A Tailored GIS-based Forecasting System of Songhua River Basin, China

C. Skotner [1], A. Klinting [1], H. C. Ammentorp [1], F. Hansen [1], J. Høst-Madsen [1], Q. M. Lu [1]
H. Junshan [2]

[1] DHI Water & Environment, Agern Allé 5, 2970 Hørsholm, Denmark, (cso@dhi.dk/Fax: +45 4516 9292)
[2] Songliao Water Resources Commission, 888 Gongnong Rd., Changchun, Jilin Province, P. R. China

Abstract
Accurate and reliable flow forecasting forms an important basis for efficient real-time river management, including flood control, flood warning, reservoir operation and river regulation. In order to achieve this objective, it has become a common practice to apply GIS based software that integrates data management and forecast modelling tools in a single environment. Such systems provide 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.

The paper describes the configuration of a novel flood forecasting system for the Songhua River Basin in north eastern China; a flood prone basin covering 557,000 km^2. The system includes several one dimensional and two dimensional hydrological and hydraulic forecast models. The forecast results are overlaid with spatial information to identify and publish evacuation routes, hydraulic structure operation rules and others.

Background
The Songhua Basin (Figure 1), located in the north eastern part of China, has a population of 62 million people. The flooding typically occurs at a time scale of the order of 20-30 days, depending on the characteristics of the weather. Typically, two kinds of weather patterns occur:

- High intensity precipitation with a short duration arriving from south, giving a relatively fast flood response
- Persistent precipitation with a small intensity arriving from north and west of the basin, giving a relatively slow flood response

Owing to the fact that about 70-80 per cent of the annual precipitation falls in the period June-September, most of the flood events occur in this period of the year. Areas at flood risk include the major city of Harbin, which is frequently affected by flooding from the Main Songhua River. Other important areas are the city of Jilin on the Second Songhua River, the industrial town of Qiqihar on the Nen River and the nearby Daqing Oilfield, which is the largest oil production area in China. During severe flood events the airport of the provincial capital can also be threatened.

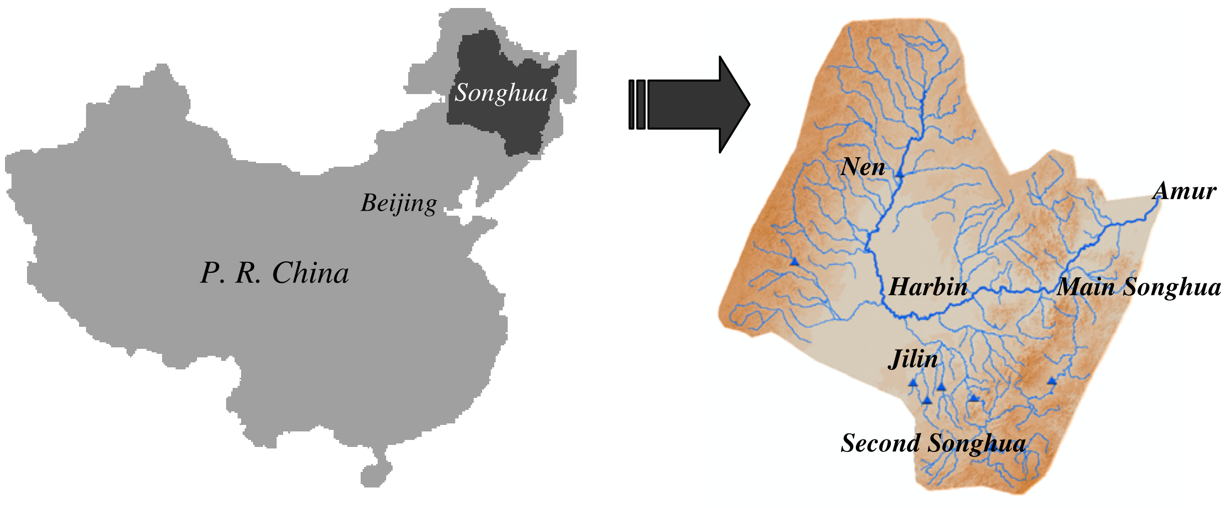

Figure 1 Overview of the Songhua Basin, including project area, catchment delineation, telemetry stations, main rivers and tributaries.

