Landslide occurrence, operational response and strategic risk management

A case study of Hurricane Tomas in St Lucia

Chris Arnold – Principal Engineering Geologist

Contents

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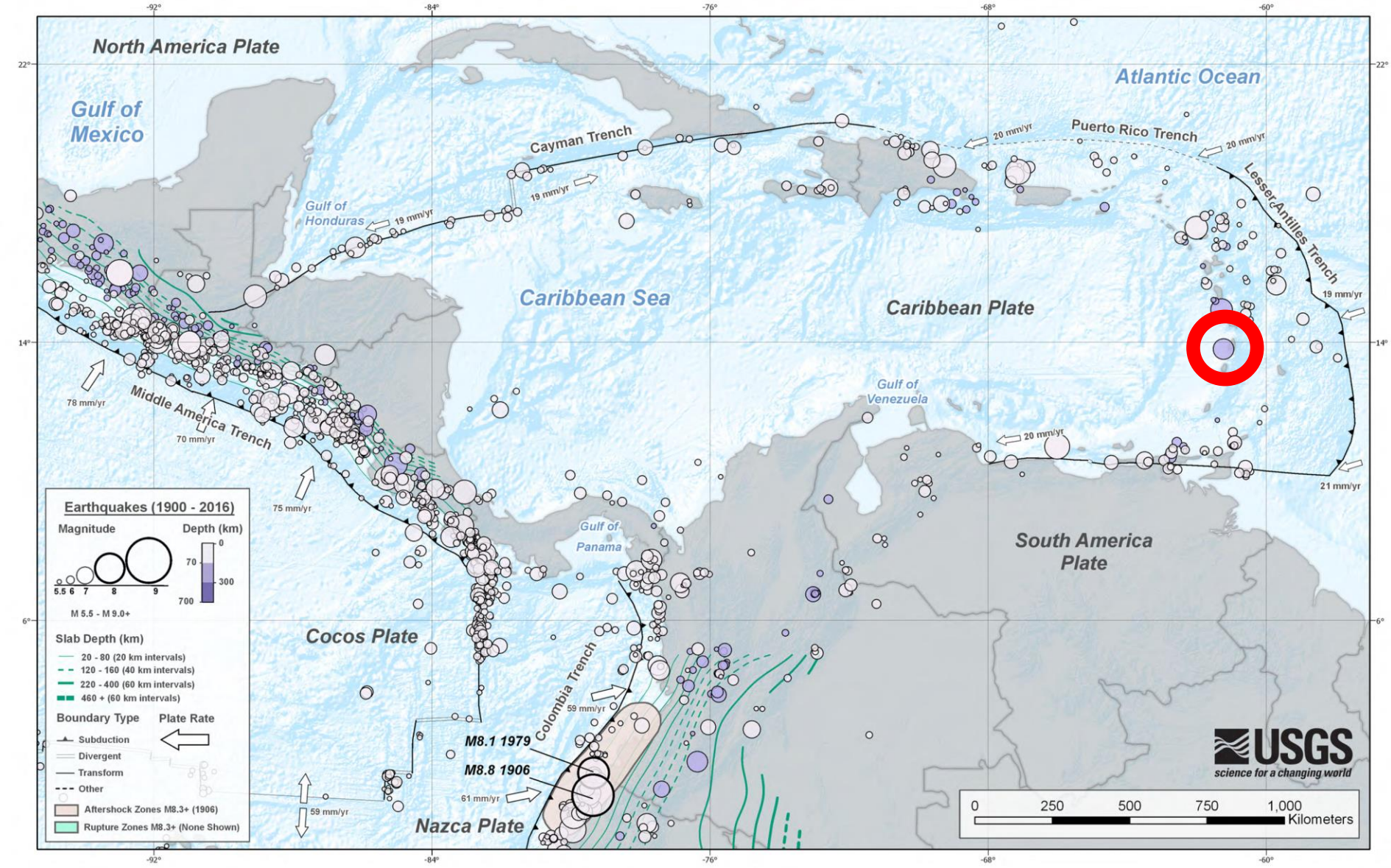
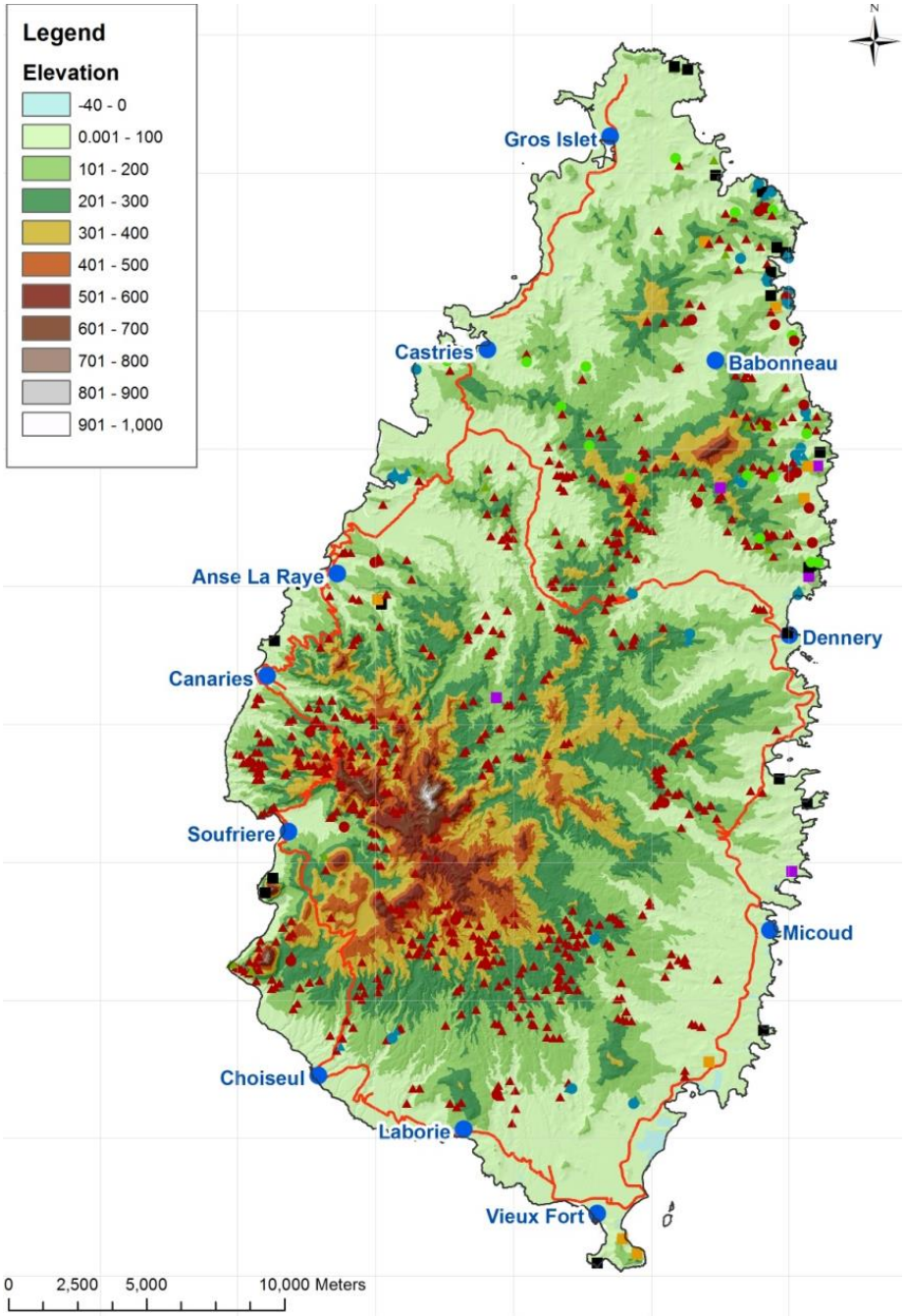
Introduction

