Topographic controls on seepage distribution in 3D mountain systems. EGU23-10167

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Outstanding Student & PhD candidate Presentation contest

Highlights

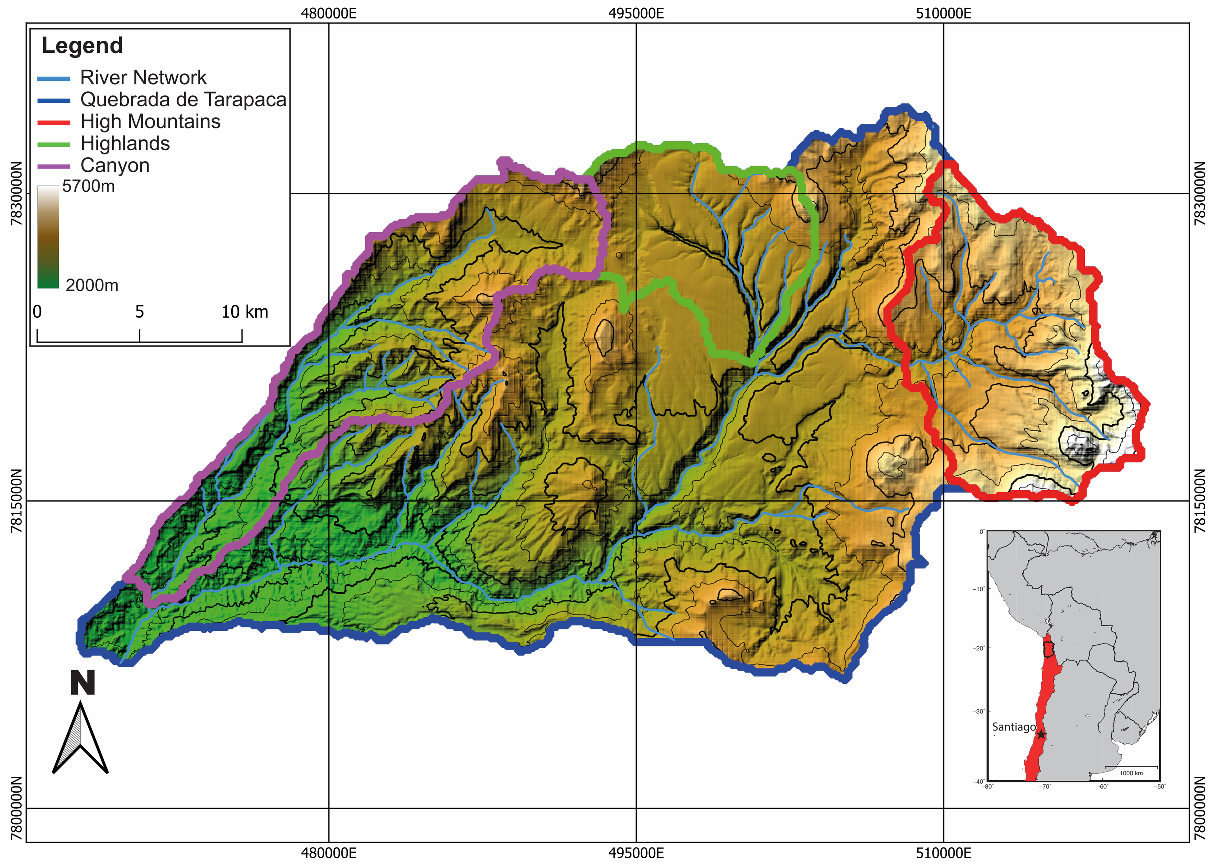
- **Defining topographic controls on groundwater-surface water interaction in mountain systems.**
- **Seepage is an indicator of groundwater-surface water interaction.**
- **Focus on geomorphological settings.**
- **3D groundwater models compared to analytical solutions.**

I. Introduction

Seepage areas, i.e., areas where the water table intersects the land surface, are strong indicators of groundwater-surface water interaction and have a critical role on ecosystems and on water quality. Numerous studies have been carried out aiming at characterizing seepage areas and the factors controlling their occurrence. Still, most of the literature focused on theoretical or synthetic systems. Then seepage areas in complex environments, such as mountain systems, are to be further studied. In this context, we propose to study the role of topographic complexity on seepage occurrence and consequently, test the pertinence of well-known and widely used frameworks, either analytical or numerical, against 3D complex systems aiming at proposing new methodological frameworks to better represent the complexity inherent to mountain systems.

