Pre-flood Inundation Mapping for Flood Early Warning

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ABSTRACT

The results of the runoff modeling were integrated in MIKE11 GIS model for flood inundation mapping based on a past flood event 27th Sept– 08 Oct. 2000 in Malaysia of the Langat River Basin area. Separate inundation maps were generated for the observed rainfall and the quantitative precipitation forecast (QPF) derive from satellite (AVHRR and GMS data) reflectance and top of the cloud temperature T_B. Modeled rainfall estimates was developed at 3-12mm/hr and used for flood simulation and inundation mapping for the observed and modeled estimates. The objective of the study is to develop pre-flood inundation map and compare with the actual observed flood map for the purpose of flood early warning. The accuracies of both maps were verified using grid point location data for flooded areas published in the DID Annual Flood Report. The verification results showed an accuracy of 70% of simulated on the observed flood map.

Keyword: *Pre-flood inundation mapping, Rainfall-runoff, Hydrological GIS Modeling, Langat river basin, Malaysia*

1 Introduction

The role of GIS in flood and hydrological simulation is multifaceted. It essentially serves as a platform for operational purposes in the implementation of the automated procedures of rainfall-runoff distributed modeling (Lanza *et al.*, 1993). It again handles the large amount of data monitored at different spatial and temporal scales. La Barbera *et al.*(1993) explained the support of a 'hydrological oriented' GIS structure to be in part, the collection of rainfall data from available remote sensors and identifying the areas of potential occurrence of extreme meteorological events on the basis of the whole set of remotely sensed information. A hydrological GIS runs the distributed rainfall-runoff procedures by using as an input, the rainfall scenarios predicted at the small scales to provide predictions and simulated hydrographs at the sections of interest along the river network for different probability levels. The objective of this study is to The objective of the study is to develop pre-flood inundation map and compare with the actual observed flood map for the purpose of flood early warning based on the available data of the rainfall and flood event of 27th Sept– 08 Oct. 2000 of the Langat River Basin.

In this study quantitative precipitation forecast (QPF) derive from satellite (AVHRR and GMS data) reflectance and top of the cloud temperature T_B. below a threshold 235 degree Kelvin. Modeled rainfall estimates was developed in the range of 3-12mm/hr to reflect the varying levels of intensity of tropical rainfall as experienced in Malaysia as against 3mm cited in literature (Arkin and Janowiak, 1991; Ba and Nicholson ,1998; Todd *et al.* ,1995; Arkin and Meisner, 1987; WCRP, 1986; Arkin *et al*., 1994 and Huffman *et al*., 1997) to be suitable for tropical area between Lat 3^o North and South of the Equator. Details of the estimation for QPF used in this study can be found in Lawal, *et.al* (2010), Lawal, *et. al* 2008 Lawal Billa (2006), Lawal Billa (2005) and L. Billa (2005). Predicted rainfall estimates were used as input a MIKE 11 GIS hydrological modeling processing to assess the vulnerability of the digital elevation of landscape model (DEM) of the river basin area with reference to the flood events and to finally produce maps of areas that will/was eventually flooded.

The study of Wilson (2002) particularly illustrates a good example of a hydrological GIS. This dynamic modeling process demonstrates the data flow in a flood modeling system for flood hazard mapping using GIS. A dynamic model is coupled with a GIS, and calibrated using data on flood distribution and boundary condition of catchment/basin understudy. The calibrated model is then used to predict inundation extent based on the hydrological catchment model and also to present "what if "hydrographic scenarios of the flood events. The output risk map for the hazard assessment is achieved by combining predicted inundation with the population and infrastructure data. By simulating many "what if" hydrographs, the probabilities of flood across the floodplain can be generated and combined with population and infrastructure data to identify locations likely to have the greatest risk of flooding.

2. Flooding in Malaysia and the Study Area

Malaysia is located from latitude 2^o to 7^o N and in the direct path of the adverse effects of periodic monsoon rainfall. Historically, the country experiences a severe flood event every three years and some form of flood every year. In Malaysia there are two monsoon seasons a year, the northeast that occur from November to March and the southwest monsoon from May to September. In between these two monsoons, there are two inter-monsoon periods in April and October and generally characterized by variable winds and thunderstorm in the afternoon. Severe monsoon rainstorms in Malaysia some-times results in flash floods that strikes quickly and in most cases without warning. Flooding is usually observed before warnings reach the vulnerable areas and usually this have a huge impact on people and properties. The consequences of these flooding are economic loss, social disruptions and sometimes loss of lives. According to Keizrul and Chong (2002), severe monsoon rainfalls are the most destructive natural disaster affecting Malaysia in respect of the cost, damage to property and the area extent**.**

