FLOODING ANALYSIS STRATEGY USING GIS

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ABSTRACT

Flooding is a common phenomenon which is invariably influenced by man's co-existence with nature. The level of the co-existence defines the extent and magnitude of flooding. The behavior of local communities and the provision of its drainage infrastructure determine how well flooding is controlled during times of inclement weather conditions. In this paper is presented an unexplored strategy which is aimed at assisting the decision making processes in a sample area of the island of Trinidad & Tobago (T&T) which is prone to flooding. The strategy is investigated using the ArcGIS software together with the Arc Hydro extension which is geared to support water resource applications. In this strategy use is made of existing data sets that generates new data sets such as DEMs, drainage basins, flood prone areas, and such like which are all used in the definition of a flooding analysis strategy for T&T.

Keywords and phrases: Flooding, GIS, drainage analysis, DEM

1 Introduction

Flooding is a major problem in the twin island of Trinidad & Tobago (T&T) in particular, Trinidad. Every year during the rainy season and at times during the dry season (when there are sudden thunderstorms) the problem persists. The government of Trinidad & Tobago has been attempting to address this reoccurring annual problem that affects the community either directly, by way of flooded properties and loss of personal valuables or indirectly, by way of higher food costs and the fall of property values.

The government has been working towards achieving a solution however their approached has proven to be insufficient and inadequate for various reasons while flooding persist. Despite this fact, credit must be given to a number of government agencies that are working towards providing solutions to the problem. The most directly related agency has been the Ministry of Works and Transportation, responsible for the dredging and widening of the main river called the Caroni River and its drainage basins. The Ministry has taken the direct approach of addressing the problem, rather than dealing with the problem systematically by performing drainage basin and natural water flow analyses. To do these analyses the use of Geographic Information System (GIS) is proposed. GIS is a tool that facilitates the capture, storage, manipulation, and visualization of spatially referenced data sets. The geographic data sets needed for such analyses in T&T are as follows: height information such as contour lines and spot heights;

sudden changes in the landform such as breaklines and their associated height information; computer generated representation of the landform; the coastline; the enumeration districts; the county boundaries; the country's population density; existing man-made drainage network; existing natural drainage network; watersheds and water basins; flood prone areas; road network; and last but not the least, housing and settlements.

Government agencies that are in a position to support the drainage basin and natural water flow analyses are Water and Sewage Authority (WASA), Lands and Surveys Division; Ministry of Works and Transportation; Central Statistical Office (CSO); and Town and Country Planning Division. These agencies have been collecting geographic data sets in the format which can be used in a GIS. They have however, not used the data to perform any drainage and natural water flow analyses. In this paper the intention is to address the flooding problem by exploring the following:

- Delineation of water basins
- Identifying the flood prone areas
- Delineate the natural water flows
- Identify the best location for a series of dams which can be used to control the flow of excessive water
- Identify the watersheds and drainage basins
- Identify the buildings prone to flooding

These analyses serve as a tool which is capable of addressing the best approach in dealing with the control of flooding in T&T.

2 Hydrology examples

There are multiple levels of hydrological implementations which are dependent on the finances and budget of the project; the technical awareness and usage by the hydrologist; the dedication and commitment of the project managers; and the support from the political stakeholders. The levels of implementation range from display and query GISs that manages existing natural and man-made water flows to that of complex drainage analysis that is capable of water flow simulations suitable for identifying flood prone areas and the positioning of dams.

In this paper emphasis is placed on *Urban Hydrology* and its associated impact on settlements. Urban hydrology is defined as the interdisciplinary science of water and its interrelationship on urban man and the living environment [Jones, 1971]. The hydrology of urban areas is quite complex for planned areas as opposed to the even more complex and complicating occurrences in the unplanned areas. As a consequence, there are many on-going researches into this field. Some of the existing urban drainage models have the ability to accurately model the effects of storms on the urban drainage basins, however, their deficiencies lie in the problems of data acquisition, storage and manipulation, [Elgy,1993]. However, to have an appreciation of the use and importance of this science, its theoretical aspects must be investigated.

Most of the work in urban hydrology studies is put into the data acquisition, manipulation and management. The traditional method of collecting the data is digitizing areas, elevations, urban structures, and such like manually from hardcopy maps and storing these data sets into a certain format as input for the computer model. Present methods of data collection include accessing shared digital data from data collection agencies and/or collecting the raw data from the field. Once the data is collected there is a wide variety of hydrological GIS software capable of performing some of the common hydrological analyses which is required on an everyday basis.

The area of hydrology which is of concern in this article is in the area of flooding as it relates to the natural water flow and the path water takes when water is dropped on a landform. The natural occurrence is that the water will take the path of fastest decent, assuming that the water does not percolate into the earth surface. The actual fact is that if water percolates then the phenomena of flooding is not a problem, however, when the surface is impervious and/or saturated, then the water will be flow over the surface. The problem of flooding is applicable to developed and developing countries.

2.1 Developed countries

In developed countries the infrastructure is typically designed to address the extreme situations where flooding is likely. However, this does not imply that in such countries flooding do not occur. The reasons for such flooding instances include under-maintained drainage infrastructure; urban sprawl with over-population; an increase of impervious surfaces in urban areas; harsh and unpredictable weather patterns such as hurricanes, tropical storms, and such like; and channel blockages due to natural features and urban littering.

Flooding is not a welcome phenomenon and when it occurs one cannot be fully prepared. The devastation is widespread for the immediate flooded areas and involves the loss of property and in some instances the loss of lives. The recent Hurricane Ivan in 2004, which affected a large proportion of the Caribbean and southern states of the US was a natural phenomenon that brought property devastations and the loss of lives. Other examples are Hurricane Floyd which was an intense Atlantic Basin Hurricane with winds reaching 155 mph. Severe flooding occurred in Eastern North Carolina due to heavy rainfall associated with Hurricane Floyd, causing an $800 million damage to property. This extensive damage required more than $100 million in post-disaster mitigation funding from the US government.

