Hillslope hydrology in landslide research

Hydrology as connection between Earth Science and Civil Engineering

- Land degradation, mass movement and landslides
- Hillslope hydrology & landslides
- Problem: how and where does the water flow?
- Tracing water within landslides
- Distributed Temperature Sensing
- Research challenges

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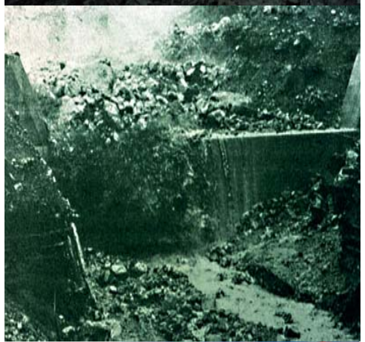
Land degradation classification

1. **Internal soil deterioration**
   - Sealing and crusting
   - Compaction
   - Waterlogging
   - Aridification
   - Urbanisation
2. **Soil material displacement**
   - Soil erosion by water
   - Soil erosion by wind
   - Mass movement
3. **Chemical soil degradation**
   - Loss of nutrients
   - Acidification
   - Discontinuation flood-induced fertility
   - Acid soil formation
   - Salinisation and alkalinisation
   - Pollution
4. **Biological degradation**
   - Reduction of soil biological activity
   - Reduction of biological diversity
   - Degradation of forest and other ecosystems

Falls - Topples - **Slides** - Spreads - **Flows**

APPENDIX 1.1 Classification of landslides suggested by Varnes (1978)

Type of movement			Type of material		
			Bedrock	Engineering soils	
				Predominantly coarse	Predominantly fine
Falls			Rockfall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	rotational	few units	Rock slump	Debris slump	Earth slump
	translational	many units	Rock block slide	Debris block slide	Earth block slide
			Rock slide	Debris slide	Earth slide
Lateral spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow	Earth flow (soil creep)
Complex			Combination of two or more principal types of movement		

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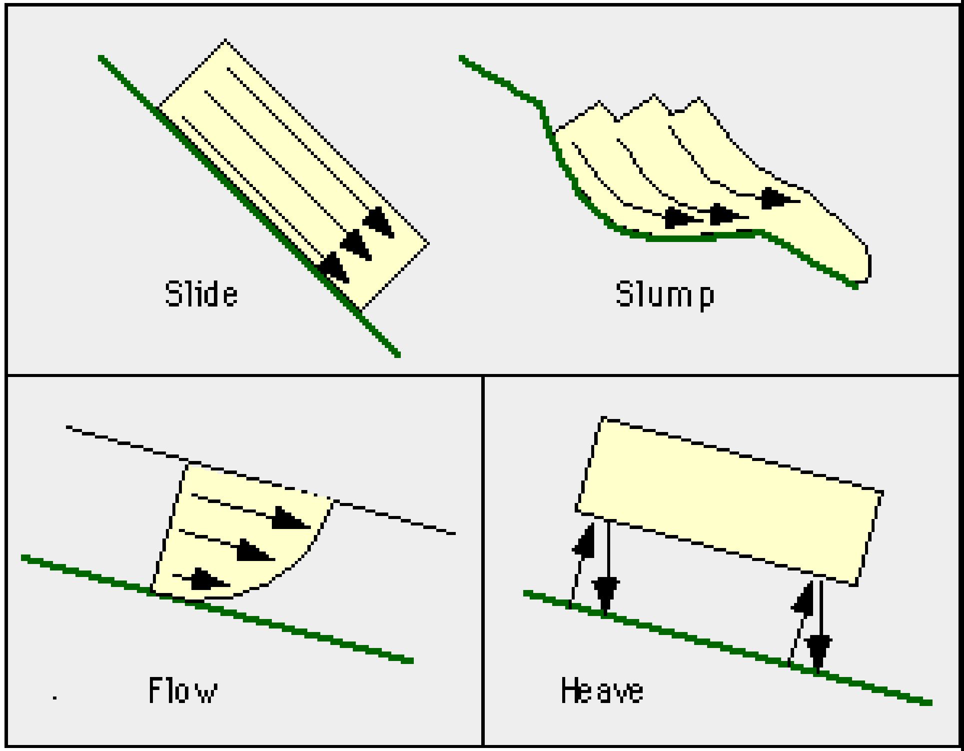
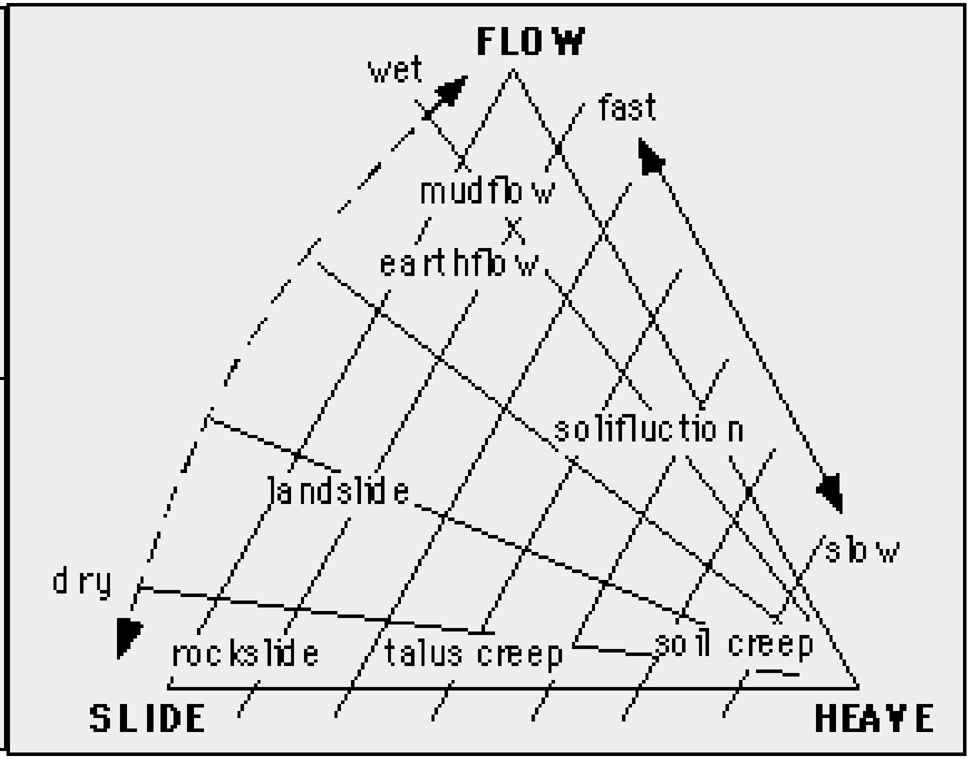
Lateral movement classification





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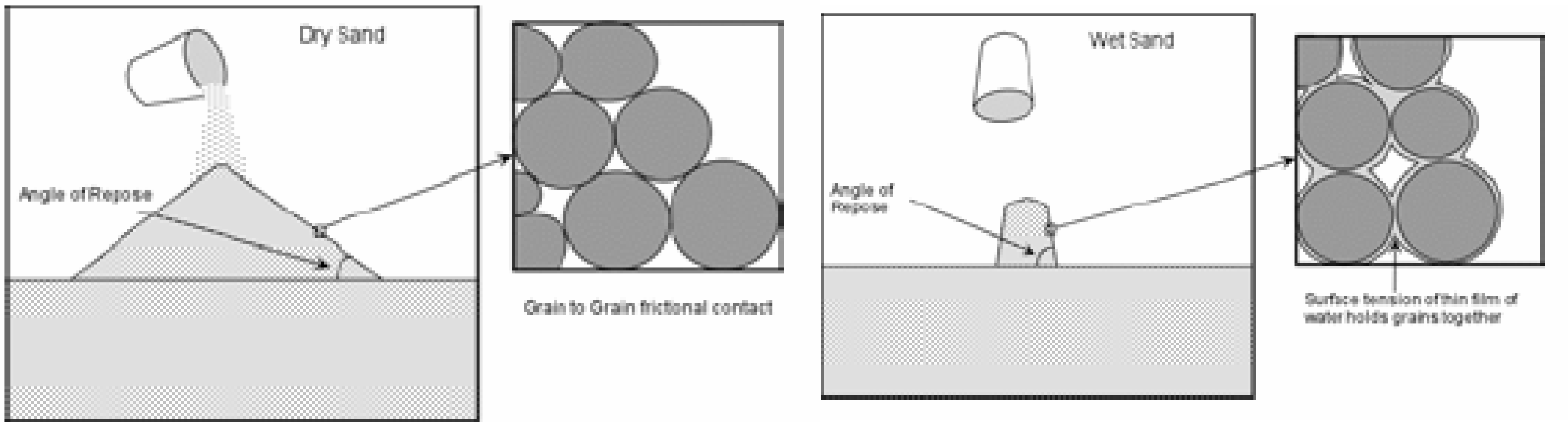
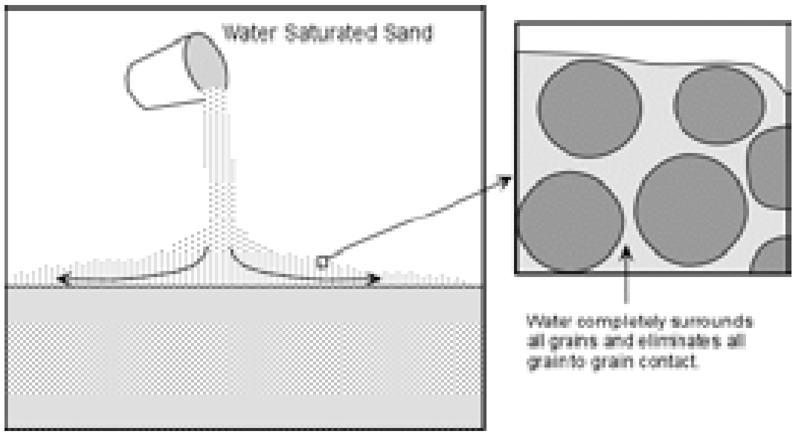
The role of water





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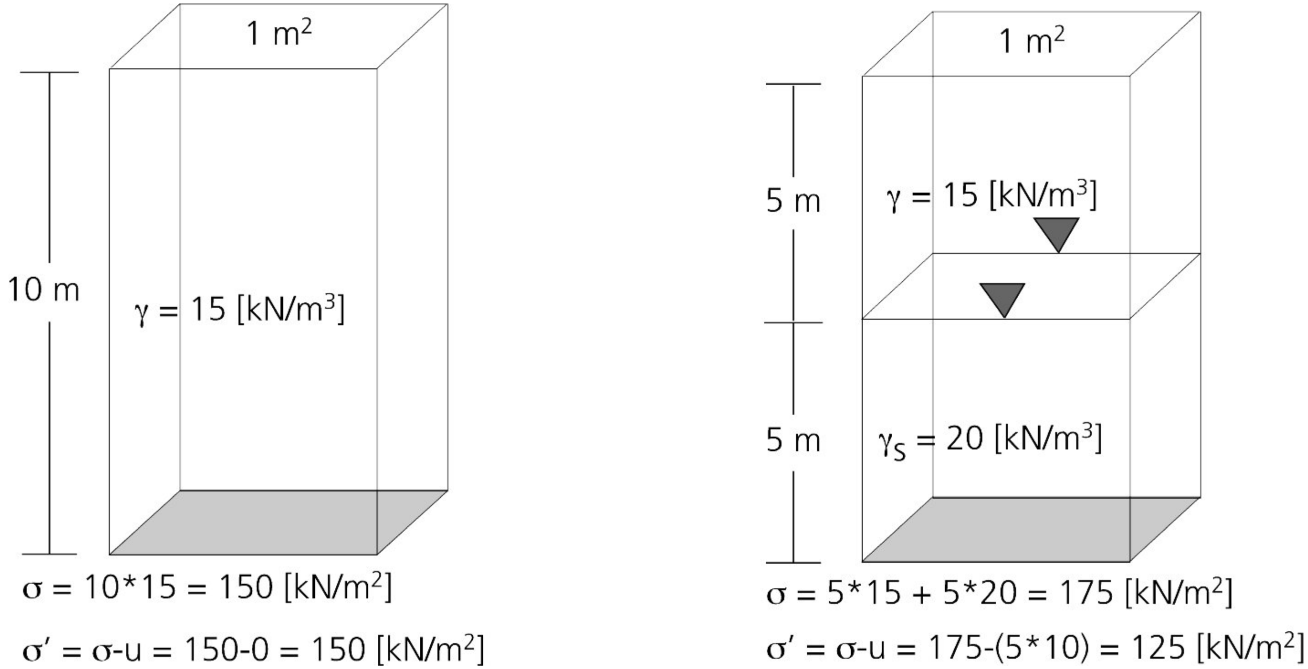
Submerged stress: principle of effective stress