The basic cause of flooding in Malaysia is the incidence of heavy monsoon rainfall (Figure 1). and the resulting large concentration of run-off, which exceeds the capacities of river systems (Ho *et al.*, 2002). Rapid urbanization within river catchments in recent years have also served to compound the problem with higher run-offs and deteriorated river capacity that increase flood frequency and magnitude. Various flood forecasting models and warning systems have been applied in Malaysia, but they have proved inadequate by their inability to predict impending floods and the possible areas that many be inundated. In respect of this, the importance of a flood map as the basis of early flood warning cannot be over emphasized. Flood maps constitute an effective media for representing the potential areas to be inundated. Its use as an early warning and emergency tool can only be effective if inundation maps are produced in advance of a flood event to provide ample time for contingence planning and also providing few false alarms.

Figure 1: Flooding in Malaysia

1.2 Langat River Basin

Despite this progress in flood modeling research, flooding continues to plague many areas of the world (Knebl *et al*., 2005). This is seen in the various implementation of models, plans, forecasts and early warning systems in Malaysia over the years which have had limited impact in addressing the continuous huge runoffs and flash flooding problem in the country including the Langat River basin. In the monsoon of 2000, a major rainfall event of late September to mid October caused extensive flooding and resulted in millions of dollars in damage the Langat River Basin. The Langat watershed area is to the southeast of Selangor state and approximately 27 km to the south east of Kuala Lumpur. The basin area (Figure 2) falls within latitudes 101° 43’E to 101° 58’E and longitudes 02° 59’N to 03° 17’N. The land surface of Langat River Basin is hilly to the north and northeast. It is heavily forested and also forms the source of the river and its main tributaries. Langat area has two major dams comprising of the Langat dam located on the Lui tributary and the Semenyih dam on Semenyih tributary. These dams together with the upper Langat catchment area is considered to be one of the important domestic water supply sources to almost 1.9 million people in Kuala Lumpur and the surrounding areas. The southern and southwest parts form the lower basin and are mainly low lying floodplains that slope gently along with the river to the Strait of Malacca. Figure 2 shows a perspective view of the surface terrain of the Langat River Basin.

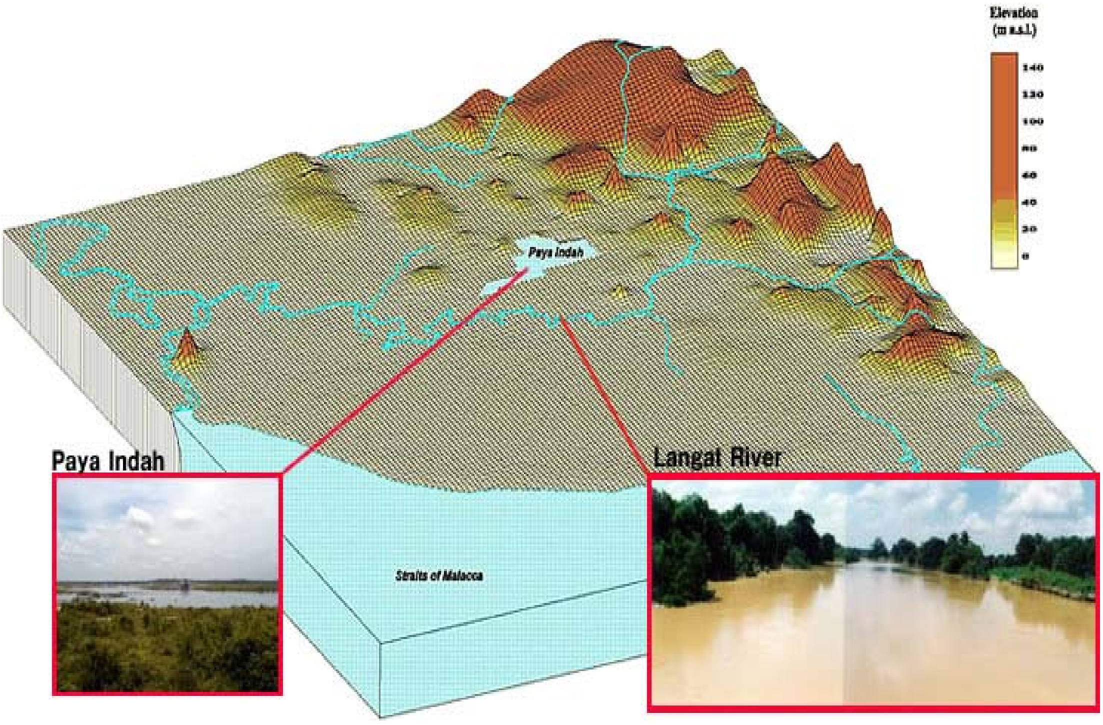

Figure 2: Perspective view of the Langat River Basin
(Source: GFLRB, 2003)

