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Flood Hazard Mapping by Integrated GIS - SCS Model

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ABSTRACT

Natural hazards have existed since the dawn of civilization. With time, they have slowly changed into disasters where the main factor gearing the amplitude of their effects is the extent of urbanization within the critical regions of occurrence. Thus, with the development, these disasters have become the cause of socio-economic losses. Amongst all, disasters of hydro-meteorological origins are most frequent and seriously damaging nature. Small countries and islands suffer much from such events, because of the precocity of their economies and lack of appropriate infrastructure. Mauritius, given its geographic location and climate, is quite prone to such extreme events, even if floods are the most recurrent ones. The aim of this research study is to explore the possibility of the relevance of an adapted flood study model to the island, and how it could better help understanding the source of the problem. The integrated GIS - SCS hydrological model is utilized to highlight the flooding problem in Mauritius. Flood sensitive zones were identified using Digital Elevation Model (DEM) and flood hydrographs were derived for two catchments namely J and M. The research article further discusses how coupling of these two techniques could help to identify even the most critical flood prone areas within a sub-catchment.

Keywords*:* GIS – SCS model, Flood hazard, sub-catchments, Mauritius.

1. Introduction

Since the beginning of civilization natural hazards have influenced human activities. The frequency of such events has increased over the years. Usually, regions affected require much time and resources for reconstruction (Scaruffi 2008; Crossley 2005). The most common natural hazards are either of geophysical nature -Earthquakes, landslides, volcanoes, mud flows, avalanches or of Hydro-meteorological nature - Floods, droughts, storm surges, cyclones (windstorms), cloudburst, and heat and cold waves. Floods are probably the most recurring, widespread, disastrous and frequent natural hazards of the world. With time, people and the environment are being constantly put under stress from the effects of natural disasters.

Mauritius is experiencing extreme events such as long spells of dry seasons, cyclones and long duration high intensity rainstorms etc. These may subsequently bring major flooding problems that have been undermining the island for the past decades, and the situation is getting even worst over time. In the past the island used to receive more than 60% of its total rainfall during the wet summer seasons, i.e. from November to April, with the flashy

Research article ISSN 0976 – 4380

rainfall patterns lasting for a maximum of two hours. Recently the island has been recording heavy intensity rainfall over long time periods which give rise to flood conditions.

Aftermath of floods can also be very incremental to the primary effects, as the affected region takes much time to recover where diseases and epidemics outbursts are frequent. Floods are usually recurrent and have massive impacts on agriculture based economies, which is the case of most small islands. Thus small countries and islands suffer a heavy burden from such events on the economic aspect. Thus, flood studies can be very useful in alleviating the already stressed economies of the insular countries. The study of floods helps to understand the characteristics of the floods, their cause and thus provide relevant data in assessment of these events. Identify the source of the problem can thus help in decision making and contingency planning. Hence the need to delineate flood prone areas is nowadays a priority for the island. In the Flood Risk Management of the European Commission (2005), several issues have been proposed and discussed, pertaining to flood hazard management, and integrated development planning. Eastman (1995) had discussed raster procedures for multi-criteria analysis. In the research article by Yalçõn and Akyürek (2002) the Geographical Information System (GIS) is integrated with Multicriteria Decision Analysis (MCDA) for analysis of the flood vulnerable areas. The Decision Support System for flood warning has also reported by few (Abebe et al 2001; Catelli et al 1998; Haimes et al 1990).

2. Methodology

The study was carried out in two stages. The first stage consist of GIS based hydrological model (HEC1) and Digital Elevation Model (DEM), to produce a map showing flood prone areas. In this stage DEM was used to identify the low elevation regions over the island. This map illustrated the vulnerable zones where runoff would accumulate over the catchment or sub-catchment during flood prone rainfall events. This map also gave more detailed information about the physical characteristics of the catchments over a smaller area.

The second stage of this study was to predict the flood hydrographs likely to be obtained during flood type rainfall. A unit hydrograph was derived using the SCS method followed by flood type rainfall data, the peak discharge was simulated at the vulnerable sub catchments. The contribution of runoff from various sub catchments within a main catchment was also highlighted.

