Flood map of Tupai River using combined 1D and 2D modeling

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ABSTRACT
Flooding is the most severe hazard in Malaysia, a country experiencing a wet equatorial climate with heavy seasonal monsoon rains (Pin-Shuo, 2003) and people lived in flood prone areas were identified as the most vulnerable to flood hazard. However, these flood prone area provide very good locations for urban expansion and development (Al-Fuagara, 2008). With the computer modeling technology flood event can be modeled and presented in graphic. In Malaysia, most of the flood modeling is in one dimensional (1D). 1D modeling can provide extremely good information about floodplain flows and depths. This technique is good in modeling flood within a river channel where direction of flood is known or can easily assume. However when information on direction and overland flow velocities is required, the better solution is to use two dimensional (2D) modeling. Nowadays, most of the modeling technique uses combination of 1D and 2D. By using 1D simulation to identify where flooding happens, and then using the combined 1D and 2D simulation to investigate the direction and depth of flood flows in these areas, users can achieve a cost-effective balance between model-building time and simulation accuracy. This study was about using 1D and 2D modeling technique on Tupai River as it serve as the main natural drainage for the town of Taiping, heavily urbanized and prone to flooding in Infoworks RS and with the help of Geographical Information System.

Keywords: River; flood; 1D; 2D; 1D & 2D modeling; Infoworks RS.

1 Introduction

Flooding is the most severe hazard in Malaysia, a country experiencing a wet equatorial climate with heavy seasonal monsoon rains (Pin-Shuo, 2003) and people who lived in flood prone areas are the most vulnerable to flood hazard.

In February 2006, the city of Shah Alam was inundated by flood waters with 4000 houses affected and 1240 people had been evacuated to relief centers. In October the same year, 4 states were affected by flood with Johor posed the most damages with about 90,000 people had been evacuated and massive loses of business and agricultural production had been reported. To worsen the condition, many parts of Johor was again submerged in January 2007. The damages increased with more than 100,000 people evacuated.

To better understand flood plain and flood behavior, a model that can represent the situation need to be created. Haestad (2003) stated that physical model is not suitable for flood plain modeling. Computer assisted flood plain model was the better choice as it low cost and easier to set-up.

The One Dimensional (1D) hydrodynamic modeling approach has been widely used in modeling flood due to its computational efficiency, ease of parameterization and easy representation of hydraulic structures in dealing with flows in large and complex networks of channels on the surface (Seyoum, 2011).

However a 1D model, when applied to floodplain flows neglect some important aspects and suffer from a number of drawbacks including the inability to simulate lateral diffusion of the flood wave, the discretization of topography as cross sections rather than as a surface and the subjectivity of cross-section location and orientation (Hunter et al. 2007; Kuiry 2010).

Mark et al. 2004 and Leandro et al. 2009, suggest that 1D surface model are economical, robust and preferred alternatives as long as the flow paths can be identified. However, during heavy flooding the 1D approximation may be insufficient and the use of 2D models to describe the surface flow is preferred.

This study shows how to produce flood maps on Tupai River using 1D and 2D coupling modeling technique. For this particular study, the modeling was done in Infoworks RS 11.5 from Innovyze (formally known as MHWSoft) and ArcGIS 9.3 from ESRI.

2 Study site

Tupai River located in the Larut Matang and Selama District, northern part of The State of Perak. Flowing more than 7.5 km in length from the Bukit Larut, and a catchment of 13.5 km², Tupai River serves the drainage system of Taiping Town, Tupai industrial area, Pokok Assam Village, Simpang residential and business area.

Tupai River has a steep upper catchment with a flat lower catchment. The upper catchment mainly forested with some development. The middle and lower catchment is made up of town area.

Figure 1 Study Site

The Taiping Drainage Master Plan (1994) reported that flooding which occurs at Tupai River along Pokok Assam Road was due to uncontrolled development of the uplands and the inability of the present rivers and drainage system to cope with the increase discharge.

Lower Section Middle Section

Upper Section

Figure 2 Tupai River Sections

Department of Irrigation and Drainage (DID) Larut, Matang and Selama District reported that the worst flood in Sg. Tupai catchment was in June 2008. 400 houses submerge in 0.2 to 0.8 meters flood waters and 70 people evacuated in the event.

Lower Section Middle Section

Upper Section

Figure 3 2008 Flooding on Tupai River

3 Data collection

Basic input needed for hydrodynamic modelings are spatial and non-spatial data.

