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MRC Initiative on Sustainable Hydropower (ISH)

IMPROVED ENVIRONMENTAL AND SOCIO-ECONOMIC BASELINE INFORMATION FOR HYDROPOWER PLANNING

ISH11 PHASE 2 REPORT: Water Quality Annex

20 December 2013

MRC Initiative on Sustainable Hydropower (ISH)

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20 Dec 2013	Lois Koehnken	ISH11 Phase 2 Report Water Quality 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 this Phase 2 Water Quality Annex.

Abbreviations and Acronyms

ADCP	Acoustic Doppler Current Profiler
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
EP	Environment Programme (of the MRC)
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)
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
PWQ	Procedures for Water Quality
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
WQMN	Water Quality Monitoring Network

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1 Context of Water Quality in the ISH11 Project

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 and release to the downstream environment. The establishment of hydropower schemes can also lead to the parallel development of new water based industries (e.g. aquaculture, irrigation) 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 was not included as a separate discipline in the ISH11 Terms of Reference (ToR), but the ISH11 Project team has identified it as an important issue with respect to hydropower development with social, economic and ecological linkages, and is considering it in this context.

2 Best Practice Water Quality Monitoring

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

2.1 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); this is described further in Section 4.3. 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.

2.2 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) 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 1). This methodology is discussed in the sediment transport Annex.

Figure 1 – Left: Depth integrating water quality sampler (http://ga.water.usgs.gov/edu/qwsampler.html), Right: Autosampler that can be set to sample at fixed time intervals, or flow levels (http://ga.water.usgs.gov/edu/autosampler.html)

Sampling techniques include the *in situ* measurement of parameters and the collection of representative water samples for subsequent analysis. Parameters that are most commonly measured *in situ* include physico-chemical attributes, several of which can rapidly alter upon collection and storage (temperature, dissolved oxygen, pH, electrical conductivity, turbidity, Oxidation-reduction potential). Other parameters may require 'fixing' in the field to stabilise the water sample during transport to the laboratory.

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 1) can be remotely deployed, and set to collect samples at fixed time intervals, or river level height. The samplers can also be used to collect composited samples collected 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.

2.3 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 interlab comparisons.

2.4 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.

3 Water Quality Monitoring in the LMB and State of Knowledge

3.1 Present Water Quality Monitoring

The MRC coordinates the catchment wide Water Quality Monitoring Network (WQMN). Under the WQMN, the MRC countries conduct water quality monitoring activities and report the results to the MRC Environment Program who are responsible for QA/QC, integrating the results into the water quality database, and reporting on the results.

The WQMN activities support the MRC Procedures for Water Quality (PWQ). The MRC Joint Committee is in the process of reviewing, approving and implementing Technical Guidelines to facilitate the implementation of the PWQ. The Technical Guidelines contain criteria and target values applicable to the protection of human and aquatic ecosystem health.

The WQMN includes mainstream and tributary sites (Figure 2, Table 1). Water quality data held by the MRC Water Quality WQMN extends back to 1985. The number of sites included in the WQMN and the number of results available for each site has varied over time, as shown in Table 1. In 2012, the WQMN included 17 Mekong mainstream sites, 5 sites on the Bassac River and 26 tributary sites (MRC, 2008a).

The 48 locations currently included in the monitoring network are divided into Primary sites and Secondary sites. Primary sites have basin-wide or transboundary relevance, whereas Secondary sites are of mainly local or national interest. Within each of these groupings 'benchmark' sites in each country have been identified which reflect the characteristics of a larger area or adjacent stations, and generally have a long time-series of results or represent an anomalous or 'hot spot' issue that merits long-term monitoring.

Water samples are collected by field teams from each country from the middle of the active channel at a depth of 0.5 m. Parameters include physico-chemical measurements, nutrients, major ions, and indicators of plant productivity and human impacts as shown in Table 2. Analyses are completed by laboratories in each of the MRC countries with results reported to MRC. The data is subjected to internal and external quality assurance processes and stored in the MRC data storage and management system (MRC, 2008a).

The results are used to derive water quality indicators for Aquatic Life, Human Impact and Agricultural Uses. A systematic analysis of the routine monitoring results was completed by the WQMN in 2008 (MRC, 2008a). This review of general water quality characteristics complemented a targeted study of water quality which included parameters associated with industrial (metals, PAHs, BTEX, Hydrocarbons) and agricultural activities (pesticides) and sediment bioassays (MRC, 2007). These indicators and the outcomes of the targeted investigations are discussed in more detail in Section 3.2.

In addition to the water quality indices, the recently developed Technical Guidelines for the Protection of Human Health and Protection of Aquatic Life contain criteria and target values. The Guidelines include parameters not routinely included in the WQMN monitoring strategy (Arsenic, cadmium, chromium, cyanide, lead, mercury, Oil & Grease, Phenol, Total Organochlorine Pesticides, Faecal Coliform). The aim is to have any additional monitoring complete by the Member Countries complement the on-going WQMN activities.

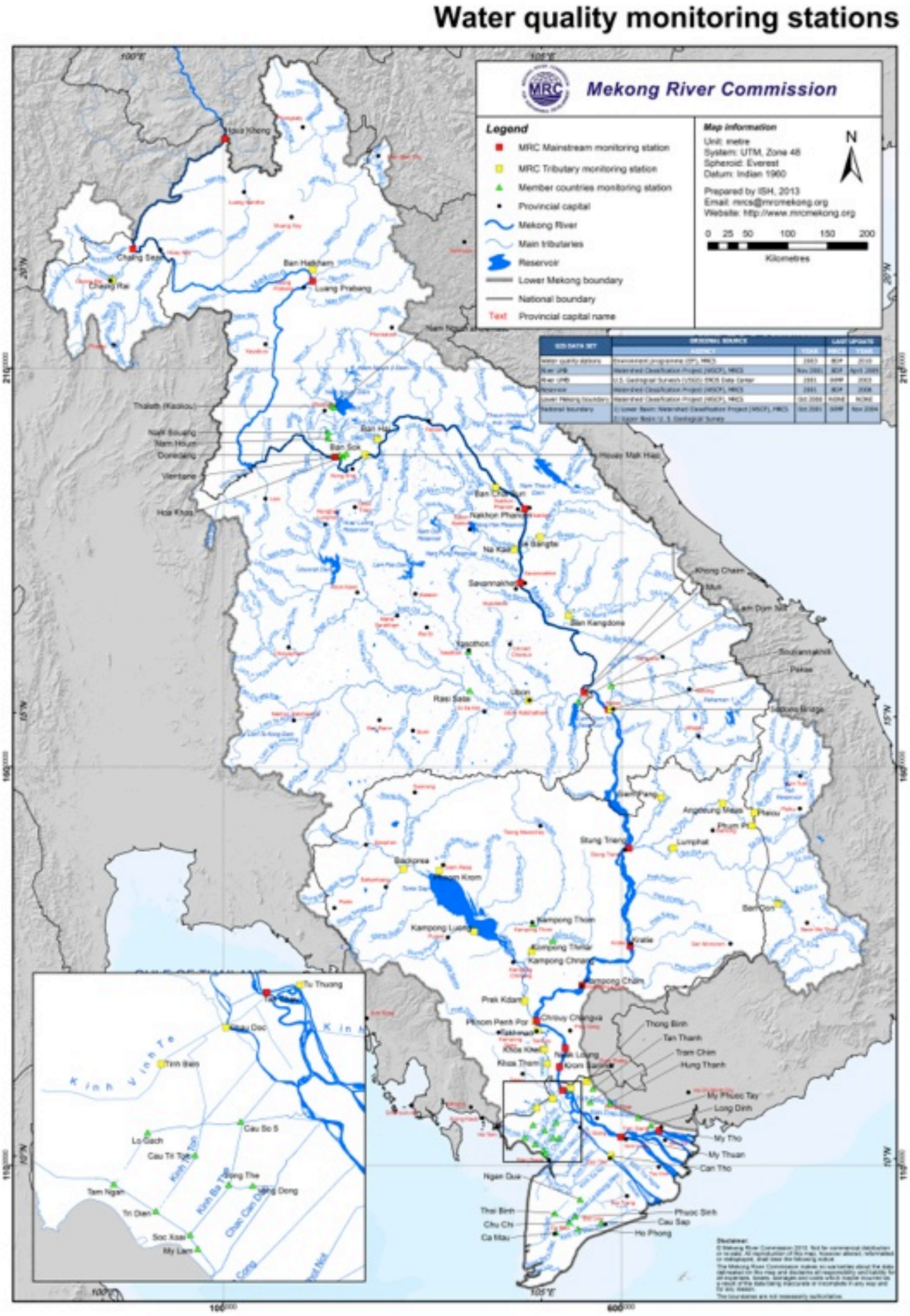

Figure 2 – MRC and Member Country water quality monitoring locations

Table 1 – Water quality monitoring sites and number of samples collected at each site over past 5 years. Data from MRC WQMN

Site Name	StatID	River	Country	Number of Water Quality Samples					
				2007	2008	2009	2010	2011	2012
Houa Khong	H010500	Mekong	Lao PDR	11	12	6	6	6	8
Luang Prabang	H011200	Mekong	Lao PDR	12	12	6	6	5	8
Pakse	H013900	Mekong	Lao PDR	12	12	6	6	6	8
Savannakhet	H013401	Mekong	Lao PDR	12	12	6	6	6	8
Vientiane	H011901	Mekong	Lao PDR	12	12	6	6	6	8
Hoa Khoa	H910103	Mekong	Lao PDR	12	12				
Houay Mak Hiao	H910108	Houay Mak Hiao	Lao PDR	12	12	6	6	6	8
Nam Houm	H231901	Nam Houm Canal	Lao PDR	5	6				
Thaleth (Keokou)	H230206	Nam Lik	Lao PDR	12	12				
Ban Hai	H230103	Nam Ngum	Lao PDR	12	12	6	6	6	8
Nam Ngum at Damsite	H230199	Nam Ngum	Lao PDR	12	12				
Ban Hat Kham	H100101	Nam Ou	Lao PDR	12	12	6	6	6	8
Donedang	H910107	Nam Pasack (That Luang Marsh)	Lao PDR	12	12				
Nam Souang	H231801	Nam Souang	Lao PDR	12	12				
Se Bang Fai	H320101	Se Bang Fai	Lao PDR	11	12	6	6	6	8
Ban Keng Done	H350101	Se Bang Hieng	Lao PDR	11	12	6	6	6	8
Sedone Bridge	H390105	Se Done	Lao PDR	12	12	6	6	6	8
Souvanna Khili	H390104	Se Done	Lao PDR	12	12				
Ban Sok	H910106	That Luang Marsh	Lao PDR	12	12				
Chiang Sean	H010501	Mekong	Thailand	12	12	6	6	6	12
Khong Chiam	H013801	Mekong	Thailand	12	12	7	6	6	12
Nakhon Phanom	H013101	Mekong	Thailand	12	12	7	6	6	12
Nam Kae	H310102	Nam Kam	Thailand	12	12	6	6	6	12
Chiang Rai	H050104	Nam Mae Kok	Thailand	12	12	6	6	6	12
Mun (Khong Chiam)	H380128	Nam Mun	Thailand	12	12	6	6	6	12
Ubon	H380104	Nam Mun	Thailand	12	12	7	6	6	11
Ban Chai Buri	H290103	Nam Songkhram	Thailand	12	12	6	6	6	12
Chroy Chang Var	H019801	Mekong	Cambodia	12	12	6	6	6	12
Kampong Cham	H019802	Mekong	Cambodia	12	12	6	6	6	12
Kratie	H014901	Mekong	Cambodia	12	12	6	6	6	12
Krom Samnor	H019807	Mekong	Cambodia	12	12	6	6	6	12
Neak Luong	H019806	Mekong	Cambodia	12	12	6	6	6	12
Stung Treng	H014501	Mekong	Cambodia	12	12	6	6	6	12
Koh Thom	H033403	Bassac	Cambodia				6	6	12
Koh Khel	H033402	Bassac	Cambodia	12	12	6	6	6	12
Takhmao	H033401	Bassac	Cambodia	12	12	6	6	6	12
Siempang	H430102	Se Kong	Cambodia	12	11	7	6	6	12
Phum Pi	H440102	Se San	Cambodia	8	6	5	6	6	12
Andaung Meas	H440103	Se San	Cambodia	12	12	6	6	6	12
Lumphat	H450101	Sre Pok	Cambodia	12	12	6	6	6	12
Kompong Thmar	H620101	Stung Chinit	Cambodia	12	12				
Kampong Thom	H610101	Stung Sen	Cambodia	12	12				
Backprea	H020107	Tonle Sap	Cambodia	12	12	6			
Kampong Chnang2012	H020103	Tonle Sap	Cambodia	12	12	6	6	6	12
Kampong Luong	H020106	Tonle Sap	Cambodia	12	12	6			12
Phnom Krom	H020108	Tonle Sap	Cambodia	12	12	6			12
Phnom Penh	H020101	Tonle Sap	Cambodia	12	12	6	6	6	12

