Slope Analysis And Monitoring Instrumentation: Case Studies In Singapore

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Agenda

- Geology and Climate of Singapore
- Landslide Triggering Mechanism
- Measurement and Instrumentation
- Prevention

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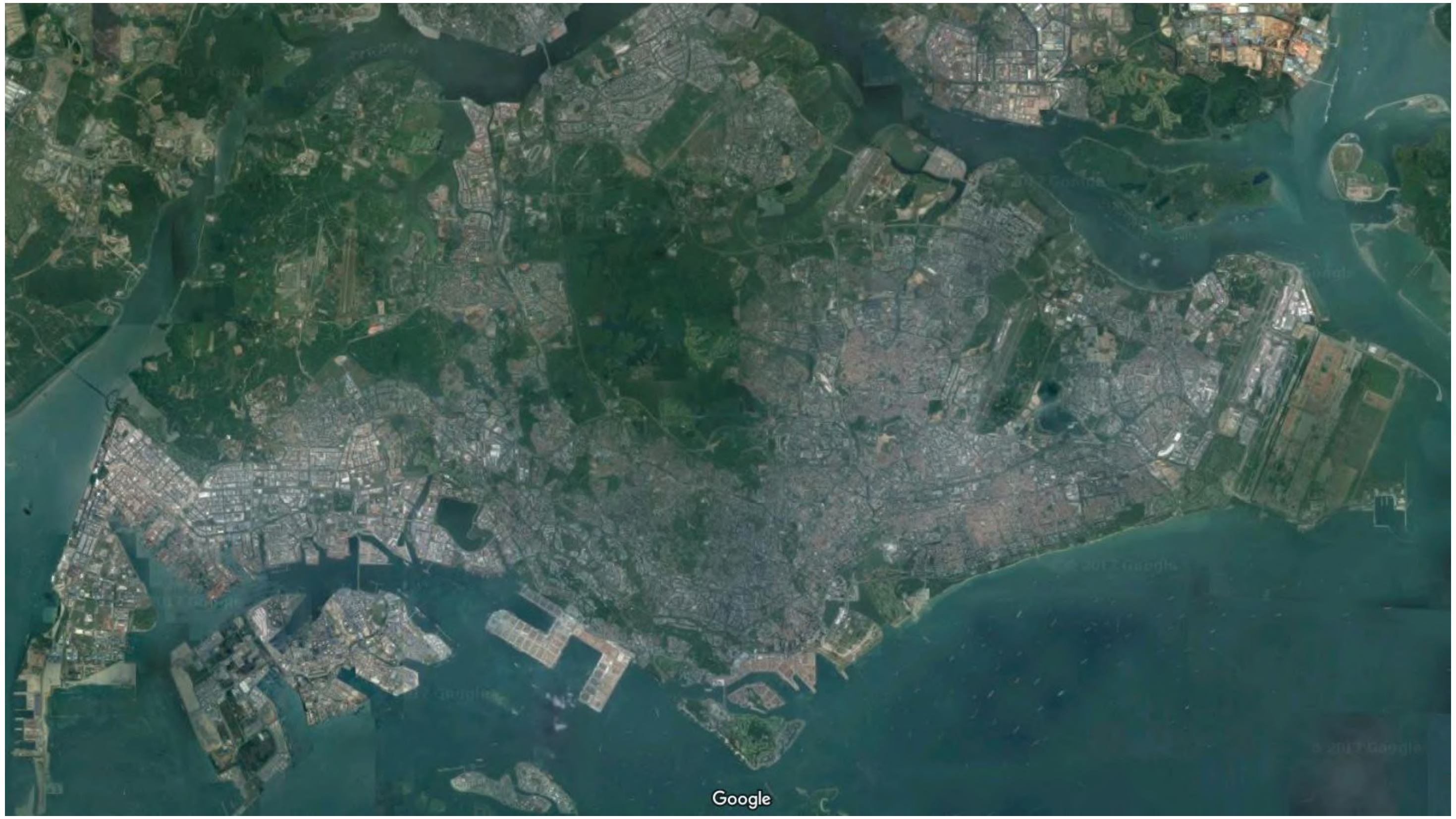
Geology and Climate

- Tropical rainforest climate

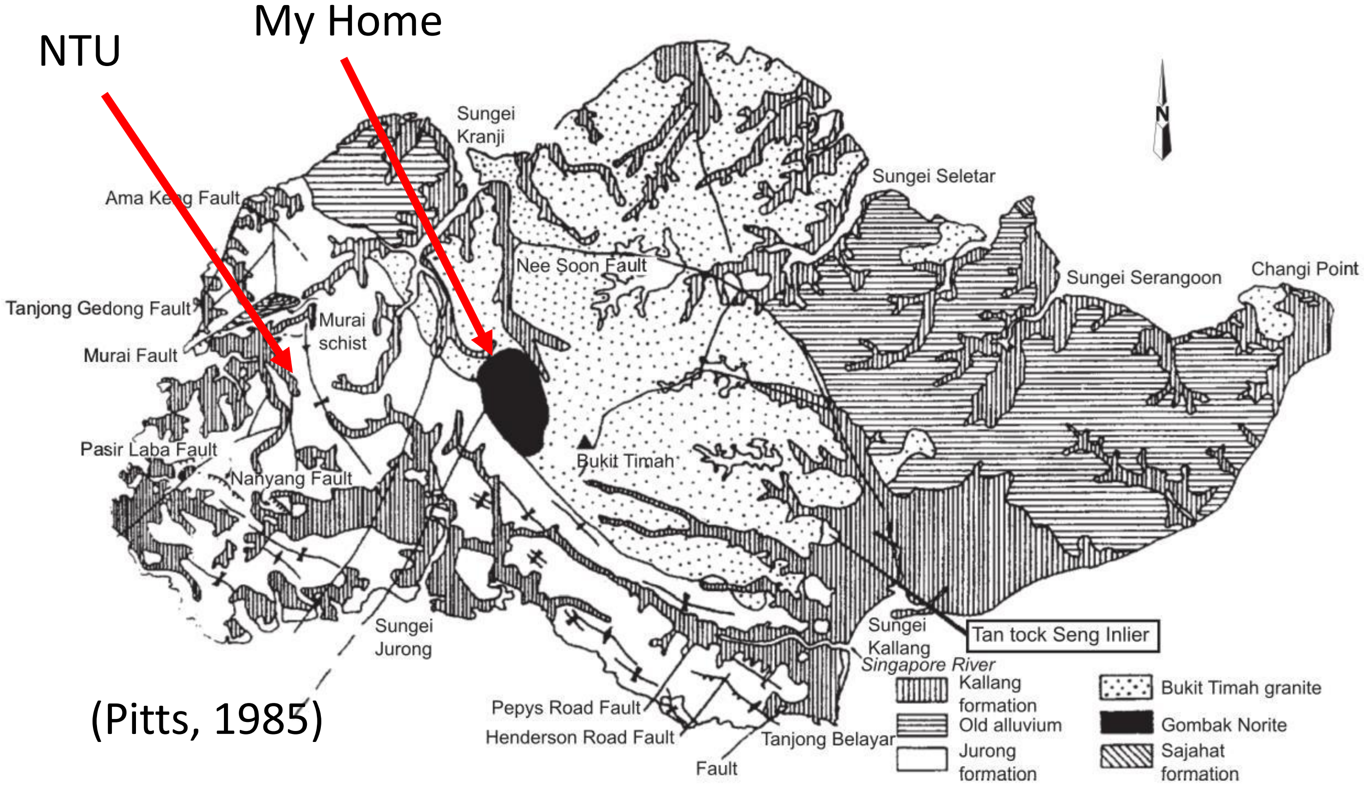


"… Almost 50% of Singapore is covered by greenery …" (NParks, 2012)

Geology and Climate

Soils property

- Tropical residual soils with clay and slit composition



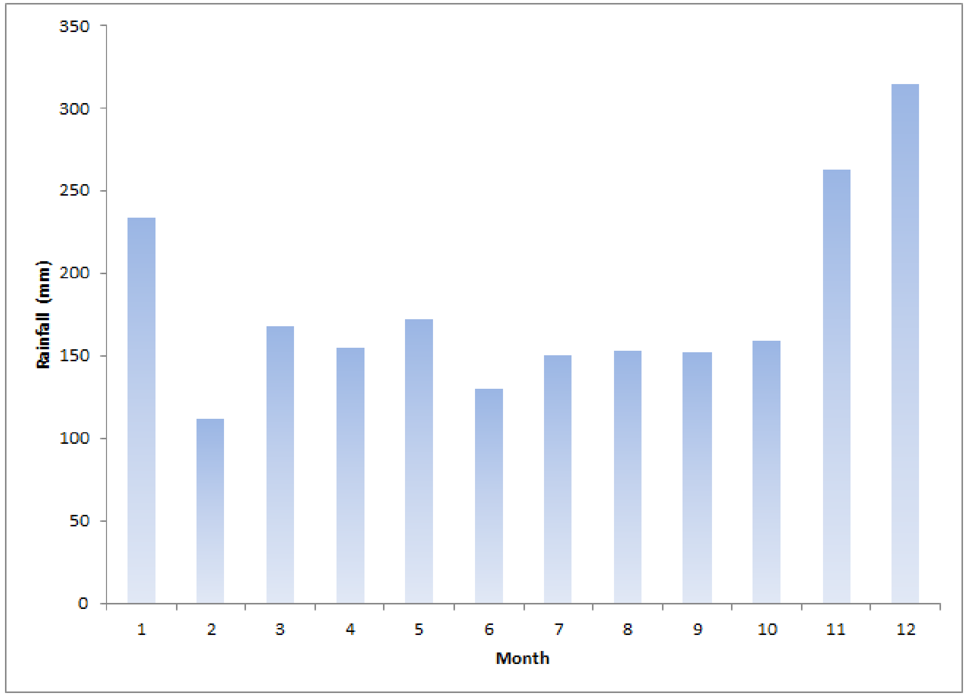
(Pitts, 1985)

Profiles of residual soil of the sedimentary Jurong formation (*Rahardjo et al., 2012)*

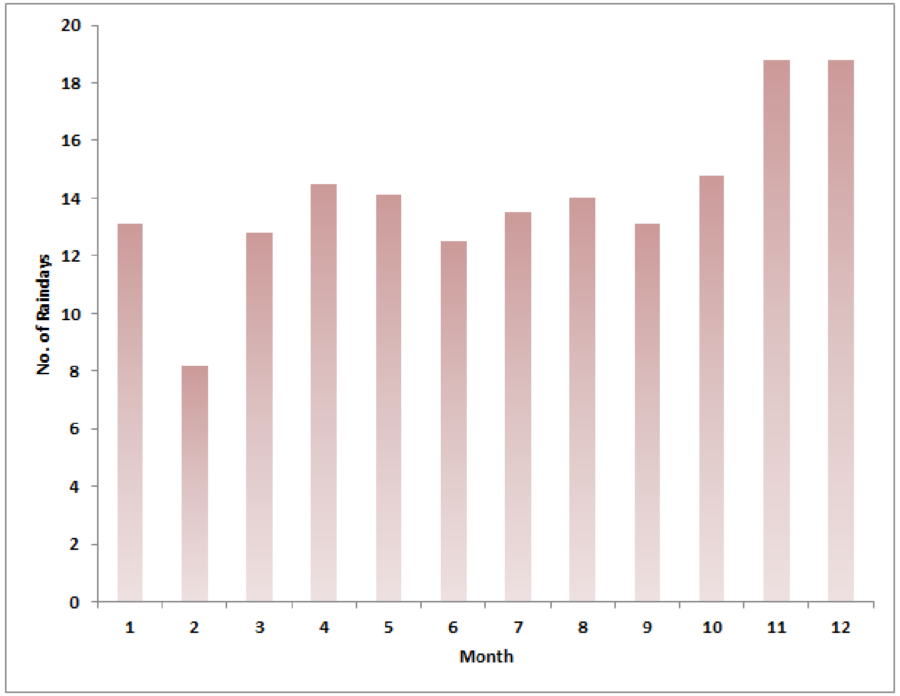
Geology and Climate

Rainfall Total annual rainfall: 2328.7mm

Number of raining days: 178 days/year



Monthly rainfall for Singapore (mm) (1982-2016)

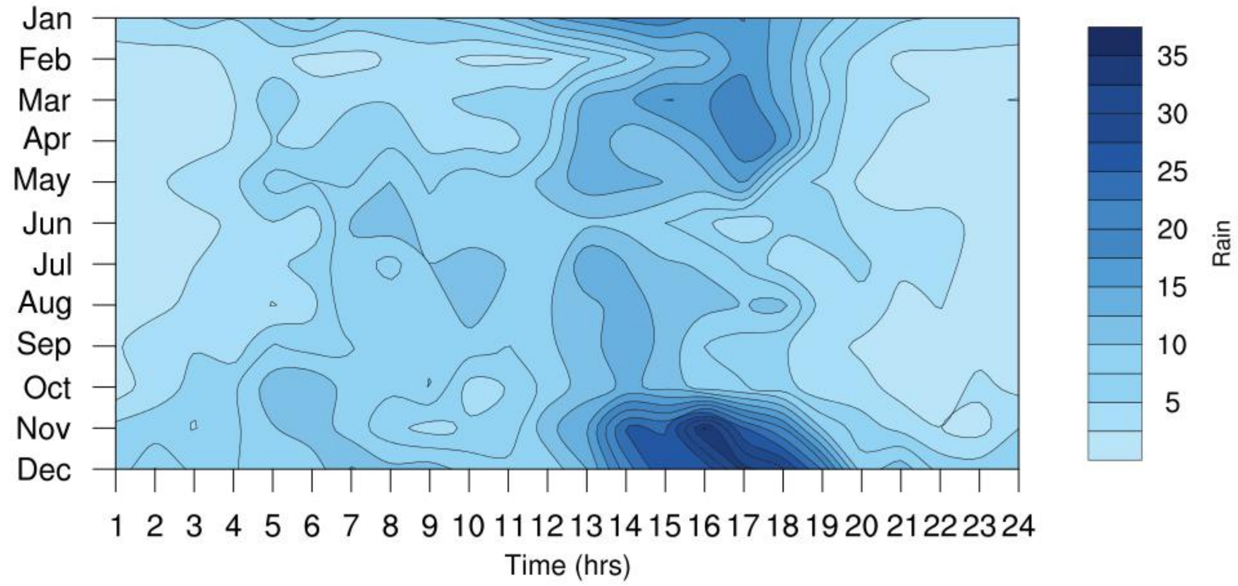


Average number of rain days per month (days) (1982-2016)

Source :Meteorological Service Singapore (MSS), National Environment Agency (NEA)

Geology and Climate

Rainfall



Annual average rainfall distribution (1982-2016)

