Rainfall-Induced Landslides

David Toll

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and

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Landslides in Australia?

- "In comparison to many other countries, much of Australia is subject to minimal landslide activity. Generally we receive little rainfall and the landscape has minimal relief being free from the processes of uplift."
- Areas that are affected by landslides commonly have either cliffs or steep colluvial deposits, gentler slopes of unstable geology, and prolonged or intense rainfall
- Areas include:
  - coastal cliffs
  - The Great Dividing Range
  - Strzelecki and Otway Ranges of Victoria
  - Mt Lofty Ranges near Adelaide SA
  - Tamar Valley and north-west coast of Tasmania.
  - More localised areas include the Illawarra Escarpment near Wollongong, the 'northern beaches' area of Sydney, the Lake Macquarie and Newcastle suburbs in NSW and the regions around Townsville, Cairns and Mt Tambourine in Queensland

- Until the Thredbo landslide tragedy in 1997 there had been little public recognition that landslides were a significant threat in Australia.

Geoscience Australia
http://www.ga.gov.au/urban/factsheets/landslide.jsp

"Slope instability occurs in many parts of urban and rural Australia. Indeed it has been estimated that virtually every Local Government Area (LGA) in Australia has landslide hazards of one form or another" - Leventhal & Walker, 2005

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Landslides in Singapore

- Empirical Observations
  - Major Landslides
  - Minor Landslides
  - Effect of Rainfall
- Field Monitoring
  - Measurements of suction in slopes in Singapore
- Numerical Modelling
  - Unsaturated Flow modelling to predict suction changes

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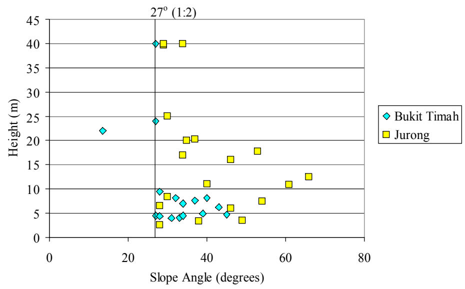
Slope Angle vs. Slope Height for Singapore Landslides



Toll, D. G., Rahardjo, H. and Leong, E. C. (1999) *Landslides in Singapore*, Proc. 2nd International Conference on Landslides, Slope Stability and the Safety of Infra-Structures, Singapore, pp 269-276.

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Landslides at NTU

Slope failures after 95mm of rainfall fell in 2½ hours
26 February 1995
Li (1995)

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Landslides at NUS

Slope failure after 166mm of rainfall
11 January 2006

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Landslide Studies at NTU

A long-term study of landslides at the Nanyang Technological University (NTU) campus in Jurong, West Singapore (200 hectares) provides useful information on minor landslides. Construction of the NTU campus started in the 1950s. Existing natural slopes were terraced and cut at either about 35° or 50-70°.

- Pitts (1983, 1985) mapped the occurrence of landslides up to March 1984. He observed spates of landslides associated with periods of heavy rain in November 1982 and January-March 1984. A total of 70 minor landslide events were observed up to this time, with another 9 additional slides due to reactivation of earlier slips.
- Chatterjea (1989) mapped the campus again after another heavy rainfall period in January 1987 and observed a further 9 slides.
- Li (1995) provides additional data after heavy rain in February 1995 when 20 more slides were observed.

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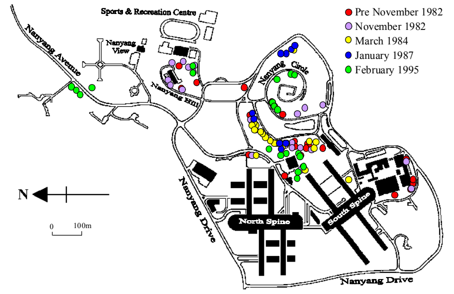
NTU Landslide



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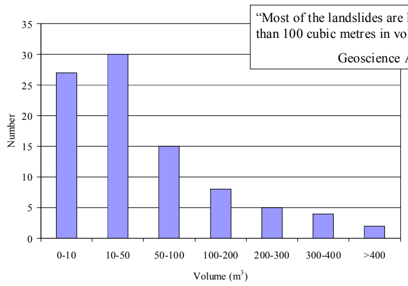
NTU Landslides (Volume)

"Most of the landslides are less than 100 cubic metres in volume."
Geoscience Australia



