CARIBBEAN NATURAL HAZARDS
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NATURAL HAZARDS AND DISASTERS

LANDSLIDES IN ST. LUCIA

Windward Islands (St. Lucia)

The Windward Islands extend south from 15° 45' to 11° 45' North latitude and from 60° 45' to 62° 00' West longitude. (Rand McNally, 1988) They are west of Barbados and northwest of Trinidad and Tobago. From south to north, the islands are: Grenada, the Grenadines, St. Vincent, **St. Lucia,** Martinique, and Dominica. Martinique is an overseas department of France. The other islands are independent countries. The Grenadines are a string of small islands extending north from Grenada to St. Vincent and include Carricou, Union Island, Mustique, and Bequia. Except for Carricou, which is part of Grenada, the Grenadines are part of St. Vincent and the Grenadines.

The Windward Islands lie within the trade wind belt. The rainy season occurs in summer and fall. Hurricanes and tropical storms pass over the islands during this period. However, the interior highlands of the larger islands also receive rainfall in the drier winter months and additional amounts in the summer months due to orographic uplift (Walsh, 1985). Annual rainfall in the interior highlands ranges from 10,000 millimeters in Dominica to 3750 millimeters for the lower elevation mountains in Grenada. Coastal areas receive lesser amounts ranging from 1000 millimeters on Dominica to 1600 millimeters at the southern end of St. Vincent.

Physiography and Geology of the Windward islands.

Grenada is the least mountainous of the Windward Islands. Its more rugged terrain is concentrated in the central part of the island. St. Catharine at 840 meters is the highest point on Grenada (Rand McNally, 1988). Grenada and St. Vincent are nearly the same size at 344 and 345 square kilometers, respectively. In St. Vincent, the steepest terrain is found around Soufriere, and 1234-meter active volcano at the northern end of the island. The remaining steep terrain extends south through the central part of the island. **On the 616-square kilometer island of St. Lucia, the central ridge hosts the steepest terrain with the north and south ends being flatter. The highest point on St. Lucia is 950-meter Mt. Gimie.** At 1,100 square kilometers, Martinique is the largest of the Windward Islands. Rugged, Steep terrain is found in the northern and central parts of Martinique. Mt. Pelee, at 1,397 meters, is the highest peak as well as an active volcano. A series of high peaks and connecting ridges runs the length of the 752-square kilometer island of Dominica. The highest peak is Morne Diablotin rising to 1, 447 meters in the central part of the island.

The Windward Islands form a volcanic island arc. Lava flows, ash, and pyroclastic deposits ranging from Miocene to Recent in age are the principal bedrock found in these islands. Some limestones are interfingered with the volcanic layers (Faribridge, 1975c). In general, Grenada, the Grenadines, and St.

Vincent are composed of basalts and basaltic andesites. Typically, lava flows outcrop on the steeper slopes and ash underlies the gentler slopes (Walsh, 1985). **St. Lucia, Martinique, and Dominica are predominantly composed of acid andesite and dacitic rocks. Pyroclasic flow deposits, volcanoclastics, and lava domes, but few ash deposits, are typical for these islands.**

Landsliding in the Windward Islands.

Debris flows, debris slides, rockslides, rockfalls, slumps, and complex landslides are among the types of landslides found throughout the Windward Islands (Faugeres, 1966, Prior and HO, 1972, Walsh 1982, DeGraff, 1985, 1987a, 1988) Most landslides involve either flow or translational movement. **Landslide mapping on St. Vincent, St. Lucia, and Dominica found the majority of landslides to be debris flows (DeGraff, 1985, 1987a, 1988). Table 4 characterizes the identified landslides on these three islands.**

The Good Hope landslide on Dominica is one of the larger identified debris slides (DeGraff, 1987b) (Fig. 7). It involved translational movement of a soil mass. Slickenslides were observed at some locations on the exposed failure plane. As it moved, the soil mass disintegrated into a disrupted mass with few discernable internal scarps or coherent blocks. Some flowage developed at the lower end of the slide mass.

