

Possibility of positioning dams to control flooding in Trinidad

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ABSTRACT

The problem of flooding is worldwide to many countries of which, the island of Trinidad and Tobago is no exception. The government of the country has been spending a large amount of its resources to address the flooding problem of which there have been no satisfactory solutions.

In this article is presented an investigated approach to determine if the ArcHydro extension of ArcGIS can supply added results which can help the government in deciding if positioning a series of dams can be a likely solution to the flooding problem. The article identifies the problems, the limitations of the data sets available, and the necessary GIS processing adopted in the ArcHydro model. The sample area selected to apply ArcHydro is an area located in central Trinidad. This is an area where flooding has become a way of life for the community and a solution is a welcome benefit.

1.0 INTRODUCTION

Flooding is a well know natural disaster that affects many societies faced with large amounts of natural water flow. This ranges from the rainfall during summer to that of melting snow during the winter months. The problem is fueled by increase population growth, changes in the weather pattern, deforestation, and many other influencing contributors. Nevertheless, societies require proper management of the natural water flow in such a manner that all of the flooding contributors can be efficiently integrated.

To properly manage water flow, computers are used to simulate realistic three-dimensional models. They are by far one of the most attractive uses of Geographic Information Systems (GIS). It captivates users who are unaware of the technology and users who are aware and working with the technology. Users can directly relate what they see on the computer monitor to that what is existing in reality.

In this paper is presented an investigative to determine if flood dams can be used to control flooding in the island of Trinidad, West Indies. Flooding has been a problem for many decades in the country and this paper seeks to present the possibility of using GIS to help the local authorities in dealing with the ever occurring problem. In the paper the methodology, the problems and the limitations associated with the development are also presented.

2.0 DEM CREATION AND PROCESSING

The use of a digital elevation model (DEM) is vital for this GIS application. This facilitates the drainage analysis that is associated with each cell of the DEM. Each cell of the DEM has a height above mean sea level which is a realistic figure. Such data can be obtained from many sources such as satellite imagery, contouring and spot heights, and lidar. The best result is obtained from drainage analysis using DEMs with very small cell resolution. The smaller the resolution the better the end results, but more expensive the project becomes.

In this paper the DEM was generated from contour lines and spot heights which were obtained from a topographic map.