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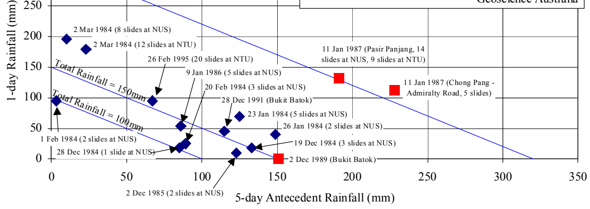
Antecedent Rainfall (5 day)

"The rainfall threshold values for slope failure are in the range 8 - 20 mm over one hour, or 50 - 120 mm over a day, depending on geology and slope conditions."
Geoscience Australia



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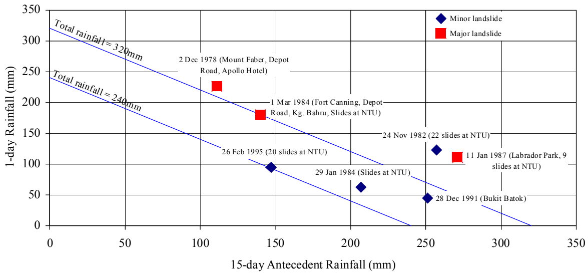
Toll, D.G. (2001) *Rainfall-induced Landslides in Singapore*, Proc. Institution of Civil Engineers: Geotechnical Engineering, Vol. 149, 4, pp. 211-216.

Antecedent Rainfall (15 day)



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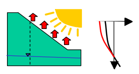
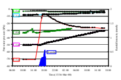
A Deeper Understanding…

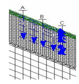
- Concepts



- Field measurements



- Numerical Modelling



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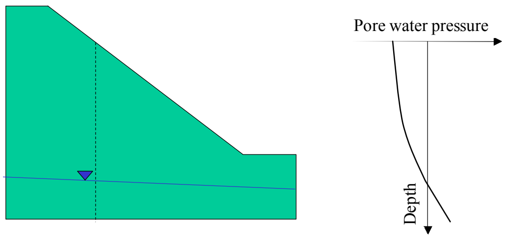
Pore water pressures – Deep water table



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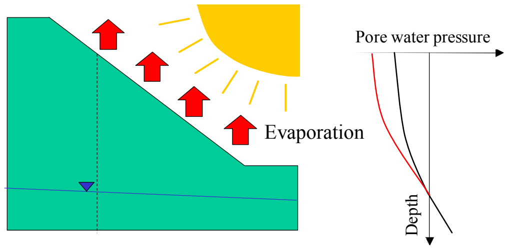
Pore water pressures



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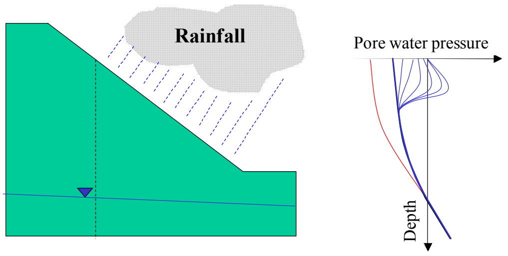
Pore water pressures



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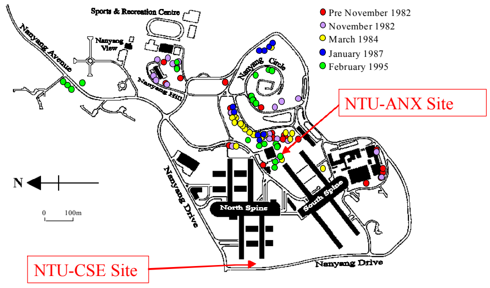
Instrumented sites

Rahardjo, H., Leong, E.C., Deutcher, M.S., Gasmo, J.M. and Tang, S.K. (2000) *Rainfall-induced Slope Failures*, Geotechnical Engineering Monograph No. 3, NTU-PWD Geotechnical Research Centre, Singapore.

