Integrated Triangular Irregular Network (ITIN) Model for Flood Risk Analysis Case Study: Pari River, Ipoh, Malaysia

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Abstract

Accurate river channel and flood plain representation plays vital part in flood risk analysis (Sinnakaudan; 2001[b]). Terrain models such as TINs and DEMs are normally used to represent floodplains. But unfortunately finding a terrain model with a high density of stream channel elevation points that are sufficient for hydraulic modeling is not a easy task. However for years engineers and researchers have developed a high-resolution cross-section data for hydraulic modeling from field surveys, photogrametries and topographic maps. This research presented here introduces the procedures for creating integrated multiresolution TIN (ITIN) models for high-resolution flood plain representation for flood risk analysis. The high-resolution river channel geometric data stored in HEC-6 hydraulic model and low-resolution flood plain data in the form of DEM created in ArcView GIS 3.2a were integrated by resolving the coordinate incompatibility in the both system. An integration procedure (ArcView extention) namely AVHEC6.avx has been developed between HEC-6 Hydraulic Model and ArcView GIS 3.2a to visualize model outputs in a more presentable manner through 3D capabilities of GIS.

Keywords:

ITIN; DEM; GIS; HEC-6; Flood Risk.

Introduction

Triangulated Irregular Network model or TIN is a finite set of points which are stored with their elevation. The model is a piecewise linear model that in 3 Dimensional space can be visualize as a simply connected set of triangles [3; 18]. The heirarchical or multiresolutional TIN model allows a mixture of different detail levels in parts of the terrain, which are very much suitable for flood plain analysis [18; 13; 17]. The idea of creating a multiresolution TIN is rather old, and detailed literature reviews can be found in the forms of graphics, GIS, algorithme foundation, and others areas [8; 9; 10].

However the usage of TINs in flood plain analysis is gaining much attention recently due to dramatic increase in the capability of desktop-based Geographic Information System (GIS) to perform more sophisticated tasks in spatial data management [1; 13; 17; 15]

Terrain representation with high accuracy would be the most important task in visualizing areas inundated by floods. Constructiong a continuous floodplain terrain model with a high density of stream channel elevation points sufficient for hydraulic modeling are cost intensive and generally not available. However for years, engineers and researchers have developed a high-resolution cross-section data for hydraulic modeling from field surveys, photogrametries and topographic maps [2; 19, 16; 13; 12].

The problem is that these high-resolution data used to simulate the hydraulic models such as HEC-6 and FLUVIAL-12 are often stored in hydraulic coordinate systems (referenced by the location of the river stations and elevations- Sta, Elv) and incompatible with GIS coordinate structure (referenced by east (x-coordinate), north (y-coordinate) and elevation (z-coordinate) [17; 13]. Currently, there are no available methods with which to integrate HEC-6 hydraulic model output data with ArcView GIS. The study presented herein utilizes the simulated results from HEC-6 hydraulic model and ArcView GIS 3.2 (with Spatial Analyst and 3D Analyst extensions) [4;5;6;7] to offer an approach to resolve this deficiency by using the hydraulic and hydrological data from Pari River catchment in Ipoh, Perak, Malaysia (Fig. 1).

The Methodology

The HEC-6 model was simulated using 2 sets of geometric data as shown in Table I. The first set of data contains only the information for river channel and flood plain within the bund (Fig.2a). The second set of data is extended to 200 meter to the left and right side of the bund (Fig.2b). The sample cross-section output for each data was shown in Fig. 3 and Fig. 4. An ArcView GIS extension namely *AVHEC-6.avx* was written in an Avenue Script language and Dialog Designer with a series of '*point and*

