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What happens when the ice is gone? A hydrological journey into the glacier forefield subsurface

Tom Müller[1], Bettina Schaefli[2], and Stuart N. Lane[1]

1. Institute of Earth Surface Dynamics, University of Lausanne, Lausanne, Switzerland
2. Institute of Geography, University of Bern, Bern, Switzerland

FNSNF Swiss National Science Foundation

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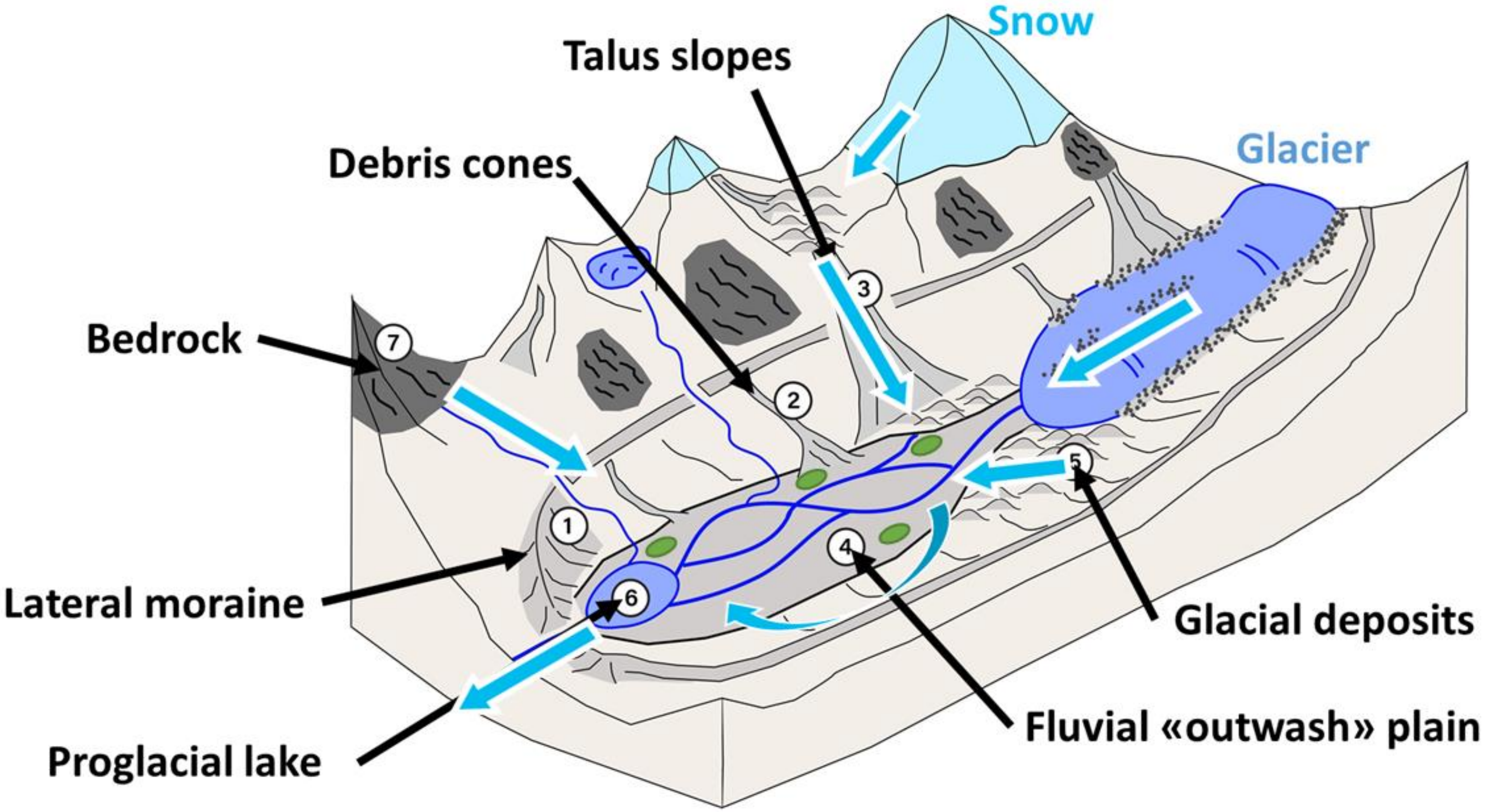
Where is water stored ?
Geomorphological landforms in proglacial zones