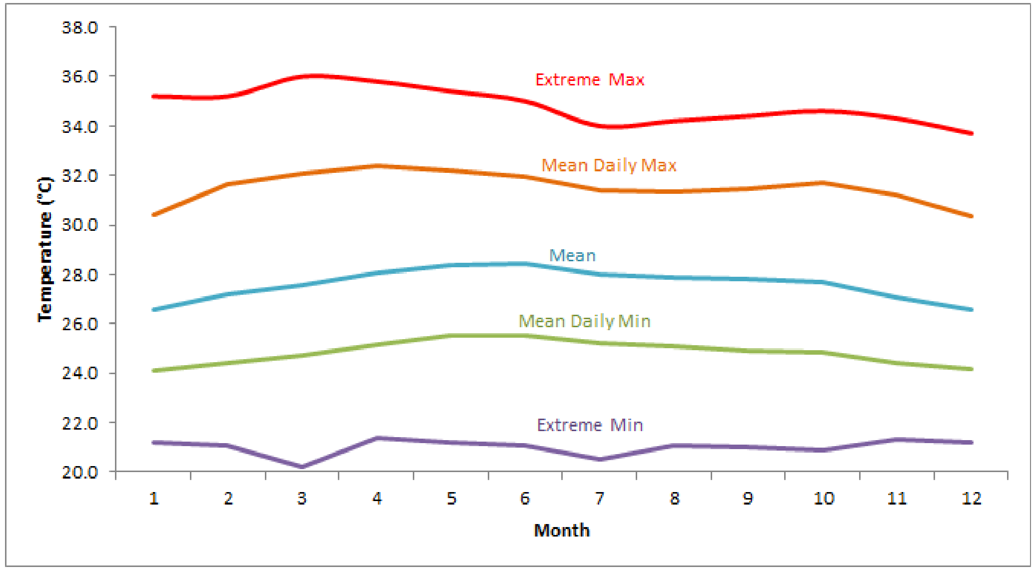
Hourly variation of rainfall for each month (1982-2016)

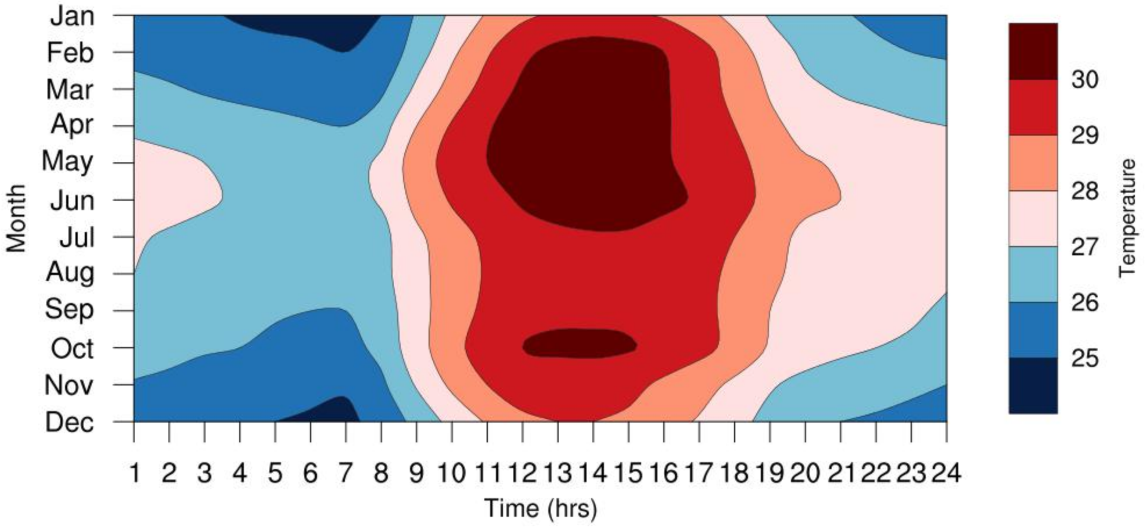
Source :Meteorological Service Singapore (MSS), National Environment Agency (NEA)

Geology and Climate

Temperature

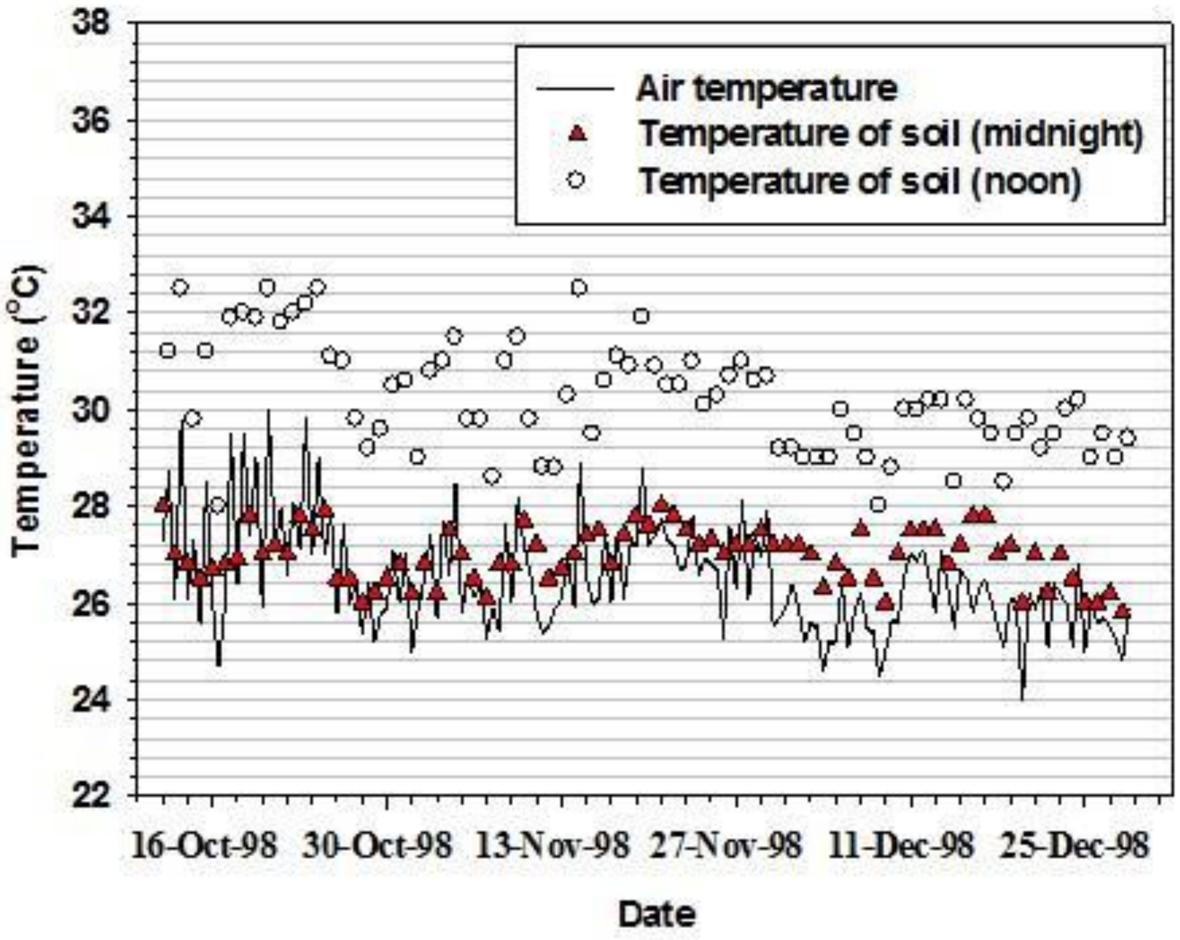
- Constantly high temperatures average monthly temperatures





Source :Meteorological Service Singapore (MSS), National Environment Agency (NEA)

Geology and Climate



Variation of air and soil temperatures for a residual soil slope from the Bukit Timah Granite at Yishun (after Rahardjo *et al.*, 2013)

Landslide in Singapore

Nature and form of a few slope failures (out of 20 slope failures) on 26 February 1995 in Nanyang Technological University Campus (sedimentary Jurong formation), (Rahardjo et al., 2012)

Slope failure at Bukit Batok (Granite formation) (Rahardjo et al., 2012)

Landslide in Singapore

(Toll, 2001)

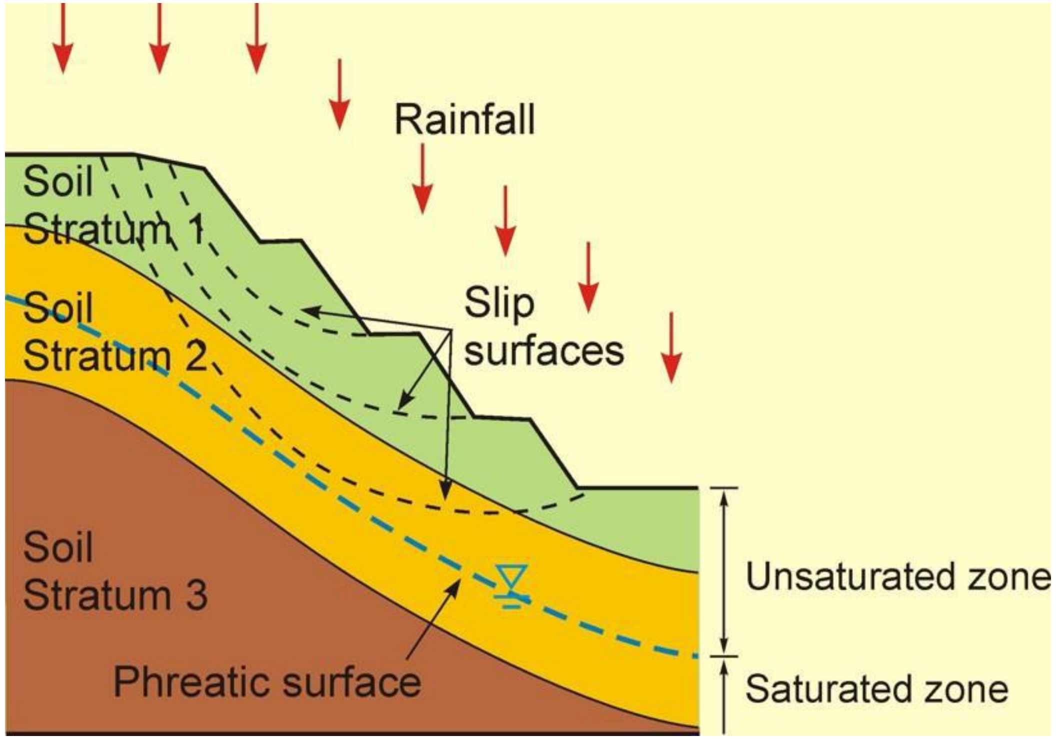
Landslide	Date	Height	Angle	Comments	Ground conditions	References
Tanjong Gul	Pre 1972	25 m	30°	A benched cut slope. The slide took place in the upper part of the slope and affected about 60 m of the slope length. A vertical backscarp of about 2 m was formed and bulging took place at the toe	Volcanic agglomerate, and shale and residual soils. The rocks were dipping steeply in the same direction as the cut	1
Hillview Estate	1982, 1983, 1984	22 m	13·5°	The first major mass movement started in December 1982 due to fracture of a water pipe, possibly caused by earlier minor movements. Further major movements occurred in March 1983 and March 1984 during heavy rainfall. The landslide involved about 50 000 m^3 of material	Residual soils derived from Gombak Norite and colluvium with some recent deposits (Kallang formation) being found at the toe. Failure probably occurred very close to the contact between the residual soil and the underlying weathered norite	1
Depot Road	1978, 1984	40 m	29°	A slope on the northern ridge of Mount Faber. A shallow slip occurred mid-slope in December 1978. The slope was originally benched. A major slide (in the form of a flow) occurred in March 1984 after a period of heavy rainfall	The crest of the slope was fill material. The failure occurred in the bench and resulted in disaggregation of the fill material which then developed into a debris flow[14]	1
Fort Canning	1984	40 m	34°	Occurred in Fort Canning Park during heavy rain in March 1984. The failure surface was shallow, about 3 m below the ground surface, but about 1500 m^2 of the slope started to move. Ground anchors were used to stabilise the slope	Residual soils (Grade VI) formed from the sedimentary Jurong formation	1
Gillman Heights	1985	17 m	34°	A cut slope for the Ayer Rajah Expressway at Gillman Heights showed signs of instability in December 1985. The slope was stabilised using soil nails	Medium dense to dense residual soils (Grade IV and V) derived from the sedimentary rocks of the Jurong formation	1
Admiralty Road	1987			A road cutting. The slope had been recently cut and graded during road widening. The initial failure occurred during a nine day wet period with a total rainfall of 413 mm. The slope failed in five places, two of which involved the whole length of the slope. The slope was regraded but failed repeatedly, each time after a period of heavy rainfall	Fill material of weathered granite overlying deeply weathered in-situ granite	6
Lorong Terigu		24 m	27°	This is part of the cut slopes formed during the construction of the Bukit Timah Diversion Canal. Since construction in the early 1970s a number of slips have occurred along the canal length with Lorong Terigu being the largest. The slip surface was found to be 5 to 6 m below ground surface at its deepest point	Loose to medium dense clayey silt near the surface, becoming very dense below 25 m. Standard Penetration Test (SPT) values varied from less than 10 near the surface to over 50 below 25 m. A weaker zone was observed at around 5 m depth	9
Central business district		17·8 m	53°	A number of slope failures occurred during the construction of a substantial excavation site in the central business district in Singapore. This was the highest slope to fail	Weathered sandstones and shales of the Jurong formation (Rimau facies). Degree of weathering changed from highly to slightly weathered within the top 10 m. The strata dipped steeply back into the slopes. The shale had softened during heavy rainfall	10
Bukit Batok / Bukit Gombak	1989	40 m	27°	A cut slope at the Bukit Batok sports complex that failed after heavy rain. A backscar of 4 to 6 m was formed by the slide and about 100 m of slope was affected. The slide was 56 m from toe to crest and the maximum depth to	The ground conditions comprised highly weathered rock of the Gombak Norite formation. The residual soil of highly decomposed granite consisted of clayey silt with boulders	11

