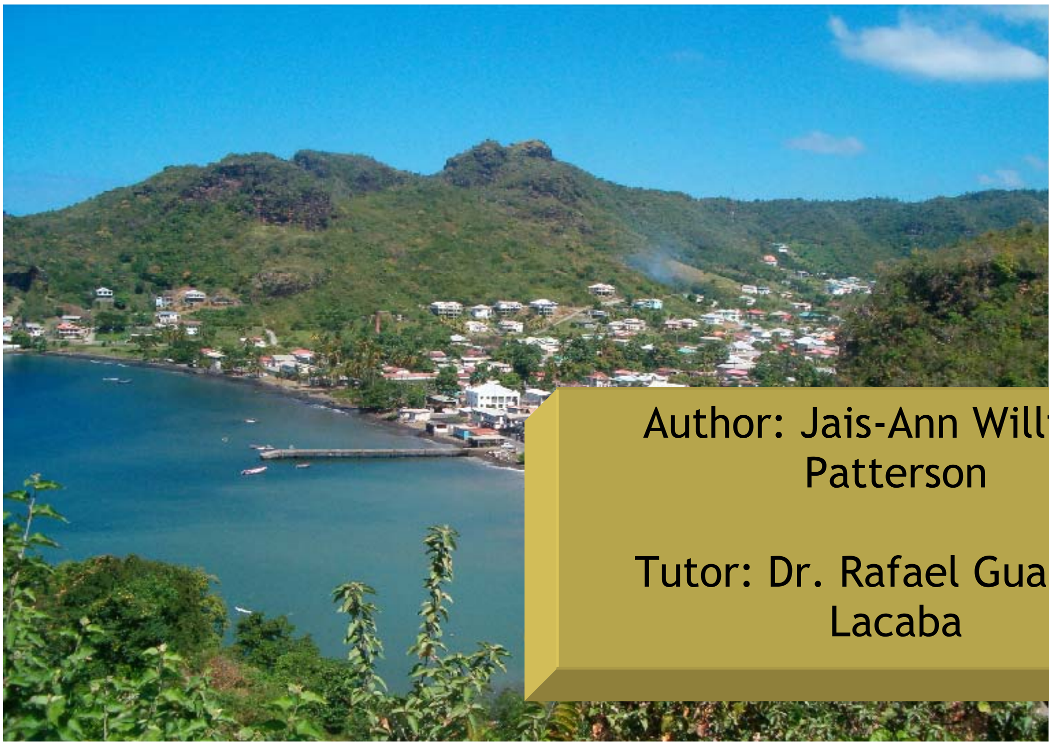
MINISTERIO DE ... ON SUPERIOR

INSTITUTO SUPERIOR MINERO METALÚRGICO DE MOA
FACULTAD OF GEOLOGÍA - MINERÍA

DEPARTMENTO DE GEOLOGÍA

Trabajo de Diploma en opción al título de Ingeniera Geóloga

Titulo: Evaluación de la Susceptibilidad del terreno frente a deslizamientos en San Vicente



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MINISTERIO DE EDUCACION SUPERIOR

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Graduate thesis in option of the title of Geological Engineer

Title: Evaluation of the susceptibility of the Island of St. Vincent towards landslides

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Pensamientos

Landslide at Maroon Hill-St. Vincent

"Con el caer continuo de los ríos por el haz de la tierra, la humedad va minando asiduamente las junturas de la piedra, y día tras día va llevándose partículas…. Esta fisura, practicada pertinazmente en una labor de siglos, llega de tal manera a debilitar las partes que royó con diente cotidiano, que llega un día en que no puede sobre llevar su peso. Entonces caen los peñones de inmensa pesadumbre: entonces aquel bloque que rodó despeñado al abismo…"

Lucio Anneo Seneca-Cuenstiones Naturals-Libro Cap xii (ED. Aguilar 1957; Pág. 886. Trad. Lorenzo Riber).

"El fruto del Espíritu es amor, gozo, paz, paciencia, benignidad, bondad, fe, mansedumbre, templanza; contra tales cosas no hay ley"
"But the Fruit of the Spirit is love, joy, peace, patience, kindness, goodness, faithfulness, gentleness and self control. Against such things there is no law

Gálatas 5:22-23

Acknowledgements

I sincerely wish to express my deepest gratitude to God for his direction on my life and for the way he has protected and endowed me with the strength throughout these years.

To my parents Lennox Williams and Annette Commissiong for the sacrifices they have made during these twenty-six years of my life. My sisters Jai-len and Shika for just being there.

To my loving husband, who has been an inspiration, a lover and a friend. Thanks a million baby!

To the following persons who although they might not be connected to me biologically have played an immense role in my life. Browne's and Williams' extended Family, Mrs. Evelyn Jordan and family, Joan Browne, The Baker Family, The Patterson Family, The Moss Family.

To extra special friends- Kasia, Nia, Pearl, Sherry……

To my dear brothers and sisters with whom I had the privilege to share those challenging yet exciting unforgettable years in Cuba. (Evert big brods-, Alanzo, Anika l'il sis, Lyn, Jared, the collective of Caribbean Students at Moa and my Cuban classmates, Yanquiel, Yanara Katuiska…)

To two dear Cuban families who have made home away from home a pleasant place to be. Dr. Jorge Felix- Dalia del Pilar Perez and family and Dra. Teresa Galano and Family

To my dear Professor and Tutor Dr. Rafael Guardado and family - thanks a million for your unconditional guidance, dedication in contributing to my development as an Engineer .

Special thanks are also due to Profe Yuri Almaguer for your paramount guidance and special attention.

To all the affiliated and non-affiliated professors of the Department of Geology, words cannot express how grateful I am for your unselfish support.

The Rector Vega and personel at Rectoria, Danilo Chachabal and personel at Extensión Universitaria. Elvita and Staff at International Relations.

To the Government of St. Vincent and the Republic of Cuba, The Prime Minister Dr. Hon Ralph Gonsalves, the Ministry of Finance and Foreign Affairs Ministry Of Transport Works and Housing with special mention to the staff and affiliates of the Chief Engineers and Drawing Office, Ex Chief Engineer Mr. John Peters and the PS Snagg, Geologist Aisha Samuel and staff of the Seismic Unit Ministry of Agriculture, Dr. Richard Roberts of the UWI St. Augustne, the Director of Audit Mr. Michael Da Silva, Ms Mathews and Mr. Morgan of the Services Commissions Dept, Physical Planning- Mr. Campbel and Mr. Bowman, The Central Water and Sewerage Authority, Manager and Staff of KFC, The New Testament Church of God.

Others who are too numerous to mention:

Nothing would have been possible if it was not for your undying unselfish support!

MUCHISIMAS GRACIAS!

CHAPTER 1

- **Climate**
- **Physiographic Characteristics:**
- **Relief and Geomorphology**
- **Hydrographic Network**
- **Geology**
- **Stratigraphy/ Lithology**
- **Volcanism**

CLIMATE

The climate of St. Vincent and the Grenadines is tropical; with temperatures ranging from 18 to 33 ^{0}C.Temperatures in the interior of St. Vincent tend to be cooler at higher elevations, Average annual rainfall ranges from 1 500 mm on the coast to 1 800 mm in the central mountains, resulting in a number of microclimates, especially on the main island.

According to the local meteorological office St. Vincent and the Grenadines seem set to experience an above normal May - July rainfall regime this 2005 year. Evapotranspiration amounts to approximately 50 inches a year along the coastal areas of St. Vincent decreasing progressively with altitude (going towards highlands).

According to the latest Precipitation Outlook issued by the Caribbean Institute for Meteorology and Hydrology (CIMH), the rainfall regime expected look as follows:

- 65% Above Normal rainfall
- 25% About Normal rainfall and
- 10% Below Normal rainfall

There are two seasons – a dry season from January to May and a rainy season from June to December. The island is situated in the hurricane zone and is still vulnerable to the effects of hurricanes. Surges and tidal motions caused by hurricanes have a disastrous impact on the coastline. Heavy rains that follow the storms cause erosion and landslides.

The island has a tropical marine type of climate, being affected by the prevailing Northeast Trade winds throughout the year.

Tropical Storms: The geographical location of SVG (61° W longitude and 13.1°N latitude) falls in the path of hurricanes and tropical storms originating in the Atlantic. Two main meteorological systems, the subtropical anticyclones and the inter-tropical convergence zone, influence local climatic conditions Fortunately, because of the islands low latitude, most tropical storms originating along the west coast of Africa have drifted further north by the time they hit the Caribbean Sea. Between 1980 and 1990, five tropical storm systems of varying intensity affected SVG (Table 6), but none of these storms were direct hits. In 1980, storm surge from Hurricane Allen forced the village of Gorse to relocate inland after the destruction of several homes. The same storm damaged the entire eastern coastline.

Storm	Year
Allen	1980
Danielle	1986
Emily	1987
Isaac	1998
Arthur	1990
Lenny	1999

Table 6: Tropical Storms Affecting St. Vincent and the Grenadines over the Last Two Decades

Although SVG did not receive any direct impact of the triple storm systems of 1995 - Iris, Luis, and Marilyn - coastal areas received considerable damage from storm surge associated with these systems. Tailwinds from Iris caused more than EC$1 million worth of damage to the port of Kingstown, including the deep-water pier.

Even though SVG did not receive a direct impact from the very unusual Hurricane Lenny, damages caused by the storm system were significant. Not only did hurricane Lenny originate in the Caribbean Basin, but it did so late in the season (November 15-19, 1999). It traveled from west to east at low latitude and impacted countries far from its track. The hurricane reached a strong category 4 Saffir-Simpson scale with winds of 240 km/h. It caused a total of 13 deaths on several Caribbean islands (NOAA, 1999).

Particularly in SVG, the hurricane produced flooding in coastal areas of the city, damaged a total of five houses, and washed away three houses and one shop. The National Disaster Coordinator estimated that total damage to houses, beaches, and the road network system was close to EC$386,250.00. The major damage observed was to the newly built EC$48.5 million Cruise Ship Complex in the capital. More than EC$2.5 million would be required to carry out restorative work to the complex (UWI, 1999).

Photo 1 Storm surge over new Cruise Ship Terminal

PHYSIOGRAPHIC CHARACTERISTICS:

Saint Vincent and the Grenadines is a small island developing state in the Eastern Caribbean chain of islands, situated at approximately 13º 15' N and 61º12' W. It comprises 30 islands, inlets and cays with a total area of 150.2 square miles (389 sq km). The volcanic island of Saint Vincent, with an area of 132.8 square miles (344 sq km), is mountainous and rugged, with numerous rivers flowing in deep, narrow valleys over short distances to the sea. The highest peak, Mount Soufrière standing at 3952 ft (1,234 m) in the northern part of the island, is associated with a stratovolcano, the Soufrière volcano. The islands of the Grenadines stretch over a distance of 45 miles to the south of the main island, St. Vincent. They are much smaller than the island of St. Vincent, less rugged and possess white sandy beaches.

Photo 2. Typical view of physiographical characteristics de St. Vincent

Structurally, St. Vincent has a central north-south mountain chain with numerous valleys that drain to the narrow coastal belt. The mountains consist primarily of pyroclastics dating back to two major volcanic eruptions during the Pleistocene Era. St. Vincent, one of the youngest of the Antillean volcanic islands, is perched on the edge of the Caribbean and North American tectonic plates. Over time, magma formed along this subduction zone has been extruded by volcanoes as lava, giving rise to the Antillean arc. St. Vincent is one of the few places where the extrusion is still occurring. La Soufrière has had five major eruptions since European settlement began--in 1718, 1812, 1902, 1971, and 1979. Most of these have been violent and accompanied by ash falls, mudflows, and avalanches of incandescent gases. The black sand beaches of the island reflect their volcanic origin (CCA, 1990).

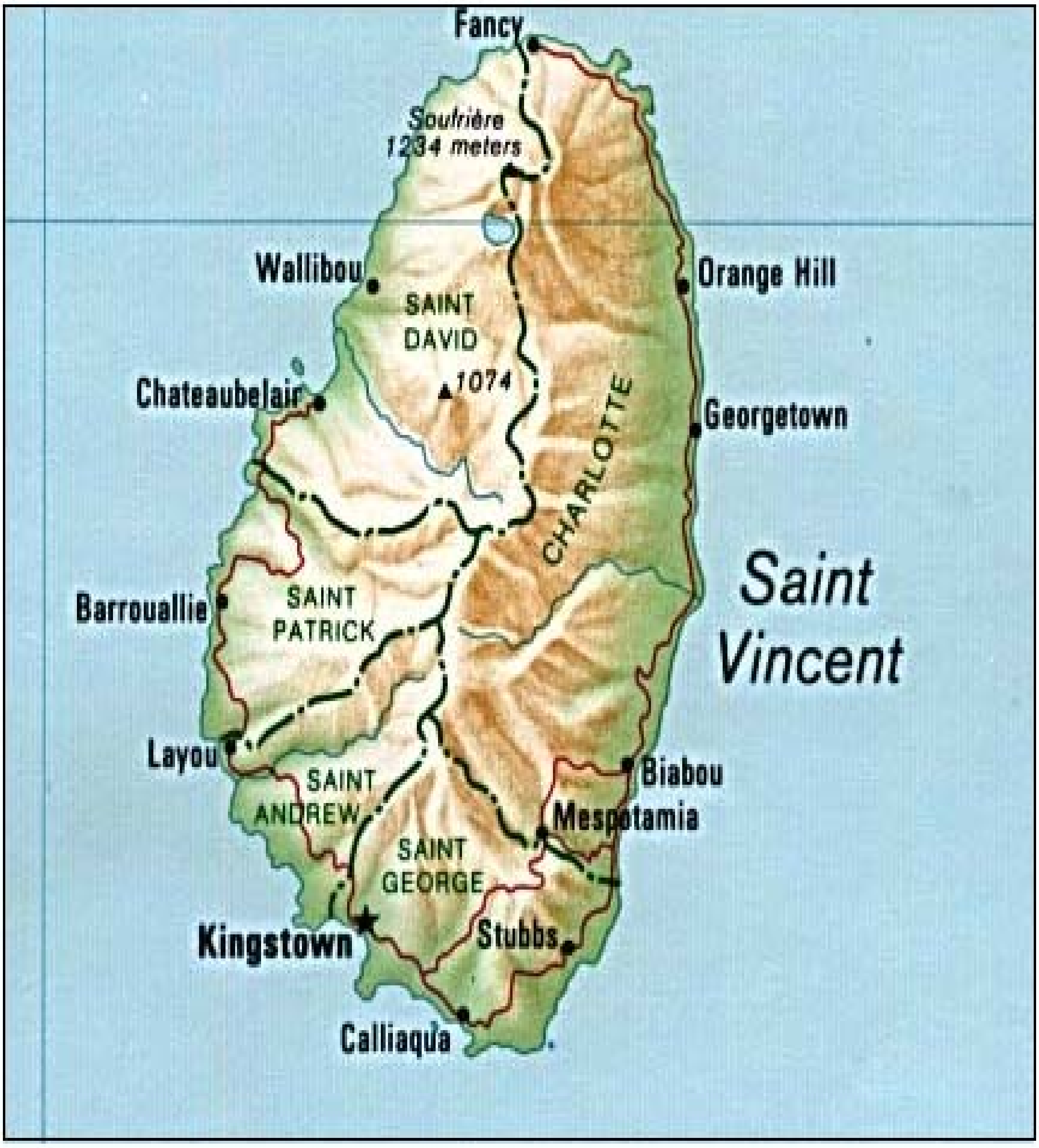
St. Vincent is characterized by rugged terrain with wet upland forests and numerous rivers. The soils of the island are fertile, with ample rainfall supporting a wide variety of agricultural commodities, of which bananas are the most important cash crop. Yet because of a scarcity of prime agricultural land, encroachment onto steep slopes at higher elevations is contributing to landslides and increased sediment transport. At the same time, building patterns along the immediate coast are increasing vulnerabilities in coastal villages and resort communities.

It is estimated that 50 percent of the island consists of slopes over 30 percent and only 20 percent of slopes less than 20 percent. La Soufrière occupies most of the northern fifth of the island and is separated from the central mountain chain by a deep trough .Two Rivers run through this trough – the Rabacca, which drains to the east, and the Walliabou, which drains to the west. The major peaks in the central ridge are Richmond, Mt. Brisbane, Grand and Petite Bonhomme, and Mt. St. Andrews. From La Soufrière, the rugged hills slope to the sea and then give way to several little islets and cays that form the Grenadines. Some of these cays appear as reefs cresting at low tide. The Grenadines are much smaller and as a rule less rugged than St. Vincent. They are more likely to have white sandy beaches due to coral-reef deposition. The protected waters of Tobago Cay are designated as a marine sanctuary. More intensive tourism development is affecting water quality and placing stress on nearshore coral reefs in both the Grenadines and St. Vincent. Located in the lower Grenadines above Grenada is an underwater volcano named Kick 'em Jenny. This is the only known submarine volcano in the Lesser Antilles and appears to be the most active volcano in the region at this time. Its summit lies at a depth of 160 m below sea level (CCA, 1990).

RELIEF AND GEOMORPHOLOGY

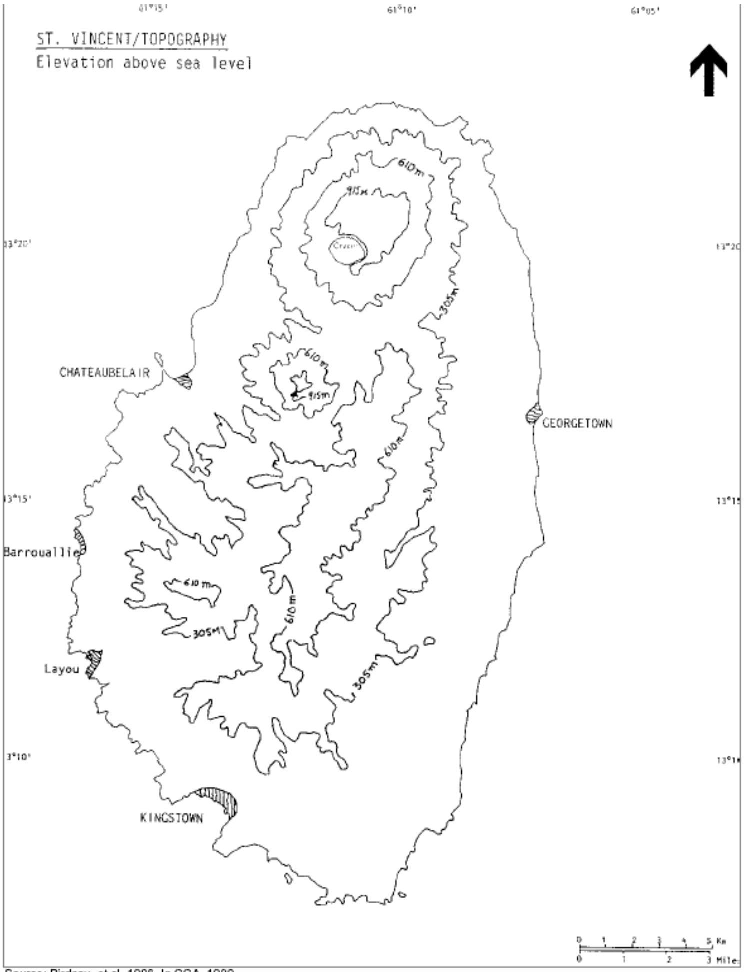
St. Vincent is roughly oval in shape with the central spine of mountains running from north to south and steep ridges radiating to the east and west. The highest mountains are in the north (The La Soufrière Mountains). In one of the peaks lies La Soufrière volcano, this last erupted in 1979. Other mountains in the range from North to south) include Morne Garu Mountains, Grand Bonhomme, Petit Bonhomme and Mount St. Andrew. A large number of very steep lateral ridges emanate from the central massif culminating in high almost vertical cliffs on the leeward coast while the windward coast has wider flatter valleys and truncated which are lower and more rounded than most of the leeward coast.

Rainfall depends on topography, ranging from less than 600 mm along leeward coasts in rain-shadow to over 5000 mm on windward slopes of mountains. Most inland areas have annual rainfall within the 1500-2000 mm per annum range. The central part of the island is covered by tropical rainforest vegetation, mountain forest and secondary rain forest that provide habitats for a wide range of flora and fauna.



Map 2

Relief Map of St. Vincent



Source: Birdsey, et al.,1986. In CCA, 1990

Map 3
<u>Elevation above se level</u>

GEOLOGY

Existing Information with respects to the geology of the island has been mastered by Vincentian Geologist Dr. Richard Robertson. The following is a synthesis of information penned by Dr. Robertson.

“The island of St. Vincent is entirely volcanic and Rowley (1978a) observed that there is "roughly an even distribution of lava flows and pyroclastics". However, recent mapping suggest that there is much variation in this distribution, so that at some centres (e.g. South-East Volcanics) lavas are dominant while at others (e.g. Grand Bonhomme Volcanic Centre), volcaniclastics predominate. Rowley (1978b) estimated that 55% of the island was mantled by well-bedded, pyroclastic fall deposits (the Yellow Tephra Formation), produced by eruptions of the Soufrière volcano during the late Pleistocene.

The rock types exposed on the island fall into four compositional groups: basalts; basaltic-andesites; andesites, and xenoliths of coarse-grained plutonic and metamorphic character. Basalt is generally the most abundant rock type in the most southern parts of the island while basaltic-andesites dominate further north. Basaltic magmas are most common during the early stages in the evolution of individual volcanic centres and andesites are most common as dykes and as the last stage dome or central plugs, which occupy the vent at some centres.