$$\tau = (\sigma - u) \cdot \tan\varphi + C = \sigma' \cdot \tan\varphi' + C'$$

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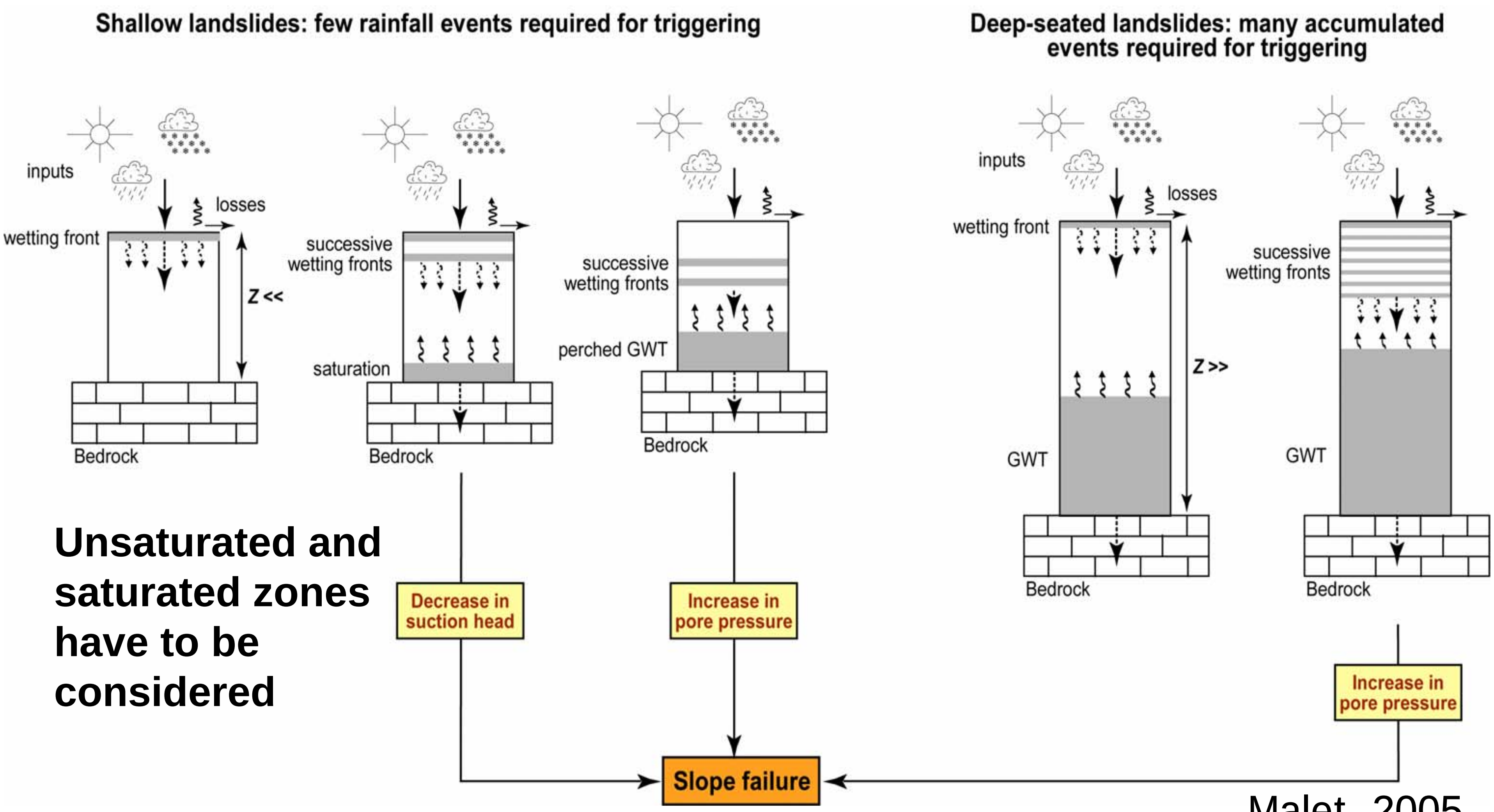
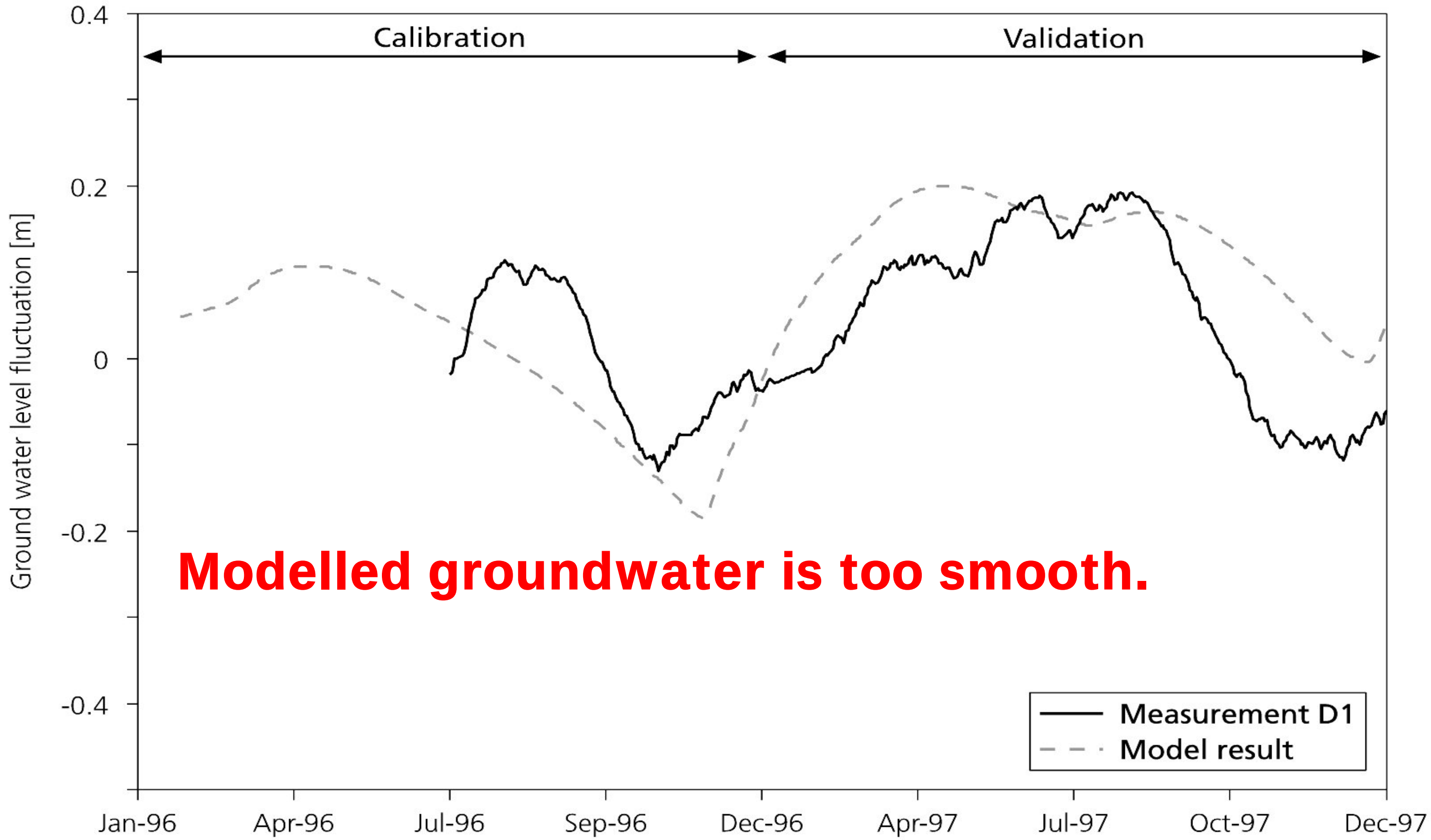
Frequency-Magnitude relationship



Unsaturated and saturated zones have to be considered

Malet, 2005

We often are only capable of modelling the groundwater fluctuation range



Bogaard, 2001

Problem: how and where does the water flow?

Super-Sauze, France

Salins-les-Bains, France

Draix, France

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Problem: how and where does the water flow?

Trieves, France

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How does water flow in hillslopes?

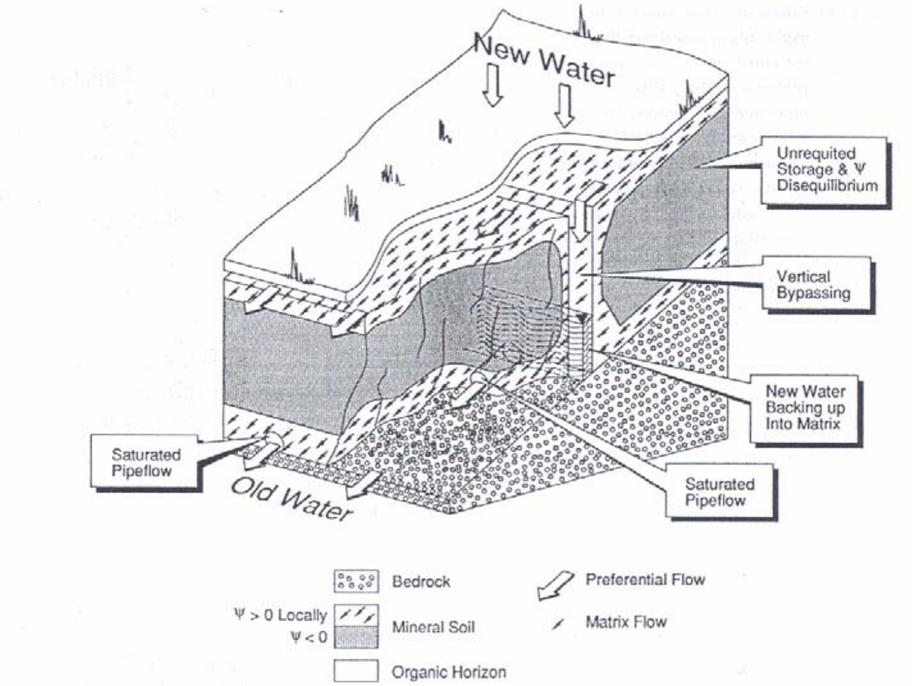


Fig. 11.10 **Perceptual runoff production mechanisms in a midslope hollow of a humid catchment in New Zealand. As shown, the precipitation rate (*P*) exceeds the hydraulic conductivity (k_0) of the mineral soil, and moves down through vertical cracks. The invading new water perches at the soil–bedrock interface, and backs up into the newly saturated soil matrix, where it mixes with the much larger volume of stored old water. Once free water (with positive pore water pressures) exists, the larger pipes in the lower soil zones quickly dissipate transient water tables laterally downslope, producing a rapid throughflow response of well-mixed, albeit mainly pre-event water. (From McDonnell, 1990.)**

McDonnell, 1990

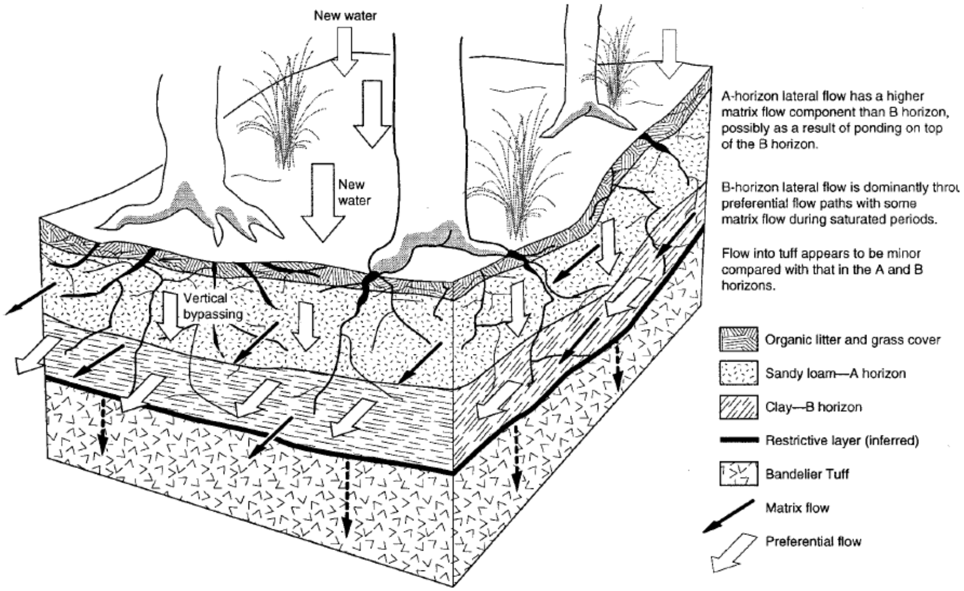


Figure 9. Illustration of the conceptual flow model for the hillslope.

