USE OF SPATIAL INFORMATION IN FLOOD DISASTER MITIGATION
A CASE STUDY IN YOM RIVER BASIN, THAILAND

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ABSTRACT

Warning and preparedness are two key areas for flood disaster reduction. Flood warning with adequate lead-time greatly help in reducing loss of life and economic damage. Preparedness calls for estimating flood risk and taking action to mitigate flood damage through both structural and non structural measures In the present study we explore a comprehensive warning and risk assessment scheme in a two stage approach considering data availability and operational ease. In the first stage, river flow is forecasted with sufficient lead-time to warn of flows that could exceed the safe river capacity. The second stage takes the forecasted river flows at the city as input to a limited area model that covers the city and simulates the inundation extent incorporating embankment overtopping.

A distributed hydrological model, which simulates all the hydrological processes, is used in the system. In stage 1, where river flow is forecasted, dynamic wave model is used to solve for river network but inundation simulation is switched off to improve computational efficiency. In stage 2, diffusive wave implicit solution scheme for both inundation modeling and river network solution is used. The modeling domains for stage 1 and stage 2 are setup such that flooding from embankment overtopping would not occur upstream of the common boundary covered in stage 1. For river flow forecasting, the river network derived from the GTOPO30 global data set whereas for stage 2 model is setup using a high resolution local DEM. The results show that for the application in Yom River basin, lead times about 14 hours can be achieved with the dynamic equation for river discharge forecasts. The discharge hydrographs are successfully incorporated as inputs in inundation modeling and employing 50m or 100m horizontal resolution grids sizes help differentiate inundations resulting from different river inflows.

1. INTRODUCTION

Asian region experiences the highest casualty rates as well as highest economic damage from floods compared with other regions in the world. Urgent measures are required in preparedness, response and mitigation to reduce this unacceptable situation, especially given the importance of a stable environment for the developing economies in the region. Preparedness calls for assessing risks and taking measures in advance to save life and property through evacuation and improving flood-fighting capability. To improve response, flood forecasting with sufficient lead times and accuracy is required. To implement appropriate mitigation strategies, it is important to analyze different flood scenarios under varied hydro-meteorological conditions as well as with different mitigation alternatives.

Flood modeling and estimation is required for planning and implementation of all of the above issues.

Flood forecasting in many Asian basins is a challenging task due to lack of historical data needed for calibration of operational hydrological models. Physically based hydrological models, where the model parameters can be estimated from catchment physical characteristics, therefore are useful in setting up and analyzing catchment responses in data deficient situations. A physically based distributed hydrological model developed at the Institute of Industrial Science, University of Tokyo, is used in the present study for the forecasting purpose.

Traditional flood forecasting schemes aim at forecasting the river flow volume at a point of interest with a certain lead-time. Such forecasting is made possible by the time taken for water to flow through various flow paths to the river and then to reach the target location. In practice, especially for large catchments, downstream forecasting is carried out based on the river flow observations at an upstream point and mathematical modeling of flow from the upstream point to the downstream point. While it is possible to make warnings based on the expected water volume at a river cross section taking into consideration the flow capacity of the river at that point, it is difficult to relate the possible impact at the residents level. In order to carry out such warning it is necessary to use coupled inundation models with the hydrological models. In general, inundation models require large computational times as iterative solutions are carried out using high-resolution spatial descretizations. For river flow forecasting, a simple model of high efficiency is desirable where quick flow computations would help in extending the lead-time.

In order to overcome these difficulties, a two-stage approach is adopted in the present study. In the first part we forecast the river flows at a downstream point based on the upstream observations using a river network model and a boundary conditions forecasting scheme. In the second stage, a coupled river network, inundation model is used to simulate the flood inundation levels corresponding to downstream river inflow conditions. The present paper describes the overview of the method with emphasis on stage 1 application, while the accompanying paper ‘Understanding Impact of Spatial data Resolution in Flood Risk Modeling in a River Basin: A Case study in Yom River Basin, Thailand’ (Dutta et. al) in the present conference and Dutta et. al (2000) describes the inundation modeling stage in detail.

2. METHODOLOGY

The outline of the two-stage flood mitigation scheme is shown in Fig 1. The point G1 refers to the upstream observation location and G2 refers to the downstream observation location. Using the observations of G1 the river flows at point G2 are forecasted using a distributed hydrological model without inundation modeling. In the second stage, the inflow hydrograph at point G2 is used to simulate the flood inundation in the target area. While inundation can occur most commonly due to embankment overtopping, other causes such as embankment failure or temporary dams may too take place. In such a situation, the backwater effects could have a significant effect on the flow quantity and time to peak. In order to capture such effects, it is necessary to use either the dynamic wave model or the diffusive wave model for the river flow simulation, which allows incorporation of downstream effects in the forecasting. The details of the mathematical models are explained in the section below. The operational model envisaged in the system is shown in Fig. 2. The river flow forecasts