See geological composite map in **Annex – map 8.** Structurally the island is aligned along a north-south axis. Slope gradients along the west of the central axis of the island are significantly greater than gradients on the east. No field evidence has been found of faulting but almost all the major river courses on the island appear to be structurally controlled. An emergent coastline found along the east coast has been suggested by Rowley (1978a) to be due to Plio-Pleistocene uplift. Erosion has severely dissected the southern volcanic centres and original structures cannot be readily identified. Arcuate scarp features located at Grand Bonhomme, Morne Garu and the Soufrière volcano have been attributed to relict caldera or collapse structures (Rowley, 1978a; Sigurdsson and Carey, 1990; Geotermica Italiana, 1992). A number of cold mineral springs are located in the southern parts of the island but fumarolic activity is confined to the Soufrière volcano.

St. Vincent has been divided into four major geologic regions: the South-East Volcanics, and the Grand Bonhomme, Morne Garu and Soufrière Volcanic Centres (Robertson 2003); based an examination of of the topography field geology, geochemistry and previous work undertaken on the island.

The pre-Soufrière Volcanic centres of St. Vincent consists of the South-East Volcanics and the Grand Bonhomme and Morne Volcanic Centres (Robertson, 2003).

The South-East Volcanics is the most southerly geologic region on the island. It is a dissected landscape of rounded hills with low topography (<210 m), which extends from the Warrawarrow River in the west to the extensive Yambou lava flow in the east. The area is dominated by red scoriaceous basaltic spatter interbedded with and often overlying, massive to well-jointed basaltic lava flows, which are intruded by dykes. It contains the oldest rocks exposed on the island (2.74 ± 0.11 Ma; Briden, et al., 1979) and is mostly overlain by fine-grained yellow ash, which are correlated with late Pleistocene Yellow Tephra erupted by the Soufrière volcano (Hay, 1959, Rowley, 1978b). The youngest deposits exposed in the area are alluvial silt, sand and gravels found in the river valleys.

The Grand Bonhomme Volcanic Centre extends from Argyle to Colonarie in the east and Sion Hill Bay to Chateaubelair in the west. It is the largest geologic region on the island and is interpreted as a large stratovolcano with interbedded sequences of block and ash pyroclastic flow deposits, ashfall deposits, lava flows and subordinate domes. The landscape is heavily forested and the interior inaccessible and composed of deeply weathered lavas and volcaniclastic deposits. This volcanic centre is a composite of several eruptive centres that are now represented by the topographic highs of Grand Bonhomme (970 m), Petit Bonhomme (747 m), Mount St. Andrews (735 m) and an unnamed peak (1021 m). These peaks are central domes or plugs of volcanoes that coalesced to form a large composite volcanic centre. Previous dating of lavas from the western flank of the Grand Bonhomme Volcanic Centre by Briden et al (1979) obtained ages of 1.33 ± 0.09 and 1.18 ± 0.10 Ma respectively for lava flows at Westwood and Chateaubelair.

The Morne Garu Volcanic Centre occurs immediately to the north of Grand Bonhomme and consists of Mount Brisbane (932 m) to the east and Richmond Peak (1074 m) to the west. These two peaks are the remnants of an eroded Morne Garu crater or caldera that is estimated to have been 3 km in diameter (Sigurdsson, et al., in prep). Morne Garu is largely inaccessible and the underlying volcanics are extensively covered with fine-grained yellow ashfall deposits. Recent ages obtained by Heath et al. (1998, 1998) from lavas at Indian Estate (11 ± 14 ka) and Black Point (180 ± 20 ka) on the western flank of Mount Brisbane indicate that volcanism may have been much younger at this centre and may have overlapped with the Soufrière Volcano to the north. The major formations exposed are lava flows, undifferentiated volcaniclastics, red scoria bombs and yellow ashfall deposits. Reworked alluvial deposits occur in the major river valleys

VOLCANISM

La Soufrière Volcano

La Soufrière is the youngest volcanic centre on St. Vincent. It occupies the northernmost third of the island and is considered to be the only volcano that is likely to erupt in the future. No detailed geological map of the volcano exists although the principal formations have been identified (Robson and Tomblin 1966; Rowley 1978; Sigurdsson 1981; Robertson 1992). The volcanic edifice consists of an older strato-cone or Somma (2.5 km diameter), which forms a steep arcuate ridge to the north, and a younger pyroclastic cone, which has been the source of historic (post 1700) eruptions, nestled within this crater. The older stratovolcano is thought to have been active during the late Pleistocene (~700 ka). The main crater of the Soufrière is about 1.6 km in diameter and is 300-600 m in depth. Located immediately to the northeast is the 1812 crater an oval shaped depression (~450 m diameter and 60 m depth), from which the volcano erupted once (27 April to 6 June 1812).

Four principal rock formations have been identified in the crater (Sigurdsson 1981). The Debris Flow formation is the lowest exposed formation and is a massive matrix supported deposit consisting of angular basaltic blocks (max. 3m diameter), in a poorly sorted sandy matrix. . Overlying this is the Brown Tuff, a 20 m thick, well-bedded succession of ash and scoria airfall deposits and minor surge layers, which contain angular basaltic lithic fragments. Thick basaltic andesite and andesite lava flows, which form the lower half of the vertical eastern and northern crater walls, are called the Crater Lavas formation. The topmost deposit exposed in the crater consists of a thick sequence of pyroclastic flow and airfall deposits, which are called the Pyroclastic Formation.

The oldest formations exposed on the flanks of the volcano are basaltic lavas, which form the remnants of the pre-historic Somma crater. These are overlain by beds of pumiceous yellow tephra (the Yellow Tephra Formation), which have been correlated with yellow pyroclastic fall deposits that mantle the island (Hay 1959a; Rowley 1978b). The yellow tephra units are often reversely graded and contain airfall beds made up of black scoria and yellow lapilli-sized pumiceous tuff that range in composition from basalt to andesite. In the river valleys, the Yellow Tephra is overlain unconformably by alluvial deposits, basaltic andesite pyroclastic flow deposits s and mudflow deposits. The mudflow deposits are massive, thick (up to 25m) and contain angular blocks of basalt and basaltic andesite. On the lower flanks of the volcano, the mudflow deposits are overlain and interbedded with basaltic andesite pyroclastic flow deposits, thin tephra fall deposits and minor alluvial deposits. The pyroclastic units are discontinuous, channel-fill deposits that show little variation in lithology. There is little distinction between deposits erupted during historic eruptions, apart from deposits from the 1979 eruption which are distinctively rich in basaltic andesite.

Historical Eruptions

During the past 4000 years the volcano has had an average of one explosive eruption every 100 years. The Soufrière volcano has displayed two distinct types of eruptions in the past (Aspinall, Sigurdsson, and Shepherd 1973):

Explosive eruptions: These are the typical "Soufrière" eruptions. They are highly explosive magmatic eruptions[1] usually preceded by frequent, strong earthquakes. Rapid rates of production result in the ejection of large volumes of new material in ashfalls from eruption columns[2] and as pyroclastic flows and surges[3]. This type of activity is exemplified by the 1902-03 and 1979 eruptions.

Non-explosive or Effusive eruptions: This type of eruption is effusive, unaccompanied by earthquakes, and involves smaller volumes of new material than type 1. This type of eruption is exemplified by the 1971-72 eruption.

A cyclical pattern of eruptive activity during the past 250 years with alternate explosive and effusive eruptions has been suggested for the volcano (Aspinall et al. 1972).

Future Eruptions

Short-term eruptive activity

In the short-term (i.e. <100 years), the volcanic hazard at the volcano is expected to be quite similar to that experienced in the historic past. The volcano would become hazardous during periods of eruptive activity, remaining for the intervening periods a threat that must be catered for in national development plans. Activity in the short term could be either explosive or effusive or both. Both events may be separated in time but can be regarded as part of a two-phase pattern of eruption. The scale of the explosive phase is expected to range from that of a 1979-type event to that of a 1902-type event. The effusive phase is expected to be quite similar to the 1971-72 eruption. The specific characteristics of these phases, as well as the hazards they are expected to pose are outlined below.

Long-term or worse case scenario

In the longer term, allowances must be made for the possibility of cataclysmic Plinian to Ultraplinian activity fluctuating with Strombolian type eruptions. Although there are no historic records of such activity, the presence of thick late Pleistocene ashfall deposits throughout St Vincent as well as thick scoriaceous ashfall on the lower flanks of the volcano demonstrates that the Soufrière has the capacity for events of this kind.

HYDROGRAPHIC NETWORK

St. Vincent has a very interesting and unique hydrographic network; it is very dense and the rivers run mainly from the central dome elevations in the rain forest towards the low lying coast. Based on the 1:25000 hydrographic map the drainage system is predominantly dendritic.

From an analysis of the stream order, within the network it was observed that there are a high number of first and second order streams, a notable amount of the third order while those of the fourth order is very rare or even absent in many parts of the island.

The network also includes several waterfalls and small rapids which are dispersed in many different locations due to the topographical and lithological setting of the island which include deep gullies, valleys and ravines.

It can be noted that all the rivers flow uniformly from the La Soufrière Volcanic dome area which is located in the north of the island, the rocks found in this area are predominantly (volcanic rocks) adesitic/basaltic and other volcanic deposits. These geological factors aforementioned encourage higher levels of surface runoff and lower levels of infiltration of rain water on the entire island.

Mainland St. Vincent boasts an abundance of surface water in rivers and streams.
Although there has been no significant decline in precipitation in SVG over the last ten years, normal flow volumes in streams and rivers have diminished. This situation is due largely to deforestation and construction activity that facilitates excessive runoff and little soil penetration. Additionally, competition for fresh water is increasing. Population growth, industrial development, irrigation, and electric power generation are all demanding an increasing quota of this limited resource.The following indicates primary water uses by watershed. Competing uses include domestic water use, hydroelectric demand, and irrigation. Any significant decreases in precipitation will severely affect development in SVG.

Major Watersheds	Water Use
Cumberland	Hydropower generation; domestic use
Buccament	Domestic; limited irrigation
Majorca	Domestic
Montreal	Domestic; limited irrigation
Colonarie	Hydropower generation; domestic use
Rabacca	Irrigation

Tabla 7: Primary Water Use by Watershed

LITHOLOGY AND STRATIGRAPHY

St.Vincent, like all the other islands of the Lesser Antilles, is predominantly volcanic in origin, thus is almost completely composed of volcanic rocks, with a few sedimentary deposits. The rock types found are the following: Tuffs (agglomerate and conglomerates); Alluvium and beach sands, Ash and scoria fall(1902-3 /recent), Ash and scoria basalt, basalt outcrops, Lavas, deeply buried Basalts, Pyroclasts and mudflow deposits (1902-3/recent); and gravels.

The La Soufrière volcanic dome area is made up of pyroclastic mudflow (1902-3/recent), ash and scoria. The surrounding area constitutes of basalt outcrop, ash and scoria. The entire central and western area is made up of pyroclastic flow and lavas. The south and southeast is made up of deeply buried basalts and lavas underlying basalts.

From a small analysis of the geological map scale 1:25000 and the lithological make up of the island, it can be concluded that the basalts were deposited before the lavas, because the lavas are shown to be below them.

The sedimentary deposits found on the island are most likely of a fluvial nature, deposited by the rivers over a period of time; some of them however are beach deposits.

CHAPTER 2

- Introduction
- Typology of Landslides

- **Causal and Condicional Factors**
- **Methodology of Investigation**

INTRODUCTION

The United Nations declared the decade of the 90's as the "Decade for the Reduction of Natural Disasters."

For many countries, by means of development, this decade also represents a period in which, to confront natural disasters is as synonymous to development: the cost of rehabilitation and reconstruction after the consumption of the available capital, reduces significantly the root of new resources.

The losses are terrifying! After the 1960's natural events like earthquakes, hurricanes, flooding, drought, desertification and landslides in the region of Latin America and the Caribbean have taken the lives of 180,000 persons, affected 100 million more and causing losses and damages to property. The index of destruction has increased decades after decades.

The adverse effects on employment, balance of trade and in the external indebtedness have been felt years after these disasters occur. The activities which have as its purpose the promotion of development, frequently aggravates the impact of the natural events. The worst cases occur in the less developed countries and specifically, the poorest sectors of these countries, are the ones who suffer the effects most.

Fortunately, of all the problems of the environment, natural risks are the most manageable: they can be identified rapidly, there are also available means of mitigation and the benefits of reducing vulnerability can greater than the costs.

Moreso, the experience has shown that the impact of these natural events can be reduced. The improvement of the systems of prevention and evaluation has reduced extraordinarily the number of death caused by hurricanes. The combination of structural and non structural means of mitigation has shown a decrease in the effects of earthquakes, landslides, flooding and drought.

The countries of the region have been slow to take action in the reduction of the vulnerability or solicit finance or we can very well say that he financial organisms that are slow to lend or pay very little attention to this aspect.

Despite the effectiveness of the many means of mitigation in function to cost, more than 90 percent of the International Funding designated for the management of natural disasters of this region, are consumed in preparation activities of, assistance, rehabilitation and reconstruction of disasters, leaving only 10 per cent designated for activities of prevention.

Nevertheless, Modern technology has provided us the option of facilitating the process of landslide mapping to a level of effectiveness. During the elaboration of this thesis a number of software were utilized.: Arc View, AutoCAD Map, Map info y Surfer. .

Arc View is a desktop Geographic Information System which allows the creation of intelligent, dynamic maps using data from virtually any source and across most popular computing platforms. It provides the tools to let you work with maps, database tables, charts, and graphics all at once. You can also use multimedia links to add pictures, sound, and video to your maps. It has a set of wizards, dialog boxes, and tools that provide easy-to-use access to advanced functionality. Create buffers, add callout labels, and perform spatial operations such as clip and merge with the help of wizards.

- **Easily use data in varying projections and datum** - The **ArcView 3.2** Projection Utility is a stand-alone wizard-based tool that lets users project shapefiles from geographic coordinates to projected coordinates or from one projection to another. It also performs datum transformations on shapefiles. The **ArcView 3.2** Projection Utility is available on Microsoft Windows platforms only
- **Powerful query and analysis** - **ArcView 3.2** gives you hundreds of new ways to query and analyze your data. You can query your data according to location, content, proximity, and intersection. For example, you can add data to maps to find the geographic factors that drive trends and distributions or locations at which particular characteristics coincide. You can aggregate data geographically by summarizing it based on areas such as census tracts, states, or sales territories. You will literally start to see things in a new light. Furthermore, the output from one analysis can be used as the input to the next analysis, enabling you to create advanced geoprocessing applications
- **Professional-quality maps and data displays**- **ArcView 3.2** provides automatic data-driven classifications, color ramps of data ranges, graduated symbols, chart symbols, standard deviations, normalization, and business graphics. **This program** comes with a huge selection of TrueType fonts and symbols. It can also be used with many types of output devices such as printers, plotters, and film output devices

- **Sophisticated reports - ArcView 3.2** allows you to easily generate professional reports, including embedded maps and charts, which help you more successfully communicate the results of your GIS analysis. The report writer extension integrates the industry-leading Crystal Reports report generation and editing.

It allows the creation of your own basemap layers with. You can modify existing maps to meet your exact needs; or if no maps currently exist, you can create your own quickly and easily. You can edit on-screen with the mouse or, for more accuracy, use a digitizing tablet (support for digitizing only available for Windows platforms).

The landslide hazard map can contribute to planning for a project's implementation. There are two situations when this map may prove beneficial, both of which are related to mitigating the potential effects of landslides. In one case, it is conceivable that if areas identified with a moderate landslide hazard are targeted for development, greater detail of those areas is needed to ensure the project design compensates for this greater hazard potential. For example, moderate or higher hazard areas may not be entirely avoidable along a proposed road. Detailed investigation can provide information on groundwater conditions and on the stability characteristics of soil and rock to ensure a stable design (Morgenstern and Sangrey, 1978).

In another case, existing infrastructure or communities may be located in previously unidentified high hazard zones. These areas should be given priority for introducing some measure of mitigation.

For example, the effect of landslides issuing into an inhabited area from nearby mountain canyons might be mitigated by constructing debris basins to trap most of the material. Where such mitigation is impossible and the risk is identified as being extremely high, relocation to a safer area may be considered.

A detailed hazard map for the specific site in question is necessary as well as preparation of a detailed landslide inventory is now necessary. The susceptibility of a given area to landslides can be determined and depicted using hazard zonation. A landslide hazard map can be prepared early in the planning study and developed in more detail as the study progresses. It can be used as a tool to help identify land areas best suited for development by examining the potential risk of landsliding. Furthermore, once landslide susceptibility is identified, investment projects can be developed which avoid, prevent, or substantially mitigate the hazard.

Determining the extent of landslide hazard requires identifying those areas which could be affected by a damaging landslide and assessing the probability of the landslide occurring within some time period. In general, however, specifying a time frame for the occurrence of a landslide is difficult to determine even under ideal conditions. As a result, landslide hazard is often represented by landslide susceptibility (Brabb, 1985). Landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. To simplify these concepts, landslide susceptibility will be referred to as landslide hazard .Comparing the location of an area of proposed development to the degree of landslide hazard present enables the planner to estimate the landslide risk. This can be used to define land use capability and identify appropriate mitigation measures.

Landslide Hazard**:** as represented by susceptibility, which is the likelihood of a potentially damaging landslide occurring within a given area.

Vulnerability**:** the level of population, property, economic activity, including public services, etc., at risk in a given area resulting from the occurrence of a landslide of a given type.

Risk (specific): the expected degree of loss due to a particular landslide phenomenon.

A landslide hazard map which identifies areas of differing landslide potential may be generated. The need for such landslide hazard information may vary according to the future land use. The degree of landslide hazard present is considered relative since it represents the expectation of future landslide occurrence based on the conditions of that particular area. Another area may appear similar but, in fact, may have a differing landslide hazard due to a slightly different combination of landslide conditions. Thus, landslide susceptibility is relative to the conditions of each specific area, and it cannot be assumed to be identical for a similar appearing area.

Even with detailed investigation and monitoring, it is extremely difficult to predict landslide hazards in absolute terms. Sufficient understanding of landslide processes does exist, however, to be able to make an estimation of landslide hazard potential. The planner can use this estimation to make certain decisions regarding site suitability, type of development, and appropriate mitigation measures. Thus, the planner is determining acceptable risk.

Natural changes as well as human-induced changes can affect the susceptibility to landslides and must be understood when assessing the landslide potential of an area.

Landslide hazard information serves as one of the many components in an integrated development planning study. Since landslide activity can adversely affect or interfere with human activity, landslide hazards constrain or limit land-use capability. For this reason, it is important to identify relative landslide hazard levels early in the planning process. This permits planners to determine the degree of landslide risk that is acceptable or unacceptable to a development program. Decisions can then be made regarding which of these measures will be taken: avoidance, prevention, or mitigation of existing and future landslide hazards in the development program.

TYPOLOGY OF LANDSLIDES

Landslides are caused when the force of gravity pulls rock, debris or soil down a slope. They are one of the forms of erosion called mass wasting, which is broadly defined as erosion involving gravity as the agent causing movement. Because gravity constantly acts on a slope, landslides only occur when the stress produced by the force of the gravity exceeds the resistance of the material. This is distinct from some other forms of erosion caused by running water, for instance, which occurs when precipitation falls on a slope or within a channel carrying a stream or river.

The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. Other classification systems incorporate additional variables, such as the rate of movement and the water, air, or ice content of the landslide material.

Landslide movement is perceptible and may take the form of falls, topples, slides, or flows. It can consist of free-falling material from cliffs, broken or unbroken masses sliding down mountains or hillsides, or fluid flows. Materials can move up to 120mph or more, and slides can last a few seconds or a few minutes, or can be gradual, slower movements over several hours or days. Accordingly, landslides are recognized on the basis of type of movement.

The most widely used classification scheme divides landslides into different types according to the material being moved and type of movement (Varnes, 1978). Speed of movement and amount of water mixed with the material are secondary parameters defining some landslide types. Recognizing the types of landslides presents in an area helps explain how and where factors have contributed to natural slope instability in the past.

Factors influencing where landslides occur can be divided into two sets, permanent and variable (Sharpe, 1938). Permanent factors are characteristics of the landscape which remain unchanged or vary little from a human perspective. The steepness of a slope or the type of rock, for example, presents changes only with the passage of long periods of time. Permanent factors such as rock type and slope steepness can be recognized and identified for specific landslides long after their occurrence (DeGraff, 1978). By examining existing landslides in an area, it is possible to recognize how permanent factors contributed to these slope failures. Identifying conditions and processes promoting past instability makes it possible to use these factors to estimate future landslides (Varnes, 1985).

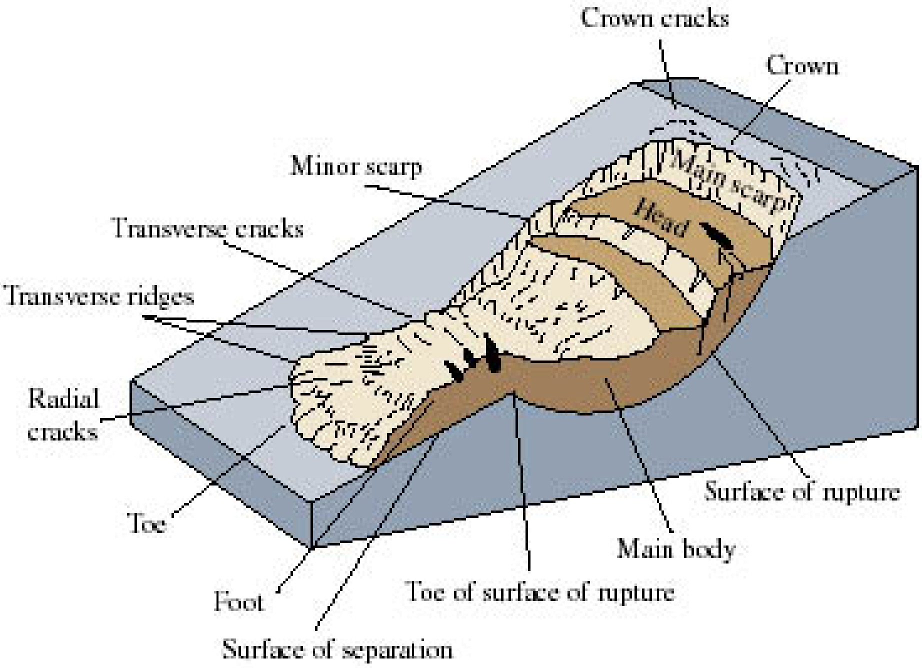


Figure 6.