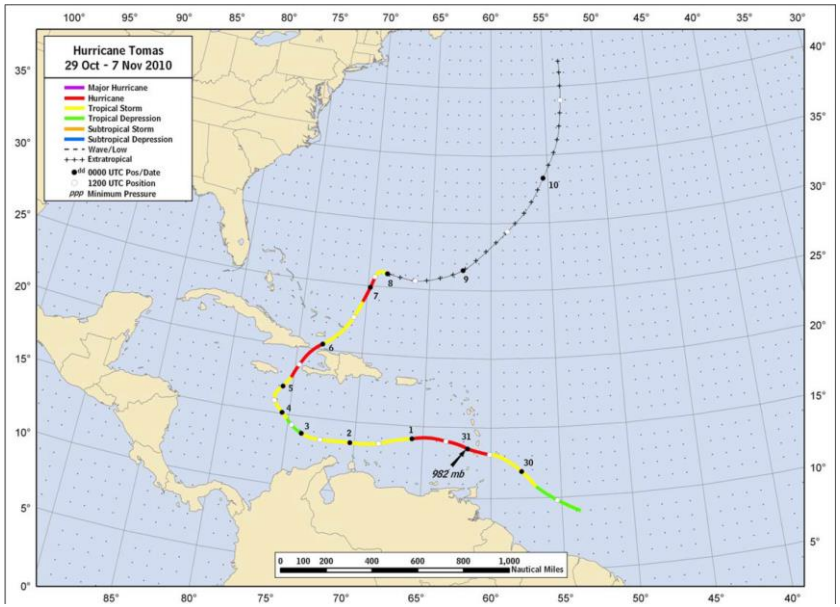

North America Plate
Gulf of Mexico
Atlantic Ocean
Cayman Trench
Puerto Rico Trench
Lesser Antilles Trench
Gulf of Honduras
Caribbean Sea
Caribbean Plate
Gulf of Venezuela
Middle America Trench
Gulf of Panama
South America Plate
Cocos Plate
Colombia Trench
M8.1 1979
M8.8 1906
Nazca Plate
78 mm/yr
70 mm/yr
75 mm/yr
59 mm/yr
61 mm/yr
19 mm/yr
20 mm/yr
21 mm/yr
Earthquakes (1900 - 2016)
Magnitude
Depth (km)
M 5.5 - M 9.0+
Slab Depth (km)
20 - 80 (20 km intervals)
120 - 160 (40 km intervals)
220 - 400 (60 km intervals)
460 + (60 km intervals)
Boundary Type
Plate Rate
Subduction
Divergent
Transform
Other
Aftershock Zones M8.3+ (1906)
Rupture Zones M8.3+ (None Shown)
USGS
science for a changing world
0 250 500 750 1,000
Kilometers

