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Generation Of Flood Inundation Model – General Approach And Methodology

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Abstract
This paper presents in general the approach, methodology and applied practice for the generation of flood inundation model. The generation of the model cover on: (1) data availability, (2) methodology, (3) flood modeling using the one-dimensional (1D) and two-dimensional (2D) hydrodynamic model, and (4) generation of flood inundation modelof integration of hydrodynamic model and flood mapping approach. The Sembrong River hydrodynamic model, Sembrong River flood mapping, and Kota Tinggi Flood Inundation Modeling are presented as an example.

Keywords: Hydrodynamic model; Flood map; Flood inundation map; Flood forecasting; Flood Risk Assessment.

I. INTRODUCTION

In the past decades, lots of damages occurred, directly or indirectly, by flooding. In fact, of all natural hazards, floods pose the most widely distributed natural hazards to life today.

A flood inundation model will be developed using hydrodynamic model and flood mapping approach. Calibration and validation of the model will be carried out using collected and historical hydrological data.

Thus the need of flood inundation modelling has increased in line with model developments and increased computational resources, but the possibility that simpler models may provide similar levels of predictive ability has not actually been considered [5].

2-Dimensional (2D) hydrodynamic models are best employed in conjunction with a Digital Elevation Model (DEM) of the channel and floodplain surface [4]. In conjunction with suitable inflow and outflow boundary conditions, allows the water depth and depth-averaged velocity to be computed at each computational node at each time step. The recent advancement in the computer technology enables the computer models to be developed by modelling the river system and perform a flood simulation, prediction can be made to avoid unexpected flood and remedial action can be taken earlier [4].Flood is well known as a silent killer. The damages caused by flood might cost a billion dollars. Damages widely occurred, to infrastructures, properties, in fact might as well capable of killing living things.

Generally, this paper presents the approach and methodology for data collection, modeling and integration of hydrodynamic model and flood mapping. Findings from previous study carried out by reference [4], at Kota Tinggi catchment area are presented as examples of the application practices for the generation of flood inundation model map in Johor.

II. APPROACH AND METHODOLOGY

Generally, the approach and methodology to generate a flood inundation map can be illustrated as in *Fig. 1*. Whereby, it covers the following steps:

- Comprehend the study area; site visiting.
- Data collections and site surveys.
- Develop hydrodynamic modeling and flood mapping.
- Generate a flood inundation map from the integration of hydrodynamic modeling and flood mapping output.

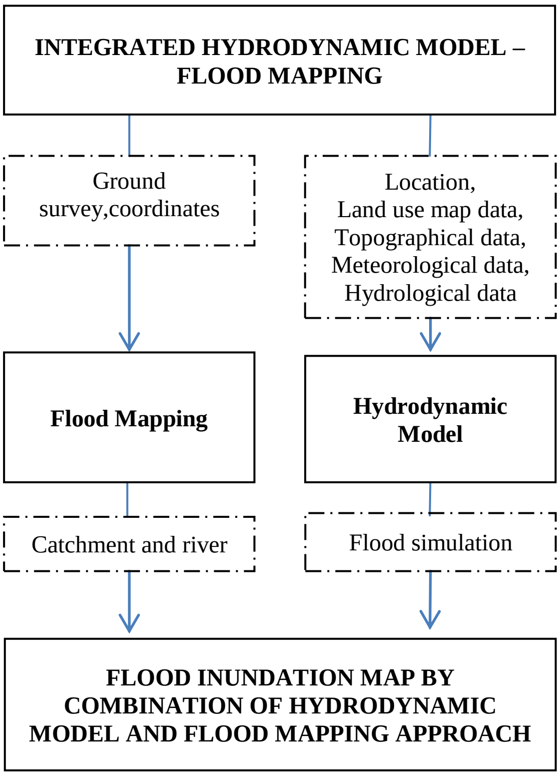

Fig. 1. Design flowchart of generation flood inundation map.