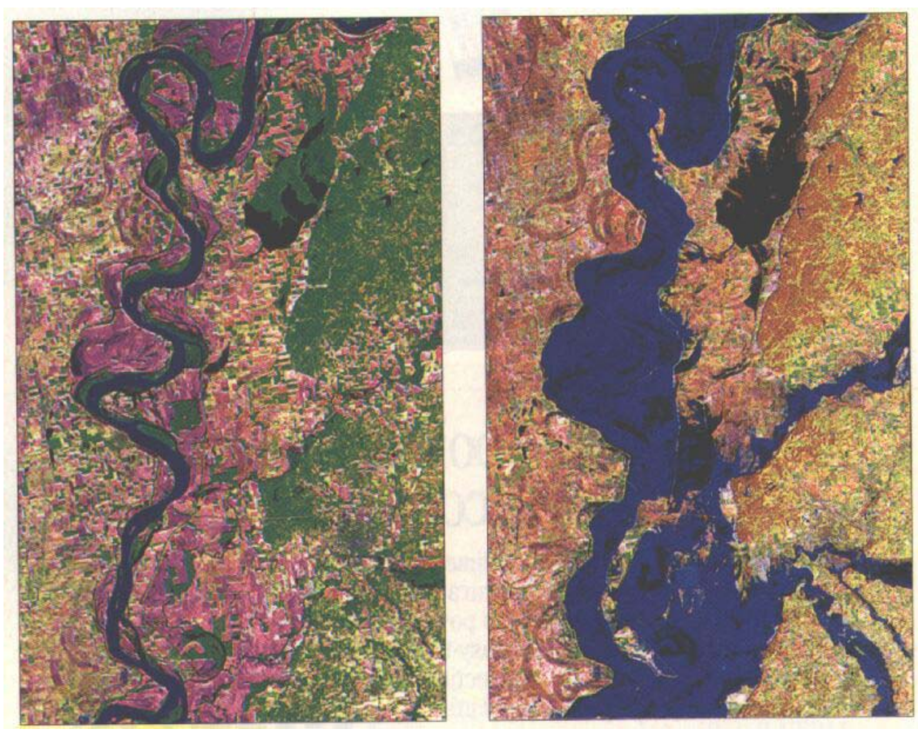

Figure 1: Before and After Landsat Imagery for the Mississippi Flood of 1997(Photo Courtesy of Space Imaging EOSAT)

Another example of flooding is the Mississippi River flooding which created havoc in the spring of 1997. Figure 1shows 25-meter resolution before and after Landsat images of the flooded Mississippi area. The photos show the Mississippi just below its confluence with the Ohio River in areas south of Cape Girardeau, Missouri. The before flooding image shown at left was taken on July 3, 1996. The post-flooding image shown at right was taken on March 16, 1997. A visual comparison of the two images clearly indicates the extremely large extent of the 1997 flood. Images like this can be effectively used in flood damage assessment and developing flood relief activities (Civil Engineering News, 1997).

McArthur (2004) stated that the San Antonio Basin of central Texas receives some of the world's most intense rainfall. The rainfall combines frequent severe storm events and one of the largest urban centers in the US which is a recipe for significant property damage and loss of life.

The adoption of GIS tools is used in the US to address flooding. A common tool is called ArcHydro. This software is executed using the Environmental System's Research Institute (ESRI) ArcGIS software. ArcHydro helps users more easily and quickly link a wide variety of data through relationships between features by tracing and connecting elements along the path of water movement, (McArthur, 2004). ArcHydro establishes the relationships between features by tracing and connecting elements along the path of water movement. The features include drainage basins, streams, hydraulic model cross sections, structures, and sources and sinks for both water quantity and quality features.

Harris County, Texas, Flood Control District (HCFCD) is using ArcHydro as the framework for its current watershed planning initiative. Their approach includes gathering and processing digital data for all of its watersheds and populating their geodatabase. Another example is South Florida Water Management District. They are responsible for the water quality, flood control, natural systems, and water supply for its customers in South Florida. They are spare heading four projects which includes flood management, natural system restoration, operations decision support, and regional modeling.

2.2 Developing countries

Flooding is relatively more prevalent in developing countries rather than developed countries for the reasons being that there are various levels of enforcement, maintenance and provisions of drainage networks. Developing countries are faced with far more hurdles to address because of the bureaucracy of the government. The planning and the enforcement of regulations and standards are typically not fully enforced and as a consequence, flooding is a common occurrence.

Flooding in developing countries is due to many contributing factors such as poor and non existing drainage infrastructure; littering which block the natural water flow; deforestation in forested areas which encourages erosion of hilly areas; no technical, competent and reliable solutions to flooding by ruling government; and such like. The other factors which are uncontrollable (such as unpredictable weather patterns) also compound the flooding problem. As a result flooding has been a way of life in most developing countries.

In Bangladesh the United Nations humanitarian agency continue to bring aid as heavy rains produced massive flooding during the monsoon rainy season. Many transport routes and utilities, inundated buildings and caused further disruptions to livelihoods, aggravating the impact of the catastrophic monsoonal floods. GIS is being used through the generation of maps and other statistics of flood damages which are disseminated to different government and non-government agencies active in relief and rehabilitation and in the field of flood disaster management in Bangladesh. The annual monitoring of flood is now a support project focusing on floods and flood characteristics.

Hurricane Ivan in 2004 has certainly spread his devastation across the islands of the Caribbean. Grenada is a well know fact, has suffered close to total destruction of the islands infrastructure and would take the island years to recover. Trinidad & Tobago was fortunate in that the effect of Ivan did not directly hit the country however there was tremendous flooding and loss of property, in particular to the island of Tobago. The monetary loss due to Hurricane Ivan is fuelled with the tremendous strength of Ivan and the lack of hurricane proof buildings which does not adhere to building standards, and inadequate drainage network. This paper provides insight into GIS as a tool which can assist in the reduction of the loss by presenting a prototype using a commonly flooded area in Trinidad.