- Ice retreat uncovers and releases large amounts of unconsolidated sediments leading to a variety of landforms
- Water storage and release time depend on the type of landforms and their assemblage is key to understand the following key processes in a context of rapid ice loss :

1. Maintaining baseflow and ecosystem diversity
2. Transmission/attenuation of future flood
3. Providing water for downstream usage



Study case : Otemma glacier (CH)

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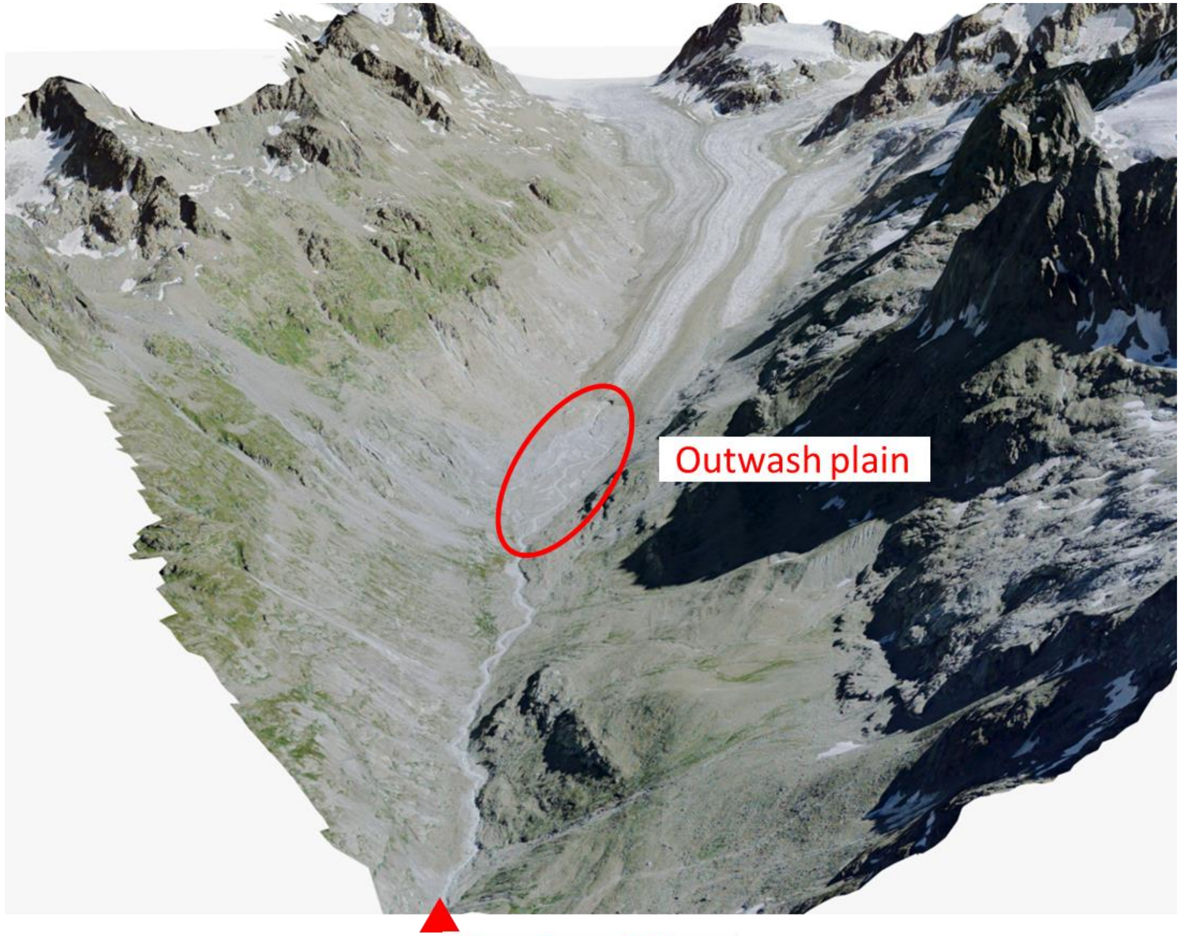
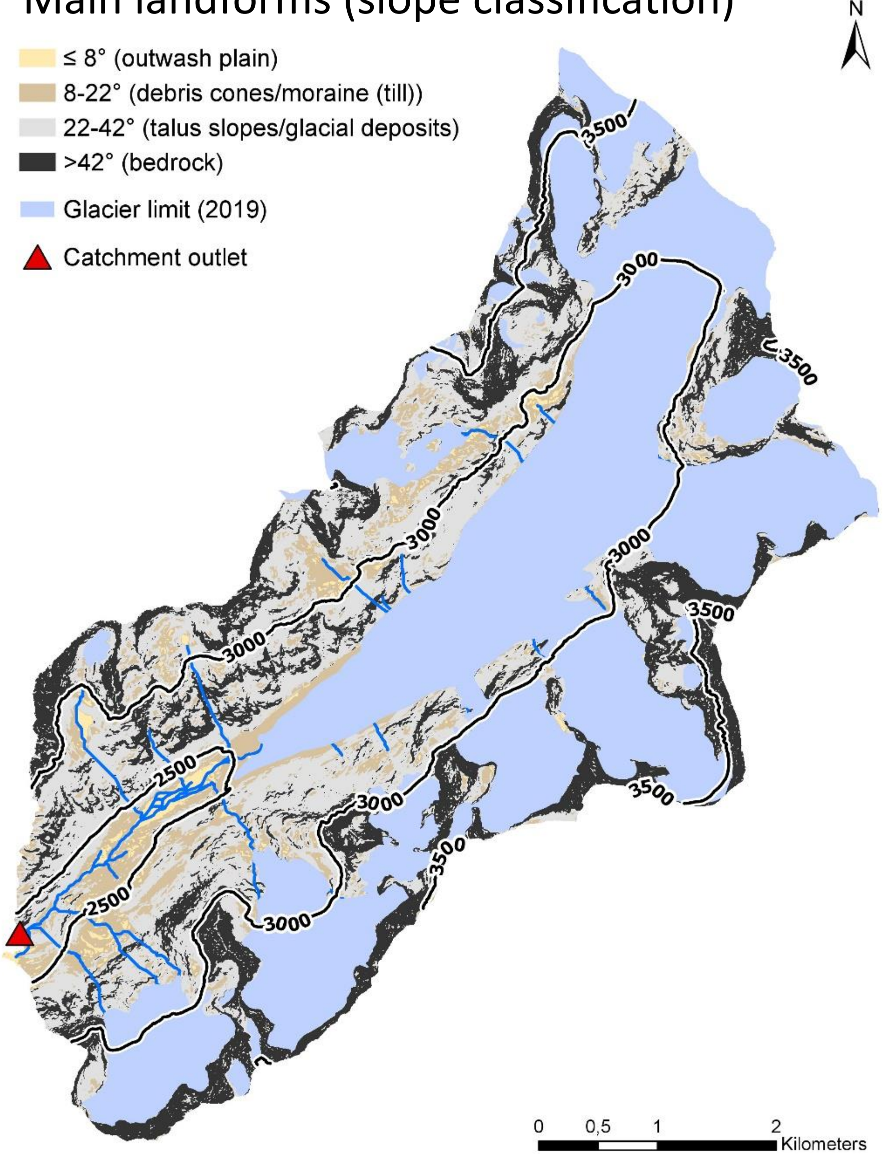