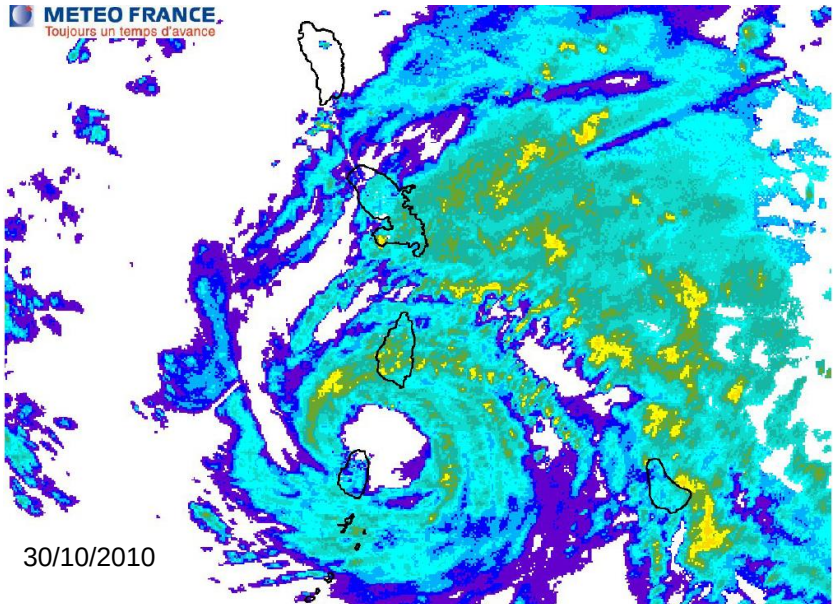
Primary road network

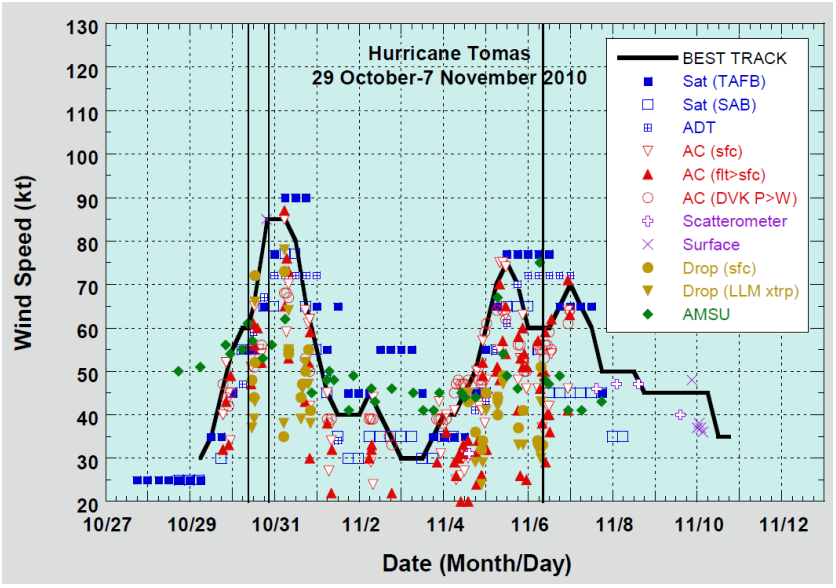
Main line	136km
Bois Cachet	0.6km
La Toc	3.6km
Millennium Highway	6.2km