3. Methods and Materials

The hydrological GIS was developed using an integrated MIKE 11 GIS in ArcView 3.2 environment (MIKE 11, 2003). Figure 3, shows the flow-chart of the data and output in the modeling process. This allowed the easy importation of MIKE11 calibrated (Madsen, 2000) results to combine with the developed Langat Basin DEM (Figure 4) for flood map development. The data developed in the GIS included the road network, river network, settlement, contours for surface terrain development and past flood data point coordinates of flood locations in the flood event. Data format was edited and standardized in meters registration and RSO projection, in the same units as used in the hydrological modeling process.

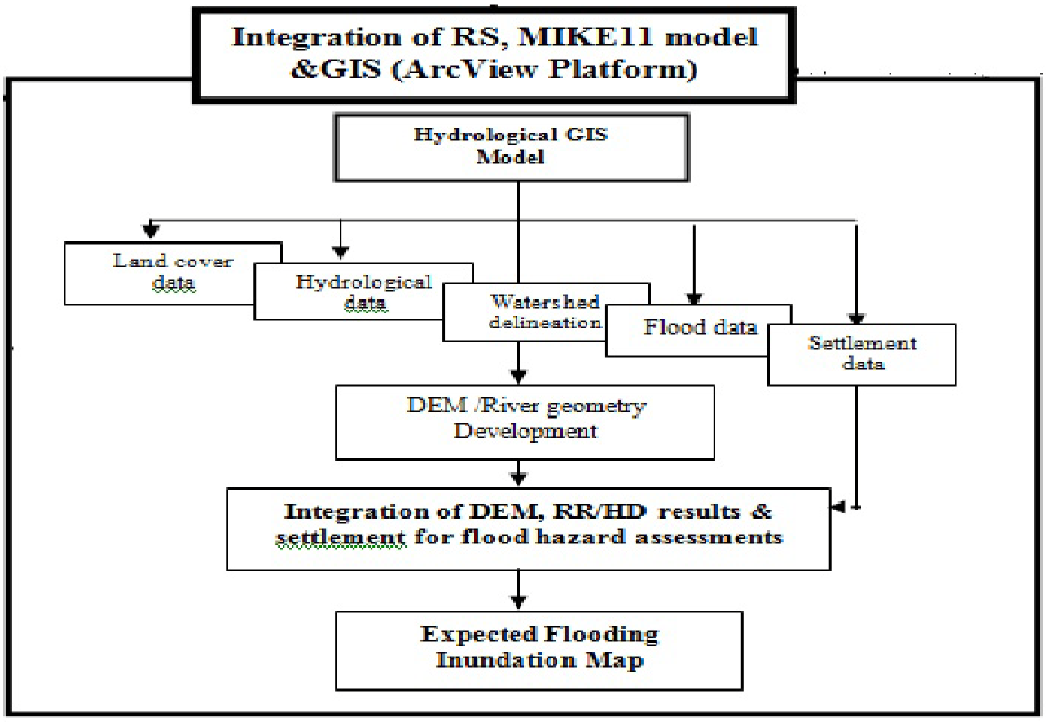

Figure 3 Flow -chart of the Hydrological GIS

The data used was of a low scale of 1: 50,000 due to non-availability of high-resolution digital data for the basin presently. The contour data had intervals of 20 meter, this ideally would not be suitable for flood modeling, however due to the size of the basin (2000 km^2) and the fact that QPF grid rainfall results based on meteorological satellite data was to be incorporated, the developed DEM was appropriate for the study. Surface terrain of basin was processed by interpolation, extrapolation, overlays techniques and manipulations in the DEM module of the integrated MIKE 11 GIS. The functionalities of ArcView 3D analyst available in the DEM module were used to register the coordinates of the area of interest (AOI) by setting the area definition in meters. Height values in the contour data were converted into XYZ mass point file that is compatible for processing in the DEM module. The mass points were then used to produce digital surface based on triangulated irregular network (TIN).

