Improved Flood Forecasting for the Yangtze River in China

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Abstract

The Yangtze River Flood Control and Management Project (YRFCMP) has designed and developed a new Flood Forecasting System (FFS) for the Yangtze River in China. This FFS is a key component of the new Decision Support System (DSS) that has also been developed by the YRFCMP to assist decision makers at the Yangtze Flood Control Headquarters with their management of floodwaters in the Yangtze River. The FFS aims to improve the reliability, accuracy and lead times of forecast flood discharges and flood levels along the upper and middle reaches of the Yangtze River.

The Changjiang Water Resources Commission (CWRC), the agency responsible for flood management in the Yangtze River catchment, has been using a combination of empirical techniques and mainly in-house developed numerical models to forecast flood behaviour along the Yangtze River. The problem with this approach is that it is not fully integrated across the catchment and relies too much on the local experience of forecasting staff. In addition, it does not provide the level of accuracy and forecast lead times desired for effective flood management. The new approach and the FFS are designed to overcome the shortcomings in the current approach.

The development of accurate hydrologic and hydraulic models for the Yangtze River catchment has been a significant challenge because of its size, nature and the complexity of hydrologic and hydraulic behaviour. Notwithstanding this, a high level of forecast accuracy has been achieved for up to 7 days lead time. Based on results to date, the level of accuracy currently achieved from the FFS is generally on par with the current methods used by CWRC for day 1 and day 2 into the forecast period. The level of accuracy achieved from the FFS for day 3 up to day 7 is generally superior to current methods. The system trials undertaken to date have identified a number of measures by which the forecast results can be improved. The implementation of these measures would further improve the FFS performance.

The new approach presented in this paper provides the CWRC flood forecasters with a user friendly, robust, web based, catchment wide, integrated flood forecasting system that can produce reliable flood forecasts with up to 5-7 days lead time. The FFS incorporates a range of new hydrological and hydraulic modelling systems and new custom built software systems. This paper provides an overview of the flood forecasting challenges in the Yangtze River catchment and describes how the new FFS assists CWRC to improve their real-time flood forecasting capability.

Keywords

Flood Forecasting, Flood Management, Real-time Forecasting, Web-based Systems, Yangtze River

INTRODUCTION

The five year Yangtze River Flood Control and Management Project (YRFCMP), which commenced in 2001 under the program of technical cooperation between the governments of Australia and the Peoples Republic of China, has developed a Decision Support System (DSS) to assist decision makers at Yangtze Flood Control Headquarters with their management of floodwaters in the Yangtze River. A key component of this DSS is the design and development of a new integrated real-time flood forecasting system (FFS) for the Yangtze River. The FFS aims to increase the accuracy and lead time of forecast flood discharges and water levels along the upper and middle reaches of the Yangtze River between Chongqing and Wuhan, and along the middle and lower reaches of the Han River.

The Changjiang Water Resources Commission (CWRC), the agency responsible for flood management in the Yangtze River catchment, has been using a combination of empirical techniques and mainly in-house developed numerical models to forecast flood behaviour along the Yangtze River. The problem with this approach is that it is not fully integrated across the catchment and relies too much on the local experience of forecasting staff. In addition, it does not provide the level of accuracy and forecast lead times desired for effective flood management. The new approach and the FFS are designed to overcome the shortcomings in the current approach.

The new approach presented in this paper provides the CWRC flood forecasters with a user friendly, robust, web based, catchment wide, integrated flood forecasting system that can produce reliable flood forecasts with up to 5-7 days lead time. It incorporates improved data acquisition and data management systems, a range of new hydrological and hydraulic modelling systems and by new custom built software systems.

This paper provides an overview of the flood forecasting challenges in the Yangtze River catchment and describes how the new system assists CWRC to improve their real-time flood forecasting capability. An overview of the DSS and flood management decision making in the Yangtze River is given in an accompanying paper at this conference (Betts *et al*, 2005).

