Reduction of Landslide Risk in Sri Lanka

Part 1 –Geomorphological and Geological Background

Time Capsule project of ISSMGE
Sri Lankan Geotechnical Society

Sri Lanka is located between northern latitude of 5 and 10 and eastern longitude of 79 and 82. It occupies an area of nearly 65,000 sq. km, stretching 435km from north to south and 224 km from west to east.

Climate varies from semi – arid to mild temperature

This variation is due to central highland region, which is surround by an extensive low land area.

Country is influenced by monsoonal and inter monsoonal periods.

Annual rainfall

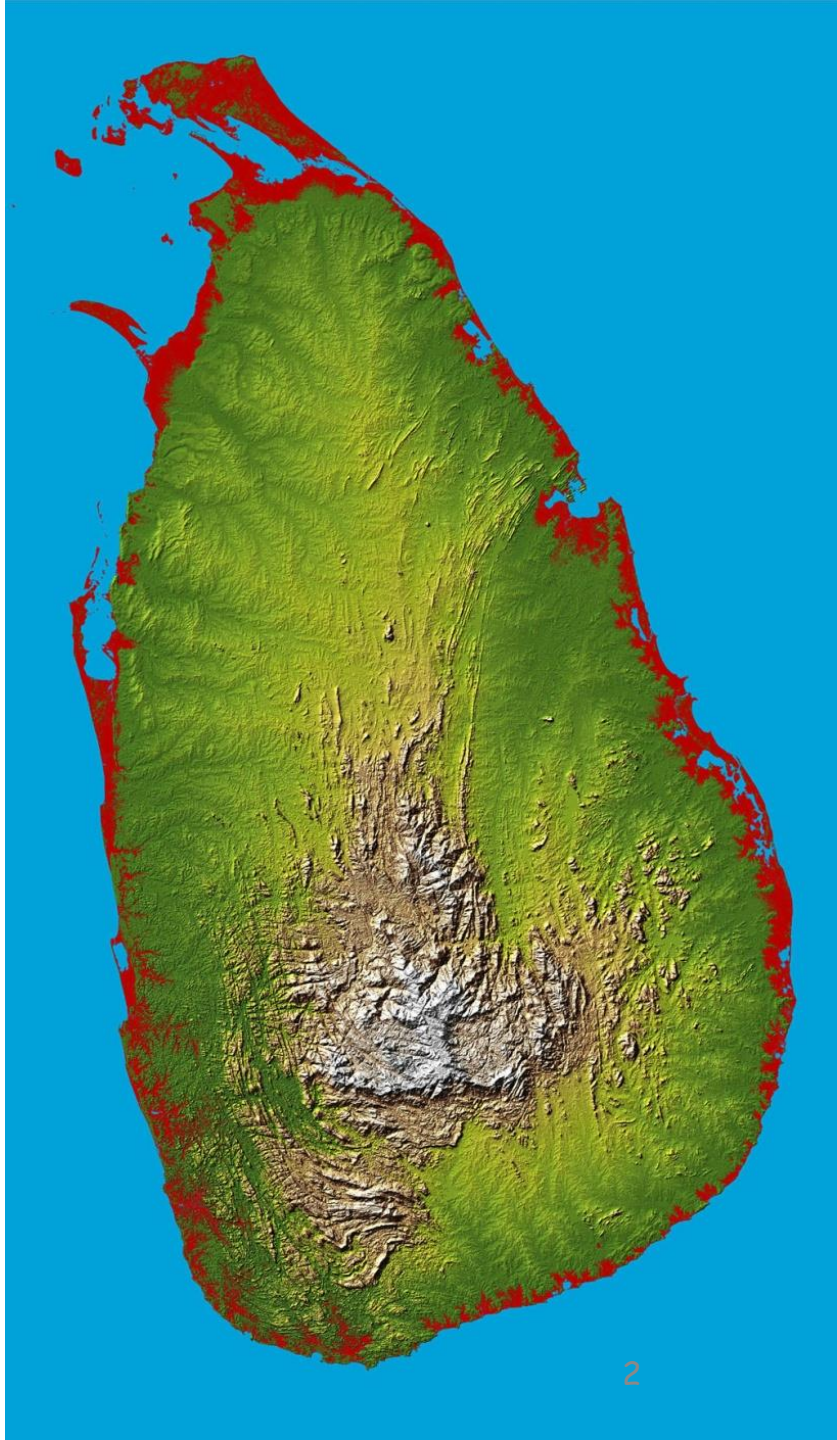
2500mm to 5000mm in the South – West – May-September

500mm – 2000mm in the North – East - December-February

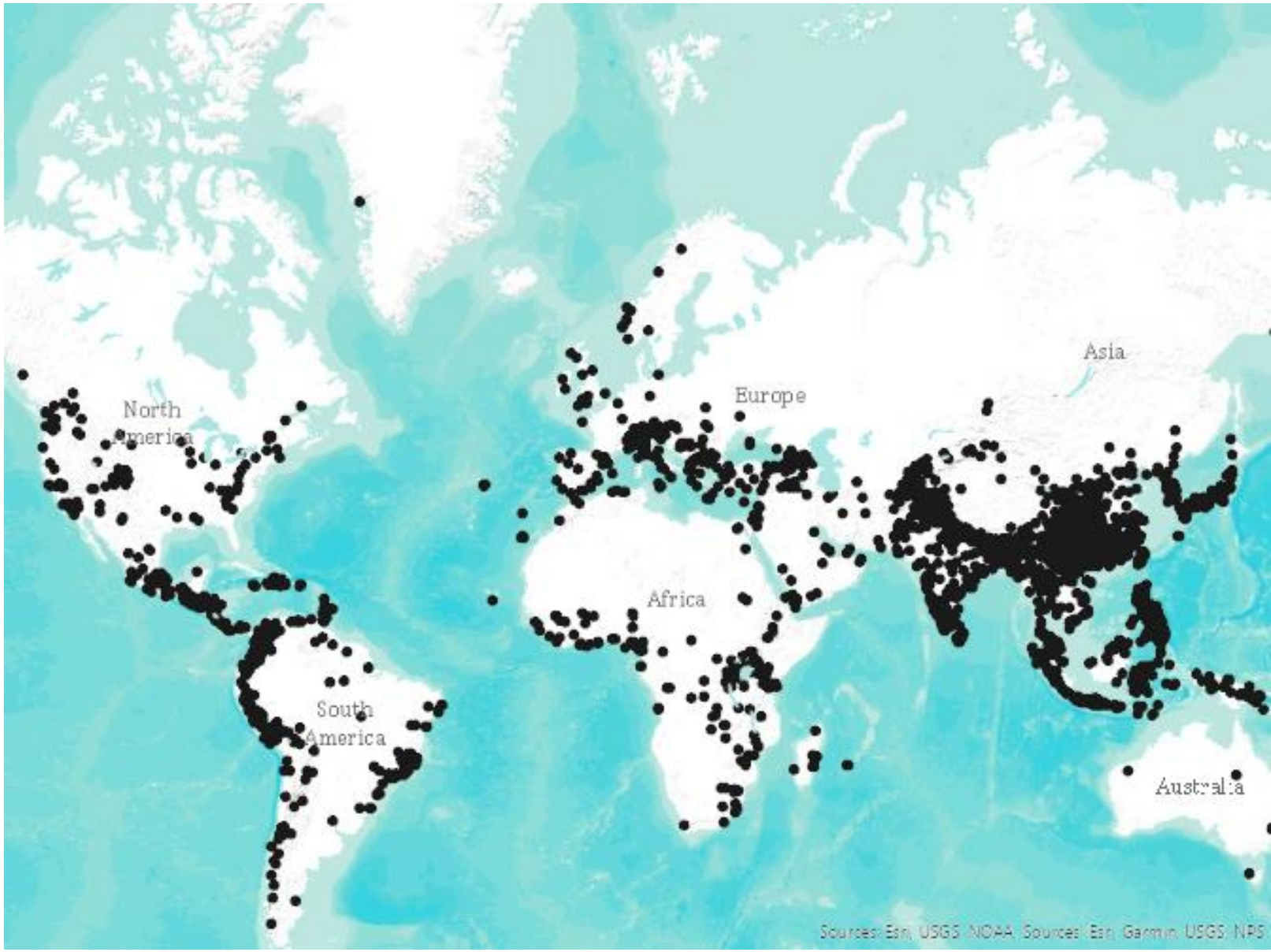
Mean annual temperature

27^{0}C (low lands) :15^{0}C (central highland).

Forests occupy 23.75% of total land area.



As observed from the landslide record databases Sri Lanka falls is in the region that is more susceptible for rain induced landslides



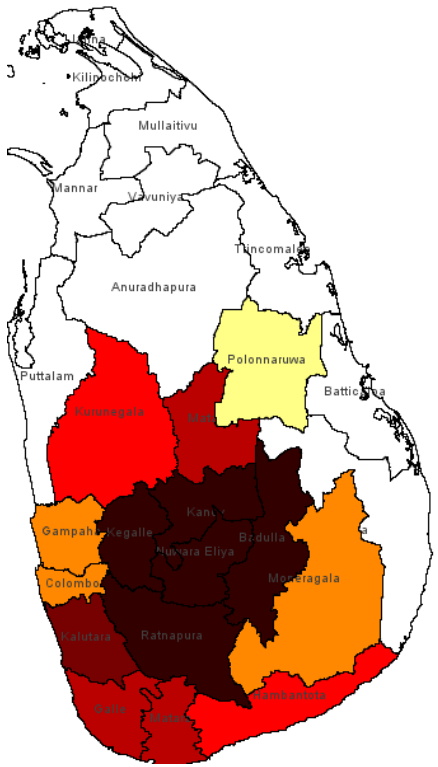
Global fatal landslide database (after Froude and Petley, (2018)

