UNDERSTANDING THE IMPACTS OF SPATIAL DATA RESOLUTION IN FLOOD RISK MODELING - A CASE STUDY IN YOM RIVER BASIN, THAILAND -

Dushmanta Dutta[1], Srikantha Herath[1] and Sohan Wijesekera[2]

[1]Institute of Industrial Science, The University of Tokyo

4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

Email: dutta@iis.u-tokyo.ac.jp, herath@iis.u-tokyo.ac.jp

[2]GAC, STAR Program, Asian Institute of Technology

P.O. Box 4, Klongluang, Pathumthani, Thailand

Email: sohanw@ait.ac.th

ABSTRACT

It is important to understand the mechanism and the consequences of floods in a river basin for various planning and managements purposes. Due to the tremendous improvements in computational technologies and mathematical modeling, from the last few years, there have been serious efforts among the researchers community in integrated modeling of flood risk in a river basin using physically based hydrological model and geographic information systems. Although such efforts of modeling show promising outputs in test basins, their practical application for flood risk management is not yet achievable due to various issues. One of the main issues involved is the resolution of spatial datasets. There are various impacts of resolution variations in modeling of floods in a river basin as they greatly depend on the spatial characteristics of the basin such as topography, landuse, etc. It is important to preserve the heterogeneity of these input spatial datasets to obtain desired level of accuracy in flood modeling. In spatial raster datasets, average values are assigned for each single pixel and how well the heterogeneity is preserved depends on the pixel size or resolution. It is important to understand the impact of spatial data resolution in model outputs before going for real world application of model for flood risk management.

In spatial and temporal modeling of floods, one of the most important datasets is topography, which is highly sensitive to the data resolution. In this paper, a case study is presented in which analysis is carried out to understand the impact of resolution variation of topography data in flood risk modeling. A GIS and physical hydrology based distributed flood risk model is used to carry out the analysis. The model was applied to simulate flood characteristics and incurred losses due to past flood events in the Yom river basin in Thailand. The model simulation was carried out for various resolutions of topography datasets and impact analysis was done for flood parameters.

The results showed that the model outputs greatly varied with input DEM resolutions. Although the 50m resolution DEM gave the best output, with 100m resolution DEM model outputs were close to the observation. In Yom basin at the present condition, 100m resolution DEM would be the most suitable for operational flood risk modeling in DHM.

1. INTRODUCTION

Demand for hydrologic prediction tools that are better able to utilize information spatial variations in precipitation, as well as land surface characteristics such as vegetation, soils and topography, are driving the evolution of spatially distributed hydrologic models (Kenward et al., 2000). Due to the tremendous improvements in computational technologies and mathematical modeling, there have been serious efforts among the researchers community in the last few years in integrated modeling of flood risk in a river basin using physically based hydrological model and geographic information systems. Although, spatial heterogeneity can be utilized in distributed models, it is important to understand the scale of such heterogeneity needed to be preserved in modeling for various applications. Without such understanding, distributed models can not be used as tools for predictions of hydrologic behavior. In flood modeling, surface and river flows are the two most important processes and topography is the driving force for these two processes. Digital elevation models (DEMs), which are used to represent topographic controls on precipitation and downslope moisture movement, form the foundation for such models (Storck et al., 1998). Previous studies have found that spatially distributed hydrological models are sensitive to DEM horizontal resolution, due especially to its influence on computed slopes and related model-derived quantities such as surface saturation (Zhang and Montgomery, 1994; Wolock and Price, 1994). For instance, Zhang and Montgomery found that the extent of saturation predicted using TOPOG, a spatially distributed model based on a steady state drainage condition (O' Loughlin, 1986), was sensitive to DEM grid scale. They found that TOPMODEL (Beven and Kirkby, 1979), which uses a topographic index related to the logarithm of topographically contributing area divided by local surface slope, increased peak discharges were predicted due to an increase in the mean topographic index as a result of increased grid size. A similar study by Wolock and Price (1994) examined 71 areas in Pennsylvania and found that degrading the spatial resolution of the topographic data resulted in higher minimum, mean, variance and skew values of the TOPMODEL (Beven and Kirkby, 1979) topographic index distribution. The result was a tendency for decreases in the predicted mean depth to the water table, and increase in the predicted ratio of overland flow to total flow. The variability of daily flows, predicted by TOPMODEl, also increased. The impact of vertical accuracy of DEM resolution on hydrologic prediction accuracy was examined by Kenward et al., 2000 and it was found that in a very small catchment of 7.2 km^2 there was 10% variation in the predicted runoff with same horizontal resolution DEMs of different sources due to their vertical resolution.

