variations (e.g. in water turbidity) directly affect capture efficiency, which confounds site and date comparisons.

Other common inland-river sampling methods that are likely to be the more applicable in the Mekong include seines, gill-nets and traps. These are also widely used by local fishers, which may allow direct calibration of standard gears against local gears. Gill-nets and traps may be used as 'passive' gears, which may reduce operator errors that could result when different field crews are operating in each country. Panel gill-nets have been successfully used in the Mekong basin in some other studies of intervention effects (e.g. Arthur *et al.* 2010, Lorenzen *et al.* 1998), based on the assumption that such gears catch a wide range of species and that their CPUE correlates with actual biomass of fish in a water-body. Gill-nets were also trialled by Lieng (2003) during testing for MRC bio-monitoring. He used six gill nets with stretched meshes of 2.5 to 10 cm set during the day at 11 mainstream sites, and recorded 59 species, a reasonable result where about 200 species are recorded over long periods by fishers using various gears. It is not clear why this work was not further developed to be included as a routine element of the EP's bio-monitoring. Lift-nets, a very common local gear, could also be adapted to be a useful standard method. Sampling with any of these gears may be easily replicated, an essential requirement to achieve required statistical power.

Figure 23 shows an example of a design for a possible standardised gear – a panel gill net. Standardisation of length, depth, hanging ratio (hung length/un-hung length), mesh sizes, floats, weights, and ropes is necessary to reduce variance in sampling results. Figures in italics are stretched mesh aperture dimensions. Float and weights are attached at one-metre intervals, omitted for clarity.

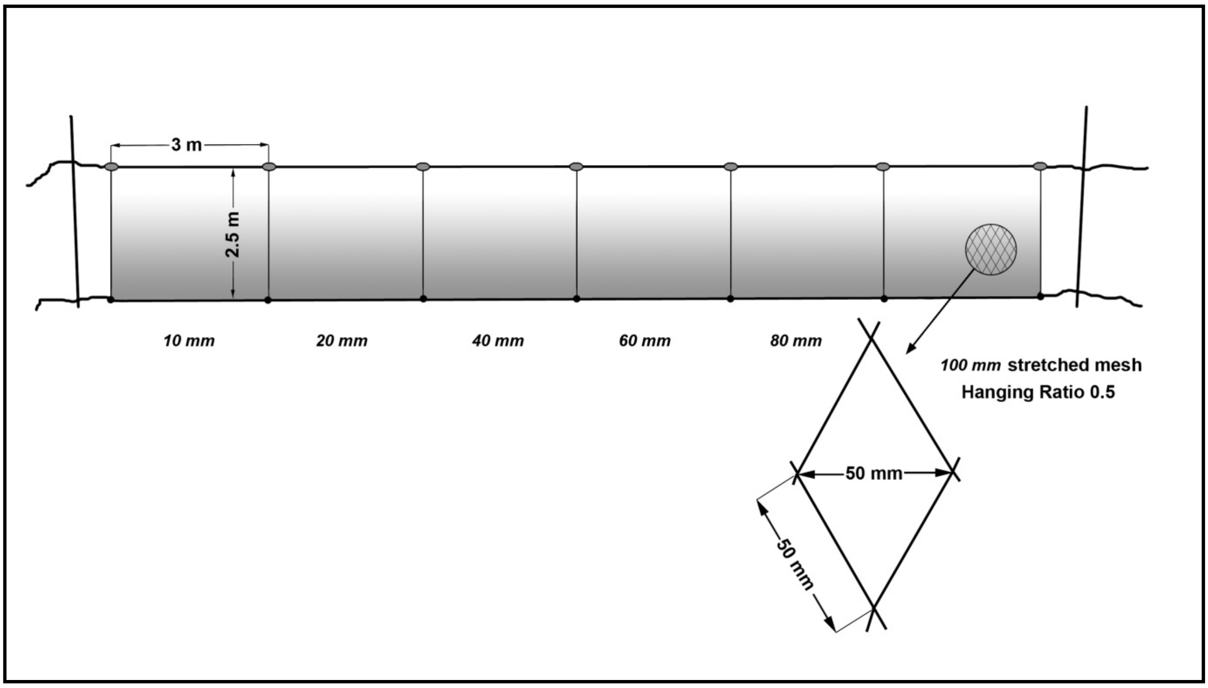


Figure 33 – Example of design for a possible standardised gear – a panel gill net

As mentioned above, to ensure consistent results over time, best-practice sampling must begin by testing and comparing proposed gears under different conditions (e.g. Growns *et al.* 1996; Neebling and Quist 2011), and it would also be useful to compare the results from standard gears with those from fisher catches. Fish and OAAs removed from gears must be identified, counted and measured, and the data recorded following standard approaches.

At present the only standard fisheries monitoring routinely employed in the Mekong by the FP is larval sampling, but monitoring of single gear types – the dais in the Tonle Sap, and lee trap and gill net monitoring in Lao PDR – are methods that are close to being standardised as the variability in gears from year-to-year is not great and catch data can be adjusted for effort, which is recorded.