In 1998, the extremely severe flooding of the Nen River and the Main Songhua River caused dike breaches at nearly a thousand different locations. The severe flood disaster hit the western regions of Heilongjiang and Jilin Provinces and the eastern region of Inner Mongolia Autonomous Region, causing several casualties, relocation of citizens and damages to property.

Project Objective

In addition to providing emergency rehabilitation assistance, the Asian Development Bank (ADB) has granted a loan to the People's Republic of China (PRC) with the objective to establish a long term solution that can provide early flood warning and help decision makers of the Songhua Water Resources Commission (SWRC) in their effort to mitigate and manage flooding. Key objectives of the project are to provide the following components, all of which are integrated into a single system:

- Hydrological and hydraulic forecast models for the entire Songhua River Basin, including joint dispatching schemes for the Baishan, Fengman and Ni'erji reservoirs;
- A real-time GIS based flood management and forecasting system;
- A web based decision support system that integrates the aforementioned components

System Components

The system has been installed in the SWRC office in Changchun. On a top level, the system comprises three different parts (refer Figure 2):

1. A data part (Gage Data Archive, Spatial Data Archive and Precipitation Forecasts Archive). The real-time gage data archive consists of point based real-time telemetry time series and precipitation forecasts, all of which are stored in SQL SERVER. The spatial data archive consists of static GIS information stored in ORACLE SERVER, which is accessed via the spatial data engine (SDE) of ArcGIS 9.1. The spatial data includes information on demography, infrastructure, damage curves and pre-cooked scenario simulations computed by use of MIKE FLOOD. The pre-cooked simulations can be retrieved in real-time and joined with relevant spatial information as a response to queries issued by decision makers;
2. A forecasting shell (On-Line System) that integrates real-time data from (1) and several one-dimensional and two-dimensional forecasting models (2). The system is described in further detail below;
3. A web server with a JAVA based web application provided by others (3).

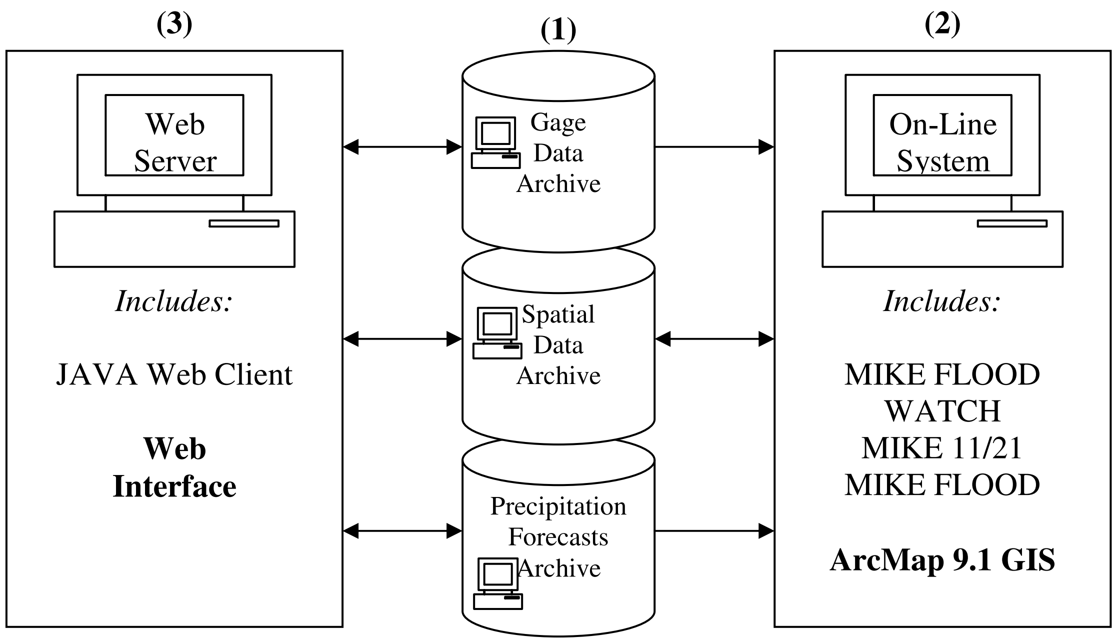

Figure 2 Outline of system components.

