Physiographic controls on pre-event hydrological states and hydrological response to extreme precipitation in the Alzette River Basin, Luxembourg

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Introduction

In recent years, several flash flood events have been observed in Luxembourg, an uncommon feature of Mediterranean river basins at higher latitudes. The design of the hydro-meteorological monitoring and forecasting systems operated in Luxembourg is not adapted to this type of extreme events and there is a pressing need for a better understanding of flash flood triggering mechanisms.

Hypotheses

i) Physiographic characteristics control the **spatial variability** of pre-event hydrological states (as expressed via storage, groundwater levels, soil moisture) in our set of nested catchments.

ii) **Hydrologic response** to (extreme) precipitation is controlled by **pre-event hydrological states.**

iii) Catchments' responsivity **(resistance)** and elasticity **(resilience)** of water yields to global change are controlled by **physiographic characteristics.**

Study area

- 41 catchments with contrasted geology, various land use and homogeneous climate (temperate oceanic) located in the Sûre River basin (4,240 km²), in Luxembourg.
- Mean annual precipitation: from 850 to 1100 mm.
- Rivers in Luxembourg are characterized by summer low flows and winter high flows.

Methodology

Geological classification → Hierarchical Cluster Analysis

Storage metrics

Nine years worth (from 2006 to 2014) of daily increments of the **water balance**:

$$S_{(t)} = [R_{(t)} - Q_{(t)} - aE_{(t)}] + S_{(t-1)}$$

→ were used to determine the **storage deficit**:

$$D_{(t)} = S_{max} - S_{(t)}$$

→ Log. daily discharge vs $D_{(t)}$ were used to determine a **hypothetical maximum storage deficit** (**D_{max}**) for each catchment

- Total storage as an envelope line extrapolated at three low flow conditions (i.e. 0.0001, 0.001, .01 and 0.1 mm.day^{-1})
- **Active storage** = max. amplitude of the $D_{(t)}$ data series

Resistance and Resilience

Resistance as a representation of the changes in the evaporative index (AET/P).

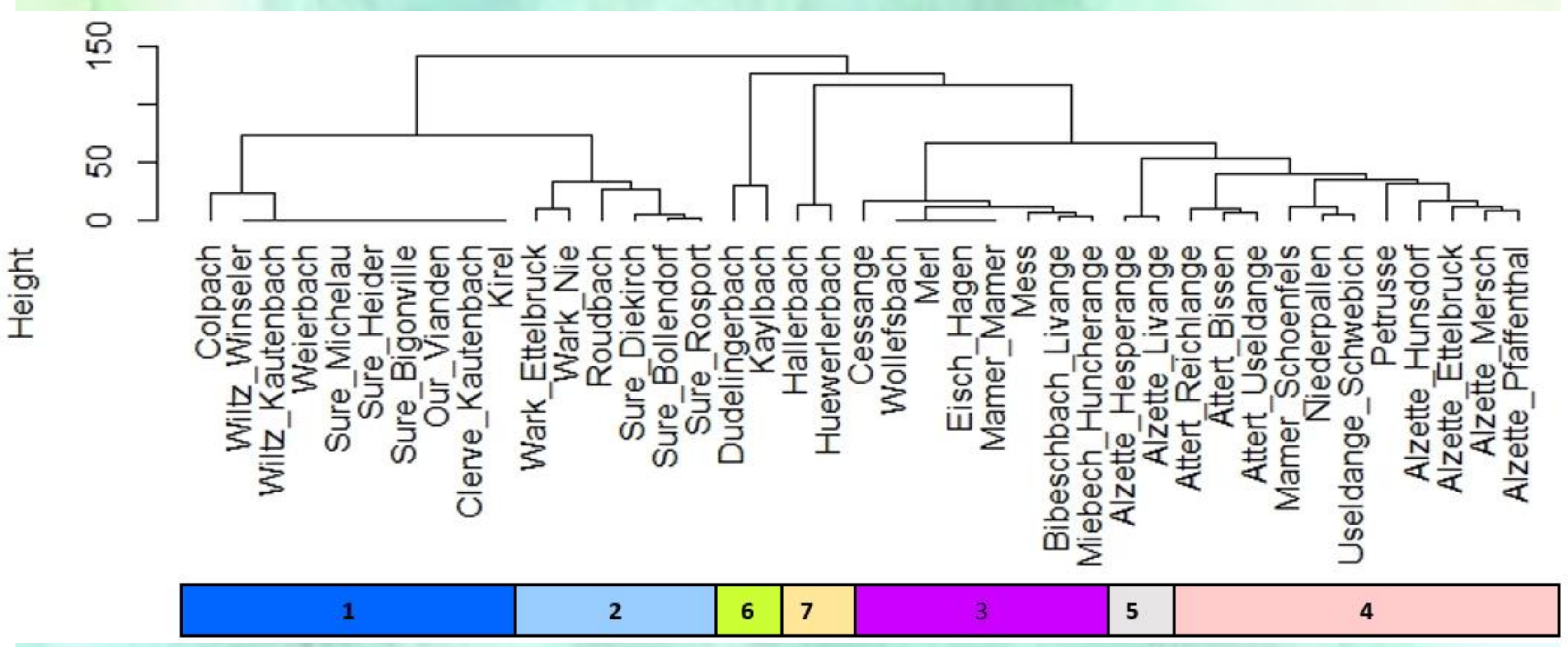
Resilience (elasticity) through Budyko's Method:

