ASSESSMENT OF RAINFALL CHARACTERISTICS AND LANDSLIDE HAZARDS IN JAMAICA

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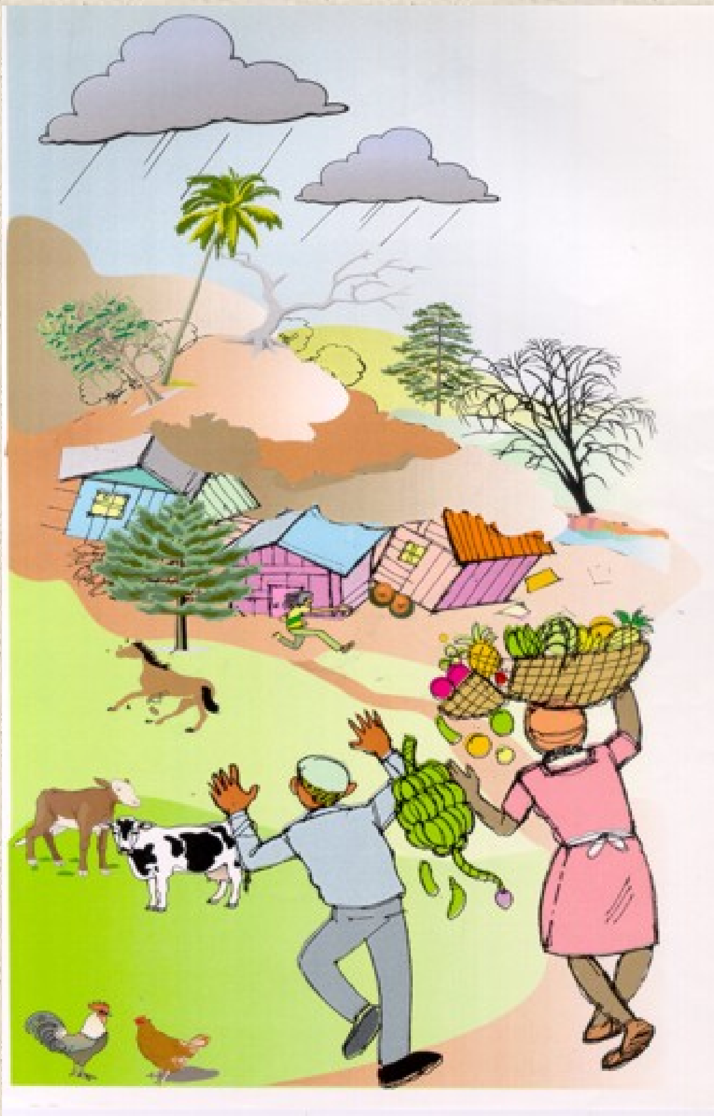
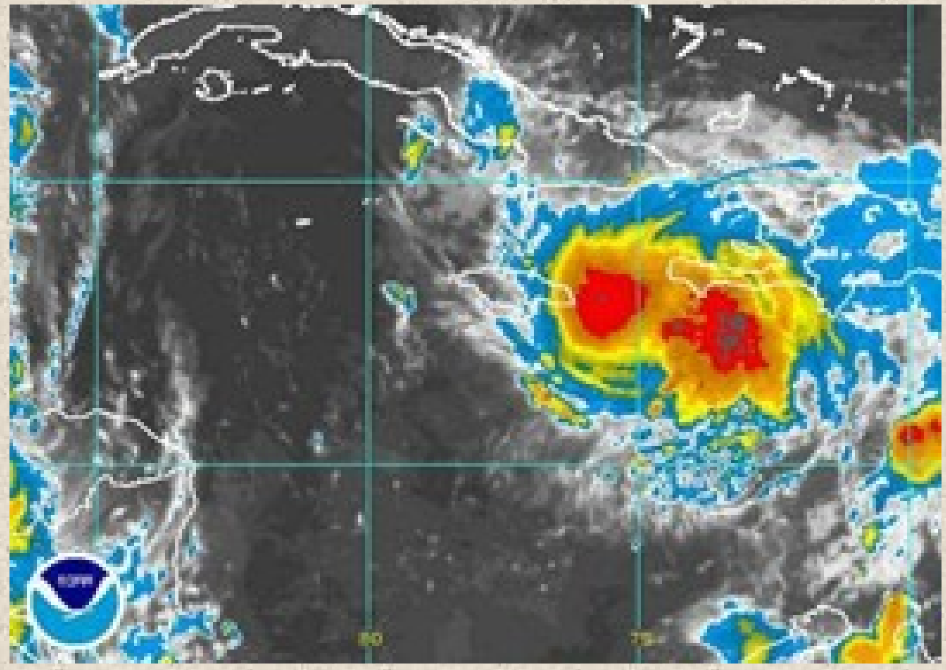
INTRODUCTION

Landslides are a common occurrence and recurring problem for much of the mountainous island of Jamaica.





The NOAA satellite image of Tropical Storm Lilli taken at 11:15 p.m. EDT on Friday, 27September 2002. From: GoPBI.com

- The intense rains on Jamaica associated with tropical depressions and storms in October-November 2001, May 2002, and September 2002 (Isidore and Lili) produced landslides in eastern Jamaica that adversely affected country’s productive capacity and the national budget.

IMPACT OF RAINFALL-INDUCED LANDSLIDES INCLUDED:

Breached eastern end of the Yallahs Fording. Photo date 1st October 2002.

SEE POSTER :
"LANDSLIDES RELATED TO PRECIPITATION IN EASTERN JAMAICA" BY AHMAD, MILLER, AND ROWE COMPLEMENTS THIS PAPER AND DOCUMENTS SOME OF THESE SHALLOW LANDSLIDES.

Unit for Disaster Studies, UWI, Mona

- **Disruption of transportation routes;**
- **Stranded communities, loss of income, closed schools, substantial property damage & community facilities, trauma of evacuation, and disruption of social fabric of communities;**
- **Destruction of domestic water supply;**
- **Loss of productive agricultural areas, especially coffee farms and farm-to-market access roads;**
- **Landslides added sediment to many river drainages raising channel levels thus increasing flood hazard;**
- **Many areas remain exposed to landslides from future periods of sustained heavy rainfall.**

PERCEPTION OF LANDSLIDES:

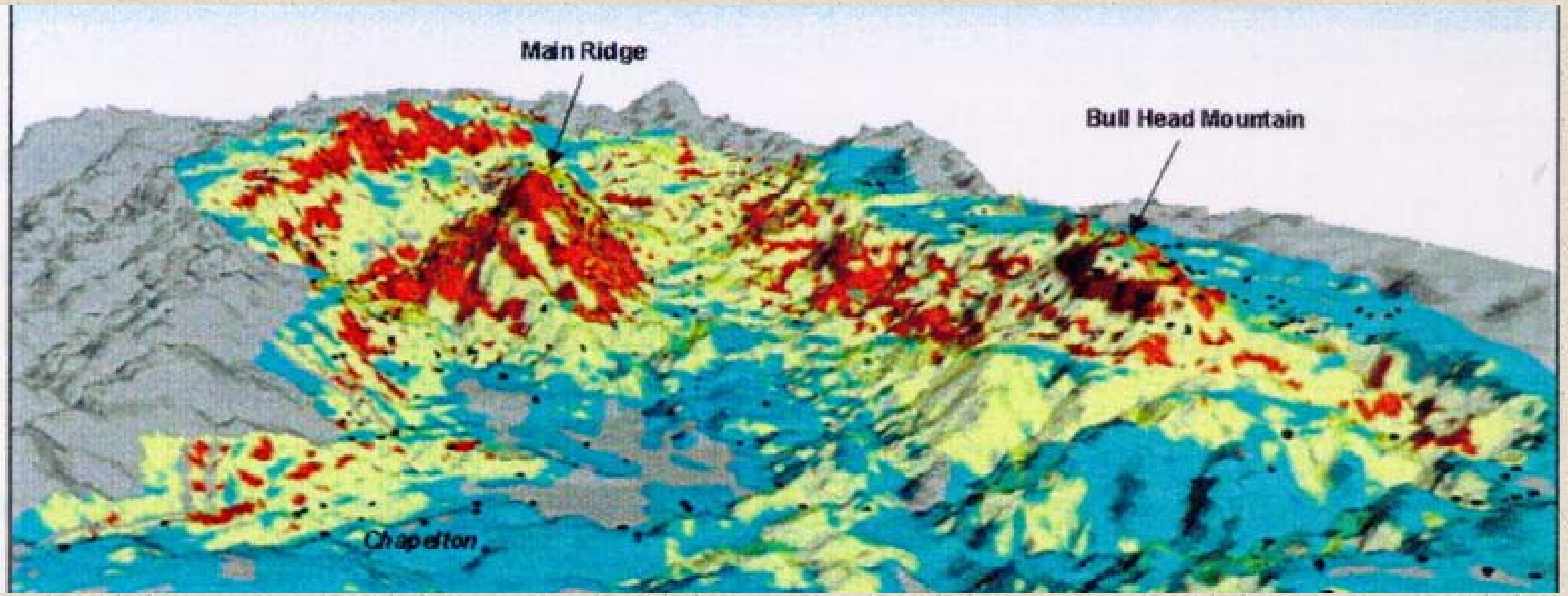
- **October-November 2001 rainfall most severely affected the parishes of Portland and St. Mary.**
- **According to Planning Institute of Jamaica the value of the damage to physical and social infrastructure and crops was estimated at <u>US$2.5 billion</u> (From ECLAC Survey, January 2002).**
- **While commenting on October-November 2002 event, Planning Institute of Jamaica further noted:**
- **"Jamaica's vulnerability to multiple hazards continued to be one of the main threats to the sustainable development of the country",**
- **"MUCH OF THE DAMAGE IN THE TWO PARISHES WAS LINKED TO <u>INAPPROPRIATE LANDUSE FOR RESIDENTIAL AND AGRICULTURAL ACTIVITIES"</u>**

Rresidents living on the flood plain of the Bull Bay river being rescued following inundation of their community in September 20002.

FROM THE GLEANER WEBSITE:
Damage caused by Tropical Storm Lili in Kingston, St. Andrew and St. Thomas / BullbayfloodC20020929IA.
Photographers:Ian Allen and Junior Dowie
9/30/2002

SCIENTIFIC PERSPECTIVE

Although not fully appreciated, it is now increasingly being recognized worldwide that landslides are the principal cause of land degradation and land productivity in the tropics including Jamaica.

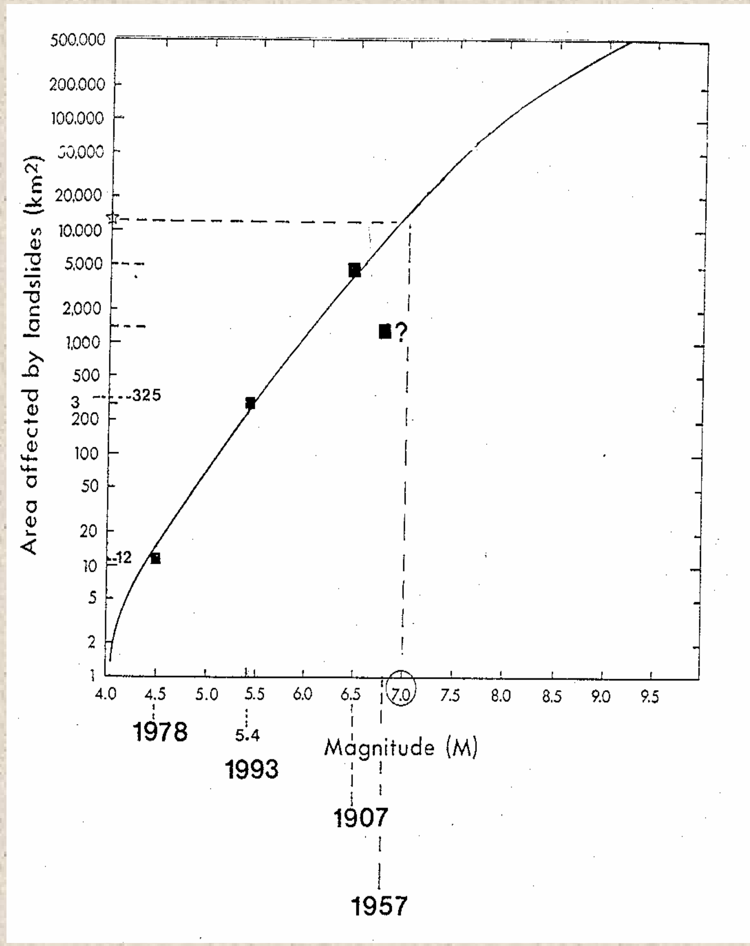


Landslide susceptibility in Clarendon and St. Catherine draped on a DEM
(Unit for Disaster Studies, UWI & British Geological Survey Project completed in 2002).

Red areas indicate high landslide susceptibility and also are sites of accelerated soil erosion.

Efforts to correct land degradation and loss of land productivity should take into consideration rainfall-induced landslides. As far as we know this is not a favoured practice. We think that initiatives such as "Ridge to Reef Project" would tremendously benefit if they were to incorporate landslide data.

- Landslides are a gravity-induced natural erosional process through which hillslopes evolve and are triggered by both earthquakes and rainfall. They are distinct from simple gully erosion and sheet wash.
- The earthquakes of June 1692 and January 1907 and flood rains of June 1979 created hundreds of landslides which caused severe deforestation and erosion on the island.



Threshold for earthquake-induced landslides in Jamaica.

- **Extensive landslide damage in Jamaica is mostly due to transported landslide debris and are prominent along debris chutes and deposition areas, often far removed from the landslide source.**
- **Much of the relatively flat land in Jamaica that adjoins mountain fronts is built by landslide debris brought over the years by debris chutes (or innocent looking dry gullies). These are the hazardous areas, or debris fans, where most of our human settlements are located.**
- **Modifications of hillslopes for urbanization and road construction have also resulted in numerous landslides.**
- **Rainfall-triggered landslides on both modified and unmodified slopes are most common and occur frequently throughout the mountainous terrain of the island.**

Landslides described in this presentation include shallow landslides that are commonly molded into landslides of flow type and include varieties known as soil slips, mud/earth flows, debris flows, debris slides, debris avalanches, and slumps (classifications after Varnes, 1978; Hungr *et al*., 2001).

Photo: J. Tyndale-Biscoe

Spectacular development of rainfall-induced shallow landslides (debris flows) on the southern slopes of the Blue Mountain Ridge, Mt. Macungo area, St. Thomas, triggered by rainfall from the hurricane Gilbert on the 12th of September, 1988.

The distribution and characteristics of 2001-2002 rainfall-triggered landslides determined by UWI Mona's Unit for Disaster Studies Landslide Project can be used as a guide to future landslide activity triggered by rainstorms in Jamaica.