<u>An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a landslide</u>

NOMENCLATURE

Main Scarp: A steep surface on the undisturbed ground around the periphery of the slide, caused by the movement of slide material away from undisturbed ground. The projection of the scarp surface under the displaced material becomes the surface of rupture.

Minor Scarp: A steep surface on the displaced material produced by differential movements within the sliding mass.

Head: The upper parts of the slide material along the contact between the displaced material and the main scarp.

Top: The highest point of contact between the displaced material and the main scarp.

Toe of Surface of Rupture: The intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface.

Toe: The margin of displaced material most distant from the main scarp.

Tip: The point on the toe most distant from the top of the slide.

Foot: The portion of the displaced material that lies down slope from the toe of the surface of rupture

Main Body: That part of the displaced material that overlies the surface of rupture between the main scarp and toe of the surface of rupture.

Flank: The side of the Landslide.

Crown: The material that is still in place, practically undisplaced and adjacent to the highest parts of the main scarp.

Original Ground Surface: The slope that existed before the movement which is being considered took place. If this is the surface of an older landslide, that fact should be stated.

Left and Right: Compass directions are preferable in describing a slide, but if right and left are used they refer to the slide as viewed from the crown.

Surface of Separation: The surface separating displaced material from stable material but not known to have been a surface of which failure occurred.

Displaced Material: The material that has moved away from its original position on the slope. It may be in a deformed or unreformed state.

Type of Movement		Type of Material	
	Bedrock	Engineering	Soils

				Predominantly coarse material	Predominantly fine material
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	Rotational	Few Units	Rock slump	Debris slump	Earth slump
	Translational	Many Units	Rock slide	Debris slide	Earth slide
Lateral Spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)

Table: 8

Classification of landslides

Adapted from Varnes, D. "Slope Movement and Processes" in Landslides: Analysis and Control, Special Report 176, Chapter 2 (Washington, D.C.: National Academy of Sciences, 1978

SLIDES: Although many types of mass movements are included in the general term "landslide," the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides. Rotational slide: This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (fig. 7A). Translational slide: In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting (fig. 7B). A block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move down slope as a relatively coherent mass (fig. 7C).

FALLS: Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs (fig. 7D). Separation occurs along discontinuities such as fractures, joints, and bedding planes and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.

TOPPLES: Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks (fig. 7E).

FLOWS: There are five basic categories of flows that differ from one another in fundamental ways. **a. Debris flow**: A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as slurry that flow downslope (fig. 7F). Debris flows include <50% fines. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility slopes.

b**. Debris avalanche**: This is a variety of very rapid to extremely rapid debris flow (fig.7G).

c. **Earth flow:** Earth flows have a characteristic "hourglass" shape (fig. 7H). The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

d. Mudflow: A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."

e. **Creep:** Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges (fig. 7 I).

LATERAL SPREADS: Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain (fig. 7J). The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state. Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason. Combination of two or more of the above types is known as a complex landslide.

The following figure (Fig 7) gives an illustration of the major types of landslides that exists:

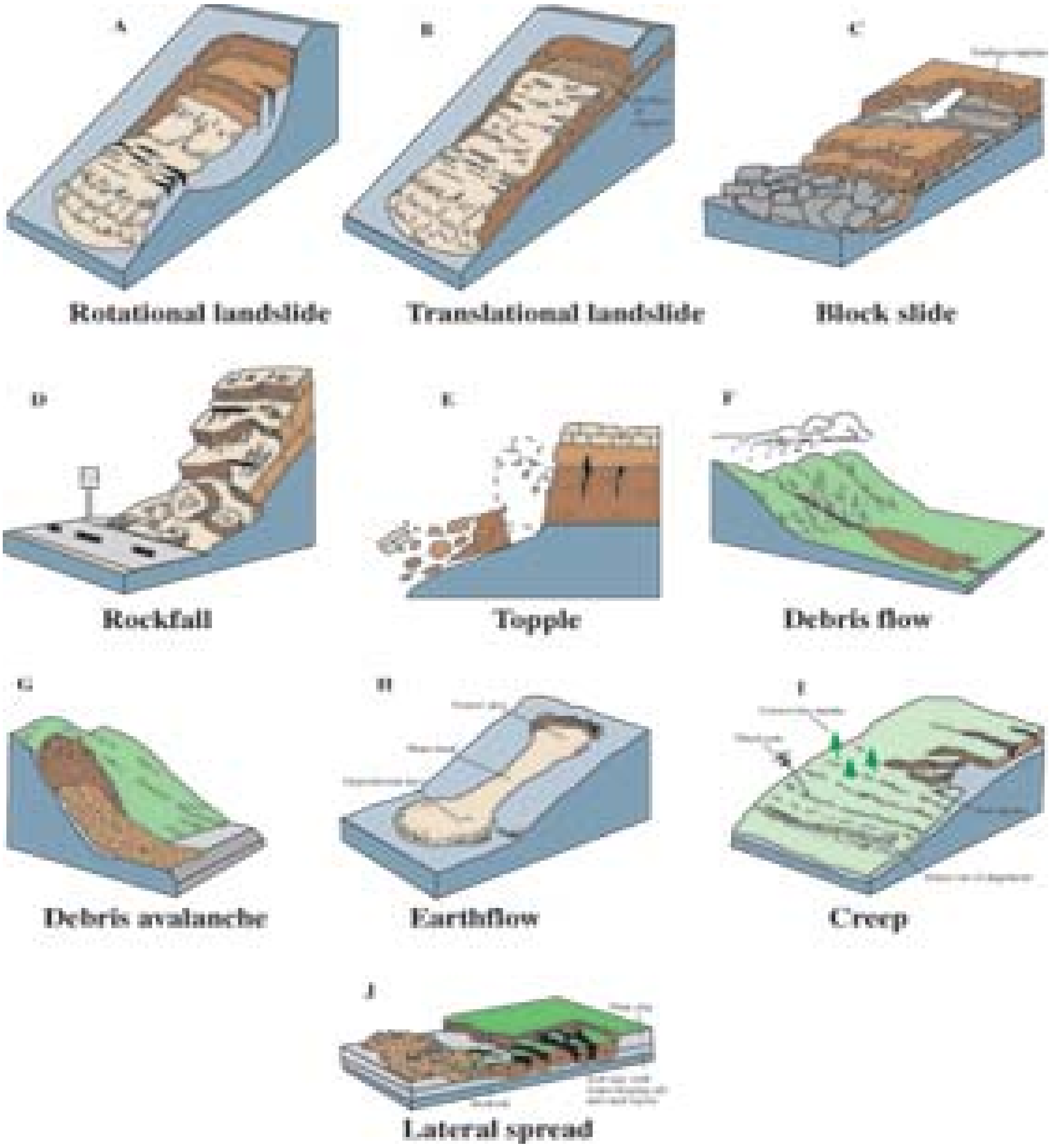


Figure 7.

These schematics illustrate the major types of landslide movement

CAUSAL AND CONDICIONAL FACTORS

Three principles guide landslide hazard assessment. First, landslides in the future will most likely occur under geomorphic, geologic, and topographic conditions that have produced past and present landslides. Second, the underlying conditions and processes which cause landslides are understood. Third, the relative importance of conditions and processes contributing to Landslide occurrence can be determined and each assigned some measure reflecting its contribution (Varnes, 1985). The number of conditions present in an area can then be factored together to represent the degree of potential hazard present.

LANDSLIDE CAUSES

1. **Geological causes**

a. Weak or sensitive materials
b. weathered materials
c. Sheared, jointed, or fissured materials
d. Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth)
e. Contrast in permeability and/or stiffness of materials

2. **Morphological causes**

a. Tectonic or volcanic uplift
b. Deposition loading slope or its crest
c. Vegetation removal (by fire, drought)
d. Shrink-and-swell weathering

3. **Human causes**

a. Excavation of slope or its toe
b. Loading of slope or its crest
c. Drawdown (of reservoirs)
d. Deforestation
e. Irrigation
f. Mining (construction materials)
g. Artificial vibration
h. Water leakage from utilities

Although there are multiple types of causes of landslides, the three that cause most of the damaging landslides around the world are :

Landslides and Water

Slope saturation by water is a primary cause of landslides. This effect can occur in the form of intense rainfall, changes in ground-water levels, and water-level changes along coastlines, earth dams, and the banks of lakes, reservoirs, canals, and rivers.

Landsliding and flooding are closely allied because both are related to precipitation, runoff, and the saturation of ground by water. In addition, debris flows and mudflows usually occur in small, steep stream channels and often are mistaken for floods; in fact, these two events often occur simultaneously in the same area.

Landslides can cause flooding by forming landslide dams that block valleys and stream channels, allowing large amounts of water to back up. This causes backwater flooding and, if the dam fails, subsequent downstream flooding. Also, solid landslide debris can "bulk" or add volume and density to otherwise normal streamflow or cause channel blockages and diversions creating flood conditions or localized erosion. Landslides can also cause overtopping of reservoirs and/or reduced capacity of reservoirs to store water.

Landslides and Seismic Activity

Many mountainous areas that are vulnerable to landslides have also experienced at least moderate rates of earthquake occurrence in recorded times. The occurrence of earthquakes in steep landslide-prone areas greatly increases the likelihood that landslides will occur, due to ground shaking alone or shaking-caused dilation of soil materials, which allows rapid infiltration of water.

Landslides and Volcanic Activity

Landslides due to volcanic activity are some of the most devastating types. Volcanic lava may melt snow at a rapid rate, causing a deluge of rock, soil, ash, and water that accelerates rapidly on the steep slopes of volcanoes, devastating anything in its path. These volcanic debris flows (also known as lahars) reach great distances, once they leave the flanks of the volcano, and can damage structures in flat areas surrounding the volcanoes. Landslide hazard has been determined with a high degree of reliability for only a few locations. These have required careful, detailed study of the Interaction of pertinent permanent and variable conditions in the target area. This can be a very expensive and time-consuming process that is unjustified for the purpose of broad-scale development planning. Landslide hazard zonation is one technique that can be used in the early stage of a planning study.

METHODOLOGY

Preliminary Research (Trabajo de Gabinete)

During the Preliminary Mission of an integrated development planning study, an initial review is made of the type and content of available information. Review was made of the all the existing information available that was pertinent to the study. The availability of geologic, topographic, hydrologic, land use, vegetation maps and aerial photographs were ascertained.

Research was done on the history of landslides and/or disasters caused by landslide events and recollection and compilation was made of the aforementioned. This information is essential for executing a landslide hazard zonation process. Also during this stage of the study, available information was collected and reviewed concerning assessments of natural hazards, including landslides and disasters, which are known to have affected before.

Consultation with made the Seismic Unit, The Central Water and Sewerage Authority, The National Archives, Public Works, Physical Planning, Land and Surveyors Dept, OAS and Disaster Preparedness proved to be very productive although mention must be made of the lack of updated information. During this period a series of basic tasks were undertaken to facilitate the graphical representation of the results including scanning maps, georeferencing and digitizing of maps.

Three principles guide landslide hazard assessment. First, landslides in the future will most likely occur under geomorphic, geologic, and topographic conditions that have produced past and present landslides. Second, the underlying conditions and processes which cause landslides are understood. Third, the relative importance of conditions and processes contributing to landslide occurrence can be determined and each assigned some measure reflecting its contribution (Varnes, 1985). The number of conditions present in an area can then be factored together to represent the degree of potential hazard present.

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Most assessment procedures for landslide hazard zonation employ a few key or significant physical factors to estimate relative landslide hazard. Some methods require a minimum of three factors : distribution of past landslides, type of bedrock, and slope steepness, and a fourth, hydrologic factor may be added to reflect the important role which groundwater often plays in landslide occurrences (Varnes, 1985, and USGS, 1982).

Due limited data information and maps and time, in this study three factors will be utilized, rainfall, landuse and geology/Lithology,and as a preliminary study and base for future studies a cualitative analysis will be done

Field Work (Trabajo de Campo)

The following materials were utilized:

- Digital Camara
- Transportation (compliments the Ministry of Public Works)
- Geological Compass
- Topographic Map (1:25000)
- Measuring Tape
- Stationery
- Picket

***Field team**: Jais Ann Williams, Tutor Dr. Rafael Guardado, Chauffeur Jimmy (MTWH), Geologist Aisha Samuel and staff at the Seismic Unit.*

During field work, a series of field reconnaissance was done in areas in and around the island. Some of the major areas that were covered were, Gomea, Belair, Gibson Corner, Dauphine and Greiggs.

Because of existing potential hazard the first step was to undertake a brief survey to establish whether landslides might have occurred in recent times. An analysis was done of the roads, and river banks as good sites for seeking signs of past landslide occurrence. Assistance was given by local authorities responsible for public works, forestry, and agricultural activities as was proven to be a valuable source of information since they were familiar with cases of past landslides in an area.

Photo3

(Above) *Measuring Landslide Rupture in Greggs*

L- R Dr.Rafael Guardado, Geologist Ms. Aisha Samuel & Eng.Jais Ann Patterson

Over the years officials fro the Public works have had to attend to this road at Greiggs. There are frequent problems of cracking and displacement. This area is located on a slope and in field observation it was determined that the area is set on head scar of an old landslide, so efforts to fix road will always result, over a period of time to rupture.

Factors that contribute to this are, the underlying soil is of very weathered volcanic rock, this type of materials is very non cohesive, the area is practically an accumulator for all run off and infiltration water and to the fact that the terrain is constantly in movement.

Photo: 4

Measuring crack and opening at Belmont SDA Church

Photo:5

Displacement in Belmont

L-R Dr. Rafael Guardado, Chauffeur Jimmy, Angelica Miller

DATA ANALYSIS

Due to a time factor that limited the actual field work, a lot of emphasis was placed on the processing data that was made available in form of maps in digital format and in map sheet.

The maps that were utilized in this study include (geology, landuse, isoyet, hazard map by De graff). They were ascertained in digital format (Corel Draw) and the landslide hazard map by De Graff was only available in map sheet 1: 25 000.

In order to facilitate the processing of the necessary information in the Geographical Information System (GIS), the maps acquired in digital format (Corel draw) were exported to JPEG and were imported into MapInfo and georeferenced with the minimum error possible, they were then digitized. This process included the digitizing of each polygon on the map that was pertinent to the study; the polygons were exported in DXF format.

The maps were then imported to ARCVEIW where the digitizing process was repeated in order to make active all the necessary information on the map.

In ARCVEIW, a table of attributes was created which provide information as to the polygon type, class ,the area of each class was then calculated and aggregated to the table of attributes. To facilitate a more comprehensive, representative version of the information ascertained in ARCVEIW, tables, pie charts and graphs were done in Microsoft EXCEL where calculation of the percentage of area of each class was done.

In ARC VEIW each map was analyzed individually:

Individual analysis of Degraff Hazard Map

Interpreting the likelihood of future landslide occurrences requires an understanding of conditions and processes controlling past landslides in the area of interest. This can be achieved by examining and mapping past landslide activity in the area. Geologic, topographic, and hydrologic circumstances associated with past landslides indicate which natural or artificially created circumstances are likely to produce landslides in the future.

An analysis was done of the relative classification made by Degraff in 1988 of the areas on the island that are susceptible to landslides, with which he made a classification of Extreme, High Moderate and Low. Special attention was given to the areas classified as Extreme and High and attempts were made to calculate the area of these classifications.

Individual analysis of Geology Composite Map

Geology/Lithology influences landslide occurrence in several ways. Weak, incompetent rock depending on its composition and mechanical and physical features is more likely to fail than strong, competent rock. On slopes where weak rock overlain by strong rock is exposed, the difference in strength increases the potential for landsliding in the stronger rock as well since the weak rock tends to erode and undermine the stronger rock.

The strength of a rock mass depends on the type of rock and the presence and nature of discontinuities such as joints or other fractures. The more discontinuities present in bedrock, the greater the likelihood of rock instability. Rock type may exert control on landsliding by influencing the strength of surface material in the area. For example, soils (in the engineering rather than agricultural sense of the term) derived from schists or shales will contain high percentages of clay. These soils will have different strength characteristics than coarser-grained soils such as those derived from granitic bedrock. There are many ways, then, that rock type or structure contributes to the instability.

Analysis was done of the Geology Composite Map with the objective of categorizing the main lithologic type that are present on the island with respects to is stratigraphc and compositional nature, area and location and the physical and mechanical properties of the same

Individual analysis of Land Use

Human activities may increase the natural tendency for a landslide to occur. Landslides which result from development activities are usually the result of increasing moisture in the soil or changing the form of a slope. Development activities such as cutting and filling along roads and the removing of forest vegetation are capable of greatly altering slope form and ground water conditions (Swanson and Dyrness, 1975). These altered conditions may significantly increase the degree of landslide hazard present (Varnes, 1985, and Sidle, Pearce, and O'Loughlin, 1985).

For example, converting a forested area to grassland or one where crops are cultivated can increase the moisture in the soil enough to cause landslide problems (DeGraff, 1979). Or building a road which cuts off the toe of a steep slope can increase landslide susceptibility. It is possible to reduce the potential impact of natural landslide activity and limit development-initiated landslide occurrence by early consideration of these effects (Kockelman, 1985).

An analysis was done of the land use map, summarising the principal landuse classes there are on the island, determining that landuse type that is most predominant and taking into consideration, the location, whether or not these landuse are in the rural or urban areas of the island

Analysis of Isoyet Map

Water is recognized as an important factor in slope stability-almost as important as gravity. Information on water table levels and fluctuations regarding St. Vincent is rarely available. In order to represent the hydrologic factor in landslide hazard assessments, indirect measures that show the influence of the area's hydrology, such as vegetation, slope orientation (aspect), or precipitation zones were utilized. Because of lack of information and the unavailability of maps the isoyet map was used to analyze the distribution of rainfall throughout the island.

Subsequently, bearing in mind that Degraffs' susceptibilidad map was used as a base map, an analysis was done of each map with respect to the classification of Degraff retro analyzing the weight that each them map has on the susceptibility of landslide in the island.

A reclassification was done of each theme map taking into consideration the three above mention factors used resulting in a suceptibilidad map for each condition and causal factor used in the study.

Finally a collective analysis was done of the information provide by all the theme maps and this was facilitated by the overlaying feature provided by the GIS used.

CHAPTER 3

- **Introduction.**
- **Case Studies.**
- **Interpretation Analysis and Results**

  Characterization of conditional factors.

  - **Land Use Factor.**
  - **Lithological Factor.**
  - **Precipitation Factor.**

  Combined Analysis of Landslide Hazard Map and each factor

- **Proposal for measures of control/ mitigation in function of the level of susceptibility**

INTRODUCTION

During this study, in order to compliment the qualitative analysis of the phenomenon of landslide in St. Vincent, in spite of the limited time and resources that were available, efforts were made not only to analyze the causal and conditional factors, but also to verify the information offered on the thematic maps with the actual field situation.

Several case studies were covered with the intention to create a database or inventory of landslides on the island (information is lacking at the present time) and to continue updating an inventory of landslide to facilitate that during the next 5 years, the island of St. Vincent will have at its disposal proper details of the nature, location and number of landslides that affect it.

Having this information at hand will make efficient the use of Geological Information Systems (GIS) in geological mapping and other investigative works done on the island which must take into consideration the effects of landslides, these include, infrastructural development, tourism, urban and rural planning, and disaster preparedness.

CASE STUDIES

The following are some examples of some major landslides that have affected the island recently; the areas include Gibson Corner, Belmont, Dauphine and Gomea.