Newman, 1998

How does water flow in hillslopes?

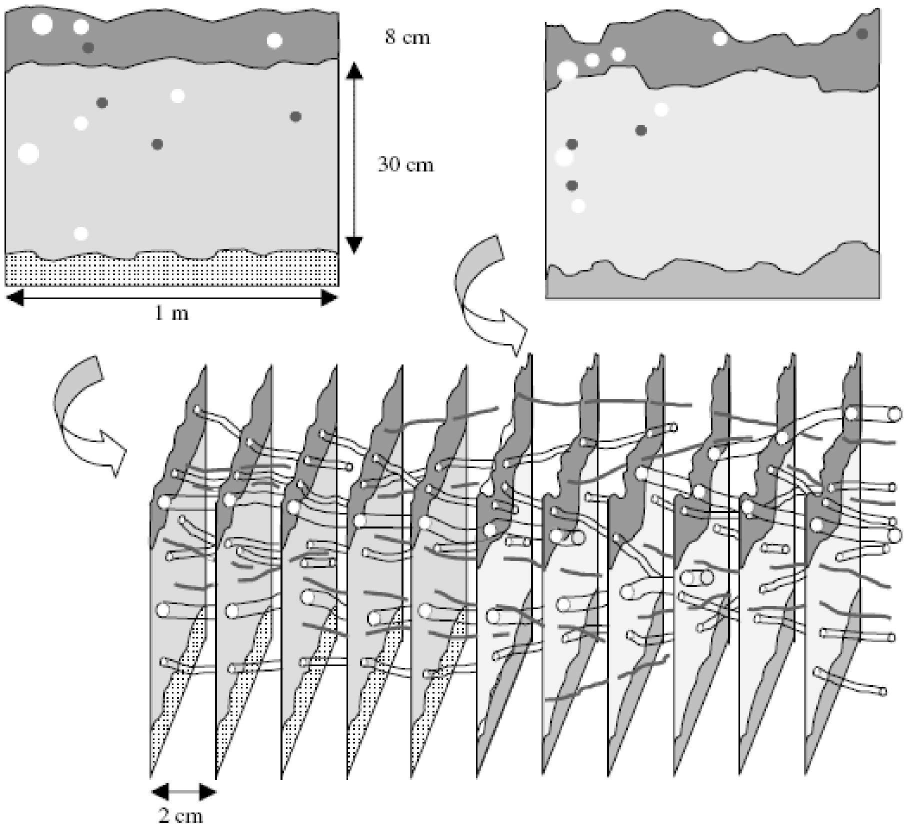
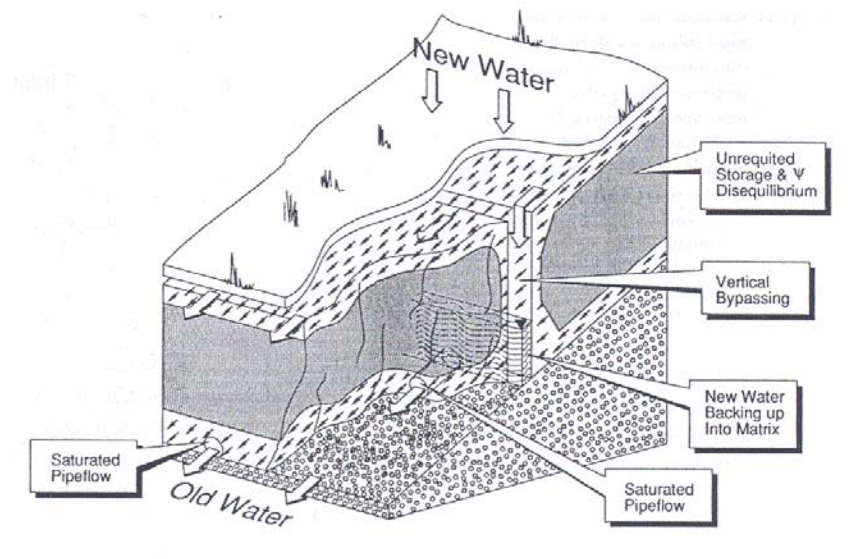
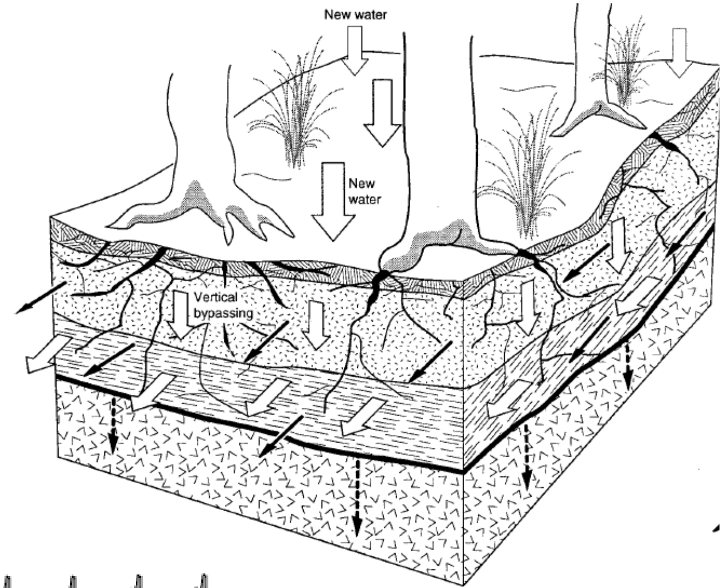


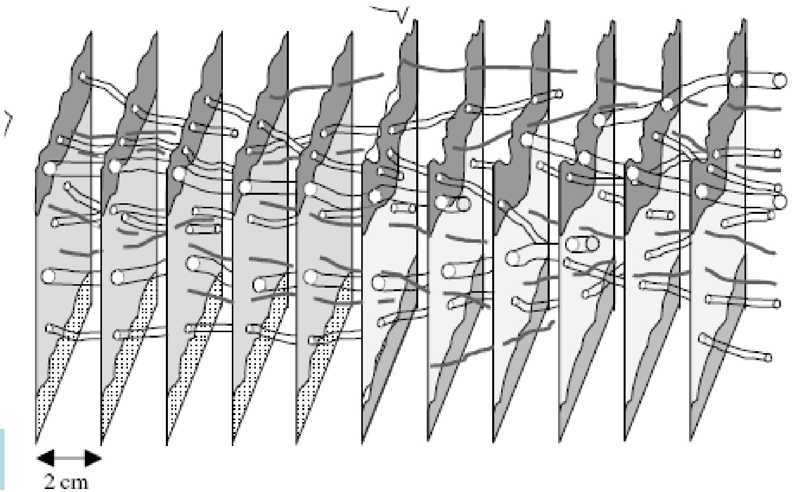
Figure 10. Schematic showing the upslope propagation of simulated macropores based in consecutive 2 cm slices in each 10 cm hillslope segment. Upslope propagation is based on randomly sampled attributes from PDFs of macropore length, diameter, and vertical and planar orientations, as well as distribution index and tortuosity *versus* length relationship

Sidle et al, 2001

How does water flow in hillslopes?







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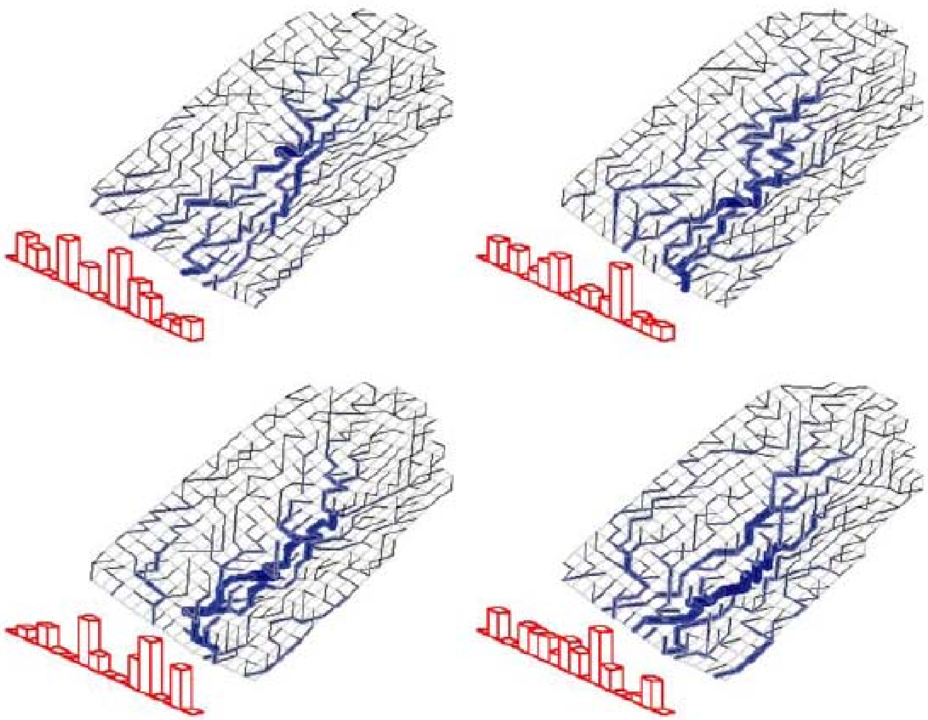
Flow in connected pipe network in hillslopes