3.0 Study area

Trinidad & Tobago (T&T) is a twin island country located at $10^{1}/2$˚N, $61^{1}/2$˚W as shown in Figure 2. It is the southernmost island of the Caribbean archipelago, and an extension of the South American continent. T&T has an approximate area of 1,980 square miles ($5128 km^2$) and has a tropical climate with average maximum temperatures of 32°C, (89°F). TIDCO (2001) stated that there is a dry season from January to May and a wet season from June to December. Annual rainfall is about 200 cm (40 inches) over most of the country. Trinidad and Tobago is just south of the hurricane belt. The estimated population of T&T is 1.3 million[1] that comprises of 40.3% East Indian, 39.5% African, 18.4% who are mixed.

Figure 2: Location of Trinidad & Tobago[2]

There has been over the past decade or more a need for a solution to the problem of flooding in T&T which is a relatively small island and with its large concentration of population located along the northern east-west, and western north-south areas of the island. There have been various speculations as to the reasons for flooding which range from the littering of the environment to that of the changes in the weather patterns due to global warming. All of such speculations do contribute to the overall consequence which is flooding. Flooding occurs from a range of causes and conditions. River flooding is the kind most commonly known. Coastal flooding is also very common but not so much in T&T. However, during hurricanes or other large storms, waves may be much higher than normal, and super-low atmospheric pressure often forces sea level to rise a dozen feet or more above normal in a “storm surge.” This restricts the normal river water flow into the sea. Other restrictions are man-made such as obstructions placed along the natural water courses. Obstructions are usually large amounts of litter and/or man-made obstacles along the natural water flow.

Floods can kill people and destroy homes in many parts of the world every year. There are a number of precautions needed to prepare for a flood. The first is to find out if you are in a flood prone area. If the area is flood prone then flooding procedures need to be discussed by families, for example, learn the safest route to high ground, and teach all family members to turn off electricity, gas, and water lines. Other precautions are to ensure that valuable items, household chemicals and food are stored at higher elevations; keep emergency supplies on hand and easily accessible; keep street drains, storm gates and flap gates free of leaves and other debris or litter; and consider buying flood insurance to protect personal properties.

In T&T the National Emergency Management (NEMA) is mandated by the government to address emergency plans and instructions for disaster situations, among other responsibilities. NEMA (1992, pg.14) presented flood safety instructions for the T&T citizens which detail the precautions: before a flood; when a flood warning is received; during a flood; and after a flood. NEMA (1992, pg.14) does not stipulate the need to identify flood prone areas in its list of safety precautions before a flood. This might be the first line of precaution that needs consideration in order to best prioritize the various flood prone areas located through out T&T. Once done then the other listed precautions maybe better applied.

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[1] http://www.cso.gov.tt/
[2] http://worldatlas.com/webimage/countrys/namerica/caribb/tt.htm

Plans of action which addresses flooding will vary between a developed and a developing country depending upon their available resources and infrastructure. The following are a set of questions and issues which will be considered in any given flood preparation plan:

1. Where are the flood prone areas? Where is the disaster response locations of services which will assist in all aspect associated with flooding? How many buildings and people are affected in the flood prone areas? What factors will indicate which communities are likely to be flooded, from which they can be prioritized?

2. What are the main systems in the community for warning people in flood-prone areas of imminent danger? Are people aware of how and where to get flood warning information? Do they actually seek or receive the information? What plans and methods do local public safety officials have for warning people if evacuation is needed?

3. Have media in the area informed people how to prepare for flooding emergencies and how to respond to flood situations?

4. What plans does the community have for dealing with flood emergencies at the time they are happening? Are evacuation plans clear and adequate? Are there plans for keeping man-made hazards (chlorine and propane tanks, petroleum pipelines, etc.) from compounding the problem? Are government and private agency responsibilities clear?

5. What steps has the community taken to prevent or minimize death, injury, and damage from flooding?

6. Have structures been built recently in any of the flood-vulnerable areas in your community? What zoning, planning, and building are affected?

7. Regulations in the local jurisdictions govern how people build in flood plains? Do they work?

8. Does the community belong to a National Flood Insurance Program?

9. What engineering approaches has the community taken to storm drainage?

The islands of T&T has a Parliamentary Democratic government. The ruling party has over the decade and more been focusing on dredging the main river in the island of Trinidad. The main river, Caroni River, rapidly collects the excessive run-off water from the various water basins located in the two mountainous areas called the Northern and Central ranges in T&T. All of its tributaries flow into the Caroni River and because of this, dredging is seen as the immediate response of all of the government's approach. Another flood prone river, Caparo River, located in central Trinidad always floods its banks after heavy rainfall. The area around this river is chosen the study area focused in this paper.

Debates between the ruling and opposition parties have been ongoing with its intent of finding a solution to the flooding in Central Trinidad. In the late 1980's, flooding increased during the then ruling party of governance, National Alliance for Reconstruction (NAR) for the period 1986 and 1991. This increase was due to the increased unplanned development that added to the problem of the cause and the effect of flooding. The government at that time finalized plans for a Project Implementation Unit between the years 1994 and 1995, which involved a first phase that encompass proposals for retention dams or lakes along the Caparo River, and sluice gate and pumps located at the mouth of the river. The next phase was to widen the river, while the last phase was to straighten the meandering along the river. In 1998 the last phase was done without finishing the other phases and as a result the flooding still persist and the success of the implementation was compromised.