From observations of exposed soil in the margins of the failure, the soil appeared residual in origin with no buried horizons, stone lines, or other indicators of significant colluvial accumulation. It is bright red and consists mainly of clay to sand-sized particles mixed with gravel-sized fragments. Some fragments could be crushed to sand by hand.

The failure plane coincided with the contact between the soil and underlying bedrock. Bedrock exposed in the failed area is a fractured, andesite. The failure plane, as defined by the surface of the bedrock, is inclined at 70 to 80 percent. The average thickness of soil over bedrock in the failed area is estimated to be 5 meters. The failed area is roughly circular in plain view and encompasses 3, 630 square meters. These figures lead to an estimated volume of 17, 000 cubic meters.

Debris slides and debris flows are common on mountainous slopes in the Windward Islands. Walsh (1985) noted the many debris slides and flows triggered by Hurricanes David and Frederic involved failure at depths of 2 meters or less. Similarly shallow depth to the failure plane for these landslide types is documented for Martinique (Faugeres, 1966). **Prior and Ho (1972) found the majority of theses slides on St. Lucia originated on slopes steeper then 35 percent.**

Rockslides and rockfalls are widespread but less abundant. Bedrock escarpments on mountain slopes, steep-sided valleys, and coastal cliffs are typical localities for these landslide types. Failure usually involves a competent rock type which often has well-defined joints or similar discontinuities. Ignimbrite defined joints or similar discontinuities. Ignimbrite deposits along valleys near Rouseau, Dominica fail as rockslides and rockfalls where the prominent vertical joints create zones of weakness within the rock mass (DeGraff, 1987a). **Failure of coastal cliffs occurs due to the oversteeping by wave erosion. Figure 8 shows a coastal rockslide near Dennery, St. Lucia. The larger, older rockslide is visible on aerial photography taken in 1977. The younger rockslide within the older feature is seen only in 1981 aerial photography indicating the more recent failure occurred between 1977 and 1981 (DeGraff, 1985).**

Slumps and complex landslides are the least common types found in the Windward Islands. Most slumps or rotational failures observed are associated with man-disturbed slopes. In Dominica, small rotational failures triggered by Hurricanes David and Frederic were only noted on cultivated slopes (Walsh, 1982). **Rotational failures seen in St. Vincent, St. Lucia, and Dominica are limited to small failures in road cuts. Prior and Ho (1972) describe complex slides involving shallow movement of the soil mantle and Moule a Chique in St. Lucia.**

The steep slopes prevalent in the Windward Islands are one of the principal conditions favoring landslide development (Fig 9.) The land rises from seal level to 800 meters or more over a distance of 3 to 6 kilometers resulting in steep rugged terrain. Examination of drainage patterns on these islands by Walsh (1985) indicates and early phase of landscape development. The resulting slopes are often at angles close to the angle of repose for the materials underlying them. Only small changes in stability conditions are required to bring such slopes close to failure.

The nature of materials underlying slopes on these islands plays a major role in landslide development. Their volcanic origin creates stratigraphic and lithologic conditions favouring landslides. Layers of alternating ash, lava, and breccia lead to locations on slopes where weaker bedrock weathers faster and undermines more competent bedrock overlying it. Location of volcanic vents in the central parts of the islands results in bedrock layers being inclined outward. The resulting presence of bedrock contacts inclined at angles less steep then the mountain slopes seems to favour landslides development. The bedrock and humid climate combine to cause deep weathering of volcanic bedrock. The resulting soil mass has a lower strength than the original unweathered bedrock. Mehigan and Hartford (1985) recognized this situation for some slopes along roads in Dominica. **In many instances, the soil contains significant percentages of clay. Prior and Ho (1972) found montmorillonite clay in soils tended to produce flow-type failures on St. Lucia.** The clay characteristics of some soil on Dominica influence the intensity of rainfall needed to induce a landslide (Rouse et al, 1986, Rouse and Reading, 1987)

