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Hazard Assessment and Mapping for Antigua and Barbuda

Summary Reports:

Beach Erosion
Inland Flooding
Drought
Inland Erosion

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

July 2001

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An Assessment of Beach Erosion Hazards in Antigua and Barbuda: Summary Report

OAS/USAID Post-Georges Disaster Mitigation Project

Implemented by the Organization of American States, Unit for Sustainable Development and Environment for USAID-Jamaica/Caribbean Regional Program

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COSALC Coast and Beach Stability Project
GIS Geographical Information Systems
OAS/USDE Organization of American States, Unit for Sustainable Development and Environment
PGDM Post-Georges Disaster Mitigation
SIDS Small Island Developing State
TS Tropical Storm
UNESCO United Nations Educational, Scientific and Cultural Organization
UPR-SGCP University of Puerto Rico Sea Grant College Program
USAID-J/CAR US Agency for International Development-Jamaica/Caribbean Regional Program

Background/Introduction

Antigua and Barbuda as a Small Island Developing State (SIDS) has a fragile economy that depends heavily on coastal tourism. In addition, the country ranks high in terms of its vulnerability to tropical storms (TS) and hurricanes. Between 1995 – 1999 Antigua and Barbuda experienced four (4) major hurricanes which caused severe damage and loss to the natural environment and critical changes in the social and economic fabric of the country. While the severe weather conditions may be attributed to climate change and possible sea level rise the consequences may be rather extensive. The severe weather conditions may be related to climate variations, climate change and possible sea level rise. It is therefore critical to analyze the changes, which occur around the coastal regions of Antigua and Barbuda and where possible to predict future trends in order to determine future development policy

On 20-22 September 1998, Hurricane Georges, a category 3 storm, struck the Eastern Caribbean islands of Antigua and Barbuda and St. Kitts and Nevis causing severe damage to economic and social infrastructure of both islands.

In response to the damage from Hurricane Georges, the US Agency for International Development-Jamaica/Caribbean Regional Program (USAID-J/CAR), has established a program entitled *Hurricane Georges Reconstruction and Recovery in the Eastern Caribbean* specially targeting Antigua and Barbuda and St. Kitts and Nevis. The activity entitled *Post-Georges Disaster Mitigation (PGDM) is* the disaster mitigation capacity building component of the program. *The PGDM is implemented by the* Organization of American States' Unit for Sustainable Development and Environment (OAS/USDE) for USAID-J/CAR.

The goal of the PGDM program is to reduce the vulnerability of people and economic activities in St. Kitts and Nevis and Antigua and Barbuda to natural hazards, including tropical storms and related flooding, seismic and volcanic hazards, through enhanced capacity for hazard mitigation

The Fisheries Division, in 1991, established a beach monitoring program within the framework of the regional 'Coast and Beach Stability in the Caribbean islands project' (COSALC), sponsored by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the University of Puerto Rico Sea Grant College Program (UPR-SGCP). Nineteen (19) beaches in Antigua and six (6) in Barbuda are monitored quarterly to measure beach profiles; changes in the profile cross sectional area and the profile width are then determined. These data, collected for the selected beaches, along with other related physical, social and economic information will be utilized in this project to achieve the required objectives. Additionally, it is hoped that this project could also be used as a model for other SIDS that experience similar conditions.

This project focuses primarily on beach changes and the various causal factors, which operate within the beach zone. The impact of hurricanes, TS and different human-induced activities will also be discussed..

One of the major objectives of the Post-Georges Disaster Mitigation (PGDM) project of the Organization of American States (OAS), is the development of national goals, objectives and actions to reduce the vulnerability of Antigua and Barbuda to the effects of natural hazards. The understanding of coastal erosion hazards gained through this project will inform national coastal development and erosion hazard vulnerability reduction policies and measures for Antigua and Barbuda.

Under this contract, a hazard assessment of coastal erosion was undertaken in Antigua and Barbuda, as well as the production of a technical and a non-technical report of the coastal erosion hazard assessment for Antigua and Barbuda.

The major objectives of this project include:

- The determination of which beaches are most vulnerable to erosion
- The development of an index for the beaches, which will demonstrate the erosion hazard.

The major constraints of this project include the following:

- Availability of suitable data (e.g. only some beaches are monitored).
- Limited time and resources.

Figures 1.0 and 2.0 provide maps showing coastal erosion hazards along the beach monitoring sites of Antigua and Barbuda.

Figure 1.0 Coastal Erosion Hazard: Antigua

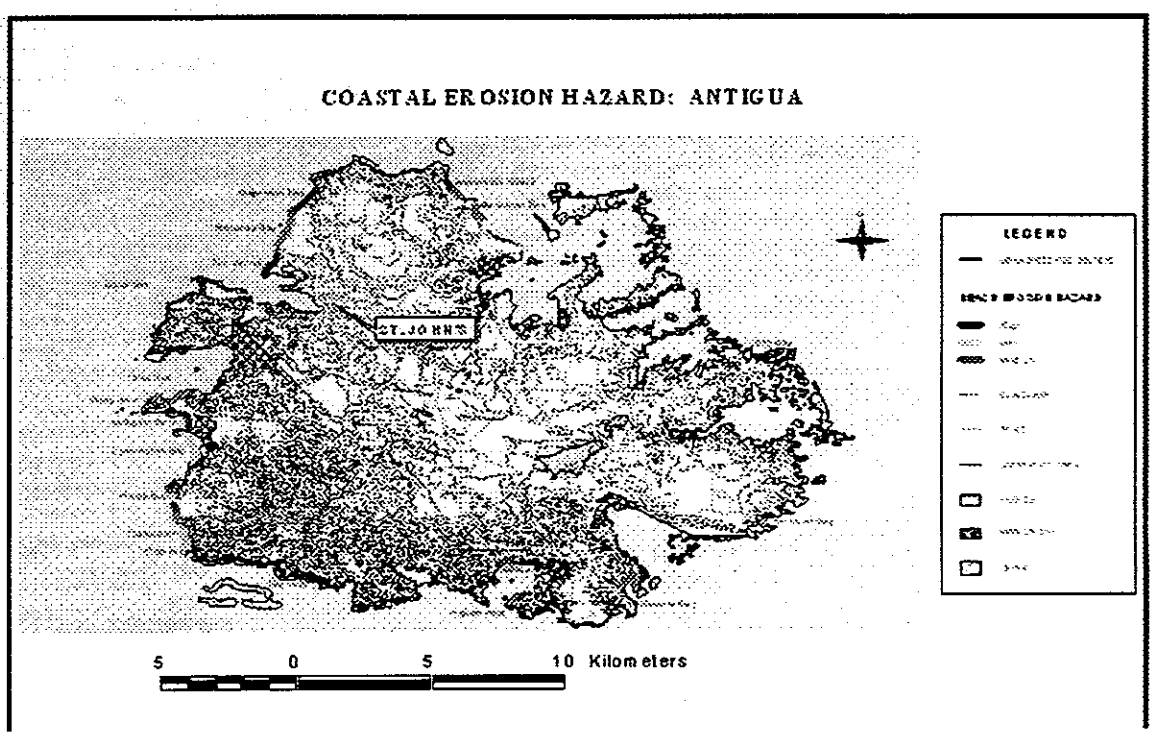
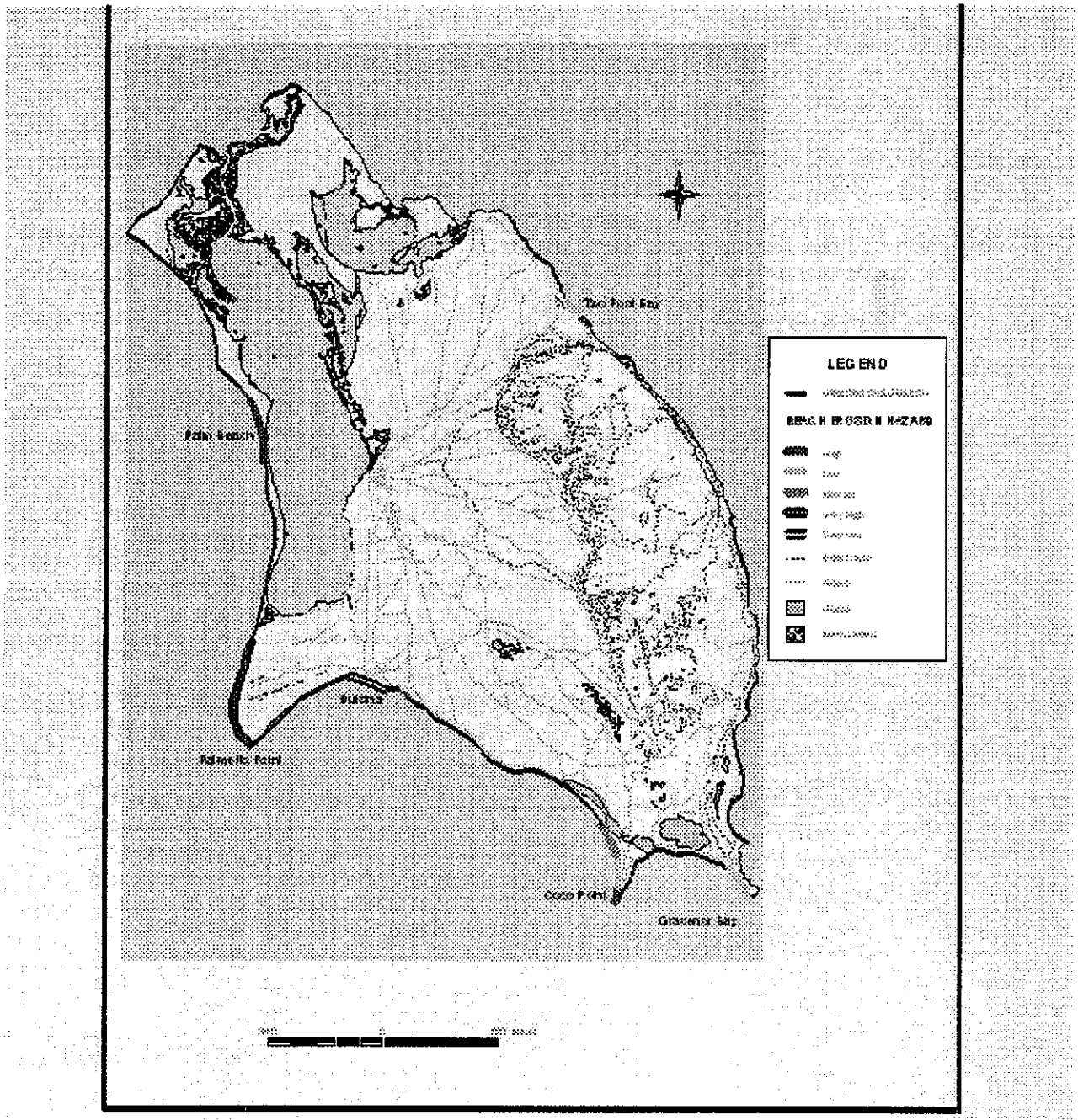


