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Post-Georges Disaster Mitigation Project in Antigua & Barbuda and St. Kitts & Nevis

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1. Introduction

This report describes a flood hazard mapping exercise recently conducted in St. Kitts/Nevis. It was done on behalf of the Organization of American States as part of the Post-Georges Disaster Mitigation (PGDM) project. The overall aim of this component of the PGDM project is to build the information base necessary for development of appropriate national hazard mitigation policies and plans on St. Kitts/Nevis. Flooding has been judged to be one of the natural hazards to which the islands are vulnerable. The aims of this component of the PGDM project were therefore: (i) to explain the nature of flood hazards on St. Kitts and Nevis; (ii) to describe the information gaps in quantifying the hazards; (iii) to explain the methodology used in producing flood hazard maps; (iv) to describe the map structure and content and the usefulness and limitations of the resulting maps; and (v) to make recommendations for improving the maps.

The report first provides a general summary of the susceptibility of the two islands to high runoff that may or may not produce flooding. This is followed by the definition of flooding adopted for the study. Its definition is limited to inundation due to extreme rainfall events. It then describes, in general terms, the nature of the hazard on the two islands. The two approaches used in the study are described, one on a larger island wide scale, the other on a smaller scale limited to particular areas identified by disaster management personnel on St. Kitts/Nevis. The manner in which each methodology was applied is described, particular consideration being given to the data adequacy for generating accurate flood hazard maps. The first approach necessarily has limited accuracy because it is concerned with macro features that provide various degrees of flood vulnerability over a large area. The second approach attempts to provide detailed mapping and high accuracy to a well defined and much smaller area. Even with detailed surveying, the accuracy of maps resulting from the second approach is limited owing to various data problems. Recommendations for improving the maps are provided, followed by recommendations for flood mitigation on the two islands.

2. Susceptibility to Flooding

Physical features of the two islands are shown in Figures 1 and 2. These two islands are located within the Caribbean and are in the historical path described by storms and hurricanes. Hurricanes are frequently accompanied by high intensity rainfall, which may trigger flooding. Another feature influencing the characteristics of rainfall experienced on the islands is their relief, both islands having mountains with elevations exceeding 1000 metres above sea level and the topography is essentially very steep, except closer to the coast where the slopes of the foothills are gentler. Such steep, elevated landforms cause much rainfall due to orographic effects. The rainfall is frequently very intense and violent. As much as the propensity of watersheds to flooding depends on being subject to high intensity rainfall, the soil characteristics, the land use and the

capacity of the drainage facilities ultimately determine whether flooding occurs within a watershed. Generally, soils on Nevis have drainage described as slow to very slow. They are mostly clays and clay loams and thus their slow infiltration rates would cause high amounts of runoff. Additionally, overgrazing that has compacted the surface of the ground reduces infiltration rates, increasing the amount of runoff and hence increasing the possibility of flooding. In St. Kitts, soils are shallow and therefore only limited amounts of rainfall can be stored as the soils quickly become saturated. Shallow soils also allow high amounts of runoff. The major part of the upper watersheds in both islands is under forest, with urbanization and agriculture occurring on the foothills. The status of use of the watersheds does not increase flood vulnerability, though the potential would surely increase if urbanization were to replace significant portions of the existing vegetated cover.

Thus, in summary, the islands do have a propensity to high runoff owing to the frequent occurrence of high intensity rainfall and watersheds that can store only small amounts of the rainfall, resulting in significant runoff. Whether flooding does occur depends on the capacity of the drainage facilities and the presence of lands with very little gradient adjacent to those drains with limited carrying capacity.

3. Definition of Flooding

Following is the definition used for flooding in this project:
"Flooding is a general and temporary condition of partial or complete inundation of normally dry land areas from overflow of inland waters or from the usual and rapid runoff of surface waters from rainfall."

Such an anthropocentric definition matches the scope of the project, which is mainly concerned with the ill effects of flooding on the economic development of the two islands. The study is limited in its consideration of the ill effects due to flooding and it makes no attempt to examine any of the positive benefits, such as production of fertile soils for agriculture on floodplains.

This definition is suitable for assessing the nature of the flood hazard on the two islands as the predominant concern is due to flooding caused by inadequate capacity of the ghauts, rivers and drains to discharge runoff from the watersheds into the sea or ponds. It does not consider inundation from storm surges. It does not consider floods due to dam breaks, as the dams on the islands are too small to be of concern.

The consideration is not extended toward damage solely caused by fast moving water that does not overflow the banks and cause bank erosion and subsequent land slippage.

Inland waters refer to the drains, rivers, ghauts and any other infrastructural component used for conveying excess water away from the lands.

The phenomenon triggering bank overflow is here limited to extreme rainfall events, not only the ones associated with hurricanes, as it is the characteristic of the rainfall, not the meteorological system causing it, that produces the runoff that may or may not cause bank overflows. In the recent past, however, most if not all major flooding has been caused by rainfall from hurricanes.

4. Nature of Flood Hazard

Floods may have detrimental effects on three aspects of the human condition—health, agriculture, and economic systems. In terms of human health, floods can cause death by drowning, impact or exposure. In St. Kitts and Nevis, fast flowing waters may sweep persons and vehicles away toward the sea, as happened recently in both islands. The main danger is at various road-crossings where ghauts may overtop the culverts and bridges and flow over the road. Several lives have been lost by persons who, unaware of the danger of fast-flowing water, attempted to negotiate crossing the swift floodwaters. In St. Kitts, persons living along Lower College Street are exposed to the danger of swift moving water when the College Street Ghaut is flowing full; likewise on Nevis, for persons in the lower Bath Ghaut area. Numerous physical injuries are possible as well, and a common effect of flooding is disease and disease transmission. Diseases commonly are associated with disruption of fresh water supply; contact with floodwaters contaminated by septic tank and wastewater treatment plant overflows; the creation of appropriate habitat conditions for certain rodents, insects and organisms that transmit diseases. Detrimental effects in Nevis on agriculture are mainly due to loss of livestock due to drowning or becoming dispersed. Destruction of crops, seeds, and stored food stocks during inundation is limited as agriculture occurs on the foothills and not on floodplains. Public infrastructure and private property may be damaged with inundation and deposition of significant quantities of silt. For Basseterre and Lower Bath Ghaut, initially ground floors of buildings and residences may be affected with rising flood stage. But with increasing stage and flow velocities, buildings and loose property can be swept away. An additional danger with such steep sloped watersheds is caused by boulders transported by the swift currents and floating debris such as cars and logs that can increase damage as they impact structures downstream. Properties on riverbanks may be in danger if riverbanks erode and trigger bank failure. Extreme examples of bank erosion exist along the College Street Ghaut, around Monkey Town, and Cayon Ghaut.

Major disruptions of the road network may affect productivity as the workforce is delayed in reaching their workplaces.

5. Methodology

Two approaches to flood mapping, differing mainly in the degree of accuracy in mapping floodwater levels, were applied. The first approach was done at the floodplain scale and the results, though approximate for lack of sufficient data, provide information on flood levels within the plain. This traditional approach required hydrological inputs and detailed hydraulic data. It is concerned with bank overflow as it considers the carrying capacity of the drainage facilities on the flood prone areas and the extent to which water from surrounding watersheds remains as "within-bank" flow. For the results to be meaningful careful analysis on the hydraulics of the floodplain is needed and the analyst must take into account all the significant features within the flood prone area that could affect water levels.

If all required information is available, and most importantly if floodwater levels have been collected from actual flood events, then the hydraulic analysis can be fine-tuned by making adjustments to uncertain inputs until the water levels from the analysis match the levels from the recorded flood events. Typically, the accuracy is within 150 mm (6 inches).

The second approach was applied because of lack of detailed information about channel geometries in other flood prone areas not subject to detailed surveys. Whereas the same runoff information as above is needed to quantify the amount of water within the flood prone area, this approach does not attempt any hydraulic analyses. Instead, the method estimates a flood depth over the entire flood prone area, which is essentially an average value derived from a simple division of the total volume of water from all runoff flowing into the flood prone area over its surficial area. This depth does not provide any information about how water depths vary within the flood prone area as it assumes that the area has the same mild slope throughout. Furthermore, this value may overestimate actual flood levels in some places, and underestimate them in other places. Such approaches may be necessary when the type of information required in the first approach is missing or unavailable, but the approach is very useful for providing basic ranking of the extent to which flood prone areas over the island is susceptible. Its approximations must be well understood so that it can be properly used. Most of the requirements can be extracted from standard topographical maps.

Island wide Scale Mapping:

1. Identify areas, called flood prone areas, having mild slopes. This can be done either via manual inspection of topographical maps or with the aid of DEMs and computer software;

2. for each flood prone area, demarcate the watershed draining into the area and then determine the ratio between the watershed area and the flood prone area (from (1) above);

3. for a particular 24-hour return period rainfall, generate runoff hydrographs discharging into the flood prone area, based on the shape, the drainage network, the soil properties and the landuse;

4. from the hydrographs, determine the volume flowing into the flood prone area and estimate an average discharge rate over the hydrograph period;

5. estimate a discharge rate from the flood prone area and use it to determine the maximum volume of water (expressed as depth of water) that is likely to be stored on the flood prone area;

6. determine the hazard category of each flood prone area according to water depth within the plain from the 100 year return period storm using the following classification:

Table 1 Hazard classification according to mean depth of water.