Instrumented Site Locations



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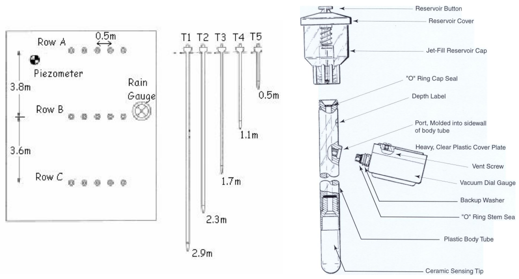
Instrumentation



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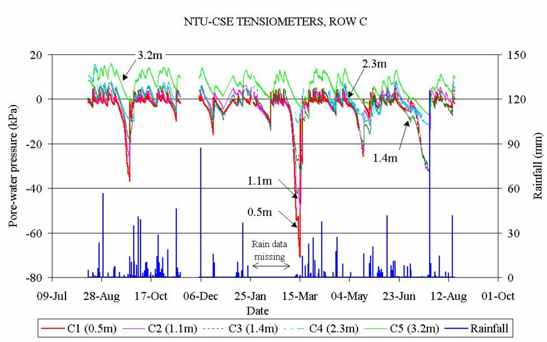

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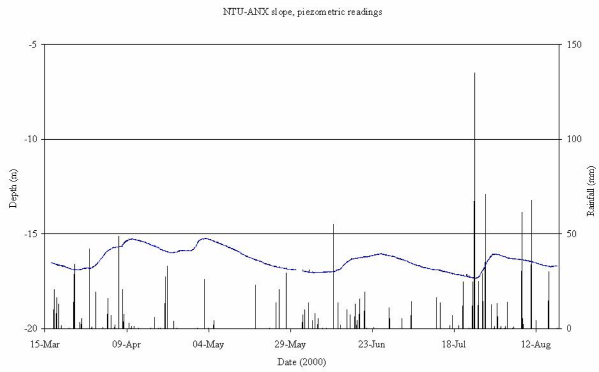
Tsaparas, I., Rahardjo, H., Toll, D. and Leong, E.C. (2003) *Infiltration Characteristics of Two Instrumented Residual Soil Slopes*, Canadian Geotechnical Journal, Vol. 40, No. 5, pp. 1012-1032.



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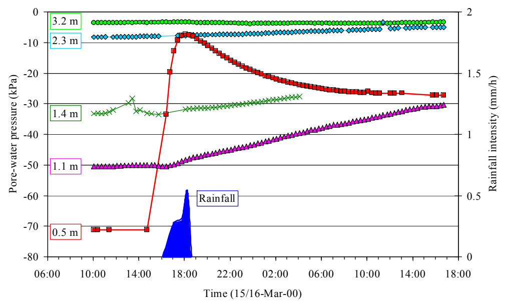
March 2000 (Dry period)



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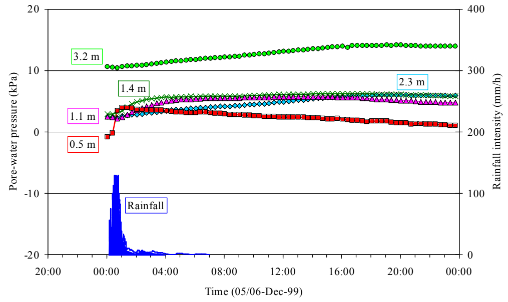
Toll, D.G., Tsaparas, I and Rahardjo, H. (2001) *The Influence of Rainfall Sequences on Negative Pore-water Pressures within Slopes*, Proc. 15th International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, Rotterdam: Balkema, Vol. 2, pp 1269-1272.

Dec 1999 (Wet period)



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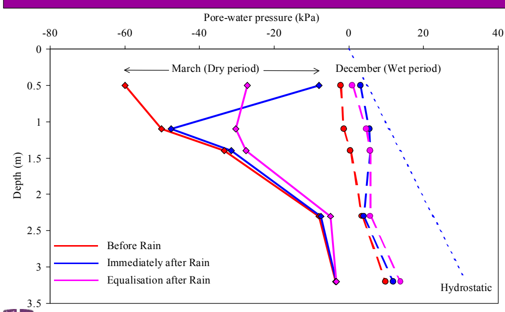
Pore water pressure profiles



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Rainfall Simulator

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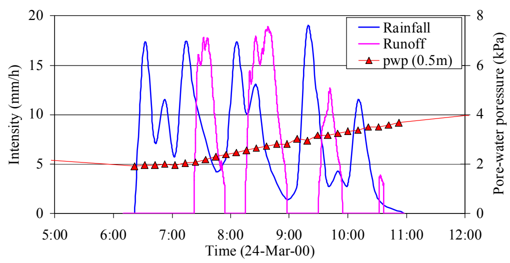
Runoff due to Natural Rainfall