In this paper the study area chosen is called Caparo (as shown in Figure 3.0), is located in central Trinidad and it can be categorized as being a rural area of Trinidad. The data used to perform the research presented in this paper was obatined from the utility organization called the Water and Sewage Authority (WASA) of T&T. The data represent the basic input needed to generate a three dimensional representation of the landform which is critical for drainage analysis. The data collected by WASA has been over the years extensive and sufficient enough to satisfy the immediate needs of the end-user customer requests such as billing queries, utility locations, property right disputes, and such like. The data can further be processed to assist in more a extensive drainage analysis, however, there is no evidence of the exploration of the data sets. This paper intends to identify such analyses which can assist in the decisions regarding flooding in Trinidad & Tobago.

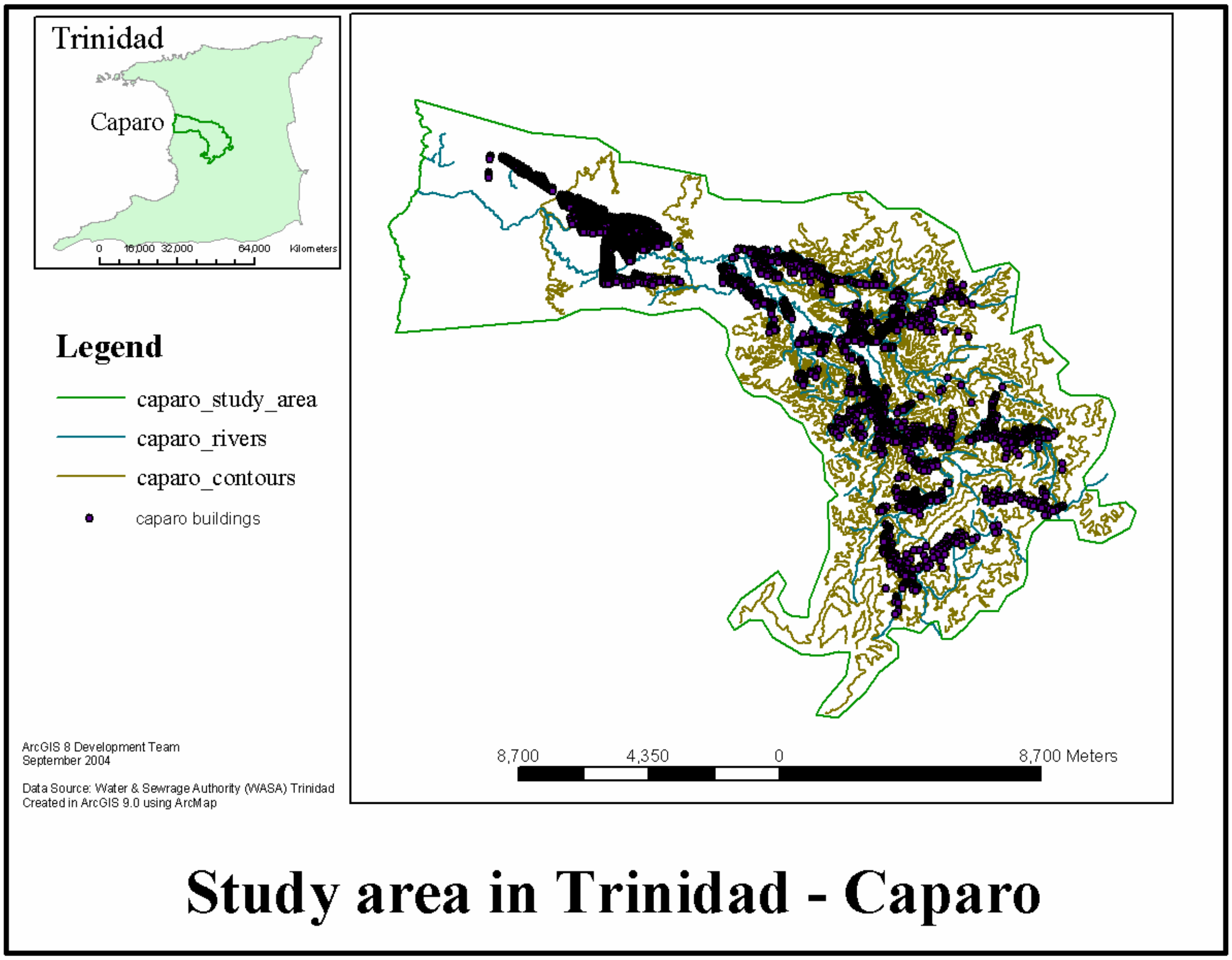

Figure 3: Study area

WASA can use its existing data sets to generate different views and perspectives of the raw data by way of generated derived data sets. The derived data sets will give better insights into the flooding problem at hand by defining the workflows which are typically done manually by the engineers. These workflows are already defined in the Arc Hydro data model (a view is shown in Figure: 4), which can be adopted into WASA's GIS strategy.