3.1 Spatial data

Spatial data includes description of terrain related to the stream channel such as the entire river network, terrain cross sections along the streams, stream bed resistance and hydraulic structures such as culverts and bridges (Al-Fuagara et al. 2008).

River sections, structures and part of flood plain area were made available from survey works done by Department of Irrigation & Drainage Larut, Matang & Selama District.

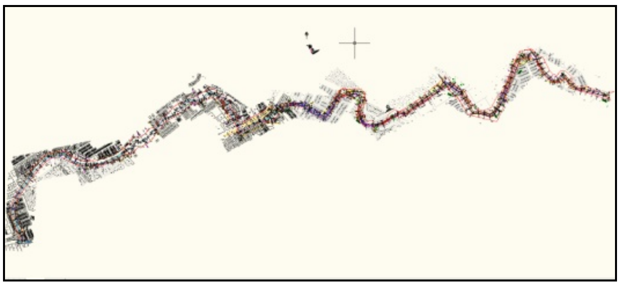

Figure 4 Tupai River Survey

The study area only covers 13.5 km^2. At the time of the study, only Department of Mapping and Survey (JUPEM) published topographic maps and river survey maps available for the study.

At 20m point interval, elevation structure such as road, bunds, even building are partly visible in the topographic maps and the river surveys conducted by DID Larut, Matang & Selama District only covers 75m river cross-sectional width.

Additional spot survey was made along the river to cover the whole flood plain area.

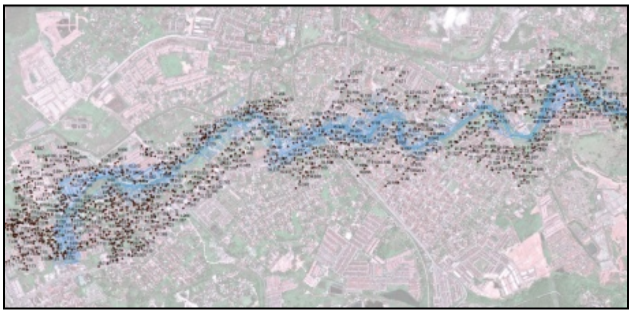

Figure 5 : Spot Survey

3.2 Non-spatial data

Rainfall data from 1971 to 2010 were collected from DID Malaysia for Bukit Larut Station. However, only data from 1981 to 2005 were chosen for the frequency analysis.

4 Data processing

4.1 River Section

DID Larut Matang & Selama District has conducted a survey on Tupai River in 2008. There are 2 ways of importing river cross-sections into Infoworks RS, either by manually drawing cross-sections one by one or by importing directly from AutoCAD drawing. The later reduced time considerably and can be used for other purposes such as digital terrain model (DTM) development and presentation.

4.2 Flood Plain Digital Terrain Data Development

Contours from JUPEM's topographic map, cross-sections from river survey and points from the additional spot survey map was combined in ARCView GIS and converted into Triangulate Irregular Network (TIN).

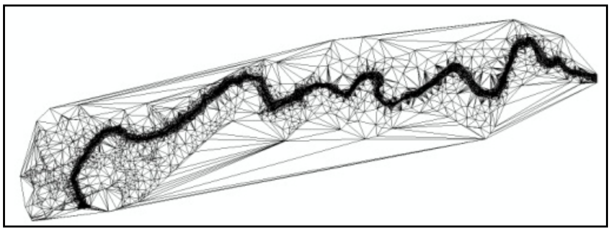

Figure 6 TIN

4.3 Catchment Properties

Rainfall data from Bukit Larut Station was processed in Stormwater Management and Design Aid (SMADA) Program. Using Distribution analysis on the data, Intensity Vs Duration Curves were developed for the selected design Average Rainfall Intensities (ARI).

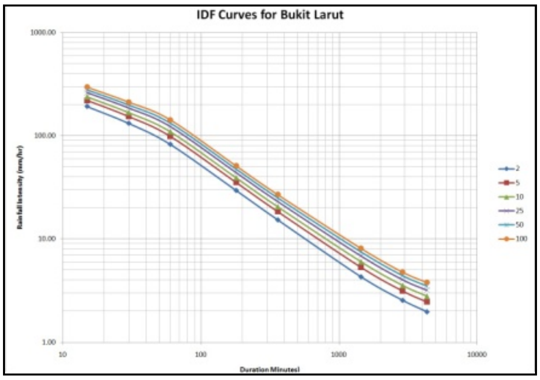

Figure 7 IDF Curves for Bukit Larut Station

Hassan, 2006, recommended the use of preliminary runoff Curve Number (CN) values based on United States Soil Conservation Services value. These values were tailored to the land use map from Department of Planning and Development.