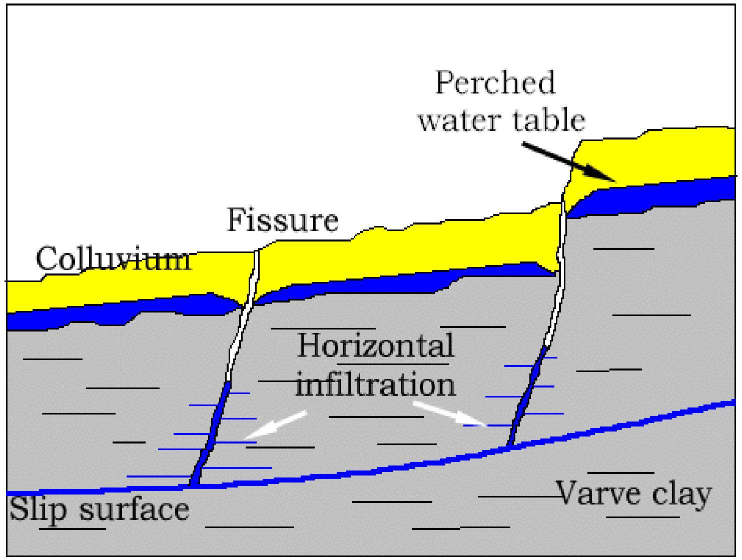


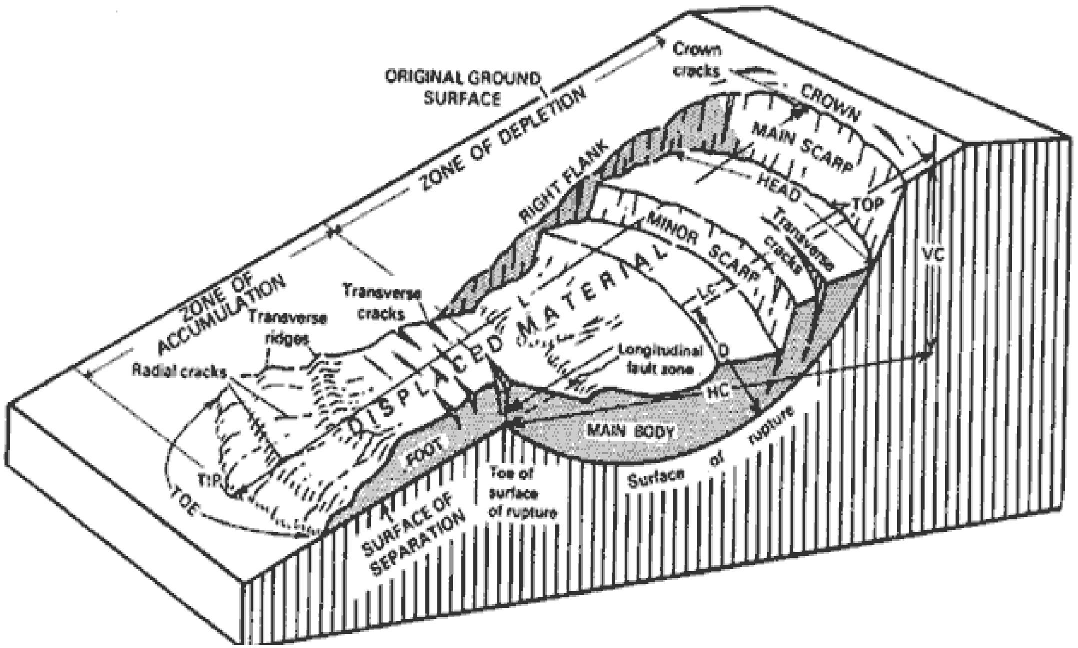
Weiler and McDonnell, 2007

Figure 8. Four realization of the potential pipe network (black lines) and the actual pipe network (blue lines) for the storm event on 25 January 1993 at a time of 27 hours (1 hour before peak flow). The thickness of the actual blue pipes reflects the relative amount of water flowing in an individual pipe. The red bar graph at the base of the hillslope shows the relative pipe outflow from each grid cell.

Landslide vs hillslope hydrology *paradox* :
Rainwater travels fast to the outlet to initiate floods but also to the groundwater to initiate failure!

Rapid rise of groundwater (Gillham, 1984)
Limited drainage
Preferential flow





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Landslide vs flood *paradox* ?

Dresden, flood

Boulc-Mondores landslide

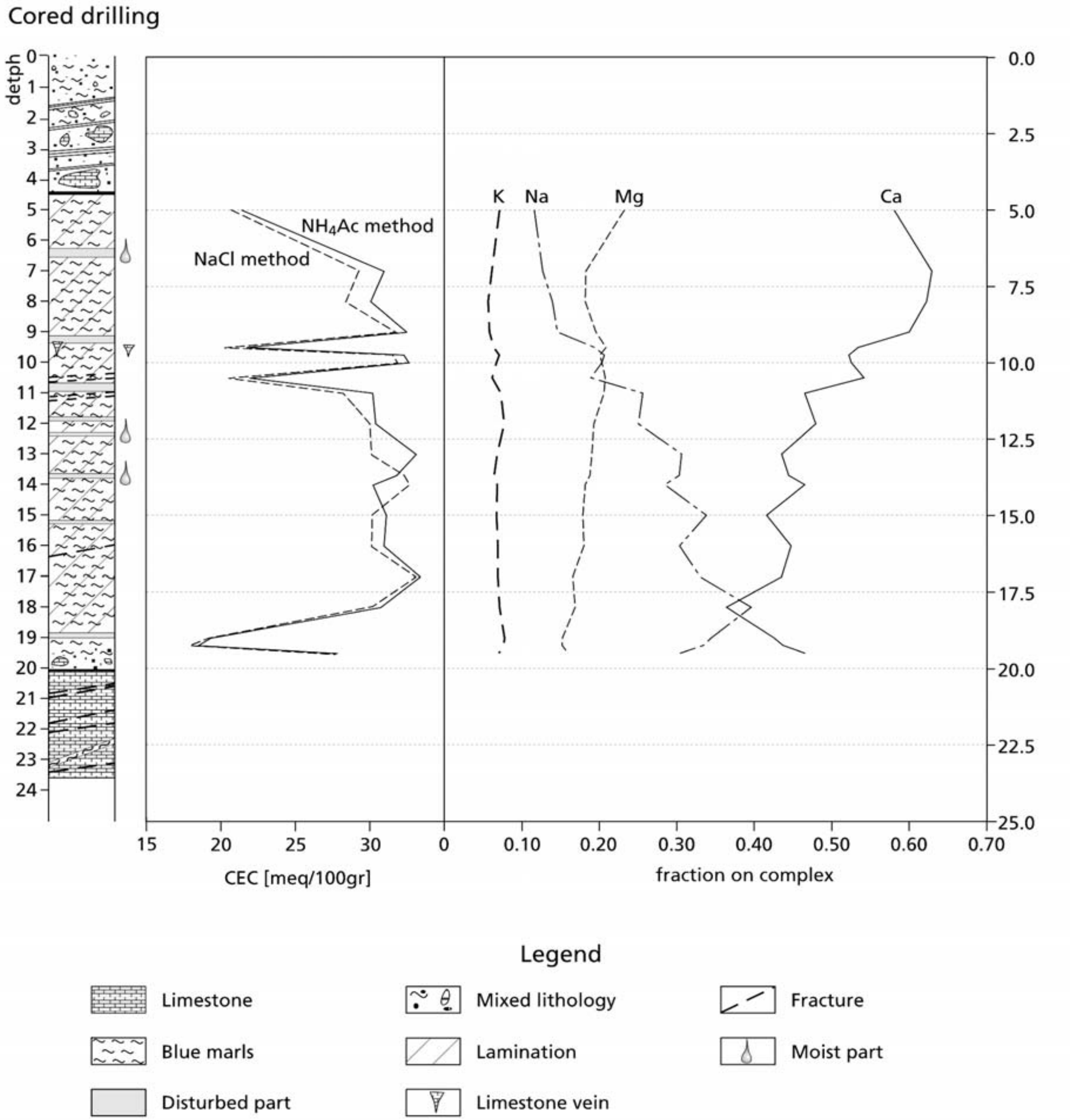
Tracing water: hydrogeochemistry in landslides

- Geochemistry: Boulc-Mondorès, Drome, France
- Hydrochemistry: Super-Sauze, Ubaye, France
- Isotopes: la Clapière, near Grenoble, France

Distributed Temperature Sensing: Fibre Optic Cable

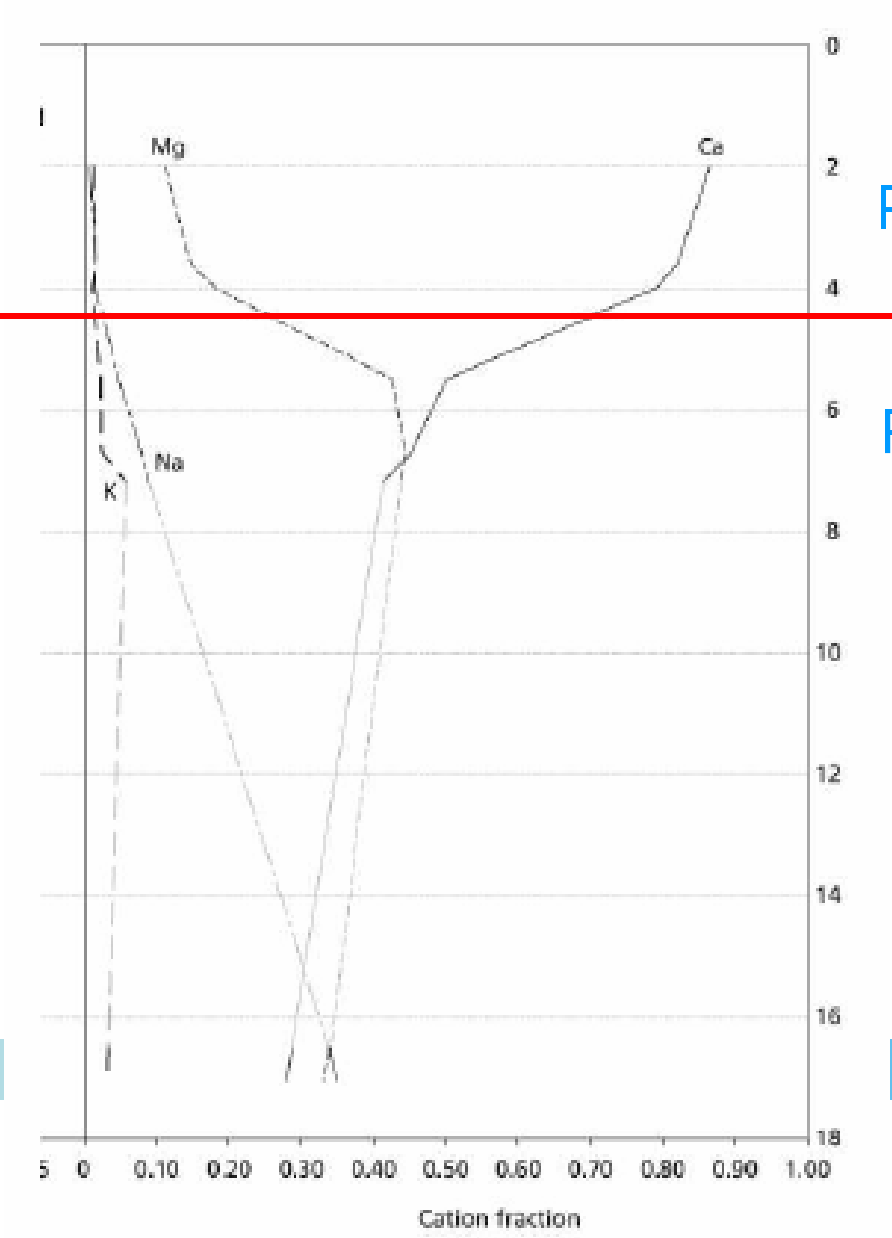
- Discharge generation headwaters, Luxembourg
- Test on landslide hydrology, Super Sauze, France