Figure 2.0 Coastal Erosion Hazard: Barbuda

COASTAL EROSION HAZARD: BARBUDA



Methodology

Several methods and techniques were used in developing this project, namely:

- Assembling of existing beach monitoring data for each island.
- Calculation of erosion/accretion rates for all monitored beaches.
- Assigning of coastal erosion risk categories (very low, low, medium, high or very high) at the measured beaches in each island.
- Production of island-wide geographic information system (GIS) data layers depicting the coastal erosion hazard risk zones.

- Production of island-wide coastal erosion hazard maps for Antigua and Barbuda, using the GIS data. Maps include a common set of reference features that were provided by the PGDM project.

Primary data collected by the Fisheries Division in its regular beach monitoring program forms the basis of this report. Nineteen beaches have been monitored in Antigua since 1992 and six in Barbuda since 1995 at quarterly intervals. Other data were obtained from the worldwide web and the Meteorological Office. Emphasis was placed on changes in the beach profile width as the primary indicator of beach change rates. If the beach profile width decreases over time, this is interpreted as an erosion rate while if the beach width increases, this is an accretion rate.

Using the Geographical Information System (GIS) layers provided by the PGDM project as a base, new layers were created to show beaches that are monitored and not monitored. Categorization was done to show the varied beach erosion hazards throughout Antigua and Barbuda

Using the beach monitoring and other data, major operational processes and activities were determined so that beaches affected by storms or other factors were identified. A coastal erosion hazard index was developed for the various beaches that are monitored around Antigua and Barbuda. The maps depict the hazard category for an individual beach or segment of the beach. The categories for the erosion index for Antigua and Barbuda are:

Rate of Coastal Change Hazard category

+3.38 to +5.28 Very low
+1.48 to +3.37 Low
- 0.43 to +1.47 Medium or Moderate
- 2.34 to – 0.44 High
- 4.25 to – 2.35 Very high

Structure and Content of the Hazard Maps

Together with the reports the hazard maps for Antigua and Barbuda form the main output of this project. The maps show erosion hazards for the various monitored beaches around Antigua and Barbuda. The base maps which show contours, roads, settlements and critical coastal habitats are drawn at a scale of 1:50,000.

The maps depict the Coastal Erosion Hazard for Antigua and Barbuda with the hazard categories shown in color for easy reference and contrast. For Antigua the relative hazard are shown as low, moderate or high while for Barbuda, where there is a greater range in the data, there are two additional categories: very low and very high, these show relatively extreme conditions.

Maps are accompanied by illustrated legends, which seek to explain the meaning of the relative rankings in both quantitative and qualitative terms.

There is a caption indicating the suggested usage and limitations of the maps. Using the given erosion rates, predictions can be made especially for short time periods. Without scientific evidence and reliable data, unmonitored beaches cannot be ranked for erosion hazard. The maps therefore do not indicate the erosion risk for beaches that are not monitored.

For up to date information on the state of the coastal areas of Antigua and Barbuda contact:

Fisheries Division
Ministry of Agriculture, Lands, Fisheries
Perry Bay
St. John's
Antigua W.I.
Tel./Fax: 1-268-462-1372
Email: fisheries@candw.ag

The logos of the sponsors or implementing agencies (USAID and OAS) are also placed on the maps. For additional

information the PGDM website is given as the main contact for the project. This is shown as http://www.oas.org/pgdm.

Results and Discussion

Available data have shown that the number and intensity of tropical storms is on the increase. This is clearly illustrated in Table 1.0. Antigua and Barbuda experienced four major tropical systems during the past five years (see Table 2.0). Several beaches have changed their shape and character as a result.

Apart from the direct effects of hurricane winds, storm surge also impacted the coastline. At the monitored beaches, the changes in beach area and width result from a combination of factors including hurricane impacts.

Table 1.0 Hurricane Frequency Between 1990 and 1999

Five Year Period	No. Named Storms	No. Hurricanes Per Year	No. Hurricane Days Per Year	No. Category 3, 4, 5 Hurricanes Per Year
1990 – 1994	8.4	4.6	13.6	1
1995 – 1999	13.0	8.2	41.4	4.0

Source: http://typhoon.atmos.colostate.edu/forecasts/1999/nov99/

Table 2.0 Tropical Systems, which affected Antigua and Barbuda between 1995 and 1999

Name	Category	Wind Speed (km/hr)	Track Location	Date
Iris	TS	93	South	27-Jul-95
Luis	4	222	Landfall	09-Sep-95
Marilyn	1	148	North	15-Sep-95
Bertha	1	139	South	07-Aug-96
Hortense	1	130	North	09-Oct-96
Erika	1	130	North	09-Jun-97
Georges	3	185	Landfall	21-Sep-98
Jose	2	157	Landfall	20-Oct-99
Lenny	TS	102	Landfall	20-Nov-99

Note: Wind speeds are for the direct time of passage over Antigua and Barbuda

Analysis of the coastal change rates along the monitored beaches of Antigua and Barbuda indicate that erosion is the dominant process on nine beaches while the other nine show accretion.. Six beaches show marked variations along their length, in that erosion and accretion dominate on the different segments of the beach. The rate of erosion appears to be independent of the location on the island. Significantly, where there is variation between the different beach segments erosion tend to dominate along the northern end of the beach.

Most of the monitored beaches on Antigua (16) fall between the medium to high hazard category with one in the medium to low (Ffryes) and two that are fully low (Crab Hill Bay and Lignumvitae Bay). These are shown in Table 3.0.

Table 3.0 Antigua – Mean Annual Rates of Coastal Change 1992 - 1999

Beach	Mean annual coastal change rate (m/yr)	Hazard category
Dickenson Bay	-2.01	High
Runaway Bay North	-0.37	Medium
Runaway Bay South	0.71	Medium
Fort James	-0.50	High
Deep Bay	-0.55	High
Yorks Bay	0.59	Medium
Stony Horn Bay	0.21	Medium
Mosquito Cove	-1.47	High
Lignumvitae Bay	2.16	low
Ffryes Bay North	-0.31	Medium
Ffryes Bay South	1.68	Low
Darkwood Bay North	-0.67	High
Darkwood Bay South	0.52	Medium
Crabhill Bay	1.49	Low
Morris Bay	-0.71	High
Falmouth	0.90	Medium
Mamora Bay	-0.14	Medium
Pigeon Point	0.30	Medium
Halfmoon Bay North	-0.70	High
Halfmoon Bay South	0.19	Medium
Long Bay	-0.47	High
Dutchman Bay North	-0.34	Medium
Dutchman Bay South	0.66	Medium
Jabberwock North	-0.74	High
Jabberwock South	0.77	Medium

The impact of storms on the beaches varies depending on several factors. These include:

- Location on island.
- The degree of shelter.
- The extent of coral reefs offshore.
- Human related activities, especially sand mining and coastal development

Although storm impacts are emphasized, other factors play major roles in determining the erosion/accretion rates along the beaches around Antigua. The role of factors such as coastal development too close to the coastline, sand-mining, dredging, coastal protection structures, beach orientation, and relief of the nearby landscape should never be underestimated.

In the case of Barbuda with its flat, low-lying landscape there is even greater contrast in the coastal change rates. Of the six beaches monitored on Barbuda two (Two-Foot Bay and Dulcina) clearly show accretion as the dominant process, while erosion is more significant for two others (Palm Beach and Palmetto Point). The different sectors of Coco Point tend to vary with accretion dominant in the north whereas the peninsular in the south is eroding.