Landslide Triggering Mechanism

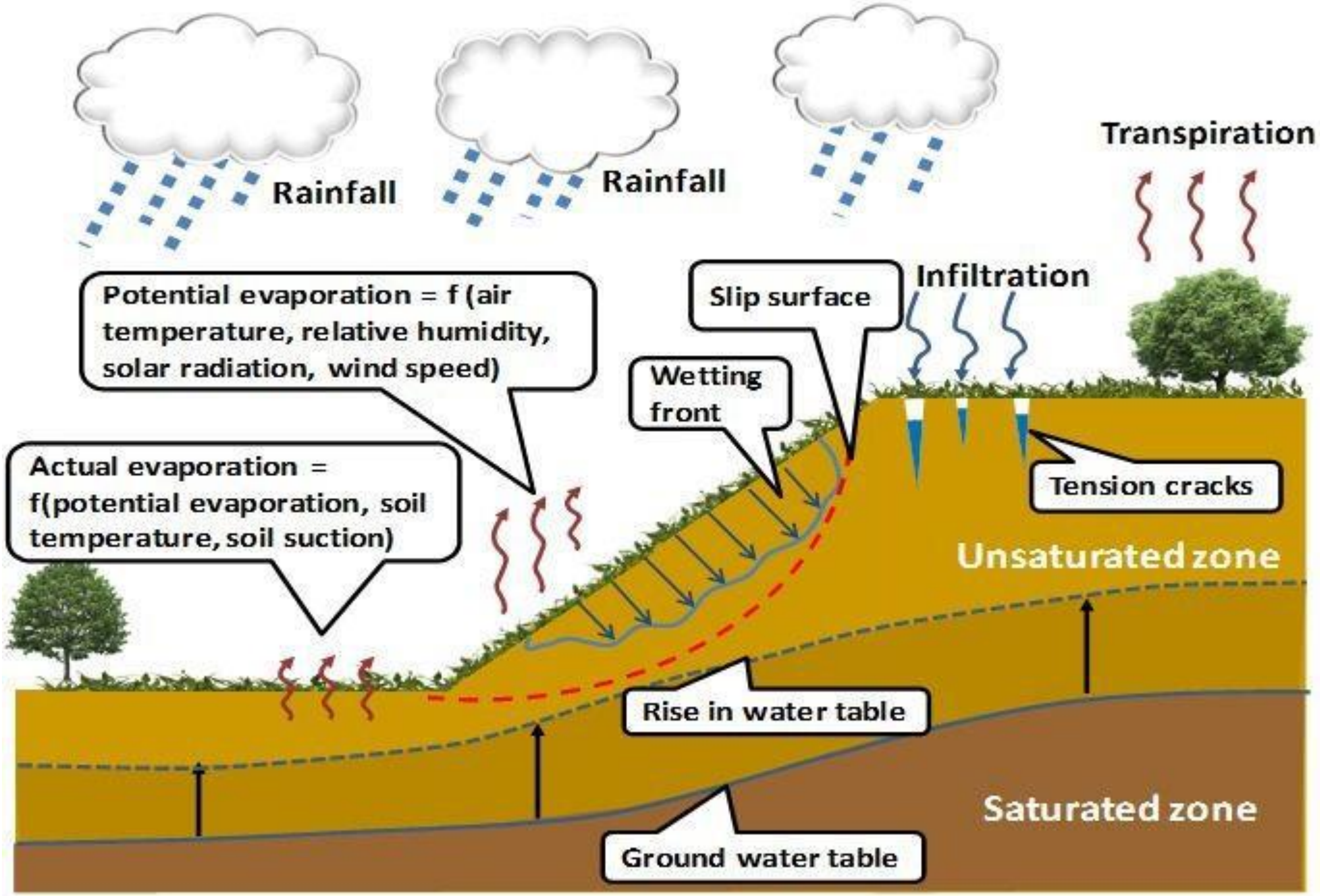
Triggers from human activities

- Removal of vegetation
- Spills from water or sewage pipes
- Incorrect cuts
- Uncompact landfill
- Waste deposits
- Building

Landslide Triggering Mechanism



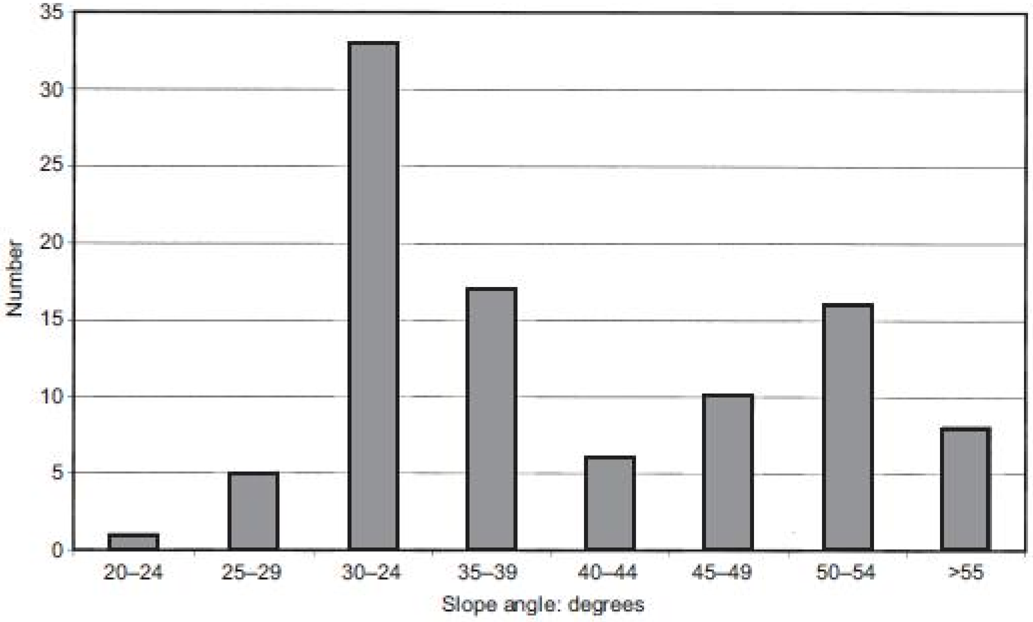
Rainfall-induced slope failure within residual soil, (Rahardjo et al., 2005)



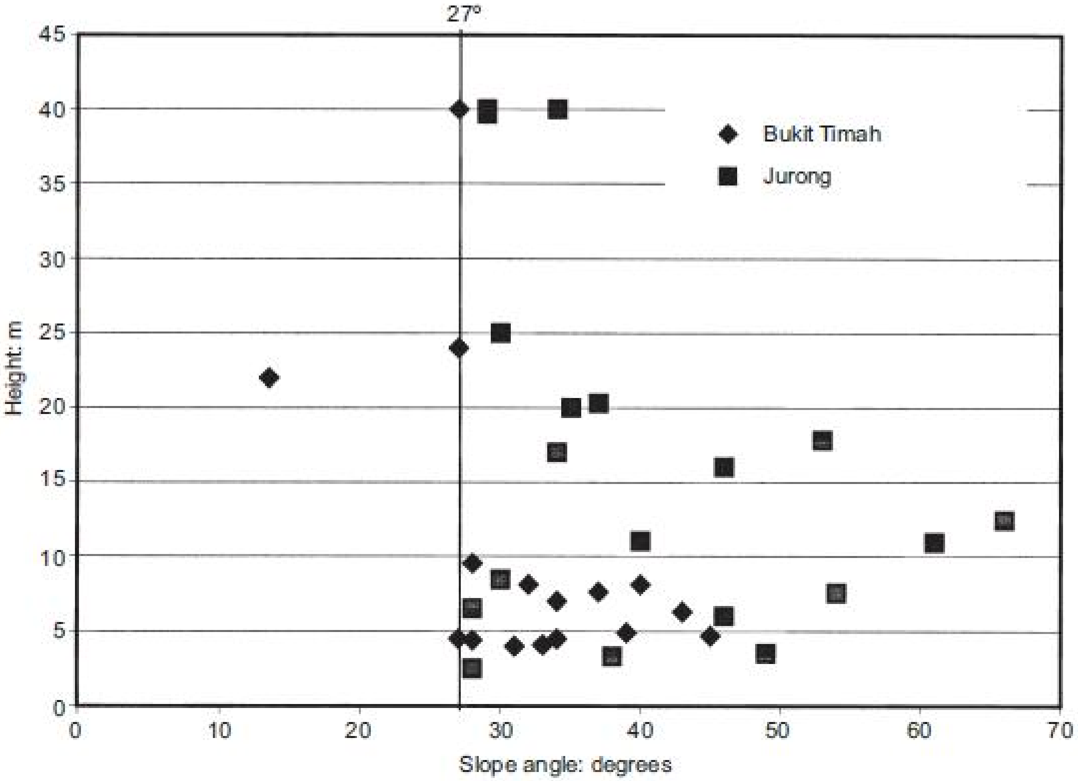
Mechanisms of rainfall-induced slope failure, (Rahardjo et al., 2012)

Landslide Triggering Mechanism

- Effect of Heavy Rain



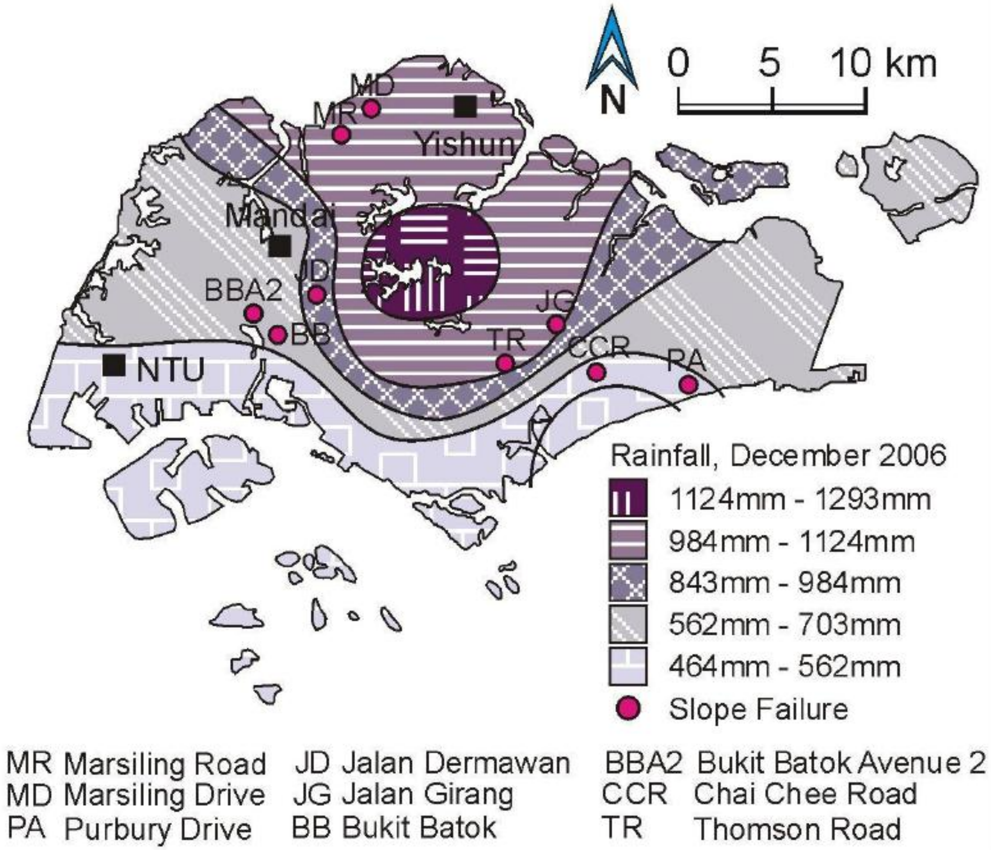
Distribution of NTU landslides by slope angle (Toll, 2001)



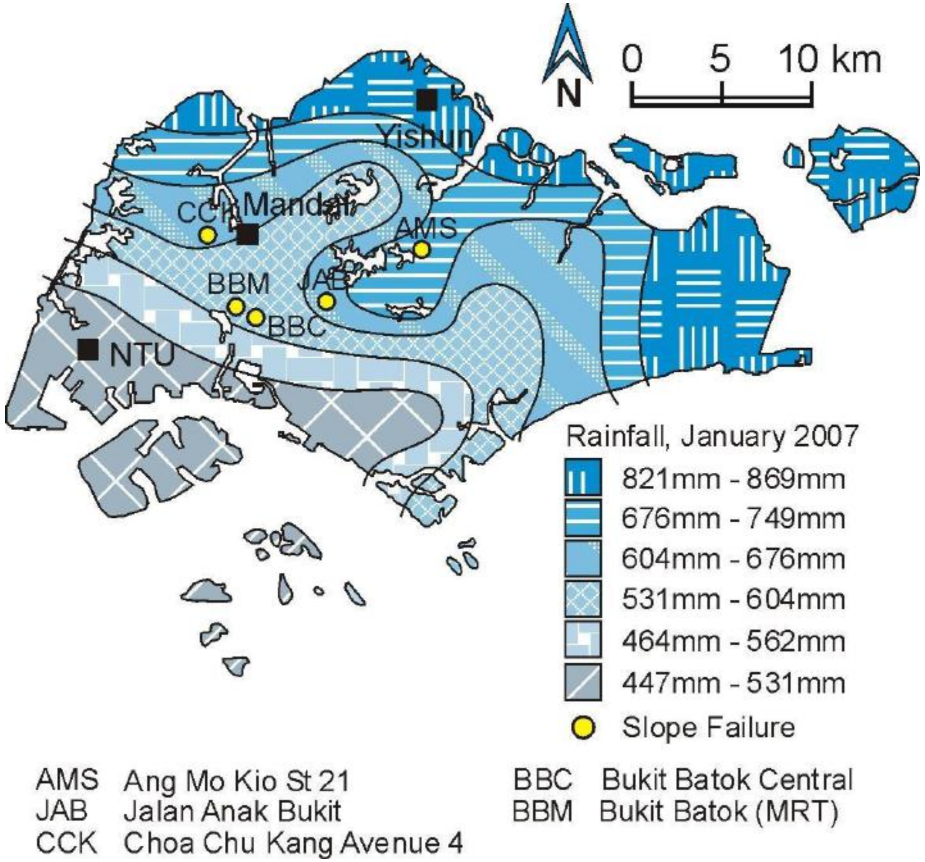
Slope height against slope angle for landslides in Singapore (Toll, 2001)

Landslide Triggering Mechanism

- Effect of antecedent rainfall



December 2006

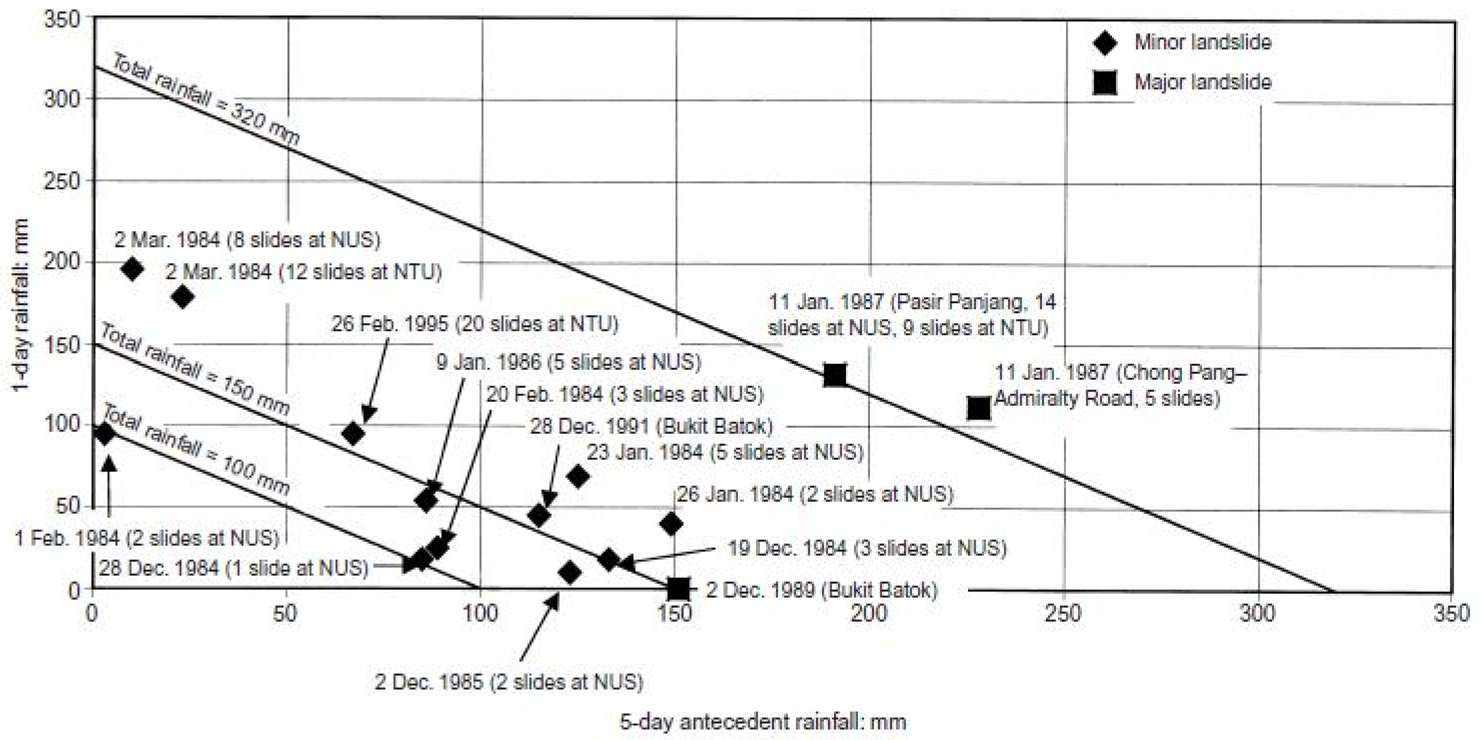


January 2007

Distribution of rainfall and slope failures (after NEA, 2006), (Rahardjo et al., 2007)

