# Flood Inundation Analysis Using HEC-6 and ArcView GIS 3.2a

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An integration procedure namely AVHEC6.avx has been created between ArcView GIS 3.2a and HEC-6 hydraulic model to perform flood inundation analysis. The procedure was tested using hydraulic and hydrological data for Pari River channel and floodplain with the reach approximately 4 km long. HEC-6 Model was simulated using Yang sediment transport equation with four flood hydrograph in 12 difference flooding scenarios and subsequent flood inundation maps were produced. The flood plain visualization was further enhanced using the ArcView Spatial Analysis and 3D Analysis. The results of these research clearly show that incorporating floodplain geometric data besides river channel data in the modeling process can produce more accurate flood plain maps. GIS is proven to provides an effective environment for flood inundation mapping and analysis. The research has further extended in the development of an embedded floodrisk analysis model that has fully operates in the GIS environment.

## Introduction

The increasing availability of very high performance GIS software packages such as ArcView GIS and ARC/INFO offers new opportunities for engineers to perform flood inundation analysis in conjunction with hydraulic models with interactive visualization within immersive decision support environments (Tate *et al.*, 1999; Ab. Ghani *et al.*, 1999; Sinnakaudan *et al.*, 2001[b]). The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the diverse sets of geo-referenced data (McDonnell, 1996; Sinnakaudan *et al.*, 2001[a]; Noman *et al.*, 2001; Anrysiak, 2000). On the other hand, hydraulics is inherently spatial and hydraulic models have large spatially distributed data requirements. The integration of hydraulics and GIS is therefore quite natural.

This paper describes the development of such a system - an ArcView GIS 3.2a extension namely AVHEC-6.avx written in an Avenue Script language and Dialog Designer to integrate with HEC-6 hydraulic model. The desire to integrate data and applications from HEC-6, an independent hydraulic and sediment transport model, is based on the limitations in stand alone hydraulic model analysis performed by researchers like Ab.Ghani *et al* (1998), Abu Hassan (1998); Ab.Ghani *et al* (1999); Yahaya (1999) and Tan (2000). The numerical output of the HEC-6 hydraulic models can be extremely voluminous and requires tedious hours of manual plotting to perform various engineering analysis (Sinnakaudan *et al.,* 2001[a], Sinnakaudan *et al.*, 2001[b], Ab. Ghani *et al.*, 1999). Abu Hassan (1998) further ease the HEC-6 output analysis by developing a Microsoft Excel 97 Macro which can be used to plot various analytical graphs with few *point & click* options. However the results still fail to show the actual flooded

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location and possible risk to the structures such as building and roads in the area in inundation maps (Sinnakaudan *et al.*, 2001[a]).

### *The study area*

The flood risk model was tested using the hydraulic and hydrological data from Pari River catchment area with the study reach is approximately 4 km long (Fig. 1). Pari river has a history of frequent flooding problems. Some of the areas badly affected by flood are Buntung New Village, Tengku Hussein Village, Datuk Ahmad Said Village, Manjoi Village, Kati River Village, and the housing areas such as Pari Garden, Merdeka Garden, Hock Aun Garden, Lim Garden, Cherry Park, Sungai Pari Tower (DID, 1994; Sinnakaudan, 1996; Ab. Ghani *et al*., 1999) Koo Chong Kong Road, Along Pari River Towers (Sinnakaudan, 1996). A study conducted within 375 flood plain dwellors by Sinnakaudan (1996) shows that the flooding problems are getting worse compared to previous years (Fig. 2). Some of the flooding scenarious shown in Fig. 3. The flood mitigation project for Pari River for a length of about 8 kilometres (Ab. Ghani *et al*., 1999) was launched in 1992 with a design channel with 50 years ARI and recently the bund level has been raised to cater more discharge in recent floods. However it can only be considered as short term solution for the flooding problem in Pari floodplains.

