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Modeling Flood Inundation in River Catchment using Hydraulic and Geographical Information System (GIS) Simulation Approach

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Abstract: Flood is the most significant natural disaster in Malaysia in terms of frequency, area extent, population affected bad damage. As a non-structural measures, flood map is very useful to be implemented mainly to prevent loss of people's lives as well as to notifying the residents of potential flood damage. This study discusses the development of flood inundation in Sungai Pulai using the XPSWMM hydrodynamic software and Geographical Information System (GIS) simulation. Floodplain mapping process includes gathering required data, hydrologic analysis, hydraulic analysis and floodplain mapping using output data sets and base maps. The results indicate that 21 flood occurrences were recorded >81 years giving the average of 3.86 or probability of 26% chance of flooding each year. About 206.433 km^2 are subjected to flood inundation areas covering flood depth between 0.2-1.5 m. This study revealed for the strength and potential of a hydrological oriented XPSWMM-GIS as a tool for flood mapping.

Key words: Flood inundation, flood mapping, hydraulic, GIS, XPSWMM, development

INTRODUCTION

Floods are one of the most serious, common and costly natural disasters that many states in Malaysia are facing including Johor. Climate change and growing Urban areas particularly in Southern Johor have dramatically increased the frequency and the severity of flood events. Apart from that it is a common occurrence because of the geographical characteristic of the country that brings an abundance of rains during the monsoon seasons and also due convection rains during the hot but humid periods. This has enhanced the interest of the scientific community and of authority into creating more accurate studies regarding the delineation of possible flood areas.

In the past decades, thousands of lives have been lost, directly or indirectly by flooding. In fact of all natural risks, floods pose the most widely distributed natural risk to life today. River flood management is the process under which different bodies try to reduce the current and the future vulnerability of human society to natural risks.

Flood management measures can be structural where the risk is modified for example dam and reservoir construction, channel improvements, bypass channels and artificial levees (Gasim *et al*., 2007). Non-structural where the flood damage and disruption is modified for example setting up flood plain management regulations such as zoning, building codes and measures where both the methods are applied (Toriman, 2010). It is clear that no protection work can offer a 100% security against floods. There is always the possibility that a threshold is surpassed and that floodwater will enter into areas where it should not go, e.g., by overtopping or breaching of dikes.

For years, floodplain management studies have been expensive and tedious task. Recently, in addition to the development of improved computational capabilities, the availability of high sophisticated 3D-GIS software continues to expand new possibilities for engineers to perform flood inundation analysis in conjunction with hydraulic models to represent water surface elevations generated from hydrologic and hydraulic models in a

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three-dimensional terrain model (Merz and Thieken, 2004). Visualization helps to bridge the gap between the engineers and decision-makers by providing a method for exploring, analyzing and verifying hypothesis from large quantities of spatially referenced data. GIS is being used in a variety of ways to plan, prepare, respond and evaluate flood events (Toriman *et al*., 2010; Othman *et al*., 2008). On the other hand, water resources management applications are inherently spatial and generate large amounts of data relating to physical phenomenon in space and time. Thereby, the multidimensional nature of this data makes it quite natural to couple hydraulics modeling and GIS environment through an appropriate interface. Through the hydraulic analyses, modeling simulations and the visualization of floodplain inundation decision-makers can obtain improved understanding and make more informed management decisions.

This study involves the application of flood modeling that integrates hydraulic modeling (1-D XPSWMM) and Geographic Information Systems (GIS) for Sungai Pulai, Johor flood plain inundation. The form of flooding frequently experienced in the study area is the monsoon flood and it can happen several times each year. In this study, the flood plain and river geometry of Sungai Pulai is incorporated in the DEM for hydrodynamic modeling of water level and discharge of 50 years return period storm design.

Study area: Sungai Pulai is one of major tributary within the Nusajaya land development area. The area of Sungai Pulai and its tributaries, Sungai Pendas, Sungai Perepat and Sungai Melayu is characterised by low-lying ground <50 m contour. The sources of the tributaries that feed these rivers are located on the hilly peaks of Gunung Pulai. The riverine systems are tidal with mangrove swamps fringing the rivers.