The basin's river cross-sections were exported from the hydrological model as an ASCII file into the hydrological GIS for development of the river geometry and integrated with the DTM. The "Assign Elevation" function was used to prepare the river geometry and flood plain by assigning negative values depending on how low the stretches of the river area were in relation to the flood plain. A visually impressive and realistic basin surface model was developed (Figure 4). Using TIN for the surface modeling ensured that less computer memory was used up in the processing and storing of surface data when compared to DEM developed from satellite data. There was thus more computer memory reserved for other processes. The developed DEM/DTM provided estimates of the elevations and other topographic indices, information vital to the hydrological modeling process to determine flooded areas.

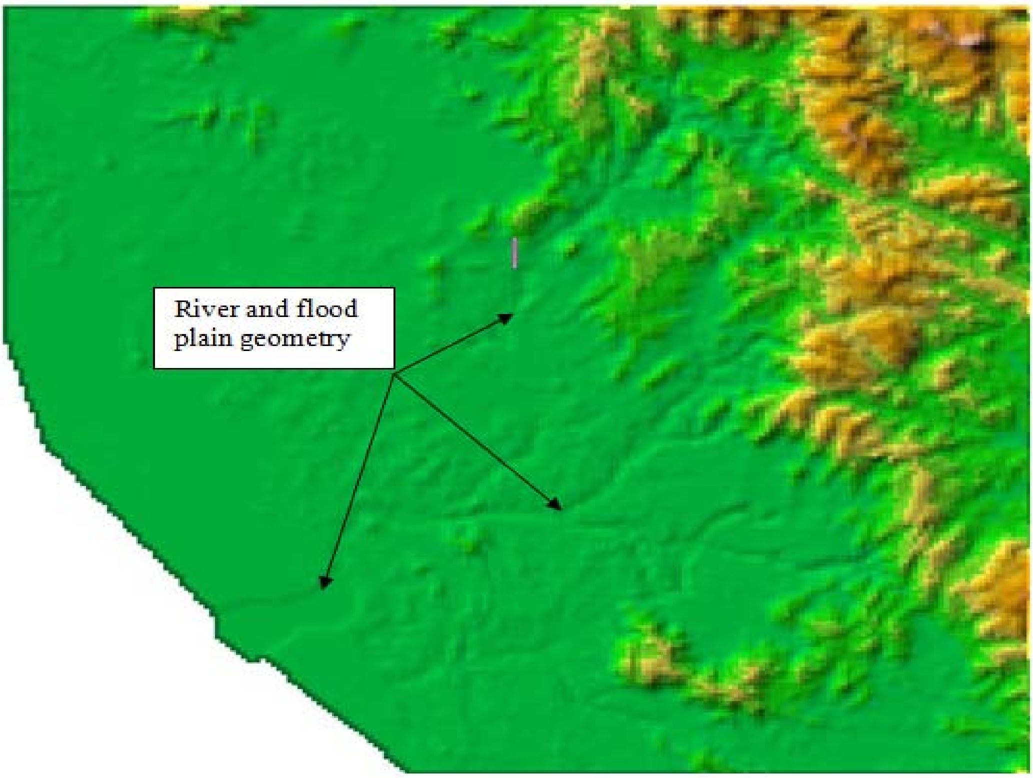

Figure 4: Basin Geometry and DEM

The basin DEM was imported as a grid file to the MIKE11 flood management module (FM) (Havno *et al* 1995), where it is integrated with the hydrological simulation results of rainfall-runoff of the Observed and QPF estimates and also hydrodynamic results of the hydrological modeling. Figure 5, shows the discharge (Q) and water level (H) points of the resulting integration. In the FM module the DEM provides an understanding of the surface elevation of the study area from which flood depth can be extrapolated, whilst runoff and hydrodynamic results provide the automated rainfall-runoff process and flood distribution modeling. Details of model calibration and simulation process can be found in HEC, 1996a; HEC, 1996a and HEC, 2000. Settlement data and other critical facilities were overlaid to visualize and assess the impact of the given flood period. Other ancillary information such as flood extent and depth were deduced from the flood map to facilitate flood impact assessment.

