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MRC Initiative on Sustainable Hydropower (ISH)

IMPROVED ENVIRONMENTAL AND SOCIO-ECONOMIC BASELINE INFORMATION FOR HYDROPOWER PLANNING

ISH11 PHASE 2 REPORT: Sediment & Geomorphology Annex

20 December 2013

MRC Initiative on Sustainable Hydropower (ISH)

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Abbreviations and Acronyms

ADCP	Acoustic Doppler Current Profiler
AHNIP	Appropriate Hydrological Network Improvement Project
ANZECC	Australian and New Zealand Environment and Conservation Council
BDP	Basin Development Plan (of the MRC)
BOD	Biological Oxygen Demand
DSMP	Discharge and Sediment Monitoring Programme
DSS	Decision Support System
DPSIR	Drivers, Pressures, State, Impacts, Responses
EDI	Equal Discharge Increment
EP	Environment Programme (of the MRC)
EWI	Equal Width Increment
EU	European Union
FP	Fisheries Programme (of the MRC)
GIS	Geographic Information System
GIZ	Technical Cooperation of the Government of Germany
HYCOS	Hydrologic Cycle Observing Station
IBFM	Integrated Basin Flow Management
IKMP	Information and Knowledge Management Programme (of the MRC)
ISH	Initiative on Sustainable Hydropower (of the MRC)
ISO	International Standards Organisation
IWRM	Integrated Water Resource Management
LMB	Lower Mekong Basin
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
Mt/yr	Million tonnes per year
NMC	National Mekong Committee
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PNPCA	Procedures for Notification, Prior Consultation and Agreement (under the 1995 Mekong Agreement)
PDR	People's Democratic Republic
PWUM	Procedures for Water Use Monitoring
QA/QC	Quality Assurance / Quality Control
SoB	State of the Basin
SWAT	Soil and Water Assessment Tool

ToR	Terms of Reference
TSS	Total Suspended Solids
UMB	Upper Mekong Basin
USGS	United State Geological Survey
WMO	World Meteorological Organisation
WQMN	Water Quality Monitoring Network
WWF	World Wide Fund for Nature

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1 Context of Sediments & Geomorphology in the ISH11 Project

Sediment transport and geomorphology are fundamental characteristics of a river which play important roles with respect to aquatic habitats, fisheries, water quality, floodplain agriculture, sand mining, navigation and river bank stability. Sediment transport and geomorphology processes need to be considered over a range of spatial and temporal time-scales, from instantaneous 'events' to progressive changes over decades, centuries and even millennia. Sediment transport must be a key consideration when designing, implementing or managing sustainable hydropower, because of the potential for hydropower development to alter sediment movements, which in turn can affect the physical and ecological characteristics of a river, with economic and social flow on effects.

Within the ISH11 Study, the objective is to enhance the availability and usefulness of information relevant to sediment transport and geomorphology in the context of hydropower information needs. These needs include:

- catchment-wide information to provide a large scale context for the siting of hydropower developments, an understanding of potential cumulative effects or impacts, and transboundary impacts;
- seasonal and inter-annual sediment delivery patterns relevant to the development and implementation of mitigation and sediment management strategies;
- regional sediment transport information relevant to reservoir and power plant design; and
- local information for predicting, mitigating and managing upstream and downstream impacts of individual hydropower projects.

Sediment transport cannot be considered in isolation. An important component of the ISH11 Study is the identification of integrated monitoring strategies which have the potential to link sediment transport processes with ecological, fisheries, social and economic information. Important linkages include the following.

- Sediment transport and sediment characteristics are critical to the distribution and condition of aquatic habitats which are linked to the distribution of aquatic organisms and to biological productivity.
- The movement and availability of sediment-associated nutrients are important for water quality and aquatic ecology, including floodplain processes and productivity.
- Sediment movement is of social relevance, in that it directly affects bank stability, river navigation, sand mining, floodplain agriculture, and the potential longevity and economic viability of irrigation and hydropower impoundments and infrastructure.
- Sediment movement at short temporal scales can be linked to larger scale, longer time frame geomorphic investigations to provide insights into the processes operating in the catchment over longer time scales.

2 Best Practice for Sediment & Geomorphology Monitoring Programmes

The movement of sediment in rivers is governed by the supply of sediment and the flow regime. How sediment moves through a river is dependent on sediment supply, size and shape of the sediments, flow velocity, and channel morphology. The total sediment load can be divided into the suspended sediment load, which is carried by the river without interacting with the river bed, and the bedload which moves via traction or saltation on or near the river bed. Fine sediments (<63µm), which rarely interact with the bed, are frequently termed the 'wash-load'. Coarser material can travel either as suspended load or bedload, depending on the flow velocity of the river. The variability of sediment transport in a natural river is demonstrated in Figure 1 where the distribution with depth of different sediment classes is shown for the Missouri River in the U.S.A. Fine-sand and larger material is preferentially transported in the lower water column near the bed, where silts and clays are transported more uniformly over the entire water column. It is for this reason that Total Suspended Solid (TSS) measurements completed on 'surface grabs' tend to under estimate suspended sediment concentrations due to sand being under represented in the sample.

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

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

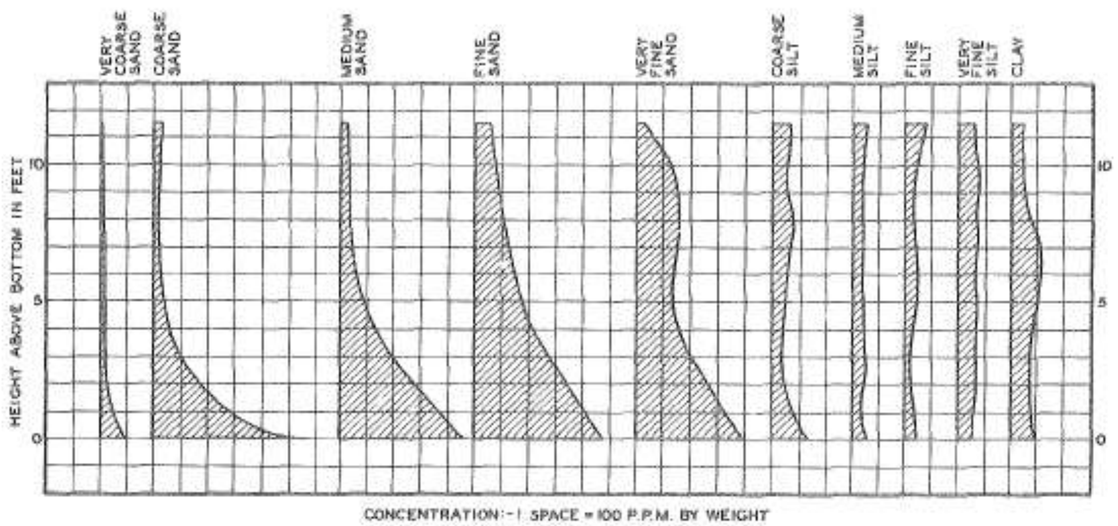

Figure 1 – Distribution with depth of different sediment classes in the Missouri River, Kansas City Missouri (Federal Interagency Project Reports, 1963)

2.1 Suspended Sediment Sampling

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

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

A representative suspended sediment sample can be collected at a point using a depth integrated, flow-proportional sampler (Figure 2). The sampler consists of an outer chamber with fins which maintains the sampler orientated into the current during sampling, and a nozzle attached to a plastic bag which fits slides into the outer unit. The sampler weighs about 60 kg which allows it to be deployed vertically in the river at flow velocities up to ~4 m/s.

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

Figure 2 – Depth integrating suspended sediment sampler (model D-96). Photos from USGS, 2005

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

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

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

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

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

Figure 3 – Suspended sediment and water quality churn splitter used to accurately subsample composited suspended sediment samples

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

2.2 Bedload sampling

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

Several styles of bottom samplers have been developed (basket samplers, tray samples, pressure difference samplers), with the BL-84 pressure sampler commonly used and adopted for use in the Mekong DSMP (Figure 4).