7.5.4 Biological analyses of fish

Best practice methods for examination of fish are detailed in Zale *et al.* (2013) and other standard references. Selected fish can be retained from the monitoring or catches, and taken to laboratories for processing. Various biological attributes can be assessed – diet, condition, growth rate, fat content, reproductive condition, concentrations of contaminants such as mercury, and presence of parasites and pathogens; these are all indicators that may change as ecological conditions change downstream of hydropower plants. Samples may also be taken for genetic analysis for long-term monitoring of stock structure.

7.5.5 Market surveys of fisheries products

A survey of the quantities and prices of the main species in local markets is a useful element of fisheries monitoring that can provide several useful indicators of how a fishery is changing. Some indicators that could be affected by hydropower dams include quantities and price of large migratory species, exotic fishes, and aquaculture fish by species, with origin where known. Best practice monitoring in this context includes defining representative markets at different levels (state to local), determining how these fit with selected zones or locations of interest for hydropower impacts, and taking account of several local factors that could have a large confounding effect on survey outcomes. Some examples include the following:

- In many markets, few fish are sold on Buddhist holidays.
- Market sellers are reluctant to talk with surveyors early in the day, until some sales have been made.
- About 80-90% of traders are women who may only be surveyed accurately by other women who speak their language.
- Bargaining is usual practice, so actual prices are less than asking prices.
- Fish prices are high in the morning and drop towards midday as sellers try to clear their stock, which affects the ‘average’ price for the day.
- Quality has a large effect on prices.
- Generally, aquaculture fish are cheaper than wild capture fish of the same species.

These and other characteristics and how to take account of them should be properly documented within ‘best practice’ SOPs for monitoring fisheries products in markets in the Mekong basin. Any market monitoring would use either interviews or logbooks, for which the merits and disadvantages should be weighed against objectives prior to implementation.

8 Socio-Economics

8.1 Important concepts

8.1.1 Social Sustainability

Sustainable hydropower relates to the concept of social sustainability, which is relevant in the context of MRC's vision of "An economically prosperous, socially just and environmentally sound Mekong River Basin", and MRC's mission "To promote and coordinate sustainable management and development of water and related resources for the countries' mutual benefit and the people's well-being".

Though social sustainability is a much debated and difficult concept, a working definition has been suggested in the following (Colantonio 2007):

"…social sustainability refers to the personal and societal assets, rules and processes that empower individuals and communities to participate in the long term and fair achievement of adequate and economically achievable standards of life based on self-expressed needs and aspirations within the physical boundaries of places and the planet as a whole. At a more practical level, social sustainability stems from improvements in thematic areas of the social realm of individuals and societies, ranging from capacity building and skills development to environmental and spatial inequalities…"

Thus, the concept of social sustainability incorporates traditional social objectives and policy areas such as equity and health with issues concerning participation, needs, social capital, the economy, the environment, and more recently, with the notions of happiness, well-being and quality of life.

The concept of social development is also relevant to revisit here. Social development can be defined as the process of moving towards social sustainability. The World Bank defines social development as a process towards:

1. Inclusive institutions that promote equal access to opportunities, enabling everyone to contribute to social and economic progress and share in its rewards;
2. Cohesive societies that enable women and men to work together to address common needs, overcome constraints and consider diverse interests; and
3. Accountable institutions that are transparent and respond to the public interest in an effective, efficient and fair way.

8.1.2 Economic Sustainability

Sustainable economic development is generally defined as development that meets the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987). Income reflects earnings from capital. Statements about meeting needs in the present and the future thus ultimately relate to the stock of capital held by a society or region. Capital takes many forms including human, physical, social, natural, financial and technological. Development implies an ability to increasingly meet societal needs and, thus, implies a growth in capital. The development of large hydropower projects represents a singular challenge to our understanding of sustainable economic development. This, as large hydropower projects alter the land- and hydro-scape and therefore natural capital in pervasive and irreversible ways. This alteration shifts a nations income from a reliance on the provisioning, regulating, supporting, and cultural ecosystem goods and services produced by so-called "green infrastructure" to a reliance on the provisioning services produced by "built" infrastructure (as per the Millennium Ecosystem Assessment 2005).

Competing ideas exist on what constitutes long run economic sustainability. These are referred to as “weak” and “strong” sustainability and are based on differing perspectives as to what extent one form of capital may substitute for another (Pearce et al., 1990). For example, to what extent can physical capital (a dam) substitute for natural capital (for example watershed function)? Technology is critical, as technological change is what enables societies to increase production of items that society needs from a limited resource base. Weak sustainability maintains that what is important is that the total stock of capital grows. If this occurs then the prospects of meeting the needs of future generations are good. Strong sustainability maintains that there is limited substitutability between types of capital. In particular, that there is limited substitutability between social and natural capital and “man-made” capital such as physical, financial and technological capital.

While there are many unresolved theoretical questions the discussion highlights the presumption that sustainable hydropower development should, at a minimum be a positive capital enhancing endeavour that sustains and grows income over the long term. This issue can be examined at different levels. At the project level, economic analysis of the costs and benefits of projects can be used to assess if a project yields net economic benefits to the national economy, as opposed to yielding simply positive financial returns to the project proponent (Aylward et al., 2001). This involves incorporating the local socio-economic impacts of hydropower facilities in terms of changes in natural, human and social capital and the income/well-being derived from them. Inevitably, such an effort incorporates social and not just economic indicators.