$$\varepsilon p = 1 + \frac{AI\, f'(AI)}{1 - f'(AI)}$$

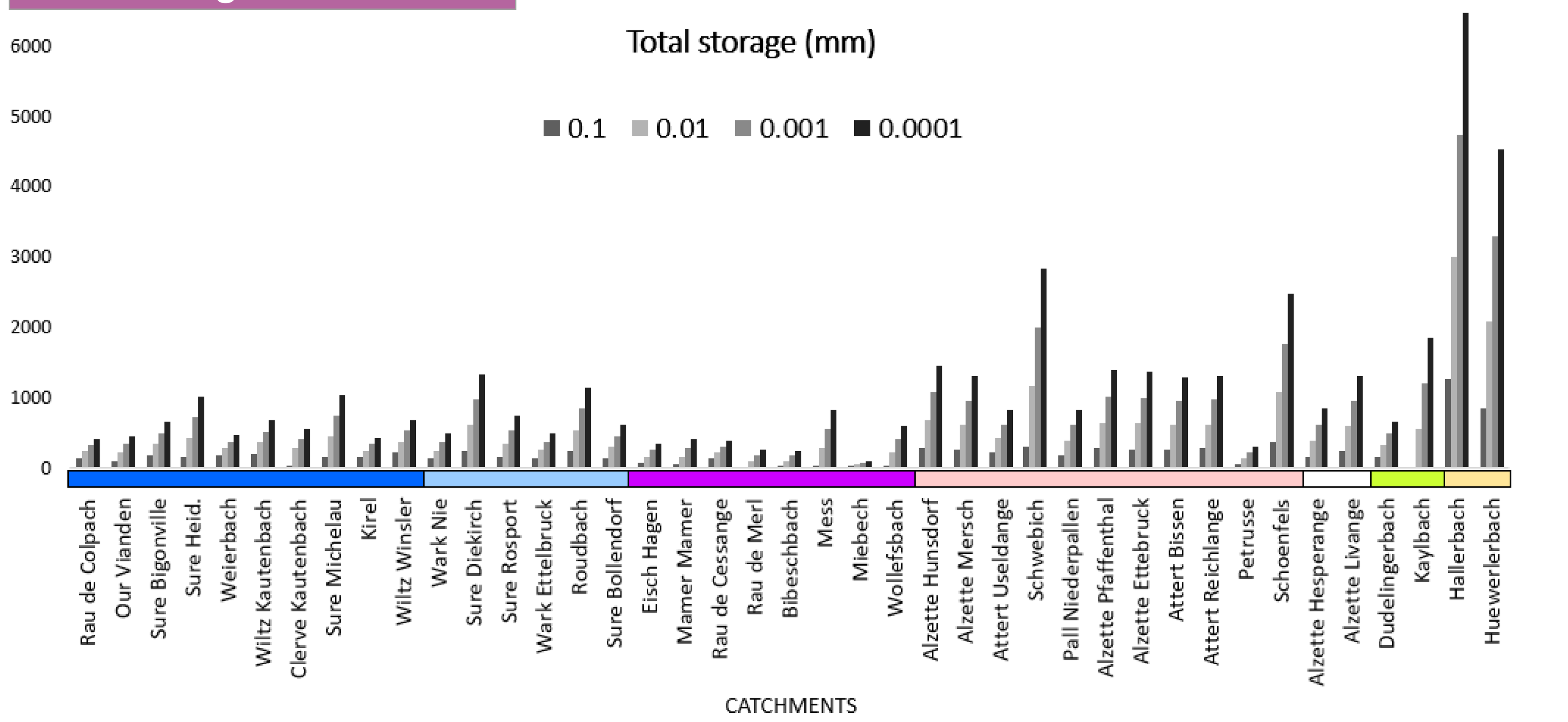
Results

Geological classification and runoff response to geological features

Group	Description	wet conditions	dry conditions
1	Schist predominant (> than 80%)	✓	✓
2	Schist predominant (< than 60%) mixed with sandstone and marls	✓	
3	Marl predominant (> than 85%)	✓	
4	Marl predominant mixed with sandstone and limestone	✓	
5	Marl and limestone alternations, alluvial	✓	✓
6	Limestone predominant (> than 60%)	✓	✓
7	Sandstone predominant (> than 70%)	✓	



