Consultancy Service for the Development of an Inundation, Flooding and Landslide National Risk Profile, Strategic Framework and Action Plans for Disaster Risk Management for the Republic of Mauritius

Vincenzo Marsala
Geological engineer
SGI Studio Galli Ingegneria SpA

Capacity and validation workshop
Swami Vivekananda International Convention Centre, Pailles, Mauritius, August 22-24, 2012

Capacity Building and Validation Workshop

Friday August 24, 2012

Session 4: Validation

11:00 - 11:30 Landslide hazard and vulnerability assessment

Vincenzo Marsala (SGI Studio Galli Ingegneria S.p.A.)

Landslide hazard and vulnerability assessment

1) The work group is characterized of a multidisciplinary experts in the field of earth science and geological engineering

LANDSLIDE WORK GROUP

Team Leader	**Vincenzo Marsala**	**Geological Engineer**	**Coordination of group, in field survey, official meeting ,**
Scientific Coordinator	**Enrico Miccadei**	**Professor of Geomorphology**	**Scientific supervision, in field survey, landslide model control**
Geomorphologist	**Tommaso Piacentini**	**PHD Geology**	**In field survey, photo-geology, GIS elaboration**
Geomorphology GIS Analyst	**Michele Rocca**	**PHD Engineer geology**	**GIS elaboration, landslide model building**
Photo-geologist	**Marco Sciarra**	**Geologist**	**Photogeologic analysis**

Landslide hazard and vulnerability assessment

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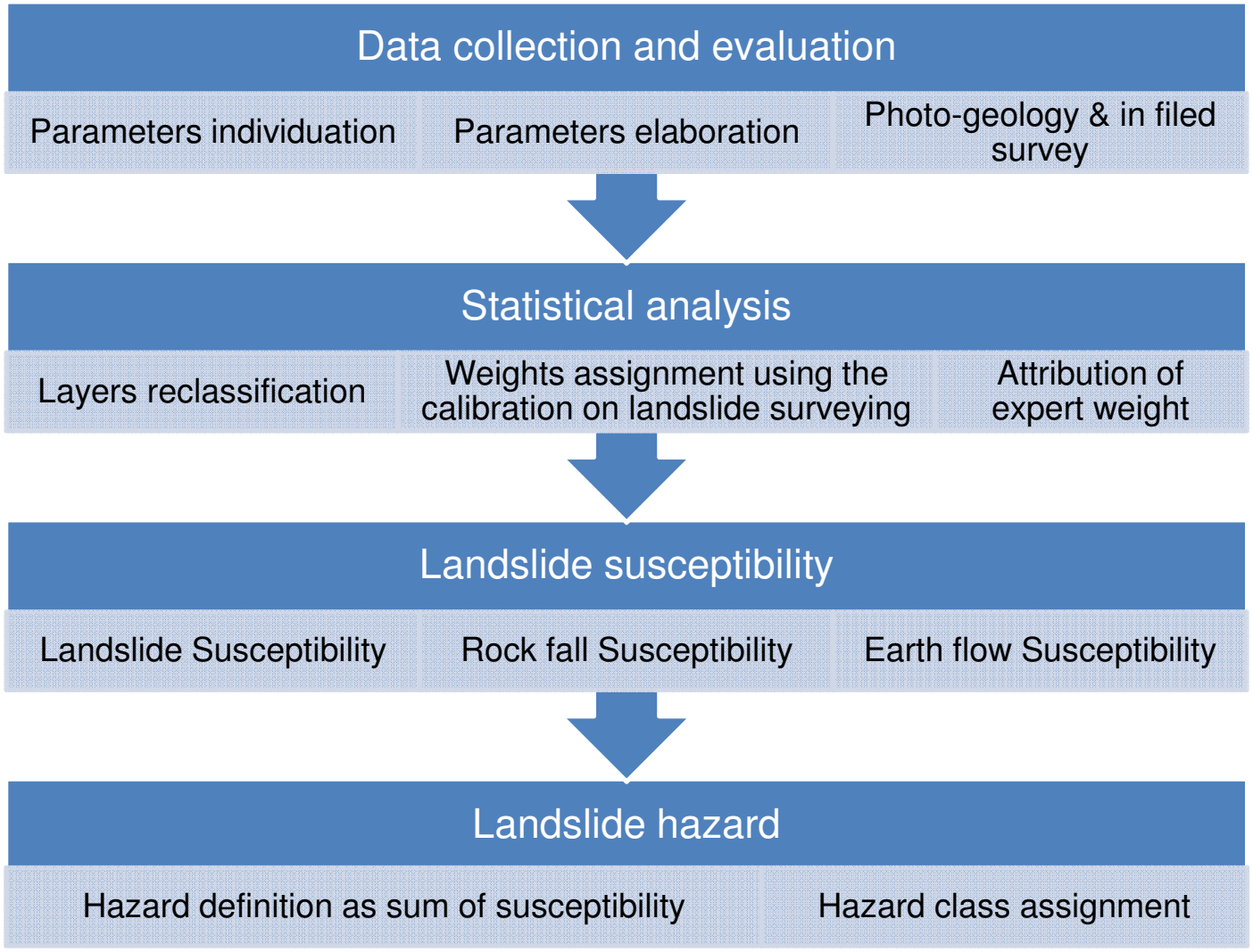
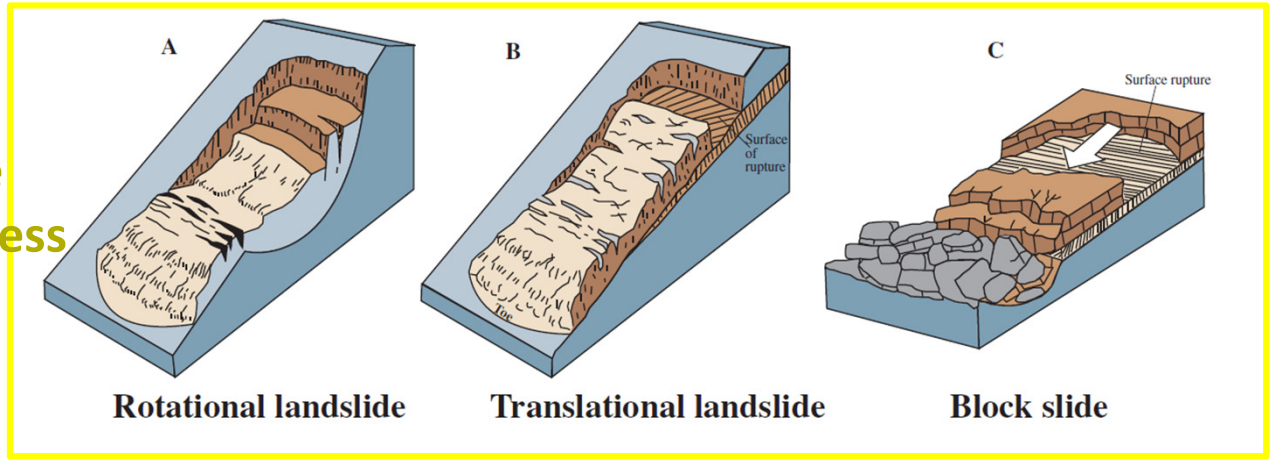
Landslide hazard and vulnerability assessment

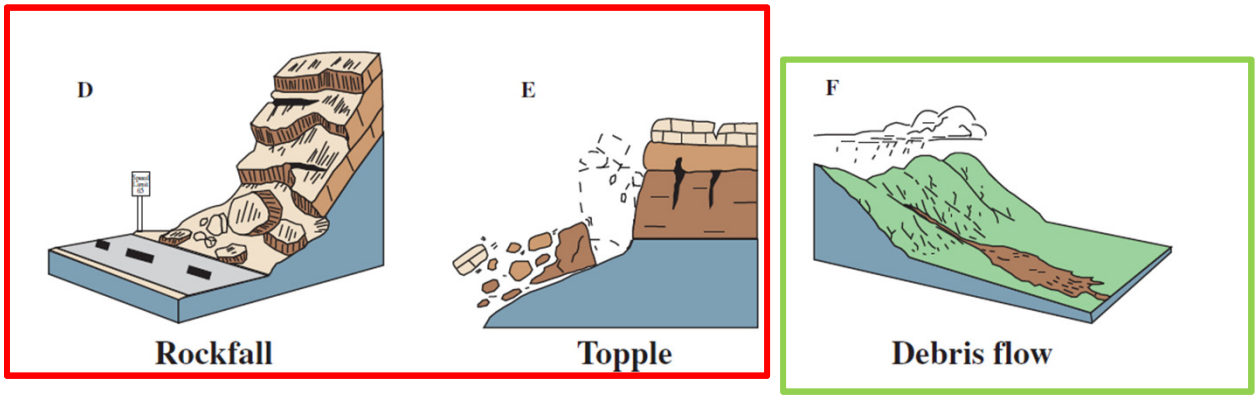
METHODOLOGY: Work flow



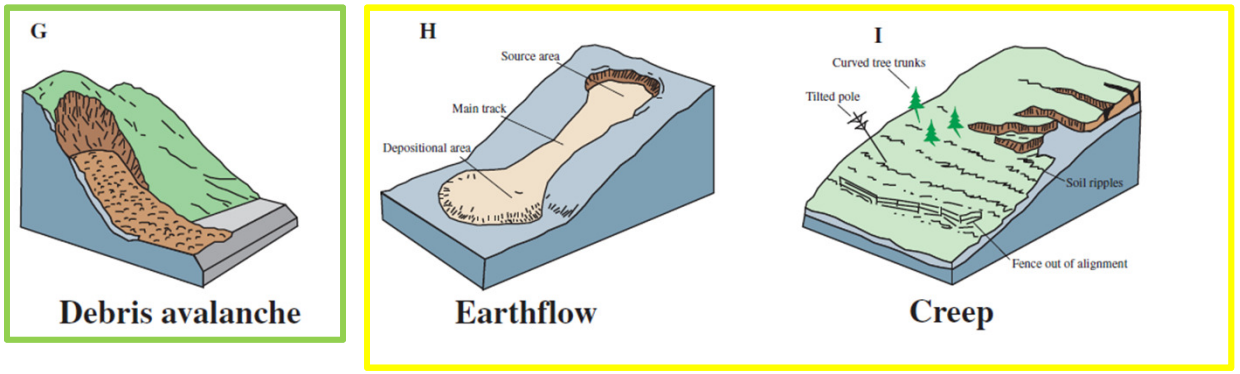
LANDSLIDE: a more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material



ROCK FALLS : movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs



RAPID EARTH FLOWS: rapid mass movement such as mudflows and debris flows and avalanches



From US Geological Survey Fact Sheet 2004-3072, July 2004

Landslide hazard assessment

TOOLS

Geographic Information System

Mainly two software have been utilized for data management and elaboration:

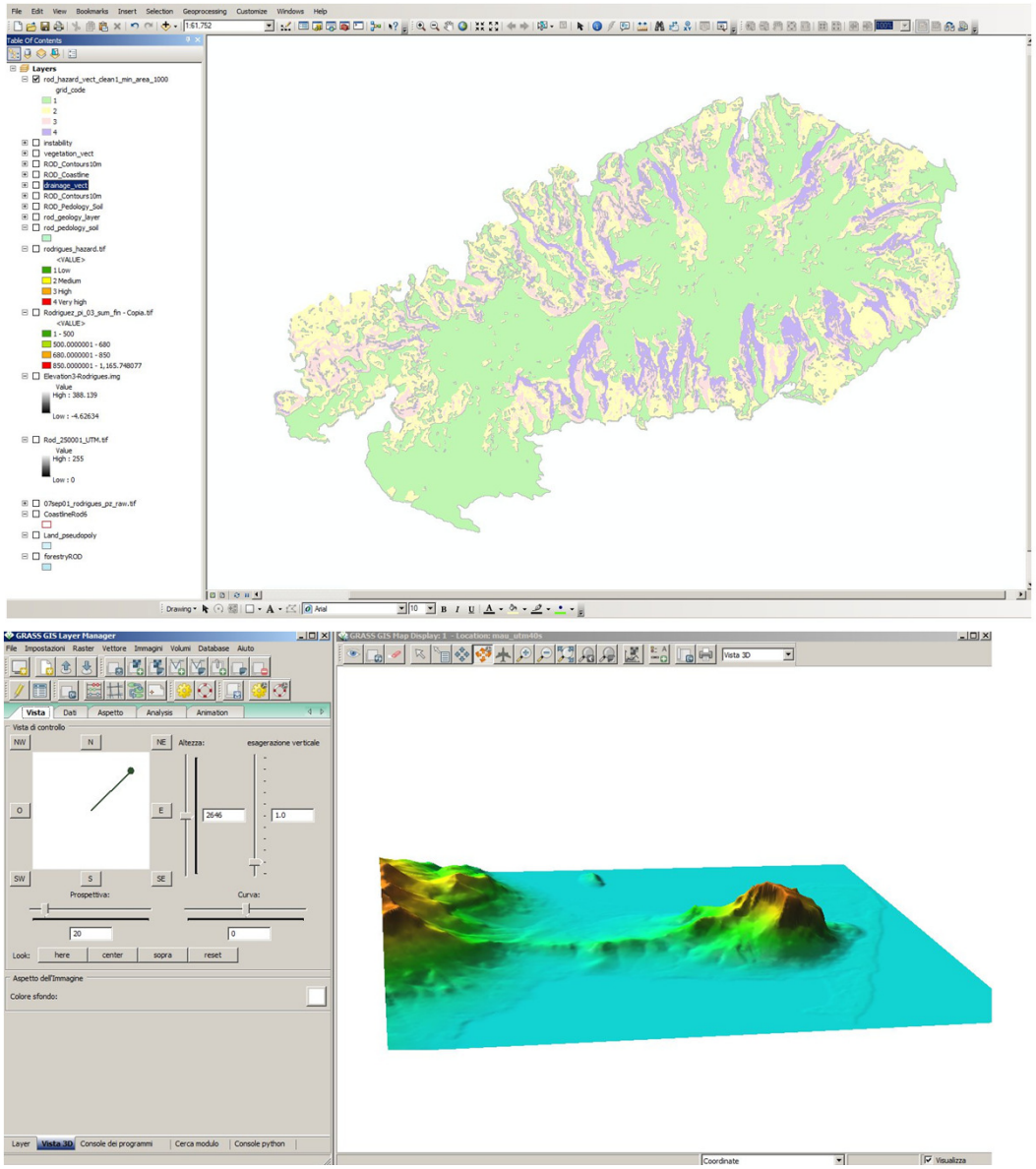
ESRI ArcGIS (commercial)

http://esri.com/

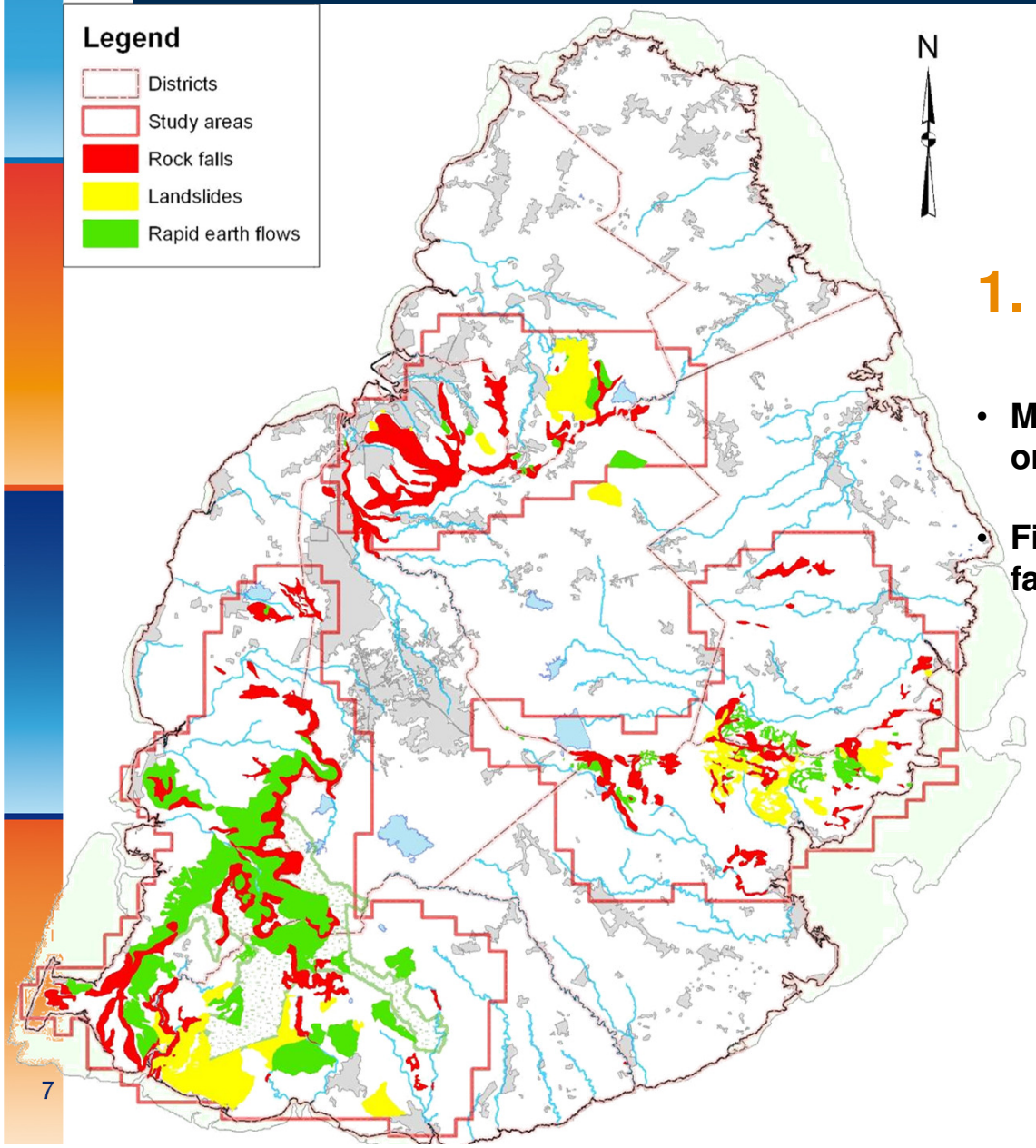
GRASS GIS Geographic Resources Analysis Support System (open source) :

http://grass.fbk.eu/

The first as the main data management platform and the second basically to perform automated procedures involved in modeling phase of the work.