II. Numerical methods & study area

- Development of 3D homogeneous and uniformly recharged numerical models at steady state using MODFLOW.
- 90m-resolution topography based on a real mountain catchment,
  ➢ Quebrada de Tarapacá (North Chile) (~900km²)
  ➢ Multiple geomorphological settings
- Sensitivity study of the seepage area,
  ➢ Recharge rate varies over 6 orders of magnitude as a proxy for climatic conditions.
  ➢ A buffer area is defined around the catchment to have naturally developed boundary conditions.
  ➢ Results are analyzed in relation to the ratio between recharge and the hydraulic conductivity (R/k).
  └→ $k=10^{-7}$ m.s^{-1}



III. Geomorphological analysis

- The Quebrada de Tarapacá is a typical Andes mountain system. We distinguish 2 zones separated at X=495,000E.

Lower zone:
- Elevation < 4000m
- Geomorphologically more unstable
- Steeper slopes

→ Subbasin: Canyon

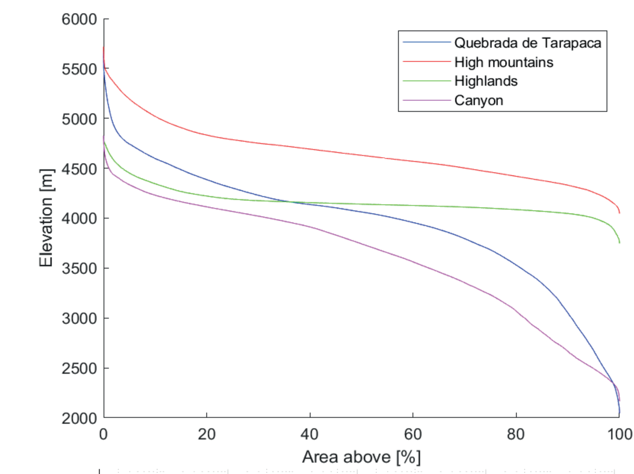
Upper zone:
- Elevation > 4000m

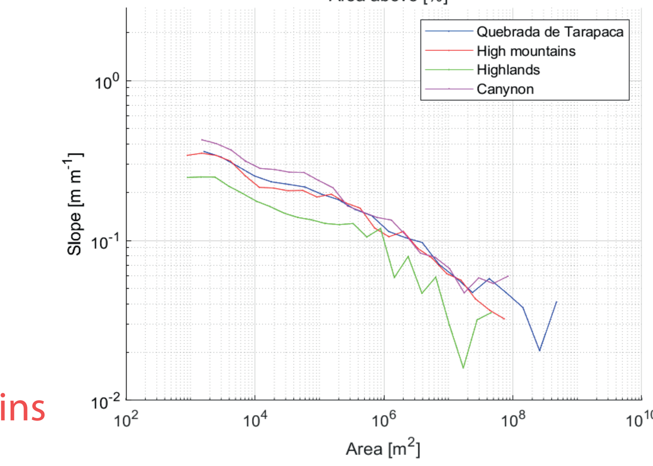
→
- Constant elevation around 4100m
- Gentler slopes
- Flat areas