Water Depth (mm)	Hazard
>600	Very High
600-300	High
300-150	Moderate
150-50	Low
<50	Very Low

The categorization of the hazard in this way provides a measure of the magnitude of flooding to be expected from such an event. It also provides a measure, certainly by rank if not in absolute terms, of the severity of flooding among the identified zones.

Detailed Flood Mapping:

1 Perform statistical analyses on the daily rainfall data and obtain amounts for various return periods.

2 Derive the critical storm for a 24-hour duration, using standard time curves, and assuming that the rainfall was the same throughout the watershed;

3 Obtain contour maps of St. Kitts and Nevis and demarcate the watersheds draining into the four chosen areas—Lower College Street Ghaut, Wash Ghaut, Lower Bath Ghaut, and Camp River—conduct field trips to confirm the boundaries ;

4 Determine the existing land use within the watersheds from topographical maps and field visits;

5 Obtain soils maps of St. Kitts/Nevis;

6 Digitize information from the map and field visit;

7 Conduct interviews with residents within the four areas to determine specific information about recent floods—the highest water level reached, the direction from which the flood waters came, the time it reached its highest level, the length of time it stayed at that level, the time it took to subside to some remembered level;

8 Survey the river or drain from which the reported flooding originated, paying attention to: (i) any natural constrictions such as a narrowing of the river cross-section, or manmade constrictions due to hydraulic structures such as culverts and bridges, or to construction of property within the waterway; (ii) the free clearance of hydraulic structures and bends; (iii) the lining of the channels; (iv) the level of maintenance of the channels; (v) the nature of the flood prone area from the river bank in terms of its coverage—pastures, wooded, urbanized;

9 Identify critical river sections based on its impact on flooding with potential for significant losses;

10 Examine the discharge point of the section to determine outlet control conditions—whether, for example flow was unhindered or under the influence of tides.

11 Conduct detailed surveys of these areas at critical cross-sections, hydraulic structures and any other important features;

12 Perform detailed hydraulic analyses using appropriate computer software.

13 Produce a flood map showing variation of water depths within the flood prone area.

The two approaches are similar in their procedure for generating inflow hydrographs and hence for generating the critical storm. The main difference is in the performance of a detailed hydraulic analysis, which is made possible by the availability of detailed geometric descriptions of the river channels. The results of the application of each approach are presented in separate sections below.

6. Island wide Flood Mapping

1. Identify potential floodplains

   ArcView 3.1 was used for identifying areas of mild slopes. As far as possible these results were corroborated with field data. Ideally, the identification prior to the field visit should have been done, but the timing of the development of this new methodology did not allow for this. It is possible that a few areas might have been missed; it is also possible that the field trip would reveal that some areas might have been oversized or undersized.

2. Determine the watersheds draining into the flood prone areas

   ArcView 3.1 was also used for defining the watersheds draining into the areas identified at 1 above. The areas (km^2) were also obtained from the software.

3. Rainfall

   The objective is to produce the critical storm that can then be used for deriving runoff hydrographs for the watersheds surrounding the flood prone areas. The critical storm is defined in terms of its depth of rainfall, duration, the distribution of the rainfall depth over the duration of the storm, and the spatial extent of the storm over the watershed. The required data include: (i) continuous daily rainfall from at least one raingauge, for at least ten years; (ii) rainfall from one automatic rainfall station that measures rainfall continuously during the event.

   For St. Kitts, twenty-three years of data, from 1977-1999, for seven gauges located on the island (see Figure 3) were obtained from the St. Kitts Sugar Manufacturing Company (SSMC). These records were from manual readings of a "pot gauge" and it is here assumed that gauges were read at 800 Hours, the universally accepted start of a hydrologic day. The elevations of these gauges are shown in Table 2 below.

Table 2 Altitude of the gauges used in characterizing St. Kitts daily rainfall

Station	Stapleton	Fahies	Lynches	Agronomy	Olivees	Cunningham	Wingfield
Altitude (ft)	467	412	333	82	468	207	184

Visits to two stations were made, Stations Agronomy and South Olivees. The gauging stations were generally well kept and carefully located to remove interference from surrounding objects. The automatic station at Agronomy, unfortunately, had never recorded any rainfall owing to improper installation. The tipping bucket gauge was still there, but it was in a state of disrepair and perhaps beyond repair.

The records from the seven stations were supplied in an EXCEL file. They were subsequently reformatted in EXCEL in a two-column format—one for the date, the other for the measured rainfall record—which facilitates manipulation of the

data set. Rainfall records collected in 1999 and 2000, at Newcastle Airport in Nevis, were provided. These records were also formatted in two-column spreadsheet. However, because of its small size, very little could have been done with this database, in terms of identifying trends and determination of long term rainfall patterns. It is believed that there is much more data available on Nevis, but these records could not have been retrieved during the short data-gathering mission. For Nevis rainfall, therefore, it was assumed that the long-term annual maximum rainfall depths were the same as that for St. Kitts. This assumption was done only to facilitate the procedure; it is advised that the flood mapping procedure be repeated once Nevis data become available, and the map updated accordingly.

From the St. Kitts rainfall records, the maximum daily rainfall for St. Kitts for each year was extracted for the statistical analysis. The resulting series is shown in Table 3 below:

Daily annual rainfall shows appreciable variation over the years of record, but variation also is appreciable over the island. In 1999, the large daily rainfall amounts were recorded during the passage of Jose over the islands. Large amounts, however, are not always associated with hurricanes, but may be more characteristic of the high relief of the islands. Associated with such topography are violent random storms, very localized and usually in the headwaters, stationary, and can dump phenomenal amounts of rainfall within one watershed. Such a meteorological event triggered the 1998 flood of Basseterre in which one person was drowned, several vehicles parked within College Street were washed away, and large quantities of silt—the depth was reported to be about 2.5 metres (about 8 feet) in some places—were deposited in the town.

A series of annual maximum daily rainfall is normally well represented by the Gumbel Type I probability distribution (Chin, 2000) and so this distribution was applied to the rainfall data. The rainfall amounts for various return periods are shown in Table 4 below.

A mean value has been determined for this set of records, but the variation of rainfall with location should be noted. The mean value was used for Nevis. For St. Kitts, the return periods for the gauge closest to the area under consideration were used.

Table 3 Annual Maximum Daily Rainfall for St. Kitts, 1977-1999

	Maximum Annual Daily Rainfall (inches) at Raingauge Station:						
Year	STAPLETON	FAHIES	LYNCHES	AGRONOMY	OLIVEES	CUNNINGHAM	WINGFIELD
1977	3.36	4.15	4.55	2.5	2.55	3.25	3
1978	4.44	5.8	6.03	3.9	5.55	2.9	4.6
1979	8	9	9.72	9	8.9	9.42	4.1
1980	2.33	4.2	4.06	2.36	1.6	3.15	2.85
1981	8	2.2	6.04	3	3.08	2	2.95
1982	3.07	6.37	3.36	3.05	1.87	2.2	2.18
1983	3.45	5.6	4.63	3.27	3.67	6.25	3.73
1984	7.51	10.05	10.24	5.44	6.65	6.75	7.67
1985	2.23	14	3.11	1.77	2.75	1.75	2.84
1986	2.76	3.05	7.6	3.17	2.55	3.1	2.59
1987	5.8	4	5.16	6.76	8.66	4.27	5.15
1988	3.27	3.48	2.91	3.42	3.43	3.38	2.64
1989	5.69	10.51	6.1	4.53	5.02	5.6	12.1
1990	8.66	2.98	9.61	7.65	6.83	6.71	3.56
1991	1.77	5.98	2.78	1.3	1.86	1.58	1.5
1992	2.61	3.64	3.04	2.86	3.17	2.13	1.92
1993	3.42	2.83	4.72	2.28	1.85	6.91	3.95
1994	4.36	1.97	3.03	4.63	4.25	4.72	6.77
1995	4.38	4.17	6.71	5.98	9.25	10.5	7.2
1996	2.36	3.8	2.69	3.13	3.28	2.04	3.26
1997	3.64	7.58	5.02	5.17	3.06	3.24	4.28
1998	4.57	7.87	3.52	8.31	4.36	6.31	13.35
1999	10.44	9.56	8.86	7.98	11.36	10.51	12.26
Mean	4.61	5.77	5.37	4.41	4.59	4.72	4.98
Std	2.39	3.14	2.41	2.24	2.75	2.77	3.41

Table 4 Annual daily rainfall for various return periods

Return Period	**Prob-ability**	Rainfall (inches) at Station:							**Mean**
		Stapleton	Fahies	Lynches	Agronomy	Olivees	Cunning-ham	Wing-field	
2	**0.5**	4.22	5.26	4.97	4.04	4.14	4.27	4.42	**4.47**
5	**0.2**	6.33	8.03	7.10	6.02	6.57	6.72	7.43	**6.89**
10	**0.1**	7.73	9.87	8.51	7.33	8.18	8.34	9.42	**8.48**
25	**0.04**	9.49	12.19	10.30	8.99	10.22	10.38	11.95	**10.50**
50	**0.02**	10.80	13.91	11.62	10.21	11.73	11.90	13.82	**12.00**
100	**0.01**	12.10	15.62	12.93	11.43	13.23	13.41	15.67	**13.48**

Temporal Distribution

As much as daily rainfall data actually recorded on the island were available, these records are not immediately useful for determining peak flows from watersheds with times of concentration considerably less than 24 hours. All of the watersheds on the island have small times of concentration (see Table 5 below). It is therefore necessary to know how the daily rainfall had been

distributed over the 24 hours and perhaps divide this daily rainfall into smaller storms having durations that match the estimated times of concentration. Had information been obtained for several storms from the automatic continuous rainfall recorder at Agronomy, then their records could have been used for determining the temporal distribution pattern of daily rainfall. In the absence of such records, use was made of the standard curves produced by the Soils Conservation Service of the United States. These curves have been derived from a very long database of rainfall measured continuously over 6-minute intervals for gauges scattered throughout the United States. Even though these curves should strictly be applied within the regions for which they have been developed, these curves have been applied in areas far removed from the United States. Various research efforts where continuous records were available have compared these standard distributions with locally obtained distributions (NEDECO, 1998). More often than not, the research found that the local temporal distributions fitted closely one of the standard curves; however, which one of the curves is most suitable need to be determined.