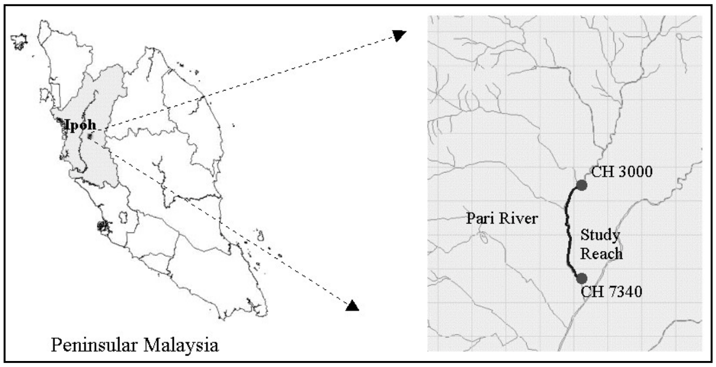

Fig. 1. Study Area

click' options to visualize the output from HEC-6 by contructing an ITIN and to perform the flood plain analysis. The *Data Import* option in AVHEC-6.avx enables the stream geometric information form HEC-6 hydraulic model to be imported to ArcView GIS 3.2a. Some of the parameters recorded are chainage number, thalweg coordinates (x, z), left and right bank station distance from thalweg, floodplain boundary coordinates (x,z), cross section distance, water surface elevation, left and right flood inundation distance from thalweg. Other parameters required for calculation were stored as global variables and will be automatically deleted when user exit from ArcView GIS 3.2a.

The ArcView parameter table then geo-referenced using *one to one* relationship by assigning three-dimensional map coordinates for every vertex for the cross-sections (Fig.5). Using these three-dimensional cross-section points, a Triangular Irregular Network (TIN) model of the stream channel and floodplain simulated in HEC-6 model is visualized in ArcView GIS 3.2a. However, a TIN created solely from this process only includes the geometry information provided in HEC-6 model, but not the surrounding landscape.

TABLE I
GEOMETRIC DATA CONFIGURATION

Extend of Modeling Geometry Data		
	Channel geometry	Channel & Floodplain Geometry
Nomber of Cross-section data	108	213
Cross-section interval length	Varies Min: 3m Mac: 70 m	20 m
Total stations (Sta, Elv - points)	18 - 23	124 - 138

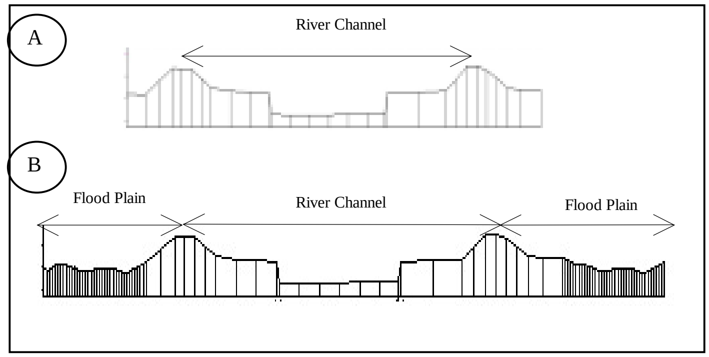

Fig. 2. Grafic representation of the cross-section

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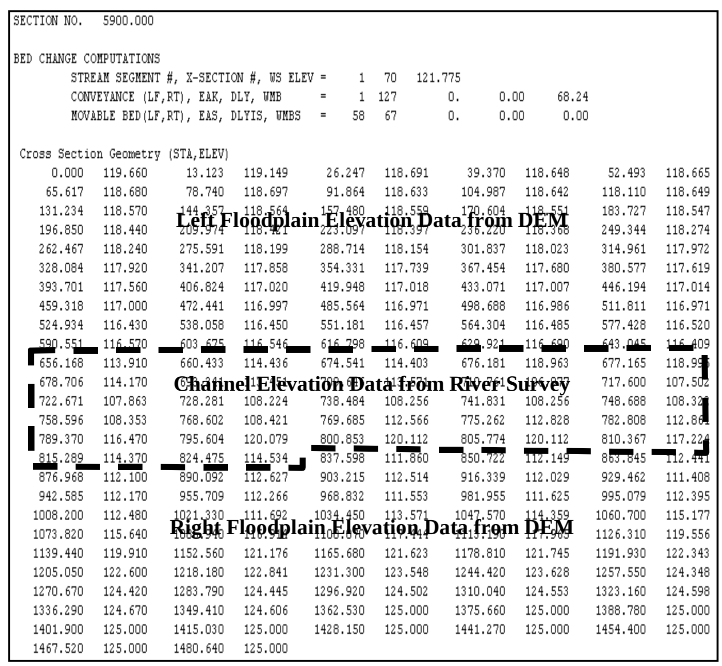
SECTION NO.   5907.000

BED CHANGE COMPUTATIONS
       STREAM SEGMENT #, X-SECTION #, WS ELEV =    1   42   124.291
       CONVEYANCE (LF,RT), EAK, DLY, WMB       =    1   17        0.      0.00     51.50
       MOVABLE BED(LF,RT), EAS, DLYIS, WMBS    =    5   12        0.      0.00      0.00