→ Subbasin: Highlands

→
- Elevation > 4500m
- Higher basin limits
- Major peaks

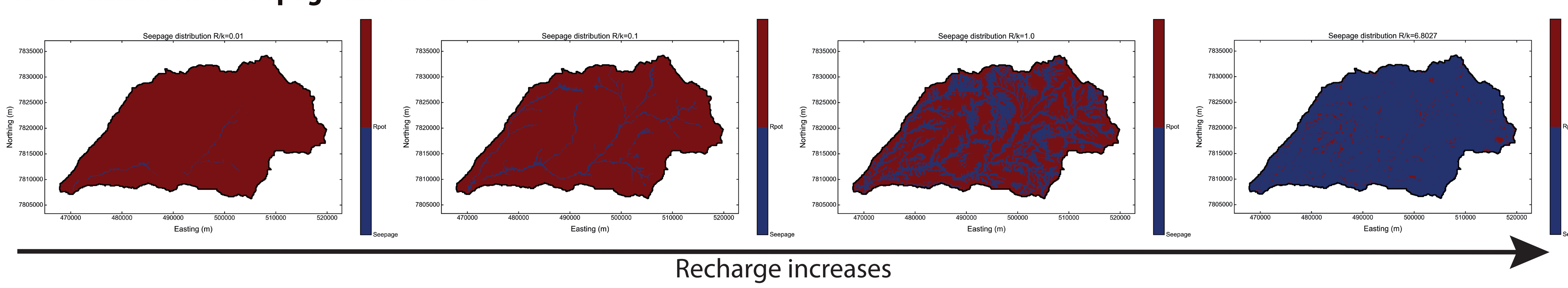
→ Subbasin: High mountains





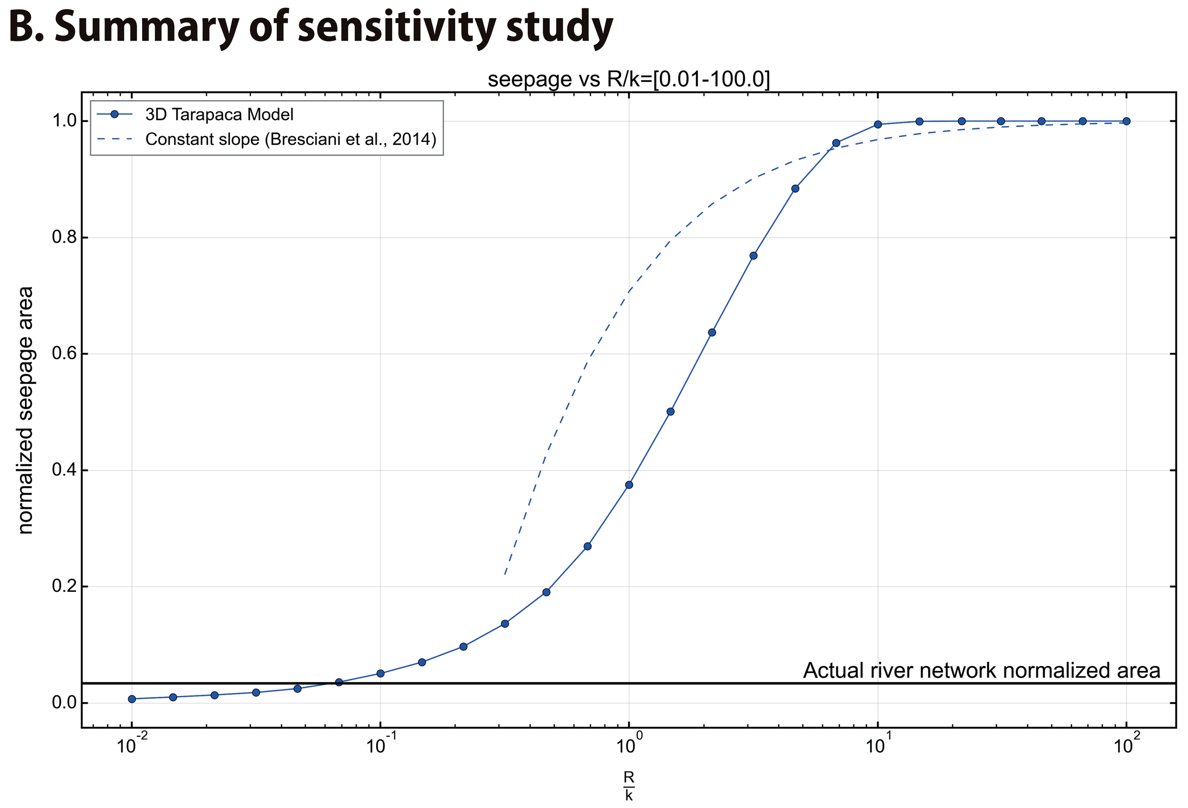
IV. Results

A. Visualization of seepage distribution



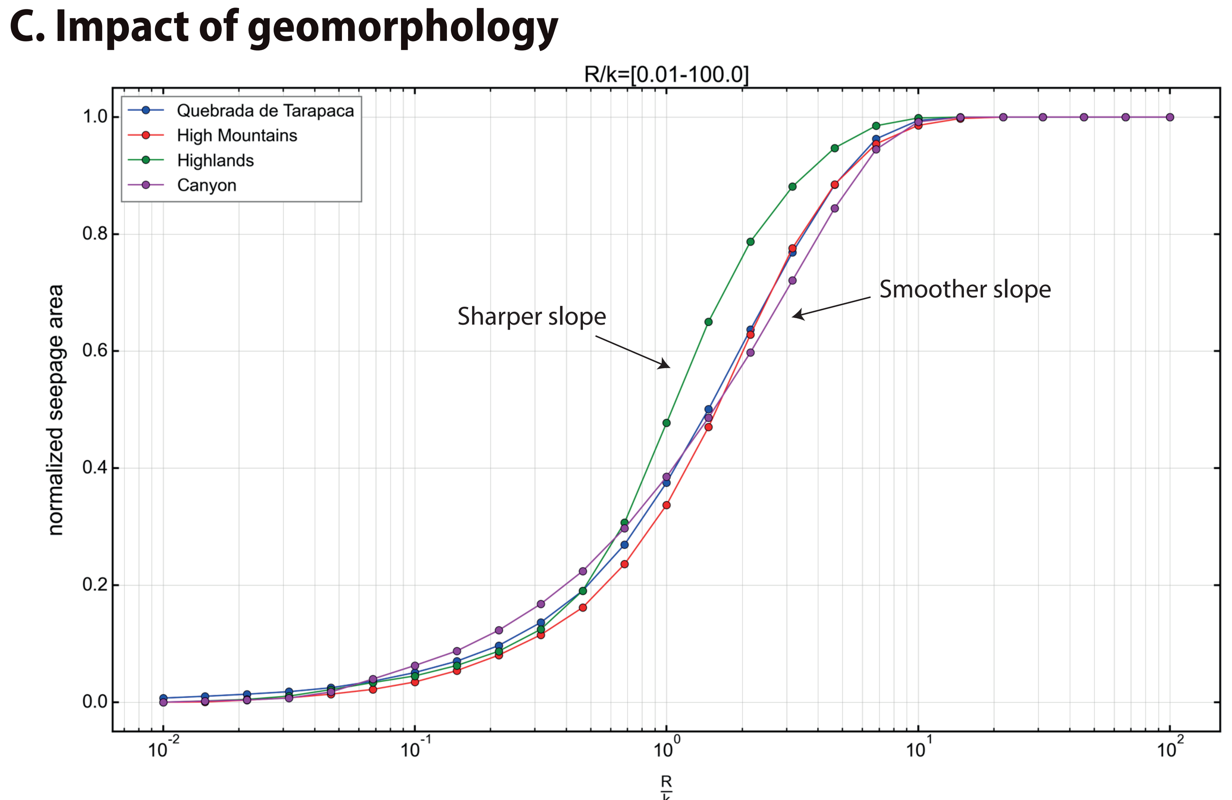
- Seepage is limited to topographic low points (e.g. deeply incised valleys).
- Seepage distribution is similar to the actual river network.
- Seepage area exceeds river network and develop at the hillslope feet and flat areas.
- Basin is nearly fully saturated, except at topographic particularities (e.g. high hilltops).