However, there has been no literature available on any research study on understanding the consequence of DEM resolution in flood inundation and risk modeling. With the improvement of computational tools and due to the ability of incorporating spatial variability of basin characteristics, many countries have been putting resources and efforts in adopting physically based distributed hydrologic model as operational model for flood disaster mitigation. However, before adopting such a model as operational model, it is needed to analysis the impact of DEM resolutions in the model outputs. This study has been undertaken to analyze the impacts of grid resolution in flood inundation simulation using physically based distributed model. The study area selected was a part of the Yom Basin of Thailand, which is one of the most flood affected river basin in Thailand. Two of the past flood events were selected for this analysis with five different resolutions of DEM.

2. MODEL DESCRIPTION

The physically based distributed hydrologic model, used in this study, was developed in the University of Tokyo, Japan (Jha et al., 1997, Dutta et al., 2000). It considers five major components of hydrological cycle, which are; Interception and Evapotranspiration, River flow, Overland flow, Unsaturated zone flow and Saturated zone flow. Interception is modeled using the concept of BATS model (Dickinson et al., 1993). Evapotranspiration component is solved using the concept presented by Kristensen and Jensen, 1995. For all other components, water movement is simulated using the physically based governing equations. The governing equations are solved by finite difference schemes. For River flow, diffusive approximation of the 1-D St.-Venant's equation is considered. An implicit finite difference scheme is used to solve the governing equations of flow for river network. Similarly, for Overland flow diffusive approximation of the 2-D St-Venant's momentum equations is considered and the governing equations are solved using an implicit finite difference scheme. For Unsaturated zone flow, 3-D Richard's equation of unsaturated zone is solved implicitly. 2-D Bossinesq's equation of Saturated zone flow is solved implicitly. A uniform grid network of square grids is considered for solving the governing equations with finite different schemes.

Within each component, governing equations are solved individually and they are coupled in each time-step of solution for exchange of parameters. The coupling time can be varied depending on the simulation requirement and resolution of input temporal data sets. For the present application of the model, coupling time step is considered as one hour for all the components but overland and river flow. For accurate representation of the dynamic exchange of flow between surface and river flow components, coupling time between these two components are considered as 300 sec. A flood compartment concept is used for coupling of overland and river flow components in which existing embankment heights along the rivers can be incorporated and exchange of flow between surface and river is calculated using a storage routing relation with the assumption of broad-crested weir flow with submergence correction (Fread, 1988). Flow can be either away from the river or into the river, depending on the relative water depths in adjacent river and surface grids. With this process, flood inundation can be simulated for both inland and river overflow flooding.

3. STUDY AREA

The river basin selected for this study is the Yom River basin, located in the Central-Northern part of Thailand between longitude 99.5°E to 100.5°E and latitude 15.6°N to 19.4°N. It is a sub-basin of the Chao Phraya River Basin with an area of 19,516 km^2 and annual average runoff of 3,684 cumec. The Phrae city, located by the side of the river Yom River in the central part of the catchment, is one of the most frequently flooded cities in Thailand. The municipal area of Phrae city covers approximately 9 km^2 with a population of nearly 20,000 (Figure 1). Flooding is a frequent occurrence in this city and in general floods occur 3-5 times a year. Topography of the city is rather flat, and gently sloping towards the river except for an elevated strip on the Northern side which appear as a remnant of an earth bund that was in place to protect part of the city. At present this feature does not indicate continuity and it is said that though it protects the inner city from most of the floods, the people experience significant problems in removing water once large floods flow over some of the lower elevated sections of this strip. During the last ten years, the city suffered from several severe flood disasters, the most severe one was in 1995, which was experienced through out Thailand as one of the most severe floods in history. It caused widespread damage and causalities affecting over 85% of the total population of Thailand (INCEDE Newsletter, 1996; Hungspreug et al., 2000). The most recent major flooding in Yom Basin was in August 2001. However, the magnitude of this flood event was lesser than the one in 1995. Considering the frequent flooding in the Phrae municipality area, flood mitigation is one of the most urgent tasks of Royal Irrigation Department (RID) of Thailand, which is responsible for flood disaster mitigation. This study was carried out in collaborative with RID. The above two events were considered for analysis in this research project towards establishing an integrated flood risk management system in the basin.

