Minutes of the MRC Regional Workshop on Discharge and Sediment Monitoring and Geomorphological Tools for the Lower Mekong Basin

21-22 October 2008, Vientiane, Lao PDR

DAY 1 – Tuesday, October 21, 2008
Opening Session: The importance of sediment in fluvial systems and what we know for the Mekong River?
Mr Erland Jensen, IKMP CTA

Welcoming Remarks
Director Te Navuth, IKMP, MRCS

Director Navuth welcomed participants and placed sediment monitoring in the context of the components and workplan of the Information Knowledge Management Program (IKMP) of the Technical Services Division (TSD). He stressed the importance of integrating hydrometeorological data into the knowledge based, and the importance of the collection and supply of quantity and quality of information to improve monitoring, forecasting, assessing development scenarios. This project of improving sediment monitoring is currently under formulation and inputs from all are sought at this workshop. Sediment monitoring will be integrated into the overall river monitoring system at the MRC.

In August, September, and October, the MRCS started to make field visits to hydrologic stations in the LMB where such collection was being undertaken. Questions arose was what methods should be used for discharge and sediment monitoring. The four member countries and NMCs were thanked for their contribution to this work.

The agenda of this workshop addresses specific issues such as consequences of hydropower development on sediment loads and morphology, and how these negative impacts can be mitigated. We will hear from modelling experts about tools for mitigating these impacts from landuse change and water resources development. We will discuss ideas for sediment discharge and monitoring with respect to other MRCS activities like water quality and biological monitoring. Participants in this workshop include representatives from government agencies, NMCs, each of the MRC programs, experts on river morphology, and sediment experts.

[The full opening speech can be downloaded as a PDF document from the MRC website along with copies of all presentations]

Participant Introduction
All participants took turns to introduce themselves and their affiliations.

Introduction to the Discharge and Sediment Monitoring Project
Dr. Sompong Boonprasert
Senior Hydrologist, IKMP, MRCS

Dr. Sompong introduced the Discharge and Sediment Monitoring Project at the IKMP. The project comes under Component 2 – data collection, processing and interpretation. A discharge monitoring project at the MRC has been on since the 1960, but has been temporally and spatially sporadic. The present discharge and sediment monitoring program is not

sufficient for current MRC programs. The IKMP workplan for 2008 requires that integrated discharge and sediment monitoring project would be formulated and implemented. It will later integrate water quality and biomonitoring. The MRC has 50 hydromet stations giving near real time rainfall and water level data --17 are currently under operation, while the rest are HYCOS stations which are under installation.
The objectives of the study were then introduced: to establish routine sediment monitoring, revise discharge monitoring activities, undertake specific field campaigns, and integrate discharge, sediment, biological and water quality monitoring stations. The study outputs are as follows: a report providing an overview of work done, MRC data/info and metadata holdings on discharge and sediment monitoring; a revised and enhanced discharge and sediment monitoring plan. The report will also be for fund raising purposes. This study project is undertaken from July to December 2008. From July to August, a needs assessment was conducted among MRC programs. Then, the four countries were consulted for data status and needs assessment. A revised and enhanced discharge and sediment monitoring plan would be prepared and information from this workshop will go into this plan. The plan will be submitted to countries and TACT in early December. The final plan is expected within this year. The objectives of the workshop would be to hear from country/expert presentations and discussion on the following:

- current discharge and sediment monitoring activities
- proposed strategy for the MRC monitoring system
- tools for discharge and sediment monitoring
- proposed initial workplan for discharge and sediment monitoring including integrating water quality and biological monitoring
- view/opinion exchange, comments and advice for the final monitoring plan.

Regional Workshop on Discharge and Sediment Monitoring and Geomorphological Tools for the Lower Mekong Basin
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Mr Erland Jensen, IKMP CTA

This session introduces what we know about the Mekong river.

Welcoming Remarks
Director Te Navuth, IKMP, MRCS

Welcomes participants. Introduces sediment monitoring as part of TSD, IKMP. Hydrometeorological data as integrated into the knowledge base. Collection and supply of quantity and quality of information to improve monitoring, forecasting, assessing development scenarios. This project is currently under formulation and inputs are sought. Sediment monitoring will be integrated into the river monitoring system at the MRC. In the view of planning and water resources planning and development. Monitoring plan currently being formulated.

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used for discharge and sediment monitoring. The four member countries NMCs are thanked for their contribution to this work.

The agenda addresses specific issues such as consequences of hydropower development on sediment loads and morphology and how these can mitigate negative impacts. We will hear from modelling experts about tools for mitigating these impacts from landuse change and water resources development. We will discuss ideas for sediment discharge and monitoring with respect to other MRCS activity like water quality and biological monitoring. And with respect to the network.

Participants include representatives from government agencies, NMCs, each of the MRC programs, experts on river morphology, sediment experts.

Will help us plan and coordinate other activities in the MRC framework. Warmly welcomes participants to this meeting and look forward to discussion on issues that will be taken into consideration.

Comments and clarifications
Cambodian representative: what is the relation between discharge and sediment?

Dr. Sompong: The more discharge you have, the more sediment. Sediment originates in the basin area due to rainfall and runoff. If we know the discharge, we can find the relationship between discharge and sediment, then we have an idea of sediment load and transport. We would like to monitor sediment load. What we have now is the hydromet network from which we know water levels. We convert this to discharge and from its relationship to sediment we are able to derive sediment loads.

Towards an understanding of Mekong River geomorphology: WWF concept for future work
Mr Marc Goichot
WWF Greater Mekong Subregion

Mr Goichot provided a perspective of the river as not being only just water, but an ecosystem with other biophysical components. Sediment is an important component in this balance, leading to changes in water quality, shape and behaviour of rivers, and affecting coastal and deltaic morphologies. Natural processes also have consequences for the economy and for decisions like river bank protection, relocation due to shifting sediment regimes (erosion/sediment shortage). Yet it is not fully understood. He stressed that we cannot cut and paste lessons from other parts of the world, but that we need to understand the Mekong.
This issue also has consequences for economy and national economy – therefore we need to understand natural processes. The Mekong Delta was named on of the three most at-risk deltas in the world, with dense population, agricultural importance, location of a large percentage of Vietnamese population and large share of the GDP in Vietnam. Agricultural pollution, salinity intrusion, lowering of water tables, and changing sediment balance have food security consequences. For example, these can affect fisheries, industries based on sand, hydropower dams, and biological diversity. This workshop is therefore critically important. WWF is also dedicated to this initiative and collaboration with the MRCS in this regard.

Comment from Chair: The MRCS is working with WWF on sediment issues and invites opportunities to collaborate with any other institutions interested in this initiative.

Keynote address: The role of sediments in fluvial systems
Professor Mathias Kondolf
University of California, USA

Dr. Kondolf's presentation is an invitation to step back and consider the role of sediment in rivers. He introduced the two important attributes of rivers with respect to sediment: 1) longitudinal continuity of sediment movement from upstream to downstream and; 2) lateral exchanges of sediment (channel-floodplain terraces). Sediment constitutes the building material of the channel, where river flow is the architect. It also provides the surface for the establishment of riparian vegetation and influences on shape of the channel. He then introduced the different kinds of sediments: suspended, bed-load, and dissolved load. He showed how dominant sediment types and load affect the shape of the channel, in turn resulting in a huge variety of channel forms and fauna and flora. Changes in sediment regimes can therefore have affects on biological environment. He demonstrated that interruptions of the longitudinal continuity of sediment movements (for example by dams) can trap sediment, releasing 'hungry water' downstream. Hungry water has increased capacity to erode and can deprive downstream reaches of sediment. He showed examples of sedimentation in reservoirs upstream of dams: the Bar-lin river, Dahan river, Taiwan. He stressed that eventually all dams will either fill with sediments or their concrete will become unstable. All these dams will then require decommissioning, at huge costs which are seldom considered in cost calculations for dams. He gave the example of the Matilija Dam on the Ventura River in Los Angeles, where $83 million was spent to remove sediment. The San Clemente Reservoir on the Carmel River diversion needed to remove sediment cost $144 million. He introduced other longitudinal impacts: the collapse of the sardine fishery and associated cultural effects in the Nile River Basin. The transformation of alluvial braided channels into single channels (e.g. Stony Creek in California after construction of Black Butte Dam in 1963).
Lateral connectivity is also important, and we must consider how actions like the construction of levees can prevent overbank flow and thus prevent sediment from depositing on floodplains. As a morphological consequence of sedimentation, deltas can be affected too by changes in the sediment regime, impacting the natural shifting and resulting in the need for artificial diversions on a large scale. Dr Kondolf concluded by stressing that a river's sediment exerts a profound influence on the river ecosystem (channel, floodplain, habitats), with substantial costs involved in mitigation measures/decommissioning of dams.

Sediment data on the lower Mekong River: A review of past monitoring activity
Professor Des Walling
University of Exeter, UK

Dr Walling introduced a small study for MRC conducted by himself in 2005. He gave a general review of past sediment monitoring on the Mekong. Monitoring activities started in the 1960s using methods based on US practice with persons working for Harza Engineering Company funded by USAID. However sediment monitoring in the Mekong has a number of problems: discontinuous records, low sampling frequency, raw concentrations data available for mainstream Mekong stations only, variations in collection practices between countries, lack of availability of Chinese data since 1990, lack of a continuous annual time series, and others. He showed some historical hydrographs and sediment records based on available data

(eg. for Luang Prabang and Pakse). There was relative stability of sediments loads throughout the LMB from 1960-2000. At the Jinghong station, there was some indication of progressive increase in loads, reflecting probably land clearance and development. Except for Mukdahan, there is very patchy data for downstream stations. With respect to suggestions for the enhancement of sediment monitoring, Dr Walling drew attention to the following issues:

- sampling frequency
  - need to know what we want the data for – what sampling frequency? what required accuracy? What data are needed? (eg not sure why they collected data in the past!)
  - solutions: reconstruction of actual concentrations or flux time series OR the use of rating curves

- use of water quality data
  - can we use what we have currently? Suspects that cross-sectional data is underestimated because of the way the data was collected; discrepancies when comparing results from nearby stations

Project overview: objectives, activities and outputs; and the important sediment issues in the LMB. Sediment data on LMB tributaries
Ms Iwona Conlan
IKMP-MRC Consultant

Ms Conlan provided an overview of the status of sediment data in the LMB. There are gaps spatially, eg. in northern and central Lao, which contribute up to 33% of the flow of the Mekong; as well as the 3S basin; parts of Cambodia, and the Delta. Temporal gaps exist also - very few samples collected before 1990. In Thailand, there has been regular sampling since 1993. She showed the downstream trends in median suspended sediment concentrations on the Mekong River – longitudinally and Mekong vs the tributaries. She pointed out that there might have been transcription errors in MRC sediment database. The tributaries of the LMB have a diluting effect on the sediment concentration of the mainstream. This, together with no distinctive downstream increase in sediment load, suggests that the LMB tributaries may have a limited sediment load contribution to the mainstream relative to the contribution from the Lancang River and that most sediment in the LMB is derived from China. However a lack of data on the large left bank tributaries in Laos, Cambodia impedes our making that conclusion.

