Vienna Doctoral Programme on Water Resource Systems
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Deciphering River Flood Change

Step changes in the flood frequency curve - Quantifying effects of catchments storage thresholds

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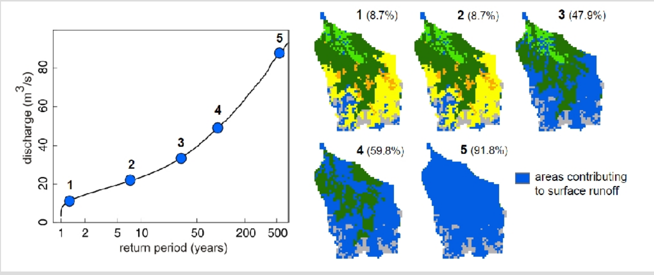
MOTIVATION

In previous work the authors have shown that **non linear catchment response** related to a **storage threshold** may lead to a **step change** in the flood frequency curve.

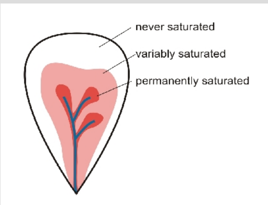


Step change in flood frequency curve due to non linear increase in contributing area [Rogger et al., 2012]

The aim of this study was to **quantify** impacts of temporal and spatial storage changes on the **magnitude of the step change.**

APPROACH

Real catchment behaviour simplified for **hypothetical catchment:**



- permanently saturated region → always contributes to flood events
- variably saturated region → contributes to flood events when storage threshold is exceeded
- never saturated region → never contributes to flood events
- **saturation excess mechanism**

Simplified **derived distribution approach** [*Viglione et al.*, 2009]:

→ stochastic precipitation model based on *Sivapalan et al.* [2005]

→ simple rainfall runoff model → combination of event runoff coefficient (r_c) with a linear reservoir:

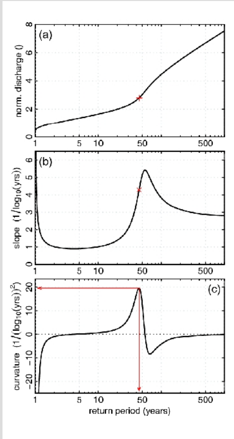
$$q_p = r_c \cdot i \cdot \left[1-\exp\left(\frac{t_r}{t_c}\right)\right]$$

q_p ..... flood peak
r_c....... event runoff coefficient
i......... rainfall intensity (block rainfall)
t_r........ rainfall duration
t_c....... time of concentration

→ r_c follows beta distribution with mean δ_c and standard dev. σ_c.

→ **threshold process** described by switch in runoff coefficient (r_c) from a lower mean δ_{c1} to higher mean δ_{c2} at the threshold rainfall volume V^*.

STEP CHANGE



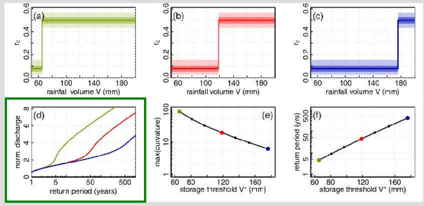
We define the **maximum of the second derivative** of the flood peaks with respect to their return period as a **new measure for the magnitude of the step change.**

(a) flood frequency curve with step change
(b) slope of the curve $dQ=dlog_{10}T$
(c) curvature of the curve $d^2Q=d(log_{10}T)^2$.
The magnitude and return period of the step change are indicated by the red arrows.

SPATIAL CONTROLS

Magnitude of the Storage Deficit

Magnitude of the soil storage deficit is represented by the threshold rainfall V^*:



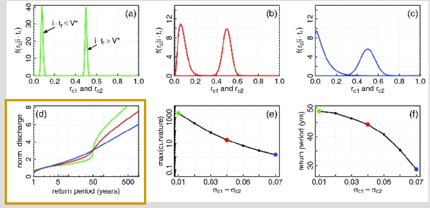
Spatial distribution of storage capacities for (a) threshold V=65.54 mm, (b) V*=118.5 mm, and (c) V*=176.0 mm (rainfall vol. with return periods of 5, 50 and 500 yrs). (d) Flood frequency curves for cases a, b and c. (e) Magnitude of the step change for varying V*. (f) RP of the step change for varying V*.*