On-Line System

The On-Line System provided by DHI is based on MIKE FLOOD WATCH (DHI, 2003, 2004), which is a modern and robust forecasting framework that integrates data management, monitoring facilities, forecast models and dissemination methodologies in a single system within a user-friendly GIS platform (ESRI ArcGIS 9.1).

Real-time data is imported into the system from the Gage Data Archive and the Precipitation Forecasts Archive and used as input to the hydrological and hydraulic forecasting models. The data is quality assured according to user-defined quality criteria and stored in the On-Line System database. The system provides automated tools for the derivation of accurate and robust forecast model input time series to help improve the forecast accuracy and reliability.

In order to ensure a high level of openness and flexibility, the installed system makes consistent use of industry standards for model interfacing. The system can interface a wide range of model types including meteorological models, hydrological models, hydraulic and hydrodynamic models, advection-dispersion models, water quality models, forecasting models, error forecast models and others. For the present project, the system interfaces one-dimensional models (MIKE 11), two-dimensional models (MIKE 21) and a combination of the former two (MIKE FLOOD).

System tasks such as import of real-time data from remote data acquisition stations, initiation of forecast modelling tasks and dissemination of selected results to emergency staff, authorities and the public, are handled using a task scheduling facility, capable of running predefined tasks upon request by a user, as scheduled or in the case of an alarm.

The system includes an alarm framework that facilitates the definition of multiple aggregated alarms, each of which is based on data thresholds, failed simulations or other states in the system. When an alarm is raised, the system automatically initiates responses; including notification of staff, dissemination of warnings, polling of the Gage Data Archive and execution of forecast model scenarios.

Pre-Cooked Scenarios and Real-Time Scenarios

The system installed in Changchun includes the capability to carry out scenario analysis. Due to the fact that two-dimensional model scenarios are not feasible to run in real-time, the scenario tool has been divided into two parts:

- Spatially detailed, i.e. two-dimensional, pre-cooked scenario simulations that can be retrieved in real-time from the Spatial Data Archive using rules based on observed data or results from one-dimensional forecast models. As such, a part of the project aims at deriving a comprehensive set of pre-cooked scenario simulations that can be used in real-time when needed;
- Real-time scenario simulations based on one-dimensional forecast models. In order to assist the SWRC in their effort to make vital decisions during a hydrological event, a list of model scenarios has been defined in the On-Line System, thus enabling SWRC staff to obtain timely and accurate answers to questions like "what happens if the embankment breaches at this location?" or "what happens if we release a certain discharge from the upstream reservoir?". In real-time the SWRC can run different scenarios and make comparative assessments in order to mitigate flooding, evacuate people or – if possible – contain floodwater in dam reservoirs and detention reservoirs.

Pre-cooked scenario simulations have been made for four important flood protection cities (Jilin, Harbin, Qiqihar, Jiamusi) and two flood detention areas (Pangtoupao, Yueliangpao). An example of a pre-cooked scenario simulation is given in Figure 3, which depicts the flood plain inundation caused by an embankment failure in the city of Jilin on the Second Songhua River. The simulation results, comprising of various hydraulic information, are stored in the Spatial Data Archive in a GIS compliant, grid based format. Once stored in the Spatial Data Archive, the data can be used in conjunction with demographic information to issue emergency action plans or similar.

The real-time scenario management tool provides a range of different scenario definitions, each of which implements one or more differences from the standard parent scenario, which is run scheduled every day. The real-time scenarios are used to investigate one or more of the following issues:

- Uncertainties in precipitation forecasts;
- Uncertainties in catchment runoffs;
- Changed operation of major dams (Baishan, Fengman, Chaerson and Ni'erji reservoirs) and hydraulic structures in the region;
- Embankment failures at key locations along the main rivers.