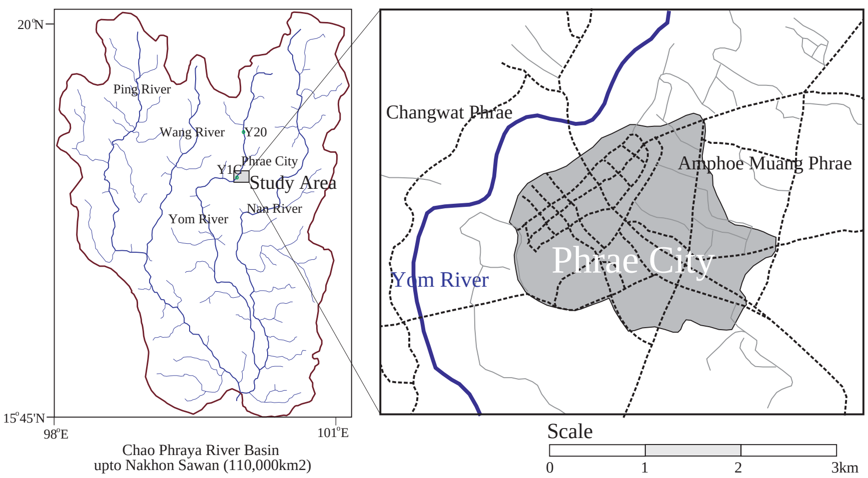

Figure 1. Location map of the study area

4. MODEL APPLICATION

4.1 Data Preparation

For setting up a physically based distributed model, a large amount of spatial and temporal data sets are required for different processes (Dutta et al., 2000). In this study, only the 2D surface and 1D river network flow processes of the model were considered with effective rainfall as the other processes do not have much influence in flood inundation. The data for setting up these two components were obtained from various sources. In the study area, there were two kinds of topography data available; one was contour maps of 1:50,000 scale with 20m contour interval for the whole basin and another was contour map of 1:4,000 scale with 50cm contour interval for Phrae city. Considering the need of high vertical resolution DEM and need of an operational model for flood control to protect Phrae city, in this study, the inundation modeling was restricted to the areas covering Phrae city for which detailed contour data of 50 cm interval were available (Figure 2). The contour maps were digitized to create contour coverage and then, converted into different grid resolutions for the model applications. Other spatial data layers including land use details of the study area were obtained from the existing GIS data base (EIC, 1998). River details including longitudinal profiles and cross-sections at every 500m interval between Y20 and Y1C gauging stations (refer to Figure 1) from RID. The roughness coefficients for surface and rivers were estimated based on the land use types. Hourly rainfall and water level data for simulation of the two selected flood events in the gauging stations Y20 and Y1C were obtained from RID along with the rating curves. For estimating the effective rainfall, the runoff coefficients for different land use types were decided based on the results of past simulation in the Chao Phraya Basin and other available information.

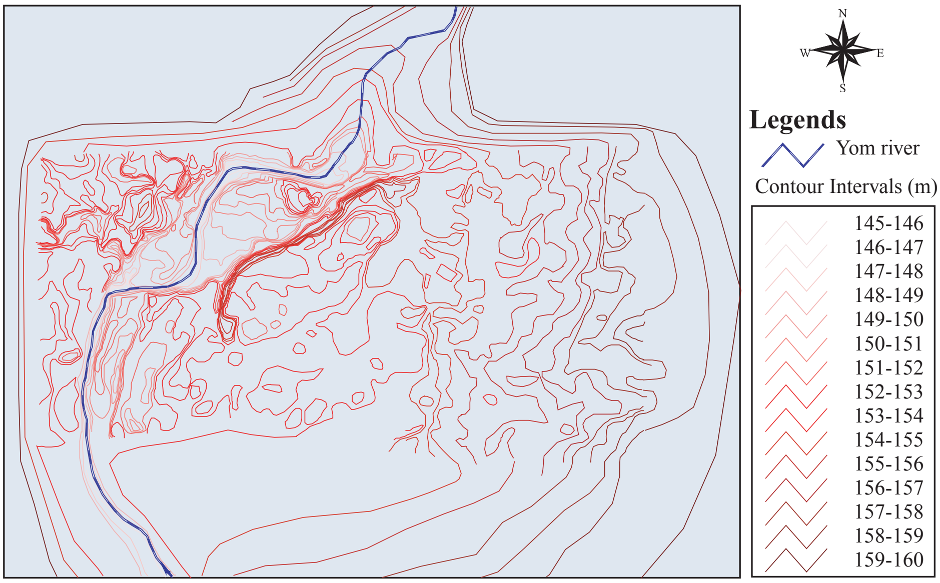

Figure 2. Contour map of the study area digitized from 1:4,000scale map

4.2 Grid resolutions for Simulations

For the analysis of impact of DEM resolutions, five different resolution DEMs were selected, which are 50m, 100m, 200m, 500m and 1000m. First four DEMs were generated from digitized contours of 1:4,000 scale map, however for 1000m resolution, existing data set of HYDRO1K prepared by USGS was taken. The river was digitized from 1:4,000 scale map and representative meandering factors were assigned for different grid resolutions to keep the river length same for all these DEMs.