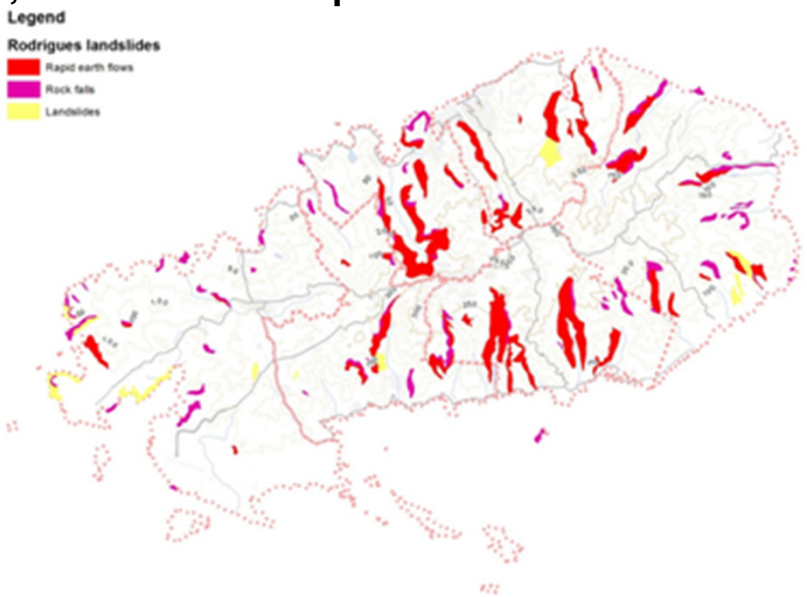
Landslide hazard and vulnerability assessment



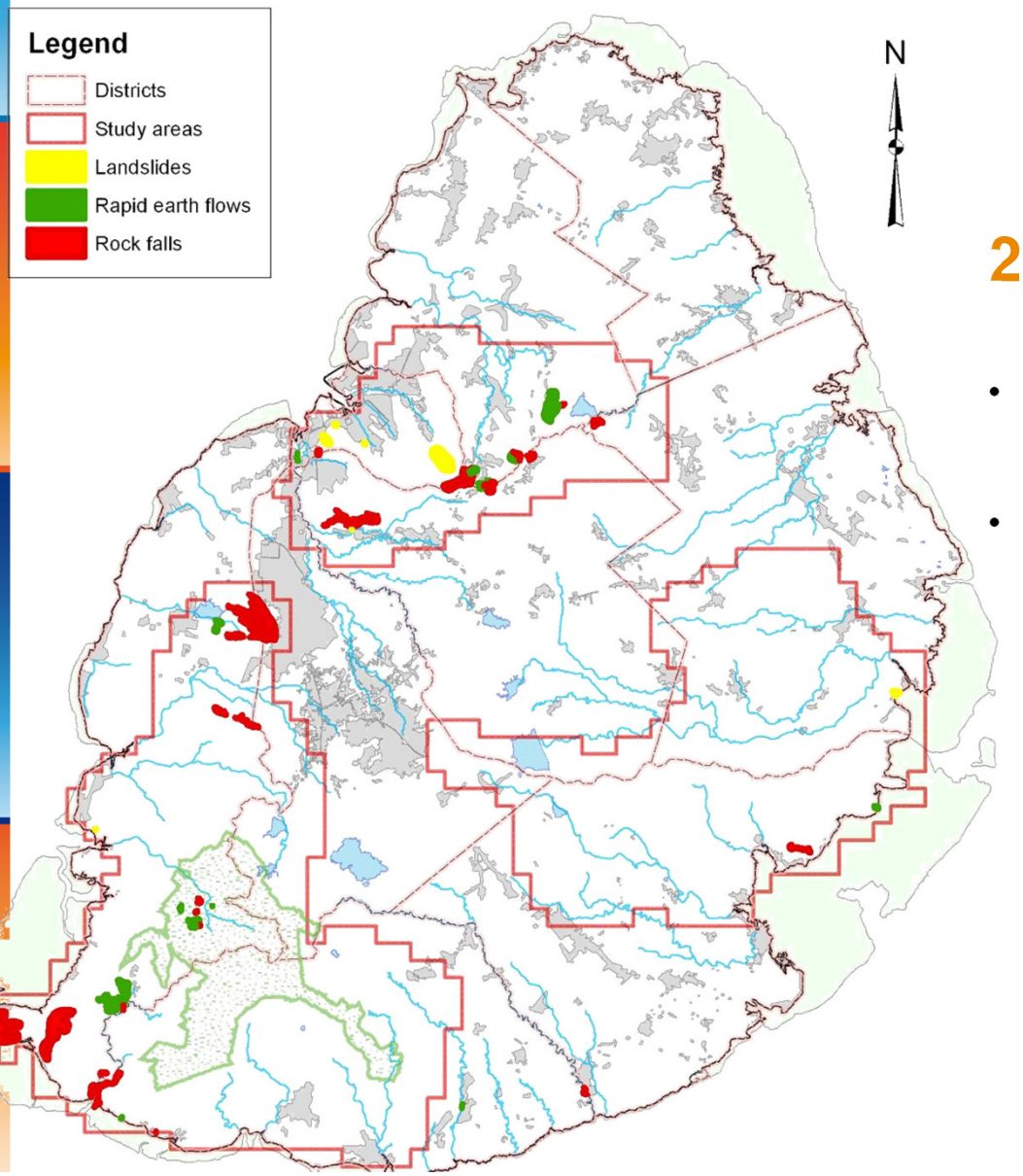
METHODOLOGY

1. Photo-geologic results

- **Mapping of homogeneous areas related to the main orographic, geomorphologic and land parameters**
- **First draft map of Landslide distingued for type : rock falls, landslides and rapid earth flows**



Landslide hazard and vulnerability assessment

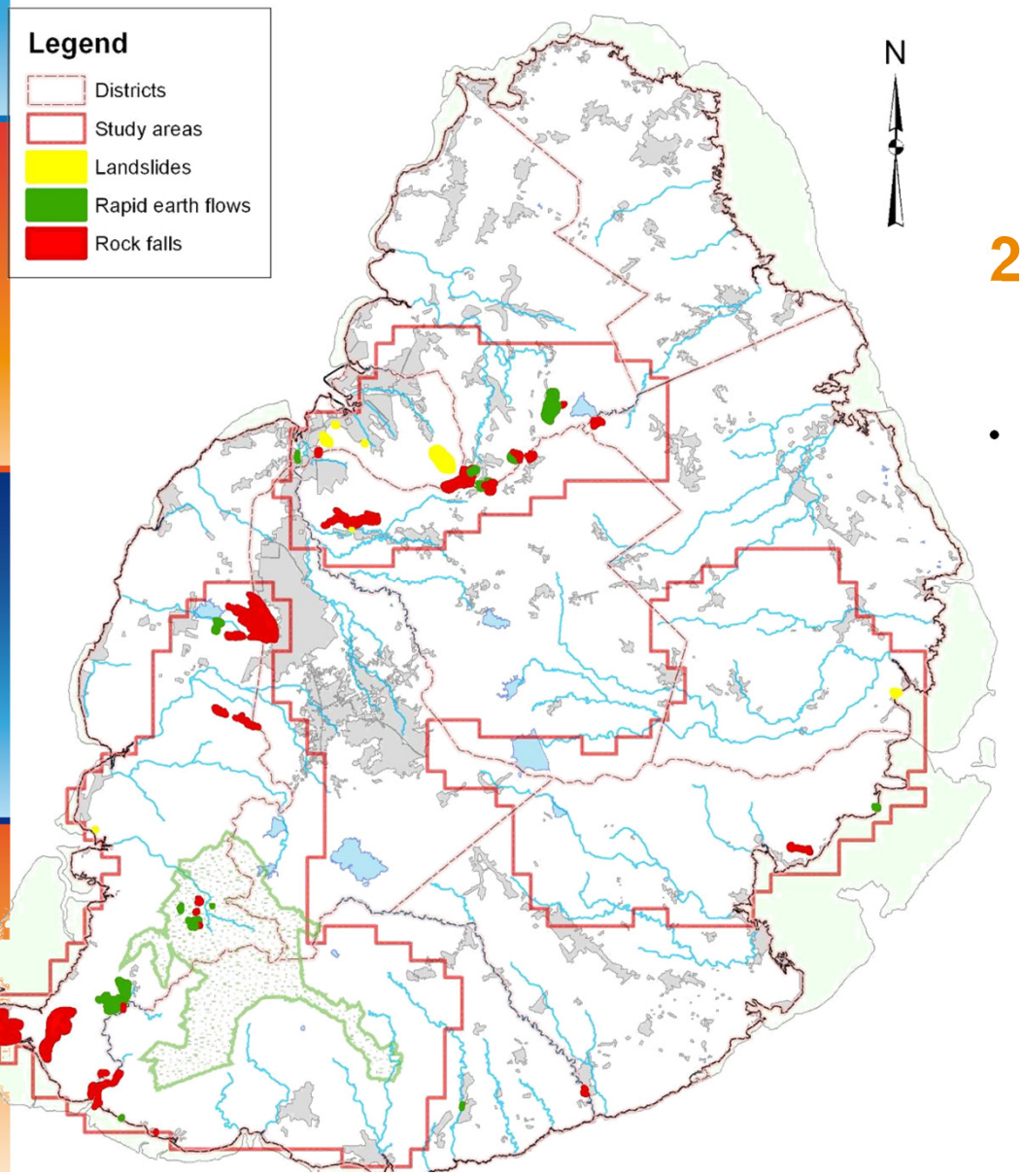


METHODOLOGY

2. In field survey

- **In field survey on the landslide prone areas included in the available documents**
- **Elaboration of geomorphological simplified profiled**

Landslide hazard and vulnerability assessment



METHODOLOGY

2. In field survey : an example

- **Preliminary definition of landslide**

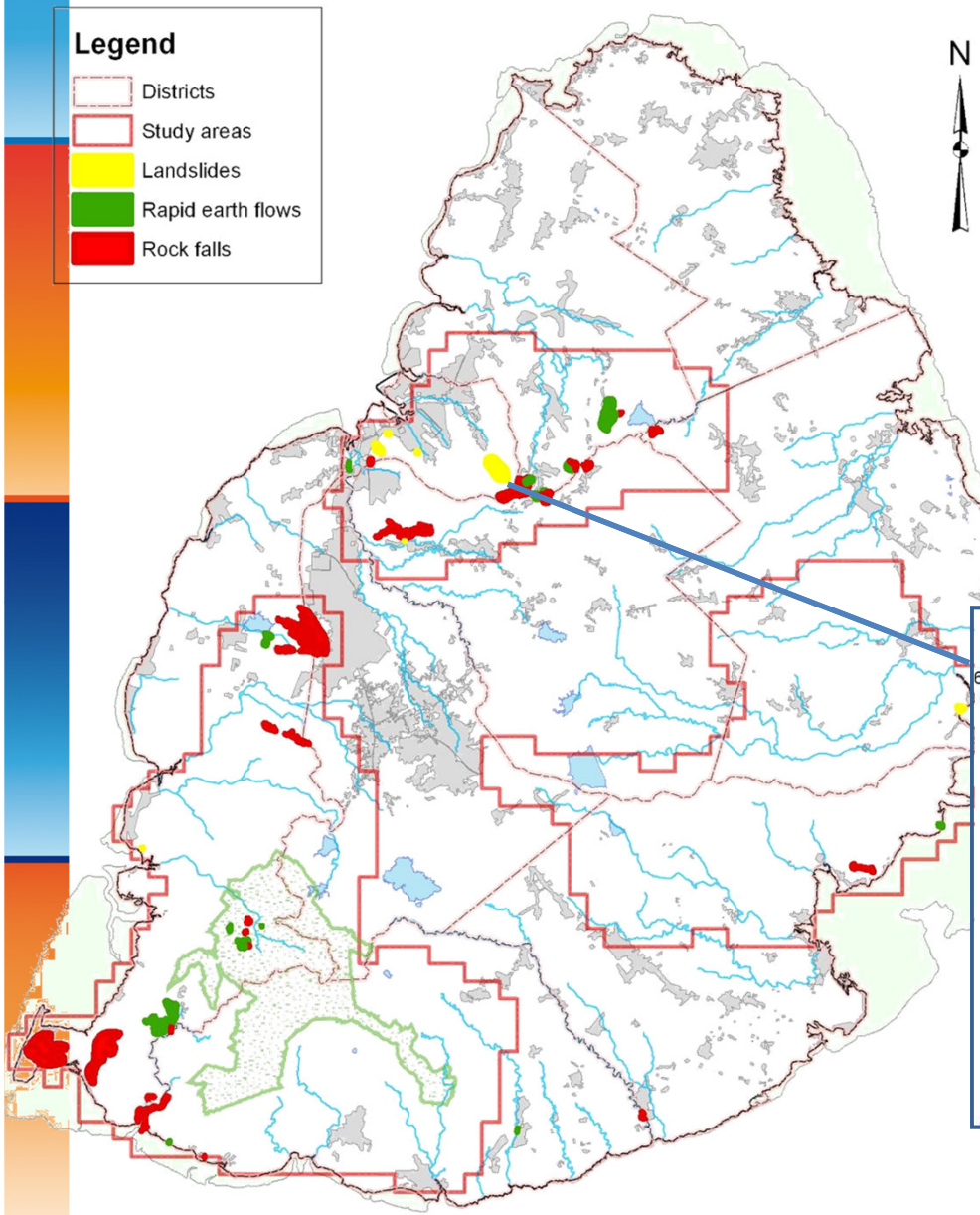
Landslide hazard and vulnerability assessment

1. Photo-geologic results

1C - VALLÉE DES PRETRES-CHITRAKOOT (PORT LOUIS DISTRIC- ZONE 1)

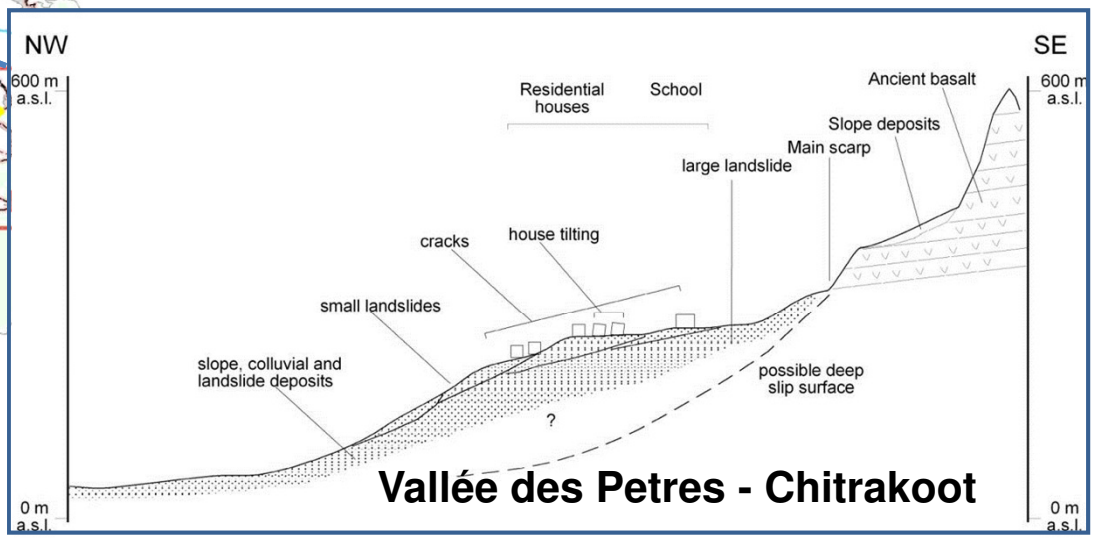
Elevation (m)	*Slope (%)*	*Hydrography drainage pattern*	*Vegetation*	*Lithology*	*Soil*	*Soil thickness*	*Slope gravity processes*
150-500	10-25	Subdendritic	Sparse tree	Landslide deposits	Brown rocky soil of moderate thickness in low slope areas	10-20	Landslides

Landslide hazard and vulnerability assessment

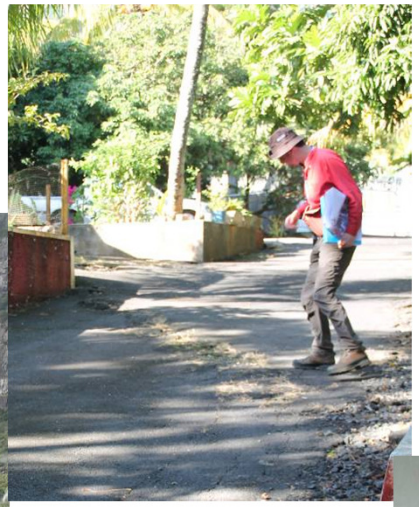


In field survey

- **Preliminary definition of landslide**



Vallée des Petres - Chitrakoot



In the upper part of the slope, a main landslide scarp is present, on the ancient basalts
In the middle part of the slope the wide gently rolling area is referable to a landslide terrace, with small counter slopes, that could be referable to a large landslide involving the whole slope, with a deep slip surface (> 20-30 m).
This area is affected also by shallow to moderately deep slow landslides involving the colluvial deposits and inducing tilting, severe cracks and damages to residential houses and to the Chitrakoot school.
According to the information collected during the in field survey and to the previous study, the landslides are reactivated by the major rainfall events. The progress of this landslide could heavily damage the residential houses and the school of the Chitrakoot area.

Landslide hazard and vulnerability assessment

METHODOLOGY

Geomorphological Factor
Slope
Aspect
Profile curvature
Planar curvature
Drainage pattern
Vegetation
Lithology
Soil
Rainfall

3. Susceptibility model

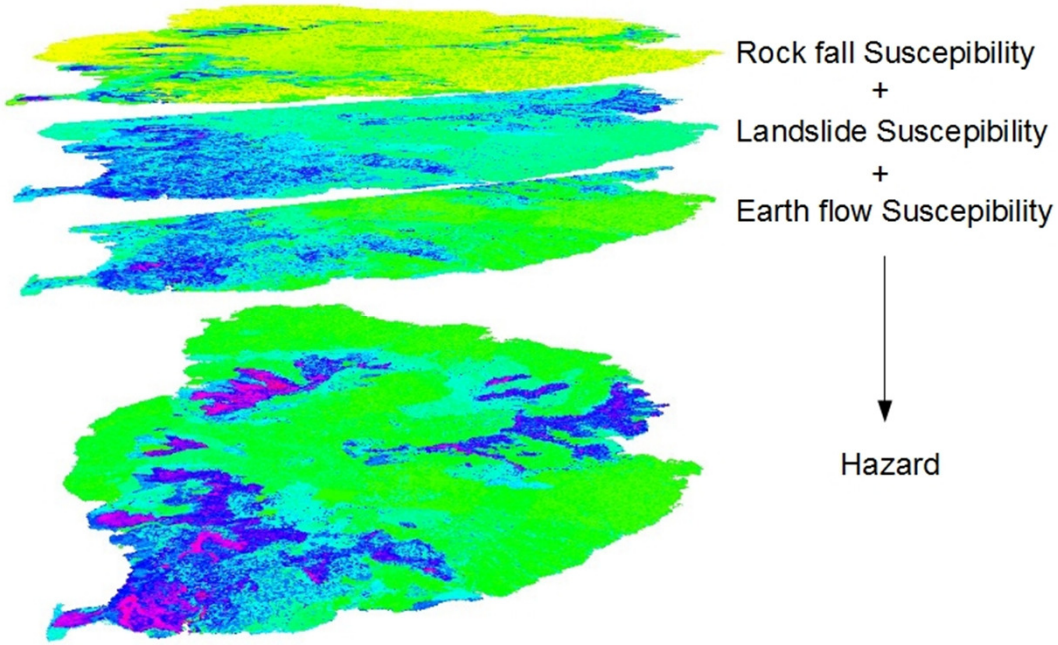
Factors used in the susceptibility model for each type of landslide:

- **Rock falls,**
- **Landslides**
- **Rapid earth flows**

Landslide hazard and vulnerability assessment

METHODOLOGY

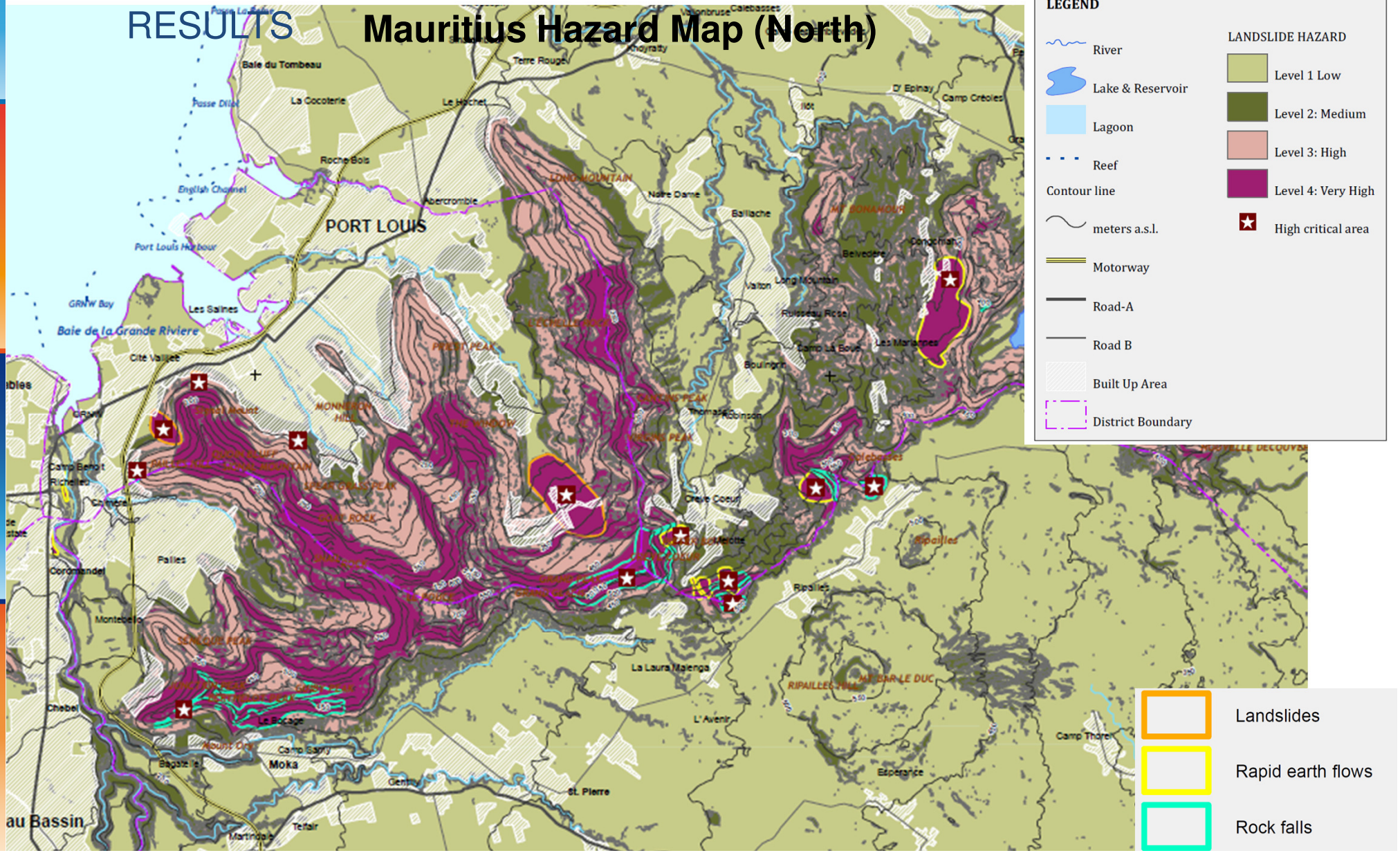
Elaboration of the landslide hazard as sum of the different three susceptibility (rock fall, classic landslide, earth flow)