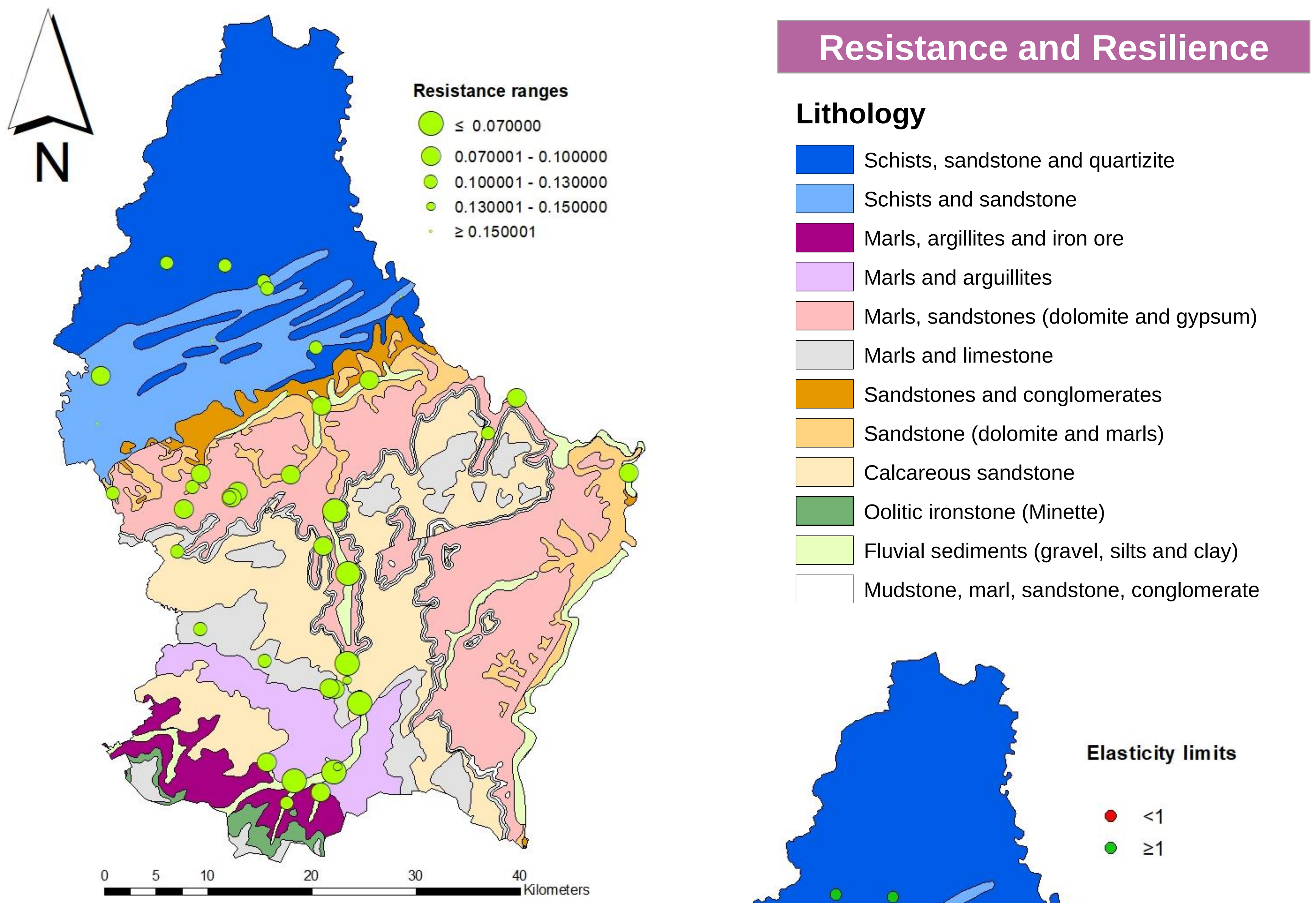
Storage metrics

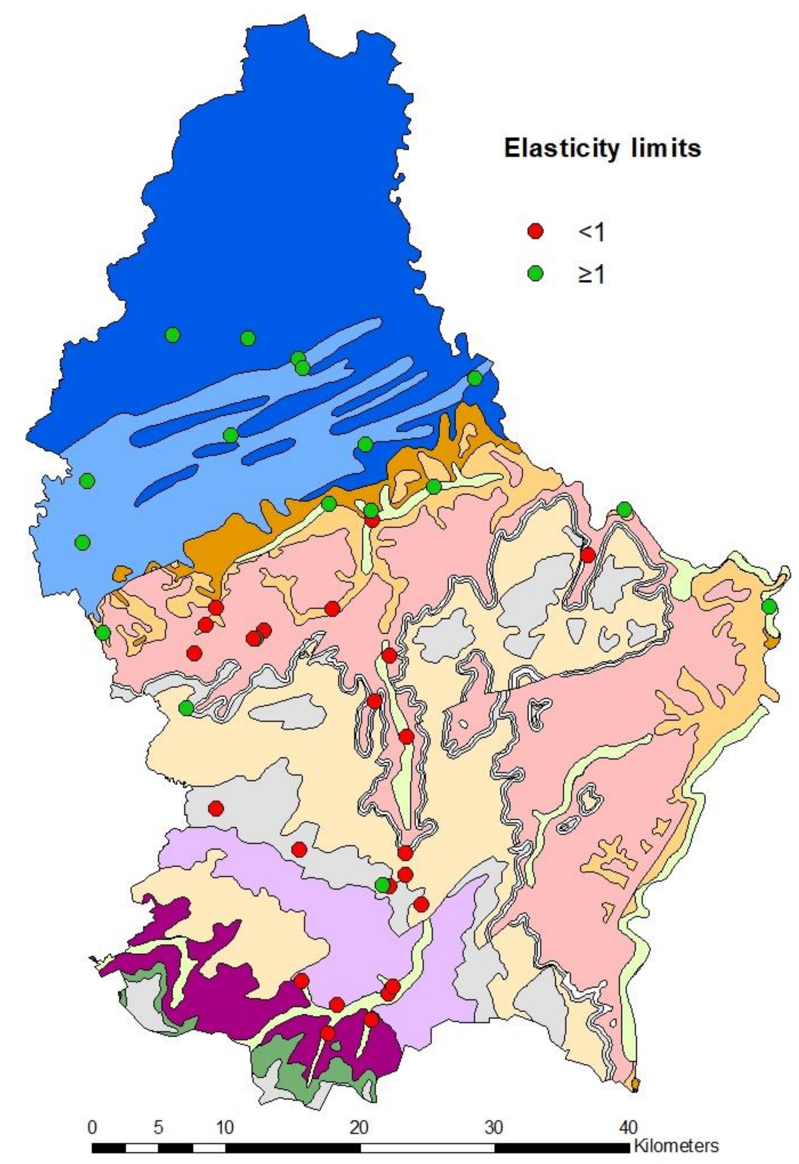


a) The hypothetical near to zero flow values (i.e. 0.0001, 0.001 and 0.01 and 0.1 mm.day^{-1}) have an effect on the determination of **total storage. Sandstone dominated catchments** shows the largest storage capacity.

b) Active storage is generally homogeneous across our range of catchments.

Resistance and Resilience





a) **Schist dominated catchments** seem to have a higher (elasticity) capacity to return to their normal conditions after a perturbation in comparison to the rest of the study area.

b) **Runoff generation** is highly responsive to **precipitation** in the marly and limestone dominated catchments.

c) In the north of Luxembourg, where **schist dominated catchments** are present, the runoff does not seem to be entirely coupled to the precipitation **(low resistance).**

Conclusions

i) Catchments with dominance in **impermeable** geological settings (schist and marls) presented a **lower total storage capacity** in comparison to those with higher permeability. **Permeability** does **not** seem to have an effect on **active storage**.

ii) In an area that is characterized by a **homogeneous climate**, the **runoff response** in our set of nested catchments is **contrasted:** The **heterogeneity in the geology** of the study area seems to be the principal factor of runoff responses.

iii) **The runoff response** to precipitation **(resistance)** and **elasticity** of our set of nested catchments vary according the predominant type of **geological setting**. The south of Luxembourg (Gutland area) seem to be more prone to generate runoff after a **rainfall event**; meanwhile the north (**Oesling area**) present a higher capacity of returning to their normal conditions after a hydrological event, disruption or perturbation **(high elasticity).**

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