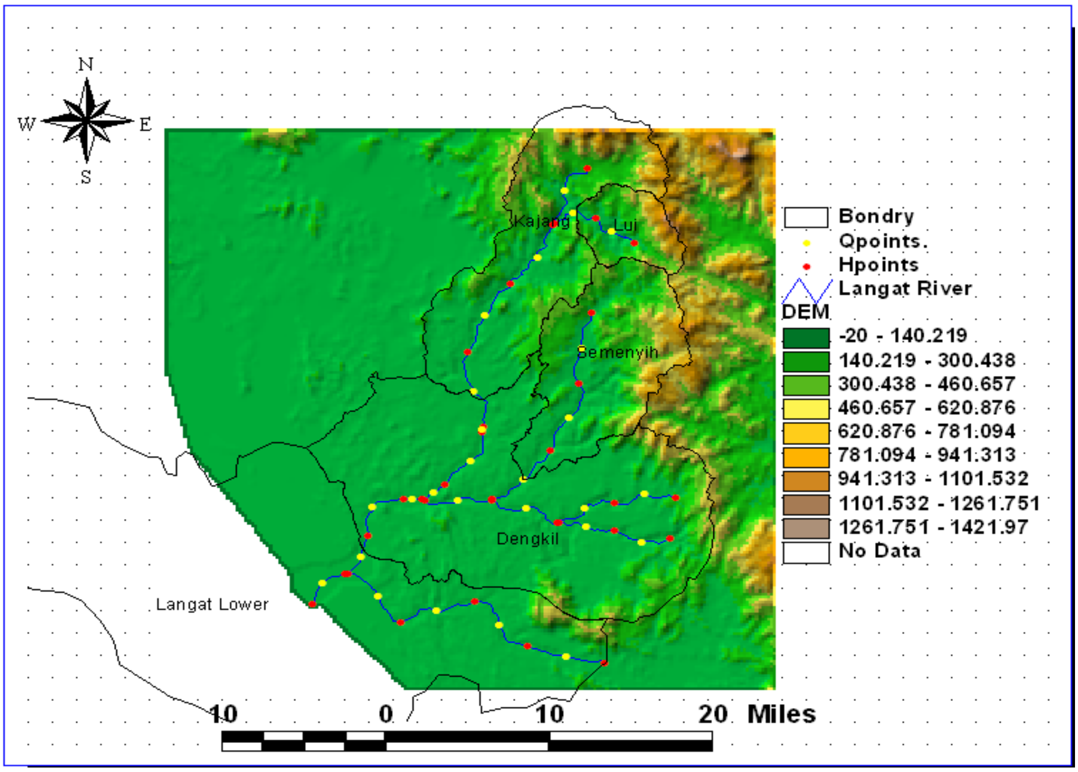

Figure 5: Integration of Hydrological Simulation Results with DEM

4. Results and Discussion

Hydrodynamic simulation was performed for a sampled point at Kajang branch of the Langat River from upstream to downstream for the water level of the storm period of 27 Sept. to 08 Oct. 2000. At pre-flood stage, water level is shown to be about 1.3 m and discharge Q was calculated as 31.05 m^3/, the flow velocity was 1.047 m/s s (Figure 6). The maximum level at flood stage was 6.8m from the bed elevation of 1.8m (msl) , while discharge at 641.3 m^3/s with the flow velocity of 2.618 m/s as shown in Figure 7. The discharge rate rose rapidly from 30m^3/s on the 28th of September to peak discharge above 581 m^3/s on the 3rd October. Discharge fell sturdily on wards for six days at the rate of about 57 m^3/s a day to about 230m^3/s on the 9th of October which is the end of the simulation period considered in the study.