A sediment budget for the Mekong River Basin is important for assessing the impact of dams on sediment loads downstream. Existing sediment issues in LMB are bank erosion, shifting islands (loss of land, national territory) and aggradation in the shipping channels and Tonle Sap lake mouth. Potential future issues are reduced sediment loads due to dams, increased sediment loads due to landuse change, and river morphology changes. Eleven hydropower dams on the Mekong River mainstream are under consideration. The two dam cascades are planned for the bedrock control reaches, with alluvial reaches in between. Where some of the dams are being planned there are major gaps in sediment data (northern and central Lao, 3S).

Ms Conlan then presented the objectives of the monitoring project formulation, important considerations on questions to be answered, how the data will be used, and appropriate methods/equipment. Activities and outputs of the planning stage were introduced.

Session 1: Status of monitoring and future data needs by the four riparian countries

Introductory remarks by Chair, Mr Erland Jensen
The aim of this session is to understand what needs the countries have and the current status of discharge and sediment monitoring.

Report on Discharge Measurement and Sediment Sampling in Lao PDR
Mr. Prasit Dimanivong, Department of Meteorology and Hydrology, Lao PDR

The Dept of Meteorology and Hydrology is responsible for hydrometeorological data collection in Lao PDR. The presenter gave the organizational structure of the Dept of Meteorology and Hydrology – at national level, it has a central administration and at provincial levels, 16 provinces and 1 special zone. The management of hydromet stations takes place at the provincial level. He then presented the methods used for discharge measurement. A conventional, mean section method for the Mekong and mid-section method for the tributaries are used. The area-velocity type current meter is used for discharge measurements. There are a total of 40 stations, with joint Lao-Thai measurements being conducted at 7 stations. The sediment sampling method is then introduced: it is done by the 2-point integration method. There are 14 sediment sampling stations. Data archiving and analysis with HYMOS is then presented. Protocols for data transmission are also presented. He concludes that the management and operation of the hydromet network are satisfactory and that the Department is capable of carrying out activities by their own personnel. There is close cooperation with Thailand in discharge and sediment monitoring. Some of the main problems are: financial support for field operations; personnel training; equipment and logistical facilities.

Recommendations: improvements in discharge and sediment monitoring may be done through technical assistance in using of high technology and training on data analysis and processing. There are also some equipment needs.

Status of existing discharge and sediment monitoring the Mekong River and tributaries Thailand, Ms. Wandee Patthanasatianpong, Department for Water Resources, Thailand

Ms Wandee introduced how discharge measurement was conducted with the point method and the use of the current meter (propeller for mainstream and cup type for smaller rivers). Sediment measurement is conducted by the depth-integrated method using US-DH 48 and 49 samplers. She presented the frequency of measurements. Different line agencies conduct measurements with a total of 7 stations on the mainstream (joint Thai-Lao project) and 121 on the tributaries. Her recommendation and needs are presented.

Recommendations: There is a need to improve equipment such as higher-tech and higher-efficiency ADCP and ADP, boat and engine, and sediment laboratory. In terms of training needs, they lie in the areas of the use of equipment, data analysis, and calibration.

Discharge and Sediment Monitoring in Cambodia
Mr Yin Savuth, Department of Hydrology and River Works, Cambodia

Mr Yin showed existing hydrological stations in Cambodia. The current meter is used for discharge measurements on tributaries, ADP is used in Phnom Penh, and the ADCP for the

Mekong mainstream (Stung Treng, Kratie and Kompong Cham stations). There were 82 stations in 2006. There are 102 stations for water level; 37 for discharge; 15 for sediment; and 21 for water quality. He showed the program for water quality monitoring and the parameters analysed. For discharge measurements, inconsistencies were found in the ADCP. Recommendations: The MRC should account for sharp rise in cost of petrol since June 2008. The ADP/ACDP needs to be recalibrated and rechecked, and the ADCP needs to be repaired. A boat with engine is also necessary for sediment sampling. Station improvement is very important to monitor hydrological data. Discharge and sedimentation observation should be extended to tributaries for update the rating. Some other equipment needs were listed.

Discharge and sediment monitoring in the Mekong River in Vietnam
Mr Giap Van Vinh – Southern Region Hydro-Meteorological Centre (SRHMC), Vietnam

Vietnam has 5 main discharge gauging stations on the Mekong, Bassac and Vam Nao rivers. These stations record different effects on the delta. For Tan Chau, Chau Doc, Vam Nao, there is a dry season tidal effect, back flow; with small tidal effect in the flood season. For the Can Tho and My Thuan stations, which are located further downstream, the tidal effect is all year, with no backflow from Sep-Oct. He introduced the methods for collecting discharge and velocity data, and frequency, for the dry and wet seasons at these two different sets of stations. Sediment monitoring is conducted at Tan Chau, Chau Doc and Vam Nao stations with three detailed sediment measurement campaigns a year during the dry season, and weekly sampling during the wet season. There is no sediment sampling at Can Tho and My Thuan. He introduced the sampler and method (depth integrated) for sediment monitoring. He also presented the method used for water quality monitoring. Water quality and discharge data are used for monitoring trends in the variation of water quality, the planning of water resources utilization, and for Environmental Impact Assessments.

Recommendations: equipment for discharge and sediment monitoring at key stations, including ADCP, boat, GPS, DGPS, suitable sampler (for suspended sediment and bed sediment), electric winches, should be upgraded; training should be provided

Water quality and ecological health monitoring in the Lower Mekong Basin
Mr. Tranh Minh Khoi, Environment Programme, MRC

Mr Tranh of the MRC introduced the context for water quality and ecological health monitoring in the LMB. The management of Mekong River water needs understanding of the linkages between hydrology and people. The MRC monitored water quality of most of the river since 1985 with participation of Laos, Vietnam and Thailand; and since 1993 in Cambodia. The Water Quality Monitoring Network consists of 87 monitoring stations across the four countries. The countries participate by carrying out sampling at stations within their national territory and performing analysis in designated national laboratories. The overall coordination is provided by the MRC. He then gave the objectives of the MRC water quality monitoring program, and introduced the 87 permanent stations on the mainstream and important tributaries. The monitoring parameters are designed to cover eutrophication, chemical weathering and loss of organic matter. The training and adherence to the international standard ISO-17025 substantially improved the countries' quality control systems and metadata. Future monitoring needs are then presented. Lastly, the Ecological Health Monitoring program on surveys of littoral and benthic macroinvertebrates (started 2004) was presented.

The history of MRC supported discharge measurements in the lower Mekong basin, and existing protocols for data analysis, transfer and sharing
Dr. Chusit Apirumanekul, Hydrologist, IKMP, MRC

Dr Chusit showed the available measured discharge data at MRC from 1960 onwards, agreeing with Dr Walling about the scattered characteristics of the data. He then presented tables of measurements for some stations. An example of a field data collection form for discharge measurement was also shown. Based on information collected, he showed how rating curves are plotted and then the discharge found for each site for each day. The rating curves used are detailed in the Annual Mekong Flood Report. The steps of data acquisition are then presented: a TOR on discharge measurement, which is sent to countries, accepted, data is collected, and data delivered to the MRC. The process is repeated each year. Data storage at the MRC is presented. Dr Chusit presented on the storage of historical vs operational data (manual reading, AHNIP, HYCOS), including the data source, database software, and type of database. A hydrological yearbook is produced annually and has been available since 1999. Requests for data can be made, and are processed in terms of commercial/noncommercial uses, purpose of data usage, etc.

---- *Lunch Break* ----

a) **Findings from site visits and consultations with countries: measurement methods, needs for equipment and training, and data needs**
b) **Draft outline of revised discharge and sediment monitoring plan**

Ms Iwona Conlan, IKMP-MRC Consultant

a) Findings from site visits and consultations with countries: measurement methods, needs for equipment and training, and data needs

The consultations with the four countries sought the discharge and sediment data needs of MRC programmes. These included the need for accurate stage-discharge rating curves for flood forecasting, predicting consequences of development scenarios, understanding hydraulic parameters and sediment data for fisheries management and research, bed load data and tools for estimating reservoir sedimentation rates, sediment transport and channel morphology data for predicting the effectiveness of navigation and bank protection works. The data needs for sediment transport modelling and priority locations for collecting sediment and channel morphology data. The key issues for discharge measurements were found to be with respect to boats and engines, equipment needing repair, calibration of equipment and ADCP errors and underestimation of discharge under existing measurements due to the effect of a moving bed and the lack of Differential GPS systems to correct for this.

b) Draft outline of revised discharge and sediment monitoring plan

The draft outline of a discharge and sedimentation monitoring plan was presented for the two Phases: Phase 1 (2009) and Phase II (2010) (see slides for more details).

Session 2: Monitoring tools
Chaired and facilitated by Prof. Des Walling, University of Exeter, UK
Introduction remarks by Chair

Discharge measurements by Acoustic Doppler Current Profilers (ADCP)
Ms Iwona Conlan
IKMP Consultant

Ms Conlan introduced the ADCP: what it is and what it measures. She showed how an ADCP measured velocity by detecting a change in pitch during the movement of suspended participles in the water column. The sound pulse emitted by an ADCP is reflected by suspended particles in the water column. The equipment needs for ADCP measurements are presented. The ADCP has good accuracy and is considered a highly accurate measure of discharge. She also introduced bottom tracking, its accuracy and how sediment movement on the bed will bias bottom tracking, giving an error in the measured discharge of about 5 to 25% in the Mekong especially in the wet season. Proposed quality control activities for the measurements were also presented.