Landslide Triggering Mechanism

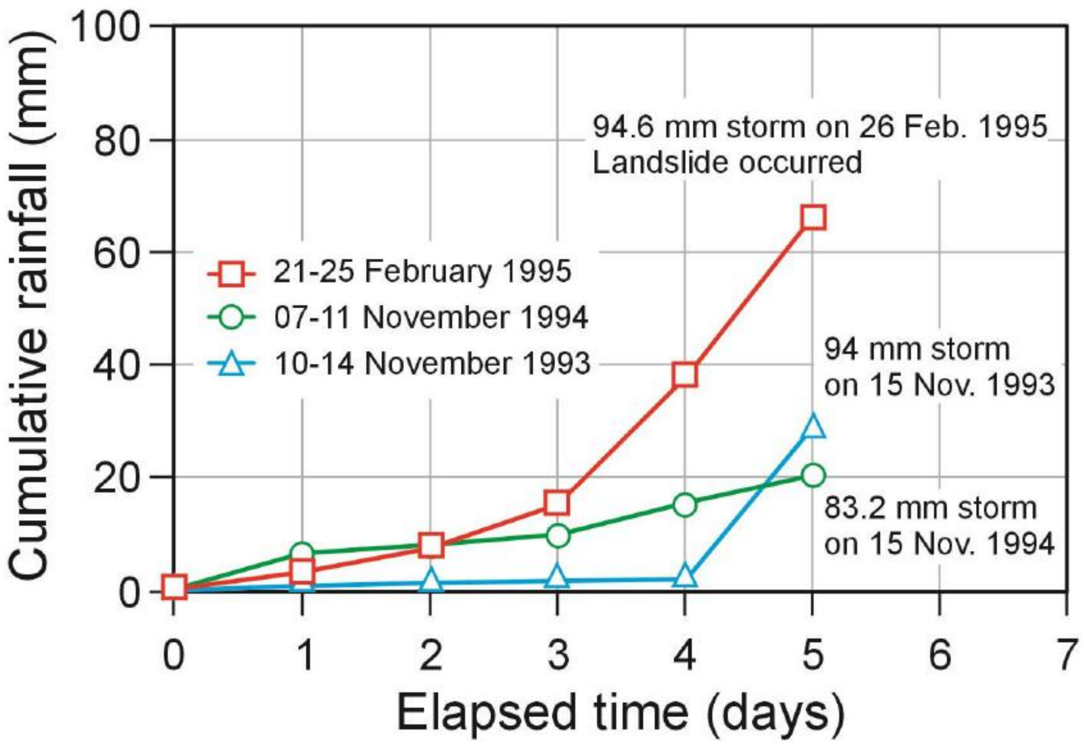
- Effect of antecedent rainfall



Five-day antecedent rainfall for landslides in Singapore (Toll, 2001)

Landslide Triggering Mechanism

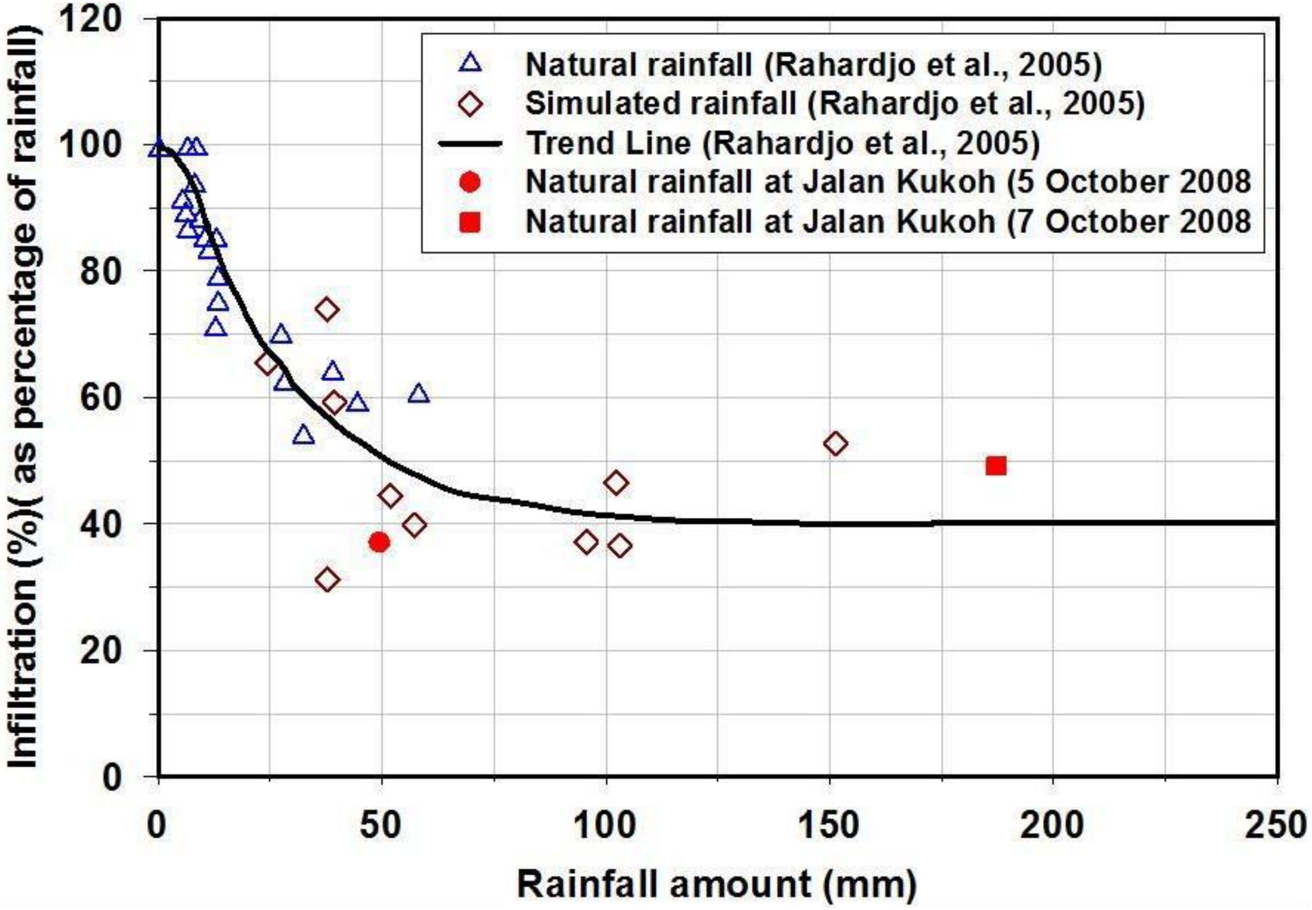
- Effect of antecedent rainfall



Relationship between cumulative antecedent rainfall and the occurrence of landslides (Rahardjo *et al.*, 2001)

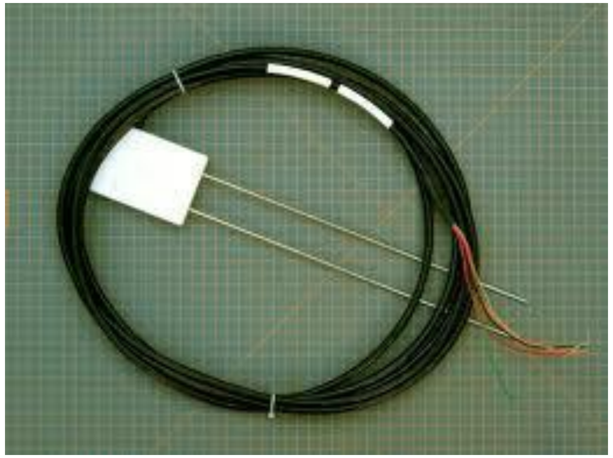
Landslide Triggering Mechanism

- Infiltration

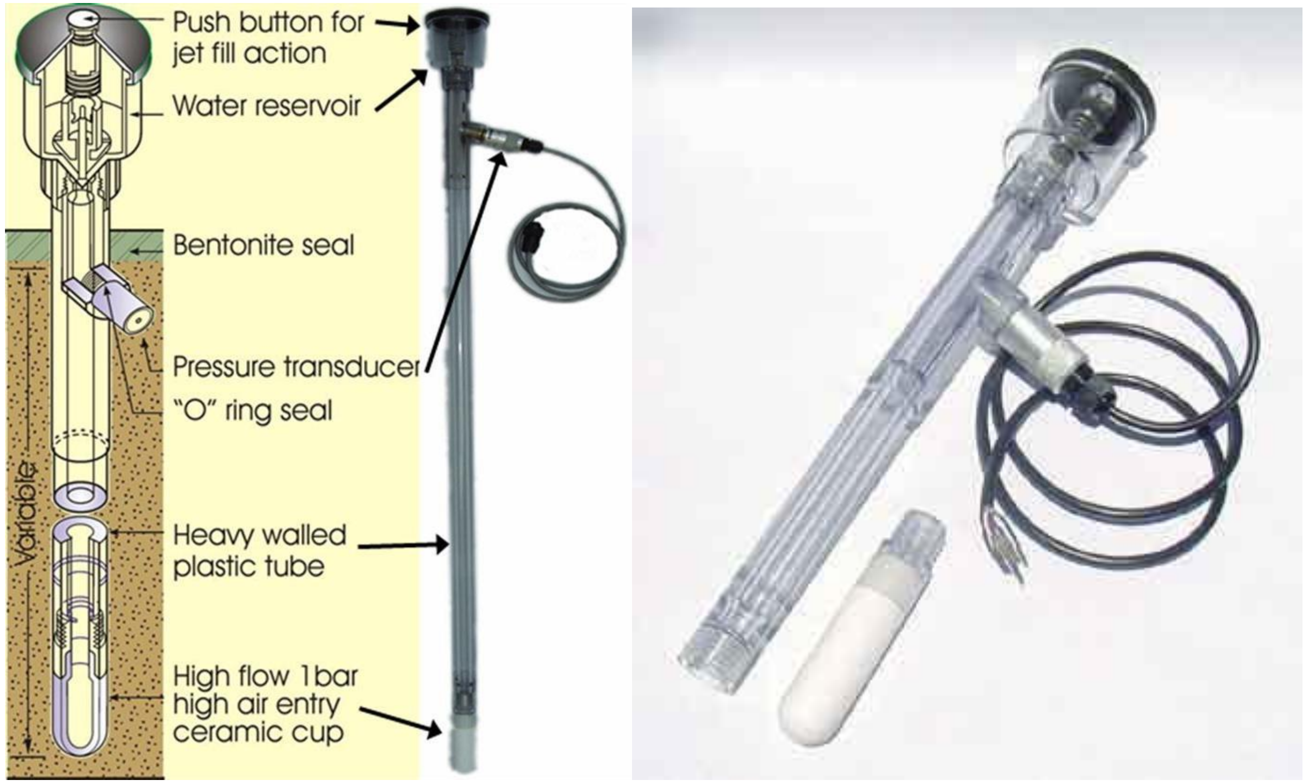


Relationship between infiltration and rainfall amount (Rahardjo et al., 2013)

Measurement and Instrumentation



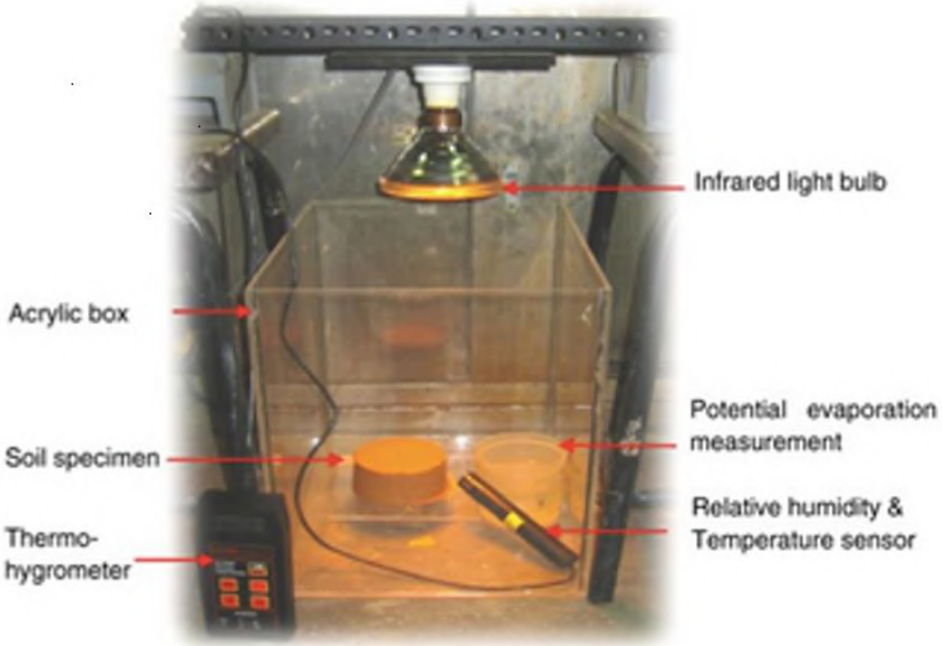
Soil moisture sensor



Tensiometer

Measurement and Instrumentation

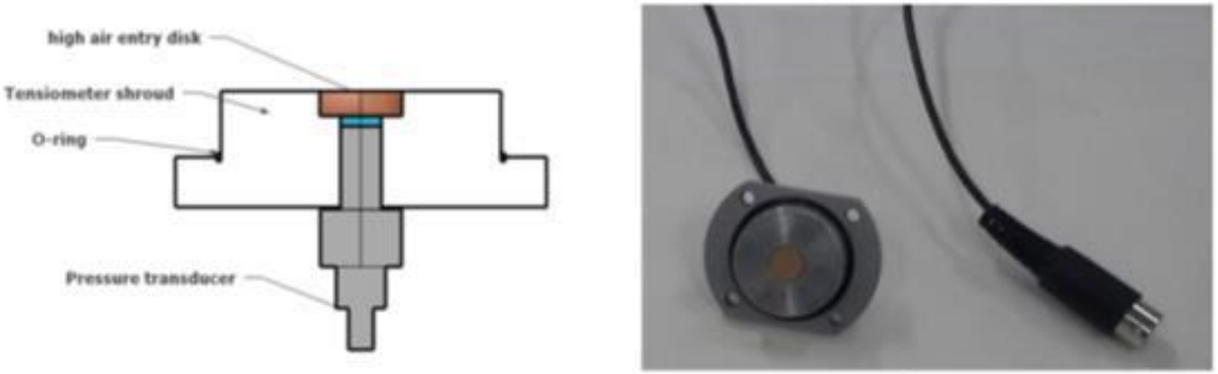
Evaporation pan, (Rahardjo et al., 2001)