The principal triggering mechanism for landslides in the Windward Islands is rainfall. Pore-water pressure increases along discontinuities within weathered bedrock and within soil masses leads to decreased shear strength. This loss of strength coupled with the added weight of water within the saturated mass leads to failure on zones of weakness such as the soil-bedrock interface or discontinuities within the bedrock (Faugeres, 1966, Walsh, 1982). Hurricanes are one source of intense rainfall. Between September 1963 and September 1987, the following hurricanes induced landslides on one or more of the Windward Islands: Edith, Beulah, Abby, Dorothy, David, Frederic, Allen, and Emily. Storm events other than hurricanes are capable of inducing landslides. Prolonged rainfall experienced during the rainy season is capable of producing landslides as the Good Hope landslide demonstrates. In St. Vincent, Tropical Storm Danielle and associated rains in September 1986 caused more landslide damage than Hurricane Emily in September 1987.

Earthquakes and volcanic activity, recognized triggers of landslides, affect this region. All of the Windward Islands are known to have experienced earthquakes in the past. However, there are no documented instances of landslides being triggered by ground shaking. Volcanic activity is associated with landslides in the windward Islands (Bolt, et al, 1975). Mudflows are described as part of the eruptive sequence of Mount Pelee leading up to the disastrous nuee ardante on May 8, 1902, which devastated St. Pierre, Martinique. Also in 1902, mudflows affecting the northeast and northwest parts of St. Vincent were among the events associated with the May 7th eruptive sequence of Soufriere, which killed 1,500 inhabitants.

Human activities are another triggering mechanism for landslides in the Windward Islands. Roads cut into steep slopes remove support from the soil or rock mass above. The road prism may interfere with natural subsurface drainage in the slope leading to higher pore-water pressures than would occur under natural conditions. Anderson and Kneale (1985) note the terrain on these islands limits the available routes making avoidance of landslide-susceptible slopes difficult. This was the case for a major road in

Dominica constructed to improve access to the southern part of the island. The route crossed a slope segment with unfavourable bedrock lithology, groundwater conditions, and slope form. This slope, near Bellvue Chopin, initially failed during road construction. It failed several times in the following years causing one death as well as impacting the road (Fig. 10). Despite stabilization efforts, it remains a potential site for future landslide activity.

Agricultural practices are another human activity contributing to landslides in the Windward Islands. Some farmers slash and burn the rainforest on very steep slopes to clear areas for planting bananas. The shallow-rooted banana plants are unlikely to contribute as much root reinforcement for strengthening the soil mass as the original trees of the rainforest. Rainfall reaching the ground is increased by replacing the solid rainforest canopy with the more open canopy typical of banana fields. It is suspected these differences make the slopes more susceptible to landslides. **The consequences of altering the vegetation on a steep slope were demonstrated to a farmer in St. Lucia (The Weekend Voice, September 17, 1988). He maintained a banana field on a 90 to 100 percent sloped cleared of forest vegetation. On September 11, 1988 following a tropical storm which drenched the island he was an eyewitness to destruction of his field by a landslide. About 3:30 p.m., the farmer observed the slope begin to move starting very slowly at the bottom and followed by the upper slope as it accelerated. Nearly 5 hectares including his entire field was carried away leaving a 1.5-kilometer long swath of exposed soil. Chief Forestry Officer Gabriel Charles and his fellow rangers inspected the site and unanimously attributed the disaster to deforestation and a slope too steep to be used for banana cultivation. Even the farmer concluded, "I think it was the absence of trees with firm roots which caused the slide. I also think the squatting and cutting of trees on the hills should be stopped...".**

Economic and Social Impact of Landslides in the Windward Islands.

Landslides are known to cause fatalities and injury to the inhabitants of the Windward Islands. **Both Dominica and St. Lucia provide Examples of this serious landslide impact.**

The unfortunate death to the nurse's daughter at Good Hope was not the first landslide-caused fatality on Dominica. Between 1925 and 1986, twenty-five Dominicans lost their lives to landslides (Fig. 11). These fatalities represent only those occurrences for which the place, time, and number of people involved could be ascertained. As such, this figure represents they minimum number of fatalities for this period. The nurse is the only injury due to a landslide, which can be documented for Dominica. It is known her injuries required a recovery period of several months.