Geochemical profile drilling Boulc-Mondorès



Bogaard et al., 2004

Geochemical profile drilling Alvera, Italy



Precipitation influence

Regional groundwater

Bogaard et al., 2004

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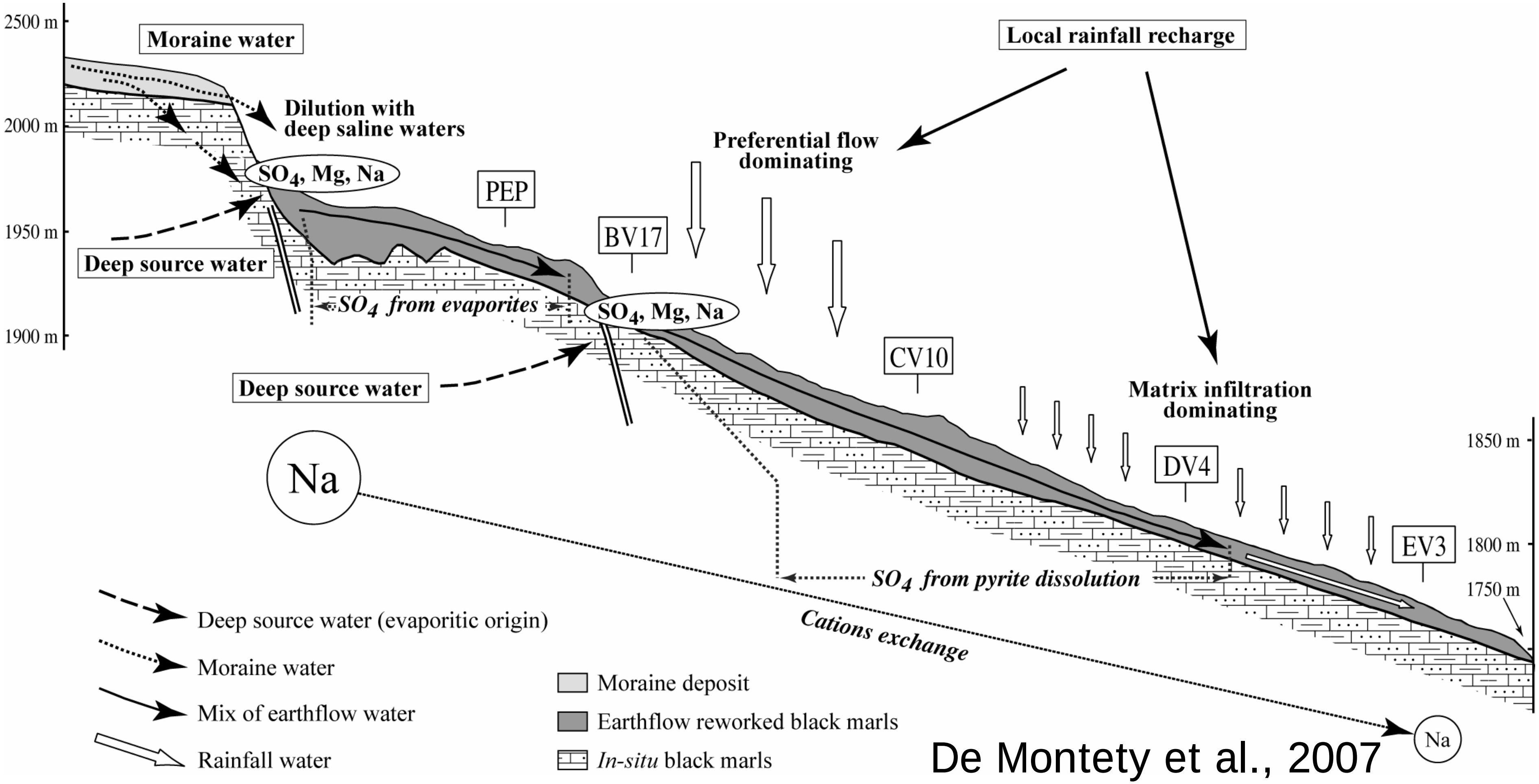
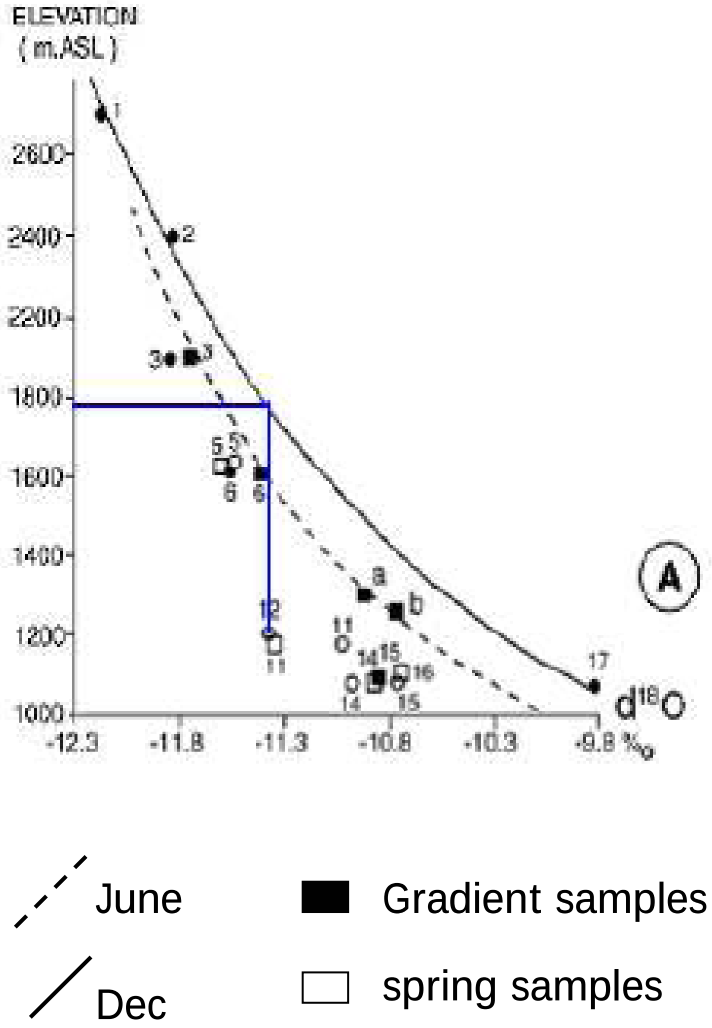
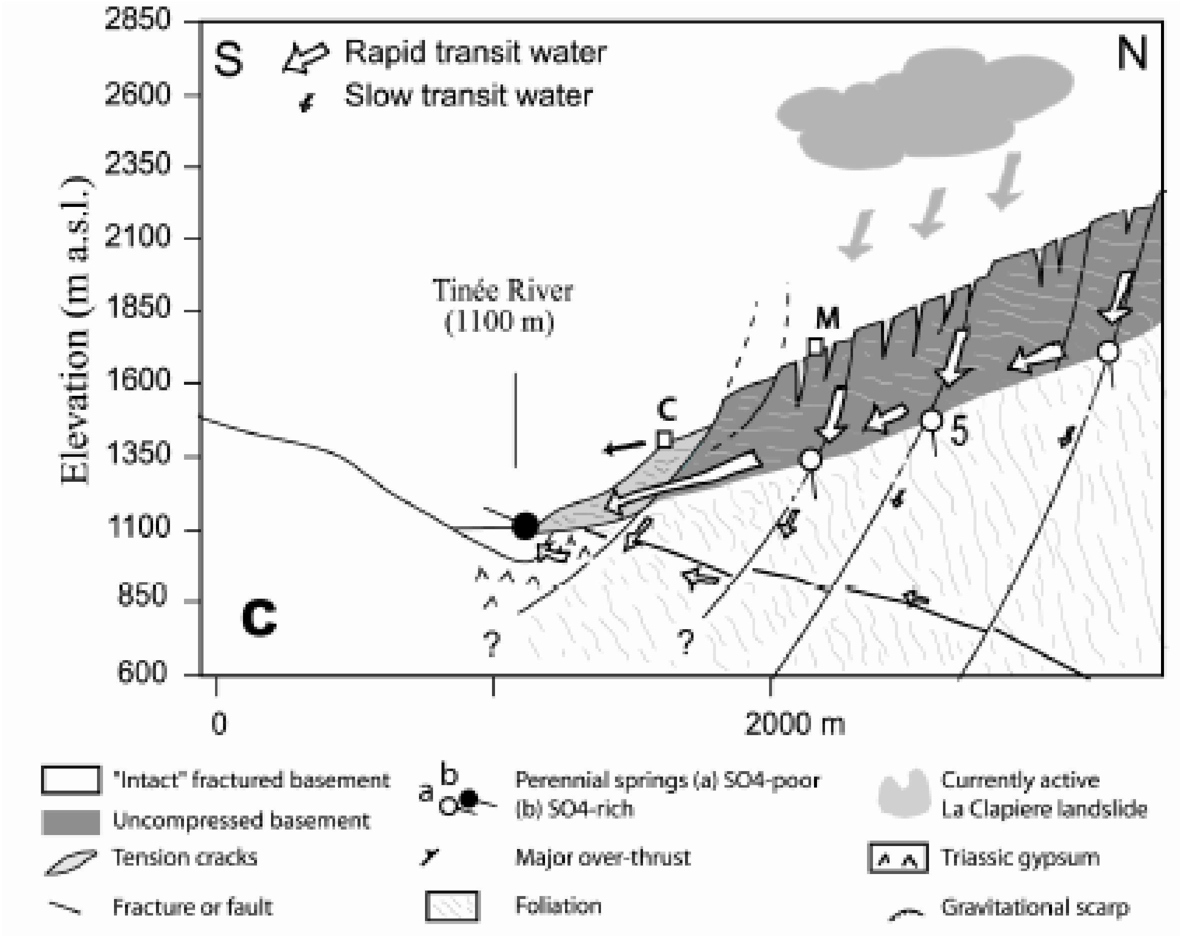
Hydrochemical synthetic cross-section Super-Sauze



De Montety et al., 2007

Elevation dependent isotopic signal: Clapière





Guglielmi et al, 2002

Distributed Temperature Sensing

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L24401, doi:10.1029/2006GL027979, 2006

Fiber optics opens window on stream dynamics

John Selker,[1] Nick van de Giesen,[2] Martijn Westhoff,[2] Wim Luxemburg,[2]
and Marc B. Parlange[3]

WATER RESOURCES RESEARCH, VOL. 42, W12202, doi:10.1029/2006WR005326, 2006

Distributed fiber-optic temperature sensing for hydrologic systems

John S. Selker,[1,2] Luc Thévenaz,[3] Hendrik Huwald,[2] Alfred Mallet,[2] Wim Luxemburg,[4]
Nick van de Giesen,[4] Martin Stejskal,[5] Josef Zeman,[5] Martijn Westhoff,[4]
and Marc B. Parlange[2]

A distributed stream temperature model using high resolution temperature observations

M. C. Westhoff[1], H. H. G. Savenije[1], W. M. J . Luxemburg[1], G. S. Stelling[2], N. C. van de Giesen[1], J. S. Selker[3],
L. Pfister[4], and S. Uhlenbrook[5]

Hydrology and Earth System Sciences

Distributed Temperature Sensing

The question: where is the discharge generated?

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Distributed Temperature Sensing

The question: where is the discharge generated?

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Distributed Temperature Sensing

Continuous temperature sensing with fibre optic cable

Westhoff et al., 2007

Slides from EGU 2007

DTS: Principles

- Fiber optic cable
- Cable length up to 10 km
- Laser pulse (5 ns)
- Reflections
- 30 s temporal resolution
- 0.01 °K at integration times of 30 min
- Spatial resolution 1 m