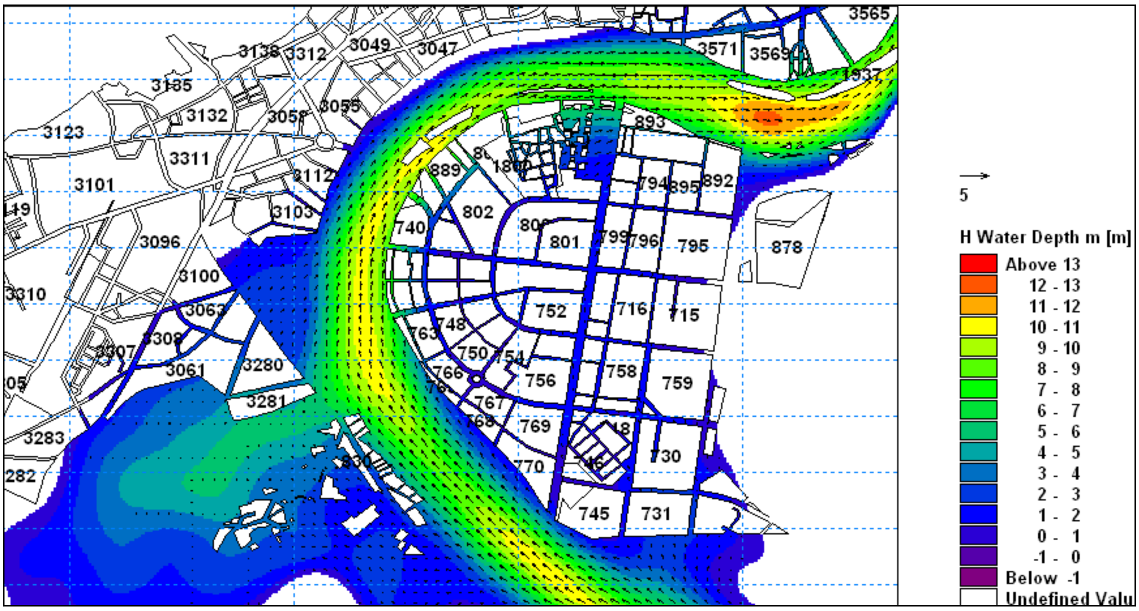

Figure 3 Example of pre-cooked scenario simulation for the city of Jilin. The simulation portrays the floodplain inundation caused by an embankment failure.

Forecast Modelling Technology

Common for all the real-time model scenarios is the fact that they make consistent use of a filtering technology in order to improve the hydraulic forecast results based on available measurements of primarily river discharge and river water level. The filtering technology uses an adapted version of the Kalman filter (Madsen & Skotner, 2005), in which the hydraulic model is continuously adjusted to match observed data for as long as measurements exist. In this part of the simulation, denoted the hindcast period, the simulation is corrected and the simulation errors are picked up and subsequently used at each measurement location to produce an error prediction in the part of the simulation period that extends beyond the time of the forecast (denoted the forecast period). The error prediction method applies general time series analysis tools such as auto-regressive, moving average models, including automatic techniques for parameter estimation. The benefit of the forecast modelling technology is that the model will match observed data as long as observations exist and apply an error forecast to improve the model prediction in the forecast period.

The state updating technology has been applied at 10 mainstream locations and 44 tributary locations spread across the basin. In the upstream part of the catchments, discharge updating has been applied, while in the downstream, highly inhabited areas, water level updating has been applied in order to predict accurately the water level in the river and on the flood plains (Figure 4).

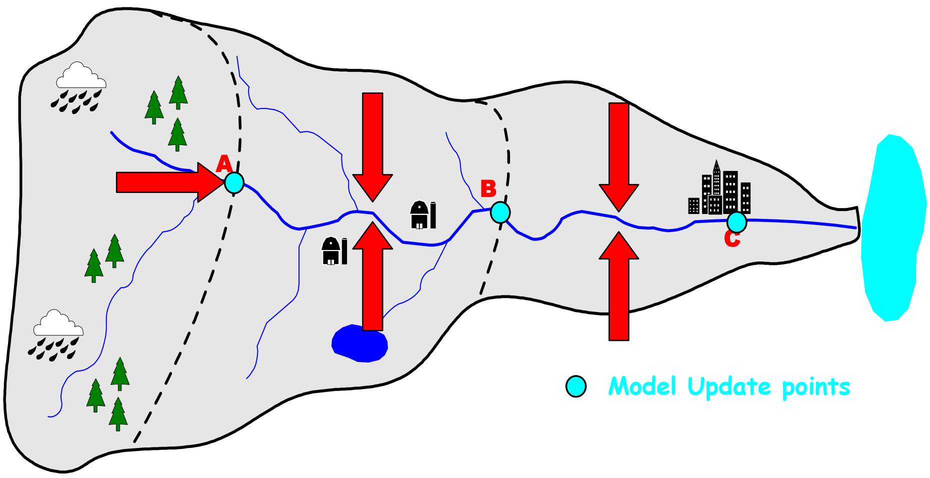

Figure 4 State updating in a hydraulic model.