4.4 Result Analysis

4.4.1 Simulation cases

For the two selected flood events of 1995 and 2001, simulation was carried out in hourly time step for 30 days with coupling time between surface and river flow modules as 300sec. The simulated duration for 1995 flood event was from 01 hr. of Aug. 20 to 24th hr. of Sept. 18. In this period, the flooding occurred in Yom basin due to tropical storm LOIS, which was generated in the South China Sea and it passed over Nan province on August 27 and moved towards Phrae and Pha Yao on 31st August, finally, reaching Lam Pang on September 1. It caused intense rainfall in north, north-eastern and eastern regions of Thailand. For the 2001 flood event, the simulation period was from 01 hr. of Aug. 1 to 24th hr. of Aug. 30. The upstream boundary conditions for both these cases were obtained from the river network simulation carried out by dynamic simulation model from Y20 to Y1C (Herath et al., 2002). The downstream boundary condition was decided based on the measured water level data at Y1C station. The river cross-sections, longitudinal profile and bank heights were determined based on the interpolation of the measured data (Figures 3 and 4).

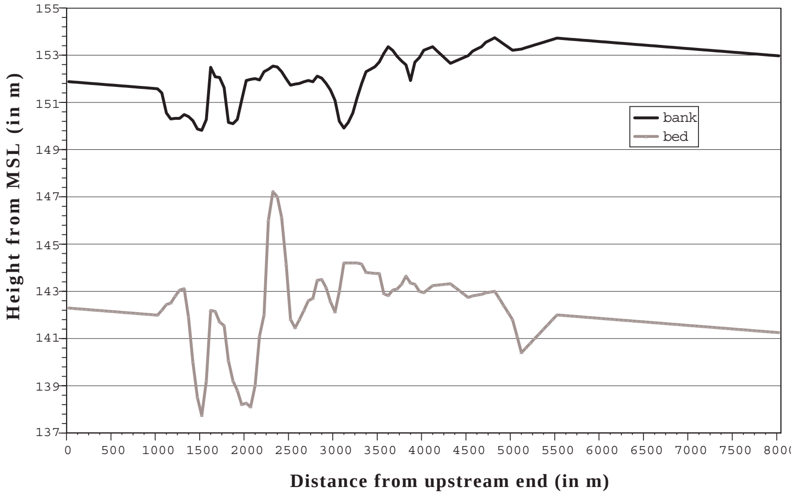

Figure 3. River bed profile and average bank heights

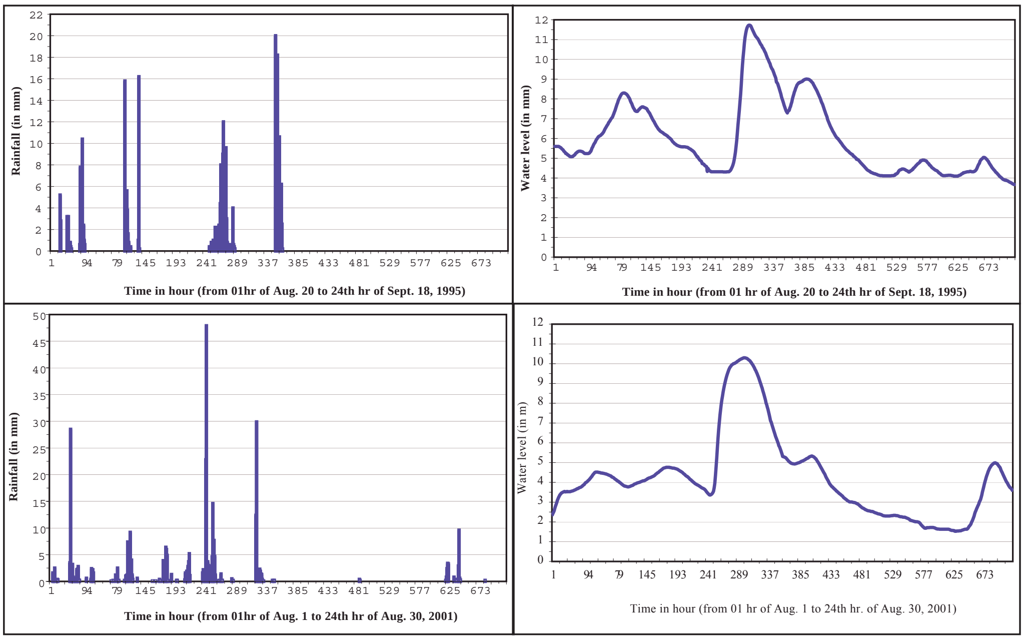

Figure 4. Input rainfall and upstream boundary conditions for the simulated flood events

