DEVELOPMENT OF IMPROVED HYDROLOGICAL FORECASTING MODELS FOR THE LOWER MEKONG RIVER BASIN

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ABSTRACT

The May 2006 Road Map Mission recognised that the introduction and development of improved hydrological models was a major step towards the improvement of flood forecasting services in the Lower Mekong River Basin (LMB) by the Regional Flood Management and Mitigation Centre (MRC-RFMMC).

In order to expedite the modelling process, an existing hydrological model, URBS, was selected as a trial model for use in the MRC-RFMMC. Eventually, it is anticipated that the URBS model will be only one of suite of hydrological and hydraulic models available to MRC-RFMMC forecasters.

The URBS model is a semi-distributed non-linear model, which 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 in a real-time environment and has several features, which readily lend itself to application as a flood-forecasting model.

Development of URBS models for the LMB will be undertaken using CatchmentSIM, a freely available 3D-GIS topographic parameterisation and hydrologic analysis package. The package automatically delineates watershed and sub catchment boundaries and includes a flexible result export oriented macro language, which allows users to fully couple CatchmentSIM with hydrologic models such as URBS.

Calibration of the URBS models developed using CatchmentSIM will be undertaken using the rainfall, height and flow data from the HYMOS database. It is expected that each model will be calibrated on several flood seasons.

This paper describes the URBS model and the features, which make it attractive as a flood-forecasting model. It also outlines the package CatchmentSIM used to develop the model and will give an example of the model in the Se Bang Fai catchment. The development work currently being undertaken by MRC-RFMMC staff and how it fits into an overall hydrological modelling plan for the LMB will also be briefly outlined.

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 LMB. Floods of these magnitudes can affect between one and eight million people throughout the LMB (Mekong River Commission Secretariat (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.

2. 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 modelling 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 affects 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.

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 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).

3. 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 the hydrologic properties of sub catchments. The model also includes a flexible result export oriented macro language to allow users to fully couple CatchmentSIM with any hydrologic modelling package that is based on sub catchment networks.

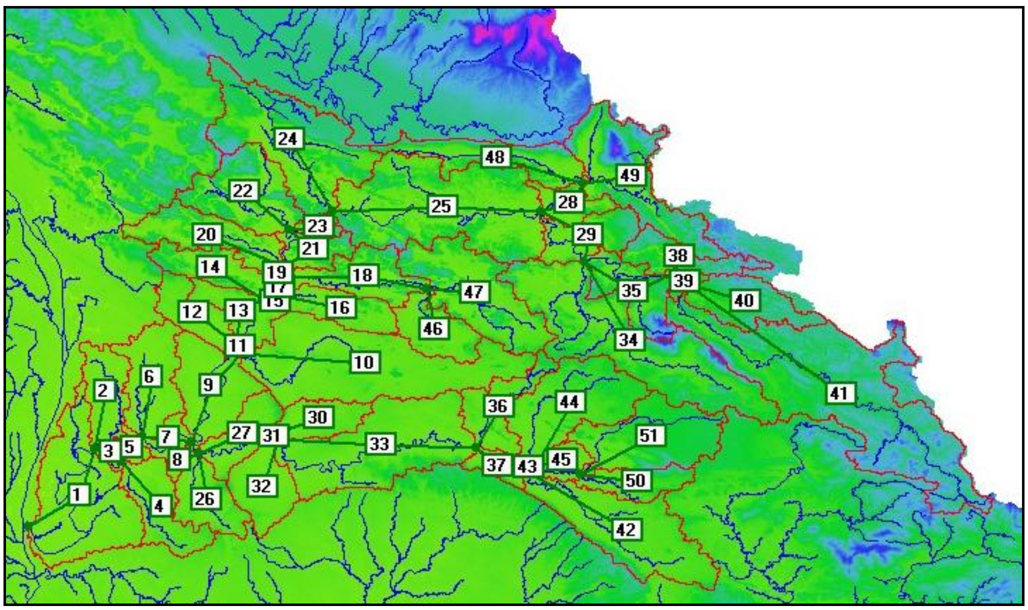

Figure 1. CatchmentSIM model of Se Bangfai

The example in Figure 1 shows the Se Bangfai catchment (Lao PDR) derived using publicly available digital elevation data from the NASA Shuttle Radar Topography Mission (SRTM).

One of the advantages of CatchmentSIM is that it includes a macro language, which enables the user to write scripts to develop any hydrological model. The package comes with scripts for several commonly used hydrological models, which may be suitable for use in the Mekong.

