TOWARDS A NEW FLOOD FORECASTING SYSTEM FOR THE LOWER MEKONG RIVER BASIN

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ABSTRACT

The RFMMC in Phnom Penh currently produces short-term 1 to 5 day flood forecasts for 23 locations along the Lower Mekong River, using the time-tested but by now outdated SSARR model. One of the major drawbacks is the fragility of the system: if data from one input station is missing the model cannot be run. As inputs from a total of 7 sources in 6 countries are used, it happens too often that one or more of these sources have (technical) difficulties, which mean the data is received late or not at all, and the forecast is made late or not at all.

The May 2006 Road Map Mission (Malone, 2006) recognised that extension of the forecasts to medium-term (10 days) and the introduction and development of improved hydrological models was a major step towards the improvement of flood forecasting services of the RFMMC.

Complementary to improving the flood forecasting models the data availability also needs attention. The input for the new hydrological models is primarily observed rainfall data; a minimum set of rainfall data for the region is available through the World Meteorological Organization Global Transmission System (WMO GTS). Still, to realise the objective of reliable short- and medium term forecasts, daily delivered rainfall data from the MRC member countries are essential. An analysis of the available daily reported rainfall for Cambodia and Lao PDR showed that supporting the improvement of a relatively low-tech network of manual rain gauges which report daily using mobile phone text messaging will substantially increase both the availability and the spatial distribution of rainfall data.

In order to have a first version of the system operational by the flood season of 2008 the Australian hydrological model, URBS, was selected as trial model for the RFMMC. The URBS model is a semi-distributed non-linear model, used extensively for flood forecasting by the Australian Bureau of Meteorology and by the Chiangjiang (Yangtze) Water Resources Commission in China. URBS combines the rainfall-runoff and runoff-routing components of the modelling process and allows users to configure the model to match the characteristics of individual catchments. The model is robust in a real time environment and has several features which readily lend itself to application as a flood forecasting model. The URBS model will eventually be one of a suite of hydrological and hydraulic models available to forecasters in the RFMMC.

URBS sub-basin models are now being developed using the GIS package CatchmentSIM. Calibration will be undertaken using the rainfall, height and flow data from the MRCS HYMOS database. It is expected that each model will be calibrated on several flood seasons.

This paper describes the first steps towards a state-of-the-art flood forecasting system based on a suite of models and an array of input data ranging from observed rainfall and water levels to satellite rainfall estimates and regional rainfall forecasts.

1. INTRODUCTION

The Mekong River Basin (MRB) includes parts of China, Myanmar and Viet Nam, nearly one third of Thailand and most of Cambodia and Lao PDR having a total land area of 795,000 km^2. From its headwaters thousands of metres high on the Tibetan Plateau, it flows 4,800 km through six distinct geographical regions, each with characteristic features of elevation, topography and land cover.

Large floods, such as those which occurred in 2000, 2001 and again in 2002, have the capacity to cause loss of life and huge property damages to the four riparian countries of the Lower Mekong Basin (LMB). Floods of these magnitudes can affect between one and eight million people throughout the LMB (MRCS, 2005).

Improved flood forecasting was recognised as a key component in the establishment of the MRC-RFMMC in 2005.

The Road Map Mission, conducted in May 2006 (Malone, 2006), recognised that the existing forecasting models were outdated and unreliable and that the development of improved forecasting methods was a major step towards the upgrading of flood forecasting services in the LMB. The introduction and development of new rain-based hydrologic forecasting models to improve reliability, accuracy and lead-time is just the first step in this process. Improved data availability and the establishment of a real-time operational database, integrated with the models, is a logical precondition for improved forecasts.

2. DATA AVAILABILITY

One of the clear drawbacks of the current flood forecasting system in use at the RFMMC is the inflexibility of data input. If water level data from one input station is missing the model cannot be run. As inputs from a total of 7 different sources in 6 different countries are used (Table 1), it happens all too often that one or more of these sources have (technical) difficulties in sending the data, which means the data is received late or not at all, and the forecast is made late or not at all. The rainfall data reported by the sources is currently only used to check the model output and adjust it manually.

Table 1. Input sources for the MRC-RFMMC flood forecast model

No.	Country	Ministry, Department, Agency	Type of data
1	Cambodia	Department of Hydrology and River Works (DHRW) Ministry of Water Resources and Meteorology	Water level data, rainfall
2	Lao PDR	Waterways Administration Division (WAD), Department of Roads, Ministry of Communication, Transport, Post and Construction	Water level data, rainfall
3	Lao PDR	Department of Meteorology and Hydrology (DoM), Ministry of Agriculture and Forestry	Water level data, rainfall
4	Thailand	Department of Water Resources	Water level data, rainfall
5	Viet Nam	Southern Region Hydro Meteorological Centre (SRHMC)	Water level data, rainfall
6	China	Department of Water Resources (DWR) Yunnan branch	Water level data, rainfall
7	USA	NOAA	Satellite Rainfall Estimate

The input for the new hydrological models now being developed is primarily observed rainfall data; a minimum set of rainfall data for the region is available through WMO GTS[1], as mentioned before. Still, to realise the objective of reliable short- and medium term forecasts, daily delivered rainfall data from the MRC member countries are essential.