4.4.2 Verification of Results

Figure 5 shows the simulated maximum flood inundation, which occurred at 17th hr. of September 1, 1995. From this figure, it can be seen that over 50% of the Phrae city was inundated with flood water depth over 5m in the areas near the river. It shows that the inundation depth was very high near the river, however the depth was much lesser inside the city. It was due to the elevated dyke existed for long time to protect the inner city from flooding, however, it was not sufficiently long to protect the city from flood water moving from the river side. Although, there was no record of spatial distribution of actual flood inundation available, based on the discussions with Regional official of RID and meetings with local people during field visit, it was found that the simulated inundation pattern was close to the actual situation. The simulation results reflect the function of dyke which reduced the inundation in the heart of the city. Also, the flood mark at the RID office at location Y1C showed the similar maximum flood height as simulated by the model (about 1.5m). Figure 6 shows two snapshots of flood inundation, 12hrs before and 24hrs after the maximum simulated flood inundation. From these results it was found that simulated duration of flood was very close to the actual flooding as explained by RID official. From Figure 6, it can be seen that due to the existence of inner dyke flood water stagnated in some of the inner city. In the actual situation, the elevation highways (refer to Fig. 1) protected the occurrence of flooding in other sides of these roads and in the simulation results also, the impact of this highways can be observed.

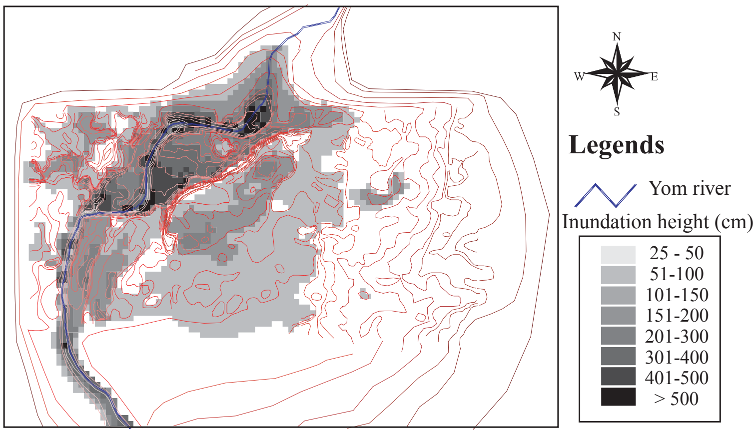

Figure 5. Simulated maximum flood inundation due to 1995 floods

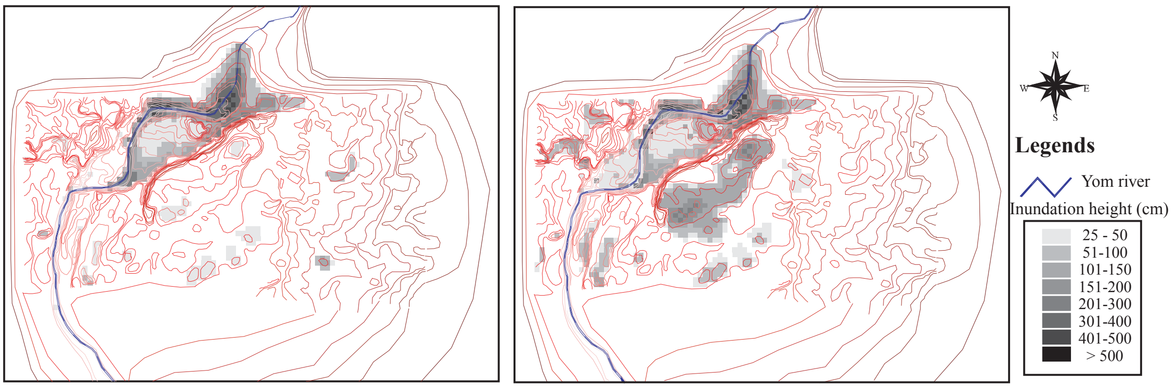

Figure 6. Simulated inundation 12hrs before and 24hrs after the maximum inundation

Figure 7 shows the simulated maximum flood inundation caused by the flood event of 2001 that occurred at 12th hr. of Aug.13, 2001. Comparing this with the Figure 5, it can be seen that the magnitude of this flood event was much lesser than the 1995 event and inundated only about 15% of the city. This time, the elevated dyke was able to protect the inner city from inundation.