The Pulai river basin has the largest expanse of forests in Iskandar Malaysia. The two main patches are the mangroves in the Sungai Pulai forest reserve/Ramsar site and the dryland (Dipterocarp) forests around Gunung Pulai forest reserve and the catchment area of the Gunung Pulai reservoir. Currently, palm oil plantations and rural land use dominate the landscape with a number of new developments in recent years including housing and industry. The Tanjung Bin power plant and the Port of Tanjung Pelepas are located at the river mouth.

MATERIALS AND METHODS

Developing river flood modelling: To execute floodplain simulation using the integration of hydraulic model of XPSWMM and GIS, two basic types of data were used to estimate an extent of flooding map; spatial non-spatial data. The spatial geometry data comprise the description of the terrain related to the stream channel including the entire river network and terrain cross-sections along the streams. On other hand, the non-spatial data include the flow data include the values of the stage and discharges. These values were imported directly from the runoff simulation was carried out using the XPSWMM-runoff mode for rainfall-runoff modeling (Toriman *et al*., 2009a; Toriman, 2008).

The major design storm standard recommended by Malaysian urban drainage manual is 50 years ARI except for major city centres where it is 100 years ARI. Therefore in this study, 3 h of 50 years ARI rainfall runoff data has been used to forecast the discharge and water level in Sungai Pulai according to the requirements of the Malaysian urban drainage manual.

ArcView GIS 3.2 was used to develop the Digital Elevation Model (DEM) for the study area. The integrated XPSWMM-GIS provided extensive tools for thorough channel and surface geometry modeling that included floodplain processing (Toriman *et al*., 2009b). The cross-section point elevations for the main tributes of the study area were collected through field surveys carried out during 2009-2010 study period. XPSWMM-GIS creates a grid-based water surface, compares it with the generated DEM and produces flood map (CUR, 1990). The incorporation of river basin models into GIS involves three major components; spatial data construction; integration of spatial model layers and GIS and model interface (Gasim *et al*., 2009). The integration of GIS has improved matters by streamlining data input, assist in visualization, design, calibration, modification/comparison and providing better interpretation of model outputs. Upon completion of the hydraulic calculations, XPSWMM exports the data back to a GIS for comparison with the elevation model (Fig. 1).

Developing flood map: Flood inundation maps were developed using the the XPSWMM hydraulic-runoff simulation modes. At the end, the module gives the different water depths (m) in the riverbed during the flood. Long section profiles are derived from flood maps at a point located on the Sungai Pulai with a chainage value of 16,782 m. A valuable byproduct of the flood maps generated with XPSWMM is that the flood depth can be determined base on the color difference.

In flood studies, not only the extent of flooded areas but also the depth of water in this area can be determined in order to help predict the damage that water will cause to land, human and property. Determining the inundated