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

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

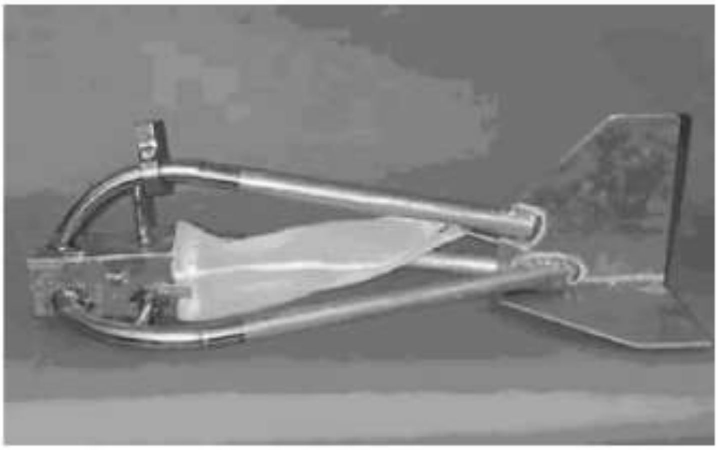

Figure 3 – U.S. BL-84 bedload sediment sampler

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

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

2.3 Bed Material Sampling

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

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

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

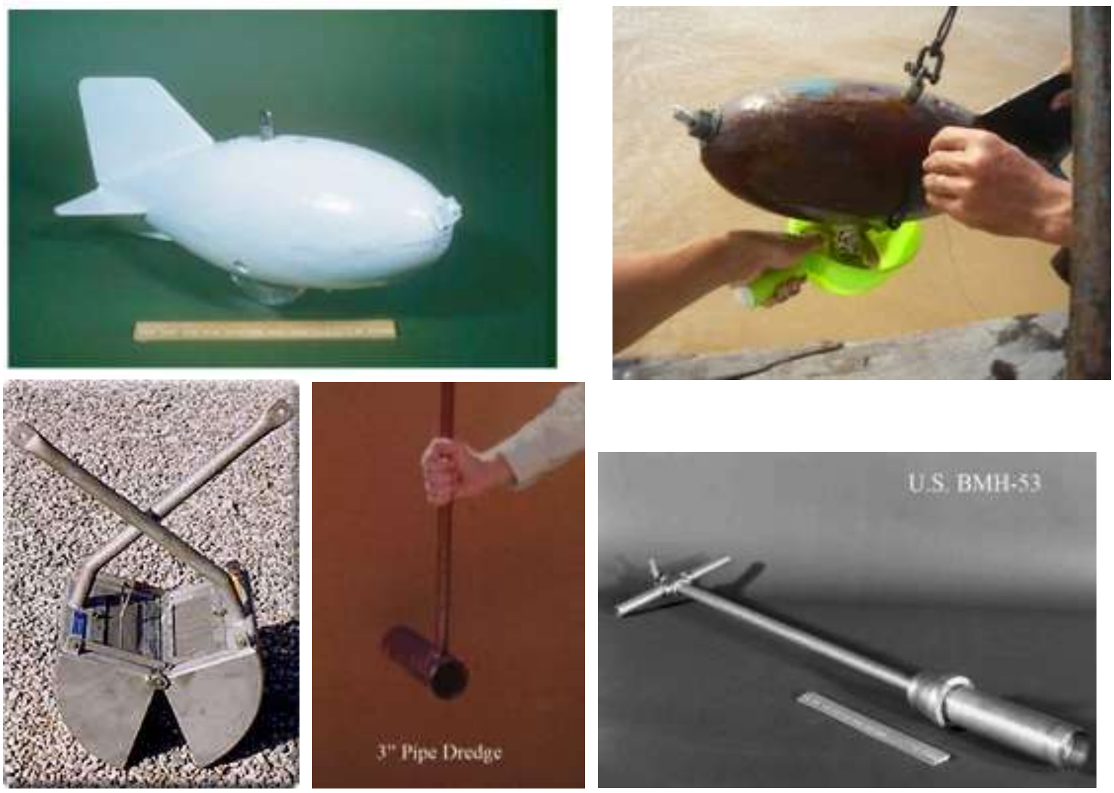

Figure 4 – Top: BM-54 spring loaded bed material sampler, and material being removed from sampler after collection, bottom: bed material grab sampler, pipe dredge sampler and piston corer. Photos from USGS manuals and publications except for top right (author's photo) and grab sampler (www.duncanandassociates.co.uk.com)

2.4 Geomorphology monitoring

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

Gaining a large-scale understanding of the geomorphic setting of a river basin is a first step to understanding fluvial geomorphology. This includes identifying the geology, climate and basin-scale developments or alternations (water diversions, impoundments, etc.) that will drive changes in the catchment over long time-scales. Geologic, topographic, climatological and hydrological information is generally integrated to identify large-scale geomorphic provenances, which have similar characteristics. GIS tools are typically used for this scale of analysis. An example of geomorphic provenances identified by Kondolf *et al.,* 2012 for the Mekong basin is shown in Figure 6.

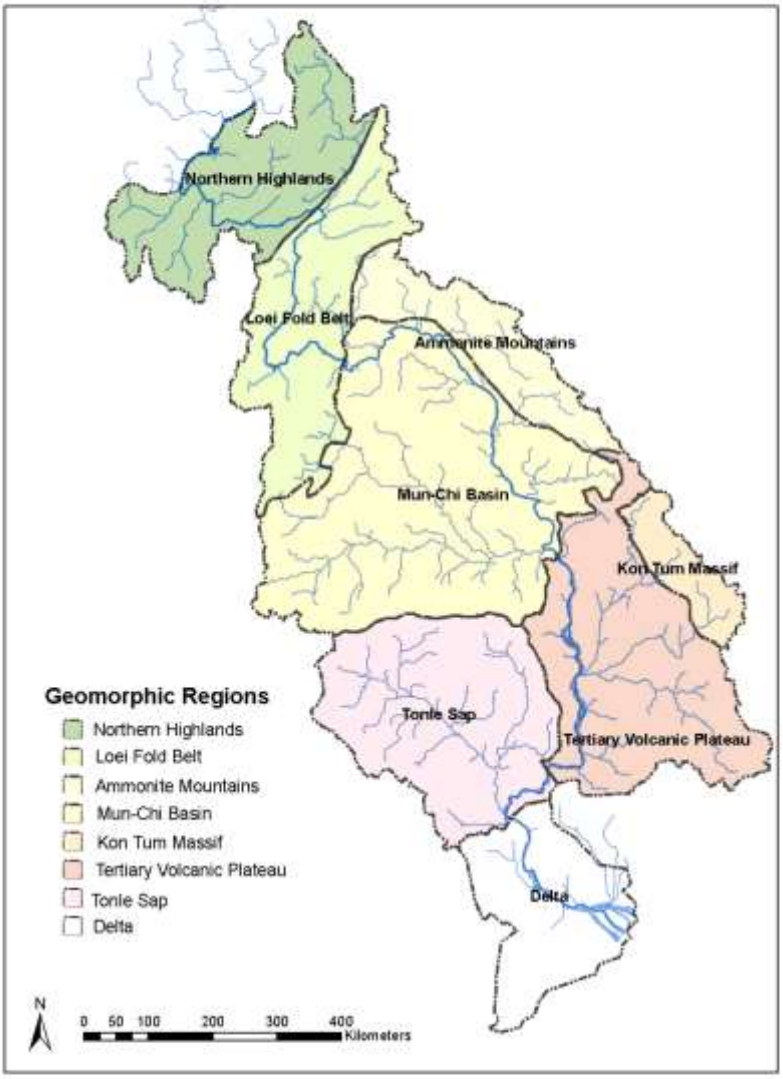

Figure 5 – Geomorphic regions in the Mekong River based on tectonic history, current relief and rock type (Kondolf, *et al.,* 2012)

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

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

At this scale, understanding and linking seasonal / annual / decadenal or longer river flow and sea level patterns and trends to geomorphic characteristics is important, such as identifying annual and greater flood or low-flow levels, estimating the duration of bank or bar inundation or exposure, recognising previous sea level stands and identifying local hydraulic features which will affect geomorphic processes at the river reach scale (gorges, pools, availability of flood plain, etc). Integrating this meso-scale level of information can assist in defining geomorphic 'zones' within rivers which have similar characteristics, and are likely to behave similarly. An example of a long-section of the Mekong showing the variability of river slope in the river and previous sea levels is shown in Figure 7, and is useful for predicting the hydraulic characteristics of different river reaches.

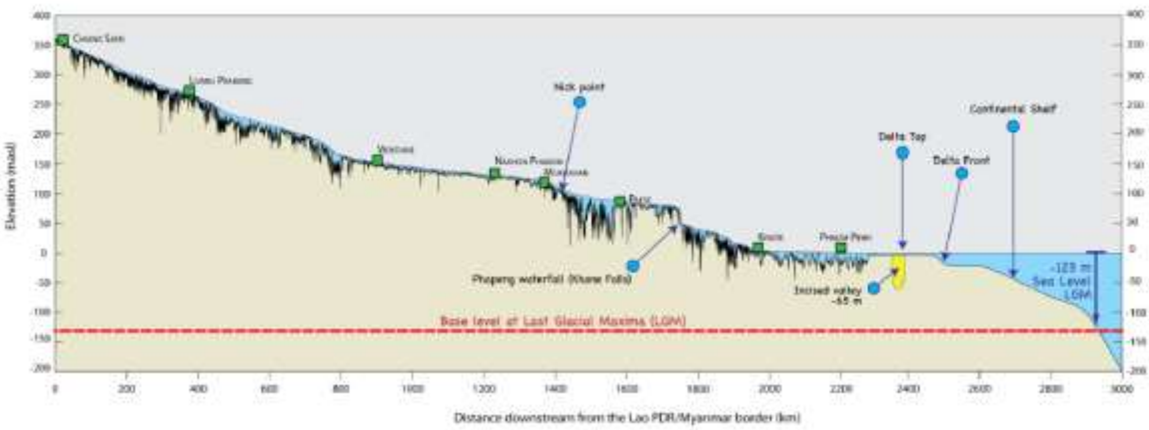

Figure 6 – Long-section of the Mekong River from Chiang Saen to the sea. Used courtesy of Tim Burnhill in Kondolf et al., 2012

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

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

3 Sediment Monitoring and State of Knowledge

3.1 Overview of Sediment Monitoring in the LMB

Ongoing sediment monitoring in the LMB is being coordinated by the IKMP through the Discharge Sediment Monitoring Programme (DSMP). Under the DSMP, each country collects flow and suspended sediment samples at monitoring sites within or on the countries border. The MRC receives the results, and is responsible for QA/QC procedures, and making the datasets available. The MRC through the IKMP has also provided substantial funding for equipment acquisition and upgrades and capacity building through the training of field and laboratory personnel.

The DSMP design for 2012-13 included the collection of suspended sediment samples at 17 sites, 13 on the mainstream, one on the Tonle Sap, and two on the Bassac River and one at the mouth of the Sekong River system (Figure 8, Table 1). Sampling is completed using Best Practice methods as described in Section 1, with depth integrated samples being collected at 5 points across the river using the EDI method. The samples obtained at each vertical are individually analysed for mass. The grain-size distribution of suspended sediments is determined at a sub-set of the sites through the collection of a large volume depth integrated suspended sediment sample which is transported to the laboratory for subsequent sieving and settling column.

The monitoring strategy includes bedload sediment sampling at the four sites indicated in Table 1.

The sampling design of the monitoring project reflects the strong seasonal discharge pattern of the Mekong, with weekly samples collected during the peak wet season, fortnightly samples collected during the onset and diminishment of high flows, and monthly sampling during the dry season. This is adequate to capture sediment variability, as >83% of sediment transport occurs between June and November (based on 2011 results, Koehnken, 2012).

Data reporting and management procedures have been developed and implemented as part of the DSMP. Standardized field sheets are used to guide monitoring, and each country reports field and laboratory results to the IKMP using a standard set of electronic data forms. These forms include quality control elements that check the internal consistency of the results. The IKMP collate the results and complete additional QA/QC procedures. The results are not yet available on the Master Catalogue but will be in the near future.

A review of the DSMP in 2012 (Koehnken, 2012) found that the project was successful at monitoring a very large and highly variable river at appropriate temporal and spatial scales. Recommendations for refining the program included:

- minor alterations to some of the sampling locations to reduce sampling bias associated with cross-channel sediment gradients;
- extending the collection of depth integrated sediment sampling into major tributaries;
- standardising grain-size analysis size classes and analytical techniques between countries; and
- the development of an integrated sediment, water quality and hydrologic database.