In most instances, fatalities on Dominica result from debris flows inundating homes. This was the case at the community of Bagatelle in 1977. Rain-saturated soil on a hill slope adjacent to the community mobilized into a rapidly moving mass. It engulfed four homes at the edge of the village killing eleven inhabitants. An exception to this circumstance is the death in 1984 at Belvue Chopin. Several landslides previously developed on the slope above the main road as noted in the earlier discussion of road construction triggering landslides. On November 6, 1984, another failure from this site sent a mass of debris down the road. This flow swept away a hapless pedestrian walking down the road during the storm.

A similar compilation of fatalities for St. Lucia has not been made. However, the greatest number of deaths at a single site due to landslide activity in the Windward Islands did occur on St. Lucia. The details of this event are known from newspaper and magazine accounts at the time.

In November 1938, the main road across the central highland of St. Lucia known as Barre de

L'Isle, was blocked by landslides (Fig. 12). For eighteen days, landslides had prevented passage along this road connecting the capital of Castries with the southeastern part of the island. A workforce of several hundred inhabitants was present near Ravine Ecrivisse and neighboring Ravine Poisson labouring to clear the road. Normally, only a dozen families farming the local area lived near these ravines.

At 9:00 a.m. on Monday, November 21, 1938, a landslide from Ravine Ecrivisse swept into the area where the workmen were assembled (The West Indian, November 24, 1938). An hour later, a second landslide issued from neighboring Ravine Poisson. The areas engulfed by these landslides were described as "a sea of mud". The following morning at roughly 4:00 a.m., a third landslide covered and area one-half mile away. A total of sixty people are known to have died in these landslides. Another 32 persons were injured. It is unknown if all the injured survived. Estimates of missing workers ranged as high as 250 (Anonymous, 1938). An area of 10 square kilometers encompassing the ravines and vicinity was ordered evacuated and resulted in the displacement of over 500 people. In terms of loss of life, injury, and short-term disruption of people's lives due to evacuation, the landslide disaster at Ravines Ecrivisse and Poisson represents one of the worst experienced in the eastern Caribbean.

Damage to facilities is the most common impact of landslides on the Windward Islands. Both structures and roads are destroyed or damaged by landslides. Roads blocked by landslide debris must be excavated to be returned to working order. Replacing or repairing facilities and removing debris are direct impacts resulting from the loss of use of damaged or destroyed facilities. **Examples of damage to facilities are documented for Dominica, St. Lucia, and St. Vincent. It is assumed comparable damage has occurred on Martinique and Grenada.**

Structural loss on Dominica is clearly represented by the destroyed heath clinic and primary school at Good Hope. Both structures were constructed of concrete block on a poured slab foundation. The landslide completely demolished the clinic building during its passage. A few meters downslope, the primary school suffered irreparable damage. The rear wall was shoved in by the impact of the slide mass. The entire structure was partially displaced from its foundation and the upslope side buried to the roofline with debris (Fig. 13).

Pipelines for hydroelectric and water systems are structures suffering landslide damage on ST. Vincent. Tropical Storm Danielle on September 8, 1986 triggered landslides, which swept away a considerable length of the pipelines conveying water to hydroelectric stations. This affected the generating capacity at South Rivers station in the northeast part of the island and Richmond station in the northwest. Altogether, the landslides reduced electrical generation capacity by 36 percent. The wood stave pipelines had to be fully repaired prior to restoring generating capacity some time later.

In May 1981, St. Vincent experienced a major storm during what is normally the dry season. Landslides occurring at three separate locations severed the 8-inch diameter pipeline for the Majorica water supply system. The damaged sections ranged from 5 to 20 feet in length. Nearly 40 percent of the population of St. Vincent was affected by this water system damage. Damage to the system left some inhabitants without water for a few days and others for nearly six months. Repair of the water line took six months due to the inaccessibility of the damaged sections and cost between $87,000 and $130,000 (Central Water and Sewage Authority, Personal Comm., 1987).