<u>OUR DATA SUGGESTS THAT HAZARDOUS AREAS INCLUDE:</u>

- **Hillslopes underlain by colluvium and fractured & weathered bedrock,**
- **Moderate to steep hillslopes, and areas directly at the base of these slopes,**
- **Drainage channels acting as debris chutes downslope from landslide prone hillslopes,**
- **Alluvial fans at the mouth of main drainage channels, and**
- **Alluvial fans at the mouth of debris chute drainages along hillslope fronts.**
- **Attempts should be made to prevent housing and infrastructure development in the above areas using landslide inventory maps.**

For hazardous areas that are already inhabited, methods of predicting and delivering landslide warnings can be developed.

One of the easiest, and most accurate ways to predict the timing of rainfall-triggered landslides, is by using a rainfall threshold.

THIS IS THE SUBJECT OF THIS PRESENTATION.

When such a threshold has been exceeded, or is expected to be exceeded by an approaching storm, a landslide warning can be issued for hazardous areas.

Two thresholds should be developed:

1. **For debris flows that commonly develop from shallow landslides during intense bursts of rainfall.**

2. **For deep-seated landslides that are usually triggered by prolonged rainfall.**

PRIMARY DATA FOR DEVELOPING RAINFALL THRESHOLDS:

a) Landslide times of occurrence based on fieldwork, sequential remote sensing imagery (Jamaica needs to make an investment in this – imagery for earth science research), and local sources,

b) Rainfall data from nearby continuously recording rain gauges, preferably through a network of telemetric network.

Since the most hazardous landslides are of flow type, gauges should have at least hourly resolution.

Data collecting capabilities of the National Meteorological Service need to be substantially strengthened if we were to mitigate natural hazards.

c) Rainfall amounts for storms that did not trigger landslides are equally important.

A systematic programme for developing a network of rain gauges, especially in collaboration with frequently affected communities, is considered very important.

<u>However, funding for this type of proactive response which prevents hazards from becoming disasters is rarely available.</u>

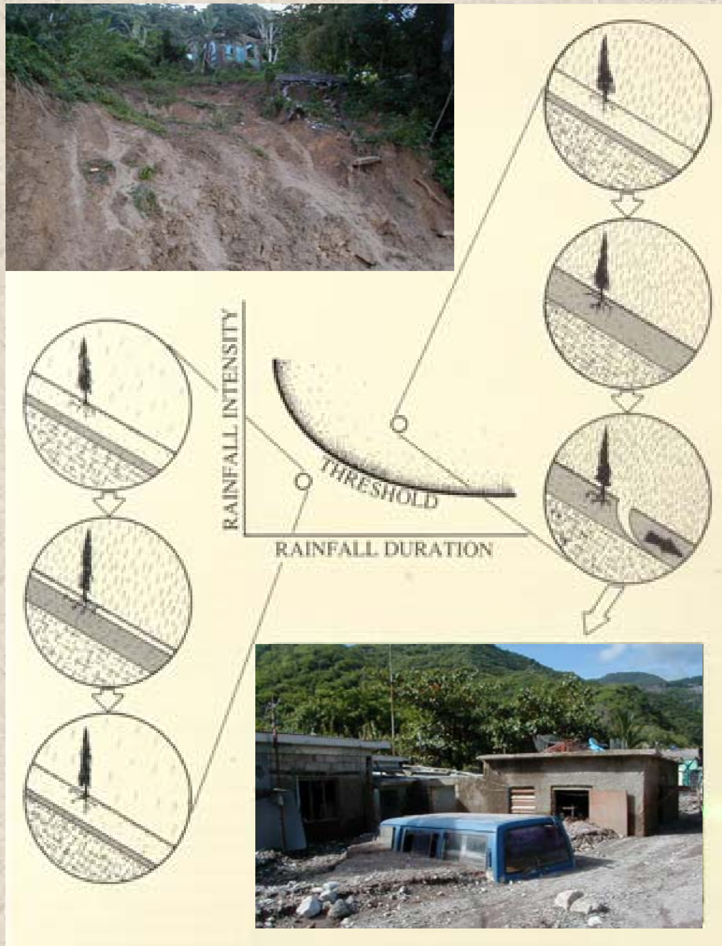
<u>Is response to hazard mitigation in developing countries is shaped by Precipitation and Politics?</u>

HOW DO THRESHOLDS WORK ?

RAINFALL THRESHOLDS FOR SHALLOW LANDSLIDES

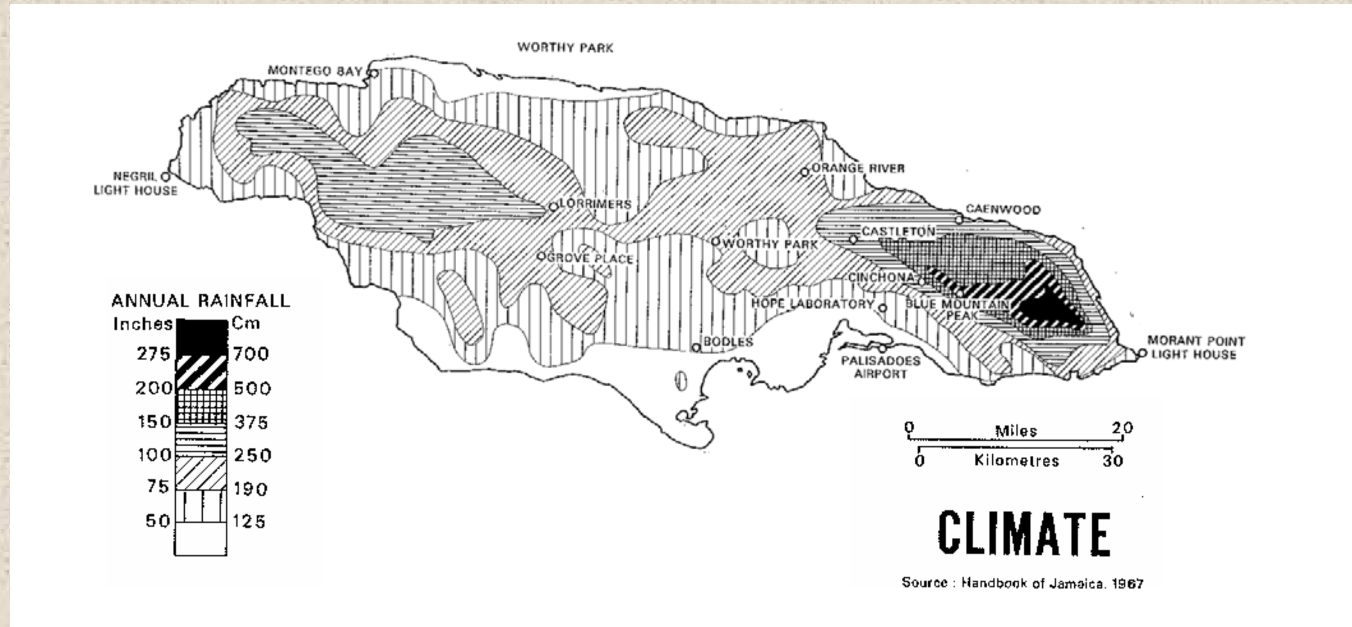
Rainfall Thresholds determine whether debris flows are triggered during rainstorms. Subthreshold storm rainfall (below left) simply raises groundwater levels in hillside soils. Rainfall conditions above the threshold (right) raise groundwater levels high enough to trigger failure in soil types that can liquefy. The resulting mass, which flows suddenly and rapidly downslope, can destroy buildings and claim lives within moments after movement starts.