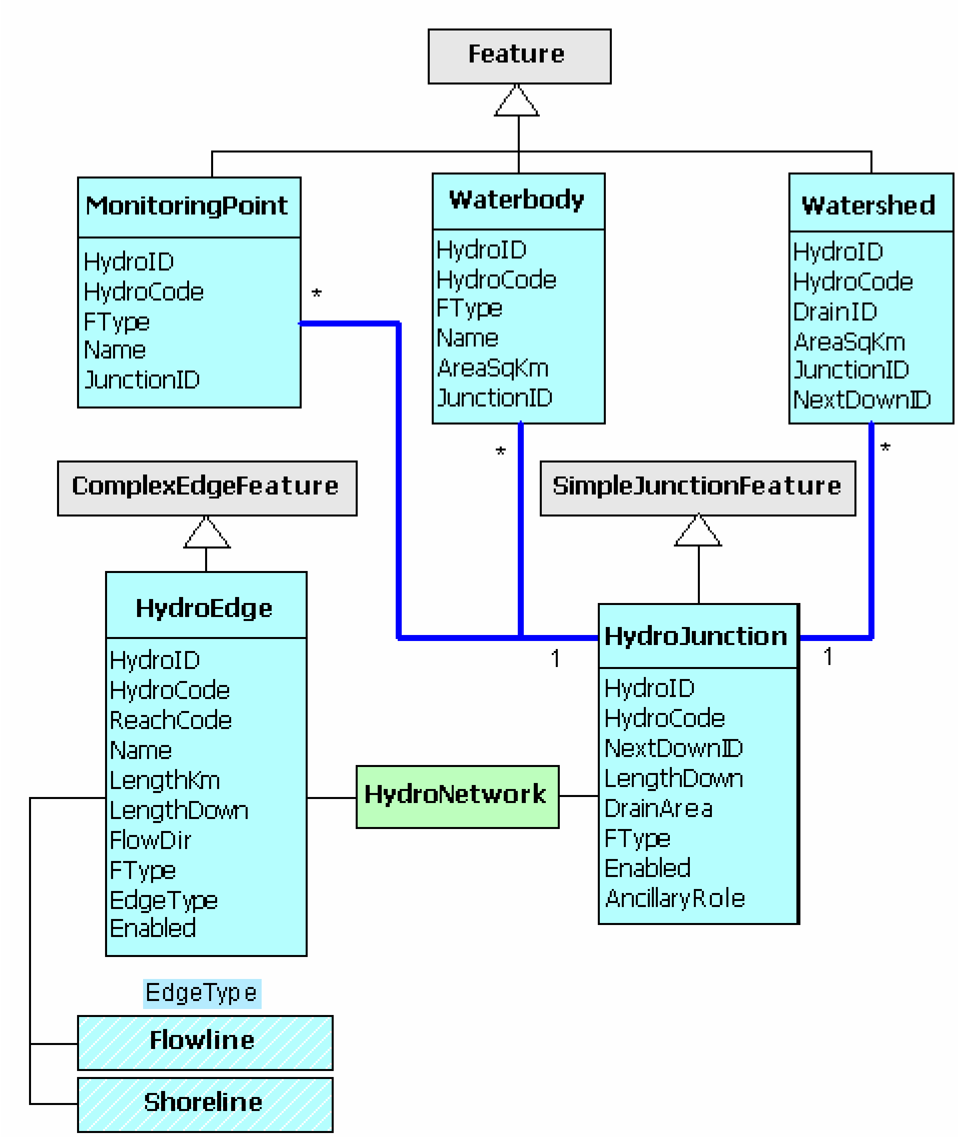

Figure 4.0 Arc Hydro data model[2]

ESRI has developed models for Water Resources focused on surface water. The ArcGIS Hydro model is available for review and download[2]. The model addresses groundwater and the full hydrologic cycle. The feature dataset contains five feature classes: MonitoringPoint, Waterbody, Watershed, HydroEdge, and HydroJunction.

MonitoringPoint represents point features from map hydrography and inventory sources used to collect water resources data.

Waterbody represents area features from map hydrography.

Watershed is a polygon feature class, which contains any subdivision of the landscape into drainage areas.

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[2] http://support.esri.com

4.0 Procedure

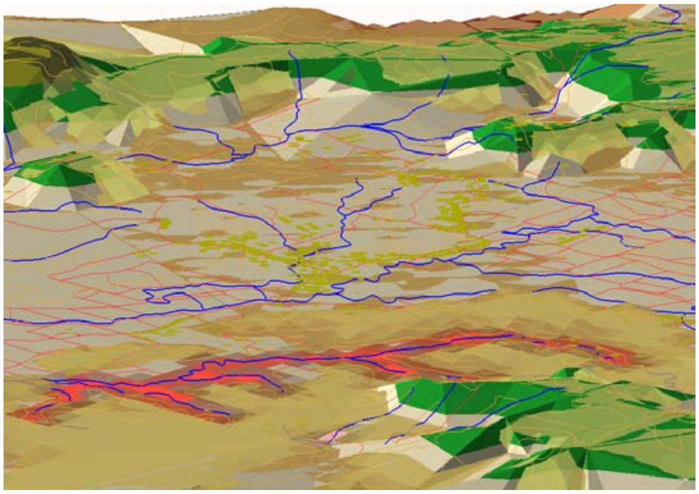
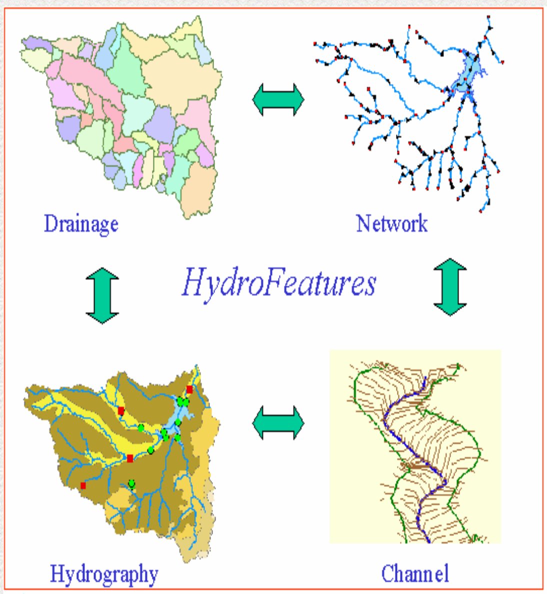


Figure 4: Model of Caparo

To assist in alleviating the flooding in T&T, a decision is needed in positioning the main drains in the community given the local, physical, social and economic characteristics and conditions of the area. To perform drainage analyses within communities a digital representation of the landform is required for use in the computer. The landform referred to here is called a *"digital elevation model (DEM)"*. A DEM is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum on the landscape (Moore et al, 1991). In principle, a DEM describes the elevation at any point of a given area in digital format and contains information of the so called *'skeleton lines'*. Skeleton lines are lines of slope reversals (drainage, crests) and breaks of slope. In contrast, a DEM is used to generate a *"digital terrain model (DTM)"*. A *digital terrain model* includes the spatial distribution of terrain attributes. A DTM is a topographic map in digital format, consisting not only of a DEM, but also slope, aspect, the types of land use, settlements, types of drainage lines and so on, [Meijerink et al, 1994].

