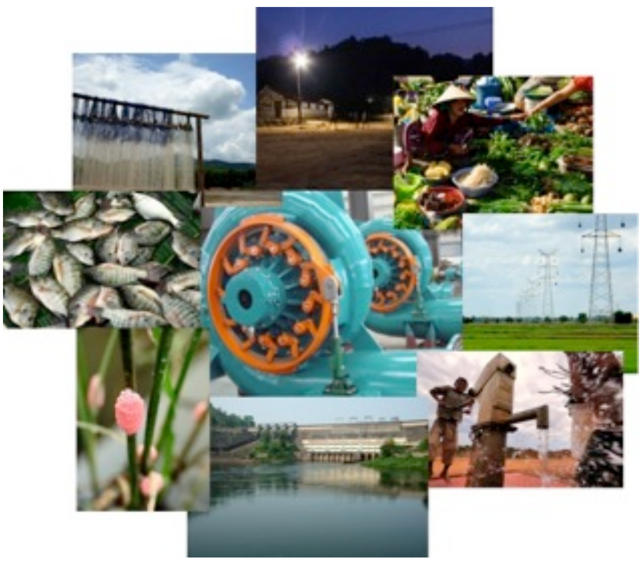
MEKONG RIVER COMMISSION SECRETARIAT

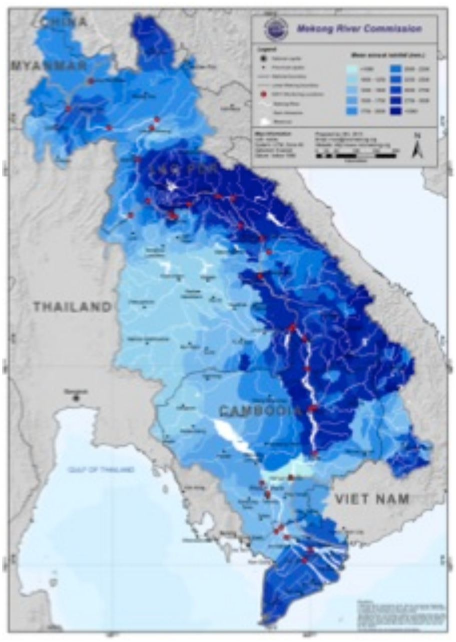
Office of the Secretariat in Vientiane	Office of the Secretariat in Phnom Penh
184 Fa Ngoum Road, Ban Sithane Neua,	576 National Road, no. 2, Chok Angre Krom,
P.O. Box 6101, Vientiane, Lao PDR	P.O. Box 623, Phnom Penh, Cambodia
Tel: (856-21) 263 263 Fax: (856-21) 263 264	Tel: (855-23) 425 353 Fax: (855-23) 425 363
mrcs@mrcmekong.org	*www.mrcmekong.org*

MRC Initiative on Sustainable Hydropower (ISH)

IMPROVED ENVIRONMENTAL AND SOCIO-ECONOMIC BASELINE IN-FORMATION FOR HYDROPOWER PLANNING

ISH11 PHASE 2 REPORT: Hydrology Annex





20 December 2013

MRC Initiative on Sustainable Hydropower (ISH)

Produced by	MRC Initiative for Sustainable Hydropower
Produced for	MRC Member Countries
ISH11 Project Team	Dr Helen Locher, Team Leader, Sustainable Hydropower Specialist Dr Jens Sjorslev, Social Specialist Dr Bruce Aylward, Economics Specialist Mr Kent Hortle, Fisheries Specialist Dr Ilse Stubauer, Aquatic Ecologist Dr Lois Koehnken, Sediment, Water Quality & Hydrology Specialist Mr Frank Lieber, Database Specialist Dr Mak Solieng, Cambodia National Consultant Dr Latdaphone Banchongphanith, Lao PDR National Consultant Dr Apichart Termvidchakorn, Thailand National Consultant Dr Nguyen van Tuan, Viet Nam National Consultant
MRCS ISH Staff	Voradeth Phonekeo, ISH Programme Coordinator Simon Krohn, ISH Chief Technical Officer Piseth Chea Inthaneth Norasingh Athanaphone Chanchouly Vansath Sisadeth, Junior Riparian Professional Socheat Penh, Junior Riparian Professional Hung Dang Van Viet, Junior Riparian Professional Janka Rokob

ISH11 Document History

Date	Authors	Status	Comment
31 Mar 2013	Lois Koehnken	ISH11 Phase 1 Report Hydrology Annex	An Annex to the ISH11 Phase 1 Report 31 Mar 2013
20 Dec 2013	Lois Koehnken	ISH11 Phase 2 Report Hydrology Annex	Information updated based on inputs and further research. Includes a status and gap analysis against the Guiding Framework. Includes more specific recommendations for improvement proposals based on further research and consultations. Annotated Bibliography and Response to Comments Received for Sediments, Water Quality and Hydrology attached to the Phase 2 Water Quality Annex.

Abbreviations and Acronyms

ADCP	Acoustic Doppler Current Profiler
AHNIP	Appropriate Hydrological Network Improvement Project
ANZECC	Australian and New Zealand Environment and Conservation Council
BDP	Basin Development Plan (of the MRC)
BOD	Biological Oxygen Demand
DSMP	Discharge and Sediment Monitoring Programme
DSS	Decision Support System
DPSIR	Drivers, Pressures, State, Impacts, Responses
EDI	Equal Discharge Increment
EP	Environment Programme (of the MRC)
EWI	Equal Width Increment
EU	European Union
FP	Fisheries Programme (of the MRC)
GIS	Geographic Information System
HYCOS	Hydrologic Cycle Observing Station
IBFM	Integrated Basin Flow Management
IKMP	Information and Knowledge Management Programme (of the MRC)
ISH	Initiative on Sustainable Hydropower (of the MRC)
ISO	International Standards Organisation
IWRM	Integrated Water Resource Management
LMB	Lower Mekong Basin
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
Mt/yr	Million tonnes per year
NMC	National Mekong Committee
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PDR	People's Democratic Republic
PFMF	Procedure for Maintenance of Flows on the Mainstream
PWUM	Procedures for Water Use Monitoring
QA/QC	Quality Assurance / Quality Control
SoB	State of the Basin
SWAT	Soil and Water Assessment Tool
ToR	Terms of Reference
TSS	Total Suspended Solids
UMB	Upper Mekong Basin
USGS	United State Geological Survey
WMO	World Meteorological Organisation
WQMN	Water Quality Monitoring Network

Table of Contents

List of Figures

List of Tables

1 Context of Hydrology within the ISH11 Baseline Monitoring Program

The hydrology of the Mekong River is inextricably linked to the social and economic well being of the people resident in the basin, and to the ecological health and functioning of the river and its floodplains. To achieve the ISH11 project goal of understanding the current state of the environmental and socio-economic conditions in the Mekong mainstream and its tributaries the hydrology of the river needs to be understood at a detailed level, to enable appropriate siting, planning and management of hydropower assets, as well as how the hydrology is linked to the ecological, economic and social functioning of the catchment.

The importance of hydrologic data was highlighted during the ISH11 1st Regional Consultative meeting where all components of the hydrologic cycle (precipitation, evaporation, river flow, groundwater) were identified by one or more Member Countries as high priority data needs.

Hydrology as a discipline was not included in the original ISH11 ToR, but its importance to all areas identified within the ToR has led to the ISH11 team to consider it as a distinct discipline to ensure hydrologic data needs within the context of sustainable hydropower development are considered, and that the hydrologic data requirements of the other disciplines are reflected in the ISH11 considerations.

2 Best-Practice Hydrology Monitoring

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, which includes the following components:

- A set of established standards for data collection such that results are reliable, reproducible and which allow results obtained by different groups or agencies to be integrated or compared;
- A data management system incorporating QA/QC measures such that reliable results can be provided to data users within an appropriate time-frame;

- A long-term reliable storage and retrieval system such that the information can be maintained for ongoing or future use; and
- A validation system which ensures the data being produced and distributed is serving the needs of the end users.

In the context of the LMB, this Quality Management System needs to ensure that accurate results are available at 'real time' for flood forecasting, water use and navigation needs. The system also needs to have systems that allow the storage and retrieval of long-term results including relevant meta-data.

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. Under network design, the following needs to be considered:

- Sampling sites, parameters and monitoring frequencies that reflect changes in the phenomena of interest;
- The spatial and temporal variability of the parameters of interest; and
- Site selection taking into account access requirements for monitoring, sampling and long-term servicing.

For hydropower information needs, monitoring / sampling sites need to include locations relevant to reservoir inflows, power station outflows and locations where minimum or environmental flows or water levels are required. Continuous recording of river level and rainfall parameters are required for accurate modelling and monitoring of extreme events. Site-specific requirements associated with hydropower information needs are discussed in Section 4.2.

