LESSONS LEARNED AND IMPROVED TECHNOLOGIES FOR REAL-TIME FLOOD FORECASTING AND WARNING

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Abstract

Technologies for flood forecasting and warning systems can significantly contribute to prevent, minimize, or mitigate people's suffering and economic losses due to floods. The direct immediate objectives for such systems should be to provide people with fast, accurate, reliable, relevant and easy-to-understand forecasts and warnings. Forecasting and warning systems should form an integrated and important part of efficient river basin management systems, including also facilities for e.g. flood control, reservoir management, water quality management, drought management, river regulation and other relevant decision support.

Based on the experience from recent implementation of more than 40 real-time flood forecasting and warning systems world-wide it is clear to see a trend in the use of technologies and the desire to obtain added values from the systems. Improved technologies include e.g. advanced data assimilation methods, use of spatially distributed data and modelling through powerful GIS, use of well proven forecasting shells designed with decision support facilities, advanced dissemination facilities through e.g. web technology and cell broadcasting. Added values from the systems include e.g. water quality forecasting, hydropower operation and optimisation, water resources management.

This paper will show how some of these new opportunities are currently being used in practice in flood forecasting and warning systems implemented recently. In the Songhua River Basin in North Eastern China a comprehensive decision support system is being implemented. Also in China an inflow forecasting system for the Three Gorges Dam has been developed. In Thailand a combined real-time flood and water quality forecasting system has been implemented for Bangkok.

Keywords: Flood forecasting, data assimilation, distributed modelling, dissemination, inflow forecasting, water quality forecasting

I. INTRODUCTION

All flood forecasting systems serve specific individual purposes and in most cases they are designed, as a minimum, to prevent, minimize, or mitigate people's suffering and limit economic losses. In general the flood prone population will require the forecasts to be:

- Fast
- Accurate
- Reliable
- Relevant
- Easy-to-understand

These requirements are a challenge not least because the forecasts are generated in a real-time environment under critical conditions. The challenging requirements have stimulated a trend in the use of new technologies and the desire to obtain added values from the systems. DHI Water & environment has observed the trend through the experience from recent implementations of more than 40 real-time flood forecasting and warning systems world-wide, see Figure 1.

Figure 1   Recent implementations of MIKE FLOOD WATCH

Some of the trends are:

Data Assimilation:

Ideally, real-time flood management decisions must be based on an understanding of the uncertainties and associated risks. It is therefore central for effective flood forecasting tools to provide reliable estimates of the forecast uncertainty. Only by quantifying the inherent uncertainties involved in flood forecasting, can effective real-time flood management and warning, be carried out. Estimating forecast uncertainty requires the estimation of the uncertainties associated with the hydrological model inputs (e.g. observations or forecasts of precipitation), model structure, parameterisation and calibration, and methodologies that predict how the uncertainties from different sources propagate through the hydrological and hydraulic system. During a flood both lives and property are at risk and therefore any means to reduce forecast uncertainty are highly desirable. WMO has identified updating or data assimilation as an essential requirement for accurate flood forecasting.

Within the EU 5th framework project FLOODRELIEF (http://projects.dhi.dk/floodrelief/), an ensemble-based approach has been developed to estimate forecasting uncertainties and reduce uncertainty using data assimilation. This general stochastic framework for flood forecast modelling is based on the Ensemble Kalman Filter. The Ensemble Kalman filter provides a natural framework for determining how the different sources of uncertainty propagate through the hydrological and hydraulic models and to reduce forecast uncertainty via data assimilation of real-time observations. Because of its improved ability to treat nonlinearity and model-independent nature, this filter is widely used in oceanography and meteorology and more recently hydrology.

Distributed data and modelling:

New opportunities for distributed hydrological modelling applied to flood forecasting are emerging from new sources of spatially distributed data such as weather radar, satellite platforms, and high-resolution meteorological models. The availability of GIS tools, together with national and global databases allows scientists and practising hydrologists the opportunity to access and use enormous quantities of spatial and temporal data. With the exponential increase in computing power it is feasible to apply high resolution distributed hydrological models to a range of water resource problems including flood forecasting. State of the art operational hydrological forecasting models usually rely on conceptual or empirical models, based to a greater or lesser degree on the physics of

rainfall-runoff. By contrast state-of-the-art hydrological modelling is represented by fully distributed physically based models, which exhibit a much greater level of complexity. In practice, the level of complexity required for hydrological modelling will depend on the available catchments data, the important catchments rainfall-runoff processes and the problem to be solved. Therefore distributed models are needed which can adapt to the available data and to different levels of complexity.