4.1 GIS Software



In this paper ArcGIS 9.0 GIS software written and developed by the Environmental Systems Research Institute (ESRI) is used with the Arc Hydro Extension (version 1.1 Beta 3, May 2003). Arc Hydro is an ArcGIS-based system geared to support water resources applications. The Arc Hydro data model provides a basic database design for water resources. The Arc Hydro Tools are a series of tools built on top of the Arc Hydro database that facilitates the analyses often performed in the water resources area.

An Arc Hydro geodatabase consists of Hydro Features connected to Time Series. Hydro Features describe the physical environment through which water flows, and the Time Series describe the flow and water quality properties of the water within those features. Every Hydro Feature is uniquely defined within an Arc Hydro geodatabase by a HydroID, and associations are formed between features by storing the HydroID of one feature as an attribute of another. These linkages can be used to trace water movement from one feature to the next, and also to associate several different geospatial representation of the hydrologic entity with one another. The Arc Hydro data model consists of five components: Network, Drainage, Channels, Hydrography and Time Series:

- The Network component contains a water resources network of streams, rivers and the centerlines of water bodies. Its main purpose is to describe the connectivity of water movement through the landscape.

- The Drainage component defines drainage areas delineated through analysis of land surface topography.
- The Channel component describes the three-dimensional shape of river and stream channels.
- The Hydrography component contains base map information on point, line and area water resource features.
- The Time Series component describes time varying water property of the features.

4.2 Drainage basin delineation

A *Drainage Basin* is the area that drains water and other substances to a common outlet. An *outlet, or pour point* is the point at which water flows out of the drainage basin. This is the lowest point along the boundary of the drainage basin.

The delineation of drainage basins is possible using depressionless DEMs generated by the ArcGIS software. To do this, the flow direction of the water is considered such that the area being drained by cells flowing into each other is delineated as basins. This GIS analysis approach is beneficial to many professions ranging from engineering who are responsible for the provision of drains to that of biologists who are interested in habitat management.

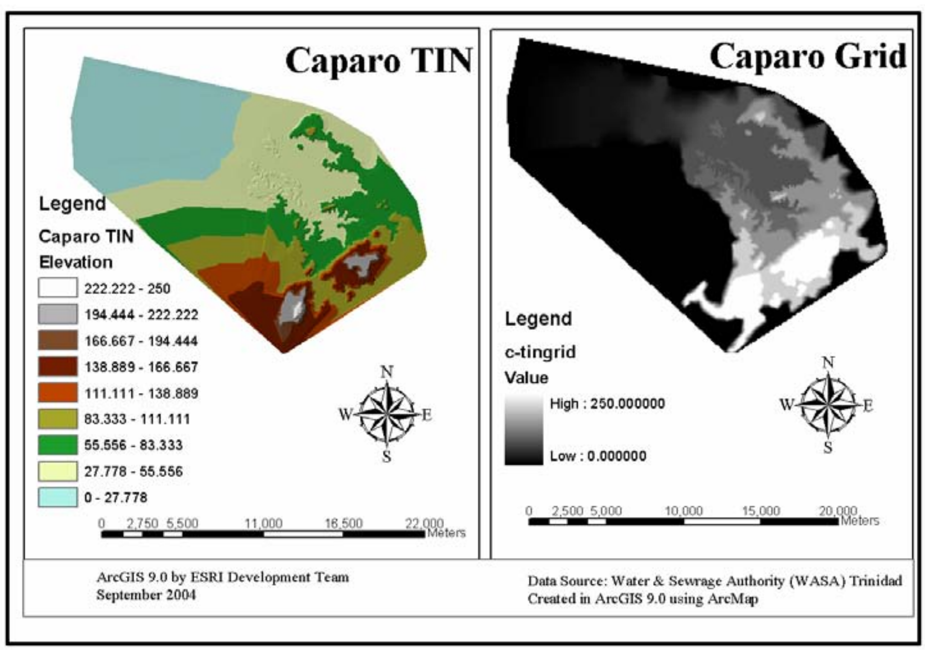


Figure 5: Caparo continuous surfaces

ArcGIS was used to generate the triangular irregular network (TIN) of the Caparo area by using the digitized contour lines. The TIN was then used to generate a second continuous surface which is a pixilated surface where each pixel has a height value above mean sea level. The two surfaces are shown on Figure 5. The landform of Caparo has a relatively undulating characteristic which drains into the Gulf of Paria sea area which was presented in Figure 2.

Using the generated DEM, a Hydrology DEM is generated which is a DEM with no sink areas. The sink areas are pixels which have heights that are lower than neighboring pixel values. For drainage analysis to proceed, all sinks need to be filled which is a readily available process of Arc Hydro.