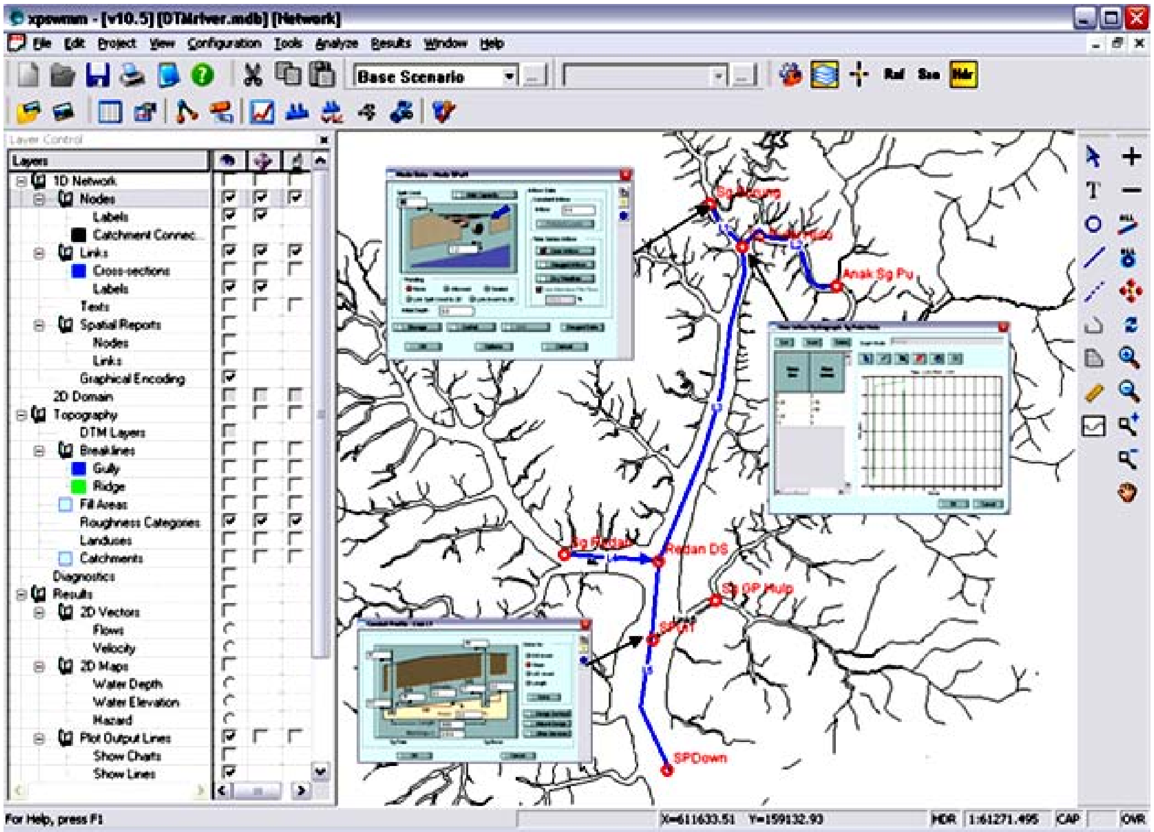

Fig. 1: The development of Sungai Pulai conduits and flow simulation

area in the flood map involves the subtraction of flood surface elevation model from the land surface elevation model at each location, resulting in negative values wherever the flood elevation is greater than the land elevation. For this study, inundation map are obtained for the Sungai Pulai catchment at the end of the simulation made for the 50 years flood (Toriman *et al*., 2009a, b).

RESULTS AND DISCUSSION

General flood scenario within Sungai Pulai catchment: In state level, the well recorded major flood events in Johor are that of 1926, 1931, 1947, 1954, 1957, 1963, 1965, 1967, 1969, 1971, 1973, 1979, 1983, 1988, 1993, 1998, 2001, 2003, 2004, 2006 and 2007. About 21 flood occurrences were recorded >81 years giving the average of 3.86 or probability of 26% chance of flooding each year. In December, 2006 and January, 2007, the Southern part of Johor including Sungai Pulai catchment experienced severe floods with return period (Annual Recurrence Interval, ARI) >100 years. This is the worst flood events in recent years occurred in quick succession. Major towns and cities suffering from the floods included areas in Iskandar region such as Johor Bahru, Kota Tinggi and Pontian have been flooded (Gasim *et al*., 2010; Kamarudin *et al*., 2009; Toriman *et al*., 2006). The December, 2006 flood was attributed to Typhoon Utor that hit the Philippines and Vietnam a few days earlier and that it was the reason for floods in Johor. Besides the continuous, widespread and very intense rainfall, some of the main reasons for the widespread flooding in the Johor state are low lying areas, land subsidence (peat swamp areas), inadequate drainage capacity and high spring tide. The second flood in January, 2007 (also referred to as the second wave flood) was worse than the first (that of December, 2006).

This was because of antecedent conditions due the first flood where the ground was already saturated and river flows were still high from the receding first flood in December, 2006. This second wave left Johor almost paralyzed when most districts were submerged by the flood. About 22,933 people were evacuated to relief centers.

Flood inundation map for Sungai Pulai catchment: Major flooding issues at Sungai Pulai catchment can be