III. COMPREHEND THE STUDY AREA; SITE VISITING

Generally, a site visit and ground truthing is conducted are to be familiar, identify, and investigate the flood-prone area and flood-affected areas. Collected data such as maps, reports and previous studies are compared with those corresponding during the site visit. Furthermore, consultation, interviews and discussion on matters related to relevant authorities, flood victims and local people could help to understand the study area.

Inspections on floodplain physical characteristic, existing flood condition, flow behavior of pre and post flooding events are paramount and a must have data to be collected during site visits. Validation and calibration data are obtained from the historical flood event. Flood-affected area and flood-prone areas ought to visit with reference to geographical data.

IV. DATA COLLECTIONS AND SITE SURVEYS

Appropriate and comprehensive data collection are significant to the effectiveness of the flood inundation map. Therefore, data are collected and obtained either from survey works or secondary sources. Data collection may be divided into categories:

i) Topography, digital elevation models (DEM), and site survey

Appropriate selection of horizontal and vertical accuracy of the DEM has significant impact on the reliability and accuracy of the produced maps [6]. Furthermore, to develop a hydrodynamic model and flood map, river survey is paramount in order to develop reliable model.

Fig. 2 is the illustration of BatuPahat District land use map (DID, 2013).

ii) Historical data

During validation and calibration processes, historical data are the most important data to be collected. This is to ensure the model accuracy to simulate future flood event. Data such as the following are to be taken in:

- Historical flood event report
- Flood maps on related areas
- Newspaper reports or article relating previous flood event at the selected area
- Rainfall data from several stations
- Water level record in the selected area
- Stream flow and evaporation record

Fig. 3(a) and *Fig. 3 (b)*illustrates land use planning of BatuPahat district for 2002 and 2020 (DID, 2013).

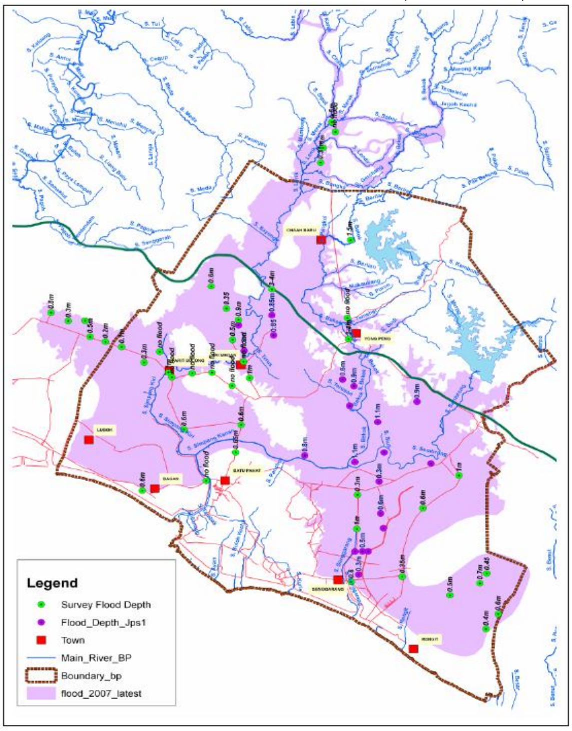

Fig. 2.Flood areas during the January 2007 flood eventintheBatuPahat district area, Johor. (DID, 2013)