Table 1 CN Value

Land Use Type	CN
Water Body	100
Industrial Area	90
Residential Area	90
Vacant Land	60
Recreational/Open Space Area	80
Business & Service Area	90
Instituitional Area	90
Transportational Area	90
Infrastructure and utility Area	90
Agricultural Area	70

In ArcView GIS, land use map overlaid unto soil map and subcatchments boundary. Curve No (CN) was calculated by averaging the CN within the same subcatchment using formula written below.

$$CN = \frac{\sum_{i=1}^{n} CN_i * A_i}{\sum A_i} \quad (1)$$

Where CN_i = CN for land use i
A_i = Area for land use i

Tc (Time of Concentration), for each subcatchment was calculated using Bransby-William equation as recommended in MsMA.

$$Tc = 58.5 * \frac{L}{A^{0.1} S^{0.2}} \text{ (Minutes)} \quad (2)$$

Where L = Length in km
A = catchment area in km²
S = Slope in m/km

And Time to Peak (Tp) was calculated using US-SCS method

$$Tp = \frac{D}{2} + 0.6 \cdot Tc \text{ (Hours)} \qquad (3)$$

Where D = Excess Rainfall in hours
Tc = Time of concentration in hours

Catchment base flow was calculated based on recommended figure in HP 11 which is 0.055 $m^3/s/km^2$.

Table 2 Boundary node properties

BD Node ID	Area (km2)	Base Flow (m3/s)	Curve No	Tp (Hours)
1	0.050	0.003	88	0.5
2	0.086	0.005	87	1.0
3	0.070	0.004	87	1.0
4	0.175	0.010	88	1.0
5	0.105	0.006	89	0.5
⇕	⇕	⇕	⇕	⇕
29	0.051	0.003	85	1.0
30	0.737	0.041	87	1.0
31	0.113	0.006	87	1.0
32	0.051	0.003	89	0.5
33	3.400	0.187	54	1.5

4.4 *Stream/River Properties*

The Gauckler–Manning coefficient, often denoted as n, is dependent on many factors, including surface roughness and sinuosity. The n value is one of the important parameter in hydraulic calculations especially in open channel flow.

From Manning's formula, the value of n can be describe as

$$n = A \cdot \frac{R^{2/3} S^{1/2}}{Q} \qquad (4)$$

Where A = area in m²
R = wetted perimeter
S = Slope in m/m

7 locations were selected to represent the river. The value of A, R and S were measured on site and the value of Q was calculated from a flow meter reading.

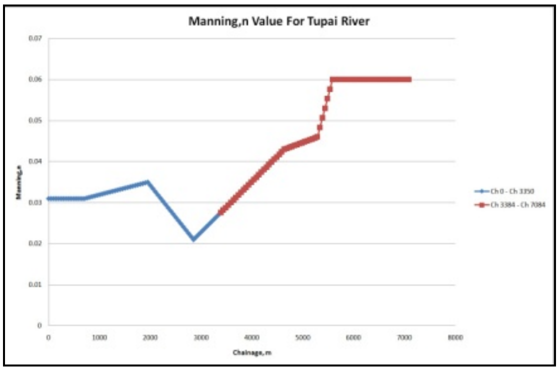

Figure 8 Manning n value

Flow data (stage and discharge) was derived from channel hydraulic capability as there was no measured data available.

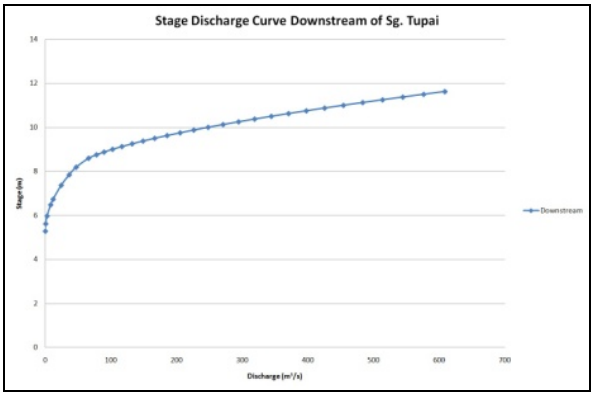

Figure 9 Stage & Discharge Relationship

5 Modeling

Modeling of the flood event was divided into 2 models. River channel modeled in 1D and flood plain modeled in 2D. 1D and 2D model connected by a spill unit in every cross-sections.