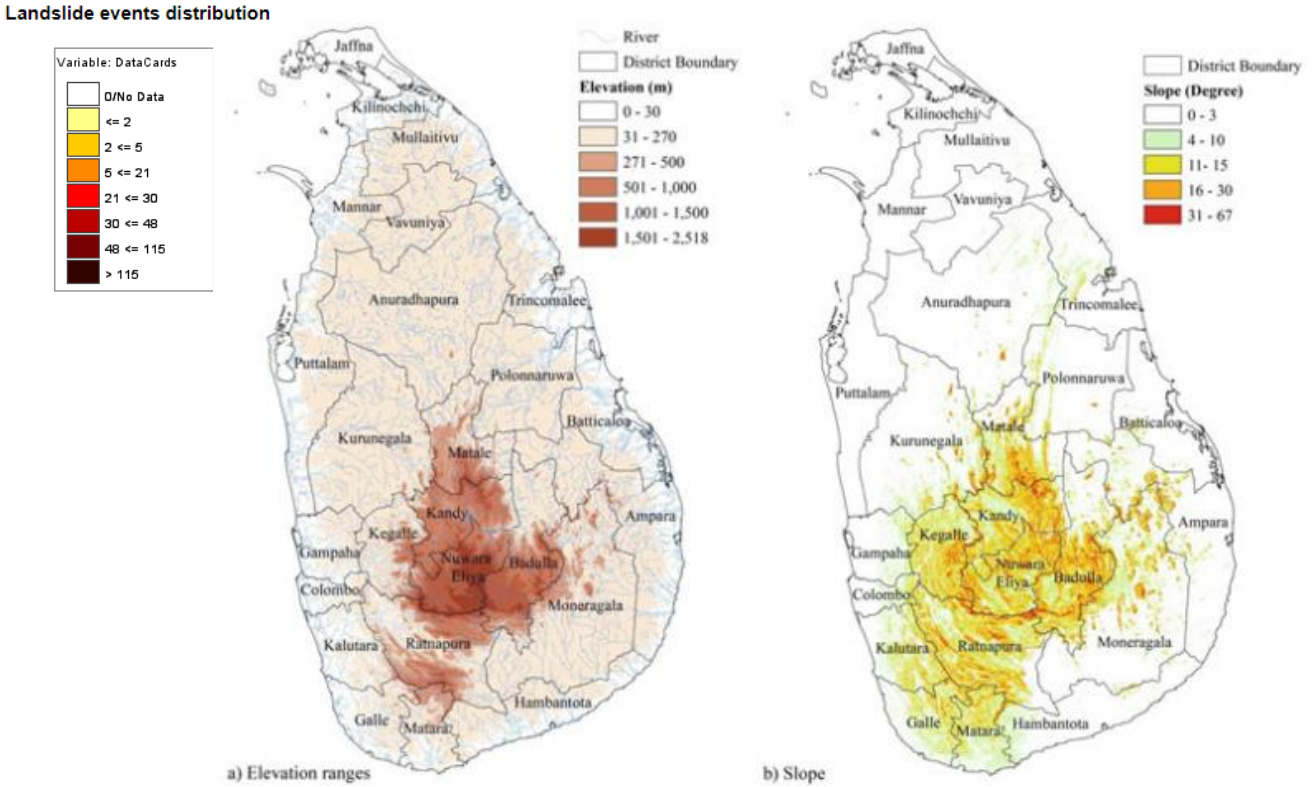
Landslide Situation in Sri Lanka

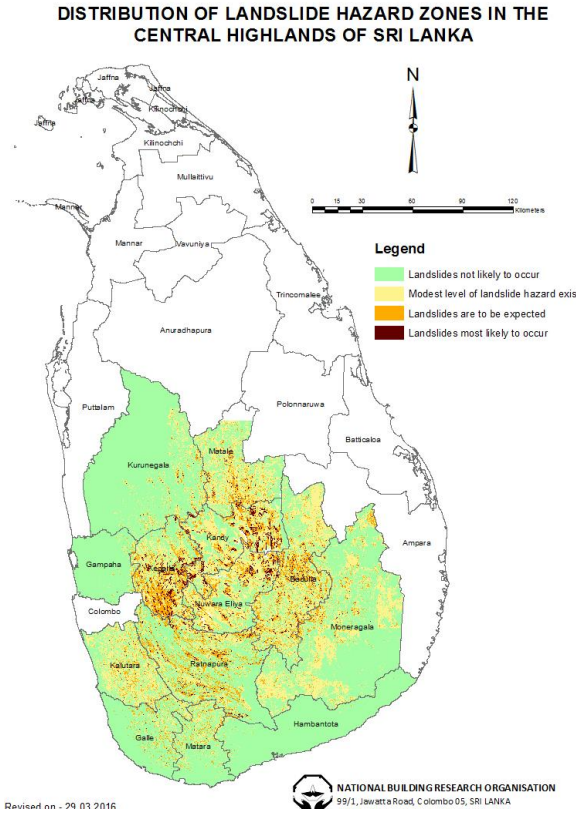
Central highland area of Sri Lanka is highly susceptible to landslides

This area is around 20,000 km^2 out of the total land area of the country (65,610 km^2)

38% of the total population live in these areas





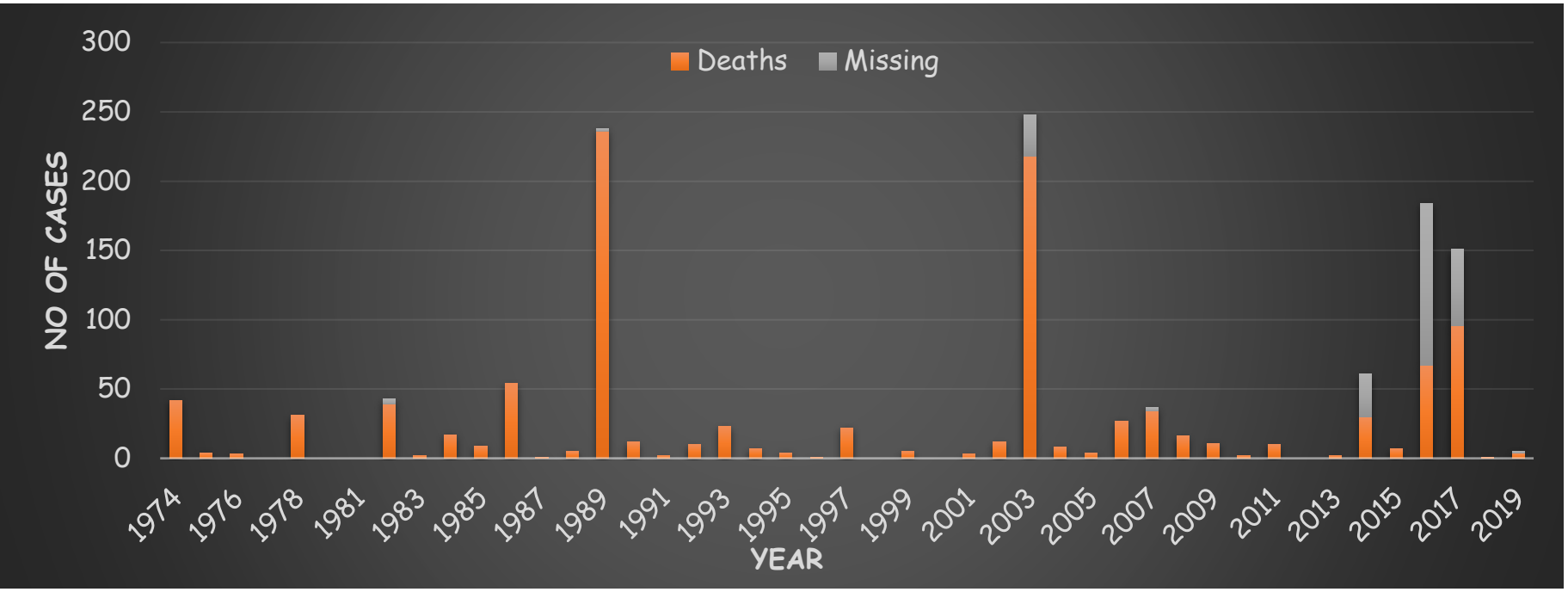


Elevation range and Slope angle (Kumarihamiy et al. 2022)

1:50,000 LHZM NBRO

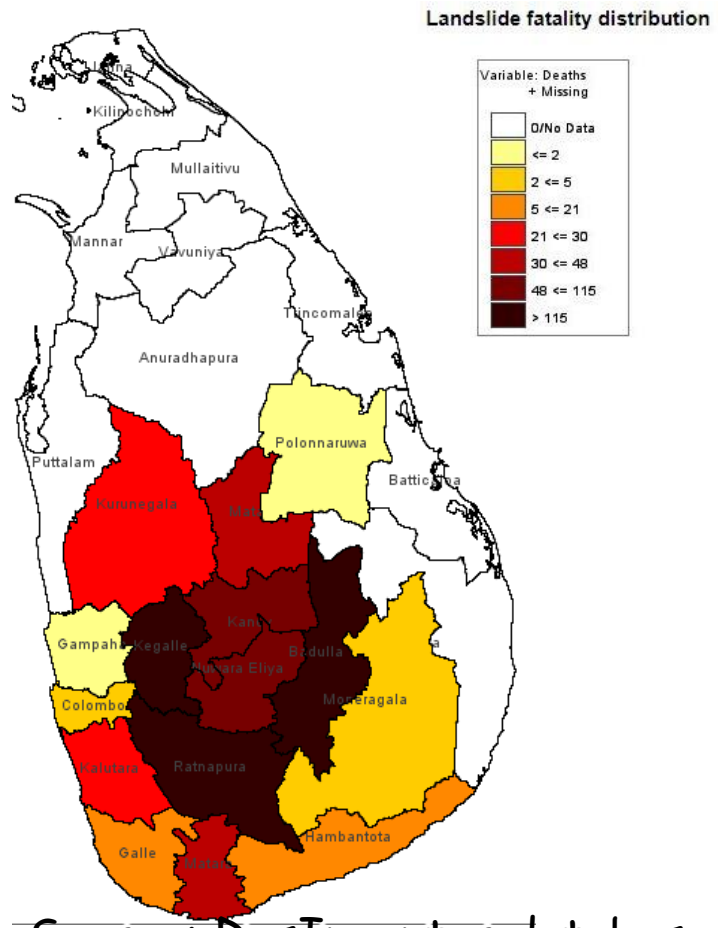
Landslide Situation in Sri Lanka

Every year landslides cause significant damage to the properties, human lives and economy of the country.



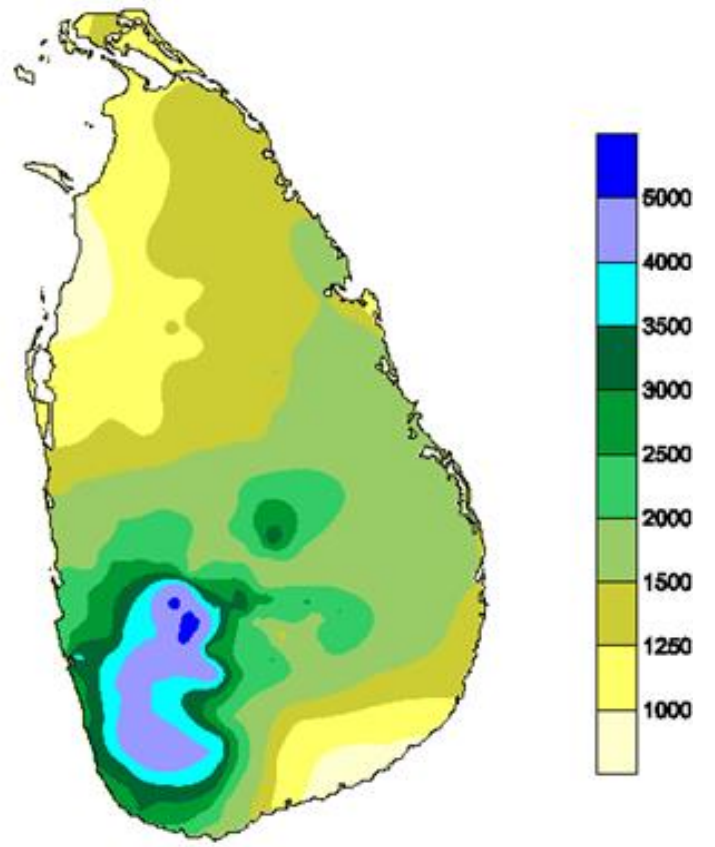
Number of deaths and missing cases each year from 1974-2019

(Total 1081 from 1974-2019)

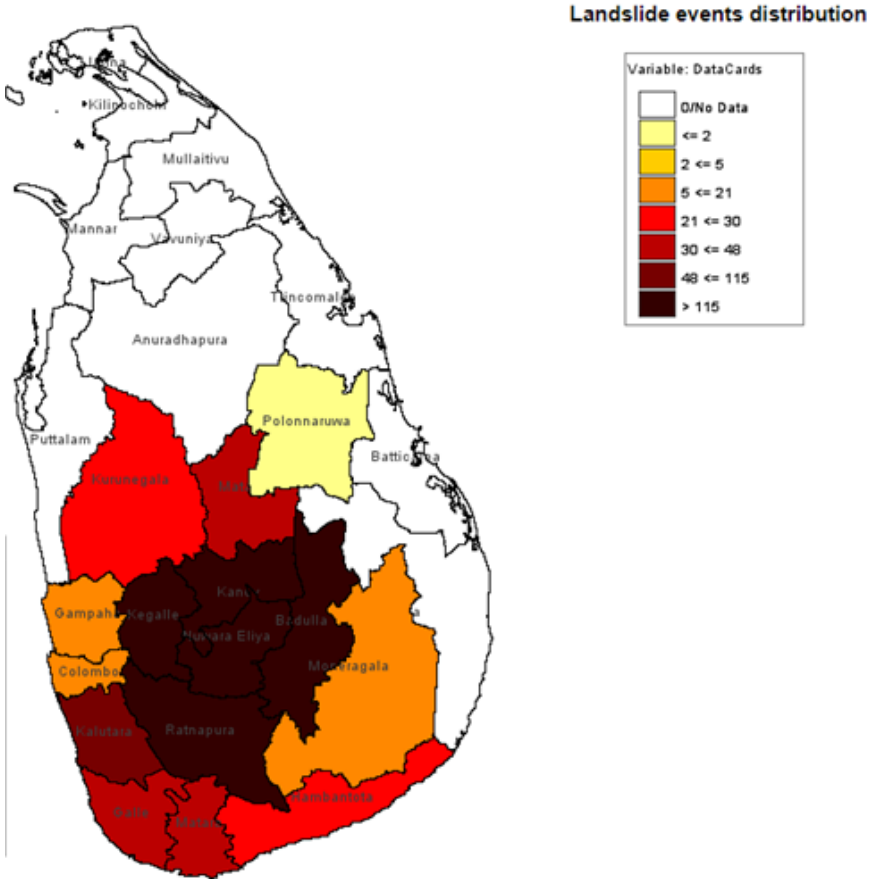


Source: DesInventar database

The main triggering factor for the landslides in natural slopes of Sri Lanka is identified as rainfall.