Landslide hazard as result of the overlaying of the susceptibility map

Landslide hazard and vulnerability assessment

RESULTS



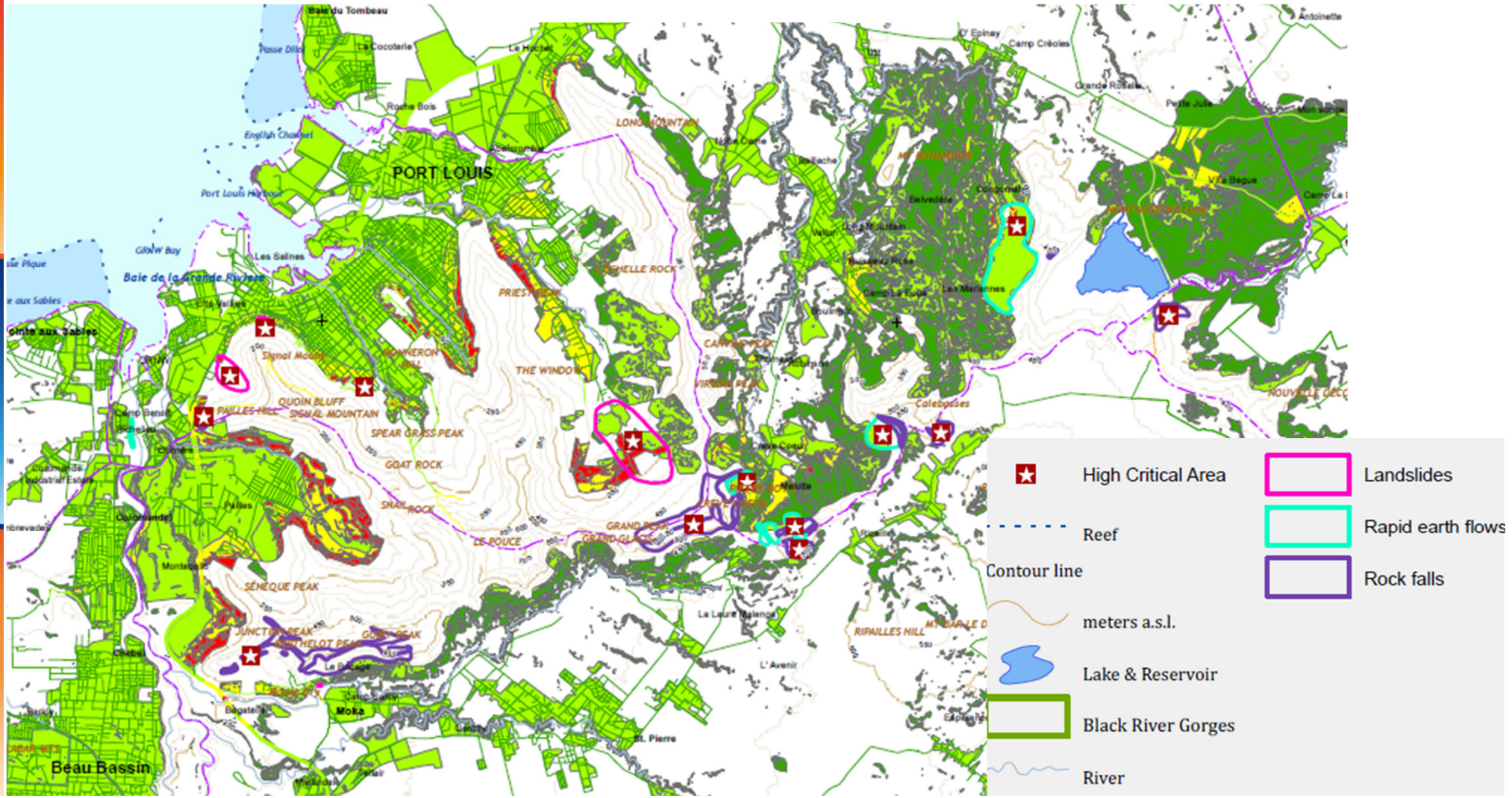
3. RESULTS

Landslide Risk Map

	Hazard level			
Feature	Level 4	Level 3	Level 2	Level 1
Natural features	none	none	none	none
Agricultural fields	low	low	very low	none
Built up area	very high	very high	medium	low
Expansion area	very high	very high	medium	low
Motorway	very high	very high	medium	low
Main road	high	medium	low	very low
Secondary road	medium	low	very low	very low

Risk Classes

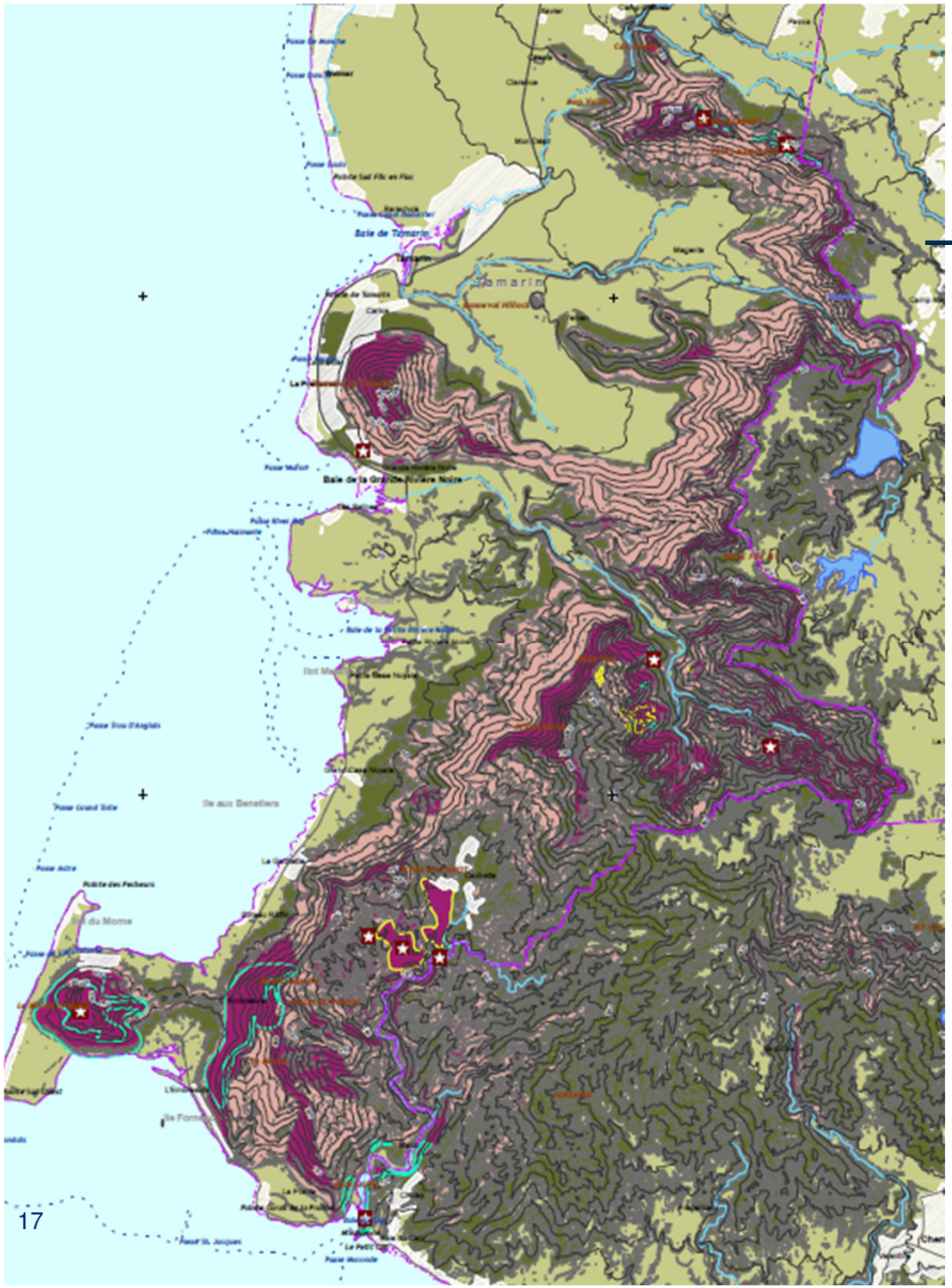
Risk Classes



Landslide hazard and vulnerability assessment

RESULTS

Mauritius Hazard Map (South west)



Landslides

Rapid earth flows

Rock falls

LEGEND

River

Lake & Reservoir

Lagoon

Reef

Contour line

meters a.s.l.

Motorway

Road-A

Road B

Built Up Area

District Boundary

LANDSLIDE HAZARD

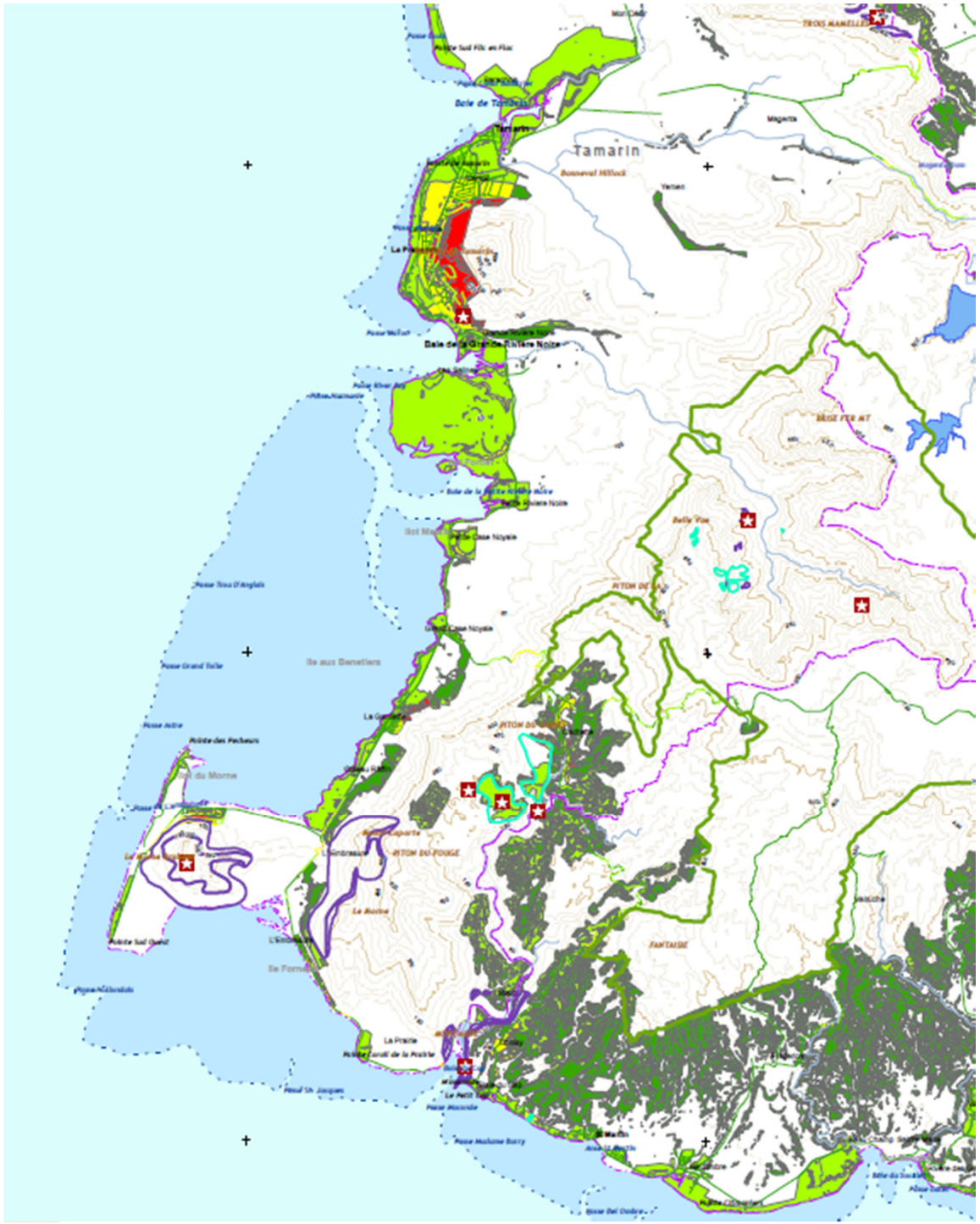
Level 1 Low

Level 2: Medium

Level 3: High

Level 4: Very High

High critical area



3. RESULTS

Landslide Risk Map

Feature	Hazard level: Level 4	Level 3	Level 2	Level 1
Natural features	none	none	none	none
Agricultural fields	low	low	very low	none
Built up area	very high	very high	medium	low
Expansion area	very high	very high	medium	low
Motorway	very high	very high	medium	low
Main road	high	medium	low	very low
Secondary road	medium	low	very low	very low

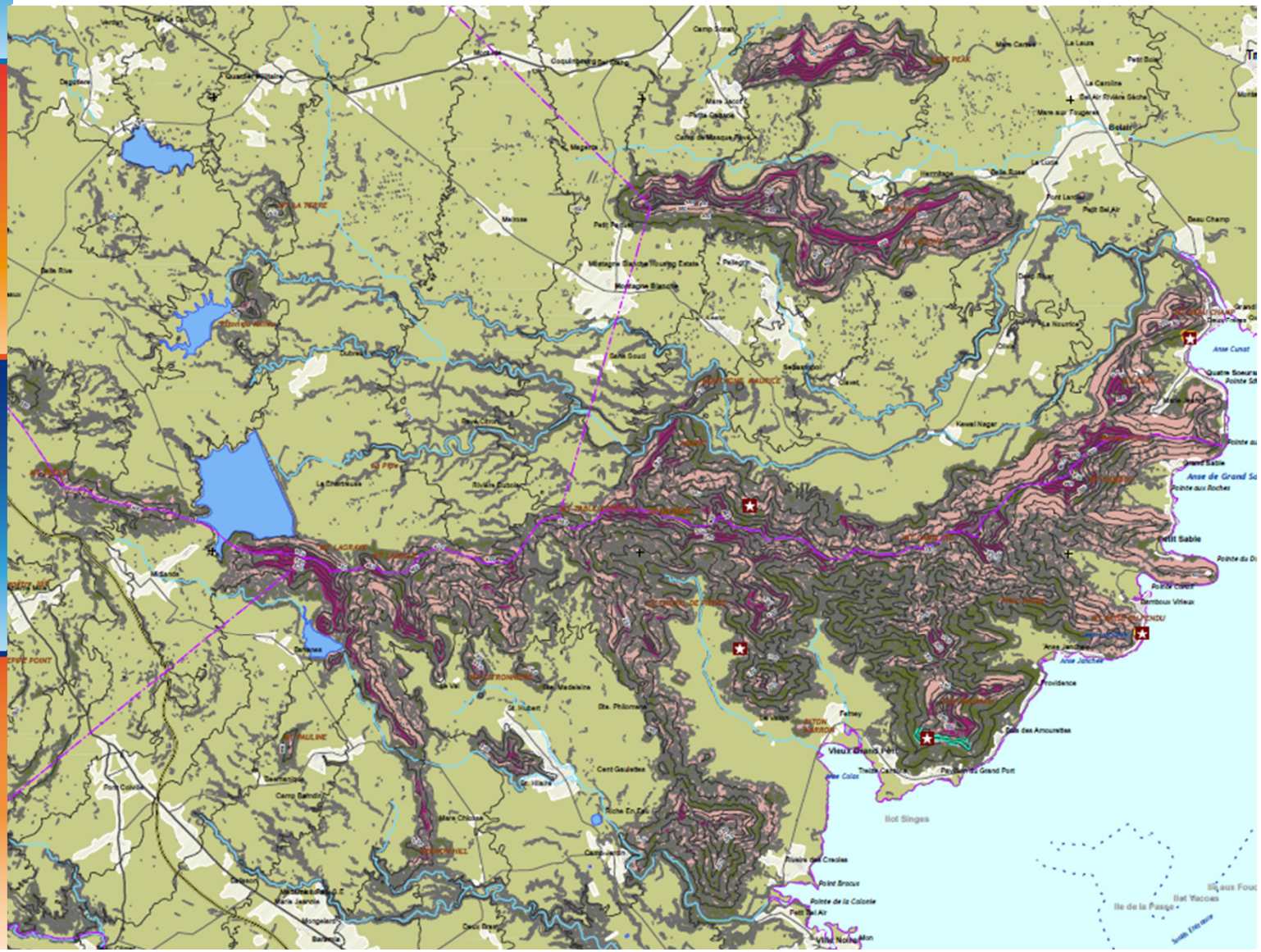
Risk Classes (rows) / Risk Classes (columns)

- High Critical Area
- Reef
- Contour line
- meters a.s.l.
- Lake & Reservoir
- Black River Gorges
- River
- Built Up Area
- Lagoon
- Landslides
- Rapid earth flows
- Rock falls

Landslide hazard and vulnerability assessment

RESULTS

Mauritius Hazard Map (East)



Landslides

Rapid earth flows

Rock falls

LEGEND

River

Lake & Reservoir

Lagoon

Reef

Contour line

meters a.s.l.

Motorway

Road-A

Road B

Built Up Area

District Boundary

LANDSLIDE HAZARD

Level 1 Low

Level 2: Medium

Level 3: High

Level 4: Very High

High critical area

Landslide Risk Map

3. RESULTS

	Hazard level			
Feature	Level 4	Level 3	Level 2	Level 1
Natural features	none	none	none	none
Agricultural fields	low	low	very low	none
Built up area	very high	very high	medium	low
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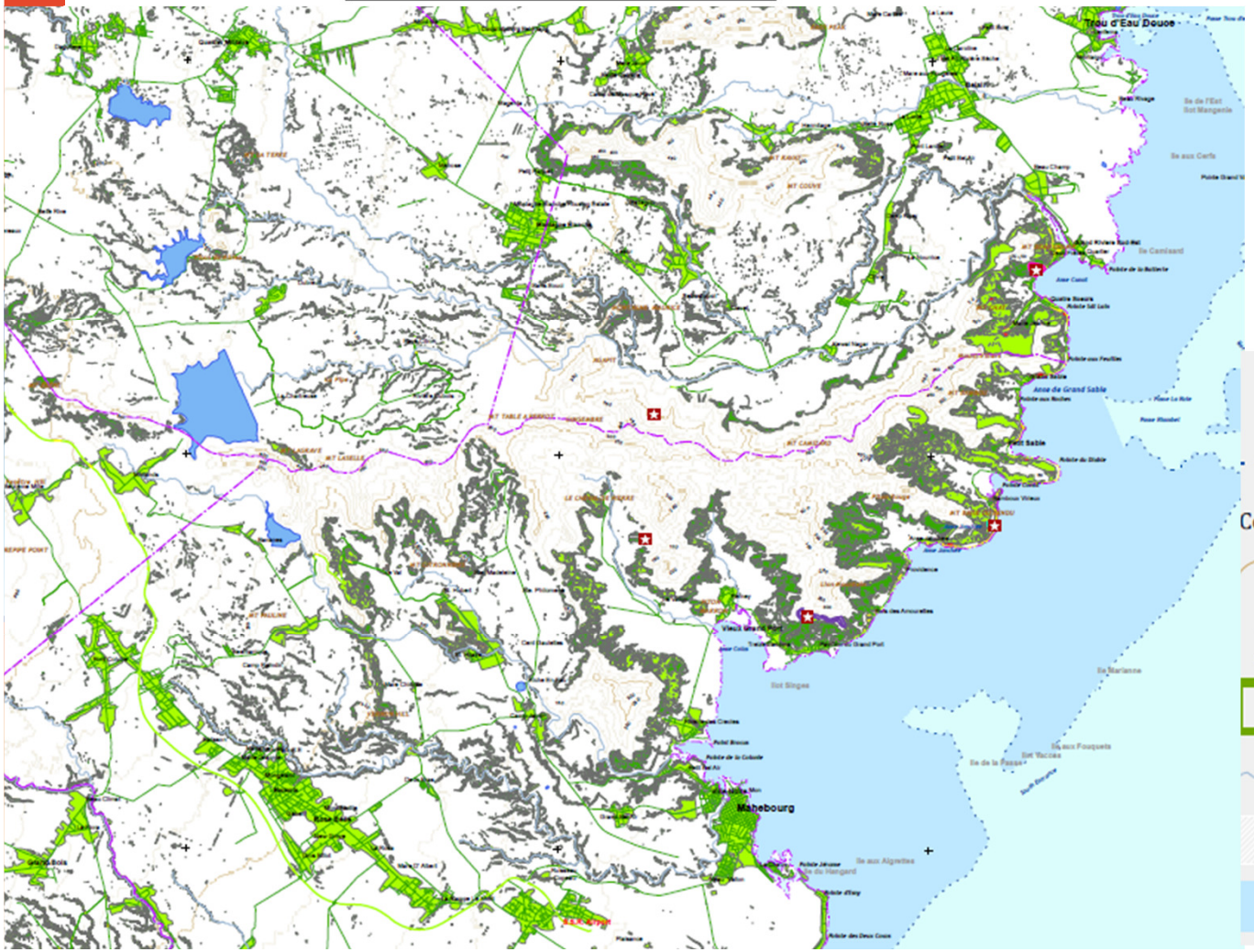
Risk Classes

Risk Classes



High Critical Area

Reef

Contour line

meters a.s.l.