Site Name	StatID	River	Country	Number of Water Quality Samples					
				2007	2008	2009	2010	2011	2012
Port									
Prek Kdam	H020102	Tonle Sap	Cambodia	12	12	6	6	6	12
Kampong Luong	H020106	Tonle Sap Lake	Cambodia	11	6	6	6	6	12
Backprea	H020107	Tonle Sap Lake	Cambodia	12	12	6	6	6	12
Phnom Krom	H020108	Tonle Sap Lake	Cambodia	12	12	6	6	6	12
My Tho	H019805	Mekong	Vietnam	12	12	12	12	12	12
My Thuan	H019804	Mekong	Vietnam	12	12	12	12	12	12
Tan Chau	H019803	Mekong	Vietnam	12	12	12	12	12	12
Can Tho	H039803	Bassac	Vietnam	12	12	12	12	12	12
Chau Doc	H039801	Bassac	Vietnam	12	12	12	12	12	12
Dai Ngai	H029812	Bassac	Vietnam	24	24	12			
Vinh Thuan	H988209	Chac Bang	Vietnam	24	24	12			
Chu Chi	H988207	Cho Hoi	Vietnam	24	24	12			
My Lam	H988315	Delta	Vietnam	24	24	12			
Soc Xoai	H988314	Delta	Vietnam	24	24	12			
Ho Phong	H988205	Delta	Vietnam	24	24	12			
Tam Ngan	H988312	Delta	Vietnam	24	24	12			
Tan Thanh	H988102	Delta	Vietnam	24	24	12			
Thoi Binh	H988208	Delta	Vietnam	24	24	12			
Thong Binh	H988115	Delta	Vietnam	24	24	18	12	12	12
Tinh Bien	H988316	Delta	Vietnam	24	24	18	12	12	12
Tu Thuong	H988114	Delta	Vietnam	12	12	12	12	12	12
Vinh Dieu	H988311	Delta	Vietnam	24	24	12			
Vong Dong	H988307	Delta	Vietnam	24	24	12			
Kien Binh	H988107	Duong Van Duong	Vietnam	24	24	12			
Cau so 5	H988306	Kinh Ba The	Vietnam	24	24	12			
Vong The	H988308	Kinh Ba The	Vietnam	24	24	12			
Tram Chim	H988105	Kinh Dong Tien	Vietnam	24	24	12			
Cau so 13	H988305	Kinh Tri Ton	Vietnam	24	24	12			
Cau Tri Ton	H988309	Kinh Tri Ton	Vietnam	24	24	12			
Tri Dien	H988313	Kinh Tri Ton	Vietnam	24	24	12			
Ngan Dua	H988210	Ngan Dua	Vietnam	24	24	12			
Cau Sap	H988204	Ngan Dua-Bac Lieu	Vietnam	24	24	12			
My Phuoc Tay	H988111	Nguyen Tan Thanh	Vietnam	24	23	12			
Long Dinh	H988113	Nguyen Tan Thanh I	Vietnam	24	24	12			
My An	H988110	No 28	Vietnam	24	24	12			
Hung Thanh	H988106	Phuoc Xuyen	Vietnam	24	24	12			
Ca Mau	H988206	Quan Lo-Phung Hiep	Vietnam	24	24	12			
Ninh Quoi	H988211	Quan Lo-Phung Hiep	Vietnam	24	24	12			
Phuoc Sinh	H988214	Quan Lo-Phung Hiep	Vietnam	24	24	12			
Rach Chanh	H988112	Rach Chanh	Vietnam	24	24	12			
Pleicu	H440202	Se San	Vietnam	12	12	12	12	12	
Ban Don	H451303	Sre Pok	Vietnam	12	12	12	12	12	
Lo Gach	H988310	Tam Ngan	Vietnam	24	24	12			

Table 2 – Summary of water quality parameters included in MRC Water Quality Monitoring Program. From MRC (2008)

Physico-chemical	Major cations & anions	Nutrients	Other
Temperature	Sodium	Nitrate + Nitrite	Chemical Oxygen Demand
Conductivity	Potassium	Total Ammonia	Aluminium
Total Suspended Solids	Calcium	Total Nitrogen[1]	Iron
pH	Magnesium	Phosphate	Silica
Dissolved Oxygen	Chloride	Total Phosphorus	Chlorophyll-a[2]
	Sulphate		Faecal coliforms[2]
	Alkalinity		

[1]Two countries do not measure this parameter; [2]added in 2007

3.2 Catchment Water Quality

The maintenance of good water quality in the Mekong Basin is imperative for public health, economic development and ecological health due to the dependence of many activities on the water resources in the basin. The following section provides a brief overview of recent water quality investigations and findings. Additional information and references related to water quality in the catchment are contained in the annotated bibliography in the *Supplement for hydrology, sediment transport, geomorphology and water quality.*

The WQMN provides the best available information about catchment-wide water quality trends in the LMB. The 2007 'diagnostic' study of water quality found the following trends in the Mekong based on the WQMN results collected in 2003 – 2004:

- The Mekong is a relatively dilute river compared to other large world rivers;
- Elevated salt levels were present in the Nam Mun. Salt levels were diluted by inflows from the Nam Chi, and levels were not elevated in the Mekong at Pakse, suggesting the saline input has little influence on mainstream water quality;
- Nutrient concentrations were elevated in areas with high population densities and / or poor sewage treatment facilities; and
- Industrial contaminants and pesticides were below detection levels in all water samples.

The WQMN's 2008 assessment of water quality trends in the LMB included the development of Water Quality Indices for aquatic life, human impact and agricultural uses. These indices have also been used to produce water quality Report Cards for the LMB (MRC, 2008b, 2010). Each index is based on whether a subset of the routine water quality parameters collected meets established guideline values. The parameters included in each of the indices are summarised in Table 3.

Table 3 – Summary of water quality parameters used to derive water quality indices by MRC

Aquatic Life	Human Impact	Agricultural Use
Dissolved oxygen pH Ammonia Conductivity Nitrite + Nitrate Total Phosphorus	Dissolved oxygen Chemical Oxygen Demand Ammonia	Conductivity

The water quality indices for Human Impact and Aquatic Life based on 2008 monitoring results are shown in Figure 3 and Figure 4, respectively. The Human Impact results show the catchment mainstream is generally lightly to severely impacted, with widespread impact documented in the delta. The results of the Human Impact assessment have progressively declined throughout the basin since 2000, suggesting that water quality pressures in the catchment are increasing (MRC, 2011).

The aquatic ecological health index shows sites in the LMB are moderate to excellent with only the most upstream site having a poor rating. Moderate aquatic ecological sites tend to correspond to sites with severe or impacted water quality with respect to the Human Impact index.

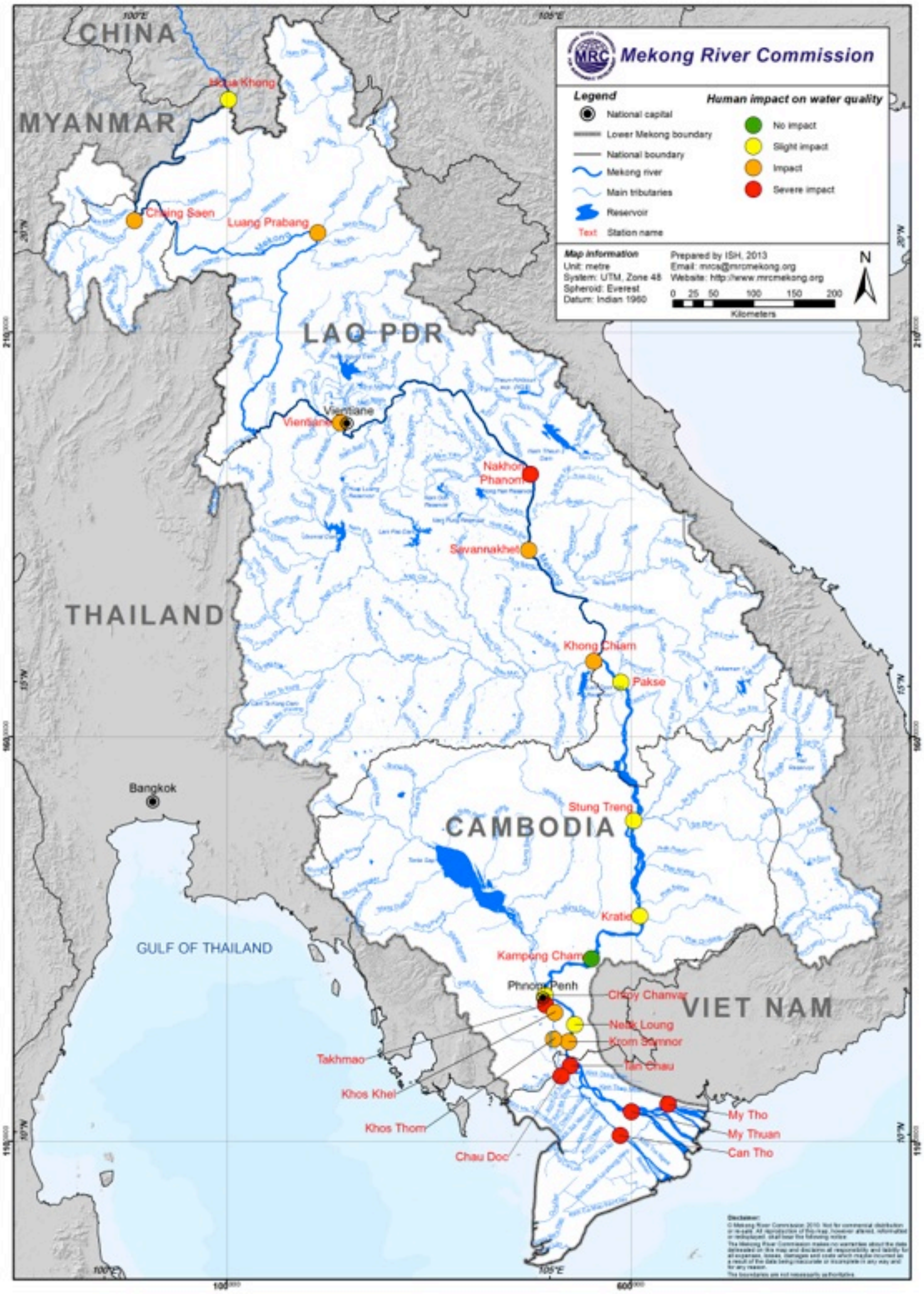

Figure 3 – WQMN Water Quality Index for Human Impacts (MRC, 2011)