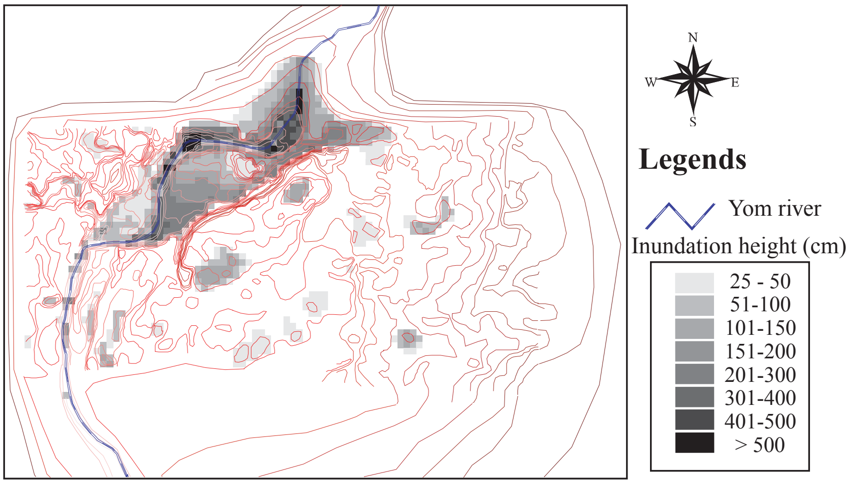

Figure 7. Simulated maximum flood inundation due to Aug. 2001 floods

For the above two cases, the flooding patterns and inundations area simulated by the model were close to the actual inundation condition as explained by the RID official. Although there was no means of independent verifications of the simulated results with actual condition, based on the explanations of the RID officials who were present in the field during the two flood events, the simulated results of the model can be considered very close to the actual condition. From this, we can conclude that simulation with 50m grid DEM could represent the actual condition to very close extent.

4.4.2 Impacts of Grid Resolution in inundation simulation

The model was further applied to carry out simulations with four sets of DEMs of different resolutions; such as 100m, 200m, 500m and 1,000m for 1995 flood event to analyze the impact of grid resolution variations in simulated inundation outputs. The results were compared in terms of maximum flooded areas, flood volumes, maximum flood height and representation of locally elevated lands such as dykes and highways.

The simulated maximum extents of flooding for different grid resolutions are shown in Figure 8. From this figure, it can be observed that in case 100m resolution DEM, the flood extent was very close to the results of 50m DEM, however for other grid sizes, the flood extents were much higher than that with 50m resolution DEM. Table 1 shows the maximum flood extents and average flood heights for these four grid resolution together with 50m DEM. From this table, it can be observed that accept for 100m resolution DEMs, all the simulated outputs for various DEM resolutions are much different from the results obtained with 50m DEM. In general, from Figure 8 and Table 1, it can be said that with the decrease of DEM resolutions, the flood extent is increasing, average flood inundation height is decreasing and there is reduced impacts of dyke and highways in flood inundation. If the results with average slope and flow paths for these different resolutions are compared, we can see that there is reduction of average slope and flow paths with decrease of grid resolution, which were main causes of impact on the simulated inundation results. A difference of over 3 times in inundation areas and heights can be observed between results obtained with 50m DEM and 1km DEM. The difference of average slope for these two DEM resolutions was about 60%.

From the above results, it can be seen that 100m DEM results were not much different from 50m DEM compared to 200m DEM. Like 50m DEM, results with 100m DEM could represent the effect of dyke and elevated highways in flood inundation, but it was less significant with 200m DEM. By looking at the required computation time for different grids with 2.1GHz Pentium PC, there was tremendous reduction in simulation time with 100m grid compared to 50m grid. As, there was not much difference of outputs between 50m DEM and 100m DEM, but computational time was much different, for an operational model, at the present condition, DEM of 100m resolution would be the most suitable. Although computational time is further reduced with 200m DEM, it can not be adopted for modeling as in that case it is needed to compromise the accuracy of the model outputs.