Main landforms (slope classification)



Otemma glacier – Focus on the outwash plain

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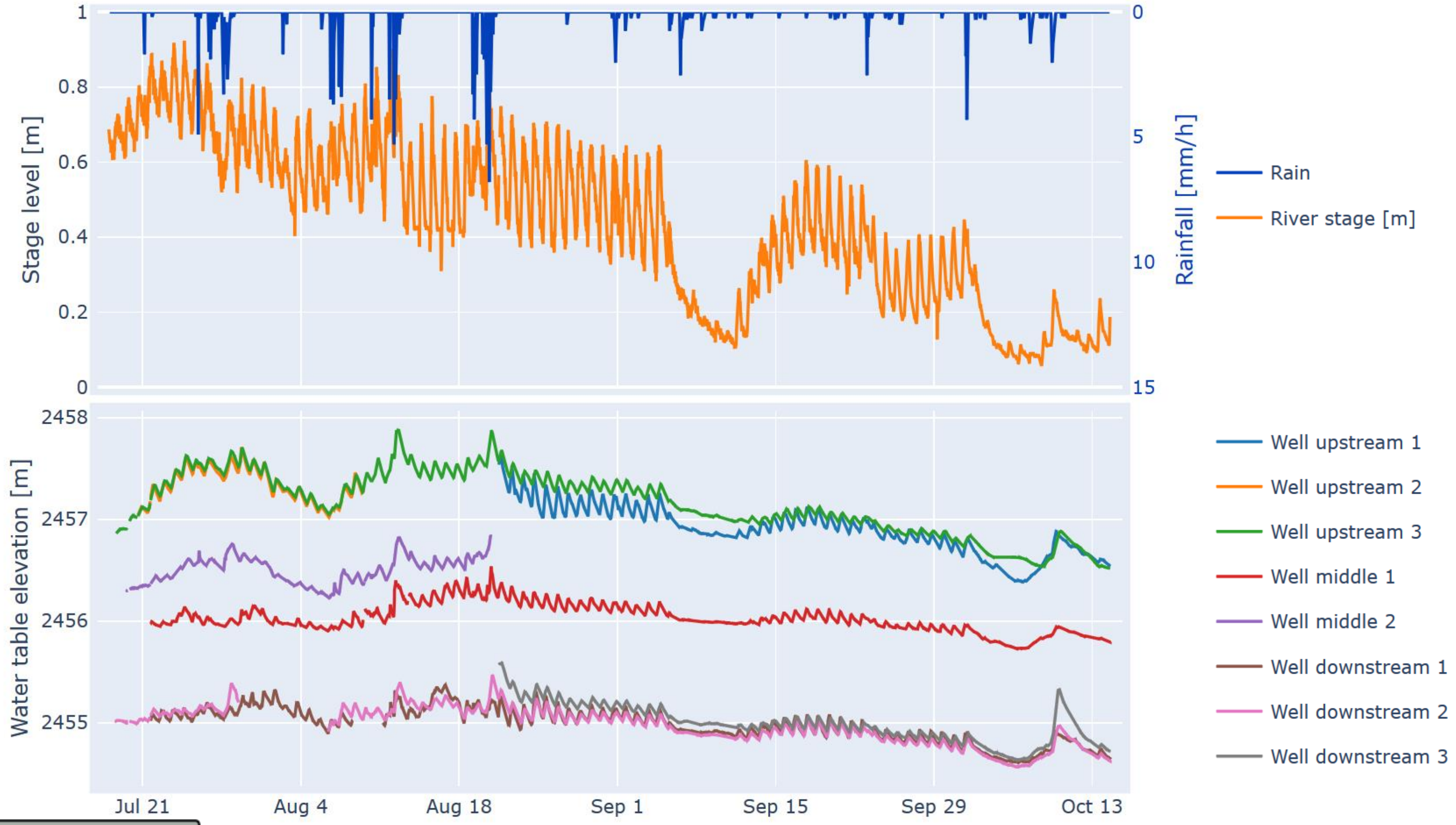
Piezometers variations in the outwash plain to determine :
1) Flow direction; 2) Hydraulic conductivity; 3) Gainging/losing reaches