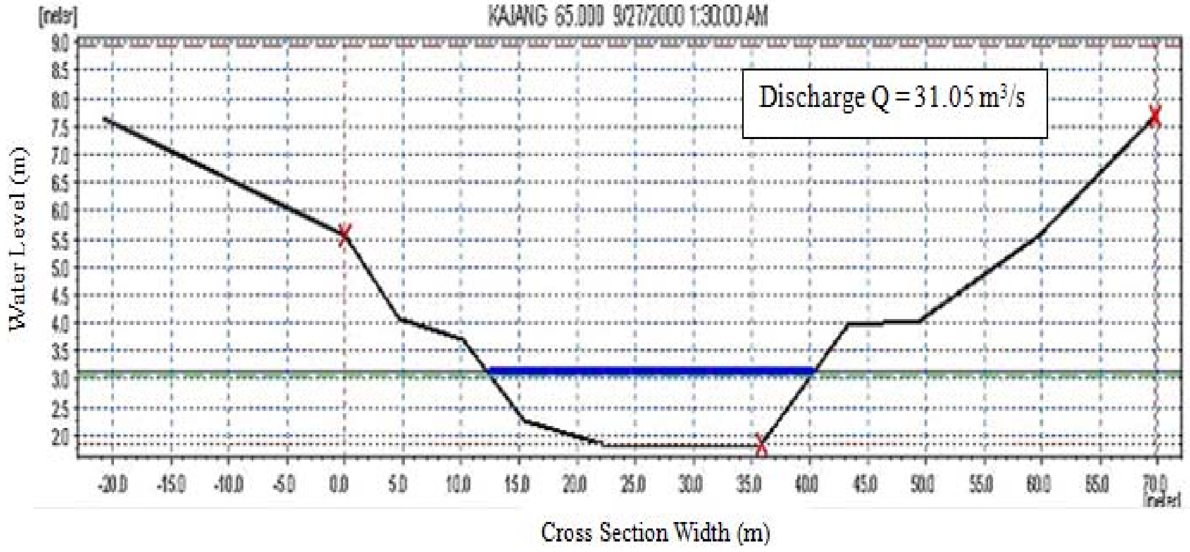

Figure 6: Lowest Water Level at Cross-section of the Simulation Point

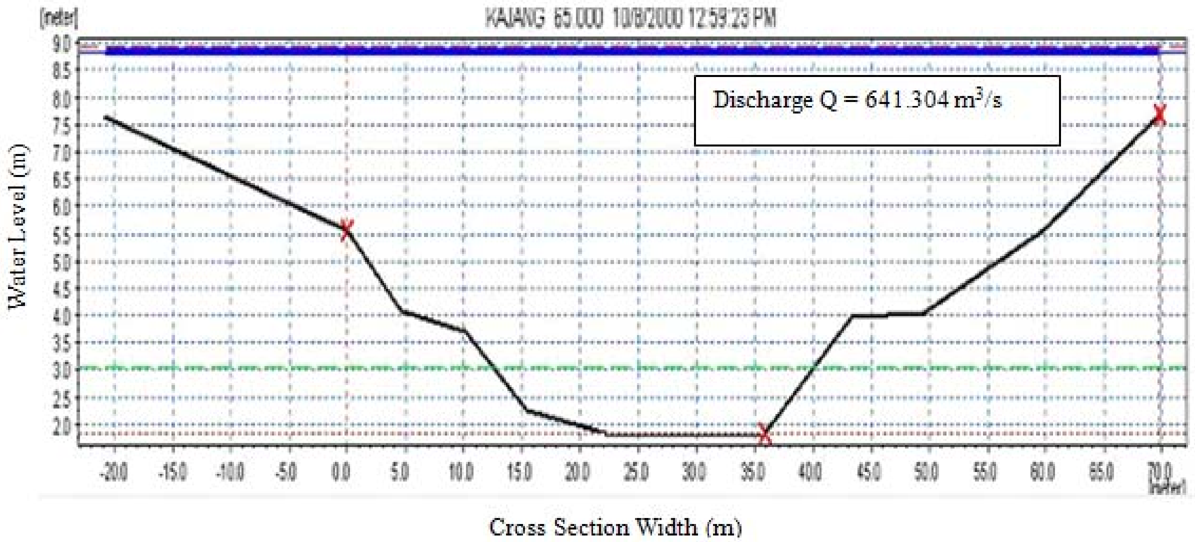

Figure 7: Highest Water Level at Cross-section of the Simulation Point

Inundation maps were developed by coupling RR simulation results for the observed and QPF rainfall to the DEM. In the map modeling, the runoff results were basically used to simulate runoff over DEM, excess rainfall is converted to lateral flow in the process to show the probabilities of flooding across the flood plain. Figure 8 shows the flood inundation map generated based on the observed RR results. It shows the distribution of flood over the Langat basin area as a result of the 12 day rainfall event from 27th September to 08th October 2000.