Equipment/Technology: Appropriate monitoring, logging and communications equipment needs to be identified which will collect the required data. 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.

In the LMB, a sound understanding of hydrology is dependent on each Member Country monitoring the same parameters, using the same or compatible methods and techniques. Of critical importance is the on-going maintenance of the network to ensure continuity of information delivery.

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 to provide data consistency and reliability. Training areas include:

- Installation of monitoring equipment, including river level recorders, rain gauges, pan evaporators;
- Field monitoring techniques, including river velocity and discharge measurements and river surveys; and
- IT components, including transmission of records from loggers to data base, QA/QC, derivation and updating of rating curves.

For the provision of long-term information to support hydropower needs, it is important that training is on-going and that a clear successional strategy is in place, such that knowledge and skills does not become concentrated in the senior personnel within Line Agencies.

Data Management: The provision of accurate and consistent results is the aim of all monitoring, and data management requires the application of QA/QC procedures, the recording and storage of meta data associated with each data set. Other components of data management may include:

- Maintenance of a reliable centralised data base; and
- Tools to enable the interrogation, analysis and visualisation of data.

Data management is an ever evolving field. As data sets extend in length, they become more valuable with respect to hydropower planning and management, as extreme events, and long-term climate change can be identified and interpreted in an appropriate context. There is a risk that as technology changes, historic results and/or associated metadata can be lost. This risk is increased in a basin management organisation such as the MRC where there is a high turnover of personnel, and information can be easily lost if not appropriately documented and stored in a central repository.

This issue becomes even more important as 'new' monitoring techniques are developed and implemented, which generate large amounts of data that requiring processing, checking, distribution and management.

Summary: The adoption of a management system approach to hydrologic monitoring will result in a long-term resource that contains sufficient background information, along with the data results, to be usable and defensible into the future. This is important as monitoring programmes frequently wax and wane due to economic, social and political changes. 'Historic' data can be extremely useful as a baseline or 'snapshot' of previous conditions, but many historical data sets are of limited value because basic information such as what methods were used to collect the results, are frequently lacking. Implementing consistent and robust data management systems is as essential as obtaining accurate measurements in the field.

3 Hydrologic Monitoring in the LMB and State of Knowledge

3.1 Overview of Hydrologic Monitoring in the LMB

Hydrologic monitoring has a long-history in the Mekong River Basin, with rainfall and river level records held by the MRC extending back to the early 1900s at some sites.

Collaborative, basin wide hydrologic monitoring using a systems approach was initiated in 2000 through the MRC's Appropriate Hydrological Network Improvement Project (AHNIP), which had the aims of improving the technical capacity of agencies in the Mekong River basin through the successful establishment, operation, maintenance and management of an automatic, real-time hydrometeorological network. This network consisted of 17 river level monitoring sites.

In 2001, the MRC embarked on an ambitious joint project with the World Meteorological Organisation (WMO) to enhance and expand hydro-meteorological data collection and transmission at the basin level in the LMB through the implementation of the Mekong HYCOS (Hydrologic Cycle Observing System). The main objective of the Mekong HYCOS project was to establish an efficient, reliable and accurate hydrometeorological data collection and transmission system at a basin level (MRC, 2012).

The Mekong – HYCOS project upgraded the 17 original AHNIP sites and established 32 new sites (Table 1, Figure 2) at which river level, precipitation and air temperature are continuously recorded and telemetered to the IKMP. The HYCOS monitoring sites include 16 Mekong mainstream river sites (including delta sites), 4 Bassac River sites and 2 Tonle Sap sites, with the remaining 27 sites located in tributaries throughout the basin.

The state of the art Mekong–HYCOS system was completed in 2012, and each country is responsible for the operation and maintenance of its part of the system with the support and coordination of the MRC (MRC, 2012). The IKMP-MRC is responsible for QA / QC procedures and data storage, and making the results available. Full details of the technical, financial and data management aspects of the network are contained in MRC (2012), which should be referred for additional information.

3.1.1 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 1). 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. The development of a 'user friendly' hydrologic database with data analysis capabilities is under investigation by the IKMP.

3.1.1.1 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.

3.1.2 Rainfall

Rainfall is measured at 44 of the Mekong-HYCOS sites (Table 1) using tipping bucket rain gauges (Figure 1). The information is logged and telemetered along with the river level data.

3.1.3 Groundwater

Groundwater information is of interest to the MRC, and the IKMP has recently installed a groundwater bore on the bank of the Bassac River at the MRC office in Phnom Penh as a trial. No data is yet available from the site.

3.1.4 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 the process of procuring and implementing 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).

Hydrological results from HYCOS and previous monitoring have been used by the MRC and other agencies for a wide range of applications, including the identification of rainfall patterns, analysis of seasonal flow changes in the Mekong, flood forecasting, irrigation development and hydropower development. It is beyond the scope of this paper to review all facets of the hydrologic cycle in the Mekong Basin, but the following sections provide a brief overview of rainfall and rainfall patterns, and river flow in the catchment. An annotated bibliography (attached to the ISH11 Phase 2 Water Quality Annex) provides additional literature sources related to hydrologic information.

Figure 1 – 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)

Table 1 – Summary of Mekong HYCOS monitoring sites

N°	Code	Station Name		River	River bank	Coordinates (WGS84)		Country	Parameter
		Full	Short		Left/ Right	Latitude	Longitude		
1	**092600**	Jinghong	JH	Mekong	L	22,01597	100,80222	China	WL/R/T/BV
2	**092980**	Man An	MA	Man An	R	21,91058	101,26401	China	WL/R/T/BV
3	**350101**	Ban Kengdone	BKD	Se Bang Hieng	L	16,18727	105,31287	Lao PDR	WL/R/T/BV
4	**120101**	Ban Mixai	BMI	Nam Khan	L	19,78606	102,18314	Lao PDR	WL/R/T/BV
5	**270502**	Ban Nape	BNA	Nam Phao	L	18,30457	105,07359	Lao PDR	WL/R/T/BV
6	**430106**	Ban Veunkhen	VKH	Se Kong	R	14,81920	106.80.566	Lao PDR	WL/R/T/BV
7	**011201**	Luang Prabang	LP	Mekong	R	19,89280	102,13418	Lao PDR	WL/T/BV
8	**320107**	Mahaxai	MHX	Se Bang Fai	R	17,41790	105,19847	Lao PDR	WL/R/T/BV
9	**100102**	Muong Ngoy	MNG	Nam Ou	R	20,57210	102,61702	Lao PDR	WL/R/T/BV
10	**013901**	Pakse	PS	Mekong	R	15,09976	105,81319	Lao PDR	WL/R/T/BV
11	**230113**	Phieng Luang	PLU	Nam Ngum	L	19,56826	103,07130	Lao PDR	WL/R/T/BV
12	**320101**	Se Bang Fai	SBF	Se Bang Fai	R	17,07652	104,98537	Lao PDR	WL/R/T/BV
13	**350105**	Sopnam	SNA	Se Bang Hieng	L	16,68719	106,21497	Lao PDR	WL/R/T/BV
14	**011901**	Vientiane KM4	VTI	Mekong	R	17,93098	102,61556	Lao PDR	WL/R/T/BV
15	**290113**	Ban Had Paeng	BHP	Nam Sonkhram	R	17,67546	104,28622	Thailand	WL/R/T/BV
16	**050115**	Ban Mai Bua Daeng	BMD	Nam Kok	R	20,02347	99,95924	Thailand	WL/R/T/BV
17	**290102**	Ban Tha Kok Doeng	TKD	Nam Sonkhram	L	17,86564	103,77433	Thailand	WL/R/T/BV
18	**011903**	Chiang Khan	CK	Mekong	L	17,90026	101,66989	Thailand	WL/R/T/BV
19	**010501**	Chiang Saen	CS	Mekong	R	20,27412	100,08855	Thailand	WL/R/T/BV
20	**013801**	Khong Chiam	KC	Mekong	R	15,32209	105,49348	Thailand	WL/R/T/BV
21	**013402**	Mukdahan	MH	Mekong	L	16,58280	104,73318	Thailand	WL/R/T/BV
22	**013101**	Nakhon Phanom	NP	Mekong	R	17,42537	104,77393	Thailand	WL/R/T/BV
23	**012001**	Nong Khai	NK	Mekong	L	17,88144	102,73220	Thailand	WL/R/T/BV
24	**070103**	Thoeng	THO	Nam Mae Ing	R	19,68843	100,18723	Thailand	WL/R/T/BV
25	**150101**	Wang Saphung	WSP	Nam Loei	L	17,29986	101,77597	Thailand	WL/R/T/BV
26	**550102**	Battambang	BTA	Sangker	R	13,09200	103,20028	Cambodia	WL/R/TV
27	**033401**	Chaktomuk	BCH	Bassac	R	11,56299	104,93529	Cambodia	WL/T/V
28	**020106**	Kompong Luong	KL	Tonle Sap	L	12,57662	104,20779	Cambodia	WL/R/T/BV
29	**640102**	Kompong Speu	KSP	Prek Thnot	L	11,45625	104,49606	Cambodia	WL/R/T/BV
30	**610101**	Kompong Thom	KTH	Sen	R	12,71483	104,88792	Cambodia	WL/R/T/BV
31	**014901**	Kratie	KT	Mekong	R	12,48141	106,01762	Cambodia	WL/R/T/BV