Annual rainfall distribution (mm) (Source: Dept. of Metrology)

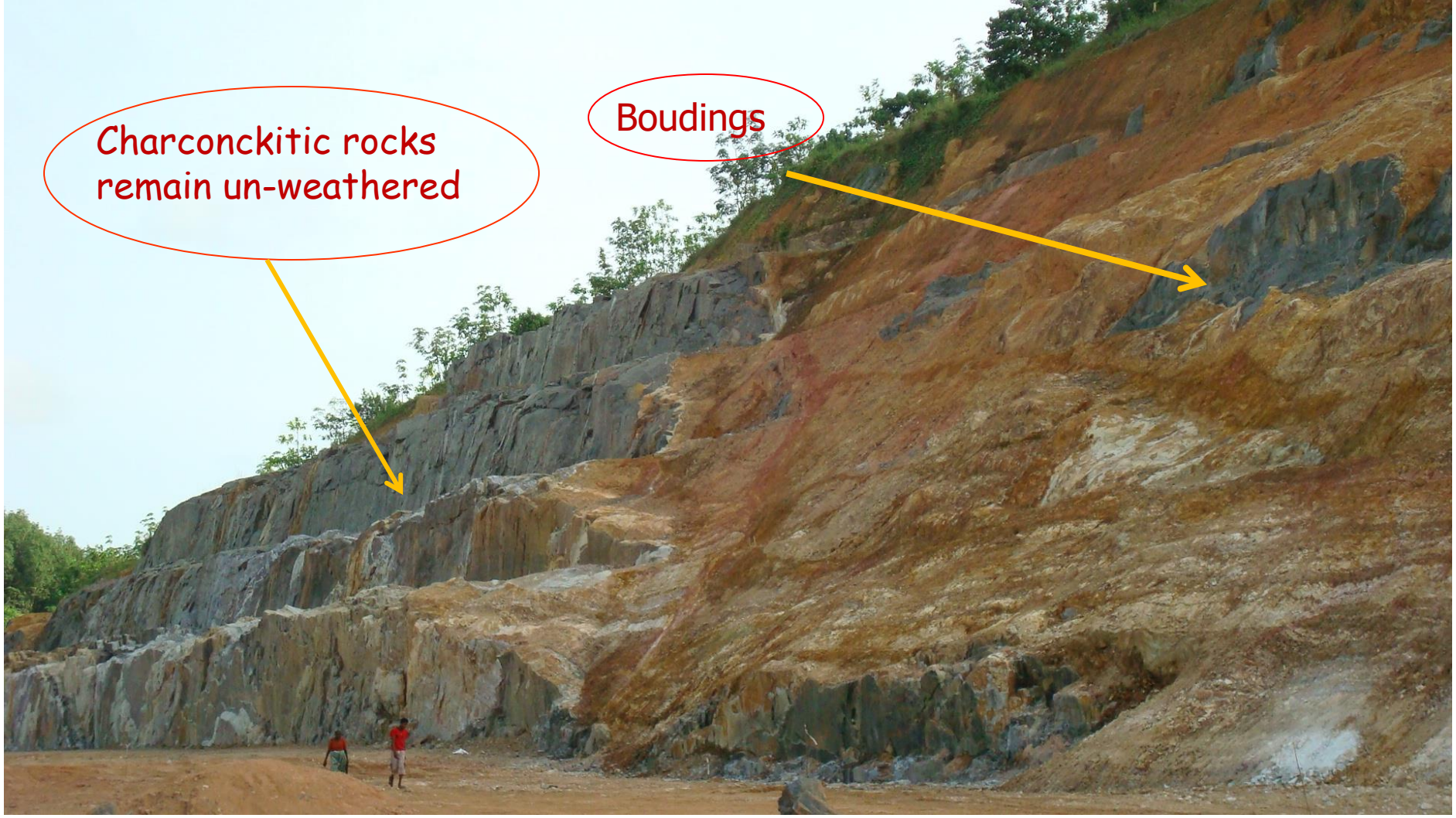


Source: DesInventar database

Sri Lanka has an extensive road and railway network covering the whole country through a very picturesque landscape. Mitigation of landslides occurring in the transport network is a huge challenge faced by the Sri Lankan Engineers

Geological Background

- Sloping grounds in Sri Lanka are formed of; rocks of different levels of weathering, residual soils and colluvial soils.
- Rocks present are mainly Metamorphic. Principal rock types are Gneisses, Charnockites, Marble and Quartzite.
- These rocks could have banded structures with one or more joint planes. Joint planes will remain as relict joints in the residual soils.



Charconckitic rocks that have high resistance to weathering remains un-weathered –known as Boudings

Highly heterogeneous-irregular soil/rock profiles due to tropical conditions of weathering and mineralogical changes in the parent rock.

Rocks with closely spaced Joints

Those will remain as "Relict Joints" in the weathered product – residual soil

Toppling (Fall) Mode of failure or sliding could take place through relict joints in residual soil formations

Toppling Failure through relict joints

Sliding failures along relict joints

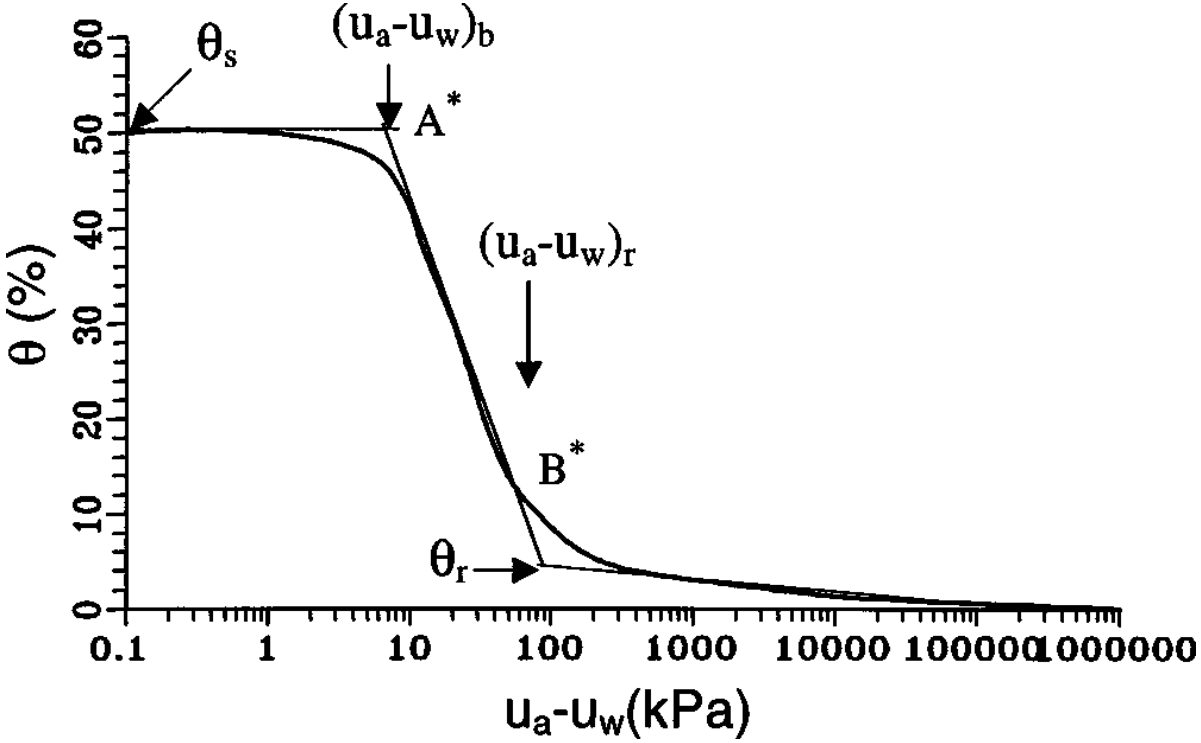
- Many of these slopes are with a low water table during periods of dry weather. Prevailing high martic suctions make them stable.

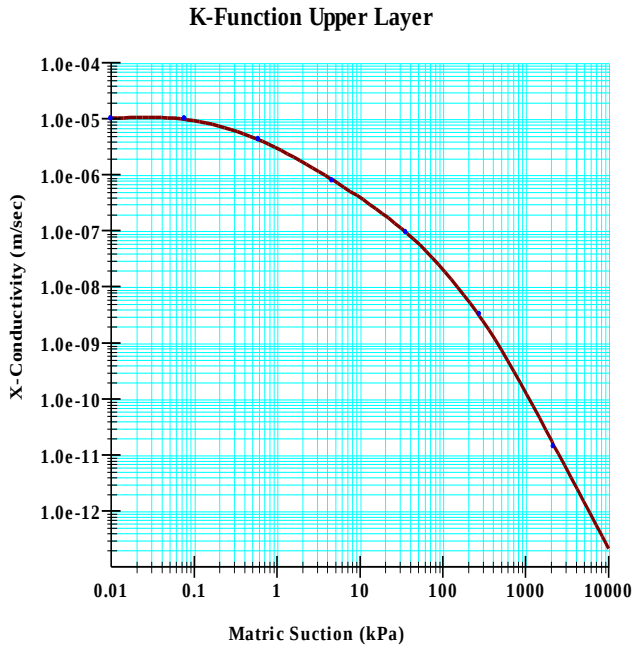
- Near vertical cuts of heights of even 10m or more would stand safe under these conditions.

- Infiltration of rainwater, loss of matric suctions and perhaps the development of a perched water table condition will make them unstable. This process can be modelled numerically.