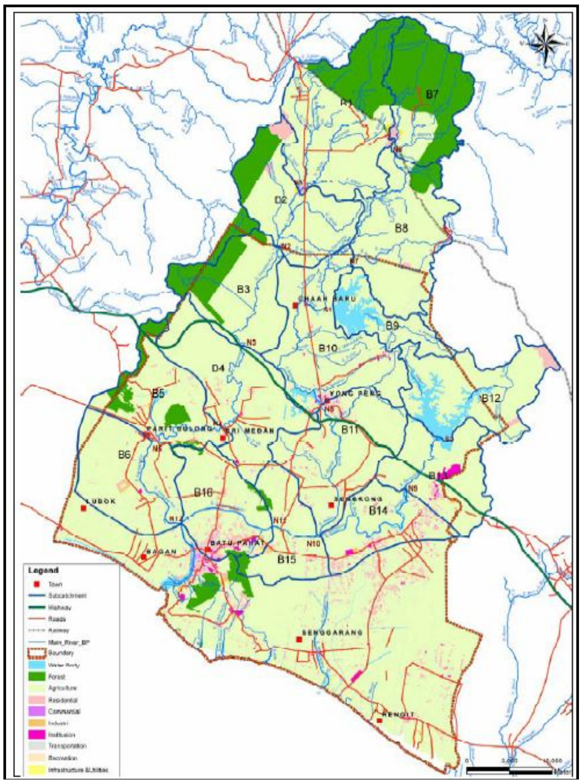

Fig. 3(a). Land Use Plan of BatuPahat District for year 2002. (Source: DrafRancanganTempatanDan Daerah 2002-2020)

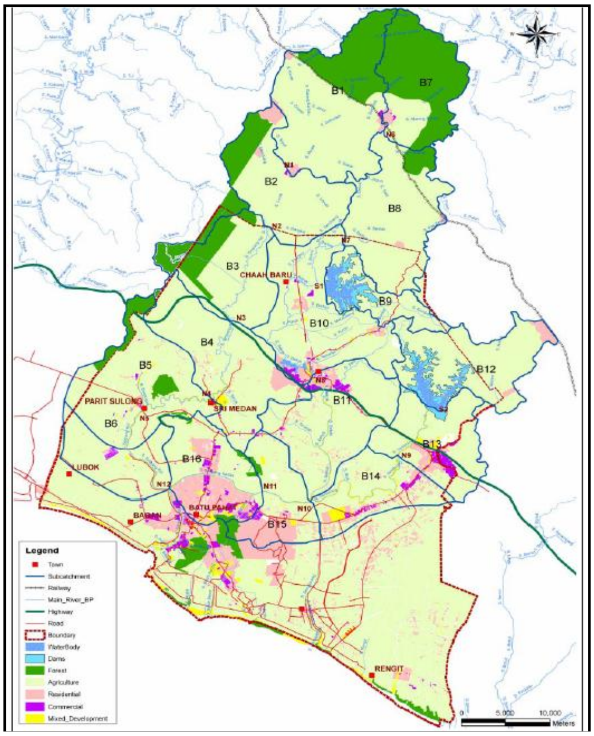

Fig. 3(b). Land Use Plan 2020 for the river basin in BatuPahat District. (DID, 2013)

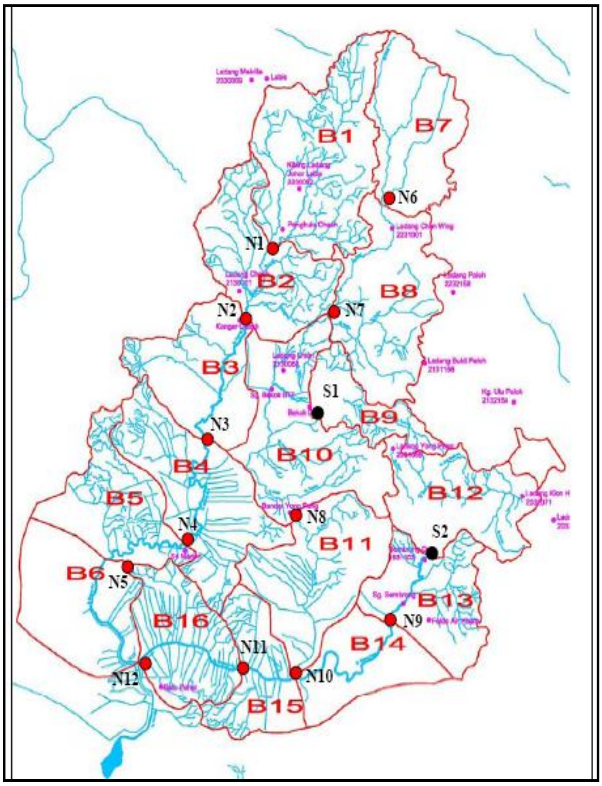

Fig. 4.BatuPahat River Basin shows the Subdivided Basins and location of Hydrological Stations. (DID, 2013)