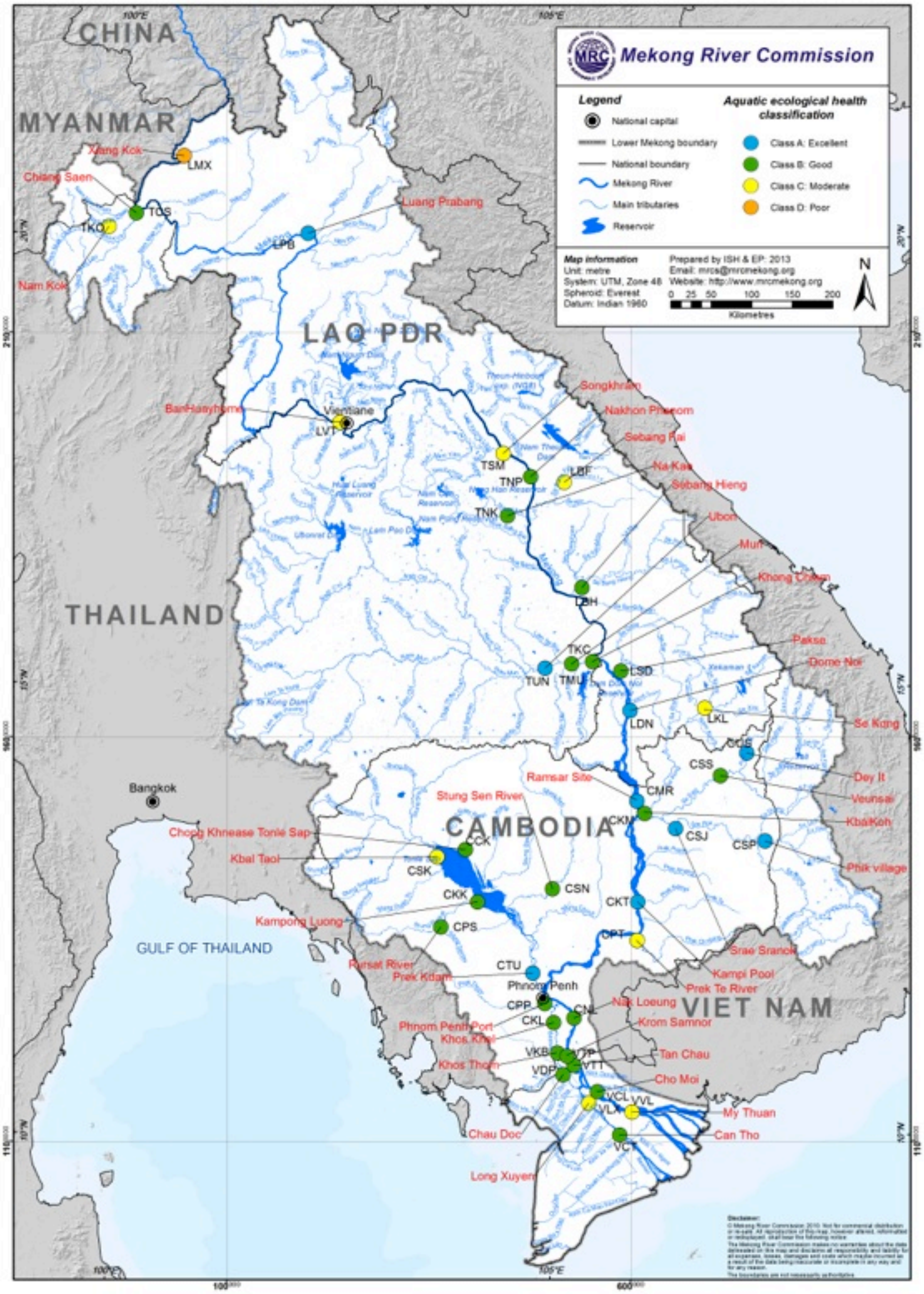

Figure 4 – WQMN Water Quality Index for aquatic health

The WQMN analysis of water quality in the catchment (MRC, 2008) identified the following issues of relevance to the Lower Mekong Basin include:

- Salinity: high conductivity water has been measured on the Khorat Plateau, where the salinity is derived from salt deposits, and in the delta, associated with seawater intrusion;
- Acidification: the presence of acid sulphate soils in the lower LMB, and particularly near the Plain of Reeds near the Cambodian / Viet Nam border, result in acid production when the soils are drained and exposed to the atmosphere. The resulting acidic water can leach metals from the soils leading to elevated levels of aluminum and potentially other metals;
- Eutrophication: An excess concentration of nutrients can lead to increased biomass growth. The cycling and interaction between nitrogen and phosphorus in the Mekong is complex, and although concentrations of these nutrients in the LMB are generally below the WQMN threshold values, there is most likely an effect on algae, periphyton and floating aquatic vegetation from excess nutrients.

3.3 Transboundary Water Quality Issues

Transboundary water quality impacts in the LMB were investigated by Hart *et al.,* (2001). Using a risk-based assessment, the investigation aimed to evaluate:

- The potential effects of municipal and industrial wastewater from Phnom Penh on both downstream Vietnam and fish migration in Tonle Sap River;
- The potential effects of municipal and industrial wastewater from Vientiane on both neighboring Thailand and fish migration in the Mekong River; and
- The influence of upstream water on the degraded water quality in the Mekong Delta.

Overall the authors found the existing water quality data was insufficient to complete the risk-based analysis, with the available parameters, monitoring locations and monitoring frequency all found to be inadequate for a statistically robust assessment. The evaluation of transboundary impacts that could be derived from the results is summarised in Table 4. The information in the footnotes to Table 4 are particularly relevant to this ISH11 study.

Table 4 – Summary of transboundary water quality impacts by Hart, *et al.,* (2001)

Issue	Effect	Issue 1 (Phnom Penh)	Issue 2 (Vientiane)	Issue 3 (Delta)
Ecological Eutrophication Toxic Effects[2] Ecosystem function[3]	 Algal blooms Fish/invert. kills To be determined	 Low-moderate risk[1] Low risk Not assessed	 Low risk Low risk Not assessed	 Low risk Low risk Not assessed
Fish migration[4]	*Adverse effects on fish movement upstream, downstream or onto floodplains*	Uncertain	Uncertain, likely to be low	Uncertain
Human health[5] Drinking water Recreation	Microbial contamination causing sickness	 Uncertain Uncertain	 Uncertain Uncertain	 Uncertain Uncertain
Agriculture Irrigation	 Increased salinity			 Low risk

[1] More likely low risk since only nutrient concentrations were used in the assessment, high turbidity and high flow would also reduce the change of algal problems

[2] Risks based on toxic effects due to low dissolved oxygen concentrations. It was not possible to assess toxicity due to toxicants (heavy metals, pesticides) because of lack of data

[3] No information is available at present, but should be developed in the future

[4] Lack of data to make assessment, present water quality sampling network cannot provide the required information

[5] Lack of data to make assessment. Risk likely to be low-moderate due to large dilution (also expect significant microbial die-off during transport to Vietnam in case of Issues 1 & 3)

Future potential water quality impacts have been evaluated with respect to development scenarios under the Basin Development Plan Programme, Phase 2, (MRC, 2010d). The assessment concluded that declines in water quality are likely due to increased development and irrigation. Under the development scenarios, pollutant loads to the rivers are projected to increase due to increased return flows from irrigated agriculture (containing pesticides and nutrients) and increased discharges of (untreated) domestic and industrial waste water (having high levels of BOD, nutrients and pollutants).

Potential changes associated with hydropower development were considered in the water quality component of the Water Utilisation Programme (WUP) (MRC, 2005). The study found that impacts on water quality downstream of impoundments are more likely to occur at the onset of the wet season, when water temperature has increased in impoundments due to storage and thermal stratification. The study also found that biological productivity in the river is generally limited by light penetration, rather than nutrient availability. Hydropower development may lead to increased biological productivity due to the capture of suspended particulates in impoundments (MRC, 2005).

3.4 Water Quality Issues in the Delta

Water quality in the Mekong Delta is affected by salt-water intrusion and the presence of acid sulphate soils. The extent of salt-water intrusion is controlled by surface water flows in the Mekong, water extractions and diversions in the delta, and the tidal regime, and can extend more than 50 km inland as shown in Figure 5 (MRC, 2010c). Excess salinity affects human health through drinking water and agricultural production. The impacts are greatest during the dry season, when Mekong flows are low.

Acid sulphate soils occur extensively in southern Cambodia and Vietnam, with up to 40% of the delta underlain by soils considered to be acidic or potentially acidic (Groger, *et al.,* 2011), and are extensively exposed in the Plain of Reeds area. The acidity generated by oxidation of the pyrite in the soils can directly and indirectly affect human health and agriculture, through acidification of waterways and soils, and mobilising manganese and arsenic. This is a significant issue in the Delta where bore water is a major source of drinking water.

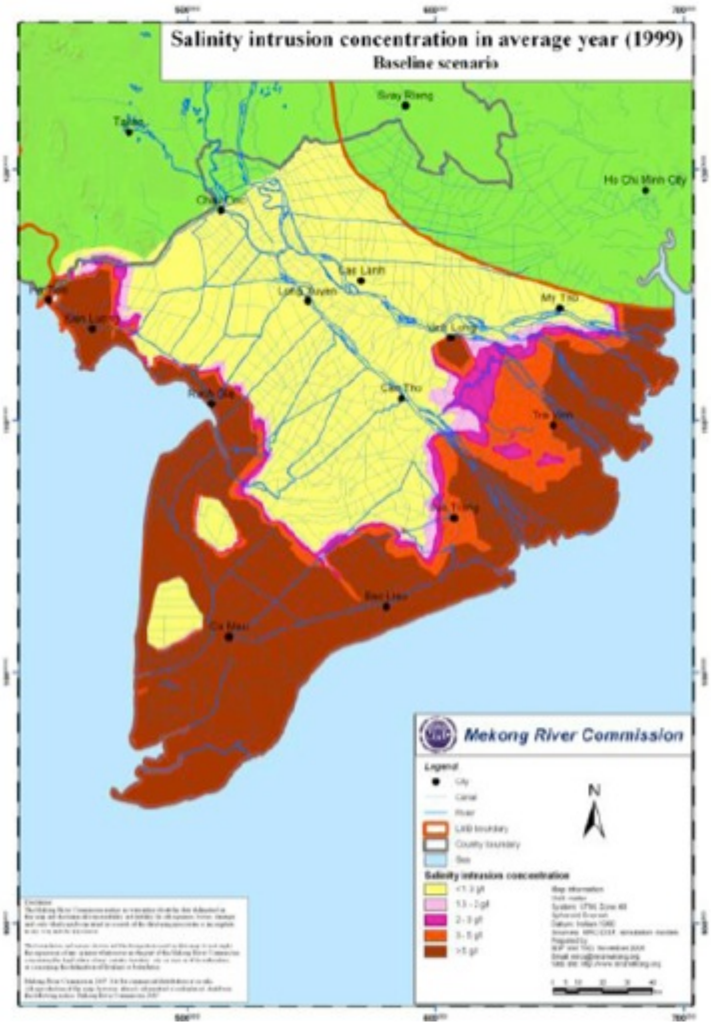

Figure 5 – Salinity intrusion in an average year during the dry season. MRC (2010c)

4 Gap analysis with respect to ISH11 Guiding Framework

4.1 Water Quality Information Needs to Support Hydropower Planning

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 6). 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.