Figure 8 – Discharge Sediment Monitoring Programme monitoring sites. One additional site has been included in 2012 – 2013 at the mouth of the Sekong River, which is not included on the map

Table 1 – Summary of IKMP Discharge Sediment Monitoring Program (DSMP) monitoring sites and parameters measured. SSC= Suspended sediment concentration, SGSA=Sediment Grain Size Analysis, BLGSA= Bedload sample and sediment grain size analysis

Station code	Abbreviation	Station name	River	Country	Lat (N)	Long (E)	Data Available in			
							2009	2010	2011	2012
010501	CS	Chiang Saen	Mekong	Thailand	19.892933	100.091811	SSC	SSC SGSA	SSC BLGSA	SSC SGSA BLGSA
011201	LBP	Luang Prabang	Mekong	Lao PDR	19.53340	102.08030			SSC SGSA	SSC SGSA
011903	CK	Chiang Khan	Mekong	Thailand	19.892933	101.663769	SSC	SSC	SSC	SSC
012001	NK	Nong Khai	Mekong	Thailand	19.892933	102.716308	SSC	SSC	SSC BLGSA	SSC SGSA BLGSA
013402	MDH	Mukdahan	Mekong	Thailand	19.892933	104.739549	SSC	SSC	SSC	SSC
13801	KC	Khong Chiam	Mekong	Thailand	19.892933	105.300000	SSC	SSC	SSC	SSC
013901	PS	Pakse	Mekong	Lao PDR	15.04330	105.33060			SSC SGSA	SSC SGSA
014501	ST	Stung Treng	Mekong	Cambodia	13.522047	105.933548			SSC	SSC
	SKB	Sekong	Sekong	Cambodia	13.513787	105.97189				SSC
014901	KT	Kratie	Mekong	Cambodia	12.282565	105.996918			SSC SGSA BLGSA	SSC SGSA BLGSA
033401	KNR	Koh Norea	Mekong	Cambodia	11.565008	104.931464			SSC	SSC

Station code	Abbreviation	Station name	River	Country	Lat (N)	Long (E)	Data Available in			
							2009	2010	2011	2012
019803	TC	Tan Chau	Mekong	Vietnam	19.8017	105.2421	SSC	SSC SGSA	SSC SGSA	SSC SGSA
020101	PPP	Phnom Penh Port	Tonle Sap	Cambodia	11.576707	104.918966			SSC	SSC
020102	PKD	Prek Kdam	Tonle Sap	Cambodia	11.815086	104.800078			SSC SGSA BLGSA	SSC SGSA BLGSA
033401	OSP	OSP	Bassac	Cambodia	11.508786	104.940270			SSC	SSC
039801	CD	Chau Doc	Bassac	Vietnam	10.7048	105.1333	SSC	SSC	SSC SGSA	SSC SGSA

3.2 State of geomorphology and sediment transport knowledge

Geomorphology and sediment transport are fundamental characteristics of the river which play important roles with respect to water quality, aquatic habitats, fisheries production, floodplain agriculture, sand mining, navigation and river bank stability. Sediment movement is also of importance to the siting, design and management of hydropower developments as sediment inflows can result in the infilling of reservoirs and damage turbines. Understanding sediment inflows patterns and sediment characteristics are critical for developing appropriate models and implementing effective mitigation measures. At the larger scale, an understanding of the geomorphology of the river will provide insights into how the river channel downstream of hydro developments is likely to respond to flow and sediment regulation.

3.2.1 Overview of geology and geomorphic setting

The Mekong River Basin has been classified into seven broad physiographic regions or geomorphic provinces, including the Tibetan Plateau, Three Rivers Area and Lancang Basin, which form the Upper Mekong Basin, and the Northern Highlands, Khorat Plateau, Tonle Sap Basin and Mekong Delta which comprise the Lower Mekong Basin. These regions vary with respect to geologic and geomorphic characteristics, which directly affect sediment availability and transport. The geology of the LMB (Figure 9) is complex, but the course of the mainstream Mekong is largely confined and defined by Mesozoic sedimentary rocks, with intrusive and extrusive igneous units major contributors to highland areas.

Investigations are presently being undertaken to better define and understand the relative sources of sediment from each region, and how existing and potential developments have or may in the future affect sediment input (Kondolf *et al,* 2011). The MRC has also recently investigated potential sediment contributions from sub-catchments using GIS layers of landscape attributes (elevation, relief, soils, Watershed Classification, Land Use, etc) combined with recent sediment monitoring results from the mainstream, to estimate relative sediment contributions in the basin (Koehnken, 2012a).

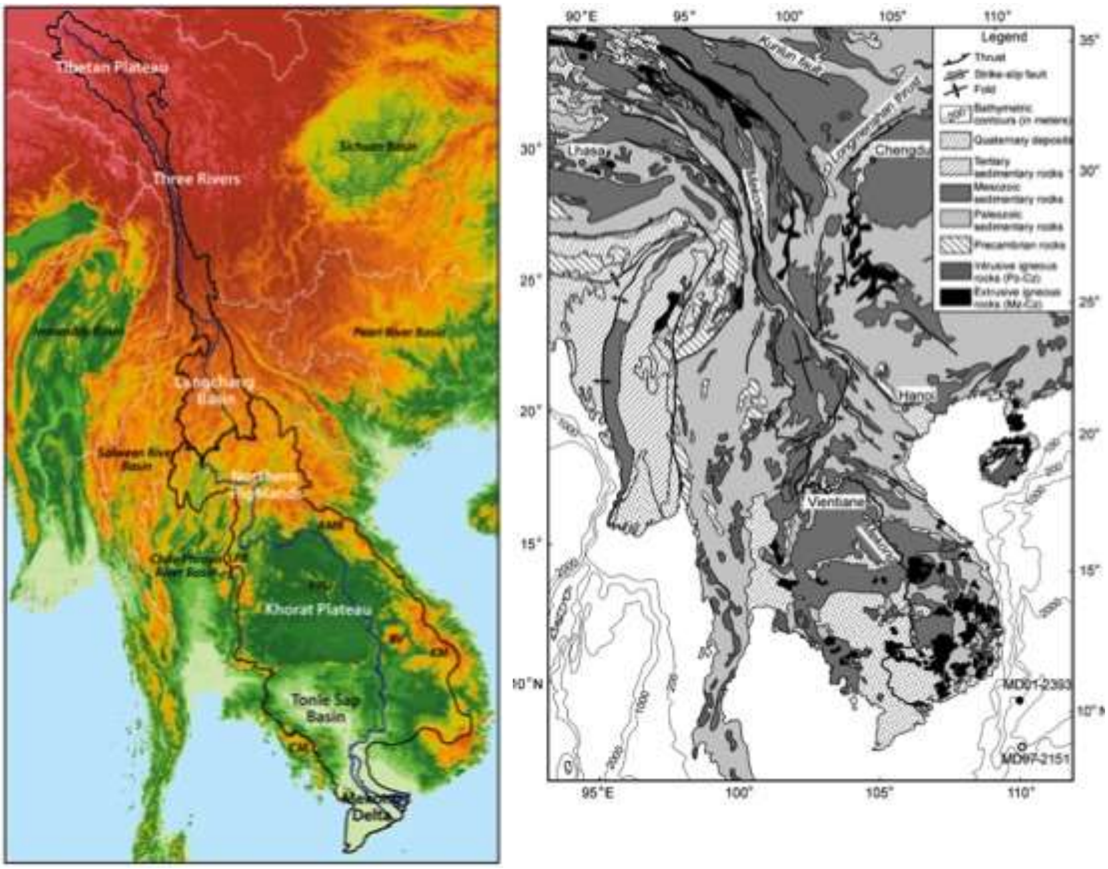

Figure 9 – Left: Physiographic provinces of the Mekong River Basin (MRC, 2010); Right: Schematic geological map of the SE Asia continent Modified after Commission for the Geological Map of the World (Liu *et al.,* 2005)

River channel morphology is an important aspect of aquatic habitats and controls how the Mekong responds to flow and sediment modifications. The UMB and the LMB between the Chinese border and near Vientiane are largely bedrock controlled, with varying levels of alluvial infill (Figure 10). Another extended reach of bedrock control occurs in the mid-LMB, where the river cuts through the Mesozoic sedimentary rocks. Alluvial reaches are limited to river reaches between Vientiane and Savannaket, and in the delta. The remaining reach, between the lower bedrock reach and the delta region contains a mix of alluvial and bedrock control.

Deep pools in the Mekong mainstream have been found along the length of the river, in both the alluvial and bedrock reaches. The pools are located in areas subject to strong currents during high flows related to local hydraulic controls. The persistence of these deep pools or channels through the dry season indicates that scour and erosion during the wet season exceeds sediment deposition during the end of the wet season in the alluvial pools. The pools have been found to provide refuges and migration links for a number of important fish species (Poulsen & Valbo-Jorgensen, 2001). The deep pools were hydro-acoustically investigated in 2003 and 2004 (MRC, 2006a), with fish mass and fish density analysed with respect to pool depth.

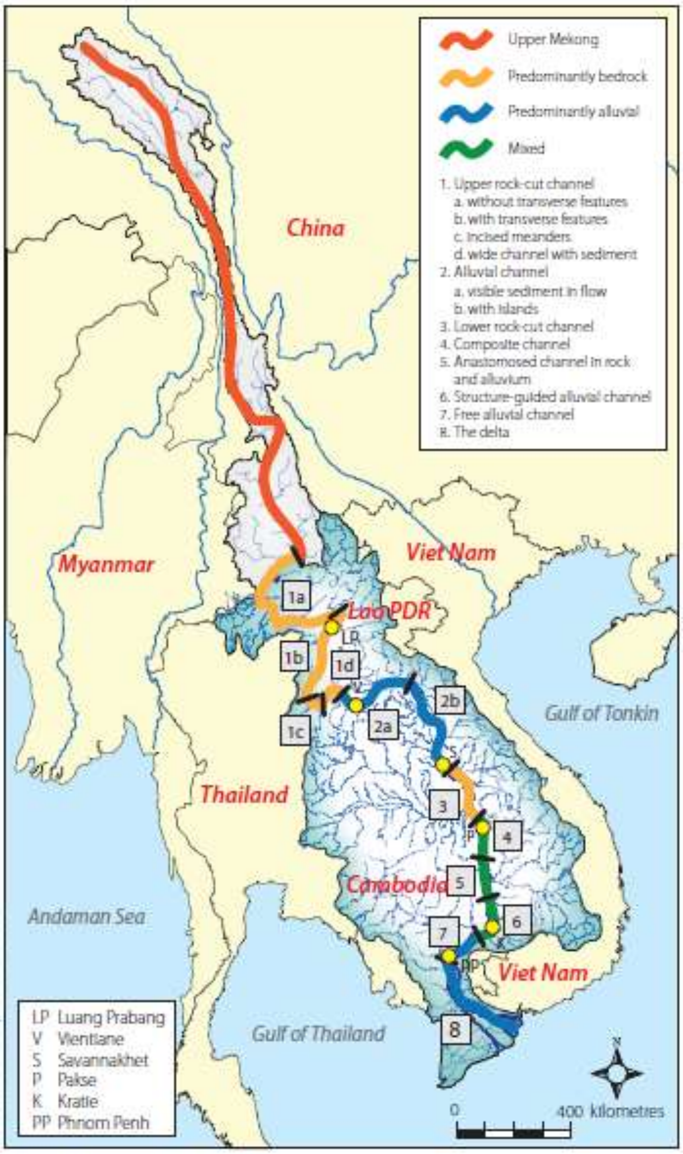

Figure 10 – Distribution of bedrock and alluvial reaches in the LMB. MRC (2010)

3.2.2 Sediment Transport

3.2.2.1 Data availability

Historically, suspended sediment measurements have been made intermittently in the Mekong with results available intermittently between 1960 to the mid-2000s at sites in the LMB as summarised in Table 2 (MRC data, Walling, 2005). These results combined with the 2009 – 2012 DSMP monitoring results are the only readily available sediment transport data sets for the LMB.