iii) Land use data

In developing the HD model, land use data are needed in order to analyze *Runoff Mode* of the model. The followings are related land use data can be obtained from subjecting authorities:

- Soil map (reconnaissance map and land use map) – Department of Agriculture
- Value added map (hydrologic soil map, soil classification map) – Department of Agriculture
- Land use map (structural plan and local plan) – Department of Urban and Rural Planning

Fig. 4 shows subdivided basins of the BatuPahat River and the location of hydrological station.

V. HYDRODYNAMIC MODELING AND FLOOD MAPPING

A. Hydrodynamic modeling

Hydrodynamic is a study of liquid motion and specifically, water. The tool which describes or represents in some way the motion of water is called hydrodynamic modelling. Before the advent widely available computer systems, a hydrodynamic model could in fact be the physical model built to scale. However, virtually all hydrodynamic models in use today are computational numerical models.

One-dimensional (1D) model is the traditional approach to simulate flow in river channels. 1D modelis often used to mathematically represent flow routing along a river reach [2]. One-dimensional (1D) model is unable to accommodate the true physical and hydrodynamic conditions that are critical to understand different river processes [3]. In additional, 1D model has few limitations such as inability to represent detailed bathymetry that affect river process. Furthermore, the 1D model unable to simulate hydrodynamic conditions those are prevalent during large scale extreme events such as river flooding and glacial out-burst floods. In fact, this 1D model also unable to represent and simulate complex river systems, for example anastomosing river. However, some researchers have the opposite opinion.

Basically, in most 1D hydrodynamic models are based on 1D unsteady state gradually varied flow equations, this basic formulais the St. Venant equations. As in (1) shows the mass conversion or continuity equation, whilst (2) is the momentum conversion or dynamic equation. Both equations are applicable for 1D hydrodynamic modeling.

$$\frac{\delta Q}{\delta x} + \frac{\delta A}{\delta t} = c \qquad (1)$$

$$\frac{\delta Q}{\delta t} + \frac{\delta}{\delta x}\left[\frac{\beta Q^2}{A}\right] + gA\left[\frac{\delta h}{\delta x} - S_0\right] + g\frac{AQ|Q|}{K^2} = 0 \qquad (2)$$

Where:

$Q(x,t)$ = discharge (m^3/s)
t = time (s)
x = streamwise direction (m)
c = lateral inflow per unit length of flow
$A(x,t)$ = cross-sectional area (m^2)
g = gravitational acceleration (m/s^2)
h = water level (m)
S_0 = bed slope (m/m)
K = conveyance (m^3/s)
β = Boussinesq coefficient

$$\frac{\delta Q}{\delta t} \text{is the local acceleration term.}$$

$$\frac{\delta}{\delta x}\left[\frac{\beta Q^2}{A}\right] \text{is convective term(responsible for non} - \text{linearity of equation).}$$

$$gA\left[\frac{\delta h}{\delta x} - S_0\right] \text{is pressure term due to change in depth over reach} - \text{ if } S_0 \text{ is neglected then } \frac{dh}{dx} \text{approximates thefriction slope based on the change in water level.}$$

$$g\frac{AQ|Q|}{K^2} \text{is source/gravity term causes water to flow.}$$

Fig. 5, *Fig. 6*, and *Fig. 7* shows example hydrograph generation, analysis process and the result in 1D hydrodynamic model.