BACKGROUND

The Yangtze Catchment

The Yangtze catchment is some 1.8 million km^2 in extent. The upper catchment, which runs from the source of the river in the Qinghai-Tibet plateau to the City of Yichang, has a catchment area of 1.0 million km^2. The middle catchment, which lies between Yichang and the City of Wuhan, has a catchment area of 0.68 million km^2. The lower catchment, which runs from Wuhan down to the City of Shanghai at the mouth, has a catchment area of 0.12 million km^2. For the purposes of the FFS (and Yangtze River flood forecasting) the upper reach is considered to be the reach between Chongqing and Yichang, and the middle reach is considered to be the reach between Yichang and Jiujiang (downstream of Wuhan). Figure 1 shows the area of the upper and middle reaches of the Yangtze River between Chongqing and Jiujiang adopted for the FFS.

Flood Management

In the middle and lower reaches, the floodplains of the Yangtze are protected by over 3600 km of primary levees. A further 30,000 km of secondary levees provide flood protection along the tributaries and minor rivers and around the cities and towns of the middle and lower reaches. In all, levees protect over 80 million people, vast areas of cropland and major industrial developments from flooding. The middle and lower reaches of the catchment contribute more than 40% of the annual Chinese GNP and the region is continuing to expand and grow (GOA & GOPRC, 2000).

Flooding in the Yangtze is major concern for Chinese authorities. Since 1877, at least 25 floods have exceeded the channel capacity of the Yangtze River. The most recent of these major floods occurred in 1998. According to Betts *et al* (2005), over 3000 people lost their lives during the 1998 floods when some 15 million people were rendered homeless, 5 million houses were destroyed, 22 million hectares were inundated and 1.8 million hectares of crops destroyed. The total damage bill was estimated to exceed $ US 20 billion.