Lake & Reservoir

Black River Gorges

River

Built Up Area

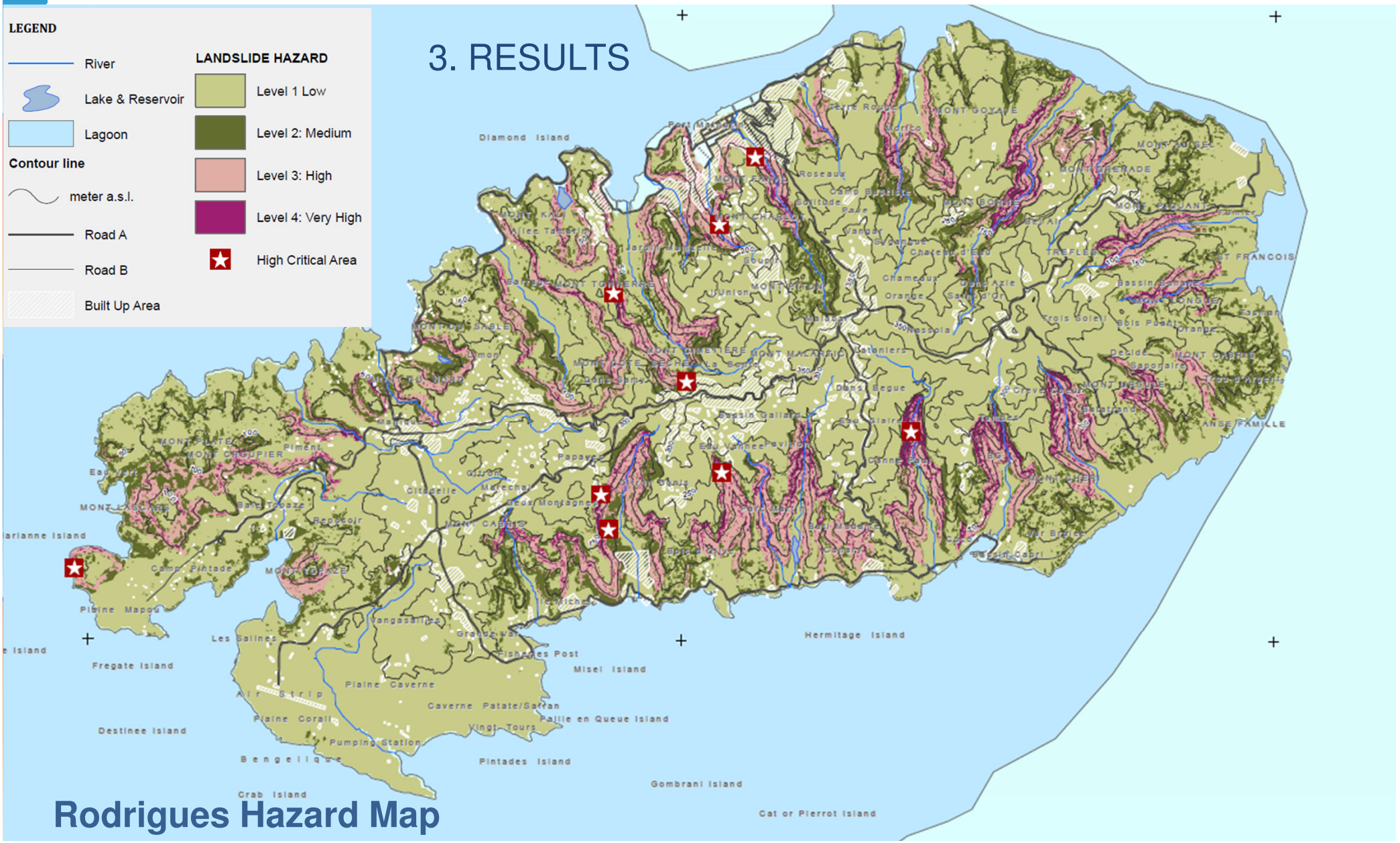
Lagoon

Landslides

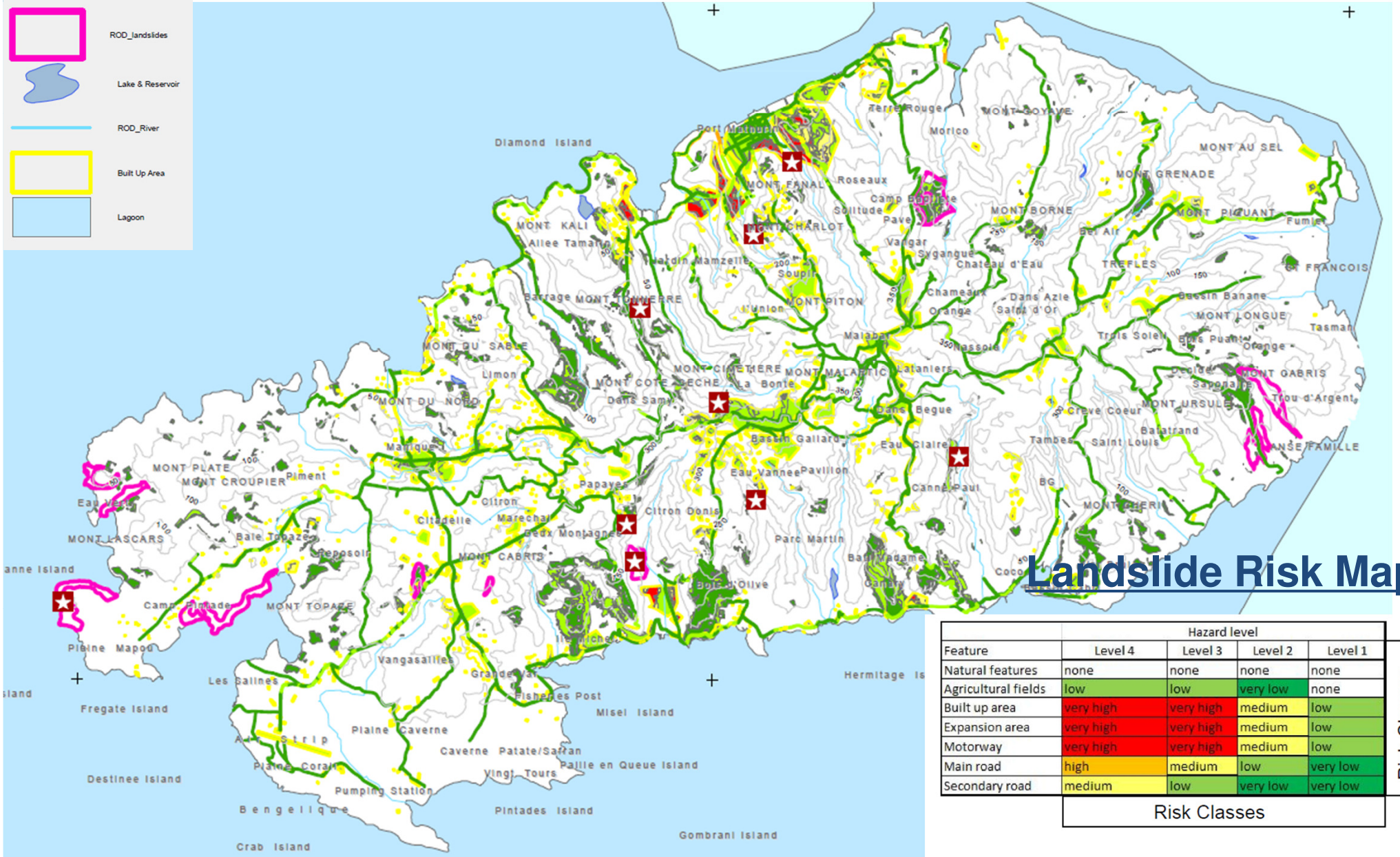
Rapid earth flows

Rock falls

Landslide hazard and vulnerability assessment



3. RESULTS



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Motorway	very high	very high	medium	low
Main road	high	medium	low	very low
Secondary road	medium	low	very low	very low

Risk Classes

Risk Classes

ANNEX A – 6.2 LANDSLIDE ALERT SHEET (EVENT REPORT)

Sheet compiled by:		Tel.:	
Administration/institution :			
Completion date:			

LOCALIZATION :

2) Extract from Map 1:50.000 or extract of another map more detailed attached separately.
On the Map should:
a) Mark out landslide area (if it is possible draw with a red felt pen).
b) Otherwise mark site with red symbol *
c) Highlight any water spring with blue symbol: △
d) Highlight any structural damage on buildings or other infrastructures (road, power line, aqueduct, etc.) with red symbol: /

2) Priority:

(considering a scale 1-5)		Number of victims:	

3) Place:

MUNICIPALITY/VILLAGE	
DISTRICT	
Coordinates if it is possible (east- north) and reference system	

4) Estimated involved area (=max length X max width):

meters		meters		m^2	

5) Landslide date (if possible):

DAY		MONTH		YEAR	

6) Prevailing land use: ("O" TYPE)

URBAN AREA	
BARE SOIL	
PASTURE	
ARABLE LAND	
Scrub and/or herbaceous vegetation associations	
FOREST	
OTHER	

7) Landslide material: ("O" TYPE)

		LITHOLOGY INVOLVED:
GRANULAR/COHESIVE DEPOSITS		
ROCK		

8) Wet area: ("O" TYPE)

NO		YES	

9) Structure involved: ("E" TYPE)

a. BUILDINGS	No	Yes	⇒ Public (quantity): / Private (quantity): / Abandoned (quantity):
b. RETAINING WALLS	No	Yes	
c. RIVER/CHANNELS	No	Yes	
d. UNDERGROUND INFRASTR. (gas pipeline, aqueduct, ...)	No	Yes	⇒ Type (power line, aqueduct, gas pipeline, sewerage, …):
e. ROUTES	No	Yes	⇒ Type: / From Km: / To Km: / Roadway – covered by landslide deposits / Failure/ chasm

Completion instructions:

The form will be fill full for each landslide area involved during an event, ex: one sheet for the date: march 26th 2006, village x, another sheet for the same date related to village y, etc.

"O TYPE" paragraphs: one answer rules out the others.
"E TYPE" paragraphs: if necessary, it is possible to give more than one answer.

Par. 1) **Extract from Map 1:50.000 or an extract of another map more detailed attached separately**
Insert or attach an extract of the Map 1:50.000, or an extract of another map more detailed, including the entire landslide area and the adjacent involved areas. Mark the North with an arrow.

Par. 1.a) **Mark out landslide area, if possible**
If possible mark out landslide area with a red polygon on the map.

Par. 1.b) **Mark site with a red asterisk**
As alternative to the par. "1.a", mark on the map with a red asterisk one landslide area site, if possible at the highest point (elevation).

Par 1.c) **Highlight any water spring with blue symbol**
Mark on the map with a triangle any water spring in landslide area and/or in adjacent areas in the related position.

Par. 1.d) **Highlight any structural damage on building or other infrastructure**
Highlight on the map any structural damage on buildings or on other infrastructures with a red diagonal line on the damaged structure.

Par. 2) **Priority**
Specify with a progressive number the appropriate priority in decreasing order (1 to 5), for the site taken into consideration with respect to the other sites that were involved by the same event (date). For example among five drawn-up alert sheets, the most serious reported event shall have priority "1" and the less severe event shall have priority "5". If it is the case specify the number of victims.

Par. 3) **Place**
Insert the Municipality, the street or the location where the event takes place. If possible insert the coordinates (east- north) and reference system, of a point in the highlighted area or of the point marked with a red asterisk on the map (only if it is available, it is not necessary to calculate the coordinates starting from the map).

Par. 4) **Estimated involved area (=max. length X max. width)** Insert max. Length, max. width in their respective fields and the corresponding landslide area involved in the phenomena .

Par. 5) **Landslide date (Date of the event, if possible)**
Insert the day, the month and the year of landslide event. Insert only already known data and leave the other boxes blank.

Par. 6) **Prevailing land use**
Mark with a cross the prevailing land use in landslide area. It is possible to specify only one type of land use.

Par. 7) **Landslide material**
Mark landslide material with a cross. It is possible to specify only one type of land use (if it is knowledge also indicate the lithology involved, for example: pyroclastic deposits, colluvial deposits, or about rocks : recent basalts, ancient basalts, etc.).

Par. 8) **Wet area**
Specify any wet area in landslide or nearby areas.

Par. 9) **Structures involved**
Specify any structure involved in landslide.

e) Referring to BUILDINGS, specify the number of buildings involved for the three different categories (private - public - abandoned) in the respective box near to "Quantity".
f) Referring to RETAINING WALLS, specify if this kind of structures were involved in landslide marking a cross in "yes" or "no" box respectively.
g) Referring to RIVER/CHANNELS, specify if this kind of structures were involved in landslide marking a cross in "yes" or "no" box respectively.
h) Referring to UNDERGROUND INFRASTRUCTURE (SUB-SERVICES), specify if this kind of structures were involved in landslide marking a cross in "yes" or "no" box respectively. If the answer is "yes", specify the kind of structure involved marking the box near to "TYPE" (ex: Water supply system).
i) Referring to ROUTES, specify if this kind of structures were involved in landslide marking a cross in "yes" or "no" box respectively. If the answer is "yes":
    - Specify the kind of structure involved in the box near to "TYPE" (ex: national) etc.);
    - Specify also the stretch of the road involved, namely the length of damaged roadbed; if this data in unknown, insert the length of the involved road stretch in meters in the box near to "from Km" (ex: 15 m);
    - Specify if roadbed is covered with landslide material or if it is broken, marking a cross near to "COVERED" and "FAILURE" respectively.

ANNEX A – 6.1 FLOOD ALERT SHEET (EVENT REPORT)

Sheet compiled by:		Tel.:	
Administration/institution :			
Completion date:			

LOCALIZATION :

1) Extract from Map 1:50.000 or extract of another map more detailed attached separately.
   On the Map should:
   a) Mark out flooded area (if it is possible draw with a red felt pen).
   b) Otherwise mark site with red symbol *
   c) Highlight any initial overflow point or line that originate the flooded area with blue symbol: △
   d) Highlight any structural damage on buildings or other infrastructures (road, power line, aqueduct, etc.) with red symbol: /

2) Priority:

(considering a scale 1-5) | Number of victims:

3) Place:

MUNICIPALITY/VILLAGE		
DISTRICT		
RIVER / STREAM INVOLVED		
Coordinates if possible (East- North) and reference system		

4) Estimated involved area:

1-10 ha	10-100 ha	> 100 ha

5) Flood event date (if possible):

DAY | MONTH | YEAR

6) Prevailing land use: ("O" TYPE)

URBANIZED AREA	
BARE SOIL	
PASTURE	
ARABLE LAND	
Scrub and/or herbaceous vegetation associations	
FOREST	
OTHER	

7) Wet area, estimated water depth: ("O" TYPE) :

0,4-1 m	> 1 m

8) Structure involved: ("E" TYPE)

a. BUILDING — No | Yes → Public (quantity): / Private (quantity): / Abandoned (quantity):

b. FACTORY / INDUSTRIES — No | Yes → Type (manufacture, chemical, etc) and n. of employer :

c. UNDERGROUND INFRASTRUCTURE (gas pipeline, aqueduct,...) — No | Yes → Type (power line, aqueduct, gas pipeline…):

d. ROUTES — No | Yes → Type: / From Km: / To Km: / Roadbed | Flooding | / break/ chasm

Completion instructions:

The form will be fill full for each flooded area involved during an event, ex: one sheet for the date: March 26th 2006, village x, another sheet for the same date related to village y, etc.

"O TYPE" paragraphs: one answer rules out the others.
"E TYPE" paragraphs: it is possible to give more than one answer, if necessary.

Par. **1) Extract from Map 1:50.000 or an extract of another map more detailed attached separately**
Insert or attach an extract of the Map 1:50.000, or an extract of another map more detailed, including the entire flooded area. Mark North with an arrow.

Par. **1.a) Mark out flooded area, if possible**
If it possible mark out the flooded area with a red polygon on the map.

Par. **1.b) Mark site with a red asterisk**
As an alternative to par. "1.a", in absence of detailed event documentation, mark only with a red asterisk a flooded area site.

Par **1.c) Highlight any initial overflow point or line that originate the flooded area with blue symbol**
Mark on the map with a triangle any initial overflow point or line that originate the flooded area.

Par. **1.d) Highlight any structural damage on building or other infrastructure**
Highlight any structural damage on building or on other infrastructure with a red diagonal line above the same structure, on the map.

Par. 2) **Priority**
Specify with a progressive number the appropriate priority for the site taken into consideration with respect to the other sites reported by the same event (date) in decreasing order (1 to 5). For example among five drawn-up alert sheets, the most serious reported event shall have priority "1" and the less severe event shall have priority "5". If it is the case specify the number of victims.

Par. 3) **Place**
Insert the Municipality, the street or the location where the event took place. If possible insert the coordinates (East- North) and reference system, of a point in the highlighted area or of the point marked with a red asterisk on the map (only if it is just available, it's not necessary to calculate the coordinates starting from the map).

Par. 4) **Estimated involved area** Put the class of the area involved into the flood phenomena.

Par. 5) **Flood event date (Date of the event, if possible)**
Insert the day, the month and the year of flood event. Insert only already known data and leave the other boxes blank.

Par. 6) **Prevailing land use**
Mark with a cross the prevailing land use in flooded area. It is possible to specify only one type of land use.

Par. 7) **Wet area, estimated water depth**
Specify the class of the water depth registered/estimated.

Par. 9) **Structures involved**
Specify any structure involved in the flood event.

a) Referring to BUILDINGS, specify the number of buildings involved for the three different categories (private - public - abandoned) in the respective box near to "Quantity".
b) Referring to FACTORY / INDUSTRIES, specify if this kind of structures were involved in flood event marking a cross in "yes" or "no" box respectively, the type of the industry, (ex: manufacture, chemical, etc.) and number of employer.
c) Referring to UNDERGROUND INFRASTRUCTURE (SUB-SERVICES), specify if this kind of structures were involved in flood marking a cross in "yes" or "no" box respectively. If the answer is "yes", specify the kind of structure involved marking the box near to "TYPE" (ex: Water supply system).
d) Referring to ROUTES, specify if this kind of structures were involved in flood marking a cross in "yes" or "no" box respectively. If the answer is "yes":
    - Specify the kind of structure involved in the box near to "TYPE" (ex: national, etc);
    - Specify also the stretch of the road involved, namely the length of damaged roadbed; if the previous data is unknown, insert only the length of the involved road stretch in meters in the box near to "from Km" (ex: 15 m);
    - Specify if roadbed is covered by flooding or if it is broken, marking a cross near to "FLOODING" or "BREAK" respectively.

Caveats and methodological challenges

The development of most of the landslides are within the quaternary deposits (colluvial and slope deposits), that are closely connected to the geomorphological features of the landscape.

The major caveat is that **the available geological map of the Mauritius and Rodrigues island** (Giorgi & Borchiellini, 1998; Giorgi et alii, 1999) **includes the mapping of several bedrock lithologies and only two main units of superficial deposits** (alluvial-eluvial deposits along the main alluvial plains and carbonate units of coral present and ancient reefs).

Many of the superficial deposits of the island are not mapped due to the scope of the previous works and scale (1:50.000) of available map.

In order to greatly improve the reliability of the landslide hazard mapping of this study, at local scale (1:10.000-1:25:000) too, new geological geomorphological and hydrogeological maps should be necessarily done.

The advances and **new methodological challenges** suggested by the results of the present study are mainly:

- **geological, geomorphological and hydrogeological study and mapping (scale 1:10.000-1:25:000**) of the Port Louis urban area; after the Port Louis area the same investigation could be extended to the other main urban and development areas of the Mauritius island and to the tourist areas too.
- **detail geological, geomorphological and hydrogeological study and mapping (scale ≥1:5.000**) of specific and significant active landslide areas such as Citrakoot, Quatre Soeres and others aimed at the correct landslide management;

Only these detailed studies will allow the knowledge of each landslide in order to design the interventions finalized at the reduction of the risk.

Measures for landslide prevention and protection

Generally landslide risk can be reduced by the following five approaches, used individually or in combination to reduce or eliminate losses:

- Restricting development in landslide-prone areas
- Standardizing codes for excavation, construction, and grading
- Protecting existing development
- Utilizing monitoring and warning systems

Activities to plan in the future

LEVEL 1 (to cover the gap of data/map)

STUDIES AT REGIONAL SCALE FOR GEOLOGICAL AND GEOMORPHOLOGICAL MAPPING (ENTIRE ISLAND):

1. **Survey and mapping of surface deposits in scale 1:10,000/25,000 for ROM**

2. **Geomorphological survey and mapping scale 1:10,000/25,000 for ROM (including a preliminary census of sinkhole due by tunnel lavas)**

The mapping ought to be performed according to guidelines already available at international level (i.e. ISPRA, Italy Geological Survey, http://www.isprambiente.gov.it/it/progetti/progetto-carg-cartografia-geologica-e-geotematica (Italian);
USGS standards and guidelines, http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html;
BGS standards and guidelines http://www.bgs.ac.uk/downloads/start.cfm?id=303 (English);
BGS landslides program, http://www.bgs.ac.uk/landslides/ (English); Wang, 2012).

A National Geological Service it's necessary to ensure the coordination and to manage the maps at District levels.