Table 2 – Historic Suspended Sediment Concentration Data Held by MRC

Station Code	Name	River	Country	Coordinates (Indian 1960 geodetic datum)		Data Availability
				Latitude	Longitude	
010501	Chiang Saen	Mekong	Thailand	20.2734	100.0834	62,68-75, 94-03
010601	Sop Kok	Mekong	Thailand	20.2417	100.1333	72-75
011201	Luang Prabang	Mekong	Laos	19.8917	102.1367	62;85-92;97-02
011901	Vien Tiane	Mekong	Laos	17.9283	102.6200	62;68
011903	Chiang Khan	Mekong	Thailand	17.8967	101.6684	67-76
011904	Pa Mong Dam Site	Mekong	Thailand	17.9850	102.4300	68;72-75
012001	Nong Khai	Mekong	Thailand	17.8767	102.7200	72-78,81-92,94-04
013101	Nakhon Phanom	Mekong	Thailand	17.3984	104.8034	72-75
013102	Thakhek	Mekong	Laos	17.3933	104.8067	62-71
013401	Savannakhet	Mekong	Laos	16.5617	104.7467	97;
013402	Mukdahan	Mekong	Thailand	16.5400	104.7367	62-82, 84-04
013801	Khong Chiam	Mekong	Thailand	15.3184	105.5000	66-69;72-80;82-86
013901	Pakse	Mekong	Laos	15.1167	105.8000	62;90;97-02
014101	Ban Mouang	Mekong	Laos	14.9383	105.9117	90;
040101	Ban Pa Yang	Nam Mae Kham	Thailand	20.2334	99.8067	80-03
040201	Ban Huai Yano Mai	Nam Mae Chan	Thailand	20.1117	99.7850	75-03
050104	Chiang Rai	Nam Mae Kok	Thailand	19.9184	99.8500	77-81;85-94
050105	Ban Tha Ton	Nam Mae Kok	Thailand	20.0600	99.3634	69-04
050201	Ban Tha Mai Liam	Nam Mae Fang	Thailand	20.0200	99.3584	69-03

Station Code	Name	River	Country	Coordinates (Indian 1960 geodetic datum)		Data Availability
				Latitude	Longitude	
050301	Ban Tha Sai	Nam Mae Lao	Thailand	19.8534	99.8434	72-03
051001	Dam Site	Nam Mae Suai	Thailand	19.7000	99.5200	75-00
051101	Dam Site	Nam Mae Pun Luang	Thailand	19.4334	99.4584	76-03
070103	Thoeng	Nam Mae Ing	Thailand	19.6867	100.1917	69-03
100102	Muong Ngoy	Nam Ou	Laos	20.7017	102.7583	90;96-02
110101	Ban Sibounhom	Nam Suong	Laos	19.9700	102.2733	91;
110201	Ban Kok Van	Nam Pa	Laos	19.9533	102.2983	91;
120101	Ban Mixay (Ban Mout)	Nam Khan	Laos	19.7867	102.1767	62;
120102	Ban Pak Bak (downstream)	Nam Khan	Laos	19.7433	102.2800	90;96-02
140101	Ban Pak Huai	Nam Heung	Thailand	17.7034	101.4150	68-76
140201	Dan Sai	Nam Man	Thailand	17.2850	101.1517	68-88;90;92-03
150101	Wang Saphung	Nam Loei	Thailand	17.2984	101.7800	68-87;89-03
150102	Ban Wang Sai	Nam Loei	Thailand	17.0517	101.5200	76-03
230101	Ban Pak Kanhoung	Nam Ngum	Laos	18.4183	102.5500	93;97-02; 05
230102	Tha Ngon	Nam Ngum	Laos	18.1350	102.6217	66-67;90-92
230103	Ban Pak Ngum	Nam Ngum	Laos	18.1450	103.1017	90;
230110	Ban Na Luang	Nam Ngum	Laos	18.9133	102.7783	90-91;96-02; 05
230201	Ban Hin Heup	Nam Lik	Laos	18.6600	102.3550	67;90-93;97-02; 05
230205	Muong Kasi	Nam Lik	Laos	19.2320	102.2570	91;
270903	Ban Signo	Nam Theun	Laos	17.8450	105.0520	96-02; 05
290102	Ban Tha Kok Daeng	Nam Songkhram	Thailand	17.8617	103.7800	66-75
310102	Nam Kae	Nam Kam	Thailand	16.9550	104.5084	75-00

Station Code	Name	**River**	**Country**	**Coordinates (Indian 1960 geodetic datum)**		**Data Availability**
				Latitude	Longitude	
310201	Ban Tham Hai Bridge	Nam Pung	Thailand	17.0800	104.2567	64-03
320107	Mahaxai	Se Bang Fai	Laos	17.4133	105.2020	90-92;96;98-02; 05
330103	Ban Na Kham Noi	Huai bang Sai	Thailand	16.7184	104.6250	85-03
350101	Ban Keng Done	Se Bang Hieng	Laos	16.1850	105.3170	62;91-92;97-00
350601	Kengkok	Se Champhone	Laos	16.4450	105.2030	97-00
370104	Yasothom	Nam chi	Thailand	15.7817	104.1417	62-03
370122	Ban Chot	Nam Chi	Thailand	16.1000	102.5767	75-03
370210	Ban Kae (Si Chomphu)	Nam Pong	Thailand	16.8667	102.1850	79-80;82-88
370805	Ban Tha Dua	Lam Choen	Thailand	16.4934	102.1284	79-92;94-03
371101	Ban Nong Kiang	Huai Rai	Thailand	16.1334	101.6667	75-78;81-03
371203	Ban Tad Ton	Huai Pa Thao	Thailand	15.9417	102.0300	77-03
371509	Ban Na Thom	Nam Yang	Thailand	16.0584	104.0384	79-03
380103	Ubon	Nam Mun	Thailand	15.2217	104.8617	62-03
380111	Pak Mun	Nam Mun	Thailand	15.3084	105.4950	72-81
380127	Kaeng Saphu Tai	Nam Mun	Thailand	15.2400	105.2484	79-88
380134	Rasi Salai	Nam Mun	Thailand	15.3350	104.1617	79-03
381206	Ban Huai Khayuong	Huai Khayuong	Thailand	15.0050	104.6384	79-03
381503	Ban Fang Phe	Lam Dom Yai	Thailand	14.6900	105.1600	69-99
390104	Souvanna Khili	Se Done	Laos	15.3967	105.8250	93;96-02; 05

3.2.3 Sediment transport - present state of knowledge

This section provides a brief overview of the present state of knowledge regarding sediment transport and geomorphology in the LMB. Additional information is available in the annotated bibliography in the *Supplement for hydrology, sediment transport, geomorphology and water quality.*

A mean annual total suspended sediment load from the river of 160 Mt/yr was frequently cited in the 1980s and 1990s based on the available historic sediment results. A sediment load of 80-100 Mt per year was attributed to the Upper Mekong basin which contributes less than 20% of the natural flow inputs (Walling, 2005, 2008). Analyses of sediment results pre- and post- dam construction in China have found varying impacts. Walling (2005) found no clear evidence of a reduction in sediment load at sites within the LMB following dam construction based on an analysis of results from 1960 to 2002, although the representativeness of some of the results was questioned as they were based on grab-samples collected at a low sampling frequency. In contrast, Lu and Siew (2005) found significant decreases in sediment load at the most upstream LMB monitoring site (Chiang Saen) in 1992 following filling of the Manwan Dam, but no statistical decline at sites located farther downstream.

The lack of reliable sediment transport measurements has led to indirect methods of sediment transport being used to estimate loads and evaluate the impact of dams on the mainstream in the UMB on sediment supply between 1962 and 2003 (Wang *et al.* 2009). The investigators found that the mean annual sediment in the Mekong probably increased during the period of dam construction (1986 – 1992) and decreased following initiation of dam operation (1993–2003) at Chiang Saen, although other catchment activities cannot be ruled out as contributing to these changes.

The relationship between monsoons, El Nino Southern Oscillation, and precipitation runoff on the dynamics of the delta was investigated by Xue *et al* (2010). They 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. The authors suggest the decrease in water slope associated with the decreased water levels has the potential to weaken sediment delivery to the delta.

Sediment investigations have also been completed on specific areas of the Mekong catchment, such as sedimentation rates in the Tonle Sap basin (Kummu *et al,* 2008) and in the delta (Nguyen Nghia, 2011).

The role of sediments and sediment transport in ecological and water quality processes is recognised and reflected in investigations and reports across many disciplines of the MRC. A sediment transport model was developed by Jirayoot (2007) using the SWAT (Soil and Water Assessment Tool) as part of the Decision Support Framework (DSF), with model results showing good agreement with previous sediment transport analyses.

The BDP, Phase 2 evaluated basin development scenarios with respect to river morphology in a Technical Note (MRC, 2010f). 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.

Sediment transport was a focus of the Expert Sediment Group convened as part of the MRCS Xayaburi Prior Consultation Project Review Report (MRC, 2011e). This group 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.

The bedload transport of sand, which is integral for the maintenance of ecological habitats, river bank and bed processes, and delta maintenance, has also been investigated through a WWF-funded project. Results suggest that the predominant sand transport mechanism varies between suspended and bed load at different locations in the mainstream (Bravard, in prep). Conlan *et al* (2008) 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'.