At the level of the macroeconomy the consequences of many such decisions can be assessed in terms of whether national capital and income are growing, and whether the overall macroeconomy is stable and well balanced. With respect to natural capital, various proposals have been made to incorporate this capital directly into the national accounts or to maintain “satellite” accounts that track the stock of capital but in physical not monetary units (UNSD, 1993). Initial efforts to apply this approach to water have been undertaken, but largely in arid areas where water scarcity drives the perception of value (Lange and Hassan, 2006). The utility of these capital accounts, however, has yet to be tested with reference to dams, and particularly in the tropics. In the meantime efforts to assess sustainability continue to rely on macroeconomic indicators of growth combined with measures of environmental and social sustainability. In the case of the MRC and dams on the LMB the improvement proposal on macroeconomics focuses on the latter, but in doing so may lay the groundwork for future efforts to examine long term issues of the fungibility of capital, long-term income growth and economic sustainability.

8.1.3 Information needs and uses

Socio-economic information is needed to provide an understanding of the social and economic conditions for, and of the positive and negative impacts of hydropower development, based on a common understanding among key stakeholders of the desired outcomes for ‘sustainable hydropower’. The information is needed at various time scales: short, medium and long-term changes; and various levels: local, national, basin-wide, and even global drivers and impacts of hydropower, as in Figures 34 and 35.

MEKONG BASIN LEVEL:		
Short: Regional energy security and trade, regional markets, navigation	***Medium:*** Regional energy security and trade, regional markets, navigation	***Long:*** Regional energy security and trade, navigation, aging infrastructure
NATIONAL LEVEL:		
Short: Energy security, electricity supply, transmission, trade, revenue, regional stimulation, GDP, balance of payments	***Medium:*** Energy security, electricity supply, transmission, trade, revenue, regional productivity, GDP, balance of payments	***Long:*** Energy security, electricity supply, transmission, trade, revenue, regional productivity, GDP, balance of payments
LOCAL LEVEL:		
Short: Job creation, employment & training, spin-off industries, infrastructure upgrades	***Medium:*** Employment, regional economic stimulation, spin-off industries, delivery of benefits	***Long:*** Sustainability of benefits and regional economic stimulation, aging infrastructure
PROJECT LEVEL:		
Short: Project costs and revenues, procurement, financial management, labour needs	***Medium:*** Financial and labour risk management, generation planning, markets, infrastructure safety	***Long:*** Generation planning, aging infrastructure safety, cost-benefit of upgrades

Figure 34 – Information Needs Relating to Economic Dimension

MEKONG BASIN LEVEL:		
Short: Basin level development status, resource dependence , food security, migration, regional cooperation, poverty reduction	***Medium:*** Basin level development status, resource dependence , regional stability, food security, migration, poverty reduction	***Long:*** Basin level development status, social cultural integration, food security, adaptive management needs
NATIONAL LEVEL:		
Short: Human Development Index status and trends, social impact management, creation of social opportunities	***Medium:*** Human Development Index status and trends, migration and impact management, delivering and sustaining social opportunities	***Long:*** Human Development Index status and trends, social stability, adaptive management to social needs
LOCAL LEVEL:		
Short: Social impact prediction and mitigation, improving living standards and ensuring sustainable livelihoods	***Medium:*** Effectiveness of social mitigation and benefit measures, management of migration-related issues	***Long:*** Sustainability of social benefits and mitigation, improved living standards, sustained livelihoods
PROJECT LEVEL:		
Short: Impact assessment and management including resettlement, community engagement & support	***Medium:*** Delivery and effectiveness of social management plans including resettlement, ongoing community support	***Long:*** Sustainability and/or hand-over of social management plans, adaptive management as needed

Figure 35 - Information Needs Relating to Social Dimension

Hydropower projects are built to address socio-economic needs, for electricity, for water management, for regional development, for human development needs.

Socio-economic information of a variety of types and geographic scales is required to understand the before-and-after conditions in the area of the hydropower project. This information informs changes both positive and negative and helps identify and monitor if mitigation measures are achieving their goals.

Socio-economic information informs if the anticipated benefits of the hydropower development are being realised.

Socio-economic information can also be analysed at the local scale in combination with environmental factors to understand cause-and-effect of changes following construction or during operations. An example might be data showing over-fishing in an area causing declining fish stocks, which clarifies that the declining fish stocks are not arising due to changed flow conditions from the power station discharges.

The MRC has occasionally made efforts to draw together socio-economic data from the LMB. These efforts however have been limited and, with the exception of SIMVA, occasional in nature. MRC does not collect, store and make available comprehensive socio-economic data on the LMB, or with respect to hydropower *per se*.

The BDP project to establish a socio-economic database aims to provide easy access to good quality official socio-economic data in a sustainable manner. The work began in April 2013, and has progressed with the establishment of a team of national statistical experts from the statistical agencies of each LMB country. It is planned that government agencies, private sector and other stakeholders in the Member Countries will be provided with easy access to basin-wide official social and economic statistical data. The MRC socio-economic database will be an important resource to the work of all MRC Programmes including for hydropower planning, the State of the Basin Report, scenario forecasts, impact assessments and so forth. All official socio-economic statistics for the MRC use will be contained in the database. The predefined thematic groupings of the data will be subject-specific according to their relevance for different purposes. Thematic grouping will be flexible so new thematic groupings can be added.