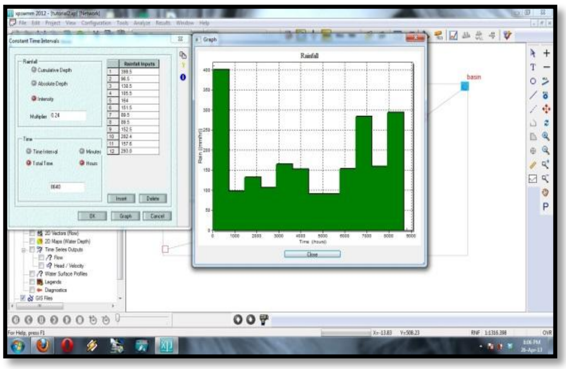

Fig. 5.Example of hydrograph generation of Sembrong River catchment area using Xpswmm tool.

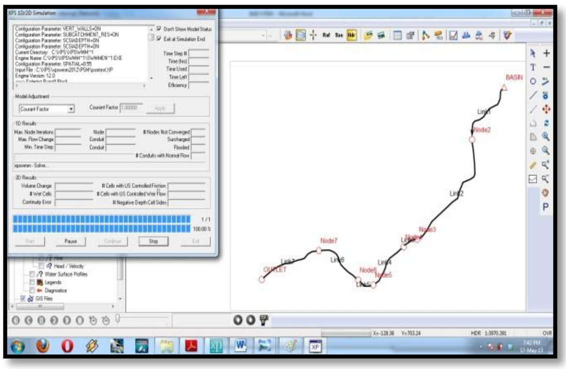

Fig. 6.Example of running analysis in Xpswmm for Sembrong River, Johor.

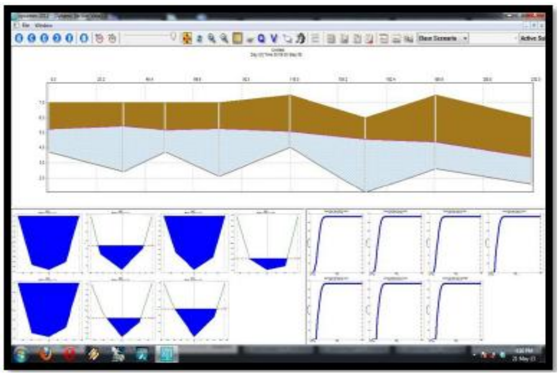

Fig. 7.Example of analysis result in 1D hydrodynamic model of Sembrong River, Johor.

Use the same principle as 1D hydrodynamic model mass conversion/continuity equation, 2D shallow water equation was introduced as follows:

$$\frac{\delta h}{\delta t} + \frac{\delta (uh)}{\delta x} + \frac{\delta (vh)}{\delta y} = 0 \qquad (3)$$

According to (3), the y axis orthogonal to the x axis, and its flow velocity v (m/s) associated.

B. Flood mapping

To describe flood patterns, the most proper approach is by developing flood mapping. As in [1], flood map can be categorized as followings:

- Flood danger map – shows the spatial distribution of the flood danger without information about the exceedence probability.
- Flood hazard maps – shows the spatial distribution of the flood hazard, i.e. information on flood intensity and probability of occurrence of single or several flood scenarios.
- Flood vulnerability map – shows the spatial distribution of the flood vulnerability, i.e. information about the exposure and/or the susceptibility of flood-prone elements (population, built environment, natural environment).
- Flood damage risk map – shows the spatial distribution of the flood damage risk, i.e. the expected damage for single or several events with a certain acceptance probability.