- Mostly the landslides occur in the colluvial layer or in boundary of; colluvial and residual layer or residual layer and rock (weathered)

Two Most Important Characteristics of an Unsaturated Soil



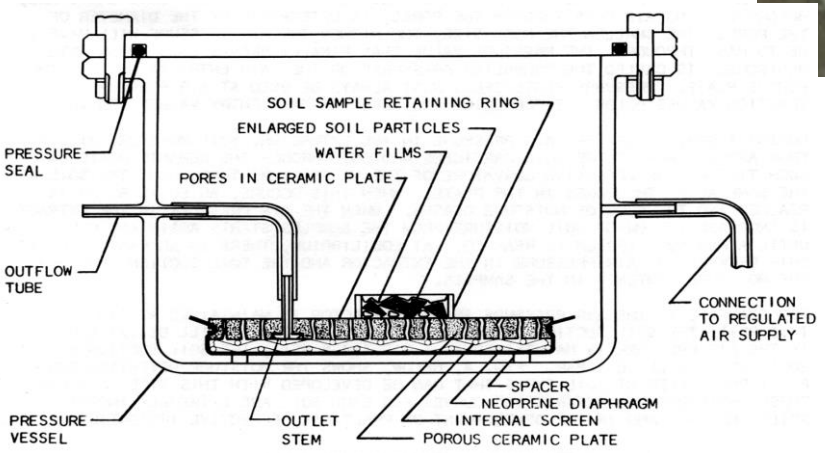


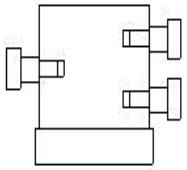
Soil-Water Characteristic Curve (SWCC)

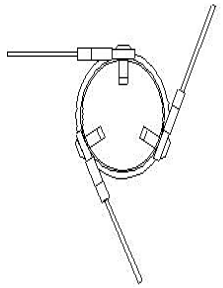
Hydraulic conductivity (Permeability) function

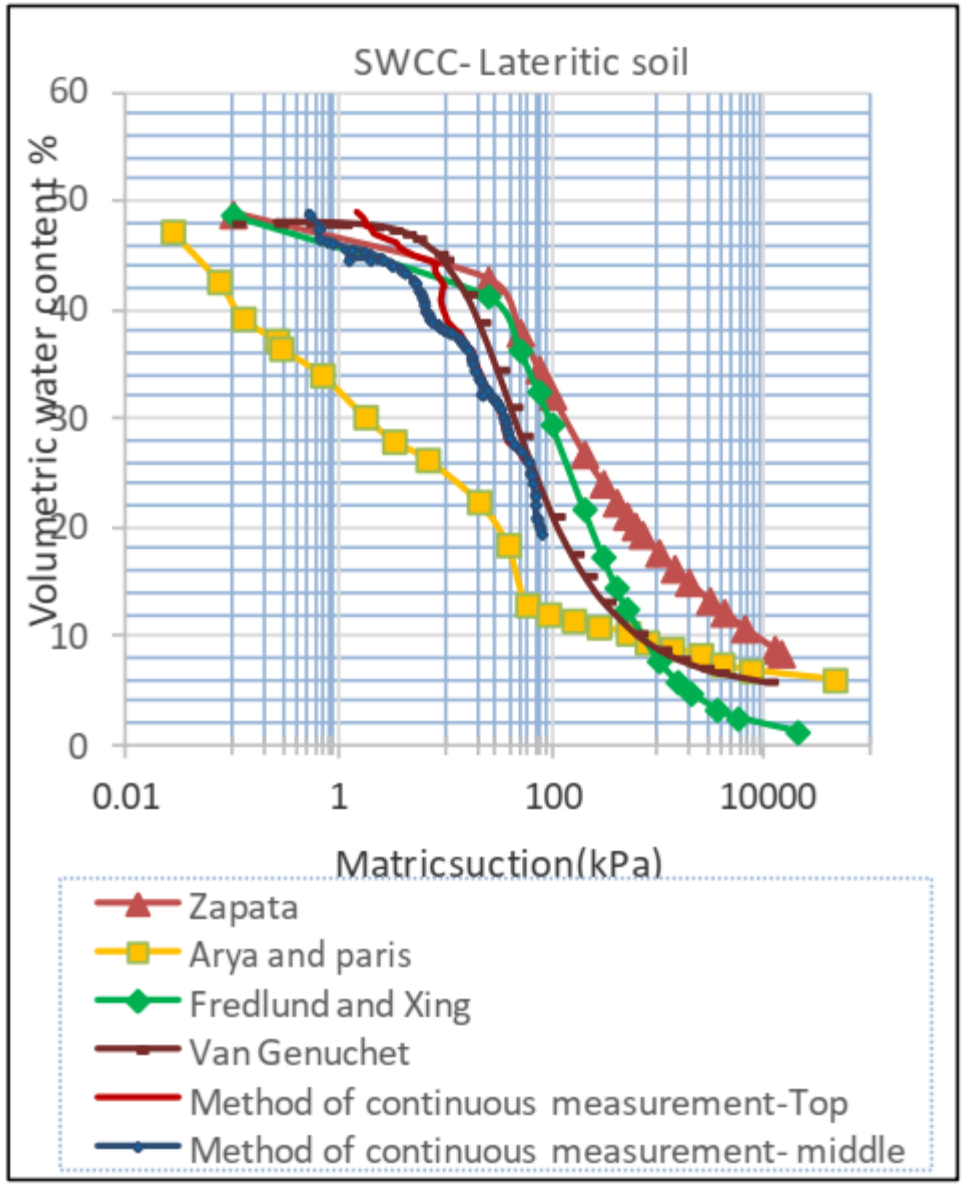
A - Air entry value

B - Residual water content





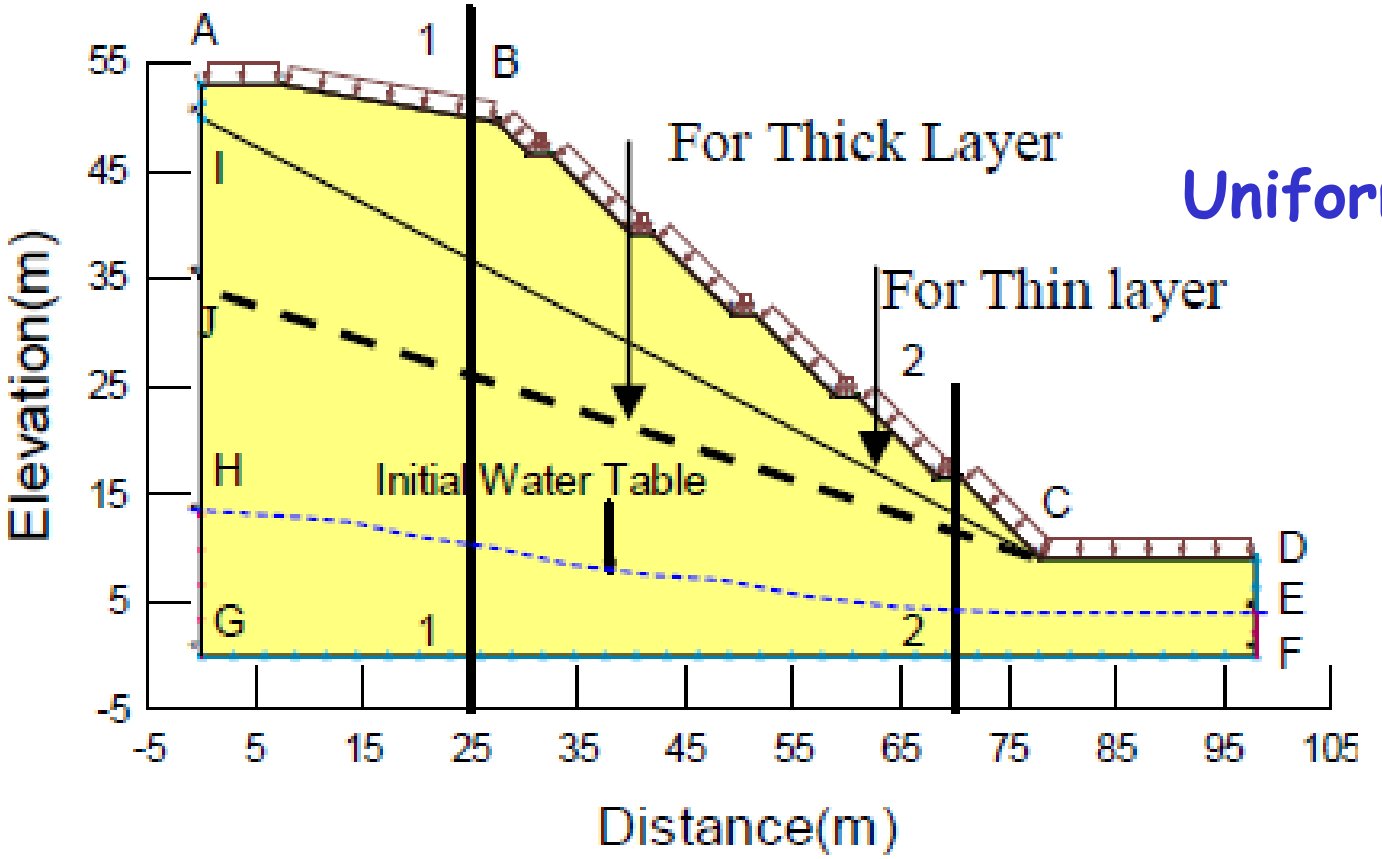




SWCC and Permeability Function for Sri Lankan Soils have been obtained through experimental and empirical techniques.

Modelling the Transient Seepage Analysis with SEEPW Software

(Research at UOM -Kulathilaka and Sujeevan 2011)



Uniform residual Soil

Boundary Conditions

AB, BC, CD= Ir (Rainfall intensity)

AH, DE, FG=Q=0m^3/s (No flow Boundary)

EF, GH=ht (Total head at sides)

Modelling the Transient Seepage Analysis with SEEPW Software

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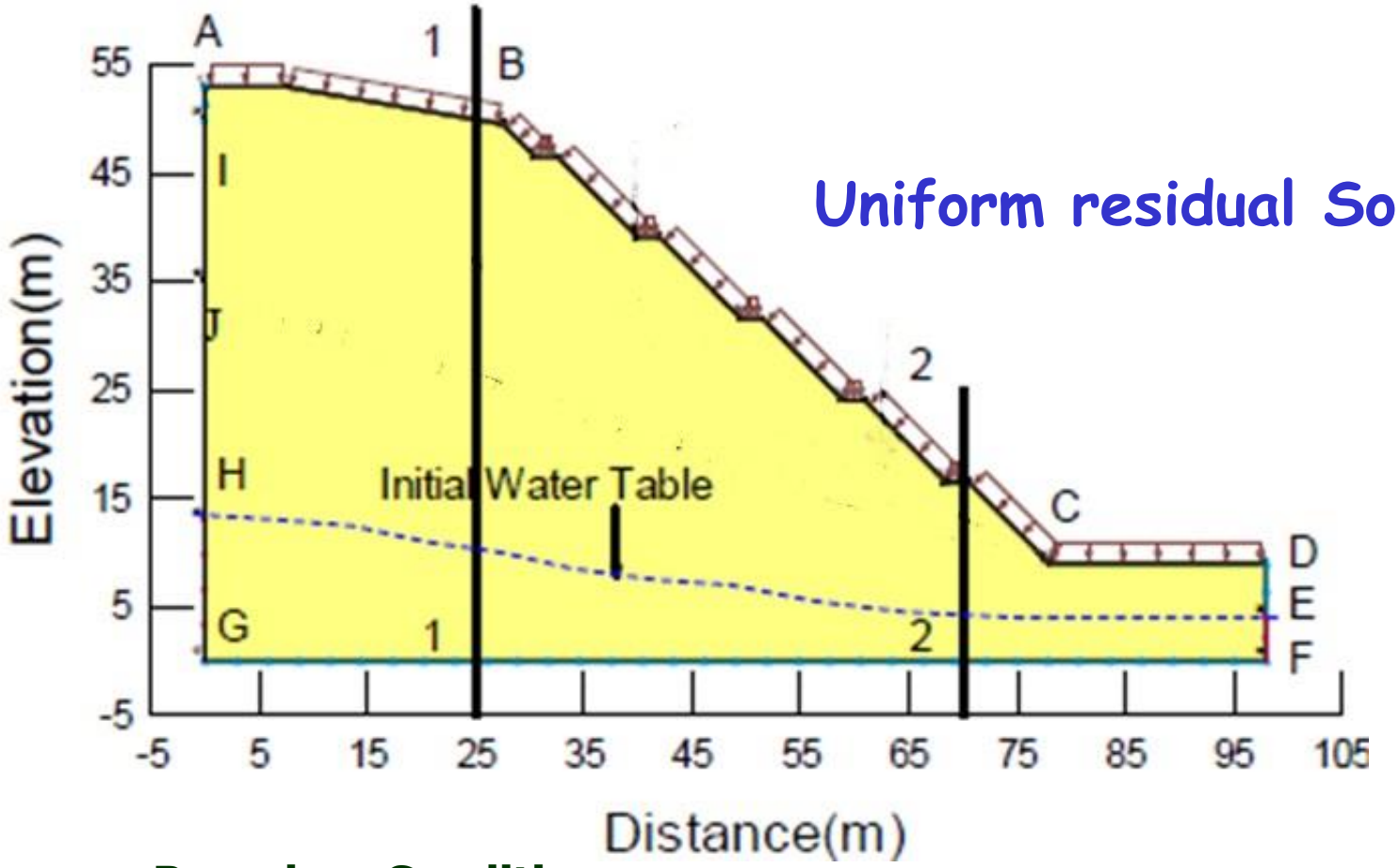