Setup of shrinkage test under accelerated evaporation using a lamp, (Krisdani et al., 2008)

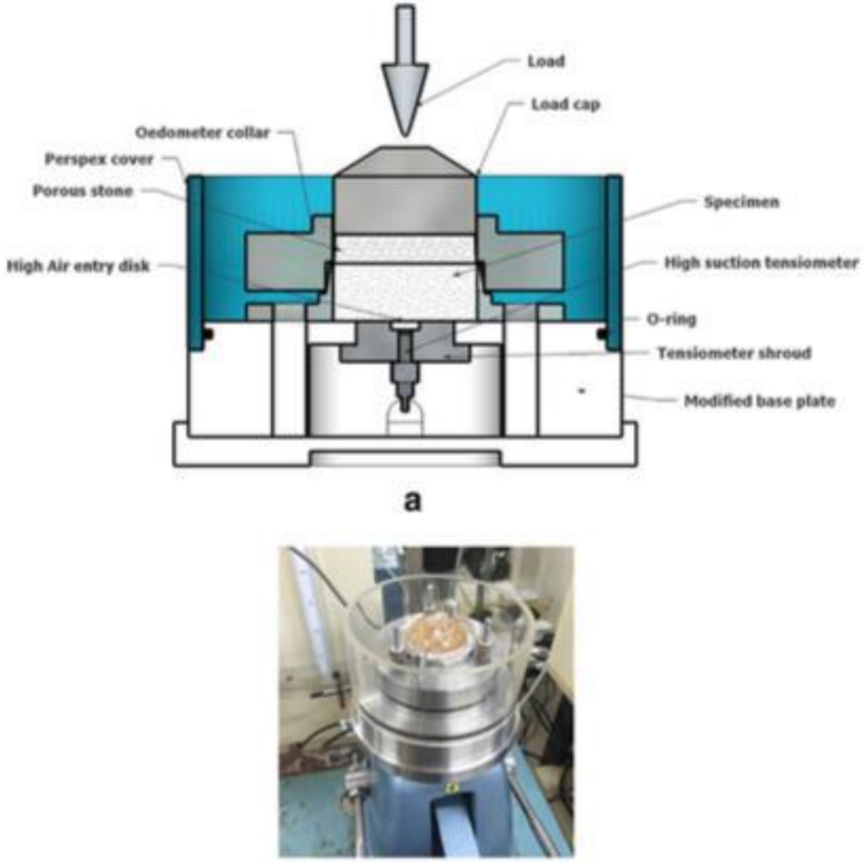
Measurement and Instrumentation

- Odeometer



a b

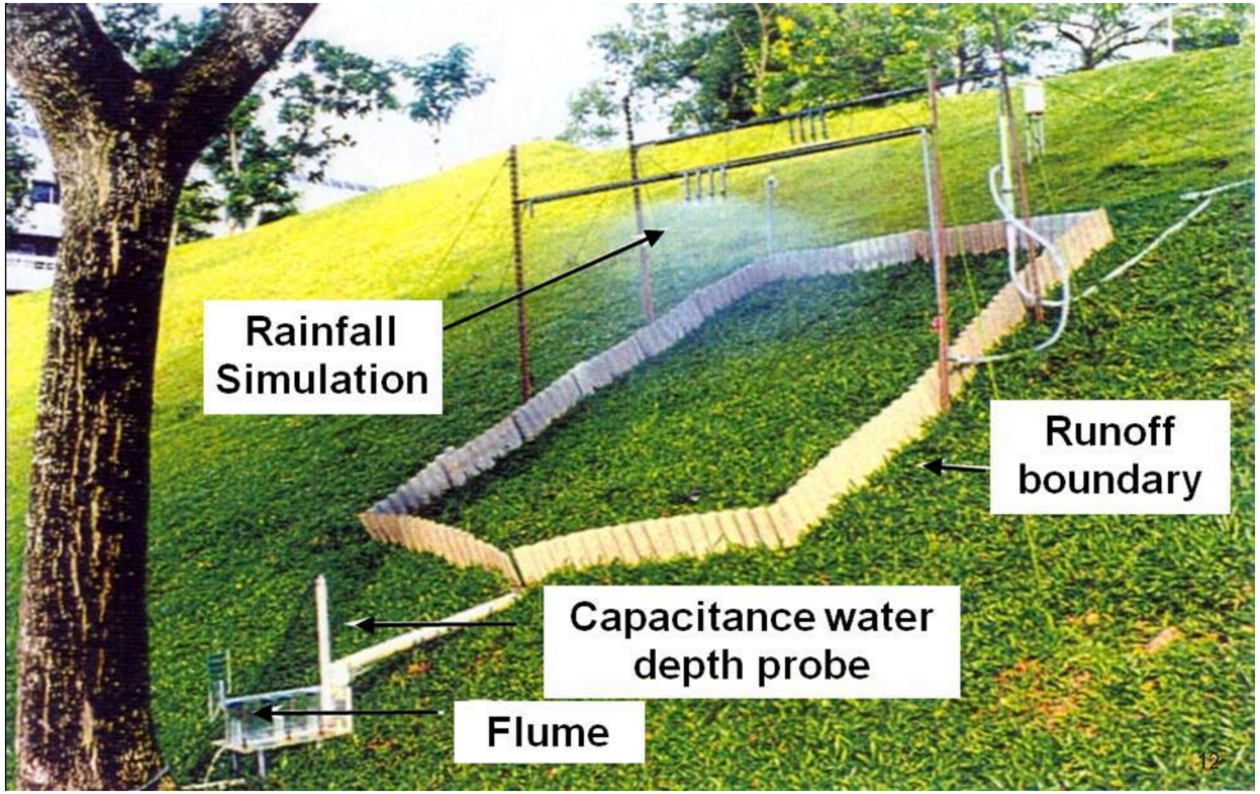
HCT which is used in this study. **a** Schematic drawing of HCT. **b** Picture of HCT (Wijaya and Leong, 2016)



b

Modified base plate and oedometer apparatus.
a Schematic drawing of the modified base plate.
b Modified oedometer apparatus (Wijaya and Leong, 2016)

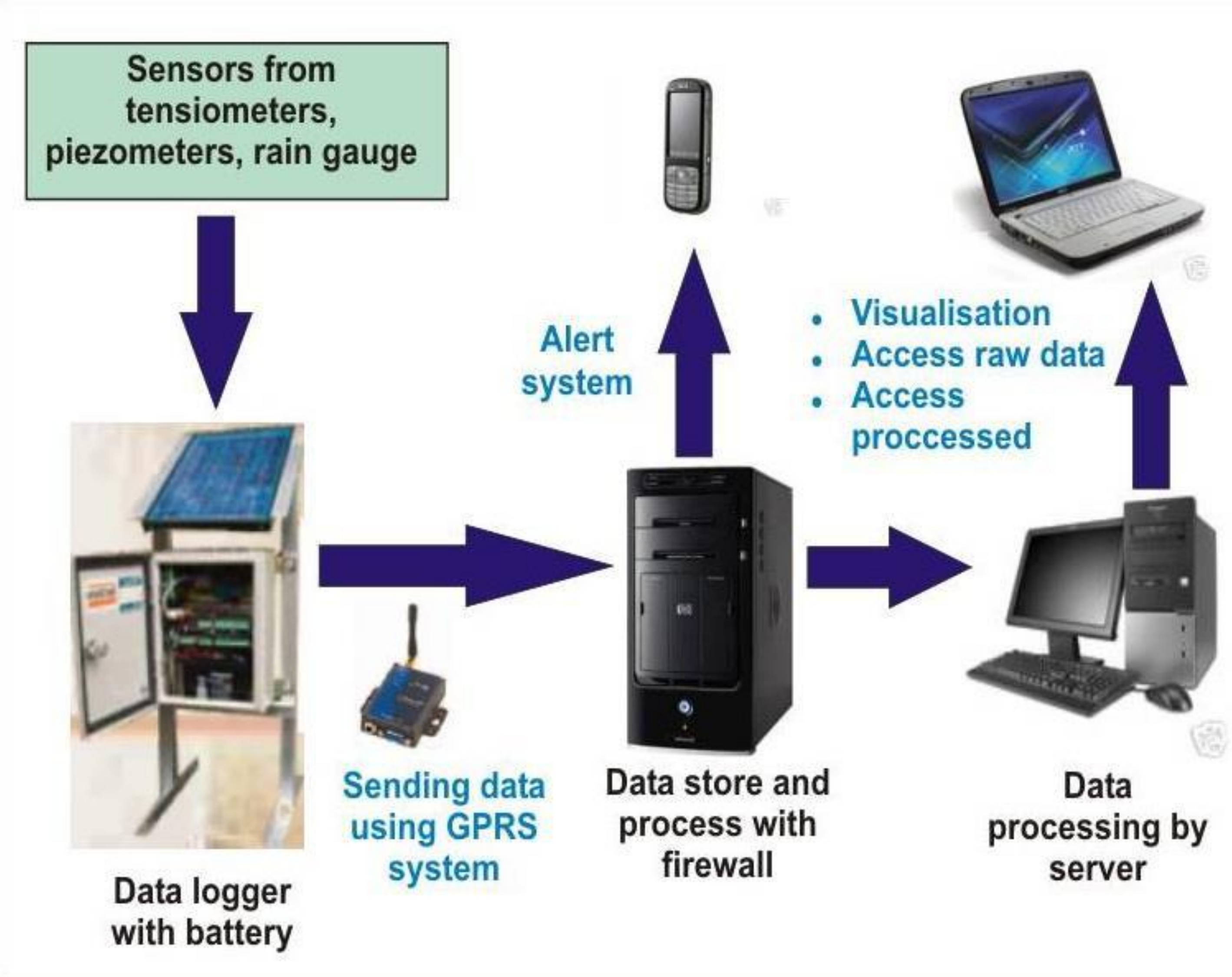
Measurement and Instrumentation



Field plot for studying rainfall, runoff and infiltration processes at NTU-CSE slope, (Tsaparas et al., 2003)

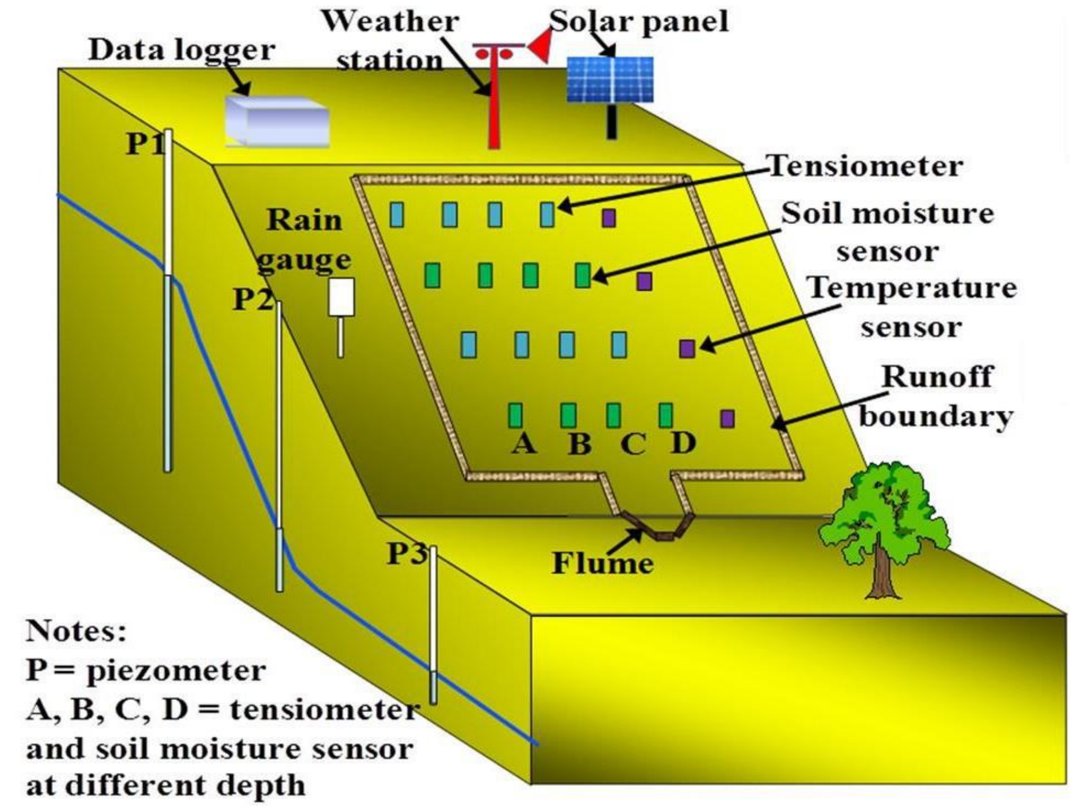
Field installation of a flume with water depth probe for runoff measurement at NTU-CSE slope, (Tsaparas et al., 2003)

Measurement and Instrumentation

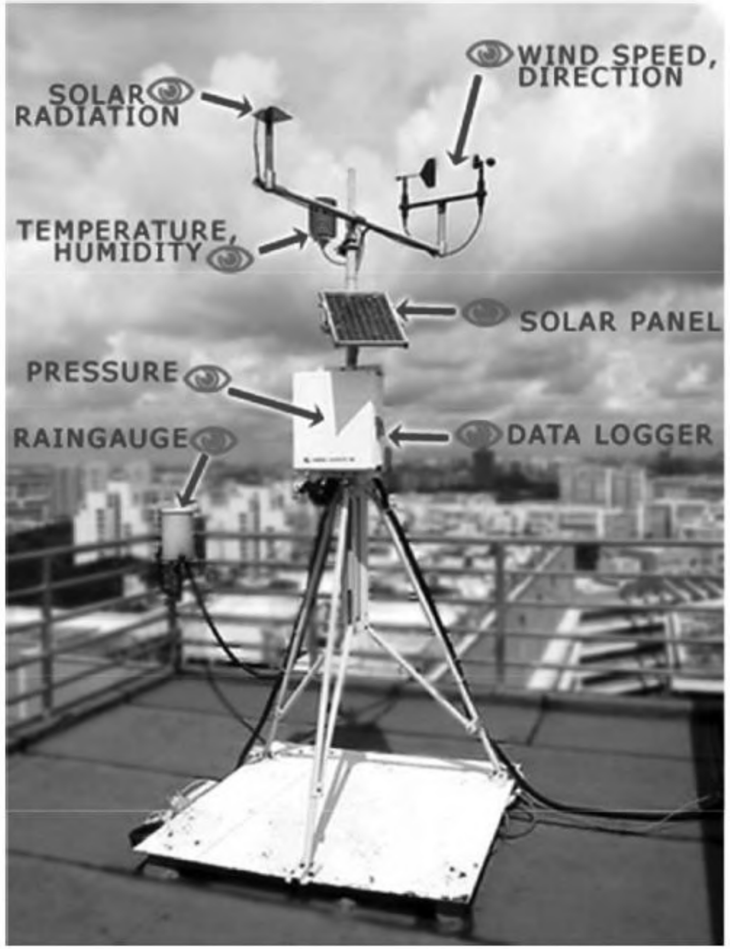


Schematic diagram of instrumentation for online monitoring system (Rahardjo et al., 2014).