8.2 Locations

Socio-economic data collection has different characteristics compared to the environmental disciplines when it comes to a long-term basin-scale information collection system. The socio-economic effects of hydropower development are both local but also geographically wider than environmental effects through various socio-economic channels such as changes in livelihoods, labour opportunities, access to natural resources, access to services, changes in prices. A significant proportion of the people who live near the Mekong River are highly dependent on the resources from the river. Fish from capture fisheries are important protein sources, vegetables grown on the riverbanks are fertilised from nutrients brought down river during the flood season, and wood and bamboo that are growing on the riverbanks are collected and used. Whilst it is of primary interest to obtain data for those communities that are most likely to be directed affected by hydropower, these are often addressed through project-specific monitoring requirements.

Over larger spatial scales, socio-economic monitoring has to consider different administrative levels, as illustrated in Table 7. Most official socio-economic data such as living condition surveys are based on sampling frames defined by villages, communes, districts etc. and are presented in those units. Different types of benefits accrue from hydropower at the local, provincial and national levels. For example, revenue benefit-sharing schemes, if such schemes exist, would have to be monitored at different administrative levels. Infrastructure improvements in connection with hydropower development such as roads will have benefits that should be monitored at district and provincial levels, for example by increases in import-export of goods. Hydropower's contributions to national income obviously must be monitored at the national scale. Developments in the policy and regulatory framework conditions for hydropower must be monitored at national and also at provincial level, in countries where provinces have a high degree of administrative and regulatory powers. Similarly, monitoring of negative impacts must consider household level impacts as well as community, district, and possibly provincial level, although negative effects become less evident at the higher administrative levels.

Table 7 - Socio-economic indicators at different spatial levels

Level	Examples of socio-economic indicators at different spatial levels
National	• National income from hydropower in the short- and long-term • Independence in energy supply • Energy security • Presence/absence of protective policies for the poor and for their access to natural resources • Adherence/non-adherence to basin-wide decision bodies • Downstream transboundary water use conflicts
Local government (Province, District, Communes)	• Infrastructure development: roads, water supply, electricity supply • Employment opportunities in connection with hydropower construction • Income from hydropower and fisheries taxes and customs • Poverty ratio (realising poverty is spatially distributed) • Livelihoods: proportions of different types • Food security • Status of cultural sites • Disease prevalence
Village/ Community	• Community activities/projects • Food security • Poverty ratio (realising poverty is spatially distributed) • Livelihoods: proportions of different types • Resettlement • Income from aquatic resources • Cooperation and conflicts over user rights to water and aquatic resources
Household	• Fish catches by source • Access to natural aquatic resources • Dependency on fish and OAAs • Capabilities (education, health, social networks) • Land ownership

8.3 Parameters

Socio-economic indicators need to be based on an understanding of the social variables at play in hydropower development in LMB (both driving hydropower development and being affected by it), and a common understanding among key stakeholders of the desired outcomes for 'sustainable hydropower'.

The parameter groups shown in Table 8 are those that could be considered for MRC socio-economic information relevant to a basin-scale perspective on hydropower. Refinement or shortening of this list could be done based on further analysis and testing. The selection of indicators must distinguish between short, medium and long-term changes; and local, national, basin-wide, and even global drivers and impacts of hydropower.

Table 8 – Parameter Needs for MRC Hydropower-Relevant Socio-Economic Information

Parameter Group	Hydropower Relevance	Potential Indicators	Possible Parameters (if needed to form indicator)
Population and Demographics	Used for per capita calculations, and to isolate changes for gender, minorities or other vulnerable social groups		Population
			Dependency ratio
			Household (HH) size
			Nos. and % of ethnic minorities
	Hydropower may lead to resettlement	No. of households (HH) resettled	
	Large hydropower construction may lead to increased in-/out-migration within or across national borders	In-migration	
Income / Employment / Poverty	Hydropower as a development activity suggests that these indicators should improve at local and/or national scale	GDP/capita	Gross domestic product (GDP)
			Power purchasing parity exchange (PPP)
		Unemployment (%)	
		Ratio of gender employment	
		Poverty rate	
		Rate of rural poverty	
Macro-economics	Hydropower may assist economic growth	Gross domestic product (GDP)	
	Hydropower may increase trade in power	Export and import of power	
	Hydropower may possibly decrease inequality of income distribution	Gini coefficient of income distribution	
	Hydropower projects may increase foreign direct investment	Foreign Direct Investment (FDI)	
	Hydropower projects may spur industrialisation	Industrial sector as % of GDP	Sectoral accounts
	Hydropower projects affect capital formation	Private and government investment	National accounts
	Large hydropower projects may affect macroeconomic stability	Inflation	CPI or PPI, traded vs non-tradeables
		Balance of Trade (BoT)	Exports, imports
		Current accounts	BoT, factor income, cash accounts
		Capital accounts	FDI, other portfolio/investment
		Public debt	
	Large hydropower projects may lead to exchange rate appreciation	Real exchange rate	
Energy	Hydropower may improve access to, and security of, energy for households	Electrification	Nos. and % of HHs connected to grid
		Electricity use per capita	GWh/capita
	Hydropower may enhance industrial development opportunities	Energy intensity	GDP / energy use
		Industrialisation	Industry share of GDP
	Hydropower may stabilise power prices	Power price	Retail price of power
	Hydropower may improve electric power system reliability	Power reliability	
	Countries investing in hydropower may see direct benefits in terms of foreign exchange earnings	Power exports	
	Countries investing in hydropower should see an increase in sectoral employment and output	Sectoral employment	No. employed; full-time/part-time
		Sectoral share / amount of GDP	$ in PPP
	Hydropower development will avoid emissions costs	Avoided emission costs	
	Hydropower development will avoid greenhouse gas (GHG) costs	Avoided GHG costs	
Capture Fisheries	Development of hydropower facilities may increase reservoir fisheries but decrease riverine fisheries	Fishery capital	
		Fishery effort	
		Fish catch	
		Sectoral employment	No. employed; full-time/part-time
		Sectoral share / amount of GDP	$ in PPP