N°	Code	Station Name		River	River bank	Coordinates (WGS84)		Country	Parameter
		Full	Short		Left/ Right	Latitude	Longitude		
32	**450101**	Lumphat	LPH	Srepok	L	13,50088	106,97115	Cambodia	WL/R/T/BV
33	**020102**	Prek Kdam	PK	Tonle Sap	Both	11,81117	104,80678	Cambodia	WL/R/T/BV
34	**430102**	Siempang	SPA	Sekong	R	14,11514	106,38795	Cambodia	WL/R/T/BV
35	**530101**	Sisophon	SSP	Sisophon	L	13,58665	102,97661	Cambodia	WL/R/T/BV
36	**014501**	Stung Streng	ST	Mekong	L	13,53250	105,95019	Cambodia	WL/R/T/BV
37	**440102**	Voeun Sai	VSA	Sesan	L	13,96858	106,88483	Cambodia	WL/R/T/BV
38	**451305**	Ban Don	BDO	Srepok	L	12,89791	107,78313	Vietnam	WL/R/T/BV
39	**039803**	Can Tho	CTH	Bassac	L	10,02680	105,76857	Vietnam	WL/R/T/BV
40	**985204**	Cau tieu	CTI	Mekong	Sea	10,27972	106,78222	Vietnam	WL/T/BV
41	**039801**	Chau Doc	CD	Bassac	R	10,70528	105,13351	Vietnam	WL/R/T/BV
42	**985401**	Dinh An	DAN	Bassac	Sea	9,53083	106,36778	Vietnam	WL/T/BV
43	**450701**	Duc Xuyen	DXU	Krong Kno	R	12,29677	107,97590	Vietnam	WL/R/T/BV
44	**450502**	Giang Son	GSO	Krong Ana	R	12,51017	108,18324	Vietnam	WL/R/T/BV
45	**440201**	Kontum	KTU	Dak Bla	R	14,34708	106,73714	Vietnam	WL/R/T/BV
46	**019804**	My Thuan	MTH	Mekong	L	10,27532	105,92632	Vietnam	WL/R/T/BV
47	**019803**	Tan Chau	TC	Mekong	R	10,80062	105,24802	Vietnam	WL/R/T/BV
48	**985203**	Vam Kenh	VKE	Mekong	R	10,27430	106,73714	Vietnam	WL/R/T/BV
49	**980601**	Vam Nao	VN	Vam Nao	R	10,57865	105,36337	Vietnam	WL/R/T/BV

Figure 2 – HYCOS monitoring stations in the Lower Mekong Basin

3.2 Present Understanding of Hydrologic Processes in the LMB

3.2.1 Rainfall and Evaporation

Rainfall in the Mekong basin is driven by the topography of the basin interacting with Southwest Monsoons and tropical cyclones from the northeast across the South China Sea (MRC, 2005; MRC, 2011). There is a general east to west decrease in rainfall, with the western Korat Plateau receiving the lowest rainfall totals in the catchment. Mean annual rainfall (Figure 3) is greatest in the mountains of northern Laos, and in the headwaters of the Sekong and Se San Rivers (MRC, 2011). Rainfall is highest in July, August and September in most of the basin, however in the lower basin September and October are the wettest months. Runoff or yield patterns in the LMB reflect rainfall patterns, with highest yields associated with the steep, elevated regions or central basin (Figure 4).

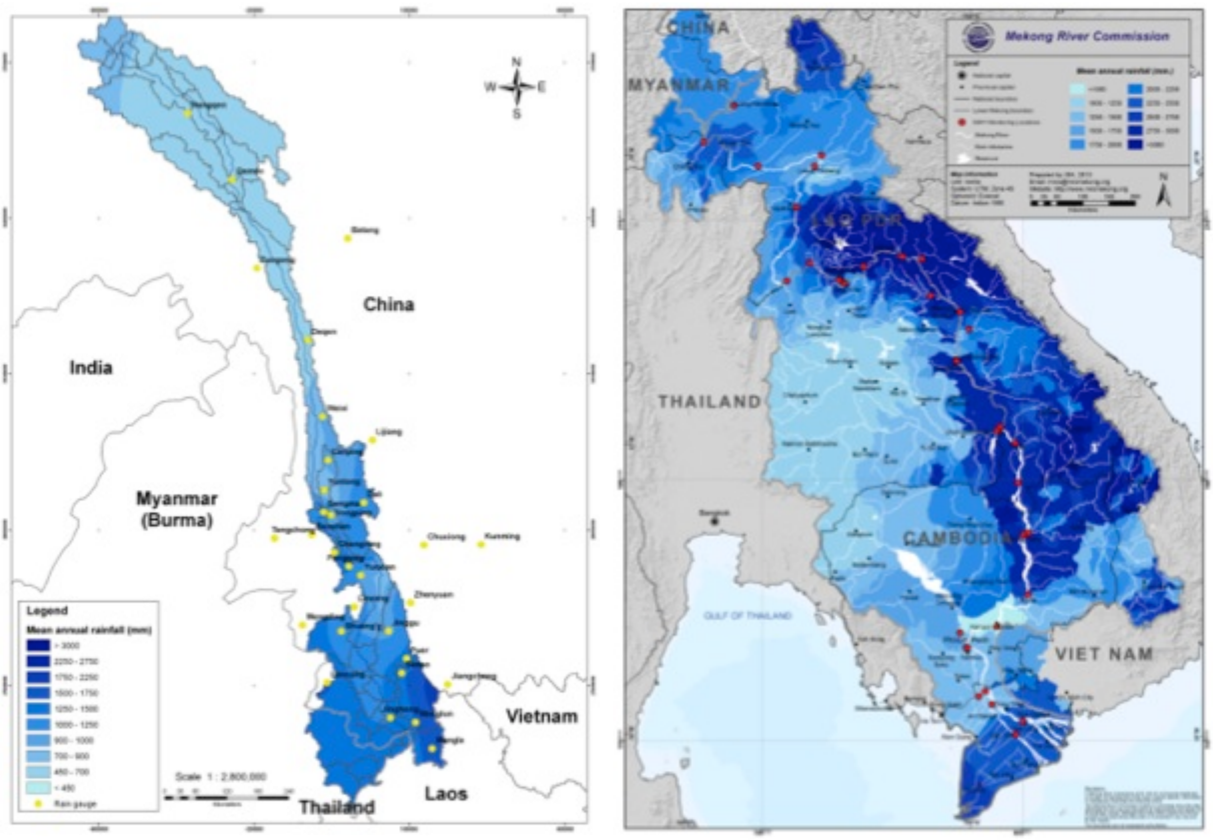


Figure 3 – Left: Mean annual rainfall in the Mekong River Basin; Right: Mean annual rainfall in the Lower Mekong River Basin. FIgure from MRC (2012) Symposium on Hydro-Meteorological Networks

Evapotranspiration in the basin ranges between 1 and 2 meters, with the high relative humidity of the region contributing to fairly constant annual values (MRC, 2005). The Mun and Chi catchments on the Korat Plateau are one of the driest areas in Southeast Asia, with a mean annual rainfall of ~1200 mm, and a mean annual rate of evaporation of 1,900 mm (MRC, 2005). Lower rates of evaporation occur in the southern basin, but are generally in excess of 1,000 mm (MRC, 2005).