The cost of clearing debris and repairing road damage to restore use is a common, serious economic impact. It is an anticipated cost when a major hurricane strikes. **Figures on the cost of clearance and damage repair are available for Dominica, St. Lucia, and St. Vincent.** It is assumed the costs for Martinique and Grenada are not dissimilar from that of their island neighbours.

In 1979, Hurricane David passed over the southern part of Dominica and was followed several days later by close passage of Hurricane Frederic. Landslide damage to roads was estimated to be $23, 000 (CEPAL, 1979). Because landslides are triggered by storms other than hurricanes, slide clearance and road repair has a long-term cumulative economic impact. Between June 1983 and July 1987, over $462, 000 was spent on Dominica on clearing landslides debris and associated repairs (Table 5). This represents an average annual expenditure of $121, 000 (G. Elwin, Written Comm., 1987).

Similar costs are incurred on St. Lucia. The cost of just clearing landslide debris ranges from $38, 000 to $146,000 per year which represents 2 to 6 percent of the annual road maintenance budget (J. Fevrier, Personal Comm., 1985). The range reflects differences between a normal year and a bad year with many triggering storms. In a normal year, $77,000 to roads would be added to the slide clearance figure. This represents expenditures for retaining walls, drainage, fill replacement, and similar work.

Records permitting tabulation of costs for clearing landslide debris and repairing damaged roads are not presently available for St. Vincent. Review of damage assessment reports made for Tropical Storm Danielle and the torrential rains which followed in September 1986, and for Hurricane Emily in September 1987 give some indication of the magnitude of this cost to roads. Totaling items noted as clearing of landslide debris or building of retaining walls from a district by district breakdown of road damage due to Tropical Storm Danielle yielded a total of $677, 00. For Hurricane Emily, the amount was $191,000. Based on the cost of road clearance and damage form these two recent storms and the experience on neighboring islands, it is estimated the average annual cost of this impact on St. Vincent is $115, 000.

Obviously, a very large landslide will result in unusually high repair coasts. The Barre de L'Isle landslide, triggered by the August 3, 1980 passage of Hurricane Allen, illustrates the cost which may result from a major landslide. This landslide initially blocked the main East Coast road on St. Lucia connecting Castries and Dennery. This severed the main route used to transport tourists arriving via the international airport at Vieux Fort to hotels and tourist facilities close to Castries. The landslide affected the main switchback curve on the East Side of the ridgecrest. The upper part of the switchback was carried away while the slide debris came to rest on the lower switchback (Fig. 14). Clearance alone would not restore the road. A masonry retaining wall at the toe and three gabion structures within the failed area were constructed to stabilize the landslide. The gabons were placed at an average cost of $ 7.00 per cubic meter (Ministry of Communications, Works, and Transport, Written Comm., 1985). This figure includes excavation of the basket sites as well as assembling and filling of each basket with rock. It also includes the clearing of small landslides induced during site excavation. Work started in October 1980 and was completed by September 1982. The entire repair cost roughly $462,000. Of this total, forty-seven percent went for materials, twenty percent for labour, seventeen percent for equipment operation, and sixteen percent for transportation. Comparable major repair sites in Dominica are found at Good Hope, Belvue Chopin and D'Leau Gommier and in St. Vincent at Windblow between the communities of Fancy and Owia (DeGraff, 1987b, 1988).

Interference with road use does not require a major landslide like the one at Good Hope to pose a problem. Main arterial and collector roads are typically narrow and often winding on the Windward Islands. Commonly, the roads follow the narrow rigdgetops to gain access to the more rugged interior. When a large landslide blocks a road, the transportation network may offer few alternative routes. The Castle Bruce-Petit Soufriere road blocked by the Good Hope landslide deadends at Petit Soufriere. The people in that community have no choice but to walk around the blocked road or use a steep, temporary by-pass into Good Hope to reach Castle Bruce and other parts of Dominica. This difficult access imposes a double hardship on the local residents because the loss of the heath clinic at Good Hope necessitates traveling another three miles the nearest clinic at Castle Bruce.