B. Summary of sensitivity study



- The seepage evolution as function of R/k presents 3 distinct parts:
  ➢ Fully saturated (10<R/k<100).
  ➢ Desaturation (0.4<R/k<10).
  ➢ Seepage tends to 0 (0.01<R/k<0.4).
- Compared to the analytical solution, the latter seems to overestimate seepage during desaturation and is unable to estimate seepage area in more realistic conditions (lower R/k).

C. Impact of geomorphology

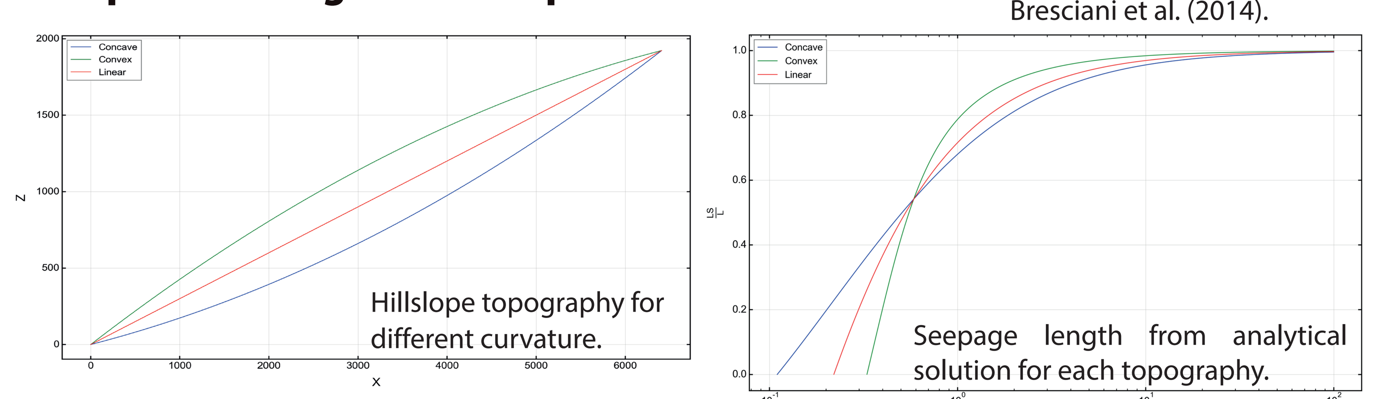


- As R/k decreases:
  ➢ Highlands subbasin remains the last one fully saturated, then desaturation follows a sharper slope.
  ➢ Canyon subbasin disconnects first from full saturation, but then desaturation follows a smoother slope.

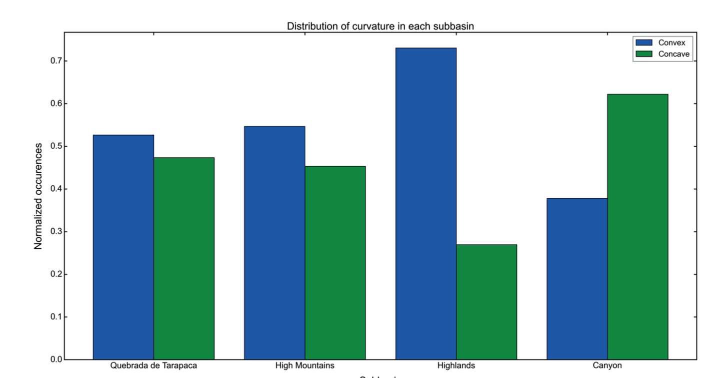
V. Discussion

A. Impact of the general shape of the basin

Analytical solution from Bresciani et al. (2014).