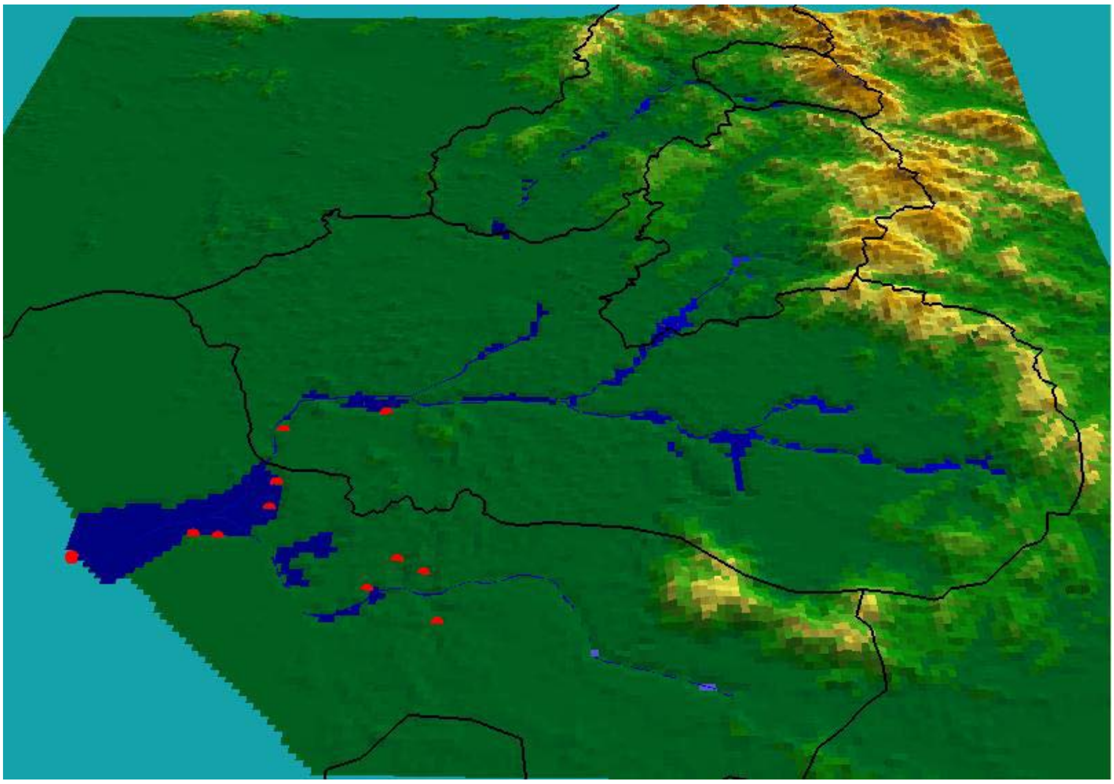

Figure 8: Flood Map Using Runoff Results from Observed Rainfall

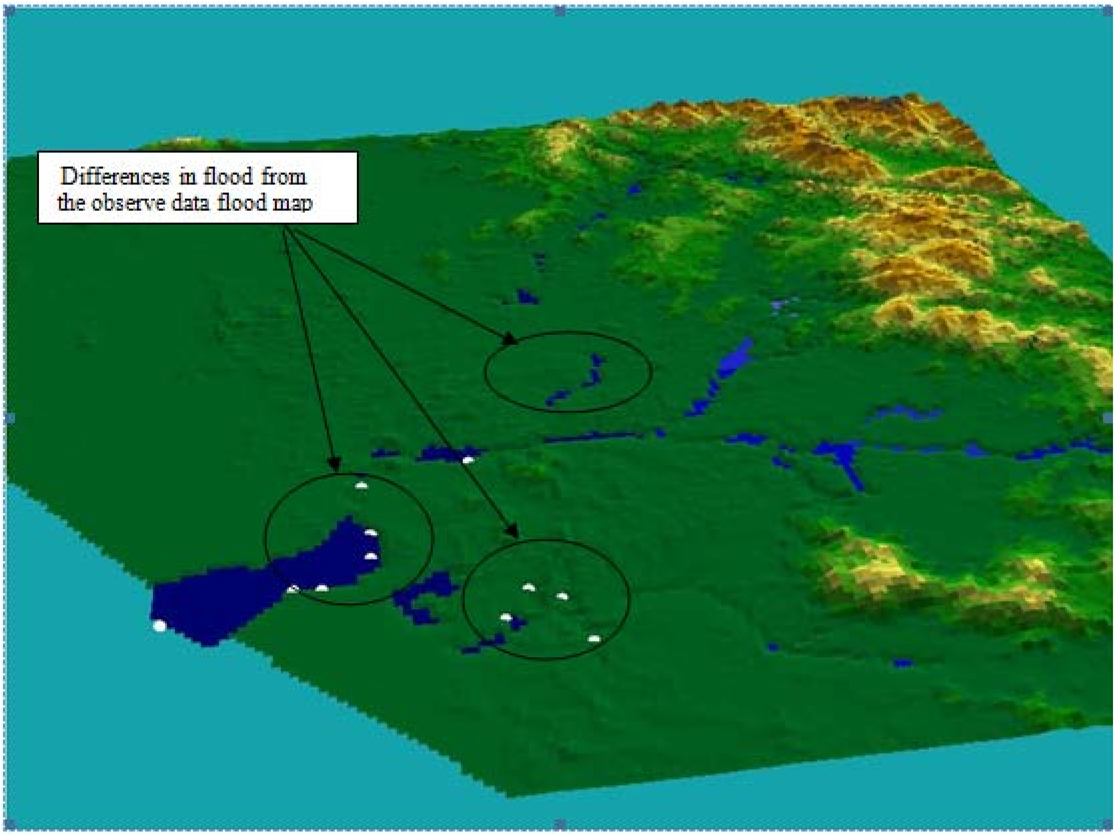

Figure 9: Flood Map Using Runoff Results from QPF Rainfall Estimates

A flood map was again generated using the RR result of the QPF rainfall estimation (Figure 10). A visual comparison shows minor difference as illustrated in Figure 9, the circled areas show the absences of flood patch that were observed. Using spatial analysis and overlay techniques, the total flood area for the two maps are calculated as 100.8 km^2 and 102.06 km^2 (Table 1) indicating a 1.15 km^2 difference in flooded area between the observed and QPF inundation map. The difference between the based on the overlay techniques are shown in Figure 10.