3.2.3.1 2011 sediment transport results

The 2011 DSMP data set was used to examine the relationship between suspended sediment concentrations (SSC) and river flow at the monitoring sites, and derive suspended sediment fluxes for each site and the basin (Koehnken, 2012). SSC is compared to flow in Figure 11 and shows that at the most upstream site of Chiang Saen, there is little variability in SSC throughout the year. With distance downstream, sediment concentrations show greater response to flow patterns.

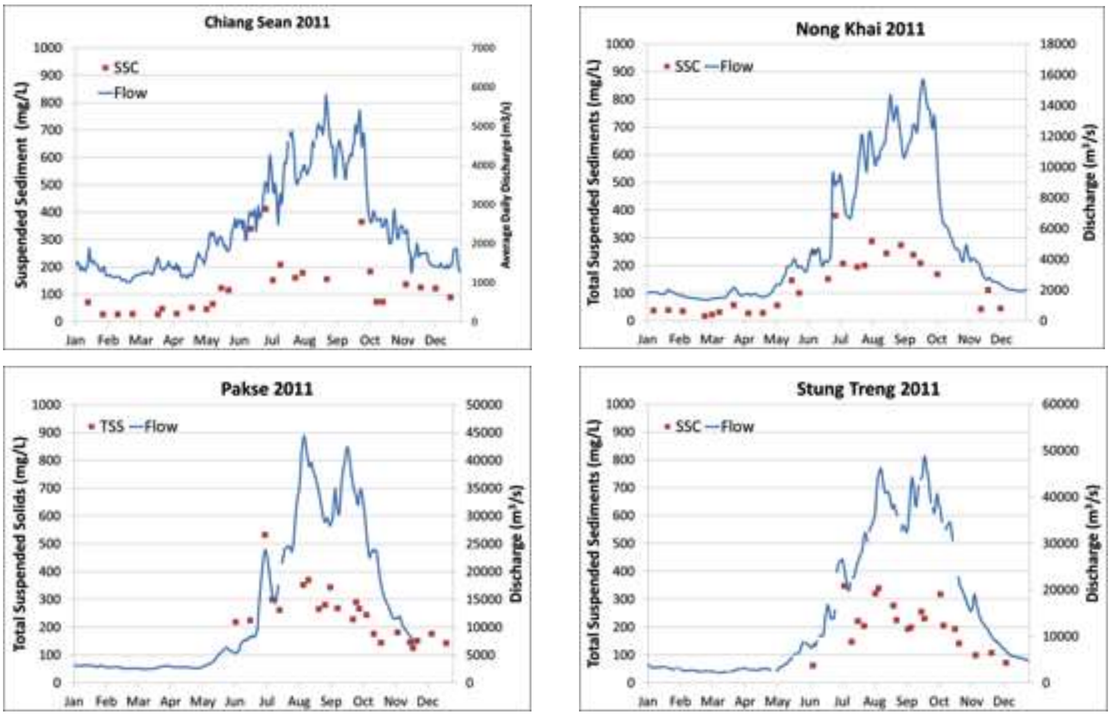

Figure 11 – Comparison of total suspended sediment concentrations (SSC) with flow at four sites in the LMB based on DSMP 2011 monitoring results

Sediment fluxes for the most of the monitoring sites are present in Figure 12 and show that the upstream sites between Chiang Saen and Nong Khai show relatively low and uniform sediment fluxes. A large increase in sediment flux is evident between Nong Khai and Mukdahan, reflecting the inflow from the left bank tributaries in Laos. The results show variability between sites, consistent with sediment transport not being a uniform process throughout the LMB.

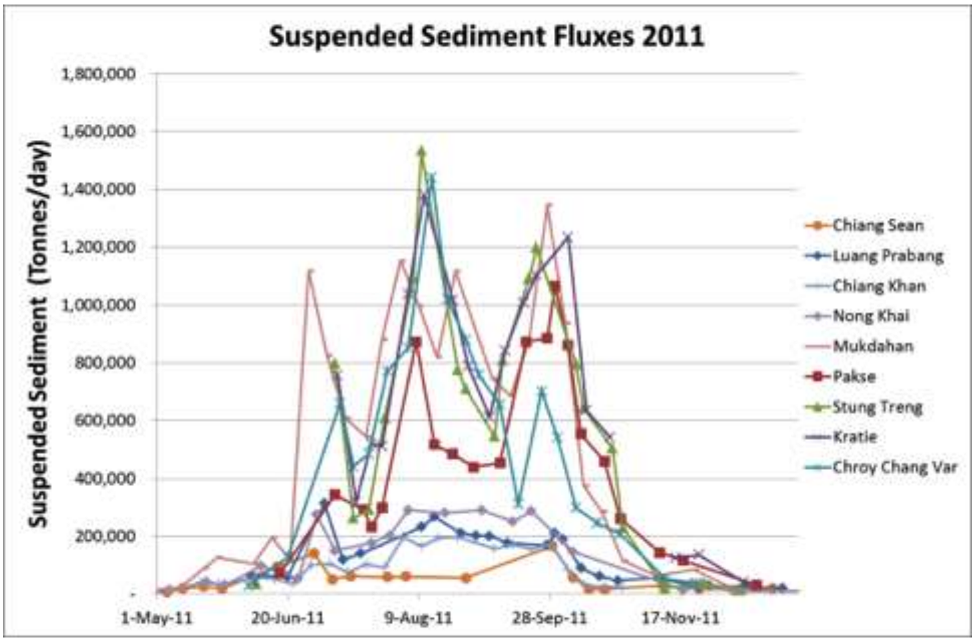

Figure 12 – Suspended sediment monitoring fluxes for 2011 based on the DSMP results

The grain-size of suspended sediments was found to fine with distance downstream, consistent with the reduction in slope of the river. Suspended sediment collected at Luang Prabang was dominated by sand sized material, whereas the Kratie samples contained predominantly silt. In the delta, clay sized material was the dominant size fraction (Figure 13).

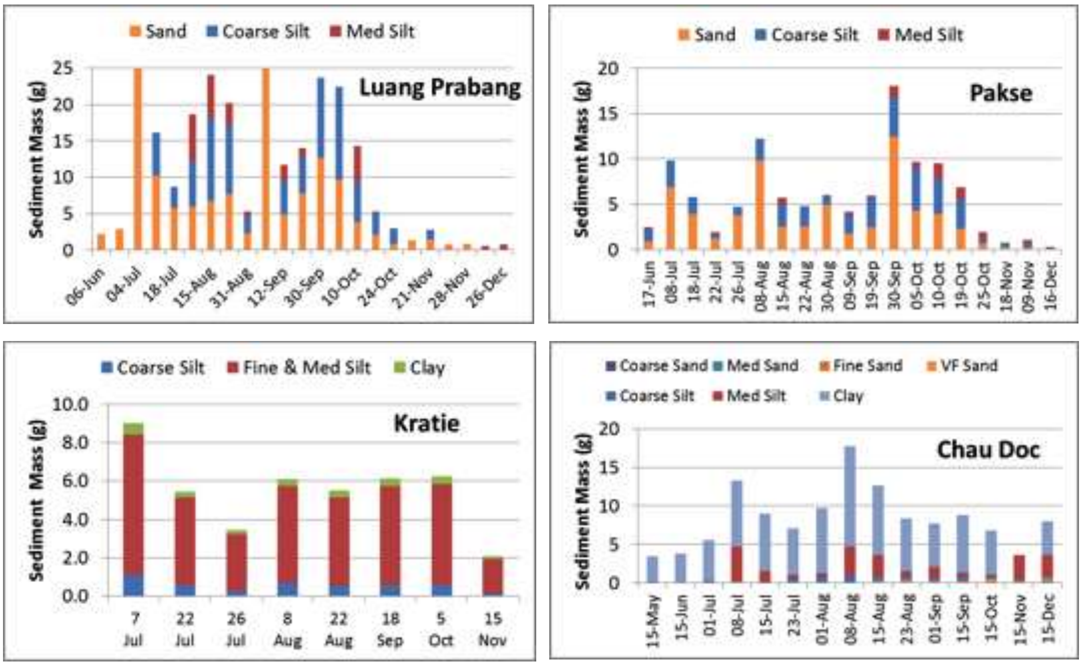

Figure 13 – Suspended sediment grain-size distributions based on 2011 DSMP monitoring results (Koehnken, 2012)

The annual sediment flux at Nong Khai, in the upper LMB was estimated at ~30 Mt/yr which is lower than previous estimates which ranged between 70 – 100 Mt/yr (Walling, 2005, Wang *et al,* 2011). In the lower catchment, the 2011 results suggest a sediment yield at Kratie of ~103 Mt/yr which is also lower than the historic estimates of ~160 Mt/yr.

The 2011 results have also been used to estimate sediment fluxes into and out of the Tonle Sap system during the year. Inflowing water was estimated to transport the equivalent of 6.4 Mt/yr of sediment at Prek Kdam, compared with 1.5 Mt/yr during the outflow. These values are similar to those obtained by Sarkkula *et al,* (2010), (5.1 Mt/yr in, and 1.4 Mt/yr out), and Kummu *et al.* (2008) (average of 5.1 Mt/yr in and 1.6 Mt/yr out).

Bedload measurements by the DSMP in 2011 (Figure 14) show a similar seasonal trend to the suspended sediment load, with the bedload contributing from 1% to 10% of the suspended sediment flux. The composition of the bedload material was predominantly medium to very coarse sands.

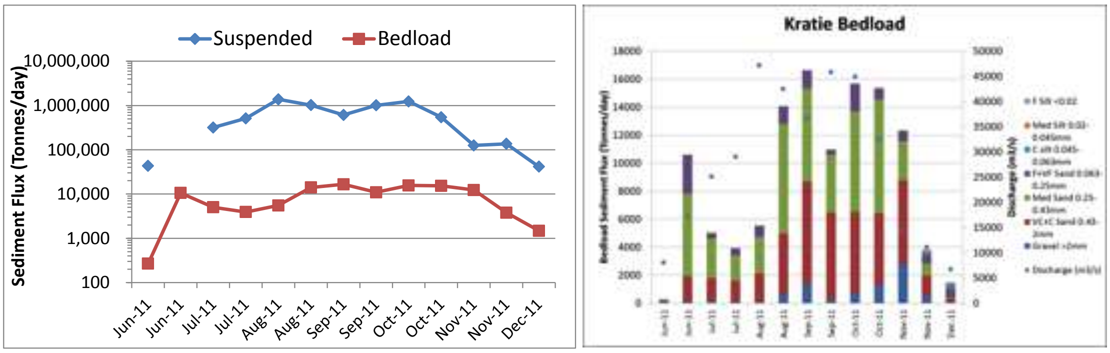

Figure 14 – Left: Bedload transport at Kratie in 2011, Right: composition of bedload material at Kratie

3.2.4 Bed Materials

The 2011 investigations included an extensive bed material survey, with samples collected at the sites shown on Figure 15 between June and November 2011. This time period incorporates a wide range of flow conditions in the river and cannot be considered to be a 'snapshot' of bed conditions at a specific time. However the results provide an indication gran-size distributions present in the river over the course of the wet season, and some of the results are summarised in Figure 15. The samples were collected from Luang Prabang and Pakse in November, so the fine grain sizes present reflect the sediment deposited at the end of the wet season. The bed material at the other riverine sites were collected during rising or peak flows, accounting for the coarser materials present. The finer material at the delta sites is consistent with a lower energy flow regime.

