# Impact of model geometry and recharge rates on catchment's residence time distributions - numerical experiments

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## 1 Introduction

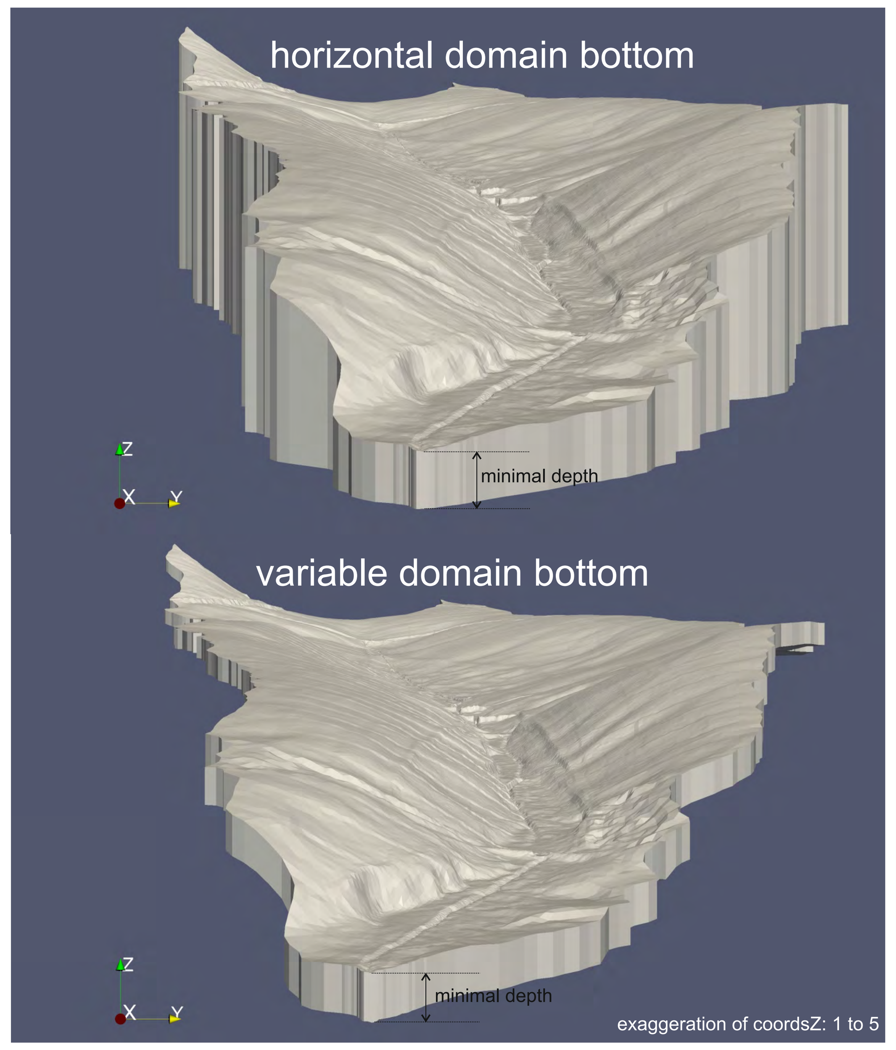
Residence time distributions (RTD) of water in catchments are promising tools to characterize and model solute transport on a larger scale. Since they can't be measured directly, numerical water flow models and particle tracking algorithms are a valuable tool. While the surface elevation can mostly be resolved in detail, the subsurface volumes and boundaries are often undetermined. A coupled surface and subsurface flow model was created for a small catchment within the Harz Mountains, Germany. We hypothesize that the effect of the model domain geometry significantly affect the RTD characteristics like shape, mean and variances. Our objectives are to systematically evaluate the impact for varying geometries and groundwater recharge rates on RTD's.