As depicted in Table 4.0, the hazard categories for Barbuda range from the extreme of very low (Dulcina) to very high (Palmetto Point). The location and local site conditions account mainly for the varying erosion rates.

Table 4.0 Barbuda – Mean Annual Rates of Coastal Change 1995 - 1999

Site	Mean annual coastal change rate (m/yr)	Hazard Category
Gravenor Bay	0.189	Medium
Coco Point A	-0.211	Medium
Cocoa Point B	2.916	Low
Cocoa Point C	-1.862	High
Dulcina	5.278	Very Low
Palmetto Point	-4.25	Very High
Palm Bay	-1.816	High
Two Foot Bay	2.689	Low

Recommendations and Conclusions

Based on the nature and importance of the coastal landscape of Antigua and Barbuda there is a need to develop strategies to cope with erosion hazard vulnerability. The following measures should be considered for the future:

- Increasing the number of measurement sites on individual beaches that are already monitored:
- Increasing the number of monitored beaches to include not only beaches directly under threat because of misuse or overuse but also beaches which are close to their 'natural state'. Specifically, a team from Barbuda should be trained so as to ensure regular monitoring of beaches on the island.
- An inventory of coastal resources and uses needs to be maintained for Antigua and Barbuda. To some extent, this process has already been initiated through the CPACC Project.
- With more time and resources, a broad-based approach should be developed to analyze coastal erosion hazards,

incorporating additional factors beside beach width.

However, despite its obvious limitations, this analysis can still be used to inform the development of national coastal development policies and measures to reduce the vulnerability to coastal erosion hazards.

Glossary of Important Terms

Accretion: accumulation of sand or other beach material due to the natural action of waves, currents and wind; a build-up of sand.

Beach is a zone of loose material extending from the low water mark to a point landward where either the topography abruptly changes or permanent vegetation first appear.

Beach Profile is a side view of a beach extending from the top of the dune line into the sea.

Erosion: wearing away of the land, usually by the action of natural forces.

Geographic Information System is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. It is regarded as the high-tech equivalent of a map.

Hazard is the occurrence of a phenomenon (e.g. coastal erosion) which has the potential for causing damage to or loss of buildings, natural ecosystems and infrastructure.

Hazard mitigation is the set of activities implemented to minimize or eliminate the risk to property and human life from a hazard.

Risk is defined as the frequency of incidents and their associated consequences. Coastal erosion risk is the combination of the frequency of erosion along the coastline and the magnitude of associated impacts on coastal development, natural ecosystems and infrastructure.

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Inland Flood Hazard Mapping for Antigua and Barbuda: Summary Report

OAS/USAID Post-Georges Disaster Mitigation Project

Implemented by the Organization of American States, Unit for Sustainable Development and Environment for USAID-Jamaica/Caribbean Regional Program

May 2001

This report was prepared by Vincent Cooper, University of the West Indies, Trinidad.

Note: The final maps that accompany this report are available online: Antigua | Barbuda

1. Introduction

This report describes the approach to mapping the natural hazard of inland floods on Antigua and Barbuda. It first presents a summary of the main cause of flooding on the islands. This is due not only to extreme rainfall, which provides the potential water for inundation, but also depends on the condition of the watersheds at the time of the event. The detrimental effects of flooding are then presented, which on the islands are mainly health hazards in terms of drowning and the contraction of diseases, and damage to economic systems including public infrastructure and private property. The data needs and adequacy for flood quantification are then discussed. For its quantification three sets of data are required, and they include rainfall data for characterizing the rainfall with potential to cause floods, the physical properties of the watershed which determine the volume and time-distribution of runoff onto low-lying areas, and the geometric features of the drainage channel which may or may not have sufficient capacity to accommodate the runoff from the watersheds. The two approaches used for flood mapping are described, followed by the presentation of the methodology implemented for producing the maps. A general summary of the findings for each island concludes this report. Among other things, it suggests what are necessary to improve the accuracy of the maps, which given the limited data, must be regarded as only preliminary maps.

2. Causes of flood

The nature of inland flooding being investigated on Antigua and Barbuda is described by the following definition: 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. In these islands, the major trigger of this inundation is extreme rainfall on the watersheds. These extreme events are frequently associated with

hurricanes that produce significant quantities of rainfall during their passage over the islands, and the slower the movement over the islands, the greater the quantity of rainfall. The most recent example the relation between rate of movement with rainfall amount was Hurricane Lenny in 1999, which hovered around these islands for about three days and dumped a phenomenal amount of rainfall on them. Widespread flooding may also occur from rainfall associated with the Intertropical Convergence Zone (ITCZ) weather system.

Whether or not floods occur within a watershed, on the occurrence of an extreme rainfall event, depends on the characteristics of the watershed. Most watersheds in Antigua and Barbuda have the following properties:

i. Soils that have generally low permeability or/and shallow depths, and therefore there is no significant reduction in the amount of rainfall available for runoff;
ii. Dense drainage networks (mainly on Antigua) that permit rapid flow within the channel banks and rapid concentration of runoff onto the floodplains;
iii. Expanding urbanization, which replaces pervious areas with impervious surfaces such as roofs and roadways; and
iv. widespread grazing by goats and cattle (mainly on Antigua) that compacts soils and reduces infiltration rates, and that also removes vegetative cover leaving the soil surface exposed to full impact of the rainfall drops and vulnerable to soil erosion.

The properties therefore provide little attenuation of the rainfall amount or little retardation of the travel of the flood volume toward the low-lying areas. Thus watersheds in Antigua and Barbuda are susceptible to flooding. Fortunately, watersheds are small, in the order of tens of square kilometers, and so the volume of runoff would be relatively small even for very extreme rainfall.

3. Effects of floods

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 Antigua and, to a lesser extent, Barbuda, rising floodwaters from overbank flows poses hazard of drowning of human beings as the floodplains are densely populated. 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; and the creation of appropriate habitat conditions for certain rodents, insects and organisms that transmit diseases. Detrimental effects on agriculture are mainly due to loss of livestock—goats, sheep and cattle—due to drowning or becoming dispersed. Destruction of crops, seeds, and stored food stocks during inundation are limited as the country has a small agriculture base. Public infrastructure and private property may be damaged with inundation. 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. The housing developments within Cook Creek, as indeed on other floodplains, are particularly vulnerable as ground floors are generally not elevated more than about one metre (about three feet), above ground level, nor are these buildings properly anchored to their foundation. Some houses floated away due to the uplift pressure of water flooding the housing developments during Hurricane Lenny. Floating debris such as cars and logs can increase damage as they impact structures downstream. Properties on riverbanks may be in danger if the toe of these banks begins to erode and trigger bank failure. Major disruptions of the road network may affect productivity as the workforce is delayed in reaching their workplaces.

4. Characteristics of Flood Prone Areas

Areas prone to flooding have the following characteristics:

- very gentle slopes that are perhaps poorly drained because their streams, creeks and drainage channels also have very gentle slopes;
- constricted natural drainage owing to, for example, heavily vegetated areas such as mangrove forests, meandering streams, or tidal influences. If communities are located around the outlet, then the hydraulic structures, such as bridges and culverts, may constrict flows owing to poor maintenance or because they become blocked with debris, and thus may further limit the natural carrying capacity of the rivers;
- large watershed areas (relative to their area) contributing runoff from rainfall;

- so positioned within the watershed that runoff from the surrounding lands concentrate at the floodplain;
- contributing areas having large runoff coefficients due to impervious soils, impervious ground cover, or/and limited abstraction losses by vegetative cover.

5. Data Needs and Adequacy for Quantifying Floods

Data needs for flood quantification can be grouped into three categories: data for describing the meteorological event which may trigger the flood; data about the watershed which are used for determining the fraction of the rainfall that would runoff the land and how it would be distributed in time; and data for describing the geometry of the drainage channels which may or may not be able to convey all of the runoff within its banks, depending on their water carrying capacity.

The Critical Storm: The definition of a critical storm is somewhat subjective and its description may vary depending on the purpose of the investigation. In all cases it is defined by four features:

i. rainfall depth;
ii. duration;
iii. the time-distribution of the rainfall depth over the duration of the storm; and
iv. the spatial distribution or the area over which the features in (i) to (iii) remain unchanged.

Historical daily rainfall records collected within the watersheds are vital to obtaining the rainfall depth. From the application of appropriate statistical analyses on these records, the depth of rainfall of certain return periods (see definition below) can be found. Daily rainfall records are normally available in plenty supply but more often than not there is little information to describe how that depth of rainfall occurs over the 24-hour period. The resulting runoff is very much dependent on this time distribution, and it is not sufficient to average the rainfall over the 24 hour period. Standard time distribution curves have been developed for the United States and some of these curves have been successfully used in the Caribbean (and indeed in other parts of the world). In the absence of time-varying rainfall data collected from within the watersheds, then these curves can be used. The storm duration is related to a characteristic of the watershed known as the time of concentration. The time of concentration, T_c, depends on the physical characteristics of the watershed, and it represents the time required for water from the furthest point in the watershed to reach the place where the hydrograph is being measured. For maximum runoff generation, the critical storm must have a duration at least equal to the T_c of the watershed. The variation in space also must be considered in developing the critical storm. The amount and timing of rainfall vary considerably from one place to the other for the same storm. Therefore, the capturing of such variability requires finding a weighted average of rainfall measured at several raingauges set up throughout the watershed. The use of one raingauge may not be truly representative of the rainfall over an entire area, but in many cases, only one gauge is available.