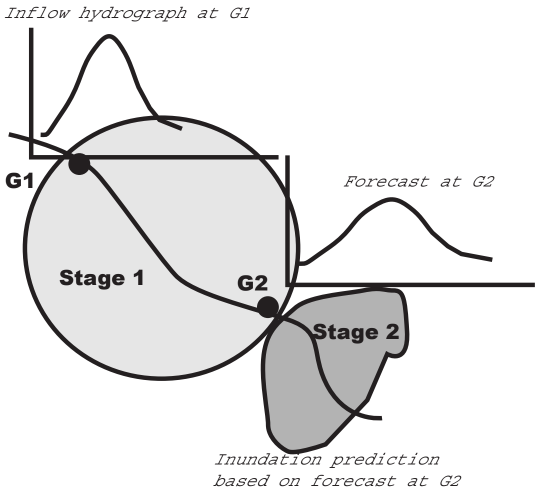

Figure 1. Outline of the two-stage flood warning and risk assessment system

are to be used to warn the basin inhabitants in case the river flows are expected to reach dangerous levels, similar to the general scheme used at present. They can be used for preliminary decision making on evacuations and general preparedness. At the same time, the downstream forecasts can be used in inundation simulations that would help in the preparation of more detailed and efficient planning for mitigation. Further, depending on the available lead-time, effectiveness of different mitigation plans can be compared that would facilitate selection of an optimum mitigation plan for the particular flooding situation.

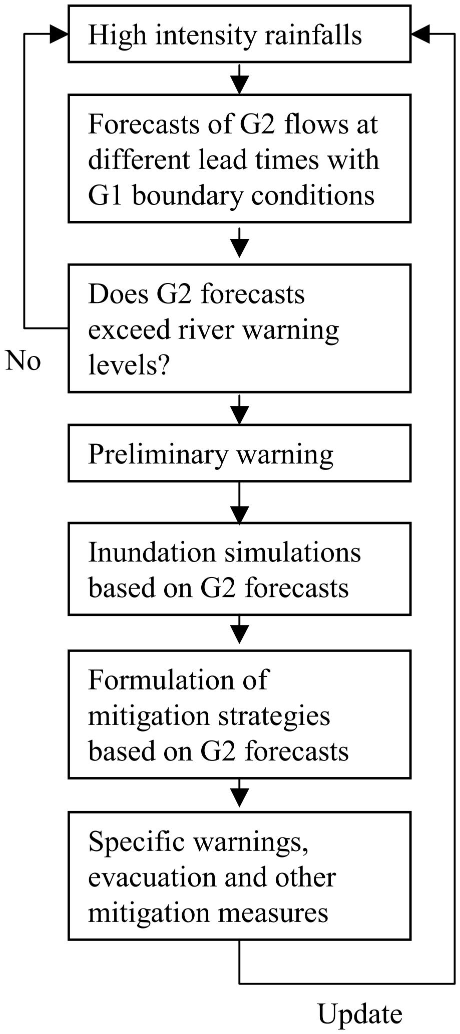

Figure 2. Operational mode of the proposed warning system

3. MODEL DESCRIPTION

3.1 Hydrological model

The system used in the modeling is a grid based distributed hydrological model developed at the Institute of Industrial Science, University of Tokyo, which is a coupled system for modeling different components of the hydrological cycle. For flood forecasting studies outlined in the present study, it is convenient to consider the flow generation components separately from the flow transport, i.e. river network modeling component. The flow generation, or the hydrological modeling system consists of interception, evaporation, surface flow, sub surface flow and ground water modeling components. Spatial distribution of catchment parameters, rainfall input and hydrological response are represented in the horizontal plane by an orthogonal grid network and in the vertical plane by a column of horizontal layers at each grid. A complete description of the model is described in detail elsewhere. (Herath et al, 1997, Jha et. al., 1997)

3.2 River network model

River Routing

In the river routing scheme (stage 1) both Kinematic approximation and the dynamic version of Saint Venant's equations are implemented. For the dynamic form, algorithms have been developed [Fread, 1976] which are solved for each time step, using the Newton Raphson method [Fread 1976]. The details of the solution scheme for a river network is given in Jha et. al (2000).