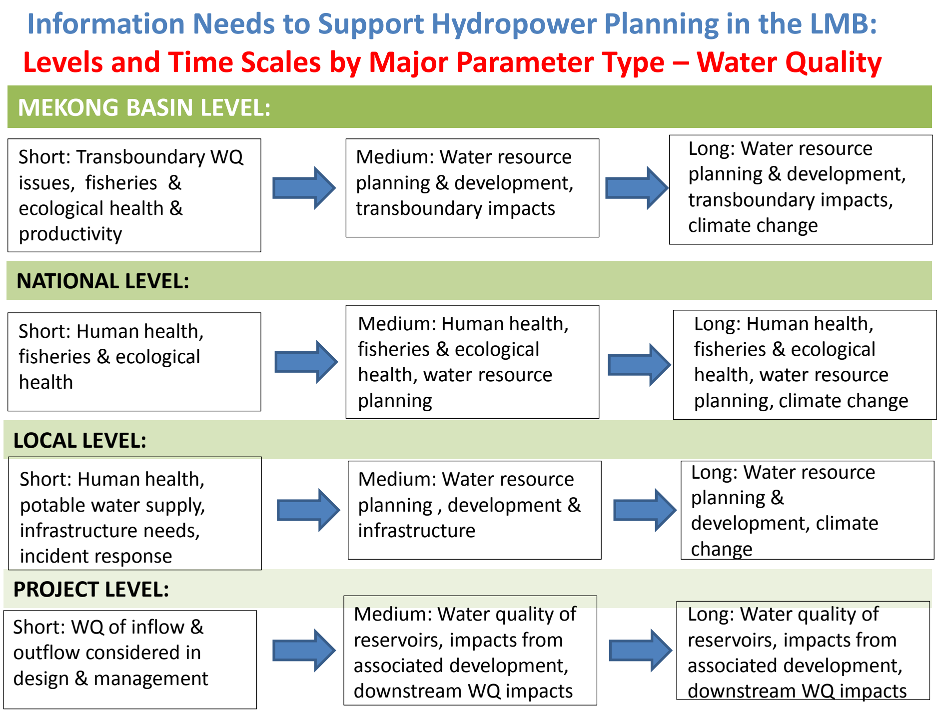

Figure 6 – Water quality information needs to support sustainable hydropower planning in the LMB

4.2 Gap Analysis – Locations

The WQMN provides good coverage of the Mekong mainstream and major tributaries at a catchment level. The present monitoring network provides information about water quality trends occurring at the basin scale over months to seasons. Improved coverage with respect to hydropower needs could be achieved by increasing sites in areas where hydropower is planned and WQMN sites are sparse. An example of this is in northern Lao PDR where multiple hydropower projects are proposed between Luang Prabang and Chiang Kong, but water quality monitoring sites are limited to Luang Prabang and Vientiane. The inclusion of a water quality monitoring site at Chiang Kong would also align water quality monitoring with MRC discharge and sediment monitoring activities at the site.

Increasing water quality monitoring to include sites upstream and downstream of hydropower projects and within impoundments is necessary to understand the impact hydropower projects may have on local water quality conditions, and to provide site-specific information for reservoir and power station management. This is especially important in cascade hydropower developments, where storage in successive impoundments can amplify water quality changes to parameters such as temperature or dissolved oxygen.

Ideally, the establishment of hydropower project-specific monitoring sites should precede the development of the project, so a good understanding of pre-hydropower conditions is gained and any impacts associated with construction can be monitored. Based on this, establishing additional water quality monitoring sites between Luang Prabang and Vientiane, and upstream of the Cambodia – Lao PDR border is considered a priority.

4.3 Gap Analysis - Parameters

Water quality parameters relevant to hydropower development can be divided into those that could have a direct effect on hydropower infrastructure or efficiency, and those that have the potential to be altered due to the implementation and operation of hydropower developments.

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.

Water quality parameters that have the potential to be altered due to the implementation of hydropower developments 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. The relevance of water quality monitoring to hydropower planning is summarised in Table 5.

Table 5 – Relevance of water quality monitoring for hydropower planning

Type of Parameter or Indicator	Relevance for hydropower planning and operation	Parameter examples
Water quality	➢ Water quality can affect hydropower infrastructure ➢ Need to understand influent water quality to predict and manage potential changes during storage, and to assess whether inflowing water is changing over time; ➢ Need to understand changes to water quality during storage so can differentiate between hydropower development impacts and other impacts (such as aquaculture) ➢ Need to understand any downstream impact on water quality due to hydropower operations, and to distinguish between hydropower impacts and other land use impacts	**Suspended sediment characteristics:** size and composition of material **Physico-chemical water quality characteristic:** temperature, pH, acidity, alkalinity, dissolved oxygen in surface and sub-surface water, **Metals:** total and dissolved iron, manganese, zinc, mercury, arsenic **Nutrients:** concentration, speciation, seasonal variability, changes during storage;

The WQMN includes many of the parameters relevant to hydropower information needs.

Three additional parameters relevant to hydropower information needs would be valuable to include in the near future, as they are directly relevant to how the implementation of hydropower could alter water quality in the future. The parameters are also relevant to fisheries and ecological health. The parameters include:

- A measure of **in situ water transparency**. This is relevant to light penetration changes which may occur within or downstream of hydropower developments where water clarity my change relative to present conditions. Measurements could be easily obtained using a Secchi disk, or transparency tube;

- A measure of **reactive phosphorus**. The WQMN suite of parameters includes total phosphorus, which provides a measure of the maximum amount of phosphorus that may be available for uptake by plants. Measuring dissolved phosphorus would provide more accurate information about the amount of this nutrient available for algal growth. Algal growth risks increase as light penetration and available nutrients increase, so understanding these factors is important for reservoir management; and
- The inclusion of a measurement of **particulate organic carbon** (e.g. FPOM, CPOM) would provide a better understanding of the link between sediment movement and ecological processes. At present, there is a poor understanding of how organic carbon is moving through the Mekong, and how hydropower developments may alter these processes. Organic carbon is important as a primary food source for aquatic food webs, and can also be involved in chemical processes leading to acidification of waterways. Organic carbon is important for complexing metals, nutrients and other compounds that can be consumed by organisms. As physical particulates, particulate organic carbon also contributes to the suspended solids load of a waterway, affecting light penetration and sedimentation rates (Schumacher, 2002, Bruckner, no date)

In addition to these parameters the periodic inclusion of metals, pesticides, total petroleum hydrocarbons (TPH) and other industrially or agriculturally derived toxicants would provide insights into the potential levels of these contaminants entering, or exiting hydropower impoundments. These types of parameters are periodically determined by the WQMN (e.g. Water Quality Diagnostic Survey 2007 or Assessment of Water Quality in the LMB 2008), and are proposed to be monitored on a routine (though low frequency basis) once the Technical Guidelines for Water Quality are implemented.

Another step, which could enhance the usefulness of the water quality parameters analysed, is integrating water quality sample collection with depth-integrated sediment sampling. This would provide a coherent and useful data set with respect to hydropower, and other catchment development needs. The WQMN monitoring protocol includes the collection of surface grab samples for subsequent analysis. It is recognised that this type of sampling may not accurately reflect water quality parameters associated with suspended solids in the water column, as the concentration and characteristics of suspended solids is not uniform with depth. Understanding the relationship between water quality parameters and suspended sediments is particularly important for hydropower planning and management, as dams can alter the movement of sediment and associated nutrients, metals or other parameters.

These additional parameters and a more integrated monitoring approach would provide a sound understanding of the linkages between sediments, water quality and hydrology. This is also the type of information that is required to run ecological models relevant to environmental impact assessment for hydropower or other basin developments.

4.4 Gap Analysis – Timing

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.

The monitoring frequency of the WQMN was monthly in 2012, and bi-monthly (once every two months) in the previous few years. Although this is sufficient for documenting long-term catchment wide trends, more detailed information through the onset, peak and recession of the high flow season would better address hydropower information needs. The large majority of water, dissolved constituents and suspended material in the Mekong are transported during the period June to November, and increasing water quality monitoring during this period would improve the understanding of water quality characteristics and trends. Obtaining water quality samples at a higher, and seasonally-proportional frequency, such as adopted by the Discharge Sediment Monitoring Program (DSMP) would also provide more detailed information during the period of highest flows through the Mekong. The flow proportional monitoring frequency of the DSMP is shown in Table 6.

Table 6 – Monitoring frequency of the Discharge Sediment Monitoring Programme in 2012

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Total**
Frequency	1	1	1	1	1	4	4	4	4	4	1	1	**27**

Water quality changes associated with power station discharge patterns can occur over very short timescales, if the power station is operating in a 'peaking' mode. An improved understanding of short-term water quality changes associated with hydropower can be gained through the deployment of continuous recording water quality probes to obtain high frequency measurements of physico-chemical parameters (temperature, electrical conductivity, dissolved oxygen, turbidity, etc.). These types of probes can provide insights into the magnitude and extent of water quality changes associated with power station operations, and can be used in 'real time' to guide power station operations if required. Continuous recording probes could be linked with the HYCOS network, providing telemetered real time information.

4.5 Gap Analysis – Information Management

The water quality monitoring results are stored in the WQMN database and available on the Master Catalogue. QA/QC processes are in place, and there are no identified gaps with respect to hydropower information needs. Future monitoring associated with the implementation of the Technical Guidelines on Water Quality will generate additional data that will ideally be integrated with the WQMN results.

4.6 Gap Analysis – Information Uses

The usefulness of available water quality data 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 water quality data with other disciplines. Information relevant to hydropower could be derived from the available water quality data set through the integrated analysis of hydrologic, water quality and sediment data. Seasonal patterns in water quality as a function of flow and sediment concentrations, nutrient fluxes and budgets, and spatial and temporal changes are all relevant parameters and potential indicators for hydropower siting, development and management. These types of analyses are also relevant to other basin development projects and MRC studies, such as the Council Study.

5 Water Quality Improvement Proposals

The gap analysis has identified areas where water quality monitoring could be enhanced with respect to hydropower information needs. Additional 'gaps' and needs have been identified during consultation with the Member Countries regarding the ISH11 Inception and Phase 1 Reports (*Supplement for hydrology, sediment transport, geomorphology and water quality.*). Collectively, this information has been used to guide development of the following proposals.

There are two issues that are considered high priority and could substantially enhance the information available for hydropower in the basin if implemented in the short term. These are the integration and analysis of existing sediment, water quality and hydrology information to increase the understanding of the present status and trends in the LMB, and integration of water quality monitoring with the sediment and hydrology monitoring. These are summarised in the following sections.

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

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria as described in Section 2.7, of 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.

Objective and Description: The objective of this 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).

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: The types of analyses to be included are time-series of water quality concentrations, seasonal nutrient fluxes, annual nutrient budgets and information about the relationship between flow, water quality and sediment movement in the river. 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 that will be made available to the Member Countries and through the Master Catalogue. The proposal also contains a capacity-building element that 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 that 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) that will enhance data interpretation capabilities of the Member Countries. It is important to note that this proposal does **not** alter the present WQMN in any way, but seeks to increase water quality monitoring for a trial period.

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.

5.2 SWH2: Water Quality Monitoring Enhancements for Hydropower Information

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria as described in Section 2.7, of the ISH11 Phase 2 Main Report would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2a) Provide inputs to indicators related to hydropower planning and management*. WQMN monitoring suite could be enhanced by integrating sediment and water quality monitoring and including additional nutrient and organic carbon parameters.
- *2. Parameters Monitored; 2c) Able to be measured and analysed at low cost.* Integration of water quality and sediment monitoring could reduce field costs at some sites.
- *2. Parameters Monitored; 2d) Able to help predict as well as explain cause and effect of changes.*
- *3. Timing of Data Collection; 3b) Frequency captures natural or operational system changes and migratory cycle.* Frequency of water quality sampling too low to capture short-term changes associated with hydropower operations.