Activities to plan in the future

LEVEL 2

STUDIES AT LOCAL LEVEL, LANDSLIDE MANAGEMET PLAN AND FEASIBILITY STUDY OF REMEDIATION WORKS (in the three main areas):

For the design of civil engineering works and for defining management / planning tools must include the following points (in the report) and maps (attached to the report):

1. Background and objectives of the work
2. Geographical context
3. Regional geological setting
4. Methods, investigations and results
   - In field surveys (geology and geomorphology)
   - Aerial photo interpretation and photogeology
   - Borehole and geophysical investigations
5. Characterization of the significant geological volume
   - Lithology and stratigraphy
   - Tectonics and structural setting
   - Geomorphology
   - Hydrogeology

Activities to plan in the future

LEVEL 2

STUDIES AT LOCAL LEVEL, LANDSLIDE MANAGEMET PLAN AND FEASIBILITY STUDY OF REMEDIATION WORKS (in the three main areas):

6. Analysis of geological hazards
7. Exposure and landslide risk
8. Reliability of the geological condition and feasibility of the planned work
9. References

Maps

- Geological map scale, 1:5,000
- Geomorphological map scale, 1:5,000
- Vulnerability exposed elements (existing and / or planned, designed),scale1:5,000
- Landslide danger map of scale, 1:5,000
- Landslide management plan
- Feasibility study of intervention to mitigate the risk

These guidelines should be implemented in the technical code for landslide management to have a suitable development and compatible use of the land (objective 3 of the DRR strategy)

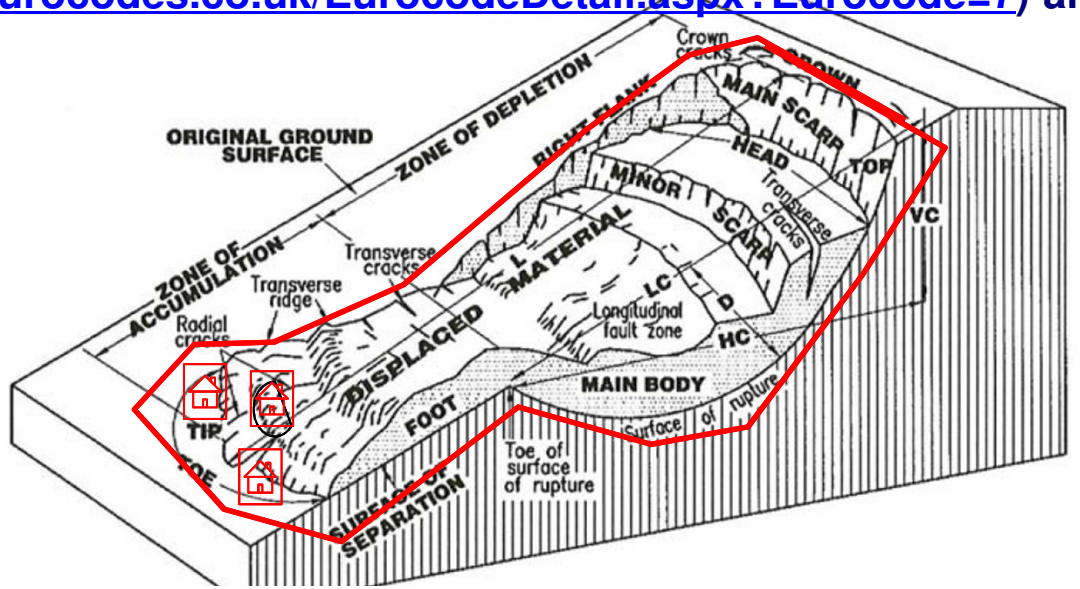
CHARACTERIZATION OF THE SIGNIFICANT GEOLOGICAL VOLUME ON A SITE

The main issue in the definition of a landslide and its hazard, according to the most relevant international literature (Varnes, 1996; Soeters and Van Westen, 1996; USGS, 2004; Reichenbach et al., 2007; Fell, 2008; Highland and Bobrowsky, 2008; GNC 2010), is the characterization of the significant geological volume and of its geomorphological features.

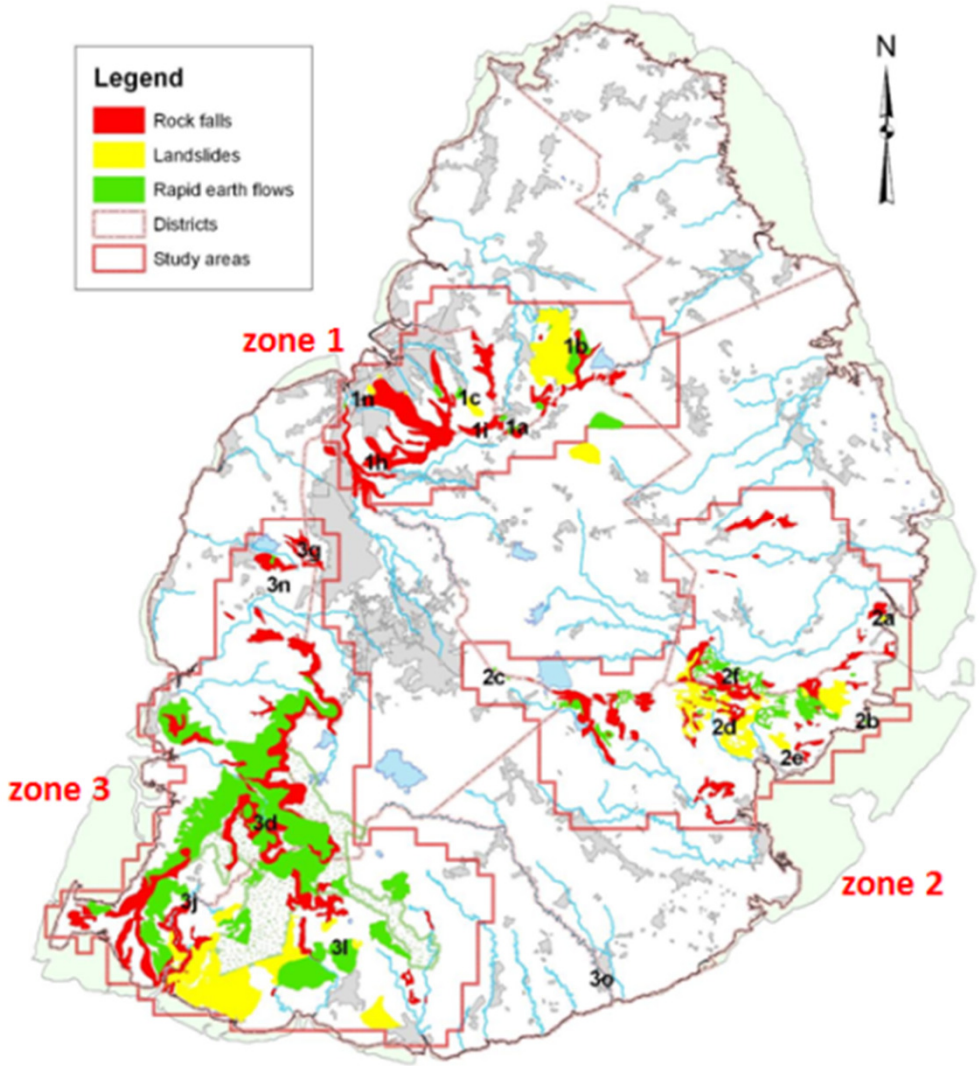
The significant geological volume operationally is, the surface area and the depth possibly involved in geological, geomorphological, hydrogeological and anthropogenic processes (particularly landslides) capable to directly or indirectly affect civil engineering works and management areas must be evaluated.

In the Mauritius area surface deposits (slope debris deposits; landslides deposits; colluvial deposits) are involved, the rock (ancient, intermediate and recent basalts) are affected considering the rock fall phenomena . In many cases also pyroclastic rocks are involved.

The processes affecting civil engineering works and management areas and the consequences of works and management on landscape and environment are many (also according to Eurocode 7, http://www.eurocodes.co.uk/EurocodeDetail.aspx?Eurocode=7) and include landslides.



Action plan – Planning activities

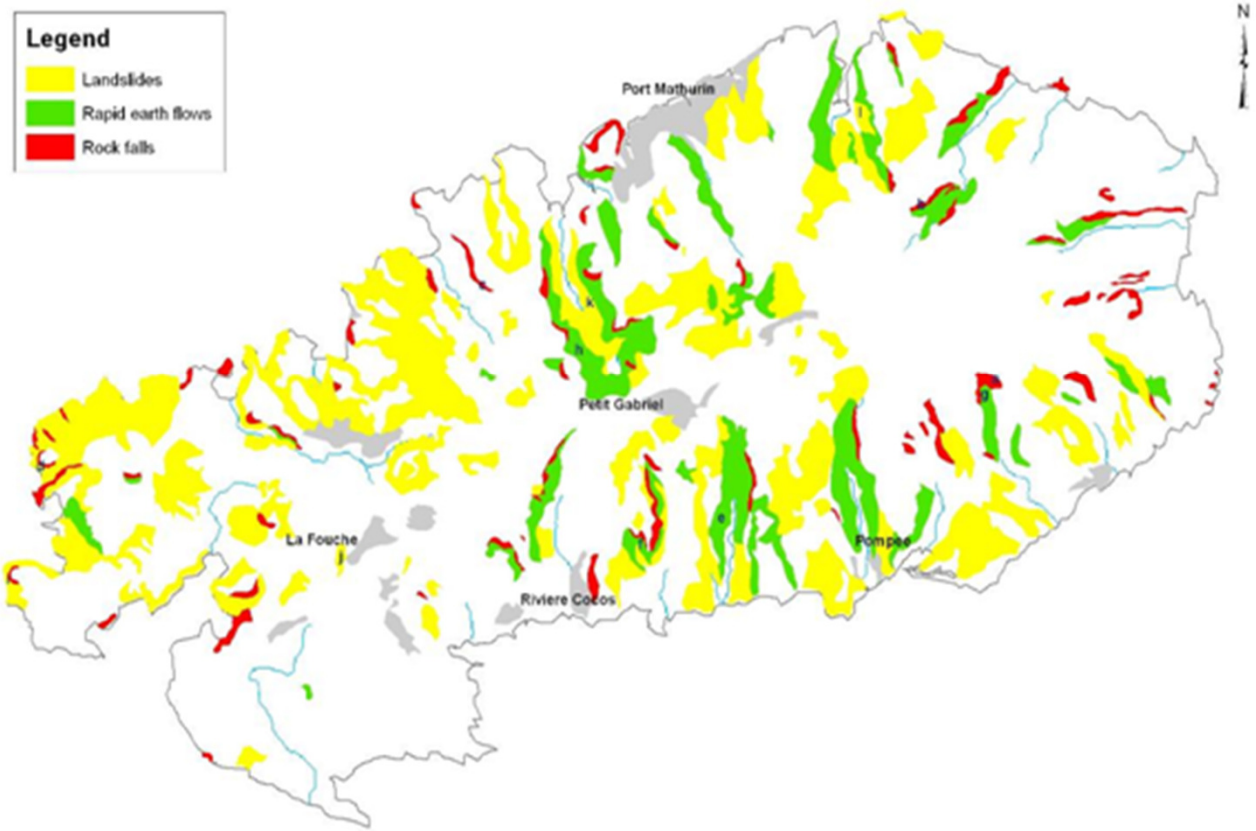


Action plan – Planning activities

			time [year]				TOTAL [MUR]	
LEVEL 1	**Studies at regional scale for geological and geomorphological mapping :**							
	1. survey and mapping of surface deposits in scale 1:10,000-1:25,000-1:50,000	**ZONE 1**	2012 10.000.000	2013	2014	2015		
	2. geomorphological survey and mapping scale 1:10,000-1:25,000-1:50,000 (preliminary census of sinkhole due by tunnel lavas)	**ZONE 2** **ZONE 3**		24.000.000	17.000.000			
LEVEL 2	**Studies at local level for landslide area, landslide managemet plan and feasibility study of remediation works:**							
	– Geological map scale, 1:5,000 – Geomorphological map scale, 1:5,000 – Landslide hazard map of scale, 1:5,000 – Vulnerability and exposed elements (existing and / or planned), scale 1:5,000 -- Landslide managemet plan	**ZONE 1**		9.000.000				
	– Landslide risk map, scale 1:5,000	**ZONE 2**				9.000.000		
	– Feasibility study of intervention to mitigate the risk	**ZONE 3**			32.000.000			
			10.000.000	33.000.000	49.000.000	9.000.000	101.000.000	TOTAL [MUR]
			270.270	891.892	1.324.324	243.243	2.729.730	TOTAL [€]

For each zone has been calculate the budget to carried out the geological and geomorphological studies during the next triennium, the total amount to caver all these zone is 100million of MUR

Action plan – Planning activities



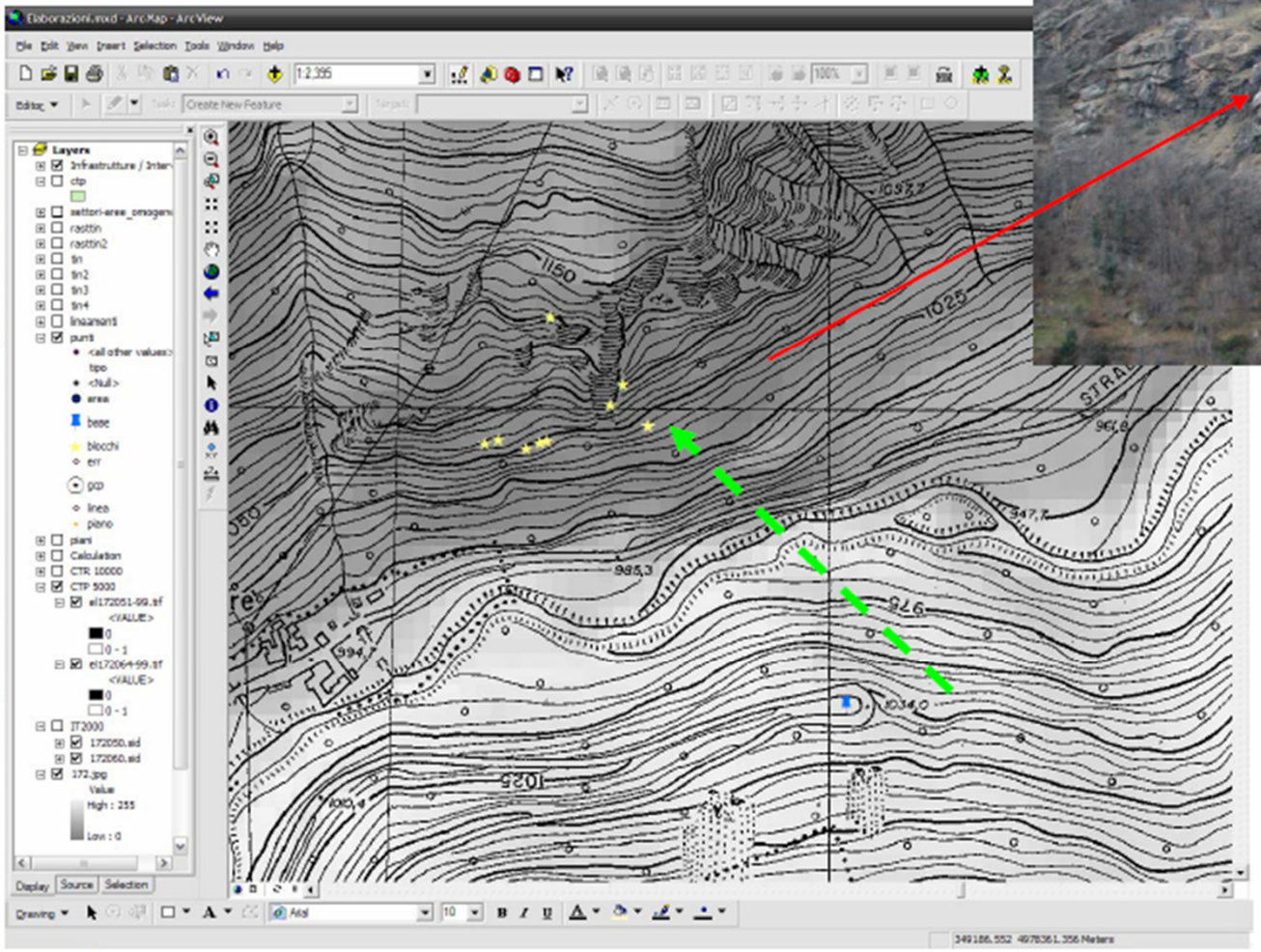
About Rodrigues it is important to improve the knowledge, considering the lack of geomorphological data since it is the first time that a landslide study has been carried out.

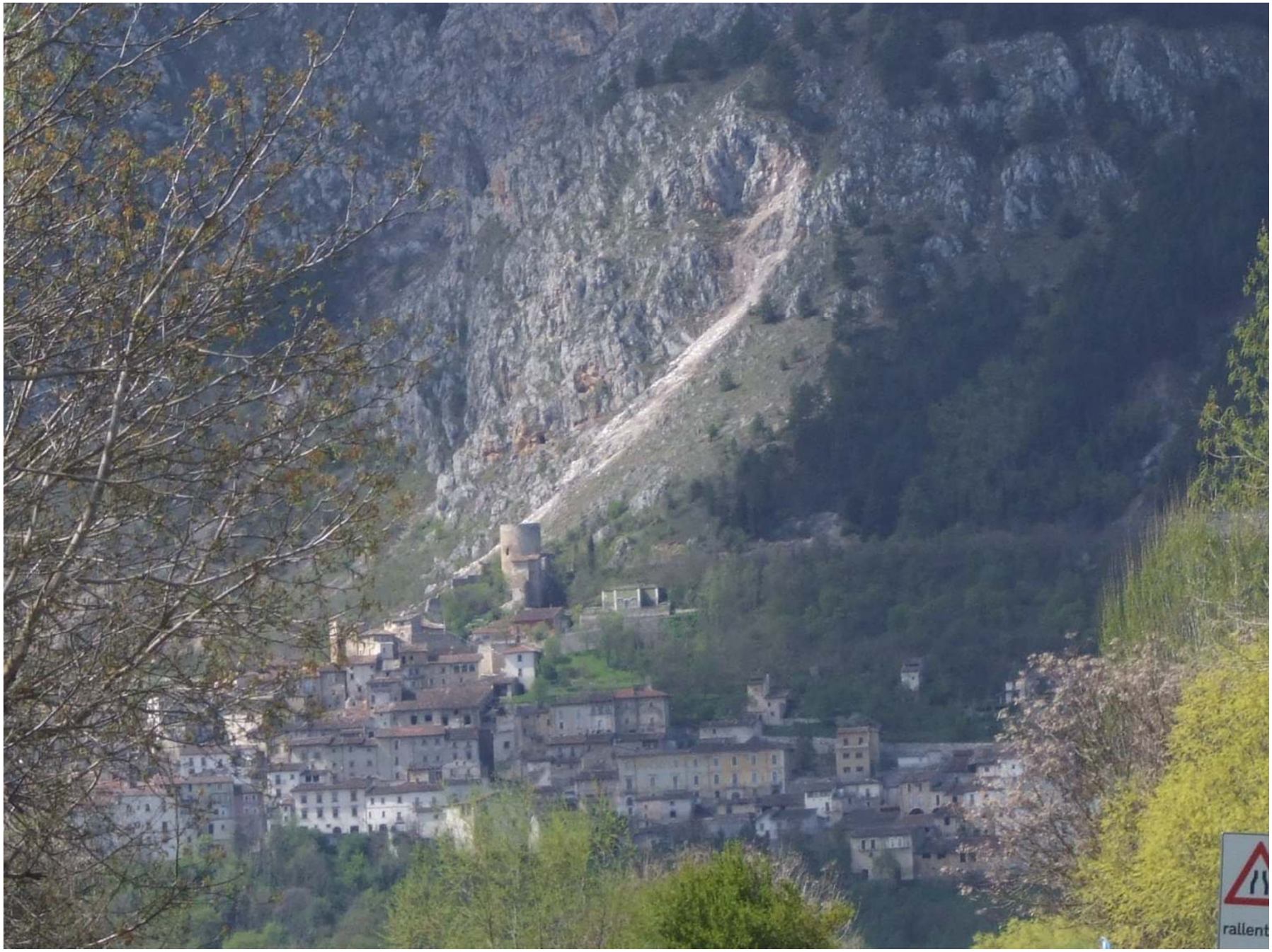
Action plan – Planning activities

		time [year]		TOTAL [MUR]	
LEVEL 1	**Studies at regional scale for geological and geomorphological mapping (entire island):**				
	1. survey and mapping of surface deposits in scale 1:10,000-1:25,000-1:50,000 2. geomorphological survey and mapping scale 1:10,000-1:25,000-1:50,000 (preliminary census of sinkhole due by tunnel lavas)	2012-2013	2014-2015		
		8.000.000			
LEVEL 2	**Studies at local level for landslide area, landslide managemet plan and feasibility study of remediation works:**				
	– Geological map scale, 1:5,000 – Geomorphological map scale, 1:5,000 – Landslide hazard map of scale, 1:5,000 – Vulnerability and exposed elements (existing and / or planned), scale 1:5,000 -- Landslide managemet plan – Landslide risk map, scale 1:5,000 – Feasibility study of intervention to mitigate the risk		12.000.000		
		8.000.000	12.000.000	20.000.000	TOTAL [MUR]
		216.216	324.324	540.541	TOTAL [€]

Next step for Rodrigues is the activation of 8 million of MUR to have during the 2013 a geological/geomorphological study at level 1; then, another 12 million of MUR to have a complete landslide characterization at level 2

LEVEL 2:
Example of detailed geomorphological study with surveying of the unstable blocks

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Action plan –Structural interventions

The study having a preliminary knowledge of the existing landslide and assessing the area of the landslide that involve the element at risk; estimate the preliminary costs for the protection works (structural measures or interventions) for landslide risk mitigation.