Mississippi and Atchafalaya Rivers Sediment monitoring programs
Mr Charles Demas, USGS, Louisiana, USA

Sediment monitoring programs in the Mississippi and Atchafalaya Rivers have been conducted since 1973. An introduction to the Mississippi and the reservoirs in the upper Missouri and Ohio were given, notably the construction of locks and dams in the 1950s and 1960s. The major sediment issues for the Mississippi and Atchafalaya Rivers are noted to be sediment accretion and transport questions, and contaminants. Two federal agencies -- the United States Corps of Engineers and the US Geological Survey (USGS) – are involved in these programs. Mr Demas presented 3 national and local programs: 1) Long term status and trends; 2) Sediment Flux; and 3) Sediment transport characteristics. He then presented monitoring activities, water quality indicators and parameters. Monitoring programs including long term monitoring sites and sediment transport studies on the mainstream to determine transport characteristics. Some results on reductions in suspended sediment loads on the Missouri were presented – these were due to the stabilization of banks and also the dams on the Missouri. The suspended sediment samplers were presented including their limitations and efficiency. He suggests the use of depth integrated over point samplers to ensure sampling speed for different water velocities. Mr Demas also introduced bedload samplers used and some issues with these and their variable success. He ended the presentation with a call to understand what additional data needs to be collected in sampling and sediment analysis decisions.

Surrogate measures of suspended sediment transport in rivers: the use of ADCP
Iwona Conlan presented on behalf of Professor Ray Kostaschuk, University of Guelph, Canada

Ms Conlan on behalf of Prof. Kostaschuk presented on the equipment requirements of ADCP: what is needed to calibrate ADCP backscatter, and showed instruments for *in situ* measurements of suspended sediment. An example from the Parana River in Argentina was given showing streamwise suspended sand flux over a study dune based on velocity and sand concentration. In summary, ADCPs can be used to measure velocity and discharge and to estimate suspended sediment concentrations and transport from a moving launch. The

approach has limitations, however, notably in the dependence of concentration estimations from backscatter on the quality of the calibration curve. Mixed load rivers require the separation of wash and suspended bed material concentrations and separate calibrations. Calibrations are often better for sand than silt/clay. The ADCP does not provide measures of velocity and backscatter close to the bed, and is therefore likely to underestimate actual transport rates. Ms Conlan ended the presentation by asking countries if they are interested in this method given these opportunities and shortcomings.

Measuring bedload transport on large rivers: A case study from the Missouri River, USA
Dr David Gaeuman, formerly USGS Columbia Environmental Research Centre, Columbia MO; now Trinity River Restoration Program, Weaverville, CA, USA

Dr Gaeuman introduced methods for measuring bedload transport -- conventional physical sampling, dune tracking and using an ADCP to measure the velocity of sediment over the bed. He also presented some of the equipment used, such as equipped boats and sonar systems. He then presented the method of dune tracking and the equation used to estimate bedload transport rates. By tracking changes in bed elevation over distance we can produce profiles of changes in sediment movement over time. On the ADCP, he showed how bed velocity is derived and cautioned that velocity is a weighted average of the immobile and mobile layers at the bed because of the way the Doppler works, and can also be affected by sediment size. He showed the use of dune tracking to validate/calibrate ADCP results, and how the relationship between bedload transport rate and bed velocity breaks down above a certain threshold. In summary, there is good correlation between dune tracking results and ADCP bed velocity measurements for bedload transport rates of 0.9 kg m^{-1} s^{-1} or less. He suggests that both methods are effective when the transport stage is less than about 17. Dune tracking probably underestimates transport at higher transport stages. Bed velocity data may be robust at higher transport stages. The relation between bed velocity and bedload transport rate cannot be described by a single stable calibration. He concluded with a suggested bedload sampling strategy for the Mekong.

Satellite remote sensing: A useful tool for rapid geomorphological analysis of large rivers
Dr Liew Soo Chin (presenter) and Avijit Gupta
CRISP, National University of Singapore

Dr. Liew began the presentation with a discussion about the usefulness of satellite imagery for monitoring large rivers – because of synoptic views of areas of interest and frequent and repetitive coverage. He noted that these are very useful for rapid assessment, wide area coverage, and study of temporal change. He introduced different types of satellites – geostationary, environmental, earth resource, very high resolution, including MODIS (wide coverage but low resolution), LANDSAT, and SPOT satellites, and very high resolution satellites. A MODIS image of Tonle Sap and the Mekong in 2003 showed large sediment deposition during the rainy season. He summarized the principles of radar remote sensing and demonstrated the uses of the synthetic aperture radar (SAR) satellites for landuse classification. Dr Liew presented on the Centre for Remote Imaging, Sensing and Processing (CRISP) located at the National University of Singapore and its satellite data on offer (www.crisp.nus.edu.sg). The rest of the presentation was devoted to a study by Gupta and Liew (2007) published in the journal Geomorphology in which they use satellite imagery to examine channel forms, their seasonal changes, landcover change and sediment properties.

The Mekong was divided into 8 basic river units. He also presented the Lower Mekong sediment study and Lower Mekong River Change (2003-2006). While not a replacement for usual field investigations, satellite remote sensing can be a useful tool for rapid analysis of large river geomorphology, also temporal change studies. Reconnaissance studies at this scale are otherwise difficult to conduct.

Spatial distributions of sediments (and chlorophyll) through the Mekong: Preliminary assessments from satellite and models.
Jeffrey Richey, School of Oceanography, University of Washington.

Professor Richey's research questions were: 1) what is the relation of landscape structure, climate (change), runoff regimes, and hydropower to sediment mobilization, transport and fate? 2) What role does the Mekong mainstem (current and future) have in setting the productivity of its floodplain waters and, particularly, the Tonle Sap? He called for a convergent strategy of enhanced measurements with optical remote sensing, surface continuous sensors, and conventional manual suspended sediment sampling. He introduced the concept of optical remote sensing of sediments in rivers/lakes and how we can derive sediment loads through interpreting aquatic spectral characteristics of the sensors combined with ground truthing to calculate spectral absorption coefficients. Frequent cloud cover contaminates sediment estimates. The sources of operational optical remote sensing data were MODIS (1-2 day cover, 250m res), MERIS (3 days, 300m), and ETM+/TM/MSS data (16 days, 30m). He showed the Amazon as a example for estimating suspended sediment concentrations and chlorophyll distributions from MODIS data. For the Mekong, changes through time of sediment in the Mekong Delta from MODIS are shown. The spatial distribution of turbidity has also been estimated. MODIS yields very useful results, for example for the Tonle Sap. Sediment distribution differences can be seen from such imagery – including a Landsat 7 ETM+ image which showed low and high sediment inputs in different parts of the lake, and differences in chlorophyll and productivity. Surface continuous sensors offer continuous monitoring of pH, dissolved oxygen, turbidity and fluorescensce. Satellite data can be calibrated with field measurements, and can be tied in with ADCP profiles to get at total suspended load. Overall, the means to extend base systematic point sampling to get at spatial/temporal change are promising – from optical remote sensing to continuous remote samplers and the use of coupled hydrology/sediment transport models.

DAY 1 PANEL DISCUSSION

Professor Jorgen Fredsoe: What is the definition of bedload?

Dr David Gaeuman: Bed material sediment can travel along the bed as bedload or in suspension just above the bed. It really boils down to how you can sample it. The opening of the bedload sampler is about 10cm high so anything that it captures is considered bedload. This is one practical and commonly-used definition.

Professor Jorgen Fredsoe: If you have a transverse flow due to slope of water, Do you consider sediment transport in the transverse direction part of the overall bedload? Modelling requires a detailed definition of bedload.

Dr David Gaeuman: Hard to hear. Are you saying if material is moving in a transverse direction, it is suspended load whereas transport in the streamwise direction is bedload? (DHI: yes. Therefore you need for modelling purposes to make a distinction between bedload and suspended load). It boils down to what transport function you are using, and also which pickup function.

Prof. Des Walling: Do countries want to comment on whether this is something they are interested in measuring? [no response from audience] Does panel want to comment on what good recommendations?

Dr. David Gaeuman: dune tracking is a potentially useful method. When you lower your suspended load sampler, you can only get so close to the bed and therefore the sampler does not pick up bedload. This can be used to differentiate bedload and suspended load.

Prof. Des Walling: Any groups interested in dune tracking?

Prof. Jeffrey Richey: Do we know on the annual curve of suspended sediments the bedload curve – is there a relationship between suspended sediment, bedload and discharge?

Ms Iwona Conlan: At the moment no, in the 1970s there were some measurements and calculations of bedload made for a reach just upstream of Vientiane. Bedload is typically assumed to be about 5-10% of annual sediment flow, but we don't have many reliable measurements.

Mr. Charles Demas: In the Mississippi all bedload transport data are estimated with no direct measurements.

Prof Jeffrey Richey: in the Amazon the proportion of bedload is about 2-3%. May be useful to estimate this for the Mekong River on an experimental basis.

Mr. Charles Demas: In certain river reaches, bedload just disappears – it is sometimes suspended and then shows up [in measurements] again further downstream. It is premature to do these experiments/sampling here without asking: 1) what would you use this information for, compared to the cost of implementing these experiments? 2) are current studies sufficient? We need to take into account the expenditure of resources versus the question you are asking. Why do you need to know?

Ms Iwona Conlan: The most urgent need for bedload data is for modelling morphological change using sediment transport models. Certain countries also want bedload data for the purpose of setting sustainable extraction quotas for sand and gravel mining.

Mr Charles Demas: from the experience of the Mississippi, in pre-regulatory days, a mining operation caused mass damage to the channel. The most valuable sediment was gravel and this was extracted, leaving a bed that became exposed to significant scouring.

Prof Des Walling: In summary, bedload is not easy to measure. We may need to begin with experimental studies. Moving on to suspended sediment samplers, should depth or point integrated samplers be used? How did national groups choose one over another?

Ms Iwona Conlan: asked Ms Wandee (Thailand) – do they prefer depth or point integrated samplers? Any good or bad experiences with the point integrated samplers?

Ms Wandee, Thailand: We use the USDH 48 and 49. We have experience in depth integrated sampling.

Representative from the Department of Water Resources in Thailand: We use the depth integrated sampler because it is more useful - we can take many samples in one, whereas for point samplers we would need to take many samples.

Ms Wandee: The (depth-integrated) USDH 49 nozzle collects water from the whole water column.

Prof Des Walling: [to Charles] what are the samplers available in the US especially with the problem of depth and limits it imposes on sampling?

Mr Charles Demas: The (depth integrated) D99 sampler would be a good option. However point samplers are very good and provide useful information to modelers, for example for coastal restoration if one is looking for sediment and not just water diversions. You need to know where the maximum concentration is. Point samplers need to be checked before they are used. Let the sampler sit there, then pull it out and check the bottom of the sampler. Any presence of water means you need to take it apart. Depth samplers are easier to use as they have no movable parts and can collect very large sample volumes. Our experience from the Columbia River where 10mg/l samples were collected, it has been found useful. In the Mississippi, we were collecting 20-30 litres of water per cross-section. We split the samples in the field between sand, silt and fine silt, and did chemical analysis on different grain sizes. The relationship between trace metals and grain size is well documented so this provides enough material. But one needs to check it beforehand. The D99 weighs about 150kgs.