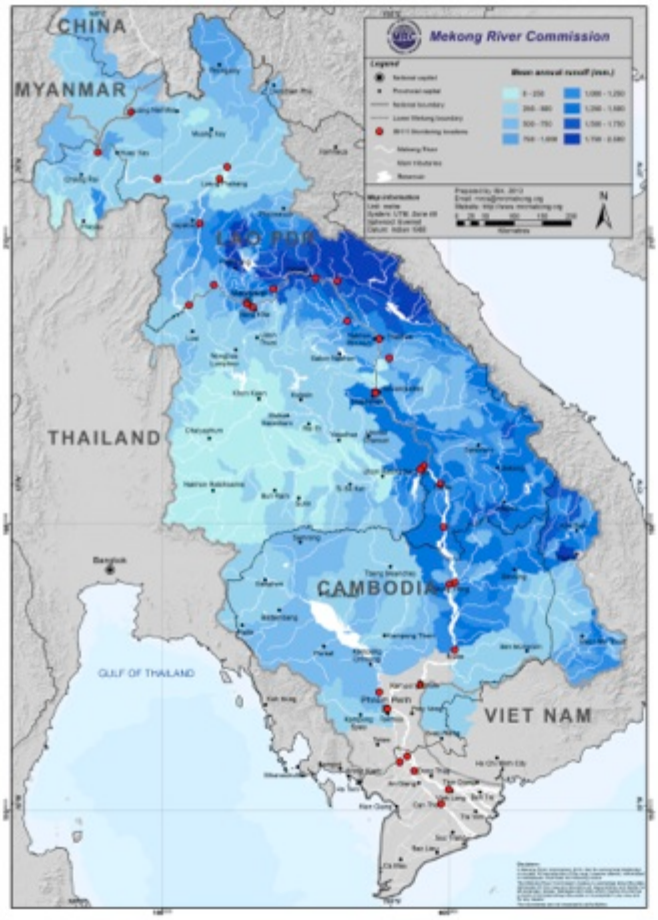


Figure 4 – Annual runoff in the LMB. FIgure from MRC (2012) Symposium on Hydro-Meteorological Networks

3.3 River Flows

River flow in the Mekong is strongly seasonal, reflecting the rainfall patterns. Mean monthly discharge at sites down the length of the mainstream are shown in Figure 5, and an example of annual hydrographs from 2011 is shown in Figure 6. Most flow in the Mekong occurs between June and November. The wet season can have more than one peak at the downstream sites, as occurred in 2011 and is attributable to the occurrence of tropical cyclones over central and southeastern Viet Nam (MRC, 2005). Overall, mean annual discharge of the river is ~475 cubic kilometres (MRC, 2005), with 80% of the flow occurring between June and October (based on monthly mean flows).

Flow contribution by reach is summarised in Table 2, showing that most water enters from left bank tributaries in the reaches between Nong Khai and Nakhon Phanom, where numerous tributaries drain the mountainous region, and between Pakse and Stung Treng, reflecting the entrance of the 3S River systems.

The flow entering the LMB from China contributes ~16% of the total river flow, however over the course of a year relative contribution of this flow varies between 15% in the wet season, to 40% in April at the end of the dry season (based on average monthly flow rates). The dry season flows in the river are attributable to snow melt on the Tibetan Plateau, and is often referred to as the 'Yunnan Component' (MRC, 2005).

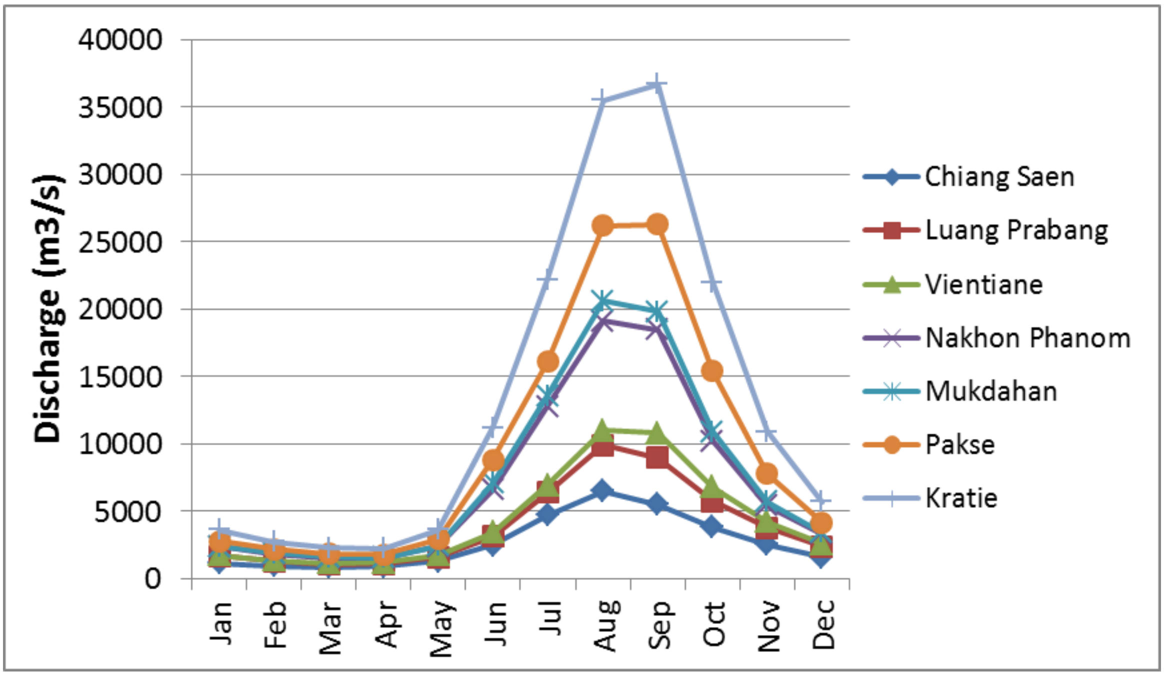


Figure 5 – Mekong Mainstream mean monthly discharge 1960 - 2004 in cumecs. Data from MRC (2005)

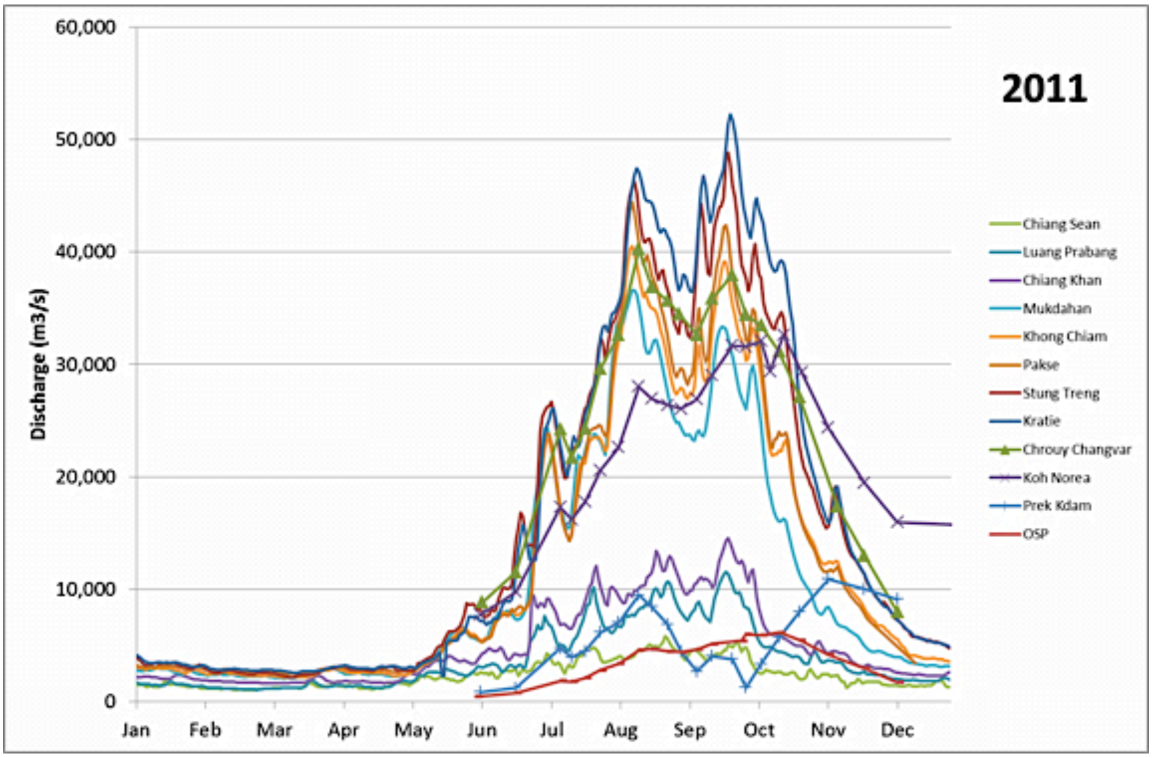


Figure 6 – Discharge in the Mekong River, Bassac and Tonle Sap in 2011 at HYCOS monitoring sites. Data from MRC

Table 2 – Flow contributions for mainstream reaches. From MRC (2005)

River Reach	Left Bank%	Right Bank %	Total %	Cumul Total
China	**16**		16	16
China-Chiang Saen	1	4	5	21
Chiang Saen – Luang Prabang	6	3	9	30
Luang Prabang – Chiang Khan	1	2	3	33
Chiang Khan - Vientiane	0	0	0	33
Vientiane – Nong Khai	0	1	1	34
Nong Khai – Nakhon Phanom	19	4	24	58
Nakhon Phanom – Mukdahan	3	1	4	62
Mukdahan - Pakse	5	6	11	73
Pakse – Stung Treng	23	3	26	99
Stung Treng – Kratie	1	0	1	100
Totals	**60**	**24**	100	100

3.4 Groundwater

There is limited information about ground water held by the MRC, or available in the scientific literature. The four types of aquifers present in the Mekong Basin are shown in Figure 7 and their attributes are summarised in the following dot-points from the MRC (2012).