 Cross Section Geometry (STA,ELEV)
     0.000   126.400      6.600   126.400      8.200   122.000     31.200   122.000     31.800   112.859
    32.800   112.859     41.000   112.859     47.600   112.859     57.400   112.859     67.300   112.859
    73.800   112.859     82.000   112.859     83.000   112.800     83.700   122.000    106.600   122.000
   108.300   126.400    114.800   126.400
```

Fig. 3 HEC-6 output table with cross-section information confined to river channel



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SECTION NO.   5900.000

BED CHANGE COMPUTATIONS
       STREAM SEGMENT #, X-SECTION #, WS ELEV =    1   70   121.775
       CONVEYANCE (LF,RT), EAK, DLY, WMB       =    1  127        0.      0.00     68.24
       MOVABLE BED(LF,RT), EAS, DLYIS, WMBS    =   58   67        0.      0.00      0.00

 Cross Section Geometry (STA,ELEV)
     0.000   119.660     13.123   119.149     26.247   118.691     39.370   118.648     52.493   118.665
    65.617   118.680     78.740   118.697     91.864   118.633    104.987   118.642    118.110   118.649
   131.234   118.570    144.357   118.564    157.480   118.559    170.604   118.551    183.727   118.547
   196.850   118.440    209.974   118.421    223.097   118.397    236.220   118.368    249.344   118.274
   262.467   118.240    275.591   118.199    288.714   118.154    301.837   118.023    314.961   117.972
   328.084   117.920    341.207   117.858    354.331   117.739    367.454   117.680    380.577   117.619
   393.701   117.560    406.824   117.020    419.948   117.018    433.071   117.007    446.194   117.014
   459.318   117.000    472.441   116.997    485.564   116.971    498.688   116.986    511.811   116.971
   524.934   116.430    538.058   116.450    551.181   116.457    564.304   116.485    577.428   116.520
   590.551   116.570    603.675   116.546    616.798   116.609    629.921   116.690    643.045   116.409
   656.168   113.910    660.433   114.436    674.541   114.403    676.181   118.963    677.165   [illegible]
   678.706   114.170    [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 717.600 107.502
   722.671   107.863    728.281   108.224    738.484   108.256    741.831   108.256    748.688   [illegible]
   758.596   108.353    768.602   108.421    769.685   112.566    775.262   112.828    782.808   [illegible]
   789.370   116.470    795.604   120.079    800.853   120.112    805.774   120.112    810.367   117.224
   815.289   114.370    824.475   114.534    837.598   111.860    850.722   112.149    863.845   112.441
   876.968   112.100    890.092   112.627    903.215   112.514    916.339   112.029    929.462   111.408
   942.585   112.170    955.709   112.266    968.832   111.553    981.955   111.625    995.079   112.395