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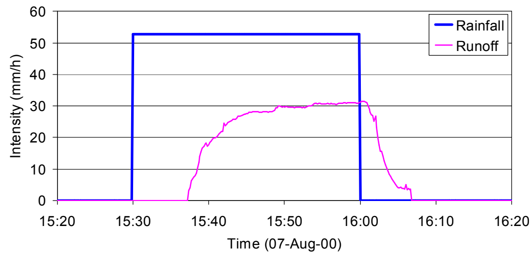
Runoff from Simulator



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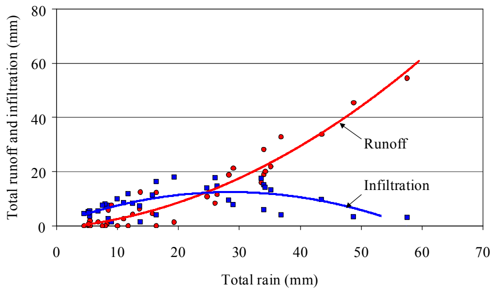
Runoff and Infiltration – Field Measurements



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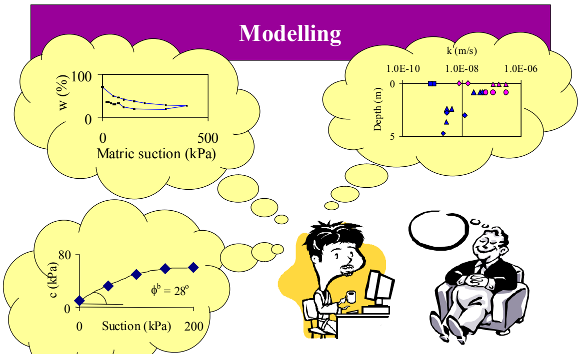
Modelling



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Numerical modelling

- Numerical modelling of transient, unsaturated flow using SEEP/W
- Comparison with field measurements from the residual soil slopes from Singapore
  - Natural and simulated rainfall events
    (6 months data – 63 significant rainfall events (>5mm))
  - Rainfall and runoff data
  - Pore-water pressure data

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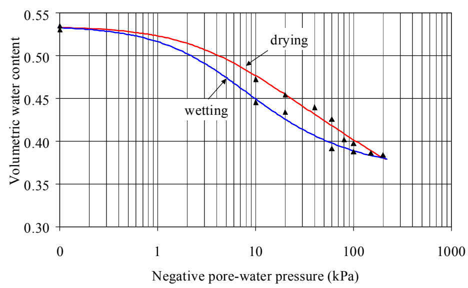
Water Retention Curve



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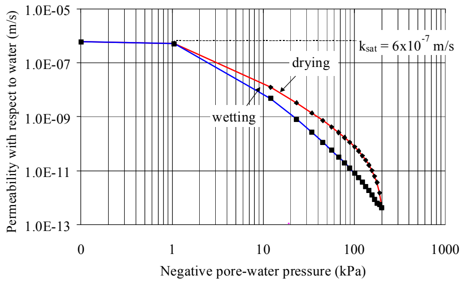
Unsaturated Permeability Function



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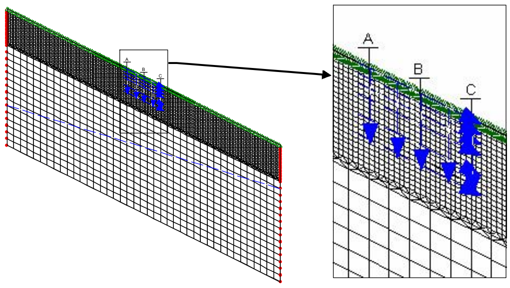
Finite Element Mesh (Seep/W)



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Preliminary modelling

- Using k_{sat}=6x10^{-7} m/s (as measured at 0.4 m depth) gave good match for pore-water pressure responses, but not infiltration
- Using k_{sat}=5x10^{-5} m/s gave good match for infiltration, but not pore-water pressure responses
- It was recognised that the presence of vegetation and surface desiccation increased permeability in the near surface material. This was modelled with a 0.25m thick more permeable surface layer (k_{sat}=5x10^{-5} m/s)

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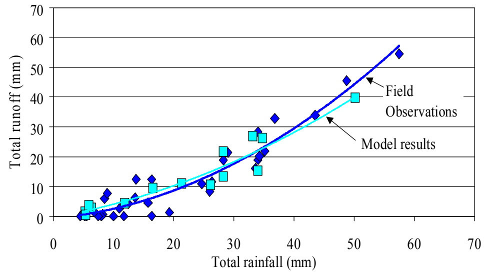
Comparison of Modelling with Field Results



Tsaparas, I. and Toll, D.G. (2002) *Numerical Analysis of Infiltration into Unsaturated Residual Soil Slopes*, in Unsaturated Soils (eds. Jucá, J.F.T., de Campos, T.M.P. and Marinho, F.A.M) Proc. 3rd International Conference on Unsaturated Soils, Recife, Brazil, Lisse: Swets & Zeitlinger, Vol 2, pp. 755-762.