Boundary Conditions

AB, BC, CD= Ir (Rainfall intensity)

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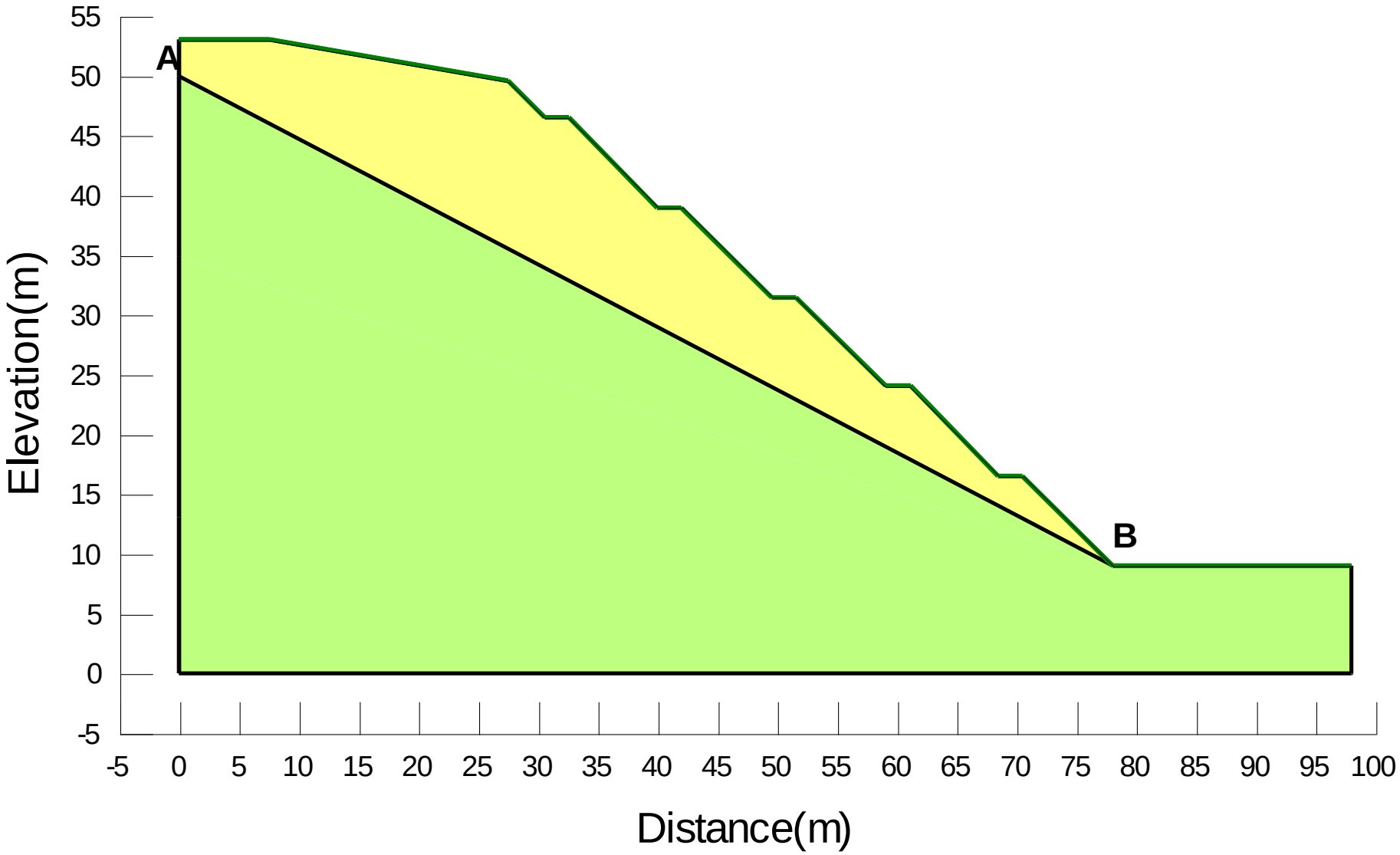
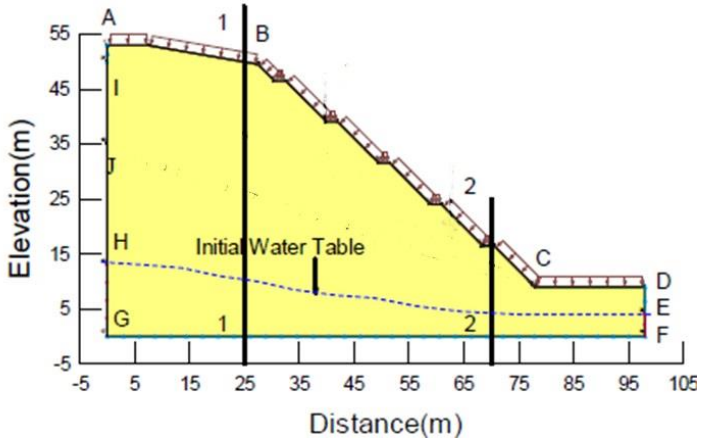
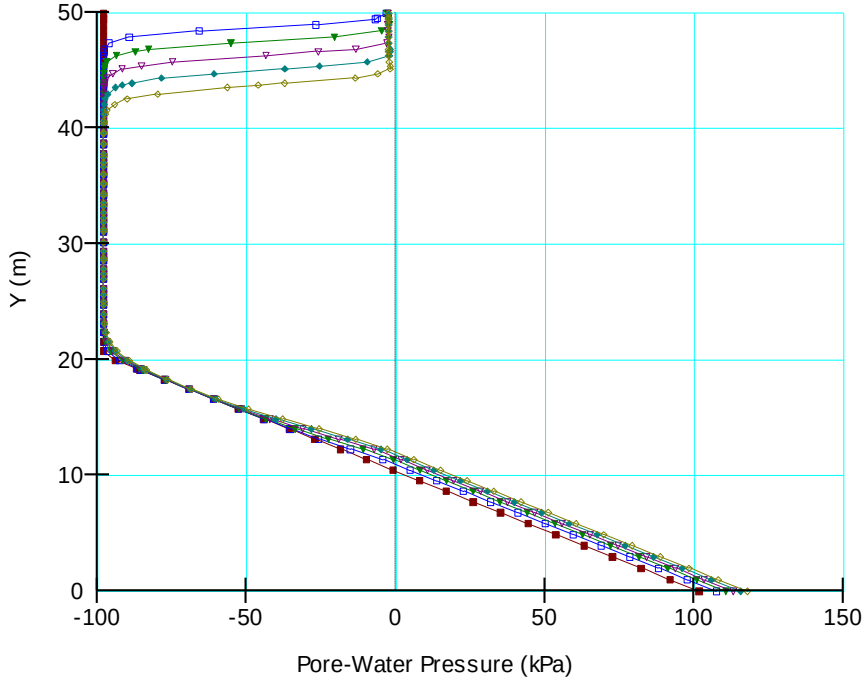
Weathered rock underlying residual soils





Pore Water Variation Along depth



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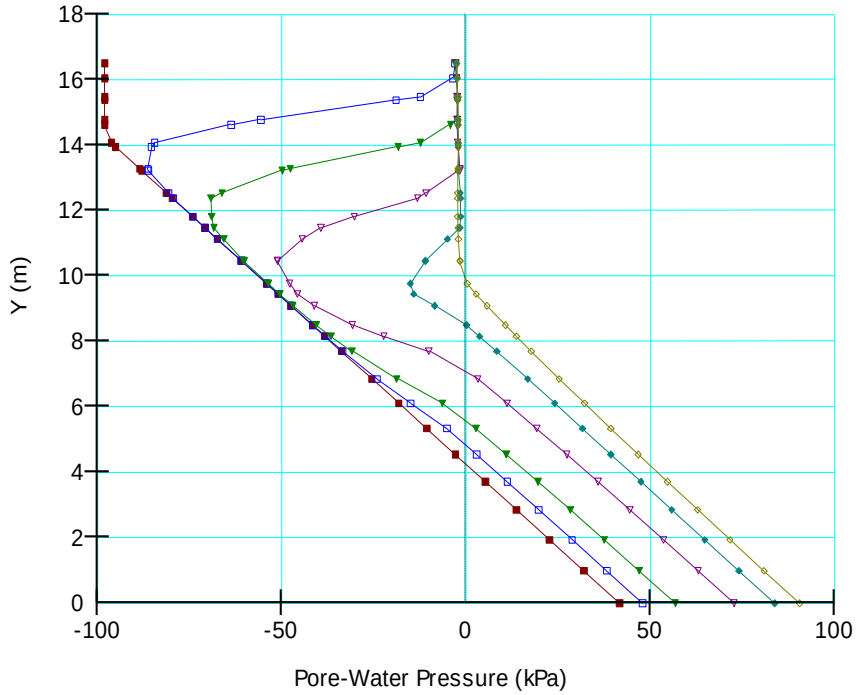
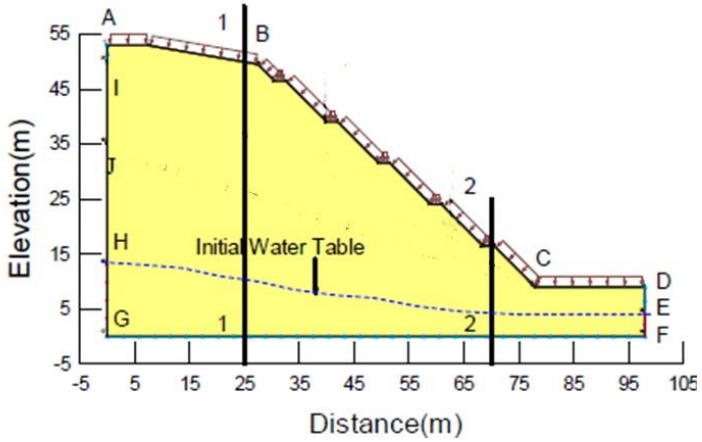
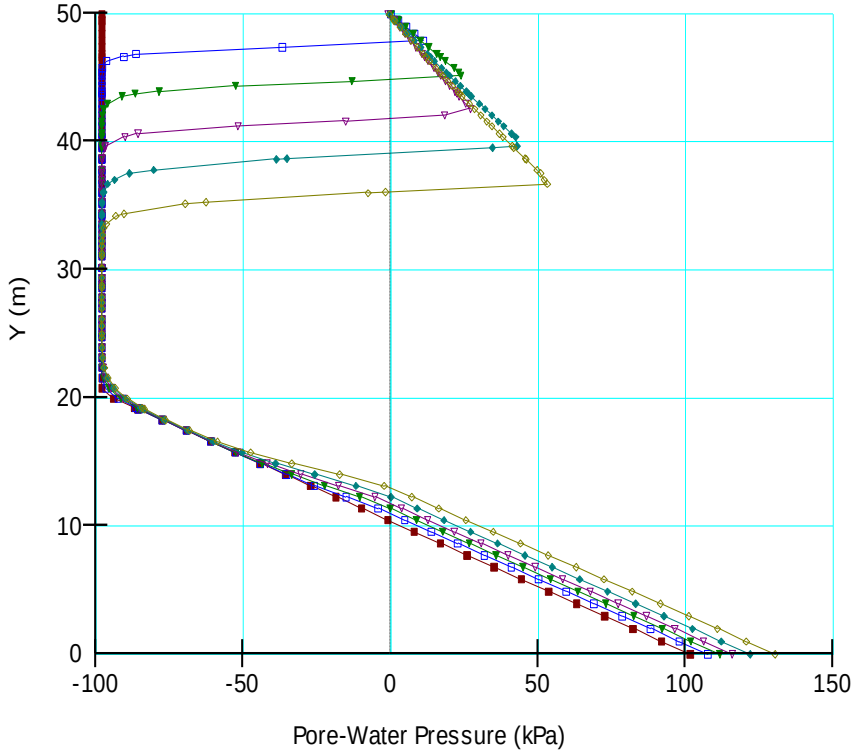