It does not require a large landslide to block or interfere with traffic for short periods. (Fig. 15). A landslide occurred in 1981 on St. Lucia's principal west coast road between Castries and Soufriere. About 765 cubic meters of debris from the cutslope late on Friday afternoon blocked the road. It was removed by Sunday (M. Henry, Personal Comm., 1985). During that time, people traveling to work between Castries and Soufriere or transporting perishable agricultural products for shipping from Castries were forced to wait or drive additional miles via the main east coast road to reach their destinations.

Agriculture is the main economic activity on most of the Windward Islands. Bananas are the principal export and cash crop throughout the year. Coconuts are nearly as important in terms of generating income. Other crops are grown for personal use and local markets. Landslide damage to banana plants and coconut trees represent and immediate loss of income for the mall farmer. Replanted bananas can be bearing within a year. Coconut trees take up to twelve years before bearing fruit. This means the loss of income for the farmer persists for one to twelve years after the landslide occurs.Monday, August 23, 1999c

Catastrophic landslides carry away or bury both cash and food crops. Agricultural losses attributable wholly to landslides are difficult to determine. For example, landslides on St. Lucia in 1981 affecting crops around Desruisseaux and the neighboring villages of DeMailly and Belle Vue (Fig. 12). While their impact led to declaring this locality a disaster area, no figures on actual crop damage were gathered (G. Charles, Personal Comm., 1985). Often, figures gathered to show losses form a major storm represent wind, flood, and landslide-caused crop damage as a lump sum.

One of the more detailed descriptions of agricultural losses due to landsliding resulted from the Good Hope landslide. While these figures represent the agricultural losses for a single large landslide, they can be taken as indicative of the general losses sustained. The Good Hope landslide affected 3.8 hectares of cultivated land. This includes the land carried away by the slide and overridden by debris. Six farmers with holdings varying form 0.1 to 1.2 hectares were affected. Bananas and coconut trees represent the principal revenue-generating crops. Other tree crops lost were bayleaf, mango, breadfuit, and citrus. Root crops for personal use and sale of surplus harvest in the markets were also destroyed. Based on Ministry of Agriculture estimates, total agricultural losses were $8,000. Of this total, $5,000 represents the loss for bananas and coconuts.

Landslides smaller that the one at Good Hope occur more often, but still inflict significant losses. In November 1981, a single, moderate-sized landslide occurred on St. Lucia southeast of the community of Forestiere (Fig. 12). Starting near the top of the ridge next to Piton Flore, this debris flow carried away bananas and coconut trees.

As the slide mass moved downslope, is swept away or buried banana and coconut trees owned by other farmers. This 1-hectare debris flow resulted in a loss of standing crop and near-future production valued at $4,000 (G. Charles, Personal Comm., 1985). On St. Vincent, a small debris flow occurred November 22, 1987 in a field near South Rivers. The narrow path of the flow swept five grown banana plants from the field and deposited them on the road at the base of the slope.

Assuming the same value for individual banana plants used in assessing the impact of the Good Hope landslide, the loss attributable to this small debris flow is roughly $250. Because farm holdings are typically small in the Windward Islands and per capita income is between $1000 and $500, the economic hardship due to landslides illustrated by these examples is not uncommon.

Table 4. Number, Size, and Area Distribution of Past Landslides on St. Vincent, St. Lucia, and Dominica*

Island	**Number of Landslides**	**Landslide Size (in hectares)**	**Landslide Density (per sq.km)**	**Terrain Disturbed (in percent)**
		Average and Largest		
St. Vincent	475	0.5 and 4.0	1.4	1
St. Lucia	**430**	**3.0 and 5.0**	**0.7**	**2**
Dominica	980	4.0 and 12.5	1.2	2

From inventories of landslides compiled by aerial photo-interpretation and limited ground verification (DeGraff, 1985, 1987a, 1988)

Table 5. Annual Cost of Landslide Damage to Roads on Dominica*

Fiscal Year (June/July)	**Landslide Costs (in thousands of dollars)**
1983-1984	92.8
1984-1985	269.0
1985-1986	71.7
1986-1987	63.0

**** Includes only the cost of clearing landslide debris and road repairs (G. Elwin, Wirttern Comm., 1987)***

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