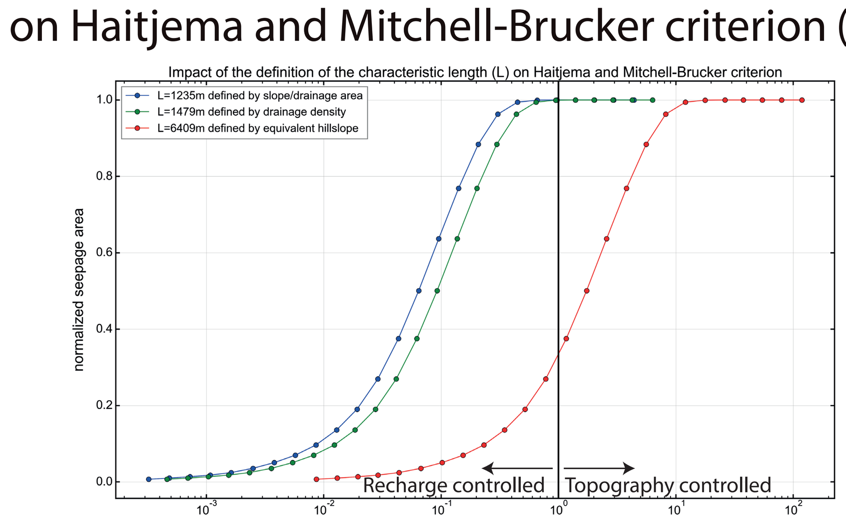


- Concave topography shows similar behaviour as the Canyon subbasin.
- Convex topography shows similar behaviour as the Highlands subbasin.



- Canyon subbasin presents an overall concave geomorphology.
- Highlands subbasin presents an overall convex geomorphology.

B. Impact of parameters definition : Example of the impact of characteristic length on Haitjema and Mitchell-Brucker criterion (2005)



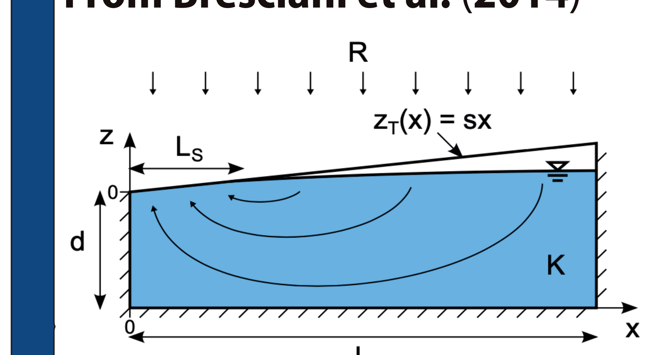
- Defining the hillslope characteristic length can be challenging in mountain context due to the high variability of geomorphologic features.

VI. Conclusions

- R/K exerts the principal control over the seepage distribution, yet, geomorphology and the general shape of the basin modulate seepage distribution singularities.
- Significant overestimation of seepage area from theoretical models in comparison to 3D fully distributed models due to their inability to incorporate details of the topography such as very high hilltops.
- Difficulty to define parameters used in analytical solution give biased results when comparing to a fully integrated 3D model.
- Concave-shaped basin proves more sustainable in terms of seepage distribution as recharge decreases : impact on ecosystems and water balance.

References
- Bresciani, E., Davy, P., & de Dreuzy, J. R. (2014). Is the Dupuit assumption suitable for predicting the groundwater seepage area in hillslopes?. Water Resources Research, 50(3), 2394-2406.
- Haitjema, H. M., & Mitchell-Bruker, S. (2005). Are water tables a subdued replica of the topography?. Groundwater, 43(6), 781-786.