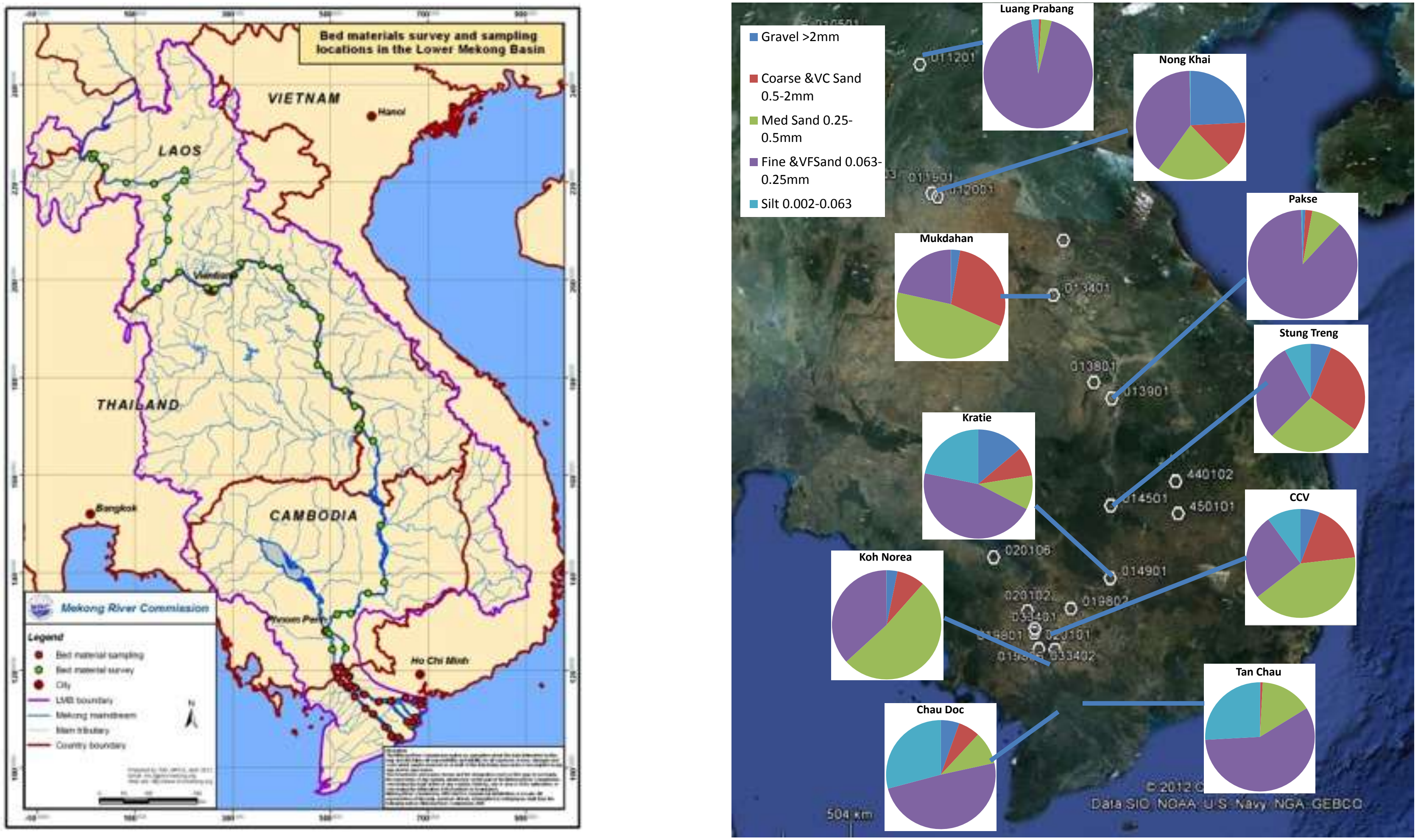

Figure 15 – Left: Bed material monitoring locations in 2011 of samples collected between June and November 2011. Right: Summary of grain-size analyses for some sites

4 Gap analysis with respect to ISH11 Guiding Framework

4.1 Information Needs to Support Hydropower Planning

The aim of the ISH11 project is support MRC Member Countries to gain a clear and scientifically sound understanding of conditions, changes and trends in the Mekong Basin to inform hydropower planning and management. The information requirements for hydropower planning vary over these scales, with an overview of potential information needs summarised in Figure 16.

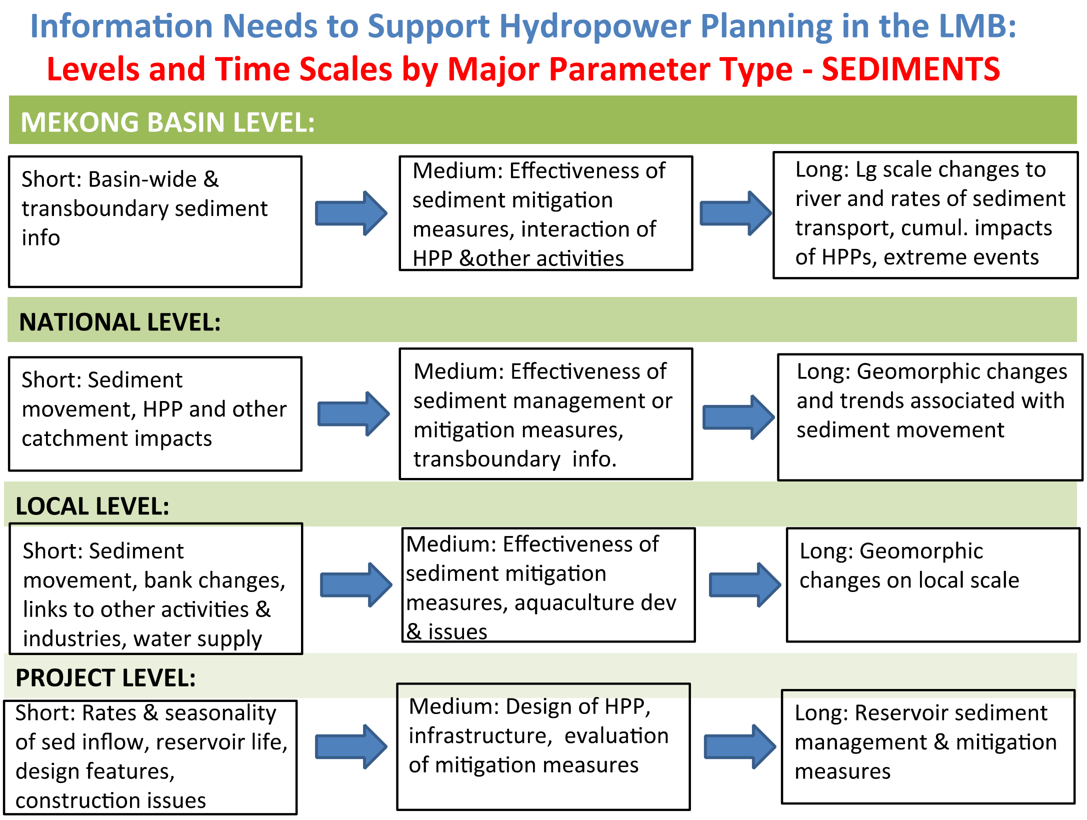

Figure 16 – Information needs to support hydropower planning in the LMB

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

At the hydropower project level, the siting and design of reservoirs and power plants, and development of effective sediment mitigation measures, must all be underpinned by appropriate and accurate information over short and long time scales. During hydropower operations, sustainable schemes need to be able to evaluate the effectiveness of mitigation measures, and have the capacity to manage and respond to changing conditions or events over a variety of time-frames, including the immediate response to flood or drought events, or long-term generation planning in response to climate change.

4.2 Gap Analysis – Locations

The existing sediment monitoring locations provide a basin wide understanding of sediment transport in the LMB. Hydropower developments affect sediment transport at a point within the river, with the impact propagated downstream. To understand the potential degree of impact and the extent to which the downstream environment may be altered requires an understanding of both local sediment transport characteristics, and the characteristics of the downstream environment (e.g. tributary inputs, storage of sediments, floodplain interactions, etc.).

Increasing the number of suspended and bedload monitoring sites included in the ongoing DSMP monitoring would provide sediment transport information at a more detailed level in the catchment. Suggested additional monitoring locations in the mainstream Mekong include sites identified for future hydropower development, the upstream extent of inundated areas, and sites providing information about transboundary impacts. These locations are relevant to most of the disciplines included in ISH11 and are discussed in the Main Report.

The inclusion of suspended and bedload sediment monitoring locations in the lower reaches of major tributaries is necessary for interpretation of sediment results from the Mekong mainstream. The tributary information can be used to develop a more detailed sediment budget, and allows sediments associated with erosion and deposition within the mainstream to be quantified. The tributary confluences considered relevant to hydropower information needs are shown on the map in Figure 17.

It is important to note that ‘important tributaries’ in this sense are not ‘significant’ tributaries with respect to MRC procedures and policies, but rather any river entering the Mekong mainstream for which sediment transport information would assist in understanding the sediment transport processes in the mainstream. The aim of the ISH11 study is not to interpret the information with respect to tributary conditions, trends or developments, but rather to use the tributary information to better understand changes and processes in the mainstream Mekong River.