Initial and Boundary conditions

To apply the river modules it is necessary to know the initial depth and discharge at each simulation node. In the case of flood forecasting these values may not be available at the start of computations as the modeling might start from an arbitrary point in time. When the initial river discharge information is not available, it is estimated from an equilibrium discharge computed using the following formula,

$$Q = \Delta A.rlf \tag{1}$$

where Q is the discharge, ΔA is the catchment area for the channel and rlf is the regional low flow factor. The upstream boundary condition of each stream link is provided as a water depth or discharge time series, and Q = 0 is assigned if there are no inputs to the starting node of a stream. For flood forecasting, there are occasions where upstream boundary condition has to be estimated for the future predictions. A simple model of the following form was used to estimate the future upstream boundary condition.

$$Q[t] = Q[t-1] + \alpha \frac{\partial Q}{\partial t} n\Delta t \tag{2}$$

where α is a regression constant, Q[t] and Q[t-1] refers to current and previous time steps, Δt is the simulation time step and n is the forecasting time step. The down stream boundary condition is not required in the Kinematic wave solution as the backwater effects are neglected in the scheme, whereas it is required in the dynamic solution. While this could be available for simulating past events, it has to be estimated when flood forecasting is carried out. For forecasting purposes, downstream discharge is estimated using the following equation,

$$Q_{ds} = Q_n - \left(\frac{Q_n - Q_{n-1}}{\Delta X_n}\right)\left(\frac{v_n + v_{n-1}}{2}\right)\Delta t \tag{3}$$

where v_n and v_{n-1} are velocities in previous time step at locations n and n-1 respectively, Δt is the time step and ΔX_n is the distance between points n and n-1. Q_{ds} is the required discharge at the d/s point and Q_n and Q_{n-1} are the discharges at n and n-1 points at the previous time step. This formulation also makes it possible to estimate the water level changes if the downstream river capacity gets reduced due to debris, etc.

4. APPLICATION TO PHRAE CITY, YOM RIVER BASIN, THAILAND

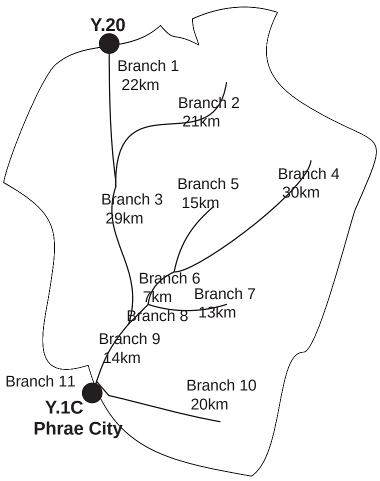

Figure 3. Location of Phrae City in the Yom River basin

Phrae city with a population of about 20,000 in the municipal area covers an area about 9 km^2 and is located at the bank of the Yom River. The city experiences flooding 3 to 5 times a year, with inundated area going up to about 50% of the city. During the heavy rain in 1995, the whole city was flooded and the economical loss was estimated at around 16 million US$. Generally, the inundation starts approximately about 3 km upstream of the city by bank over topping. There is a gauging station (Y1C) near the city and the catchment area at this location is 7624 km^2

Fig 3. shows the river network generated from the 1 km resolution GTOPO30 data set and the catchment area from the upstream gauging station Y20 to downstream gauging station Y1C. The upstream observation point Y20 is taken as the G1 point in the warning system scheme described earlier. For the downstream point in river flow forecasting (point G2) is selected on the basis of the change of river gradient. The riverbed profile and the right hand side bank elevations are plotted in Fig. 4. At the location G2, the river profile changes from steep gradient to a mild gradient at the Phrae city outskirts. The bed profile also shows the scouring and deposition at the gradient change location, and flooding from embankment overtopping generally takes place downstream of this point.

An example of stage 1 forecast is shown in Fig. 5. The downstream hydrographs forecasted with 1 to 12 hour lead times do not vary much from each other. Similar results were obtained for different flood events. The lead-time is constrained not by the accuracy requirement of the forecast, but rather the numerical stability of the forecast, especially due to the downstream boundary condition forecasting.