Table 1: Difference in Total Flood Area

	Grid Pixel Count	Area (km^2)
Observed Flood Map	1120	100.8
QPF Flood Map	1134	102.06

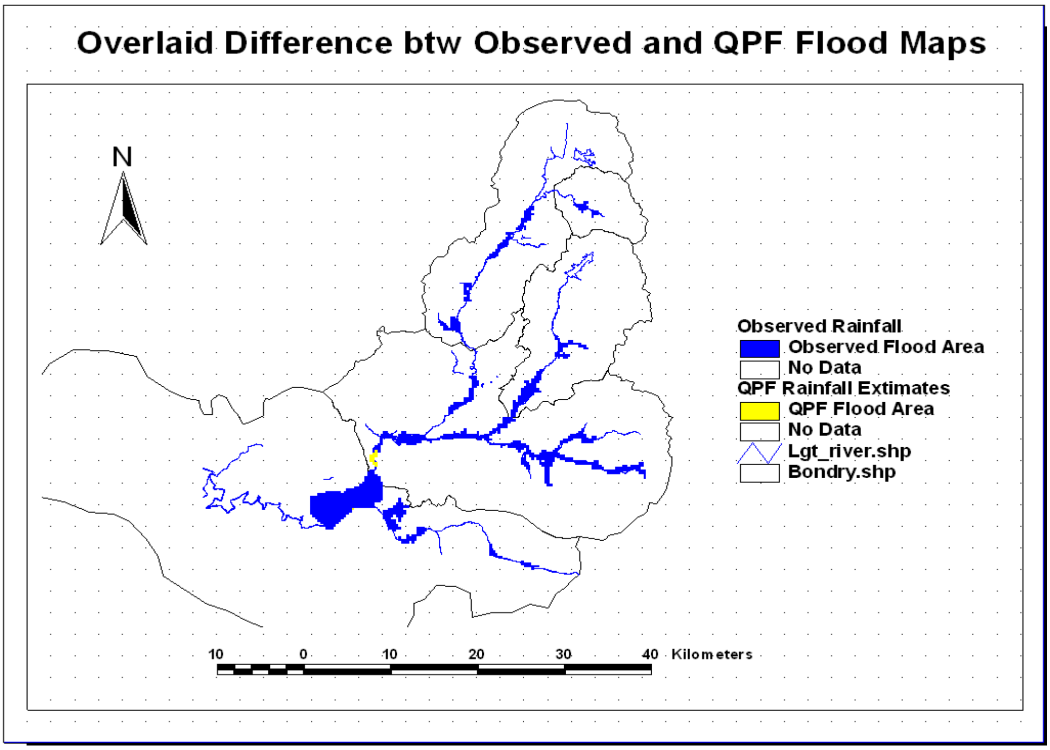

Figure 10: Overlay Difference Btw Observed QPF Flood Maps

The validations were not entirely sufficient, due to the non availability of Synthetic Aperture Radar (SAR) data coverage for the flood event under study. However , the techniques used was adequate enough based on cross validation made using in-situ point coordinates of actual observed flooded location published in the gazette of the Department of Irrigation and

Drainage,(DID,2000) Malaysia. The ten gazette point shown on both maps (Figures 9 and 10) present an over-all accuracy of 70%. .

5. Conclusion

The study has demonstrated the potential of developing pre-flood map for flood early warning. Pre-flood rainfall estimate (QPF) was processed in a suitably calibrated MIKE 11 rainfall runoff model for Langat Basin. Simulation results where then coupled to the DEM of the study area developed in the hydrological GIS to generate flood inundation maps. Generally, the maps generated showed accuracy of 70%. Improved verification could have possible with the availability of synthetic aperture radar (SAR) data for that flood event 27th Sept to 8th Oct. 2000. Overall this study has demonstrated techniques and tool to developing a hydrological GIS modeling process and to generate flood inundation maps for pre flood early warning and to provide ample time for contingency planning.

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