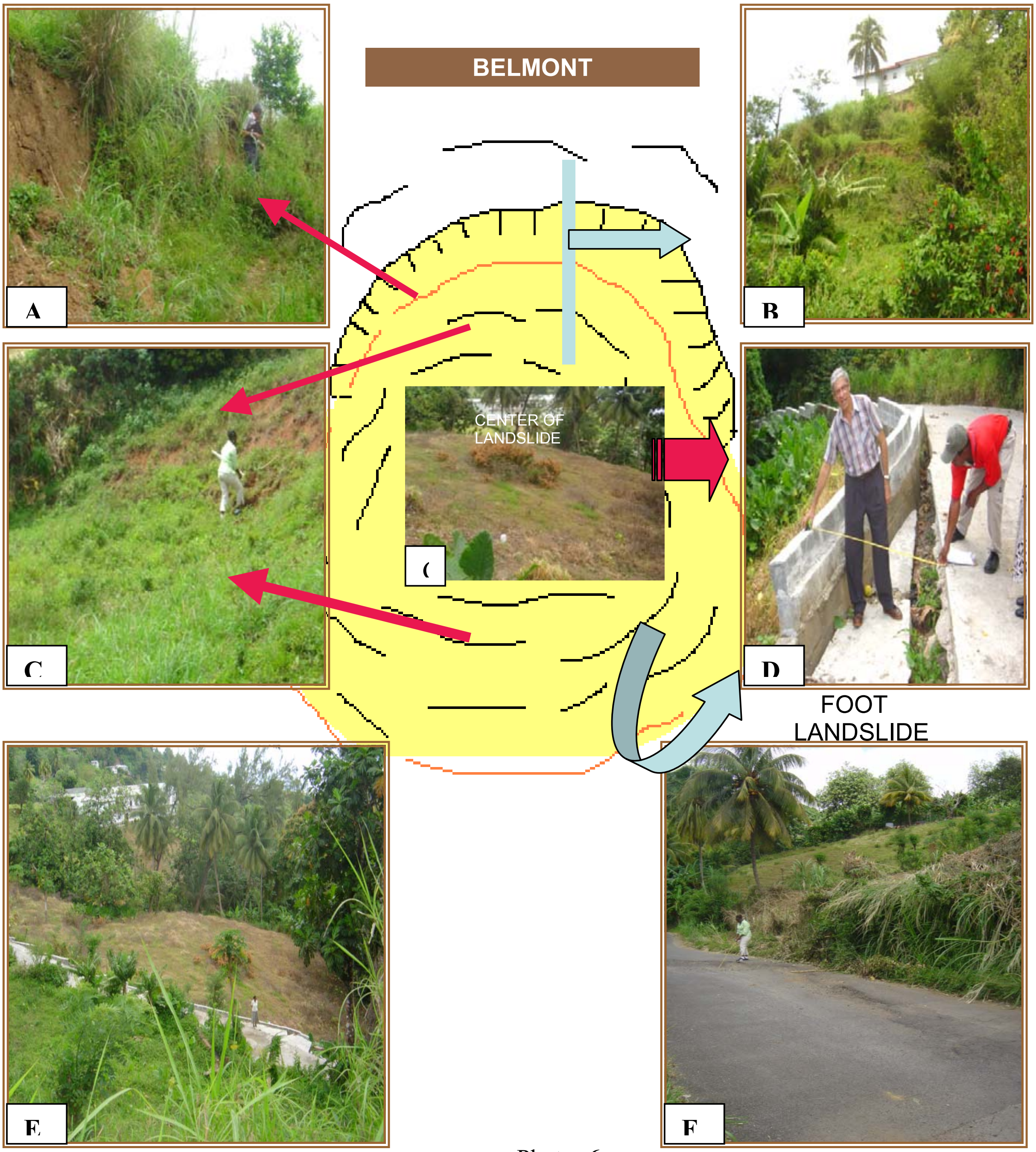


Photo: **6**

A. Landslide scar
B. Terraces and displacement of vegetation suggesting past movement
C. Terrace-like scar
D. Displacement of retention wall
E. Displacement downhill of terrain in direction of movement
F. Resulting crack and undulating of road suggesting movement.
G. Center of landslide

Belmont is considered as an area that is in a continuous process of movement. The area is characterized by many slope-shaped bench-like terraces which suggest that the area is susceptible to landslides and that in the past has been affected by landslides. The soil in that area is brown in colour, sandy like and **non-cohesive,** with a variable slope ranging from 10-40 degrees. The terraces in the area each approximates a height of approximately 30 ft. and have been cut by infrastructural development, houses and roads. At the base of the slope lies a river that acts as an accumulating and transporting agent for the material that is in constant movement downhill.

During Field investigations, evidence of movement were seen at the Seventh Day Adventist Church and the neighbouring houses and roads, where cracks and joints we seen in concrete walls and road although recently done displaces in the direction of the land movement. (See photos 7, 8, 9)

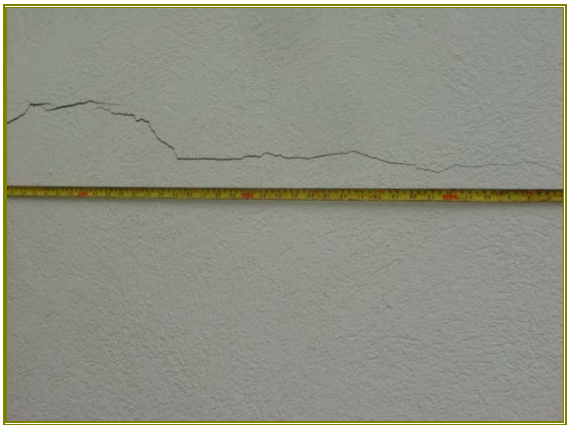


Photo **7**
Measuring cracks at SDA Church -Belmont

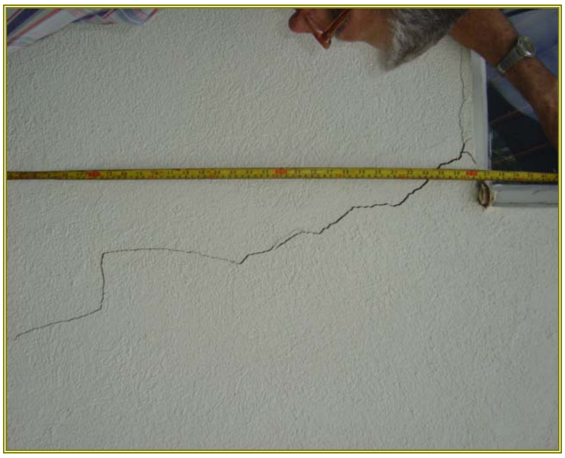


Photo **8**

<u>Joints and cracks in concrete walls at SDA Church</u>

Photo **9**

<u>Downward displacement of road</u>

Many attempts have already been made fix these joints, cracks and displacement but have all proven futile because the land area in continuous movement.

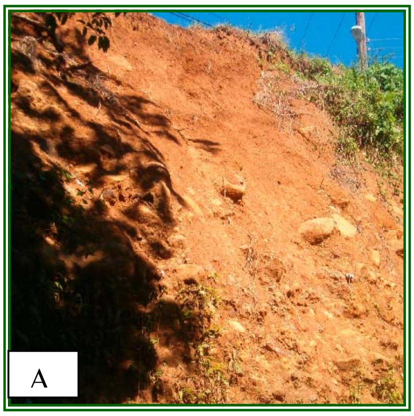
Photo **10**

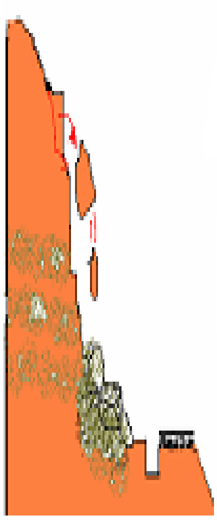
Bench and terrace like scars and displaced vegetation

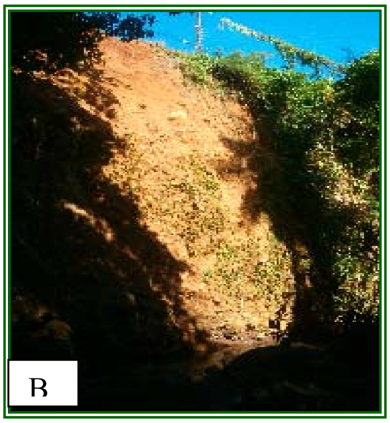
The continuous movement of land in this area has cause the displacement of the terrain, evidence of this are the cracks opening that are seen at the Seventh day Adventist Church. Rainfall, slope, loose non cohesive soil, man induced factors, and past occurrences of land movement are some factors that contributed to the instability in the area.

Special attention should therefore be given to this area by the necessary authorities so as to find means to control and or mitigate the effects of any possible occurrence of mass movement.

Gomea







Debris Slide

Photo **11:**

- **A.** Brown loose soil with alluvial deposits
- **B.** Landslide scar
- **C.** Height of landslide with accumulation debris material at foot
- **D.** Underlying river that undermines material

This land movement in Gomea can be described as a **debris slide** based on the type of materials and the way that they have been displaced. It is important to note that the type of soil is of a brown sandy matrix with clasts of hard rock associated with an alluvial terrace. The debris slide reaches a height of approximately 20 meters with and inclination 70-82 degrees, the underlying river at the foot of the slide and the road cut for constructional purposes are factors which have contributed to the instability and eroding and transportation of materials. Another factor is the cut of the road for construction purposes that has made the terrain unstable.

Dauphine

Landslide at Dauphine is characterized as an earthslide.The downward movement of a land mass is at a distance of approximately 20m.The soil is sandy ash like material that has little content of clay. This type of soil when wet stays together by when dry breaks apart easily. It is yellow/brown in colour and non cohesive. The landslide has an angle of 80 degrees and a wide expanse of displaced land. At the underlying base of this slide is river that has played a vital role in the erosion of base materials. (See photos)

In **photo12**, observe the height, at which the land has displaced from the head scarp, in a step like way suggesting that the land has found its repose and adverting that should the triggering factors continue will continue to be displaced towards downwards. This existing pressure cause the occurrence of cracks and jointing in houses, an example is demonstrated in **photo 13.**

Photo **12**

Surface rupture at head scarp, destroyed house

Photo **13**

Cracks and joints in house

Gibson Corner

This study area is located in the vicinity of Gibson Corner along the tributary of the Kingstown North River, Kingstown. It has a slope angle ranging from 15- 60 degrees and a height of 650 feet and is considered to be very steep.

The land consists of fine grained brown soil with loose and sandy when dry. This type of soil when saturated holds together and becomes heavy and swollen. The sub soil material consists of river and landslide deposits with an old lava flow unit at the base.

There are a number of characteristics of the topography which suggests that the area is unstable and that landslips and rock falls have occurred in the past, these include:

- The presence of a number of bench-like terraces at the base of the valley slope. In addition there are a number of similar features in the surrounding highlands which feed into the river terraces produced as mobile material come to rest at the base of higher slopes.
- The presence of numerous discrete boulders embedded in the top-soil and generally strewn along the slope as well as along the base of the outcrop of old lava flow at the ridge top.
- The presence of unusually thick, unsorted deposits of silt, soil, gravel, pebbles and boulders along the bed of the river valley and along its immediate sides. Such deposits exhibits the characteristics of material transported rapidly down slope.

In addition to these signs of past land movement the following present day conditions would create an unstable land surface.

- The presence of an excessive amount of water along the valley sides immediately next to the river flow. The soil is therefore well saturated and heavy making further movement down the river valley easier

- The steep gradient of the area increases the tendency for downslope movement of soil and other earth materials. In addition the steep gradient and valley shape concentrates overland water flow down into the river.

- The presence of an active erosive agent (the river) at the base of the valley constantly undercutting and removing material from the base of valley slope. The lateral support of the land along the valley in therefore being constantly undermined by the river.

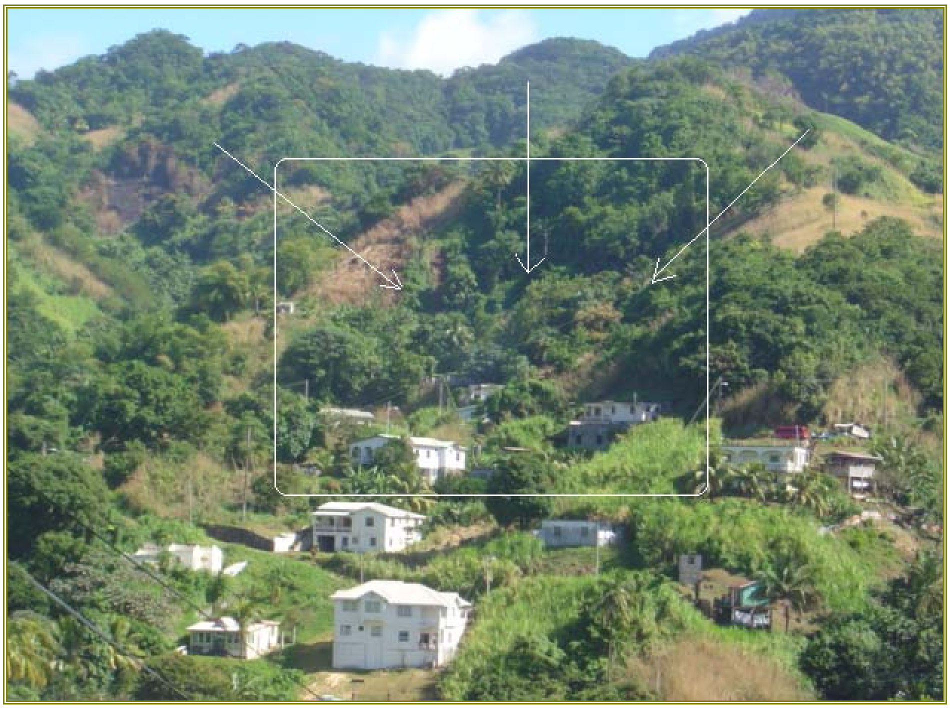


Photo **14**
Landslide area at Gibson Corner

The above is a panoramic view of the landslide area at Gibson Corner. Observe in **photo 14** at the area highlighted that this area is a remnant of old landslide occurrence. This is made evident by the spoon-like scar that is present that is covered by vegetation. The direction of the slope also suggests that the area is unstable and unsuitable for building purposes.

In **photos 14-15** owing to the intensity of movement and the weight of the causal factors which include , an oversaturated soil, slope steepness, the non cohesivenes of soil, the force of land use on (overlying material-vegetation, infrastructural development), this causes cracks and opening in the foundation of building.

Photo **15**

Evidence of movement in one of the houses at Gibson

Photo **16**

Crack opening in foundation of house

INTERPRETATION / ANALYSIS AND RESULTS

CHARACTERIZATION OF CONDITIONAL FACTORS

As mentioned before in the methodology, three conditioning factors were utilized and a retro-analysis was done to detect the influence each of them has on landslide occurrence in the island of St. Vincent using the landslide hazard map (Degraff,1988) as base.

Degraff's Hazard Map utilizes four (4) relative classifications: Extreme, High Moderate, and low.
(see annex map 6)
The three conditioning factors applied in this study were **Land Use**, **Geology/Lithology and Precipitation**. Each factor is being supported by its base map - land use, composite geology and isohyet consecutively.

The **Degraff Hazard Map** with respects to each classification occupies a specific area in the island, areas classified as extreme occupies 56.51 Km^2 or 16 % of land, while areas classified as high occupy 255.67 Km^2 or 74%, classification moderate has 24.11 km^2 or 6 % while the areas that have been considered as low by Degraff has an area of 8, 71 km^2 or 2%.

So as can be observed in Fig **8,** over eighty percent of the lands of St. Vincent are considered as land that is very susceptible to landslides

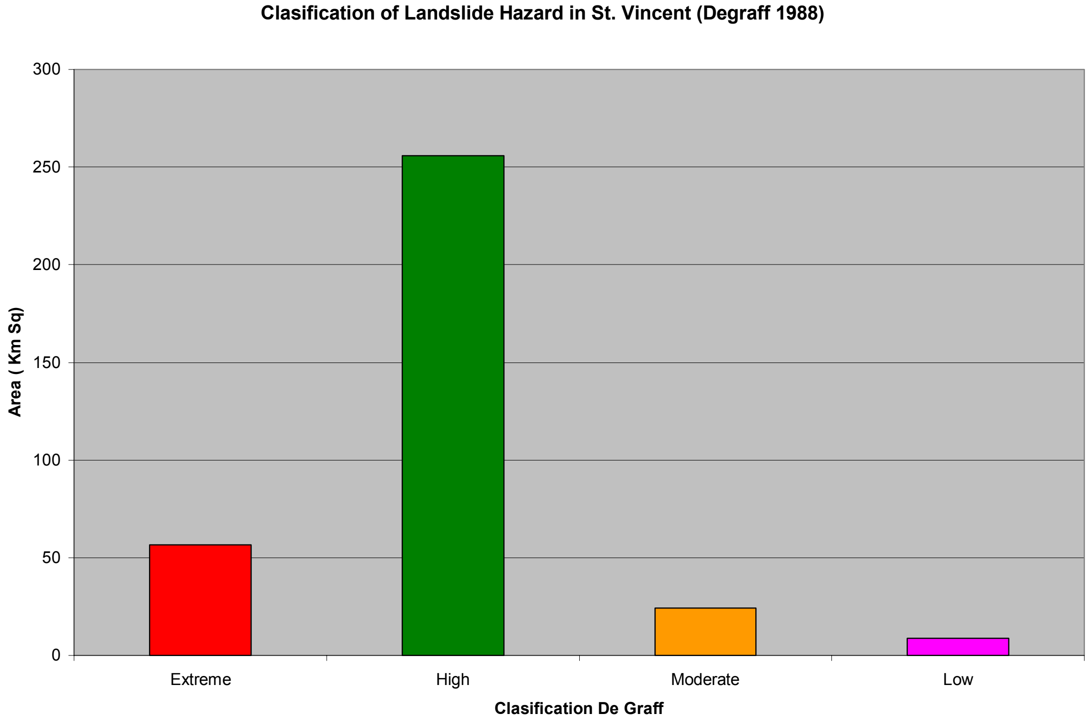


Fig 8

Landslide Susceptibility in St. Vincent (Degraff)

- **Land Use Factor**

There are a total of 11 land use classes on the island of St. Vincent; natural vegetation occupies 59.28 km ^{2}. or 17% or terrain, banana/ root crop 45 km ^{2}, or 13%, root crop 8.65 or 2 %, forest 131.85 km ^{2} or 38%, banana/coconut 30.25 Km. sq or 8 %, built-up areas 58 km ^{2} or 17.01 %, industrial site 0.56 km ^{2} or 0.1 %, banana 3.75 km ^{2} of 1 %, vegetable 0.41 km ^{2} or 0.1%, vegetation root crop 4,68 km ^{2} or 1.35 %and pasture 2.13 km ^{2} or 0.6%. (See fig **9**)

As is noted Forests occupy the largest of land use area on the island with while natural vegetation occupy 59 Km ^{2} of land, This is due to the fact that St, Vincent is extremely mountainous and these areas are inaccessible and therefore would lack any urban/infrastructural development., the island depends on agriculture as major income for the economy and all the cultivation crops including Root Crop, Banana, Vegetable, Coconut occupy a 35.96 Km ^{2} of land. Mention must be made that the built-up areas or areas of urban and rural development occupy a 58.76 Km ^{2} of land and this is according to the landuse map at hand because day after day built-up areas increases as the economy boosts.**(See Fig 9)**

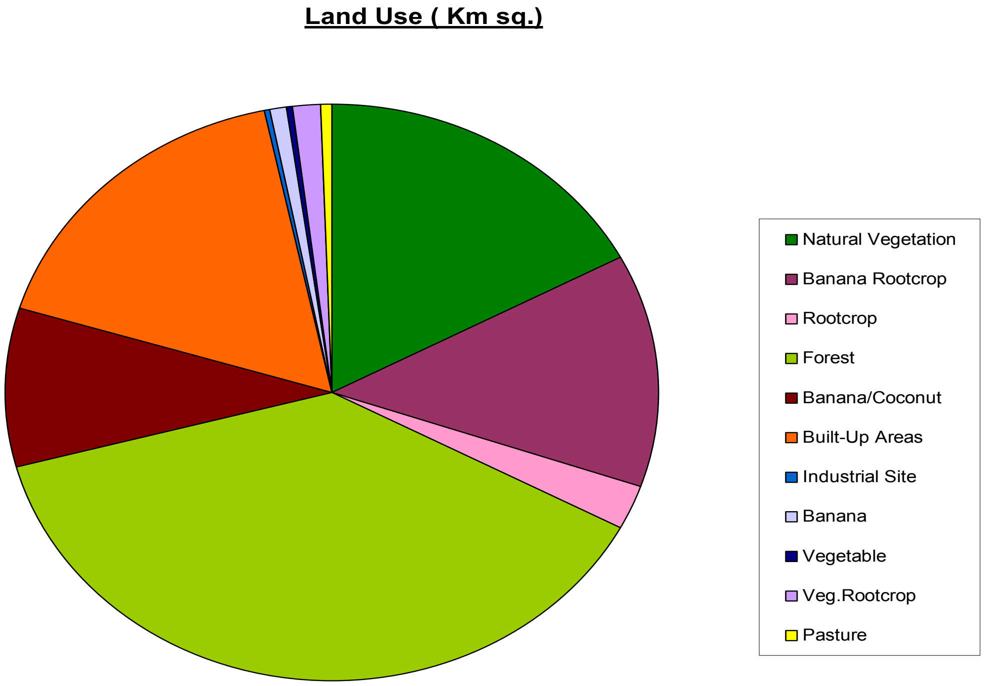


Fig. 9

Land use in St Vincent

- **Lithological Factor**

With respects to the geology/lithology of St.Vincent., according to the geology composite map (Robertson 2002) there are eight (8) classes of rock type, Rabacca and Wallilabou Gravels , Lava Underlying Basalts, Basalt Outcrop, Pyroclast and Mudflow, Ash and Scoria Fall (1902-03), Belleisle Cinder Deposits, Deeply buried Basalts and Mt. Brisbane Richmond Pyroclasts. The rock type that assumes the most area in the island are the Mt. Brisbane/Richmond Pyroclast with a 174 Km^2 of land, the Ash and Scoria fall deposits(1902-03) of 25.27 Km^2, Basalt Outcrops of 57.34 Km^2 and the Lava Underlying Basalts of 57.34 Km^2 Owing to the fact that the island is of a volcanic nature all the rock are igneous rocks or have been derived from. (See fig **10**)

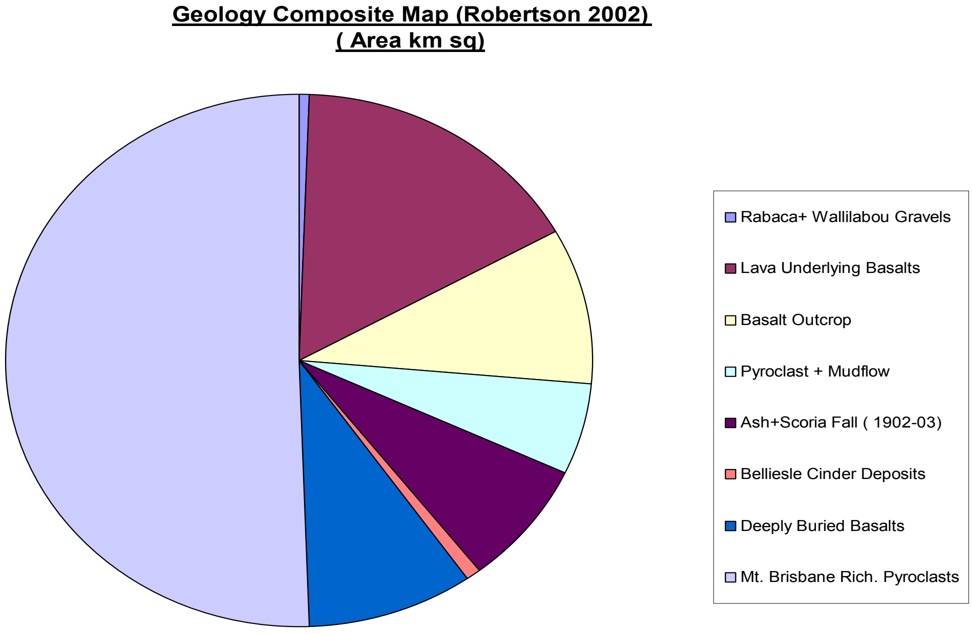


Fig 10

Composite Geology of St. Vincent

- **Precipitation Factor**

In St. Vincent, according to the existing isohyet map, rainfall ranges from 1700 to 7000 mm of annually. In the interior, most mountainous part of the island rainfall exceeds approximately 5000m. In the Northern part of the island there is an abundance of rainfall that ranges from 3001-6000 mm, whereas in the South rainfall intervals ranges from 1700-3000 mm. In the Western terrain of the island rainfall falls in the range of 1700-5000 while in the east the interval range from 3001- 4001mm.