4. 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 river 55 km downstream of Thakhek (170404). The seasonal southwest and the northeast monsoons, which occur from May to October, primarily generate 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).

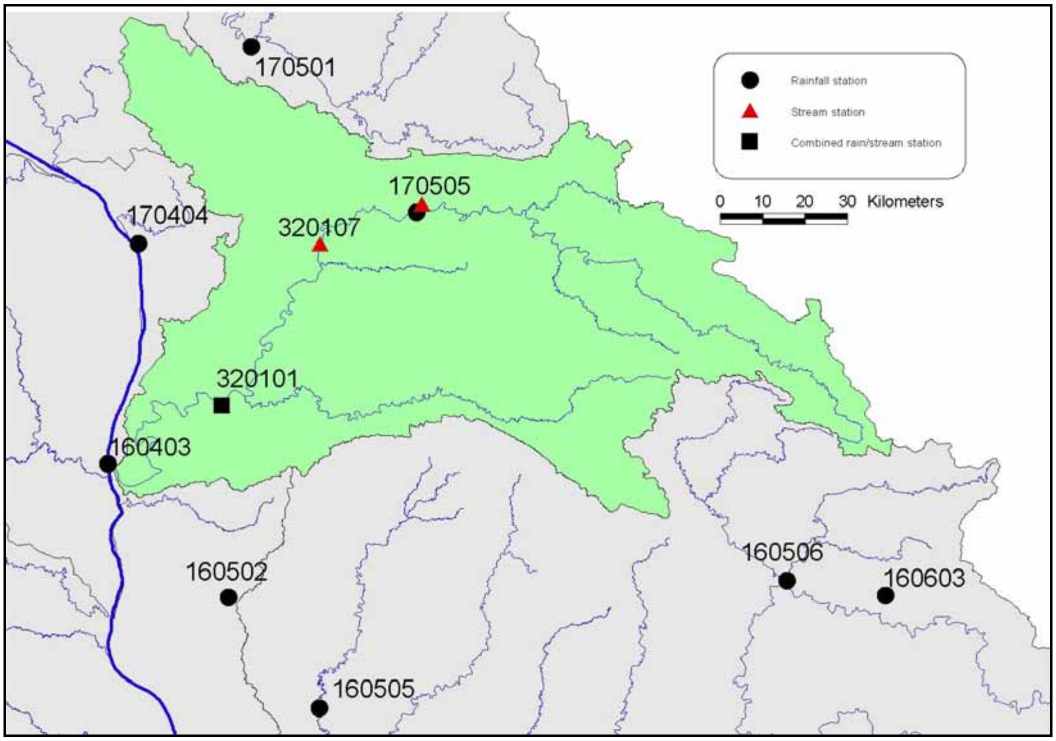

Figure 2. Se Bangfai River

The Se Bangfai model was selected as a trial catchment for testing of the model in the flood seasons from 1999 to 2005.

Firstly, CatchmentSIM was used to compile an URBS model of the Se Bangfai River as shown in Figure 1. The model consists of 55 sub-areas representing 9,300 km^2.

Rainfall and stream flood data from the stations shown in Table 1 was extracted from the MRC HYMOS database for use in the model. The rainfall stations available from HYMOS, shown in Figure 2, do not provide accurate 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 1. Rainfall and stream data

Stations		Event						
		1999	2000	2001	2002	2003	2004	2005
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

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 2 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 3 shows as example of the calibration at Ban Se Bangfai in 2004.

