# Field observations of persistent preferential flowpaths in volcanic ash soils as a result of hydrophobicity

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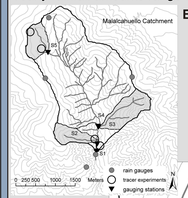
## Research question

Which processes control runoff generation in young volcanic ash soils?

## Research area

The research area is situated in the Reserva Forestal Malalcahuello, in the Precordillera of the Andes, IX. Region, Chile.
The catchment of the Tres Arroyos is located on the southern slope of Volcan Lonquimay (38°S, 71°E) and has an area of 6 km². Elevations range from 1080 m to 1856 m above sea level, with average slopes of 40%.
95% of the catchment is covered with native forest, there is no anthropogenic intervention.
Yearly rainfall amounts range from 2000 to >3000 mm.




**Experimental set up**
**- Dye tracer experiments**
tracer: brilliant blue
concentration: 4g/l
applied with: hand-pressurized pesticide sprayer
application rate: 8.3 mm/h
Total amount 25 mm
plot size: 1.2 x 1.2 m²

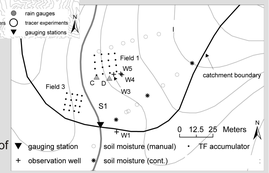



Fig. 1: Map of research area

**Experimental set up - Soil moisture measurements**
sensor: Delta T Profile Probe (PR1), measuring in 6 depths
Installation in 3 locations along the hillslope, temporal resolution 10min
manual measurements at 11 other locations, irregular time intervals

## Volcanic ash soils

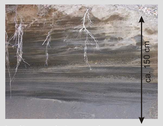



Fig. 2: The soils in the catchment are young, strongly layered, heterogeneous volcanic ash soils. Saturated hydraulic conductivities are high and generally range from $10^{-4}$ to $10^{-3}$ m/s. Porosities range from 60 to 80 %.

## Visualization of preferential flow with dye tracer experiments

**Results:**
13 experiments
12 under forest, one on bare volcanic ashes above tree line
all 12 experiments under forest showed preferential flow paths

Fig. 4: Preferential pathways marked by blue dye. (Profile excavated one day after application)



Fig. 3: Application of brilliant blue to one of the forest plots

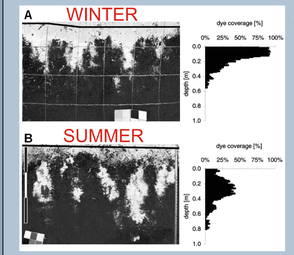



Fig. 5: Comparison of winter and summer flow patterns

**More results:**
winter: "comb pattern"
summer: "frying pan pattern"
winter: high soil moisture content
summer: low soil moisture content

Temporal pattern: seasonal variability

SPATIAL RESOLUTION ★★
TEMPORAL RESOLUTION ★

CAN BE EXPLAINED BY

## Hydrophobicity

Potential hydrophobicity was measured with the Water Drop Penetration Time (WDPT) test for 12 air dried soil samples from 3 different locations within the catchment. For this test a water drop is applied to a soil sample and the time between application and infiltration into the soil is measured. Water drop penetration times for air dried soil have been classified into 5 classes of water repellency, from wettable (<5s) to extremely water repellent (>3600s) (Dekker and Ritsema 1994). Samples showing water repellency were submitted to 12 tests with the WDPT method.
**Results:** It was found that while the top horizons show strong to extreme repellency, samples from greater depths are wettable.

Fig. 6: Water drop on ash soil

Table 1: The number of measurements falling in the different classes of water repellency.

| location | depth (cm) | wettable | slightly water repellent | strongly water repellent | severely water repellent | extremely water repellent |
|---|---|---|---|---|---|---|
| forest 1 | 5-10 | no | / | / | 5 | 7 |
| | 10-15 | no | / | 2 | 3 | 7 |
| forest 2 | 10-20 | no | / | 12 | / | / |
| | 20-60 | yes | / | / | / | / |
| | 60-80 | yes | / | / | / | / |
| forest 3 | 10-20 | no | 3 | 9 | / | / |
| | 20-60 | yes | / | / | / | / |
| | 60-80 | yes | / | / | / | / |

The drier the soil, the higher the water repellency (Ritsema and Deckker, 1994)

Temporal pattern: seasonal variability

## Decimeter scale soil moisture variability

Profile probes measure predominantly in one direction.
→ 3 measurements, each time turning by 120°
**Results:**
pronounced differences in soil moisture around the probe
pattern persistent over time
68% of the sensors show directional variability (> 1.8 Vol%)
29% of all sensors have a variability >3 Vol%