Objective and Description: The objective of proposal SWH2 is to build upon the existing depth-integrated sediment and water quality monitoring through through**:**

- the collection and analysis of depth-integrated water quality samples at the DSMP sediment monitoring sites; and
- increasing the number of water quality parameters analysed on the existing samples taken at the present WQMN monitoring sites.

The collection of depth-integrated samples for water quality analysis would provide a more accurate measure of the concentrations of water quality parameters associated with suspended solids, which are not uniform through the water column. This type of information is of particular relevance to hydropower planning and management, as it will provide an understanding of the linkages between and processes affecting sediments and water quality parameters, such as nutrients. Including a measure of water clarity, and including the analysis of dissolved reactive phosphorus and particulate organic carbon, will provide a better understanding of nutrients that are relevant to hydropower planning and management.

Linkages:

- This proposal is consistent with Outcome 1 and Outputs 1.1, 1.4 and 1.5 of the EP Work Plan relating to environmental monitoring, assessment and reporting; Outcome 3 and Outputs 3.2 and 3.3 relating to early warning and impact assessment for emerging environmental issues; and Output 4 on capacity-building.
- This proposal has the potential to enhance both the IKMP DSMP and EP WQMN monitoring programmes through the provision of integrated water quality and sediment results. The information will also be of use in providing a more detailed context within which the monthly WQMN samples can be interpreted.
- The proposal is directly relevant to the ISH through the provision of information about how nutrients and organic carbon may be altered by hydropower development, and will provide other monitoring programs, such as conducted by the EP and FP, a context within which to analyze results.
- This proposal supports capacity-building linked to decentralization, and can support BDP processes, the Council and Delta studies and RSAT information needs.

Relevant MRC Procedures or Guidelines: An improved understanding of water quality is relevant to the Procedure on Water Quality and the Technical Guidelines for Implementation of the Procedure for Water Quality.

Proposed Activities and Outputs:

1. Set up dialogue with EP, IKMP and ISH to establish coordination and implementation plan and budget.
2. Establish the required logistics associated with implementing this proposal. This requires cooperation and coordination between the EP WQMN and IKMP DSMP monitoring programs, and the Line Agencies in each country involved with water quality and sediment monitoring. It is envisaged that field work would involve personnel from both Line Agencies, with the sediment agency representatives responsible for obtaining additional depth-integrated water samples at the deepest vertical in the sample transect, and the water quality agency representatives responsible for the handling and transfer of the collected water samples into appropriate water quality sampling containers
3. For the successful integration of sediment and water quality monitoring, it is proposed that field and laboratory capacity-building exercises be completed in each country so the teams associated with the DSMP and WQMN monitoring programmes become familiar with the objectives of the integrated monitoring, and understand the field and laboratory requirements for each discipline. This type of capacity building activity should complement existing capacity-building plans of the EP and IKMP, and support decentralization.
4. As a trial, integrate water quality and sediment sampling at the ISH11 recommended locations identified in Section 2.2 for the 2014 calendar year. Monitoring at these locations would provide more detailed information throughout the LMB and would complement the on-going monitoring at the remaining sites.
5. Report on findings and future actions.

Resource Requirements and Implementation Commitments: As this proposal does not alter or affect the WQMN, additional resources are required for the following. Cost estimates have been requested but not yet received.

- *Field costs:*
  - Transport and DSA for 1 WQMN person to accompany the DSMP field party on 27 occasions over the year
  - Field water quality monitoring probes (pH, EC, T, DO) if needed (up to ~$5,000 if 1 new set of probes purchased for each country)
  - Instrument costs associated with Secchi disk (or equivalent)
- *Laboratory costs:*
  - In relative terms, 54 additional WQ analyses would be required from each country (based on 2 sites being included in each country in the trial). This is roughly equivalent to adding 4.5 additional WQMN sites (monitored 12 times/year) to each country.
  - Additional resources will be required for the dissolved phosphorus and organic carbon parameters. These additional expenses should be relatively small as the analytical methods are similar to other methods currently used for total Phosphorus and TSS.
- Additional funding may also be required to cover costs associated with development and negotiation of the ToRs, and the development and implementation of capacity-building exercises. This work could require up to 3 - 4 weeks of time.

Depending on the availability of resources, the proposed activities could be conducted at a smaller scale through reducing the frequency of depth-integrated water quality sampling (e.g. limit to transition and high flow seasons) and/or reducing the number of water quality parameters analysed (e.g. omit faecal coliform, COD and major cations) from the trial.

Sustainability Considerations: If adopted beyond a trial, the success of integrating water quality with depth-integrated sediment monitoring is dependent on the on-going cooperation and coordination between the Line Agencies in each country to complete the field and laboratory work, and between the IKMP and EP for coordination of the logistics and data management. It is important that countries continue to use the established field and laboratory protocol for the collection and analysis of depth-integrated water and sediment samples following decentralisation. Optimally the trial should be implemented in calendar year 2014, prior to the decentralisation of sediment monitoring, and be used as a capacity-building opportunity in the areas of water quality and sediment monitoring, data management and data interpretation (as described under proposal SWH1).

For the activity to provide maximum information, integrated monitoring should commence well before the onset of the wet season so that any issues with the contracts, methodologies or sampling handling protocol can be resolved prior to the commencement of high flows, and extend through the cessation of the wet to avoid any gaps in the monitoring results, thus providing maximum information.

Outcomes and Benefits: Aligning the collection of water samples with depth-integrated sediment sample collection, and including additional parameters relevant to hydropower needs, would have the following benefits.

- More representative (depth-integrated) samples obtained for water quality analysis.
- Immediate access to this information for the Council Study and the Delta Study for the trial year.
- Water quality and sediment transport and flow information provided from the same monitoring points at the same time so the data sets can be easily integrated. Load calculations are also likely to be more accurate when flow, sediment and water quality information is all collected at the same time.
- The frequency of water quality monitoring increased to align with sediment monitoring would provide more detailed water quality information during the transition and high flow periods of the hydrologic year (samples collected fortnightly or weekly during these periods). These results would provide a detailed water quality record through the wet-season, including ‘first-flush’ events, when high levels of dissolved species and solids are likely to be transported by the river.

6 Conclusions

The ISH11 project has identified opportunities for enhancing MRC water quality monitoring for hydropower information needs. The proposals identified as highest priority include the interpretation of existing water quality, sediment and hydrologic information to derive hydropower-specific indicators, and the integration of water quality sampling with suspended sediment and discharge monitoring. These proposals complement and build upon the existing MRC monitoring activities, and if implemented, would provide an integrated understanding of the present status of the LMB which is necessary to guide the development of sustainable hydropower in the basin.

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.

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Attachment 1 – Annotated Bibliography

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Adamson P, 2006, An evaluation of land use and climate change on the recent hydrological regime of the Mekong. Report to the Environment Programme, Mekong River Commission, Vientiane, Lao PDR.	This report provides an overview of the broad hydrologic characteristics of the Mekong relevant to IBFM and examines changes already occurring due to climate change, which were not identified on a catchment scale
Adamson P, 2006 Hydrological Background and the Generation of Exploratory Flow Regimes for the Development of the Impact Analysis Tools, IBFM Report	Describes components of the hydrological regime of the Mekong River believed to be relevant to IBFM processes and susceptibility to land use changes, and develops hypothetical future flow scenarios reflecting likely future changes due to development
Adamson P, 2006, Generation of Exploratory Flow Regimes for the Development of the Impact Analysis Tools, IBFM Report	Outlines the development of 5 'hypothetical' future mainstream flow regimes reflecting the likely direction of resource development and other man induced changes upon the hydrology of the Mekong over a 20 to 30 year time-frame
Adamson, P, 2007 draft, An Assessment of the Statistical Nature of the IBFM Flow Seasons and Indicators and their Potential Vulnerability to Regional Water Resources Development. IBFM Final Report	This report reviews and refines the flow seasons recognised through the IBFM and develops a preliminary procedure for evaluating their susceptibility to man-induced flow changes. Flow indices identified as most susceptible to change are the hydrology of the dry season and timing of the onset and end of flow seasons
Adamson P, 2009, An assessment of the hydrology at proposed dam sites on the mainstream of the Mekong upstream of Vientiane. Report for the Ministry of Energy and Mines, Dept. of Electricity, Lao PDR. January 2009	Referenced in MRC reports – copy being sought

Reference	Comment
Adamson P, 2009, An exploratory assessment of the potential Rates of reservoir sedimentation in five Mekong mainstream reservoirs proposed in Lao PDR. MRC Internal Report. Mekong River Commission, Vientiane, Lao PDR.	Referenced in MRC reports – copy being sought
Adamson P, and King JL, 2009, The nature of the Mekong – environmental flow indicators for a large tropical monsoonal river system. In press.	Referenced in MRC reports
Adamson P., Sopharith, T. 2006, Hydrological database development for the tributary system of the Tonle Sap great lake, IBFM, Mekong River Commission, Vientiane, December 2006	Provides reliable hydrologic data for the Tonle Sap system based on the collection, quality checking and analysis of available water level and flow results. Data gaps were filled using linear regression techniques and new rating curves derived based on the results
Brown, C., 2007, Integrated Basin Flow Management 4 Review of Flow-Assessment Tools Draft Final Report – 2007. IBFM Report	A review of existing DSS tools for application in the LMB, with emphasis on fisheries models. The report concluded that no existing DSS addressed all needs of the MRC for river management, and recommended a discipline specific integrated approach.
Carling, P, 2005, Geomorphology and Sedimentology. MRC IBFM Phase 2 series of reports.	Describes the fluvial geomorphology of the lower Mekong River and identifies five geomorphic zones in the LMB. Each zone is evaluated with respect to IBFM flow scenarios FR1-FR3 and four key indicators of change are identified
Carling, P, 2009, BDP Scenario assessment specialist report: Geomorphology and sediment. Mekong River Commission, Vientiane	Assessment of sediment and geomorphic impacts associated with the BDP scenarios
Conlan, IA, Rutherfurd ID, Finlayson BL, and Western AW, 2008, The geomorphology of deep pools on the lower-Mekong River: Controls on pool spacing and dimensions, processes of pool maintenance and potential future changes to pool morphology, Final Report to MRC; *and,* Sediment Transport through a Forced Pool on the Mekong River: Sand Dunes Superimposed on a Larger Sediment Wave? Marine and River Dune Dynamics, 1-3 April, 2008, Leeds, United Kingdom.	This work tracked the bedload movement of sand through a pool upstream of Vientiane, and found that the sediment moves as a large coherent wave over the course of the wet season with smaller dunes superimposed on the 'wave'

Reference	Comment
Conlan, I. 2009, Discharge and Sediment Monitoring Project 2009-2010, Final Draft Project Proposal prepared for the Information and Knowledge Management Programme, Mekong River Commission	Provided a 'blue-print' for implementing depth integrated suspended sediment monitoring in the LMB
Eastham J, Mpelaskova F, Mainuddin M, Ticehurst C, Dyce P, Hodgson G, et al., 2008, Mekong River Basin water resources assessment: Impact of climate changes. CSIRO Water for a Healthy Country National Research Flagship report. CSIRO, Canberra. Available from: http://www.clw.csiro.au/publications/waterforahealthycountry/2008/wfhc-Mekong-WaterResourcesAssessment.pdf	Models likely climate change by 2030 in Mekong catchment, and predicts increase in temperature, rainfall, and glacial melt.
Fu KD, and He DM, 2007, Analysis and prediction of sediment trapping efficiencies of the reservoirs in the mainstream of the Lancang River. *Chinese Science Bulletin* 52 (Supp.II) 134–140.	The authors compared the measured sediment trapping efficiency (TE) of the Manwan Reservoir with modelled results and found good agreement with TE=60% using both methods. TE Model results for other impoundments in upper Mekong ranged from 30 to 66%.
Galappatti, Ranjit and Bounvilay, Bounthanh, 2005, Hydraulics. MRC IBFM Phase2 series of reports. DRAFT only	Identified flow indicators which linked river hydraulics with physical and ecological riverine processes, and evaluated 3 potential flow regimes (FR1-3) with respect to these indicators
Gupta A, and Liew S, 2006, The Mekong from satellite imagery: A quick look at a large river. *Geomorphology* 85 (3–4), 259–274.	Used SPOT imagery combined with MRC maps and hydrologic information to identify 8 river units in the Mekong channel
Harden PO, and Sundborg A, 1992, The Lower Mekong Basin suspended sediment transport and sedimentation problems. Hydroconsult, Uppsala, Sweden.	Referenced in MRC reports – copy being sought
Hart BT, Jones MJ, Pistone, 2001, *Transboundary Water Quality Issues in the Mekong River Basin*. Report to the Mekong River Commission, 77 pp.	Examined a range of potential transboundary water quality issues but analysis concluded there was insufficient information available to determine risks