Westhoff et al., 2007

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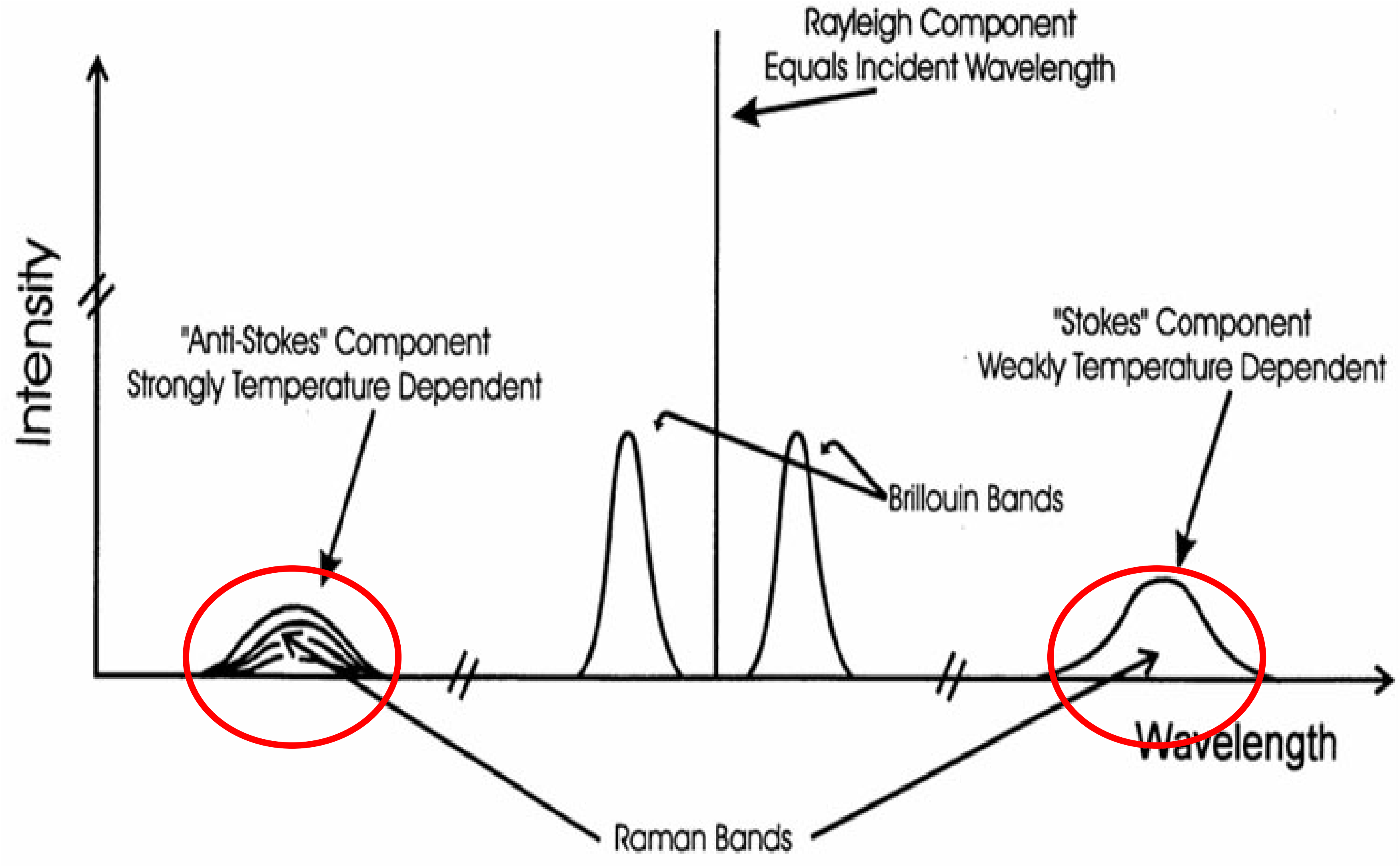
DTS: Principles



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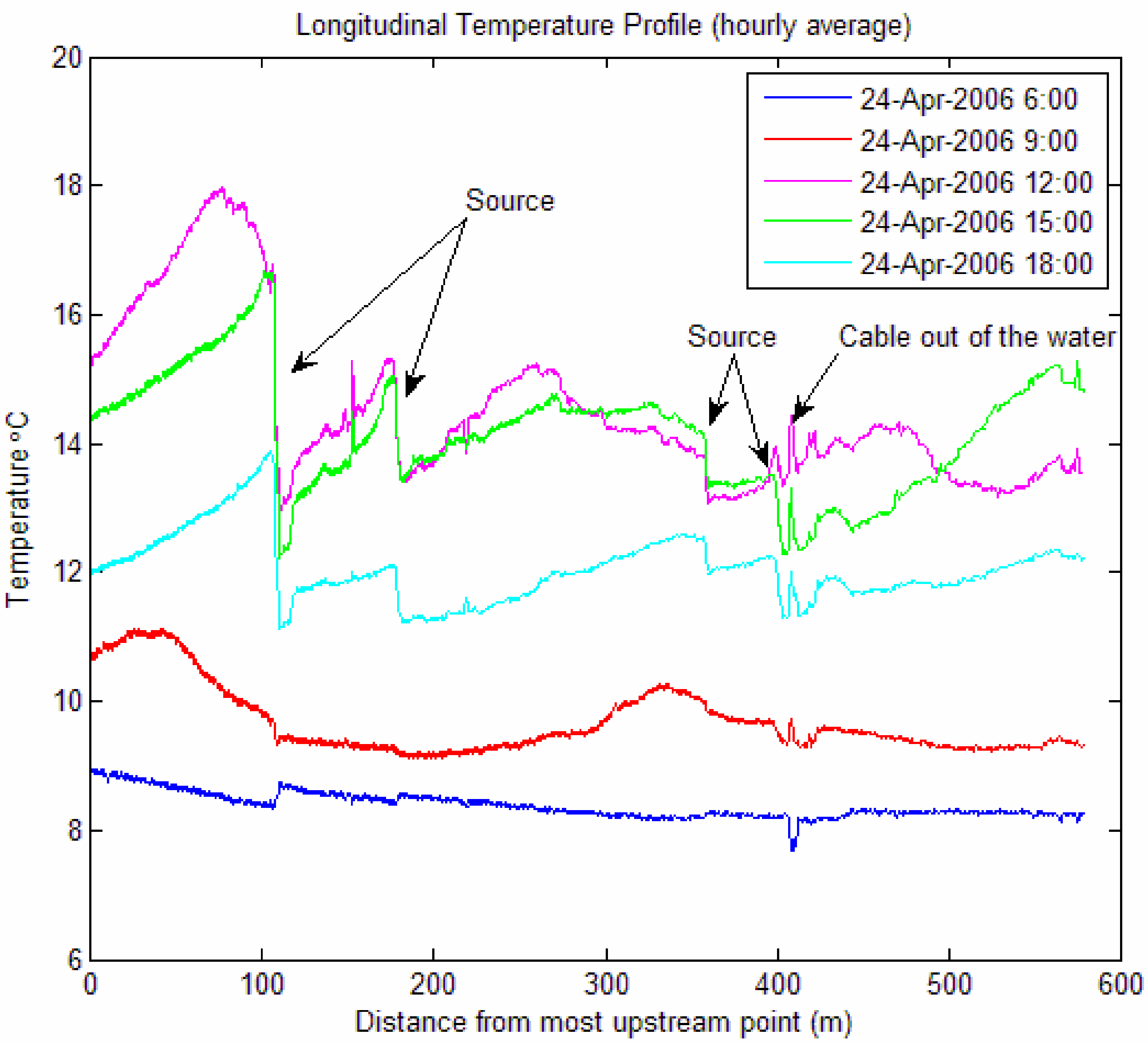
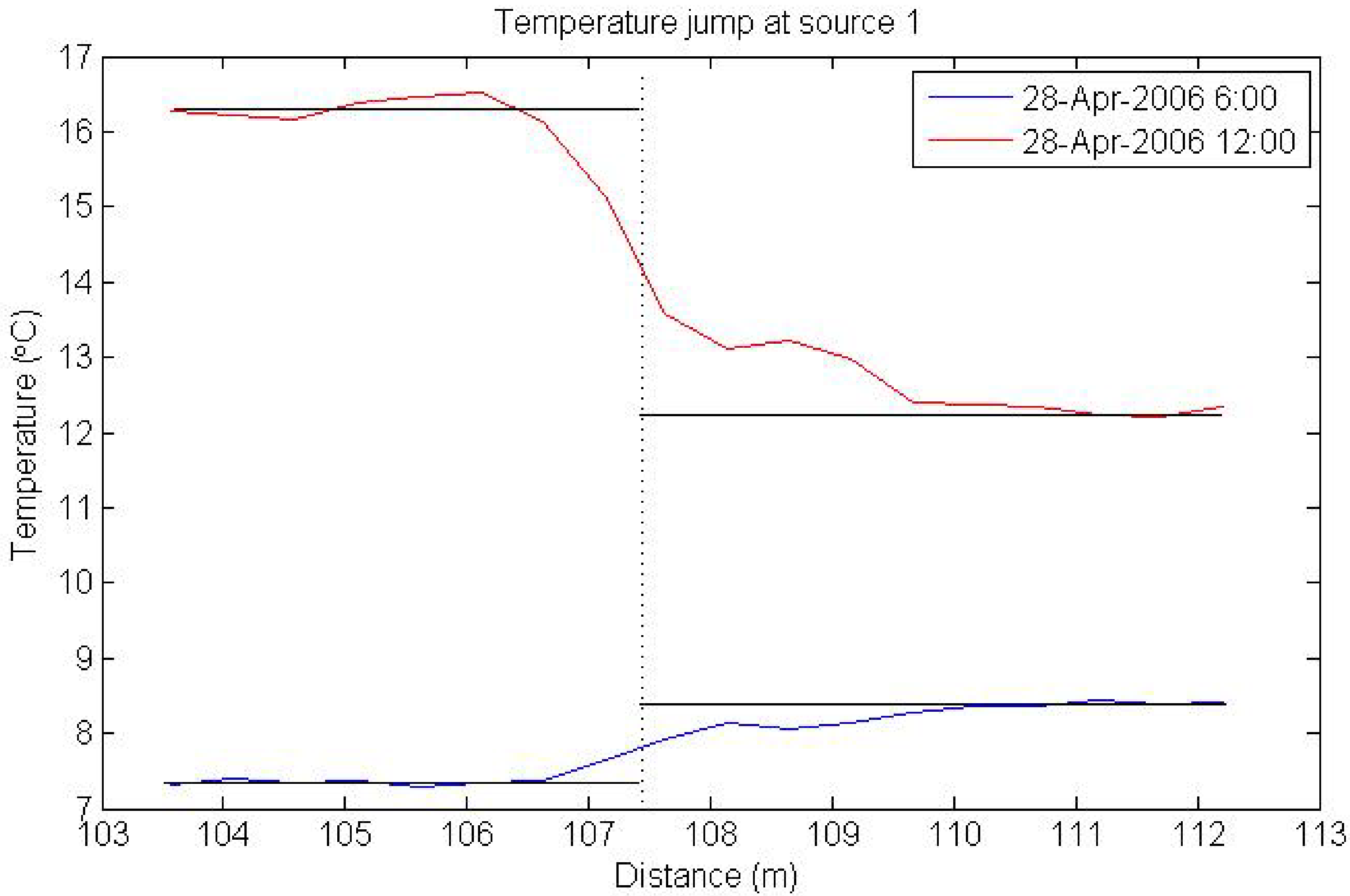
DTS Example: Lateral inflow in 1st order stream