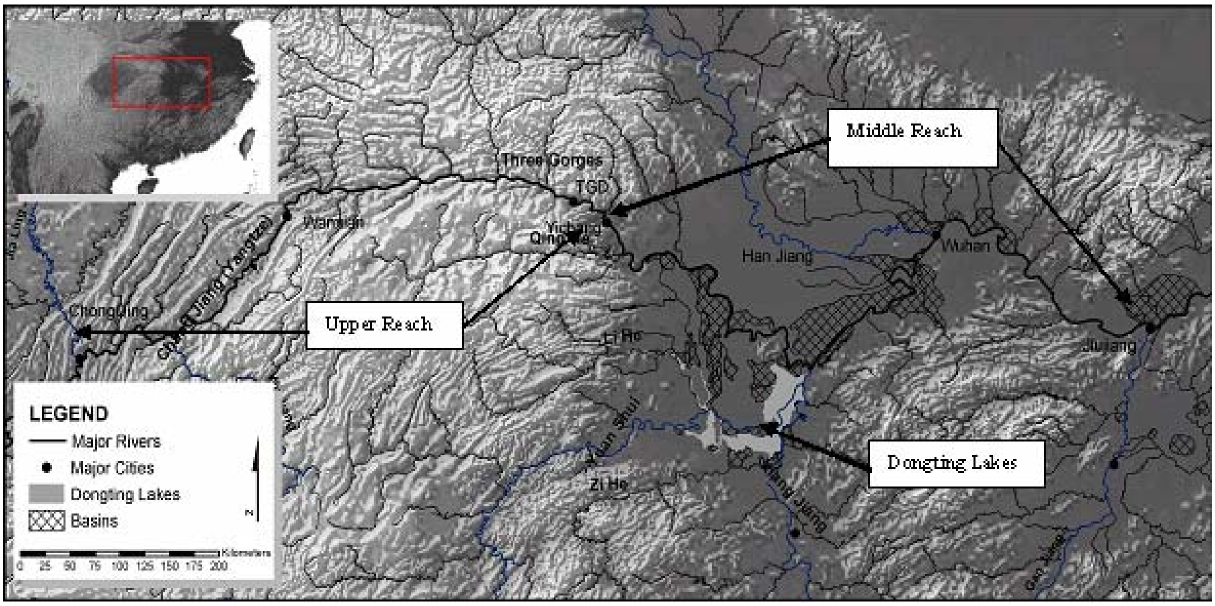

Figure 1. The Upper and Middle Reach of the Yangtze River

The focus of the FFS is to improve the accuracy and lead time of discharge and water level forecasts along the middle reaches of the catchment where some 40 flood management detention basins are located. A critical flood management decision for the Chinese authorities is whether or not to open up these basins to store floodwaters and relieve downstream flood levels. The decision to open the basins involves the evacuation of large numbers of people (up to 300,000 in the Jianjiang Basin) and substantial flood damage to crops, houses and infrastructure within basins, which may be flooded to depths of 8 to 10 meters for several months (GOA & GOPRC, 2000). Thus, there are substantial social and economic penalties for opening up a basin when it is not required, and when necessary, for failing to open a basin and imperiling downstream levees. This highlights the need for more accurate and reliable flood forecasts with as long as possible lead time.

New Approach

The YRFCMP design mission attributed the prevailing less than desired accuracy and lead time in forecast flood discharges and water levels to the following shortcomings (i.e. deficiencies):

- Inappropriate Numerical (hydrologic and hydraulic) models used to simulate and forecast flood behaviour;
- Inadequate real-time monitoring of rainfall, water level and discharge data during flood events;
- Inefficient communication systems used to transmit real-time flood data to receiving stations; and
- Inefficient and ineffective data acquisition and management systems at receiving stations.

YRFCMP has addressed the above shortcomings by:

- Introducing new and more appropriate hydrological and hydraulic models to provide more accurate and timely forecasts of discharges and water levels at key locations;

- Upgrading rainfall, water level and discharge monitoring and communication systems;
- Installing new data management systems; and
- Developing a catchment wide integrated flood forecasting system.

The flooding behaviour in the Yangtze catchment is quite complex. Therefore, the key to the successful implementation of a FFS is a full understanding and accurate modelling of the markedly different hydrologic and hydraulic behaviour of the upper and middle reaches. An overview of the hydrologic and hydraulic behaviour of the Yangtze River and the challenges faced when modelling the Yangtze River are described in Clark *et al* (2005a,b) and Markar *et al* (2004; 2005).

OVERVIEW OF THE FFS

The Yangtze River FFS is a web-based flood forecasting system. Figure 2 shows a conceptual view of the web-site architecture. Details on the FFS architecture and software and hardware systems are given in Markar *et al* (2005).

The heart of the FFS consists of hydrologic and hydraulic flood forecasting models. Hydrologic models are used to forecast the tributary (local) inflows which are then routed through hydraulic models to forecast discharges and flood levels along the main stems of Yangtze and Han Rivers, and the Dongting Lake System. The FFS links all the hydrologic and hydraulic models seamlessly into an integrated catchment wide modelling system (see Figure 3). At present, the FFS incorporates three hydrologic models, namely Xinanjiang (Chinese), URBS (Australian) and API (Chinese), and one hydraulic model (Mike 11 – Danish). The hydrologic models are run directly through the FFS software. The hydraulic model (due to proprietary license constraints) is run through the FFS using a custom designed and written software interface. The evaluation and selection of models for use in the FFS are described in Markar *et al.* (2004). The use of these models within the FFS is described in Clark *et al* (2005a, b).