## 2 Modeling approach

### Model Setup

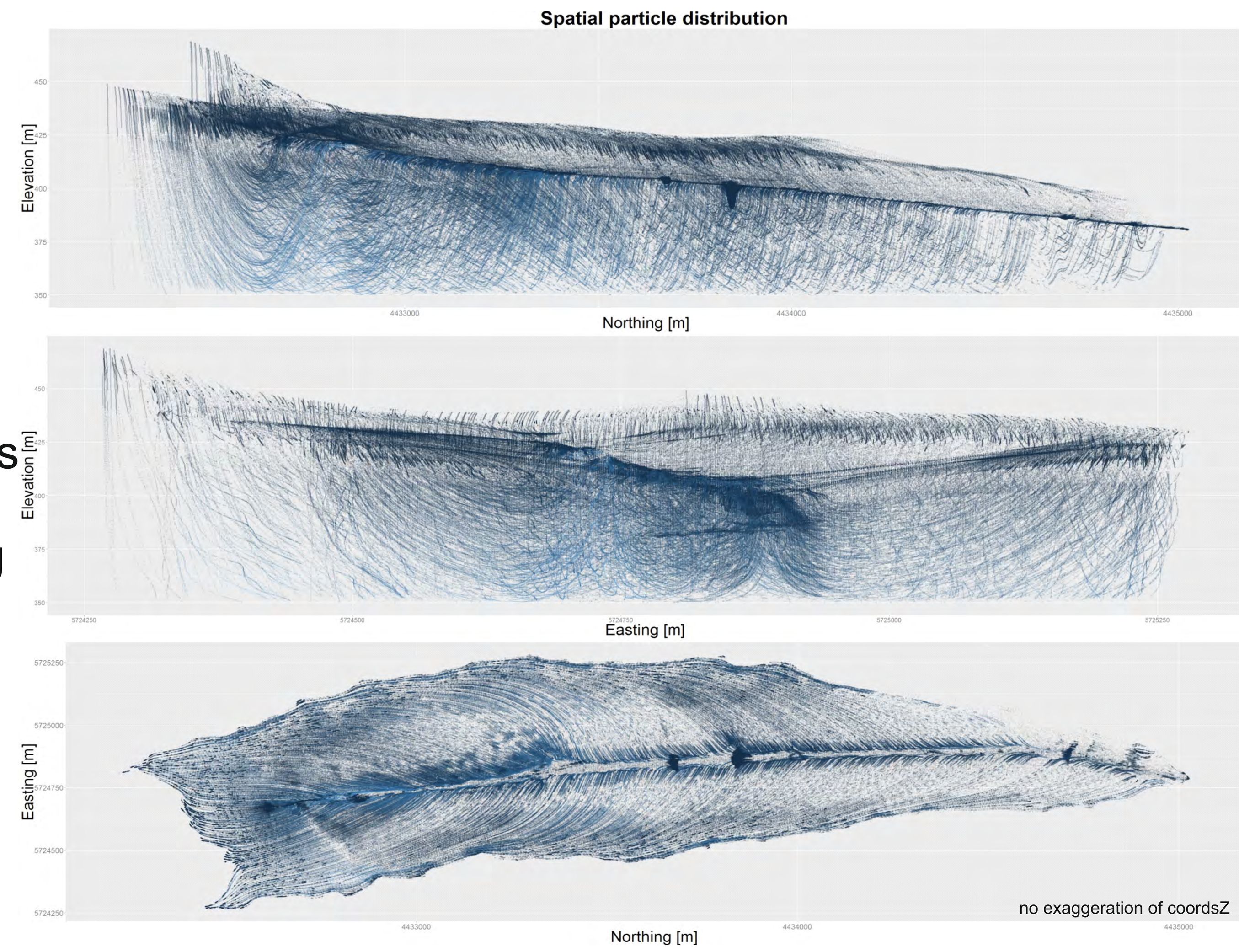
- HydroGeoSphere[1] (HGS - Aquanty Inc.)
- Steady State simulation for
  - fixed two-layered setup with homogeneous soil properties (material and $k_f$ parameters)
  - Two main domain bottom geometries (variable and horizontal)
  - Variation of lower boundary depths and groundwater recharge rates

- model topography:
  - resolution = 2 to 10 m (const.) node = ~ 850,000
  - volume = 0.003-0.143 km³ area = ~ 1.6 km³ (const.)
  - min. depth = 2 to 50 m (n=5) kf-val. = 0.05 to 2.5 m $d^{-1}$
- model input:
  - recharge rate = 0.1 to 15 mm $d^{-1}$ (n=15)
  - boundary = recharge applied to surface layer (input), critical depth boundary condition (outlet), remaining boundary as no flow condition
  - total runs = 58
- model output:
  - head, saturation, velocity field (xyz scalars), overland flow for each printout time and node - calculation of groundwater surface




### Particle Tracking

- Conversion from HGS output to a readable Paraview[2] steady state flow field file
- Application of a forward particle tracking algorithm for:
  - 80,000 randomly selected surface seed points (representation statistically)
  - removing of zero time particles
  - Individual tracking of each particle until surface (resulting in overlandflow) or critical depth boundary condition[3] (resulting in discharge) is matched
- Statistical (mean, variance, ...) and graphical analysis (ggplot2 package[4]) performed in R[5]