COMBINED ANALYSIS OF LANDSLIDE HAZARD MAP AND EACH FACTOR

Landslide Hazard Map and Landuse Map

Based on the combined analysis of the Degraff Hazard Map with the land use maps the following results were reached:

Extreme landslide susceptibility resulted in the areas of Forest, Natural Vegetation, Agricultural Crops and Built up areas. The land use that has the critical susceptibility to land sliding is the forested area, this areas is typically considered as the high and mountainous and is located in the central interior past of the island. Its ranges from the highest peaks of the Soufriere Mountains. Susceptibility in these areas can be justified by the presence of volcanic soil type, that is prone to landslide because of it mechanical and physical properties. Also this area receives an average annual rainfall as high as 7001 mm. Similarly the areas of Natural vegetation are presented daily with problems of landslide due to high precipitation, steep slopes and volcanic soil composition. Another landuse that predominant with landslide are the built up areas and this is of major concern both to owner and the government of the country.

Areas classified as high susceptibility include built up areas, areas that are used for the cultivation of agricultural crops and some natural vegetation areas. Agricultural practices are often times exaggerated, thus, overworking leaves it brittle, exposed and weathered thereby more susceptible to mass movement. (see annex Map 7)

Landslide Hazard Map and Geology Composite Map

The combined analysis of these two maps revealed that the rock types / Lithology, that were considered to have an extreme susceptibility to landslides were the Mt. Brisbane Pyroclasts, ash and scoria fall and some deeply buried basalt rocks. (See annex Map 8)

These are volcanic rocks, or sediments derived from them, and have proven to be the originating Lithology for landslides. These sediments often contain ash and clay materials that facilitate movement. Poorly-consolidated sediments, particularly those of Cretaceous, Tertiary and Quaternary age, appear to have a tendency toward land sliding. The types of material identified for each slide or flow appears to generally correspond to well-defined topographic settings: Earth slides and flows occur most often on more gentle slopes with less vegetation the foothills and river courses. Debris slides and flows generally occur in the steeper, mountainous areas and in areas covered with vegetation.

Landslide Hazard Map and Rainfall

Rainfall is a very important conditional factor that contributes to the occurrence of landslides on the island, in the combined analysis of the isoyhet and the susceptibility map, it was determined that the central most interior part of the island which constitutes the highest mountainous areas receive the maximum annual rainfall of up to 7001mm, this areas is also classified as the area of extreme landslide hazard. In this central area which reaches over 1000ft. predominate the mature and secondary rainforest which are characteristically known for its shallow roots which does not provide enough holding strength to the soil, also Lithology type in this are is representative that are recent volcanic material like pyroclasts, tuffs and basalts.

It is also noted that the lower lying areas that are classified to have low to moderate landslide susceptibility these areas also coincide to be those that receive rainfall ranging from3001- 1000mm annually. (See annex 9)

Analysis of susceptibility theme Maps

After an individual and collective analysis of the factor that were analyzed as conditional and causal factor namely, rainfall, theology and land use towards the stimulating of landslides in the island of St. Vincent. A reclassification was done of the weight that each of these has on the phenomena. (see annex map11,12)

In the case of the landuse susceptibility a classification was made of Extreme, High and Moderate and its is evident that high lying areas which receives the large amount of rainfall and which has a predominance of weathered volcanic rocks,also areas of increased infrastructural development is classified as high and extreme and the areas of less rainfall, low lying areas which presents rock of volcanic origin but of more resistance as moderated. But as can be observed on the maps over 80 percent of the terrain of St. Vincent can be declared as lands that are very susceptible to mass movement.

PROPOSAL FOR MEASURES OF CONTROL/ MITIGATION IN FUNCTION OF THE LEVEL OF SUSCEPTIBILITY OF THE AREAS

Due to an increase of effects of land sliding on the island of St Vincent urgent efforts must be made in order to lessen its impact, mitigation measures should be seen as a basic investment fundamental to development in high risked areas.

Mitigation measures for landslides are intended to reduce the loss of life or injury, and loss of property. Although the ill-effects inflicted on humans by landslides are not completely avoidable, their consequences can be substantially reduced through preliminary investigations, proper land-use management, and the undertaking of appropriate mitigation measures.

The measures for preventing and controlling landslides are complex and various. They depend on the landslide type, geological and lithological conditions and especially on the hydrological and geomorphologic land peculiarities.

The main measures are:

- interception (capture and drainage) of ground water (in some cases also of the surface runoff) from the area affected by landslides (and sometimes from up-hill)
- Forest planting to stabilize the terrain and improve of the biological drainage.
- Special consolidation works where buildings, roads, highways, railways, bridges or other objectives of economic or social interest are to be protected.

Currently, St. Vincent does not have a nationwide program designed to investigate and evaluate its landslide hazards.

- Our building codes should require special studies for areas prone to landslides and should implement regulations and professional guidelines which require stability evaluations for man-made slopes (i.e., earthen dams, etc.).
- Slope stability evaluations should consider the triggering effect landslide has on slope and include continual cosmetic re-contouring (repair) of the failed slope

- Implement pre-construction investigation and slope evaluation for possible old existing slide features or inherent slope instability.

- Re-zonation of urban development to areas where there is not an overload of infrastructural development

In addition, the following mitigating measures can be used help reduce economic and property loss from landslide-related damage.

- Establish protocols and a program for research on landslide initiation and processes, landslide hazard delineation, mapping, control, the collection and dissemination of information.

- Adopt effective land-use regulations and building codes based on scientific research. Through land-use planning, discourage new construction or development in identified hazard areas without first implementing appropriate remedial measures.

- Post warnings of potentially hazardous areas and educate the public about areas to avoid, such as; (a) existing old landslides, (b) on or at the base of a slope, (c) in or at the base of a minor drainage hollow, (d) at the base or top of an old fill or steep cut slope, and (e) on developed hillsides where leach field septic systems are used.

- Require remedial techniques (i.e., buttresses, shear keys, sub-drains, soil reinforcement, retaining walls, etc.) of existing landslides that are in close proximity to public structures

- Educate the public about signs that a landslide is imminent so that personal safety measures may be taken. Some of these signs include:

    - Springs, seeps, or saturated ground in areas that have not typically been wet before.
    - New cracks or unusual bulges in the ground, street pavements or sidewalks.
    - Soil moving away from foundations, and ancillary structures such as decks and patios tilting and/or moving relative to the house.

- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.
- Broken water lines and other underground utilities.
- Leaning telephone poles, trees, retaining walls or fences.
- Sunken or dropped-down road beds.
- Rapid increase in a stream or creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels even though rain is still falling or just recently stopped.

CONCLUSION AND RECOMMENDATIONS

Conclusions

After conducting a detailed analysis of the geology/Lithology, rainfall and land use as some causal and conditional factors that affect the island of St. Vincent, the following factors were reached:

- Over 80 percent of the lands of St. Vincent is considered as lands that are susceptible to landslides

- The innermost central mountain ranges of the island which present Formations Mt Brisbane of lava flows, scoria, yellow ash fall deposits, reworked alluvial deposits or deeply weathered volcanoclastic deposits, is the area with respect to geology/Lithology that presents the greatest susceptibility to landslides. These soils are sketal bouldery soils, that are shallow and uncemented

- The Central part of the island that possesses the highest mountain ranges, with tropical rainforests, mountain forest and secondary rainforest and which receives annual rainfall of over 2000mm annually is most conducing to landslide activity

- The scarcity of Prime agricultural lands and the resorting to agricultural activity on hillsides and slopes has contributed in the creation of landslides activity

- The volcanic origin of the island where there are layers of alternate ash, lava intense slopes where weaker bedrock weathers faster and undermines more competent bedrock overlying it is also a catalyst for mass movement

- Apart from the forest areas another landuse that gives rise to land and mass movement is the built-up areas or areas of intense urban and infrastructural development, this include building in areas that are unfit, cutting of road that destabilizes the natural stability of the terrain, improper drainage facilities

Landslides are one of the primary natural processes shaping the land. Human activities that frequently cause significant increases in landslide activity include:

1. Excavation of a steep slope or the toe of an existing landslide, thus removing support of the upslope mass,
2. Addition of material to the head (top) of a landslide which pushed the slide material down slope,
3. Addition of moisture to the landslide mass, increasing the weight and decreasing the strength

For constructional purposes, excavation of a steep slope or the toe of an existing landslide, thus removing support of the upslope mass, and addition of material to the head (top) of a landslide, pushes the slide material down hill

- There is also evidence that recent landslide movements on the island often reactivate smaller sections of older, unstable landslide masses.

Recommendations

A comprehensive map of existing slide areas throughout the state would greatly improve the capability to prevent development in ancient slides areas, however, many landslides cannot be predicted and can be activated by multiple factors including earthquakes, high precipitation, overgrazing, and deforestation (especially from forest fires).

In St. Vincent, as urbanization and development increase, particularly in the mountainous regions, the potential for large losses from landslides also increases. Landslide risk should be evaluated on a case-by-case basis to reduce or eliminate exposure of public infrastructure development. Many, if not most, high-risk areas can be identified on the basis of past landslide activity.

Many recent landslides are small, relatively minor events within the boundaries of older, much larger ones. Recognition of the larger framework, as well as mapping current landslide locations, is paramount to understanding the problem.

The consequence of improper utilization of areas subject to landslide for building and development may range from minor damage in extremely fortunate cases, to total destruction of structures and accompanying loss of life. Maintenance of structures in active slide areas is very costly, and in many cases will equal or exceed the price of the structure prior to expiration of its useful life.
Below is a summary of recommendation to contribute to the mitigation and control of landslides on the island:

- Conduct feasibility studies before any urban/rural infrastructural development so as to ensure that the underlying bedrock is suitable and this purpose.
- Improve and actualize geological, engineering geotechnical studies on the island which include the creating/updating of maps and geological inventory of landslides.
- Utilize new mapping database technology for example (GIS).

- Implement and reinforce building codes that specify constructive norms for drainage, building heights, slopes roadwork, foundation building and type of materials for construction.
- Train personnel in each Ministry that specializes in the mitigation of problem relating to slop instability

BIBLIOGRAPHY

Aleotti, P. y Chowdhury, R. (1999). “Landslide hazards assessment: summary review and new perspectives”. Bull. Eng. Geol., Vol. 58, 21-44

Anonymous, 1938, West Indian Landslide kills Hundreds: Engineering News Record, Vol.121.

Ahmad and others (1993). The Impact of Slope Movements on a rural community: lessens from Jamiaca. In: Merriam a Brewit (Eds), natural Disasters.

Barrows, A.G., 1993, California’s Landslide Hazard Identification Project: California Geology, Volume 46, Number 5, pp. 132-139.

Brabb, E.E. "Innovative Approaches to Landslide Hazard and Risk Mapping" in IV International Symposium on Landslides, vol. 1 (Toronto, 1984), pp. 307-323.

Creath, W.B., 1996, Home Buyers’ Guide to Geologic Hazards: Arvada, Colorado, American Institute of Professional Geologist, p. 13-16.

Cronin, V.S., 1992, Compound Landslides: Nature and Hazard Potential of Secondary Landslides within Host Landslides, *in* Slosson, J.E., A.G. Keene, and J.A. Johnson (editors), Landslides/Landslide Mitigation: Geological Society of America Reviews in Engineering Geology, Volume IX, p. 1-9.

Thomas Telford. London. Pp 447-460

Campbell, R.H. Landslide Maps Showing Field Classifications, Point Dume Quadrangle, California, U.S. Geological Survey Field Studies Map MF-1167 (Reston, Virginia: U.S. Geological Survey, 1980).

Canadian Int’l Development Agency Underwood Mc Lellan and Associates Ltd. Canada, 1971, Government of St. Vincent and the Grenadines Water Resource Study for St. Vincent and the Grenadines

Chacón J.; Irigaray, C. y Fernández, T. (1992) “Metodología para la cartografía regional de movimientos de ladera y riesgos asociados mediante un Sistema de Información Geográfica”. III Simposio Nacional sobre Taludes y Laderas Inestables. La Coruña. Vol1. 121-133 pp.

Chacón J.; Irigaray, C. y Fernández, T., (1993) “Análisis y cartografía a gran escala de factores condicionantes de movimientos de ladera mediante un SIG” V Reunión Nacional de Geología Ambiental y Ordenación del Territorio, 2, 585-594, Murcia

Corominas, J. (1989) “Clasificación y reconocimiento de los movimientos de ladera” En Corominas, J (Ed) “Estabilidad de Taludes y laderas naturales”. Monografías nº 3. Sociedad Española de Geomorfología. Barcelonam 1-30 pp.

Corominas, J y García Yagüe, A. (1997) “Terminología de los movimientos de ladera”. IV Simposio Nacional sobre Taludes y Laderas Inestables. Vol. IV, 1051-1072. Granada

DeGraff, J. F., 1985, Landslide hazard on St. Lucia, West Indies- Final Report: Washington D. C., Organization of American States, DeGraff, J. F., 1987, Geologic reconnaisance of the 1986 landslide activity in Good Hope, D' Leau Gommier, and Belvue Slopes, Commonmwealth of Dominica, West Indies: Washington D. C., Organization of American States.

DeGraff, J. V., 1987, Landslides on Dominica, West Indies- Final Report: Washington D. C., Organization of American States.

DeGraff, J.V., 1988, Landslide Hazards on St. Vincent, West Indies: Washington D. C, Organization of American States.

DeGraff, Jerome. V., Bryce, R., Jibson, R. W., Mora, S., and Rogers, C. T., 1989, Landslides: Their extent and significance in the Caribbean, in: Brabb and Harrod (eds.), Landslides: Extent and economic significance: Balkema, Rotterdam.

DeGraff, Jerome.V. 1991, Determining the significance of landslide activity: examples from the Eastern Caribbean:, Caribbean Geography, vol. 3, No.1

DeGraff, Jerome. V.1990 Assesment Landslide hazard for Regional Development Planning in the Eastern Caribbean, Washington D. C, and Organization of American States.

Federal Emergency Management Agency, 1997, Chapter 9, Landslides, *in* Multi-Hazard Identification and Risk Assessment, A Cornerstone of the National Mitigation Strategy, p. 96-105.

Godt, J.W., 1997, Digital Compilation of “Landslide Overview Map of the Conterminous United States” by Dorothy H. Radbruch-Hall, Roger B. Colton, William E. Davies, Ivo Lucchitta, Betty A. Skipp, and David J. Varnes, 1992: U.S. Geological Survey Open-File Report 97-289 3 p.

Godt, J.W., L.M. Highland, and W.Z. Savage, 1997, El Niño and the National Landslide Hazard Outlook for 1997-1998: U.S. Geological Survey Fact Sheet 180-97, 4 p.

Ivor Jackson and Associates, 2004, Environmental Investigation and Cataloguing, St.Vincent Cross Country Road

Jibson, R.W. and D.K. Keefer, 1992, Analysis of the Seismic Origin of a Landslide in the New Madrid Seismic Zone: Seismological Research Letters, Volume 63, Number 3, p. 427-437.

Jibson, R.W. and D.K. Keefer, 1993, Analysis of the Seismic Origin of Landslides: Examples from the New Madrid Seismic Zone: Geological Society of America Bulletin, Volume 105, Number 4, p. 521-536.

Jibson, R.W. and D.K. Keefer, 1994, Analysis of the Origin of Landslides in the New Madrid Seismic Zone: U.S. Geological Survey Professional Paper 1538-D, 23 p.

Jibson, R.W., E.L. Harp, and J.A. Michael, 1998, A Method for Producing Digital Probabilistic Seismic Landslide Hazard Maps: An Example from the Los Angeles, California Area: U.S. Geological Survey Open-File Report 98-113, 20 p.

Keefer, D.K., 1984, Landslides Caused by Earthquakes: Geological Society of America Bulletin, Volume 95, Number 4, p. 406-421.

Keefer, D.K., 1993, The Susceptibility of Rock Slopes to Earthquake-Induced Failure: Association of Engineering Geologists Bulletin, Volume XXX, Number 3, p. 353-361.

Kehew, A.E., 1995, Geology for Engineers and Environmental Scientists, Second Edition: Englewood Cliffs, New Jersey, Prentice-Hall, p. 357-393.

Landscapes, Engineering Geology; Urban Geology, Vol XIV: landslide control

Organization of American States. Integrated Regional Development Planning: Guidelines and Case Studies From OAS Experience (Washington, D.C.: Or

McFarland, J.D. and C.G. Stone, 1995, Hot Springy Dingy Landslide, Hot Spring, AR, Prepared as a memorandum to W.V. Bush, Arkansas Geological Commission, 3 p.

McFarland, J.D., 1992, Landslide Features of Crowley's Ridge: Arkansas Geological Commission Information Circular 31, 30 p.

Nilsen, T.H., R.H. Wright, T.C. Vlasic, and W.E. Spangle, 1979, Relative Slope Stability and Land-Use Planning in the San Francisco Bay Region, California: U.S. Geological Survey Professional Paper 944, 96 p.

Nuhfer, E.B., R.J. Proctor, and P.H. Moser, 1993, The Citizens' Guide to Geologic Hazards: Arvada, Colorado, American Institute of Professional Geologist, p. 71-84.

Organization of American States Disaster, Planning and Development: Managing Natural Hazards to Reduce Loss. Department of Regional Development and Environment, Executive Secretariat for Economic and Social

Robertson, R.E.A. 1992. Volcanic Hazard and Risk Assessment of the Soufrière Volcano, St. Vincent, West Indies. MPhil, Earth Sciences, the University of Leeds, Leeds.

Richard E. A Robertson, Making Use of Geology- the relevance of geology and Geological Information to the Develoment process in St. Vincent and the Grenadines

R J Small, Geomorphology and Hydrology, Longman Modular Geography Series

Schuster, R.L., and R.W. Fleming, 1986, Economic Losses and Fatalities Due to Landslides: Association of Engineering Geologists Bulletin, Volume 23, Number 1, p. 11-28.

Swanston, D.N. and R.L. Schuster, 1989, Long-Term Landslide Hazard Mitigation Programs: Structure and Experience from Other Countries: Association of Engineering Geologists Bulletin, Volume XXVI, Number 1, p. 109-133

BIBLIOGRAPHY FROM INTERNET

http://mona.uwi.edu/cardin/virtual_library/web%20sites%20to%20ex

http://www.reliefweb.int/rw/rwb.nsf/db900SID/OCHA-64BU49?OpenDoc

http://www.maptools.com/UsingUTM/UTMdetails.html

http://www.agiweb.org/environment/publications/mapping/graphics/california1.pdf

http://isis.uwimona.edu.jm/uds/GEOHAZARDS_2001/GEOHAZ2001-030.html

www.pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

www.earthscience.org/geopro/massmov/massmov.html

www.oas.org/usde/publications/unit/oea66e/ch10.htm

www.rockwave.com/catalog/pages/arcview3xfaq.html

www.gisdevelopment.net/tutorials/tuman006.htm

www.avirtualdominica.com/geology.cfm

www.natureisland.com/MTPNatpark.html

www.photius.com/wfb/wfb/1999/dominica/dominica_economy.html

www.isis.uwimona.edu.jm/uds/land_Dominica.html

www.en.mimi.hu/gis/isopleth_map.html

GLOSSARY

Angle of repose: angle at which material will remain stable

ARC/INFO: a vector and raster based GIS software developed and distributed by ESRI.

Debris basin: a concrete, bowl-shaped pit built on a mountainside to catch debris from mud and rock slides

Earth flow: when the wet ground breaks up and falls down a mountainside, making a rounded, tongue-like shape; usually occurs on clay, silt, or sand; the slowest, driest flow of weathered material down a hillside

GIS (Geographical Information System): A GIS is an information system designed to work with data referenced by spatial / geographical coordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data.