- A suite of basement of rocks (granites, basalts, and high-grade metamorphic rocks) which do not support a coherent subsurface flow regime, but which support groundwater storage in weathered and fractured zones.
- Late Palaeozoic strata, which, being sedimentary rocks (sandstones and limestones), possess the primary and secondary rock properties of porosity, permeability and connectivity. However, these aquifers were severely deformed during the Indosinian Orogeny, and are mostly fragmented into regions of localised flow which discharge mainly to the Mekong mainstream, but also into important tributaries.
- Mesozoic strata comprised predominantly of massively bedded sandstones. These provide regional aquifers, which, with intrinsic permeability, porosity and regional hydraulic heads will host the main groundwater flow regime in the basin. The Mesozoic aquifer is locally compartmentalised due to faulting, folding, or jointing, which occurred during the Himalayan Orogeny. However, the Mesozoic section also contains thick, and occasionally diapiric, deposits of rock salt (Halite), which contaminate groundwater in areas such as the Khorat Plateau and the Vientiane Basin.
- Holocene alluvial/fluvial deposits in upstream areas of the basin and the alluvial/deltaic/ marine sediments of the Mekong Delta. These are intrinsically porous and permeable aquifers. However, the alluvial aquifers are continually reworked by present day river processes and their lateral continuity will be defined by bed-form geometries. The deltaic sediments, which comprise a complex body of inter-fingering marine and freshwater depositional bodies, are considered to be a major resource, but some local water-quality concerns, such as saline intrusion from, may occur in the marine and brackish deposits.

The transboundary nature of the aquifers was considered by Zaisheng *et al.,* (2010) and the four transboundary aquifers were evaluated using a Drivers, Pressures, State, Impacts, Response (DPSIR) indicator approach. The authors recommended a coordinated and joint management approach to provide the scientific basis to achieve sustainable use of water resource groundwater resources.

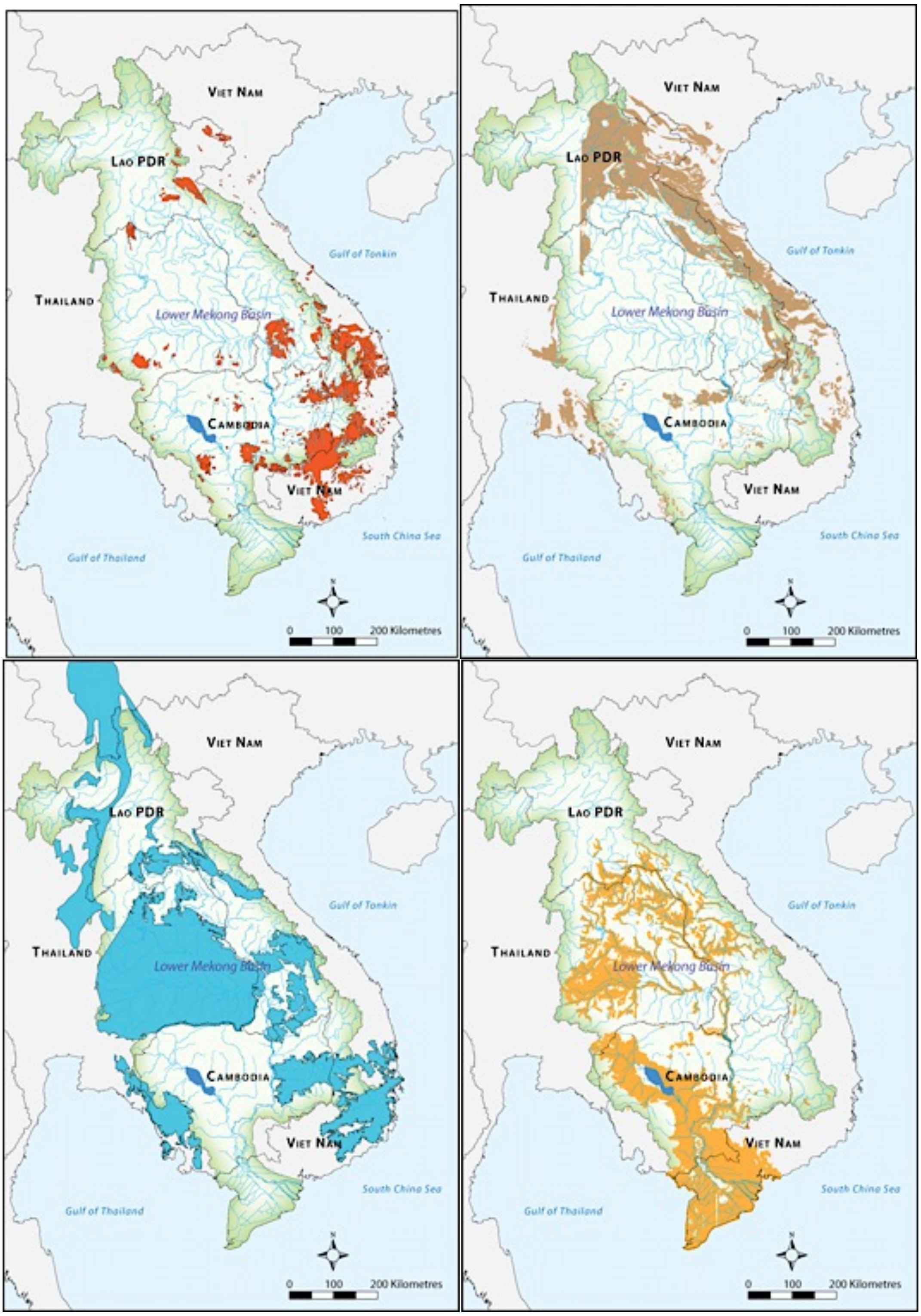


Figure 7 – Types of aquifers in the Lower Mekong Basin: Top left: Basement rocks (granites and high-grade metamorphic rocks), groundwater storage in weathered and fractured zones; Top right: Late Paleozoic strata (sandstones and limestones), fragmented aquifers discharging to the Mekong mainstream and tributaries; Bottom left: Mesozoic strata (sandstones), regional aquifers, hosting the important groundwater flow regime in the Khorat Plateau; Bottom right: Alluvial/fluvial deposits in upstream areas and

alluvial/deltaic/marine sediments of the Mekong Delta, important aquifers. Figures from MRC Symposium on Hydro-Meteorological Networks (2012)

Nguyen *et al.,* (1990) found that fresh groundwater in the Mekong plain as well as in other big river plains in south eastern coastal Asia exist mainly in the Pliocene-Pleistocene deposits which were formed prior to the Holocene marine regression. The authors describe the water resource as 'fossil' and non-renewable, and assert that over-estimation of its dynamic reserve could lead to catastrophic environmental problems.

With respect to groundwater movement, volumes or distribution, most work has focussed on the Lower Mekong and delta areas. A USGS Water Supply Report (1978) summarises the findings of a ground water reconnaissance mission in the Mekong Delta, identifying both shallow perched aquifers and deeper units as important sources of freshwater for agriculture and drinking water supply. The impact of groundwater irrigation in the Lower Mekong was investigated by Roberts (1998), including the modelling of groundwater flow in the wet and dry seasons (Figure 8 – 10), which shows an increase in groundwater levels of several meters during the wet season east of the mainstream Mekong.

Kazama *et al.,* (2007) used modelling techniques to examine how the extent of flooding in the lower Mekong affected the availability of ground water resources. Unpublished ground water level data from the Cambodian Hydrological Department was used to calibrate the model. The results suggested that reductions in flooded areas of 19% and 42% in the region bounded by Kampong Cham, Tan Chau, Chau Doc and Prek Kdam translated into reductions in groundwater availability of 31% and 42%, respectively. The authors conclude that even though flood control activities are important, they also negatively impact groundwater resources.

The IUCN released a discussion paper in 2011 that summarises groundwater conditions and trends over a 30-year period in the Vietnamese portion of the delta. The paper identifies a decline in groundwater levels over the 30-year period, which is attributed to extensive drainage, exploitation and interception of recharge waters (Figure 11). A decline in groundwater quality is also reported, related to urban, industrial and rural pollutants along with the concentration of natural contaminants and salt water intrusion associated with excessive pumping of groundwater reserves.