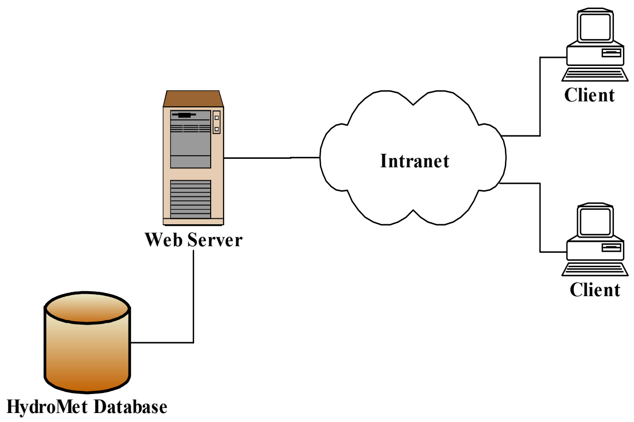

Figure 2. FFS Website Architecture

To date, over 100 contributing tributary catchment hydrologic models and 3 hydraulic models for the Yangtze and Han River main stems have been incorporated into the FFS to model the hydrologic and hydraulic behaviour of the upper and middle reaches of the Yangtze River and the Han River. Configuration data for these models, together with real-time hydrometeorological data and rainfall forecasts are extracted from a central database and converted to model input files. The models are then run (multiple times for different input scenarios, if necessary) and the output files are stored, compared, and a final (i.e. adopted) forecast discharges and level scenario selected and managed within the above fully integrated web-based FFS framework. The FFS at present forecasts flood discharges and levels at over 70 locations throughout the modelled reaches of the Yangtze River system for up to 5-7 days in advance.

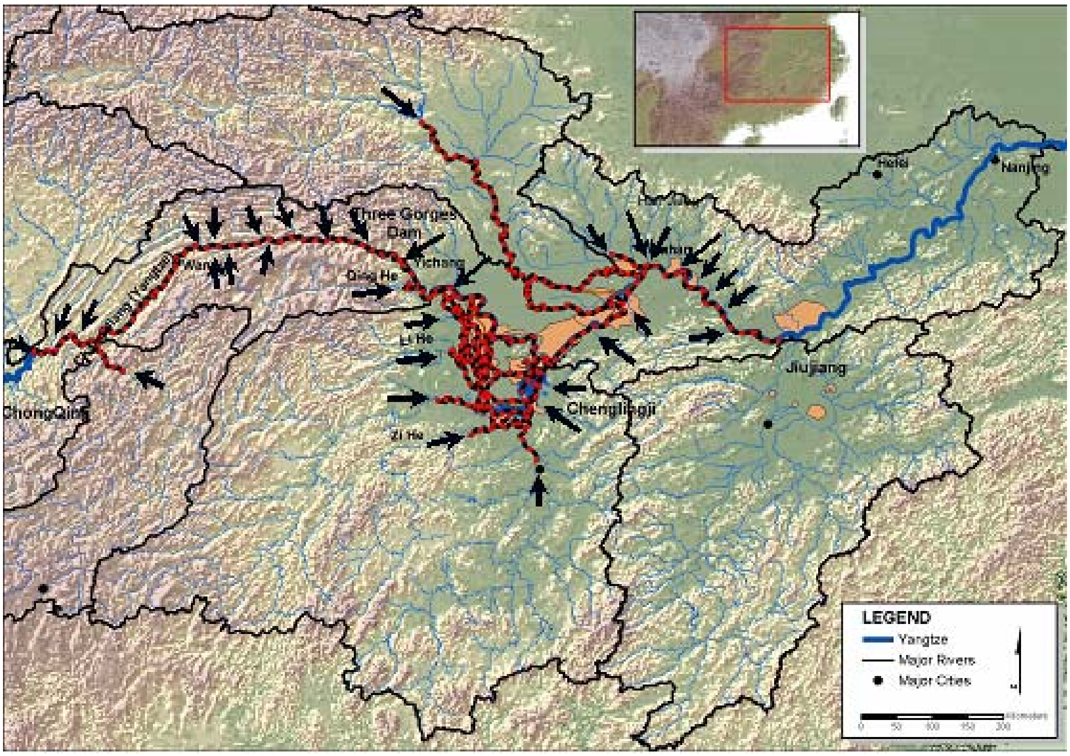

Figure 3. Linkage of hydrologic (tributary inflows) and hydraulic (main stem) models in the FFS

FFS CAPABILITY

The FFS, which is configured and operated via the Yangtze River DSS web site, provides flood forecasters with a user friendly interface to develop, calibrate and run hydrologic and hydraulic models, and then analyse and manage results using a web browser. The key operational features and functionality of the FFS include the ability to:

