REAL-TIME FLOOD INUNDATION MAPPING FOR FLOOD INTELLIGENCE – A CASE STUDY FROM INDIA

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ABSTRACT

Bihar is India's most flood-prone State, with 76 percent of the northern population living under the recurring threat of flooding. Annual monsoon floods claim lives and destroy homes and livelihoods, seriously impacting the economy and poverty alleviation efforts. The Bagmati River is one of Bihar's major rivers, draining the Kathmandu Valley in the foothills of the Himalayas before entering flat agricultural plains of Northern Bihar.

With no pre-existing flood modelling or mapping, this project started with a blank worksheet, with the objective to forecast flooding a week ahead of occurrence, and generate real-time inundation mapping resulting from embankment failure. The project established a flood forecasting framework which loads and processes data from national and international sources and provides an interface for real-time hydrologic and hydraulic modelling.

The project faced many challenges, particularly related to availability of data. Despite these challenges, a flood forecasting framework has been established which provides capacity for evolution of the system, has supported local capacity building and will greatly improve understanding of flood behaviour. The system represents a step-change improvement for flood forecasting systems integrating multiple hydrologic and hydraulic models, and allowing forecasters to understand in real-time the impact of topographic changes to the floodplain.

BACKGROUND

PROJECT GOVERNANCE

The Government of India has been allocated funds from the South Asia Water Initiative Multi-Donor Trust Fund towards the cost of Strengthening Flood Modelling Capacity in the Water Resources Department, Government of Bihar. The funds are administered by the International Bank for Reconstruction and Development (IBRD) and International Development Association (IDA). The Flood Management Improvement Support Centre (FMISC) in Bihar allocated these funds to development of a flood forecasting model and inundation mapping tools for the Bagmati-Adhwara River Basin. BMT, an international multi-disciplinary engineering, science and technology consultancy, was appointed to deliver the project.

STUDY AREA

The Bagmati River originates in the Himalaya Mountains, and drains the Kathmandu Valley in Nepal. It is the largest tributary of the Kosi River, which itself is one of the major tributaries of the Ganga.

The study area extends from the headwaters of the Bagmati River to the confluence with the Kosi River, encompassing a catchment area of 14,390 km^2. Many towns and villages are located throughout the study area, including the major town of Dharbanga. More than half of the catchment is located in Nepal.

Many of the waterways in the study area are braided and highly mobile; it is not unusual for long sections of rivers to change course during a monsoon period. Some sections of the rivers are trained with large earthen embankments. There are approximately 1,000km of embankments in the study area.

FLOOD PROBLEM

Bihar is India's most flood-prone State, with 76 percent of the northern population living under the recurring threat of flooding. Annual monsoon floods claim lives and destroy homes and livelihoods, seriously impacting the economy and poverty alleviation efforts. Floods develop over many days and weeks, and water levels can remain elevated for months, damaging crops, houses and infrastructure, and isolating communities.

Sections of river embankments periodically fail during a monsoon. These breaches heighten the flood risk of villages behind the embankment, through increased inundation and due to the accelerated rate of inundation. Breaches can sometimes be predicted if regular, on-ground inspections are undertaken.

There are many towns and villages in the study area, however these are mostly rural developments with generally lower levels of education and income than more urbanised areas of India. Flood prone land is usually occupied by residents with limited ability to rebuild in safer areas. As a result, residents will frequently rebuild properties after a flood, and continue to be flooded in subsequent monsoons.

METHOD

BMT developed a flood forecasting framework which encompasses an interconnected set of tools. These tools can be used by FMISC to prepare flood inundation maps for both current and forecast situations, understand areas at risk of flooding, investigate changes to flood behaviour in the event of embankment collapse, and ultimately use this information to prepare flood warning messages.

FRAMEWORK ARCHITECTURE

The framework uses a small number of software tools to undertake multiple processes. These tools are:

- **Delft-FEWS**. The Delft-FEWS flood forecasting software is used for all hydrographic data management, modelling and forecasting operations. Delft-FEWS has been configured to ingest rainfall and stream level observations, and rainfall forecasts from the various available sources. The Delft-FEWS framework prepares and runs hydrologic and hydraulic model simulations, manages the results, distributes to other systems and can be configured to dispatch email and SMS alerts as required.
- **URBS**. The Unified River Basin Simulator (URBS) is a runoff-routing networked model of sub-catchments based on centroidal inflows. It undertakes hydrologic modelling of flood flows using observed and forecast rainfall and interfaces directly with Delft-FEWS.
- **TUFLOW**. TUFLOW is a computer program for simulating depth-averaged, one and two-dimensional free-surface flows such as occurs from floods and tides, with the 2D solution occurring over a regular grid of square elements. TUFLOW is simulated through the Delft-FEWS interface for the Bagmati-FEWS system. A fast one-dimensional model is used for rapid simulation and generation of forecasts, and a more complex two-dimensional model is used for the inundation mapping.