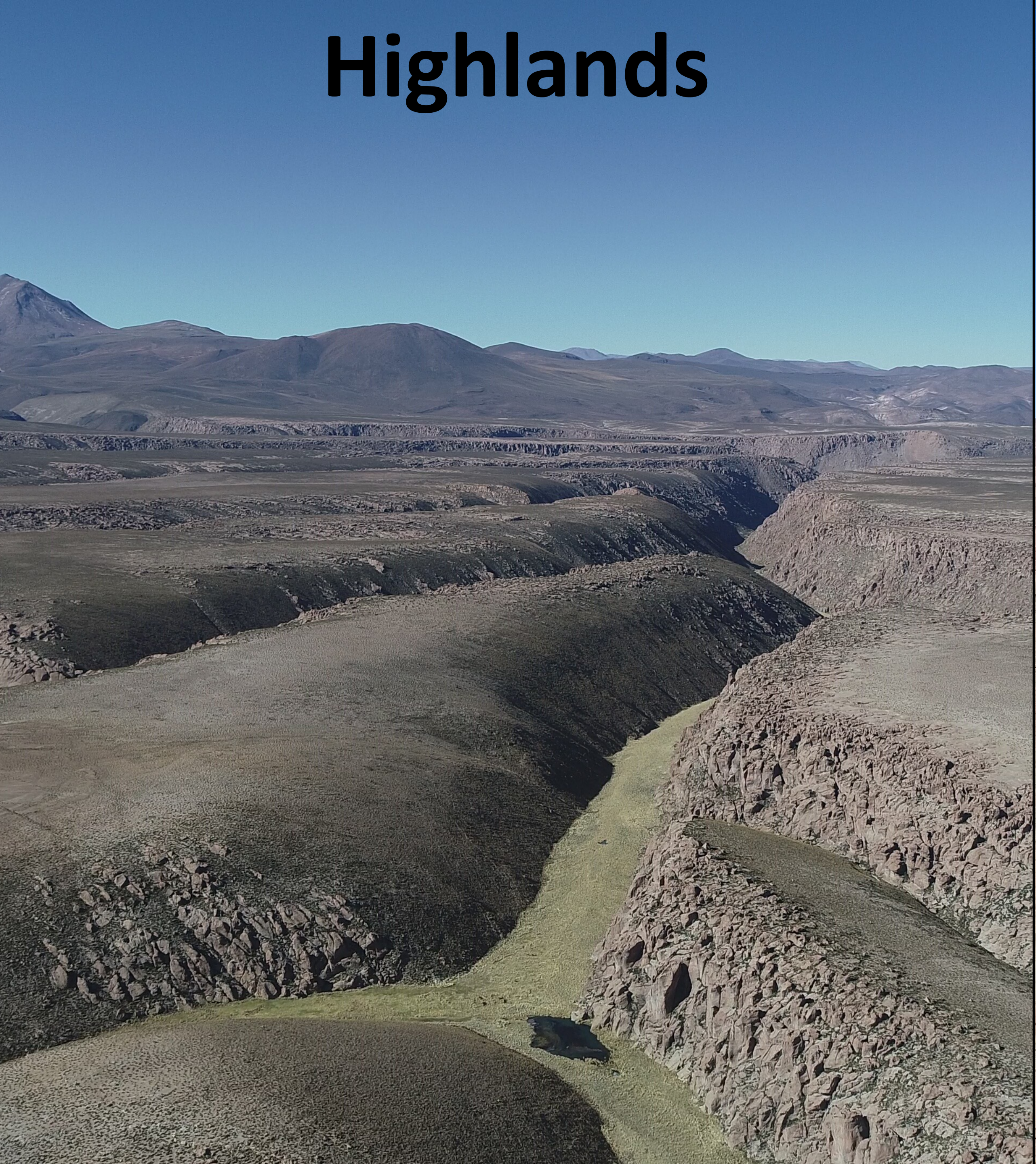
From Bresciani et al. (2014)