Developing a 3D map is time consuming, challenging and of course highly cost. A set of detail fieldwork dataset consist of Northing Easting magnitude and elevation is needed. Field survey has to be conducted in order to obtain the fieldwork dataset. In creating a 3D flood map, northing easting magnitudes are presented as x-axis and y-axis, and z is presenting elevation. Z value then connected along the lines of constants X and Y to create wireframes right after contour lines are produced. Digital Elevation Model (DEM) has to be setup for overlapping process in order to create a 3D map. For an impressive flood map, kriging gridding method can be used as interpolation techniques [4].
Fig. 8 below shows the dataset of XYZ, *Fig. 9* till *Fig. 12* shows examples of the contour map, wireframes, 2D and 3D maps for a Sembrong River catchment area.

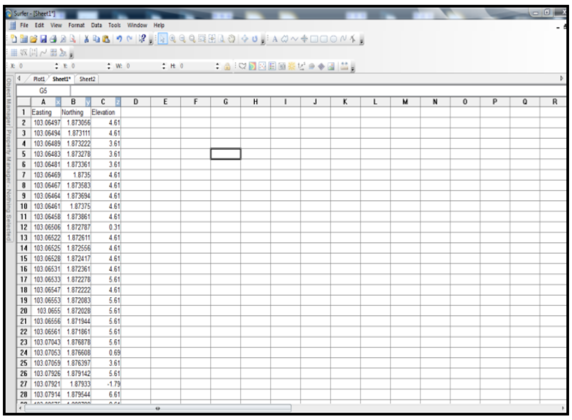

Fig. 8. Example of a data set consists of a northing easting magnitude and elevation.

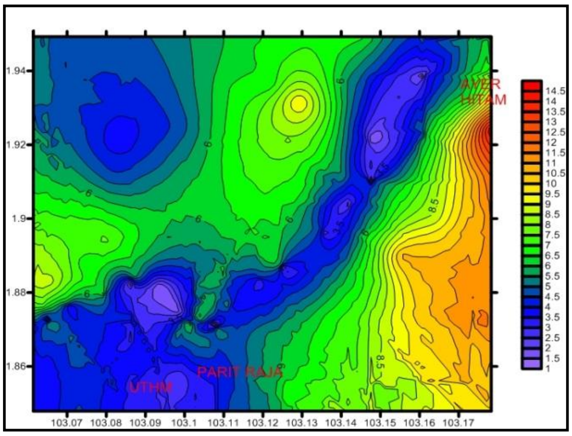

Fig. 9. Example of contour lines produced for Sembrong River, Johor.

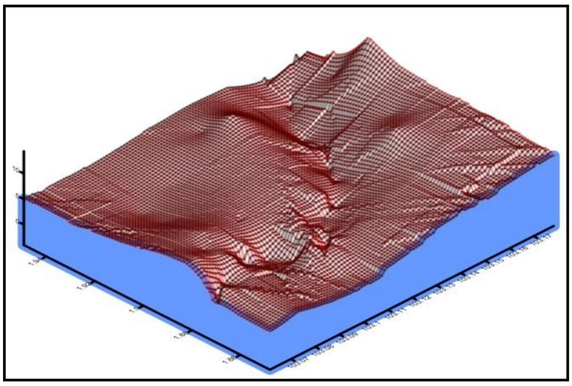

Fig. 10. Example of wireframe produced for Sembrong River catchment area.

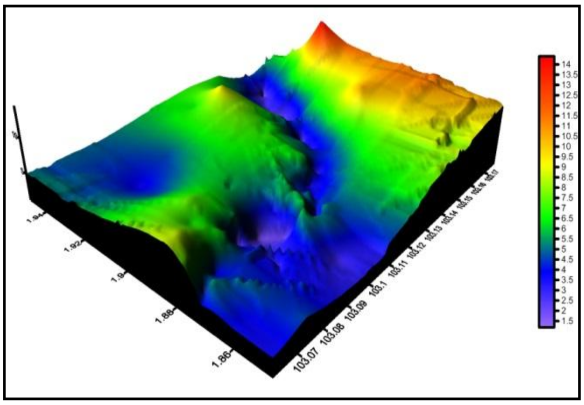

Fig. 11. Example of 3D map produced for Sembrong River catchment area.