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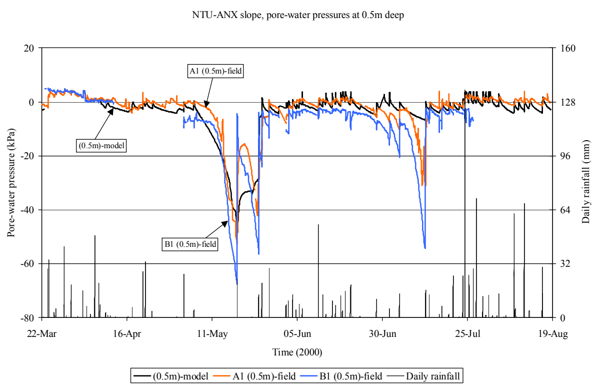

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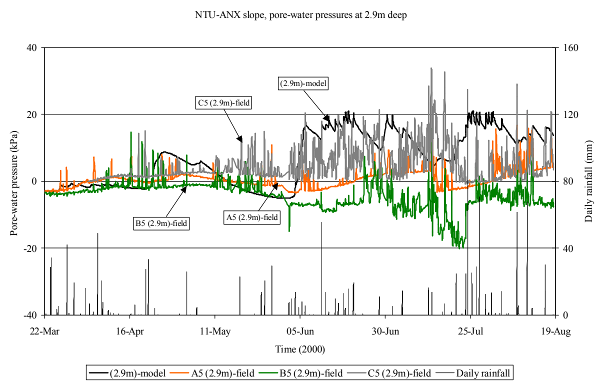

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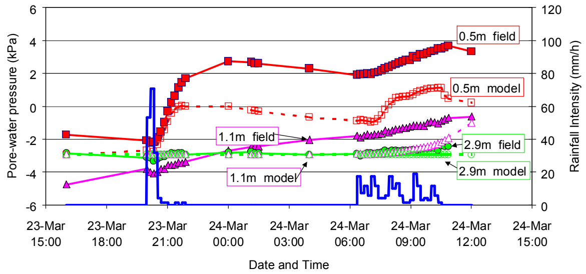
Comparisons of Pore-Water Pressure changes



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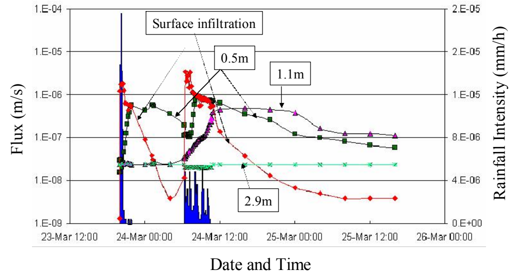
Flow Patterns with Depth



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Tsaparas, I. and Toll, D.G. (2003) *Factors affecting Infiltration into an Unsaturated Soil Slope*, Proc. 2nd Asian Conference on Unsaturated Soils (UNSAT-ASIA 2003), Osaka, Japan, pp. 463-468.

Conclusions (Field data)

- Rainfall is the dominant triggering event for landslides. In Singapore, the periods when a significant number of major slips occurred were periods of very heavy rainfall (>110mm/day). Minor landslides occurred after lower rainfalls if a total rainfall of 100mm had fallen within a six day period.
- During dry periods, small amounts of rain can produce significant changes in pore water pressure. However, when the ground is wet, large quantities of rain may produce only small changes in pore water pressure.
- To understand the pore water pressure response we need to be able to identify the balance between runoff and infiltration.

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Conclusions (Modelling)

- ❑ Agreement between runoff/infiltration measurements and pore-water pressure trends from numerical modelling could only be achieved by assuming the presence of a more permeable surficial layer (due to the presence of vegetation and surface cracking)
- ❑ A perched water table develops and pore-water pressures increase to hydrostatic values near the surface. Downslope flow takes place within this near-surface zone.
- ❑ Only small amounts of rainwater infiltrate to lower levels and therefore only small changes in pore-water pressure occur at depth

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