For Antigua, six years of daily rainfall from a single station at Jolly Hill was used to produce the critical storm. At this station the rainfall recorded from Hurricane Lenny was 460 mm (about 18 inches) over three days, 242 mm (about 9 inches) occurring within a 24-hour period. This daily rainfall was chosen as the critical storm and the Type III time distribution curve—a designation used to describe one of the standard curves in which most of the rainfall occurs within a small fraction of the 24 hour period—was used to distribute the rainfall in time. It was also assumed that this critical storm was spatially uniform and would have had the same rainfall depth and time distribution everywhere on the island.

Runoff: Having defined the critical storms, it would then be possible to estimate runoff properties from the surrounding watersheds. The amount of water available as runoff from the rainfall and the distribution of this runoff in time are controlled by the features of the watershed. The important features are:

- Size of the watershed;
- Soil infiltration rates and depth of storage;
- Land cover;
- The total length of all the rivers and their tributaries;
- Shape, slope and ruggedness of the watersheds.

The first three features control the amount of water available as runoff onto the plains. The other features control the timing of the hydrograph peak. Most of the required data are available on standard maps. Most are natural conditions,

but the land cover and, to some extent, the length and characteristics of the rivers and tributaries can be altered depending on the human activities occurring within the watersheds.

All required data can be extracted from standard maps and land capability reports, and these were all readily available, some in digital format.

Geometric Features of the Drainage Channels The geometric properties of the drainage channels and the nature of their lining determine the flow rate that can be accommodated within their banks. Meanders on channels reduce their capacity, so too would reduced slopes. Capacity is also reduced with increasing roughness of the channels. Carrying capacity is affected by man-made hydraulic structures, such as bridges, weirs, sluice gates culverts, that may be constructed within the channels.

Normally, detailed surveys are required to gather the geometric data for describing the drainage channels. Some surveys were carried out, but this was limited, and only within Cook Creek.

6. Approaches to Flood Mapping

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 still 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 plains 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 plain 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 the channel geometry. Whereas the same runoff information as above is needed to quantify the amount of water within the floodplain, this approach does not attempt any hydraulic analyses. Instead, the method estimates a flood depth over the entire floodplain, which is essentially an average value derived from a simple division of the total volume of water from all runoff flowing into the plain over the surficial area of the plain. This depth does not provide any information about how water depths vary within the plain as it assumes that the plain is flat 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 floodplains 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.

7. Methodology

Islandwide Scale Mapping:

i. Identify areas, called floodplains, having mild slopes. This can be done either via manual inspection of topographical maps or with the aid of digital elevation models (DEMs) and computer software;
ii. for each plain, demarcate the watershed draining into the plain and then determine the ratio between the watershed area and the floodplain area (from (i) above);
iii. for a particular 24-hour return period rainfall, generate runoff hydrographs discharging into the plain, based on the shape, the drainage network, the soil properties and the landuse;
iv. from the hydrographs, determine the volume flowing into the plain and estimate an average discharge rate over the hydrograph period;
v. estimate a discharge rate from the plains and use it to determine the maximum volume of water (expressed as depth of water) that is likely to be stored on the plain;
vi. determine the hazard category of each plain according to water depth within the plain from the 100 year return period storm (roughly equivalent to the maximum 24-hour rainfall period within Hurricane Lenny), using the

following classification:

Table 1 Hazard classification according to mean depth of water.

Water Depth (mm)	Hazard
>600	Very High
600-630	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.

For detailed flood mapping:

- Perform statistical analyses on the daily rainfall data and obtain amounts for various return periods.
- Derive the critical storm for a 24-hour duration, using standard time curves, and assuming that the rainfall was the same throughout the watershed;
- Obtain contour maps of Antigua and demarcate the watersheds draining into the floodplain. and conduct field trips to confirm the boundaries;
- Determine the existing land use within the watersheds from topographical maps and field visits;
- Obtain soils maps of Antigua and Barbuda;
- Digitize information from the map and field visit
- Conduct interviews with residents within the floodplains 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.
- 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 floodplain from the river bank in terms of its coverage—pastures, wooded, urbanized;
- Identify critical river sections based on their impact on flooding with potential for significant losses;
- Conduct detailed surveys of these areas at critical cross-sections, hydraulic structures and any other important features.
- Examine the discharge point of the section to determine outlet control conditions—whether, for example flow was unhindered or under the influence of tides.
- Perform detailed hydraulic analyses using appropriate computer software.
- Produce a flood map showing variation of water depths within the floodplain.

8. Summary Results

Antigua

For Antigua, extensive flooding is confined to about four regions mainly within the north where the majority of the population lives. Two of these regions are of critical importance, the floodplain of Cook Creek Watershed, which is densely populated with basic housing, and the Fitches Creek floodplain, also densely populated and containing important road links to the international airport. The other two areas at Potter Village and Parham Village also have significant population and are vital to the island road network. Many of the problems are owed to the physical characteristics of the watersheds and their floodplains and the inadequacy of the natural drainage channels. Poor infrastructure design, construction and infrequent maintenance serve to exacerbate the flooding. Additionally, there are pressures for developing the watersheds for housing that, if unchecked, have potential for increased runoff and more severe flooding in these areas.

Apparently there is a well-developed raingauge network collecting daily rainfall over the island. The database, however, is not in a form that makes for ready retrieval of the data and was not available for the project. The control points for establishing coordinates on the national grid are not easy to locate. The negatives of several maps, including the 1 in 5000 series, suffered water damage during a hurricane thus precluding extraction of fairly detailed topographical mapping of the floodplains. Information on the irrigation network, including drainage cross-sections and details of the hydraulic structures may be available, but could not be readily accessed.

The map was prepared using baseline information on other topographical features prepared for the PGDM project. The difficulties in incorporating surveyed data into the project base DEM are mentioned in the technical report.

The implementation of the methodologies, described above, was constrained by time and therefore, at best, the resulting maps should not be considered more than preliminary. Still, with sufficient time, the methodologies can be followed during subsequent map improvement exercises.

The acquisition of a longer dataset of rainfall records and detailed surveys within the floodplains is required for improving the accuracy of the map. The models used for conducting the study are readily available and there is adequate technical support for their proper use.

Barbuda

For Barbuda, runoff is generally rapid owing to its very thin soil depths and outcrop rock surfaces that provide very little infiltration and relatively low flow retardation. Its watersheds are primarily undeveloped with scrubby vegetation covering most of the area. No rivers, and not many gullies exist and therefore runoff is mainly as sheet flow. Runoff only accumulates in depressions; otherwise it may flow through Codrington, the main town, on its way to be discharged in the salt ponds and the sea. The roads appear to function as drains and just north of Codrington where several roads merge, runoff is concentrated there from a catchment area of about 15 km^2. This was the area noted to have suffered worst from Hurricane Lenny. It contains several abandoned quarry pits whose limestone lining has since become blocked with a thin impermeable soil layer. Water collected in these pits from runoff would remain impounded for several days to weeks owing to slow infiltration rates of the lining. Drainage infrastructure is minimal consisting of small box drains and small circular culverts through Codrington.

One rainfall gauge exists on the island, thanks mainly to the interest of the current school principal. There are seven years of daily rainfall, the time since the raingauge has been established, and records are readily available in electronic format. The database should further be developed so that data can be provided in universal ASCII format. Detailed topographical maps at resolutions better than 1 in 10000 do not seem to be available, or if they exist, they are not readily accessible.

The implementation of the methodology, described above, also was constrained by time and therefore, at best, the resulting maps should not be considered more than preliminary. Detailed flood mapping done for Antigua may not be appropriate for Barbuda as it has no pronounced rivers.

The map was prepared using baseline information on other topographical features prepared for the PGDM project. Field surveys within the demarcated flood zones are required to more accurately define the flood zone and perhaps to qualify flooding according to the desired guidelines of the project.

The proper maintenance of the raingauge and the continued collection, processing and analysis of rainfall records are necessary for upgrading the map. If not done as yet, then the arrangement of rainfall data collection should be formalized with the Meteorological Office in Antigua, or with the Barbuda Council.

Definitions

Flood: 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.

Hydrograph: A flood wave passing a particular place in the river. It represents how the stage (water elevation) or the flow in a river changes with time.

Return Period: This is an expression of the probability of a particular rainfall depth of a given duration occurring. The rainfall depth corresponding to a specified return period will be equaled or exceeded at a probability equal to the inverse of the return period, that is the relation can be expressed as follows: *Return Period = 1 / (Probability of occurrence).* For a 10 year return period: So the probability that the rainfall depth for a 10-year return period will be equaled or exceeded is 0.1 (1/10)

Critical Storm: The rainfall input used for producing the hydrograph. It represents what is viewed by the analyst to be most important in predicting the effects of the rainfall on runoff. The rainfall depth, the duration of the storm, the type of distribution of the rainfall depth in time and the uniformity of the distribution of the storm over the watershed must all be specified for complete specification of the critical storm.