5.1 *1D Modeling*

River Network were created from the river survey (Figure 4) and link to each other from upstream to downstream. Manning, n values were taken from Figure 8.

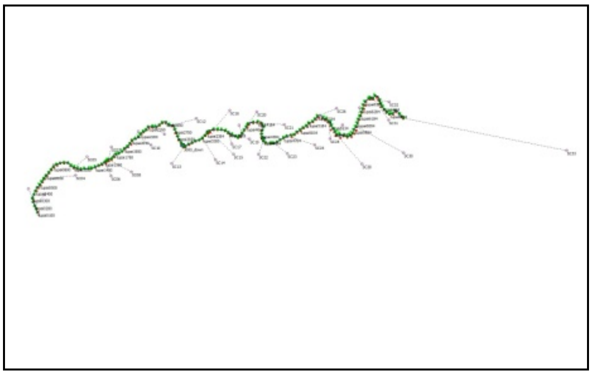

Figure 10 River Network contains cross-sections and boundary nodes

At the downstream of the network, a boundary condition was set-up using flow data from Figure 9.

Boundary nodes that represent subcatchments contain informations as listed in

Table **2**. Location of the nodes were based on subcatchment boundaries and connected to a cross-section at the outlet to the river.

Test on rainfall duration (refer to Figure 11)has indicated that the critical duration for the study area is 180 minutes. Therefore design rainfall duration of 180 minutes were adopted in the analysis.

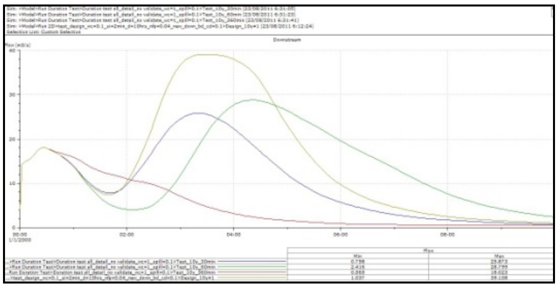

Figure 11 Discharge at downstream for different rainfall duration

Design Rainfall Pattern in Figure 12 was used in the model to develop discharge hydrograph for each sub catchment for a particular event. This Design Rainfall Pattern was produce using suggested urban rainfall pattern in Manual Saliran Mesra Alam (MaSMA).

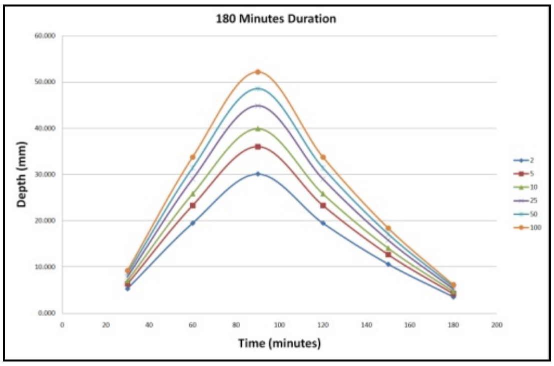

Figure 12 Design Rainfall

5.2 2D Flood Plain Modeling

In 2D modeling, the demarcation of flood inundated area is simpler than 1D modeling. 2D simulation boundaries can be created along the river without knowing exactly where the flooding will occur. However, slow computing time should be expected.

In this study, two 2D simulation boundaries were created along the river based on year 2008 flood event.

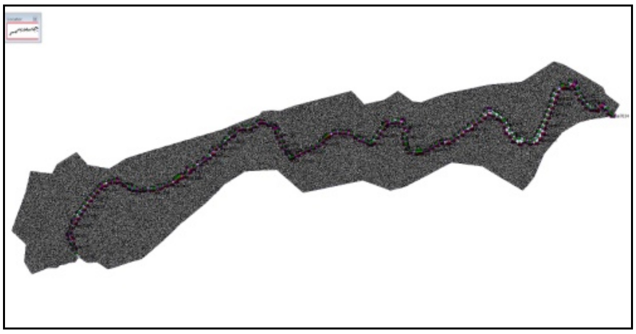

Figure 13 2D Simulation Boundary

2D Meshes in the boundaries were generated within Infoworks using Shewchuk Triangle meshing functionality. Heights at the vertices of the generated mesh elements are calculated by interpolation from Figure 6.

1D river network nodes and 2D flood plain meshes were connected using spill units linked to a cross-section node.