Low-cost, arduino-based piezometer and weather station

Piezometer : General trend in summer 2019

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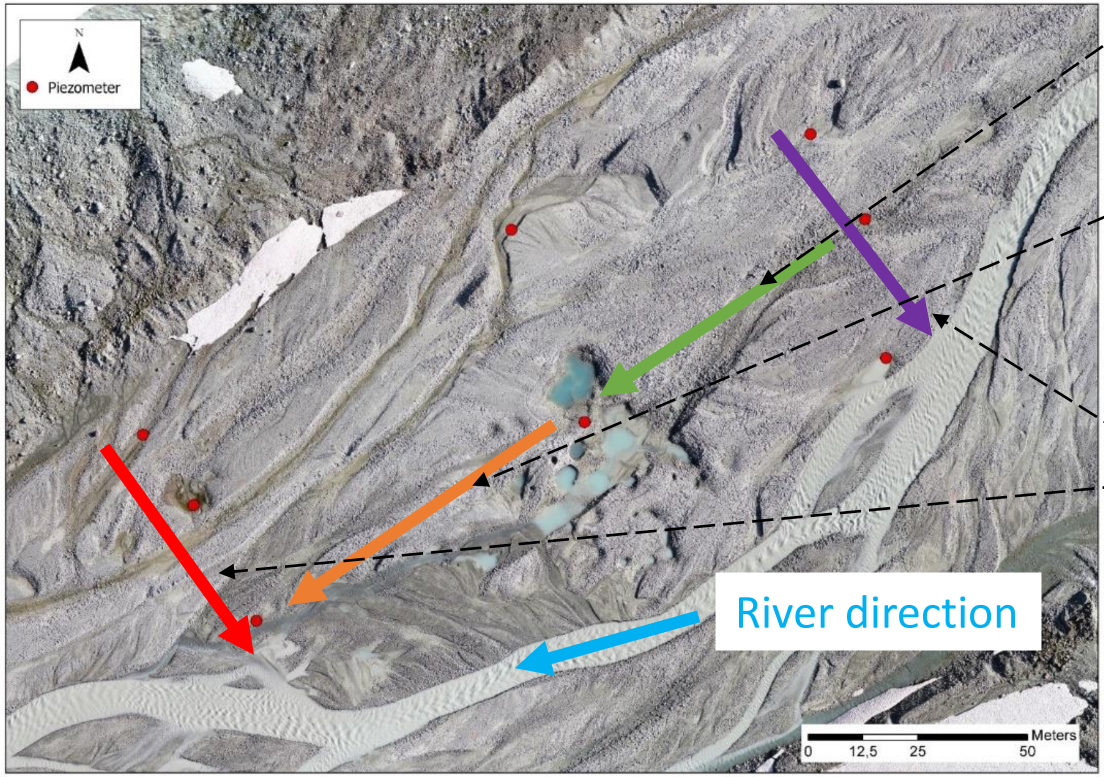
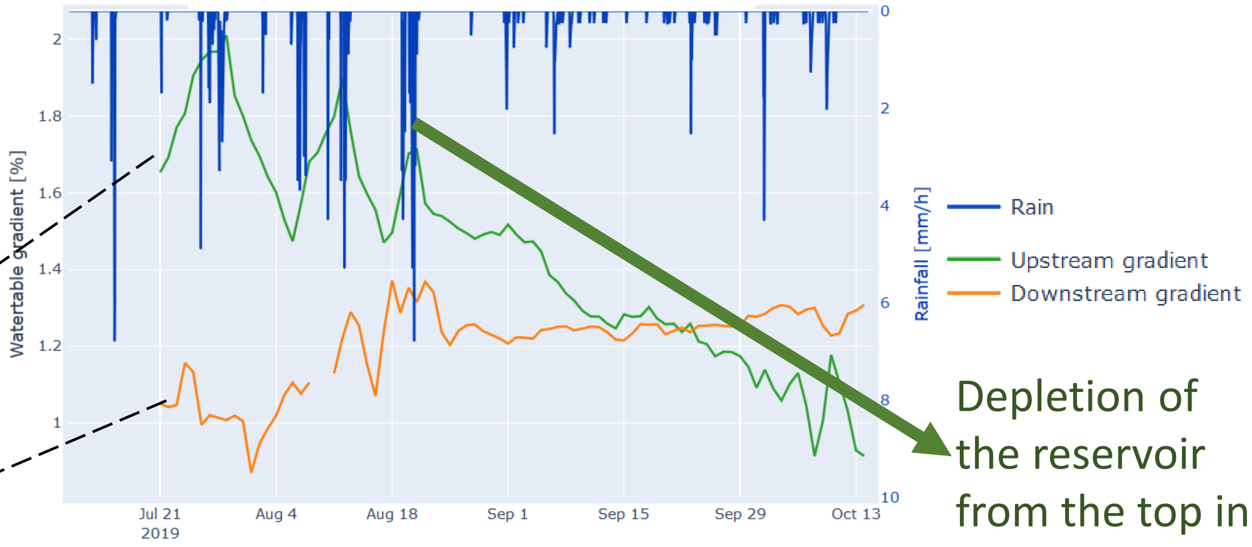
- General **gradient follows the terrain** slope of (1-2%) (parallel to river)
- **River contributes** to the aquifer recharge in early summer