Return period of step change similar to return period of the threshold *V**

TEMPORAL CONTROLS

Temporal Variability of Initial Storage

Antecedent moisture conditions represented by changes in σ_{c1} and σ_{c2} of runoff coefficient:



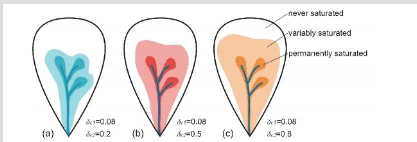
Density functions of runoff coefficients (r_{c1} and r_{c2}) for δ_{c1}=0.08, δ_{c2}=0.5, and (a) $\sigma_{c1}=\sigma_{c2}$=0.01, (b) $\sigma_{c1}=\sigma_{c2}$=0.04 and (c) σc1=σc2=0.07 ; V=118.5 mm (d) Flood frequency curves for cases a, b and c. (e) Magnitude of the step change for varying $\sigma_{c1}=\sigma_{c2}$. (f) Return period of the step change for varying $\sigma_{c1}=\sigma_{c2}$.*

Step change decreases with increasing temporal variability in initial storage

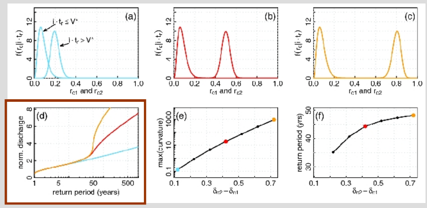
SPATIAL CONTROLS

Size of the Variably Saturated Region

Variably sat. region represented by varying mean of larger runoff coefficient δ_{c2}:



Schematic illustration of varying size of variably saturated region

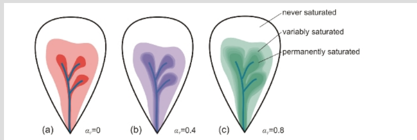


Density functions of runoff coefficients (rc1 and rc2) for δc1=0.08 and (a) δc2=0.2, (b) δc2=0.5 and (c) δc2=0.8; V=118.5 mm (d) Flood frequency curves for cases a, b and c. (e) Magnitude of the step change for varying δc2-δc1. (f) Return period of the step change for varying δc2-δc1.*

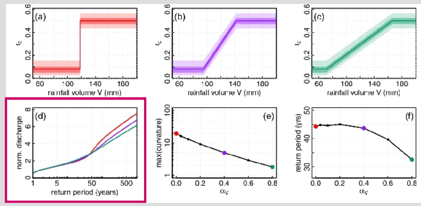
Step change increases with increasing size of variably sat. region

Spatial Distribution of Storage Deficits

Gradual increase in storage deficit represented by a gradual increase in δ_c:



Schematic illustration of a gradual increase in storage deficit



Relationship between the mean runoff coefficient δc and the rainfall volume V for (a) αV=0 and (b) αV=0.4 and (c) αV=0.8; V=118.5 mm (d) Flood frequency curves for cases a, b and c; (e) Magnitude of the step change for varying αV. (f) Return period of the step change for varying αV.*

Step change decreases with increasing spatial storage variability

CONCLUSIONS

→ **Magnitude of step change** depends on temporal and spatial storage variability:
↓ temporal variability in initial storage
↑ size of variably saturated region
↓ spatial storage variability

→ Return period of step change is similar to return period of rainfall volume needed to exceed threshold

→ is **important for the estimation of extreme floods**; may not be represented by data if flood records are short, but fitting a smooth distribution function will underestimate extreme flood discharges

→ important to check whether step change is expected or not

Rogger, M., A. Viglione and G. Blöschl (2013) Quantifying effects of catchments storage thresholds on step changes in the flood frequency curve, Water Resources Research, 49, 6946–6958, doi:10.1002/wrcr.20553.

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Sivapalan, M., G. Blöschl, R. Merz, and D. Gutknecht (2005), Linking flood frequency to long-term water balance incorporating effects of seasonality, Water Resour. Res., 41,W06012, doi:10.1029/2004WR003439.

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