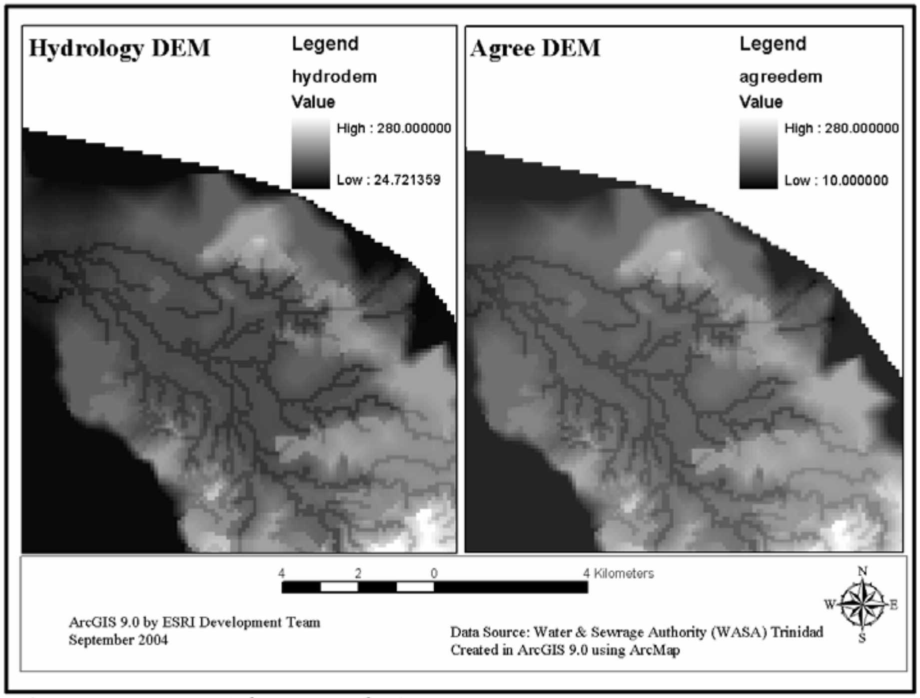


Figure 6: Hydro and Agree DEM

In Figure 6, the Hydrology DEM shows the DEM in which the sinks were removed and all the runoff from the DEM will reach its edges. This is a correct assumption but in some cases that is not correct (e.g. lakes).

The Agree DEM is the enforced linear drainage pattern (vector) onto the Hydro DEM (grid). In this paper the linear features used is the location of the existing Caparo river. The Hydro and Agree DEM for Caparo are similar as shown in Figure 6.

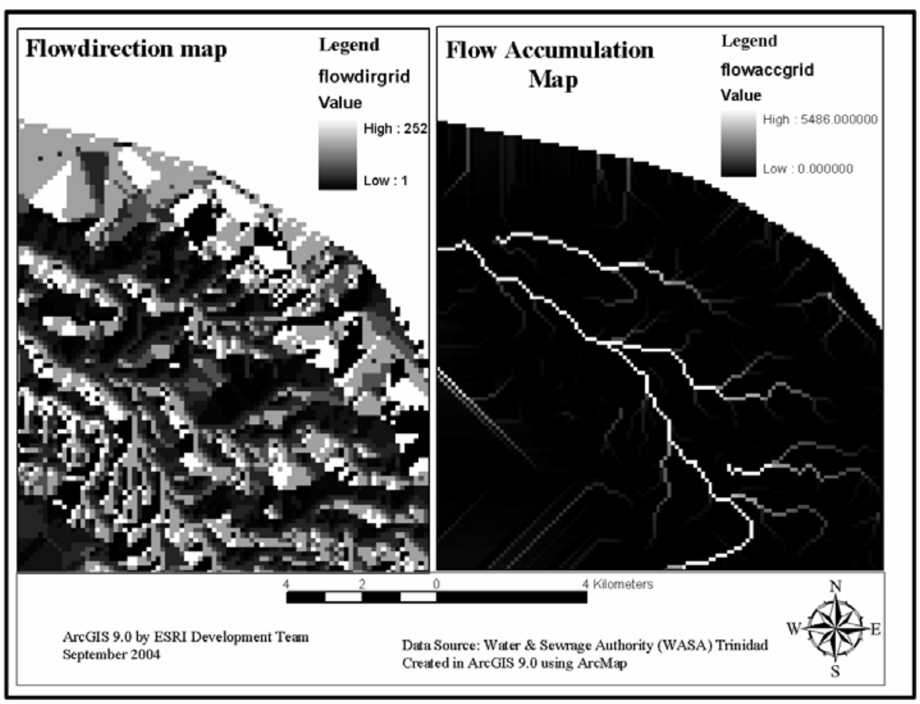


Figure 7: Hydrology maps

A flow direction grid is then generated using the Agree DEM. The flow direction grid is the output computation of the corresponding flow direction grid where values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. The next step in the hydrology analysis is to compute the flow accumulation. This is a function that takes as input a flow direction grid and computes the associated flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid. Figure 7 shows the two hydrology grids.

The accumulated flow grid shows the white lines as the cells which have the highest accumulated flows and as such shows the path water will follow to get to lower grounds.

The location of the sink areas is useful in this analysis for the main reason that it identifies the flood prone areas. In Figure 8 is shown the flood prone areas in Caparo. The area shown in red is the largest area and it covers an area of 163 acres. This is an area which always flood every time when there is and excessive amount of rain and as a result affects the surrounding rural residential buildings. Other flood prone areas range between 1.7 to 163 acres.