Rural Development	Development of hydropower may increase funding flows to rural development	Areal extent	
		Production (physical units)	
		Sectoral employment	No. employed; full-time/part-time
		Sectoral share / amount of GDP	$ in PPP
Transport and Navigation	Development of hydropower may increase road and river transport opportunities	Distance to main road	
		Time to reach market	
		Nos. of households using river transport	
Health	Hydropower as a development activity suggests that these health-related social and economic indicators of development should improve at local and/or national scales. Positive or negative change in these indicators may particularly be observed in communities near hydropower facilities.	Life expectancy at birth	
		Disease occurrence	Occurrence HIV/Aids
			Occurrence of liver fluke
			Occurrence of malaria
		Access to health care	HH average distance and travel time to facilities
		Access to clean water	Nos. and % of HHs with clean drinking water
		Access to sanitation	Nos. and % of HHs with access to sanitation
		Food security	Malnutrition rate
		Protein (by source)	
		Sectoral employment	No. employed; full-time/part-time
		Sectoral share / amount of GDP	$ in PPP
Education	Hydropower as a development activity suggests that these health-related social and economic indicators of development should improve at local and/or national scales. Positive or negative change in these indicators may particularly be observed in communities near hydropower facilities.	Access to education	
		Education achievement level	Education achievement
			Literacy rate
		Sectoral employment	No. employed; full-time/part-time
		Sectoral share / amount of GDP	$ in PPP
Culture and Religion	Hydropower projects may endanger cultural and religious sites and disrupt local cultures	Retention of established religious and cultural sites of importance	
		Retention of or funding for cultural traditions	

The Table 8 content reflects the many facets of socio-economics information relevant to hydropower. Hydropower relevant socio-economic indicators and their supporting parameters cover a broad spectrum. Different aspects of socio-economics information relating to hydropower will be more or less important depending on the perspective of those looking at the information.

Basic population and demographic data is always a necessary input, and limitations in geographical detail and accuracy of these parameters will affect the further indicators. Indicators for rural development, such as access to services, and indicators for importance of capture fisheries and transport/navigation, can be used to track how livelihoods change over time in response to hydropower projects. Social indicators include health, education and cultural/religious parameters. Economic indicators include fundamental metrics in the sphere of influence of hydropower projects such as income and employment growth. Energy sector related indicators are likewise important as they provide the context for hydropower planning and assessments. Macroeconomic indicators can portray development trends over time.

Many social and economic parameters are relevant for several sectors. Data from the Member Countries needs to be harmonised to allow for comparison between countries.

8.4 Timing

MRC information to support hydropower planning and management should take into account the following timing needs and considerations important to socio-economics.

- Socio-economic changes may be **inter-generational**, so long datasets for a selected group of indicators are valuable.
- Socio-economic changes may be precipitated and/or influenced by **events** (e.g. natural disaster, new industrial development), so mechanisms that can capture and record these assist interpretation not only of socio-economic but also environmental information.
- The **varying timetables and periodicity** for socio-economic data collection in the Member Countries (e.g. by census or survey) needs to be recognised, and **harmonisation** mechanisms developed so that status and trends can be determined in a comparable and consistent manner.
- The MRC already has periodic reports drawing on socio-economic data, such as the BDP scenario assessments and State of the Basin reports; socio-economic data needs to be as **recent** as possible in a harmonised form for these reports to be of the most use.

Timing is a critical consideration for socio-economic information over large spatial scales. The general economic and social data currently collected are relevant for the planning horizons for hydropower as they are indicators of overall societal development. The data represent both conditions for, and goals of, development efforts including hydropower development. Time series of socio-economic data will be required for making projections into the future and scenarios of different development options.

The periodicity of national statistics varies from country to country. Timing of national census's and surveys follows national schedules (Figure 36). A dataset of, for example, poverty ratio would refer to 2008 for Cambodia but to 2005 for Lao PDR. How to get around this problem needs careful consideration; for example, whether to use the latest available data together with the growth/decline rate from the second latest data point - and/or use averages of data values for the period 2005-2012. In the past the lack of time series has been a significant limitation of social assessments of various development scenarios. To address this challenge requires data harmonization based on agreed principles to establish a baseline. A starting point is to obtain the most recent data and then in the next stages to get time series of those variables. Macroeconomic and energy information would need to be collected on an annual basis, and systems need to be set up to enable this.