Figure 1: Location of Trinidad

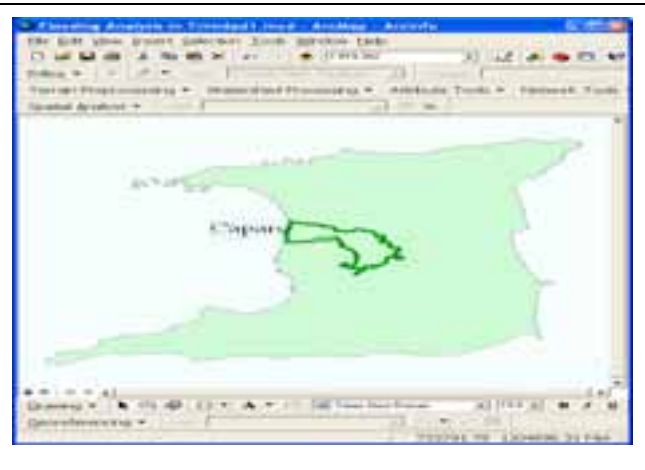


Figure 2: Study Area

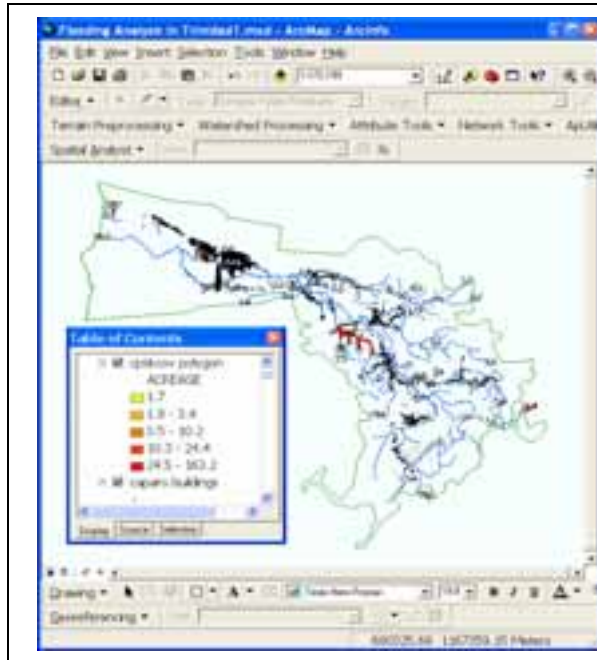


Figure 3: Flooded areas and buildings

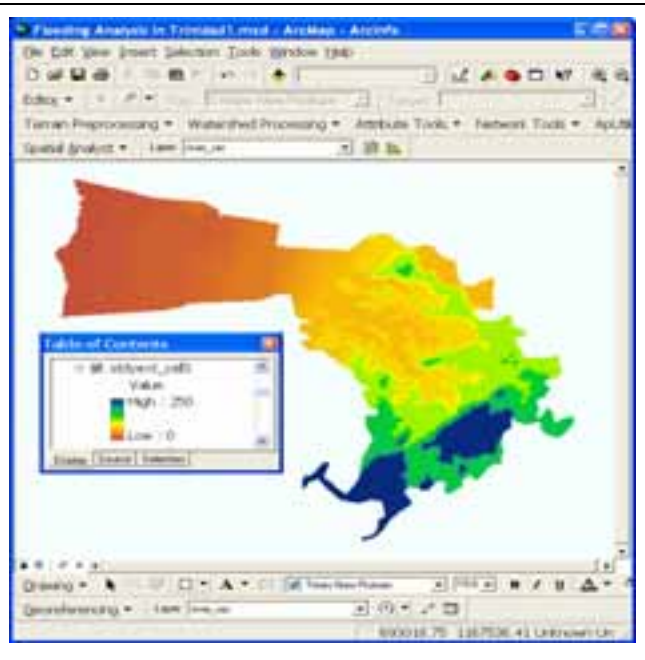


Figure 4: Study Area DEM

In order to present the general location of island of Trinidad, Figure 1 shows the location of the island in relation to the Venezuela in South America. Trinidad & Tobago (T&T) is a twin island country located at $10\frac{1}{2}^{\circ}\text{N}$, $61\frac{1}{2}^{\circ}\text{W}$. It is the southernmost island of the Caribbean archipelago, and an extension of the South American continent. In this paper the study area chosen within the island of Trinidad is called Caparo (as shown in Figure 2.0), is located in central Trinidad and it can be categorized as being a rural area of Trinidad. The

study area is prone to flooding for decades whenever there is any extensive rainfall. It becomes a norm for the locals during the rainy season from June to December. The government has been trying to resolve the problem for many years but they have been unsuccessful.

The island is a developing country and they do have the capability in solving the problem. In this paper a possible solution is being proposed. Figure 3 shows the natural water courses, building locations, and the areas affected when water is collected after flooding.

To fully model the flooding phenomena for the study area, a Digital Elevation Model (DEM) was generated from contour lines digitized from topographic maps. The DEM shown on Figure 4 has a resolution of 3meter. Using the DEM, an AgreeDEM was generated using ArcHydro. The terrain processing tools used on the DEM is summarized on Table 1.

Tool	Description
DEM Reconditioning	Enforce linear drainage pattern (vector) onto a DEM (grid). Implements AGREE methodology.
Fill Sinks	Fill sinks for an entire DEM (grid).
Flow Direction	Create flow direction grid from a DEM grid.
Flow Accumulation	Create flow accumulation grid from a flow direction grid.
Stream Definition	Create a new grid (stream grid) with cells from a flow accumulation grid that exceed used-defined threshold.
Stream Segmentation	Create a stream link grid from the stream grid (every link between two stream junction gets a unique identifier).
Catchment Grid Delineation	Create a catchment grid for segments in the stream link grid. It identifies areas draining into each stream link.
Catchment Polygon Processing	Create catchment polygons out of the catchment grid.
Drainage Line Processing	Create streamlines out of the stream link grid.
Adjoint Catchment Processing	Create adjoint catchment polygon for each catchment in the catchment polygon feature class. Adjoint catchment is total upstream area (if any) draining into a single catchment.
Drainage Point Processing	Create a drainage point at the most downstream point in the catchment (center of a grid cell with the largest value in the flow accumulation grid for that catchment).