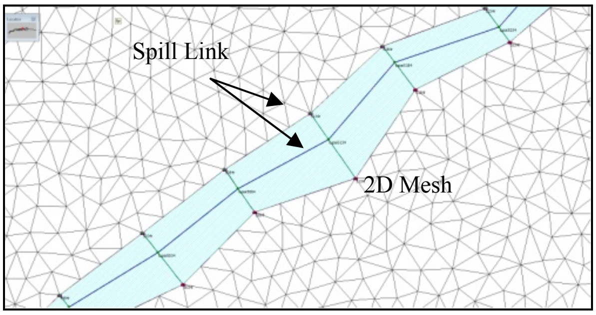

Figure 14 2D Mesh and Spill

6 Result

A run on the model for 100 year design return period produced flood map for the study area as Figure 15 below.

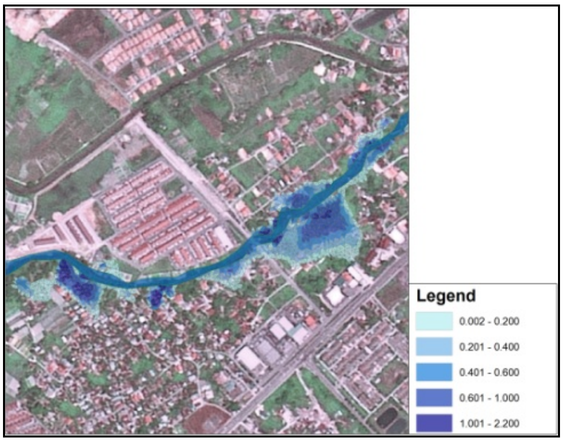

Figure 15 100 years ARI Flood Extent

Surface velocity information as in Figure 16, can be use for further analysis especially in assessing damages done by flood waters and potential hazard to the people affected.

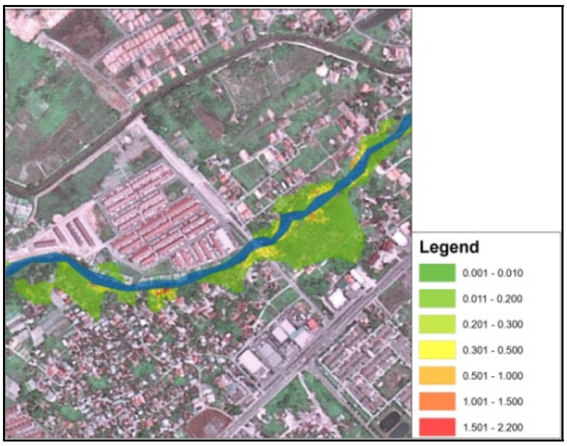

Figure 16 Velocity variation at maximum extent

Figure 17 demostrate the direction of flood water flow busting out from the river bank.

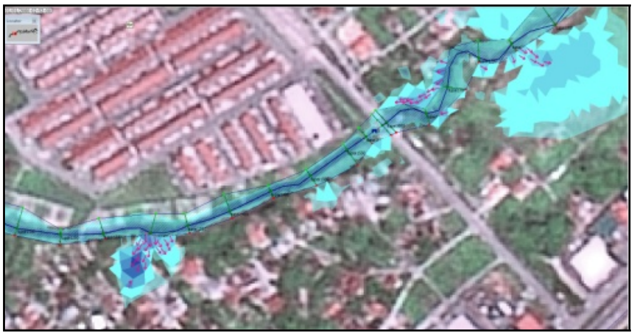

Figure 17 Flow Direction at 2.50 Hours

At 4.30 hours the flood water goes back into the river. The pink arrows in Figure 18 shows where the flood water from an upper section flows back into the river through another section.

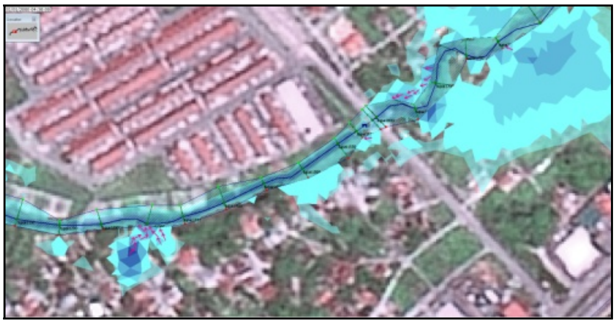

Figure 18 Flow Direction at 4.30 Hours

7 Conclusion

Combined or hybrid 1D and 2D modeling is now and the way forward in flood modeling.

Cost-effective balance between model-building time and simulation accuracy to describe flow in the channel stream and the surface flow in the flood plain can be achieve with 1D and 2D modeled together.

Acknowledgement

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