2.1 Method 1 - The GIS/HEC1 Model

Arc GIS Desktop software was used for the purpose of the model development. The first step was to create a DEM and for that a hard copy of 10 m contour map procured from the local authority, Ministry of Housing and Lands was used. The contours were first digitised using AutoCAD and exported to Arc GIS. Using the Kriging Interpolation method, the DEM was generated and rasterised. From the predefined raster DEM, the

Research article ISSN 0976 – 4380

flow definition model was developed. In this study, the DEM developed have the following properties:

Number of Columns (478),
Number of Rows (552), and
Cell size (109.11 x 109.11 m).

2.2 Flow Routing (Defining flow directions)

The flow directions are computed by calculating the steepest descent from neighbouring cells, using the surface elevation values. When flow directions have been defined, a flow accumulation grid is obtained. This step involves the assigning of a unit weight to each of the cells, and the accumulated number of cells upstream for an outlet point can be known, by the summation of all downwards flow according to the flow direction. Areas smaller than the threshold value were considered to be dominated by sheet or overland flow. For this study, the threshold used was 10 cells, which refers to an area of about 0.11 km². In essence, sheet flow is considered to occur over a maximum radius of about 100m if the contributing area is considered as a semi-circular region.

When the stream network has been defined (Figure 1), the catchment for a given stream is delineated (Figure 2). This hence has defined the catchment grid according to the elevation of the surface. Hence, the natural barriers considered are only the slope and aspect of the land. The sub-catchment delineation is derived primarily for a stream. A stream is considered and the drainage area relative to it is delimited. When this step has been completed, the batch catchment delineation is done.

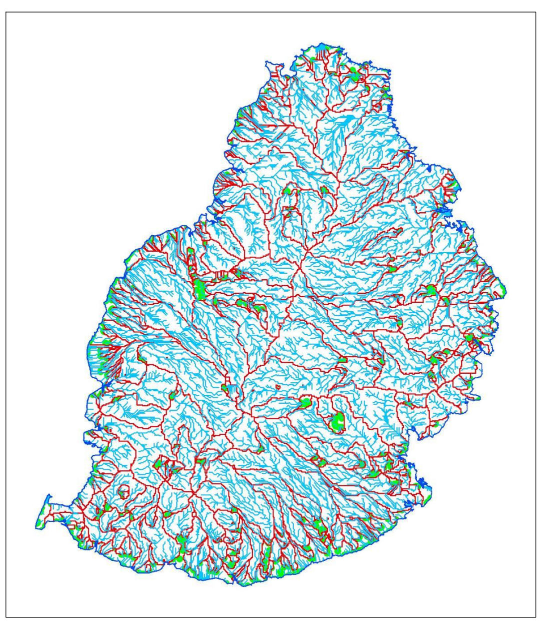


Figure 1: Catchment outline (red), flow lines (blue) and surface storage (green)