Erosion: the natural wearing away or weathering of rocks or soil

Landslide: A general term for a mass movement landform and a process characterized by moderately rapid to rapid (greater than 30 cm per year) downslope transport, by means of gravitational stresses, of a mass of rock and regolith that may or may not be water saturated.

Landslide Hazard: as represented by susceptibility, which is the likelihood of a potentially damaging landslide occurring within a given area.

Landslide inventory: the systematic mapping, through various techniques (i.e., field surveys, aerial-photo interpretation, site measurements, historical records)

Landslide susceptibility (or propensity): an estimate of the slope-instability conditions of a region mainly based on the qualitative judgment of the investigator eg. of past and recent landslides in a region.

Mass movement: Dislodgement and downslope transport of soil and rock material as a unit under direct gravitational stress. The process includes slow displacements such as creep and solifluction, and rapid movements such as landslides, rock slides, and falls, earthflows, debris flows, and avalanches. Agents of fluid transport (water, ice, air) may play an important, if subordinate role in the process.

Mudflow: when a slope is so heavily saturated with water that it rushes downhill as a muddy river, carrying down debris and spreading out at the base of the slope; the fastest, wettest flow of weathered material down a hillside

Quicksand: a mass of loose, wet sand that becomes fluid when suddenly vibrated; heavy objects will sink into it

Risk (specific): the expected degree of loss due to a particular landslide phenomenon.

Rock fall: when fragments break away from the face of a steep slope and fall

Rock slide: similar to rock falls, except they take place on lower slopes, closer to inhabited areas, and are thus more dangerous

Sinkholes: rapid and sudden manifestations of subsidence most frequently experienced in areas underlain by gypsum or limestone substrata

slump: A mass movement process characterized by a landslide involving a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to that slope so that the slump surface often exhibits a reversed slope facing uphill. (ii) The landform or mass of material slipped down during, or produced by a slump.

Slumping: the slow and gradual slippage of all layers of soil so that the bottom of a hillside becomes level with the lowlands or even tipped upward

Soil creep: the gradual downhill slide of weathered material; the slow, gradual movement of a hill's upper layers caused by the pull of gravity on loose stones, gravel, and soft topsoil

Subsidence: the vertical fall of earth, usually caused by the loss of underground water or gas support, sometimes resulting from man-made pumping and sometimes from seismic action

Vulnerability: the level of population, property, economic activity, including public services, etc., at risk in a given area resulting from the occurrence of a landslide of a given type.

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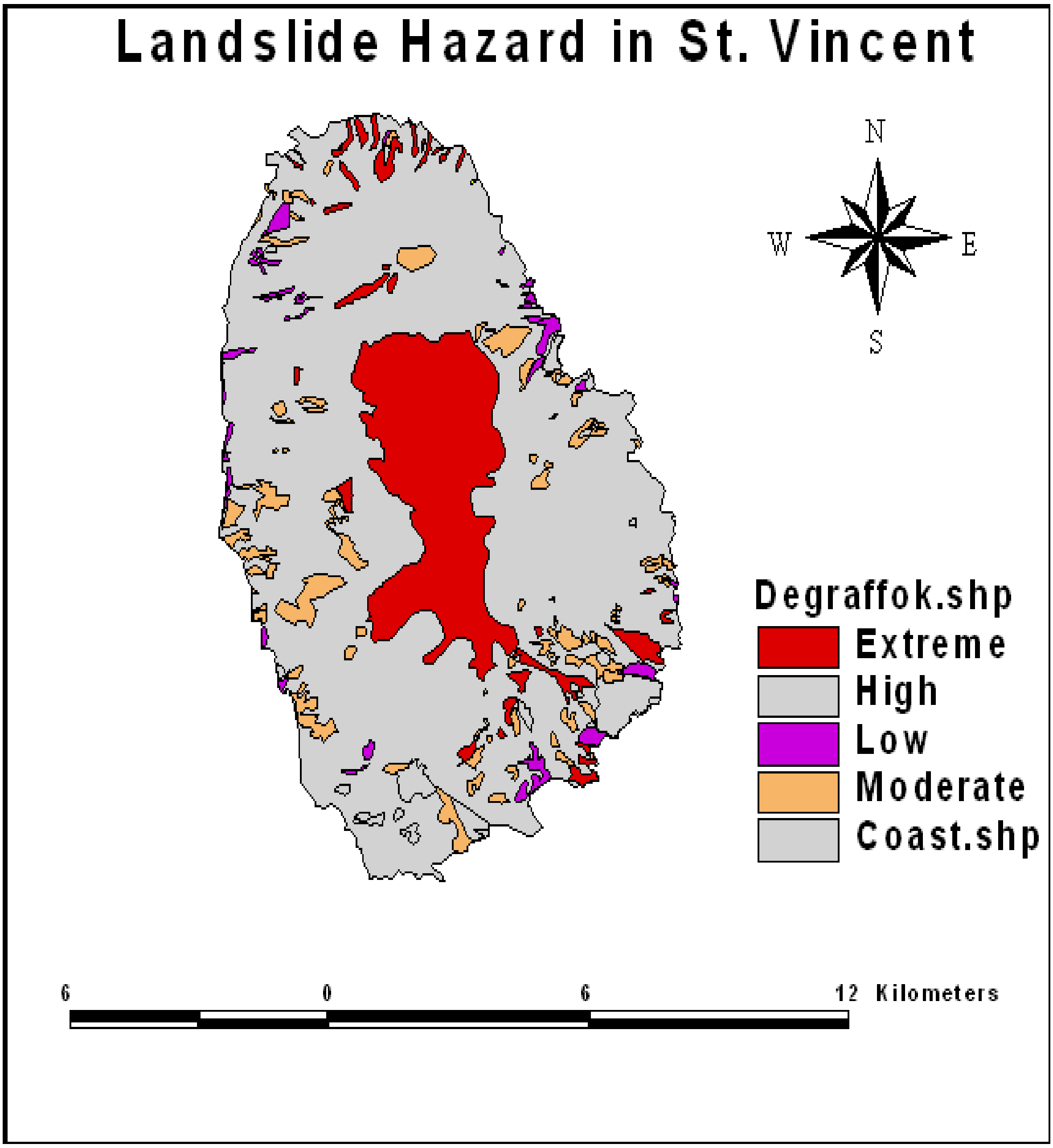

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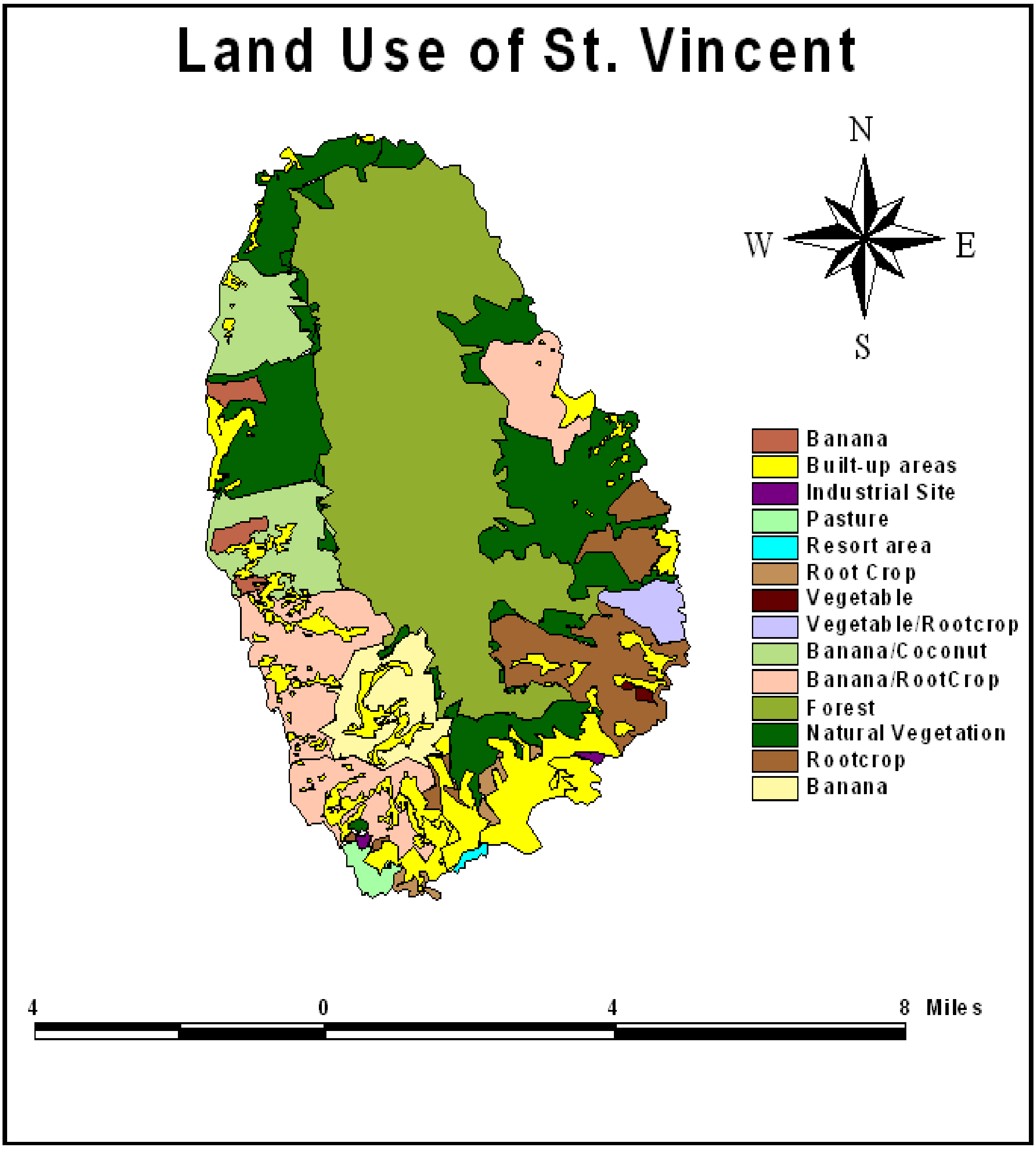
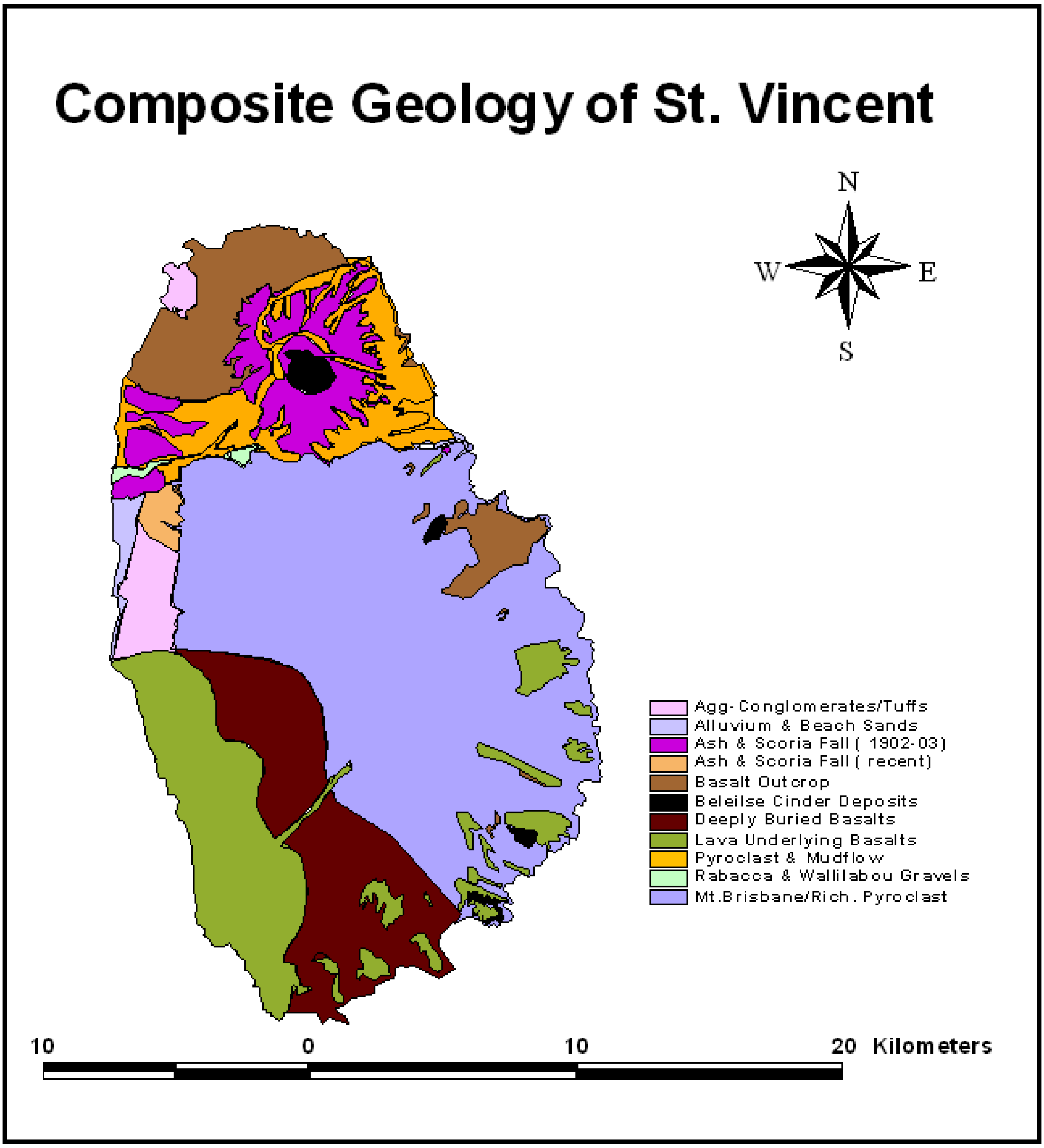
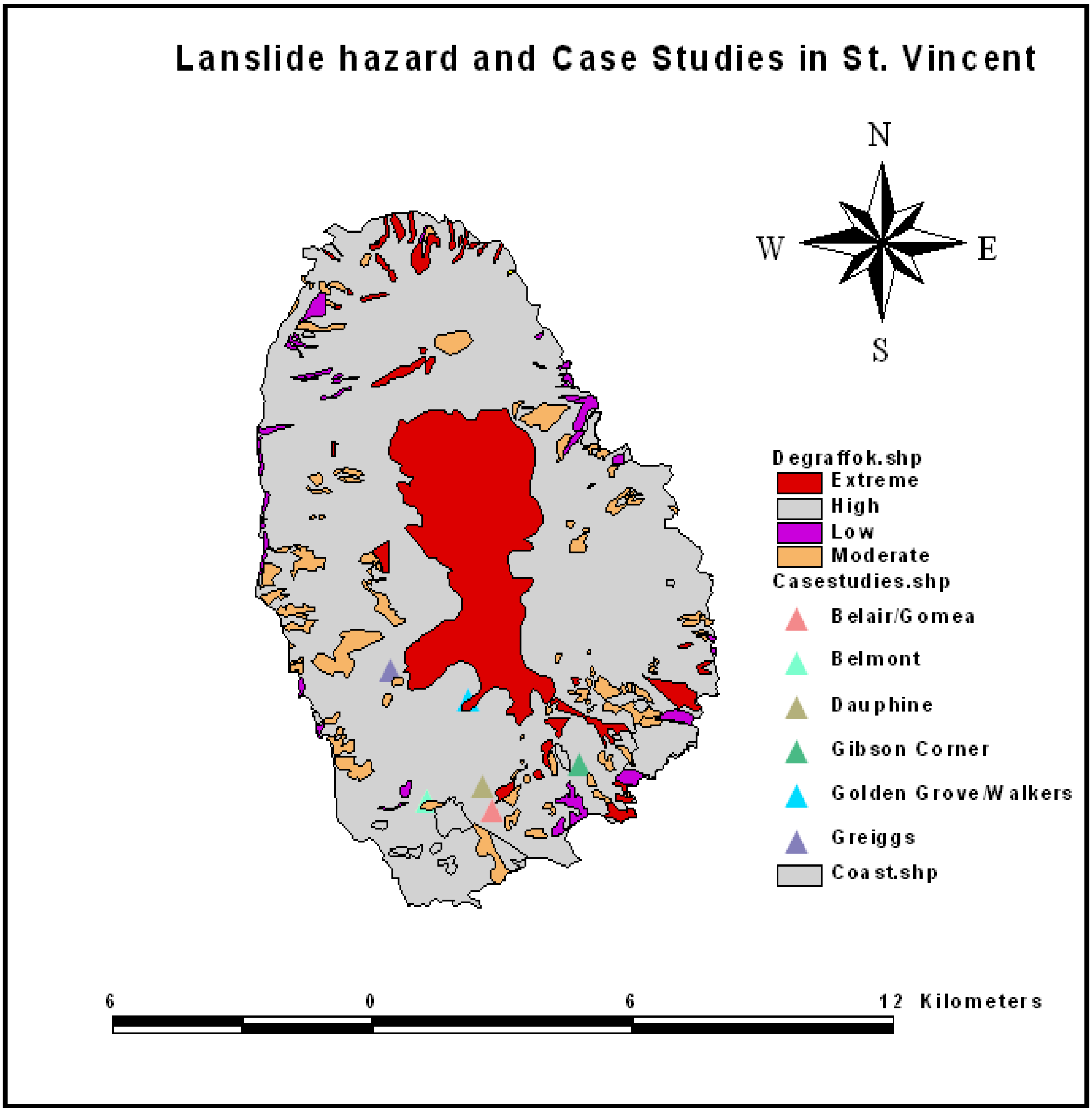
Map 6.
Landslide Hazard in St. Vincent
Source: De Graff 1986