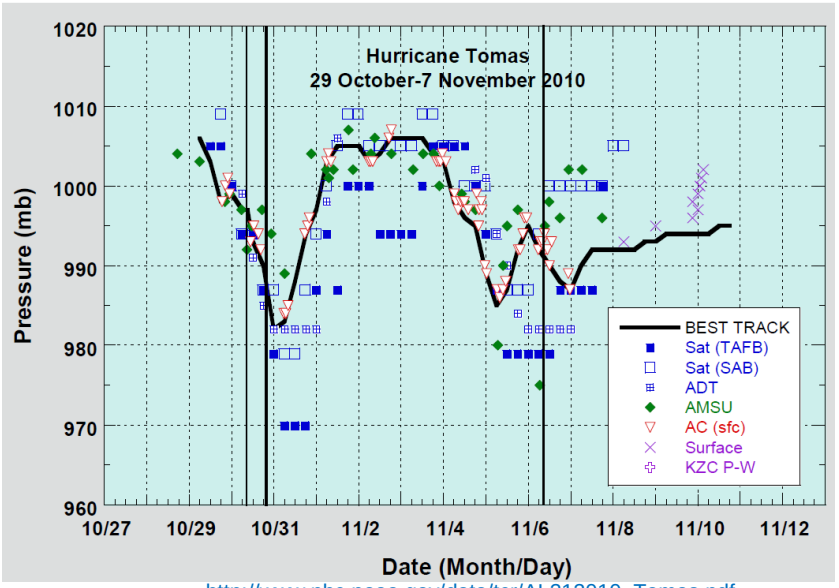


Hurricane Tomas



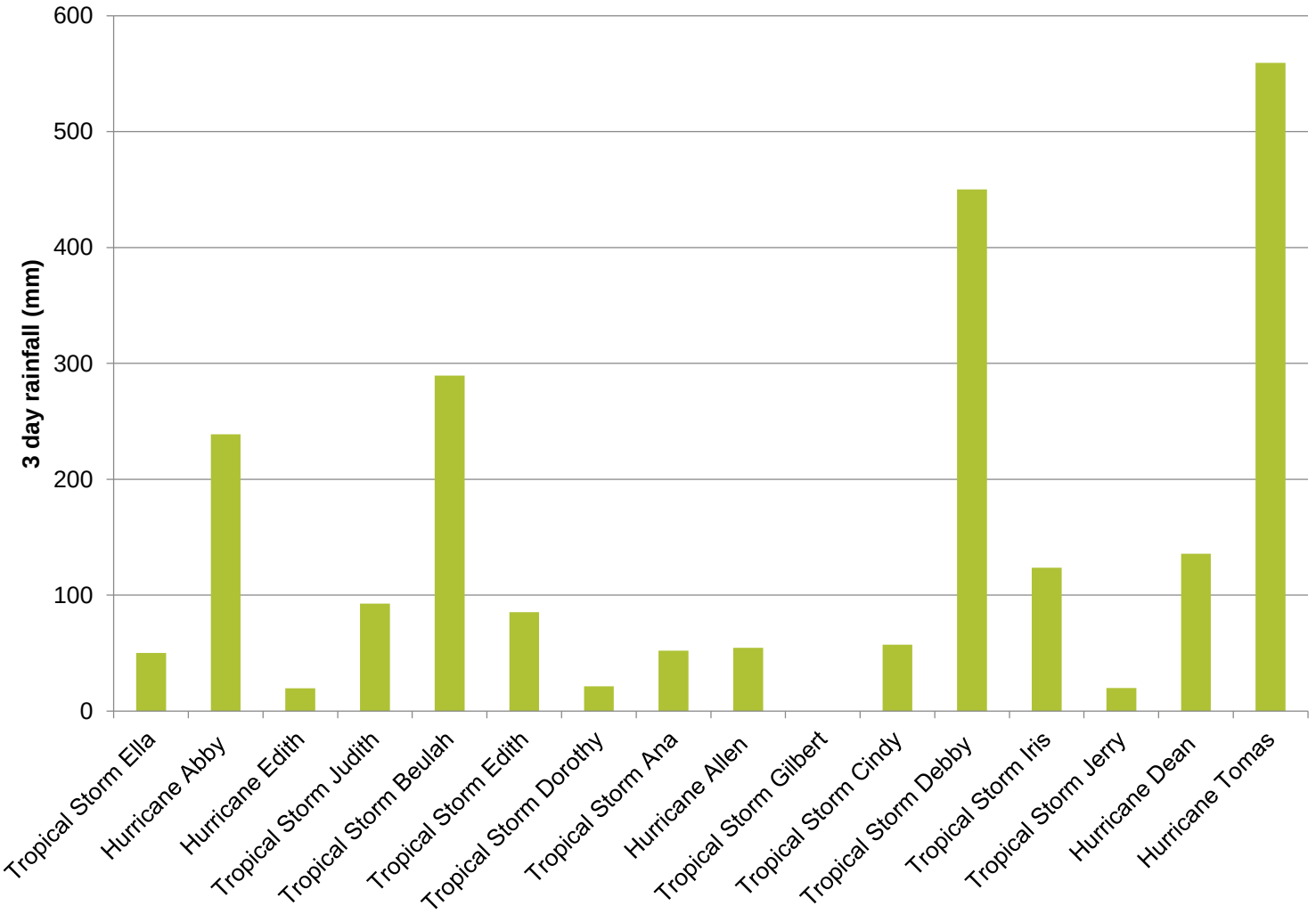






http://www.nhc.noaa.gov/data/tcr/AL212010_Tomas.pdf

Hurricane Tomas



http://www.nhc.noaa.gov/data/tcr/AL212010_Tomas.pdf

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Impact of Hurricane Tomas

Seven dead / missing as a result of landsliding

Major sections of primary road network impassable

Several communities completely isolated

US$45M damage to road transport sector (ECLAC, 2011)

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GOSL, UN

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Hurricane Tomas

Impact on Primary Road Network

Cul de Sac – Ravine Poisson

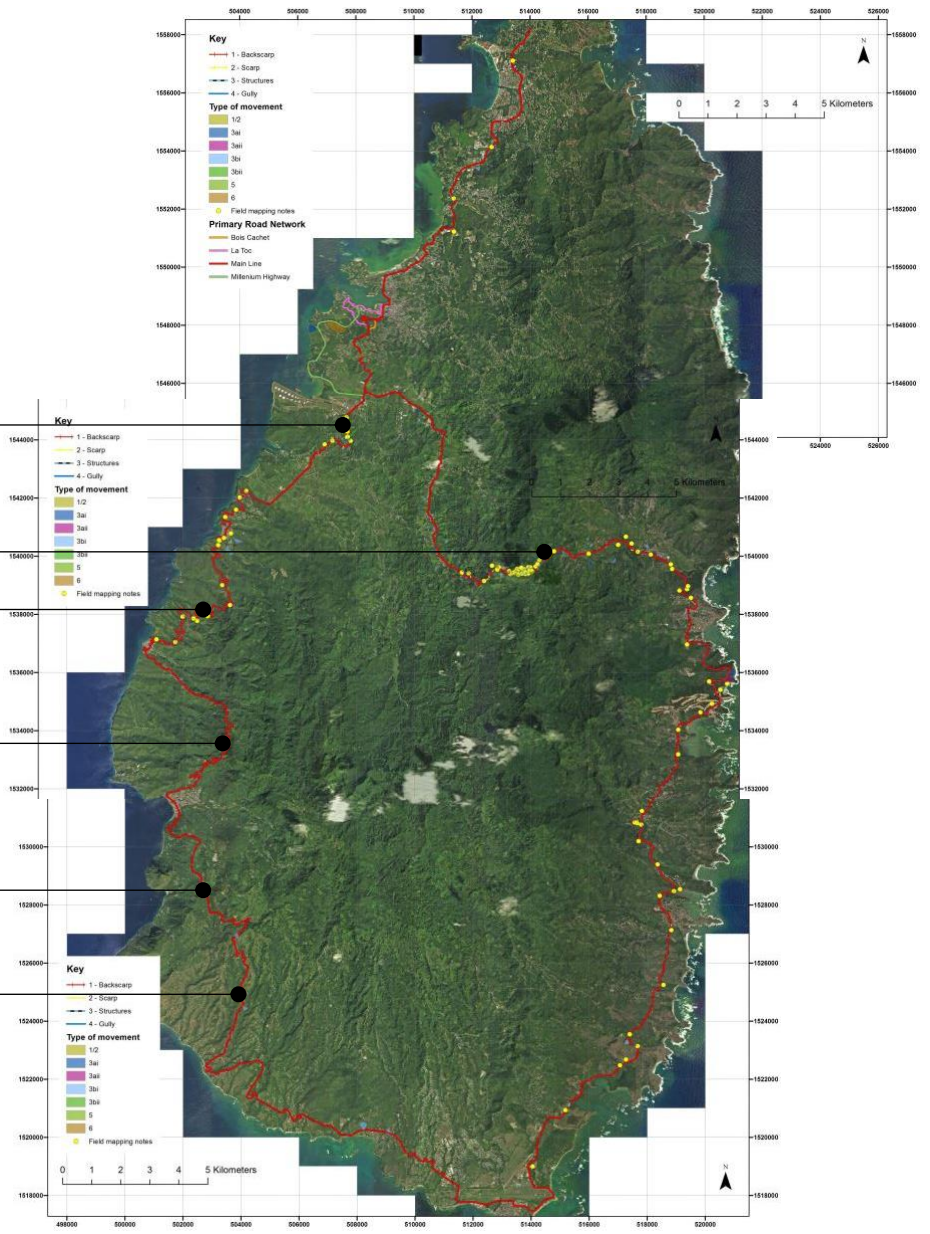
Barre de Lisle – Hill top Dennery

Anse La Raye - Canaries

Quart Chemin – Soufriere

Myers Bridge - Soufriere

Choisel Village Bridge – Myers Bridge



Hurricane Tomas Damage Assessment – GOSL / FDL Consult Ltd.

Map – Mott MacDonald

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Response

Immediate response

Landslide Response Plan

National Emergency Management Organisation

Zone Engineers

Barre De L'Isle – Strata Engineering Consultants Ltd.