Analysis of the hydromet network in the Lower Mekong River Basin

An analysis of the available daily reported rainfall for Cambodia and Lao PDR shows that supporting the improvement and extension of a relatively low-tech network of manual rain gauges which report daily using mobile phone text messaging will substantially increase both the availability and the spatial distribution of rainfall data.

As one of the main objectives of the MRC is to facilitate data exchange, it is not surprising that several projects and programmes have been carried out with the express aim to improve the hydro-meteorological network in the MRC Member States. Analysis of the raingauge network carried out under these projects (MRCS, March 2001) and others consistently shows that for Thailand and Viet Nam the average coverage is sufficient but the spatial distribution needs improvement. Mostly Cambodia and Lao PDR suffer from inadequate network coverage. It is also mentioned that 'the network operation and maintenance problems are serious in Cambodia and Lao PDR' while Thailand and Viet Nam need only limited support for operation and maintenance (O&M) (MRCS, 2001).

Because capacity building was a major objective in the projects, state of the art telemetry equipment and rainfall and water level loggers were installed. Because of the earlier mentioned lack of resources for O&M these projects and instruments have often been beset by problems. For instance, the Appropriate Hydrological Network Improvement Project (AHNIP) network, while now 90% operational, has been operating at around 50% or less until mid- 2006. To illustrate this: the MRC-RFMMC uses AHNIP data but relies on the manual readings made twice daily (for calibration purposes) as input for the Flood Forecasting System.

[1] World Meteorological Organization Global Transmission System

The objective may have been to move immediately to modern technologies; however, when evaluating the present meteorological networks it is clear that the situation in Lao PDR and Cambodia still is far from ideal. To understand this one should consider the following observations:

- it appears that the responsible organisations in Cambodia and Lao PDR do not have adequate funding to ensure proper operation and maintenance. Moreover, all spare parts have to be imported at considerable cost;
- the advantage of a data logger with telemetry is the fact that data can be read immediately or at high frequencies. However, for water level data at the main stream the daily fluctuations are usually not very big and it is considered that loggers provide limited advantages over reliable manual observations in these cases;
- to date the number of automatic telemetry stations is far too low, even after the new Mekong Hydrological Cycle Observing System (M-HYCOS) project is implemented. This is especially true for rainfall stations in Cambodia and Lao PDR;
- the overriding reason to introduce automatic telemetry stations in Western countries has been the rising costs of labour. Investment and maintenance costs are high; they are offset by much lower costs for operation. This advantage does not apply in Cambodia and Lao PDR, where investment and maintenance is higher and observers are paid comparatively low salaries.

In this paper it is proposed to significantly increase the number of rainfall stations which report daily to their respective head offices by using simple but robust and adequate technology. As an example the situation in Cambodia is analysed

Analysis of situation in Cambodia

A detailed analysis of the situation regarding rainfall stations in Cambodia was made (MRC-RFMMC, 2007a).