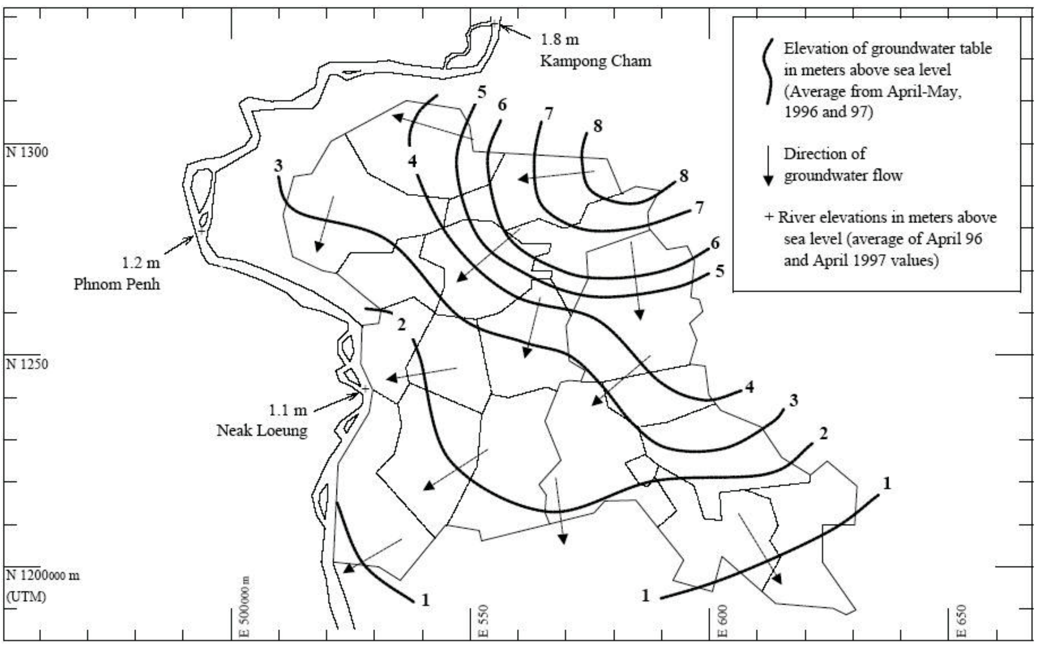


Figure 8 – Modelled groundwater levels and flow in the Lower Mekong during the dry season. From Roberts (1998)

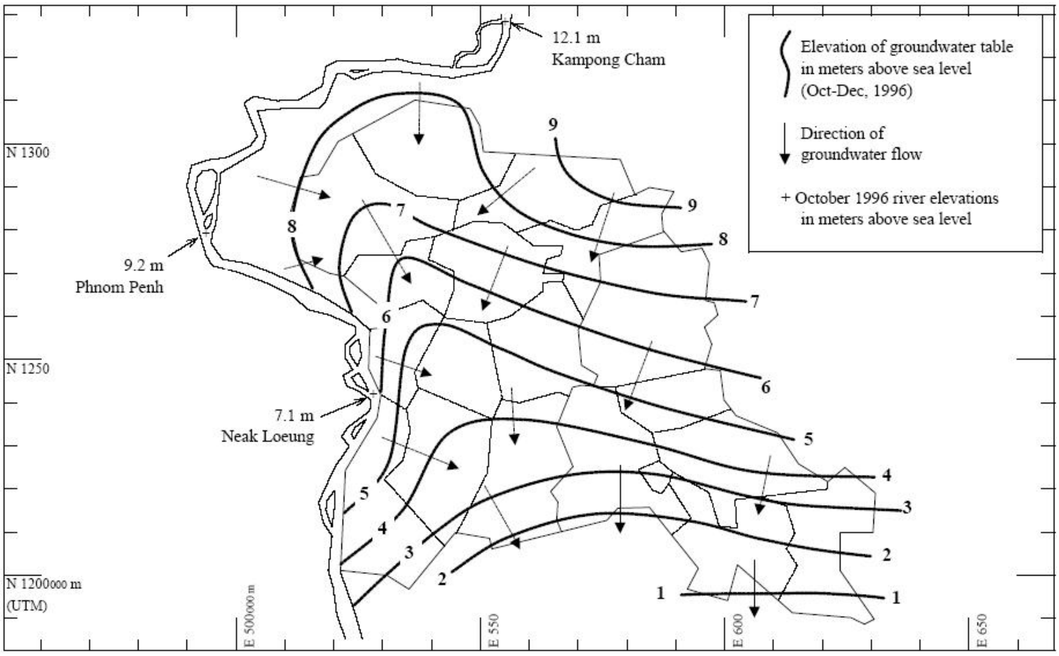


Figure 9 – Modelled groundwater flow in the Lower Mekong during the wet season. From Roberts (1998)

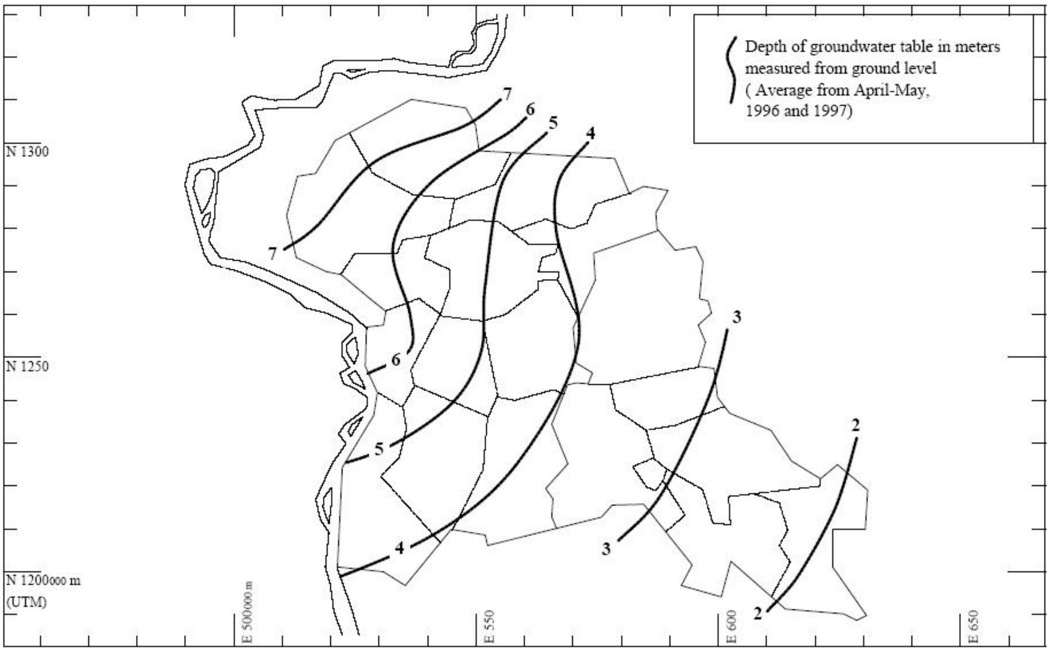


Figure 10 – Depth to water table in the Lower Mekong Basin during the dry season. From Roberts (1998)

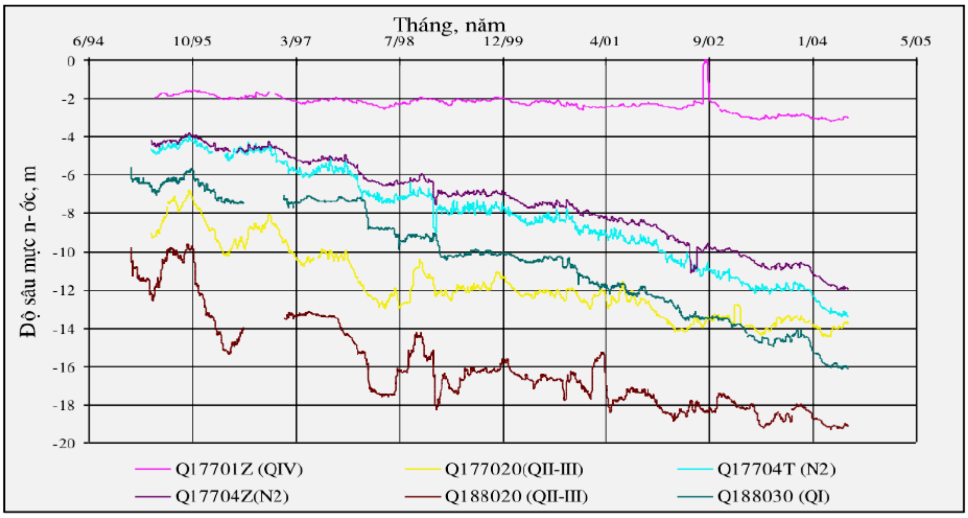


Figure 11 – Groundwater level in bores in the Mekong Delta between June 1994 and May 2005. IUCN (2011)

4 Gap Analysis with Respect to ISH11 Guiding Framework

4.1 Hydrologic Information Needs to Support Hydropower Planning

The aim of the ISH11 project is to make recommendations that can build upon and enhance present monitoring to improve the availability of information needed to develop and manage sustainable hydropower. This requires identifying target parameters and indicators relevant to the siting, design, construction, management and potentially decommissioning of hydropower developments. 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.