Effect of 5mm/hr Rainfall in a Uniform Slope



Pore Water Pressure Variation Along depth



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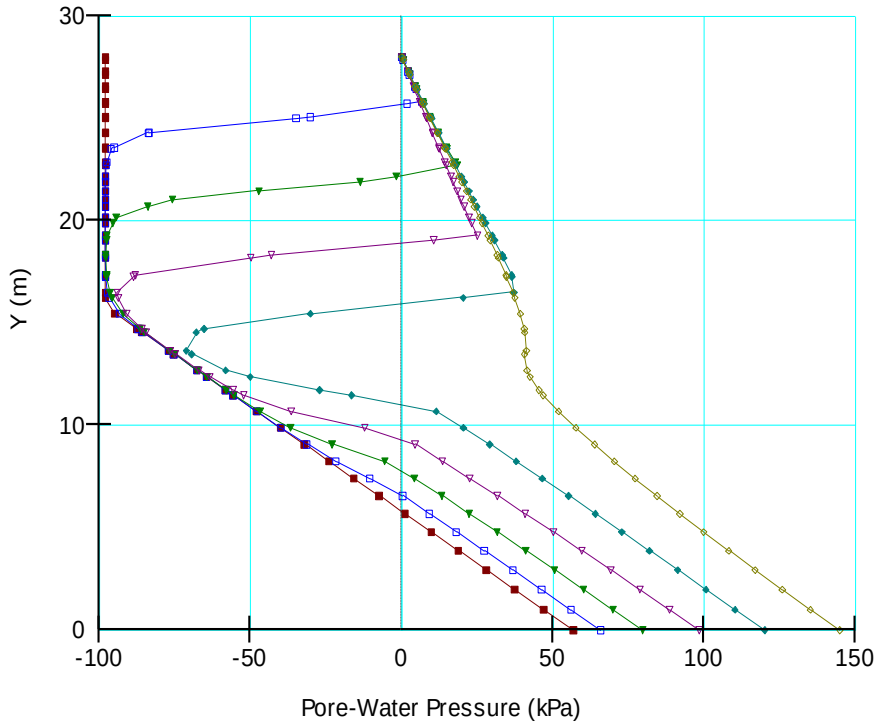
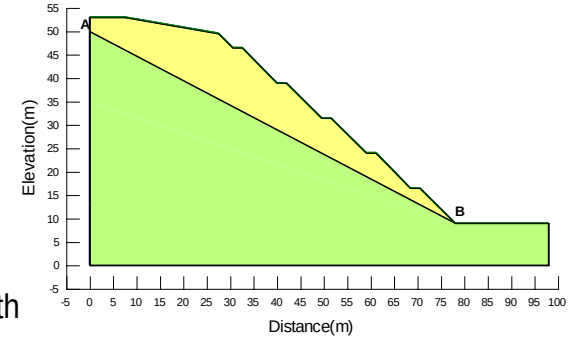
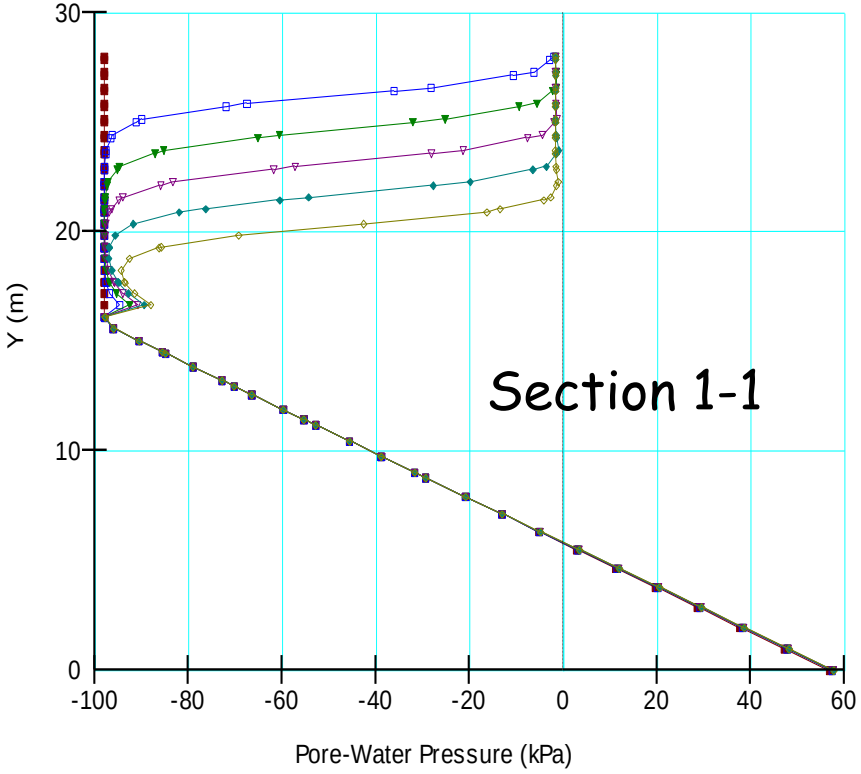


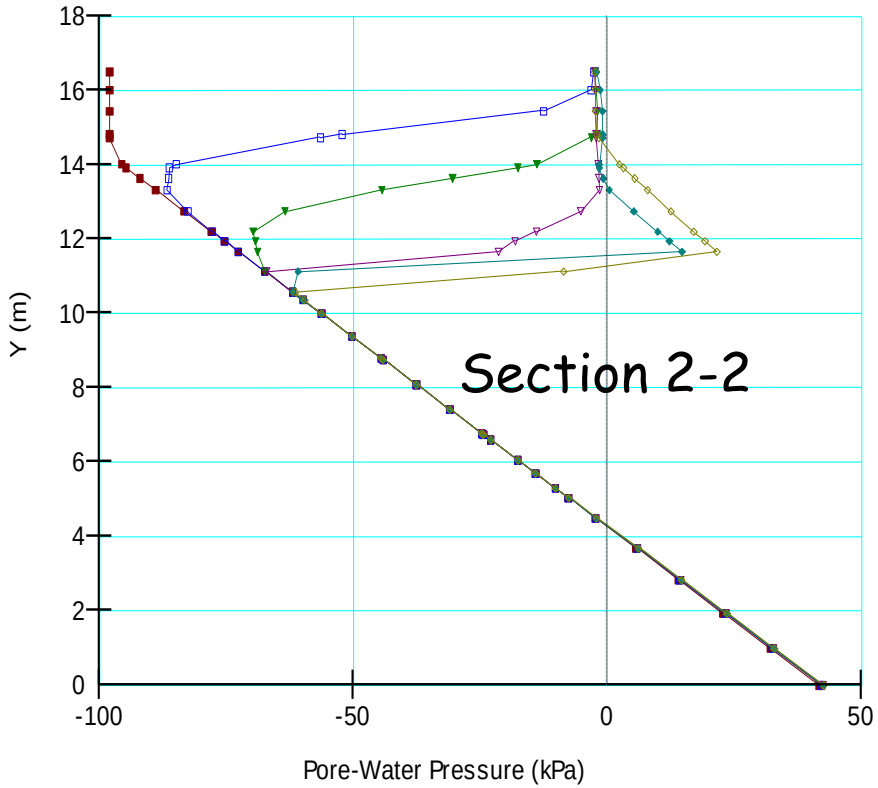
Effect of 20mm/hr Rainfall in a Uniform Slope



Pore Water Pressure Variation Along Depth



Pore Water Pressure Variation Along Depth



Effect of 5mm/hr Rainfall in a stratified Slope
With the presence of highly impermeable weathered rock layer below the residual soil layer

- With the infiltration of water due to rainfall, matric suction will be reduced or completely lost.

- Positive pore water pressures (perched water table condition) may also develop

- Presence of layers of different degrees of weathering (permeability) will affect the changes in the pore water pressure regime.