Immediate response

Landslide Response Plan

National Emergency Management Organisation

Zone Engineers

Long-term response

Reconstruction

Revegetation

Landslide risk assessment

Long-term response

Reconstruction

Revegetation

Landslide risk assessment

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Landslide risk assessment

Hurricane Tomas

Landslide risk assessment

- Analyse and assess slope stability, drainage and geotechnical conditions
- Map levels of risk
- Identify primary and secondary causal factors of slope movement
- Suggest cost effective slope stabilisation, protection and landslide remediation measures
- Enhance the capacity of the GoSL to manage landslide hazards

Hurricane Tomas

Landslide risk assessment

Increasing frequency / decreasing condition

Increasing severity of damage

LANDSLIDE RISK MATRIX FOR SAINT LUCIA'S PRIMARY ROAD NETWORK	FREQUENCY					
	Event considered possible, but has no precedent in the historical record	Event likely to occur in prolonged, near-stationary Hurricane event (e.g. Tomas), once every 100+ years	Event likely to occur in a major tropical storm (e.g. Debby), once every 50 to 100 years	Event likely to occur in intense rainstorm event, possibly in combination with earthquake	Event likely to occur during "normal" rain storm event	**Rainfall and/or hurricane triggering events**
SEVERITY LEVEL: Direct Impact on Road. *Notes: outer carriageway is typically constructed of fill. Debris on road may include trees and shrubs*	Slope in good condition. Failure might occur in exceptional circumstances e.g. landslide is conditional on failure of a man-made structure	Mature trees present. Signs of slope distress, but landslide is conditional on failure of a man-made structure (e.g. retaining wall)	Event likely to occur in next 10-50 years. Slope in moderately poor condition and expected to deteriorate	Event likely to occur in next 5-10 years. Slope in poor condition and expected to deteriorate	Event likely to occur in next 1-2 years. Slope in very poor condition and expected to deteriorate	**Slope condition assessment**
A. Complete loss of road. Road not serviceable.	11	16	20	23	25	*Note all Severity Levels include the possibility of fatalities/injury for landslide impact to traffic*
B. Loss of outer carriageway fill or deformation/settlement of road surface. Road serviceable, but one-lane traffic flows.	7	12	17	21	24	
C. Partial loss of outer carriageway fill. Temporary blockage of 2 carriageways, road out-of-service.	4	8	13	18	22	
D. Temporary blockage of inner carriageway. One-lane traffic flows.	2	5	9	14	19	
E. Debris on road e.g. rocks or soil. Damage to inner carriageway road drain. Road remains usable.	1	3	6	10	15	
	P <0.002 (< 1 in 500 years)	P = 0.02 - 0.002 (1 in 50 to 1 in 500 years)	P = 0.1 - 0.02 (1 in 10 to 1 in 50 years)	P = 0.2 - 0.1 (1 in 5 to 1 in 10 years)	P = 1 (1 in 1 year)	**Indicative Annual Probability of Event**
	ANNUAL PROBABILITY					

Use both approaches to estimate frequency of slope failure

High Risk
Medium Risk
Low Risk
Very Low Risk

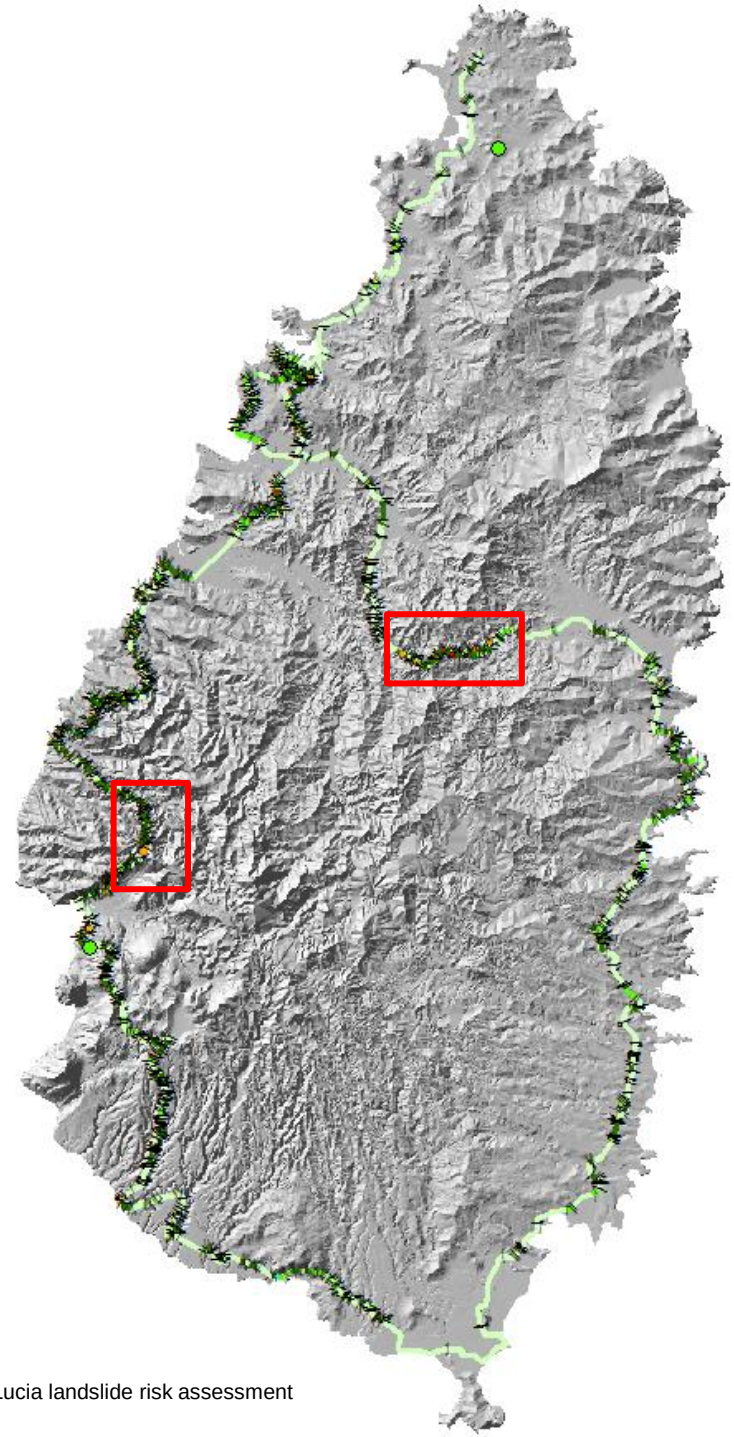
0 = Negligible Risk

Hatched fill signifies risk level considered 'as low as reasonably practicable'