  1008.200   112.480   1021.330   111.692   1034.450   113.571   1047.570   114.359   1060.700   115.177
  1073.820   115.640   [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 1126.310 119.556
  1139.440   119.910   1152.560   121.176   1165.680   121.623   1178.810   121.745   1191.930   122.343
  1205.050   122.600   1218.180   122.841   1231.300   123.548   1244.420   123.628   1257.550   124.348
  1270.670   124.420   1283.790   124.445   1296.920   124.502   1310.040   124.553   1323.160   124.598
  1336.290   124.670   1349.410   124.606   1362.530   125.000   1375.660   125.000   1388.780   125.000
  1401.900   125.000   1415.030   125.000   1428.150   125.000   1441.270   125.000   1454.400   125.000
  1467.520   125.000   1480.640   125.000
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Fig. 4. HEC-6 output table with cross-section information to the left and right side of the flood plain.

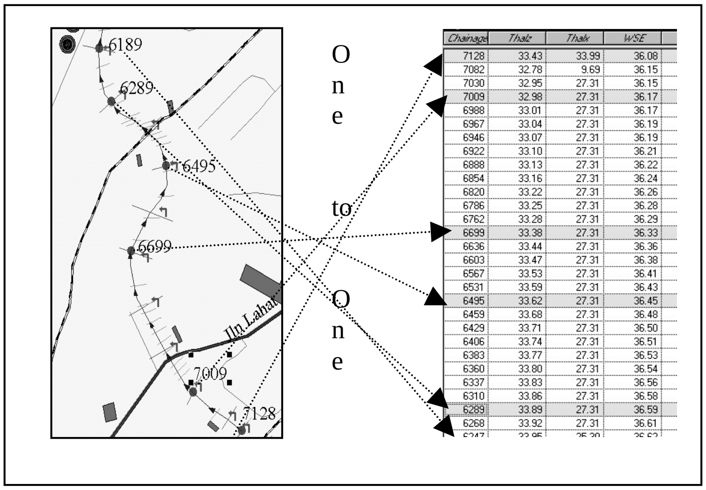

Fig.5. O*ne to One* relationship between ArcView parameter table and reference points

To best represent the terrain, a continuous landscape should be build and for this, the TIN should include areas both inside and outside the river channel in order to give a sense of context. The Digital Elevation Model (DEM) is the standard data model used for small-scale representation of the land surface [11]. In order to create a comprehensive TIN, a method to integrate relatively low-resolution DEM data with comparatively higher resolution vector stream channel/floodplain data generated from HEC-6 model is applied. The raster DEM is then converted to vector elevation mass point theme and all the points falls within the cross-section boundary were deleted.

Three input files were needed to create an Integrated TIN namely, ArcView parameter table, mass elevation points that fall outside the cross-section boundary and channel breakline information (left bankline, right bankline and thalweg). One could simply triangulate the data set given in Table II by following the given options by using Delaunay Triangulation procedure. It is common to use the Delaunay triangulation because it attempts to create well-shaped triangles. The intended result is a continuous three-dimensional landscape surface that contains additional detail in stream channels as shown in Fig.6.

AVHEC-6.avx has also the capability of building a water surface elevation TIN (WSE TIN) for the computed water surface elevations from HEC-6 model and visualizes the resulting floodplain in accordance with ITIN. The input themes needed are ArcView parameter table and water surface extends to the left and right from thalweg which are stored in ArcView parameter table. The water surface TIN development criteria as shown in Table III. The flood plain representation with ITIN using the first set of geometric data shows that the inundation mapping cannot be visualized accurately. This is due to the modeling process in HEC-6 is limited between the left and right bund of the Pari River and no additional geometric information availlable to visualize the calculated water overflow from the bund. (Fig. 7 & Fig. 8).