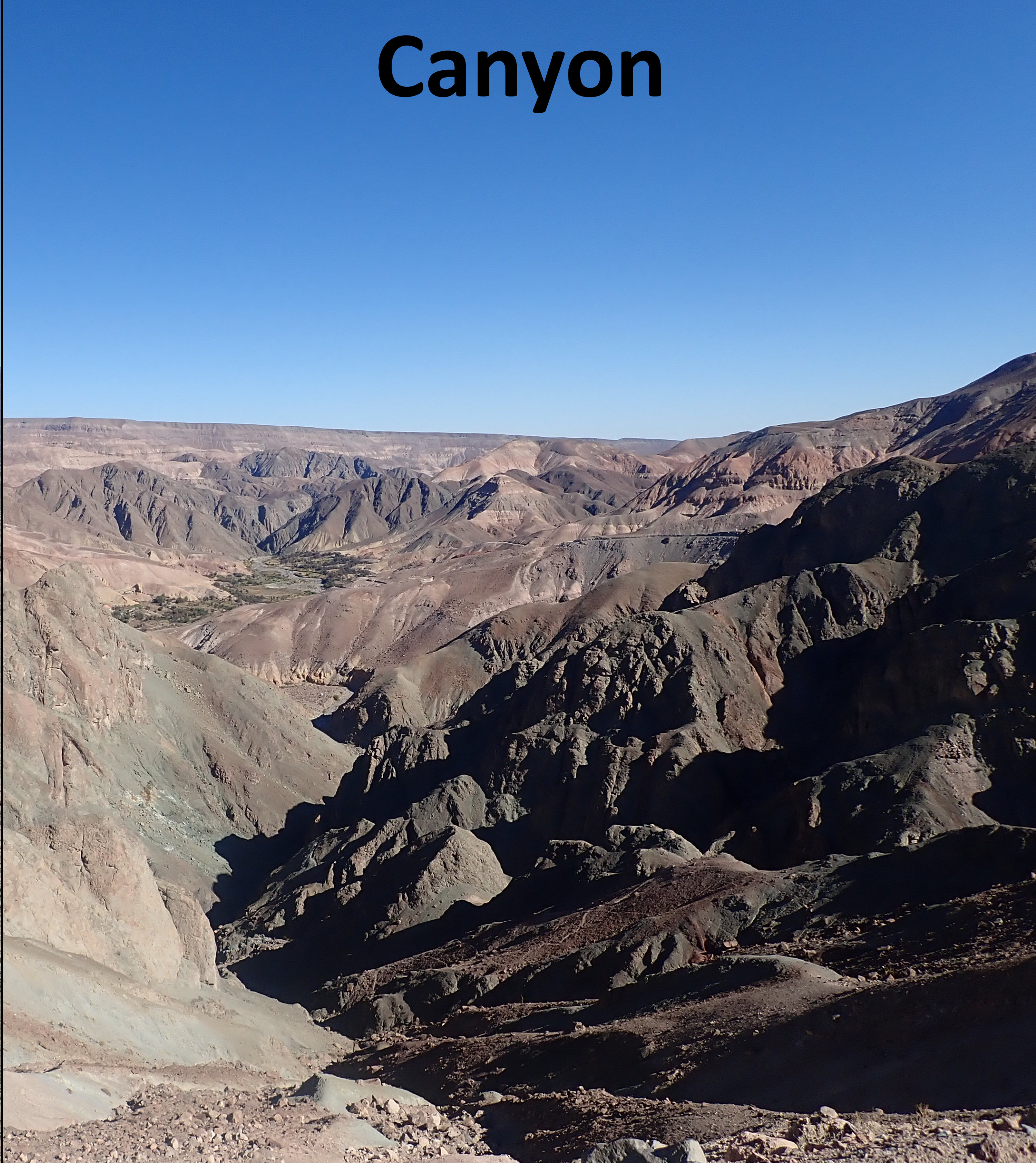


With :
- d [L]: depth to impervious base below the streambed
- L [L]: hillslope length
- L_S [L]: seepage length
- K [L.T^{-1}]: hydraulic conductivity
- R [L.T^{-1}]: available recharge rate R
- s [-]: topographic slope

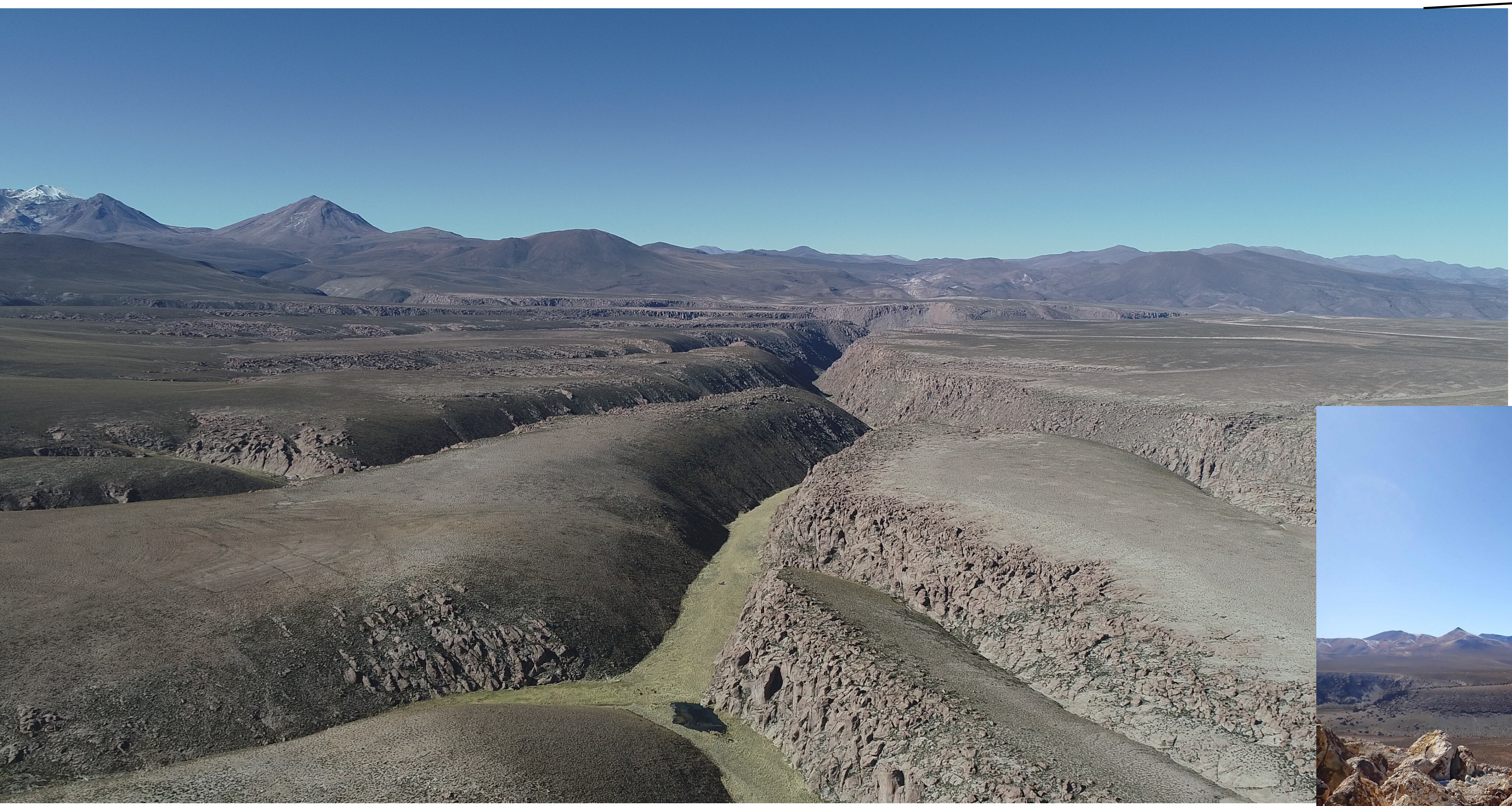
- Under Dupuit flows conditions:

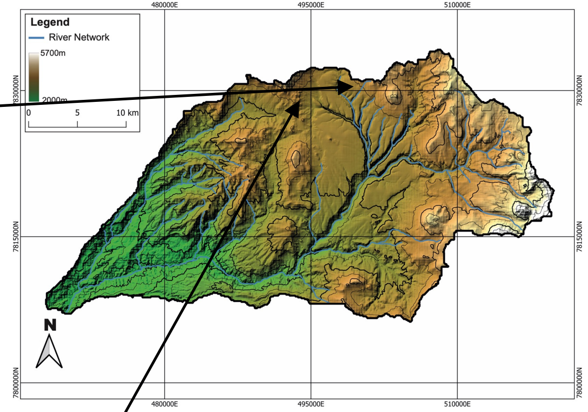
$$\frac{L_S}{L} = \frac{1-\frac{sKd}{RL}}{1+\frac{s^2K}{R}}$$

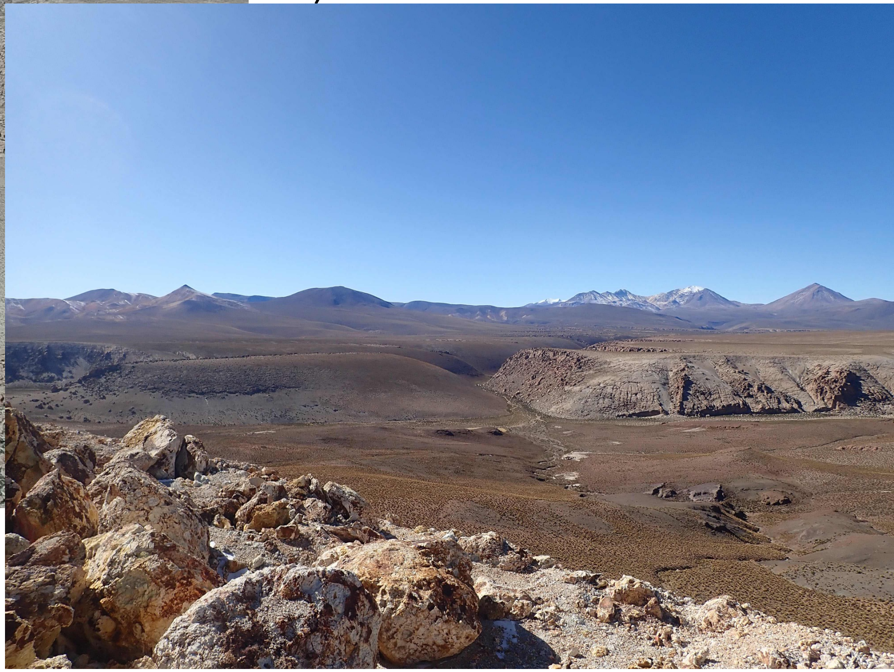

Highlands


Canyon

Highlands field trip identification







Canyon field trip identification