The following matrix relates different typical intervention works with the landslide type

STRUCTURAL MEASURES (intervention works)	Rapid earth flow	Rock fall	Landslide
Groundwater drainage: adit and drainage well, etc.			X
Direct consolidation action : pile wall, caisson or beam and active anchor			X
Underground drainage : gabion and drainage trench	X		X
Sediment control dam, dikes, embankment, etc.	X		
Rock slope protection works: wire mesh, anchor, grouting, etc.		X	

Action plan –Structural interventions: Annex 8

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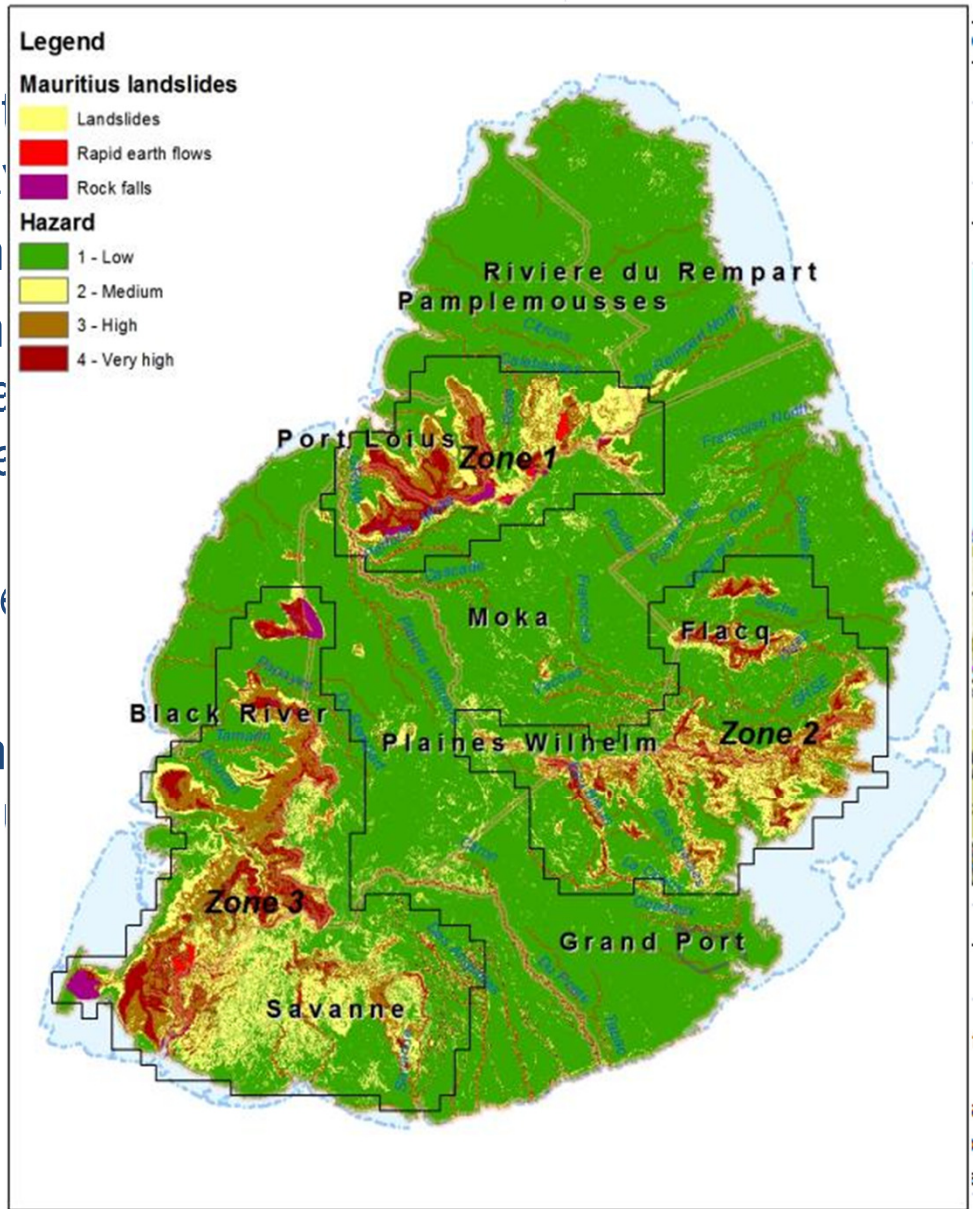
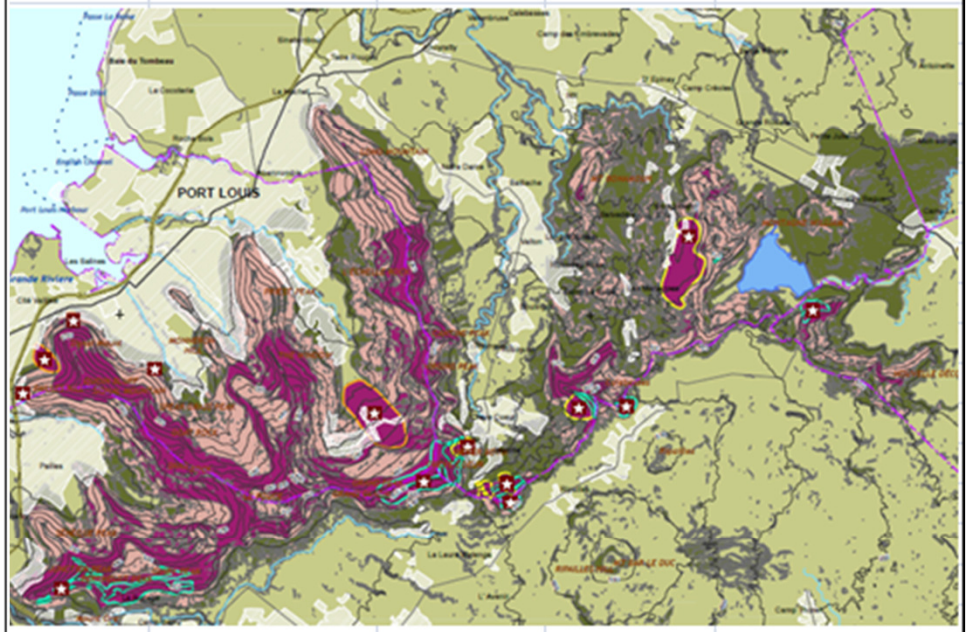


ACTION L_1/1,4,2

ort Louis and northern mountainside (zone 1)

Action plan to mitigate landslide risk in urban and suburban area

Port Louis and part of Pamplemousses, Moka Flacq Districts



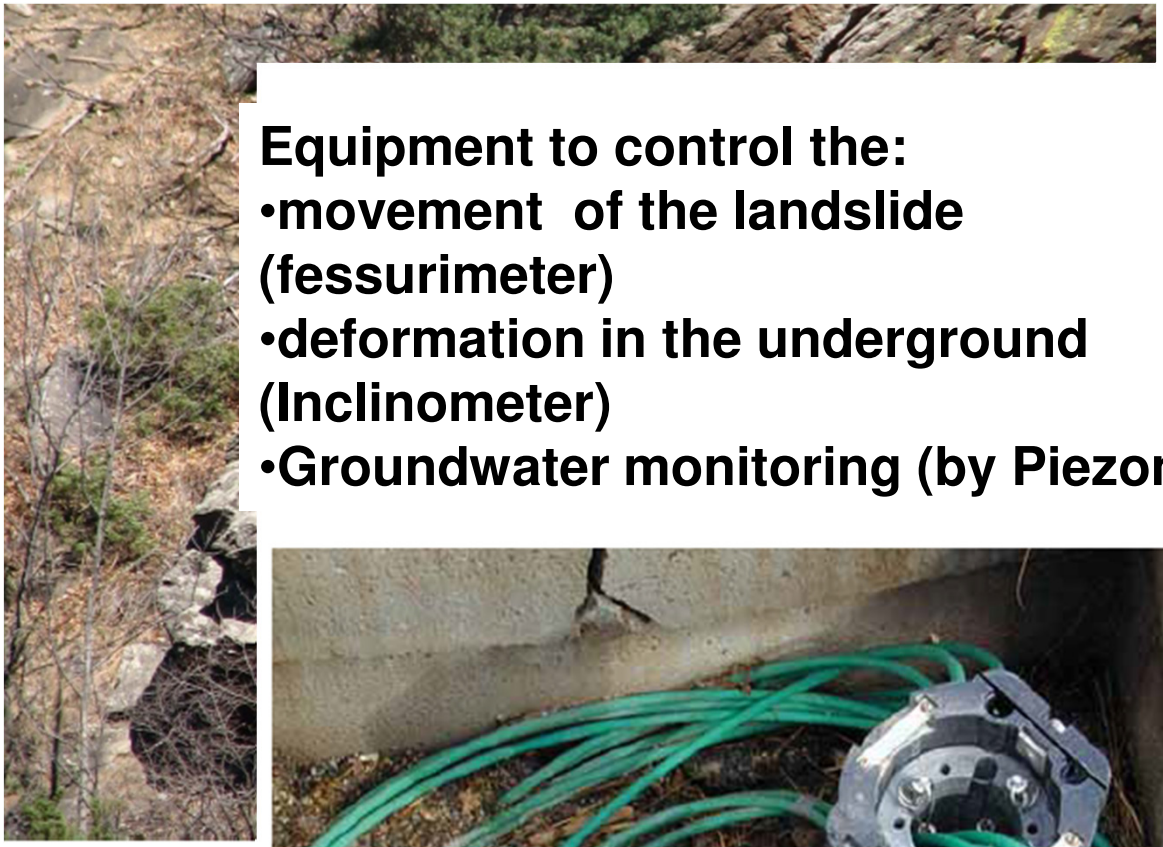
for Port Louis takes into account actions to reduce the risk and severity of landslide
area of Port Louis city and surroundings (Vallée des Petres - Chitrakoot, Temple Road
an area of Port Louis there are many existing landslides and other potential areas
rtant to increase the knowledge on these areas. Plan of interventions defines various
age caused when the landslide events happen including:

Action plan –Structural interventions

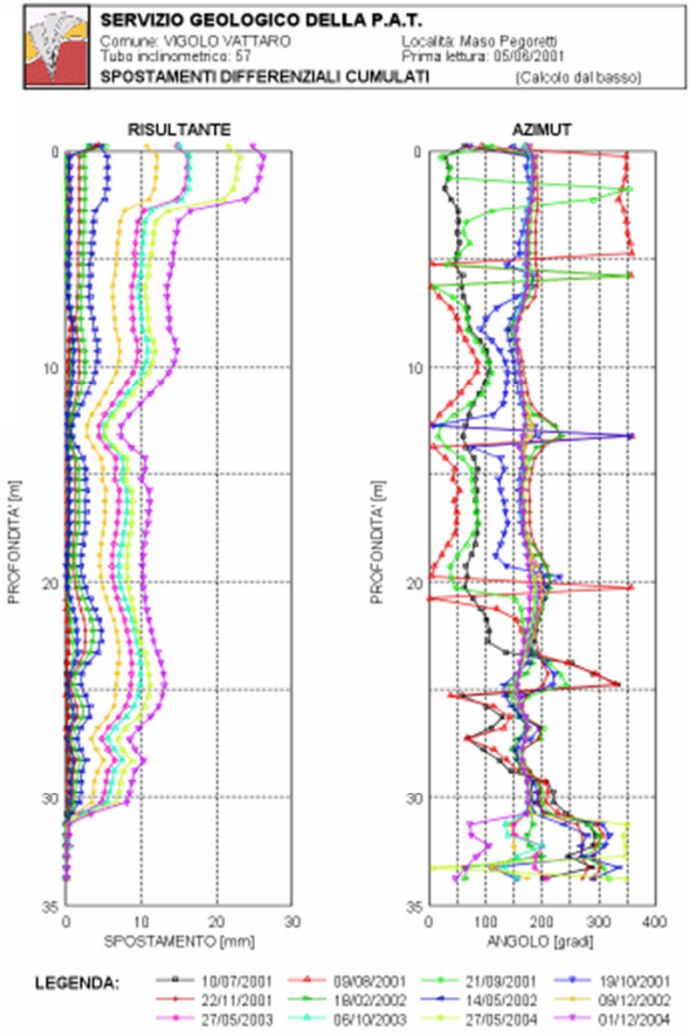
- the planning activities,
- the actions in terms of structural measures,
- the competent authority,
- the related costs.

- planning activities				
LEVEL 1 : Studies at regional scale for geological and geomorphological mapping including survey at scale 1:10,000-1:25,000-1:50,000 and a preliminary census of sinkhole due by tunnel lavas LEVEL 2 : Studies at local level for landslide area and preliminary design of remediation works at scale 1:5,000 including landslide managemet plan and feasibility study of remediation works				
- structural measures				
Groundwater drainage: adit and drainage well, etc.				
Direct consolidation action : pile wall, caisson or beam and actif ancor				
Underground drainage : gabion and drainage trench				
Sediment control dam, dikes, embankment, etc.				
Rock slope protection works: wire mesh, anchor, grouting, etc.				
Competent Authority: Government of ROM and local authority				
Cost of intervention [mil MUR]:	**1.480**			
- cost of planning activities (LEVEL 1 + LEVEL 2)	20			
- cost of structural and non-structural measures	1.460			
Budget of intervention:				
Year	**2012-2015**	**2015-2018***	**2018-2021***	**2021-2024***
Amount	20	487	487	487
**: a prioritization of structural measures could be more precise after the studies at level 1 and 2*				

Monitoring equipment to control the evolution of the rock fall

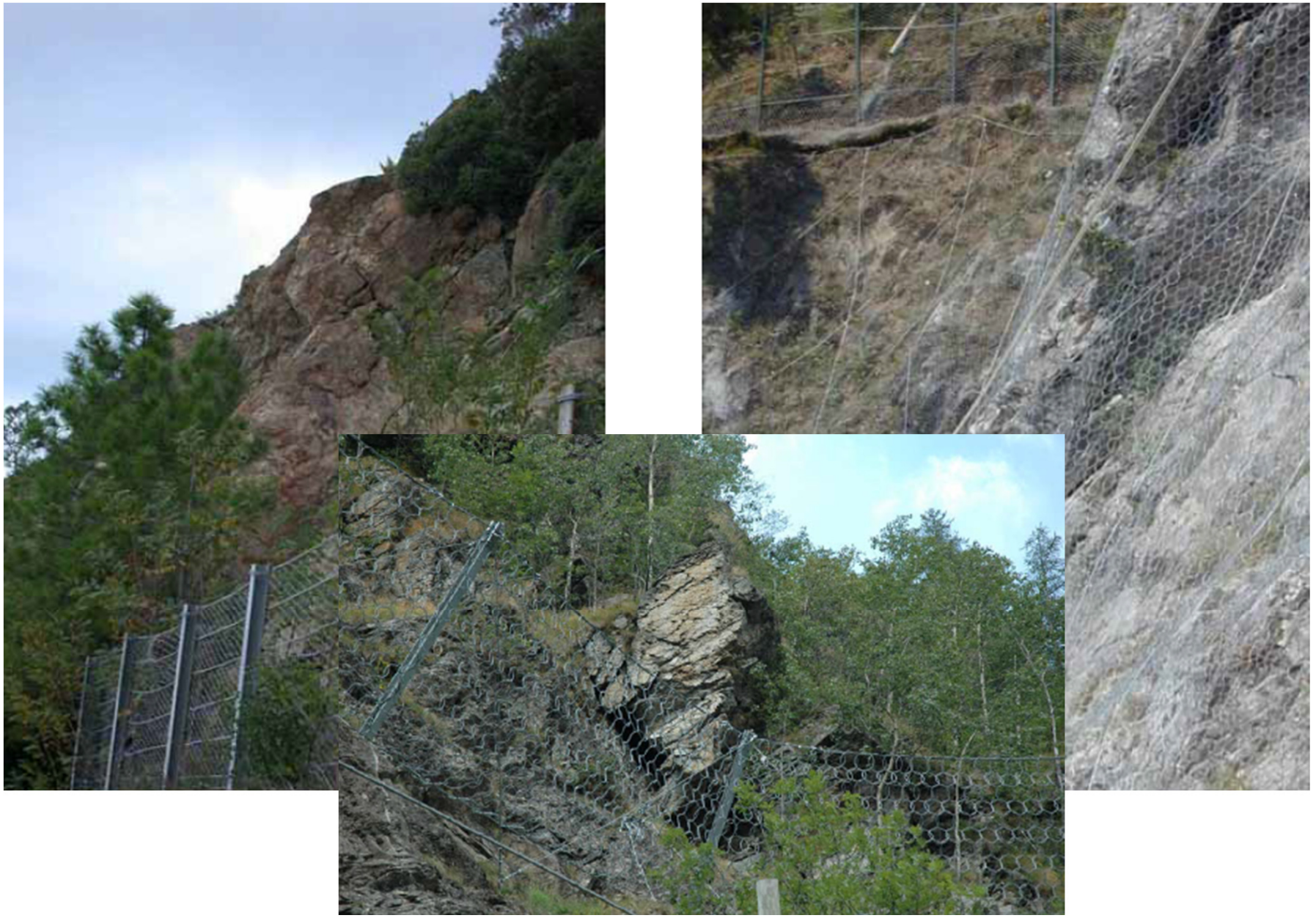


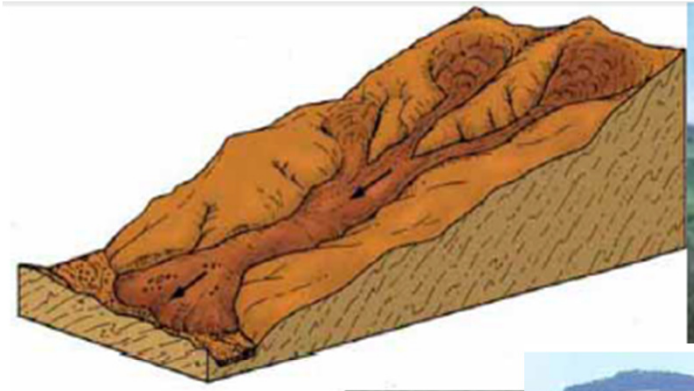
Equipment to control the:
- **movement of the landslide (fessurimeter)**
- **deformation in the underground (Inclinometer)**
- **Groundwater monitoring (by Piezometer)**



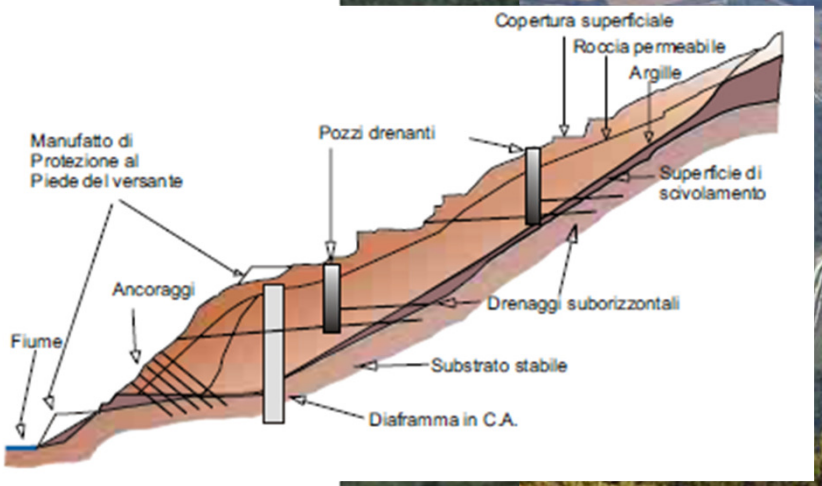
Example of graph of the underground deformation

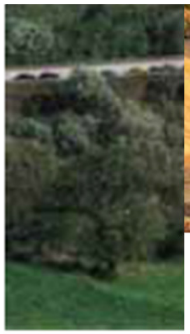
Structural action such us massive intervention of slope protection: wire mesh, anchor