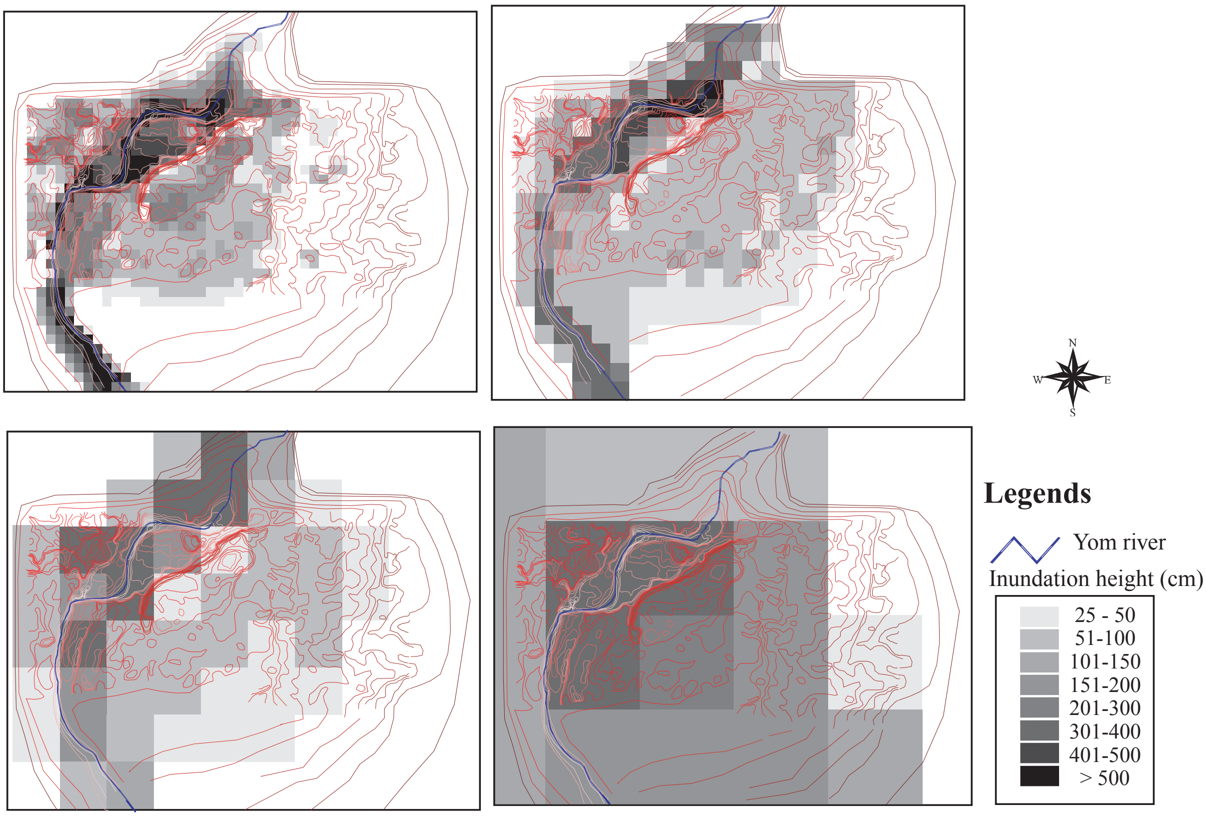

Figure 8. Maximum simulated inundation due to 1995 flood event with 4 different resolutions of DEM (in the order of 100m, 200m, 500m and 1000m)

Table 1. Comparison of results of simulation with different resolutions DEM

Item	DEM resolutions				
	50m	100m	200m	500m	1000m
Average slope (%)	94.8	75.6	52.8	37.5	30.2
Computational time required (hr)	28	13	6	2.5	1.5
Maximum flood extent (sq. km)	6.3	7.1	9.8	11.5	16.3
Average flood height (m)	0.70	0.68	0.53	0.41	0.361

5. CONCLUSIONS

This study was carried out to analyze the impacts of resolution of DEM in flood risk modeling. The model used for carrying out the analysis was a physically based distributed hydrological model and in this study, the 2D surface and 1D river components of the model were used which were derived based on diffusive approximation of St.-Venant's equations. The study selected for the analysis was Yom River basin of Thailand, which was most frequently affected by floods and a flood risk management system was an urgent need in this basin. Two past major flood events of

1995 and 2001 were selected for the analysis with five different resolutions of grids; 50m, 100m, 200m, 500m and 1000m.