(Modified from S.E and B. Rogers. 1996)



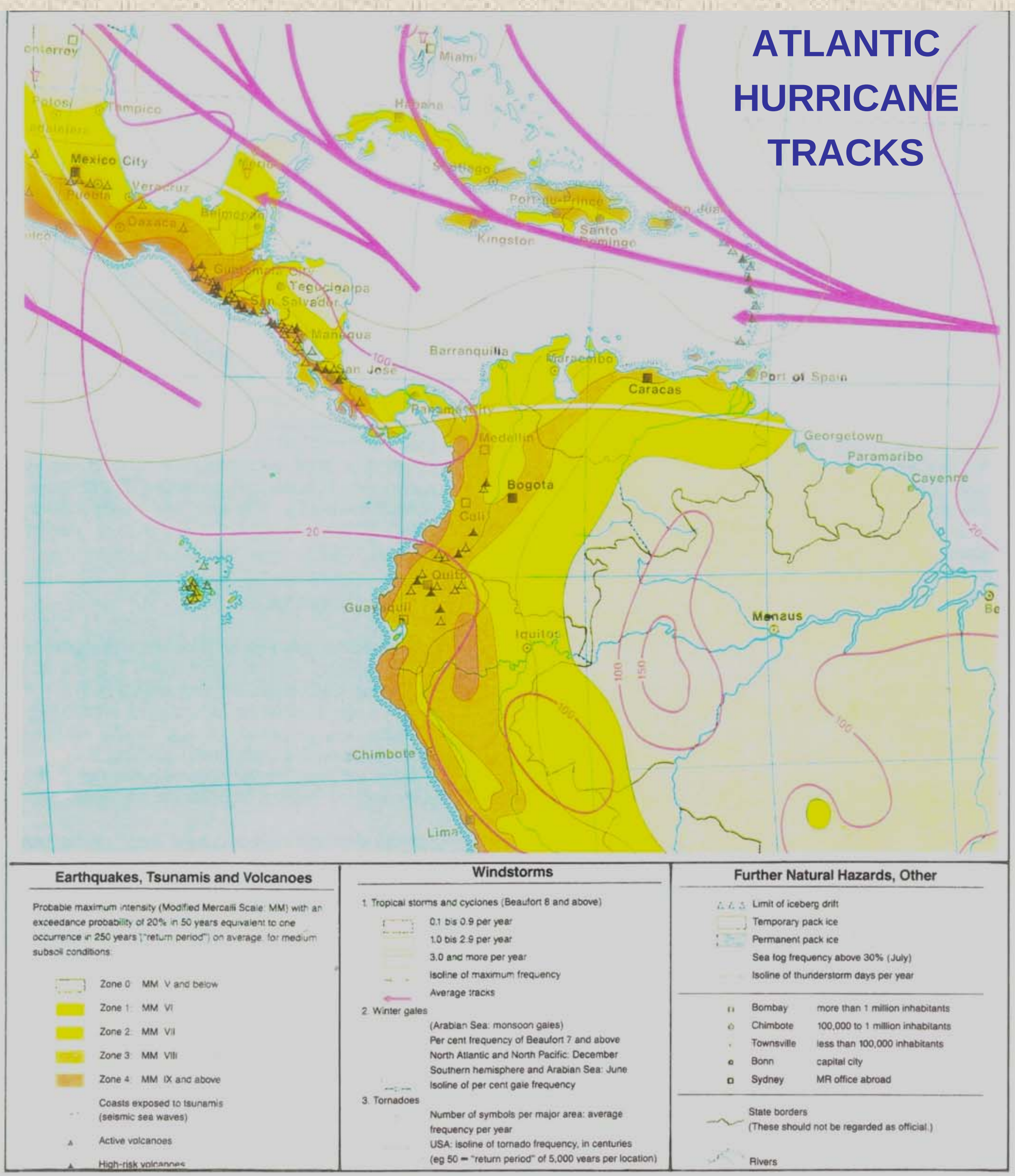
Impermeable bedrock - Hatching
Soils – Dotted Pattern
Groundwater – Grey shading

RAINFALL PATTERN IN JAMAICA

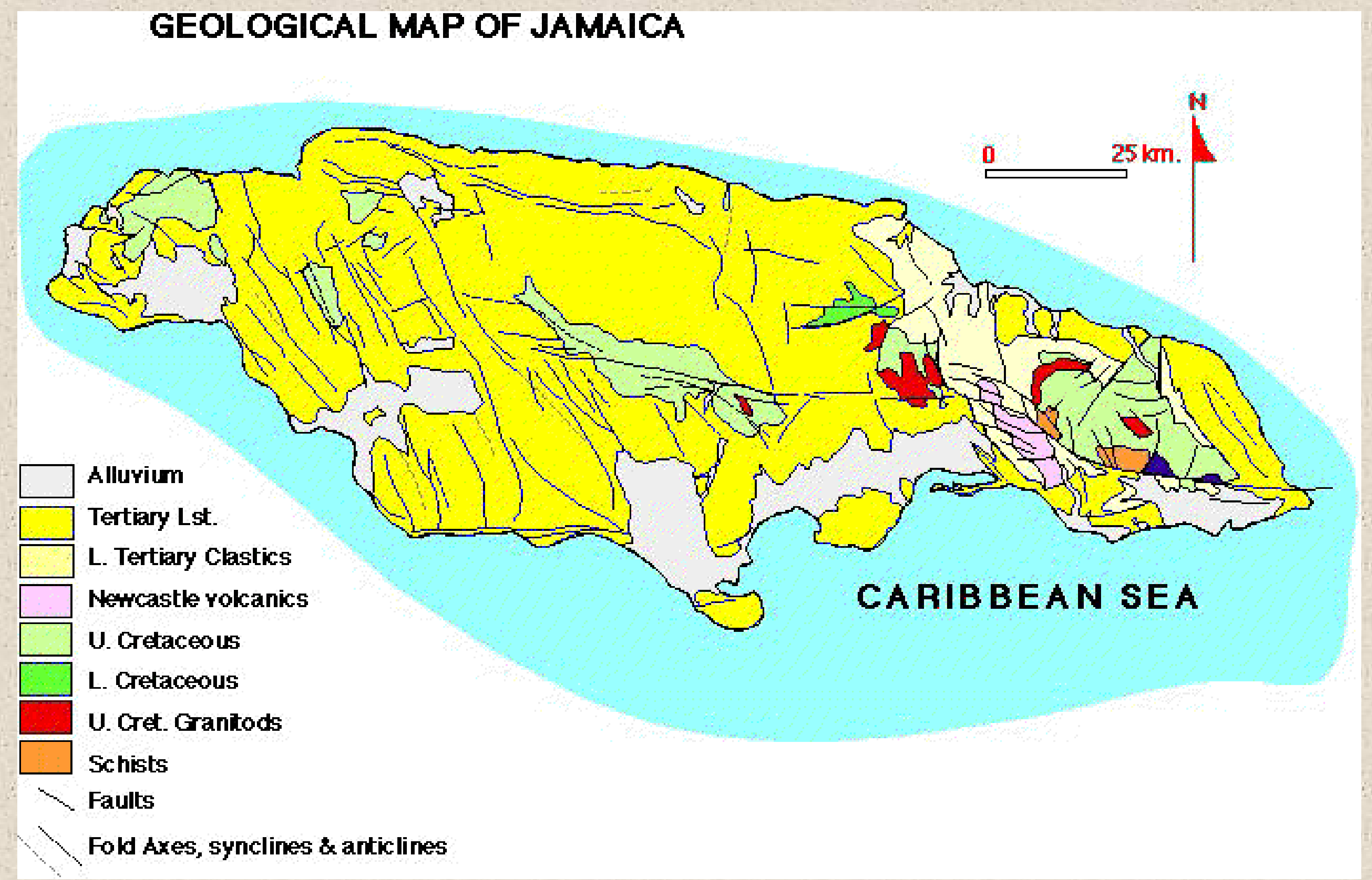


Much of the yearly rainfall on Jamaica is delivered by tropical waves, depressions, storms, cold fronts, and hurricanes.
Annual rainfall ranges from < 125 cm to > 700cm and varies because of the orographic effects of approximately E-W trending mountain ranges.