Web Based Decision Support System

Complementing the GIS based On-Line System a web based decision support system has been developed by Chinese Institute of Water Resources and Hydropower Research (IWHR) to enable users to gain remote access to the Gage Data Archive, the Spatial Data Archive and the Precipitation Forecasts Archive. The system provides the capability to monitor the full system, visualize temporal and spatial data, issue spatial queries and initiate new forecast simulations in the On-Line System.

Recent Application to Chemical Spill Disaster Management

On 13 November 2005 an explosion at a chemical plant in the city of Jilin generated a major spill of chemicals that entered into the Main Songhua River. Benzene and nitrobenzene were the two major pollutants from the explosion. The plume of contaminated matter travelled downstream through the city of Harbin, eventually entering Russia via the Amur River. For many days, the pollution of the river water caused an abandonment of the normal water supply system, and clean water therefore had to be brought into the city from other sources by large trucks.

In order to assist the Chinese authorities in their effort to manage the disaster, one of the mainstream flood forecasting models was adjusted to work as a water quality model for the river system. The adapted forecasting model was applied to predict the journey of the pollution plume as it travelled downstream of Jilin, though the city of Harbin. As shown in Figure 5, the model was capable of simulating accurately the arrival of the plume at the city of Harbin, thus providing valuable assistance for the authorities in their effort to monitor the plume and ensure safe drinking water supplies.

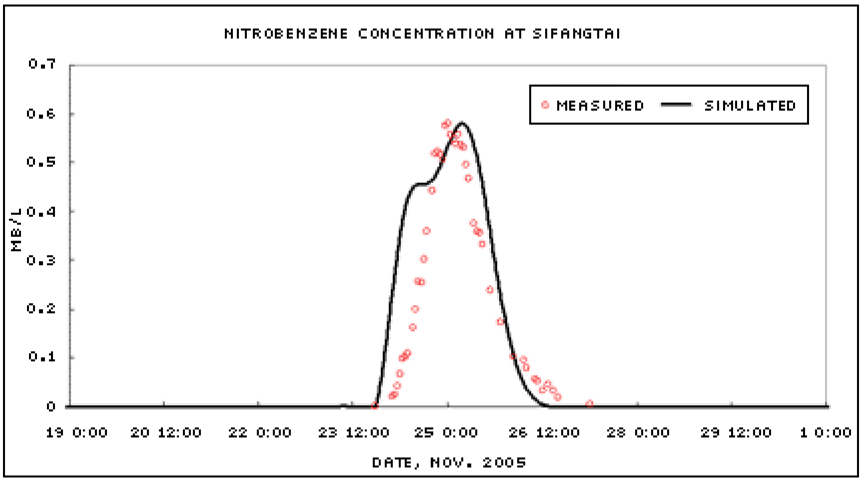

Figure 5 Nitrobenzene concentration at the water intake in the city of Harbin.

Additionally, the model was used to simulate the further advection and dispersion of the plume downstream of Harbin towards Russia. It predicted very accurately that the pollution plume would reach Heilongjiang (Amur River) on 8 December 2005.

Conclusions

A comprehensive real-time forecasting system is under commissioning with the Songhua Water Resources Commission in Changchun in north eastern China. The system comprises several real-time telemetry databases, hydrological and hydraulic forecast models and a water quality forecast model, which was used in late 2005 to predict the journey of a poisonous plume of benzene and nitrobenzene as it travelled through the major city of Harbin and eventually entered Russia via the Amur River.

The system includes highly visual tools for examining observed and forecasted hydrological and hydraulic data – both point based and grid based – and in a web environment the system provides users with the capability to issue spatial queries that join selected hydraulic, infrastructural and demographic information. The system is used to make scenario simulations, support viable decisions, issue warnings and generally manage disasters the best way possible.

References

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