Colamento lento

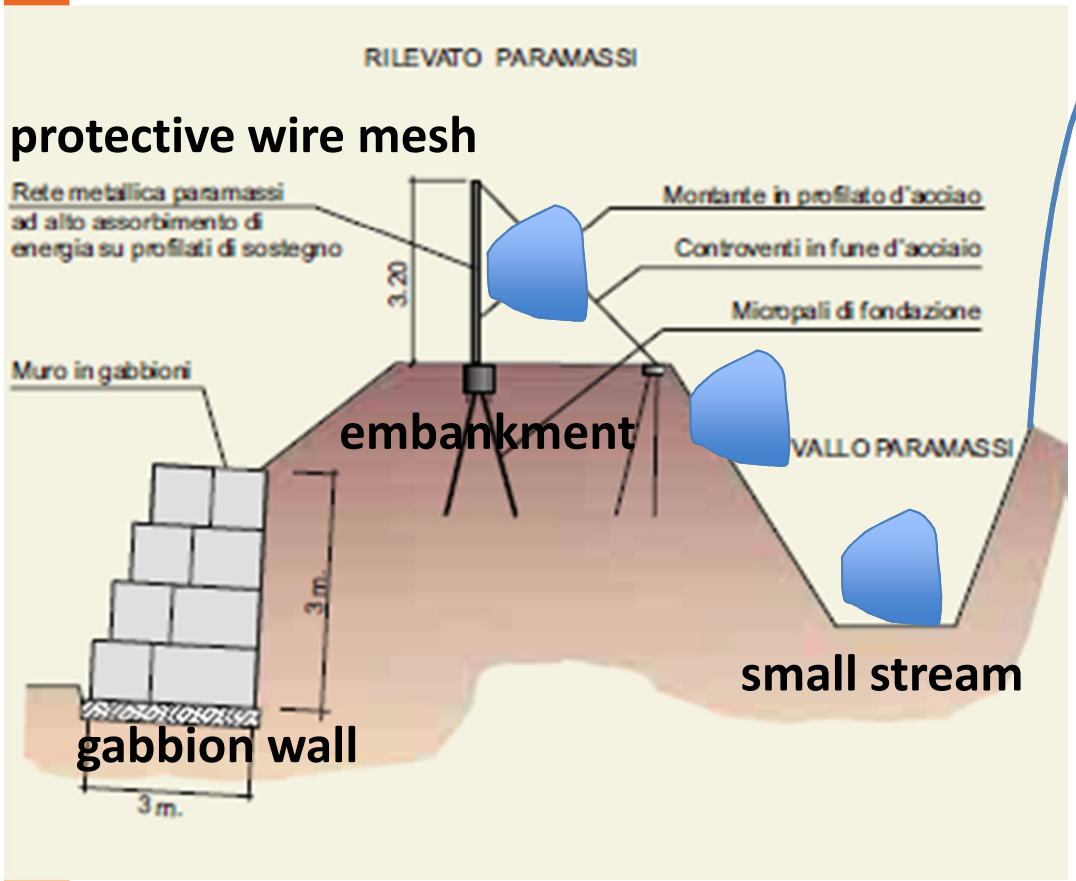




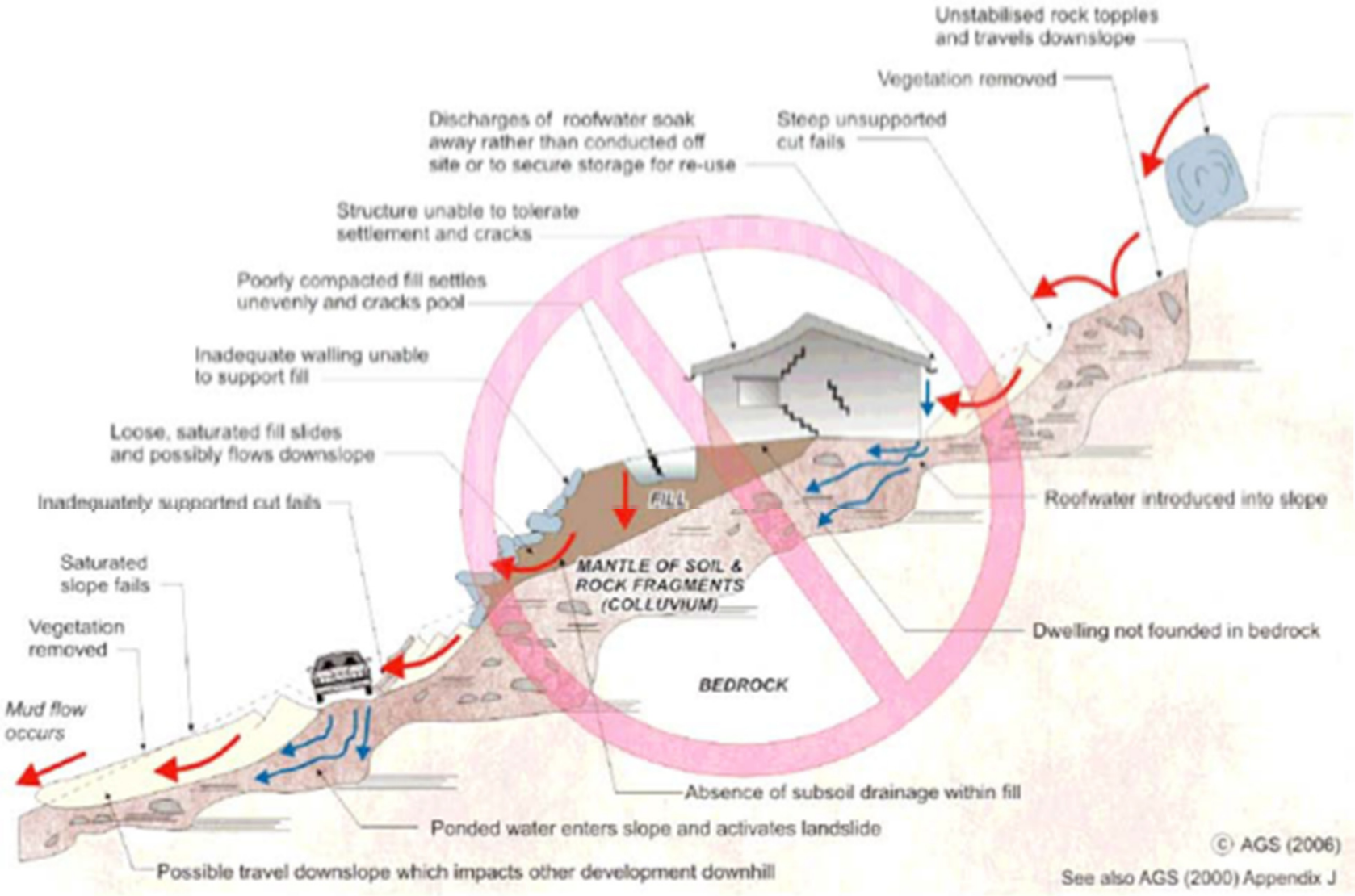
TODAY

Frana in loca

Rock boulder

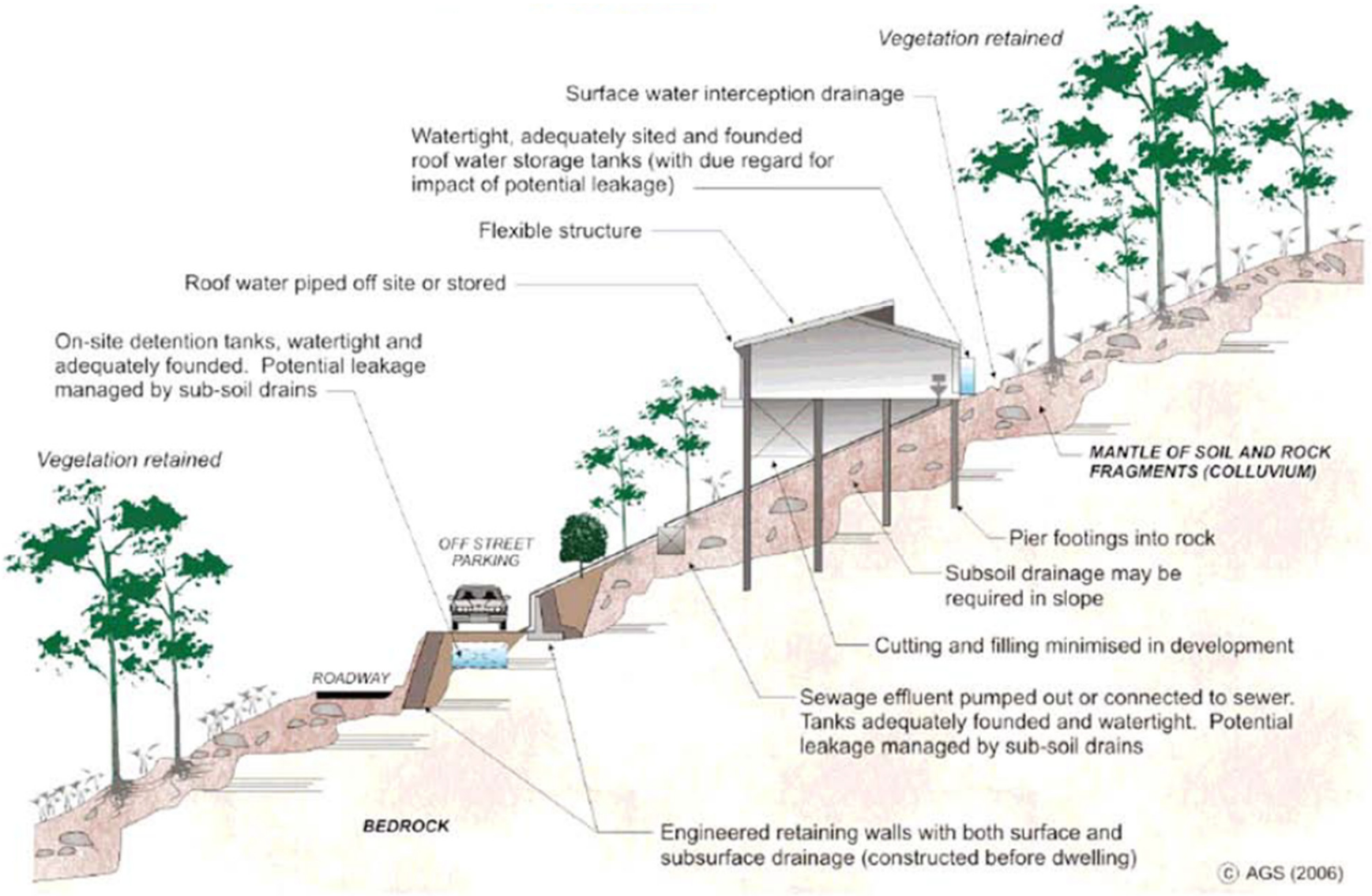


Example of poor hillside practice



from Australian Geomechanics Journal and News of the Australian Geomechanics Society Volume 42 No 1 March 2007

Example of good hillside practices



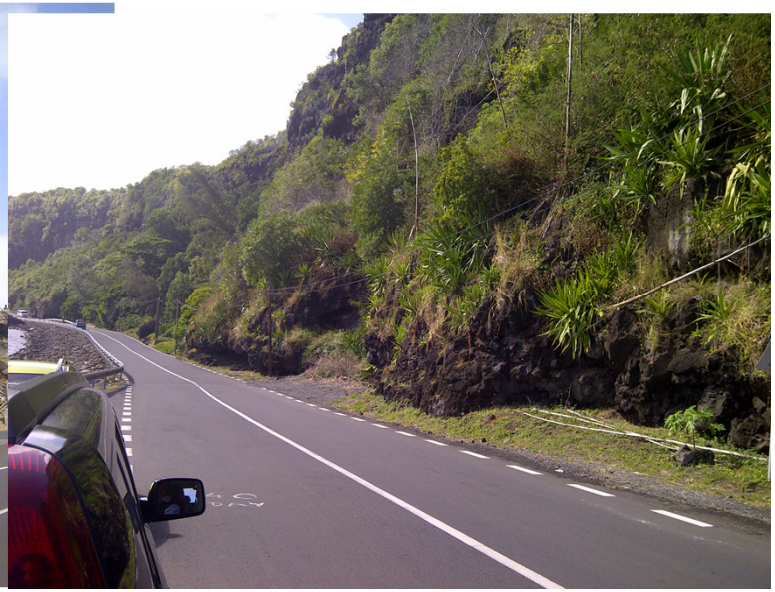
from Australian Geomechanics Journal and News of the Australian Geomechanics Society Volume 42 No 1 March 2007