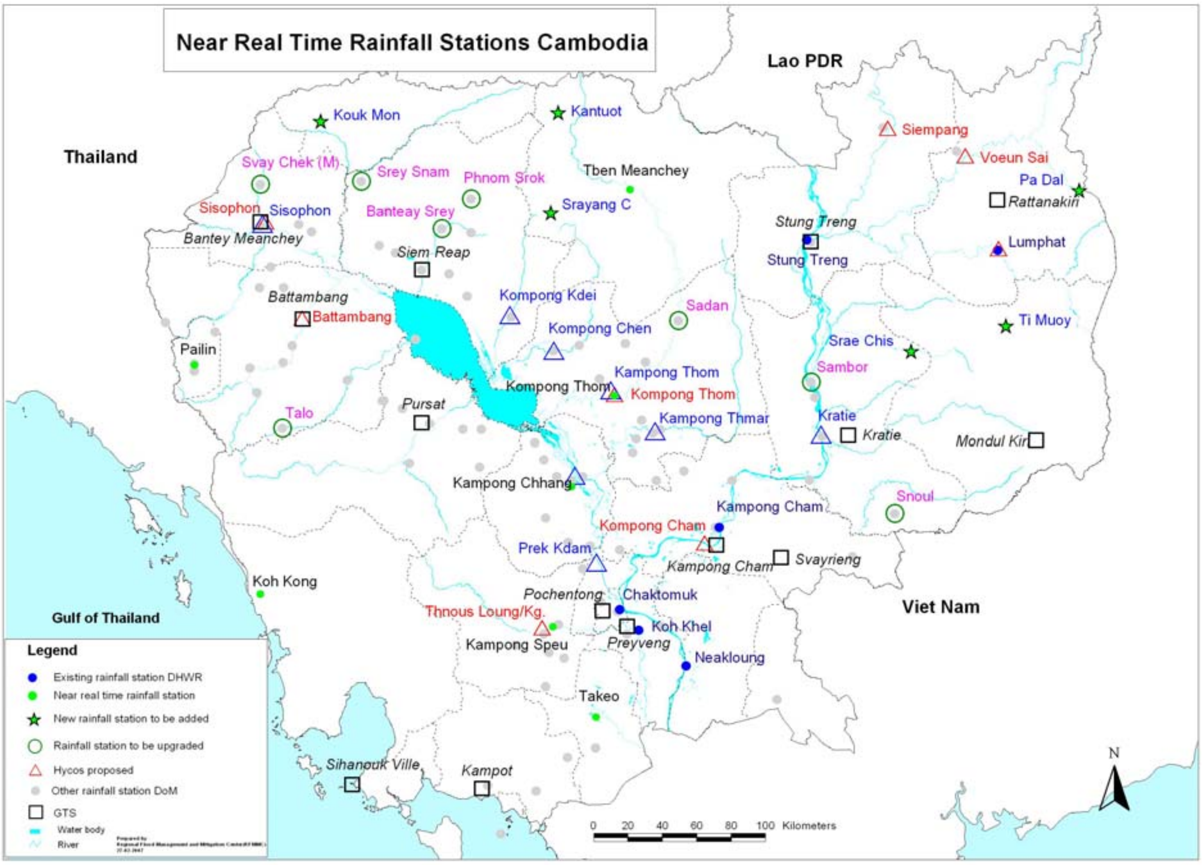

Figure 1. Map daily reported rainfall stations in Cambodia

Presently the MRC-RFMMC obtains its model input data from the Department of Hydrology and River Works (DHRW) of the Ministry of Water Resources and Meteorology. This mostly concerns water level data from 7 stations, while for 5 of these stations rainfall data is also available. It is recommended that for the 2 other stations rainfall data is collected (by DHRW or from a Department of Meteorology (DOM) meteorological station nearby) and also transmitted daily. Further, 6 water level stations have been identified for which the reporting of water level data can easily be upgraded to daily. Two of these will be upgraded under the M-HYCOS project. For the other 4 it is recommended to establish a means of communication, and to also include rainfall data in the daily report. Then there are another 8 proposed M-HYCOS stations that will, after implementation, be a source of daily (or even real-time) rainfall data. Overall, this means that at the DHRW the number of stations that reliably provide daily rainfall data can be increased from 5 to 17.

The other agency responsible for meteorological data is the Department of Meteorology (DoM), also of the Ministry of Water Resources and Meteorology. Presently, 21 stations report daily, of these 14 are synoptic stations. To improve the network coverage it is proposed to upgrade 9 'historical' rainfall stations to daily reporting. Even then the network coverage shows large gaps. In order to fill these gaps, it is recommended to establish 6 new rainfall stations. The locations are selected by overlaying the map of available daily reported rainfall data with the map of villages, roads and schools in Cambodia. The proposed locations are accessible by road and in a village with a school. For the most reliable management, data collection and delivery new stations in remote areas should preferably be located at a school, and data collection and transmission should be done by the (head) teacher of this school. Overall, this means that at the DoM the number of stations that reliably provide daily rainfall data can be increased from 21 to 36, with relatively limited effort.

For Cambodia, with relatively simple and inexpensive methods, the number of daily reported rainfall stations can be increased from 26 to 52, and the network coverage will also be greatly improved. While there is a certain level of overlap, it is suggested that the two agencies join together in their efforts and exchange (rainfall) data on a daily basis. The map in Figure 1 shows the situation for Cambodia.

Lao PDR, Thailand and Viet Nam

A detailed analysis of the situation regarding rainfall stations in Lao PDR was also made (MRC-RFMMC, 2007b). Presently the MRC-RFMMC obtains its model input data from two agencies in Lao PDR:

1. Waterways Administration Division (WAD), Department of Roads, Ministry of Communication, Transport, Post and Construction in Vientiane, responsible for most of the Mekong main stream water level stations and rainfall stations;
2. Department of Meteorology and Hydrology (DMH), Ministry of Agriculture and Forestry, in Vientiane: responsible for water level stations and rainfall stations on the tributaries and mainstream in the south.

WAD now provides water level data and rainfall data from 8 stations, while DMH has a network of 25 daily reported rainfall stations (5 of them record also the water level, and 20 are Synoptic stations). Most of the present stations are close to or on the Mekong River or the main tributaries. A large area in the headwaters of the tributaries has very limited coverage for daily reported rainfall. As is the case with Cambodia, it is proposed to upgrade selected historical raingauge stations by supplying a reliable means of communication; and for the remaining gaps to investigate the possibility of setting up new manual raingauge stations.

The above means that, for Lao PDR, with relatively simple and inexpensive methods, the number of daily reported rainfall stations can be increased from 33 to more than 50 and the spatial distribution of the network can be greatly improved.