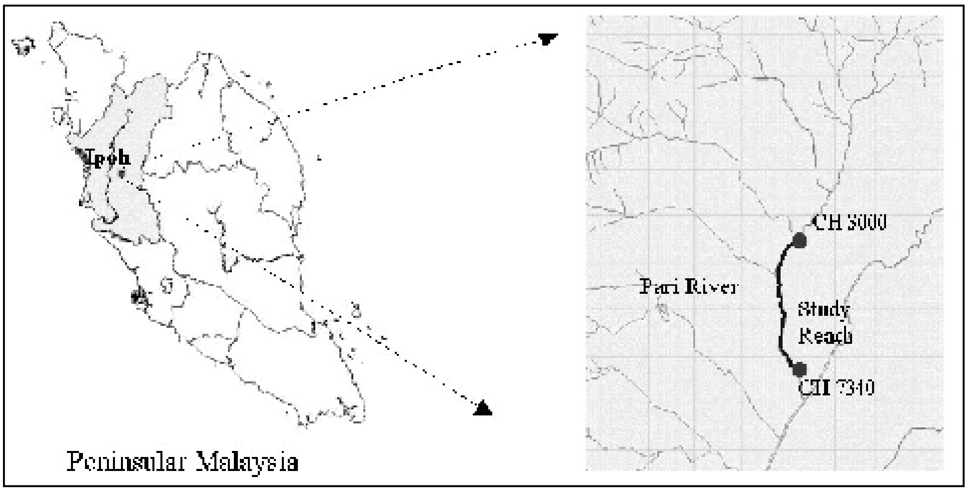



Fig 1. Study Area -Pari River

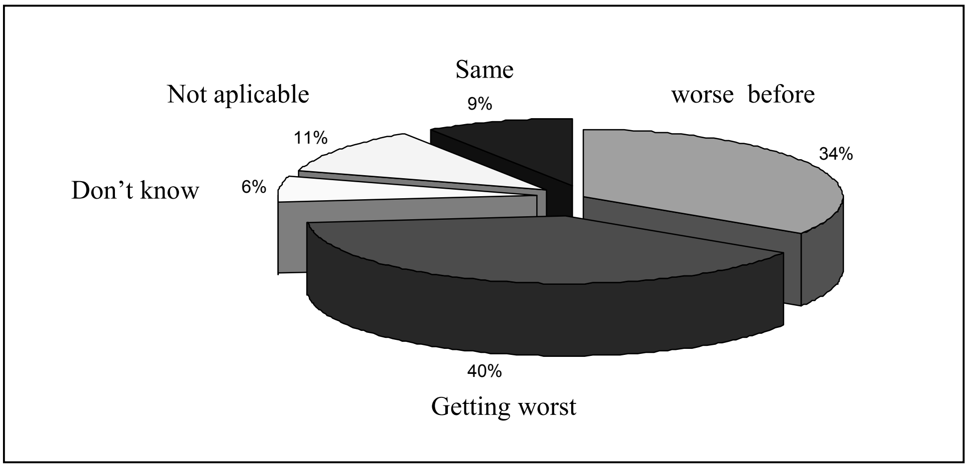



Fig 2. Perception of the floodplain dwellors (Sinnakaudan, 1996)

a. Flood damage at the back of a house in Manjoi Village, Pari River during the 5 Disember 1996 Flood (Sinnakaudan, 1996)

b. Pari River overflow during flood on 19th September 1997 (Sinnakaudan *et al*., 2001[a])

Fig.3. Flood Scenarios at Pari River

## *The Methodology*

The hydraulic modelling and spatial integration involves five major components: (1) HEC-6 hydraulic model simulation (2) Spatial data construction (3) Development of AVHEC-6.avx Integration procedure (4) Integration of spatial model layers and HEC-6 output (5) Flood inundation mapping.

## *HEC-6 Hydraulic Model Simulation*

HEC-6 is a one-dimensional movable boundary open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and/or deposition in rivers (ASCE, 1993). Three main input data components for HEC-6 model are Geometry Data, Sediment Data and Discharge Hydrograph. The elevation mass points, cross section, bed forms and other physical characteristic of the river were obtained from the river survey and hydrograph between August and November 1997 provided by Department of Irrigation and Drainage Malaysia (DID). Extensive field data samplings on sediment transport in Pari River were carried out to obtain sediment distribution size and sediment load. The geometric representation of study reach in HEC-6 model is done by series of standard 20 metres interval cross sections with the total of 213 sections. Each section has a range of 124 – 138 station-elevation points. HEC-6 Model was simulated using 1997 flood hydrograph, design flood hydrograph for 50 year ARI (present land use condition) and 100 year ARI (future land use conditions - year 2020 and 2060). The sediment transport processes were simulated using Yang equation that gives the best overall estimation of the observed sediment transport rate with 70 percent of the prediction within discrepancy ratio of 0.5 and 2.0. The previous study which used for comparison limits the hydraulic representation of channel with a total of 108 cross-sections which has 3 metre to 70 metres interval and a range of 18 to 23 station-elevation points. A sample input and output file portion is shown in Fig 4. and Fig 5. Although HEC-6 gives a variety of output control options, the only output has the great intrest in this study is the water surface elevation at each cross section for diffrent flooding events.