- Run the system at different levels of complexity ranging from a single model run to running all models for a selected reach;
- Run the system with and without forecast rainfalls;
- Choose from a range of available hydrologic models;
- Check and choose data from manual or automatic rainfall and water level stations;
- Run models interactively in continuous 'mode' for short periods using a 'hot start' feature;
- Operate the system in real-time in a very flexible manner;
- Update model parameters in real-time and re-run models (i.e. multiple model runs) within a single forecasting session;
- Apply real-time 'error corrections' to flood forecasts along the main stems of the Yangtze and Han rivers;
- Compare results between different catchments and forecast scenarios and between different hydrologic models;
- View and check hydro-meteorological data, model input data, model output data in tabular, graphical and map formats;
- Provide different user access levels and audit user activity;
- Operate the system in either Chinese or English language GUI menus;

- Provide forecast discharges and flood levels at any number of nominated locations for up to 7 days in advance; and
- Run all hydrologic and hydraulic models of the Yangtze catchment and provide forecast discharges and water levels at all key locations in about 1 hour (on average).

Details of the adopted FFS structure for the upper and middle reaches (including the Dongting Lake system and the Han River) and the operational components are given in Markar *et al* (2005).

FFS PERFORMANCE

The FFS has been put through extensive performance trials in hindcast mode for past flood seasons and in real-time during the 2004 flood season. The 2004 trials provided the first opportunity for the system developers and users to test the performance of the FFS functionality and the forecast accuracy in real-time. During these trials, a number of issues were identified concerning the functionality and accuracy of the FFS, resulting in a number of enhancements to the FFS. Results of this testing program and the enhancements are described in Markar *et al* (2005). The improved FFS is being put through further trials during the current (2005) flood season.

Table 1 provides statistics regarding the accuracy of the FFS in forecasting discharges and water levels at 2 key locations along the middle reach of the Yangtze (Shashi and Wuhan) during the 2004 flood season. The level/discharge error at peak shows the predicted water level or discharge minus the observed equivalent value. The average level/discharge error shows the average error over the full period of simulation. The coefficient of determination (DC) is a measure of the goodness of fit between the predicted and observed level/discharge hydrographs for the entire flood season. Figures 4 and 5 show a comparison between the predicted and observed water levels and discharges at Yichang, Shashi and Wuhan for the 2004 flood season. Note that predicted results are shown with and without real-time error correction.

Table 1. FFS Forecast Accuracy at Shashi and Wuhan during the 2004 Flood Season (Without the application of real-time error correction)

Parameter	Shashi		Wuhan (Hankou)	
	Water Level	Discharge	Water Level	Discharge
Error at Peak	0.30 m	3.8%	0.14 m	2.5%
Average Error	0.11 m	0.4%	0.04 m	0.8%
Coeff. of Determination (DC)	93.1%	99.3%	98.9%	98.6%

The development of accurate hydrologic and hydraulic models for the Yangtze River catchment has been a significant challenge because of its size, nature and the complexity of hydrologic and hydraulic behaviour. Notwithstanding this, a high level of forecast accuracy (that meets the Chinese National Standards, 2000) has been achieved for up to 7 days lead time. Based on results to date, the level of accuracy currently achieved from the FFS is generally on par with the previous methods used by CWRC for day 1 and day 2 into the forecast period. The level of accuracy achieved from the FFS for day 3 up to day 7 is generally superior to previous methods. The system trials undertaken to date have identified a number of measures by which the models performances (i.e. forecast results) can be improved (Markar et al, 2005). The implementation of these measures would further improve the FFS performance.