It has been suggested that for the Caribbean Region, the Type III curve is most adequate. This is the curve used for the southern regions of United States and Puerto Rico whose precipitation patterns resemble that of the Caribbean region. A recent project in Trinidad, which is the most southerly of the Caribbean islands, found that data from continuous rainfall recording of several rainfall events fitted the Type III curves best. It does not necessarily imply that all the other islands bounded by the southern United States in the north and Trinidad and Tobago in the south would also have rainfall matching the Type III curves, and indeed, site records are required for verification of the chosen curve.

Nevertheless, in the absence of any other information, the Type III is perhaps an adequate starting point.

Spatial Distribution

Table 4 above highlights the variation of daily maximum rainfall depths with location. It means that there can be significant errors in using data other than from a station close to the area under investigation. Thus, a critical storm for each rainfall station was developed, each being representative of the areas within its immediate vicinity. So, for example, the rainfall station at either Stapleton or South Olivees, or maybe the mean of the two could be used for the College Street Ghaut Watershed; the Cunningham Station is appropriate for the Wash Ghaut. Since no rainfall records were available for Nevis, it was assumed that the mean values determined from the seven St. Kitts rainfall stations were good for any place on the island. The same caution mentioned above about the use of St. Kitts data for Nevis applies here.

Storm Duration

There is a critical minimal storm duration at which all lands within a watershed and upstream of its outlet begins to contribute runoff at the outlet. This duration is related to the time of concentration, which is the time taken for the most remote area of a watershed to contribute to flow at the outlet. At longer times of concentration, the entire watershed contributes to runoff. The time of concentrations were determined above for particular watersheds (see Figure 4 to 6) using the Kirpich formula (below), and these values are shown in Table 5.

$$T_c = 0.00013\frac{L^{0.77}}{S^{0.385}} \qquad (1)$$

where, L is the length of the longest channel (feet) and S is the mean slope (feet/feet) along the channel.

Traditionally, storms of 24-hour duration are used for flood studies. Certainly this is necessary for large watersheds whose times of concentration may be in the same order of magnitude of one day. Many of the watersheds on these islands are small and their times of concentration are all less than one (1) hour. When using long storm durations, it is important to ensure that the intervals over which the storm duration is divided are roughly equal to the time of concentration of the watersheds. In this way storms with durations longer than the T_c are conceptualized as several small consecutively occurring storms, each having a duration of about T_c, and each causing maximum contribution of runoff from the watershed.

The hyetograph—rainfall distribution with time—of the 24 hour Type III curve is shown in Figure 7.

Although storm durations of 24 hours are being used here, it is very likely that flooding is caused by shorter duration storms. The Type III curve suggests that the bulk of rainfall falls over a very short period of time, (here about 40 % of the rainfall falls within two hours) which is the experience in the Caribbean. Short but very intense rainfall predominates during the wet season. The critical storm duration may be of the order of 3 hours, but determination of this requires continuous data collected on the islands.

Critical Storm

For determining the flood hazard island wide the 24-hour 100 year return period storm was used. The critical storm for Nevis, which uses the mean rainfall depth from the seven St. Kitts recording stations is shown in Figure 8. The rainfall depths at each of the seven stations on St. Kitts were used for constructing the critical storm at each station.

Table 5: Time of concentration for some watersheds in St. Kitts and Nevis

Watershed	ID. Point	Location	Stream Length (m)	Elevation Upper (m)	Elevation Lower. (m)	Slope (m/m)	T_c (hr)
St. Kitts							
College Street Ghaut	1**	Bridge at top of College Street	5900	33	460	0.07	0.72
Wash Ghaut	2	At Main Road	2240	65	275	0.09	0.31
Nevis							
Bath Ghaut	1	At Upper Bridge	4500	840	15	0.18	0.41
Camp River		At Nisbett Plantations	4200	365	30	0.08	0.53

** See Figure 4 to 6.

4. Runoff Estimation from the Critical Storm

Given a critical storm the observed runoff hydrograph is a function of the properties of the watershed, in terms of its landuse, soil type, its current antecedent moisture condition, and its geomorphological properties including its ruggedness, its drainage network density and its slope. These characteristics could normally be extracted from maps and field visits.

To obtain information for characterizing the watersheds, the following were required:

- Topographical maps of St. Kitts and Nevis for studying the watersheds, paying attention to the landuse and the drainage network density;
- Soils maps of St. Kitts and Nevis;
- Field visits to St. Kitts and Nevis at least once for walking through the watersheds being studied, and noting differences in landuse and modifications to the drainage pattern from that shown on the maps;
- Conversion of the information above into digital format.

The island was divided into several major watersheds as shown in Figure 5. Each watershed was further subdivided into its floodplain and sub-watersheds feeding into the plain. For the Lower Bath Ghaut floodplain, as for all the other watersheds, the runoff hydrographs for the sub-watersheds were

estimated via the HEC-1 model using the critical storm and the physical characteristics of the watershed as inputs. The required input data included: soils type and landuse shapefiles for determining the curve number (CN) values for the watershed; slopes and channel lengths for time of concentration estimates, and the critical storm—24-hour 100 year return period rainfall—derived earlier. The CN is a measure of the fraction of rainfall expected to run off the land and its values range from 0 to 100. Runoff increases with increasing CN values. The procedure used by HEC-1 is given in Technical Release (TR) 55 (USDA, 1986). It was assumed also that the antecedent moisture condition was very wet and so very little infiltration would have occurred. The resulting hydrographs for the sub-watersheds are shown in Figure 9.

The volume of runoff and the peak values from each sub-watershed are tabulated in Table 6.

Table 6. Peak discharges for floodplain modeling of Bath Ghaut Watershed

	Point on Map		Hydrograph Property:	
Watershed		**Location**	**Volume (1000m^3)**	**Peak Flow (m^3/s)**
Lower Bath Ghaut	1**	Upper Bridge	534	71.4
	2	Lower Bridge	345	43.7

**See Figure 5

It is to be noted that these are model generated results that could not have been validated owing to lack of streamflow information. All attempts were made at measuring input parameters as accurately as possible to minimize errors in defining the physical characteristics of the watersheds. When streamflow data become available, then they should be used to verify the results obtained here.

5. Estimation of Discharge Rates of the Floodplains

Having estimated the volume of runoff from the surrounding watersheds onto the plains, estimates of discharge rates are needed to determine the maximum amount of water expected to be stored on the plains. This normally requires site specific surveys for defining the physical features of the drainage facilities. Of interest were physical forms that might have limited discharge from the plain so features such as (mangrove) forests, river meanders, constricting landforms, urbanized areas, or tidal discharge outlets were noted. No attempt was made to quantify the discharge characteristics except to make some rough estimates of the mean discharge throughout the event and then to express it relative to the inflow rate. The, discharge was classified as follows:

Table 6 Quantification of the drainage rate relative to the inflow rate

Drainage Description	Fraction of inflow rate
Unrestricted	>0.80
Partially restricted	0.66 – 0.80
Restricted	0.50-0.66
Very restricted	<0.50

7. Classification of the Floodplains into Hazard Zones

In the absence of rainfall data, an estimate of the mean depth on the flood hazard zone can be obtained from consideration of the following properties that govern the volume and shape of runoff hydrographs. These are:

1. **Ratio of the contributing watershed area to the area of the floodplain (R_a)**—This is one of the major determining factors. Large ratios mean that the relatively large volumes of water from surrounding lands can lead to significant depths of water within the flood prone area;

2. **Runoff coefficient of the watershed, (R_c)**—Even though the ratio above may favour flooding, runoff coefficients determine the volume of water available for flooding. Small runoff coefficients attenuate flooding; high runoff coefficients increase the chance of flooding. Runoff coefficients depend mainly on land cover.

3. **Slope, Ruggedness and Drainage Network Density of the watershed, (R_G)**—This also affects the arrival of the hydrographs peaks as it determines the time of concentration of the watershed. T_c values have importance in relation to the storm duration. Full contribution of the watershed to runoff occurs if T_c is shorter than the storm duration; for watersheds with large ratios, the smaller are their hydrograph peaks and hence the lower is the flood hazard. Shorter T_c's occur with increasing mean slope, increasing drainage network density, and decreasing ruggedness. R_G may here be defined as a ratio of the Tc and the storm duration.

4. **Nature of the drainage, (D)**—As described above.