Prof Des Walling: Would countries be willing to take on a 150-kg sampler?

Representative from the DWR, Thailand: if you take a sample in the same site with a depth and point integrated sampler, what is the error between the two?

Mr Charles Demas: We data-tested the samplers before they were used. And they were within 10% of each other. The maximum depth you can integrate with a point-integrated sampler is 9m. With beta testing it was way off. A Federal regulation agency made new guidelines and depth integration did not comply. We are doing a lot of modelling and those samples are collected at specific points in the water column. Depth integration didn't give us the data we needed for modelling and other specific purposes so we went back to point sampling with point-integrated sampler.

Prof Des Walling: What about the usefulness of these for the Mekong?

Mr Charles Demas: Again, you need to decide what problem you want to answer because this will affect your decision on samplers.

Ms Iwona Conlan: One option for the future monitoring plan would be that countries would equipped with new depth integrated bag samplers which can sample deeper depths than the existing samplers. These have an expandable plastic bag (3-6 litres). If you want to combine

all the samples in one analysis, you end up with a 9-litre sample. The advantage of a point sampler is that a glass bottle is used, which is easier to clean and give s smaller sample sizes. The bag is collapsible and will therefore trap sediment, resulting in an underestimate of the suspended sediment concentration. You really need a good washing technique to get the sand out. This is a potential problem in Mekong where there is a lot of sand in suspension so you can end up underestimating suspended sediment loads.

Prof Des Walling: Let us address surrogate measures on suspended sediment measurements. Definite values are ideal but laborious. One solution that has been brought up in presentations is the ADCP. The other is as Jeffrey's presentation introduced, was the continuous recording of turbidity. Jeffrey's presentation showed us a good record going through the year. A continuous record in addition to manual sampling in the cross-section may be very useful as it can be calibrated with the cross-section averaged sample concentrations to provide a daily record of suspended sediment concentration. Comments from Jeffrey about this?

Prof Jeffrey Richey: Yes, these records are pretty robust. At the University of Washington we are doing a nitrate study, where, for example after storms, the continuous measurements have been good for picking up the sediment flux over the time storm-flow takes to return to baseflow.

Mr Charles Demas: If you analyse samples from verticals and points separately, with the point sampler you may find a vertical with too much sediment. And this makes it easier to identify outliers. Occasionally you could use a depth sampler, work out how much in each section, to use as quality control.

Prof Des Walling: On to the frequency of sampling. How often will you take samples? Depends on why you want the data. And what about the possibilities for sampling – what frequency is feasible? What about Thailand?

Representative from the DWR, Thailand: We collect data that is sufficient to estimate transport load annually, and also as our budget allows. The existing sampling frequency [4 times per month in wet season and 2-3 times in dry season] is sufficient in order for us make annual rating curves. We relate sediment concentrations to discharge.

Prof Des Walling: We have lots of comments on the need for particle size data, but we have a number of different methods of categorizing and measuring grain-size, e.g sedigraphs etc. These will give different results. If we are working as a region, we need standardized techniques.

Dr. David Gaeuman: I have a comment on surrogate measures of suspended sediment using an ADCP. It is a very difficult to calibrate the ADCP. I want to discourage the MRC and countries from investing in this.

Des: Any comments on use of ADCP for suspended sediment transport estimates?

Representative from the DWR, Thailand: Agrees with use of ADCP in the region. Vietnam, Thai and Cambodia are using ADCP but we have not seen the result of these measurements…is this good for estimation and better than the older method? It is good because no need for lab sampling. Maybe it is good to supply ADCP to the countries.

Prof Des Walling: Yes, we could test the ADCP on an experimental basis.

Mr Charles Demas: We have to collect and check samples in order to calculate/calibrate the ADCP measurements.

Dr David Gaeuman: The one difficulty is that sediments absorb some of the acoustic energy. Even after correction, you have a packet of particles. You calculate this once and you have to then take this out to take in the next sample. Sediment absorption of acoustic energy is therefore a problem.

Prof Jeffrey Richey: What is the level of error? Depends on why you want this information.

Dr David Gaeuman: The error can potentially be very large.

Ms Iwona Conlan: On depth integrated sampling - Thailand collects samples from 3 verticals. Vietnam collects over 6 verticals. To the panel - what is the minimum number of verticals to ensure a representative sample of the whole cross-section?

Mr Charles Demas: We went to a cross section and collected 20 sections and worked from there by cutting out verticals successively until we reached the minimum number of verticals where the estimated concentration was still within 95% of the concentration calculated from the original 20 verticals. We found 5 verticals were sufficient but this number is likely to be site specific.

Ms Iwona Conlan: Would the countries be willing to undertake extra sampling, say at 20 verticals for a short period of time to allow us to determine the minimum number of verticals required for a representative sample?

Mr Erland Jensen: In 2009, we can conduct a pilot study to answer some of these questions. By end of this year we need to see what questions we need to answer. If countries would be willing to do the work, then IKMP can help support it.

DAY TWO – 22 October 2008

Session 3: Understanding and predicting sediment yield from catchments
Chaired and facilitated by Mr. Erland Jensen
Introduction remarks by Chair

Understanding and quantifying sediment budgets
Des Walling, Department of Geography, University of Exeter

The aim of this presentation is to demonstrate the importance of calculating sediment budgets – not just output but what is going on inside the catchment, i.e the sinks in the system. In the lower part of the system, the key process is sedimentation on floodplains before it reaches the river mouth. Indirect and direct ways of estimating overbank sedimentation rates are presented. For a long term perspective, fallout radionuclides can be used: caesium-137 from weapons testing and lead-220 from natural geogenic sources. These can be used to identify floodplain surfaces from particular years and therefore to calculate accretion rates. A paper by Spencer Wood et al dated some sediments in a floodplain near Chiang Saen which showed

an accretion rate of about 1cm a year. Phosphorus storage can be calculated as well. In the upper part of the system, sediment source fingerprinting can be used to understand where sediment is coming from: Collect sediment from a river, and then from various potential sources in the catchment, and compare these for properties like geochemistry, mineral magnetics, radionuclides, and isotopes. Statistical tests can help in source discrimination.

Clarifying questions from the floor
Dr David Gaeuman: What possibility is there of subsidence in the floodplain that might suggest a major sink for sediment?
Prof Des Walling: Yes, we need to consider where sinks might be. Sediment load data suggests sediment may be disappearing somewhere so important to look at this issue.

Representative from Vietnam: On hungry water. 1) Is there a way of fixing the problem of hungry water (more sediment for water)? 2) Role of sediment in fluvial system. Time for investigating these compared to the timing of hydropower developments in the basin? 3) Iwona's presentation: sediment contribution from LMB tributaries is limited, as most come from the mainstream in China. This is a source of worry as the pace of deforestation and erosion in China is high. Thinks we should not discount the tributaries as a source of sediments.

Chair: These questions to be addressed later by Dr Kondolf's afternoon presentation and the next panel discussion.

Measuring and modelling sediment yield at the small catchment scale: ongoing works of the MSEC project
Dr. Olivier Ribolzi
IWMI/IRD, Lao PDR

The MSEC, or the Management of Soil Erosion Consortium, is an international project established in 1997 involving some SE Asian countries. The aims are to produce and disseminate knowledge on geophysical and other processes, build capacity in assessments and monitoring, and conduct *in situ* measurements of environmental parameters. The project asks: what are the main processes that govern sediment generation in fragmented lands (for example shifting cultivation lands)? The project looked at the geomorphic and hydrologic processes occurring at the sample plot, micro-catchment to hillslope scale, and the small stream to main river catchment scale. The question was: do undergoing landuse changes in Laos threaten the environmental services provided by upland areas to the downstream? An experimental catchment in Luang Prabang province was found to yield sediment losses beyond 'tolerable losses' between 2001 and 2005. Bedload transport from hillslope catchments was also high. A number of approaches for sediment modelling in small catchments were presented, including statistical modelling and dynamic modelling. Tracer-based hydrograph separations helped in understanding flood and sediment generation proceeses at the small catchment scale. The project also used a Darcy multi-domain approach for integrating surface/subsurface for 3D modelling. In conclusion, we need to reward and acknowledge environmental services (clean water production) from uplands, and acknowledge the importance of long term catchment studies for monitoring impacts of landuse changes and test innovative conservation practices. Scale considerations are also of utmost importance. For the Mekong, he proposes a similar upscale approach to support the MRC modelling platform to validate the current SWAT approach at the basin scale. – 1 x 1 km grid for main tributaries, and then larger grids as we scale up.

Monitoring landuse change with remote sensing data: Application to sediment yield modelling
Dr. Liew Soo Chin and Avijit Gupta
National University of Singapore

Dr Liew gave an introduction to sediment loss factors and uses of different types of remote sensing data for measuring different aspects of landuse change (vegetation cover, soil type, precipitation, slope gradient). In a study published in *Geomorphology* 44 (2002), they studied the northern part of the Mekong and showed changes in seasonal variations (dry and wet) in slope exposure and vegetation cover and sandbars on sides of channels between two years through mapping parameters like landcover change, slope of land where vegetation loss occurred, river channel width, and sediment storage within the channel. Dr Liew demonstrated how you can generate a slope image from a DEM produced from a SPOT stereo pair → can generate slope image. The findings were: a large proportion of cleared land has steep to very steep slopes; the growth of bars in Mekong River channel; land clearing on steep slopes leads to erosion and may reach the main channel. A land cover change and environmental vulnerability maps can be generated.

A second study on the 'Remote sensing of water turbidity and suspended sediment' by the presenter was then described. Dr Liew introduced reflectance and water quality parameters, and how to derive water reflectance from water constituents by looking at the optical properties of water. His study detected highly turbid river waters, and retrieved suspended sediment concentrations from these measures. He then explained how water turbidity is defined, measured and calculated from the use of multispectral satellite imagery, and then converted into a sediment concentration map.