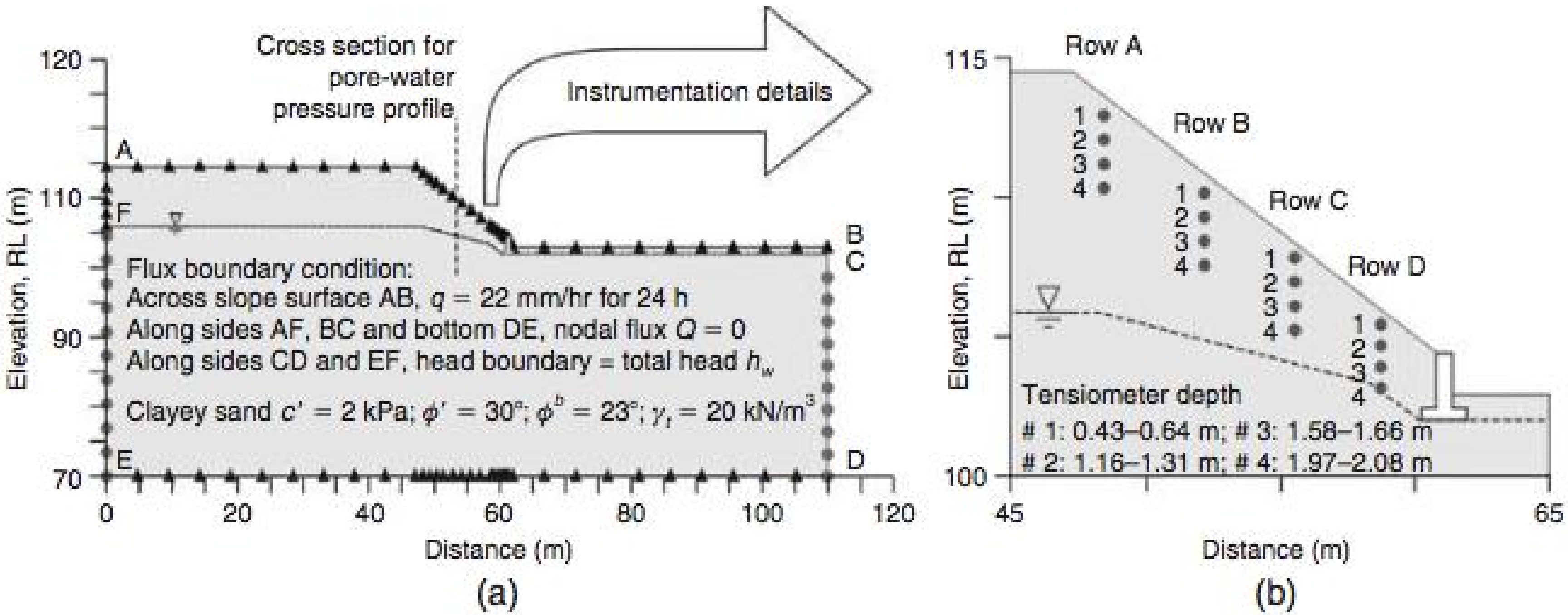
Measurement and Instrumentation



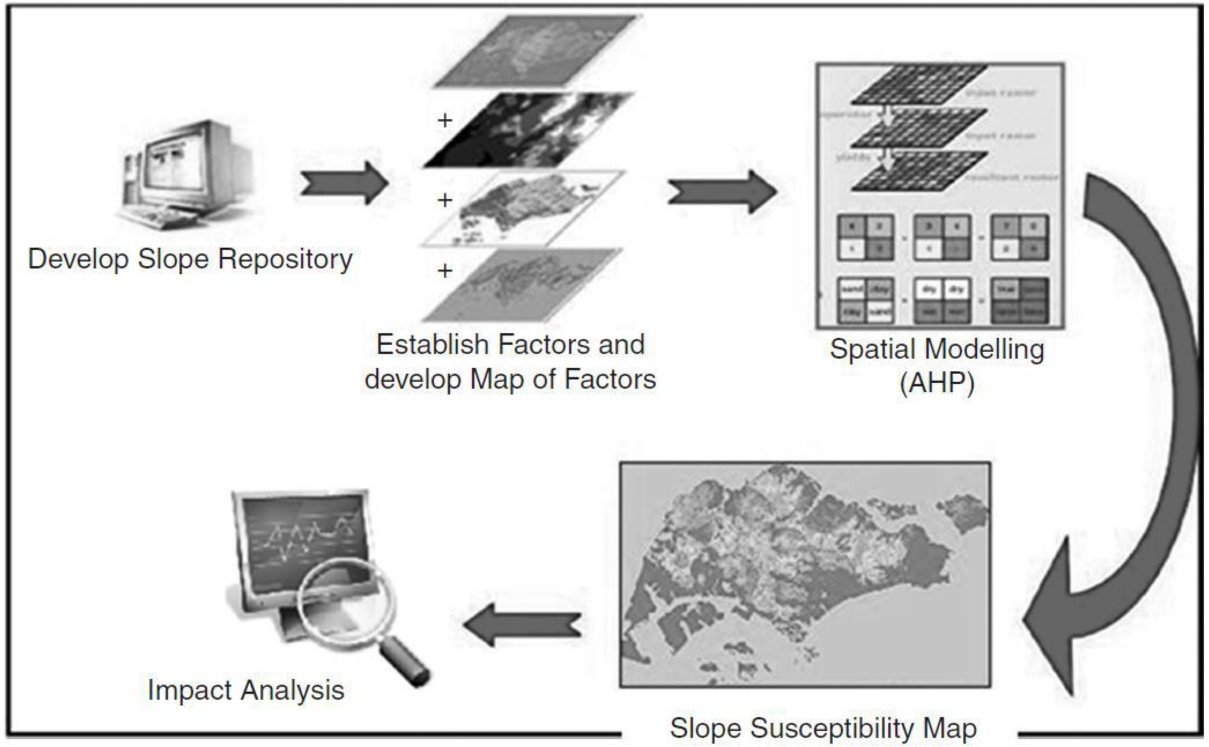
Typical layout of slope instrumentation, (Rahardjo et al., 2004)



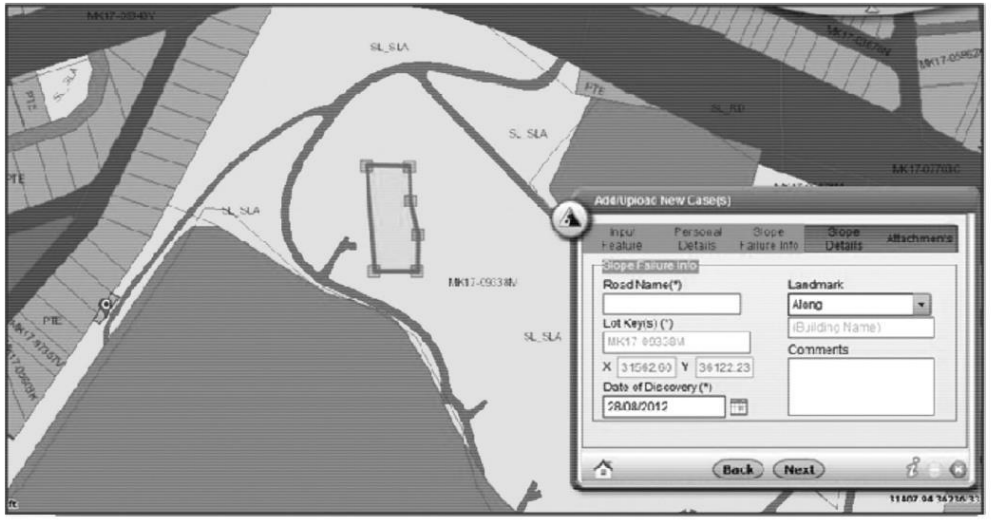
Measurement and Instrumentation



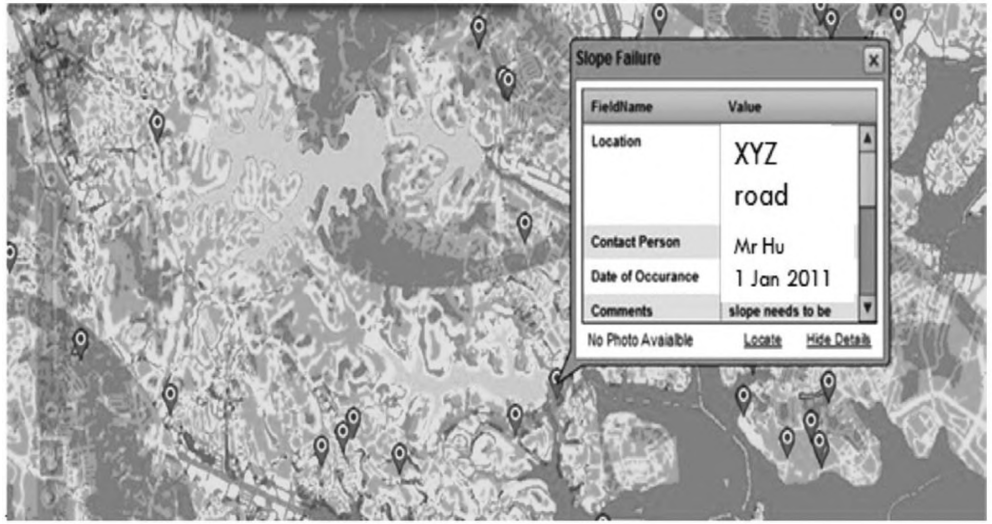
Slope parameters and instrumentation details (a) soil profile, properties, and flux boundary conditions used in seepage analyses with the incorporation of unsaturated soil mechanics equations; (b) tensiometer location and depth for direct measurement of matric suction to compare with results from parametric study (*After* Rahardjo *et al.*, 2007)



Conceptual idea of SHARES (Slope Hazard Analysis & Repository System)



Capturing of data from past slope failures.



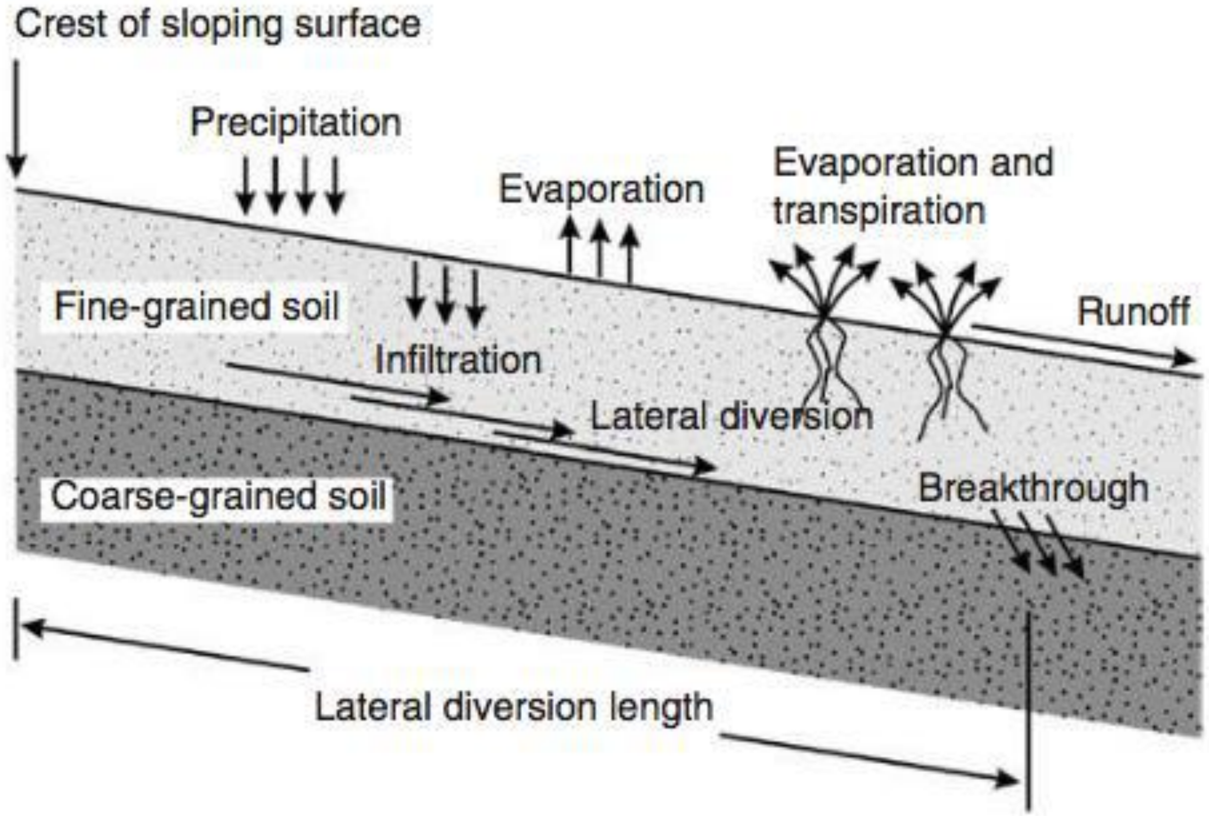
Displaying captured past slope failure on a map.

Prevention

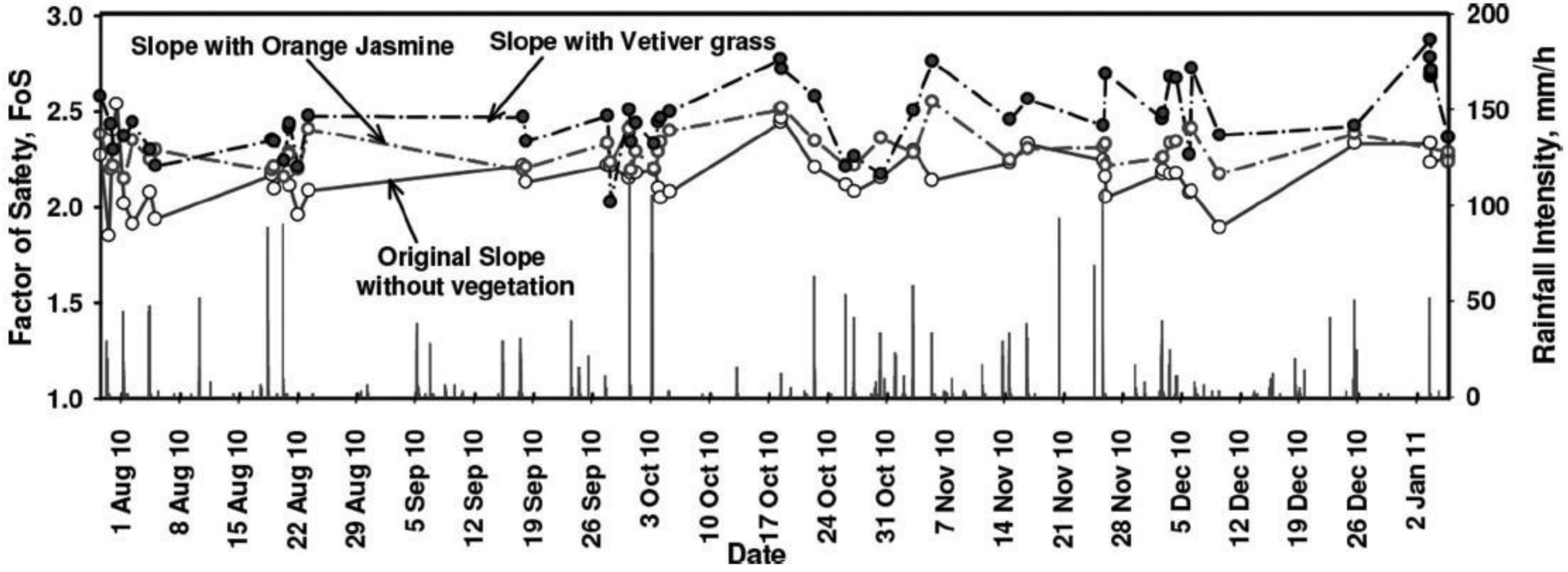
- Slope failures may damage and destroy residential, commercial properties and agricultural land.
- The cost of repairing slopes is more expensive than preventive measures of the slope.