Time of Concentration: The time elapsed between the start of the rain and the runoff from the most remote point in the watershed to reach the place where the hydrograph is being measured.

Organization of American States

USAID

Antigua and Barbuda Drought Hazard Assessment and Mapping Summary Report

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

April 2001

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INTRODUCTION

This document, which summaries the results of a drought hazard assessment and mapping study for Antigua/Barbuda, was commissioned by the Organization of American States (OAS) as part of its Post-Georges Disaster Mitigation Project (PGDM).

One of the major objectives of the PGDM is the "development of national goals, objectives and actions to reduce the vulnerability of Antigua/Barbuda ... to the effects of natural hazards."

There were two major component products of the study, namely:

- A drought hazard assessment technical report and;
- Island-wide drought hazard data maps for both Antigua and Barbuda, which were used to identify areas of different categories of risk to drought. These data maps were used to prepare separate drought risk maps for Antigua and Barbuda.

Data for map preparation and for drought assessment were collected from secondary sources, reports, maps, personal communication and limited field observations. Maps were first manually prepared and then digitized, using GIS application, Arc View.

DEFINITION OF DROUGHT

Drought is a recurrent feature of Antigua/Barbuda's climate. It occurs when there is an extended period of deficiency in precipitation (relative to what is considered normal). Drought has three critical but inter-related components:

- Meteorological drought was defined in the report for both Antigua and Barbuda. For Antigua, it occurs when rainfall falls below 30.74 inches per year, which is 80% of the annual average of 40.98 inches. For Barbuda, meteorological drought occurs when annual rainfall drops below 27.79 inches, which is 80 % of the annual

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rainfall of 34.74 inches.
- Agricultural drought, where extended dryness reduces moisture in the soil to the point that plants and crops are adversely affected.
- Hydrological drought, where the reduction of water levels in wells, surface reservoirs and dams severely affect livestock or where water must be rationed to households, hotels and other sectors.

Land use practices, such as clearing of vegetation, overgrazing by livestock and farming without trying to conserve soil and moisture make the country more vulnerable to all forms of drought. Vulnerability to drought can be reduced if such practices are changed.

PAST DROUGHTS AND THEIR EFFECTS

Between 1960 and 2000, there were eight years in which rainfall for Antigua fell below 30.74 inches. During the period 1965 to 2000, annual rainfall fell below 27.79 inches in Barbuda on 10 occasions.

The perception of what constitutes a drought year varies between persons and sectors of the economy. What can be considered the most severe drought in recent times occurred in 1983-84. The year 1983 was the worst year, when annual rainfall recorded at the Coolidge Met Office was 22.31 inches.

During the drought, damage to crops and death of livestock resulted in major income losses to farmers. Households were without piped water for months and hotels had to truck water onto properties. The country imported water to help meet local demands.

Antigua was particularly vulnerable because the Potworks Dam, at that time, provided over 50% of water used for domestic, commercial and industrial purposes. Largely as the result of the devastating effects of the 1983-84 drought, government turned to water desalination, which accounts for 62% of the island's water consumption. In addition, a number of hotels installed reverse osmosis (RO) plants to help meet their own water needs.

Antigua is now less vulnerable to meteorological or hydrological drought because of water desalination. Barbuda remains vulnerable because it remains dependent on ground water as the primary source of water supply.

Two of the factors to be considered with respect to future vulnerability to drought are the management of existing resources and growth in water demand. Present water supply averages 4.5 million cubic meters per year. However, according to the Ministry of Planning 42% of total water supply was unaccounted for, 31% was used by domestic consumers, 17.7% by commercial and hotel users and 4.4% by agricultural users. The unusually high percentage of water not accounted for is said to result from un-metered consumption and leaks but the relative amounts have not been described.

Assumptions made by the Ministry of Planning are that the population will grow to 72,300 by 2000 and 81,000 by 2010, and that per capita domestic water consumption would remain at 0.63 cu meter/day through to 2010. It estimates that total water demand will increase to 5.8 million cu meters/yr by 2010. Before production is increased to meet the growth in anticipated demand, attempts should be made to reduce the amount of water that is lost from the system.

Water projections should however be carefully monitored because there is a degree of uncertainty associated with water demands – one reason being the difficulty in predicting growth in the tourism sector.

Water demand management therefore is major issue for drought mitigation for two reasons:

- Insufficient information on unaccounted for water;
- High production costs and hence high consumption costs, which are believed to mask true demand from the agricultural sector.

FUTURE VULNERABILITY

Crops

At the time of the 1983-84 drought, Antigua relied on surface water reservoirs to provide most of its potable water. Water supply was readily affected by meteorological drought and the country was highly vulnerable during periods of low rainfall.

Because of desalination households and hotels have become significantly less vulnerable to deficiencies in rainfall. However, vulnerability remains high for crop farming because many farmers perceive the cost of water as one of the factors working against profitability.

A heavy reliance is still placed on rainfall to provide the moisture needed by crops, even when mains water is available for irrigation.

Variable climate and precipitation remain over-riding critical natural factors contributing to the vulnerability of crop farming to drought. Practices (human factors) contributing to vulnerability include:

- ***Poor crop location in relation to soil and other factors that restrict plant growth and crop yield.*** Failure to match crops to land capability remains a problem. OAS produced land capability maps for Antigua and Barbuda in 1992. These should be used as the basis for building the awareness of farmers for better crop selection, along with improved soil and water conservation practices.
- ***Cost of irrigation.*** The cost of water is likely to remain a major constraint to irrigated farming. Farms without irrigation will continue to be affected by dry spells. For farms with irrigation, high water costs is likely to have to have a negative impact on profits during droughts.
- ***Water conservation practices.*** Mulching is being used at Claremont Farms to conserve moisture in the growing of pineapples. A micro-irrigation (drip) system is used to conserve water. This is one of a growing number of examples where water conservation is being practiced. Unfortunately, most farmers are not inclined to use such conservation methods. The cost of mulch (organic or plastic) and the cost of water saving irrigation systems may act as deterrents to better conservation practices.
- ***Soil conservation practices.*** Mulching not only conserves moisture but also protects soil from the forces of erosion. Soil particles do not bond adequately in the absence of soil moisture. As a result, erosion accelerates during periods of drought. Sloping terrain and areas exposed to wind are mostly affected. Nutrient loss accompanies erosion, so that crop yield is affected. Vulnerability can be reduced if constraints to wider use of mulch by farmers are removed.
- ***Absence of drought insurance.*** Farmers will continue to shoulder financial losses resulting from drought, because it is unlikely that local insurance companies will provide drought insurance for crops in the near future. Consideration should however be given to the design of a drought relief program by government, which could seek to access donor funding to assist farmers.

Livestock

Overgrazing. Overgrazing is perhaps the primary contributing factor to Antigua and Barbuda's vulnerability to drought. Reducing vulnerability in this respect requires drastic reduction in the goat populations and rigid control over where livestock are allowed to graze.

To achieve these aims without causing unbearable economic dislocation and hardship to livestock farmers will require strategic planning, broad-based consultations with stakeholder groups and public awareness to build public support for actions to be taken.

Such actions should derive from a national program and campaign to reduce the impacts of goats on the landscape, environment and crops. The program should have two primary components:

- Population control, seeking to achieve population grazing density limits that can be sustained;
- Restoration of forest or landscape areas that are displaying desert-like characteristics due to overgrazing.

Adequate resources would need to be applied for research, institutional building, public awareness and policy formulation in the implementation of the program.

Policy Issues

Reducing vulnerability to drought for both crop and livestock farming will require a number of critical policy initiatives, including:

- Incentives to achieve better soil and water conservation practices;
- Reduction in water rates for irrigation, through subsidy or other means;
- Development of adequate institutional infrastructure and coordinating mechanisms for drought planning and management, drought preparedness and drought warning. (This is relevant to other sectors, also, including tourism and settlements).
- Support for drought related research, monitoring, planning and mitigation;
- Regulation of livestock access to public owned lands;
- Stiffer penalties for farmers for damage to crops and gardens caused by their livestock.

Tourism

After the 1983-84 drought a number of hotels installed reverse osmosis (RO) plants and have become less vulnerable to droughts as a result. Most hotels, guesthouses, villas and other forms of visitor accommodation properties still depend on APUA for most of their potable water supply.

Although the existence of the desalination plants makes water supply more dependable, properties without the capacity to produce most of their potable water are still affected by rationing.

The extent of their vulnerability could not be determined in this assessment because a detailed survey of on-site water infrastructure, including production plants, roof catchment and storage capacity was not possible.

Based on discussions with a number of hotel managers, water conservation practices by hotels are limited to the use of water saving toilets and showerheads which have become standard for many manufacturers of bathroom fixtures.

A lot of water is believed to be still wasted on properties due to leaks, poor irrigation practices, absence of a reliable level of wastewater treatment to allow reuse for landscaping and failure to meter water for different major property uses so as to detect waste.