An areal interpolated 4 metres resolution DEM was used to obtain elevation points for floodplains as shown in Fig 6.0. The original elevation data for the DEM was obtained from contours, spot heights, finish floor levels, finish road levels and field surveys.

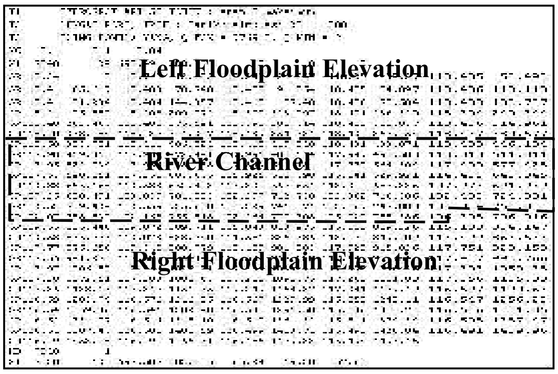



Fig. 4 Input File for HEC-6 Model

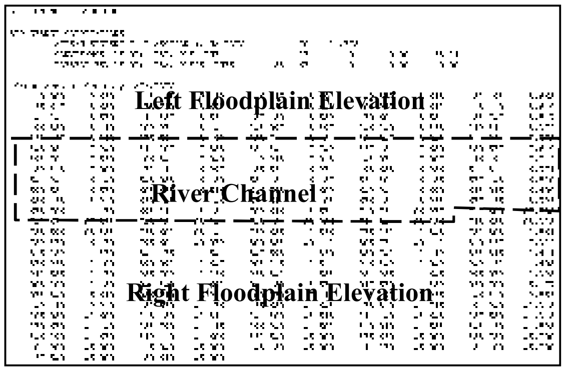



Fig. 5 Output File for HEC-6 Model

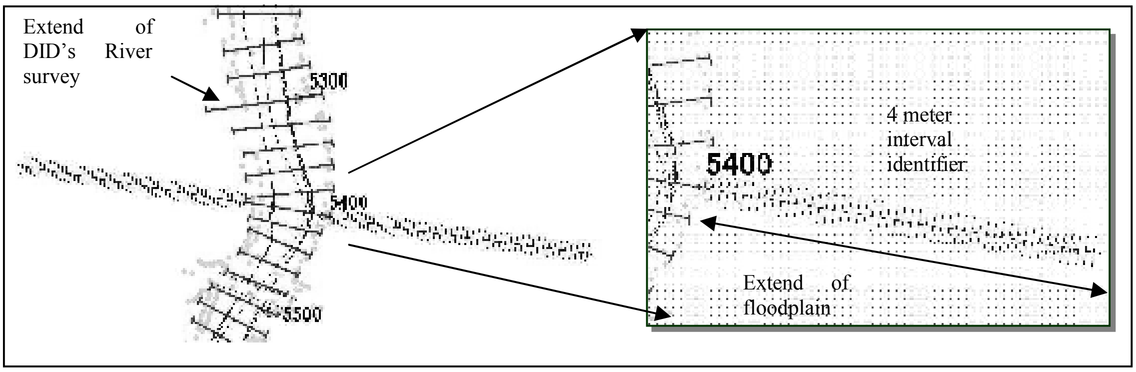



Fig 6. Elevation sources for river channel and flood plain

### *Spatial data construction*

An accurate database is the foundation for the delineation of the floodplain boundaries for Pari River. Wide variety of data sources were used in this study to digitise various themes such as aerial photographs, topographical maps, roadmaps, Ipoh town map, DID river surveys and also field observations. The major obstacles in this step are to accurately geo-reference the data since each source has its own coordinate system and level of accuracy. A special attention was given to make the root mean square error (RMSer) as minimum as possible. Some of the spatial data developed and verified for this study are shown in Table 1.