Numerous Python scripts were also developed for the collection, processing and archiving of continuous data streams, as well as to allow users to test embankment breach scenarios.

DESIGN CONSIDERATIONS

A number of considerations guided the design of the framework, including data availability, timing considerations, matching the operational needs and experience of FMISC operators, and ensuring the system had the ability to grow.

Topographic data was limited in some areas, particularly bathymetric data. This issue is exacerbated by the dynamic nature of the waterways, which can result in changed bathymetry every monsoon season. Availability of rainfall and river gauges also presented some challenges in the project. The coverage of rain gauges in Nepal (the upper half of the catchment) is sparse and data availability is inconsistent, introducing high uncertainty in the hydrologic forecasts.

Timing is a key issue for the system design. Real-time models must be completed sufficiently quickly for operators to test options, while also providing sufficient detail to inform confident decision making.

KEY OPERATIONS

Multiple operations are undertaken by the system to better understand current and future flood behaviour.

To account for the sparse coverage of rain gauges in Nepal, an ensemble of hydrology simulations is used to provide inflows to an ensemble of hydraulic simulations using observed data from the past five days. Every day of the monsoon period, 49 rainfall scenarios are tested in the fast (one-dimensional) hydraulic model. Results from the fast hydraulic model are assessed using Nash-Sutcliffe performance testing against observed river data, with results used to select the preferred rainfall scenario.

The preferred scenario is then simulated again in the fast hydraulic model using observed data from the past five days and forecast data for the next five days. This simulation also produces a file with initial conditions for the next day's ensemble. Use of initial conditions provides 'hot start' conditions for the model to ensure that the simulation captures the build-up of flood water in the catchment during the entire monsoon period.

This process produces hydrographs for numerous locations of interest throughout the study area, allowing FMISC operators to understand the likely flood levels and timing over the next few days. The forecast can also be simulated in a more detailed two-dimensional TUFLOW HPC hydraulic model to produce daily flood inundation mapping.

FMISC operators are also able to test embankment breaches in real-time. The system is highly flexible and adaptive, allowing operators to test breaches at any location, for any length of breach within the 1,000 km of embankments, and with any timing for the start and duration of the breach. Boundary conditions (water levels) can be derived from forecast fast hydraulic model results, or interpolated between observed river gauge levels.

Breach information is entered via the customised Bagmati-FEWS interface. An automatic process is then triggered which generates a geo-referenced files of the breach, and starts a hydraulic model simulation incorporating these new files. At the designated breach time, the topography in the hydraulic model will change to reflect the embankment breach and simulate a steady erosion of the embankment. The simulation is executed using the detailed hydraulic model to more accurately predict the progression of water across the floodplain. Detailed mapping of flood depths and extents resulting from the breach is then passed back to the Bagmati-FEWS interface for viewing by the operator.

RESULTS AND DISCUSSION

The flood forecasting framework is being tested during the current 2018 monsoon, which commenced in June. A series of training sessions have been undertaken with the operators at FMISC to build local-skills to operate the system and interpret results. These sessions have resulted in some changes in the system to find the right balance between automation and providing operators with options to test a range of scenarios.

Limitations in topographic, bathymetric and telemetric data have impacted the ability of the flood models to well-predict flood levels, however these limitations have been somewhat addressed by implementing technical solutions (such as data filling and interpolation) and procedural solutions (such as testing ensembles of events and daily performance testing).

NEXT STEPS

The framework was designed to be highly flexible and able to adapt to updated data, information and procedures as they become available. Some of the key changes which are currently being considered for future updates include:

- Development of additional rating curves to better understand stage-height relationships
- Introduction of new observed and forecast data feeds
- Capture and inclusion of cross-sectional bathymetry data
- Extension of the system to other catchments in Bihar
- Improvement of redundancy and data archiving
- Ongoing training of operators in the lead up to next monsoon season and during monsoon
- Development of a public-facing interface to distribute key information to the public (e.g. via a Flood Intelligence System).

CONCLUSION

The flood forecasting system developed for the Bagmati River is in its infancy, yet already represents a significant step-change in responsive, real-time flood forecasting systems around the world. System design responds to unique design challenges, however uses advanced techniques which could be adopted in similar forecasting systems elsewhere. In particular, the ensemble approach to forecasting helps to address the types of data gaps seen in many locations. Challenges associated with long duration monsoon flooding are addressed through the creation of rolling 'hot start' files to track the volume of water in the catchment throughout the monsoon.

The embankment breach system established for this study is unique, providing operators with the ability to test changes to topography at any location in the study area using real-world flood conditions and in real-time. This approach could be readily applied for other locations where topographic changes such as scour, breach or failure are expected.