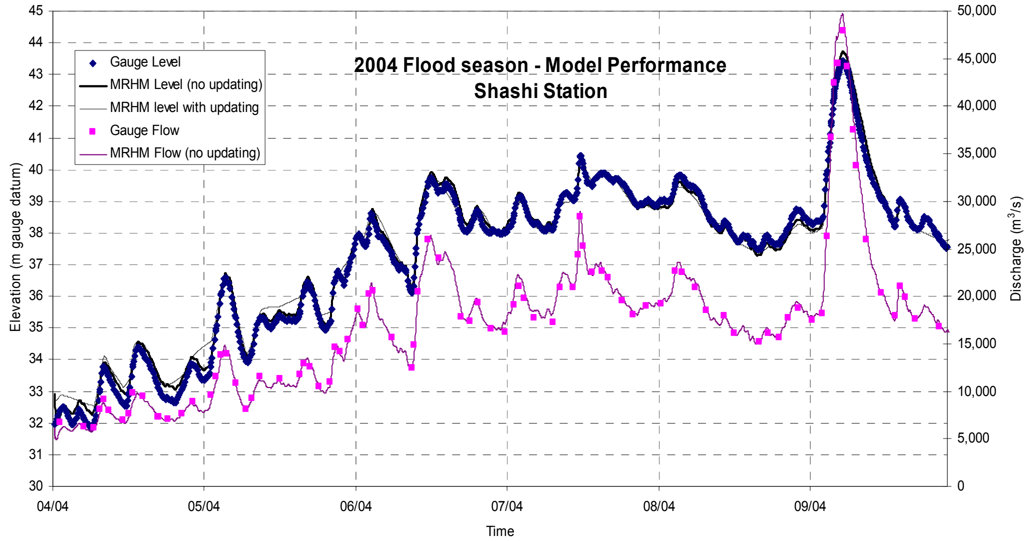

Figure 4. Comparison between the predicted and observed water levels and discharges at Shashi for the 2004 flood season (MRHM – Middle Reach Hydraulic Model)

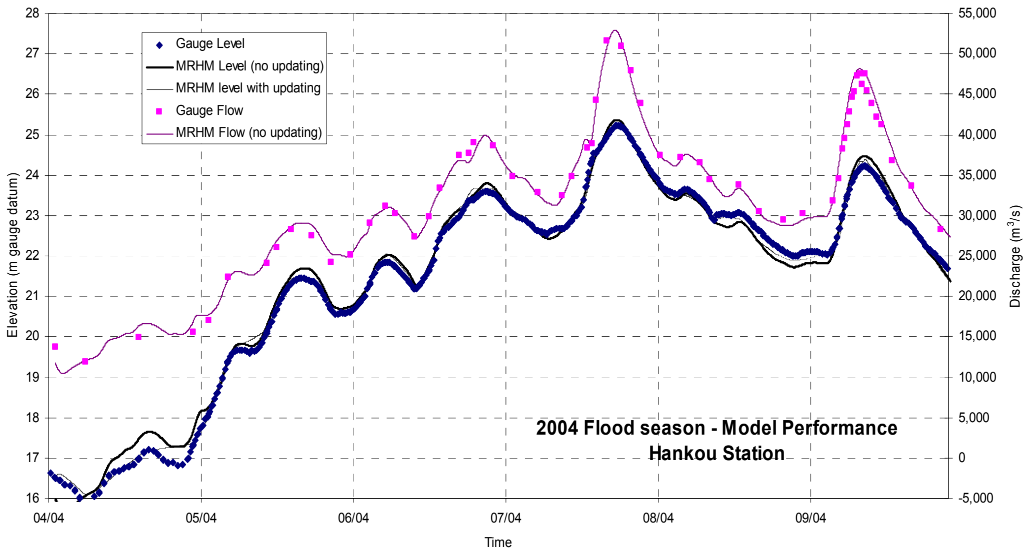

Figure 5. Comparison between the predicted and observed water levels and discharges at Wuhan (Hankou) for the 2004 flood season (MRHM – Middle Reach Hydraulic Model)

CONCLUSIONS

The development of accurate hydrologic and hydraulic models for the Yangtze River catchment has been a significant challenge because of its size, nature and the complexity of hydrologic and hydraulic behaviour. Notwithstanding this, a high level of forecast accuracy has been achieved for up to 7 days lead time. The new approach has provided Changjiang Water Resources Commission (CWRC) with an integrated catchment wide flood forecasting system.

The trials undertaken to date have demonstrated that the new flood forecasting system developed for flood forecasting in the Yangtze River catchment is user friendly, robust, reliable, quick, and can satisfy the forecasting needs of the CWRC. The system trials to date have shown that the level of accuracy achieved from the system is good for the current stage of system development and has the potential for significant improvement in the future. A number of measures that can improve the FFS performance have been identified during system trials.

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