Research article ISSN 0976 – 4380

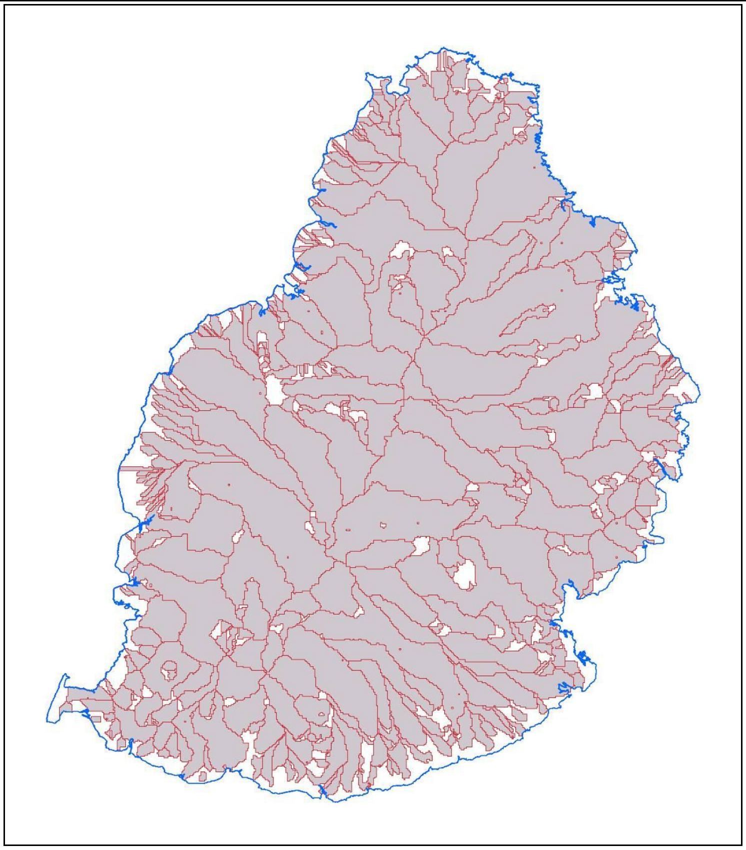


Figure 2: Catchment delineation

In catchments delineation map (Figure 2) it is seen that there are several areas not linked with any basins. Practically, they form part of a drainage area or catchment. They are however characterised by a relatively flat profile where drainage is less likely to occur, or have boundaries that have higher elevations than the central parts of that area or the adjacent catchments. Therefore, flow occurring over these regions is mostly towards the central parts of the area and thus making these regions prone to accumulation. These regions can hence be regarded as flood sensitive zones.

After the drainage lines and points have been obtained, the longest flow path with a major catchment can be computed. This links up the outlet for a major basin to the furthest point upstream of the drainage line for each sub-catchment.

2.3 Method 2: Hydrograph Simulations using the SCS Model

The purpose of second stage was to simulate a flood hydrograph for two selected basins. A unit hydrograph for these two basins was derived using the output of the GIS model to work out the SCS curve number. The soil types and land use were analysed for each basin and the SCS curve number was derived using data from tables 1 and 2.

Research article ISSN 0976 – 4380

Table 1: Land Use Types

Land Use Type	Corresponding SCS Land Use
Urban and Roads	Residential
Sugarcane and Tea	Sugarcane, planted on contours, variable hydrologic conditions
Forest and Mountains	Woods, Fair Hydrologic Conditions

[Source: NCRS, 2004]

From the Hydrologic Soil Cover Complexes tables (NEH 2004), the corresponding values for the SCS runoff curve numbers were identified and are included in Table 2.

Table 2: SCS Land Use Types and Curve Numbers

SCS Land Use Category	Hydrologic Soil Group			
	A	**B**	**C**	**D**
Residential & Paved	57	72	81	86
Sugarcane	25	59	75	83
Woods – Natural Forests	36	60	73	79

For the areas under consideration, the paved road areas have been combined with the residential use type, given the relatively low area occupied by these, and the sugarcane data is based upon the conditions prevailing in Hawaii and have been adapted for Mauritius Island.

3. Study area

The study areas chosen are the catchments of “Rivière du Poste” and “Rivière Des Anguilles”. Both catchments are located in the southern region and are almost adjacent to one another. The characteristics of each catchment (WRU, 2003) are as described in Table 3.