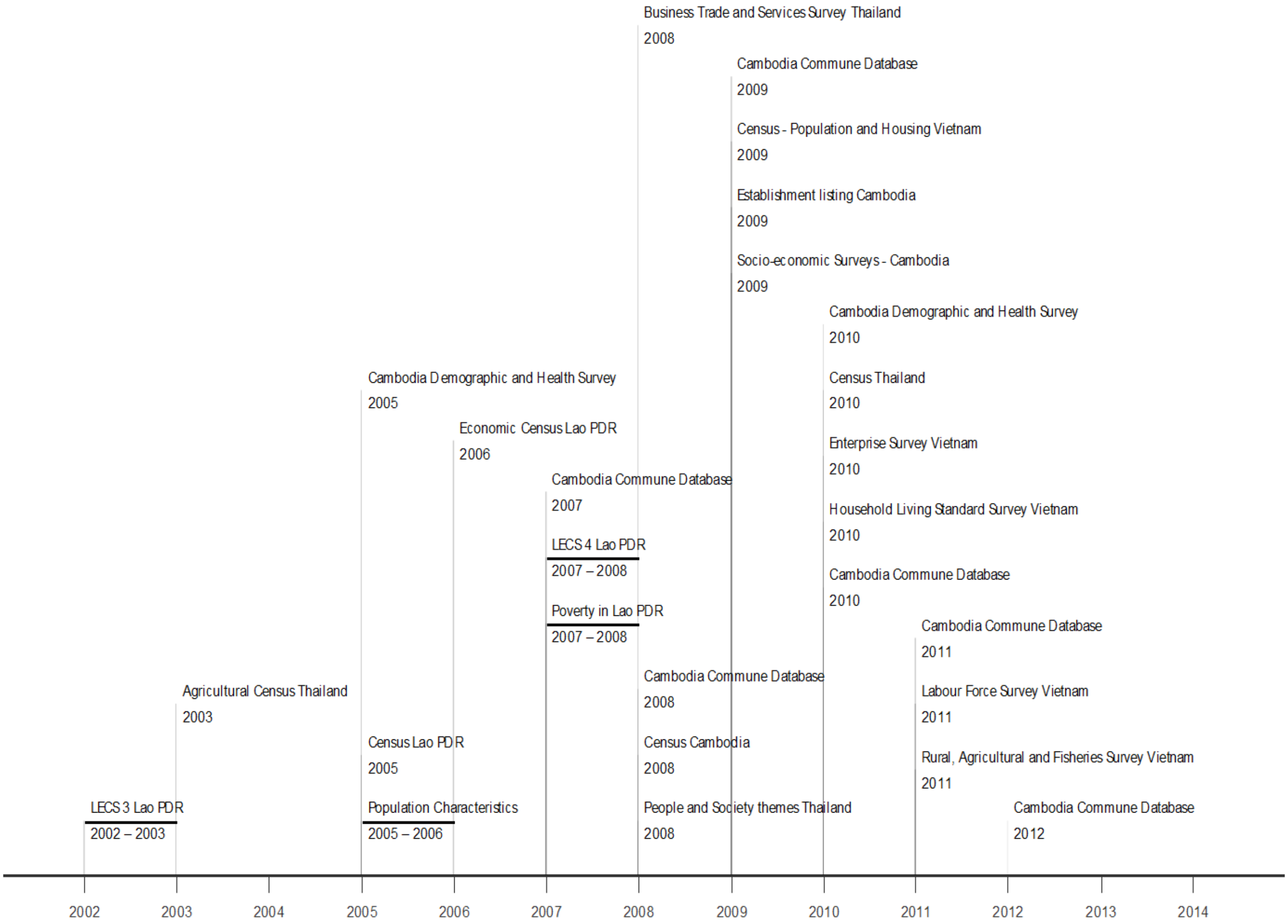


Figure 36 – Timeline of National Census's and Surveys

8.5 Methodological Considerations

8.5.1 Optimising social impact monitoring for hydropower information

The Social Impact Monitoring and Vulnerability Assessment (SIMVA) is the MRCS's tool for obtaining longitudinal information on the social conditions of the LMB, especially along the mainstream, where use and dependence on river aquatic resources is most visible. The social impact monitoring has the objective of describing how changes in the availability of aquatic resources affect social vulnerability over time.

The Environment Programme under MRCS has carried out SIMVA since 2004 and has completed three phases: Phase 1 was an extensive literature review conducted from 2004-2006; Phase 2 was a preliminary or pilot survey to determine the validity of indicators and research tools, from 2008-2009; Phase 3 was a baseline study to generate baseline data on socio-economic, dependence on water resources, resilience, shocks & trends, and climate change associated vulnerabilities conducted from 2011-2012. The 2011 survey covered 135 villages and 2,720 households within 15 km on each side of the Lower Mekong River, increasing to 40 km at the floodplains. The 2014 SIMVA increased the sample size to ~5,000 households, and reduced included area around flooded areas to 15 km.

Supplementing the existing quantitative methodology with a more participatory long-term monitoring system in priority hydropower locations would enable the SIMVA programme to better support hydropower information needs. Such monitoring should focus on socio-economic trends in selected communities along the mainstream. Information on the deeper causes that lead to changes in the socio-economic conditions would be obtained and provide a context for assessing the impacts of hydropower.