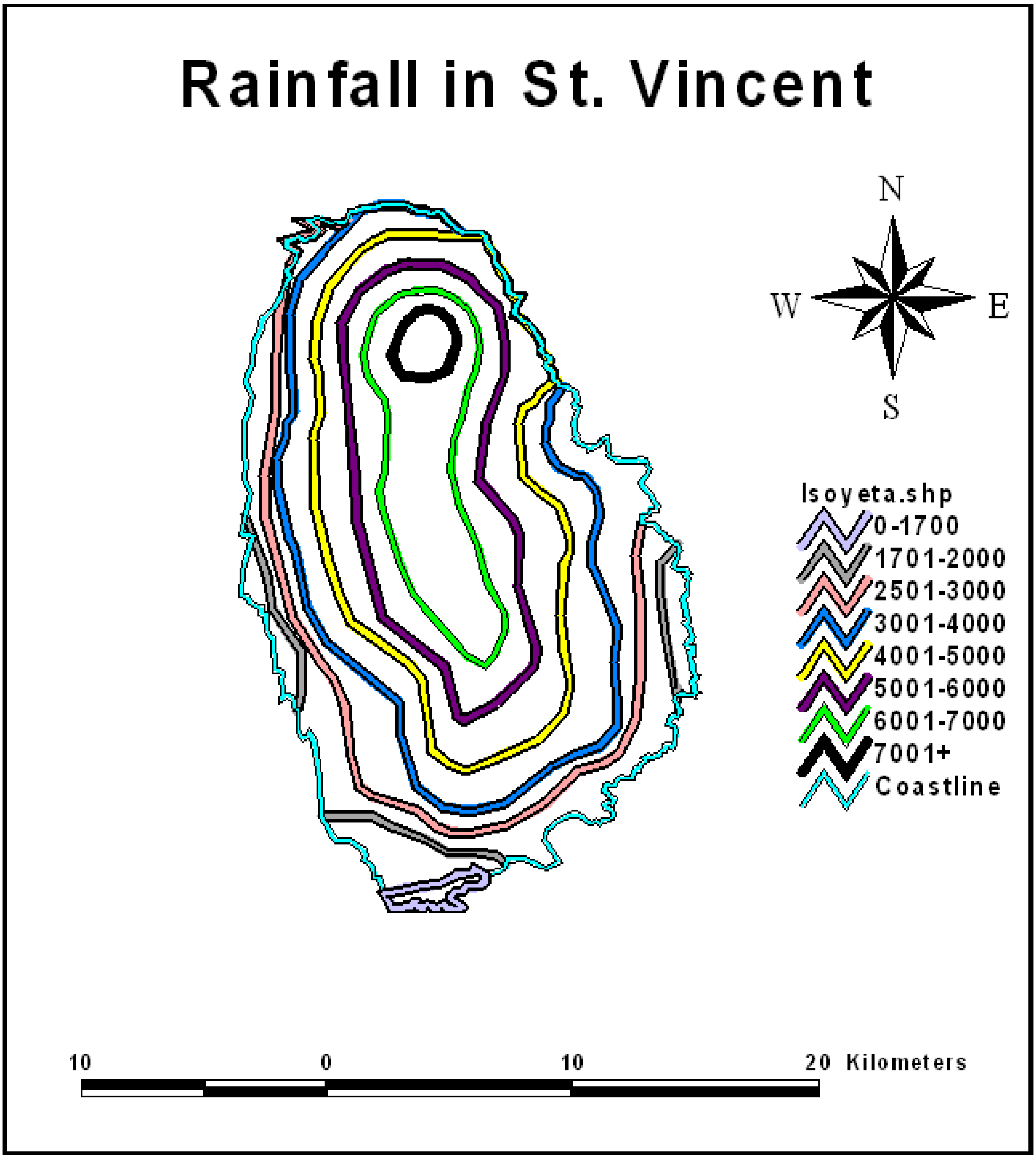
Map 7.
Land Use Map of St. Vincent



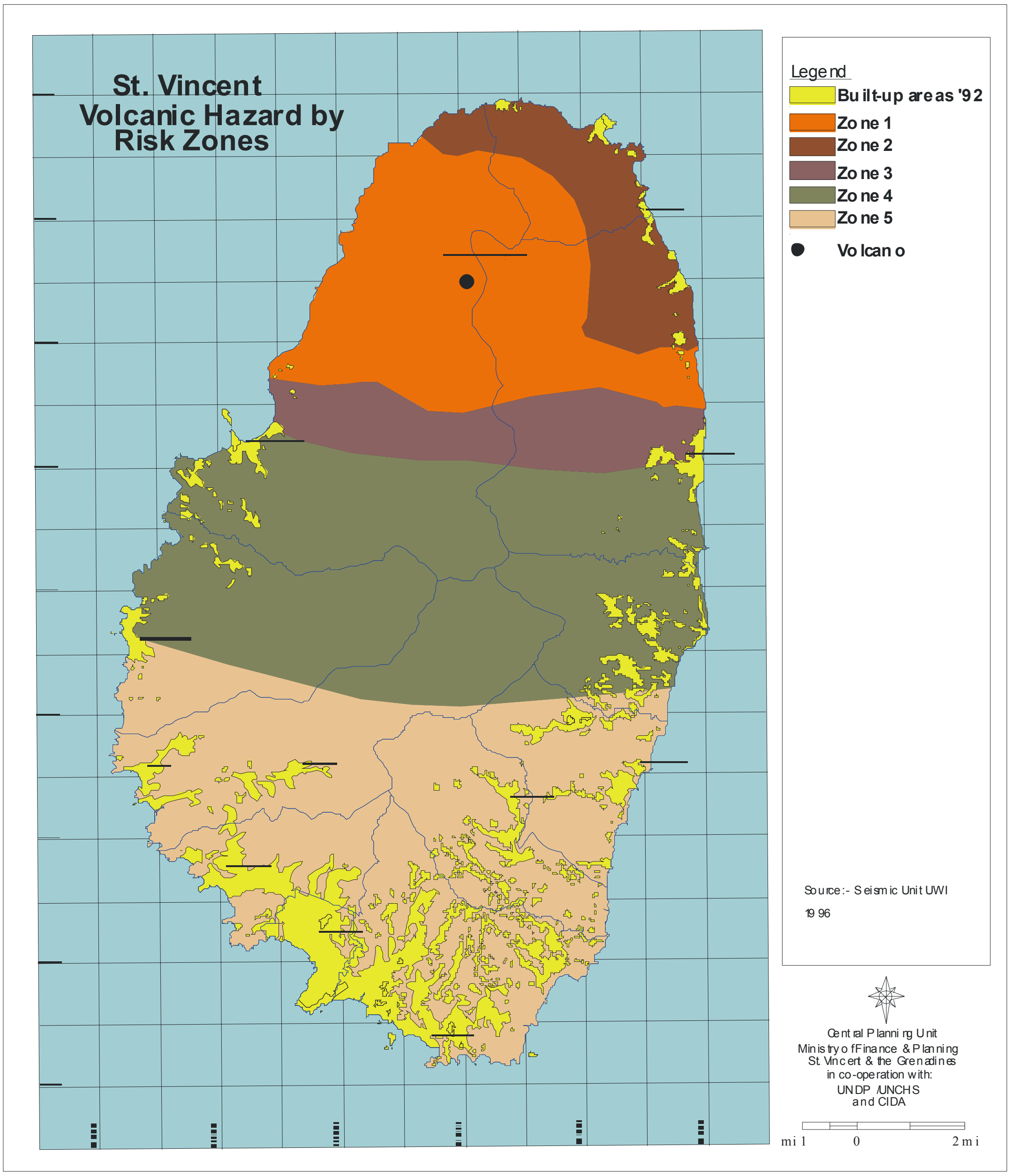
Map 8.
Composite Geology Map
Source Dr. Richie Robertson



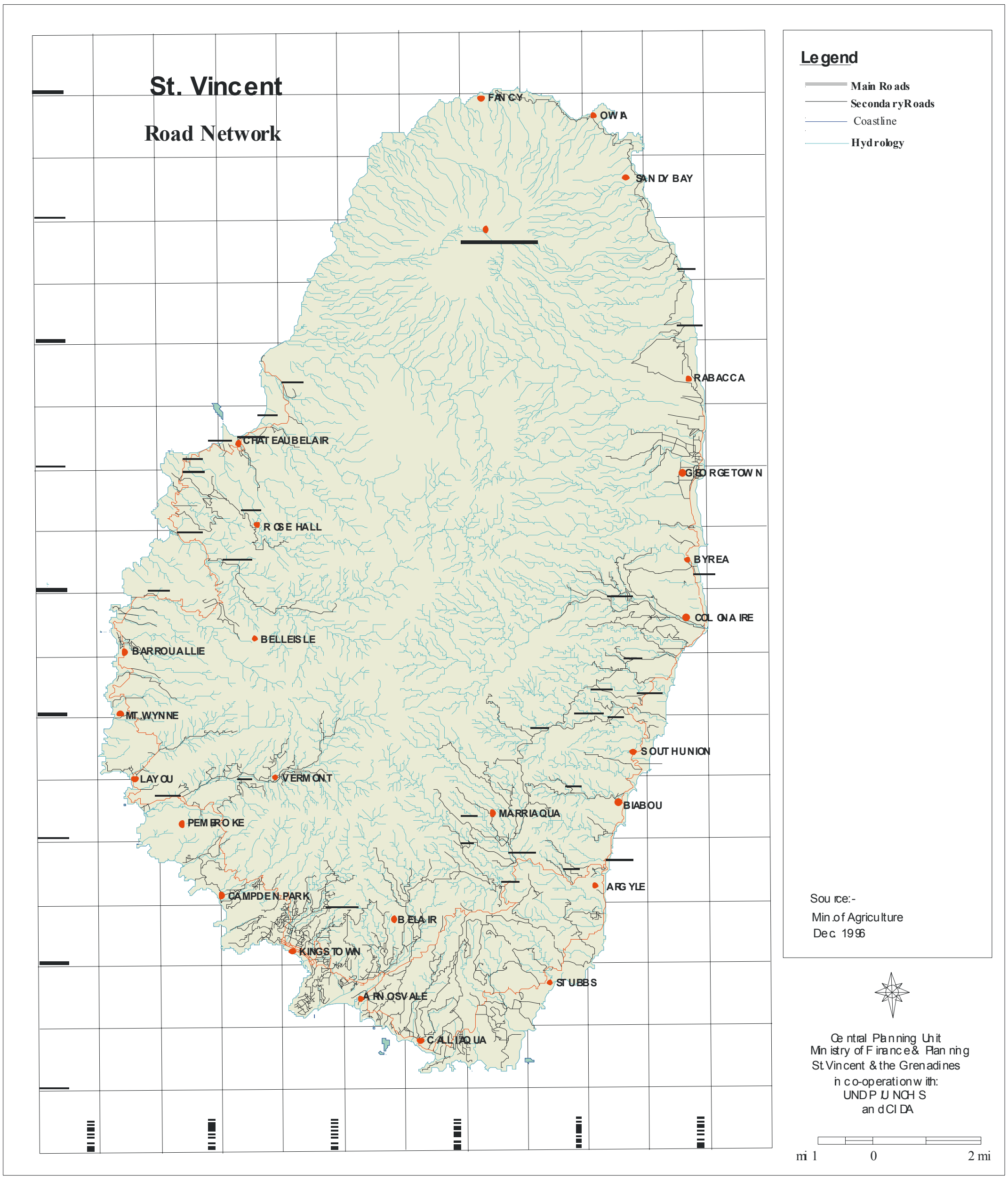
Map 9
Landslide in St. Vincent with case Studies



Map 10
Rainfall in St. Vincent

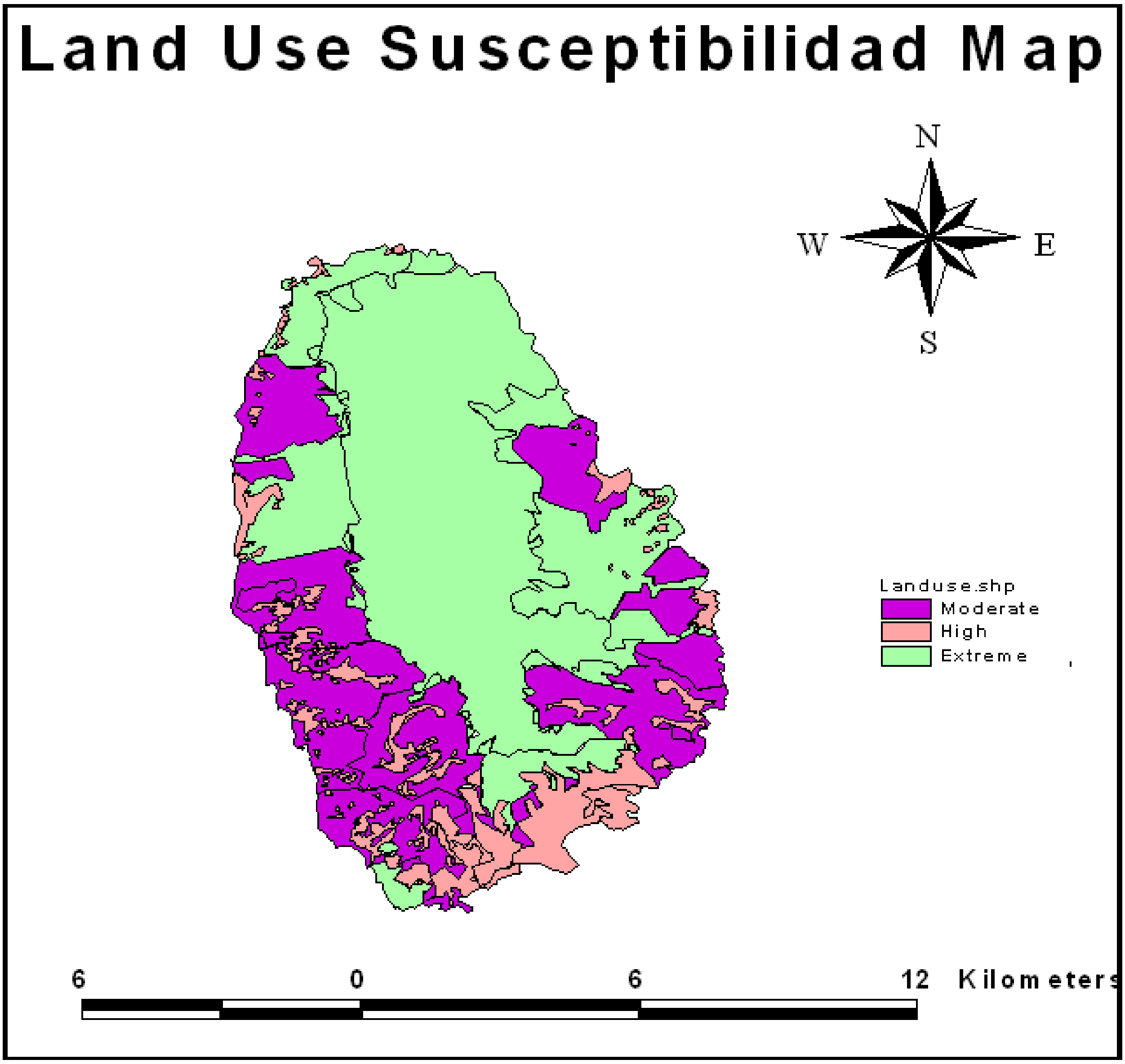


Map 4
Volcanic Hazard risks

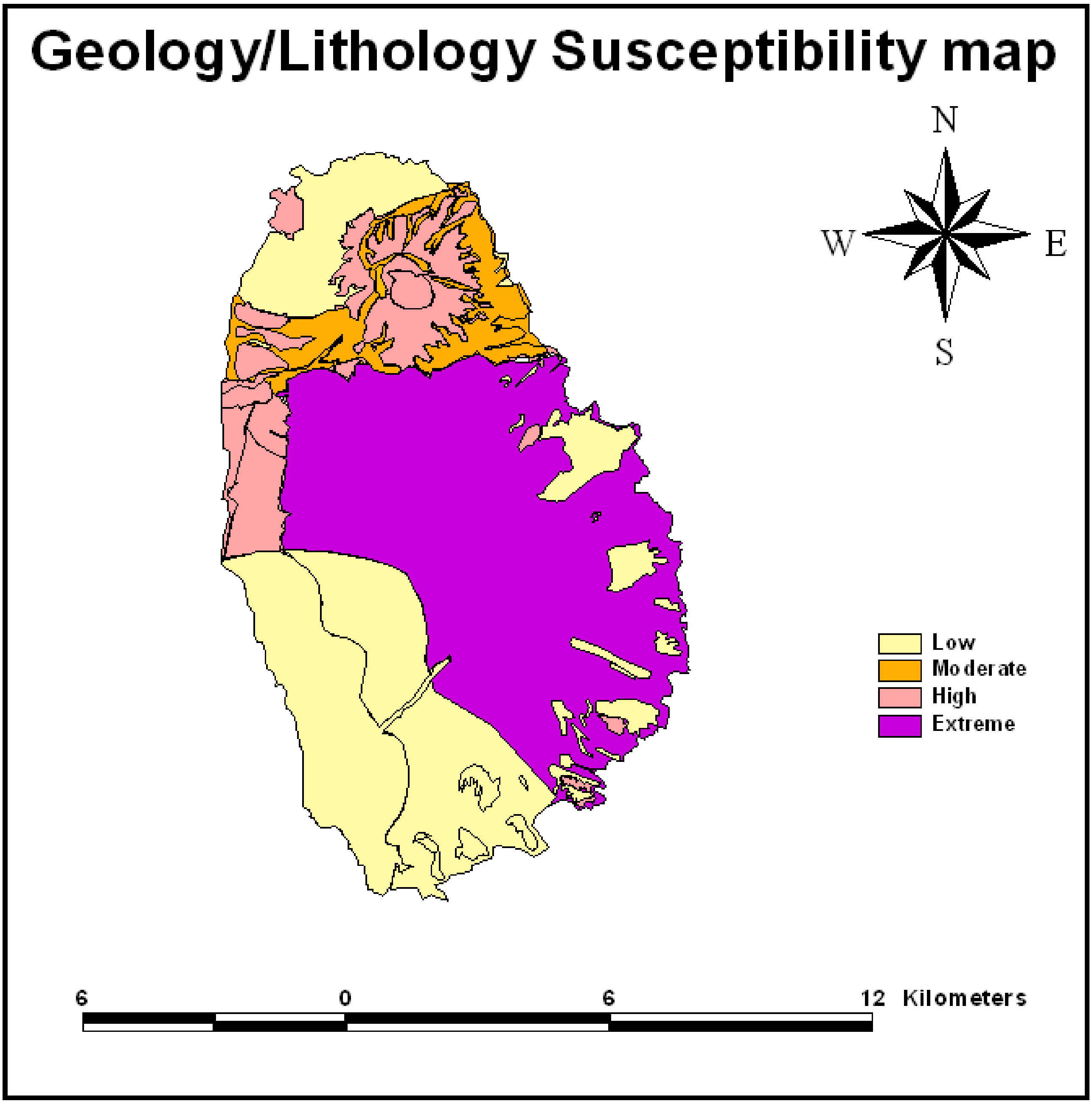


Map 5

Hydrology Map



Map 11
Land Use Susceptibility map



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Lithology Susceptibility map

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Class	Area (Sq mi)	Area (Km Sq)	%
Extreme	22.98	56.51	16.37971
High	98	255.67	74.10725
Moderate	8.54	24.11	6.988406
Low	2.98	8.71	2.524638
Total	**132.5**	**345**	100

Fig 8
<u>Clasification of Landslide Hazards in St. Vincent</u>

Land Use	Area Sq mi)	Area (km sq)	%
Natural Vegetation	22.89	59.28	17.161219
Banana Rootcrop	17.42	45.11	13.059086
Rootcrop	3.34	8.65	2.5041253
Forest	50.91	131.85	38.169817
Banana/Coconut	11.68	30.25	8.7572012
Built-Up Areas	22.69	58.76	17.010682
Industrial Site	0.22	0.56	0.1621168
Banana	1.45	3.75	1.0856035
Vegetable	0.16	0.41	0.1186926
Veg.Rootcrop	1.81	4.68	1.3548331
Pasture	0.82	2.13	0.6166228
Total	133.39	345.43	100

Tab: 9

Land Use in St. Vincent

Lithology	Area(Sq mi)	Area (km sq)	%
Rabaca+ Wallilabou Gravels	0.44	1.44	0.416739
Lava Underlying Basalts	22.14	57.34	16.59432
Basalt Outcrop	12.36	32.01	9.263761
Pyroclast + Mudflow	7.65	19.81	5.733056
Ash+Scoria Fall (1902-03)	9.76	25.27	7.313191
Belliesle Cinder Deposits	1.14	2.95	0.853736
Deeply Buried Basalts	12.37	32.03	9.269549
Mt. Brisbane Rich. Pyroclasts	67.43	174.69	50.55565
Total	**133.29**	**345.54**	**100**

Tab: 10

Composite Geology of St. Vincent

COMMENTS

COMMENTS

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DEDICATION

To all those persons who have contributed meaningfully towards the advancement of my life.

Those who have been instrumental in motivating and inspiring me even when I felt as if things were not progressing.

I DEDICATE THIS THESIS TO YOU!

My dearest mom Annette Commissiong, Dad Lennox Williams
My loving husband
Eng. Rawlson Patterson, and sisters Jashika and Jai-len Williams, Friends.

! THANKS A MILLION!

Resumen

La Isla de San Vicente y las Grenadinas forma parte de un arco de islas del Caribe Oriental las que han sido afectados por una serie de deslizamientos durante los últimos años.

En la actualidad, debido a su configuración montañosa los problemas relacionados con los movimientos de masas en laderas y taludes han sido multiplicados; incidiendo en ello los siguientes factores: las elevadas precipitaciones, taludes abruptas, medios de drenaje inapropiados, un suelo no cohesivo-no consolidado, arenoso muy fino de origen volcánico, la existencia de movimientos sísmicos y volcánicos, y el desarrollo infraestructural de áreas urbanas y sub-urbanas sin normativas constructivas.

Este estudio,"***Evaluación de la Susceptibilidad del terreno frente a los deslizamientos en San Vicente*"** se realiza con el propósito de analizar las condiciones ingeniero geológicas de la isla, a fin de conocer las causales y condicionales que dan origen al surgimiento de los deslizamiento y a su vez desarrollar una metodología que permita analizar los factores que inciden sobre el surgimiento de los mismos apartir de un mapa de susceptibilidad de riesgos de deslizamientos y valorar el peso de cada factor sobre lo anteriormente mencionado..

El método desarrollado esta basado en el mapa de riesgo de deslizamiento confeccionado por De Graff (1988) donde brinda una clasificación relativa de los deslizamientos en la isla. La base de datos geotécnicos e ingeniero geológicos se basan en los trabajos de campo, que permitieron la cartografía geotécnica de riesgos por deslizamientos en formato digital a través de un Sistema de información Geográfica (GIS) apoyado en software ARCVEIW, MAP INFO y AUTOCAD MAP y SURFER.

Al mismo tiempo el modelo de susceptibilidad fue verificado con observaciones reales y estos parámetros fueron incorporados de una manera que refleja con mayor claridad la situación existente en el medio geológico.

El trabajo incorpora un análisis de los diferentes tipos de movimientos, sus causas y condicionales, los mecanismos y dinámica. Brinda una zonificación de los deslizamientos y su relación con el incremento de la población en la isla.

La cartografía de los riesgos por movimientos de masas en taludes y laderas en la isla nos permite conocer las zonas de mayor vulnerabilidad y riesgos a los deslizamientos y la influencia de los factores contribuyentes.

Summary

The Island of St.Vincent forms part of an Island Arc of the Eastern Caribbean, these islands has been affected by a series of landslides over the years.

Presently, due to the mountainous configuration of the islands, the problems of mass movements in hills and slopes have been multiplied; some of the factors that give rise this mass movement include, elevated rainfall, non-cohesive type soils, steep slopes, in appropriate drainage systems, sandy and fine soil materials that are of volcanic origin, the existence of seismic and volcanic movements and the development of urban and rural infrastructure without constructive norms or building codes.

The study entitled, "***Evaluation of the susceptibility of the Island of St. Vincent towards landslides,"*** is aimed at analyzing the engineering-geological conditions present in the island, with the purpose of finding out the causal conditional factors that give way to the development of landslides and at the same time develop a rational methodology which can be applied to the susceptibility assessment of landslides in the island of St. Vincent. This will be done with the use of a landslide hazard map as base.

The method developed by the author is validated using available data from recent landslides which have occurred on the island utilizing a map of landslide hazards done by Degraff in 1988 where he made a relative classification of the landslides in the island. The data base includes geotechnical and geological information; field observations of some case studies of landslides together with digital cartography, geological and other theme maps which include land use, isoyet etc.

The data at hand was introduced in a Geographical Information System (GIS) making full use of software ARCVIEW, MAP INFO and AUTOCA D MAP, which made easier the application of methods and allows the combination of different layers through the necessary algorithm.

The predicted susceptibility model is compared to real field observations. The parameters are subsequently recalibrated in order to obtain a new model which fits better the observation.

Finally the model is applied to the retro-analysis of the effects of various factors that contribute to occurrence of landslide in the island.

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Special Introduction

- Introduction
- Objectives y Justification
- Previous Work Done
- Geographic Location y Economic Interest

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INTRODUCTION

The Windward Islands extend south from 15° 45' to 11° 45' N and from 60° 45' to 62° 00' (Rand McNally 1988). They lie 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.