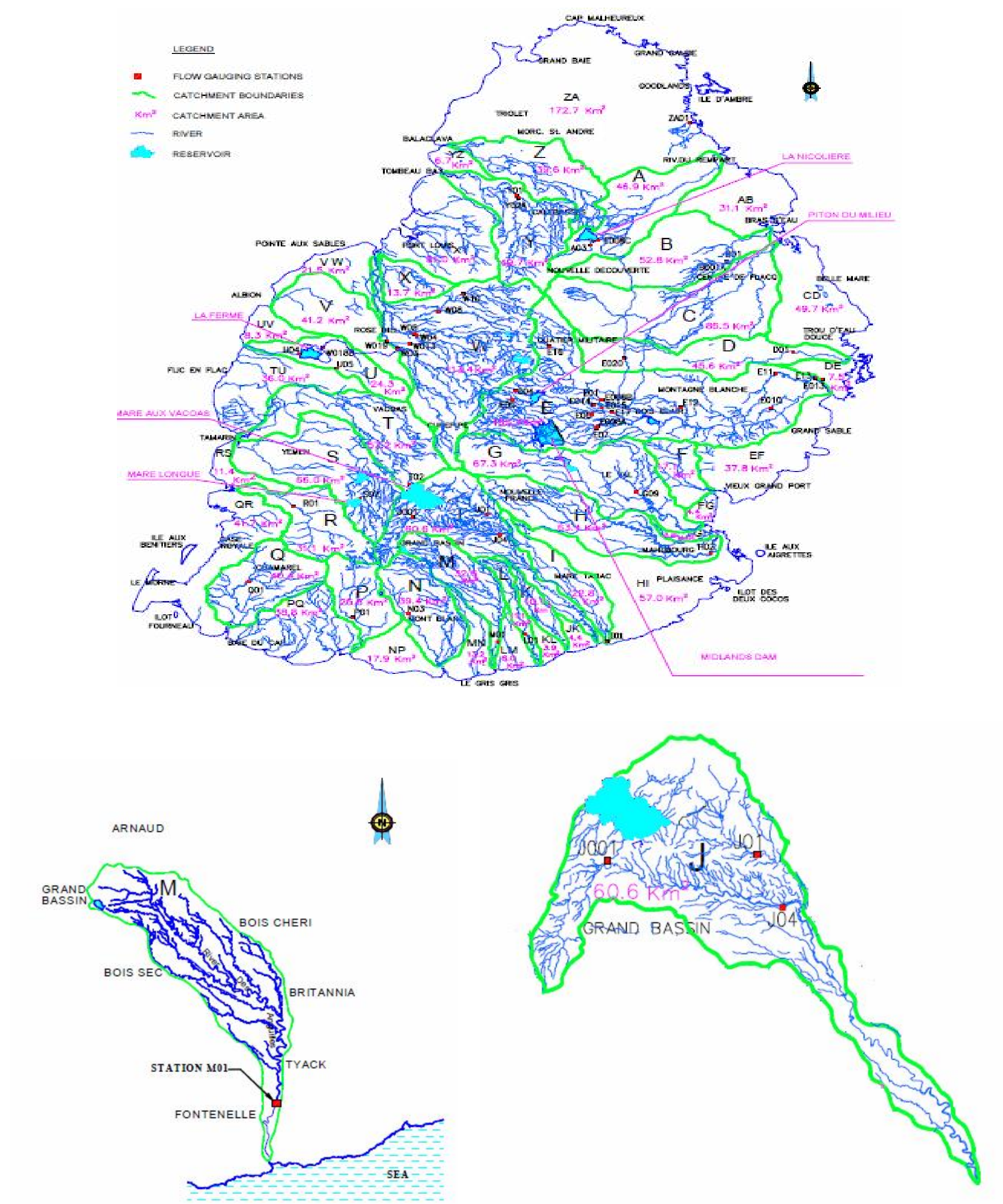
3.1 Basin 1: Rivière Du Poste (Catchment Code J)

This basin is denoted as a major basin bearing the catchment code J. There is an important stream network within this basin, almost all of which contribute to the river commonly known as “Rivière Du Poste”.

Research article ISSN 0976 – 4380

3.2 Basin 2: Rivière Des Anguilles (Catchment Code M)

This basin is a major basin, bearing catchment code M. It also consists of a significant stream network, which contribute to the river, commonly known as "Rivière des Anguilles" (Table 3).



Catchment J – River Du Poste **Catchment M– River Des Anguilles**

Figure 3 : Images showing catchment region

Research article ISSN 0976 – 4380

3.3 Basin 1: Catchment J

For this catchment up to the point of consideration, the land use is mostly made up of natural forests, and the remaining part of the area is under sugarcane plantation. Also, the forest areas are found on rocky to very rocky grounds, requiring a weighted average for the curve number.

3.4 Basin 2: Catchment M

The land use type for this catchment consists of a mix of sugarcane and tea plantations and some residential areas. Again a weighted average for the curve number was calculated. Values obtained for each region are given in Table 4:

Table 4: Area Distribution over Catchment

Land Use %	Basin 1	Basin 2
Forest	70	15
Sugarcane and Tea	30	65
Residential	0	20
Weighted Curve Number	75	75

3,5 Time of Concentration

The time of concentration was calculated for each of the catchments above. The SCS Lag equation was used. Data required such as the longest flow path and the average watershed slope were extracted from the GIS wherever possible. The results are shown in Table 5.

Table 5: Time of Concentration

Parameters	Basin 1	Basin 2
Longest Flow Path (m)	6,750	16,150
Elevation at start (m)	587	605
Elevation at station (m)	351	85
Average watershed slope (%)	4.5	3.6
Hydraulic length of watershed (ft)	22,146	52,990
Lag time, L (hrs)	2.07	4.66
Time of concentration, T_c (hrs)	3.46	7.76

From the relationship $L = 0.6\ T_c$, the time of concentration is hence obtained. These values of T_c require further refining, which depends on other factors such as type of flow and land use. This can hence be understood to be a 'rough' or 'raw' value.

INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
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Research article ISSN 0976 – 4380

3.6 Unit Hydrograph Derivation

Based upon the physical characteristics of the catchments, SCS curve numbers, time of concentration, duration of excess rainfall, the time to peak and peak discharge were obtained for each sub catchment, following a unit rainfall (Table 6). This unit hydrograph was then used to predict peak discharge likely to be obtained from flood type rainfall, which tends to occur during cyclonic periods.