Establishing a long-term partnership with villages located near priority monitoring locations would make it possible to correlate the water quality, fisheries, sediments, biological and hydrological data with socio-economic long-term trends.

8.5.2 Organising socio-economic information

A number of approaches and conceptual frameworks have been developed for structuring economic and social monitoring and data analysis. Some widely applied frameworks include:

- the Pressure, Condition, Response model recommended by OECD (see OECD, 2007), which is a simpler version of the 'Poverty and Social Impact Assessment (PSIA) framework and tools (World Bank, 2003); and
- the Drivers, Pressures, States, Impacts, Responses (DPSIR) approach to defining environmental and socio-economic indicators (OECD, 2008).

A very relevant framework that has been developed specifically relating to hydropower is provided through the Hydropower Sustainability Assessment Protocol (the "Protocol"; IHA, 2010).

The Protocol presents a comprehensive set of sustainability topics and criteria agreed through international processes to be important to hydropower. Of the three frameworks above, it is the only one specific to hydropower projects and socio-economic issues. It consists of sustainability assessment tools appropriate to each of the four key life cycle stages of hydropower projects: Early Stage, Preparation, Implementation, and Operation. The Protocol applies an integrative perspective with a broad categorisation into environmental, social, technical and economic/financial perspectives, while recognising that individual topics are not always neatly labelled as a particular perspective. Some topics are integrative in nature, such as governance for example. In the social and economic dimensions, household economics and livelihoods are integrative in the sense they extend into both dimensions (i.e. socio-economics), and into the environment dimension as well.

Two topics, namely Project Benefits and Project-Affected Communities & Livelihoods, are considered particularly pertinent to socio-economic considerations. The parameters included in those two topics are included in the proposed parameters for ISH11 baseline monitoring. For ease of reference they are presented in **Error! Reference source not found.**9.

Table 9 – Hydropower Sustainability Protocol Guidance Notes, Examples of Socio-economic Parameters

Guidance notes from topic: **Project benefits**	Guidance notes from topic: **Project-Affected Communities & Livelihoods***	**Relevant socio-economic parameters (mainly at household level)**
Training, capacity building and local employment Support for other water usages such as irrigation, navigation, flood/drought control, aquaculture, leisure Non-monetary entitlements to enhance resource access – project affected communities receive enhanced local access to natural resources	Lowering of living standards, loss of income sources or means of livelihoods as a result of (i) acquisition of land, (ii) changes in land use or access to land, (iii) restriction on land use or access to natural resources including water resources, legally designated parks, protected areas or restricted access areas such as reservoir catchments. Loss or constraints on livelihoods: loss of paddy lands, of home gardens, of riverbank gardens; loss of ownership, access to or use of sacred sites, community forest, or other natural resources, etc. impacts on cultural practices;	Employment/occupation Consumption, Income, Savings, Health, Education, training Nutrition (food security), Housing. HH landownership HH access and use rights to commons: Land, incl. river banks, Aquatic resources incl. wetlands, and reservoirs etc.
Infrastructure such as bridges, access roads, boat ramps	Loss of assets or loss of access to assets	Access to transport Time to reach nearest market town/hospital/health station
Improved services such as for health and education	Changes in environment leading to health concerns or impacts on livelihoods.	Access to health services, educational services
Increased water availability for industrial and municipal water supply		Access to clean water and sanitation
Benefits through integrated water resource management		Access to and use of irrigation
Equitable access to electricity services – project affected communities are among the first to be able to access the benefits of electricity services.		Access to and price of electricity
Revenue sharing – project affected communities share the direct monetary benefits of hydropower according to a formula and approach defined in regulations		HH and Community level: Direct cash transfers

*Resettlement and Indigenous Peoples are sub-sets of this topic, and so both physical and economic displacement considerations are included

8.5.3 Socio-economic data management system

With the planning and construction horizons of large hydropower infrastructures in the Mekong, the system for socio-economic monitoring with data collection, management, and dissemination, must be able to function over many years. It must be able to produce data that are comparable over time and between countries even in the face of inevitable institutional changes in the countries, changes in MRC itself, and changes in the level of funding for this purpose. Thus a key consideration for the monitoring system is how it is to be sustained over time. This is a challenging task that requires building a strong institutional base and institutional linkages for the system, and ensuring resources for its management, operation and maintenance.

With regard to macroeconomic and other national statistical data these are routinely collected by the national agencies in each of the LMB countries. These are collected for many different purposes of which MRC information needs is just one. MRC activities must therefore adapt to the procedures, timelines and regulations that govern these activities in each countries. Regional and global efforts and standardisation and harmonisation are likewise driven by concerns other than those of the MRC, but can result in the provision of information useful to the MRC needs for hydropower relevant information. National level statistics available from international institutions to which the LMB Member Countries belong, such as the Asian Development Bank, the United Nations Development Programme, the World Bank, and the International Monetary Fund are useful as they are subject to the standardisation and harmonisation procedures of these international entities.

The system for monitoring hydropower relevant socio-economic data needs to consider the following points (based on Kusek 2004).