DTS Example: Lateral inflow in 1st order stream



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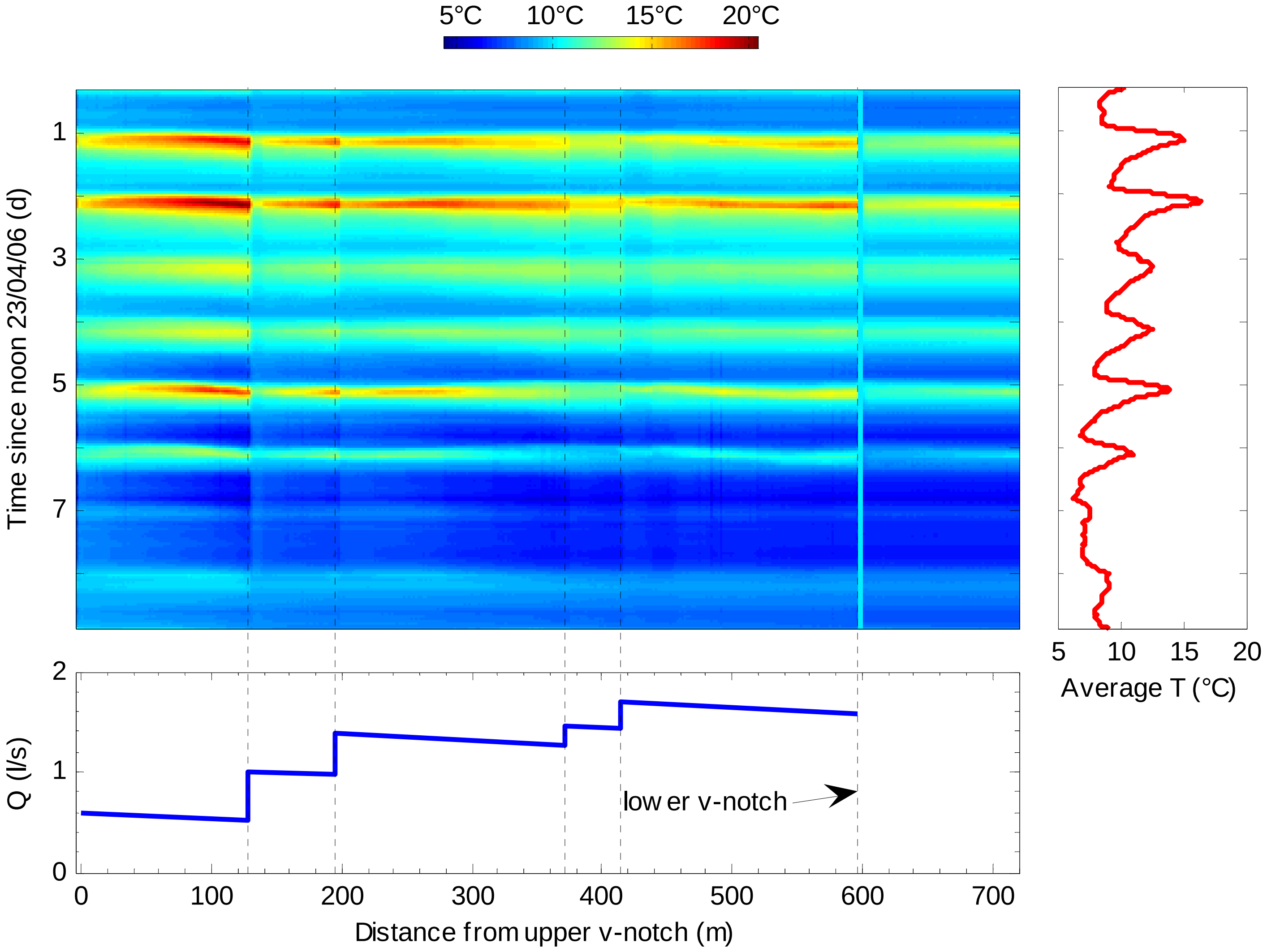
DTS Example: Lateral inflow in 1st order stream



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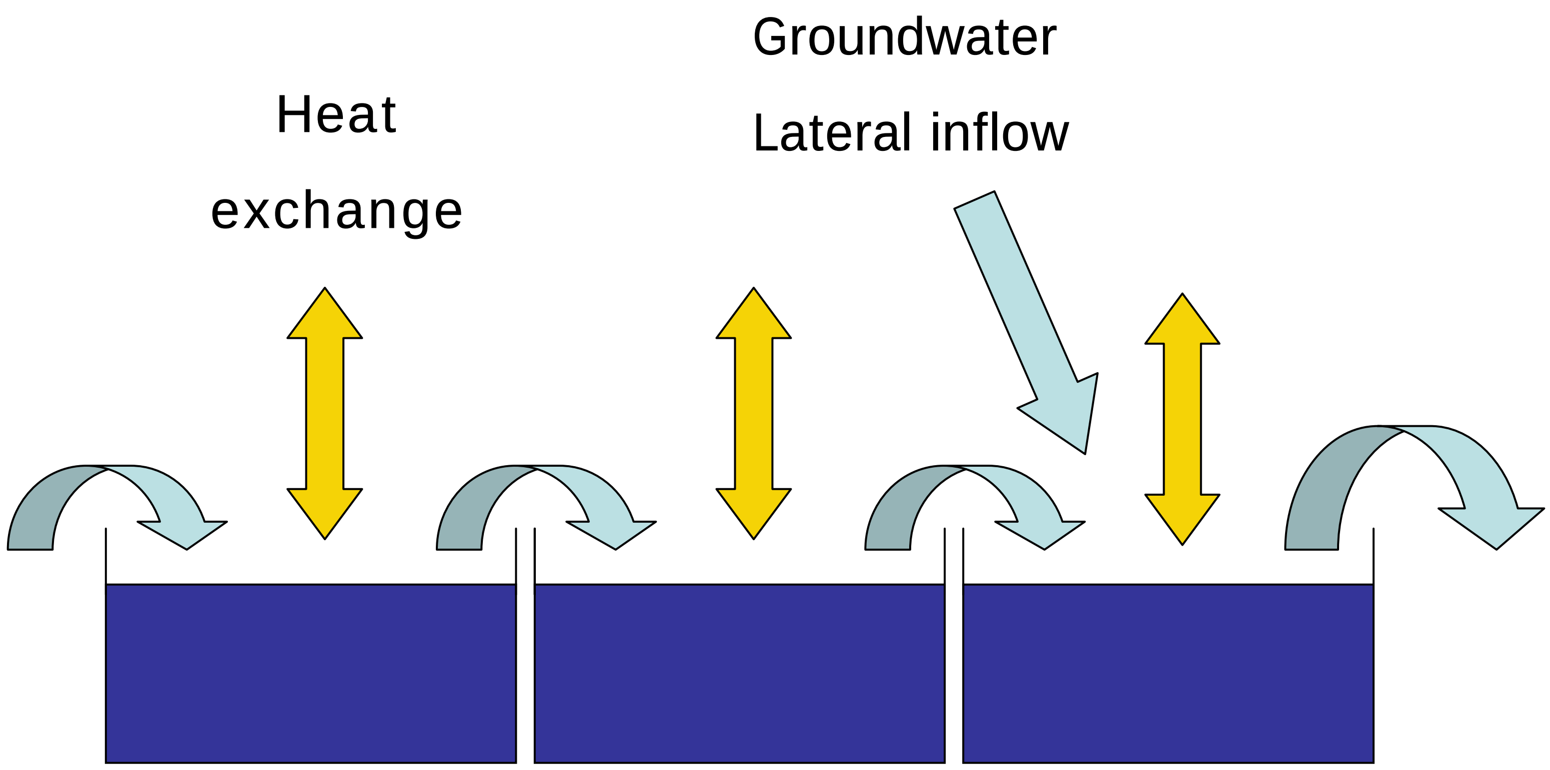
DTS Example: Energy Balance Model



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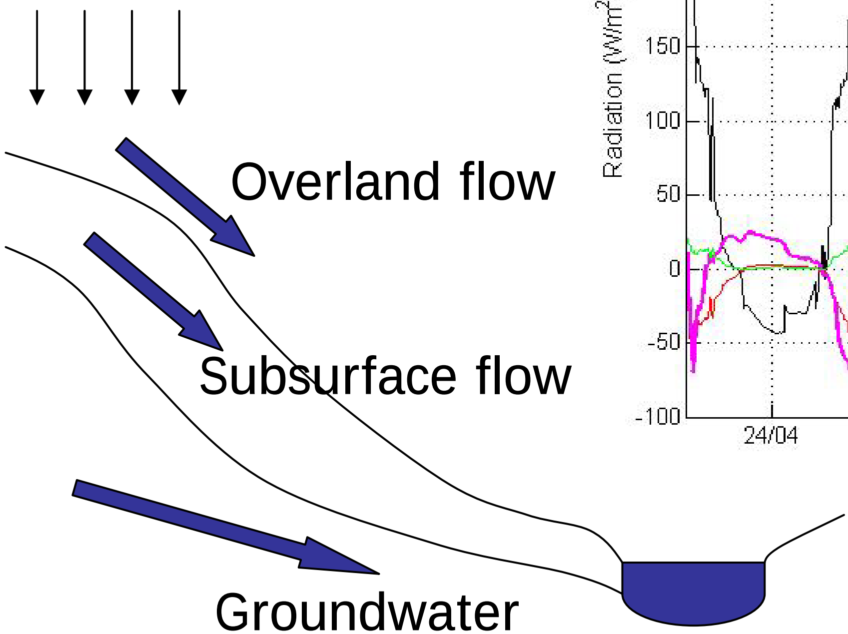
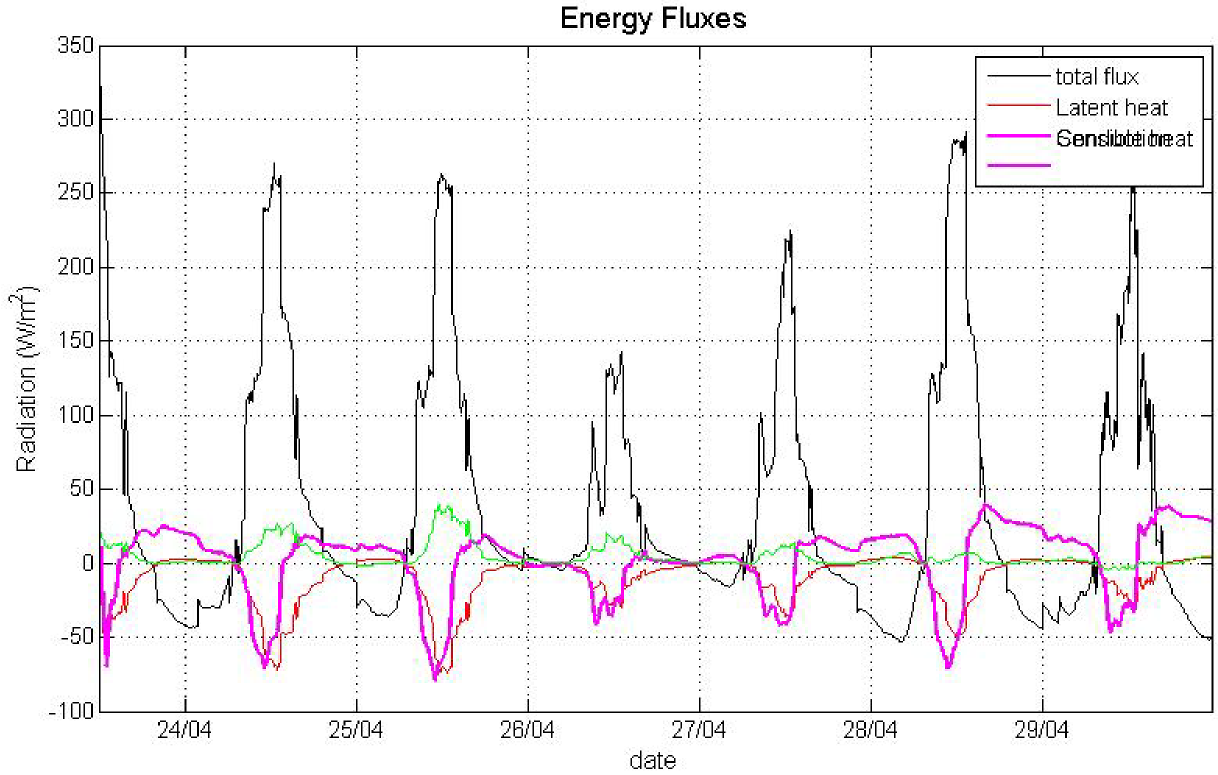
Quantify runoff components: energy model