Further analysis of the available rainfall stations in Viet Nam and Thailand is needed; however, it seems that a sufficient number of rainfall stations is reported daily or at higher frequencies (MRC-RFMMC, 2007c and 2007d). This means that an agreement on a method of timely and efficient data delivery to the MRC-RFMMC will be the next step. In several of the 'gaps' identified in the border regions of Lao PDR, rainfall stations in Viet Nam may already be available (MRC-RFMMC, 2007c). However, a certain level of redundancy in rainfall stations is desirable and will result in a much more robust and dependable data network.

3. MODELS

As the RFMMC needed to have a first version of the system operational by the flood season of 2008 the Australian hydrological model, URBS, was selected as trial model. The URBS model is a semi-distributed non-linear model, and is used extensively for flood forecasting by the Australian Bureau of Meteorology and by the Chiangjiang (Yangtze) Water Resources Commission in China. URBS combines the rainfall-runoff and runoff-routing components of the modelling process and allows users to configure the model to match the characteristics of individual catchments. The model is robust, developed for use in a real time environment and has several features which readily lend itself to application as a flood forecasting model. The URBS model will eventually be one of a suite of hydrological and hydraulic models available to forecasters in the RFMMC.

URBS sub-basin models are now being developed using the GIS package CatchmentSIM; however, the results of CatchmentSIM can be used with any hydrologic modelling package that is based on sub catchment networks. Calibration will be undertaken using the rainfall, height and flow data from the MRCS HYMOS database. Each model will be calibrated on several flood seasons.

URBS

The conceptual runoff routing model, URBS (Carroll, 2004), is a computer based, hydrologic modelling program that enables the simulation of catchment storage and runoff response by a network of conceptual storages representing the stream network and reservoirs.

The URBS model combines two hydrological modeling processes into one model:

- rainfall runoff modelling, which converts the gross rainfall into net or excess rainfall;
- runoff routing modelling, which takes the excess rainfall as input and converts it into flow.

Users can select from several bucket-type rainfall runoff models that may be applied uniformly or spatially varied over a catchment. The selection of the most appropriate rainfall runoff model and its associated parameters is carried out as part of model calibration.

After the excess rainfall has been determined, the runoff routing component of the model routs the excess rainfall through a series of conceptual non-linear storages to determine the distribution of flow in the catchment. The runoff routing component can be applied in either the basic or the split mode. In the basic mode, the effect of sub-catchment and channel storage is treated as a lumped storage at the centre of each sub-catchment. In the split mode, the effects of the sub-catchment and channel routing are calculated separately. Firstly, the excess rainfall on a sub-catchment is routed through a conceptual storage at the centre of the sub-catchment to the creek channel. The lag of the sub-catchment storage is assumed proportional to the square root of the sub-catchment area. Next, the channel inflow is routed along a reach using a linear or non-linear Muskingum method, whose lag time is assumed proportional to the length (or derivative) of the reach. The split mode provides more flexibility and is the preferred mode, adopted at the RFMMC.

In this way, the temporal and spatial variation of rainfall across a catchment can be taken into account and generally provides more accurate results than traditional lumped models such as the unit hydrograph.

The URBS model can be set up as a rainfall runoff routing model or as a simple runoff routing or flood routing model and it can be used as a design or as a flood-forecasting tool. The model may be applied as an event model or for continuous simulation. Typically for flood forecasting, the model is calibrated as an event model and then applied as a continuous simulation model.

The URBS model has several features that readily lend themselves to application as a flood-forecasting model:

- *enhanced data management.* Input data such as rainfall and water level data are separate to the model and are accessed during running;
- *robust performance.* The model still runs if key gauging station data is missing;
- *forecast rainfall.* Forecast rainfall can be added to the model with a variety of techniques using results from external sources;
- *linked ratings.* Known stage-discharge relationships can be incorporated into the model to produce both flow and height results at gauging stations. Dependent ratings, where the upstream water level is dependent on downstream water level can also be used;
- *reservoir behaviour.* Runoff can be routed through reservoirs using known storage characteristics and simple operating rules applied;
- *matching.* This feature forces the model to fit the observed data at gauging stations thereby improving the forecast accuracy at downstream locations;
- *adaptability.* One of the key features of the model is that it can be readily incorporated into any flood forecasting system.

The Bureau of Meteorology, Australia, uses the URBS model as an event model extensively for flood forecasting on basins up to 250,000 km^2 (Malone, 2000 and 2003). It was tested against five other hydrologic models in the Yangtze River Flood Control and Management Project (Markar, et al., 2002) and was one of three hydrologic models adopted for real-time use as a continuous simulation model in the project (Markar, et al., 2005).

CATCHMENTSIM

CatchmentSIM (Ryan, 2004) is a freely available 3D-GIS topographic parameterisation and hydrologic analysis model. The model automatically delineates watershed and sub catchment boundaries, generalises geophysical parameters and provides in-depth analysis tools to examine and compare hydrologic properties of sub catchments.