Ownership: Stakeholder ownership at every level is critical; if there is no ownership at some levels stakeholders will not be willing to invest time and resources in the system and it will degenerate. Ownership is most effectively achieved through primarily financial, subsidiary in-kind, or human resource contributions of the involved parties. As this is planned to occur some years into the future, the ongoing work on establishing the MRC socio-economic database focuses on building ownership through engaging NMCs and national statistical agencies directly, and using the opportunity for further international collaboration between the statistical agencies as an incentive for participating. At the establishment phase MRC is seen as the owner of the socio-economic database, and this may continue for some time. Within MRC there is a need for identifying the longer-term ‘primary custodian’ of the socio-economic database and allocate the necessary resources. The Scoping Report for the Establishment of the Socio-economic Database (MRC December 2013) outlines options for institutional anchoring in MRC and for oversight arrangements.

Management: It must be clear who, how and where the system will be managed. It is essential to agree on a data management system that will ensure data quality, data comparability, and routine updating. Further data users must know which data are available. The socio-economic data management system is set in the context of decentralization of MRC core functions. It is proposed to apply a DevInfo software platform, which can be managed centrally in MRC while having national implementations that can be linked to existing databases in the countries. Whether NMCs will establish socio-economic database teams operating national databases, or a leaner, more centralized setup will be used is planned to be worked out in 2014. Further, it is proposed to establish a Socio-economic Expert Technical Working Group in MRC comprising national statistical experts and socio-economists from the MRC programmes, as well as socio-economists from the NMCs. This working group would oversee the management, operation, maintenance and updating of the socio-economic database.

Maintenance: The monitoring system will require periodical rebuilding, renewal and strengthening. As in the case of data management, maintenance of the monitoring data system requires incentives and sufficient financial, human and technical resources for the involved organizations: NMCs, national statistical agencies and MRC. Individual and organizational responsibilities must be clear for all involved. New advances in data management and technology should also be taken into account.

Credibility: Especially in the transboundary context of the LMB, credibility of data is essential for the monitoring system to fulfil its purpose. If people think the data and information is motivated or tainted by political or special interests they will not trust and use it. The socio-economic database will contain only official statistics from the member countries. Credibility is thereby vested in the national government agencies. For SIMVA data, credibility is sought through the extensive consultation process with NMCs and national stakeholders.

9 Closing Considerations

This report has outlined many considerations related to the collection of reliable basin-scale data to inform hydropower related management questions. Long-term data is necessary to understand conditions and trends, and to evaluate whether observed changes require a management response. Monitoring multiple disciplines at the same sites provides inter-disciplinary linkages and enhances data interpretation, thus considerably increasing returns for monitoring effort in terms of supporting communication and decision-making needs. Monitoring locations need to be carefully sited to ensure that the collected information can answer questions related to hydropower and transboundary issues. Tributary data, at least from near the confluence of the tributaries with the mainstream Mekong (but sufficiently upstream to avoid Mekong backwater influences) is necessary to interpret data for the mainstream Mekong.

There would be some transition required to meet all of the considerations identified in this report in the LMB, and resource allocations and decision-making must take into account broader considerations than those outlined here. The decentralisation process provides some concerns about extending existing activities beyond those already undertaken by the Member Countries and the MRCS programmes.

There is some potential to re-orient or build on existing monitoring programmes, which were not designed with hydropower information needs as an objective, to enable the data to better align with hydropower information needs. Much of the necessary data is already collected from consistently monitored locations, but different disciplines are not well-aligned to the same locations, which limits the value to hydropower needs.

Beyond re-orienting or evolving existing monitoring programmes, there is a need for some dedicated studies to help with the long-term programme design and value. In some cases it is not possible to define indicators of change without some more detailed study and data collection to improve basic information and to understand important processes. There is no point in having indicators if it is not clear what they are indicating because of gaps in understanding of the underlying processes. Therefore, selected parameters and indicators must help increase understanding of the processes at play in the basin. Research to fill knowledge gaps is required to be sure that any selected or developed indicators are meaningful and useful in the basin context. Numerous previous studies have identified the need for additional information or dedicated studies to support an understanding of river condition and its influencing factors and response pathways. Consistent long-term monitoring assists this understanding and also provides valuable input to the above mentioned research studies but on its own will not answer all questions.

There are a number of practical challenges that are encountered in the course of developing a centralised monitoring program, including:

- resource availability;
- political sensitivities, and differing national interests and views;
- insecure financial support of monitoring programmes;
- continuation of monitoring programmes in line with the decentralisation process;
- lack of existing tributary information, and ability to put monitoring locations in tributaries, which inhibits the ability to understand mainstream conditions;
- difficulties with monitoring site access;
- differences in (application of) field and laboratory methods between the Member Countries;
- differing paces and capacities amongst different countries in programme development and implementation;

- cultural challenges including different languages, different national holidays, variable nomenclature for site names, and different calendars;
- developing communication tools appropriate for range of stakeholders; and
- ensuring Member Countries have ownership of the long-term monitoring programme.

These considerations on transboundary monitoring for hydropower information in the LMB are designed for long-term applicability. Improvements will be embedded both incrementally and in step changes as opportunities arise.

In closing, good information leads to good decisions and to stakeholder trust in those decisions. Also, the value from the investment in information collection is maximised if the whole value chain is taken into consideration.

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