The simulated results show that there were large impacts of resolution of DEM in simulated flood inundation by the model. The results show that model outputs with 50m and 100m resolution DEMs were close to the real situations; however the grid resolutions beyond this range reduced the accuracy of the results. The difference between maximum inundation areas and average flood heights with 50m and 100m resolution DEMs was only about 5%. However, for other resolutions of DEM, the difference increases largely and it becomes almost 3 times in cases of 1000m resolution DEM. It was observed that with decrease of spatial resolutions of DEM, maximum flood extent increases and average flood depth reduces. It can be attributed to reduction of slopes and flow paths with decrease of spatial resolution of DEM. In Yom river basin, the existing model can provide forecasted water level in Y1C 14hrs in advance based on the measurements at Y20. As the inundation simulation model requires simulated u/s boundary condition for river flow forecasting model, for any operational purposes the model computational time should be within this limit. Considering the existing computational facilities and need of an operational model for this basin, 100m resolution DEM should be the most suitable DEM for flood risk modeling.

Acknowledgement:

The authors gratefully acknowledge the tremendous helps provided by the regional Directors Mr. Tada, Mr. Panaya and Mr. Somchai of RID, Thailand during the field study and thank them for providing the datasets for successfully conducting this research study.

6. REFERENCES

Beven, K.J. and Kirkby, M.J., 1979. A physically based variable contributing area model of basin hydrology, *Hydrologic Science Bulletin*, 24, 43-60.

Dutta, D., S. Herath and K. Musiake, 2000. Flood Inundation Simulation in a River Basin Using a Physically Based Distributed Hydrologic Model, *Hydrological Processes*, John Wiley & Sons, Vol. 14, No. 3, pp. 497-520.

EIC, 1998. Thailand on a Disk, E*nvironmental Information Center, Thailand Environment Institute*, Bangkok, Thailand.

Fread, D. L., 1988. "The NWS DAMBREAK model: Theoretical Background/User Documentation, *National Weather Service (NWS)*, NOAA, USA.

Herath, S., Dutta, D. and Wijesekara, S., 2002. Use of spatial information in flood disaster mitigation-Case study of Phrae City of Yom river basin, Thailand, *Proceedings of the International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Science*, Hanoi, Vietnam.

Hungspreug, S., Khao-uppatum, W. and Thanopanuwat, S., 2000. Operational flood forecasting for Chao Phraya river basin, *Proceedings of the International Conference on The Chao Phraya Delta: Historical Development, Dynamics and Challenges of Thailand's Bow*l, December 12-15, 2000, Kasetsart University, Bangkok, Thailand

INCEDE Newsletter, 1996. 1995 Floods in Thailand, *Vol. 4, No. 4*, January- March 1996, pp.

Jha, R., S. Herath, and K. Musiake, 1997. Development of IIS Distributed Hydrological Model (IISDHM) and its Application in Chao Phraya River Basin, Thailand, *Annual Journal of Hydraulic Engineering*, JSCE, Vol. 41, 227-232.

Kenward, T., Lettenmaier, D.P., Wood, E.F. and Fielding, E., 2000. Effects of Digital Elevation Model Accuracy on Hydrologic Predictions, *Remote Sensing and Environment*, 74, 433-444.

Kubo, N. and Hotta, C., 2000. Proposal for enhancing flood retarding capacity in the Chao Phraya Delta, *Proceedings of the International Conference on The Chao Phraya Delta: Historical Development, Dynamics and Challenges of Thailand's Rice Bowl*, December 12-15, 2000, Kasetsart University, Bangkok, Thailand

Storck, P., Bowling, L.C., Wetherbee, P., and Lettenmaier, D.P., 1998. Application of a GIS-based hydrology model for prediction of forest harvest effects on peak streamflow in the Pacific Northwest, *Hydrological Processes*, 12, 889-904.

O'Loughlin, E.M., 1986. Prediction of surface saturation zones in natural catchments by topographic analysis, *Water Resources Research*, 22, 794-804.

Weesakul, S. and Thammasittirong, S., 2000. Operational flood forecasting for Chao Phraya river basin, *Proceedings of the International Conference on The Chao Phraya Delta: Historical Development, Dynamics and Challenges of Thailand's Rice Bowl*, December 12-15, 2000, Kasetsart University, Bangkok, Thailand

Wolock, D.M. and Price, C.V., 1994. Effects of digital elevation model map scale and data resolution on a topography-based watershed model, W*ater Resources Research*, 30, 3041-3052.

Zhang, W., and Montgomery, D.R., 1994. Digital elevation model grid size, landscape representation and hydrologic simulations, *Water Resources Research*, 30, 1019-1028.