Table 1: ArcHydro Terrain Processing Tools, (Maidment, 2002)

The ArcHydro Attribute processing tools used on the DEM is summarized on Table 2.

Tool	Description
Assign HydroID	Assigns a unique identifier (HydroID) to a feature. HydroID is unique across a geodatabase.
Generate From/To Node for Lines	Generates from-node/to-node topology based on physical line connectivity for a line feature class (does not require hydro network). Nodes are defined as ends of lines. They are not created as a separate feature class, but rather just identified and accounted for internally.
Find Next Downstream Line	Find the HydroID of the next downstream linear feature class and store it in the NextDownID field of the feature. The directionality is based on the digitized direction. Connectivity is established by the physical connection of the linear features (does not require hydro network).
Calculate Length Downstream for Edges	Calculate length from the downstream end of a hydro edge to the outlet of the hydro network (requires hydro network). The length is stored in the LengthDown field.
Calculate Length Downstream for Junctions	Calculate length from a hydro junction to the outlet of the hydro network (requires hydro network). The length is stored in the LengthDown field.
Find Next Downstream Junction	Find the HydroID of the next downstream junction and store it in the NextDownID field of the junction feature (requires hydro network).
Store Area Outlets	Identify most likely hydro junction that drains an area. The HydroID of that junction is stored in the JunctionID field for the area feature class.
Consolidate Attributes	Summarize the values of a numerical attribute of a feature class and store them in a field in another (or same) feature class. Relationship between the from and the to feature class is established through related IDs. Operators include sum, min, max, average, median, mode, standard deviation, and count. User specifies the from and the to feature classes, what field to summarize and in what field to store the summarized values. The tool can use the same feature class as both from and to objects to operate on.
Accumulate Attributes	Summarize the values of a numerical attribute of a feature class and store them in a field in another (or same) feature class. The tool selects the upstream objects by tracing either using the geometric network or a NextDownID relationship, and summarizes the selected objects. Operators include sum, min, max, average, median, mode, standard deviation, and count. The selectable objects are either the traceable objects, or can be in an ID-related feature class (using existing relationship classes). User specifies the from and the to feature classes, what field to summarize, and in what field to store the summarized values
Display Time Series	Display the values of the selected parameter as a function of time.

Get Parameters	Extract characteristics associated to polygon features: area, average elevation, maximum elevation, minimum elevation, relief, slope, land cover, precipitation.
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Table 2: ArcHydro Attribute processing tools

The ArcHydro network tool used in defining the drainage network is shown in Table 3.

Tool	Description
Hydro Network Generation	Generate a hydro network (hydro edges and hydro junctions) from drainage lines, catchments, and drainage points. The function updates all the connectivity fields in input feature classes.
Node/Link Schema Generation	Generate schematic (node-link) network by connecting centers of catchments/drainage areas and junctions, and junctions and junctions. Connectivity is established through connectivity fields (attributes), not physical connectivity.
Store Flow Direction	Store information about hydro (geometric) network element's directionality into an attribute of the feature matching the element.
Set Flow Direction	Define flow direction for a geometric network based on digitized direction or an attribute for the feature.

Table 3: ArcHydro Network processing tools, (Maidment, 2002)

To remove the sinks from the raw DEM the fill sink function is used. The output from such a processing is the HydroDEM which is shown on Figure 5. The AgreeDEM has the existing rivers and its tributaries included into the HydroDEM as shown on Figure 6. DEM reconditioning function modifies HydroDEMs by imposing linear features onto them (burning/fencing) which generates the AgreeDEM. The input is the rasterized existing drainage network, and the HydroDEM. The AgreeDEM is then used to generate the FlowDirection (Figure 7) and FlowAccumulation (Figure 8) grids. The FlowDirection grid assigns a flow direction liquids will follow, while the FlowAccumulation grid assigns the number of cells which are flowing into each cell.

The Stream Definition function takes the flow accumulation grid as input and creates a Stream Grid based upon cells having a value of more than 1000 set as the threshold. This threshold is defined either as a number of cells (default 1%) or as a drainage area in square kilometers. The output is called Stream Grid which is shown in Figure 9.