SPATIAL RESOLUTION ★★
TEMPORAL RESOLUTION ★★

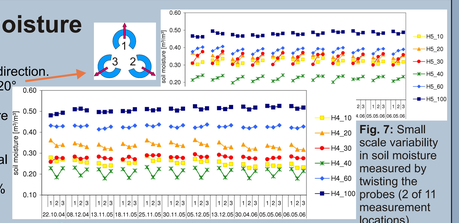



Fig. 7: Small scale variability in soil moisture measured by twisting the probes (2 of 11 measurement locations)

Temporal pattern: persistency

CAN BE EXPLAINED BY

## Combining dye tracers and soil moisture measurements

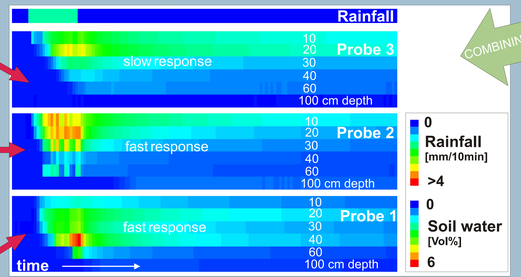




Fig.8: Dye tracer application on moisture probe plots - time axis 1 day (May 2006).
**Results:** moisture patterns correspond to dye patterns. As fast vertical infiltration was also observed at probes 1 and 2 one year earlier (e.g. Fig.9), flow paths seem to be persistent in time.

COMBINING METHODS

CONCLUSION

## Preferential flow dominates subsurface water transport

Successful combination of methods with different temporal and spatial resolution

AFFECTS

## Soil moisture dynamics on event basis

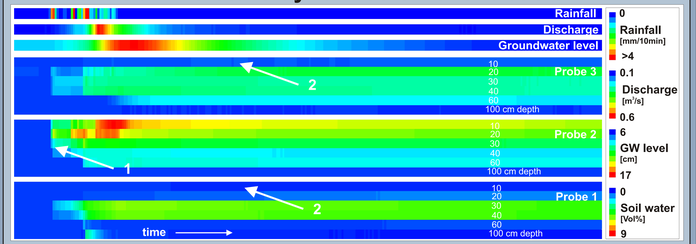



**Fig. 9:** Rainfall event March 3rd 2005 (the plot shows a two day period).
Total precipitation 52 mm, highest intensity 6mm/10 min. Lowest antecedent moisture content of all events studied.
**Results:**
Interpretation of patterns: **1)** extremely **fast vertical water transport** , due to high rainfall intensities and high hydraulic conductivities **2)** very little reaction at 10cm depth for probes 1 and 3. This is probably due to **hydrophobicity** resulting from the dry antecedent moisture conditions. This pattern was observed **only for the 3 driest occasions**.
Soil moisture increase below the hydrophobic layer must be due to lateral inputs.
Slower moisture response in winter (wet conditions) (see Fig.10), but fast summer response typical for probes 1 and 2 (Fig.10).

SPATIAL RESOLUTION ★
TEMPORAL RESOLUTION ★★★

Temporal pattern: seasonal variability, interannual persistency

COMBINING METHODS

## Effects on overall catchment response?

Lag times between onset of rainfall and first response were analyzed for 27 rainfall events between December 2004 and April 2006.
S20, S30, S40: soil moisture sensors at 20, 30 and 40 cm depth
GW: ground water level at well W1
Q: stream flow.
**Results:**
Response lags of all parameters show similar behavior over time: response times are short from January to April (summer). This is probably the result of a) enhanced preferential flow due to hydrophobicity and b) higher rainfall intensities. Surprisingly, the soil moisture sensors often react slower than stream flow. This could either mean that rainfall is not uniformly distributed over the catchment or that these sensors are bypassed by preferential flow paths. Surface runoff is unlikely, due to high infiltration rates and porosities .

Temporal pattern: seasonal variability

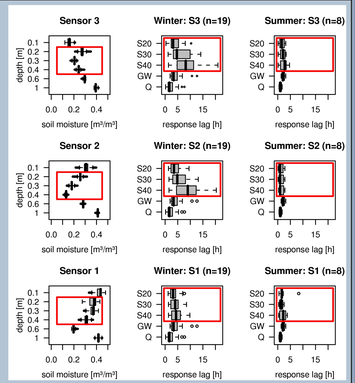



**Fig.10:** Response times for soil moisture, streamflow and groundwater levels.

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