Table 1 Spatial data developed for the study

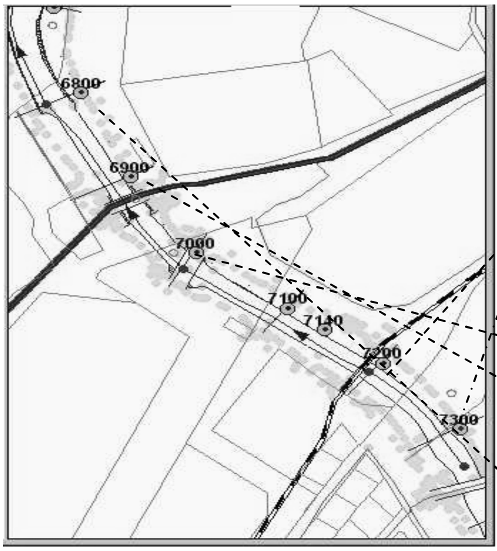
| Theme | Description | File Format |
|---|---|---|
| Land use | Land use map of Study area | *.shp - poligon |
| Land mark | Location of important places | *.shp - point |
| Road | Road network | *.shp - line |
| River | Pari River | *.shp - line |
| Surveybound | Boundary of DID survey | *.shp - poligon |
| Cross chainage | Channel survey line | *.shp - line |
| Cl | River center line | *.shp - line |
| Chainage | River Chainage location | *.shp - poligon |
| Building | Building along the floodplain | *.shp - poligon |
| 1 km buff | 1 Kilometre modelling buffer boundary | *.shp - poligon |
| Thalweg | Thalweg of Pari River | *.shp - line |
| arealpari | Areal photo of Pari River | *.jpg – image file |

### *Development of AVHEC-6.avx Integration procedure*

The integration procedure is merely an ArcView extension which was written in Avenue script language and ArcView Dialog Designer with a series of '*point and click*' options (ESRI, 1997). The Graphic User Interface (GUI) for the AVHEC-6 extension comprises of two main menus namely the AVHEC-6 and the AVHEC-6_Tools and a tool bar to format the river centerline. Each menu item is connected with an Avenue script to perform special task in flood plain mapping (Sinnakaudan *et al*., 2001[a]). It has the capability of analyzing the computed water surface profiles generated from HEC-6 model and producing a related flood map in ArcView GIS 3.2a (Sinnakaudan *et al*., 2001[b]).

### *Integration of spatial model layers and HEC-6 output*

The very important step in the modeling process is to source out computed water surface profiles and cross section geometry output generated from the HEC-6 model (Fig. 5) and reproduce them in the cross-section parameter table in ArcView GIS (Fig. 6a). Once the parameter table was imported in to ArcView database format, various analysis and relationships either one-to-one or one-to-many can be established. Fig. 6 shows *one-to-one* relationship between chainage location/control points and ArcView parameter table.