5. **Shape of the surrounding watershed and its location relative to the floodplain, (S)**—This determines the arrival of the hydrograph peaks from the various sub-watersheds surrounding the floodplain. A ranking of the flood potential for three basic shape configurations are as follows:

Table 7 Basic shapes of watersheds and their flood hazard ranking

Conceptual Shape	Hazard Rank
A. Floodplain surrounded by subwatersheds, each almost equidistant from the centroid of the floodplain	Very High
B. Floodplain surrounded by subwatersheds, about 50% of the subwatershed area being equidistant from the centroid; the other 50% also equidistant but about 2 times removed as the first set	Moderate
C. Floodplain lower than the subwatershed feeding into it.	Very Low

For its application, various weights have to be assigned to each factor and then the aggregate scores used to assign flood hazard rankings to the floodplains. At this stage of development of the procedure no weights were assigned but each factor was assigned as follows (Table 8):

Table 8 Hazard Levels for flood factors

Factor	Hazard Level				
	Very High	High	Moderate	Low	Very Low
R_a	>5	3-5	2-3	1.5-2	<1.5
R_c	>0.8	0.8-0.6	0.45-0.6	0.3-0.45	<0.3
S	A		B		C
R_G	<0.2		1		>2
D	Very Restricted	Restricted	Partially restricted	Unrestricted	Unrestricted

** The hazard levels may be quantified from 1 to 5, 1 for Very Low and 5 for Very High

In Table 8, each factor is separately assigned hazard levels independent of the other. So for example, the D factor has a very high hazard ranking if its drainage is very restricted perhaps due to a combination of a heavily vegetated outlet affected by tides. Similarly, an R_c value less than 0.3 means that the maximum runoff volume from rainfall inputs would be no more than thirty percent (30%) of the rainfall volume.

As an example of the application of the method, Table 9 below shows the assessment of the flood prone areas on St. Kitts into various hazard zones. The floodplain at Conaree has received a ranking of very high mainly because of its restricted drainage and its basin shape. While the flood plain is relatively large in relation to its watershed (and therefore, it has a relatively small R_a value), the "wrap" around shape of the sub-watersheds means that runoff concentrates very quickly on the flood prone area. Furthermore, the drainage is restricted due to a combination of very flat drainage slopes, poorly maintained concrete drains and the possibility of tidal influences to the free drainage of the floodplain.

Table 9. Flood hazard ranking of the watersheds on St. Kitts Island.

Location	Area (km^2)	Watershed Area (km^2)	R_a	S	R_c	R_G	D	Hazard Rank
Newtown Ground	0.16	1	6	C	>0.75	>2	Unrestricted	Low
Industrial Site	1.6	3.97	2	C	>0.75	>2	Partially restricted	High
Conaree Hills	2.1	7.7	4	A	>0.75	>2	Restricted	Very High
Belle Vue	0.11	0.96	9	C	>0.75	>2	Unrestricted	Low
Dieppe Bay	0.24	1.96	8	C	>0.75	>2	Partially restricted	Low
Belle Tete	0.68	6.6	10	C	>0.75	>2	Unrestricted	Low
Half Way Tree	0.19	4.2	22	C	>0.75	>2	Unrestricted	Low
North Friar's Bay	0.27	0.27	1	A	>0.75	>2	Unrestricted	Low
Half Moon Point	1.82	2.8	2	A	>0.75	>2	Partially restricted	Moderate
Lower College Street Ghaut	0.2	8.8	44	C	>0.75	>2	Partially restricted	Moderate

8. Detailed Flood Mapping

Detailed flood hazard maps were required at four areas because of various hazards associated with flooding within them. These areas were: In St. Kitts, College Street Ghaut where it passes through Basseterre, Wash Ghaut where it crosses the main island road; in Nevis, Lower Bath Ghaut and Camp River in the vicinity of Nisbett Plantation. These areas are shown in Figure 4 to 6.

Items 1 to 6 in Section 3—Produce input hydrographs for chosen rivers

Input hydrographs at various points within the study areas (see Figure 4 to 6) were estimated using the procedure described under island wide flooding. For St. Kitts, along various reaches for College Street Ghaut and Wash Ghaut; for Nevis, detailed surveys in the Lower Bath Ghaut Catchment and Camps River around Nisbett Plantation.

Items 7 to 11 in Section 3—Field visits and interviews to determine nature of flooding

Two field trips to the sites were made with a land surveying crew to first determine the cause of the flooding, and then to lay out the limits of the required land surveying. Terms of reference were subsequently developed for the surveyors who obtained reference benchmarks from the local land surveying department so that the flood maps could be placed on the national grid.

Item 12—Detailed hydraulic analysis

The HEC-RAS computer model, Version 2.2, produced by the United States Army Corps of Engineers was chosen for the hydraulic analysis. This software has enjoyed extensive universal use and, therefore, there is a wealth of documentation for diverse modeling environments. Its technical documentation is also comprehensive and it is relatively simple to use. Furthermore, an extension, called HECGeo-RAS has been developed to permit interfacing between the hydraulic model and ArcView and thus greatly facilitate mapping.

The procedure can be summarized as follows:

- From the land surveys, obtain XYZ coordinates of the drainage channel and its floodplain. River cross-sections typically are at every 25 metres, but additional sections must be taken at closer intervals to pick up important alignment changes (horizontal or vertical). The cross-sections should normally extend to about 100 metres away from the bank. (Limitations on the survey resources prevented sections beyond about 20 metres of the drainage channel.)
- Supplement the floodplain field data with XYZ points lifted from large-scale (1 IN 2500 where available) topographical maps.
- Merge the two sets of data into one file in ASCII format.
- Within ArcView, create a TIN model from the coordinates in the ASCII file.
- Follow the procedure in the HECGeo-RAS to formulate the geometric input file required by HEC-RAS and then export it to the hydraulic model.
- Within HEC-RAS, input additional detailed information, such as bridge dimensions, to complete the model of the drainage channel.
- Input inflow hydrographs developed from HEC-1, and run the model, making modifications, as required, for calibrating the model.
- Export the output file—flood level boundary and water level variations within the boundary—to ArcView
- Follow the HECGeo-RAS procedure for generating flood water elevation shape files.

A few problems were encountered in generating a TIN model of the combined data—the PGDM's DEM and the data from the field—and eventually, a limited DEM from the 1:2500 series contour maps were developed within the reaches being investigated. This DEM is not compatible in the Z direction with the PGDM's DEM.

Various assumptions and approximations were necessary to model the physical system as time and resources didn't permit for any more extensive surveying. These are shown in Table 10 below and discussed following.

Table 10. Model input and approximations for HEC-RAS modeling.

	College Street	Wash Ghaut	Bath Ghaut	Camps River
Channel Roughness	0.035 (natural) 0.014 (paved)	0.035	0.035 (natural) 0.014 (paved)	0.035
Overbank roughness	0.05	0.05	0.05	0.05
Sharp Bends	0.1 to 0.3; 0.2	0.1 to 0.3	0.1 to 0.3	0.1 to 0.3
Downstream condition	Weir flow	Cascade flow	1 metre high tide	Normal flow
Upstream condition	Normal flow	Normal flow	Normal flow	Normal flow
Inflows along the reach	Not significant	Not significant	Flow increase at two cross-sections	Not significant

Assumptions and Approximations for Modelling the Ghauts

The modeling on College Street Ghaut started just above the railway crossing. The College Street Ghaut reach between the railway and the bridge at the top of College Street is earthen. Several drop structures have been constructed at regular intervals to check the flow by grade reduction. To simplify the model, it was assumed that the grade within this reach was constant (given by the fall in elevation from the railway to the bridge over the reach's length). This assumption may not result in serious errors as the distance between drops are relatively short, drowning out their effects at high flows;

The channel section consists of highly erodible soils. In any one event, especially during high discharges, the bedform would be actively changing. This is a very complex process and one that is difficult to model. This phenomenon also occurs in other alluvial channels, but normally the conditions at the start of the event are assumed to be persistent throughout. This approximation was made here for College Street Ghaut, and indeed for the other ghauts.

The roughness number for the earthen reaches was taken as 0.035, equivalent to an earthen section with some vegetation; the roughness

number for paved surfaces—asphalt and concrete—was taken as 0.014; the roughness number for over the bank flow was taken as 0.05. These are values suggested by Ven Te Chow (1959)

Detailed survey information was picked up within the channels at regular intervals, on average every 25 metres. However, the surveys could not extend to the floodplain bordering each bank. Floodplain elevations are needed for modeling and so these elevations were taken from the 1 in 2500 maps. Corrections between these sources of elevations were done so that one elevation dataset could be used as input to HEC-RAS.

Sharp bends were modelled by changing the contraction/expansion coefficients accordingly.

In one modelling scenario of College Street Ghaut, the boundary condition at the downstream end for flows at the various return periods was assumed to be that equivalent to flow over a rectangular broad crested weir, crest at 1.2 metres above the channel bed. It was reported that a freight container was swept away from its College Street position to Bay Street where it lodged broadside across the pedestrian bridge at the outfall of the ghaut. Its top elevation exceeded the sea level. The other scenario assumed that there was no restriction to discharge of the ghaut.

The boundary condition at the upstream end was assumed to be at normal depth.

The metric system was used for modeling.

Modelling Results

Bath Ghaut: One of the outputs in the Nevis Flood Hazard Map shows the extent of flood waters generated by rainfall at the 1 in 2, 1 in 10 and 1 in 100 frequency. Another output in the map is a raster file showing water levels within the flood extent of the three return periods. The resulting calibration so far is broadly consistent with reported water levels: It rises onto the road running parallel to the ghaut a few hundred metres before the coastline; it spills onto residential property behind Caribbean Cove; it backs up behind both bridges but does not cross the road; it spills within the school compound only at occurrence of rare events. The extent of the flood waters for the three return periods are provided in this report in Figures 10.