Table 2. 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

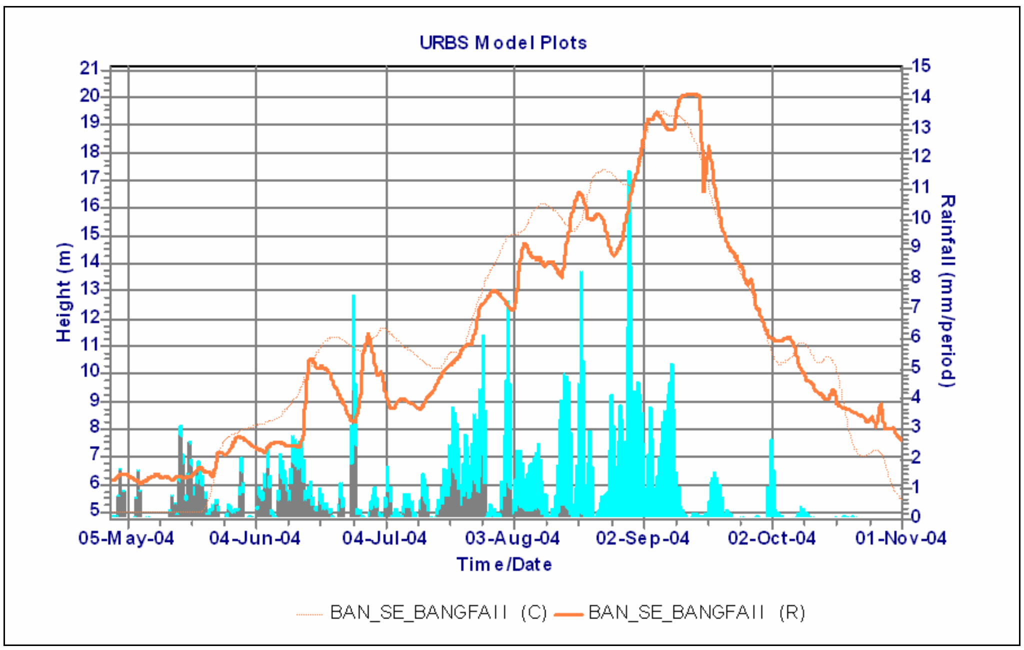

Figure 3. Model calibration at Se Bangfai 2004

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.

5. FUTURE DIRECTIONS

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 only 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 49 hydrologic models, as shown in Figure 4. Of these, 33 will require individual calibration. The parameters for the remaining 13 models will be inferred from adjacent catchments. Stage 1 will cover the LMB from Chiang Saen to Kratie while Stage 2 will cover the basin downstream of Kratie. Eventually, it is envisaged that the hydrologic models will provide the inflows into a real-time hydraulic model of the LMB.

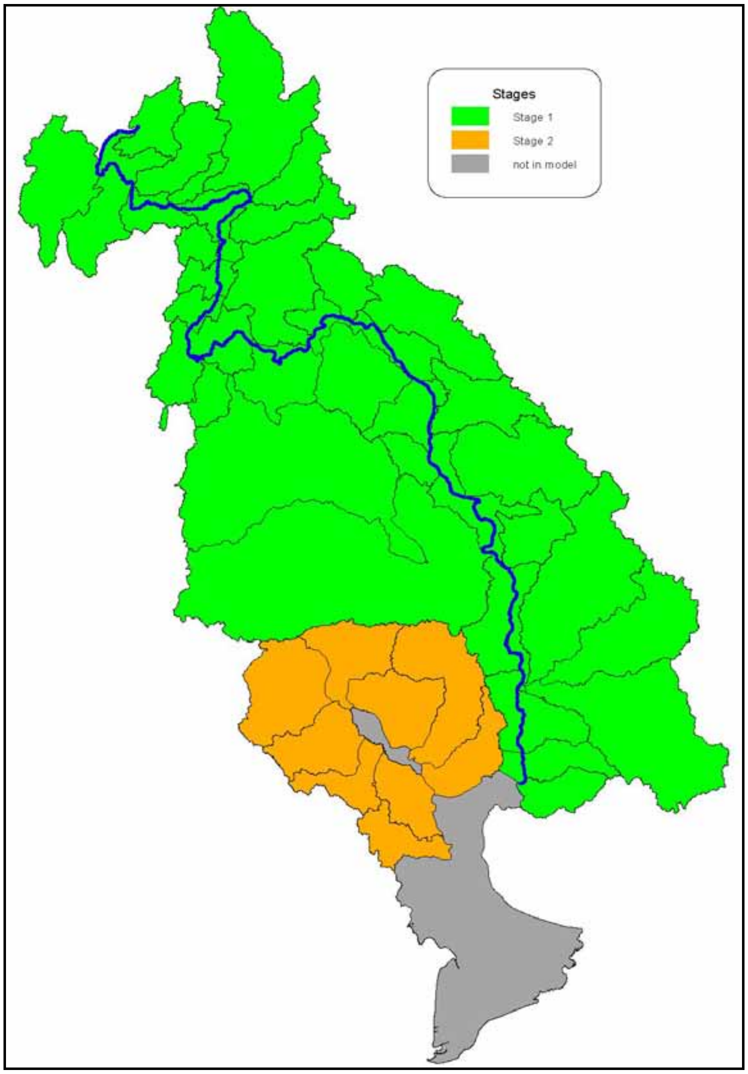

Figure 4. Hydrologic model layout

As each model is finalised, a calibration report outlining the modelling processes, inputs and outputs will be produced. 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 also being developed.

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.

The linking of the individual hydrological models with a hydrodynamic model of the Mekong main stream will be considered at a later stage.

6. 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. It is anticipated that the models will be completed by the end of 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.

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