| Chainage | Thalz | Thalx | WSE | CSDist | LBankX | LBankZ | RB |
|---|---|---|---|---|---|---|---|
| 7340 | 31.10 | 229.46 | 34.89 | 0.00 | 213.46 | 36.04 | |
| 7320 | 31.26 | 218.25 | 34.89 | 20.61 | 202.25 | 35.95 | |
| 7300 | 30.78 | 221.70 | 34.89 | 40.33 | 205.70 | 35.39 | |
| 7280 | 30.20 | 222.69 | 34.89 | 56.88 | 206.69 | 35.11 | |
| 7260 | 30.47 | 222.57 | 34.89 | 75.71 | 206.57 | 35.04 | |
| 7240 | 30.32 | 220.54 | 34.89 | 94.39 | 204.54 | 35.51 | |
| 7220 | 30.41 | 223.44 | 34.89 | 114.39 | 207.44 | 35.67 | |
| 7200 | 30.77 | 241.95 | 34.89 | 132.16 | 225.95 | 35.83 | |
| 7180 | 30.38 | 236.21 | 34.89 | 151.76 | 220.21 | 35.63 | |
| 7160 | 30.52 | 232.72 | 34.89 | 172.03 | 216.72 | 35.50 | |
| 7140 | 30.51 | 239.58 | 34.89 | 190.57 | 223.58 | 35.43 | |
| 7120 | 30.79 | 240.76 | 34.89 | 212.45 | 224.76 | 35.17 | |
| 7100 | 30.48 | 228.29 | 34.89 | 229.79 | 212.29 | 35.11 | |
| 7080 | 30.57 | 220.40 | 34.89 | 253.54 | 204.40 | 34.28 | |
| 7060 | 30.85 | 218.41 | 34.89 | 273.61 | 202.41 | 34.32 | |
| 7040 | 30.65 | 235.10 | 34.89 | 292.50 | 219.10 | 34.47 | |
| 7020 | 31.00 | 240.62 | 34.89 | 310.02 | 224.62 | 34.52 | |
| 7000 | 31.00 | 240.23 | 34.89 | 328.79 | 224.23 | 34.57 | |
| 6980 | 30.73 | 223.77 | 34.89 | 357.37 | 207.77 | 34.46 | |
| 6960 | 30.91 | 225.10 | 34.89 | 378.03 | 209.10 | 34.42 | |
| 6940 | 30.83 | 228.99 | 34.89 | 401.25 | 212.99 | 34.56 | |
| 6900 | 30.94 | 213.48 | 34.89 | 439.30 | 197.48 | 34.52 | |
| 6880 | 30.96 | 215.76 | 34.89 | 460.84 | 199.76 | 34.75 | |
| 6860 | 31.15 | 218.42 | 34.89 | 481.72 | 202.42 | 34.71 | |
| 6840 | 31.18 | 225.42 | 34.89 | 500.91 | 209.42 | 34.27 | |
| 6820 | 31.41 | 241.96 | 34.89 | 520.84 | 225.96 | 34.17 | |
| 6800 | 31.81 | 252.21 | 34.89 | 539.78 | 236.21 | 34.00 | |

a. Actual location of reference points in real world coodinates

b. ArcView parameter table

Fig 6. One-to –One relatioship betweem map and imported parameter table from HEC-6

By executing series of point and click option in the AVHEC6 menu, an Integrated Triangular Irregular Network (ITIN) Model was created by combining geometry information from the HEC-6 model and Digital Elevation Model (DEM) for the areas outside the modeling extend. A more detailed description about the procedure for creating the ITIN was given in Sinnakaudan (2002).

### *Flood inundation mapping*

The same procedure was followed to extract water surface elevation information from the ArcView parameter table and plotted as a 2D Water Surface Elevation (WSE) line (Fig.8). The extreme left and right boundary of the water surface lines then were connected to create a 2D flood inundation polygon (Fig.8). The 2D flood inundation map then assign 3 D coordinates (3D WSE TIN) by spatial interpolation with ITIN and water surface elevation for each cross-section.

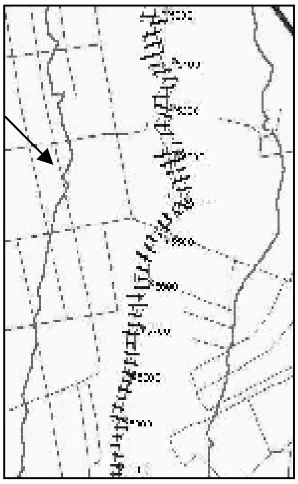



Fig. 7 Flood inundation lines

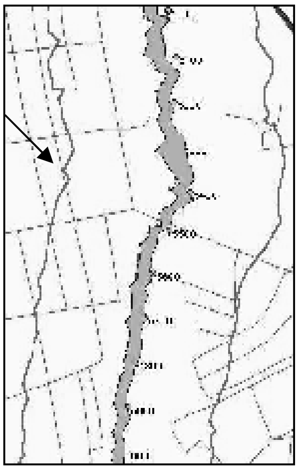



Fig. 8 Flood inundation polygons

Flood inundation maps were produced for the subsequent flood scenarios (Table 2- Table 5) by with the 2D flood inundation polygons draped over an ITIN. Some of the maps created were shown in Fig. 9. The 3D visualization capabilities of ArcView 3D analyst was further utilized to enhance the visual representation of the flood inundation maps (Fig. 10).The results of these study clearly shows that GIS provides an effective environment for flood inundation mapping and analysis.