Prevention

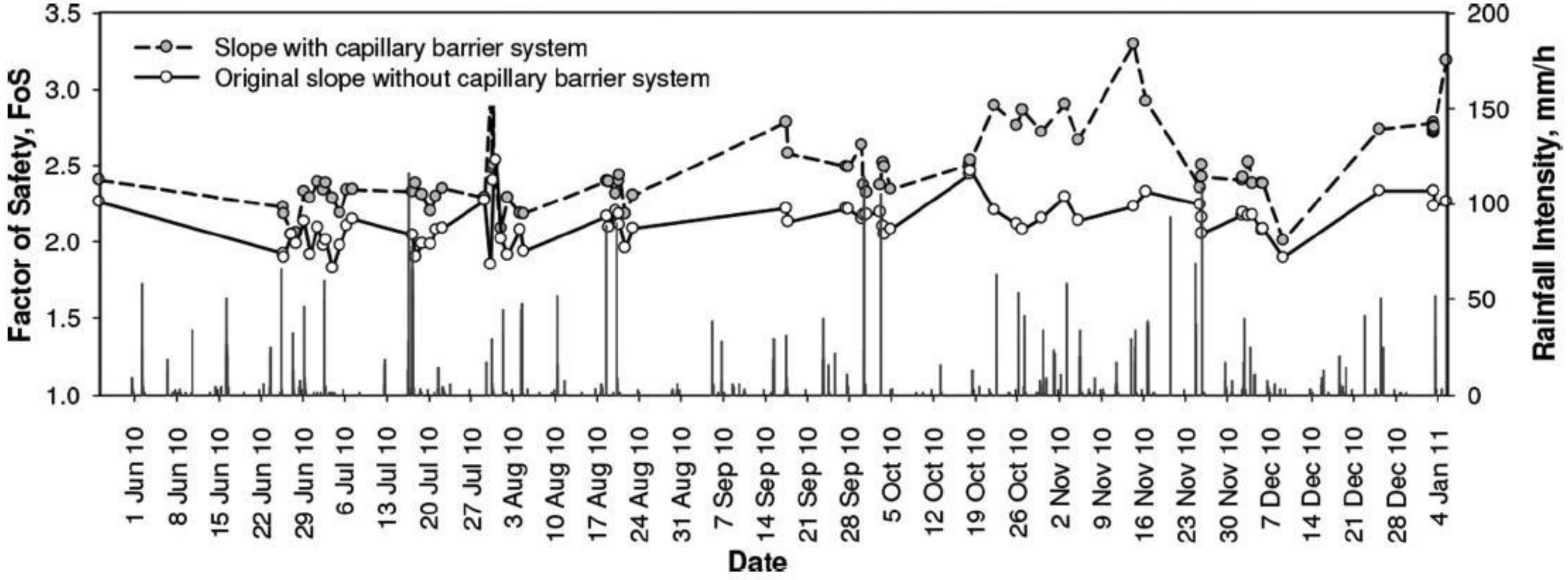
- Construction of capillary barrier system for stabilising a residual soil slope in Singapore



Concept capillary barrier (Rahardjo *et al.*, 2012)



Factor of safety variations for slope with and without vegetative cover (after Rahardjo *et al.*, 2014c).



Factor of safety variations for slope with and without capillary barrier system (after Rahardjo *et al.*, 2013b)

Prevention

(a) Placement of top soil on top of the fine-grained layer of the capillary barrier system

(b) Drainage provision

(c) Grass planting on slope surface after placement of the top soil on top of the capillary barrier (boxes on the slope surface are tensiometers

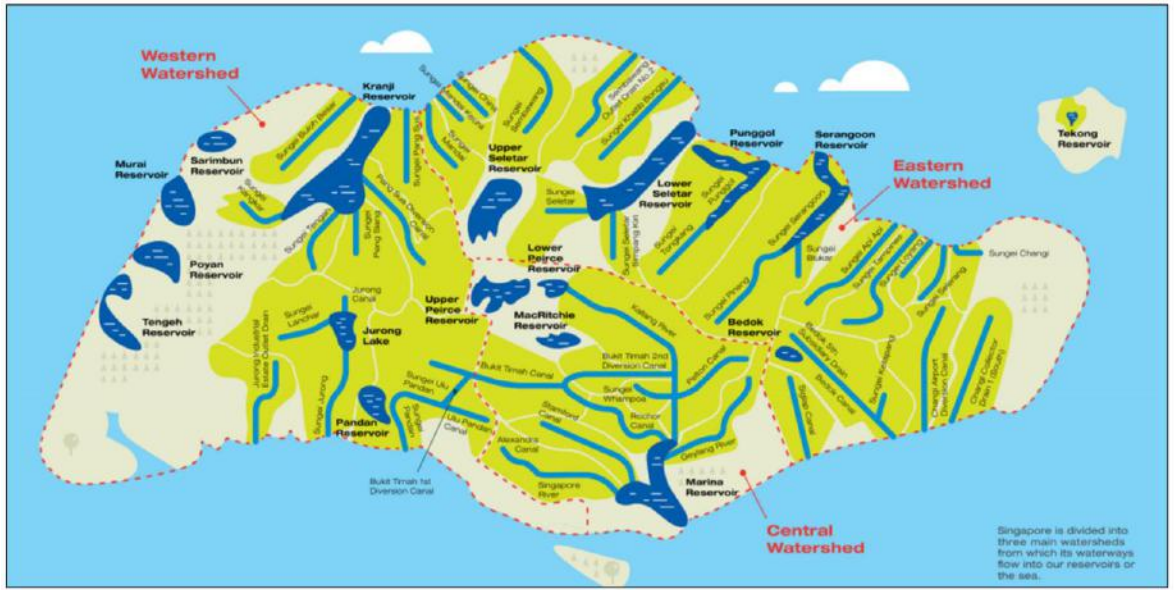
Prevention

(a) Slope with vertical and horizontal drain

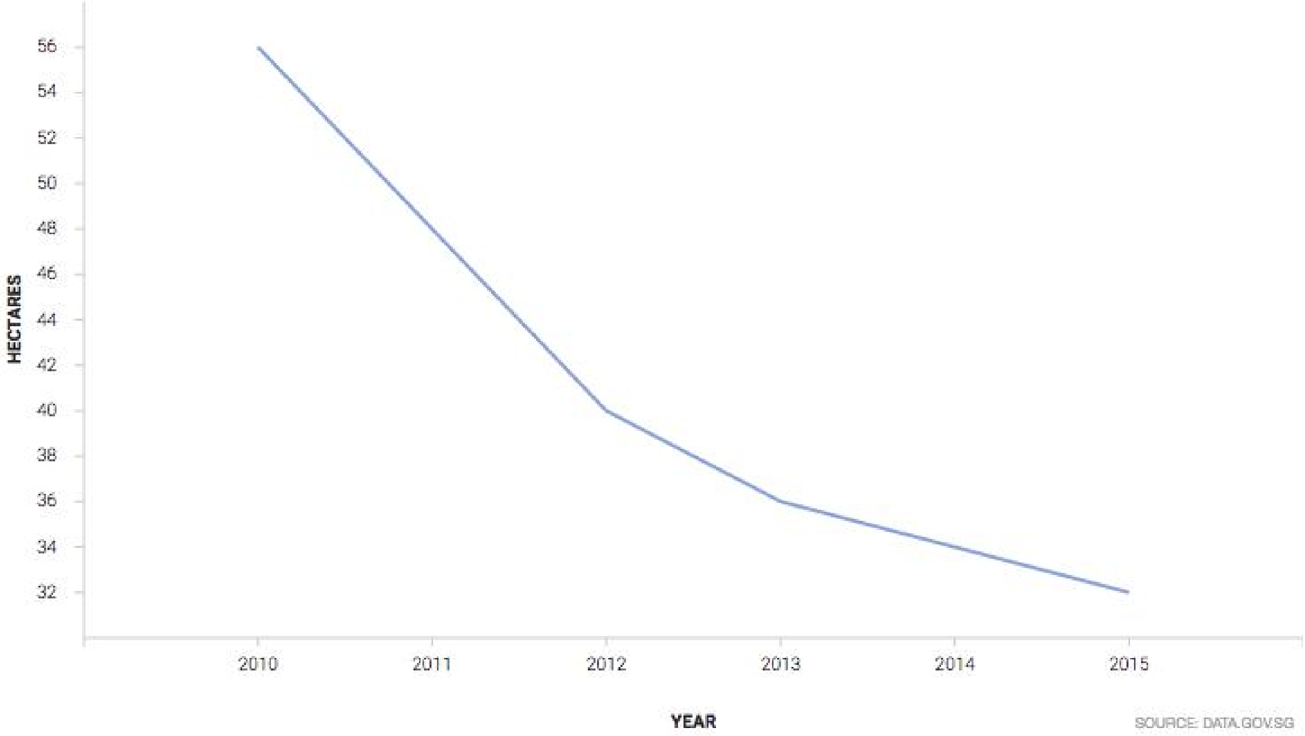
(b) Slope with horizontal drain

Fig (a) & (b) A well maintained slopes (source : Ministry of National Development)

Prevention

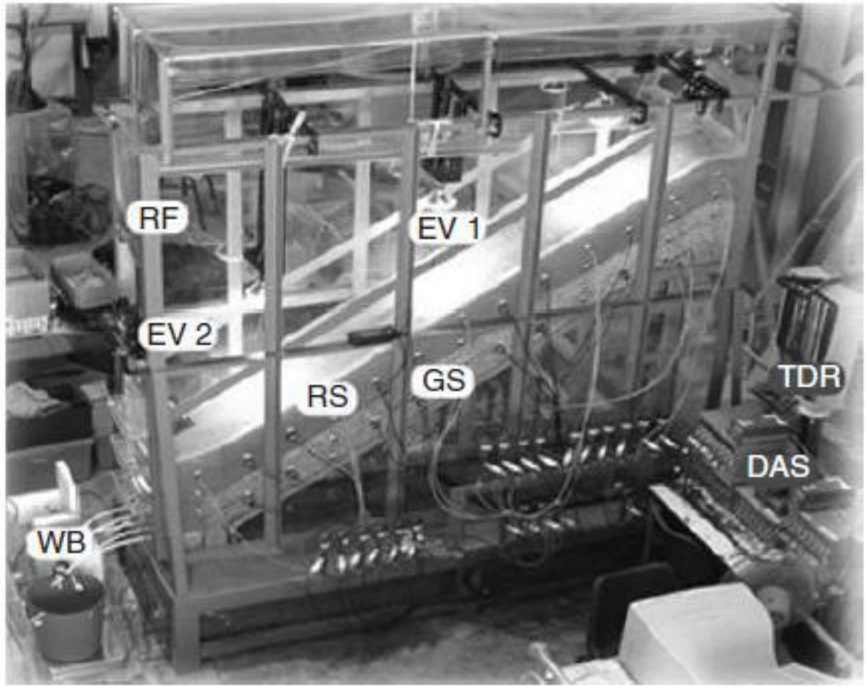


Improvement of drainage island-wide



Reduction of Flood prone area (data.gov.sg)

Prevention



A laboratory setup of a physical model of capillary barrier system for studying the effectiveness of a capillary barrier for slope stabilisation.

RS : residual soil layer (fine-grained soil)
GS: gravellier sand layer (coarse-grained soil)
RF: rainfall simulator
EV1: lamp to enhance drying process
EV2: fan to enhance drying process

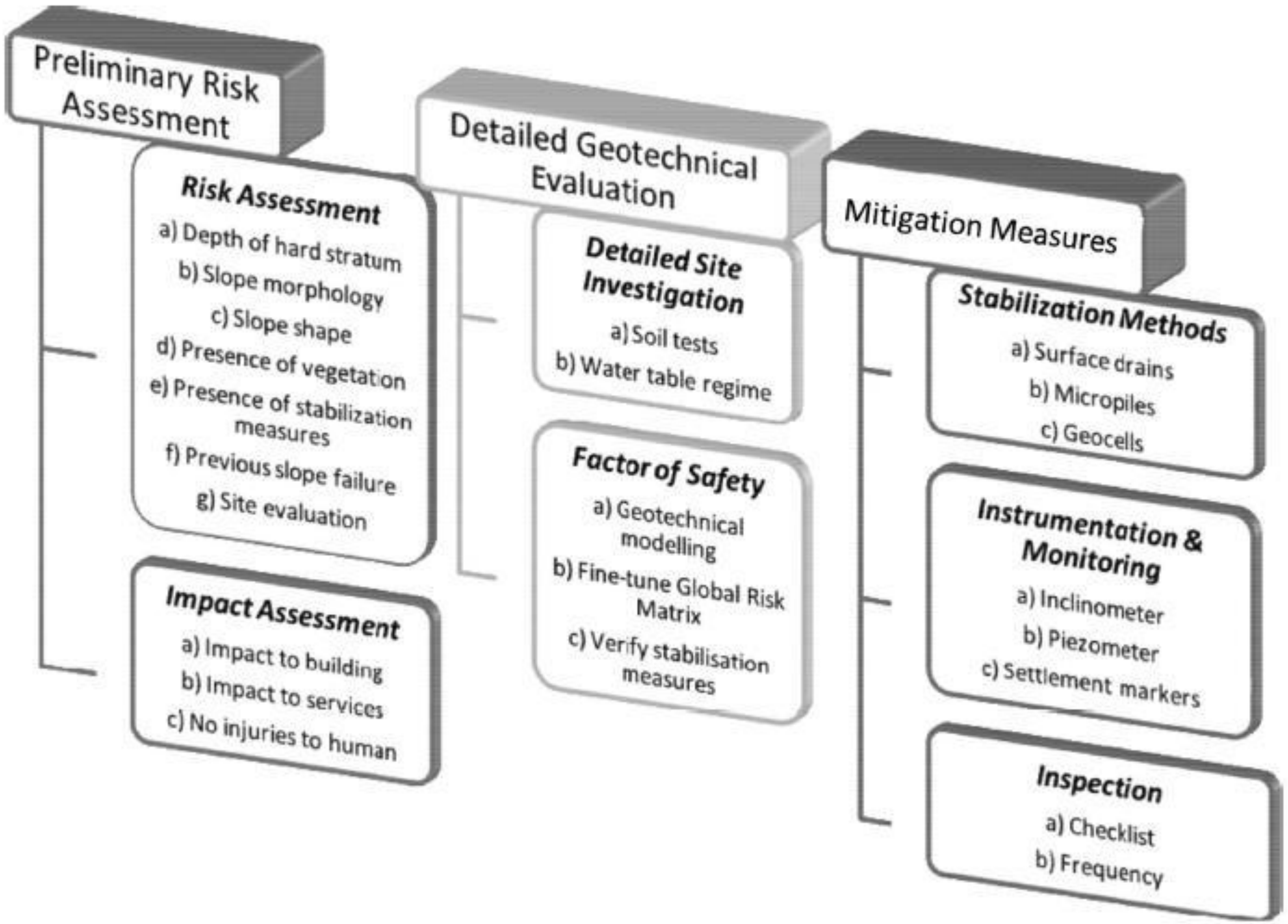
WB: weighing balance to measure runoff, lateral diversion, and breakthrough amount