An inventory or audit of tourism properties, including marinas and golf courses, should be considered to determine their preparedness to deal with future droughts. The inventory or audit should be done with the involvement of the Antigua Hotels and Tourism Association (AHTA) and should cover among other things:

- Sources of water supply;
- On-site water production capacity, where appropriate;
- Onsite water storage;
- Irrigation systems;
- Water conservation practices;
- Methods for detecting water loss from leaks and faulty equipment.

Settlements

Like hotels, water supply to settlements has improved with the use of desalinated water by APUA. Vulnerability has been reduced with respect to water supply but most settlements are still affected by water rationing during droughts. This is expected to continue in the future unless APUA decides to increase water production from desalination on its own or with the use of private contractors.

The relatively higher cost of producing desalinated water compared to ground and surface water is a major constraint to providing water that would not be affected by variable rainfall. High cost notwithstanding, a commitment to increasing desalinated water production may be required to reduce the vulnerability of settlements as water demands increase in the future.

In Antigua, water loss from evaporation and seepage at surface reservoirs is an issue without a cost-effective solution. In Nevis, where potable water is stored in tanks, such loss from evaporation and seepage does not occur.

Despite the need to ration water in droughts, water is frequently lost due to leaks from supply mains that APUA is often slow to repair. The occurrence of this in the future will increase the country's vulnerability to drought.

In Barbuda, the major ground water aquifer has been affected by sand mining activity. Land and resource use will need to be managed in the future to ensure that this key water resource is not further compromised.

Finally, although most building supply stores carry water saving toilets, showerheads and faucets, there has been no national water conservation campaign that targets households.

New homes should be provided incentives to install water-saving fixtures and old households provided similar incentives to retrofit fixtures in order to conserve water. This would lessen the impact of drought on households.

DROUGHT RISK CRITERIA

Factors critical to drought were used to develop a set of criteria for ranking areas according to their level risk, namely:

Low drought risk
Moderate drought risk
High drought risk
Very high drought risk

These factors (termed drought risk criteria) fall into three categories as summarized below.

Environmental Meteorological

- Rainfall < 35 inches
- Exposure to wind and marine influences
- Shallow soils
- Slopes >11°
- Cactus scrub vegetation

Hydrological/Infrastructural

- Limited water resources (wells, aquifers)
- Inadequate livestock dams/ ponds

Human/Landuse

- Crazing
- Crop location
- Population density of over 5000 persons per sq. mile

Once the drought criteria were determined data maps were produced in digital format, using the GIS application Arc View. The data maps for Antigua and Barbuda are as indicated:

- Mean Rainfall Isohyets (Antigua)
- Vegetation (Antigua and Barbuda)
- Slope (Antigua and Barbuda)
- Watersheds (Antigua and Barbuda)
- Soils (Antigua and Barbuda)
- Land Use (Antigua and Barbuda)

DROUGHT RISK RANKING

Digital data were analyzed and manipulated to determine the levels of risk by watersheds. The watershed is considered the appropriate geographic and hydrological unit for managing drought among other things. Antigua was divided into 13 watersheds and Barbuda 10 in accordance with boundaries used by OAS in a natural resources project assessment project for agriculture. In the drought hazard assessment areas were ranked by:

i. Analyzing the spatial occurrence of vulnerability themes in the various watershed units;
ii. Overlaying (intersecting, as opposed to merging in ArcView GIS terminology) the themes to determine areas of critical risk.

The results for both Antigua and Barbuda are as shown.

Drought Risk Ranking of Antigua Watersheds

Level of Risk	Watersheds
Low	1, 2, 3
Moderate	4-11, 12-20, 21-26,
High	47-53, 54-62, 63-66, 78-84, 85-86
Very High	27-46, 67-77

Drought Risk Ranking of Barbuda Watersheds

Level of Risk	Watersheds
Low	--
Moderate	I, V, VI, VII, VIII, X
High	II, III, IV, IX
Very High	--

AREAS AND ISSUES FOR PRIORITY ATTENTION

Areas

The east, north and southeast of Antigua contain areas of high and very high risk to drought. Environmental and land use factors combine to make that region of the country the most vulnerable to drought. Within this region, the area requiring the most urgent attention falls within watershed 27-46, one of two watersheds ranked as being at very high risk to drought.

The area is at the extreme southeast of the island (between English Harbour and St. James's Club). Environmental and human (landuse) factors combining to make this area highly vulnerable to drought include:

- Low rainfall;
- Shallow soils;

- Slopes exposed to wind and marine influences;
- Overgrazing; the area has one of the highest goat populations in the country.

Denuded slopes and narrow valleys in areas forming part of the Nelson's Dockyard National Park provide visual images of a severely degraded landscape and imminent desertification.

Similar trends are being experienced in other watersheds but perhaps not with the same degree of devastation. It is suggested that watershed 27-46 be considered for undertaking a pilot project seeking to provide strategies for reducing vulnerability and risk to drought.

The project should include:

- Forest monitoring program, particularly for cactus scrub and dry forest areas subject to threats from overgrazing. One objective would be to determine carrying capacity for livestock grazing and livestock population densities that should be allowed;
- Ecosystem studies aimed at better understanding the critical relationships between dietary requirements of goats and sheep, soil and moisture needs of preferred plant species and other ecosystem characteristics critical to understanding how plants and animals respond to drought;
- A landscape restoration component aimed at reversing trends towards desertification;
- The development of methodologies and approaches to involve livestock farmers in mitigating livestock impacts;
- The development of policy initiatives to reduce vulnerability and risk to drought.

Successful results of the pilot project would be replicated in other parts of the country.

In Barbuda, the flat lands around and south of Codrington are considered the areas of greatest risk to drought.

Major issues

While the pilot project for Antigua is being used to test approaches for mitigating the impacts of drought, actions should be considered and implemented to address other issues, including:

- ***Overgrazing***. This is perhaps the most critical factor contributing to the country's vulnerability to drought. Trends in vegetation, habitat and landscape degradation, key factors contributing to the country's vulnerability to drought, will not be reversed until overgrazing is controlled.
- ***Meteorological data***. A nationwide network of meteorological stations is needed collect data and monitor rainfall, evapo-transpiration, relative humidity, etc., to improve the country's database for informed analysis and decision making;
- ***Vegetation classification and mapping***. Existing vegetation data is inadequate for drought management. A vegetation classification and mapping project should be undertaken to improve the capacity required for managing various vegetation zones against drought impacts. Classification should include a description of soil and moisture requirements of key plant species within each vegetation class;
- ***Agricultural water storage infrastructure.*** The mapped data indicate an imbalance in the distribution of agricultural storage reservoirs and ponds. Vulnerability to droughts could be reduced for livestock and some crops by investment in additional reservoir and pond capacity in selected watersheds. The Ministry of Planning (1999) and the OAS (1992) made proposals to this effect.
- ***Potable water.*** Water rationing by APUA in February and March, 2001, indicates that desalinated water has reduced but not eliminated vulnerability in respect of potable water supply. Since rainfall does not affect water production by desalination, rationing is necessary because of limitations or constrains in the supply of ground and surface water, which account for 33% of total production. Additional water production capacity and/or storage are required if vulnerability is to be reduced in the future. This will be more so if significant growth occurs in the hotel and commercial sectors.

MAP USE AND LIMITATIONS

Use and limitations of the data maps and drought risk maps are described in the technical report. Difficulties in gathering data for mapping were key constraints in the assessment. Updating of the data maps should therefore be

considered as new information becomes available.

INDICATORS FOR FUTURE IDENTIFICATION OF DROUGHTS

This section summarizes and describes indicators that suggest approaching or actual drought conditions. These indicators are discussed under the following categories:

- Meteorological/Environmental;
- Hydrological
- Agricultural
- Socio-economic

a) Environmental Indicators

Reduction in biomass production of common grass species. Early warning is wilting, as grass roots become progressively damaged by lack of soil water; Grass cover becomes patchier as fallen leaf debris is blown away by wind in exposed areas. Home owners have no need to use lawn mowers;

Leaf fall and litter in Forests. The Forestry Division uses the increase in leaf fall and litter (detritus) on the forest floor as one indicator of drought. No measurement of volume of weight is done. Since leaf fall varies between species, measurement would need to be correlated with plant associations.

In Cactus Scrub forests, xerophytes (plants growing in dry areas) with small hard leaves can reduce water loss in extended dry periods by various methods including dropping their leaves.

Damage to "indicator" plant species. The Ficus, planted as hedge or trees; normally stays green; its small and shiny leaves limit moisture loss and its wide spreading root system allows it to seek moisture and nutrients beyond its drip line. When the Ficus looses a lot of its leaves it is an indication that the country is in a period of prolonged drought.

Some types of xerophytes, (succulents, such as cacti and agaves) utilize stored water in dry periods without noticeable damage. In fact, such plants can survive for weeks when uprooted, so that signs of damage (dried leaves or broken stems) may be an indication of negative water balance resulted from extended drought.

b) Hydrological

Reduction in Ground Water Levels. The APUA Water Division uses ground water levels at various well fields as an indicator of hydrological drought.

There is a time lapse between meteorological and agricultural drought conditions and hydrological drought as indicated by ground water levels. The latter occurs later but the time lapse cannot be accurately predicted in the absence of rainfall data that could be correlated with rates of pumping and recharge, for the watersheds in which the well fields occur.