Table 2 Discharge for August till November 1997 hydrograph

| Time step | Q ($m^3/s$) | Water Surface Elevation ( m ) |
|---|---|---|
| Initial | 11.33 | 34.89 – 36.65 |
| 122 | 114.68 | 37.12 – 38.59 |
| 195 | 15.56 | 34.10 – 37.10 |

Table 3 Discharge for design hydrograph ARI 50 years

| Time step | Q ($m^3/s$) | Water Surface Elevation ( m ) |
|---|---|---|
| Initial | 12.50 | 34.93 – 36.70 |
| 122 | 220.00 | 37.28 – 39.08 |
| 195 | 50.00 | 35.94 – 37.93 |

Table 4 Discharge for design hydrograph ARI 100 years- year 2020

| Time step | Q ($m^3/s$) | Water Surface Elevation ( m ) |
|---|---|---|
| Initial | 13.00 | 34.95 – 36.71 |
| 122 | 266.00 | 37.28 – 39.25 |
| 195 | 58.00 | 36.11 – 38.05 |

Table 5 Discharge for design hydrograph ARI 100 years- year 2060

| Time step | Q ($m^3/s$) | Water Surface Elevation ( m ) |
|---|---|---|
| Initial | 13.00 | 34.95 – 36.71 |
| 122 | 317.00 | 37.28 – 39.30 |
| 195 | 60.50 | 36.16 – 37.98 |

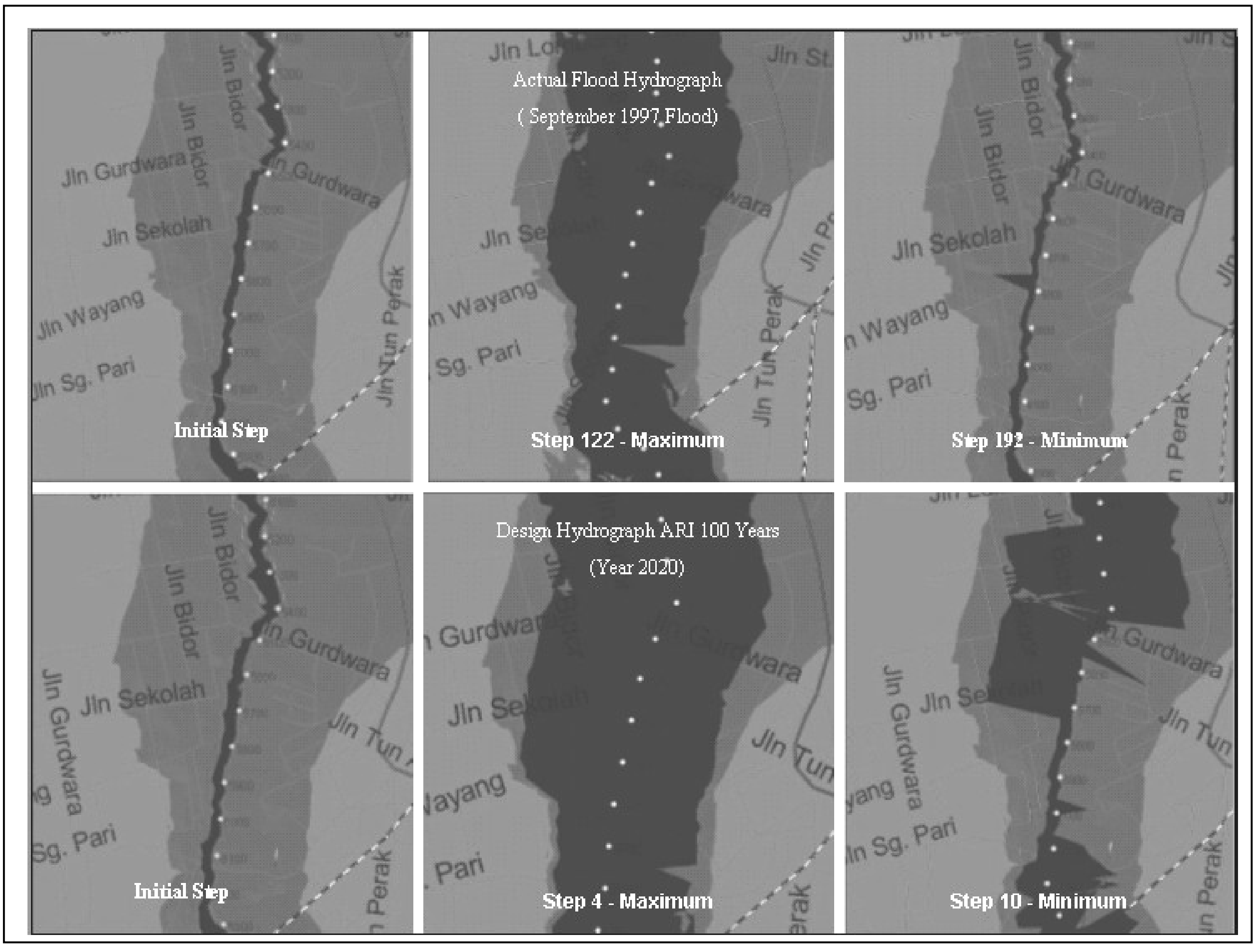
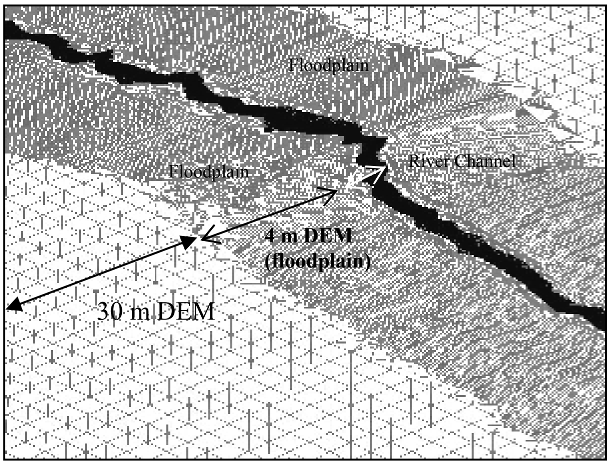
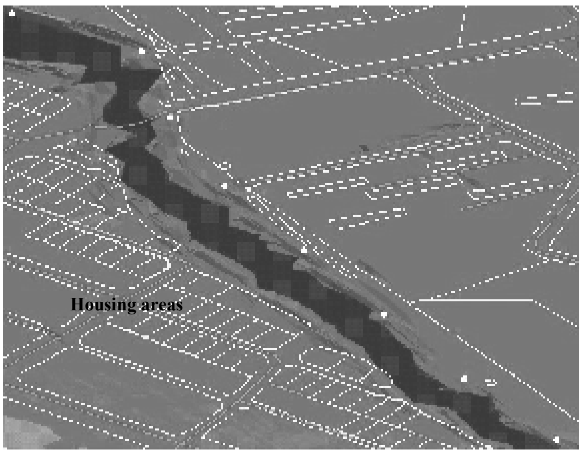