Fig.1 Relief map depicting the Windward Islands viewed from 512,000 feet (approx. 156 KM).

The Island of St. Vincent along with the other Windward Islands has had to confront the issue of mass land movement over the years.

Debris flows, debris slides, rockslides, rock falls, slumps, and complex landslides are among the types of landslides found throughout the these Islands (Faugeres, 1966, Prior and HO, 1972, Walsh 1982, DeGraff, 1985, 1987a, 1988)

Factor such as steep slopes prevalent in the Windward Islands is one of the principal conditions favoring landslide development.

According to a study done by the Unit of Disaster studies at UWI Mona, the nature of materials underlying slopes on these islands plays a major role in landslide development. Their volcanic origin creates stratigraphic and lithologic conditions favoring landslides. Layers of alternating ash, lava, and breccias lead to locations on slopes where weaker bedrock weathers faster and undermines more competent bedrock overlying it. They also consider that the principal triggering mechanism for landslides in the Windward Islands is rainfall. They have also taken into consideration anthropic activity such as agricultural practices another factor that contributes to landslides in these islands.

Volcanoes, earthquakes, hurricanes, storm surges, floods, landslides and coastal erosion are potential disaster issues facing these countries. Over the past 20 years, the country fortunately has not been hit by a direct hurricane, but it has experienced the damaging effects of storm surges, floods and landslides which often accompany these events. Coastal erosion is a continuous threat to property and communication networks, along with anticipated sea level rise that make the coastal zone particularly vulnerable to beach erosion, loss of habitat for marine life, loss of fresh water aquifers, and damage to coastal infrastructure.

In the case of St. Vincent over the past few years the problem of landslide and mass movement has always been a theme of interest. Special reference must be made to the fact that the severity of the effects of this hazard has somewhat increased its intensity of impact recently. The Gibson Corner Landslide and other latest cases like the Dauphine.
These cases have urged the necessity for the Government and people of the island to take the problem into serious consideration.

In this thesis, efforts were made to study the areas that have been affected by land slides, special emphasis was placed on an analysis of some causual factors with the purpose of retroanalysing the to what extent they contribute to the susceptibility of the island to the occurrence of landslides.

APPLICATION FIELD

This thesis provides information that will serve as base work for future investigation, with respects to the analysis of geological risks and hazards that affect the island of St. Vincent, a theme that is of very keen interest to the author.

The author aspires to broaden the scope of the study and along with a follow-up of a study on landslides, with much detail hopes to address other geological hazards, such as flooding, coastal erosion, volcanic risks, in future studies.

The thesis has important applications in the following Fields/Ministries:

- Ministry of Communication of Works- Engineering
- Physical Planning
- Disaster Preparedness
- Central Water and Sewerage Authority

OBJECTIVES Y JUSTIFICATION

Object: Landslide in the island of St. Vincent

Problem: Lack of knowledge about the causes and conditions of the phenomenon of mass movement in hills and slopes, as well as the absence of a regionalization of the susceptibility the island of S. Vincent to the occurrence of landslides.

General Objective: Evaluate the susceptibility towards the occurrence of landslide in St. Vincent

Specific Objectives:

- Study the geological conditions of the terrain
- Evaluate the causal factors of landslides Lithology, tectonics, hydrogeology, geomorphology, geotectonic, and volcanism
- Establishment of a cartographical system related with mass movements in hills and slopes.
- Propose a mitigation plan with respects to the grade de susceptibility of the area

Hypothesis:

If the aerial location of the mass movements is known, as well as causal factors, the influence within the system, then it is possible to determine the level of susceptibility of the area towards landslides and likewise propose a plan of action to mitigate these types of disasters.

Justification:

The need for an inventory and geotechnical study of landslide risks that permit a better use of the terrain for rural and urban planning.

Novedad Scientifica:

- First time that a study is being done which includes an analysis landslide risks on the island applying cartographical methods like Geographical Information Systems (GIS) that facilitate suitable and effective decision for territorial planning.
- It offers a series of mitigation measures that permit the improvement of the way of life with respect to the ubication of zones that are suitable for construction.

PREVIOUS WORK DONE

In 1985, Jerome DeGraff of the Forest Service, USDA, in collaboration with the Government of Saint Lucia produced a landslide risk map of Saint Vincent and the Grenadines.

Hazard categories are determined applying a procedure used by the OAS that employs geomorphic (areas with past landslides), geologic (bedrock type) and topographic (slope) factors. Low, Moderate, High and Extreme are the four categories used on the map. Areas of extreme hazard include central mountains and lands on the leeward flanks of the central ridges. The latter includes skeletal soils that are bouldery and shallow. Uncemented and unconsolidated rock material and steep slopes are often associated wit the areas of high and extreme landslide hazards. Debris slide, typically of soil and highly weathered bedrock is the most common type of landslide within the study with rockslides and rock fall associated with cliffs and the coast and bedrock escarpments on the upper part of steep slopes being less common. The map shows where landslides will occur in the future and their probability of occurrence, rather than their actual occurrence.

Low Hazard (L*)* - indicates that the probability of occurrence of landslides is very limited, even with strong triggering factors.

Moderate Hazard (M) - indicates that some mass movements can be generated under the influence of strong triggering factors

High Hazard (H) ***-*** means that considerable amounts of mass movements can be generated from strong triggering factors

Extreme Hazard (E) - means that considerable mass movements can be expected under weak triggering factors *(***see annex for map 6)**

Table 1 characterizes landslides on these islands

Island	Number of Landslides	Landslide Size (hectares)	Landslide Density (per sq.km)	Terrain Disturbed (%)
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

Table1: Number, Size, and Area Distribution of Past Landslides on St Vincent, St Lucia, and Dominica

Source: inventories of landslides compiled by aerial photo-interpretation and limited ground verification, De Graff and al., 1989)

Landslides are a significant process shaping the landscape of many Caribbean islands. According Degraff et al. the geology and climate of the Caribbean contributes to the prevalence of landslides. The ubiquitous steep slopes resulting from tectonic and volcanic forces provide abundant locations for landslide occurrence. Other erosional processes such as waver action along island coasts and stream erosion provide a continual means for maintaining many slopes at inclinations close to the angle of repose for the materials underlying them. Tectonic and volcanic activity also creates lithologic and stratigraphic conditions favoring the occurrence of landslides.

The warm, wet climate influences the material involved with land sliding and serves as the most common mechanism for their initiation. The rapid weathering of bedrock under humid conditions creates a regolith generally weaker than the parent rock. The presence of clay either inherited from parent sedimentary bedrock or derived from weathering of metamorphic and volcanic bedrock contributes to the tendency of soil masses to fail. The seasonal pattern of rainfall punctuated with intense storms serves as an efficient means for triggering landslide in this regional.

Most landslide types are found within the Caribbean. Debris flows and slides are by far the most prevalent form. Many factors contributing to general slope instability favor development of these landslide types. Earthflows, rockslides, rock falls, and slumps are other common but less frequently occurring landslide types.

Fatalities and injuries are a primary loss attributable to landslide in the Caribbean. Destroyed or damaged structures, especially roads, is another major loss attributable to landslides. Clearance of slide debris and repair of damage are the main impacts to roads. On the narrow roads often found in the Caribbean, It does not take a large landslide to create a major impact. In St. Vincent, St. Lucia, and Dominica of the Windward Islands, the average annual cost for landslide damage to roads ranges from $115,000 to $121,000 in normal years. The average annual cost of landslide investigation, repair, and maintenance in the larger islands of Trinidad and Tobago is $1.26 million and $0.96 million, respectively. On an average year, it is estimated the coast of repairing landslide damage to roads throughout the Caribbean amounts to $15 million. In St.Vincent, water lines severed by landslides in 1981 left nearly 40 percent of the population without water for periods varying from a few days to six months. In 1986, landslides damaged pipelines to hydroelectric generating stations and reduced the total electrical generating capacity of St. Vincent by 36 percent until repairs could be made.

Losses of bananas to smaller landslides on St. Lucia and St. Vincent yield losses of $4000 to $250 for individual farmers. Because agriculture is carried out mainly by individual farmers, with per capita incomes ranging from hundreds to a few thousand dollars, losses of this magnitude represent a severe burden to the economies of both individual families and island nations.

(Abstract taken from: DeGraff, J.V., Bryce, R., Jibson, R.W., Mora, S., and Rogers, C.T. 1989. Landslides: Their extent and significance in the Caribbean. In E.E. Brabb and B.L. Harrod (eds), Landslides: Extent and Economic Significance. p. 51-80. Rotterdam: A.A. Balkema.)

In 1990, Vincentian Geologist Dr. Richard Robertson, by request of the then Housing and Lands Department, conducted a study at Gibson Corner to evaluate the following aspects:

- The nature of the subsoil in the area so as to assess the potential for slippage in light of reported incidence of this occurrence in the past
- To carry out tests to determine soil type and the probability of landslide in the area
- To assess the land suitability for residential purposes

Base on the analysis done by Dr. Robertson, it is evident in his report that there were signs of past landslide movement and the area had the possibility to result as and unstable land surface.
This area has continued to be faced with a serious threat of land movement and precisely in the year 1998. Mention must be made that contrary to the advice of Geologist Robertson infrastural development bloomed in that area resulting in a catastrophic landslide occurrence ,which caused the Government of St. Vincent and the person who owned lands in that area to suffer economic and material losses.
Later on in the study the area will be elaborated on. (See case study Chapter 3)

RESEARCH METHODOLOGY

In the execution of this project, the author develops a series of investigations structured to attain the above mentioned objectives. With this purpose the work was divided in the following stages:

- Research of Information and an analysis of previous work done about topic in question
- Field Work and Laboratory- this covered geotechnical , engineering and mapping of the different mechanism of mass movements in slopes and hillsides
- Landslide Risks Analysis- determination of the different causal conditions that give way to the distinct mechanisms of landslides and its evaluation
- Selection of a cartographical method of risks based in a Geographical Information System (GIS)
- Office Work and Research

This study has been divided into three main parts:

Chapter 1 is based on the general information of the geological and geographical setting of the region of study. In this chapter special emphasis is placed on those factors like relief, rainfall, geological situation, tectonic, volcanism that affect the island

Chapter 2 provides the methodology applied in the study as well as information on the different mechanism of mass movement, taking into consideration the causal and conditional factors that give way to the occurrence of landslides. This permits the analysis of the triggering factors of the same. During the elaboration of the study, a series of software applied in the Geographical Information Systems (GIS) including Map Info, Arc View, and AutoCAD Map were applied. These software were selected because of its efficiency, in the overlaying and merging of thematic maps to give way to a better interpretation for a landslide maps.

Chapter 3 provides a wide elaboration of the causal and conditional factors and a classification of the specific types of landslides that affect the island of St Vincent. Including case studies Finally the work include a conclusion and a recommendation with the purpose to give a proper interpretation of the different factors like type of landslides, cartography, and it's dynamics, In such a way that it provides numerous solutions to the pertinent problems that affect the island.

The author provides a glossary of terms and definitions that permit a better comprehension of terms and terminology that have been used in the project.
Also the work is accompanied an annex which include, tables, photos, maps and graphs that are necessary to argue the analysis of landside risk.

GEOGRAPHIC LOCATION Y ECONOMIC INTEREST

Map 1

Map of the Caribbean illustrating the exact location of St. Vincent and the Grenadines

St. Vincent and the Grenadines consists of over 30 islands, inlets, and cays. The largest island, St.Vincent, is located at latitude13o15' N, longitud 61o12' W. The other islands extend south for 75 km. St. Vincent and the Grenadines is part of the Windward Island chain in the Lesser Antilles. Neighboring islands include Grenada to the south, St. Lucia to the north and Barbados to the east.

The Grenadines are enchanted, idyllic islands scattered down the Eastern Caribbean from St. Vincent in the north to Grenada in the south, approximately 1600 miles southeast of Miami. Each island is very individual in style and appeal although all are unspoiled with irresistible white sand beaches, warm clear seas and remoteness from the pressures of life. Discovered by Columbus in 1498, this multi-island state belonging to the British Commonwealth became independent on October 27, 1979. The main city and financial center, Kingstown, is situated on St. Vincent Island.

ECONOMY

St. Vincent and the Grenadines remains heavily dependent on agriculture for its economic base. The relative proportion of gross domestic product (GDP) accounted for by agriculture has declined in recent years **(Figure 2).** As late as 1990, agriculture still accounted for about 20.0 percent of GDP but by 1996 its share declined to 11.9 percent. Still, in 1996 it continued to employ nearly 60 percent of the workforce.

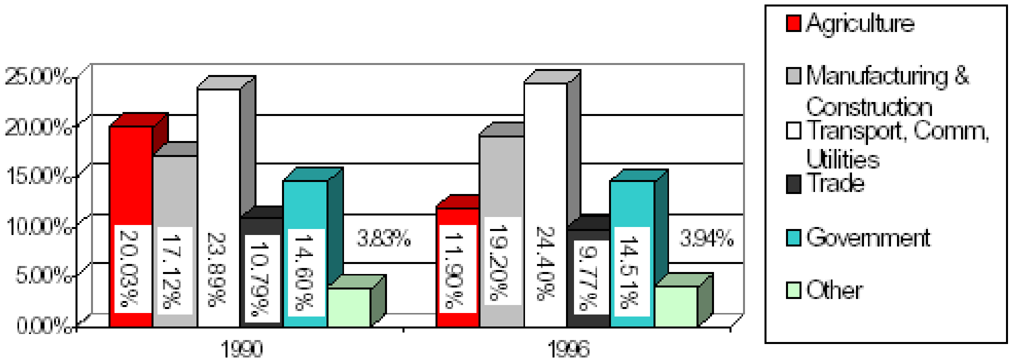

Fig.2
Gross Domestic Product by Sector, 1990 and 1996

The economy has prospered in the recent past, with annual growth rates from the late 1970s through the early 1990s averaging 13.3 percent (SVGG, 1997). A favorable external environment, concessionary aid, and preferential market access that led to high banana prices were the primary impetus to economic expansion. A fall in banana prices beginning in 1992 followed by unfavorable weather conditions caused a substantial decline in the value of agricultural output. Revenues from banana exports fell from EC$170.3 million in 1990 to EC$20.2 million in 1995.

In 1996, the Gross Domestic Product (GDP) amounted to EC$631.0 million **(Table 2).** Of that figure, 11.9 percent is derived from agriculture, 8.0 percent is from manufacturing, 14.5 percent is from trade, and 16.3 percent is from government services (SVGG, 1997). The average annual per capita income is currently EC$5673. The unemployment rate is estimated to be 22 percent, and underemployment is high with the decline in banana revenues. Inflation rate is modest, currently running at 3.6 percent. The value of imports has remained fairly constant in recent years, now totaling EC$355.9 million, but the value of exports has fallen from EC$210.9 million in 1992 to EC$125.3 million in 1996 (SVGG, 1997).Consequently, the trade deficit has increased by 58 percent during this time period (SVGG, 1998).

Sector	Gross domestic product 1980	1990	1996	Percentage of total 1980	1990	1996
Agriculture	23.20	95.98	79.68	14.6%	20.0%	11.9%
Manufacturing	14.49	38.51	53.77	9.1%	8.0%	8.0%
Construction and Mining	18.86	43.50	74.77	11.9%	9.1%	11.2%
Transportation	18.30	61.91	84.99	11.5%	12.9%	12.7%
Communication and Utilities	21.72	52.58	78.41	13.7%	11.0%	11.7%
Finance, Ins., Real Estate	14.89	46.67	65.39	9.4%	9.7%	9.8%
Trade	17.66	51.70	97.17	11.1%	10.8%	14.5%
Services	7.25	18.35	26.36	4.6%	3.8%	3.9%
Government	22.6	69.97	109.07	14.2%	14.6%	16.3%
Sub-Total	158.97	479.17	669.61	100%	100%	100%
Less Imputed Service Charge[a]	7.41	26.19	38.66			
Total GDP	138.67	452.98	630.95			

[a] Not deducted in calculating relative shares by sector.
Source: St. Vincent and the Grenadines Statistical Office\ECCB.

Table 2.
Gross Domestic Product by Sector for 1980, 1990, and 1996 in Current Prices (EC$ Million)Agriculture, Industry, and Tourism

Primary agricultural products include bananas, mangos, coconuts, citrus fruit, and root crops including arrowroot, dasheen, eddoes, yams, and sweet potatoes. Bananas continue to be the most important agricultural commodity, with 8,000 acres allocated to fresh banana production. They account for 65.7 percent of agricultural exports, down from 92.6 percent in 1990, when fresh banana exports were valued at EC$170 million.

St. Vincent is the world's largest producer of arrowroot, which is used for flour, meal, and starch. Collectively, root crops are important domestically and for export to neighboring Caribbean islands. Industrial activity consists of food processing, metals fabrication, furniture, clothing, and starch production.Agriculture and tourism are the foundations of the economy. While bananas and arrowroot starch (used as a food thickener and in paper finishing) are our primary exports, efforts are being made to diversify. **Figure 3** gives a general idea of land use in the island. In the Annex 1there is a map of landuse of St. Vincent See, annex 1 landuse map of St. Vincent.

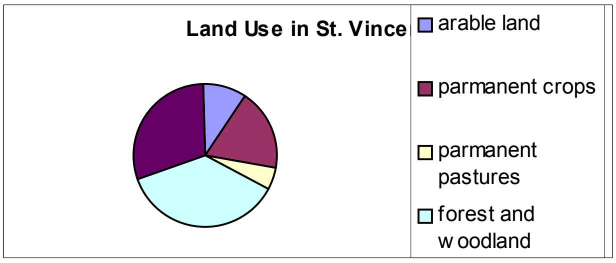

Fig 3 Pie Chart representing land use in St. Vincent

In recent years, millions of dollars have been invested in the fishing industry infrastructure. Also in an effort to foster diversification there have been an augment in services mainly tourism, telephone and internet based marketing and offshore financial services Its per capita GDP is an estimated US$2,900

(2002 est.) with the sectors of agriculture, industry and services contributing 10%, 26% and 64% respectively to the GDP (CIA World Fact book 2003)

Tourism growth has been steady with particular attention paid to upscale markets. Small hotels, inns and guesthouses are the backbone of our tourism industry. Thanks to good harbors and well-operated marinas, a number of our islands have a long-standing favorable reputation among yacht visitors. A modern cruise ship berthing facility and inter-island ferry has recently been constructed in the capital city. In general, over the past two decades, the economic trend has been positive, with improving personal income and upgraded social services, as well as responsible fiscal controls on the part of the government. Our society is stable and our population is enjoying the benefits of improved education.

POPULATION

The population of St. Vincent and the Grenadines grew by 33.2 percent between 1960 and 1991, as is indicated in Figure and Table 2-1. The most rapid rate of growth occurred during the 1970s, when the population grew by 13.4 percent. The current population is estimated at 111,105 **(Tab3)** Of that population, 102,375 residents, totaling 91.4 percent, live on mainland St. Vincent. The remaining 8,730, 8.6 percent, lives on the Grenadines (SVGG, 1997). The population is predominantly Afro-West Indian with some remnants of indigenous Carib Amerindian assimilated into the majority population. Whites of European descent and East Indians comprise the majority of the remaining population.

	1960	1970	1980	1991
Population	79,948	86,314	97,845	106,499
Rate of Change		7.96%	13.36%	8.84%

Source: St. Vincent and the Grenadines Statistical Office.

Table 3
Population Trends in Census Years 1960-91

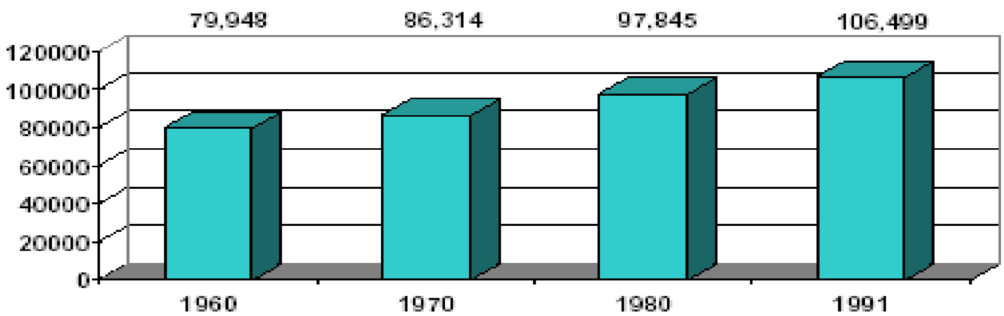

Fig.4

Population in Census Years 1960-91

Criteria	1990	1994	1997
Population	105,715	109,534	111,224
Relevant Areas (Km²)	340	340	340
GDP(1994 MEC$)	$ 453.0	$ 552.7	$ 666.6
GDP per capita (1994 US$)	$ 1587	$ 1869	$ 2220
Estimated % of the informal sector in GDP		10%	
% of industry in GDP	8.5	9.2	7.9
% of services in GDP	19.5	22.0	22.1
% of agriculture in GDP	21.2	11.1	10.1
Land area used for agricultural purposes (Km²)		10,675	12,368
Urban population as % of total population		43.7%	
Livestock population			
Hoofed	38,580	36,950	40,150
Poultry	222,000	270,000	315,000
Forest area (Km²)		12,689	
Population in absolute poverty[a]		37.9	
Life expectancy at birth (males/females)	68/73	68/73	68/73
Literacy rate	80%	80%	80%

[a] Central Statistics Department, Ministry of Finance and Planning.

Tab. 4

Population in Census Years 1960-91

	1991	2001	2011	2021
Population	106,499	114,005	121,675	130,765
Rate of change		7.05%	6.73%	7.47%

Source: St. Vincent and the Grenadines Statistical Office.

Tab. 5

Population Projections for the Years 1991-2021