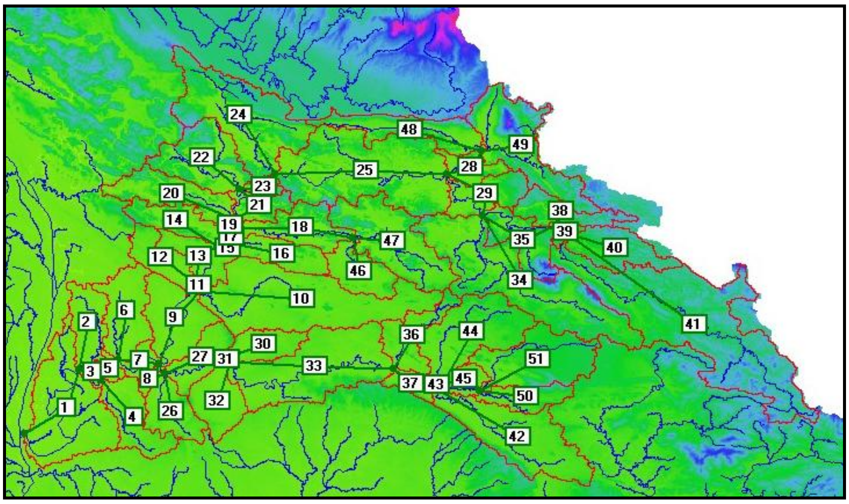

Figure 2. CatchmentSIM model of Se Bangfai

One of the advantages of Catchment-SIM is that it includes a macro language, which enables the user to write scripts to develop any hydrological modelling package that is based on sub catchment networks. The package comes with readily available scripts for several commonly used hydrological models, which may be suitable for use in the Mekong.

The example in Figure 2 shows the Se Bangfai catchment (Lao PDR) derived using publicly available digital elevation data from the NASA Shuttle Radar Topography Mission (SRTM)

APPLICATION ON THE SE BANGFAI RIVER

The Se Bangfai is a medium sized tributary of the Mekong River located in the central part of the Lao PDR and joins the main stream of the Mekong 55 km downstream of Thakhek (170404). The seasonal southwest and the northeast monsoon rains, which occur from May to October, are the primary cause of floods in the Se Bangfai. The Se Bangfai catchment is characterised by mountain ranges in the East, which slope down to the plain area near Mahaxi village (320107). The river then flows through a transition area before finally entering the flood plain around Se Bangfai (320101). The Se Bangfai model was selected as a trial catchment for testing of the model in the flood seasons from 1999 to 2005.

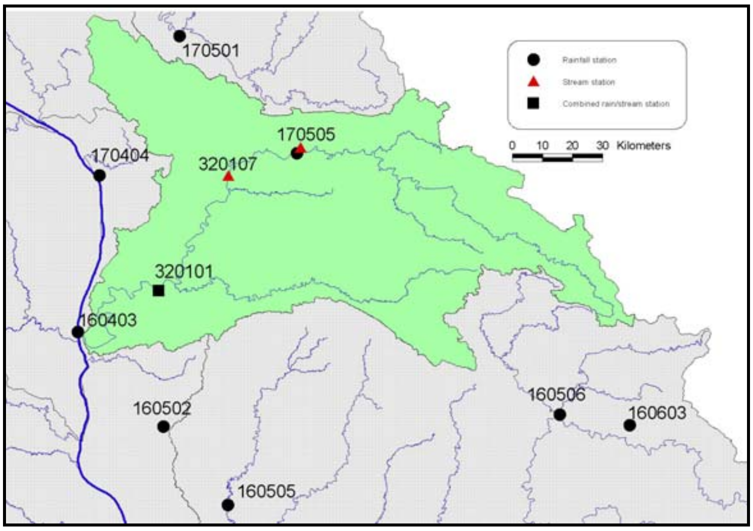

Figure 3. Se Bangfai River

Firstly, CatchmentSIM was used to compile an URBS model of the Se Bangfai River as shown in Figure 2. The model consists of 55 sub-areas representing 9,300 km^2.

Rainfall and stream flood data from the stations shown in Table 2 was extracted from the MRC HYMOS database for use in the model. The rainfall stations available from HYMOS, shown in Figure 3, do not provide full coverage of the observed rainfall in the catchment. There are no stations to indicate the rainfall in the headwater areas in the eastern and southern parts of the catchment.