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 stages to guide design criteria, generation plans, mitigation measures, and management strategies regarding associated developments, such as water supply or aquaculture.

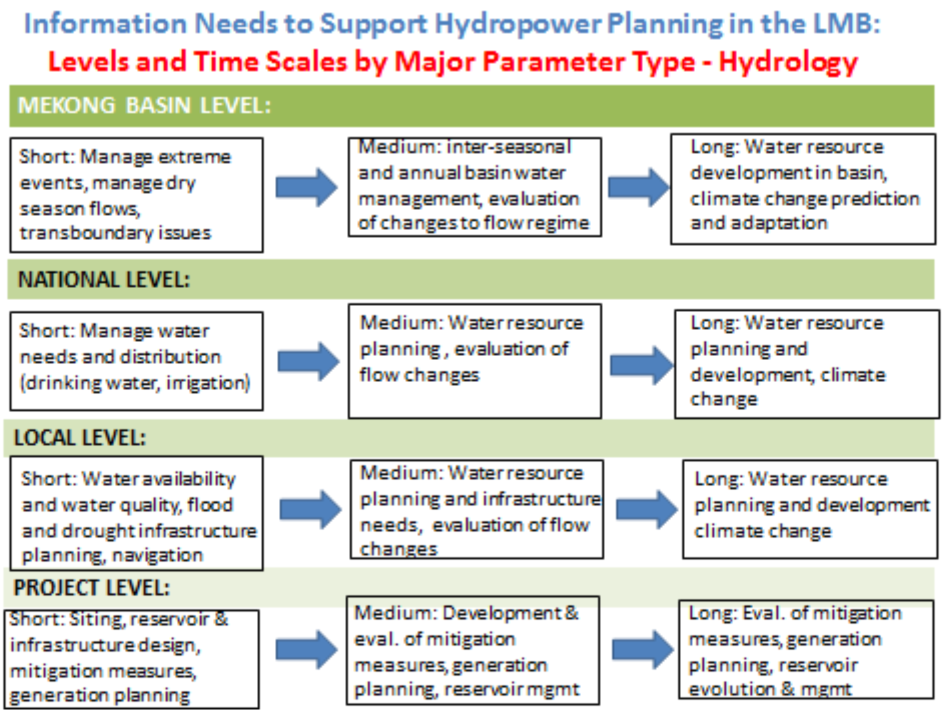


Figure 12 – Spatial and temporal information needs to support hydropower planning in the LMB

These information needs, and the Guiding Framework for hydropower information needs developed in the ISH11 Phase 2 Main Report are compared with the information being generated by the present monitoring programmes to identify gaps for hydropower planning.

4.2 Gap Analysis – 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 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.

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

- Hydrologic modeling 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 modeling). Modeling 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 interpret the results from other monitoring projects, such as sediment, fisheries or aquatic ecology.

4.3 Parameters Relevant to Sustainable Hydropower Development

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 define rainfall / runoff characteristics for sub-catchments, which are needed to define the water resource for hydropower (or other water resource) development. Rainfall patterns and intensity are required for the appropriate design of dams and 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), spillway and sluice gate design. River flow readings need to be collected at close intervals (near continuous) to provide information about rates of water level change, and to capture minimum and maximum events.

Groundwater information is relevant to hydropower development because it can affect the rate of impoundment filling or be important for identifying losses from storages. Locally, water levels will increase around impoundments, and can affect slope and vegetation stability, so the nature and transmissivity of local aquifers needs to be considered. Downstream of power stations, the rate of change of released flows can affect bank saturation and stability, and understanding the current rate of 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.

A summary of the parameters considered to be relevant for hydropower is provided in Table 3.

Table 3 – Summary of parameters relevant to hydropower siting, design, implementation and management

Type of Parameter or Indicator	Relevance for hydropower planning and operation	Parameter examples
Hydrological	➢ 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[1]).	**Rainfall**: total, intensity, seasonality **Other climatic variables:** Evaporation, wet bulb temperature **River Flow:** Magnitude, duration, seasonality, rate of change, minimum, maximum **Groundwater:** Level **Tidal dynamics:** flow direction, flow magnitude,

Based on the information held by the MRC, and as previously discussed, there is reasonable coverage in the LMB for recording rainfall and river flow at appropriate time-steps. Although national

[1] Procedures for Maintenance of Flows on the Mainstream

monitoring networks likely record other climatic parameters, there is no basin-wide real-time monitoring network that can be readily drawn upon. Similarly for ground water and tidal dynamics, monitoring is completed in the basin, but the information is not readily available through the MRC for hydropower power information needs.

These gaps could be addressed over time by using the Mekong-HYCOS infrastructure and communication network as a 'backbone' for implementing additional types of monitoring which take advantage of the investment already made in the existing infrastructure and data management network. Examples of this include:

- The establishment of additional meteorological parameters, such as evaporation or wet bulb temperature at select sites which are useful for climatic investigations or modelling;
- The implementation of continuous recording water quality probes at river sites to provide a continuous record of parameters such as electrical conductivity, pH or dissolved oxygen which can assist in the understanding of water quality trends or ecological processes at time scales of hours to days. These types of installations are especially useful downstream of power stations where conditions may change rapidly associated with power station discharge patterns; and
- The establishment of groundwater bores near HYCOS sites to better understand the relationship between surface water and groundwater levels and movement. Potential applications with respect to hydropower development include monitoring the effect of inundation and discharge patterns on local groundwater levels, and understanding saline water intrusion as a function of dry season flow rates.

The present trial of groundwater monitoring being conducted by the IKMP at Chaktomuk (OSP) with data being logged via HYCOS is an example of this approach.

4.4 Gap Analysis – Timing

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 outlined in Figure 12.

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.

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.

These issues are not considered a gap with respect to hydropower planning, but rather an important on-going issue with respect to information needs relevant to all water resource issues in the LMB.

4.5 Information Management

The HYCOS system has established information management systems which include robust QA/QC measures and storage of hydrologic results. Monitoring results are made available on a timely basis for use in flood forecasting and modelling.

Historic hydrologic results are available in a database which is on the Master Catalogue, while more recent results are generally available in spread-sheet format on request. The IKMP are in the process of implementing a hydrologic software management system that will assist with the development of rating curves and has the capability of tracking changes to the rating curves over time, and will provide data analysis tools.

Based on the current IKMP activities and work plan directions, there are no gaps related to hydrologic data management with respect to the guiding framework for hydropower needs.

4.5.1 Gap Analysis - Information Uses

Hydrologic information has many applications in the LMB, as evident in the attached annotated bibliography (Sediment, Water Quality Hydrology Supplement).

The usefulness of the information with respect to hydropower information needs could be enhanced through work on indicators and analytical tools with particular attention to integration and interpretation of existing hydrology data with other disciplines. The hydrology of the Mekong is a major driver of physical, biological, social and economic processes in the basin. The magnitude, frequency, duration, seasonality and rate of water level change are all important parameters which need to be considered in integrated river management and river development scenarios. Much work has been completed to date with respect to analysing the flow regime of the lower Mekong River (see various Adamson references), but there is room to improve the understanding of the river through linking the hydrology of the river to the physical attributes of the river channel. This could be initiated by quantifying specific monitoring sites with respect to the hydraulic indicators that have been identified by Gallapatti *et al* (2005) and the geomorphology and sediment indicators identified by Carlin (2005) through the IBFM project. There is also potential to identify additional indicators which are relevant to hydropower planning and development.

These analyses could be completed through the interpretation of ADCP profiles collected at each of the DSMP sites during each monitoring run. The ADCP profiles show the channel form, cross-sectional area, water flow velocity regime and the discharge at the section. Combining this information with water level information from HYCOS will allow quantification of parameters such as maximum water depth, flow velocity distribution, hydraulic radius, wetted area, and the Froude number. Computing these variables for successive monitoring run will provide an indication of how the hydraulics of the river change between flow seasons.

The use of existing hydrologic data can also be expanded by integrating hydrologic, sediment and water quality monitoring results to derive sediment and nutrient budgets for individual monitoring site, and to link fisheries and aquatic ecology monitoring results with the physical environment.

5 ISH11 Improvement Proposals for Hydrology

The gap analysis has identified some areas where hydrologic monitoring could be enhanced with respect to information important for hydropower development and management. Whilst some of these gaps may be addressed through monitoring associated with individual hydropower projects or site-specific issues, there are two issues which are considered high priority and which will enhance the information available for hydropower in the basin. These are the on-going maintenance of the HYCOS system, and the integration and interpretation of hydrologic information with other monitoring disciplines.