This figure highlights the differences in the results from the two approaches. There only a fraction of the area described by the island wide mapping may indeed be inundated. On the other hand, there are some areas covered with more than two feet of water. There were some approximations and assumptions made in the detailed modeling, most due to inadequate data. Additionally,

information for calibration of the models with measured water levels were not available. As much as the model results cannot be regarded as final, it is unlikely to vary considerably from the results shown here. Therefore, the comparison of the results from the two methods does point to the need to follow up island wide mapping with detailed flood mapping. The island wide approach is very useful in that it signals broadly to the areas likely to be prone to flooding, and suggests the order in which detailed investigations should be carried out.

College Street Ghaut: The results for this ghaut were reasonably consistent with reports on the 1998 Basseterre flood. Water flowed along College Street and Market Street, and some distance along Cayon Street and Central Street. It was reported to be up to about 1.2 metres at the cinema in the vicinity of "The Circus," a few hundred metres to the east of College Street.

Wash Ghaut: Modelling of Wash Ghaut was done from the government quarry to the Main Island Road where the ghaut flows over the road. The problems experienced with matching the DEM from the survey data with that from the 1 in 2500 maps have not been completely resolved, and so modelling results do not seem to be completely consistent with expectations. The floodplain shown in the flood hazard map was mainly based on model outputs, but some judgment was used in completing it.

Camps River: Modelling of this ghaut was along the reach starting from the bridge at Nisbett Plantations and the first tributary upstream of the bridge. Problems similar to that described above have been experienced.

9. Map Structure and Content

The hazard maps, entitled St. Kitts Flood Hazard Map and Nevis Flood Hazard Map, respectively show the flood prone areas on St. Kitts and Nevis. The island wide flood hazard coverages were developed from base map coverages of contours, roads, streams, and cliffs provided by the PGDM project. The scales of the maps are 1 in 50000 and 1 in 25000 for St. Kitts and Nevis, respectively.

The detailed maps are shown in separate sheets.

For the study, the hazard zones have been divided according to the mean water depth expected to be ponded over the entire zone. The categories are very high, high, moderate, low and very low and the corresponding mean water depths distinguishing the zones are shown in Table 1 above (repeated in the table below):

Table 1 Flood Hazard Ranking based on mean water depth on the plain.

Water Depth (mm)	Hazard
>600	Very High
600-300	High
300-150	Moderate
150-50	Low
<50	Very Low

The categorization does not attempt to provide precise water levels at various places within the flood prone areas, but rather is based on the maximum volume of water expected to be ponded within the flood prone area from the 24 hour, 100 year return period storm. The extent of the hazard zone may be larger than the actual area inundated during such a rainstorm, and water depths are likely to be greater in areas close to the riverbank and in depressions. These categories are provided in a legend and the meaning of the different categories is specified in notes on the maps.

The detailed flood mapping provides some indication of the variation of water depth within the flooded area. These maps are produced in separates sheets from the island wide maps.

The geo-referencing information used for producing the base map coverages are given.

10. Use and Limitations of the Map

The information for island wide flooding of St. Kitts was developed using an adequate rainfall database containing seven gauges located around the island, and therefore the derived daily extreme rainfalls are likely to be good approximations. On the other hand, there was only very limited data for Nevis, which meant that the mean rainfall depth for St. Kitts was used as an approximation of Nevis rainfall. Rainfall from Nevis should be obtained as soon as possible, and the procedure repeated with this new data.

Inadequate topographical data meant that several critical assumptions were necessary. As such the resulting flood prone areas should be regarded as preliminary, pending updating the input files with measured field data.

Nevertheless, the map identifies major areas prone to flooding. The Conaree Hills district on St. Kitts frequently floods owing to its restricted drainage. The floodplain of the Lower Bath Ghaut in Nevis also is a high hazard area owing to the partial drainage restricting effect of the mangrove forest, tidal influences and inadequately designed bridges.

The delineated boundaries are not to be taken as rigidly defining the extent of flooding. This is only possible with detailed surveys and solving the data

limitation problems mentioned above. No information on floodwater elevations have been provided here for the same reason of data inadequacies, and also to avoid the perception of absoluteness in the presented map.

Although the expected flood levels at the 100 year return period rainfall cannot be accurately inferred from the maps, it, nevertheless, provides the general areas within which flooding of various magnitudes are likely to occur. This is useful information for planning and allocating resources for undertaking flood mitigative works.

The map may also provide some indication of inadequate drainage infrastructure that may help in prioritizing capital works. In the case of Nevis, the map shows areas that require detailed study to remove localized flooding. Of note is the Newcastle Airport area where flooding has disrupted airplane landings on several occasions.

The information on the flood prone area ranking is useful in planning and executing emergency evacuation procedures.

It can be used as a guide for determining areas for further detailed flood studies.

The maps have focused on the flood hazard linked with inundation. They do not show incidental hazards caused by erosion of fast flowing water within the ghauts.

11. Recommendations for Further Work

The flood hazard on both islands is generally low, being limited to well defined areas. Owing to various shortcomings, the maps are only preliminary indications of the flooding on St. Kitts and Nevis. It is believed that sufficient data already exist for producing more accurate maps, given more time on data gathering and information extraction.

To improve the flood hazard maps, the following are required:

- **Availability of a longer data series of daily rainfall data from Nevis:**
  The rainfall frequency analysis for Nevis must be done and its results used to update the flood maps for Bath Ghaut and Camps River. For this, a longer data series, ideally twenty years, from rainfall gauges close to each site is required.

- **Establishment of an automatic raingauge site on each island to obtain site evidence of the temporal distribution of rainfall on the island:**
  Efforts should be made to install a continuous rain recorder at one site on St. Kitts and on Nevis. Suitable sites should be identified, but at least for

St. Kitts, the preferred site is the Agronomy station to replace the malfunctioning one there. These gauges should be installed for at least three consecutive wet seasons—there is no need to have it installed during the dry season, if resources for maintaining the gauge are limited. Within that period, there should be sufficient rainfall events to determine the nature of the temporal distribution of rainfall on St. Kitts and so confirm whether the assumption of the Type III curve was correct.

- **A comprehensive field interviewing exercise within the flood prone areas to map as accurately as possible flood level information of recent floods, including the notable 1998 and 1999 extreme rainfall events in College Street Ghaut catchment in St. Kitts and Lower Bath Ghaut and Camps River in Nevis:**
  This information will be useful for validation of water levels generated by the hydraulic models used for mapping;

- **Establishment of at least one crest gauge at major road crossings:**
  Verification of the estimated hydrographs requires streamflow measurements for about five rainfall events under similar conditions, namely saturated soils. Inasmuch as an automatic streamflow station at a stable river section would provide the data for comparison, such an installation may be cost prohibitive and perhaps not fully useful, given the ephemeral nature of flows in the ghauts. As an alternative, manual measurements would perhaps suffice, at least of some critical points on the hydrograph. A crest gauge can be installed at the control section and this would yield the peak elevation of the discharge during the storm. Manual observation can record the time at which such river stage was reached. The time for the river to return to pre-event conditions also can be recorded manually. If there is sufficient interest to verify the results submitted here, then the inconvenience associated with measurements during a storm event would be unimportant. With these minimal points, namely the peak stage, the time to peak, and the time to recession, done for enough events, then there should be enough observed data to improve on the estimated hydrograph from the critical storm.

- **Extension of such detailed work to include hazard due to fast flowing water:**
  The work requires an assessment of the erosive potential of the ghauts at various rainfall return periods. Much of this work may have already been done in the inland erosion component of this project. But the production of accurate maps may require considerable data collection, much of which may already be available in existing maps.

- **Training of Public Works or/and NEMA personnel to apply HEC-1, HEC-RAS or similar programmes for updating the coverages when additional information becomes available:**
  These programmes are robust and have been used extensively. There is adequate documentation from the software developers, short hands-on training workshops are conducted frequently, and there is ample technical support by many vendors. Routine computer facilities are required for running the models.

12. Recommendations for Flood Mitigation

Frequent maintenance of the ghauts especially at road crossings will assist in reducing the likelihood of a flood; or at least it would reduce the severity of it. In sizing culverts and bridges, it is not sufficient only to provide the waterway for carrying peak discharges. The evidence is that the waterway areas may be adequate but not sufficient consideration has been given toward determining the extra waterway area for sediment deposition. Additionally, an appropriate design for silt traps and trash racks is required. At the airport in Nevis, an improved method of security at places where the ghaut passes under the runway is needed. The present arrangement of construction of a steel cage at the entrance of the culvert contributes to flooding when, invariably, debris becomes entangled there. Some consideration should be given to diverting these crossing to the ends of the runway. That is to say, consideration should be given to constructing an interceptor drain running parallel to the runway but outside the enclosed limits of the airport. The cost of such an undertaking might outweigh costs associated in closing the airport due to a flooded runway.

The major problem in Nevis seems to be one of enforcement of the land use zoning regulations, especially in the Hermitage region. Failure to enforce would only aggravate the existing flood problems in this area and it would no doubt extend to other areas that may currently not be affected by flooding. In St. Kitts, any consideration to replace the sugarcane plantations by housing developments should be mindful of the increased runoff downstream and the potential for increased velocities and hence increased erosion potential within the ghauts.

Serious consideration should be given to diverting the lower reach of College Street Ghaut away from its current alignment through the town centre. Performance of an economic analysis will determine whether the major capital investment for such an undertaking is justified by (i) the savings in averted losses, and (ii) revenue lost because of postponement of any planned development until the flooding problem has been solved. In the interim, some early flood warning system could be put in place to alert residents, at least in College Street, of the pending flood wave. This does not have to be a sophisticated system, but it should be based on measurement of rainfall in the upper parts of the ghauts and an awareness of the soil saturation levels at the time of rainfall. But even if this cannot be done, use can be made of the observations of persons living in the upper watershed. More often than not,

persons living in the upper reaches of the ghaut see the ghaut flowing full. Only minor work is required to correlate water levels in the ghaut there with the expected flood at College Street. As much as relaying their observations to College Street dwellers would only provide about 20 minutes lead time, this may be sufficient at least in minimizing the loss of life.