ATLANTIC HURRICANE TRACKS



Source: Munchener Ruckversicherungs-Gesellschaft. World Map of Natural Hazards, scale 1:30,000,000. (Munich, Federal Republic of Germany, 1978).


GEOLOGICAL MAP OF JAMAICA
N
0
25 km.
CARIBBEAN SEA
Alluvium
Tertiary Lst.
L. Tertiary Clastics
Newcastle volcanics
U. Cretaceous
L. Cretaceous
U. Cret. Granitods
Schists
Faults
Fold Axes, synclines & anticlines

Materials mobilized by rainfall-induced shallow landslides:

- In Jamaica, two-thirds of the area is located in mountainous zones.
- Because of the scarcity of relatively flat lands, residential areas have been built at the hillsides and on the hills.
- Severe erosion (*aided by landslide processes*) on steep hills that consist of relatively easily erodible geological materials has resulted in abundant colluvial (debris) accumulations. These are called debris or alluvial fans.

    Colluvium (debris)- *usually weathered material lying on the surface of a hill or slope which is transported across and deposited on a low-angle slope or on a footplain. Being the result of wash and gravity-induced mass movement processes over different distances, a colluvium contains grain sizes related to the bedrock of the source area.*

Table 1. SUMMARY OF GEOLOGY, GEOMORPHOLOGY, SOIL AND WATER RESOURCES, NATURAL HAZARDS AND LAND USE ON JAMAICA. (Note: Marine environment is not included)

	Morphotectonic Unit:LIMESTONE PLATEAU WITH HILLS	Morphotectonic Unit: INTERIOR MOUNTAIN RANGES	Morphotectonic Unit:COASTAL PLAINS AND MARSHLANDS.
BEDROCK	693000ha (64% of island) mainly in central and western sections of the island. Tertiary limestones with subordinate clastic rocks; extensively jointed and faulted.	238000 ha (22% of island) in eastern and central sections. Cretaceous and Tertiary volcaniclastic rocks, andesites, granodiorite and subordinate schists, limestones and serpentinites. Bedrock intensively jointed, faulted, altered and deeply weathered.	152000 ha (14% of island) mostly along the southern coast, fringing uplands. Quaternary sediments comprising unconsolidated to poorly consolidated gravels, sands, silts and clays.
GEOMORPHOLOGY	Elevation 700-1000m,Slopes > 25o;Highly dissected;Karst topography & inland drainage;Fault scarps common, average annual rainfall 125-375 cm.	Highly dissected; WNW-ESE trending mountains forming the core of the island; maximum elevation 2254 m in Blue Mountains; fault controlled valleys; fault scarps; high drainage density; slopes > 30o; host all the watersheds on the island; average annual rainfall 190-700 cm.	Alluvial fans; river valley deposits; terraces; sand dunes; raised coral reefs; poljes; Palisadoes tombolo; average annual rainfall 190 cm.Major population centres are coastal cities.Airports.
VEGETATION	Montane Mist forest; Wet & Dry Limestone forest, pasture & ruinate land	Montane Mist forest; Lower Montane Mist forest, pasture & ruinate land.	Pasture and ruinate land; Mangrove forests.

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SOILS(Maximum thickness about 1 m)	62% of all the soils are on limestones. Residual soils includes: *Eutric* and *Frralic Cambisols*; *Chromic Vertisols*; *Rendzinas*; *Humic* and *Ferralic Acrisols*; Orthic and *Rhodic ferralsols*. Bauxite deposits.	24% of all soils. Residual soils including *Eutric*, *Vertic*, *Dystric Cambisols*; *Eutric* and *Dystric Regosols*; *Orthic*, *Luvisols*; *Chromic Vertisols*.	14% of all the soils. Transported soils including *Eutric* and *Dystric Cambisols*; *Chromic* & *pellic vertisols*; *Halpic* and *Calcaric Phaeozems*; *Thionic* & *Eutric Fluvisols*, *Eutric Histisols*.
WATER RESOURCES	Limestone aquifers provide 96% of the groundwater;3294Mm3 yr-1 . Springs.	Act as basement aquicludes; provide 666 Mm3 yr-1 of water as surface runoff. Springs.	Alluvium aquifers provide 4% of the groundwater; 124 Mm3 yr-1.Springs.
LANDSLIDESUSCEPTIBILITY Triggers: Earthquakes and precipitation.	Moderate to high	Very high.	Low
FLOODING POTENTIAL	Moderate to high.Alluvial fan flooding.	Very high.Alluvial fan flooding.	Very high; subject to both coastal and riverine flooding. Alluvial fan flooding. Tsunami and storm surge hazard.
SEISMIC HAZARDSources: On land and offshore faults of plate boundary zone.	Moderate to high, depends on location.Moderate to high, depends on location.High; some areas subject to liquefaction. Tsunami hazard.	Moderate to high, depends on location.Moderate to high, depends on location.High; some areas subject to liquefaction. Tsunami hazard.	Moderate to high, depends on location.Moderate to high, depends on location.High; some areas subject to liquefaction. Tsunami hazard.

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EROSION RATES(~area affected)Landslide related.Moderate to high; (685000 ha)Very high(250000ha)Low to moderate(120000ha)	EROSION RATES(~area affected)Landslide related.Moderate to high; (685000 ha)Very high(250000ha)Low to moderate(120000ha)	EROSION RATES(~area affected)Landslide related.Moderate to high; (685000 ha)Very high(250000ha)Low to moderate(120000ha)	EROSION RATES(~area affected)Landslide related.Moderate to high; (685000 ha)Very high(250000ha)Low to moderate(120000ha)
POPULATION DENSITY (persons/ha)81.3; very low in Blue Mountains>12	POPULATION DENSITY (persons/ha)81.3; very low in Blue Mountains>12	POPULATION DENSITY (persons/ha)81.3; very low in Blue Mountains>12	POPULATION DENSITY (persons/ha)81.3; very low in Blue Mountains>12
MINING ACTIVITIESCommercial exploitation of bauxite and limestone.Commercial exploitation of gypsum and shales; gold mining.Commercial exploitation of sand and gravel and silica. sands.	MINING ACTIVITIESCommercial exploitation of bauxite and limestone.Commercial exploitation of gypsum and shales; gold mining.Commercial exploitation of sand and gravel and silica. sands.	MINING ACTIVITIESCommercial exploitation of bauxite and limestone.Commercial exploitation of gypsum and shales; gold mining.Commercial exploitation of sand and gravel and silica. sands.	MINING ACTIVITIESCommercial exploitation of bauxite and limestone.Commercial exploitation of gypsum and shales; gold mining.Commercial exploitation of sand and gravel and silica. sands.

DATA COLLECTION

Rainfall records from National Meteorological Service of Jamaica have been used. Data for 23 storms, 1951- 2002, have been used. These included landslide producing storms and also those that did not. As far as possible, rain gauges located close to landslide sites and with an hourly resolution were used. These may represent maximum landslides at a particular site. A summary of those data are given in Tables 2-4.

Fieldwork, newspaper archives, agency reports form the basis for landslide data.

At this stage of research, our landslide producing data are obviously incomplete. Although there were many storms that produced or did not produce landslides in Jamaica, this paper includes only those storms that produced verifiable landslides, 2-3m deep, and in tens-hundred.