Application of SWAT model for erosion and sediment transportation in the Lower Mekong River Basin
Mr John Forsius on behalf of Mr Phoungphanh Souvannabouth, Water Resources Modelling Expert, MRCS

Mr Forsius presented the objectives of the MRC's SWAT hydrological model for erosion and sediment transport, This was followed by a discussion of data availability and analysis. A list of sampling stations was shown. There are 7 sediment inlet points into the mainstream. Sediment rating curves are used to generate sediment concentrations from daily observed flow. For the setup and calibration of the model, parameters control for the following: maximum sediment concentration that can be transported, sediment transport, channel erosion, sub-basin erosion, type of tillage, crop management variables, biomixing efficiency, slope. In conclusion, Mr Forsius noted some limitations on the sampling points used for calibrating the sediment model, and noted that the annual sediment loads estimated were consistent with Dr Walling's 2005 study. Point calibrating proved useful and was adopted. One concern was that only one value of USLE_C (Universal Soil Loss Equation crop management factor) was used and this not enough for large watershed with high variability in real crop management practices)

PANEL DISCUSSION ON SESSION 3

Panel: Des Walling, Olivier Ribolzi, John Forsius, Liew Soo Chin
Chair: Erland Jensen

Mr Erland Jensen: Back to the question brought up by Vietnamese delegate in the clarification part after Dr Walling's presentation.

Ms Iwona Conlan: Regarding sediment loads from tributaries. From our initial analysis of the concentration data only, it appears that tributary sediment concentrations are low in comparison to the mainstream. However, there are many gaps in the data. Perhaps each individual tributary does not contribute a significant sediment load to the mainstream but we have to consider that cumulatively, all the LMB tributaries together would be expected to supply a large amount of sediment to the Mekong River.

Vietnamese delegate from previous Q&A: [clarifies question.] The conclusion for us of whether most of the sediment comes from China or from LMB tributaries is very important – how can sediment management and monitoring meet requirements for our current development situation now? The answer is sufficient for now.

Mr Erland Jensen: Any more clarifications?

Representative from Lao PDR: What is the contribution of bedload compared to suspended load in the SWAT model?

Mr John Forsius: Sediment transport modelling in SWAT does not distinguish between bedload and suspended sediment. There is only a parameter that helps you match observed and modeled concentrations [which are typically only of suspended sediment]

Dr David Gaeuman: I have a question for Dr. Ribolzi. The result that the less runoff the more groundwater and the more surface erosion seems unintuitive. Was it a surprising result?

Dr. Ribolzi: it depends on the surface, soil surface types. Generally (not shown in presentation) in shifting cultivation land there is one year of burning and cultivation followed by several years of fallow. On average the experimental sites have a 5 year rotation. After 5 yrs of fallow, the farmer cuts the vegetation and cultivates it. But the macropores in the soil still exist. The farmers then till the soil surface – permeability of soil remains high. This means that there is high suspended sediment, low contribution of overland flow. The year after, farmers abandon the land but the vegetation cover isn't so dense. During this time the macroporosity of the soil continues to reduce and a crust forms on the surface which gives higher overland flow the year after and low sediment yield rate. This is our hypothesis. We are trying to demonstrate this by measuring the hydrodynamic properties of soil and developing specific tools to measure these hydrodynamic properties, e.g. slope, which is quite challenging.

Dr. David Gaeuman: So the change in groundwater discharge and surface runoff covaries with sediment production because of the clearance of the field and increase in soil permeability.

Dr Ribolzi: The most important thing to emphasize is that groundwater contribution is very important if one wants to understand suspended sediment concentration even in larger rivers. You need a good hydrological model to understand sediment.

Mr Erland Jensen: Groundwater is an important focus point. Any others?

Ms Iwona Conlan: Can SWAT handle groundwater?

Mr John Forsius: SWAT can distinguish overland and subsurface flow so it would be possible to look at groundwater. But we must remember that in SWAT everything is schematic – e.g. constant dimensions of the channel in each subcatchment. Our parameters are not sophisticated so sediment cannot be modeled in much detail in small catchments

Ms Iwona Conlan: There is a need within the MRC to model different scenarios of landuse change on sediment yields in rivers. What we would like to get out of this session and discussion panel is an answer to the question of whether the MRC are currently in a position to model such scenarios; and if not, what do we need to do to improve the current models (SWAT)?

Mr John Forsius: I think we can use SWAT to get some results but how representative there are of reality is another question. For example from Ribolzi's study found that if you till the soil, you get less sediment in the river - this seems contradictory.

Dr. Ribolzi: Calibrating and validating models are different things. An up-scaling approach may be used to validate a model calibrated with data from a smaller catchment. Maybe at first you can compare different approaches – starting at small tributaries with most relevant datasets, and then move towards prediction. Dr Walling's presentation on fingerprinting and source work can also be used to validate models like SWAT.

Dr David Gaeuman: You could consider using channel conditions at tributary mouths as an indicator of what is going on in the catchment.

Ms. Kynam from VNMC in Vietnam: Investors need total sediment loads for planning their developments. Do we have enough data at this point to achieve this given the time lines of the developments?

Mr Erland Jensen: We do not know enough to answer these questions. There is a clear understanding we need to extend the discharge and sediment monitoring program. We want to know to what extent we need to do that, and the point of this workshop is to get your opinions on this, the requirements of the countries, to define what we can and will do.

Prof Lu Xi Xi: A comment on subsurface flow versus surface flow. Ribolzi's work may be an overestimate. From the graph for use of tracers, subsurface flow is quite high on the rising limb, but don't know how much in terms of what percentage this is of total runoff.

The model in terms of soil erosion and sediment: Models are powerful but have limitations. The submodel for SWAT is a modified USLE model. For the original USLE, models assume a gentle terrain, but this is not the case for the Mekong especially for the upstream (Yunnan etc). Landuse -- these only consider agricultural land but upstream, the land cover is not

cropland but largely trees and shrubs. The question is how to modify the variables to make full use of the model in this region.

Dr. Ribolzi: On subsurface flow. What we have is not an original result. Previous work demonstrates there is a high contribution of old water [groundwater stored from pervious years] to floods. At the beginning of the flood, groundwater on average contributes 70% to the total runoff from forested catchments. You are right it is high but the important thing is to understand why. Our main issue in the fragmented land is the behaviour of such catchments: why do they behave like forested lands?

Prof Des Walling: On the current use of SWAT model. This model seems to be giving accurate sediment loads. Do we have information on changing landuse in some of these subcatchments? It would be useful to look at some of these catchments and if the model can be validated against these changing landuses. Has this been done?

Mr John Forsius: We did not look at changing landuse in this study. I would like to point out that there are 7 or 8 combinations of parameters that would match with observations and these are not related to sediment yield in catchment area but in-channel characteristics. So I don't think that SWAT can give very accurate picture of the actual sediment yield at the subcatchment scale. The results were impressive but they are mainly the result of calibration and alteration of in-channel parameters.

Session 4: Sediment transport in the Mekong River and tributaries: understanding the potential consequences of water resource development
Dr Peter Adamson, Consultant to the MRC

Introductory remarks by Chair, Dr. Peter Adamson, Consultant to the MRC
Dr Adamson showed the location of the Mekong in relation to other large rivers around the world on a graph of latitude versus unit area mean annual discharge (cumecs per 1000 sq km). The Mekong is one of the top 6 or 7 largest in terms of discharge, and 10th in terms of catchment area. The Rhone is similar in therms of unit area mean annual discharge. The Mekong is evidently one of the world's largest rivers.

Now we largely focus on dams and reservoirs and how to manage them in terms of sediment. Yesterday's points were quite interesting on relative contribution of bedload and suspended sediment. The ICOLD guidelines have stipulations on the time it should take for sediment to flush through turbines – they have guidelines on the relative contribution of bedload to size of the reservoir. This is related to the amount of erosion in the catchment. Under these guidelines, bedload as a proportion of total load is 15-25%. The other point is sediment accumulation. Over 20cm of sediment accumulated in gardens next to the river during the last large flood in Vientiane this year. The question is whether these large floods contribute large amounts of sediment to the floodplains.

There has also been a lot of discussion about models but not statistical analysis of the data; yet we have a considerable body of data at the MRC. We have to balance the analytical side with the modelling side. It is not always useful to focus on absolute accuracy, but relative statements and this is what the focus should be on. In terms of sediment monitoring in the MRC, we need to know what the shortfalls are so that we can address these shortfalls.

Hungry water: Managing sediment in rivers
Mathias Kondolf, University of California

Hungry water is water that has energy in excess of its sediment load – It has more stream power to transport than available sediment and as a result, it tends to erode its bed and banks to compensate. This is explained in the context of the effect of dams and sediment mining. Dr Kondolf reiterated the importance of the different zones of sediment transport: zone of sediment production, zone of transport, zone of deposition. The transport zone is like a conveyor belt. On geologic timescale this transport of sediment is continuous, with temporary storage during floods. What happens when we interrupt this transport (build a dam)? Sediment is stopped by the dam. Most dams will trap 100% of bedload whereas they will trap some percentage of suspended sediment load. If not managed, reservoirs can fill completely with sediment, creating dangerous and expensive problems for the future (example of San Clemente reservoir on the Carmel River). Downstream of dams, hungry water has excess transport capacity as it is starved of sediment. It erodes bed and banks, incising channels often down to bedrock. Smaller, easily transportable grains are transported downstream leaving only coarse gravel. This has consequences for sand bars and sand beaches – for example affecting the multimillion dollar camping/tourism industry in Glen Canyon on the Colorado River. How to manage/mitigate for reservoir sedimentation and hungry water downstream? A few options are presented: the sediment pass-through, gravel sediment augmentation, and mechanical dredging. The catchment context (especially systemic interconnectivities) needs to be considered in thinking about management. Some examples from sediment/gravel augmentation in the River Ain and the Rhine are shown.

Climatic and anthropogenic causes of reduced sediment in large Chinese rivers
Lu Xi Xi
GIS and Map resource unit
Department of Geography, NUS

The presentation focused on a study of large Chinese rivers and the differentiation of the impact of climate vs human activities on their hydrology and sediment loads. It was noted that the Chinese rivers have high sediment fluxes (the Mekong is the 7th highest), yet are experiencing dramatic decline in sediment loads in proportion to discharge, which is not declining as significantly. Part of the decline is due to dam construction, but climate may also be a factor. The study assessed both effects. To assess climate change impacts, double accumulative curves of water discharge vs precipitation and sediment load vs water discharge were used. To evaluate the retention of sediment by the reservoirs of dams, sedimentation data from 5 'mega reservoirs' were used. Sand mining initiated in the economic boom of the 1990s was also found to be a cause of sediment loss resulting in channel downcutting. In conclusion, the study found that in arid and semiarid environments, climate (mainly rainfall reduction) was the primary reason for sediment loss, with human effects being secondary. For large rivers in humid environments (e.g. Changjiang, Zhujiang, Qiangtangjiang, Minjiang etc), anthropogenic (human) causes were the primary reason (30-70%) for declining sediment loads, with climate being a very minor factor (<10%).