Reference	Comment
Hawkins, P, and Silapanuntakul, S, 2005, Water Quality. MRC IBFM Phase 2 series of reports.	Summarises present water quality characteristics of system and discusses potential changes due to proposed development. Riverine water quality is suggested as being relatively insensitive to hydro power development, but substantial water quality changes are predicted associated with the creation of impoundments, including temperature, dissolved oxygen, water clarity and nutrient concentrations
Hoanh C.T., Jirayoot K., Lacombe G. and Srinetr V. 2010, Impacts of climate change and development on Mekong flow regime. First assessment – 2009. MRC Technical Paper No. 29. Mekong River Commission, Vientiane, Lao PDR.	This paper investigates climate impacts on the BDP scenarios using the Decision Support Framework (DSF) models
ICEM, 2008, MRC SEA Hydrology & Sediment Baseline Assessment Working Paper, Report for the Mekong River Commission prepared by the International Centre for Enviornmental Management	The investigation divides the Mekong Basin into six hydro-ecological zones to summarise information and analyse potential development scenarios identified by the BDP
ICEM, 2010, Strategic Environmental Assessment of Hydropower on the Mekong Mainstream Final Report. Report for the Mekong River Commission prepared by the International Centre for Enviornmental Management.	Final report summarising available information and assessing changes associated with potential hydropower development scenarios
Jirayoot K, 2007, SWAT Model Application for Erosion and Sedimentation of Lower Mekong River Basin. Report to Mekong River Commission.	The Soil and Water Assessment Tool was used as part of the Decision Support System (DSS), with model results showing good agreement with sediment transport results
King J and Brown C, 2010, Integrated basin flow assessments: method and concept developments in Africa and South East Asia, Freshwater Biology, v55 , 127-146	Describes an approach for environmental flow assessment and summarises IBFM work completed in the Mekong catchment in the early 2000s.
Koehnken L, 2012, *Potential sediment contribution in the Lower Mekong River Basin based on GIS analyses and sediment monitoring results.* Contribution to the MRC IWRM Technical Report on Significant Tributaries to the Mekong River System.	A GIS based investigation using landscape attributes to estimate potential sediment input from sub-catchments. Results are integrated with actual sediment monitoring results where available.

Reference	Comment
Koehnken, L, 2012, *IKMP Discharge and Sediment Monitoring Programme Review, Recommendations and Data Analysis, Parts 1 & 2.* Report to the MRC, IKMP.	Reviewed the 2011 depth integrated suspended sediment monitoring program managed by IKMP, presented preliminary data analysis and recommendations for program improvements. The 2011 results showed substantial reductions in sediment transport compared to the long-term estimate of 160 Mt/yr, and additional sediment monitoring was recommended to better understand the sediment transport processes, trends and variability in the river
Kondolf, M, Alford, C, and Rubin, Z, 2011, *Cumulative Effects of Tributary Dams on the Sediment Loads and Channel Form in the Lower Mekong River*: Progress Report through 30 September 2011.	Provides a GIS based geomorphic analysis of sediment sources in the LMB and models the potential changes associated with different development scenarios
Kummu M, and Varis O, 2007, Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River. *Geomorphology* 85, 275–293.	This work examines TSS records and shows there has been a reduction in the Mekong since 1993, and derives theoretical trapping rates of reservoirs. Also discusses downstream impacts of reduced TSS
Kummu, M, Lu, XX, Wang, JJ, Varis, O. 2010. Basin-wide sediment trapping efficiency of emerging reservoirs in the Mekong. Geomorphology, V119, 3-4, p181-197.	Develops a methodology for assessing the Trapping Efficiency of reservoirs in the Mekong, and discusses potential trapping rates in LMB with respect to proposed developments and the distribution of sediment sources in the catchment
Kummu, M. Perry, D., Sarkkula, J., Koponen, J. 2008, Sediment: Curse or blessing for Tonle Sap Lake? Ambio Vol 37. No 3, May 2008 pp158 – 163/	The authors synthesized radiocarbon dating results and concluded overall deposition rates in the Tonle Sap are low, and have been for several millennia, however sedimentation rates at the lake margin and on the floodplain are high and may present a range of issues

Reference	Comment
Kummu,M, Savuth, Y,, Sarkkula, J, and Koponen, J, 2006, Sediment dynamics of Tonle Sap Lake, WUP-FIN Phase II Technical Paper No.8 – DRAFT	Uses TSS results from tributaries and Tonle Sap to derive a sediment budget for the Tonle Sap lake, showing ~70% of sediment is derived from Mekong and 30% form the tributaries,with ~80 of total trapped in the lake. TSS results are also used to explore sedimentation patterns in the lake and show the importance of vegetation in sediment trapping on floodplains
Kummu,M, Savuth, Y,, Sarkkula, J,, Koponen, J, Adamson, P, and Sopharith, T, 2006, Tonle Sap Lake water balance calculations. WUP-FIN Phase II and IBFM Phase III Technical Report 5	Presents a water balance of the Tonle Sap system based on available results for use in understanding the present status of the system and for evaluating potential future impacts
Li, S and He, D, 2008, Water Level Response to Hydropower Development in the Upper Mekong River	Hydrological records between 1960 and 2003 were examined to identify effects at three upstream sites associated with damming. The results showed that changes were significant at the daily and hourly time-scales, but small or not apparent at longer time scales where other processes exerted strong control (climate change, solar activity)
Liu S, Lu P, Liu D, and Jin P, 2007, Pinpointing source of the Mekong and measuring its length through analysis of satellite imagery and field investigations. *Geo-spatial Information Science* 10 (1) 51-56.	This investigation combined satellite remote sensing with field investigations to identify the source of the Mekong and calculate its length
Liu, Z, Colin, C, Trentesaux, A, Siani, G, Norbert, F, Blamart, D, Farid, S, 2005, Late Quaternary climatic control on erosion and weathering in the eastern Tibetan Plateau and the Mekong Basin, Quaternary Research 63:316-328;	This work investigates chemical and physical weathering patterns in the Tibet Plateau and Mekong over the past 190,000 years based on sediment characteristics. Discusses connection between sediment characteristics and processes such as monsoonal weather pattern and glaciation
Lu XX and Siew RY, 2006, Water discharge and sediment flux changes over the past decades in the Lower Mekong River: possible impacts of the Chinese dams. *Hydrology and Earth System Sciences* 10, 181–195.	Reports on an analysis of suspended sediment results which found significant decreases in sediment load at the most upstream LMB monitoring site (Chiang Sean), but no statistical decline at the other sites

Reference	Comment
Lu, XX and Siew, RY, 2005, Water discharge and sediment flux changes in the Lower Mekong River, Hydrol. Earth Syst. Sci. Discuss., v2, 2287-2325.	Same work as described above
Mekong River Commission, 2005, Overview of the Hydrology of the Mekong Basin. Mekong River Commission, Vientiane, November 2005. 73pp.	Summary of hydrologic characteristics of the Mekong River at numerous sites in the LMB
Mekong River Commission, **2003**, State of the Basin Report. Mekong River Commission, Vientiane, Lao PDR.	Comprehensive summary of the LMB
Mekong River Commission, 2005, Overview of the present knowledge of the lower Mekong River ecosystem and its users. IBFM Report 7, Vientiane, 10 November 2005	Summarises the physical characteristics of the lower Mekong River, and presents an understanding of the significance of locations, river attributes or human activities based on the discipline specific IBFM reports
Mekong River Commission, 2006, Hydro-Acoustic Survey of Deep Pools in the Mekong River in Southern Lao PDR and Northern Cambodia. MRC Technical Paper No 11. Mekong River Commission, Vientiane, Lao PDR.	Investigation of Deep Pools which included analysing fish mass and fish density with respect to pool depth
Mekong River Commission, 2006, Hydrological, environmental and socio-economic modeling tools for the Lower Mekong Basin: Tonle Sap Water balance calculations. MRCS and WUP FIN, Vientiane	Referenced in MRC reports – copy being sought
Mekong River Commission, 2006, IBFM - Hydrological Background and the generation of exploratory flow regimes for the development of the Impact Analysis tools, Mekong River Commission, Vientiane, October 2006	Same report as Adamson, 2006
Mekong River Commission, **2007,** Diagnostic study of water quality in the Lower Mekong Basin. MRC Technical Paper No. 15. Mekong River Commission, Vientiane.	This study analysed river water and river-bed sediments for a wide range of conventional parameters, and micro-pollutants The investigation found low levels of measurable pollutants, but several sites showed a positive toxic response to bio-assays.

Reference	Comment
Mekong River Commission, 2008, An assessment of water quality in the Lower Mekong Basin. MRC Technical Paper No. 19. Mekong River Commission, Vientiane	This report derives water quality indices with respect to protection of aquatic life, human impact and agricultural use, and used the indices to evaluate the results of the water quality monitoring programme. Three water quality issues emerged from the investigation: widespread salinity issues due to saltwater intrusion in the delta; acidification arising from the oxidation of acid sulphate soils in the delta and southern Cambodia; and the potential for eutrophication in the mainstream.
Mekong River Commission, 2008, Deep pool mapping and research. *Catch and Culture* 14 (2) September 2008.	General summary of the importance of deep pools as fish habitat
Mekong River Commission, **2008,** The Mekong River Report Card on Water Quality (2000-2005): Assessment of Potential Human Impacts on Mekong River Water Quality. Volume 2, June 2008. Mekong River Commission, Vientiane, Lao PDR.	Presents a summary of water quality and water quality trends in the LMB based on comparing water quality results with established water quality indicators
Mekong River Commission, 2009, The Flow of the Mekong. MRC Management Information Booklet Series No 2, pp11. Mekong River Commission, Vientiane, Lao PDR.	Summary of the hydrology of the Mekong River generally based on the 2005 Hydrology Report
Mekong River Commission, 2009, The impacts of Xiaowan dam in China on the hydrology of the lower Mekong mainstream. Internal Technical Note. Mekong River Commission, Vientiane, Lao PDR.	MRC Internal Technical note referenced in other MRC publications
Mekong River Commission, 2009, The Modelling the Flow of the Mekong. MRC Management Information Booklet Series No 3, pp11. Mekong River Commission, Vientiane, Lao PDR.	Summarises the impact on hydrologic flow indicators of three potential development scenarios related to potential hydropower and irrigation development scenarios