## 3 Results

### Analysis of groundwater recharge rates on residence time distributions

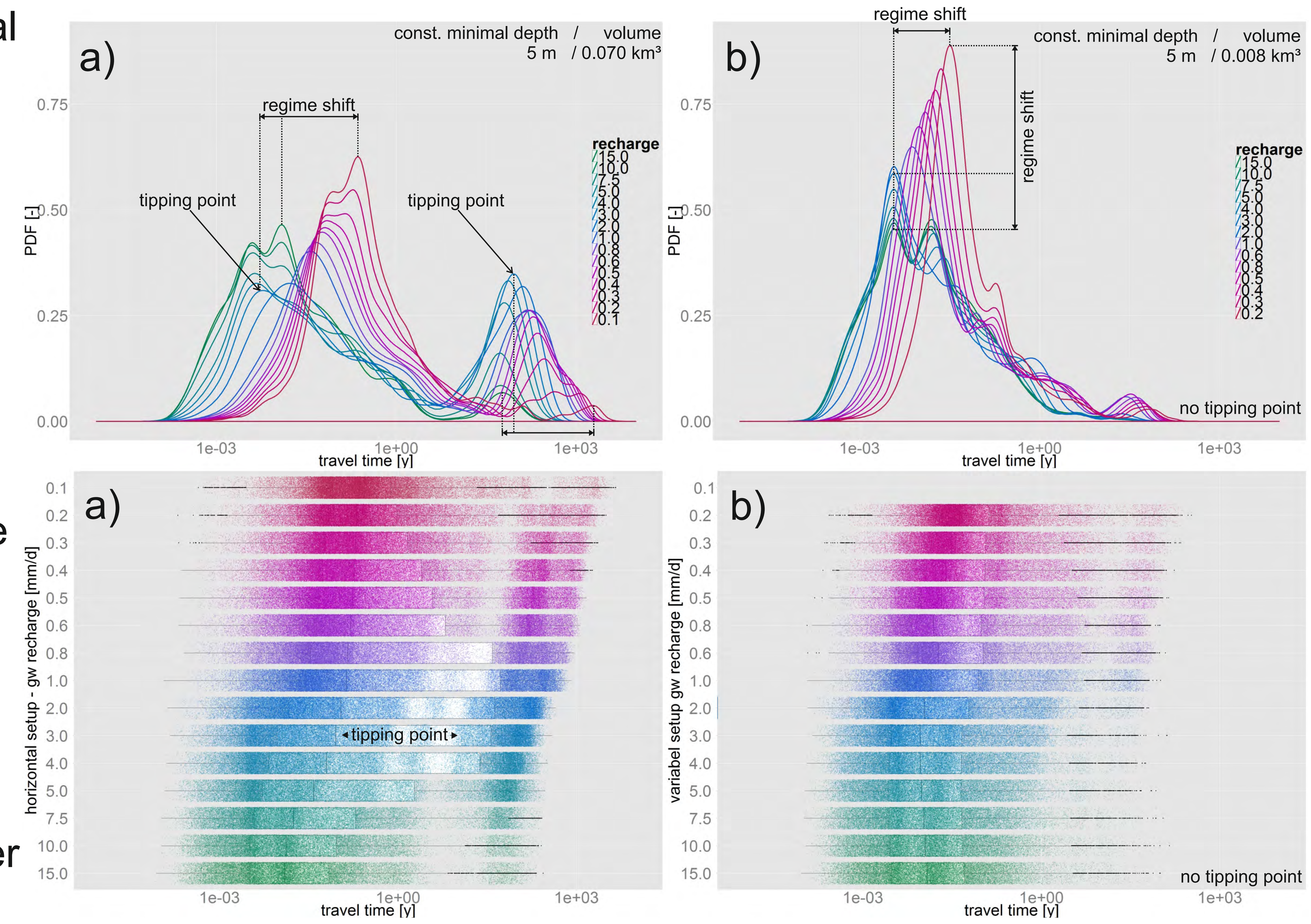
- RTD spans particle ages from hours to serveral years showing complex shapes depending on groundwater recharge & geometrie setup