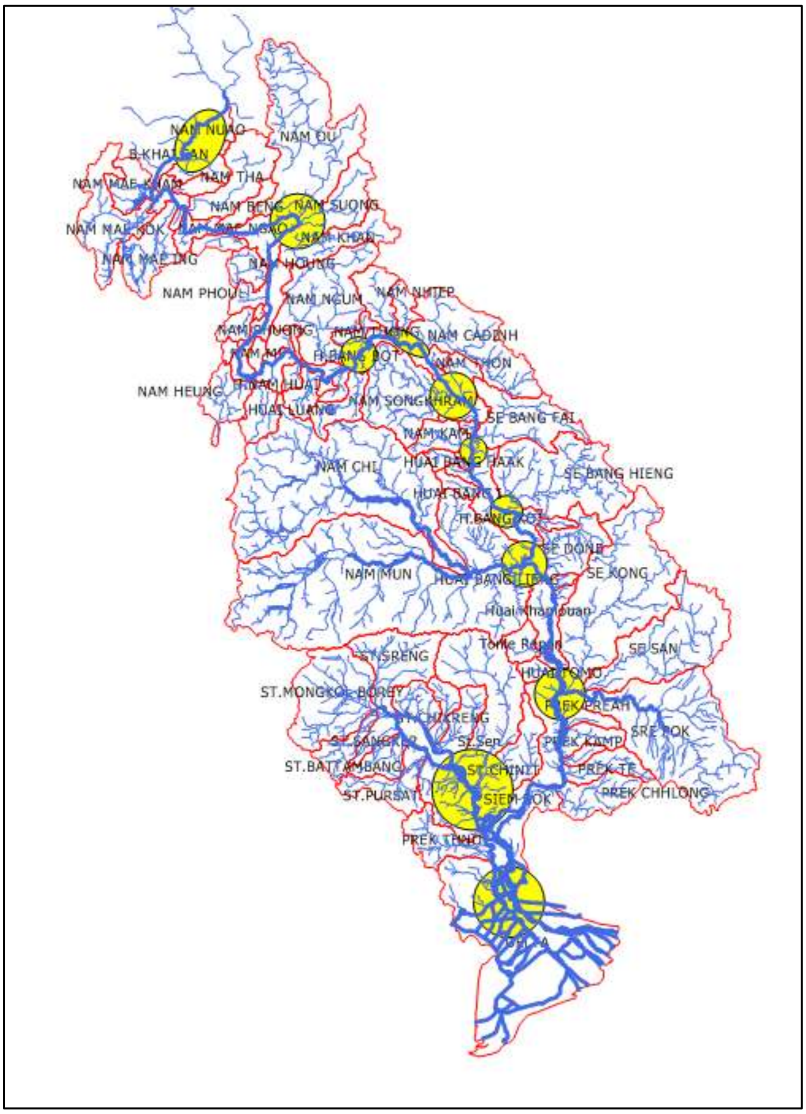

Figure 17 – Lower Mekong River Basin showing tributary confluences identified for potential incorpoation in sediment transport monitoring

4.3 Gap Analysis - Parameters

Parameters included in a monitoring programme for hydropower-relevant information must reflect the range of attributes and conditions, which are likely to affect hydropower development and operations.

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

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

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

Hydropower is not the only type of development that can alter and affect sediment transport and geomorphic processes in a river system. Sediment budgets and geomorphic processes can be affected by land clearing and land use practices, flow extractions and runoff associated with irrigation developments, extractive gravel and sand mining, and hard rock mining which can increase sediment inflows through runoff and discharges. In order to separate out 'cause' and 'effect' associated with hydro developments from these other impacts is a challenge, and requires a detailed understanding of the sediment transport and geomorphic processes and rates operating in the catchment.

The parameters prioritised by the ISH11 study include sediment characteristics, river morphology, and river and tidal dynamics.

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

The morphology of the river can be documented and investigated using bathymetric survey methods (ADCP, echo sounder), remote sensing (aerial or satellite photos), mapping (e.g. distribution of woody debris or land slips), or repeat photo monitoring of small scale features such as individual banks or bars. This information is relevant to understanding the geomorphic processes operating in the river, which determine the distribution and quality of habitats in the river. River morphology generally changes on time-scales of years to decades, so annual or 5-yearly repeat surveys are useful for documenting channel changes and can be used to estimate rates of change. Episodic events, such as extreme floods, can result in large changes over short periods of time, and surveys designs should include sufficient flexibility to capture changes caused by these events.

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

Table 3 – Monitoring parameters relevant to sustainable hydropower

Parameter Group	Relevance for hydropower planning and operation	Parameter Types and Examples
Sediments and Geomorphology	➢ Influx of sediments to impoundments is critical for siting and design of hydro schemes ➢ Need to understand sediment and geomorphic processes to design appropriate mitigation measures ➢ Changes to sediment fluxes downstream of power stations can affect geomorphological and ecological processes and have social impacts ➢ Separating changes due to hydropower from the effects of other basin developments/actions at transboundary locations.	**Sediment characteristics:** suspended and bedload fluxes, seasonality, grain-size, organic content, mineralogy, lithology **Geomorphic characteristics and habitat quantity & quality:** Channel cross-sections, longitudinal channel profiles, planform features (e.g.channels, sinuosity, braiding), presence of woody debris **Geomorphic rates:** rate of channel migration, rates of channel infilling or incision, bank stability, , **River dynamics:** coefficient in variability of depth, heterogeneity of current velocities floodplain connectivity, Tonle Sap reversal **Tidal sediment dynamics:** rates of change and locations for transport, deposition, erosion

With respect to sediment transport parameters, the DSMP incorporates suspended and bedload monitoring, and grain-size analysis of both types of sediment. However, the bedload monitoring and analysis of grain size distribution is limited to only a few sites in the DSMP. The monitoring strategy includes the collection of bedload at 4 sites, and grain-size determinations of suspended material at 8 sites, but due to various reasons, these measurements have not been consistently obtained at all of the sites. Increasing the number of sites at which consistent measurements of bedload and suspended sediment transport and grain size distribution are completed would be beneficial with respect to hydropower information needs.

There is also potential to trial new technology which has the capacity to determine the grain-size distribution of suspended material *in situ*. Measuring *in situ* grain size would allow the collection of grain size distribution information at more sites, and remove the potential for grain-size changes during drying and grinding associated with laboratory processing.

Parameters relevant to large scale geomorphic processes, such as the rate of bank erosion or channel change based on aerial photo analysis, or tracking changes in cross-sectional shape or area are not included in the DSMP. These large-scale parameters provide an understanding of rates and trends in the LMB a context within which the sediment transport information can be interpreted. Interpreting this type of information at approximately 5 yearly intervals would relevant to hydropower information needs over long time periods.

4.4 Gap Analysis – Timing

The frequency of monitoring in the DSMP alters through the year, with more samples collected during the high flow period (weekly) and fewer samples collected during the dry (monthly). This monitoring frequency is appropriate, providing more information when the majority of flow occurs in the river.

One element of timing that has been identified as an issue, is the gap in sampling which can occur due to the contracting delays. The contract 'year' runs from July to June, and there have been occasions where due to delays in contracting, sediment sampling has not occurred in July. This is a very important part of the sediment cycle, as the rising water associated with the onset of the wet season has the potential to transport large volumes of sediments. Aligning contracting with the calendar year would result in the negotiation of contracts during the dry season, when sediment transport is low, and ensure continuity of monitoring through the wet season.

4.5 Gap Analysis – Information Management

The sediment transport results are obtained by each country according to Standard Operating Procedures (SOPs) and reported to the IKMP on standardised worksheets. Worksheets have been developed for the field based components associated with discharge, suspended sediment and bedload sediment measurements, and the laboratory determination of sediment mass and grain-size distribution. There are also worksheets for annual summaries of the measurements. Recent versions of these worksheets include QA/QC components.

To date, the forms are held by the IKMP, and QA/QC of the 2011 results has been completed. The IKMP is in the process of completing QA/QC procedures, and the final results will then be available on the Master Catalogue. The time required for the checking and compilation of sediment results has led to a time-lag between monitoring, and the availability of the results.

A large number of ADCP channel profiles and aerial photographs are also held by the IKMP. The ADCP profiles require specialised software to view and to date have not been placed on the Master Catalogue. Some aerial photos have been converted to digital format and available on the Master Catalogue, with additional photos on film.

4.6 Gap Analysis – Information Use

Preliminary data analyses of the DSMP suspended and bedload monitoring results have been completed through the IKMP with respect to sediment concentrations, sediment fluxes, and temporal trends. Better indicators and analytical tools for hydropower relevant information needs are required, as is an understanding of the larger scale geomorphic processes operating in the LMB over timescales of years to decades.

Greater information could be derived from existing monitoring information through integration and analysis of existing sediment monitoring results with hydrologic and water quality results. Sediment monitoring results from 2009 to 2012 could be integrated and analysed with hydrologic and water quality results to provide a picture of the present status of sediment transport in the LMB. Useful analyses which could be determined using the existing data set include, but are not limited to:

- quantification of seasonal variations in sediment concentrations;
- calculation of sediment fluxes;
- construction of sediment balances (downstream, into / out of Tonle Sap, entering the head of the delta);
- linking of nutrient and sediment information to determine nutrient fluxes and budgets; and
- linking sediment grain-size distribution with river channel cross-section velocity profiles.

This exercise could also be used as the basis for a capacity building exercise to assist countries with basic data interpretation, and possibly revisiting of analytical tools available on the MRC website to provide those that assist with production of better end-use information for the user.

The results from the DSMP could also be used in the context of a large-scale understanding of geomorphic rates and trends in the LMB. The results from the DSMP would be more meaningful in the context of a large-scale understanding of geomorphic rates and trends in the LMB. The MRC holds a large number of historic aerial photos extending back to the 1950s, which, if converted to digital format, could be used as the basis of an aerial photo analysis and provide information about the rates and trends of large scale geomorphic processes such as bank erosion, channel migration and mid-stream and point bar changes. The rates and trends derived from the analysis could be linked to the smaller scale analysis of changes in channel cross-section, changes to longitudinal profiles, and floodplain connectivity as determined by comparing ADCP and river channel cross-sections. Examining geomorphic changes at the mega (aerial photo), meso (ADCP, channel cross-sections) and process (sediment monitoring) scales will provide an in-depth and robust understanding of the linkages between hydrology, sediment transport, and channel morphology and provide a context for hydropower (and other catchment) planning and management.

5 ISH11 Improvement Proposals for Sediments and Geomorphology

5.1 Approach and Rationale

The existing MRC coordinated DSMP monitoring programmes provide a strong basis for documenting and understanding sediment transport in the LMB river system. The improvement proposals relating to sediments build on the existing monitoring and also relate to and build upon the existing water quality and hydrologic monitoring activities. The proposals:

- provide an accurate and integrated understanding of the physical and chemical characteristics of the river;
- ultimately integrate sediment information with flow, water quality, ecological and fisheries monitoring results to provide a better understanding of the linkages between the physical and ecological systems in the Mekong, and to develop indicators to support sustainable hydropower planning and management; and
- promote and provide capacity-building to the Member Countries in collaboration with the IKMP in relation to the above objectives and to support the on-going decentralisation process.