During heavy rainfall the colluvium is easily weakened, which often leads to debris flows that present a great threat to areas downstream.

Debris flows initiation of requires three fundamental conditions and at least one triggering condition.

Fundamental Conditions (subjective):

- **Abundant debris**
- **A steep slope angle**
- **A lot of surface and subsurface water**

Triggering conditions:

- **Heavy rainfall**
- **Highly variable topography**
- **Abrupt changes in vegetation**
- **Slope failures**

Debris (rock, soil, woody debris) is mobilized from hillslopes and channels by the addition of sufficient moisture.

Table 2. Date of occurrence and rainfall characteristics of 2001-2002 storms that triggered tens to hundreds of landslides in eastern Jamaica. **Rainfall Data from National Metereological Service, Jamaica.**

LEGEND: CF, Cold Front; H, Hurricane; HR, Heavy Rainfall; TD, Tropical Depression; TS, Tropical Storm. mm, millimetre; h, hour, mm/h, millimetre per hour.

Date	Storm Type	Accumulation (mm)	Duration (h)	Intensity (mm/h)
25.05.2002	CF	93	1	93
29.09.2002	TS	74	1	74
18.09.2002	TS	68	1	68
25.05.2002	CF	65	1	65
27.09.2002	TS	52	1	52
26.05.2002	CF	46	1	46
19.09.2002	TS	26	1	26
29.10.2001	TS	1058	48	22

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Date	Storm Type	Accumulation (mm)	Duration (h)	Intensity (mm/h)
08.11.2001	TS	476	24	20
29.10..2001	TS	426	24	18
28.10.2001	TS	420	24	18
07.11.2001	TS	376	24	16
29.10.2001	TD	337	24	14
07.11.2001	TS	339	24	14
04.11.2001	TS	159	24	7
06.11.2001	TS	484	144	4

Table 3. Date of occurrence and rainfall characteristics of 9 rainfall events (1993-1999) that were not observed to have triggered significant landslide events in eastern Jamaica. **Rainfall Data from National Metereological Service, Jamaica.**

LEGEND: CF, Cold Front; H, Hurricane; HR, Heavy Rainfall; STIT, Surface Trough Induced by Tropical storm; STIH, Surface Trough Induced by Hurricane; TD, Tropical Depression; TS, Tropical Storm; TW, Tropical Wave. mm, millimetre; h, hour, mm/h, millimetre per hour

Date	Storm Type	Accumulation (mm)	Duration (h)	Intensity (mm/h)
04.06.1997	TS	229	24	10
12.11.1994	STITS (Gordon)	141	24	6
19.11.1996	TS (Marco)	90	24	4
15.09.1993	STITS (Gert)	63	24	3
16.09.1993	STITS (Gert)	82	24	3
24.09.1998	STIH (George)	63	24	3
11.08.1995	STITS (Felix)	40	24	2
02.10.1995	STIH/TW (Opal)	41	24	2
15.11.1999	STIH (Lenny)	54	24	2

Table 4. Date of occurrence and rainfall characteristics of 1951-1998 storms that triggered tens to hundreds of landslides in eastern Jamaica. Rainfall Data from National Metereological Service, Jamaica.

LEGEND: CF, Cold Front; H, Hurricane; HR, Heavy Rainfall; STIT, Surface Trough Induced by Tropical storm; STIH, Surface Trough Induced by Hurricane; TD, Tropical Depression; TS, Tropical Storm; TW, Tropical Wave. mm, millimetre; h, hour, mm/h, millimetre per hour

Date	Storm Type	Accumulation (mm)	Duration (h)	Intensity (mm/h)
12.05.1979	LP	865	10	87
12.09.1988	H (Gilbert)	36	1	36
06.10.1963	H (Flora)	663	24	28
27.10.1998	CF (Mitch)	28	1	28
12.09.1988	H (Gilbert)	27	1	27
18.09.1951	H (Charlie)	406	24	17
16.10.1973	TD (Gilda)	411	24	17
05.11.1998	CF (Mitch)	346	24	14
12.09.1998	H (Gilbert)	240	24	10
12.09.1998	H (Gilbert)	823	168	5
05.05.1986	HR	485	120	4

CHARACTERISTICS OF STORMS THAT TRIGGERED LANDSLIDES

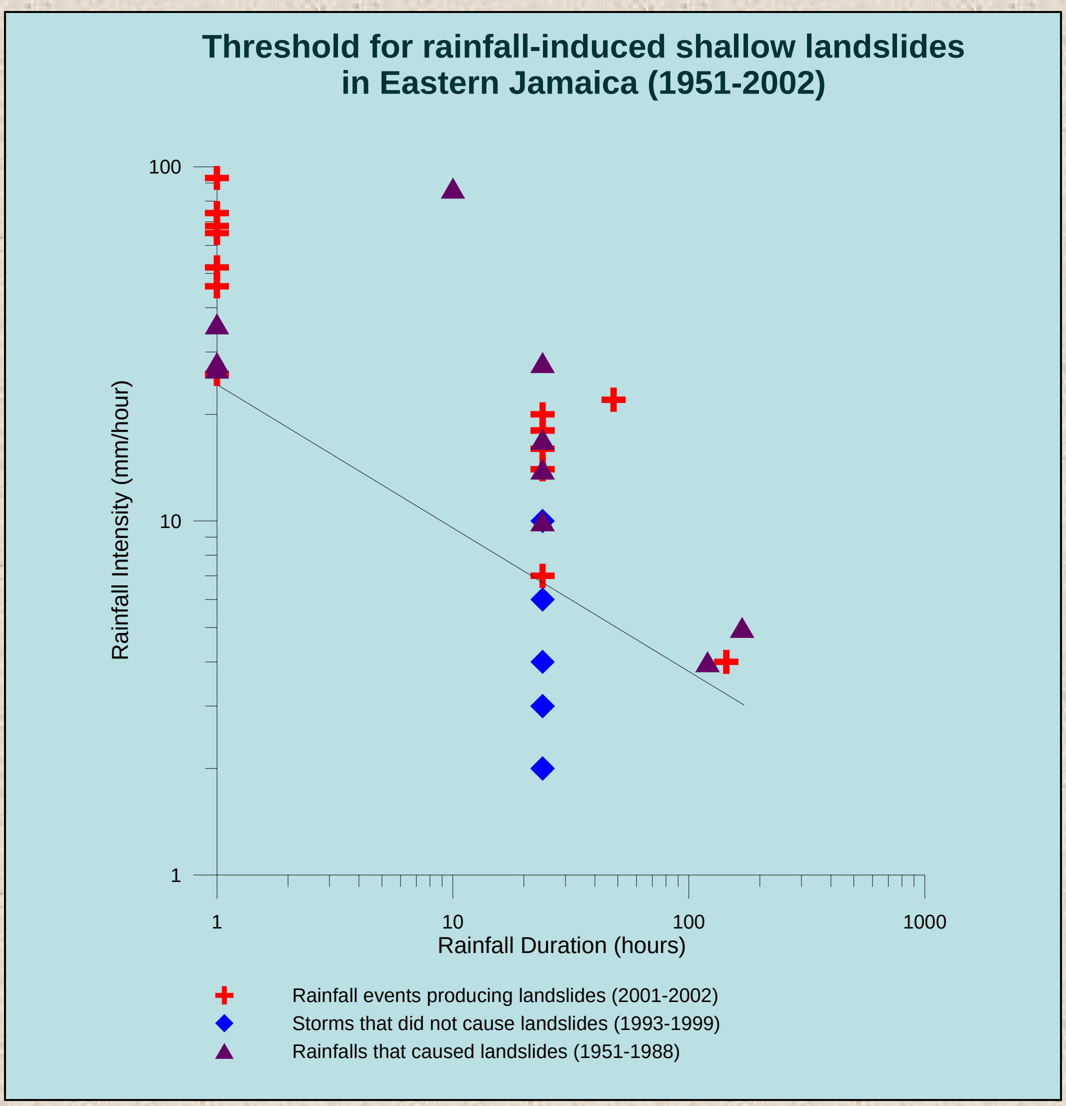
(From the point of view of natural hazard management)