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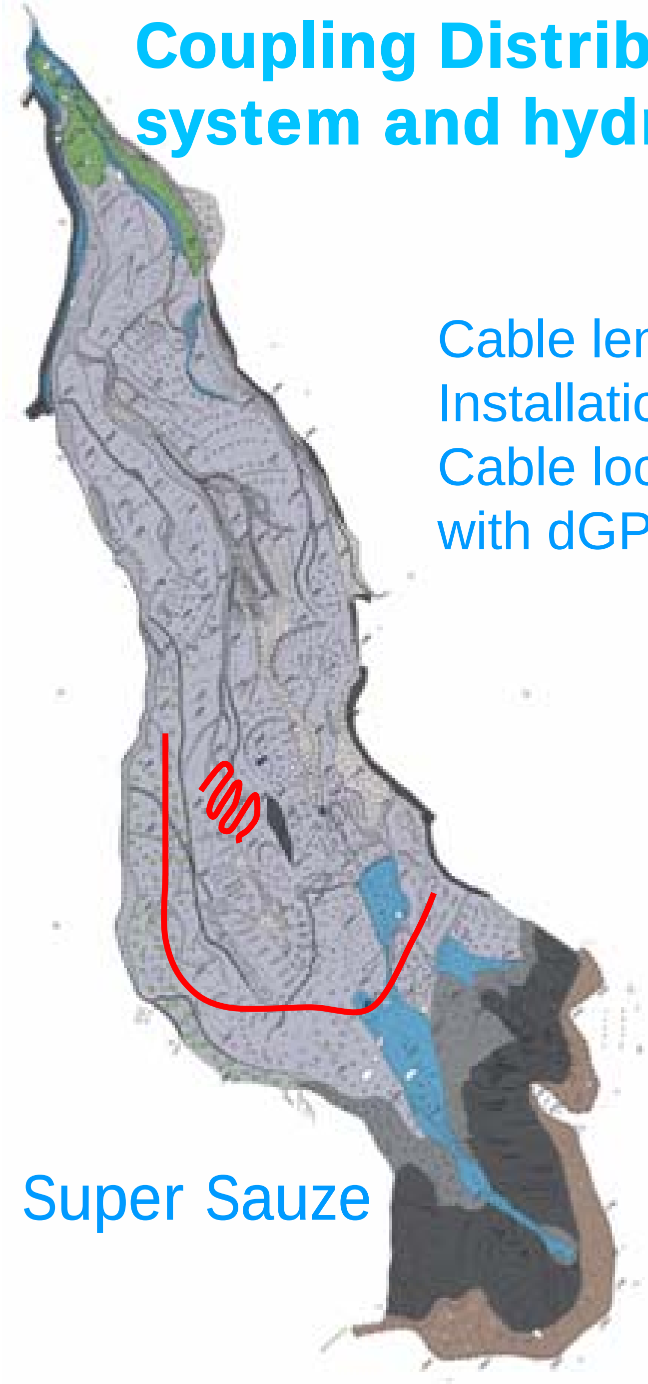
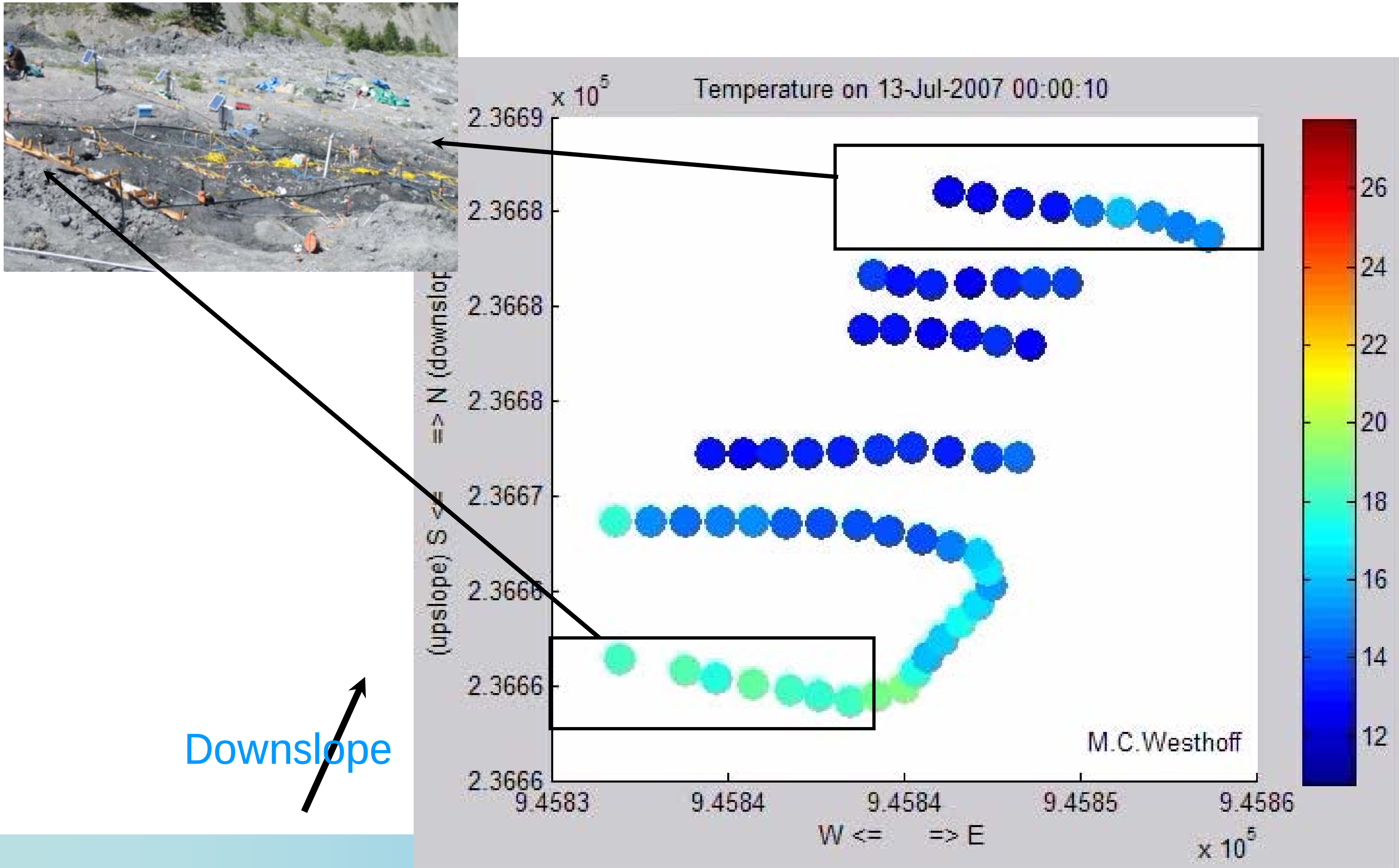
Coupling Distributed Temperature Sensing to fissure system and hydrology in landslide research: S Sauze



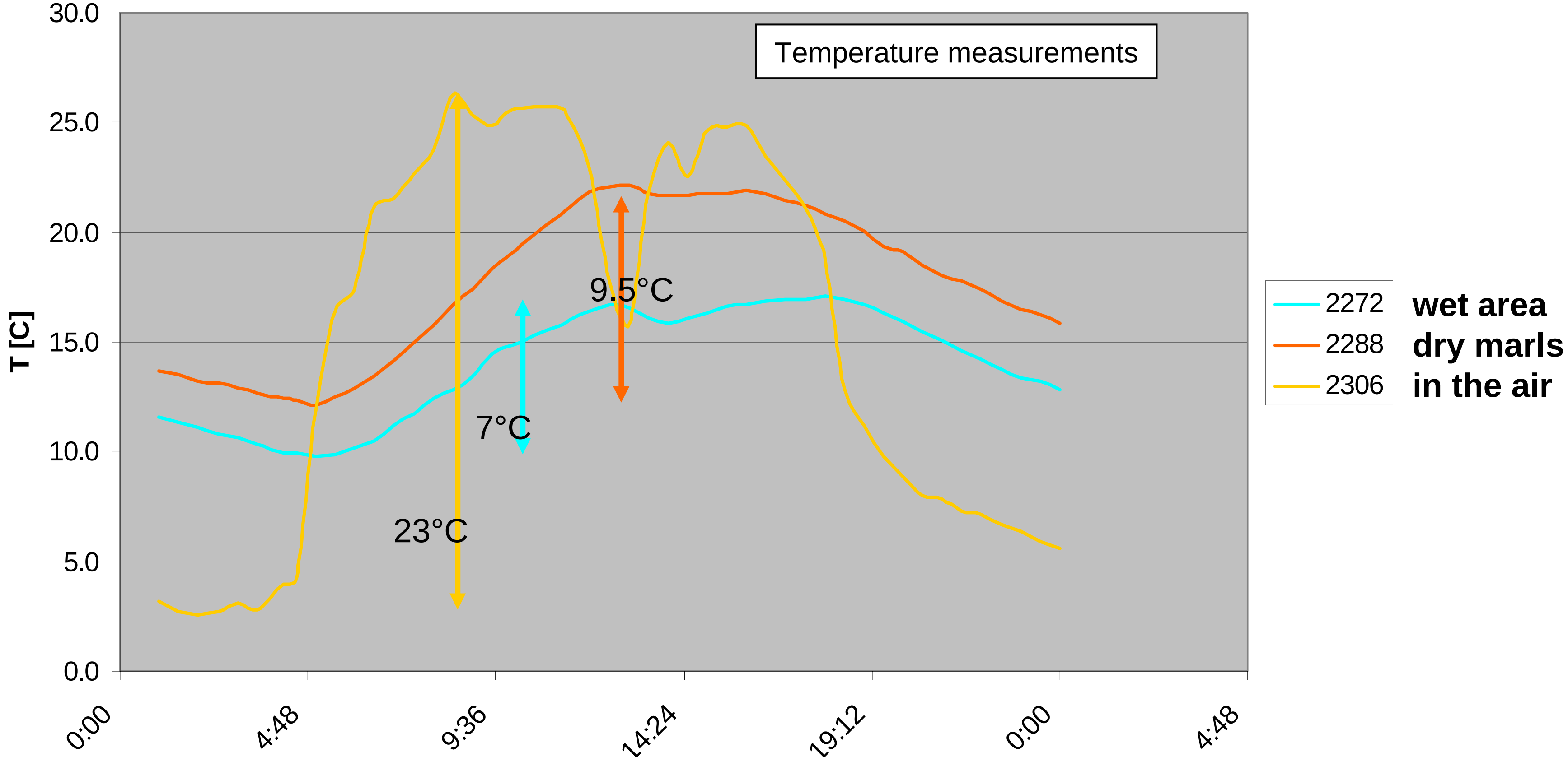
Cable length: 100 and 300m.
Installation depth = ± 0.25m.
Cable location determined with dGPS.

Super Sauze

DTS at Super-Sauze large scale infiltration experiment



DTS Super Sauze long profile: Identifying fissure system and hydrology



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DTS: Identifying fissure system and hydrology

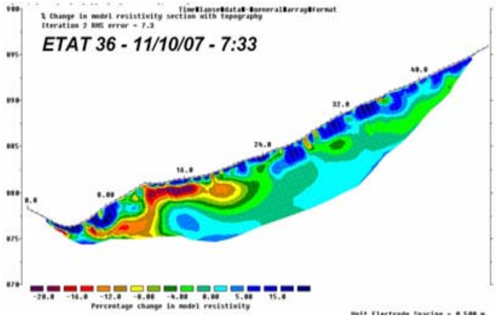
Short interpretation:

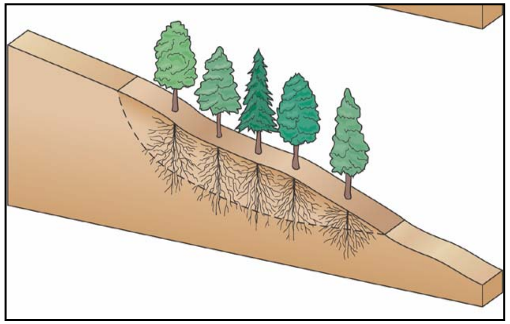
- Difference between the areas where the cable is in the soil and where it is in the air can be clearly observed
- Difference in temporal behaviour of the measured soil temperature in the wet and dry areas

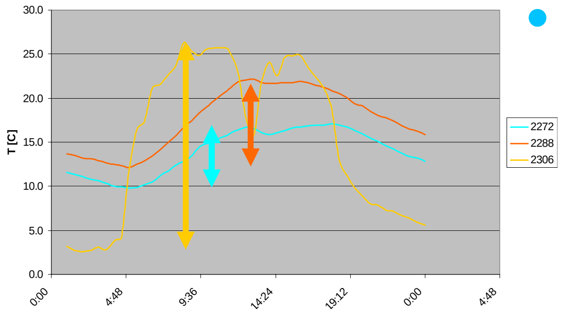
Forthcoming objective:

- Invert the temperature signal to estimate soil moisture and position of GWL
- Try to relate dT signal to soil bulk density and thus to fissures

Summary







- Fast development in hillslope hydrology and surveying techniques like hydrogeochemistry and geophysics
- Challenge is to quantify spatial and temporal distribution of hydrological responses within a slope and of vegetation
- Further development of Distributed Temperature Sensing and apply it to hillslope hydrology and landslide hydrology