TDR: Array of time domain reflectometry wave guide and tensiometer probe assembly for soil water content and pore-water pressure measurements

DAS: data acquisition system
(*After* Tami *et al.*, 2004b)

Prevention

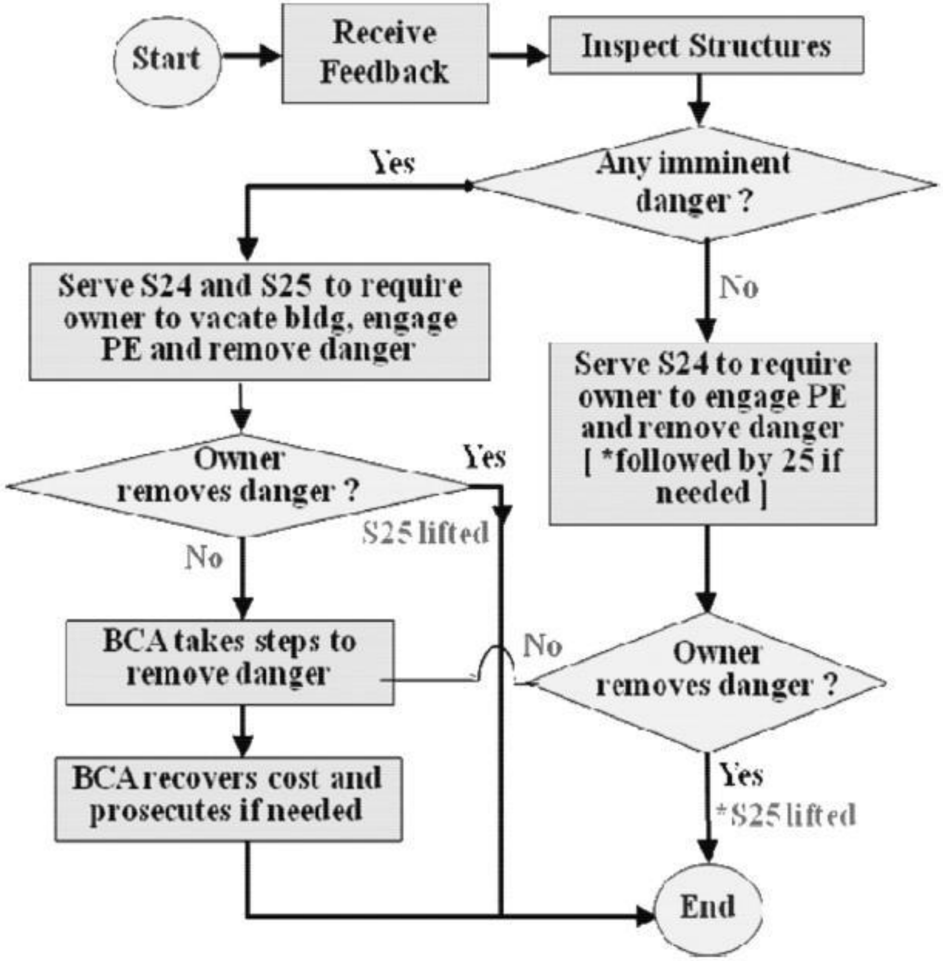
- Building Regulation



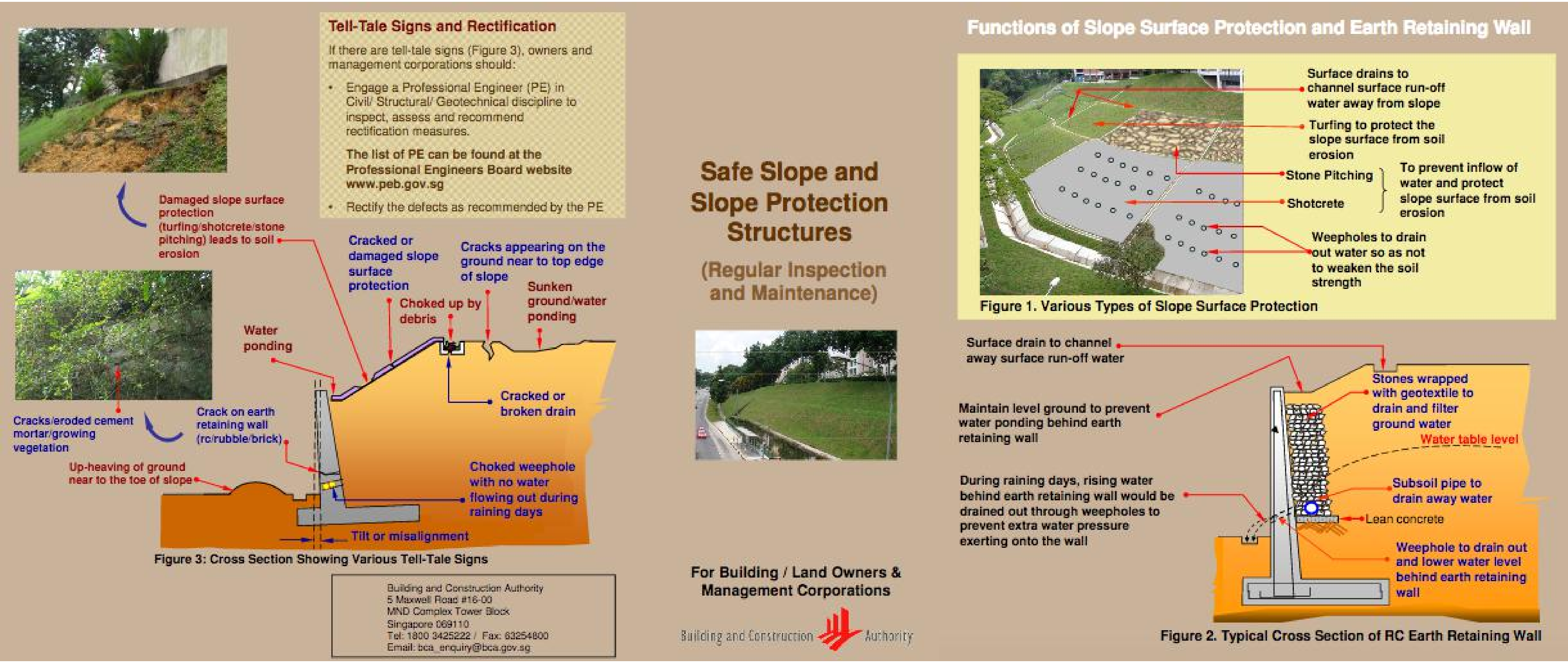
Overview of 3-stages slope management system (BCA regulation)

Prevention

- Building Regulation



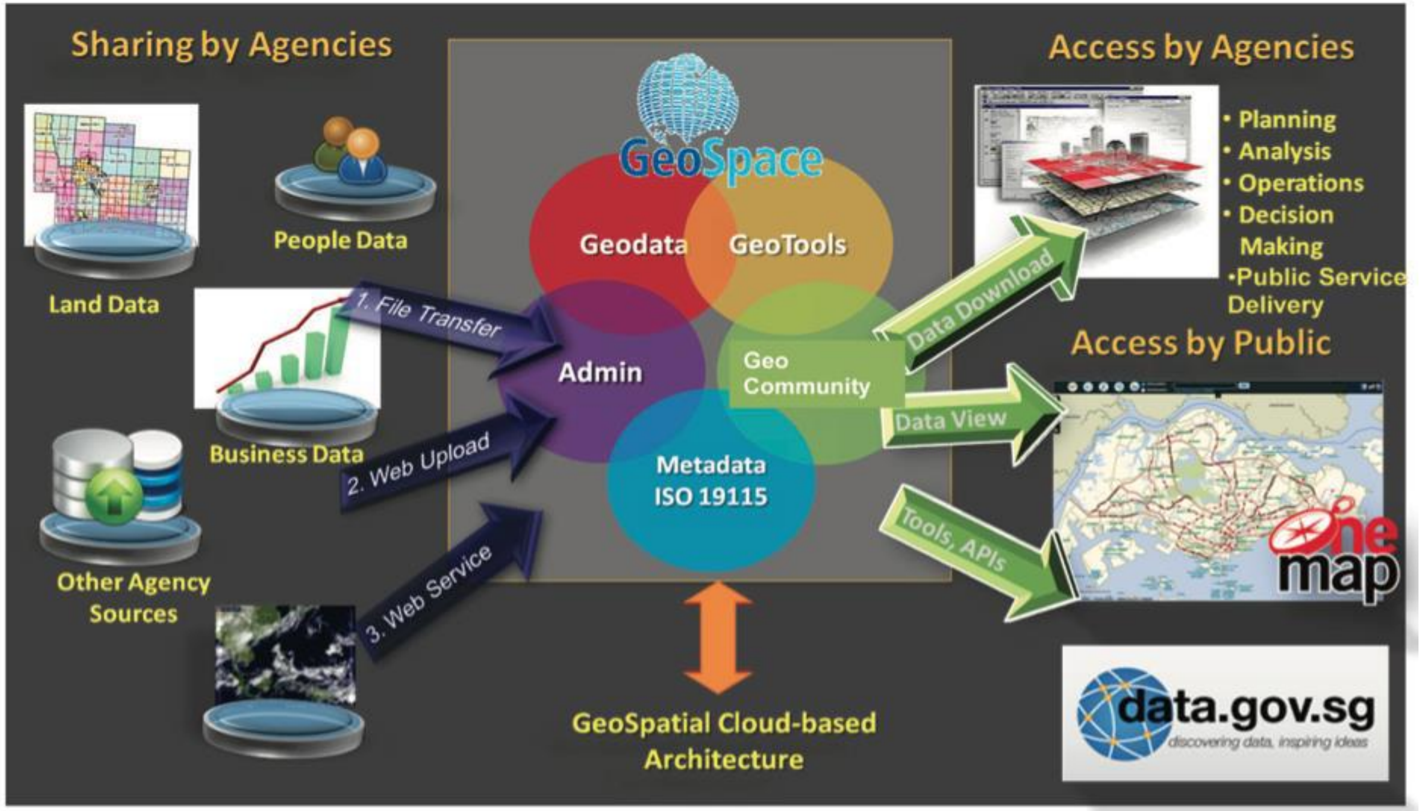
BCA work procedure to serve S24A and S25



Regulation from Building and Construction Authority (BCA), Ministry of national development

Prevention

- Public and private sectors collaboration

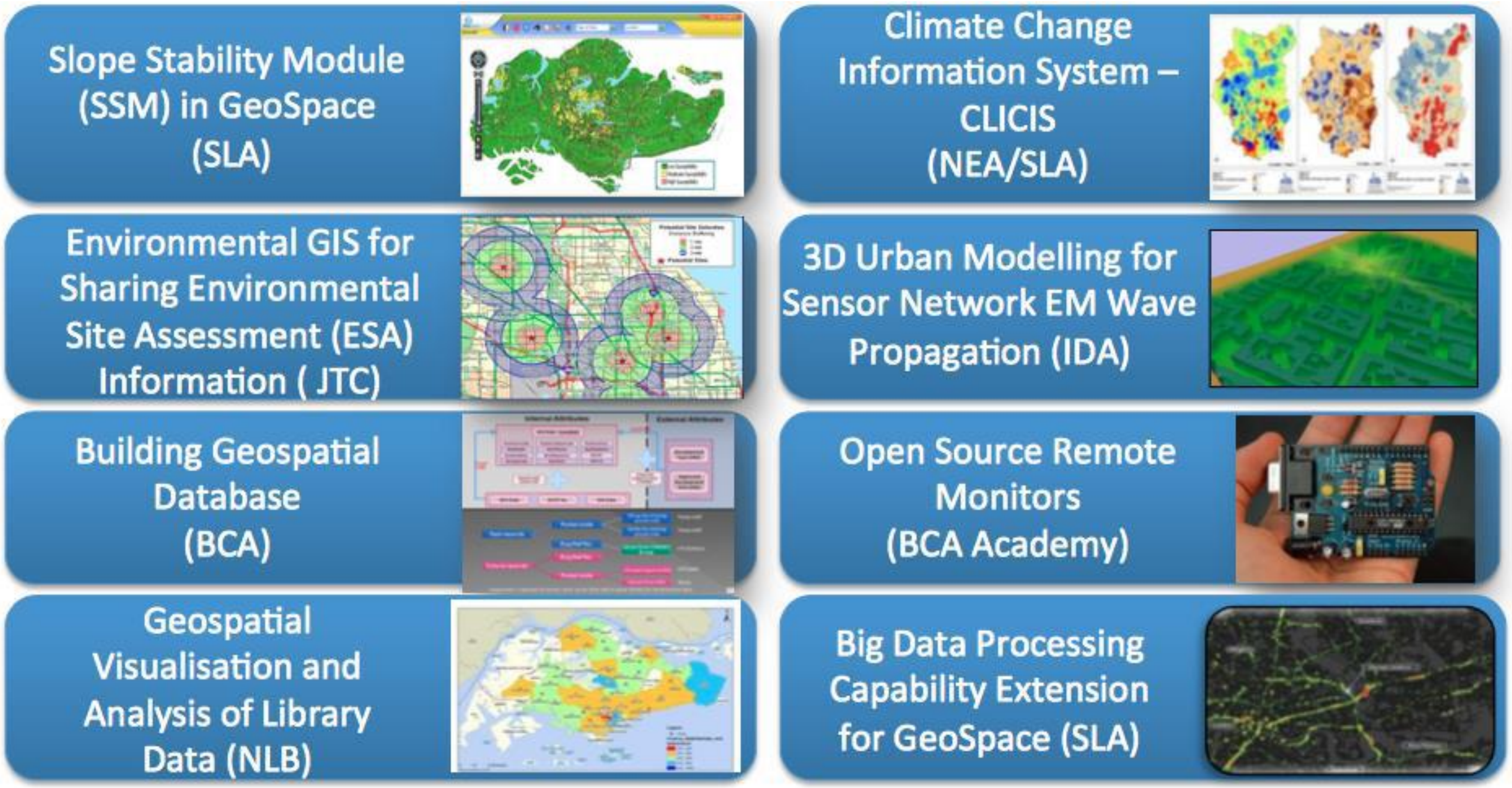


Accessible geospatial data to public and private sectors (SG-SPACE/2012/3)

Prevention

Singapore Land Authority 2014

Prevention



Singapore Land Authority 2014

Conclusion

- Rain is the primary factor of slope failure in Singapore
- Measurement from multi-sensors integration is suggested
- Prevention is preferable
- Open data to attached the crowd

- If you are interested in-depth details of the works, please checkout the research from Prof Harianto Rahardjo, Prof. Leong Eng Choon, and their team in School of Civil and Environmental Engineering, NTU