13. Concluding Remarks

The available database structure is in place, but, for Nevis, it needs to be improved to allow for ready retrieval of information when requested. Furthermore, the rainfall frequency analysis for Nevis must be done with the rainfall data that have been collected for many years on the island.

The maps produced are preliminary. They highlight the main areas on both islands that are prone to flooding and they perhaps give a reasonable representation of the extent of flooding expected for various rainfall return periods on St. Kitts and Nevis. The application of the methodology when additional data for Nevis become available should improve the accuracy of demarcation of the flood prone areas.

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Figures

Figures

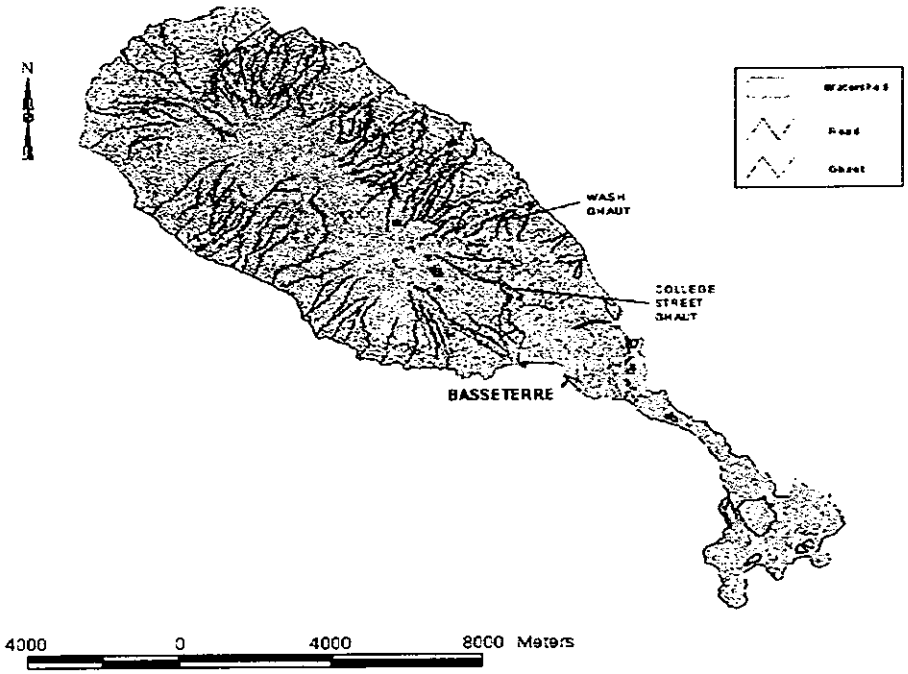

Figure 1. St. Kitts Island

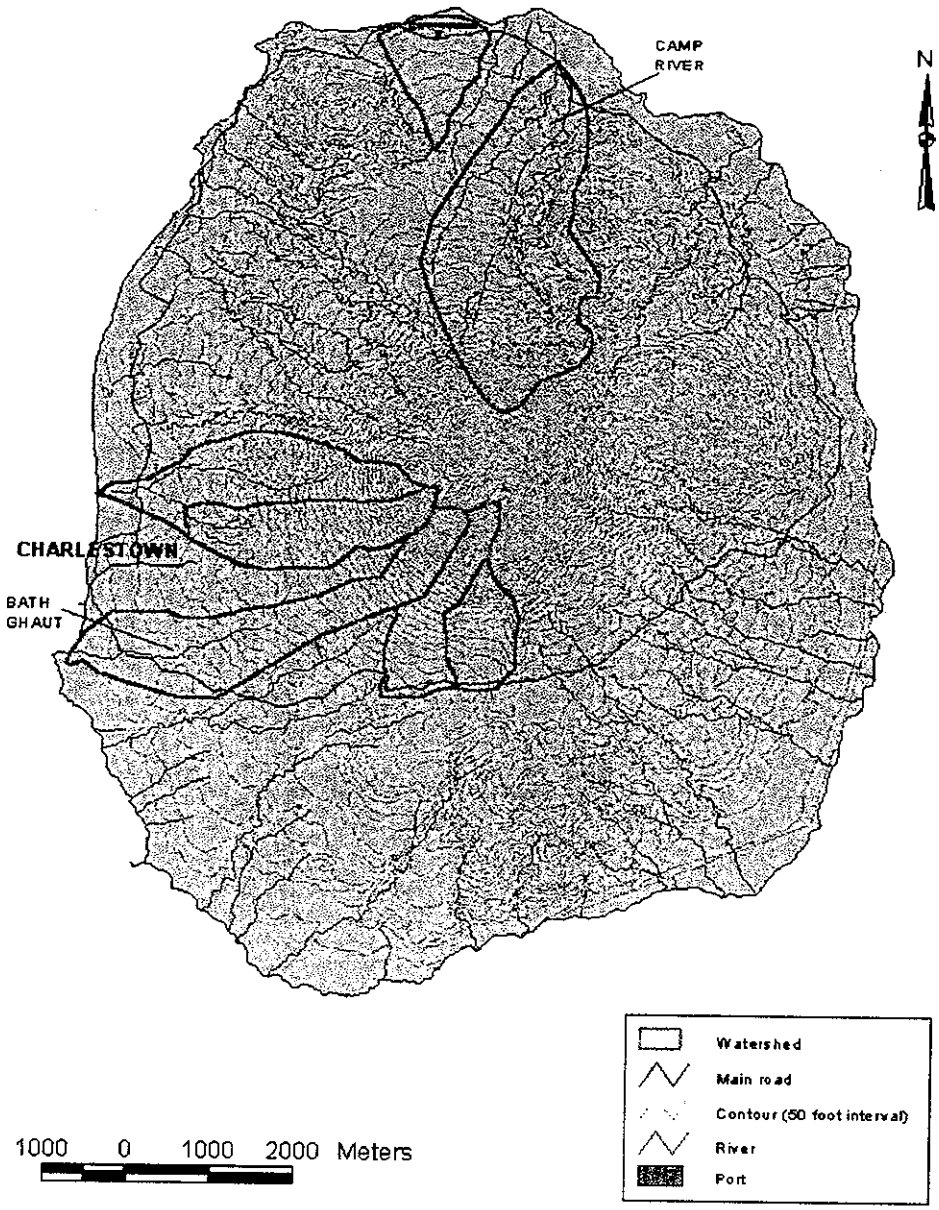

Figure 2 Nevis Island

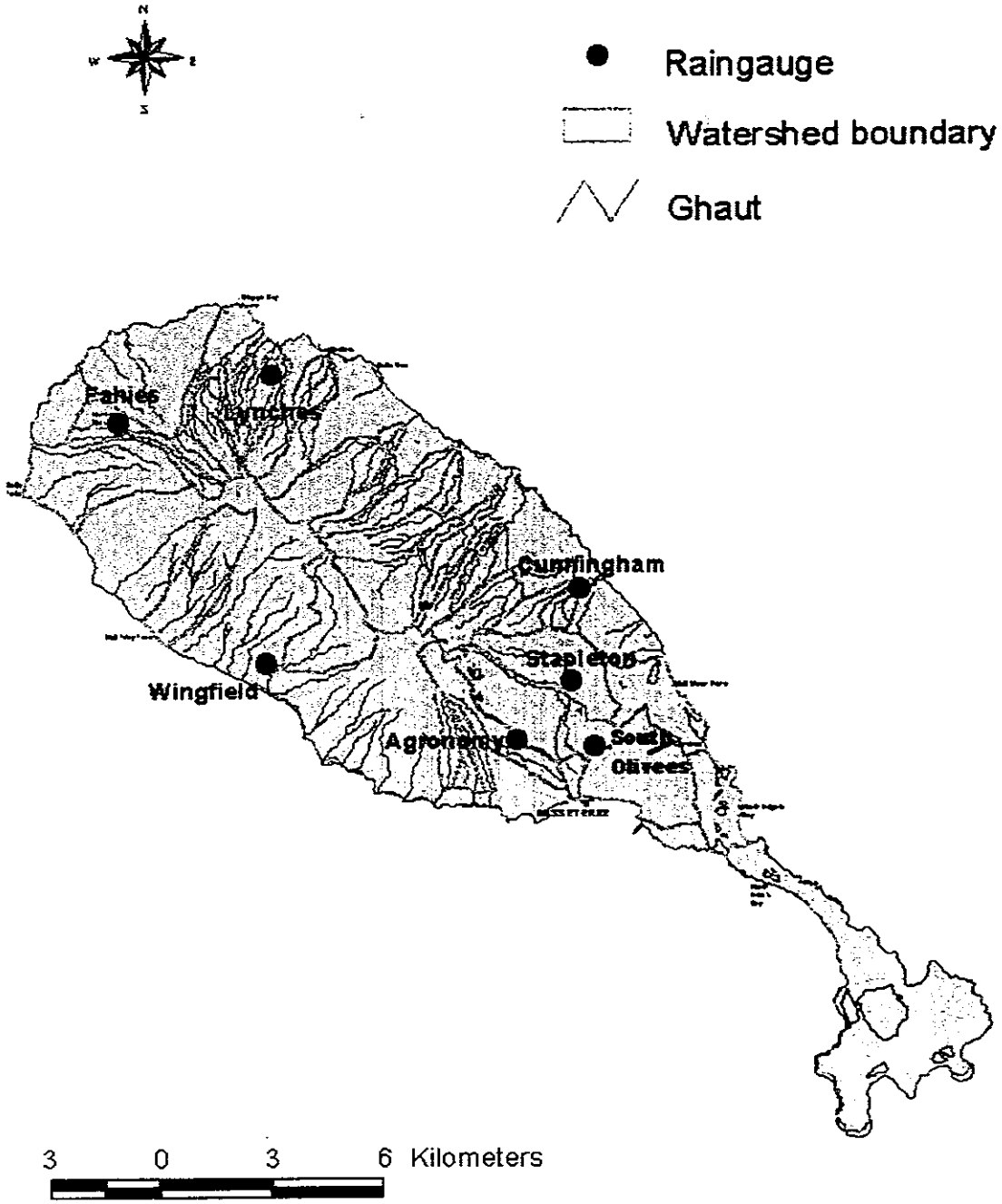

Figure 3. Raingauges on St. Kitts

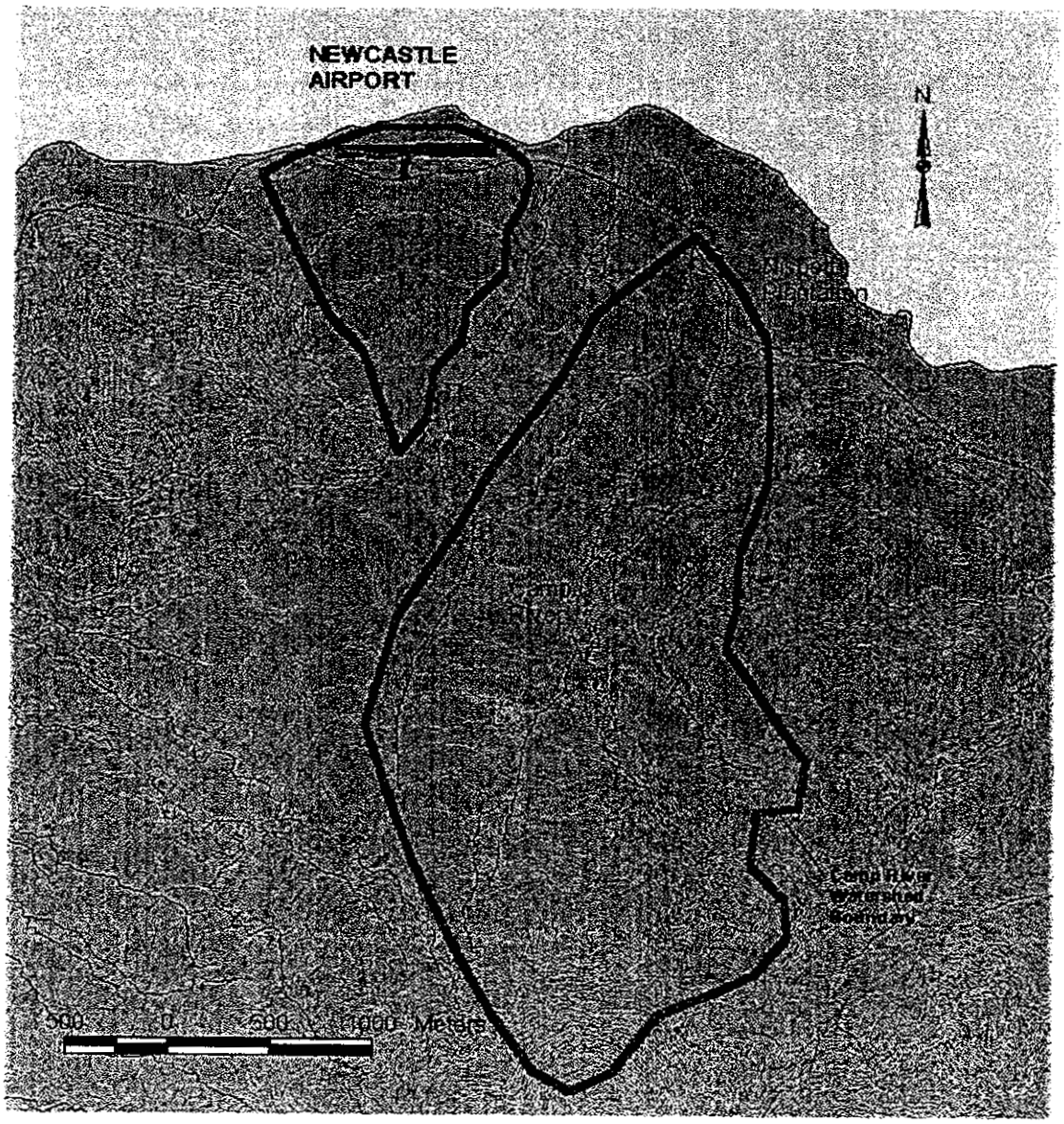

Figure 4. Camp River Watershed

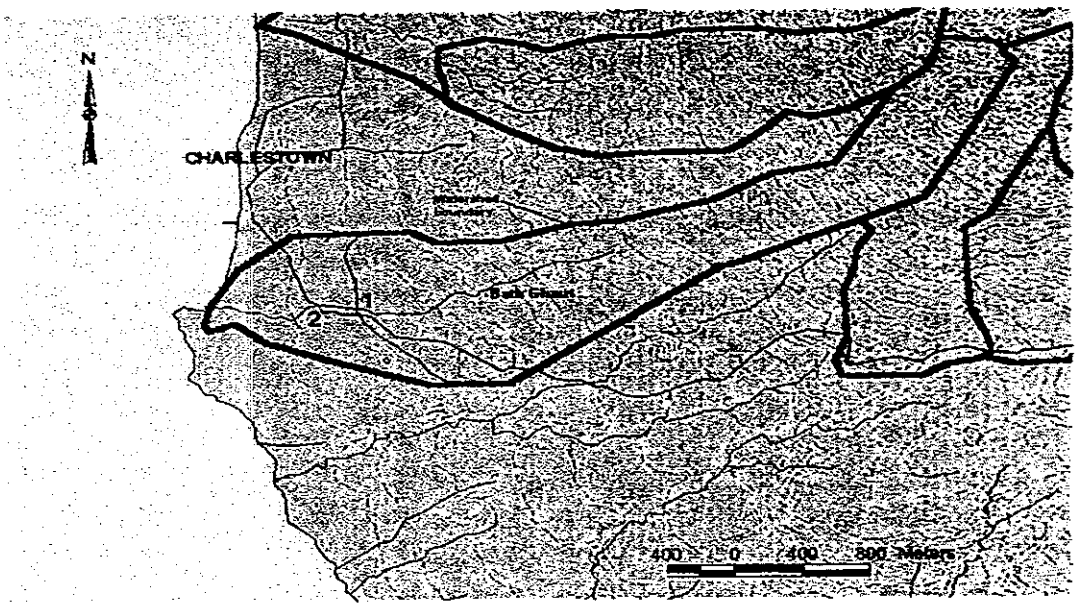

Figure 5. Bath Ghaut, showing the positions at which hydrographs were estimated.

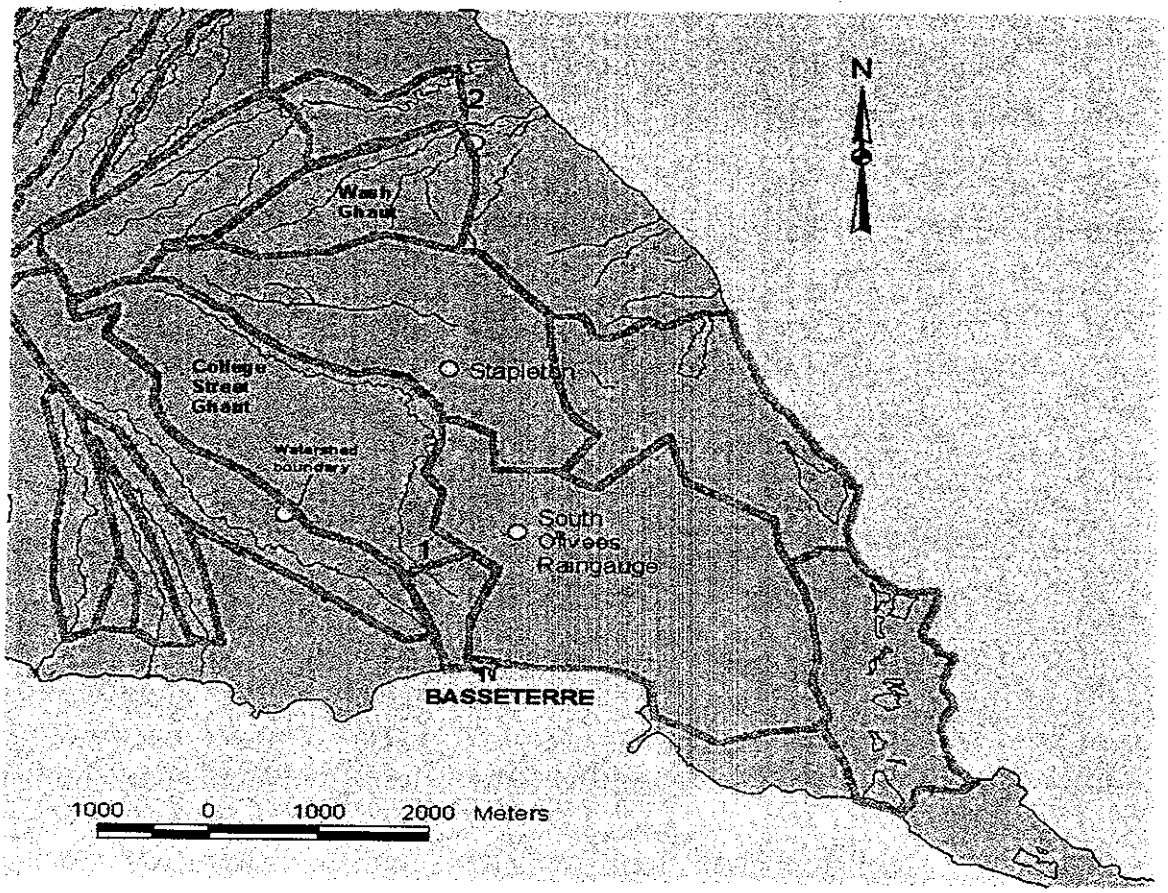

Figure 6 College Street Ghaut and Wash Ghaut Watersheds.