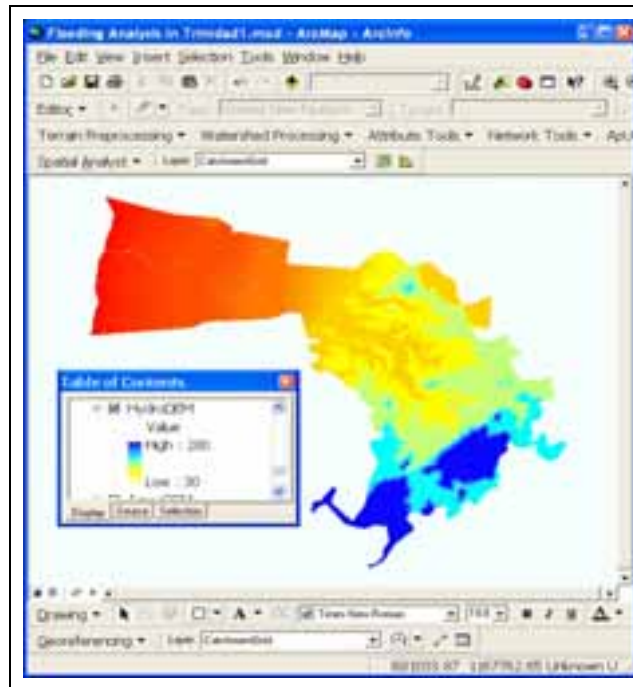


Figure 5: HydroDEM

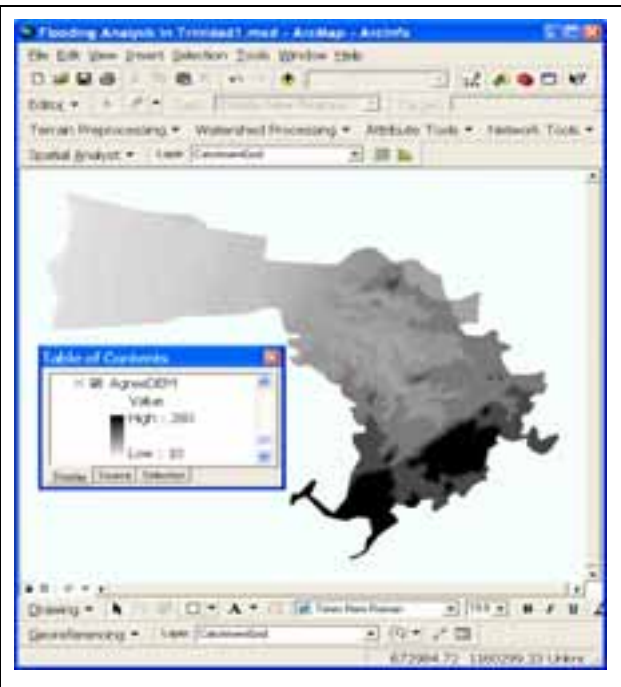


Figure 6: AgreeDEM

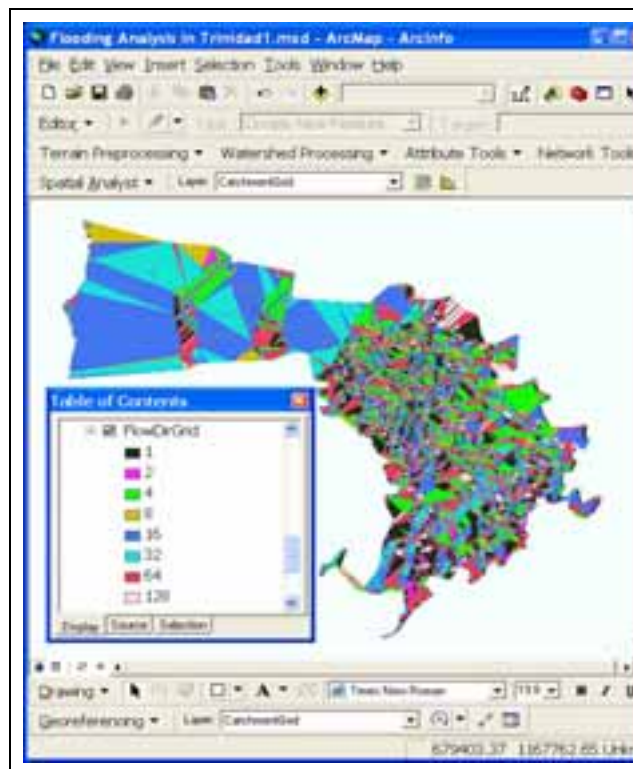


Figure 7: Flow Direction Grid

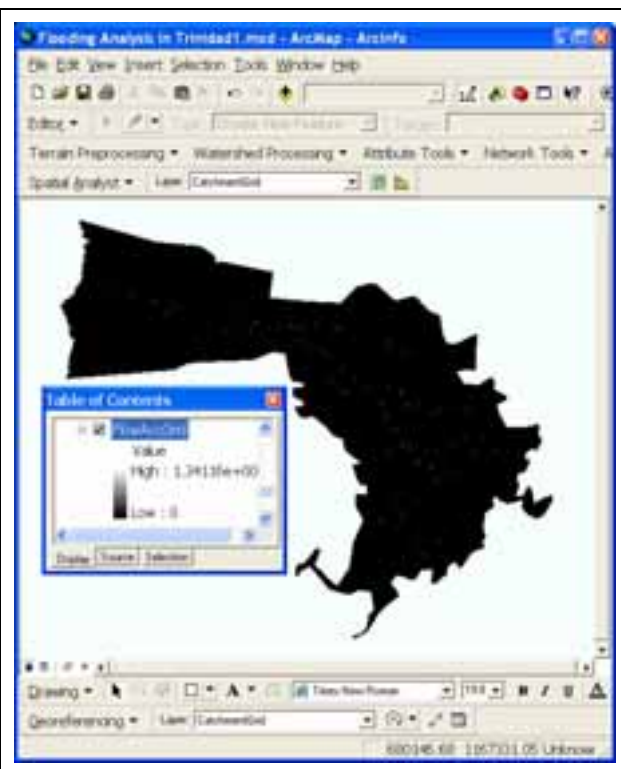


Figure 8: Flow Accumulation Grid

The Stream Segmentation function creates a grid of stream segments that have a unique identification. The input to such a function is the FlowDirection and Stream Grid which produces the Link Grid (Figure 10).