Within the EU 5th framework project FLOODRELIEF (http://projects.dhi.dk/floodrelief/), a general modelling framework has been developed, which allows alternative model structures for the rainfall-runoff processes and channel routing to be explored. Any evaluation of the accuracy of deterministic hydrological models for hydrological simulations and forecasting must address four sources of uncertainty. They are the random or systematic errors in the model inputs or boundary condition data, random or systematic errors in the recorded output data, uncertainty due to sub-optimal parameter values and errors due to incomplete or biased model structure. A critical choice in applying mathematical models to hydrological problems is the selection of model structure. Selecting an appropriate model structure encompasses determining the most significant hydrological processes to be described, the mathematical description of these processes and their spatial representation.

Dissemination through cell broadcasting:

The intensive use of cell phones world-wide has now enabled the development of a new and very powerful methodology for dissemination of flood warnings to populations exposed to flooding. The dissemination of flood warnings to people living in flood prone areas have often been ineffective, late and of limited value. Quick and efficient mass communication during critical hours of natural disasters is a challenge in any society.

Cell broadcasting is now available to provide very efficient and focused dissemination of flood warnings to flood prone people. The new technology is based on digital flood maps as produced e.g. by MIKE 11 and cell broadcasting services developed by Innovative Business Software A/S, Denmark. It is made possible to disseminate important flood warnings through cell broadcasting in order to utilise all active cell phones within a given flood prone area for important warnings. The digital flood maps are simply interpreted by the cell broadcasting software and transformed into cell phone messages to a limited geographical area.

Cell broadcasting is an existing function of most modern digital mobile phone systems such as GSM and UMTS. It differs from SMS in that, while it does put text messages on the screen of the phone like SMS does, it does this to 'all-at-once' and not one-at-a-time as SMS does. The solution of communicating important flood warnings through all active cell phones in a flood prone area can potentially be widely used in the coming years. Many flood forecasting systems in heavily populated areas will really be able to benefit from this dissemination concept.

General:

Other improved technologies include e.g. extensive use of powerful GIS facilities, general decision support facilities, advanced dissemination facilities through web technology. Added values from the systems include e.g. water quality forecasting, hydropower operation and optimisation, water resources management.

II. DECISION SUPPORT IN THE SONGHUA RIVER BASIN

For the Songliao Water Resources Commission (SWRC) DHI Water & Environment together with Mott MacDonald Ltd and the Institute of Water Resources and Hydropower Research are implementing a state-of-the-art Flood Management Decision Support System (FM DSS) for the Songhua River Basin. It covers an area of 557,000 km2 and serves a population of 53.5 million

people. The project is a technology transfer project with the ultimate aim to develop the necessary expertise and technology in the SWRC to actively and effectively manage floods.