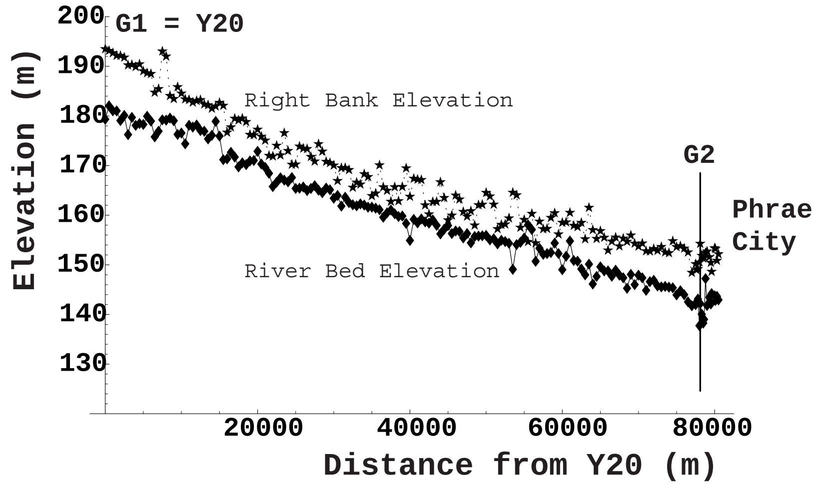

Figure 4. Elevation of riverbed and right bank from Y20 station

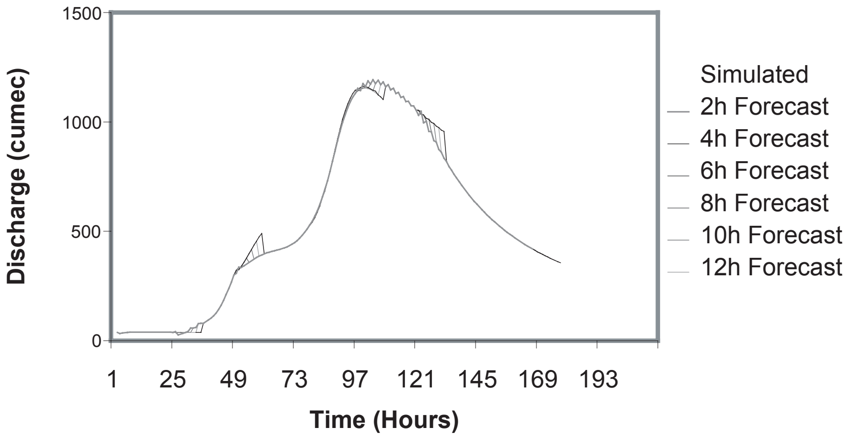

Figure 5. An Example of flood forecasting in Yom River basin (Aug 5- Aug10, 1995)

Fig. 6 shows the peak inundation extent modeled for two different river discharge hydrographs, where the left hand simulation is a inundation resulting from 90% of flow hydrograph that produce the inundation shown in the right hand side figure. The different flow patterns demonstrate that while the inundation modeling can preserve the sensitivity of the river flow forecasts, the accuracy of flow forecasts is important in the assessment of possible impacts.

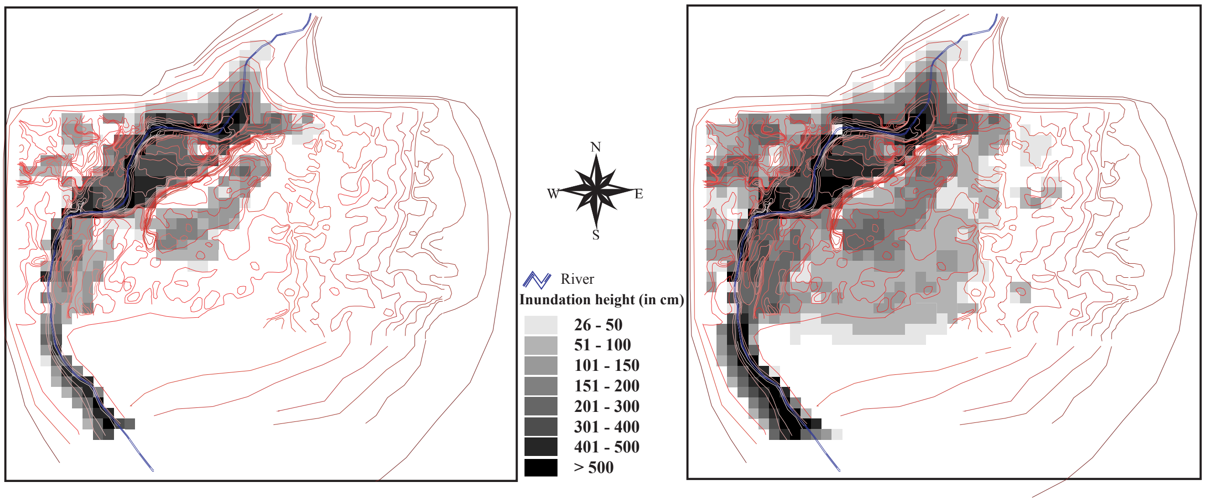

Figure 6. Flood inundation simulation (stage 2) for two different river hydrographs

7. RESULTS AND DISCUSSION

A two-stage approach is described in the present study for flood warning and risk analysis. The study shows that it is possible to combine effectively river flow forecasts using available regional coarse data sets with detailed inundation modeling, which require high-resolution local data. By considering a limited area for the inundation forecasts, it is possible to use high-resolution spatial descretization for the inundation modeling that enables use of all the information provided in the river flow forecasts. Although in the present study a decoupled approach of stage 1 forecasts and stage 2 forecasts (i.e. river flood forecast and inundation modeling) has been adopted, in the future it is necessary to couple them in real time to improve the forecasting accuracy. Improvement of forecasting accuracy as well as lead-time increment can be expected by the improvement in downstream boundary condition for the river flow forecasts. While currently the downstream boundary condition is estimated from flow quantity, this can be better estimated from the inundation modeling at each time step.

8. REFERENCE

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