Table 6: Time to Peak and Peak discharge for basins 1 and 2

Unit Hydrograph characteristics	Basin 1	Basin 2
Duration of excess rainfall, ΔD (hr)	0.45	1
Time to Peak, Tp (hrs)	2.3	1
Peak Discharge m^3/s	39.20	28.2

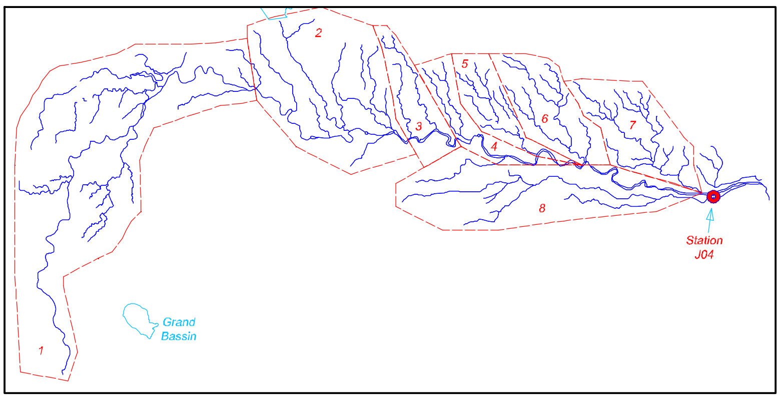

Figure 4: Sub basin wise delineation of Basin 1

3.7 Simulated Flood Hydrograph

The flood hydrographs were obtained from simulation using the HEC-HMS software and the following data: base map of the drainage area and sub-basin characteristics: sub-basin areas, lag time, SCS curve number, rainfall data, and Initial Abstraction.

Basin 1 was then divided into 8 sub basins (Figure 3) to study the contribution to the flood hydrograph from each sub basin.

3.8 Catchment Characteristics

For the derivation of the flood hydrographs, several catchment properties were used to derive characteristics and required inputs for the simulation. These are listed in the table below:

INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 1, No 3, 2010

Research article ISSN 0976 – 4380

Table 7: Catchment Characteristics and Lag Times

Sub Basin	Area (km²)	Longest flow path (m)	Average catchment slope (%)	Curve Number	Maximum potential retention (mm)	*Lag time (mins)*
1	5.7	6,423	2.65	75	85	*155.88*
2	2.5	2,535	3.04	75	85	*69.17*
3	1	1,883	6.16	75	85	*38.29*
4	1	2,544	5.03	75	85	*53.89*
5	1	2,057	6.17	75	85	*41.05*
6	1	2,038	6.38	75	85	*40.08*
7	1.5	2,261	4.87	75	85	*49.87*
8	3	3,803	4.44	75	85	*79.10*

From this table, the variations between the different sub-catchments can be seen in terms of area, length of longest flow path and slope. These factors incur variations on the lag times. For this analysis, a single weighted curve number was used. Given the uniform land-use patterns within each single sub-catchment, it is preferable to use a single weighted curve number, as compared to the complex derivation of a singular curve numbers for each of the sub-basins, even if the latter would have provided better results. The lag time was computed using the SCS lag equation. This was carried out to simulate flood hydrographs from each sub basin following a flood rainfall event.

3.9 Storm event – Cyclone Gerry (11/02/2003 – 13/02/2003)

This storm event is defined by a total precipitation of 228.4mm of rainfall over the 3 days, with an isolated period of intense rainfall; the rainfall intensity varying between 10mm/hr to 30mm/hr within a period of 7 hours (Figure 4). The flood hydrograph was simulated using the software HEC1.