Sedimentation processes in the Mekong River Delta, Vietnam
Dr Nguyen Van Lap, Vietnam Academy of Science and Technology

Dr Nguyen presented a study by his group on sedimentation processes in the Mekong River Delta. The natural and human causes of erosion, impacts on the depletion of mangroves,

changes in deposition and erosion over time 1885-2001 and the effects of monsoons on these processes were presented. It was found that there has likely been a decrease in sediment supply due to sand mining from Mekong River (but little data). The monsoon effect (esp 1985-2004) is a major factor in erosional and depositional morphological changes in the delta. A decrease in sediment supply was detected in recent surveys (2005 and 2006). The researchers also found that the beach profile is a good indicator showing the erosional and depositional status of the coast. There is a need to compare sediment supply from the Mekong River to the delta and coastal variations in deposition and erosion. Satellite imagery analysis can be usefully combined to look at human impacts/effects of landuse changes on the delta as well.

Xayaburi Hydroelectric Power Project
Mr Natee Yanpirat, TEAM Consulting Engineering Co. Ltd.

The Xayaburi Hydroelectric Project was one of the projects identified by the 1994 MRC Mekong Mainstream study. The MOU for this project was signed on 4 May 2007. The feasibility study finished in June 2008, and construction will take place from 2010 to 2017. Mr Natee showed the main features of the project. With a catchment of 272,000 sq km and 1260 MW total installed capacity, the project will have a navigation lock on the right bank and in the design phase build a fish passage facilities for migration in both upstream and downstream directions. The spillway will open from June to end of November during the high discharge months. A water quality study was conducted this year. There will be a sand sluice located at every 2 units of the power house, to allow for sand flushing without halting operations; sediment flushing units will be operative in the night time only when power demand is lower.

Why and how to flush a reservoir without environmental impacts
Dr Francis Fruchart
CNR, France

The presentation focused on whether and how to employ ‘hard flushing’ or ‘environmentally friendly flushing’ of sediment from reservoirs, and what the incentive was for hydropower plants to flush. Dr Fruchart pointed out the different possibilities for the flushing of sediment from a reservoir, especially with respect to maintaining the safe operation of the dam and the result of different flushing methods on downstream sediment concentrations and ecology. Hard flushing was found to be detrimental as the high velocity would result in high and uncontrolled sediment concentrations downstream and the destruction of biodiversity downstream. No flushing may also be an option, but with consequences as well. Another option is environmentally friendly flushing, which is to send downstream only the concentrations of sediment that the environment can withstand. An example of the mechanisms for this type of flushing for the Verbois-Chancy-Genissiat dams was given (every 3 years since 1970 for one week). Flushing was found to prolong the lifetime of the dam, transmit sediments from the Swiss watersheds and guarantee biodiversity. It was found that environmentally flushing required heavy organization and monitoring but was efficient and cost-effective compared to dredging. He recommended that to flush a cascade of dams one needed appropriate structures such as an appropriate bottom gate and at least one mid depth gate for the downstream dam so as to provide less turbid water for mixing with the sediment laden bottom water. Dr Fruchart then gave the example of Hoa Binh Dam in Vietnam where sediment aggradation downstream of the dam, siltation in reservoir and a

decrease of flood magnitude called for flushing for mitigation. Dams should be 'transparent' to both sediment transport and floods [which can then redistribute the sediment]. Building appropriate structures with comprehensive knowledge of the river downstream, and its material transport capacity, can help to mitigate negative environmental impacts.

Questions – Chair asked for 3 one-sentence questions

Mr Ton Lennaerts: To Mr Natee. He mentioned that the Xayaburi feasibility study has been completed. Did this feasibility study expect any accumulation of sediments in the dam in the dry and wet seasons? The reservoir is small so to his understanding, there will be no accumulation in the wet season but there may be in the dry season, but that this might be flushed through the spillway gates when the wet season arrives.

Mr Natee: We think sediment will not impact much because sediment will flow through spillway in the wet season. In dry season we will have a mechanism to flush the sediment.

Mr Ton Lennaerts: At the beginning of wet season there will be flushing. Fish populations may be impacted because of the concentration of sediments at the beginning of the wet season. Has the feasibility study looked into how concentrations of sediments downstream of dams will increase at the beginning of the wet season?

Mr Natee: No.

Mr Sompong: [helping Mr Natee clarify] This will be taken into account in the design of the dam. Hydraulic model will be developed during the design stage.

Session 5: Geomorphological tools for predicting consequences of water resource development
Chair and facilitator: Dr Peter Adamson, Consultant to the MRC

Modelling sediment transport and morphological changes: Problems and opportunities
Dr. Stephen Darby, Department of Geography, University of Southampton, UK

The rapidity of changes in the LMB calls for knowledge of current and future (50-100 yrs) trajectories of change and associated system responses. Predictive approaches are needed. Predictive morphological models must address the catchment-scale drivers while identifying local responses. A number of options are available. Nested models offer strategic, basin-wide overviews of morphological processes. Empirical approaches need 5-10 years of high quality bedload and suspended sediment data, which may not be feasible for the rapid developments in the Mekong. The solution may be the 'retrodiction' of (analysis of past) channel changes for prediction. The flow hydraulics model, sediment transport model and bank erosion model are also options with differences in scale, scope, and science. Calibrating such models requires high quality data. Dr Darby showed a simulation of bank erosion done by the team at Southampton University, in which fluvial bank erosion was predicted and bank roughness surveyed. In conclusion, he suggested using a range and combination of tools: morphodynamic models, 1D modelling to identify critical stages then 2D or 3D to identify hotspots, scenario design based on realistic future conditions, regional climate models linked to hydrological modelling to give an improved picture of discharge change, and catchment-

scale sediment models to evaluate sediment change. Channel modelling could also be linked to basin modelling.

Existing capability and challenges in modelling sediment transport on the Mekong River: results of the 1D ISIS model
Mr Bongvongsar Toch, MRC Modeller

The iSIS sediment model simulates water quality and cohesive sediment transport and changes in cross-section riverbed profiles. It uses a range of sediment transport equations. As of now, iSIS can only calculate in-channel sediment, with no capability to simulate floodplains, reservoirs, spill or interpolated river sections. About 441 cross-sections and 31 boundaries are defined in the model. The cross-sections and boundary conditions are defined with data from 1985-2000, with data available from the MRC Hydrographic Atlas (1999), DEM of the river channel and floodplain, and flow, water level and suspended sediment concentration data from various mainstream and tributary stations between Chiang Saen and Pakse. Data is still not sufficient for setting up the model, especially data from the tributaries. The sediment rating curve at Chiang Saen is used as a boundary input for the mainstream. Tributaries are estimated by rating curves for Mae Kok (90-03) and Nam Khan (90-02). The results are sediment concentration variations over time. In conclusion, the results depend on assumptions made (input grain size distribution, cohesive or non-cohesive bed, armouring, heavy erosion on some cross sections. The iSIS model is suitable for modelling sediment transport in the upstream part of the LMB. The results show good simulation of water level and flow. The model has potential for sediment simulation but more data collection and analysis is needed. Cross section data used should be revised and additional info collected.

Existing capability and case studies of 3-D hydrodynamic modelling at MRC
Dr. Matti Kummu, Jorma Koponen, Juha Sarkkula
Helsinki University of Technology, Finland

Dr Kummu presented the use of the EIA 3D Model as a project that was part of the WUP-FIN project under MRC (2001-7). The 3D modelling tools, capabilities, data needs were among the issues addressed. The EIA 3D model is a fully 3D model applied to Mekong at Tonle Sap, a short reach between Vientiane and Nong Khai, the LMB floodplains, Chaktomuk confluence, Vietnam delta and the Nam Songkhram floodplains in NE Thailand. The inputs to the model are a DEM, land-use maps, boundary conditions etc. output – flooding characteristics, 3D currents, suspended sediment concentration and sedimentation, salinity, dissolved and other water quality indicators. Its sediment module can model bedload, suspended load (cohesive and not cohesive). The different data needed from the modelling point of view are presented, for suspended sediment, bedload, and sedimentation. What can be modeled with the software package is also listed. The model was applied to 3 areas in the Mekong: the Tonle Sap, Vientiane-Nong Khai, and the Vietnam delta, showing what was modeled, some results, and the policy implications.

Modelling bank erosion on the Mekong River
Mr. Hai Quang Trieu, University of Southampton, UK

The purpose of the project is a river bank erosion model development and simulation. The processes to be modeled are bank retreat as a combination of mass wasting and fluvial erosion. The study sites river reaches near Vientiane and Pakse. Mass wasting needs to be

modelled to account for bank material strength and bank profile morphology. Mr Hai showed a computational logic diagram for coupling mass wasting and fluvial erosion simulations. The geotechnical and hydrology data needed for simulations were presented. A seepage model is also integrated with a slope model. It was found that fluvial erosion is modelled by a widely accepted model but this has poor predictive ability, so the project has been focusing on methods to estimate parameters for bank erodibility – sampling by extracting cores for this was done in Vientiane and Pakse. The parameters calculate include shear stress partitioning and bank roughness. In the future, the study would like to identify key controlling factors and driving processes, and critical erosion zones for management planning. It is also the intention to expand study sites to Cambodia and Vietnam and link more to MRC's projects. A demonstration of the simulation of erosion at the Friendship Bridge in 1966 was then shown.

PANEL DISCUSSION ON SESSIONS 4 AND 5

1) What are the likely consequences of dams on the Mekong River for sediment load and river channel morphology?

Prof. Kondolf: Potential responses of alluvial reaches to cut-off of sediment supply is very interesting. A very useful exercise would be to link river response to changes in sediment loads and ask what will happen in alluvial (response) regions, either with hungry water, bed and bank erosion.

Dr. Steve Darby: At one level we already know a lot about the consequences of dam construction (eg. 50-60 years of data on response to dams in US and around the world). for the Mekong, yes we need to know a bit more about resilience and sensitivities of the river, but one of the largest concerns is what are the specific design and operation regimes of the dams on the Mekong. This is an unknown but there is also an opportunity to change these variables since the projects are now under the initial feasibility study stage. How we can best predict consequences – we have existing conceptual tools to get an idea of the baseline picture of response of the river. 1D models in future will be good for simulating primary effects.

Prof. Fredsoe: How far downstream from the dam is water hungry?