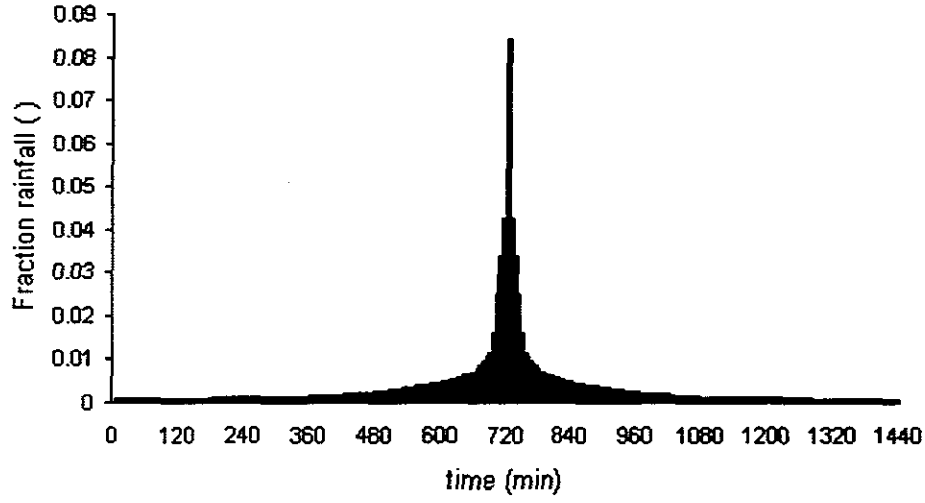

Figure 7 SCS normalized hyetograph for the Type III curve.

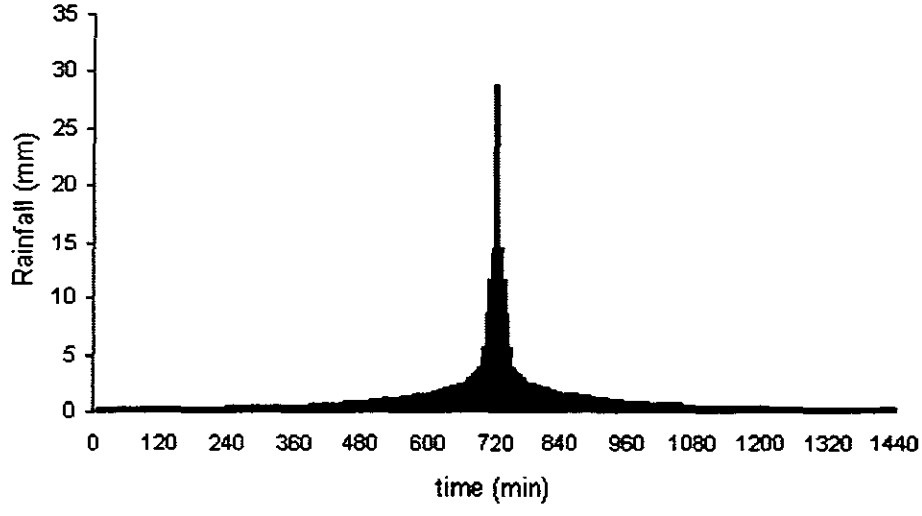

Figure 8 Critical Storm for Nevis based on the mean 100-year return period daily rainfall from St. Kitts.

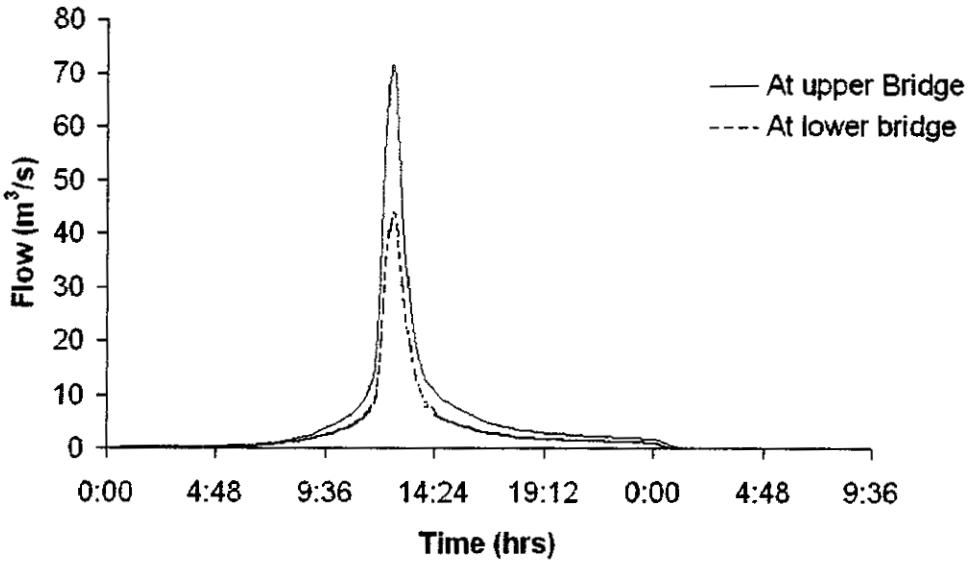

Figure 9. Runoff hydrographs from sub-watersheds in the Bath Ghaut Watershed.

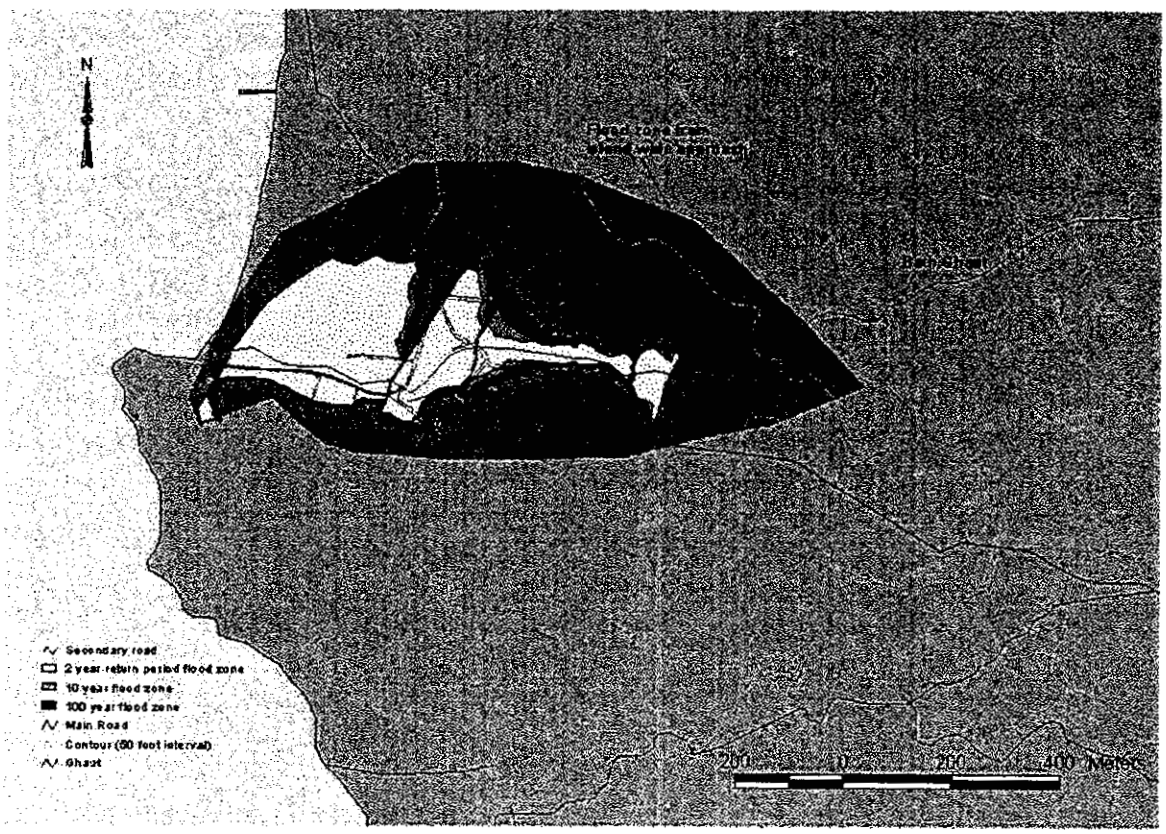

Figure 10. Flood zone within Lower Bath Ghaut generated by HEC-RAS