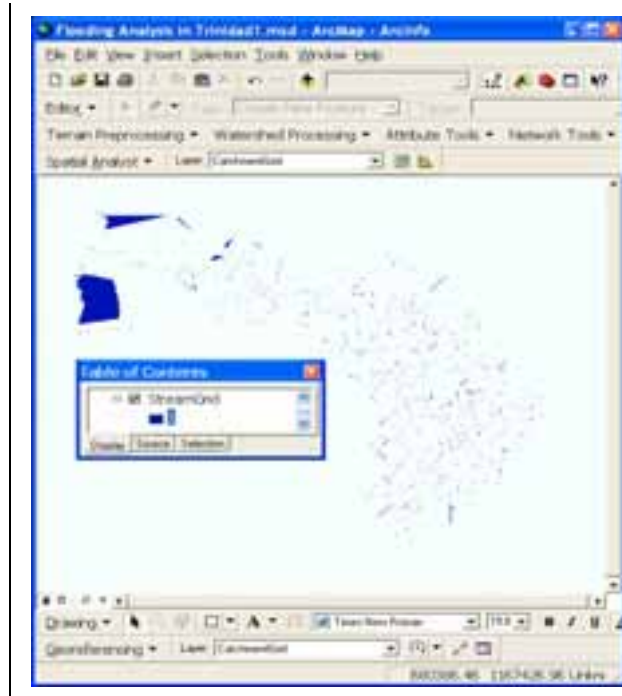


Figure 9: Stream Grid

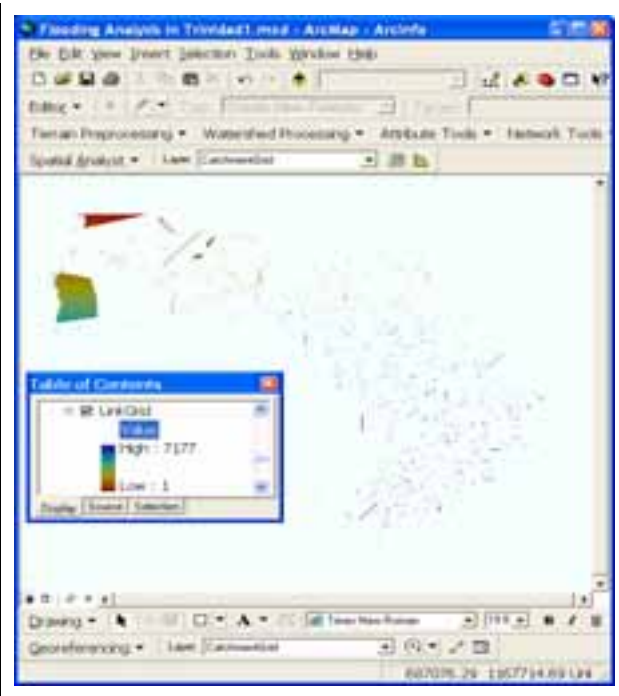


Figure 10: Link Grid

The Catchment Grid Delineation function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid. The input to such a function is the FlowDirection Grid and the link Grid. The output is called the Catchment Grid as shown in Figure 11. The Catchment Grid is then used to identify the vector polygons representing the Catchment areas for the study location as shown in Figure 12.

The Link Grid and FlowDirection Grid are used to generate the DrainageLine vector feature class. The FlowAccumulation and Catchment Grids are used to generate the DrainagePoint vector feature class. These two vector feature classes are shown in Figure 13.

HydroNetwork is a geometric network composed of the HydroEdge and HydroJunction feature classes from the Network dataset. These feature classes (as shown in Figure 14) are generated using the Arc Hydro Tools function Hydro Network Generation.