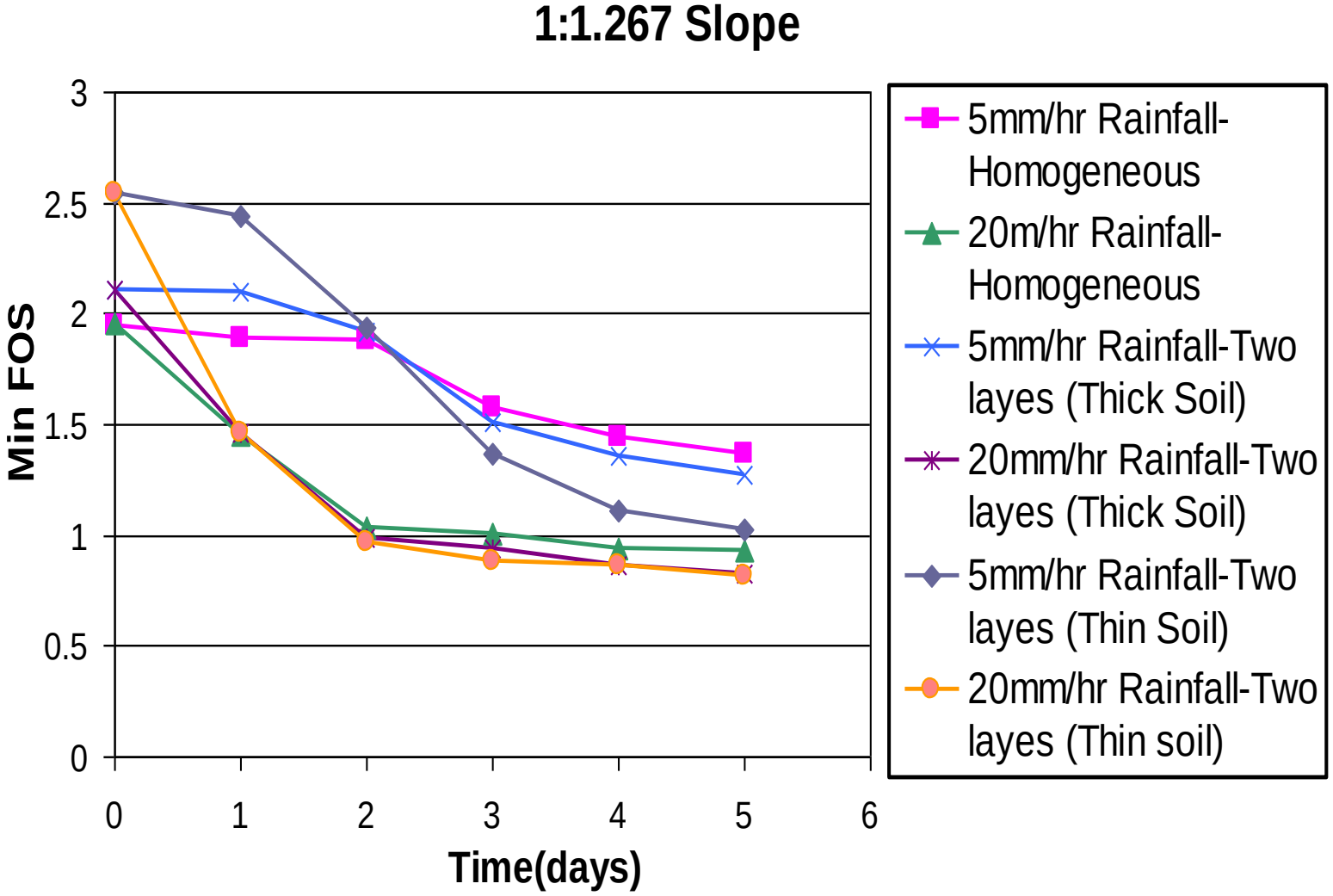
- The shear strength τ_f will decrease

$$\tau_f = c' + (u_a - u_w)\tan \phi^b + (\sigma - u_a) \tan \phi'$$

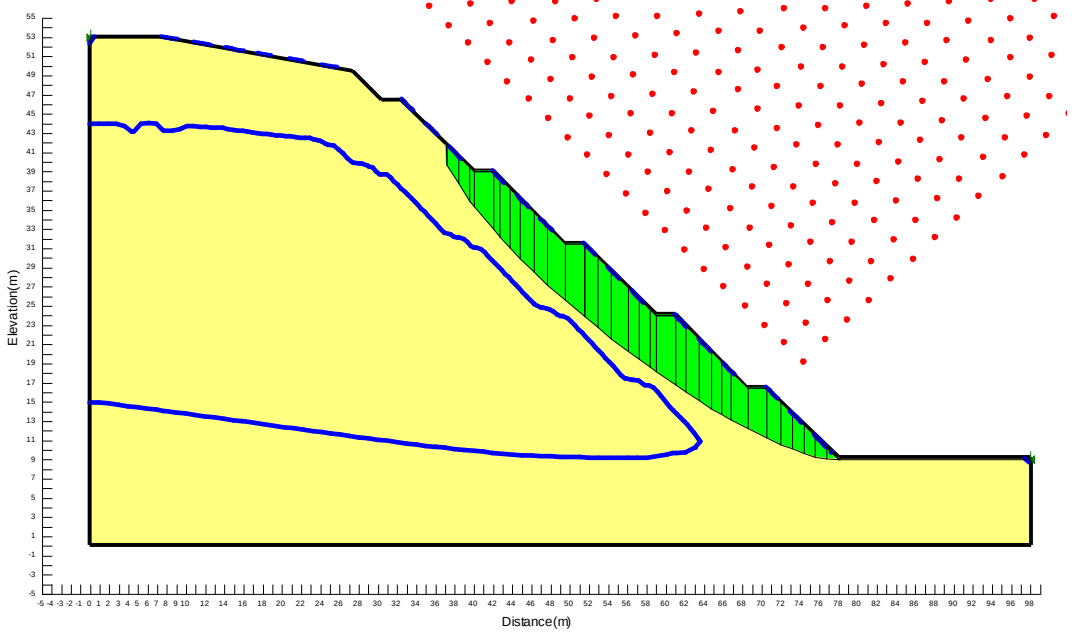
and the Factor of safety τ_f / τ_m will reduce. When it approaches unity slope failures will occur

$$FOS = \tau_f / \tau_m$$

Stability was assessed with SLOPE/W incorporating the pwp changes

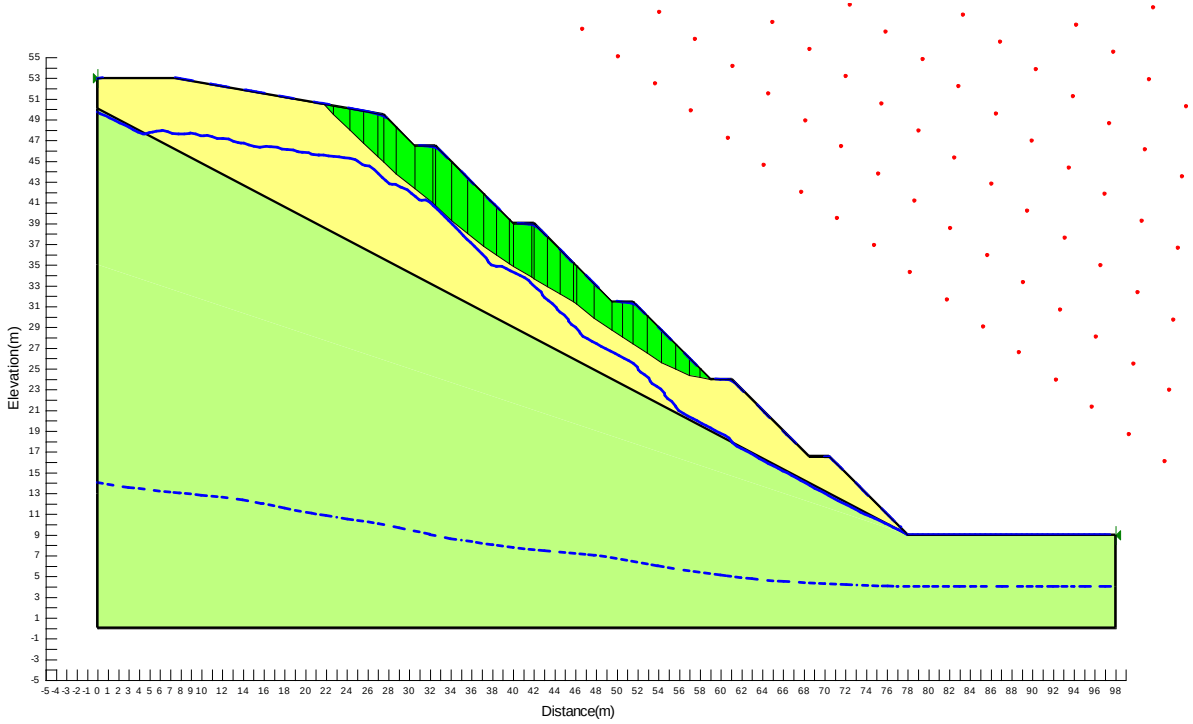


Variation of factor of safety with duration of rainfall – Slope with gradient 1:1.267