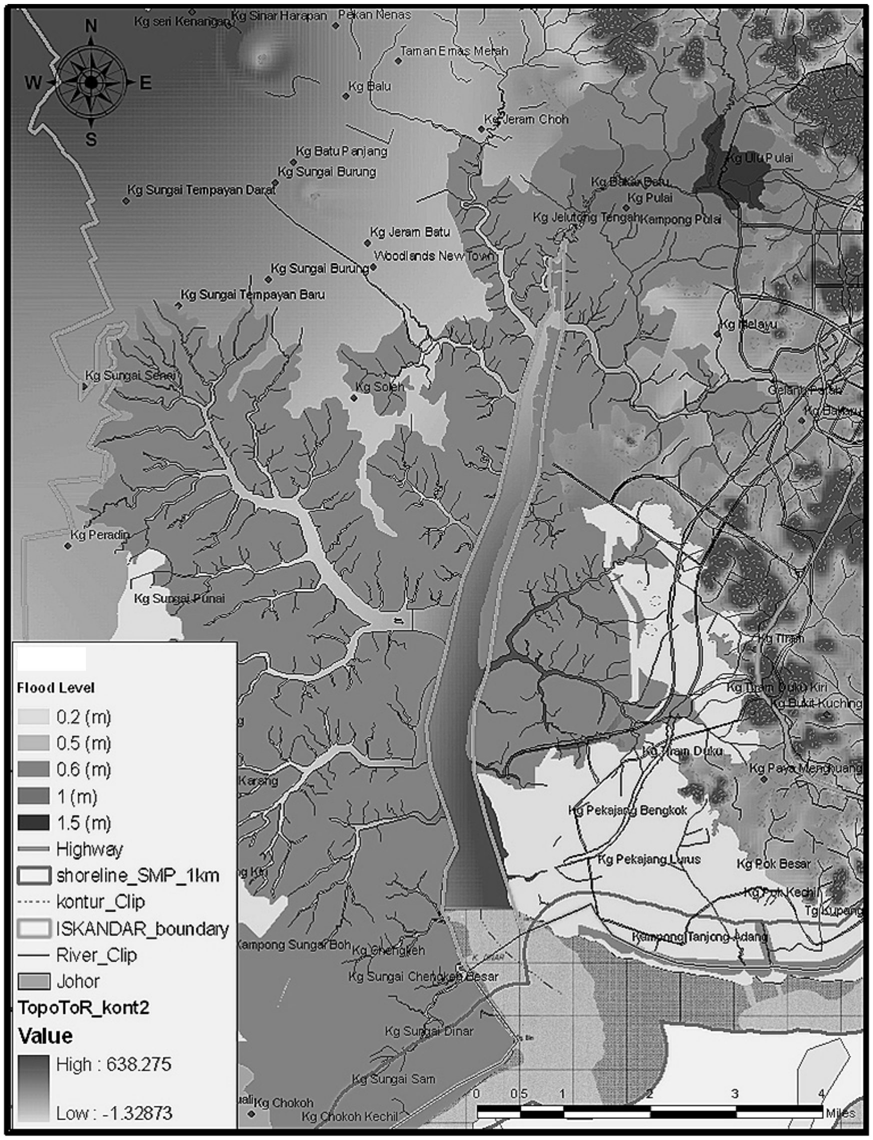

Fig. 2: Flood prone map for Sg. Pulai catchment

Table 1: Flood risk information based on flood depth (m) for Sungai Pulai catchment

Flood water level (m)	Area of inundation (km^2)	Major land use	Name of location
0.2	40.110	Urban, agriculture, swamp and forest	Kg. Ulu Pulai Kg. Sg. Choh Kompleks Penghulu Pekan Nanas Kg. Sawah
0.6	166.323	Urban, agriculture, forest and swamp	Kg. Ulu Pulai Kg. Sg. Choh Kompleks Penghulu Pekan Nanas Kg. Sawah
1.0	7.996	Urban, agriculture and forest	Kg. Ulu Pulai Kg. Sg. Choh Kompleks Penghulu Pekan Nanas Kg. Sawah
1.5	1.424	Agriculture and forest	Kg. Ulu Pulai Kg. Sg. Choh
Σ	206.433		

triggered by tidal flood and overland flow within the floodplain and lowland areas. Figure 2 shows flood prone area with subject to different flood level. Areas subject to flood including Kg. Ulu Pulai, Kg. Sg. Choh, Pekan Nanas and Jeram Batu with flood period is between 1-4 days. Detail flood map information is shown in Table 1.

CONCLUSION

Floods are uncontrollable natural events causing loss of lives and damage to public property. Flood maps produced by GIS in allow users to overlay additional digital information in the form of roads, buildings and critical facilities to give as much information as possible to land-use planners, local authorities, emergency services and the people who may be affected. XPSWMM hydrodynamic model and an integrated ArcView GIS were used to simulate water level, rainfall-runoff and generate flood map for the highest water depths obtained in the riverbed for the forecasted 50 years floods. In addition, the flooded areas corresponding to the maximum water depth (m) is obtained and presented in digital format for visual interpretation and further analysis. Generally, the study revealed for the strength and potential of a hydrological oriented XPSWMM-GIS as digital support system for flood forecasting and mapping.

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