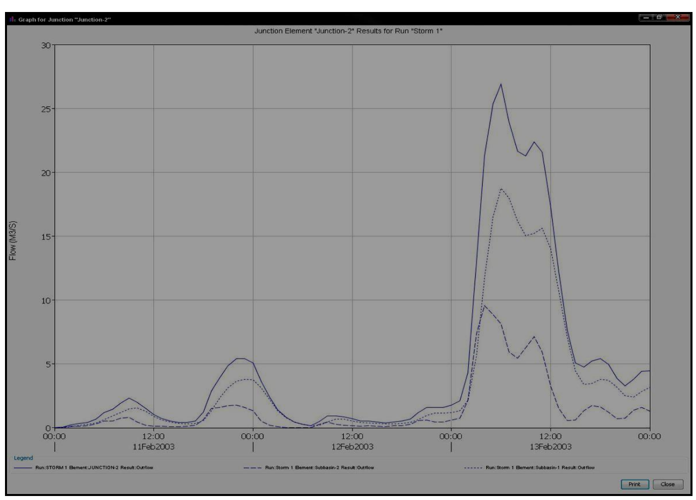

Figure 5: Hydrograph resulting from Storm event: cyclone Gerry

INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 1, No 3, 2010

Research article ISSN 0976 – 4380

The outflow at the junction of two sub basins, 1 and 2, was also simulated. Figure 5, illustrates the contribution to the flood hydrograph from sub-basins 1 and 2.

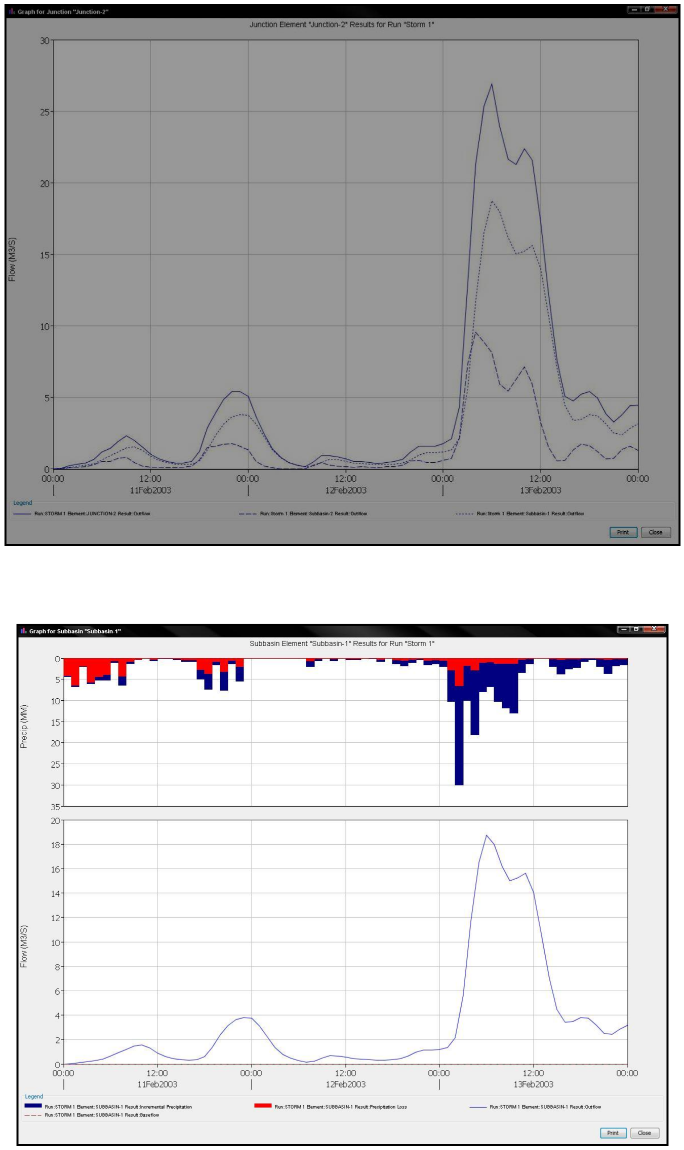

Figure 6: Flood hydrographs contribution from 2 sub basins

4. Discussion and Conclusion

This study aimed to provide an insight on the combined possibilities of the use of geographical information systems and hydrological models in the assessment of a particular natural hazard, more precisely floods. This problem was analysed with a view to provide a decision-making tool for these events, and thus the applicability of these techniques to such use was analysed. While the GIS study helped in provided more detailed information about the nature of the sub-basins making up a main basin, the SCS

Research article ISSN 0976 – 4380

Hydrological Model, was used to simulate the flood hydrograph which was generated from each sub-basin. This sub basin wise information helps in identifying which sub-basin is more vulnerable and where corrective measures could be focussed to alleviate the consequences of floods.

This approach can therefore help in terms of decision making for flood-prone regions, where the focus for remedial actions that can be implemented, is shifted from a larger catchment to the smaller sub-catchment. Thus, further consideration can be provided to the aspects of planning and use of counter measures such as flood routing and provision of water retaining structures.

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