Shape of typical critical failure surface -two layers of soil at a later stage

Shape of typical critical failure surface – homogeneous slope at a later stage

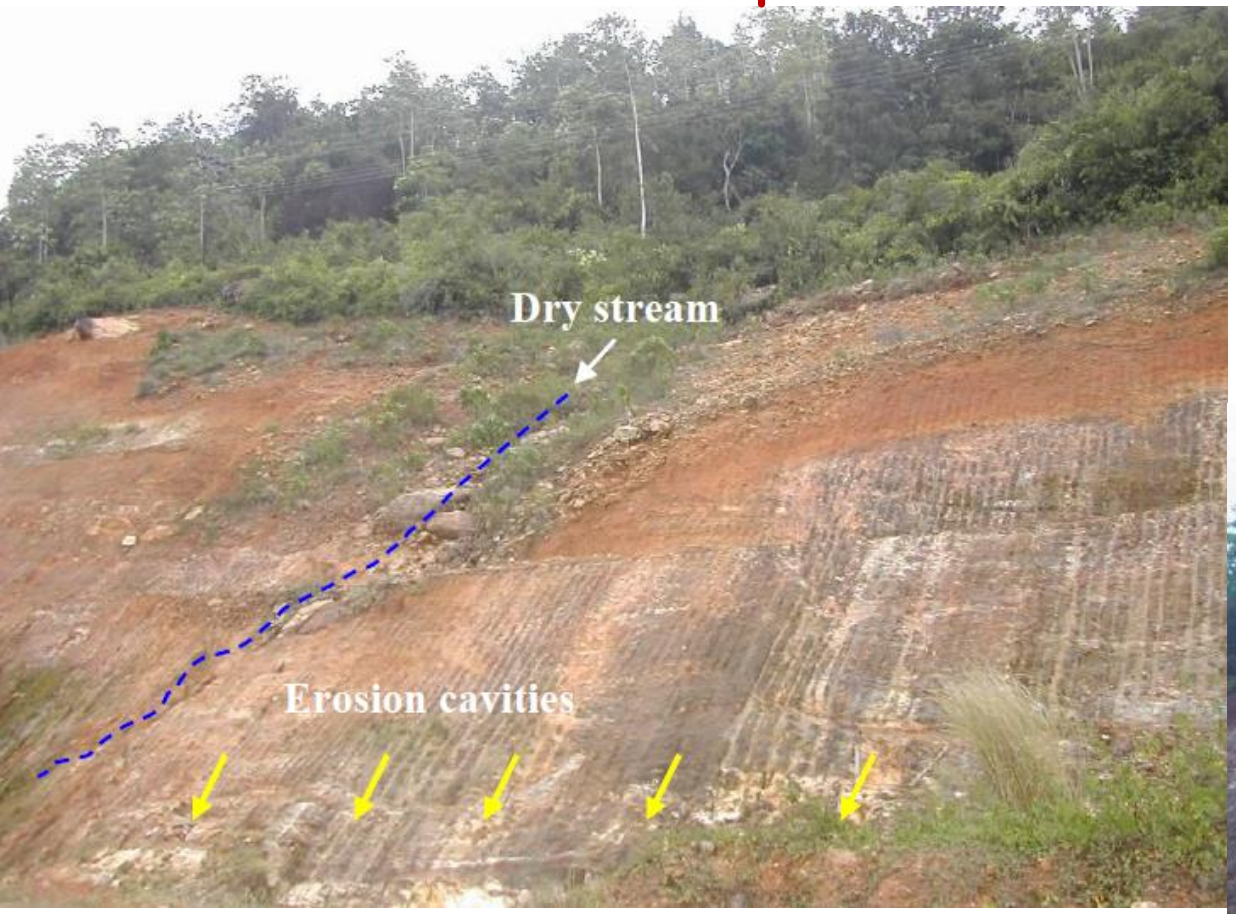


Non-Engineered Construction

Immediately after
cutting 24-3-2014

Two months later after
the rain 14-5-2014

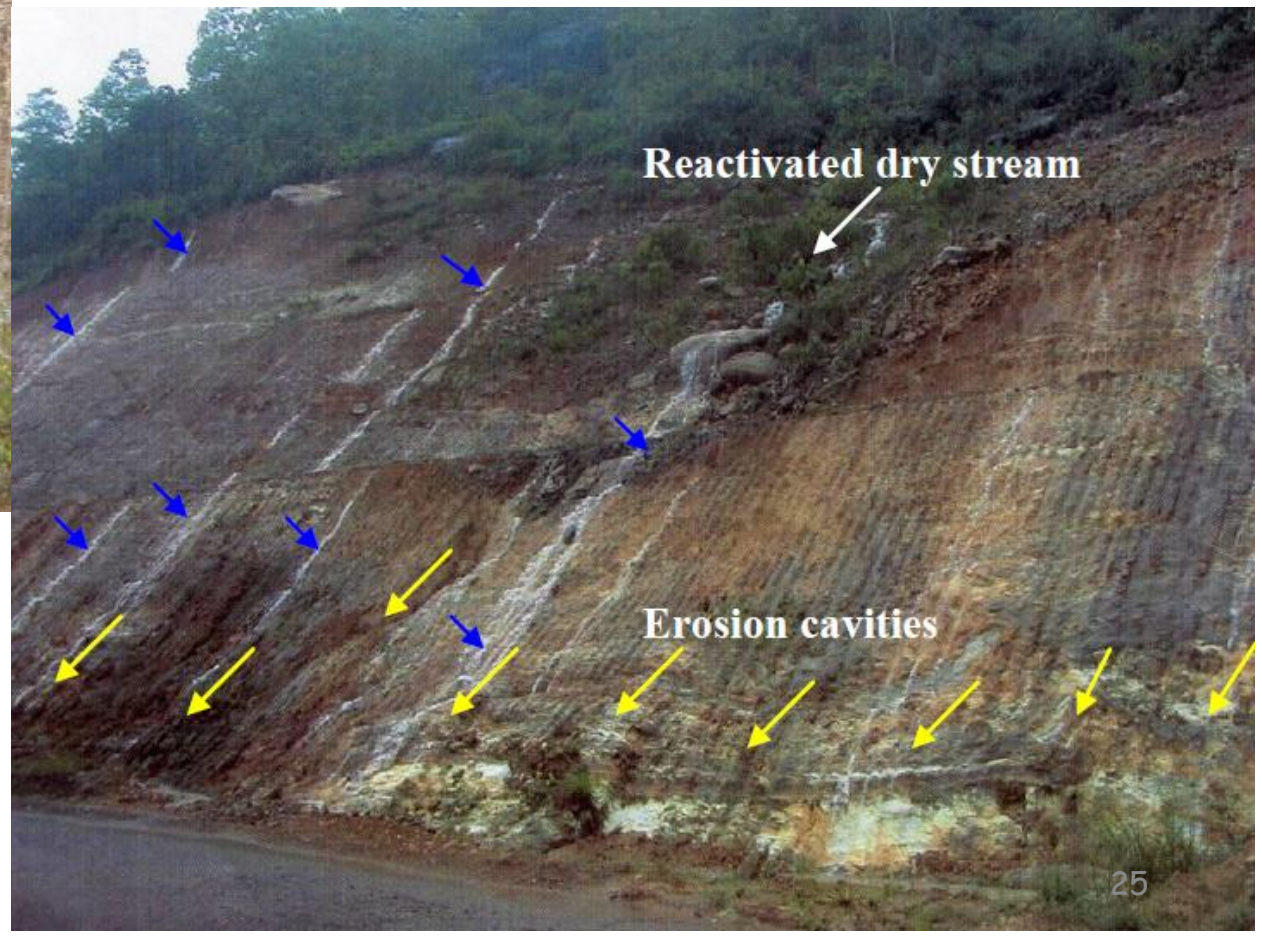
A cut slope in STDP – Galle – Matara segment



Slope during a dry period of weather

Slope was cut but drainage measures were not implemented

Uncontrolled flow of water and infiltration during rainy season

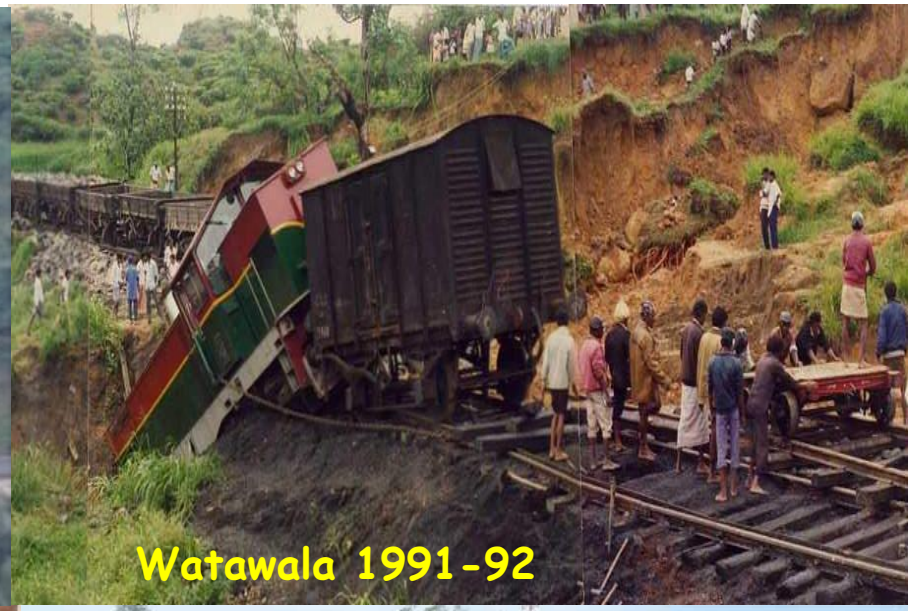


Ended up as a catastrophic failure

A Failure in Southern Expressway at Welipenna

some disturbances in the berm drains and cascade drains installed

Landslides in Sri Lanka (in road network)



Landslides in Sri Lanka (natural slopes)

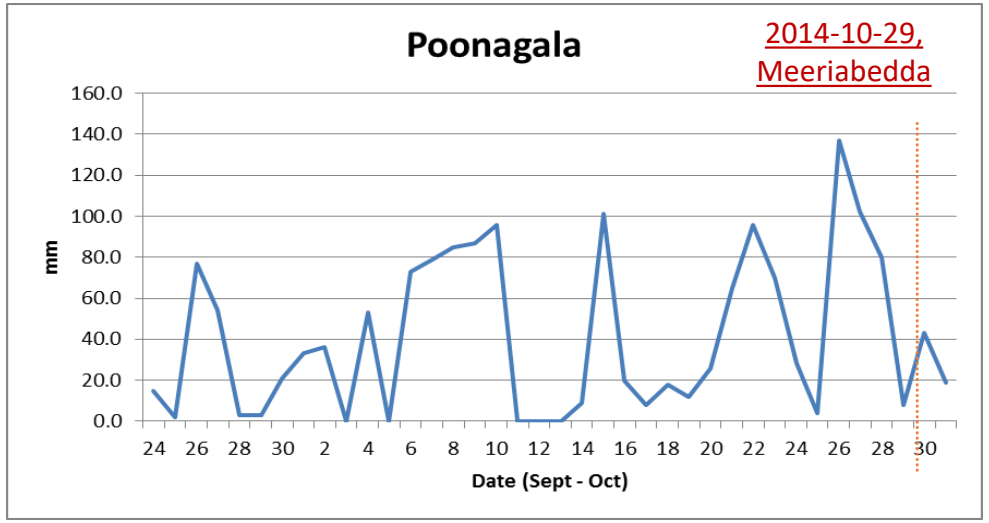

Mulhalkele 1986

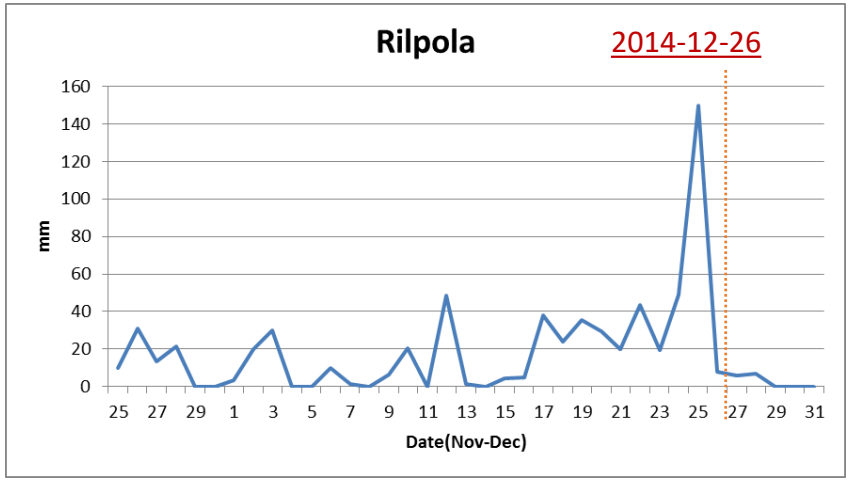

Kalawana 2003

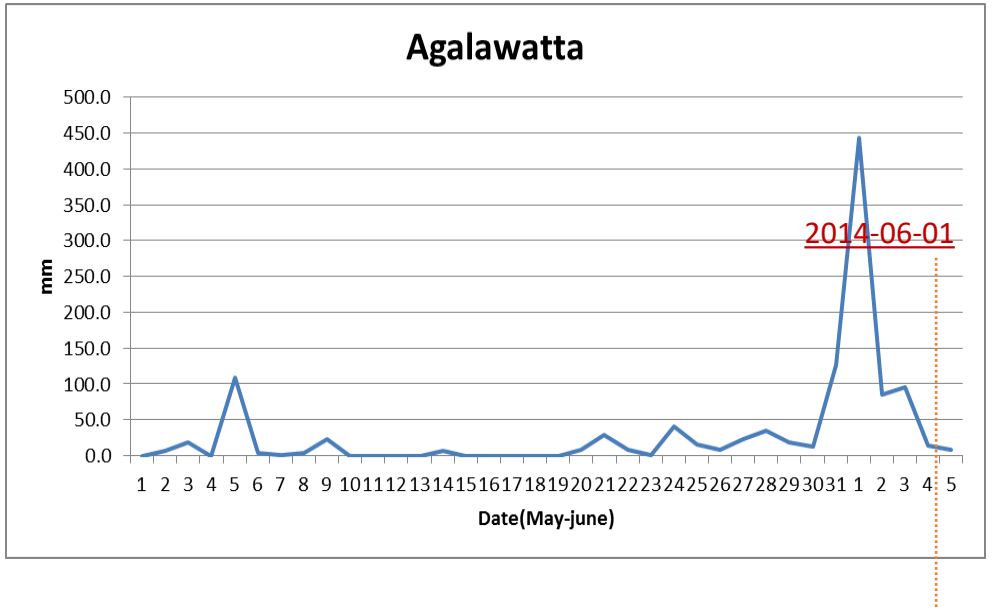

Reactivation of Beragala Landslide (Badulla District) 2009

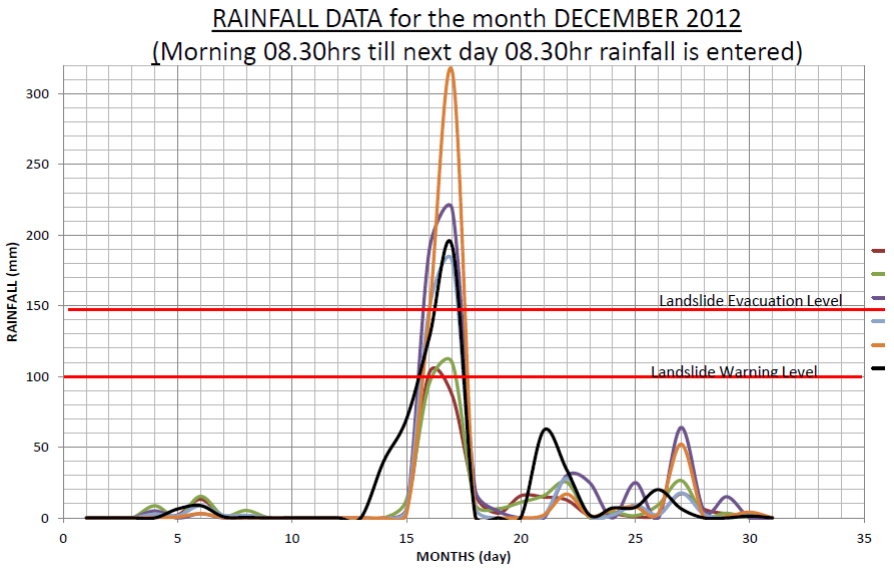

Ladupita,Kiriwanella- Nuwara Eliya District 2007

Main triggering factor is rainfall









Thank You