Recovery from meteorological and agriculture droughts occurs in advance of the replenishment of ground water to average levels. Again, the data does not exist to accurately predict the gap in time between these events.

Reduction of Water Levels at Municipal Reservoirs. Receding water levels at municipal reservoirs is another drought indicator used by APUA. However, it was not determined if specific indicator levels for the various municipal reservoirs were established. Indicator levels at selected reservoirs could be determined over a period of time by widening the scope of monitoring to consistently measure meteorological and hydrological data, including, rainfall, temperature, wind speed, evaporation and seepage.

Water Rationing. APUA begins to ration water before ground water levels recede to critical points. In fact, the decision to begin rationing water appears to be influenced by perceived meteorological and agricultural drought conditions.

Reduction of Water Levels at Agricultural Reservoirs. This is another indicator observed but not measured by

authorities.

Agricultural

Livestock

Goats adapt well to drought by using physiological measures to conserve water. Despite this, they and other livestock will show signs of stress during extended drought, including:

- Weight loss
- Higher incidence of disease
- Unusual high incidence of miscarriage among pregnant females

Crops

Indicators may include:

- Negative water balance, as evidenced from wilting and ultimately death of plants in extended droughts;
- Unusually high incidence of disease as plants are unable to obtain needed moisture and nutrients from the soil;

c) Socio-economic

Socio-economic indicators include changes in water use practices by households and businesses:

- Storage of water in existing or temporary storage facilities as a result of water rationing;
- Reduction of water used for landscaping of household and hotel gardens;
- Regular trucking of water to meet water deficit due to rationing;
- Higher incidence of respiratory ailments due to excessive dust in a very dry landscape. Respiratory ailments related to drought are not recorded for Antigua and Barbuda but are generally considered a drought related health impact.

Organization of American States

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Antigua and Barbuda Inland Erosion Hazard Assessment, Mapping and Mitigation Summary Report

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

April 2001

This report was prepared under contract with the OAS by David Lang (Dominica).

Erosion hazards– what are they?

1. Kinds of erosion

'Erosion' is natural forces at work. The word erosion is an inclusive term for:

- wearing away and removal of soil or rock material by the effect of:
  - rainfall: water washing across the land or a rivulet or stream wearing away its bed or its banks, and depositing its load somewhere else, on land, in the stream bed or at sea, the processes that are thought of as 'normal' erosion
  - wind: wind-driven loose particles scouring the land surface and blowing away to be deposited against the nearest obstacle– perhaps a clump of bushes or a house – common only where the surface is bare and very dry and the wind is strong
  - percolating water dissolving rock: solution – especially in limestones and young volcanic ash, but difficult to analyse. This type of erosion is omitted in this report.

- rock falls and landslides slips etc, which are together called 'mass movements', and which are like any movement of unsecured objects under gravity.

Erosion by running water is usually divided into several phases, some of which have names which are reasonably well known:

sheetwash describes erosion where water flows across land more or less in a sheet, and picks up particles of soil and carries them away. Its effects are often not very obvious to casual observation and it grades into

rilling is where flowing water makes very shallow sometimes broad channels across land and also picks up and wears away soil. Both sheetwash and rilling leave patches of deposited material wherever the gradient slackens and the slower flow will not carry all the load. When there is heavy rain and a large load is carried, deeper deposits form, often where the flow crosses a flat track or road and so becomes

much more obvious.

gullying is where quite deep and relatively narrow channels are formed, by water running off the land. These may become very deep and large like the St. Kitts ghauts, and cut below the soil into underlying soft rocks. Gullies sometimes develop from the joining of rills but more often start because the existing natural drainage system has become overloaded as a result of a change of land use or a massive burn etc. Gullies usually start short, but may lengthen quickly with the head of the gully moving back up slope. At the lower end gullies may produce a deep fan of outwash material.

stream cutting: established streams have courses which change all the time. For long periods there may appear to be very little change but whenever the river flows really full—full to the top of its banks or overflowing—it will scour its bed and cut away at bends.

All of these are normal natural processes, but human activity often multiplies them greatly, both in frequency and size. Sheetwash and rilling are not common under natural vegetation in these islands, except where fire or hurricane has bared the land, but they have become very common on certain soils when farmed. Gullying is uncommon under natural vegetation but where vegetation has been disturbed by hurricane or burned off, which can happen naturally in volcanic territory and may explain the ghauts, gullying will occur.

Mass movement—landslide and rock fall—is relatively common under natural vegetation in the steeper landscapes of the Lesser Antilles. There are several different types of landslide, partly dependent on the kind of materials involved, but we can generalise by saying that most landslides (not rock falls) occur when, or just after, a mass of porous material is saturated or super-saturated with water. Prolonged heavy rain brings landslides. Rock falls may be triggered by rain in the odd case, but seismic events and gradual loosening under weathering are more common causes. However human activity once again multiplies the frequency and size of these events.

Wind erosion, where the wind picks up and carries light small soil particles (especially organic matter) and bounces or rolls larger particles along the land surface, cannot occur under a vegetation cover and is only found naturally in the formation of dunes in dry sandy beach or desert areas, or where some other factor has left a bare surface.

2. Impact of human activity on erosion hazard

Human activity is usually effective in the following main ways:

- reducing the rate at which water enters the soil, and thereby promoting rapid runoff, by cultivation, and more especially by covering land with impervious material– houses, roads etc., or compacting soil. More and more rapid runoff leads to greater erosive power of water, and greatly increased erosion, up to more than a thousand times increase
- making drainage systems which concentrate runoff water but do insufficiently control outflow, which then causes erosion, often in the form of gullies
- making excavations which leave unstable slopes which may slide or fall, providing loose material to be washed away

3. The nature of the hazards to human communities

The hazards caused by erosion include those caused by the deposition of eroded material, which can have a greater impact on land use and human activity or at least a more obvious impact than the loss of soil.

Rill and sheetwash erosion is mainly of consequence for farmers. Surface erosion mainly affects the part of the soil most valuable for farming, the organic topsoil. Losses of one or two centimetres—the maximum likely loss over a few years under normal conditions here—will probably not bother anyone else, but make a critical difference for farmers.

Deposition of fine materials (mud) at the foot of a slope on a farm may destroy crops and make tillage more problematic. By contrast a float of mud on a road may mean a few hours of inconvenience and some work for a machine—hardly a major problem.

Gully erosion could be more serious for other land users than for farmers, through the need for costly controls to avoid further expansion and the disruption of works already underway. Roads for example may be cut. Farmers may be able to contain gullies by using simple bush dam structures, filling and covering with vines etc., but for construction sites some kind of well-planned diversion may be required.

Mud and sand deposits at the outfalls of gullies, probably at the foot of a slope where the angle suddenly becomes more gentle, may be deeper than those from rills and gullies and more difficult to deal with.

Stream bank erosion need not be a great problem—it is simply natural adjustment to the course of the river—unless structures are built within the banks of the river or very close to them. It is a problem for some bridge footings, which must be built near the banks of rivers and streams. The effects of deposits from stream bank erosion should be insignificant, since they will either occur within the stream course, on natural levees or as shallow deposits on terraces, for which farmers at least are prepared. If a meandering river cuts a new course, on its flood plain, the area at hazard is somewhat more extensive. However it should be clear that such areas are subject to flood damage even apart from new stream courses. For any infrastructure construction in these areas, there needs special justification and planning.

Wind erosion is usually very damaging to young farm crops, because of the cutting action of particles whipped along by the wind. Tall, well-developed crops provide their own defence, to a great extent. Deposition is governed by wind direction and may take place anywhere. Probably in our conditions only a little material 'flies' in suspension and most 'bouncing' and rolling particles will be halted by the nearest bush or building. On the whole, the consequences are not likely to be very large.

Landslides and rock falls can be dangerous. Landslides have engulfed villages and killed people on many occasions in the Lesser Antilles, and there have also been many narrow escapes. Most landslides and rock falls contain relatively small quantities of material which moves only a short distance, but they can still present a threat to life. In steeper lands where there is potential for long distance travel, a long fall may provide the momentum to ride up an opposing slope. Flow slides, which are primarily found in allophane soils and little-weathered pumiceous ash, can travel long distances down quite gentle slopes. In areas where the more dangerous sorts of landslide / rockfall are possible (part of the areas of highest hazard class), it will be worthwhile to check whether buildings are in a potential landslide or rock fall path and monitor them. The hazard should promote caution but not be allowed to cause an excessive reaction. Many buildings in Dominica, a much more landslide-prone island than either Antigua or Barbuda, which appear to be prime candidates for landslide damage have existed with the potential threat for many years.

Mitigating erosion hazards

General

The best mitigation takes the form of avoiding, as far as possible, the practices which are conducive to erosion, and using defences only where that is not practical.

The maintenance of a good vegetation cover, preferably forest, is the best insurance against rainfall-based erosion and landslides. Dense grass cover, if tall, is nearly as good, unless it is tussocky like lemon grass, but it offers little protection from landslides. The most vulnerable conditions of the land are where extensive hillsides are completely cleared, something that occasionally happens when a major land use change takes place, but which can be very largely mitigated if standard conservation measures are used.