Table 2. Rainfall and stream data

Stations		1999	2000	2001	2002	2003	2004	2005
		Event						
Rainfall								
160403	That Phanom	x	x	x	x	x	x	
160502	Seno	x		x	x	x	x	
160505	Ban Kengkok		x					
160506	Phalan			x	x	x	x	x
160601	Muong Tchepon		x					
160603	Ban Dong	x						
170404	Thakhek	x	x	x	x	x	x	x
170501	Signo		x					
170505	Ban Kouanpho	x		x	x	x	x	x
320101	Ban Se Bangfai						x	x
Stream								
320108	Kuanpho			x	x	x	x	x
320107	Mahaxi	x	x	x	x	x	x	x
320101	Ban Se Bangfai	x	x	x	x	x	x	x

x - Data available

Table 3. Se Bangfai calibration parameters

Event	Rainfall-runoff parameters			Runoff-routing parameters			Coefficient of determination
	IL	PR	IF	Alpha	M	Beta	
1999	0	0.1	1750	1.0	0.8	7.5	0.829
2000	100	0.2	500	1.0	0.8	7.5	0.836
2001	175	0.1	1000	0.5	0.8	7.5	0.574
2002	100	0.3	2000	0.8	0.8	7.5	0.709
2003	200	0.1	2000	0.7	0.8	7.5	0.836
2004	75	0.1	1000	1.3	0.8	7.5	0.880
2005	250	0.2	2000	0.9	0.8	7.5	0.840
Average	130	0.2	1500	0.9	0.8	7.5	0.786

A technique, based on the methodology described by Wei, et al. (1973), was used to estimate the rainfall on each sub-area in the catchment. The Australian Bureau of Meteorology (Malone, 2000) and the Chiangjiang (Yangtze) Water Resources Commission in China (Markar, et al., 2005) adopted this same methodology.

For each flood season, rainfall runoff and runoff routing model parameters were varied to obtain the best fit to the observed water level data at the Se Bangfai gauging station located near the outlet of the catchment. Table 3 shows the estimated parameters for each flood season. The Coefficient of Determination is a measure of the goodness of fit at the Se Bangfai station; 1 being considered perfect. With the exception of the 2001 flood, the model fits the observed data reasonably well. Figure 4 shows an example of the calibration at Ban Se Bangfai in 2004. While model performance based on daily rainfall data is adequate, it is expected that accuracy will improve using data from more (near-) real-time stations in the catchment, especially as more frequent rainfall observations than daily data become available.

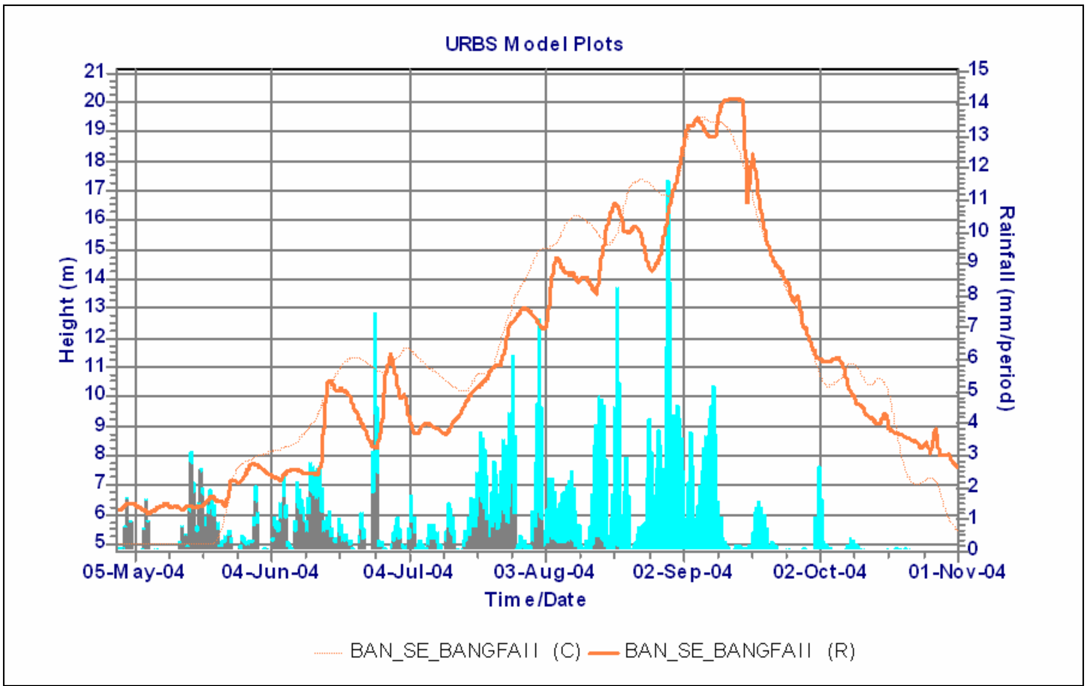

Figure 4. Model calibration at Se Bangfai 2004

4. PLANNING AND FUTURE DEVELOPMENTS

The MRC-RFMMC has considered that the URBS model shows sufficient potential for use as a flood-forecasting model that it has embarked upon a program to develop a suite of models for the Lower Mekong River Basin. It is envisaged that, in the future, URBS will be one of many hydrologic models that will be available to forecasting staff in the MRC-RFMMC. However, for expediency, it has been selected as the initial model to fast track the introduction of improved forecasting techniques.