The three ISH11 improvement proposals relating to sediments and geomorphology are:

- *SWH1: Integrating Sediments, Water Quality and Indicators for Hydropower Indicators,* which addresses gaps relating to the ability to predict as well as explain cause and effect, and availability of useful tools and analytical methods for decision-support and analysis;
- SWH3: *Sediment Monitoring Enhancements for Hydropower Information, which* addresses identified gaps relating to parameters and in the present data sets; and
- SWH4 *Geomorphic Methods for hydropower Information, which* addresses the gap of large scale geomorphic parameters against the Guiding Framework.

Also relevant to sediment monitoring is proposal SWH3 *Water Quality Monitoring Enhancements for Hydropower Information,* which proposes to integrate water quality monitoring with the existing DSMP monitoring. This proposal is discussed in detail in the Phase 2 Main Report and in the Water Quality Annex.

The sediment and geomorphology proposals are described in the following sections.

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

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria 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: Examples of the types of analyses to be included are shown in Section 3 and include time-series of sediment concentrations, sediment fluxes, annual sediment budgets and information about the grain-size distribution of material being transported in suspension and as bedload. The analysis will examine a range of potential indicators for use in hydropower and other basin development planning. It is intended to summarise the results of the analyses in a Technical Report or similar document which will be made available to the Member Countries and through the Master Catalogue. The proposal also contains a capacity-building element which aims to improve data analysis skills within the Line Agencies of Member Countries in cooperation with the IKMP and EP.

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

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

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

5.3 SWH3: Sediment Monitoring Enhancements for Hydropower Information

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2a) Provide inputs to indicators related to hydropower planning and management*. Gaps in spatial coverage of bedload and grain-size data collection.
- *2. Parameters Monitored; 2c) Able to be measured and analysed at a low cost.* Sediment work is labour-intensive, and there is potential for alternative emerging technologies.
- *2. Parameters Monitored; 2d) Able to help predict as well as explain cause and effect of changes.* Missing parameters at key locations limits interpretative abilities.
- *3. Timing of Data Collection; 3b) Frequency captures natural or operational system changes and migratory cycles.* Monitoring frequency good, but gaps in record during onset of wet season due to contracting delays.

Objective and Description: The objective of this proposal is to enhance the existing sediment monitoring regime to increase the data and information available for hydropower and other basin planning and water related activities. The DSMP collects depth-integrated suspended sediment samples at all monitoring sites, with bedload sampling and the determination of grain-size distribution of suspended sediment completed at a small sub-set of the monitoring sites in the LMB. It is proposed to:

- extend bedload sediment to more of the existing monitoring sites; and

- determine grain-size distribution of suspended and bedload material at up to two additional existing DSMP sites in each country during 2014.

The collection of these samples along with depth-integrated water quality samples at the same sites at the same time would provide a complete 'picture' of what is moving through the river at each of the sites throughout the year.

Linkages:

- This proposal extends existing DSMP monitoring activities to additional sites, which is consistent with the DSMP objectives, and Outcome 2 and Outputs 2.1, 2.3 and 2.5 of the IKMP Work Plan. These outcomes and outputs aim for a well-functioning basin-wide river monitoring network linked with other MRC monitoring systems, and ensures upgrading and strengthening of existing activities, mapping and analysis of data, and adequacy and timeliness of information availability.
- 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: The provision of an increased understanding of sediment movement through the Mekong mainstream is relevant to the PWUM and PWQ, as understanding sediment movement is as important as understanding water flow in the context of basin management and planning.

Proposed Activities and Outputs: It is proposed to undertake the following activities.

1. Increase the sediment parameters monitored at the same locations as where depth-integrated water quality samples are collected. This would provide a complete picture of what is moving through the Mekong mainstream (water, suspended sediments, bedload sediments) at the same locations and points in time.
2. Trial new technology which has the potential to measure the mass and size distribution of suspended sediment *in situ*. Trialling of this instrumentation at the same sites as where the additional sediment sampling is being conducted would provide an opportunity to compare the results obtained from the various methods. If the *in situ* probe is determined to provide reliable results, then determining the grain-size distribution of suspended material in the river could become a less resource intensive activity.

The deployment and trialling of the *in situ* sediment probe could also contribute to a field-based capacity-building exercise. The aim of the exercise would be to review the existing sediment monitoring methods and field safety procedures, and provide the countries with an opportunity to trial the *in situ* probe. This field-based component could be part of a larger sediment-focussed capacity-building exercise which would include data management and QA/QC, and data analysis. Conducting capacity-building exercises in 2014 would provide timely support for the countries, as decentralisation of sediment monitoring is scheduled to begin in 2015.

Resource Requirements and Implementation Commitments:

- *Field expenses:*
  - Additional DSA if the additional work cannot be accommodated within the existing field time and for deployment of *in situ* particle size analyser and field-based capacity-building exercises
  - Additional bedload samplers (up to $5,000 depending on number needed to be purchased. About $1000/each to purchase, but could be constructed based on plans locally for less)

  - Additional petrol associated with increased bedload and WQ sampling: Assume $100/site/monitoring = $5400/country x 4 countries= $21,600
  - Hire of *in situ* grain-size analyser: 40 days(?) x $280/day=$11,200+shipping/insurance

- *Laboratory expenses:*
  - Additional grain-size analyses of suspended sediment samples: assume $100/sample x 34 samples per year = $3,400
  - Additional analysis of bedload samples: assume $100/sample x 119 samples = $11,900

- IC or MRC Technical staff time to facilitate contract negotiations, develop and implement capacity-building exercises, arrange hire and oversee use of *in situ* particle size analyser, and interpret integrated results: up to 60 days

- Approximate total estimate: The actual costs will need to be negotiated with each country, as the above estimates reflect costs as contained in 2011 DSMP ToR documents = ~$52,000/year.

Sustainability Considerations: Similar to proposal SWH2, if adopted beyond a trial, the success of obtaining additional sediment samples from additional stations is dependent on the on-going cooperation of 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 sediment and bedload 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).

Outcomes and Benefits: The implementation of this proposal, as well as proposal SWH2, will result in an integrated hydrologic, water quality and sediment dataset which accurate captures water is being transported by the river. If maintained into the future, the integrated dataset will reflect seasonal and longer-term basin changes and be relevant to hydropower and other basin development planning and management.

5.4 SWH4: Geomorphic Methods for Hydropower Information

Gap Addressed in Guiding Framework: The following Guiding Framework criterion would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2a) Provide inputs to indicators related to hydropower planning and management*. Missing geomorphic parameters.

- *3. Timing of Data Collection; 3b) Frequency captures natural or operational system changes and migratory cycle.* There is presently no monitoring of geomorphic processes at the time-scale of years to decades.

Objective and Description: Understanding the large scale geomorphic process operating in the LMB is necessary to assess and predict potential changes due to hydropower or other catchment development. Whilst sediment monitoring is occurring over short time scales, there is a need for a better understanding of geomorphic processes and rates and trends on the basin scale over time frames of years to decades. This proposal aims to utilise existing resources, such as historic aerial photographs, channel cross-sections, ADCP channel profiles and long-sections, to investigate geomorphic changes over time scales of years to decades.

It is proposed that one or two river reaches in each country be chosen for initial analysis, with reach selection targeting alluvial areas which are more susceptible to change.

Linkages:

- This proposal is consistent with Outcome 2 and Output 2.3 of the IKMP Work Plan relating to a well-functioning basin-wide river monitoring network linked with other MRC monitoring systems, and more specifically to implementing the network and database for sediment monitoring. Activity 2.3.1 of the IKMP work plan, to provide coordination and technical support to the implementation of Discharge and Sediment Monitoring and Geomorphology Tools Project, is directly supported by this proposal.
- Understanding large scale geomorphic processes will assist in providing a context within which modelling results generated through the MRC Toolbox can be interpreted. The IKMP Work Plan states 'Assessment/analysis will put a greater emphasis on sediment movement, geomorphology/bank erosion, water quality, temperature and environmental modelling.' This proposal will provide a context for establishing and interpreting these types of models.
- This proposal can support BDP processes, the Council and Delta studies and RSAT information needs.

Relevant MRC Procedures or Guidelines: Understanding the large scale geomorphic processes operating within the basin is relevant to the PMFM, and is relevant to the Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin (2009).

Proposed Activities and Outputs: The MRC holds a large collection of historic aerial photos extending back to the 1950s, which could be used to document changes to the Mekong over the past 50 years. This would provide an indication of the present rate of change in the river with respect to channel widening or constriction, or channel migration. At a smaller scale, channel cross-sections and ADCP profiles collected at HYCOS and DSMP monitoring sites could be compared to provide an understanding of how the river cross-section changes between seasons, and through time.

As a first step, it is proposed to develop a scope of works which includes developing an inventory of the available resources, identifying the resource needs associated with converting historic aerial photos to a usable digital format, and identifying relevant reaches in each country to be included in a subsequent analysis.

Resource Requirements and Implementation Commitments: Resources are required to assist the IKMP to develop the scope. Initial steps to obtain inventory of available aerial photos, identify methods of conversion to digital format and develop scope of works are estimated to require approximately 2 weeks of IC time, with assistance provided by JRPs.

Sustainability Considerations: The types of large scale analyses included in this proposal are typically completed at intervals of ~5 years on a basin scale. Establishing tools and procedures appropriate for the Mekong would provide a basis for future repeat analyses at 5 yearly intervals.

Outcomes and Benefits: Obtaining an understanding of the large scale geomorphic processes operating in the basin, and estimate of rates and trends would provide a context within which smaller scale changes could be interpreted. This level of information is important for understanding, interpreting and evaluating the relevance of channel changes occurring over decades associated with hydropower projects.

6 Conclusion

The ISH11 project has identified opportunities for enhancing MRC sediment transport and geomorphic monitoring for hydropower information needs. The proposals identified as highest priority include the interpretation of existing sediment, water quality and hydrologic information to derive hydropower-specific indicators, the collection of bedload sediment samples and additional grain-size analysis of suspended material at more sites, and the analysis of ADCP and aerial photos to provide an understanding of geomorphic processes over longer time scales. 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

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

Attachment 2 – Response to Comments Raised in National Consultations

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