Landslide risk assessment

Hurricane Tomas

Landslide risk assessment



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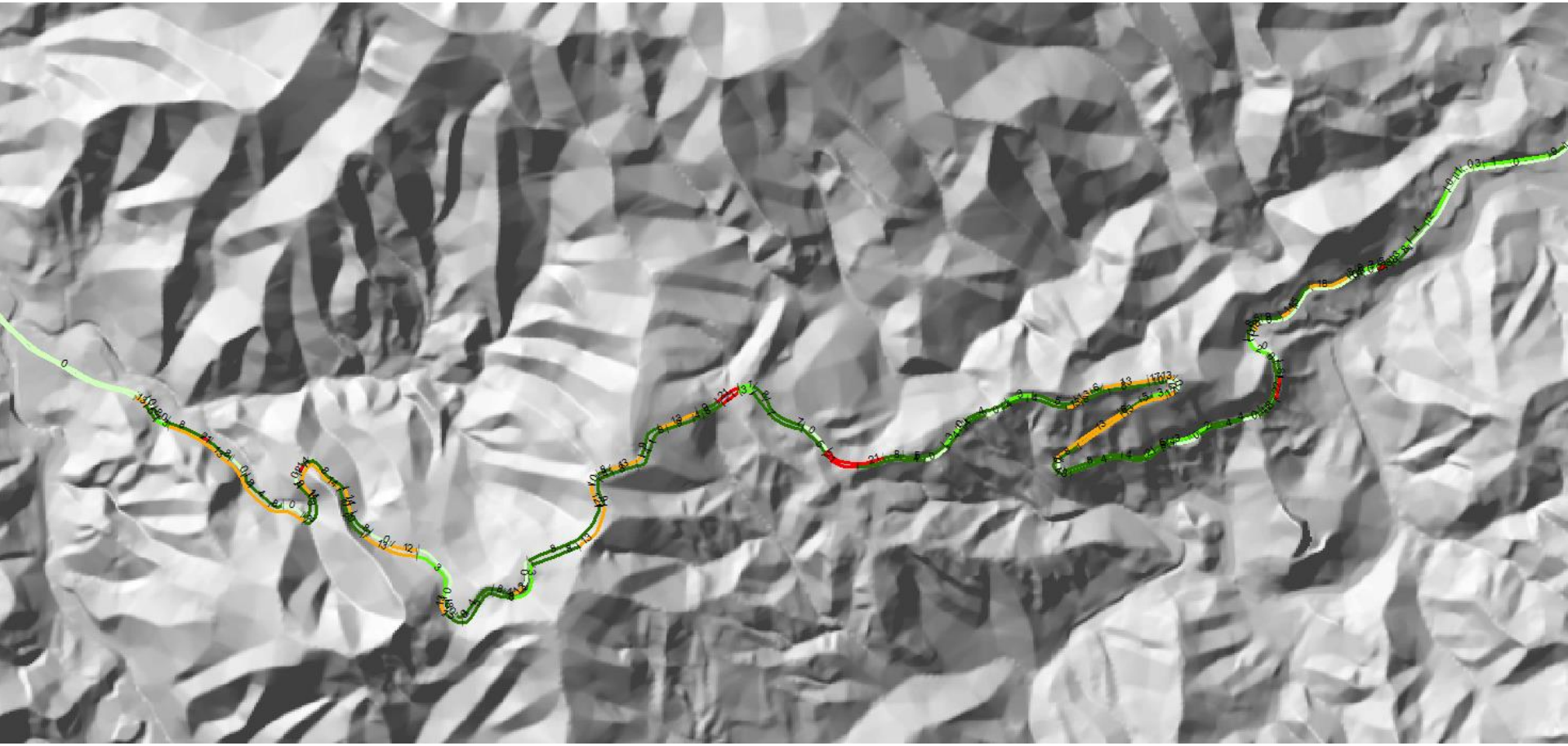
Landslide risk assessment