In February 2007, MRC-RFMMC members were trained in the use of CatchmentSIM and URBS. Guidelines for the use of the packages were also developed. In conjunction with consultants, a plan was established for hydrologic model development in the LMB. In all, the plan requires the development of 50 hydrologic models, as shown in Figure 5. Of these, 30 will require individual calibration. The parameters for the remaining 20 models (representing a relatively small area of the LMB) will be inferred from adjacent catchments. Stage 1 will cover the LMB from Chiang Saen to Kratie (Basin 2, see Figure 6 and 7) while Stage 2 will cover the basin downstream of Kratie (Basin 3 and 4). A simple model for Basin 1, the Upper Mekong Basin, has been made, but calibration is difficult because of a lack of historical data.

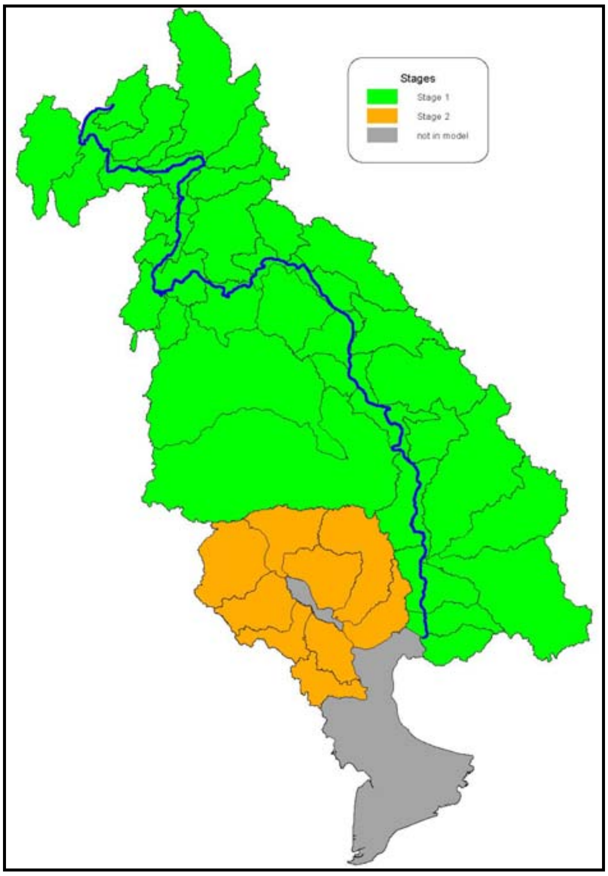

Figure 5. Hydrologic model layout

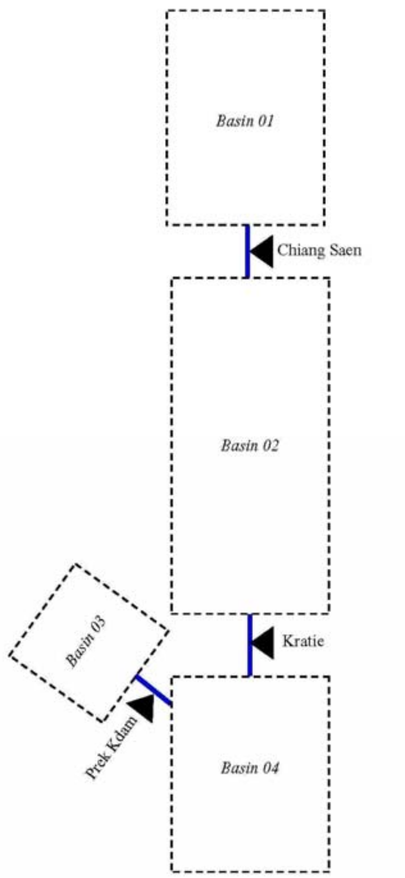

Figure 6. Overall model schematic URBS models

An overview of the entire system (schematic) is in Figure 6. Eventually, it is envisaged that the hydrologic models will provide the inflows into a real-time hydraulic model of the LMB. The linking of the individual hydrological models with a hydrodynamic model of the Mekong main stream will be considered at a later stage.

As each model is completed, a calibration report outlining the modelling processes, inputs and outputs will be produced. These reports will be stored in the model database system and instantly retrievable. It is expected that the program of individual model development will be completed by the end of 2007.

A flood routing model of the main stream between Chiang Saen to Kratie, using the inflows from the individual calibrated URBS models, is at an advanced stage of development.