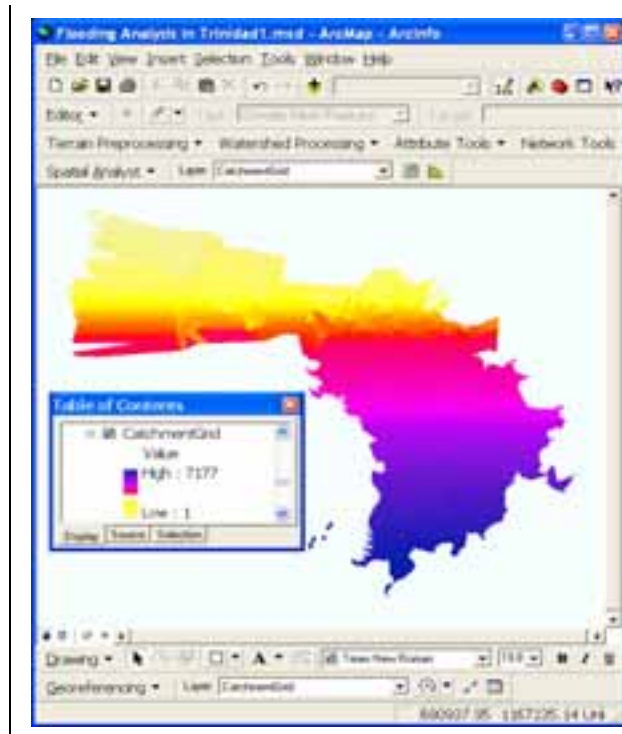


Figure 11: Catchment Grid

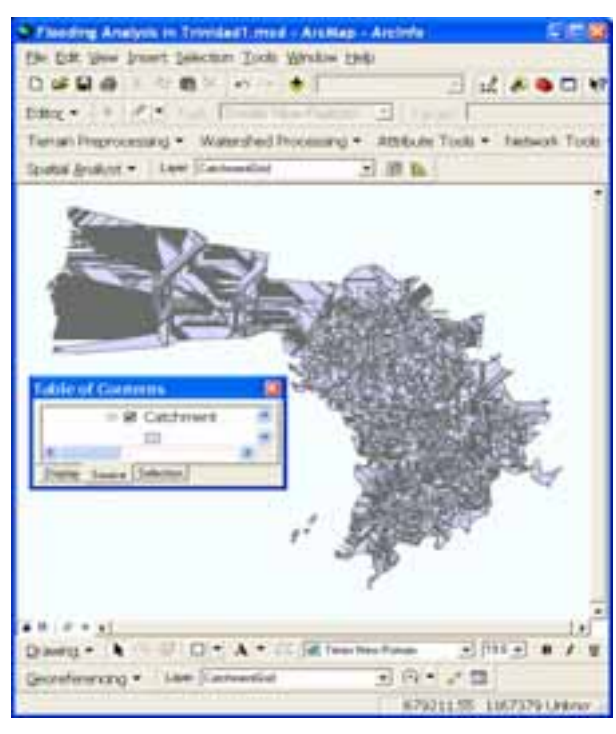


Figure 12: Catchment

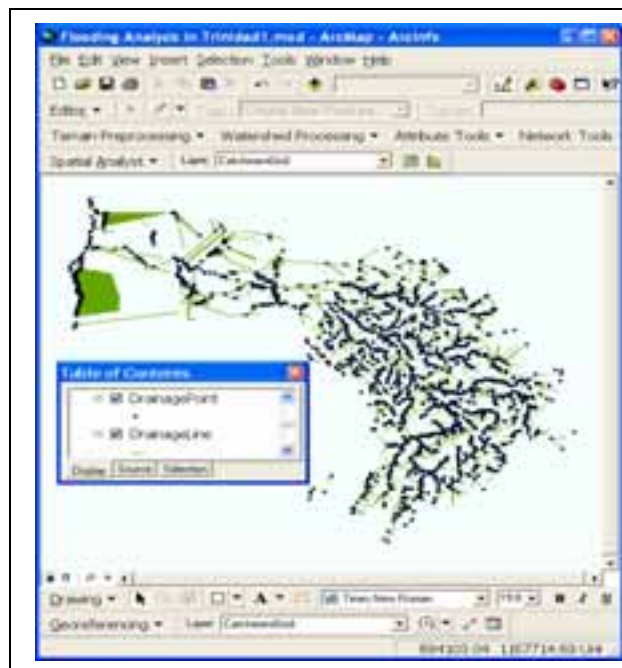


Figure 13: DrainagePoint and DrainageLine

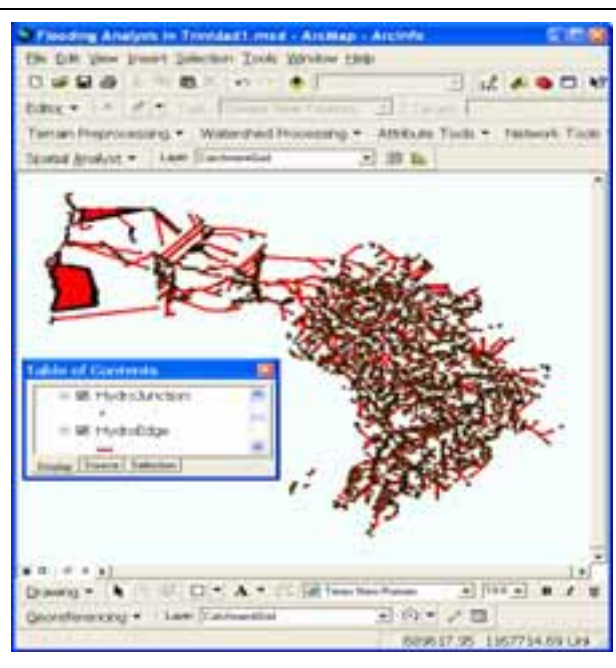


Figure 14: HydroJunction and HydroEdge

A ProfileLine is a longitudinal view of a channel, using lines drawn parallel to the stream flow. Various types of ProfileLines can be drawn (as shown in Figure 15):

- The Thalweg is the ProfileLine through the lowest point of the stream channel at each CrossSection.
- Banklines show the intersection of the water surface and the land surface on each side of the channel.
- Floodlines can be drawn in the flood plain to symbolize the main direction of water flow when the flood plain is inundated.
- Streamlines can be drawn anywhere in a water flow, for example to depict the water surface profile for a particular design discharge in the channel.