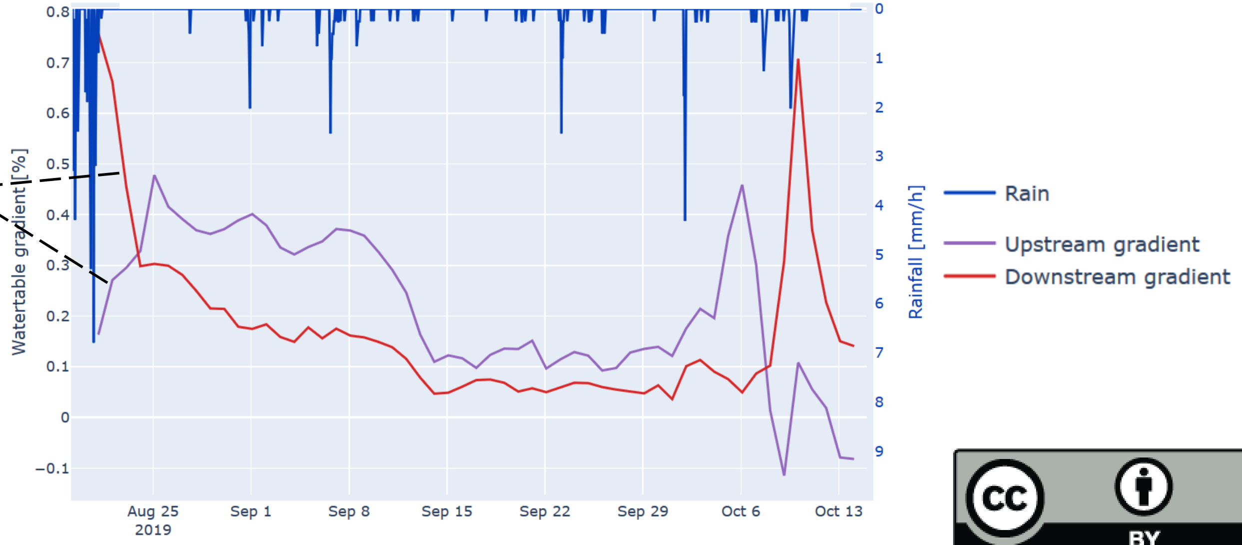


Gradient : **parallel** to river [%]



Depletion of the reservoir from the top in late summer

Gradient : **perpendicular** to river [%]



Characterization of the outwash plain

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- **Depth** of the **aquifer sediment** is about **10-15 meters** (from ERT data)
- Saturated hydraulic **conductivity** of outwash plain is **0.5 to 4 x 10^{-3} m/s**
- Available **water storage is about 10 mm** (but represents only 0.5% of the catchment)