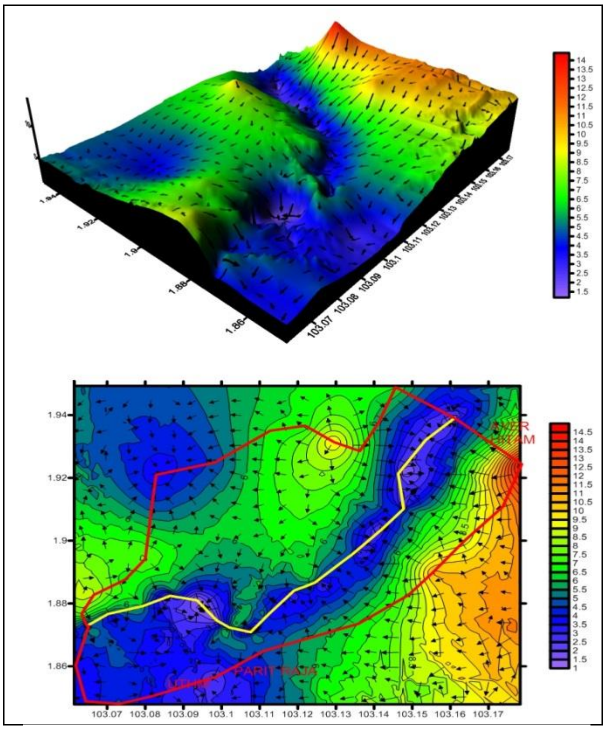

Fig. 12. Examples of 3D and 2D maps indicate water movement into Sembrong River.

VI. FLOOD INUNDATION MAP – INTEGRATION OF HYDRODYNAMIC MODEL AND FLOOD MAPPING APPROACH

A flood inundation model is developed with integration of hydrodynamic model and flood mapping approach. The results of the flood simulation of hydrodynamic model will be visualized through the development of flood map. A flood inundation model for a certain historical flood event will be constructed for analysis to produce an inundation map. With flood mapping approach, catchment and river mapping will be produced, and flood simulation results will be obtained from developinga hydrodynamic model. The results of flood mapping and hydrodynamic model will be combined through semi-automated process where the topography will subtract from the water surface to get the inundation extent.

Before finalizing the flood inundation model, validation and calibration are a crucial step to be done in order to minimize the discrepancies between the developed model and the ancient river condition.

Fig. 13 below shows the example of flood inundation model for Kota Tinggi River for January 12th, 2007 event.

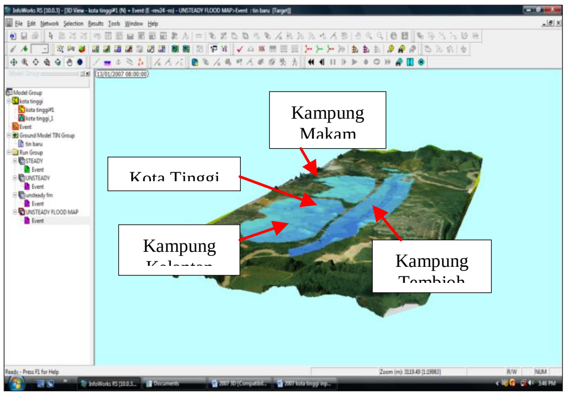

Fig. 13.Example of flood inundation model for Kota Tinggi River.

VII. CONCLUSION AND RECOMMENDATIONS

The flood inundation model could be very useful and valuable tools in flood management of river basins in Malaysia. It may be used as a tool for rivers development planning, flood mitigation measures, addressing public awareness, and flood evacuation planning.

As a flood inundation model would be very useful and helpful for local authorities in flood management, however to obtain the information needed to develop the model is difficult and complicated. Therefore, it is recommended that flood information, data needed to develop the model and developed model are compiled in web-based system. By this way, the information can easily retrieve and disseminate either by public or professionals.

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