**a) variable domain bottom:**

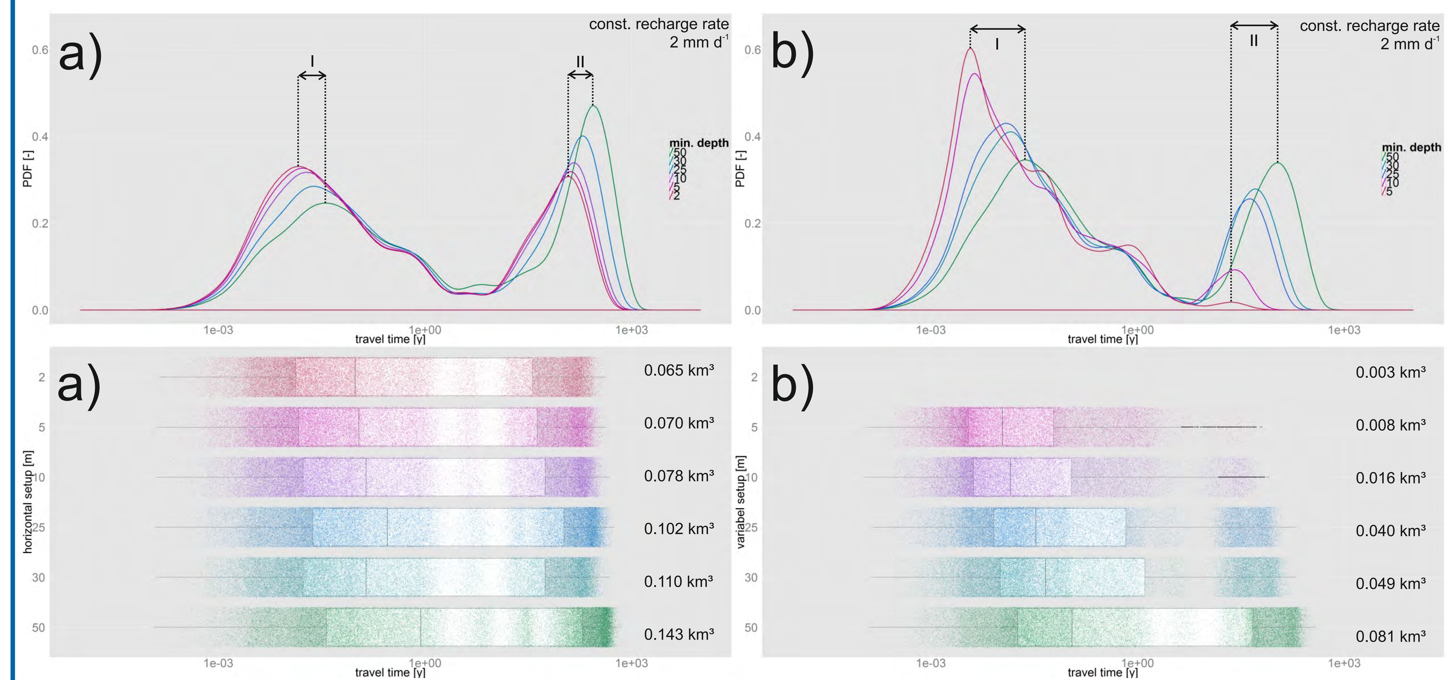
- High groundwater recharge rates predominantly result in unimodal RTD's and low variances
- A decrease of groundwater recharge activates longer flow paths which results in bimodal structure and higher variances
- Tipping point at medium groundwater recharge rates (ca. 3 mm $d^{-1}$) indicates a regime shift to older age distributions
- Low groundwater recharge shifts back to unimodal behaviour and low variances

**b) horizontal domain bottom:**

- Unimodal behaviour present for all groundwater recharge scenarios, no changes in variance




### Analysis of minimum depth setups on RTD's




- residence time is increasing for higher volumes - less shorter and more longer flow paths become dominant (cf. I & II)

**a) variable domain bottom:**

- remaining bimodal behaviour for higher volumes
- no increase of variances and mean travel time for higher model volumes

**b) horizontal domain bottom:**

- bimodal behaviour can be observed for variable setup
- increasing variance and mean travel time for higher model volumes

### Conclusions

- Simulations indicate a strong influence of model geometry and groundwater recharge rates on RTD's characteristics:
  - varying groundwater levels activate different particle flow paths
  - mean travel time and variances differ significantly for changing volumes and recharge rates
  - choice of domain bottom geometry representation is indirectly connected to observed RTD's due to the resulting change in model volume
- Reactive solute transport simulations will be strongly influenced by the choice of the model domain bottom
- Strong depedence of RTD on recharge rates in the steady state models hint to a complex transient behavior under varying recharge rates over the year

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References:

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