Prof. Kondolf: We can address this through modelling. What is important is the contribution of sediments from tributaries, and regulation by the mainstream dams. For the efficiency of trapping of sediments we have some rules of thumb to measure. 90% is trapped by large reservoirs. For run-of-river dams, the trap efficiencies are likely to be smaller. I am concerned about what will happen in the Delta. Coastal erosion is likely to exacerbate and processes will change. Much of what we will see in Mississippi delta – without sediments from tributaries, we will have no compensation for subsidence and sea level rise. This would exacerbate land loss in Mekong delta which is very serious.

Mr Ton Lennaerts: We (Basin Development Programmes) are now assessing impacts of development scenarios and are interested in mainstream dam impacts. I think sediment monitoring work needs to begin very soon. Mainstream dams on Mekong have very small storages and we assume that in a year all sediments can pass. Preliminary designs show that 60% of the river width is open between river and dam [bottom sluice gates]. I expect there will be some trapping of sediments in dry season and then quick flush of sediments through

these openings at start of wet season. Are there any examples from other parts of the world for dam designs so that there is 0% trapping? Then, is there a need to model these dams for the near term to predict seasonal fluctuations for sediment fluctuations? And what data would we need to do this?

Prof. Kondolf: The run-of-river dams would probably reach some equilibrium with respect to sediment trapping. As Steve pointed out, reviewing detailed designs would be very useful. The MRC could provide an outside technical panel to review this. For the potential benefit of environment but also sustainability of dams (make them more reliable and less expensive to maintain).

Dr Steve Darby: There is no experience of dams with 0% net trapping – this figure is probably technologically impossible. Needs for modelling – yes there is a need. Recall in a previous presentation, in one of the slides a hydrograph overlaid with a sedigraph showing early exhaustion of sediment load. It is the relationship between the timing of water and sediment flow that is important to conditioning the boundary of the channel and what determines where the sediment ends up. What's being proposed is similar to this: it is useful to explore how sensitive beds and channels are to subtle variations to sediment load changes in relation to the various phases of the annual hydrograph. This is not known and can be addressed by simple scenario-based modelling.

Mr Ton Lennaerts: The sustainability of dams is at stake. In other parts of the world do project developers model these processes in the processes of designing a dam?

Dr Francis Fruchart: Sustainable dams in the world do not exist. It is easier to be sustainable if the dam is transparent to fish and sediments. For bigger dams, we should put in measures like gates and mixing freshwater and other water as shown in my presentation. The MRC should put in the ToR for developers, the maximum rules for sustainable management of dams in this sense.

Dr Peter Adamson: Private developers see water going through sluice gates (and not through turbines) as loss of profit. Unless there is central state regulation it is difficult to get this implemented. Even though there is some state regulation, designers put in minimum mitigation. One needs to show the sustainability of dams to do so. But private developers usually don't do this.

Prof Des Walling: We are rightfully focusing on run-of-river dams. But we have heard little about the impacts of Chinese dams on headwaters. We know there is a lot of sediment coming from China, and in 2010 the gates of the Xiaowan Dam will be closed. Are we getting preoccupied with LMB dams and not China dams? We should not forget this.

Dr Matti Kummu: From our studies, we know that (Jinghong?) has a sediment trapping efficiency of 90%, and Manwan Dam is 68%. This sounds like about the right magnitude. The quality and not just quantity of sediments is also very important, for productivity. This is not well understood and should be studied.

Prof Lu Xi Xi: This information is very hard to get. How dams are operated and hydrological data are very confidential issues for Chinese developers. Yes, I agree about the importance of the 3 dams -- especially Xiaowan. In terms of the impact on hydrology and sediment, they will not be as severe as Manwan dam. Although Xiaowan is the largest, it is upstream of the

Manwan – so I don't think the impact will be huge compared to Manwan. We don't have clear ideas about dam design, much less sediments. We still don't have a clear understanding. We need more research.

Dr Peter Adamson: There is a good parallel between the situation in the Mekong and the Tigris/Euphrates in terms of confidentiality of data. The Turkish are very protective of information on weirs especially for Iraqis and Syrians. We should consider looking at the Tigris and Euphrates Rivers as examples of what could happen with Chinese dams.

Prof Des Walling: I came across some data from Chinese researchers from a water resources agency on modeled effects of these dams. Xiaowan will have trap efficiencies of 68%, and within 10 years only 10% of Manwan's sediments would be going downstream. Even the Chinese researchers admit this. But while there is little information, there is a potentially big problem there.

Ms Iwona Conlan: Question to Steve Darby: Can the bank erosion model be coupled with other sediment transport model so we can have one tool for assessing particular reaches. What additional data would be needed to make this work?

Dr Steve Darby: Yes. Part of the design criteria for the bank erosion analysis is the potential for coupling it with a sediment transport model. We have carried out quite a range of detailed geotechnical surveys on bank materials, shear strength testing, bank profile, fluvial erosion models, flow velocity. What Hai is suggesting is the need for understanding the details of bank erosion processes. We are trying to constrain some of the factors in our model…we want to use the information to build a statistical emulator to the complex model. This is our strategy in the next year. The ideal is to have a tool parameterized with data and used rapidly.

Addressing some of the other other questions/issues for the discussion panel:

4) What other issues can a sediment transport model be used to investigate and what are the priority applications for the lmb (nav improvement or bank protection works)

Mr Lieven Geerinck: Last week we [MRC Navigation Programme] had a seminar with the Yunnan Navigation Affairs Bureau. Four countries have given the green light for blasting rapids south of Golden Triangle. The MRC would like to do its own monitoring. Is there any chance we can obtain information upstream and downstream of this site? Modelling of rock blasting to help us see impacts on channel geomorphology?

Dr. Francis Fruchart (CNR): We are afraid of rigorous erosion at the rock blasting site. We did modelling to identify potential sites of erosion downstream.

Dr. Matti Kummu: From the modelling point of view it is possible to do this study and very useful to do monitoring before the blasting. It is timely.

Mr Erland Jensen: We are supposed to provide services for the programs under MRC. If there is a good reason this could be a priority area for 2009.

Session 6: River transport of nutrients, carbon and contaminants
Chair: Dr. Lu Xi Xi

Ideas for integrating MRC-supported water quality, biological, discharge and sediment monitoring activities
Ms Iwona Conlan
Consultant to the MRC

Ms Conlan presented the objectives of the new programme, which aims to integrate some of the MRC monitoring programs: Discharge (TSD, weekly), sediment (TSD, weekly), water quality (EP, monthly), biological (EP, yearly), fisheries (FP). This integration would involve sampling at the same place and same time as far as logistically and scientifically possible, with no change to the agencies currently responsible for the sampling and analysis of data. Additional investigations may be planned for existing sites. In the existing situation, there are disparate sampling points not in the same location, which makes it hard to establish relationships since suspended sediment, water quality, fish data etc are not synchronized. Ms Conlan presented some benefits of synchronized data and how it would work practically. There are also some limitations (e.g. transport and access to monitoring sites, potential loss of a long time series of WQ data) to consider. Synchronized data is needed for certain areas. Coordination with line agencies is also necessary. The presentation ends with a proposal for a feasibility study for selecting integration sites.

Land use, soil erosion and water quality: implications for the transport and storage of nutrients and contaminants.
Dr. Alain Pierret
International Water Management Institute/IRD, Lao PDR

The aim of the project presented is to assess water quality along small tributary of the Mekong, and soil erosion and carbon transport along sloping lands. Based on a hypothesis in an 1998 UN report which said humans have little effect on river water quality, a study was launched at over 34 observation points in Huay Xon catchment in Luang Prabang province in northern Laos. The question was asked: Do large river based surveys reflect the community level reality? It was found that in the catchment there was a mosaic of landuses. There was limited access to sanitation, and waste disposal and wastewater discharge to streams had negative effects on dissolved oxygen levels. Continuous urbanization of the riparian zone effected total bacteriological flora. Tillage erosion was a source of sediment. The question was also asked of agricultural soil erosion, of whether it was a carbon source or sink. In conclusion, Dr Pierret presented a series of studies showing relationships between contaminants and other functions of erosion and deposition, and particle size in mediating in influencing water quality.

The importance of flood pulse and nutrients on biological production: case Tonle Sap Lake
Dirk Lamberts and Matti Kummu (presented by Matti Kummu)

This study models water quality and productivity in the Tonle Sap Lake for the purposes of ascertaining potential primary production. The research question is: how much will different flow scenarios affect the ecosystem? The characteristics, volume, catchments of the lake are

introduced. The flood pulse is stressed as the main driving force of the productivity of the Tonle Sap Lake and floodplain ecosystem. Ongoing developments will impact the flood pulse. Other productivity drivers include floodplain habitats, chemical quality of floodwater, sediment load, and the amount of floodplain exogenous matter that is carried into the ecosystem. Cross-sectoral impact assessment looking at the impact of flow on the productivity of ecosystem as a whole was done. The combined tools of the hydrodynamic modelling of the Tonle Sap and modelling of the primary production of the lake served as a powerful tool to assess impact of flow alterations on the productivity of Tonle Sap. A vast majority of primary organic matter entering the secondary food webs in Tonle Sap was found to be produced locally. All flood parameters were found to be going down, and the floodplain area is also decreasing. The productivity model is spatially explicit and largely quantitative with gaps filled by qualitative data. Potential primary production was generated based on four groups of primary producers. The results were a picture of the current situation and the simulation of the development situation for phytoplankton. The cumulative monthly exposure time in euphotic volume for the Tonle Sap ecosystem was also found. In conclusion, an effective set of models to assess impacts on flood pulse and potential primary production is needed to supplement a 'traditional' EIA which is not enough for assessing development impacts.

Transport and emission of carbon in rivers: towards a catchment carbon balance (without and with reservoirs), or 'bringing sediment to life'
Professor Jeffrey Richey, School of Oceanography, University of Washington

The research questions for the study presented are: First, what are the spatial and seasonal variations in the composition and magnitude of the sources and fates of organic carbon and carbon gases in the Mekong? Next, what role does the evacuation (outgassing) of carbon dioxide and methane from the river system to the atmosphere play in the carbon cycle of the humid tropics relative to fluvial carbon export to the ocean? It is important to not just consider the bulk of these gases within the carbon budget of the river basin, but also the composition (fractions). A case study conducted in the Amazon River system at Obidos was presented. It found carbon dioxide outgassing occurring in central Amazon to be 13 times the total organic carbon that goes out to the ocean. How do these results map to the Mekong? The SEA-BASINS project (between Chulalongkorn University, National University of Laos, and a Cambodian higher education institution in Phnom Penh) was initiated to find out seasonal changes in Mekong dissolved gases. From carbon-13 and carbon-14 isotope signatures, the Mekong is found to be super saturated in carbon dioxide and methane compared to the atmosphere. More terrestrial contributions come in during the wet season. There is also greater importance in older terrestrial organic matter during the wet season than previously suggested. The Mekong is comparable to other large systems. A question is posed on what might happen to the Mekong River carbon cycle with the introduction of dams? Only a few systematic studies in the tropics on dam impacts have been conducted: these include studies in Brazil, French Guiana and Balbina reservoir near Manaus. The implications of these results for a cascade of reservoirs on the Mekong is that Mekong organic carbon and gas dynamics are very active and fed by terrestrial inputs, and the cascade is likely to have a significant greenhouse gas footprint.