5.1 Maintenance of HYCOS System

Whilst not an "ISH11 improvement proposal", maintenance of all aspects of the HYCOS network is crucial for maximising the available hydrologic data for hydropower and other catchment planning activities and for maximising the return on the monitoring-investment made to date. Consequently it is emphasised here. Maintenance of the system includes:

- Maintenance of the physical components (monitoring equipment, telecommunication equipment);
- Implementation and compliance with the quality management systems to ensure that the correct procedures and methods are used, when collecting, transmitting, checking and distributing the results;
- On-going training and successional planning to ensure continuity of the system;
- Capacity building with respect to the use and interpretation of hydrologic results.

These issues are consistent with the aims and outcomes of the IKMP work plan, and there is no specific ISH11 proposal related to the physical maintenance of the system, but the importance of maintaining this system is highlighted to emphasis the necessity of reliable hydrologic information on a basin scale to underpin hydropower and other water resource management projects and activities.

5.2 Proposal SWH1: Integrating Sediments, Water Quality and Hydrology Data for Hydropower Indicators

The objective of this ISH11 improvement proposal is to convert data into information that is relevant to hydropower and other catchment issues. Integrating and interpreting existing hydrologic, water quality and sediment monitoring results will provide a basis for understanding past and present characteristics and processes operating in the LMB, and assist in identifying appropriate indicators for hydropower development and management. The integration of results will allow time-series and budgets for sediment and nutrient parameters to be constructed and interpreted with respect to present catchment developments, such as the dams in the UMB. The types of analyses will build upon preliminary data analyses conducted through the IKMP in 2012, and will be expanded to incorporate historic monitoring results as well as results collected during the DSMP (2009 – present).

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria from the ISH11 Phase 2 Main Report would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2d) Able to help predict as well as explain cause and effect of changes.* Existing sediments, water quality and hydrology data can provide more information through integration and further analysis.

- *5. Information Use; 5b) Links to tools are available for decision-support and analysis.* Some decision-support tools are available but not specifically targeted at hydropower information needs; need better indicators and tools for hydropower-relevant information.

Linkages:

- This proposal contributes to IKMP work programme activities, specifically Outcome 3: An Information System of the MRC (MRC-IS) which comprehensively integrates MRC data and information, is consolidated, regularly updated and made available for internal and external uses, and Outcome 4: MRC provided tools and related modelling services extensively used by target regional and national agencies for planning, forecasting and impact assessment.
- This proposal directly supports BDP's development of the MRC Indicator Framework, and can further support capacity-building linked to decentralization, the Council and Delta studies and RSAT information needs.
- This activity promotes integration of disciplines. The outcomes of this activity will have direct linkages to the ISH, IKMP, EP, BPD and FP activities, as it will provide information about the present state of the river, and where historic information is available, information about trends leading to the present conditions. This will assist Programmes in interpreting results from other monitoring activities (ecological health, fisheries, etc.) in a physical context, and allow monitoring strategies to be evaluated and potentially revised within a better understanding of the processes operating within the LMB with respect to hydrology, water quality and sediments
- This proposal is strongly linked to the information end-use proposal IU2 to facilitate application of hydropower-relevant indicators.

Relevant MRC Procedures or Guidelines: Accurate information about the state of the mainstream Mekong with respect to hydrology, water quality and sediments is fundamental for providing a context within which the procedures and guidelines related to water flow, water quality and water and information sharing (e.g. PDIES, PWUM, PMFM, PWQ, Technical Guidelines on Water Quality) can be meaningfully implemented.

Proposed Activities and Outputs: Examples of the types of analyses to be included are time-series of hydrology, sediment concentrations, sediment fluxes, annual sediment budgets and information about the grain-size distribution of material being transported in suspension and as bedload. The analysis will examine a range of potential indicators for use in hydropower and other basin development planning. It is intended to summarise the results of the analyses in a Technical Report or similar document which will be made available to the Member Countries and through the Master Catalogue. The proposal also contains a capacity-building element which aims to improve data analysis skills within the Line Agencies of Member Countries in cooperation with the IKMP and EP.

Resource Requirements and Implementation Commitments: Initial work on this activity has already commenced through a cooperative ISH/IKMP/MRC/GIZ study, with work focussing on providing a general overview of conditions and trends in the catchment. Following completion of the IKMP/ISH/GIZ sediment data analysis study, an additional 2 - 3 weeks of IC time would be required to focus specifically on Hydropower indicators. This would require coordination with those working on hydrologic indicators.

Sustainability Considerations: One of the objectives of this work is to identify meaningful indicators which can be used into the future to monitor and track changes in the system. The identification and adoption of uniform indicators by the Member Countries is vital to successful future monitoring, especially in light of the decentralisation process. The work will provide information which will assist Programmes in refining on-going monitoring programmes to ensure that the information being collected is relevant to the planning needs of the basin, into the future. It is also proposed to use the results of this analysis to guide the development of data interpretation tools, and capacity-building exercises in conjunction with the relevant MRC Programmes (IKMP, EP) which will enhance data interpretation capabilities of the Member Countries.

Outcomes and Benefits: The primary outcome will be an improved understanding of the processes, rates, trends and changes occurring in the LMB in the areas of hydrology, water quality and sediments. It is anticipated that analysing existing results will also assist in identifying gaps and redundancies in monitoring networks, which can assist in refining future monitoring plans and strategies and ensure the efficient use of available monitoring resources. This is an especially important consideration as decentralisation of monitoring activities progresses over the next few years.

6 Conclusions

The ISH11 project has identified opportunities for enhancing hydrologic monitoring in the LMB, including adding locations relevant to hydropower developments, increasing parameters measured through the HYCOS network, expanding monitoring to include ground water, establishing temporary low-tech hydrologic sites, and greater integration of hydrologic data with other disciplines. All of these activities are consistent with the long-term aims and goals of the IKMP and other MRC Programmes. All of these activities are recommended to be considered under the long-term work plans of the MRC, and implemented on a project-specific or site-specific basis as required.

One ISH11 improvement proposal regarding hydrological data is considered high priority by the ISH11 team, *SWH1: Integrating Sediments, Water Quality and Hydrology Data for Hydropower Indicators*. Expanding the existing data analysis project to include the development of indicators relevant to hydrologic, sediment and water quality processes in the LMB is considered to be of benefit in the immediate future.

Following national and regional consultation on the ISH11 Phase 2 report, the ISH11 team aims to work with and through the MRC Programmes to identify funding opportunities for implementation of the ISH11 proposals agreed upon by the MRC Member Countries.

7 References

Hamilton, S., 2012, The 5 Essential Elements of A Hydrological Monitoring Program, Aquatic Informatics, http://pages.aquaticinformatics.com/DownloadedWhitepaper_Download_Whitepaper.html , downloaded 3 March 2013.

IUCN, 2011, Groundwater in the Mekong Delta, Discussion Paper.

Kazama, L., Hagiwara, T., Ranjan, P., and Sawamoto, M., 2007, Evaluation of groundwater resources in wide inundation areas of the Mekong River basin, Journal of Hydrology, v340, Issues 3-4, p233-243.

MRC (2005) *Overview of the Hydrology of the Mekong Basin.* Mekong River Commission, Vientiane, November 2005. 73pp.

Mekong River Commission, 2012, The Mekong Hydrological Cycle Observing System Mekong-HYCOS, A Hydrological Information System in the Mekong River Basin

Mekong River Commission, 2011, Basin Development Plan Programme Planning Atlas of the Lower Mekong River Basin.

Mekong River Commission, 2012, The Value of Hydro-Meterorologial Observations, Symposium on Hydro-Meteorological Networks, Siem Reap, Cambodia. Surface and groundwater maps included in the conference materials

Nguyen, Cuong Kim. Origin of Fresh Groundwater in the Mekong Plain [online]. In: Water Down Under 94: Groundwater/Surface Hydrology Common Interest Papers; Preprints of Papers. Barton, ACT: Institution of Engineers, Australia, 1994: 411-415. National conference publication (Institution of Engineers, Australia); no. 94/10. Availability: <http://search.informit.com.au/documentSummary;dn=751448504619452;res=IELENG> ISBN: 085825607X. [cited 08 Mar 13].

Roberts, Michael. 1998. Groundwater Irrigation in the Cambodian Mekong Delta, M.S. thesis, Cornell University, Ithaca, New York.

Zaisheng, H., Jing, H., and Lei, N. 2010, Transboundary Aquifers in Great Mekong River Basin, International Conference 'Transboundary Aquifers: Challenges and New Directions (ISAEM2010) 6-8- December 2010.

Attachment 1 – Annotated Bibliography

Please, see ISH11 Phase 2 Report: Water Quality Annex.

Attachment 2 – Response to Comments Raised in National Consultations

Please, see ISH11 Phase 2 Report: Water Quality Annex.