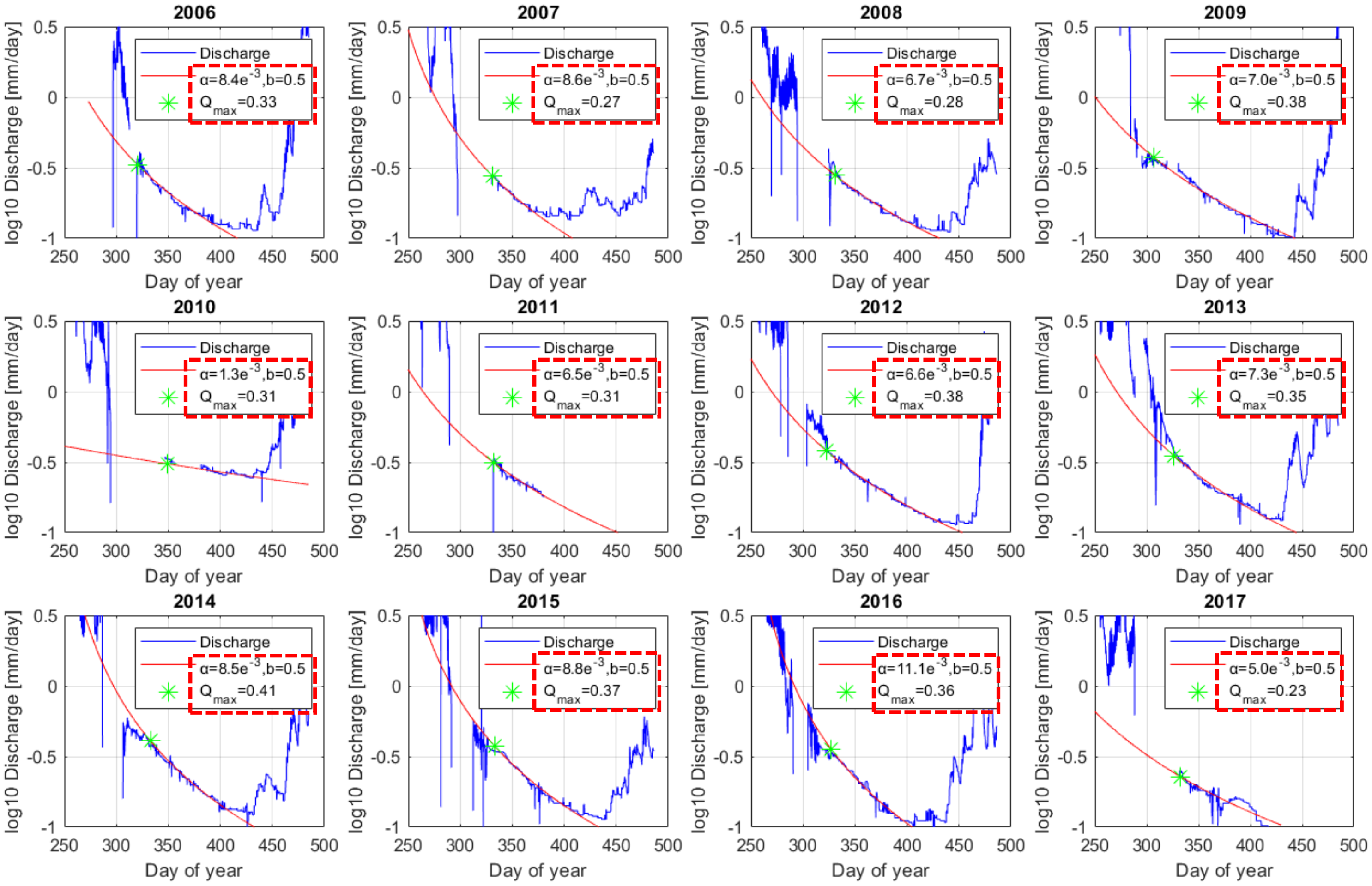
Calculation of hydraulic conductivity based on different methods

Slug tests	Diffusion model	Salt injection + ERT
$1 \cdot 10^{-3} – 5 \cdot 10^{-3}$ [m/s]	$0.5 \cdot 10^{-3} – 4 \cdot 10^{-3}$ [m/s]	$3.5 \cdot 10^{-3}$ [m/s]
Point measurement	Integrated over 100m	Flow path over 10m

Catchment scale recession analysis

- Recession analysis shows a slowly decreasing discharge with similar pattern each year with a recession rate similar to what is expected of the outwash plain
- A small cold-season dynamic **water storage of about 20 mm** is estimated for the entire catchment
- Based on the outwash aquifer characteristics and preliminary MODFLOW simulation, **discharge may be mainly sustained by the outwash plain (~50%)** with some contribution from moraine deposits.
- Preliminary electrical conductivity and isotope samplings confirm the important role of the outwash plain

Non-linear recession analysis with best fit calculation $Q_t = Q_{max}(1+\alpha t)^b$