Tables 2-4 suggest that in our data set:

- **Only 6 of 36 events were hurricanes; remainder were tropical disturbances and cold fronts.**
- **A majority of the landslide triggering storms occurred during the hurricane season (June through November).**
- **Storms which triggered landslides also occurred in May, the time period between the last of the cold fronts and the first of the tropical waves.**

RAINFALL INTENSITY-DURATION THRESHOLD FOR SHALLOW LANDSLIDES IN EASTERN JAMAICA:

Using data for 19 storms, 1951-2002, a threshold relation between rainfall intensity-duration and landsliding was established



RAINFALL INTENSITY-DURATION THRESHOLD FOR SHALLOW LANDSLIDES IN EASTERN JAMAICA

Using data for 19 storms, 1951-2002, a threshold relation between rainfall intensity-duration and landsliding was established.

A threshold fitted to the lower boundary data points reflects the approximate minimal rainfall conditions necessary to trigger shallow landslides in eastern Jamaica.

This rainfall threshold relation is defined for storms that had durations between 1-168 hours and average rainfall intensities between 2-93 mm/h.

The threshold relation indicates that for rainfall of short duration (about 1 h), higher than 36 mm/h, are required to trigger landslides. Low average intensities of about 3mm/h appear to be sufficient to cause landslilding as storm duration approaches approximately 100 h.

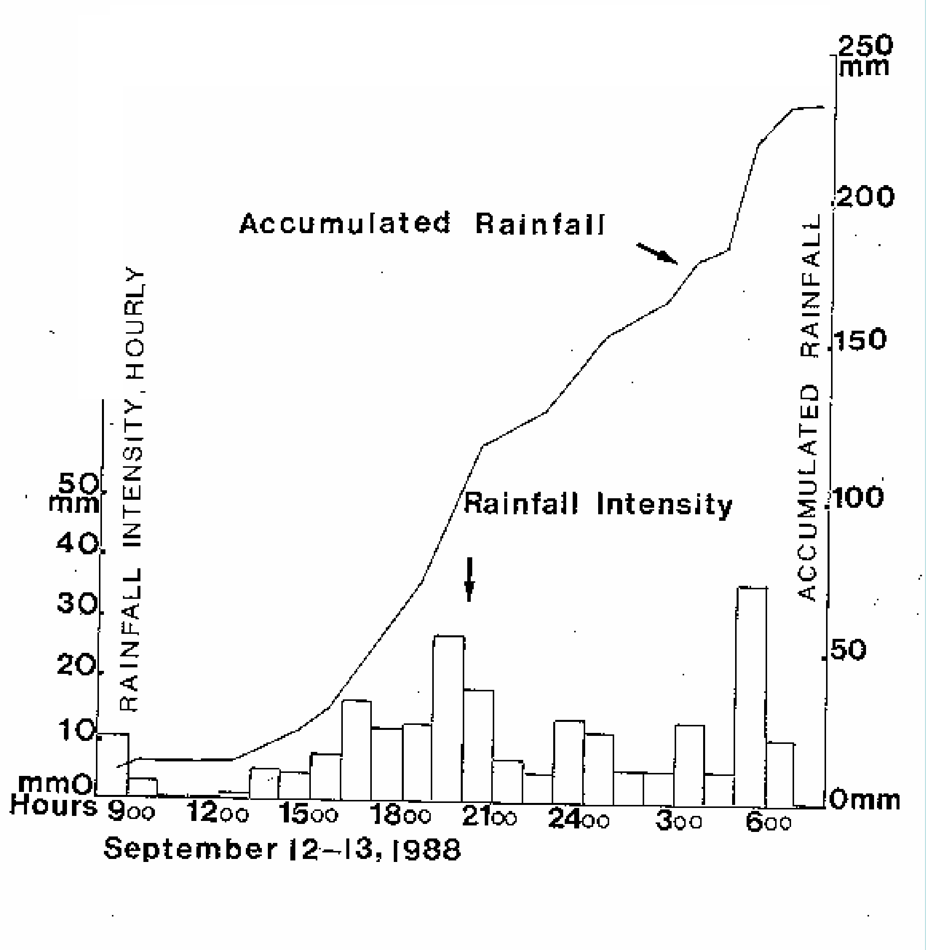
There is a relation between landslide characteristics and the position of the landslide-triggering storm on the threshold line. Storms near the short-duration/high intensity end of the threshold line trigger mostly shallow landslides by causing an excess pore pressure in shallow colluvial zones. Such landslides were typically associated with 2001-2002 type storms.

In contrast, storms near long-duration/low intensity end of the threshold have triggered the largest, deepest landslides in eastern Jamaica, e.g., Flora, Gilbert, 2001 rainfall.

We are trying to establish the effects of antecedent soil-moisture conditions. It appears that these may not be very significant in May or beginning of the hurricane season. It is at the end of the hurricane season that increased soil moisture becomes important.

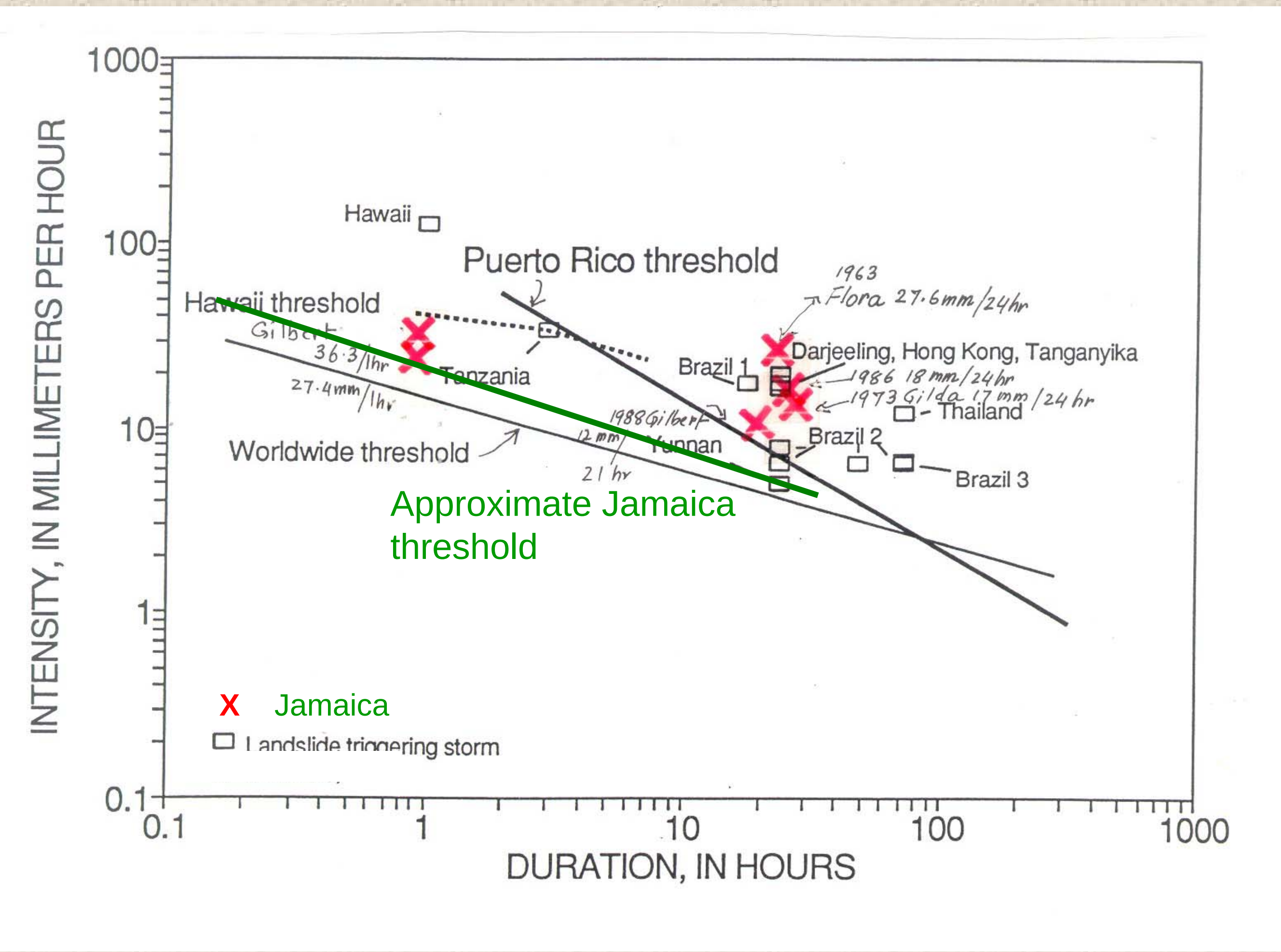
Given hourly rainfall intensity resolution and accurate timing of landslides, it is possible to establish fairly robust intensity-duration relationships, e.g. Hurricane Gilbert analysis