The FM DSS will provide easy access to all relevant flood information with extensive use of GIS. Further, it will enable hydrological and hydrodynamic modelling including real-time flood forecasting and reservoir management. A major component of the FM DSS is the real-time forecasting system MIKE FLOOD WATCH, which is now widely used in China. The MIKE FLOOD modelling package (integrating MIKE 21 and MIKE 11) is used for combined one-dimensional and two-dimensional flood modelling. MIKE 11 is applied extensively in the river basin. The FM DSS will provide the user with a selection of decision support tools, which can assist SWRC during serious floods. The FM DSS provides the ability to interface telemetry, manage real-time data, carry out manual, event driven or scheduled forecasts, publish results and generally serve as a tool for making decisions in real-time. In a web environment, the forecast results are overlaid with spatial information to identify and publish evacuation routes, hydraulic structure operation rules and others.
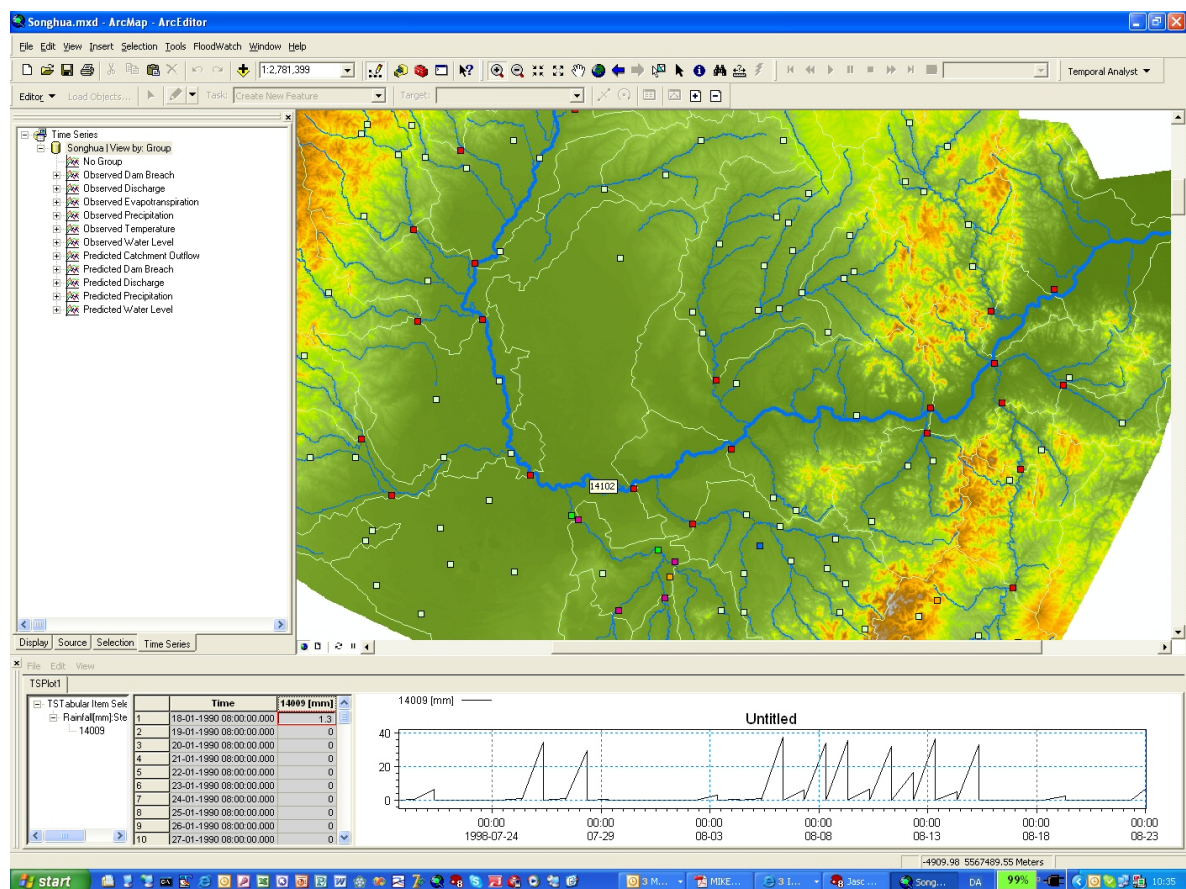

Figure 2 Flood Management Decision Support System for the Songhua River Basin

On 13 November 2005 an explosion at a chemical plant in Jilin City, China, generated a major spill of chemicals into the Songhua River. Benzene and nitrobenzene were the two major pollutants from the explosion and the contamination plume was subsequently been moving downstream towards Harbin City and further downstream towards the Russian boarder.

Within very few days the Songhua River Basin flood model was adjusted and modified to also work as a water quality model for the river system. It was applied to simulate the movement of the pollution plume downstream of Jilin. The model was able to simulate the arrival of the pollution at Harbin City very accurately, see Figure 3.
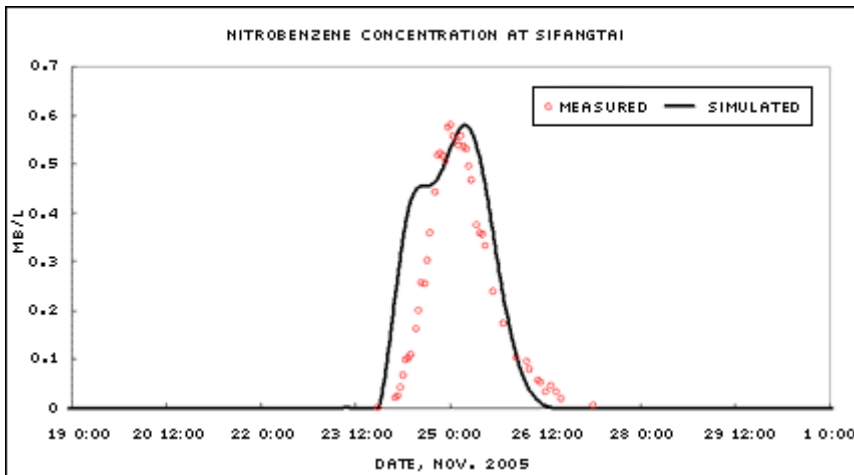
Figure 3 Nitrobenzene concentration at water intake in Harbin City

The model was also used to simulate the further movement of the pollution plume downstream of Harbin City towards the Russian boarder. It predicted very accurately that the pollution plume would reach Heilongjiang (Amur River) close to the Russian boarder at 8 December 2005.