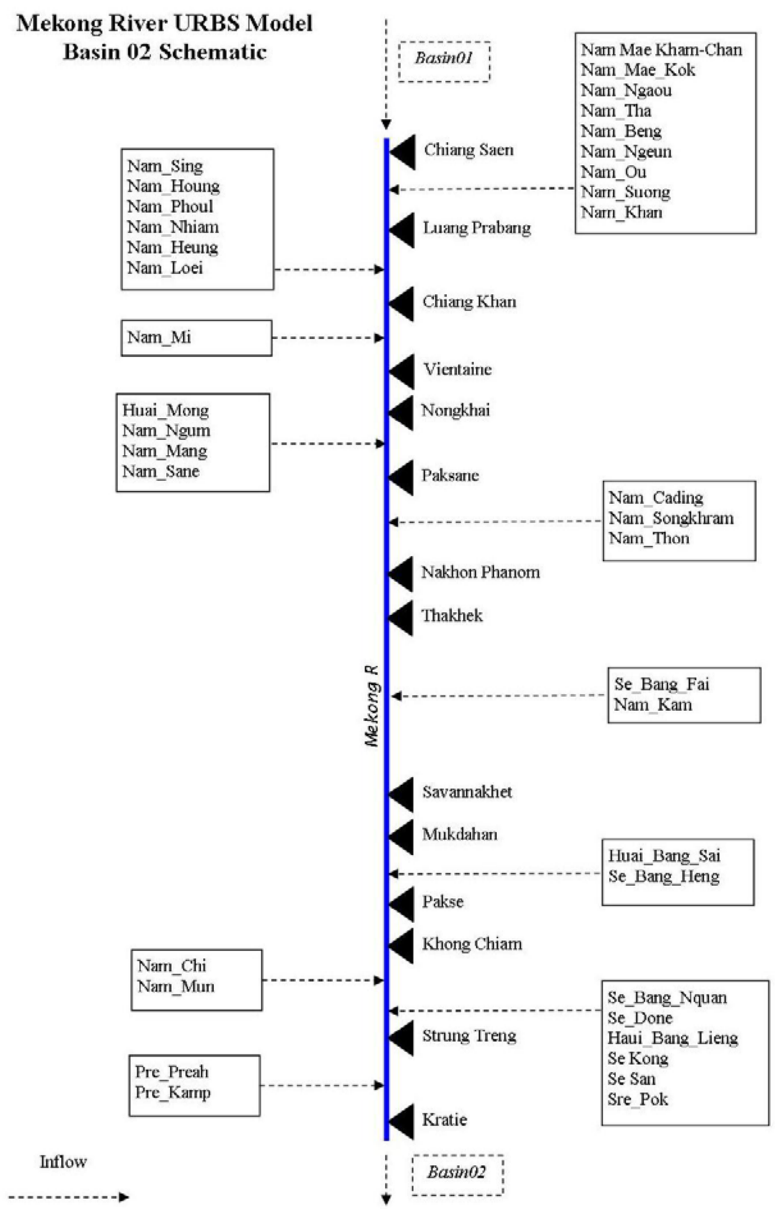

Figure 7. Schematic model layout Basin 2

Following completion of the model calibration programme, the next challenge for the MRC-RFMMC will be to link the models to the real-time database and include forecast rainfall in order to extend forecast lead-times.

An important challenge is to match the expectations of the potential users of the RFMMC flood forecast products with a realistic view of the accuracy that can be achieved, especially for medium range (4-10 day) forecasts. The dissemination of the results should reflect the inherent uncertainty of forecasts.

When looking increasingly further into the future means increasing uncertainties of especially weather patterns. This issue has to be resolved by intensive contacts and discussions with the intended target group and by using international best practices in flood forecasting and especially dissemination of the results.

5. CONCLUSIONS

The URBS model has been demonstrated to be a useful flood-forecasting model in Australia and China on large river systems. A trial calibration on the Se Bangfai catchment in Lao PDR has shown that model has the potential to perform reasonably accurately within the Lower Mekong River Basin. As such, MRC-RFMMC has embarked upon a programme to develop and calibrate hydrologic models for the entire Lower Mekong River Basin. A first version of the models is now completed (September 2007). If sufficient real-time data is made available to the MRC-RFMMC in time, the models could be deployed prior to the wet season in 2008.

It is recommended to start upgrading existing historical (rainfall) stations by providing a simple but effective means of communication at short notice. During discussions with the respective agencies it became clear that it is relatively simple and inexpensive to set up new manual rainfall stations; the logistics are more difficult as by definition it concerns remote areas. While most of the institutes now use VHF radio, the vast and ongoing improvement of GSM (mobile phone) coverage means that text messaging using a mobile phone by the observer is a now viable option. The text messages will be automatically received by a modem linked to a computer at the agencies head office, and can be easily used, stored and forwarded. A first trial has been successfully conducted in Cambodia; further trials are planned this year in Cambodia and Lao PDR.

The AHNIP and proposed M-HYCOS system may in future provide real-time data to the MRC-RFMMC at higher frequencies. However, for the time being and considering all other constraints in the data delivery to the MRC-RFMMC, it is realistic to focus efforts on improving the delivery of flood forecasting input data on a dependable daily basis. For this purpose the daily manual reporting of the AHNIP and in future M-HYCOS stations will be sufficient; it is expected that the manual system will remain as a backup. If the MRC-RFMMC is to increase the frequency of its flood forecasting many more than the presently operational and proposed AHNIP and M-HYCOS stations are needed, and the focus should be much more than now on rainfall data.

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