LANDSLIDE INTENSITY-DURATION RELATIONSHIP FOR HURRICANE GILBERT



COMPARISON WITH OTHER THRESHOLDS

Caine (1980) established a worldwide threshold (modified from Matthew Larsen and Simon, 1993, Puerto Rico data).
It has the form: $I = 14.82\ D^{-0.39}$
In which I is the rainfall intensity (mm h -1), D is the duration of rainfall (h).
This may also be stated in terms of depth (d, in mm) and duration (D) of the rainfall:
$D = 14.82\ D^{0.61}$
Puerto Rico threshold lies above the worldwide threshold of Caine.



Jamaican data generally agrees with Caine's (1980) limiting curve.
As storm durations approach 100 h , all thresholds converge, indicating that geomorphological and climatological differences between humid tropics and temperate environments may not be significant when hillslopes receive large amount of rainfalls over a prolonged period.
These data indicate that evolution of landforms is to a significant degree directly influenced by landsliding processes.

CONCLUSIONS

- In Eastern Jamaica, rainfall threshold relation is defined for storms that had durations between 1-168 hours and average rainfall intensities between 2-93 mm/h.

- The threshold relations reported here are reasonable first approximations.

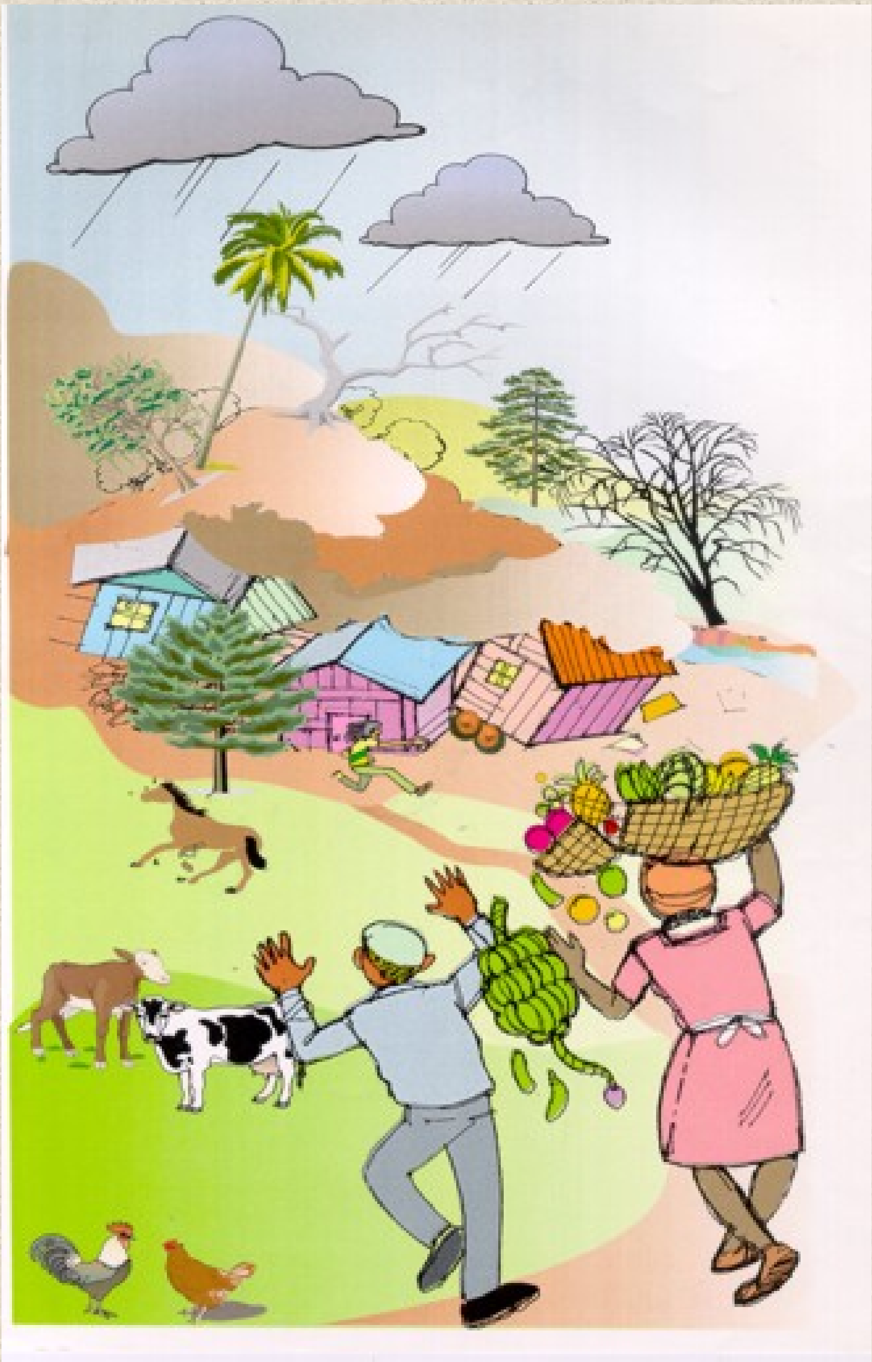
- The threshold relation indicates that for rainfall of short duration (about 1 h): Intensities > 36 mm/h, are required to trigger landslides. These storms trigger mostly shallow landslides by causing an excess pore pressure in shallow colluvial zones. Such landslides were typically associated with 2001-2002 type storms.

- Low average intensities of about 3mm/h appear to be sufficient to cause landslilding as storm duration approaches approximately 100 h. These triggered the largest, deepest landslides in eastern Jamaica, e.g., Flora, Gilbert, 2001 rainfall.

- Thresholds provide a key element of landslide warning system.

ACKNOWLEDGEMENTS

Grateful thanks are extended to the Staff of the National Meteorological Service Jamaica, Faisal Butt, Michelle (from the National Meteorological Service) and Debbie (Deborah-Ann Rowe).



THANK YOU