Exploring hydrogeological controls on river and groundwater vulnerability to droughts using synthetic models

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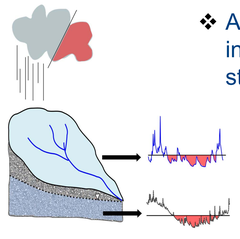
Introduction

Due to changing climatic conditions, identifying regions vulnerable to drought is crucial.

- Low-flow dynamics of streams are still poorly understood
- The contribution of groundwater to low-flows is crucial but often not considered appropriately

Objectives



- Assess vulnerability to droughts in an integrated way: groundwater and streamflow
  - Develop a tool to identify regions vulnerable to droughts based on their surface and subsurface properties

Methodology: synthetic models

- HydroGeoSphere[I] software: physically based, fully distributed model, coupling surface water and groundwater
- Systematic analysis of the influence of catchment properties on the surface and subsurface dynamics
- Ranges of properties based on observed data
- More than 500 models with varying parameter combinations
- Input : time series of measured daily rainfall
- Outputs: storage volume (groundwater) and streamflows are analysed.

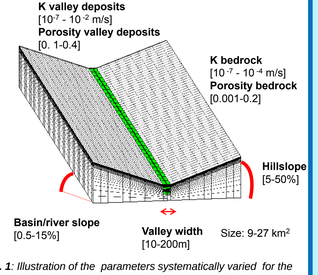


***Fig. 1**: Illustration of the parameters systematically varied for the elaboration of the synthetic models. The aspect ratio is also varied.*

Low-flows and groundwater dynamics

Output indicators:

Q95 for streamflows

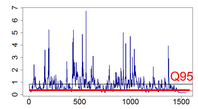
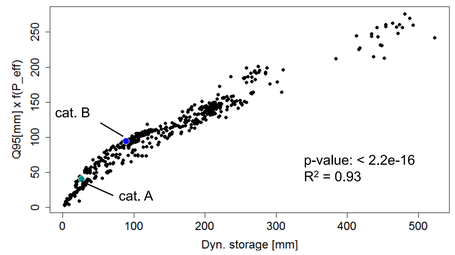
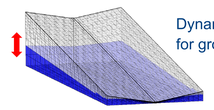


***Fig. 2**: Low flows (Q95 multiplied by a function of precipitation corrected for ET) are linearly correlated to the dynamic groundwater storage*



- Low-flows governed by dynamic storage volume
- The bigger the dynamic volume the higher the low-flows



Vulnerability (example):

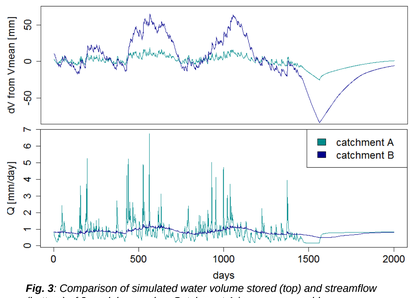


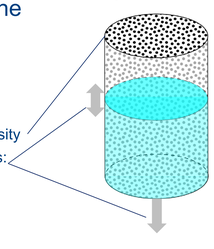
***Fig. 3**: Comparison of simulated water volume stored (top) and streamflow (bottom) of 2 model examples. Catchment A is more permeable*

- Main difference: catchment B has a higher hydraulic conductivity
- Buffering effect of groundwater on stream flows
- Which system is more vulnerable?

What influences the dynamic storage?

- The dynamic storage is highly sensitive to the hydrogeological properties of the bedrock and to the hillslope configuration (p values < 10^{11}).
- Conceptualisation of dynamic storage volume dynamics:
  - Total storage volume determined by geometrical parameters and porosity
  - Ability of storing and releasing water governed by dynamic parameters: hydraulic conductivity and slope gradients

***Fig. 4**: Conceptualisation of water storage volume*



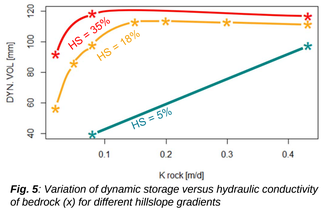


***Fig. 5**: Variation of dynamic storage versus hydraulic conductivity of bedrock (x) for different hillslope gradients*

- Limiting factor: influence of parameters depend on how constrained the dynamic storage is

=> interdependency of parameter influence

Estimation of Q95 based on basin properties

- To better understand combined effect of parameters on dynamics, dimensionless combinations are tested
- Dimensionless number Π is obtained.
- Combination of precipitation, geometrical parameters, slope gradients and hydraulic conductivity

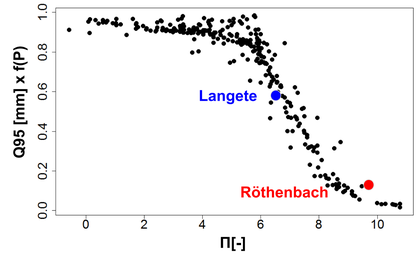


***Fig. 6**: Relationship between dimensionless number obtained with catchment properties and precipitation*

- Q95 can be estimated with catchment physical properties and precipitation only!
- Validated with observable data of 2 catchments:

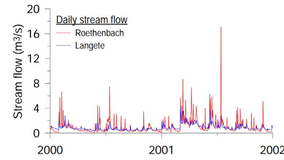


***Fig. 7**: Measured streamflows of two 60km² Swiss catchments.*

- Variability largely explained by hydraulic conductivity and slope gradients:

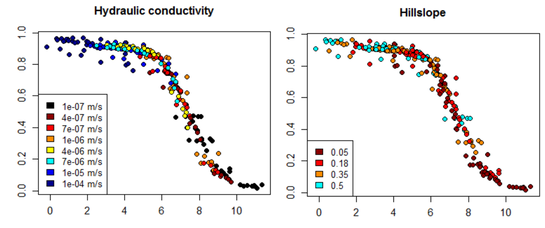


***Fig. 8**: Variability of low-flow dynamics and dimensionless number linked to hydraulic conductivity and hillslope*

Conclusions and outlook

- Low-flows are governed by groundwater storage dynamic.
- Strong control mechanism of hydrogeological properties on catchment dynamics.
- Estimation of low streamflow discharge based only on catchment properties and precipitation data.
- To assess vulnerability of water resources to droughts, geological and hydrogeological data are crucial.

NEXT STEPS:

- Validate results with sensitivity analysis, with more complex models and more observable data
- Expand results to prediction of groundwater vulnerability.

References:

- [I] Therrien, R., McLaren, R.G., Sudicky, E.A., Park, Y.-J. : HydroGeoSphere: A three-dimensional numerical model describing fully-integrated subsurface and surface flow and solute transport, User Guide, Aquanty Inc., Waterloo, Ontario, Canada, 2012.