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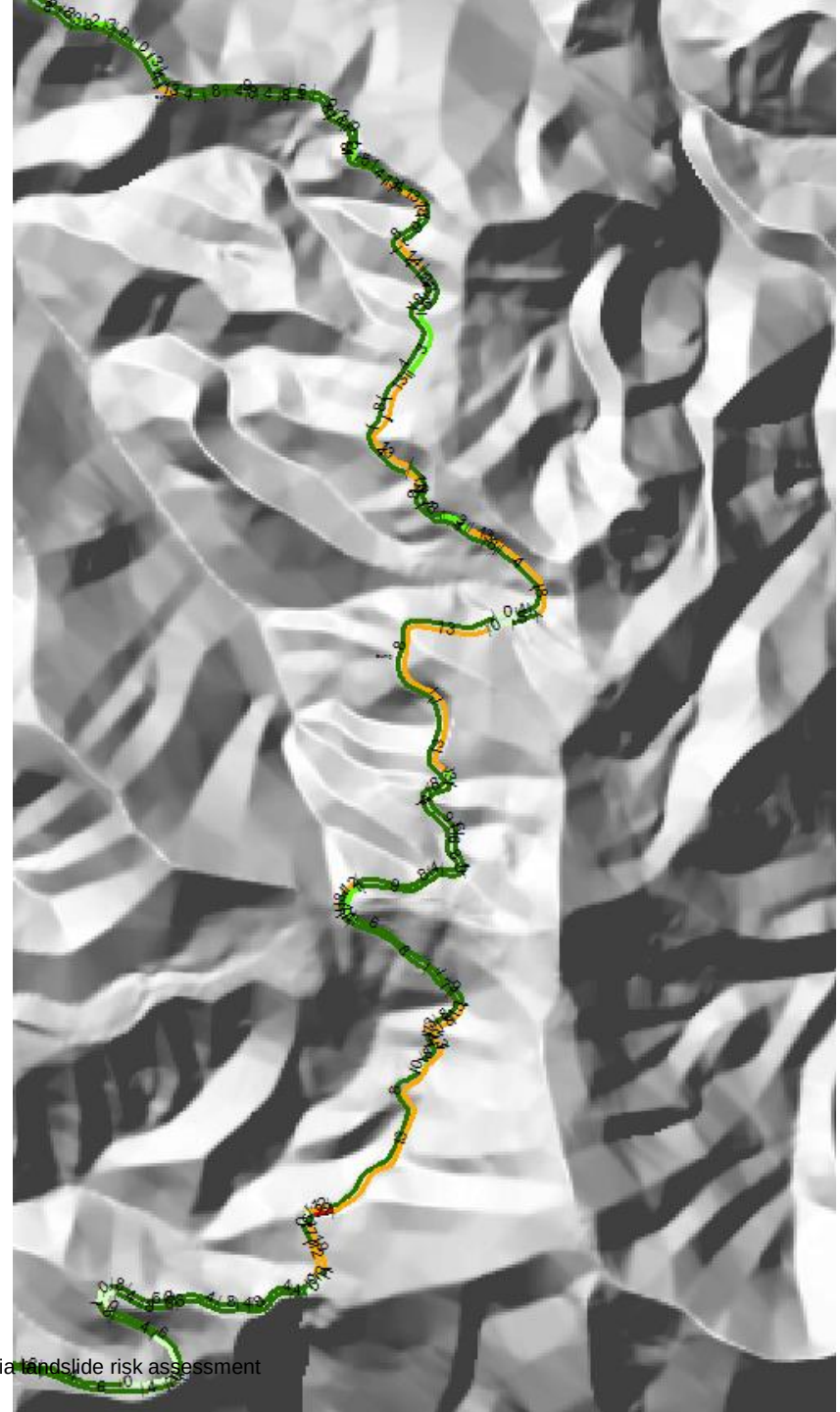
Landslide risk assessment



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Strategic risk management and preparedness

Hurricane Tomas

Outcomes of risk assessment and strategic risk management

249km

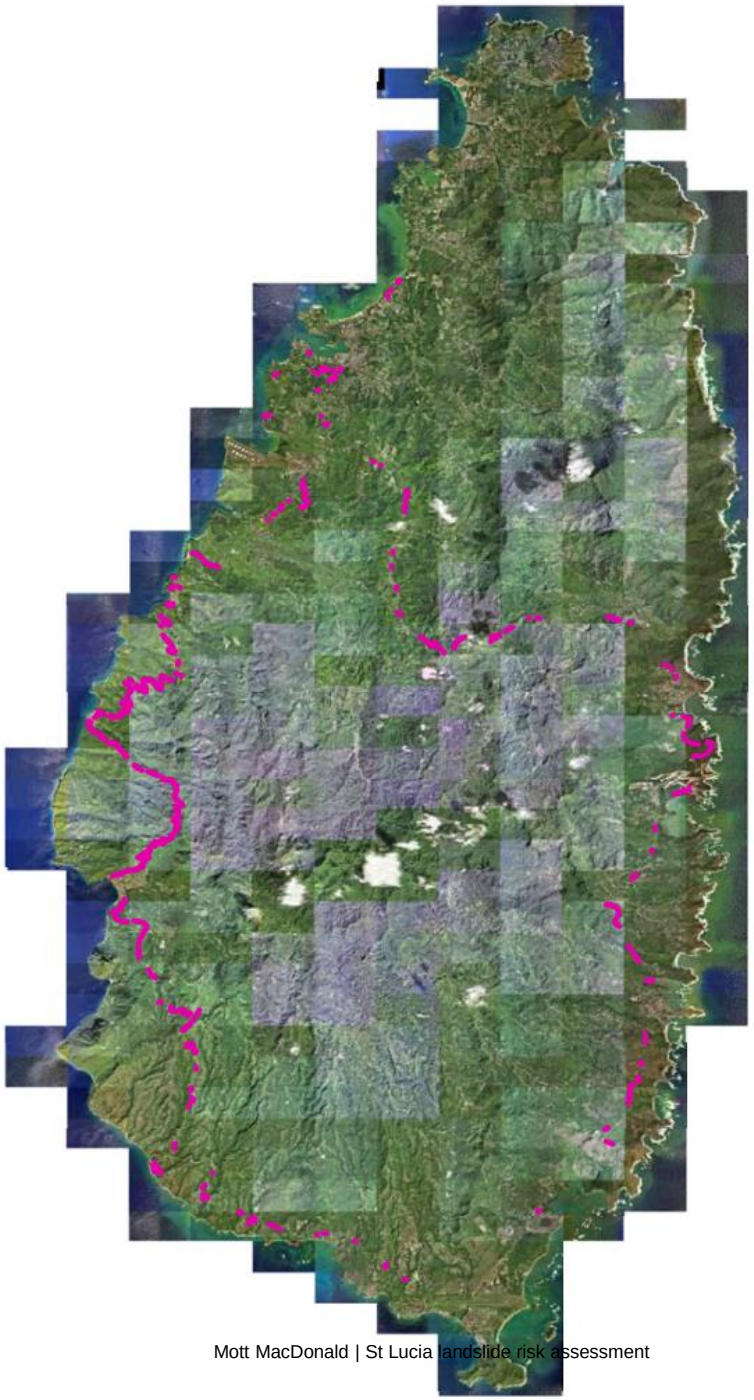
≥Hurricane Tomas event to cause landslide