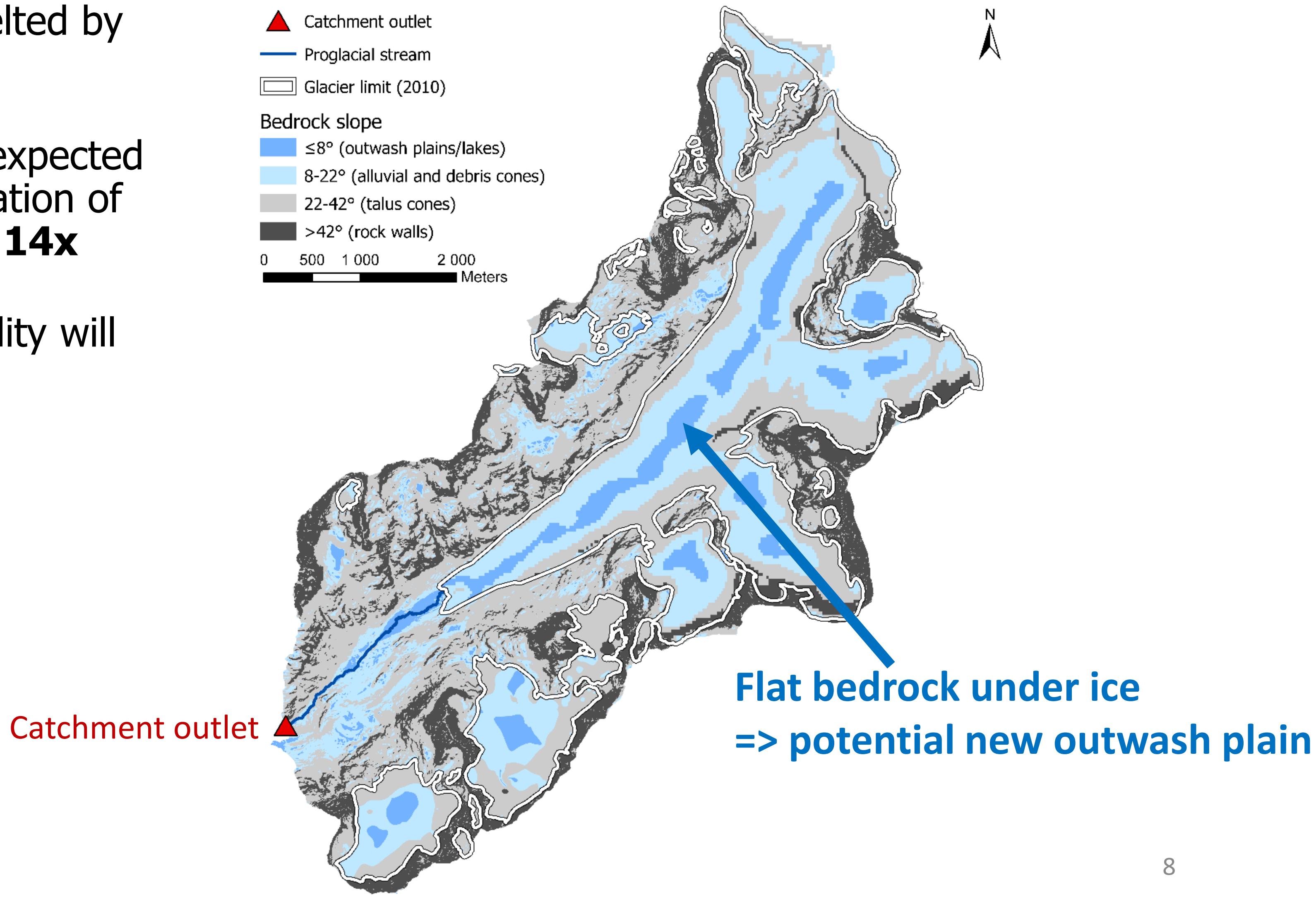
Potential future of water storage under the ice

- Most of the Otemma glacier will be melted by 2070

- **Flat bedrock / overdeepenings** is expected below the ice, which may lead the creation of **much larger outwash plains up to 14x**

- Bedrock erosion and sediment availability will govern the accumulation of sediments

Otemma bedrock slope classification under ice



Key messages

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- River baseflow may increase due to larger areas of sediment deposition with retreating glaciers
- Sediment release may create new water storage in glaciated catchments but sediment production/exportation is still not clear
- The role of biofilm and algaes to promote vegetation and stabilization may be important
- More research is needed to properly characterize both single landform hydrological functions and compare with catchment scale reponse !

3 more transdisciplinary research years are planned… So stay tuned !

More details in the review article to come and for EGU 2021 !
Don't hesitate to contact me : tom.muller.1@unil.ch