SIMILAR PROBLEM IN MAURITIUS

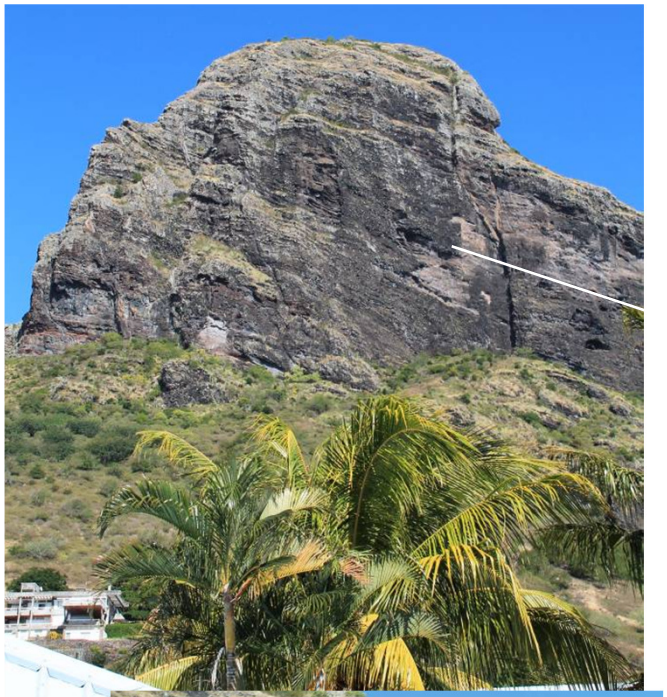
ROCK FALLS

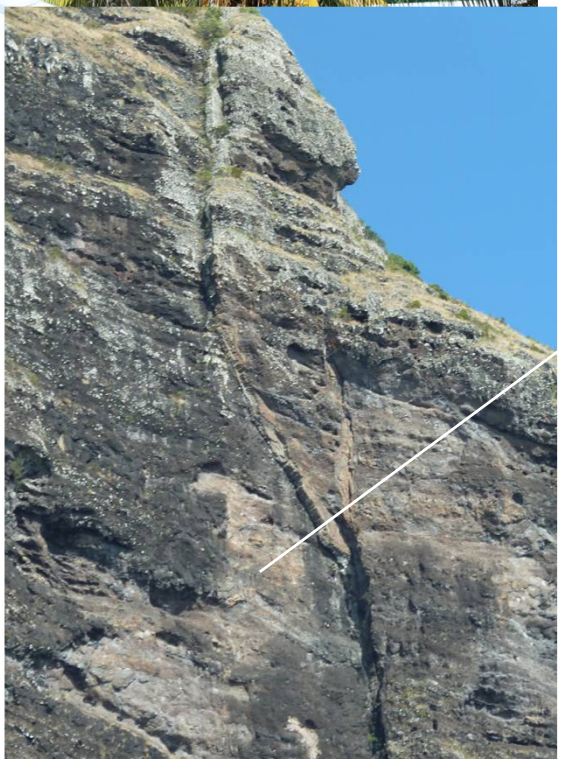
CAMP CHAPELON

BAIE DU CAP



SIMILAR PROBLEM IN MAURITIUS





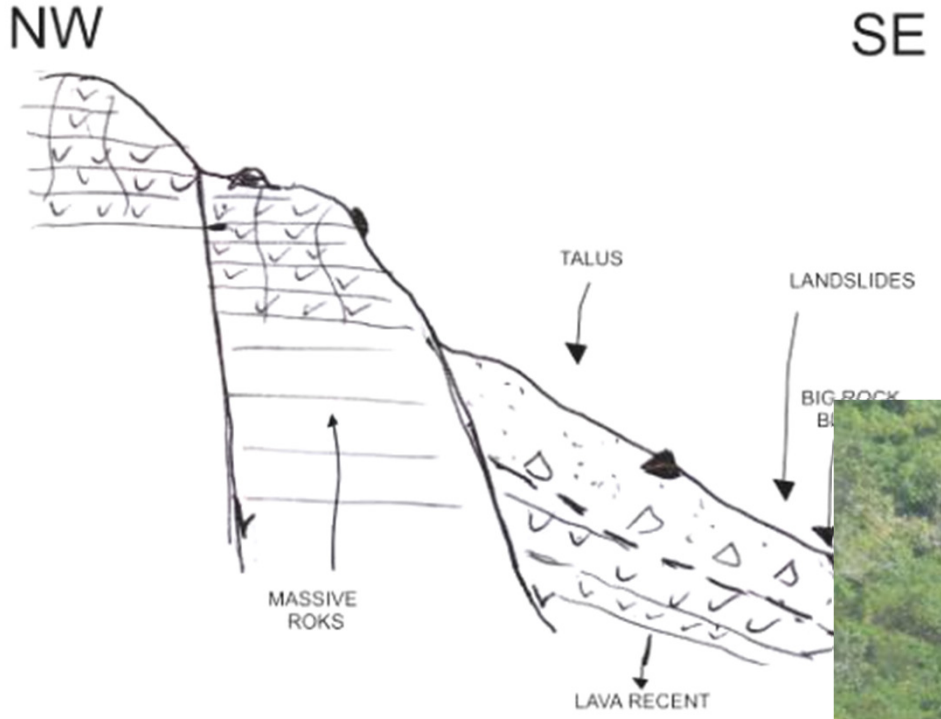
ROCK FALLS

LE MORNE BRABANT

SIMILAR PROBLEM IN MAURITIUS

ROCK FALLS

CORPS DE GARDE RIDGE



SIMILAR PROBLEM IN MAURITIUS

ROCK FALLS

CALEBASSES

SIMILAR PROBLEM IN MAURITIUS

LANDSLIDE

MGR. LEEN STREET LA BUTTE

QUATRE SOEURS

SIMILAR PROBLEM IN MAURITIUS

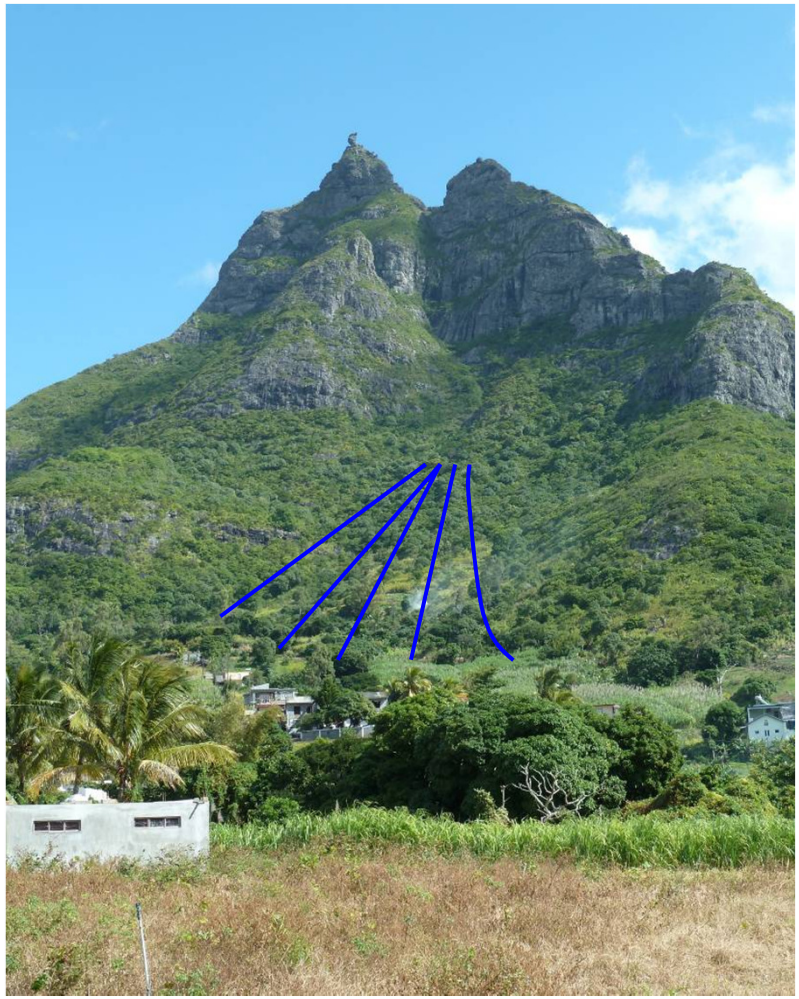
LANDSLIDE

VALLÉ DES PRETES – CHITRAKOOT

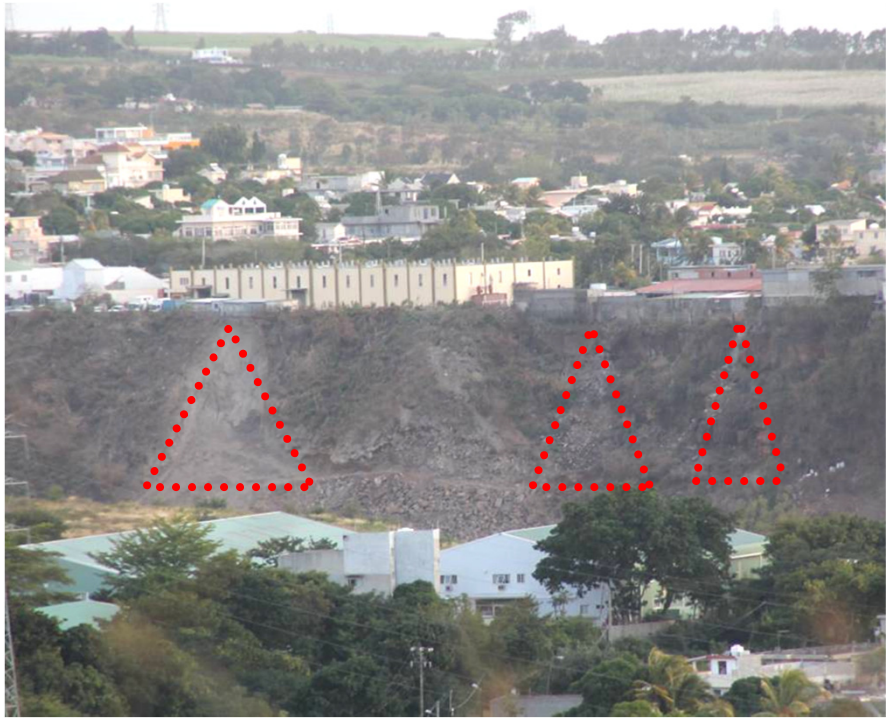
SIMILAR PROBLEM IN MAURITIUS

RAPID EARTH FLOWS

TEMPLE ROAD CREVE COEUR



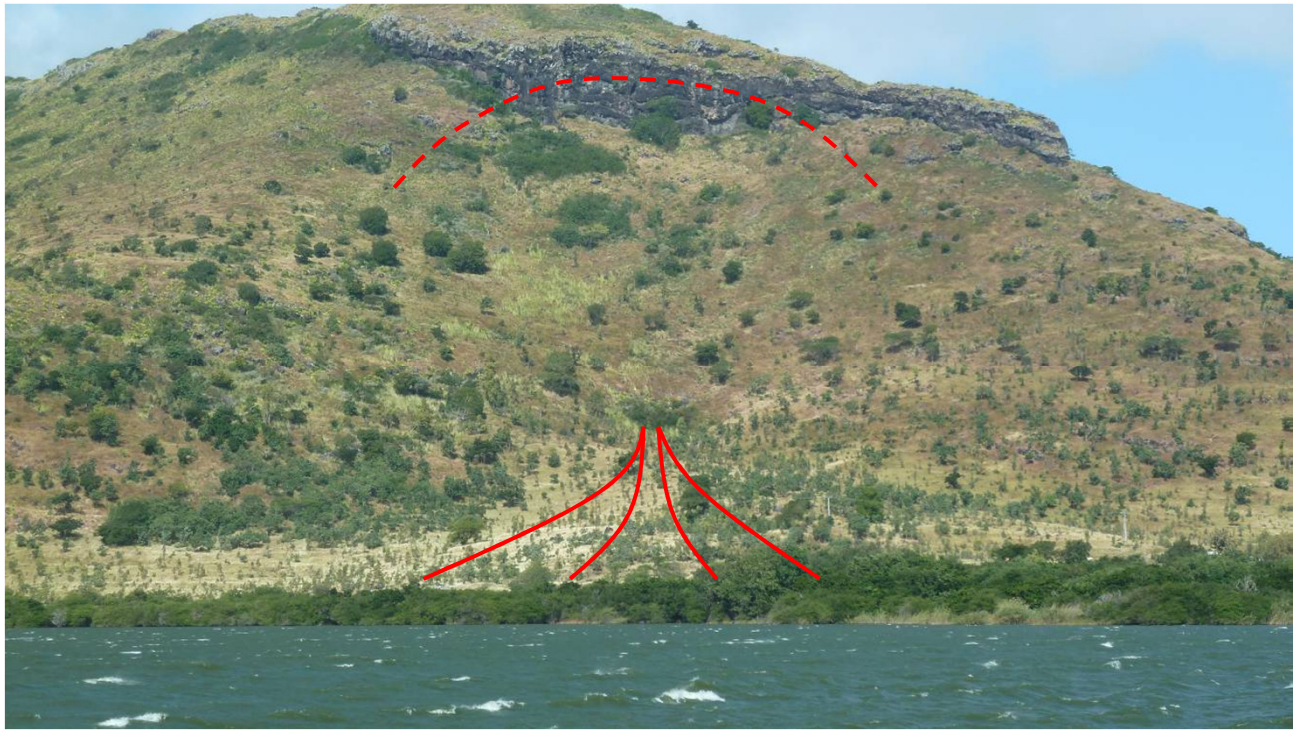
MORCELLEMENT HERMITAGE COROMANDEL



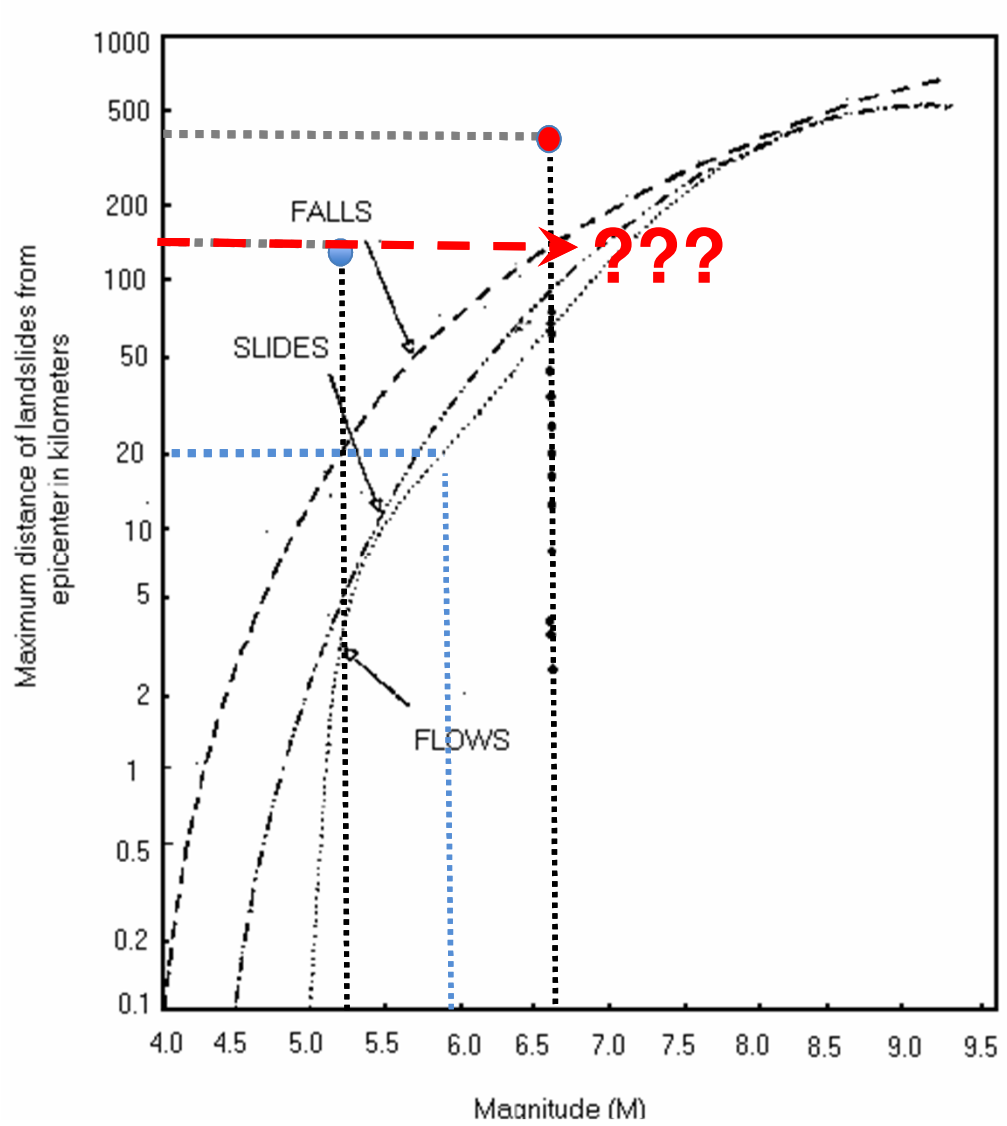
SIMILAR PROBLEM IN MAURITIUS

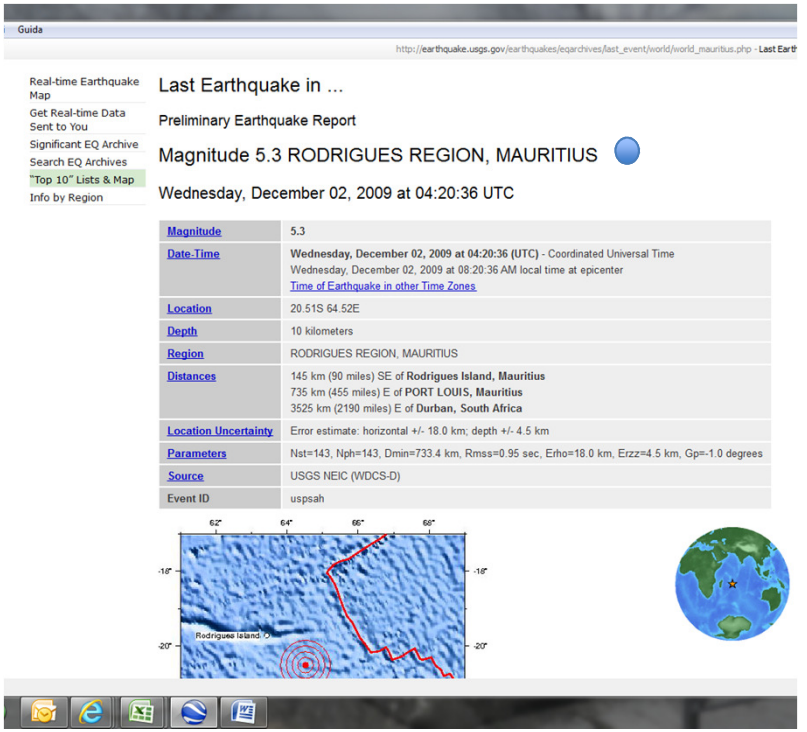
RAPID EARTH FLOWS

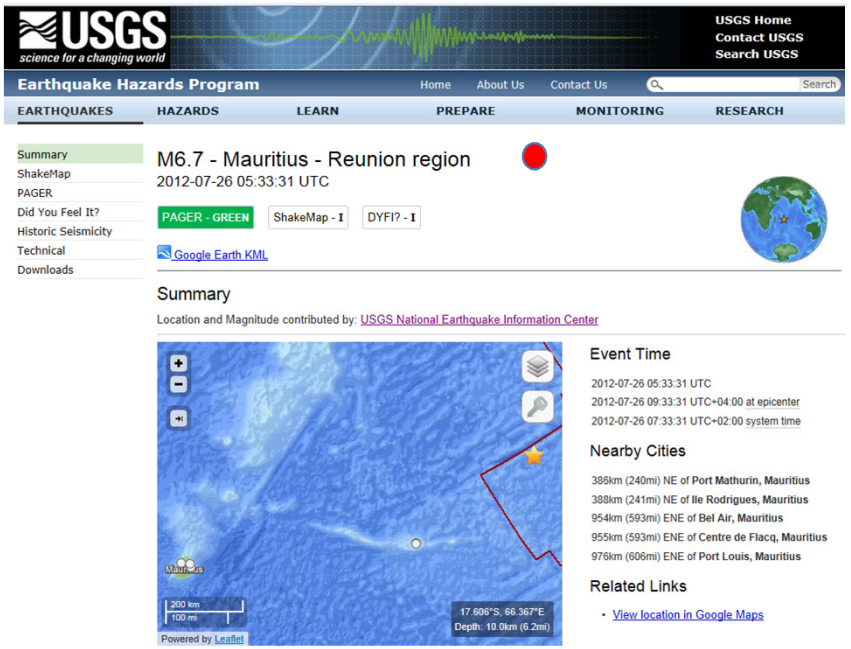
M. SAINTE PIERRE CASCAVELLE - LA FERME RESERVOIR



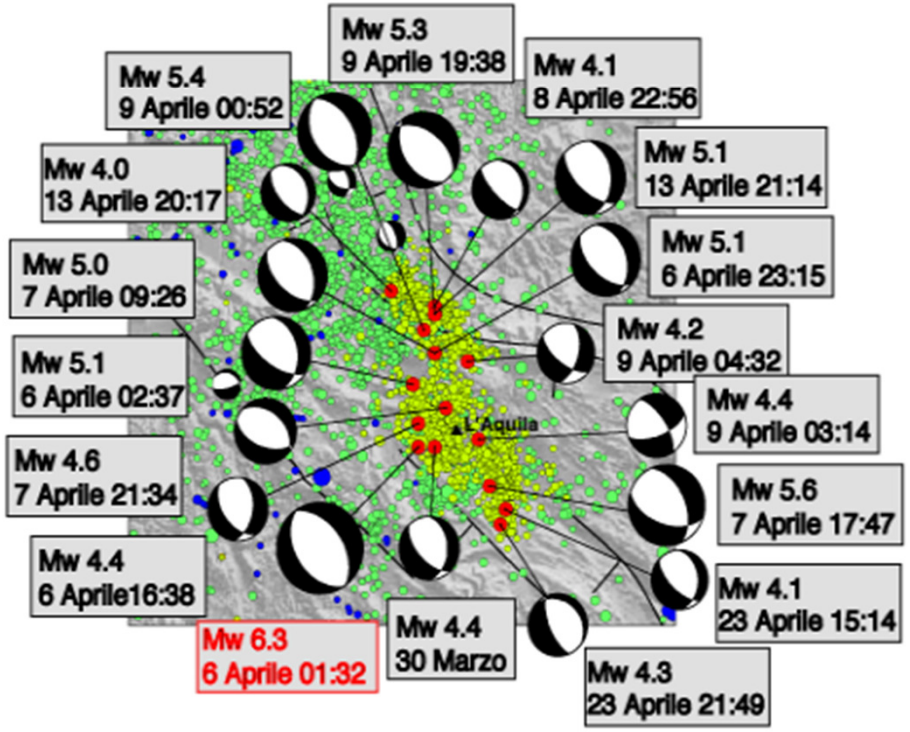
http://earthquake.usgs.gov/earthquakes/eventpage/usb000bgdg#summary

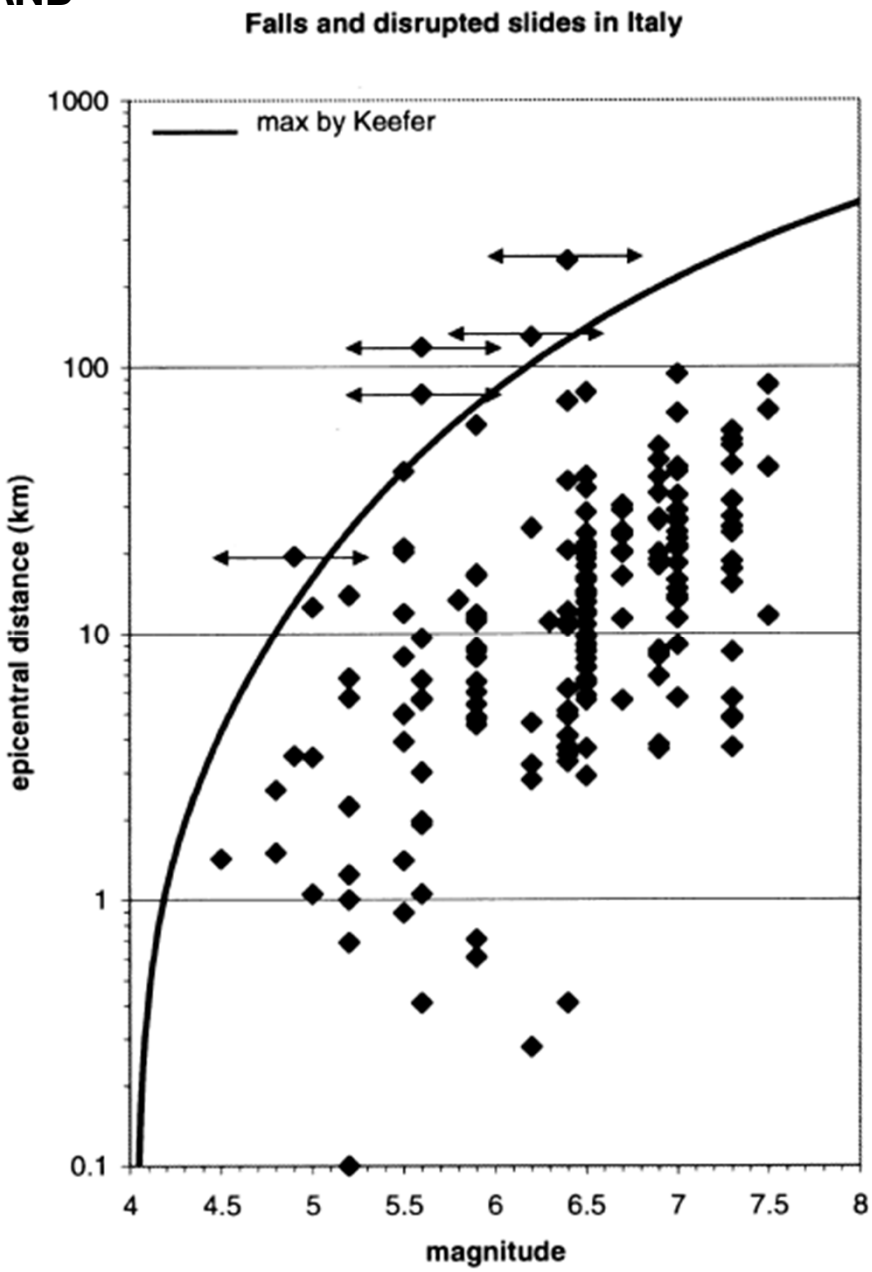






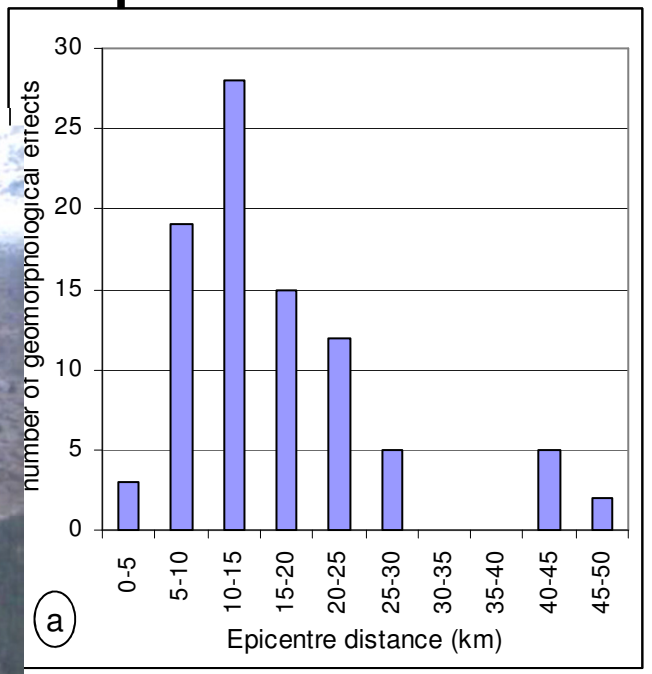
THE HISTORICAL ITALIAN EARTHQUAKES AND RELATED CO SEISMIC LANDSLIDE

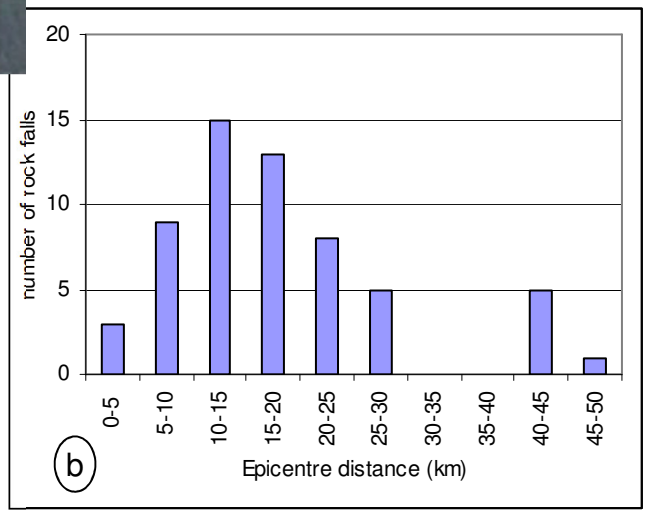




Prestininzi A. and Romeo R. Univ. of Rome (2000)

Geomorphological effects of the L'Aquila earthquake April 6th 2009





Frequence istogram: a) geomorphological effects vs. distance from the epicentral area; b) rock falls vs. distance from the epicentral area.

E. Miccadei, T. Piacentini & N. Sciarra - University of Chieti-Pescara

Co seismic landslide (Roc fall)
n the S. Venanzio Gorge

Co seismic landslide (Rock fall) in the S. Demetrio site

Co seismic landslide (Rock fall and rock fall) during the earthquake of Gemona (Noth Italy) - 6 may 1976

Crollo avvenuto durante il terremoto del 6 maggio 1976, Comune di Gemona del Friuli (UD)

ANNEX A – 7 PRACTICAL LANDSLIDES RECOMMENDATIONS

Recommendation for people concerning landslide risk reduction

This document include some general information for people concerning landslides and recommendation for landslide risk reduction:

1) **what-where-why landslides,**
2) **recognition and safety,**
3) **warning signs,**
4) **what to do before a landslide,**
5) **during a storm/landslide**
6) **after a landslide**

Thank you for your attention