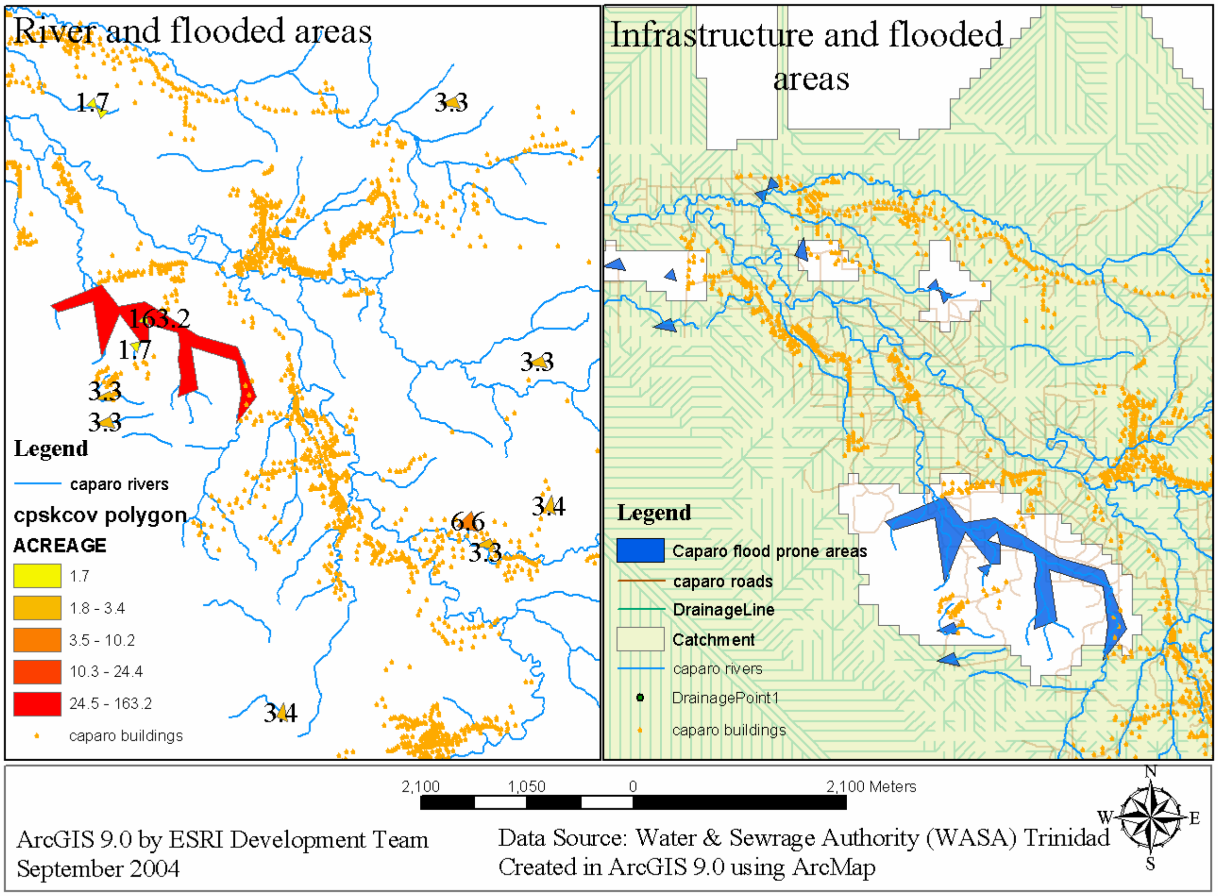


Figure 8: Flood prone areas in Caparo

5.0 Future research

The methodology presented in this paper is a valued approach by making use of collected base data sets and processing them to generate derived data sets which can assists the governing bodies involved in T&T to make valued and critical decisions regarding the hydrology in its flood prone areas. The results from this paper include the creation of a DEM upon which other physical features are draped onto such a continuous surface. The flooded areas are derived and can be validated out in the field. The flooded areas can then be overlaid onto the continuous surface and together with the building data set, the number of affected and acreage flooded can be determined.

The results from this hydrology analysis need to be extended to include the location of dams which can be used to control the flood waters. A dam is a structure that creates an artificial lake, or reservoir, by blocking a river or stream. Dams may harness the energy of falling water or provide flood control. Further research is needed to investigate how ArcHydro can be used to address the appropriate locations of such dams.

6.0 References

Carter, J. R., (1989). Relative errors identified in USGS gridded DEMs. Proceedings of Auto-Carto 9, Ninth International Symposium on Computer Assisted Cartography, Baltimore, pp. 255-265.

Dias, L. A. V. & C. E. Nery, C. E., (1992). Evaluation of interpolators for digital elevation models. Proceedings of the ISPRS and OEEPE Joint Workshop Data by Photogrammetric Methods, Oxford. OEEPE Publication No. 27, pp. 257-212.

Domingue, J. O. & S. K. Jenson, (1988). Extract topographic structure from digital elevation model data from Geographic Information System analysis. Photogrammetric Engineering and Remote Sensing, Vol. 54, No. 11, pp. 1593-1600.

Elgy, J., (1993). Matching standard GIS packages with urban storm drainage simulation software. HydroGIS 93 : Application of Geographic Information Systems in hydrology and water resources, (Proceedings of the Vienna Conference). IAHS publication number 211.

Jones, D.E. Jr., (1971). Where is Urban Hydrology Practise Today? Proceedings Am. Society Civil Engineer, Hydrology Division, 97(HY2):257-264.

Li, Z., (1988). On the measure of digital terrain model accuracy. Photogrammetric Record, 12(72), pp. 873-877.

Meijerink, A. M. J., H. A. de Brouwer, C. M. Mannaerts & C. R. Valenzuela, (1994). Introduction to the use of GIS for Practical Hydrology. Published by UNESCO.

Moore, I. D., R. B. Grayson & A. R. Ladson, (1991). Digital terrain modeling: A review of hydrological, geomorphological and biological applications. Edited by K. J. Beven and I.D. Moore.

NEMA, 1992. 'Emergency plan and instructions for disaster situations'. National Emergency Management Agency (NEMA) of Trinidad & Tobago. Trinidad & Tobago Parliament Library, Port-of-Spain, Trinidad, West Indies.

Robinson, G. J., (1994). The accuracy of digital elevation models derived from digitized contour data. Photogrammetric Record 14(83), pp. 805-814.

Shmutter, B. & Y. Doytsher, (1990). DTM - accuracy estimates. Proceedings of the Fourth International Symposium on spatial data handling, Zurich, pp. 263-272.

Tempfli, K. , (1980). Spectral analysis of terrain relief for the accuracy estimation of digital terrain models. ITC Journal, 1980-3, pp. 478-510.

TIDCO, 2001. 'About Trinidad and Tobago – Geography' Tourism and Industrial Development Company (Trinidad and Tobago) Limited, Trinidad, West Indies.

http://www.visittnt.com/General/about/geography.html (Accessed on July 12th, 2004).

McArthur, K., (2004). 'Texas partnership initiates innovative watershed management with GIS'. ESRI ArcNews, summer, 2004, page 28.

Civil Engineering News (1997). "Mississippi River Flooding." News Brief, September 1997, Page 26.