TABLE II
DATA CONFIGURATION FOR INTEGRATED TIN

Theme name	Title	Input Criteria
breaklinestep	Left bankline, Right bankline Thalweg	Input as : Hard Break Lines Height Source : Shape
cross	Cross-section	Input as : Mass points Height Source : Shape
pointoutchannel	DEM elevation mass points	Input as : Mass points Height Source : Grid_Height

TABLE III
DATA CONFIGURATION FOR WATER SURFACE ELEVATION TIN

Theme Name	Title	Input Criteria
wseext	Flood extend to the left and right side of the channel from thalweg	Input as : Hard Break Lines Height Source : aras air
wseboundary	Flood boundary	Input as : hard Clip Poligons

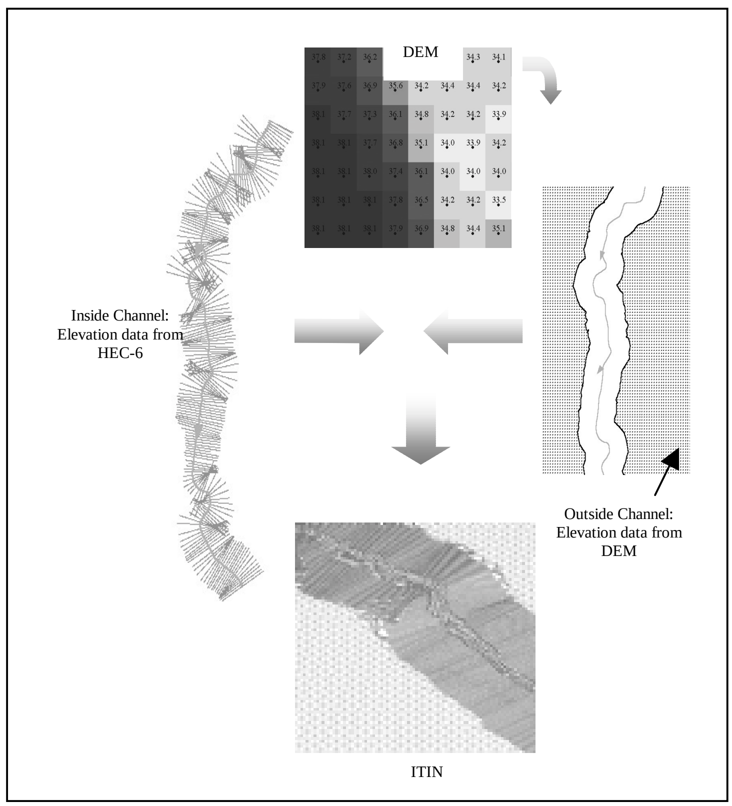

Fig. 6. Integrated Multi Resolutional TIN

This deficiency in using first set of data for modeling is then verified and eliminated by using second set of data which give more satisfactory results (Fig. 9 & 10)

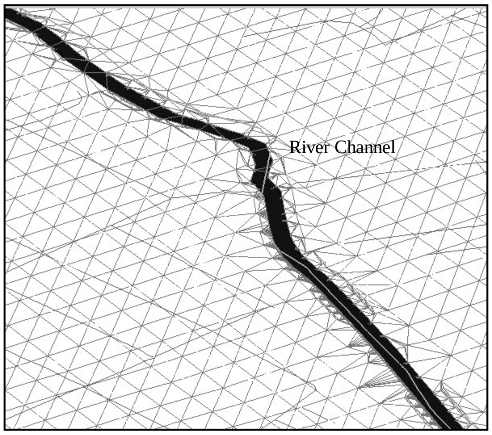

Fig. 7. WSE TIN draped over ITIN for first set of data

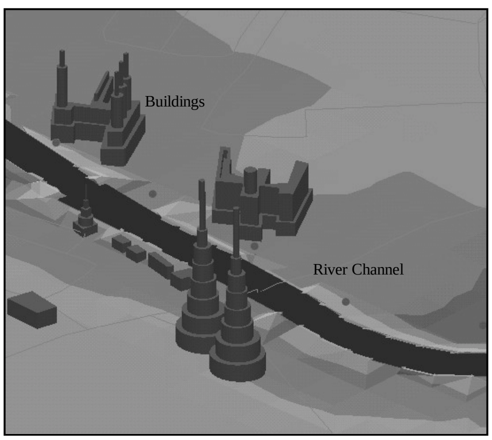

Fig. 8. Inundation mapping limited to river channel

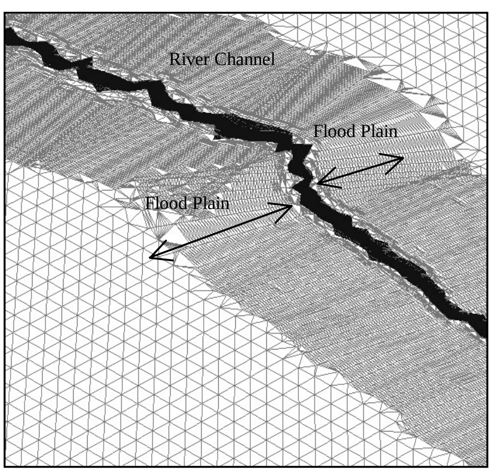

Fig. 9 . WSE TIN draped over ITIN for second set of data

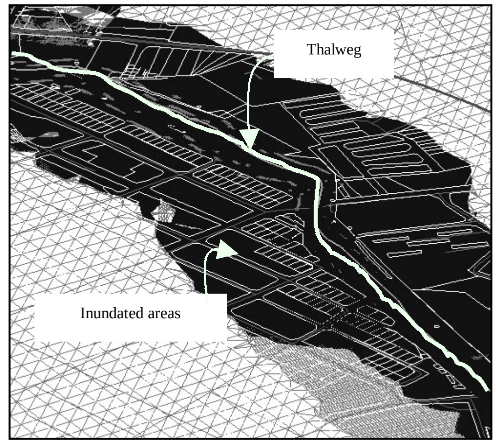

Fig. 10. Inundation mapping extended to left and right flood plain

Conclusions

This research gives engineers a new toolbox to support the dynamic task in flood plain analysis using HEC-6 and ArcView GIS 3.2a. The procedure for creating integrated multiresolution TIN model alleviate the possibilities of using a loose coupling method within Arc View GIS and HEC-6 hydraulic model for flood risk analysis. The AVHEC-6.avx extension that was created can be used to visualize various flood phenomenons for different catchment areas by simulating the HEC-6 model and processing the HEC-6 model output file. The methodology followed here is suitable for any river assuming that it was geometrically defined channel. This study shows that definition of the floodplain in HEC-6 model controls the resulted ITIN and WSE TIN for flood risk analysis in ArcView GIS 3.2a. However, it is recommended that more emphasis be given to the development of embedded flood risk analysis model within GIS environment. Overall, the results of the study indicate that GIS provides an effective environment for flood risk analysis and mapping.

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