III. INFLOW FORECASTING FOR THREE GORGES DAM

An inflow forecasting system for the Three Gorges dam has been developed by DHI Water & Environment in cooperation with the Yangtze Water Resources Commission. The main purpose of the system is to provide decision support for the operation of the dam, so that the power production can be maintained while ensuring sufficient storage to control river water levels downstream and avoid flooding.

The inflow forecasting system for the Three Gorges Dam is linked to a network of real-time rainfall and river stations, providing data every 15 minutes. The MIKE 11 model includes the structures in the dam, including the 26 power units, 10 sediment and debris gates and 66 spillway gates to meet given operational targets for each structure. Complementing the hydrological and hydraulic model is a new data assimilation module, which utilizes an efficient updating technique that improves the model state through a feedback process; thus matching the available observations prior to the time of forecast and correcting the model predictions in the forecast period. The combination of the updating technique and the advanced dam operation strategy makes it possible for dam operators to carry out comparative assessments on the fly and identify appropriate structure operation schemes that enhance the operation of the Three Gorges Dam.

All the structures included in the model can be operated as defined by the user or automatically, to meet given target water levels. This is done in a pre-defined sequence: the specified target power is generated first using the required number of power units considering the water levels up- and downstream the dam, turbine characteristics etc. The ship locks and sediment and debris gates are then simulated in accordance with the actual and planned use. The spillway operation is finally performed as defined by the user or automatically, depending on the selected control mode. In the automatic mode, the gates are operated to keep water levels within given limits. The forecasting process is controlled by MIKE FLOOD WATCH, which runs automatically at regular intervals. It imports the required real-time data, performs the forecast calculations, and issues the forecasts and recommended gate operations.

The level of the reservoir will be raised by the end of 2006 and again in 2009, when the dam and all power units have been completed. This will provide a significant flood retention volume, which can be freed whenever the forecasting system predicts a major inflow event. The dam can in this way be applied to avoid or at least reduce the floods, which for centuries have been a threat to the huge population along the Yangtze River.
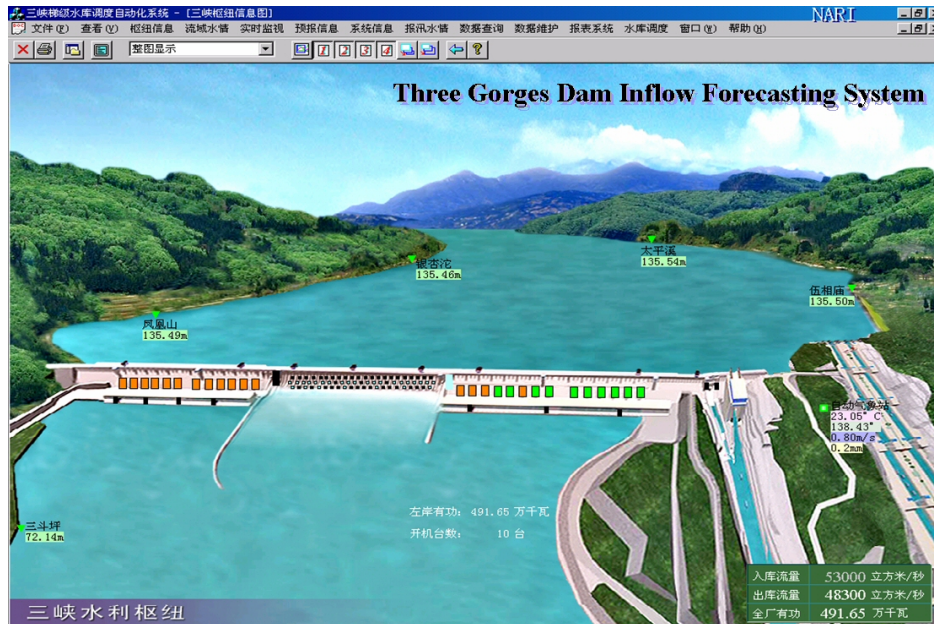
Figure 4 The three Gorges Dam

IV. FLOOD AND WATER QUALITY FORECASTING IN BANGKOK

For the Bangkok Metropolitan Administration (BMA) a real-time urban flood forecasting system has been developed. The system provides timely, accurate and reliable forecasts of the urban flooding and the system is tailored to provide important early warnings to the responsible forecasting officers. The system is resilient and robust with multiple back-up servers in a real-time environment. It consists of the following components:

- A database with real-time observations of river stage and rainfall.

- SCOUT, a rainfall forecasting system that applies real-time radar images for short term forecasts and output from a numerical weather model for long term forecasts.