Attention needs to be paid to land use management. Farmers may or may not need to be instructed in conservation, but more investment in ensuring that good conservation practices are employed is necessary, to minimise both loss of fertility and the problems created by sedimentation.

Attention also needs to be given to Town and Country Planning. Concern expressed over reworking of stream banks, and natural excavation of stream courses by the stream in spate, indicate that planning has been neglected. Building roads across an occasional stream without providing adequate culverts and permitting house construction within a gully or on the edge of vertical stream banks in weak materials is not good practice. Mitigation of earthquake-induced rock falls and landslides also requires more careful recognition of potential recipient sites during Town and Country

planning.

Specific

Mitigation of water erosion: sheet erosion, rilling, gullying

1. *Plan adequate drainage systems*
2. *Take action in response to land use change*

The main problem with dealing with water erosion is that land use is changed without appropriate conservation measures being taken. For example, converting a piece of land under bush to dwelling house lots results in a marked reduction in infiltration (the way water enters the soil) and a marked increase in runoff. The surface drainage of the area needs to be considered and linked to existing drainage in such a way that the drains will accommodate the flows produced by storms under the changed land use. This is a matter where planners need to enforce some rules. The second problem relates to the design of drainage systems in general. There are obvious examples in Antigua of drainage systems, which do not lead anywhere. They may be effective in arresting flows and allowing delayed entry of water into subsoil during low intensity storms, but they need outlets when larger intensity storms occur, or they will make their own, new gullies, with probable damage to infrastructure. Drainage systems need to be planned to deal with a whole sub-catchment. Those that do not, and do not integrate all factors, can cause more trouble than no system at all. Although no particular problems were evident during field visits to Antigua and Barbuda, the alignment and construction of roads and particularly the provision for road drainage can provide long term instability problems and have been the initiator of major landslides and gullying throughout the Windwards. Again, this is a matter of planning, in which the planners need to ensure that developers including Public Works and farmers have given the matter adequate consideration.

There is no lack of knowledge within government departments of the means—planning, specific conservation measures—by which rainfall-induced erosion can be mitigated. But, for want of urgency, it is being neglected.

Mitigation of problems produced by wind erosion

1. *Retain windbreaks, avoid large areas of exposed soil, use vegetation strips*

Wind erosion is only serious where literally bare soil is exposed to strong wind. The serious examples in Europe and North America ("dust-bowls") have occurred where large expanses of soil have been completely bare. In Europe, areas that had grown grains in fairly small fields without real problems were badly damaged by wind after the removal of hedges. Here any form of strip cultivation (provided it is not continuous over long distances, so as to provide a funnel), should be effective. This is a problem for agriculturists to tackle, but one which will affect others, so planners should be involved.

Mitigation of mass movement induced problems

1. *Monitor and avoid areas at hazard*
2. *Provide cut-off drains*
3. *Use stabilising techniques (a costly last resort)*

Mass movement under gravity is not something which can be easily stopped. Some land use practices increase the hazard of mass movement– removal of trees and loading weak slopes (with buildings or roads) for example– and should be proscribed as a matter of common sense, since we all have to pay for the resulting damage. Building on sites in the recipient area of such movements should be discouraged and would normally be a matter for rejection where Environmental Impact Assessments (EIA) are required. Again, planners should be able to minimise these problems.

Rock falls, simply a movement of loosened lumps of material under gravity, can only be mitigated by:

- minimising damage:
    - quarantining the predicted receiving site
    - identification and regular monitoring of potential falls, and provision of a catch site or barricade if that

appears likely to be cost effective
  - terracing—this is costly and not particularly effective / appropriate where a vertical cut has higher land behind
- minimising the likelihood of a fall:
  - identification and artificial protection – such as sealing cracks where infiltrating water may remove some material or assist slipping

Landslides (and some rock falls) may be mitigated by:

- minimising the likelihood of a slide:
  - reducing lubrication to the slide by cutting ditches above the likely slide site to carry water away from the slide plane
  - avoiding loss of tree cover from such a site
- minimising damage:
  - monitoring likely areas and minimising use

Mitigation of problems caused by stream bank erosion / stream reworking / new courses

1. *Keep drainage ways clean of impediments– do not fill with solid waste etc*
2. *Avoid using potentially endangered land for permanent structures*
3. *Use structures to deflect damage to sites or reduce reworking effects (a costly last resort)*

Stream courses can be canalised, as they often are where they pass through towns, but to prevent the adjustments which are natural processes of stream development will often be unreasonably expensive elsewhere and sometimes very difficult. It might be less difficult in Antigua but would still be costly and rarely giving a beneficial return commensurate with cost. The task is for planners to provide the right information.

These problems can really only be mitigated for the long term by:

- avoiding the likely sites of reworking which are easily predictable from channel shape
- canalisation of a long stretch of the stream— this is not likely to be cost effective in St Kitts, but might be in some cases in Antigua
- finding a means of reducing maximum flows (e.g. dams)

Temporary protection can be effected by:

- providing walls supporting the attacked site
- baffles, deflecting the stream flow

But it is unlikely that these will be cost effective except in a few instances.

Mapping the hazards

Because of the tendency of most agriculture to accelerate natural erosion processes, erosion has been the subject of observation in relation to agriculture. Observations have been of two kinds:

- surveys, for example, of the effects of rain or wind storms on soils
- studies of sample plots

These observations have led to the development of mathematical models used to estimate erosion losses or potential erosion. The main concepts are that each identified soil type has an intrinsic susceptibility to erosion (erodibility), that each rainstorm has a specific capacity to erode (erosivity) which can be assessed, and that land cover / vegetation has a major modifying effect on erosion potential.

As a land forming process, however, erosion is also very important in geomorphology, for its role in the development of

slopes and stream courses and thus of natural landscapes.

The models used in this study have been developed using the general understanding that has developed of the processes involved and the role of various land characteristics in these processes. They are simple models using the following land characteristics as variables to estimate the effects of the apparent processes:

- Topography: slope, aspect, etc.
- Physical geology: tectonics / lithology
- Geomorphology
- Soils: physical and chemical
- Rainfall
- Wind
- Present and antecedent Land Use / Vegetation
- Current status of erosion / landslide
- Hydrology

Models similar to these are widely used in the absence of local experiment and the kind of local data which engineers might provide.

The data used in these models is often a simpler version of what appears to be the appropriate data, which are used because they are available and the "better" data are not. Some better data can and should be obtained.

Hazard maps

1. Single feature maps

1. Simple models were used to produce hazard scores for each land unit. The score is an estimate of the relative likelihood of the hazard at the land unit, but it has no physical meaning, like 'days per year' or 'tons per acre', etc.
2. To make the scores more useable, they have been classified. For each hazard, the scores have been divided into 5 classes having equal land area (representing very low, low, medium, high and very high groupings)
3. Combining the effect of different types of hazard would be likc adding apples and pears, with no common element like calorific value to use. Adding classes rather than scores reduces this problem. Composite maps were produced by adding classes and then reclassifying.

2. Composite maps, choosing the most appropriate classes for defining land-based erosion hazard for development sites

Erosion hazards are most commonly defined in relation to open land either under agricultural use or intended for an agricultural use. The application to development sites where some kind of construction is intended is related to localised incidents rather than a general picture. This emphasises the need for data at a more appropriate scale, which are not available at present.

1. Overall, *rill and sheet erosion* should be given little importance in assessing possible impacts on building development sites, while gullying is important.
2. The natural evolution of *streams* means that bank erosion is inevitable without canalisation of the stream course. Overall the stream bank erosion / stream adjustment effect could be important for development sites.
3. *Wind erosion*, although it can cause problems in certain circumstances, is unlikely to affect a building site seriously at the levels at which it is probable in the present circumstances except in Barbuda, where it might cause problems and other types of erosion are of less importance.
4. *Mass movement*, on the other hand, both the site from which the movement takes place and the destination of material, can produce major difficulties for building development.

The final map for Antigua combines gullying and mass movement (landslides and rock falls). This is done by adding together the land unit by land unit values for gullying and mass movement. For Barbuda alone, with a generally lower level of hazard, wind erosion is included. It should be noted that in the recent past in Barbuda, more damage was caused

to soil, vegetation and some buildings by incursion of the sea, than by events originating on land.

3. Individual hazard maps and composite maps presented

The final maps (one each for Antigua and Barbuda) are composites, derived from the whole set of individual "erosion" process maps for each island. The full set, shown below and available as larger maps, comprises:

Antigua

Composite A: Combined hazard of gullying and landslides. (The hazards of sheet and rill erosion and of wind erosion in Antigua are not considered of great importance in relation to building development sites)

1. Rill erosion, bare soil, hazard classes
2. Landslide overall hazard classes
3. Wind erosion hazard classes
4. Gully hazard (an overlay on 1, Rill etc)

Barbuda

Composite: Combined hazards of wind erosion and rock falls / debris slides. (The hazards of sheet and rill erosion and of gully erosion in Barbuda are minimal but wind erosion is relatively important and may provide a building development hazard)

1. Rill erosion, bare soil, hazard classes:
2. Wind erosion hazard:
3. Barbuda rock fall hazard is not mapped separately, Gully erosion hazard is near zero

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