Reference	Comment
Mekong River Commission, 2010, Hydrological Assessment. Assessment of basin-wide development scenarios, Basin Development Plan Programme, Phase 2 Technical Note 3. Mekong River Commission, Vientiane, Lao PDR.	Investigation compares hydrologic conditions in 2000 with various proposed development scenarios, including dams, hydropower, irrigation expansion, cropping patterns and future domestic and industrial water supply demands at different points in the future. The impact of these developments on flows, water level, seasonal dry flows, average and peak flows and flooded areas was assessed using the MRC's Decision Support System (DSS)
Mekong River Commission, 2010, Impacts on Changes in Salinity Intrusion. Assessment of basin-wide development scenarios, Basin Development Plan Programme, Phase 2 Technical Note 8. Mekong River Commission, Vientiane, Lao PDR.	This report summarises investigations into changes in the extent of salt water intrusion associated with a reduction in low river flows
Mekong River Commission, 2010, Impacts on River Morphology. Assessment of basin-wide development scenarios, Basin Development Plan Programme, Phase 2 Technical Note 4. Mekong River Commission, Vientiane, Lao PDR.	This study found that changes in the flow regime and sediment supply associated with dam construction and power station operations are likely to be localised and limited in the short-term, but increase over decadal time-scales
Mekong River Commission, 2010, Impacts on Water Quality. Assessment of basin-wide development scenarios, Basin Development Plan Programme, Phase 2 Technical Note 5. Mekong River Commission, Vientiane, Lao PDR.	Describes the potential for water quality impacts associated with increased development and irrigation scenarios. The pollutant loads to rivers are projected to increase due to increased return flows from irrigated agriculture (pesticides and nutrients) and increased discharges of (untreated) domestic and industrial waste water (BOD, nutrients and pollutants).
Mekong River Commission, 2010, State of the Basin Report 2010. Mekong River Commission, Vientiane, Lao PDR. 232 pp.	Comprehensive summary of the LMB
Mekong River Commission, 2010, State of the Basin Report.	Provides a comprehensive summary of available hydrologic, sediment transport and water quality information for the LMB

Reference	Comment
Mekong River Commission, 2010, The Mekong River Report Card on Water Quality: Assessment of Potential Human Impacts on Mekong River Water Quality, Volume 2. June 2010, Mekong River Commission, Vientiane, Lao PDR.	Presents a summary of water quality and water quality trends in the LMB based on comparing water quality results with established water quality indicators
Mekong River Commission, 2011, BDP Programme Planning Atlas of the Lower Mekong River Basin. Mekong River Commission, Vientiane, Lao PDR. 101 pp. River Commission, Vientiane, Lao PDR.	An atlas which summarises social and environmental aspects of the LMB
Mekong River Commission, 2011, Prior Consultation Project Review Report for the Proposed Xayaburi Dam Project. Mekong River Commission, Vientiane, Lao PDR. 99 pp	Considered the impacts of hydrologic change associated with the construction of the Xayabury Dam on fisheries, sediment transport and morphology, nutrient balance, water quality and navigation
Mekong River Commission, 2012, The Mekong Hydrological Cycle Observing System Mekong-HYCOS, A Hydrological Information System in the Mekong River Basin. Final Report for the Symposium on Hydro-Meteorological Networks (September 2012). Mekong River Commission, Vientiane, Lao PDR.	This report summarises the implementation of the HYCOS system, including equipment descriptions, time-tables and resource requirements associated with the project
Nguyen Nghia H, 2011, Sediment dynamics in the floodplain of the Mekong Delta, Viet Nam. Institute fur Wasserbau, Universitat Stuttgart.	Investigation of sediment dynamics and water quality in the Plain of Reeds on the Mekong Delta, and quantified deposition rates
Nguyen V, Ta K and Tateishi M, 2000, Late Holocene depositional environments and costal evolution of the Mekong River Delta, southern Viet Nam. *Journal of Asian Earth Sciences*, 427–439.	This work discusses possible reasons for the very fast progradation of the delta, which has occurred since 4500BP. High sediment loads, changing sea levels, the inclination of the depositional basin and presence of mangroves are all identified as potential factors
Nguyen, AD, Savenije, HHG, 2006, Salt intrusion in multi-channel estuaries: a case study in the Mekong Delta, Viet Nam. J. Hydrol. Earth Syst. Sci., 10, 743-754	This investigation compared modified an existing salt-intrusion model to accurately predict salt intrusion in the Mekong estuary. The work used actual measurements to calibrate the model.

Reference	Comment
Penny D, 2006, The Holocene history and development of the Tonle Sap, Cambodia. *Quaternary Science Reviews* 25, 310–322.	Biostratigraphic and sedimentological data was used to examine the development and history of the Tonle Sap system. Findings include the depth of the lake was less variable in the past and may have been affected by saline tidal waters associated with higher-than-present seas levels
Poulsen AF & Valbo-Jorgensen J, 2001, *Deep Pools in the Mekong River*. Mekong Fisheries Network Newsletter, 7:1, September 2001.	Describes investigations of deep pools in the Mekong and describes how these habitats provide refuges and migration links for a number of important fish species
SIWRP 2008, The assessment of impacts of sea level rise on the flood and salinity intrusion in the Mekong River Delta and lower basin of Dong Nai River. Southern Institute for Water Resources Planning 2008. Southern Institute for Water Resources Planning, Ho Chi Minh City, Viet Nam.	Referenced in MRC reports – copy being sought
Ta TK, Nguyen VL, Tateishi M, Kobayashi I, Tanabe S and Saito Y, 2002, Holocene delta evolution and sediment discharge of the Mekong River, southern Viet Nam. *Quaternary Science Reviews* 21, 1807–1819.	Sedimentological evidence from 6 bore holes in the lower delta plain show that over the past 3000 years the delta has prograded under increased wave influence and southeastward sediment dispersal. Deposition rates suggest the sediment load has remained stable over this time period, and similar to present load of 141 Mt/yr.
Tamura T, Saito Y, Sotham S, Bunnarin B, Meng K, Im S, et al. 2009, Initiation of the Mekong River Delta at 8 ka: Evidence from the sedimentary succession in the Cambodian lowland. *Quaternary Science Reviews* 28, 327–344.	The evolution of the Mekong delta and lower river system over the past 8,000 years is revealed through 3 cores in the Cambodian Lowlands, and show a shift from estuarine to fluvial conditions since 6300BP. An increase in sedimentation rates is observed between 1000 and 600 BP and is suggested as being linked to human activities.

Reference	Comment
Thorne C, Annandale G, Jensen K, Jensen E, Green A & Koponen, 2011, Review of Sediment Transport, Morphology, and Nutrient Balance. Report to the Mekong River Commission Secretariat prepared as part of the Xayaburi MRCS Prior Consultation Project Review Report, Nottingham University, UK February 2011. 82pp.	This expert sediment panel examined the potential for transboundary impacts and long-term cumulative effects associated with construction and operation of the Xayaburi Dam in the context of other existing and planned dams. The group considered a range of development scenarios and estimated that sediment trapping by reservoirs is likely to vary between 40%, under the 2000 baseline scenario to 75% to 100% under a Foreseeable Future Scenario which includes all planned and existing mainstream dams in China, 6 mainstream dams in Lao PDR, 5 mainstream dams in Cambodia, and 71 tributary dams
Walling DE, 2005, Evaluation and analysis of sediment data from the Lower Mekong River, Report prepared for the Mekong River Commission.	Analysis of sediment data between 1960 and 2005 which found no clear evidence of a reduction in sediment load at sites within the LMB following dam construction, although the representativeness of some of the samples was questioned
Walling, DE, 2005, Analysis and evaluation of sediment data from the Lower Mekong River. Report submitted to the Mekong River Commission, Department of Geography, University of Exeter.	In depth analysis of available depth integrated and TSS data to provide an analysis of sediment transport in the LMB over time.
Walling, DE, 2008. The changing sediment load of the Mekong River. *AMBIO* 37 (3): 150-157.	Journal article based on work presented in MRC report.
Wang JJ, Lu XX & Kummu M, 2009, Sediment Load Estimates and Variations in the Lower Mekong River. River.Res. Applic. 27:33-46 (2011). Published on line 22 December 2009 in Wiley Online Library.	The investigators used indirect methods of sediment transport to estimate loads and evaluate the impact of dams on the mainstream in the UMB on sediment supply between 1962 and 2003 The authors conclude that the mean annual sediment transport in the Mekong probably increased during the period of dam construction (1986 – 1992) and decreased following initiation of dam operation (1993–2003) at Chiang Sean, although other catchment activities cannot be ruled out as contributing to these changes.

Reference	Comment
Wang, JJ, Lu XX, and Kummu M, 2011. Sediment load estimates and variations in the lower Mekong River. River Research and Applications 27:33-46.	Same as above
Wolanski E, Huan, NN, Dao, LT, Nhan NH, Thuy, NN, 1996, Fine-sediment dynamics in the Mekong River Estuary, Viet Nam. Estuary, coastal and shelf science 43, pp565-582	Referenced in MRC reports – copy being sought
Wolanski E, Nhan NH, Spagnol S, 1998, Sediment dynamics during low flow conditions in the Mekong River estuary, Viet Nam. Journal of coastal Research 14:2 (Spring 1998), pp472-482	Referenced in MRC reports – copy being sought
Xue, Z, Liu, JP and Ge, Q, 2010, Changes in hydrology and sediment delivery of the Mekong River in the last 50 years: connection to damming, monsoon and ENSO. Earth Surface Processes and Landforms, 36:296-308	This investigation found that since the construction of dams in the Mekong basin, runoff shows a closer connection with regional rainfall, and maximum and minimum water levels at the delta monitoring sites have decreased. It is suggested that the decrease in water slope associated with the decreased water levels has the potential to weaken sediment delivery to the delta

Attachment 2 – Response to Comments Raised in National Consultations

The following comments have been extracted from minutes associated with the ISH11 Regional and National Consultation meetings. Details of the meetings and general information related to general comments about the ISH11 Project is contained in Attachment 3 of the Phase 2 Report. The following comments are specific to the disciplines of hydrology, water quality and sediment. They are presented in chronological order.

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1 Cambodia, 1st National Cambodian – 5 April 2013

Comment: Important concern is whether the monitoring station at Prek Kdam can cover enough the Tonle Sap area, particularly for some disciplines such as aquatic ecology, sediment and geomorphology.

Response: The ISH11 Project will be working in cooperation with the existing MRC Programmes and monitoring projects to enhance information available for hydropower planning. If there is potential within an existing monitoring programme to extend the ISH11 recommendations to additional or new monitoring sites, then coverage can be extended. Line Agencies within each country can also use the recommendations to guide national monitoring activities;

Comment: For Sediment, in 2013 Tonle Sap location will be included for monitoring. It was also suggested to add to Sediments & geomorphology proposals the followings:

- Capacity building and joint river survey on geo-morphology to Staff of DHRW/MOWRAM, and
- Equipment Maintaining and technical support for sediment survey.

Response: Any ISH11 funded or related capacity building activities will be coordinated with and delivered through existing MRC Programme activities. Initial discussions between ISH11 and IKMP have identified potential areas for capacity building which would target the collection and use of geomorphological data and the operation and maintenance of sediment monitoring instruments. All ISH11 Proposals associated with hydrology, sediments and water quality contain capacity building components. The Joint River Survey was proposed in earlier ISH11 reports, but based on feedback received it is no longer an ISH11 proposal.

Comment: Additional point suggested to water Quality Proposal was Upgrade equipment and Capacity building for WQ Office/DHRW/MOWRAM.

Response: Any ISH11 funded or related capacity building activities will be coordinated with and delivered through existing MRC Programme activities The EP-WQMN has an activity directed towards evaluation of laboratory capacity. The ISH11 Proposal SWH2: *Water Quality Monitoring Enhancements for Hydropower Information*, contains a capacity building component, and if implemented would aim to complement with on-going WQMN capacity building to extend to field techniques associated with water quality monitoring, including *in situ* measurement of parameters including pH, EC, DO, clarity, etc., collection of depth-integrated water samples, and sample handling and transport.

Comment: Two additional points to Hydrology Proposal were suggested, including:

- Install new hydrology station at the down-stream site of Hydropower dam for monitoring down stream flow from dam, (Ex. Xayabori dam need install down- stream site, and 3S need install the last dam at downstream to monitoring flow to DS); and
- Capacity Building on Rule Curve Analysis (reservoir operation flow) to MOWRAM Staff.