PANEL DISCUSSION ON SESSION 6

1) How important is the role of sediment in transporting nutrients and contaminants and how can we best monitor this?
2) What are the benefits of integrating the monitoring activities for the LMB? And how do we practically do it?
3) What are the priority sites for integrating activities?
4) What kind of additional investigations are required and where? (eg spatial and temporal variation in WQ parameters at a site, storage of nutrients and contaminants in bedload sediment?
5) What data do we need for calculating a catchment carbon balance?

Prof Lu Xixi (facilitator): Invites questions for the four presenters. None? Moving on, let us address question 2 on integrating monitoring activities for the LMB. From my studies there were a lot of benefits for integration but also some concerns and issues. How can we integrate these? Water and sediment are integrated already. How to integrate this with water quality and fisheries and biological monitoring? Sampling methods and frequency are different. Even filtering papers are not the same. For water quality measurements you need high quality filters whereas for sediment you do not require high quality filter papers. Consistency issues should also be discussed. Do we really need integration? What are the priorities in terms of monitoring?

Prof Jeffrey Richey: Basic question: water quality is a term we use extensively. What parameters are we talking about? An evaluation of the methodologies for sampling should also be made. Having seen the different labs I am concerned that the parameters and method of analysis vary between sites.

Ms Iwona Conlan: Can I ask someone from the Environment Programme to join the panel, as Koy from EP gave a presentation on the water quality network yesterday? The EP water quality network analyse about 15-20 parameters and have a quality control program in place in each laboratory. They are working towards certification for each laboratory.

Mr Khoi Tranh Minh (EP): We have 19 physical and chemical parameters and most of these are focused on the characteristic of water chemistry and others relate to nutrients.

Prof Lu Xixi: Are you more interested in nutrients than contaminants?

Mr Khoi Tranh Minh (EP): Yes total nitrogen, etc.

Ms Iwona Conlan: Perhaps there is a need for more intensive sampling in specific areas, but this has to be separate from what we are trying to achieve in the immediate future i.e. integration of existing monitoring activities. The second step may be to add sampling sites and adding parameters.

Prof. Lu Xix: In terms of sampling, the persons responsible for collecting samples will remain unchanged, so it is more integration of sampling time and location right?

Ms Iwona Conlan: Yes, we don't want to disrupt the existing water quality network. Water Quality sampling has been ongoing for 20 years or more. The countries are fund 75% of the cost of the programme which makes it a sustainable activity, so we don't want to jeopordise

this. But at the same time we want to get as much information as possible from the sampling programmes.

Prof Lu Xixi: Can they share the boat, the labs, and other facilities?

Mr Charles Demas: What the USGS do for discharge and sediment we also do for water quality. Pesticides etc are associated with sediments. It depends on what you want to do with the data but you get more power with data if you collect sediment, discharge and water chemistry simultaneously. Another project has a broader reach, more information collected (including biological data), collected same time every year so there are no impacts of intra-annual climatic variation.

Prof Jeffrey Richey: I respect not disrupting the network, but we may need to evolve. The key dynamics need to be found at certain sites and maybe these need integrated. And then a second level of sites where there may not be a need for this.

Ms Iwona Conlan: I believe the existing EP water quality monitoring sites were selected to address particular questions (the effect of a major city on water quality).

Prof Des Walling: The problem is if you have 20 years of record at a site and this gets interrupted. It is best to maintain statistical continuity for existing sites and continue sampling at these sites.

Ms Iwona Conlan: Yes, I agree. That is why we have proposed that we monitor at two locations for a year of two (the existing WQ site and the discharge/sediment site) and then evaluate if there is any difference between the two. If there is a significant difference then we might decide not to move the WQ site permanently.

Dr Olivier Ribolzi: As a geochemist, when I start to work in a catchment, the first thing I do is a systematic survey all along the stream and tributaries to determine the spatial and temporal variability in the parameters that I am interested in. This gives an overall map at one time, a picture of the overall geochemistry of the catchment. Doing so if there are existing monitoring places, I can talk about the representability of this place and select other places according to the issues we want to look at. Couldn't it be possible to have such a way of having a picture of the Mekong with intensive sample collection and also many parameters, and then select the most relevant parameters like what you showed (variation in the cross section)?

Ms Iwona Conlan: We're thinking of looking at spatial variability in the reach scale and not just cross-sections. We can certainly look at 5-10 km reaches (not the entire Mekong). This is definitely something to think about.

Mr Charles Demas: You have 87 sites. There is usually a good relationship between major ions and electrical conductivity and dissolved solids. You can relatively quickly get a lot of points, at the vertical and cross section. That would get information similar to a 4 year system at a relatively cheap price.

Ms Iwona Conlan: Thanks for that idea.

Prof Lu Xixi: Frequency in my own experience is a very important issue. Are weekly discharge measurements undertaken at stations on the main river?

Ms Iwona Conlan: Yes, that is the existing measurement frequency at most mainstream stations on the lower Mekong River.

Prof Lu Xix: A much higher frequency is needed at least for sediment because we miss a lot of the peaks.

Ms Iwona Conlan: We have automatic water level monitoring hourly at most mainstream gauging stations. By measuring discharge weekly the countries develop a rating curve between stage and discharge and from this can estimate a daily discharge.

Prof Lu Xix: For sediment once a week is not enough.

Ms Iwona Conlan: Professor Walling showed us yesterday that weekly sampling gave us a good estimate (within 5%) of the annual sediment load. The main interest in terms of sediment data is annual loads. Monthly loads are useful so we while can potentially look at daily surface or turbidity measurements, we cannot go out and manually sample for suspended sediment everyday. This is not logistically feasible for the countries.

Prof Lu Xixi: In China and Vietnam, they do daily sampling for important stations. You cannot use the rating curve for large river. For small catchments this is possible.

Dr. David Gaeman: For sediment you can get more value when you use a hydrograph to predict when sediment concentrations are likely to be highest and fluctuate the most, for example in the rising limb. At low flows, you may not need to sample that much. One can use turbidity probes to interpolate between samplings.

Prof Jeffrey Richey: On carbon balance. There is a glaring gap on Tonle Sap work especially with critical issues which requires systematic measuring campaign, also linked to fisheries production in the lake. A systematic approach is really necessary.

Ms Iwona Conlan: Prof. Richey's comment links to the question of what are the priority sites for integration of MRC monitoring programmes. Do any of the countries have suggestions regarding this (e.g. model boundaries, priority sites?) Carbon is not measured now and a new campaign would be needed if this were to be measured.

Prof Jeffrey Richey: We can exploit what we know about carbon-oxygen relationships to understand carbon better.

Ms Iwona Conlan: We can perhaps add these parameters to the existing water quality monitoring. We should talk further about this issue and its feasibility with the Environment Program (in charge of water quality monitoring for the MRC).

-- End of discussion session --

Closing remarks from Dr. Sompong Boonprasert, Senior Hydrologist, MRCS

Thank you for the invitation to close this workshop. I feel privileged and a great pleasure to give the final remarks on behalf of the organizing committee. Our two day workshop on Discharge and Sediment Monitoring and Geomorphological Tools for the LMB is now coming to a close. The workshop has been quite a big gathering of country representatives and experts in this field from various parts of the world. The total number of participants is about 70, with 9-10 persons from each country. Sediment issues have long been faced in the lower-Mekong Basin, however not much effort for the proper management of sediment has been made so far. The sediment monitoring project that we are aiming at, if implemented, would help provide much needed information for a better understanding on how to properly manage our water resource and ecological system for the sustainable benefit of all people in the region.

During the two day workshop, we have seen and heard many interesting presentations and discussions. Much useful information relevant to our ongoing Sediment Monitoring Project formulation has been exchanged. On the first day of the workshop the emphasis was on knowledge and understanding of the role of sediment in fluvial systems, work done in the lower-Mekong Basin including country activities, and the available tools for future monitoring of discharge and sediment transport. We also heard about lessons learned from other river basins around the world and experts' suggestions on the way forward for sediment monitoring in the LMB.

The second day of the workshop focused on tools for estimating geomorphological changes and impacts of water resource developments and land-use change. A strategy for the monitoring plan was discussed and experience on applying knowledge about sediment processes in the design of dams for mitigating adverse impacts was exchanged. Also discussed were interesting topics on sediment budgets, direct and indirect measurement of sediment transport and storage in floodplains, upstream soil erosion/loss measurement and prediction, environmentally friendly dam design and sediment flushing from reservoirs, sedimentation issues in the Mekong River delta and coastal areas, geomorphological modelling, and the role of sediments for river water quality, nutrient loading and fishery productivity. The idea of 'hungry water' has also been elaborated, making clear the potential adverse impacts of dams and reduced sediment supply on river morphology. I am sure, if we can cope with hungry water, what we can achieve is the potential for reducing the potential for hungry people in the basin. The information and knowledge shared in this workshop are very relevant and interesting. With your permission and under MRC regulations, we will try to make the workshop minutes and power point presentations (in PDF format) available for download from the MRC web site.

We all realise that the need for discharge and sediment monitoring and also water quality and ecological health monitoring is high. The integration of all monitoring activities could provide appropriate data and information for further analysis by MRC programmes and country programmes as well. I would say that this workshop has produced many fruitful results that will be useful for the MRC in implementing its various programme objectives.

In conclusion, on behalf of the organising committee, I would like to thank all participants, particularly all experts and session chairpersons and facilitators for your time, active participation and valuable contributions to this meeting. I would also like to thank all supporting agencies including the National Mekong Committees, national line agencies,

private companies, and international agencies/educational institutions for their support and effort in sending representatives to attend and present in this meeting. Altogether they have made this meeting possible.

I think that you have enjoyed this workshop and the city of Vientiane during your stay here. I wish all of you a safe journey back to your home countries and all the best to everyone. We look forward to cooperation and collaboration with you in the future. It is now time for ending the two day Regional Workshop on Discharge and Sediment Monitoring, and Geomorphological Tools for the LMB. Therefore, I would like to declare the closing of this workshop. Let us show our appreciation to everyone. Thank you very much and good evening.