Fig. 9 Inundation maps for diffrent flood scenarios




a. Water Surface Elevation TIN draped over ITIN




a. WSE TIN draped over ITIN with surface tone

Fig 10. 3D Flood inundation map for initial step with Q = 12.50 $m^3/s$ ,
1997 hydrograph (Sinnakaudan *et al.*, 2002)

## *Findings*

Proper GIS database or flexible yet accurate modelling procedures would be the most vital part in this study. Some of the significant findings that can improve flood inundation analysis and mapping are listed below:

- More channel cross-section in terms of lesser section intervals and more station – elevation points.
- Source of elevation data - channel or flood elevation data from ground surveys provides more accurate terrain representation and flood inundation results
- Continuous terrain data provides more reliable flood plain maps.
- Extend of geometrical representation of the flood plain in the hydraulic model limits the flood inundation mapping
- Loose coupling methods provides lesser user friendly modelling environment
- Tailor-made integrated and embedded hydraulic and sediment transport model in GIS may promise a better and sustainable modelling approach. The conceptual framework of the new modelling approach was shown in Fig. 11

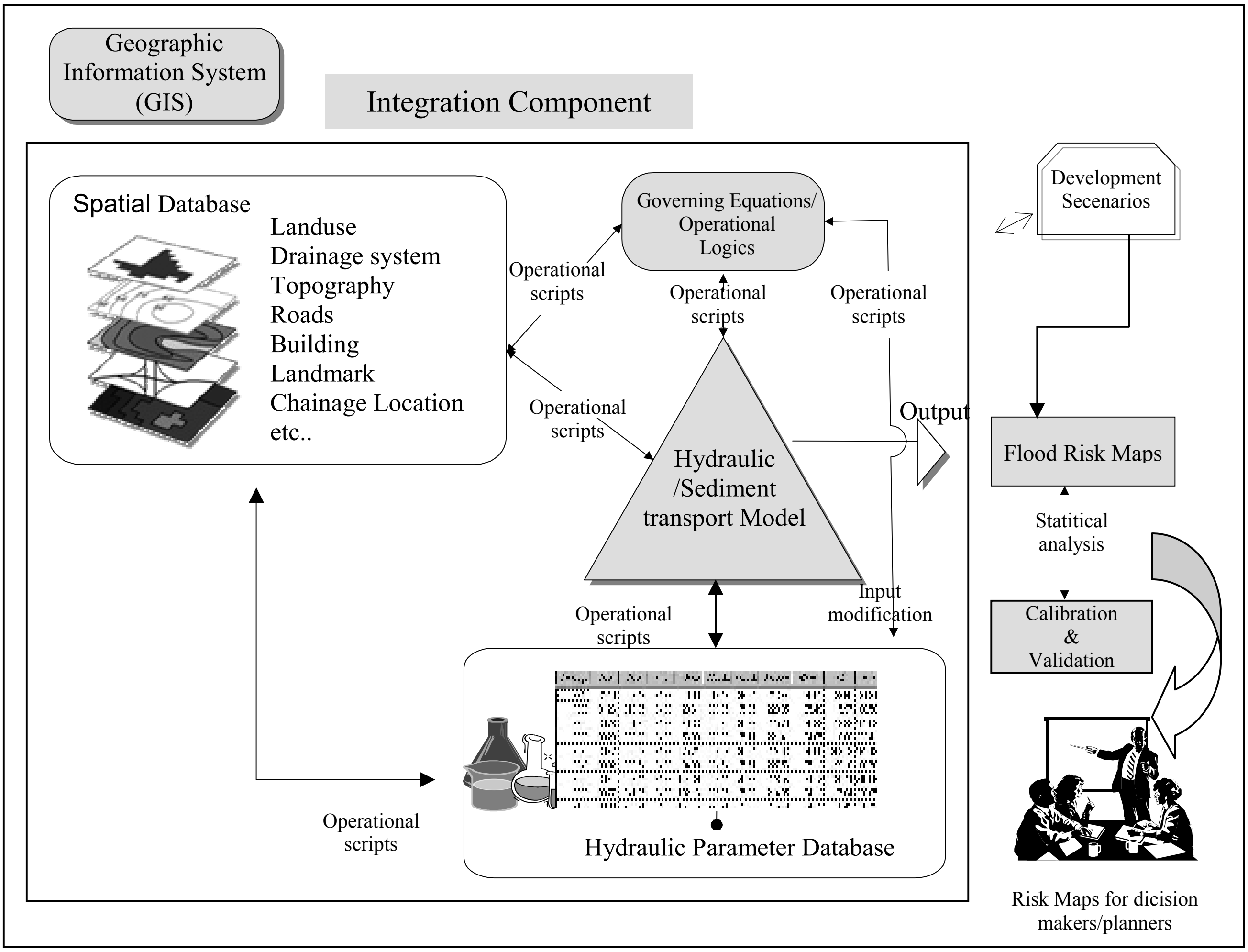



Fig. 11 Conceptual Framework for Future Work

## Conclusion

Due to page limit, detailed hydraulic modelling procedures and results are not shown here. Only floodplain maps which are the end-product of this study were presented. The AVHEC6.avx extention seamlessly enables ArcView GIS to read HEC-6 output through a series of user-friendly graphic menus. The tool steamlines the whole proses of HEC-6 model output for flood inundation analysis, and thereby greatly speeds up a tedius and time consuming modeling process. Like any other software, the AVHEC6.avx tool still has the limitation and need further fine tuning before can be applied to any other geometrically defined river channel. HEC-6 model is a very complex hydraulic model and demand highly professional knowledge to ensure error induced and reliable output. A window based flood risk analysis tool using more simplified and user friendly is in greater demand. However this research has proven that flood inundation analysis and mapping can be tremendously improved using Geographic Information Systems. In this study, the flood profile was successfully visualized within the channel boundary and the flood plain. However, more emphasis will be given to the development of simplified yet accurate embedded flood risk analysis model within GIS environment.

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