ALARP – accept the risk

Reassess risk following large storm events

Regularly inspect structures and drainage, and maintain as required

Respond to events as the occur



40km

5-50 year storm

Not complete loss of road

Accept the risk

Reassess risk following large storm events

Regularly inspect structures and drainage, and maintain as required

Respond to events as the occur

1km

Normal rainfall → Tropical Storm

Partial to significant loss of serviceability

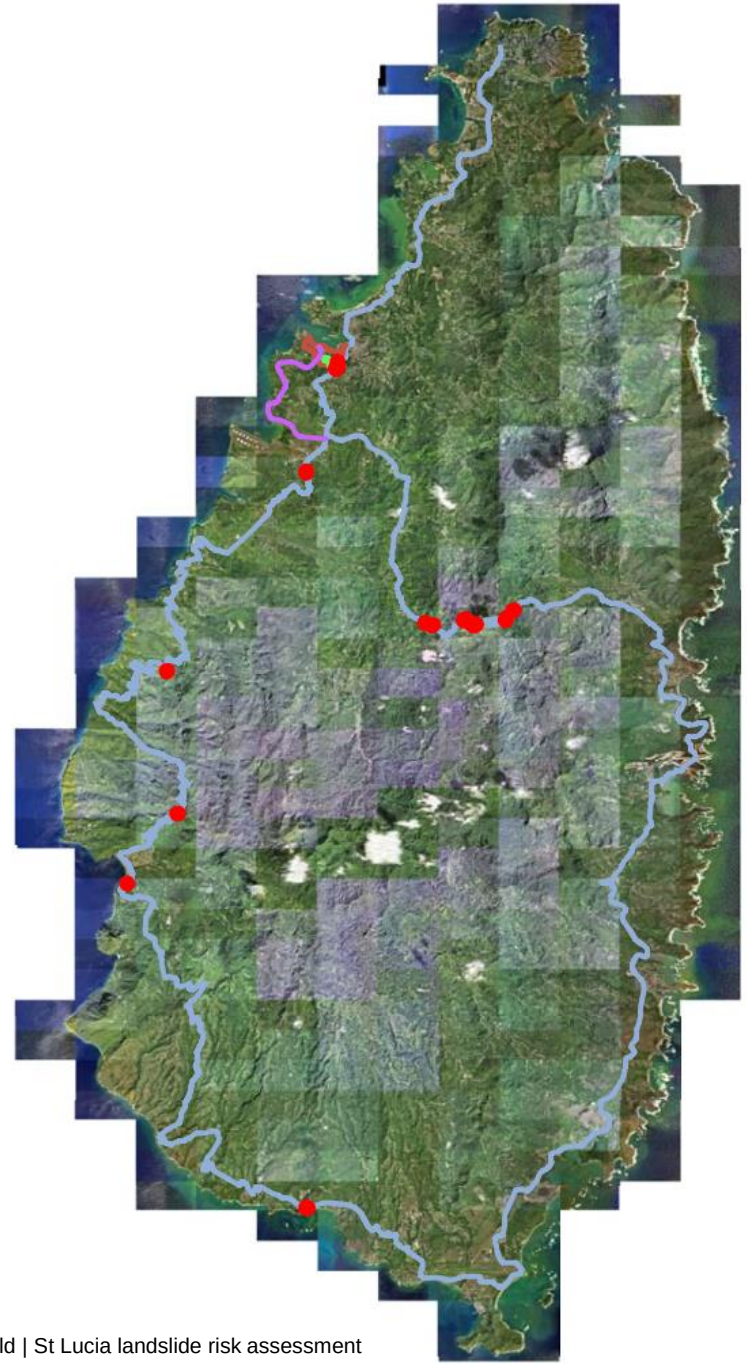
Respond to events as they occur

Mitigation/remedial works in selected cases

0km

Complete loss of serviceability

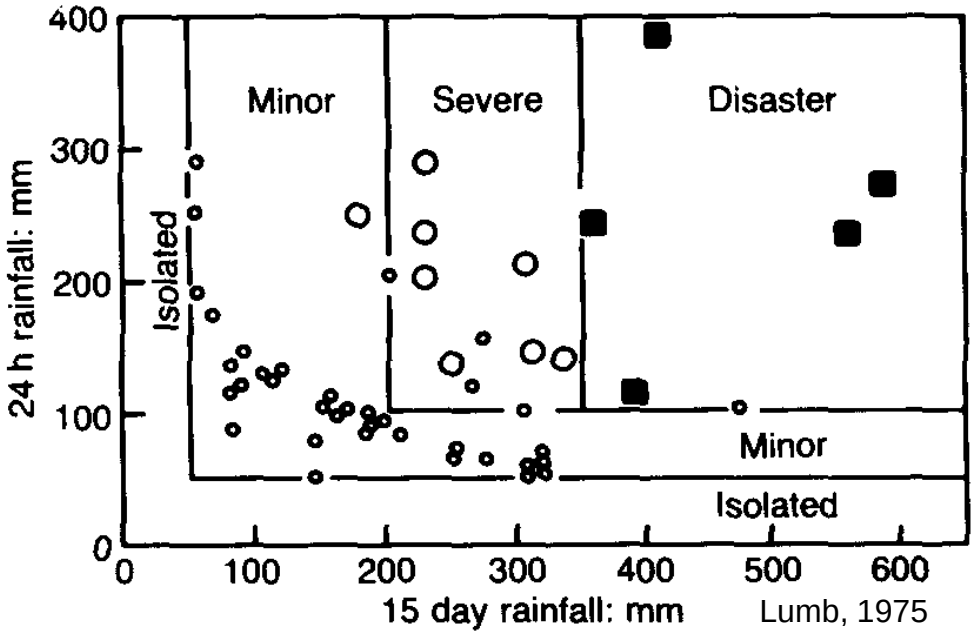
High priority remedial works / preventative measures required



Hurricane Tomas

Outcomes of risk assessment and strategic risk management

- Research and set rainfall monitoring triggers to predict when events are more likely to occur and potentially restrict access to parts of the network under such storm conditions



Lumb, 1975

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Conclusions

Hurricane Tomas

Conclusions

- Ministry and zone engineers responded admirably
- Lessons are not always being learnt or passed on
- Data management and landslide inventory required
- Drainage

Acknowledgements

- Ministry of Infrastructure, Port Services and Transport - Jude Regis, Nicholas Johnny
- Strata Engineering Consultants Ltd - Roosevelt Issacs
- Mark Lee, Prof. Norbert Morgenstern, Fred Matich
- Colleagues at Mott MacDonald especially Peter Phipps & Elizabeth Ward


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Thank you