- MIKE 11 hydrological and hydraulic models, including a state updating facility for forecasting purposes.

- The MIKE FLOODWATCH system that integrates real-time data from telemetry, the SCOUT system and the MIKE 11 flood forecasting model in a single environment.

- A dissemination facility to provide warnings efficiently to the public.

The forecasting system has been expanded to also include water quality forecasting. Bangkok and the surrounding area have a network of canals or khlongs, which over the past decades have been in serious decline with regard to water quality. The network of channels covers hundreds of square kilometres, linking the Chao Phraya with the neighbouring rivers Tha Chin and Bang Pakong to the west and east, respectively. The network is an invaluable asset containing numerous uses such as:

- drainage channels for storm water and flood overflows

- navigation routes for water transport

- conveying of sewage via the main rivers to the sea

- conveying of irrigation water to the northern area

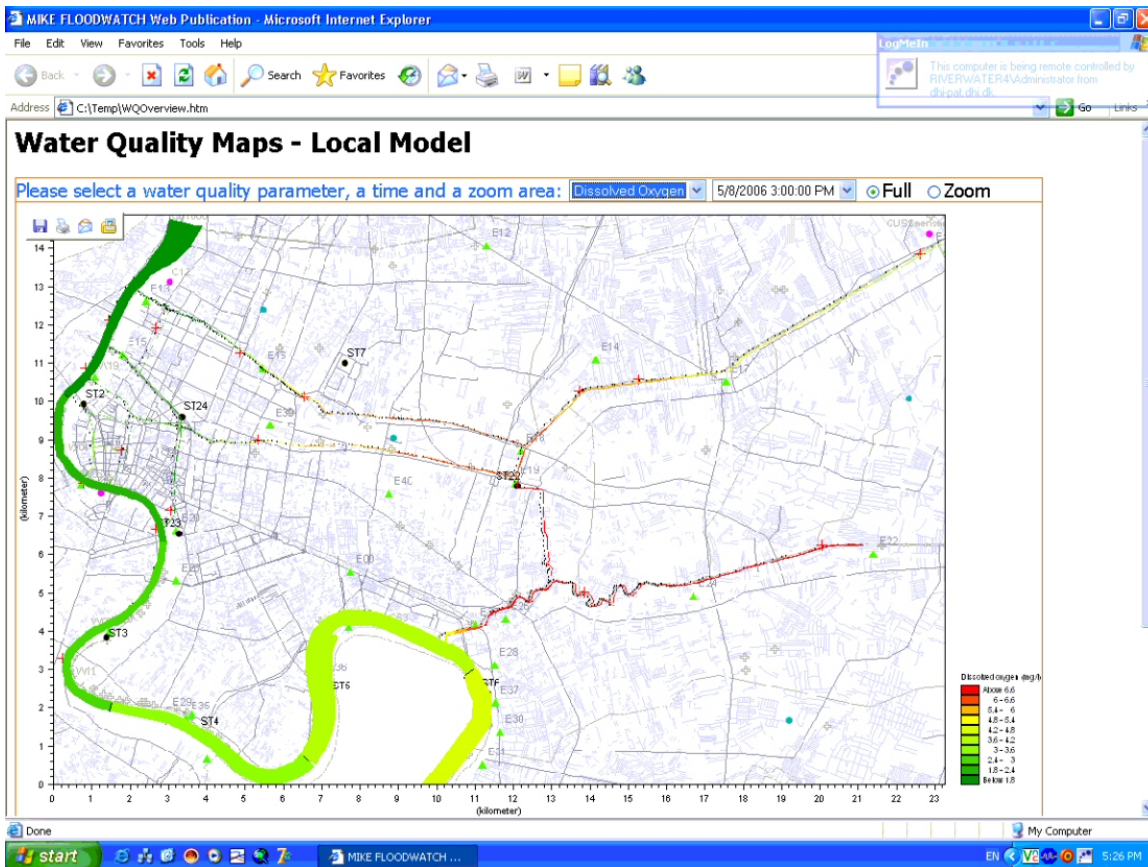- circulation of brackish water among the shrimp farms in the south

Figure 5 Water quality forecasting in Bangkok

To improve the water quality a number of measures are undertaken by the BMA. In parallel with the construction of sewage treatment facilities an advanced water quality surveillance and decision support system has been implemented. The system is composed of advance sensor and database technology, model updating in real time and GIS and it provides BMA with a unique decision support system to address such important issues as:

- Identification of major pollution sources

- Forecast of water quality

- Procedures and routines for efficient operation of hydraulic structures in order to maximise flushing of khlongs without violating water quality standards for the Chao Phraya.