Response: ISH11 has recommended monitoring locations of high priority for hydropower information needs (see ISH11 Phase 2 Main Report Section 2.2.2), some of which would be new monitoring locations. The ISH11 study will not be establishing new monitoring sites. Any new sites would need to be agreed to and established by the existing monitoring programmes. ISH11 personnel have held discussions with the IKMP about capacity building exercises addressing the use of hydrologic data. Inclusion of topics such as 'Rule Curve analysis will be considered for inclusion in workshops.

Comment: Capacity on data collection technique, sampling, data keeping, and analysis and interpretation for additional parameters are required.

Response: ISH11 Proposal SWH1, *Integrating Sediments, Water Quality and Hydrology for Hydropower Indicators,* SWH3: *Sediment Monitoring Enhancements for Hydropower Information* have capacity building components which aim to deliver training in the collection, management and analysis of multi-disciplinary data. Capacity building would be developed and delivered cooperatively with the IKMP.

Comment: Geomorphology monitoring is very important and new to monitoring staff at MOWRAM. Therefore, there is need to develop capacity on technique and equipment use.

Response: ISH11 Proposal SWH4, *Geomorphic Methods for Hydropower Information* is will specifically address the need for a greater understanding of large scale geomorphic processes in the LMB, and will include capacity building on how to undertake monitoring and interpret results where possible.

Comment: Short training course will not be enough, there is need to have opportunity for learning by doing process with enough time for theory and practical work to learn fast and to gain enabling capacity in monitoring work.

Response: Discussions between ISH11 and the IKMP are continuing about the potential to develop and deliver field and classroom based capacity building exercises in the area of hydrologic and sediment monitoring. These activities are considered very important due to sediment monitoring scheduled for decentralisation beginning in 2015. This will be discussed during national consultations.

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2 Viet Nam, 1st National Consultation - April 18

Comment: Agreed that the (ISH11) project should focuss on the Mekong mainstream and lower tributaries important to understanding mainstream processes and condition. However, at the begining, the signficant tributies or lower tributaries should be defined for common understandings, those even could be used in ISH project report.

Response: ISH11 has identified the need for additional information from tributaries in order to better interpret monitoring results from the Mekong mainstream. Tributary locations are included in the 33 locations identified as important to hydropower information needs (see Section 2.2.2 in the ISH11 Phase 2 Main Report). The ISH11 Phase 3 will not include the establishment of new monitoring sites. Any new sites would need to be identified and agreed through the existing MRC Programmes and member countries.

Comment: Some modern technologies including some GIS tools, remote sensing photos should also be considered during its baseline monitoring programme design.

Response: ISH11 proposal SWH4: *Geomorphic Methods for Hydropower Information* proposed the use of ADCP profiles, aerial photos and potentially other GIS related techniques to better understand large scale, longer term geomorphic processes in the LMB. ISH11 proposal SWH3: *Sediment Monitoring Enhancements for Hydropower Information* proposes deployment and trialling of an *in situ* sediment probe to measure the size and mass of suspended sediments.

Comment: There should be more activities on national capacity building strengthening, especially technical training on (modeling, tools, data processing and analysis….),

Response: Each of the ISH11 proposals associated with hydrology, water quality or sediments contains capacity building components.

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3 Lao PDR, 1st National Consultation - May 9-10, 2013

Comment: On new monitoring stations, the meeting provided a floor to the participants to shares opinions on the five newly proposed monitoring stations (1. Xayabouri; 2. Pak Chom; 3. Nongkhai-Nakhon Phanom; 4. Pak Kum; and 5.Khongchiam/Ban Singsamphane). The main issues concerned were if the proposed new monitoring stations would be economically effective, efficient, and sustainable.

Response: The ISH11 team is acutely aware of the importance of maintaining the existing HYCOS sites. The ISH11 study will not establish any additional monitoring sites. Rather, additional sites need to be considered in the longer term by the MRC Programmes, with resource availability a major consideration.

Comment: One suggestion rose from the representatives from the Department of Meteorology and Hydrology said that the project ought to add “meteorological data” to provide better understanding on the climate change in the region.

Response: The ISH11 gap analysis has identified monitoring additional meterological parameters (evaporation, wet bulb temperature) as part of the HYCOS network would be beneficial. This is best addressed collaboratively between the countries and the MRC through the on-going development of the HYCOS network.

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4 Cambodia, 2nd National Consultation - 12-13 September

Comment: Information about landscape and fisheries are also needed.

Response: ISH11 proposal SWH1: *Integrating Sediments, Water Quality and Hydrology for Hydropower Indicators*, and SWH4: *Geomorphic Methods for Hydropower Information* both contain elements aimed at increasing the understanding of fluvial geomorphic processes over short to long-term time scales. Other aspects of landscapes are beyond the scope of the ISH11 study, but it is agreed these can be highly important in the locations of specific hydropower projects. Fisheries is addressed in the ISH11 study through the Fisheries Annex to the ISH11 Phase 2 Report.

Comment: The impacts of hydropower on the Tonle Sap Lake is identified as a high priority issues, therefore data and information are very valuable for Cambodia. It was suggested that additional monitoring of this important ecosystem is needed. The Tonle Sap Authority strongly proposed the ISH11 Team to consider an additional monitoring location at Phat Sanday, which is the bottle neck part of the Tonle Sap Lake due to it is a hot spot site (where important wetland is located), this monitoring site can detect impact from hydropower on the upstream of Stung Sen River (planned project) on the wetland and the Tonle Sap Lake.

Response: The ISH11 team recognises the importance of the Tonle Sap, and has identified the need for sufficient monitoring to accurately understand water and sediment fluxes entering and exiting the system to the Mekong. The ISH11 study is not establishing additional monitoring sites. The long-term monitoring recommendations to be made in ISH11 Phase 4 are likely to continue to reflect this need for increased understanding of the Tonle Sap system.

Comment: The data analysis from ISH11 should help the riparian countries in providing information about the impacts of hydropower development to decision makers. At the moment, it is not clear to what extent data analysis can help.

Response: The ISH11 Proposal SWH1: *Integrating Sediments, Water Quality and Hydrology for Hydropower Indicators* is aimed at identifying the types of analyses of most use in tracking and understanding flow, sediment and water quality changes associated with hydropower projects. These types of analysis can be incorporated into capacity building exercises to provide a common group of indicators / parameters related to hydropower in the LMB. ISH11 Information Use improvement proposals (see Main Report Section 4.7) are aimed at finding ways to improve linking information monitored to decision-making needs.

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5 Viet Nam, 2nd National Consultation - 10- 11 Oct 2013

Comment: At the moment, the MRC survey on fine sediment, but in the ISH, survey would be on bed load sediment, is there any **big difference** and how to harmonize these. It is therefore necessary to clearly identify which parameters could be used for specific analysis and collection. Which sites are selected and which models should be used.

Response: Suspended load and bedload sediment movement are both important to understand. Suspended load tends to comprise the majority of sediment transported by a Mekong, but bedload is important because it tends to be important for bank and island formation and maintenance, and is the material which is trapped in reservoirs. The aims of the ISH11 SWH2: *Water quality Monitoring Enhancements* for Hydropower *Information* and SWH3: *Sediment monitoring enhancements for Hydropower Information* are to provide a snapshot of *everything* moving through the river at a specific place and point in time. This promotes a better understanding of the river and allows accurate water, sediment, water quality time-series, fluxes and budgets to be derived.

Comment: There should be more clearer activities on national capacity building strengthening, especially technical training on (modeling, tools, data processing and analysis….),

Response: Each of the ISH11 proposals associated with hydrology, water quality or sediments contains capacity building components. Capacity building would be integrated with existing MRC Programme capacity building exercises.

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6 Lao PDR 2nd National Consultation - 31 October-1 November, 2013

Comment: The representative from the Department of Meteorology and Hydrology suggested to have a separate table for priority hydrological monitoring stations with consistent stations name, location (N and E), located river names, station IS code, zero gage of station, country name and distance from sea. It is also suggested that ISH11 from each country should coordinate with the Department of Meteorology in member countries to complete this table before next national consultation workshop.

Response: The ISH11 Hydrology Annex contains a list of HYCOS sites, including river names, country names and station codes. A more detailed table, including distance from the sea and zero gauge level could undoubtedly be compiled based on information available from the IKMP. This is beyond the scope for Phase 2 of the ISH11.

Comment: In general, the participants agreed in principle to have more monitoring locations as proposed by the project team. However, it is widely understood that the government is having difficulties in the maintaining the existing monitoring stations. Thus, many participants suggested to use the limited available fund to upgrade the existing monitoring stations, especially those hydrological monitoring station along the mainstream. Specific suggestions for upgrade include replacing the manual measuring equipment with automatic measuring equipment to ensure accurate and consistent data collection

Response: The ISH11 team has identified maintenance of the existing HYCOS network as necessary for the provision of information relevant to hydropower needs. The ongoing maintenance of the network is beyond the scope of the ISH11 study, but will be considered when discussing future directions with Member Countries and MRC Programmes.

Comment: In 2011, MRC had conducted geomorphic survey on the mainstream from Chiang Sean to Pakse, but the report is not yet published so far. The representative suggested the project team to check if the report is already available at the MRCs.

Response: The channel cross-sections and bed material analyses completed in 2011 have not yet been published in a report. The information is being included in the multi-disciplinary data management project currently being completed by MRC/IKMP/ISH/GIZ, and the information will be available to draw on if the proposal SWH1: *Integrating Sediments, Water Quality and Hydrology for Hydropower Indicators* is implemented.

Comment: It was also suggested to increase the analysis of risks and impacts and emphasize on information exchange. The information should be introduced to school education to enhance risk management awareness at local level and to better mitigate the negative impacts relating to hydrological changes.

Response: The ISH11 project is aiming to provide information relevant to hydropower needs, which can be used by community based projects to assist the community to understand, predict and manage hydropower related impacts. ISH11 Information Use improvement proposals (see Main Report Section 4.7) are aimed at finding ways to improve availability of hydropower-relevant information for different end-users, including educational uses.

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7 Thailand, 1st National Consultation - 4 July 2013

No comments specifically related to hydrology, water quality or sediments.

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8 Cambodia, Technical Workshop - August 2013

Comment: HYCOS works well, except a small missing data which occurred when the mobile Information system changed the point name. Water level and rainfall monitoring continues, however, there is a lack of spare parts, which will become a bigger problem in the future.

Response: Maintenance of the existing HYCOS network including data management, training and adherence to SOPs has been recognised by the ISH11 team as necessary for the provision of information to underpin hydropower development and management. The on-going maintenance of the network is beyond the scope of the ISH11 study, but will be considered when discussing future directions with the MRC Programmes and Member Countries.

Comment: Sediment is measured together with discharge with the purpose to detect changes in river morphology and in sediment transport, but now this monitoring ends. It is hoped that the ISH11 Project will provide financial support to continue the monitoring work.

Response: The ISH11 team is aware that the IKMP is in the process of resolving the funding issue for sediment monitoring, and monitoring is scheduled to recommence.

Comment: The monitoring team also indicated the need for capacity building with respect to the analysis and interpretation of hydrologic, sediment and water quality results.

Response: ISH11 Proposal SWH1, *Integrating sediment, water quality and hydrology for Hydropower Indicators*, and SWH3: *Sediment Monitoring Enhancements for Hydropower Information* have capacity building components which aim to deliver training in the collection, management and analysis of multi-disciplinary data. Capacity building would be developed and delivered cooperatively with the IKMP.

Comment: The potential for conducting inter-lab comparisons between laboratories was discussed and supported.

Response: This aspect of capacity building will be discussed with the EP – WQMN and implemented if agreed.