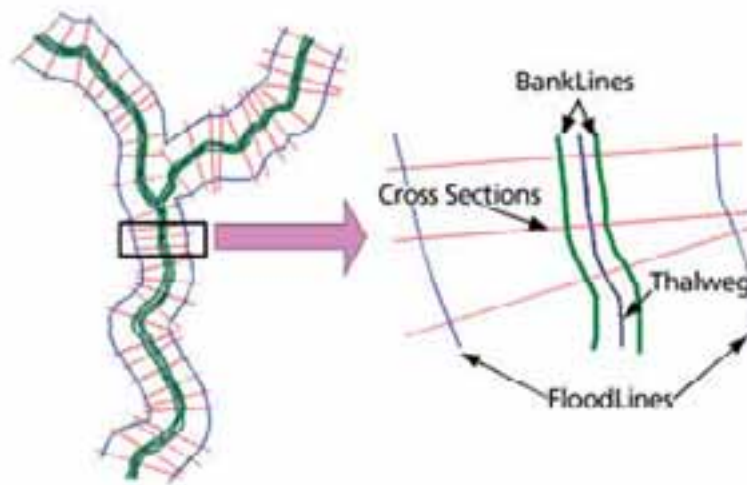


Figure 15: Profile line of a river, (Maidment, 2002)

The profile line of the drainage network of the study area is shown in Figure 16. The Bank lines, Thalweg lines, Profile lines and Cross Section lines were all digitized on-screen. The data sets generated from ArcHydro are to be used to perform pre- and/or post-processing of GIS data which will generate results for flood inundation mapping in ArcGIS. This is facilitated using the Hydrologic Engineering software extension for ArcGIS called HEC-GeoRAS.

HEC-GeoRAS is being developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) which was formed in 1964. Their responsibility is to institutionalize the technical expertise that subsequently became known as hydrologic

engineering. HEC has been developing computer programs for hydrologic engineering and planning analysis procedures since its inception in 1964. Software has evolved from computerized procedures to complex modeling systems.

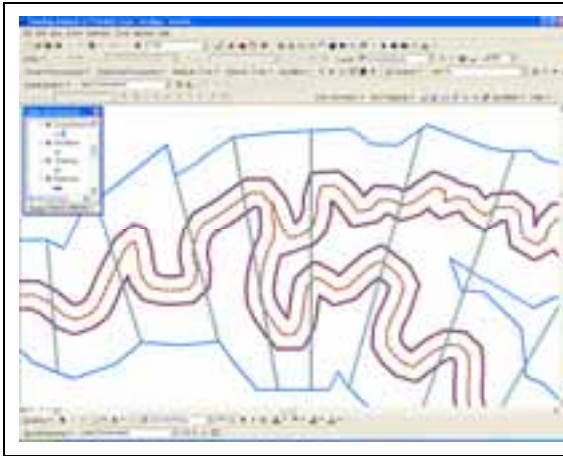


Figure 16: Profile lines of Caparo area

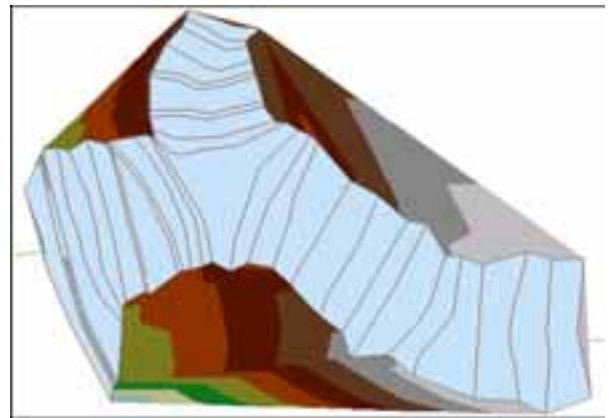


Figure 17: Projected Flow Analysis (Merwade, 2006)

3.0 FURTHER RESEARCH

The use of the HEC-GeoRAS software is being researched. The intent is to use the output from ArcHdro such as drainage basins, HydroDEM, and the Drainage Points, in the HEC-GeoRAS software. The cross sections along the river will be generated along the thalweg, and the floodlines will be incorporated to simulate the flooding of the area as shown in Figure 17 of a sample result in which the water flow is shown as blue and the cross sections as brown lines.

References:

Maidment, R. David (2002). *“Arc Hydro GIS for Water Resources”*. ESRI Press, 380 New York Street, Redlands, California. ISBN – 13: 978-1-58948-034-6

Merwade, V. (2006). *“Tutorial on using HEC-GeoRAS with ArcGIS 9.1”*. School of Civil Engineering, Purdue University. Email: vmerwade@purdue.edu

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