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Impact of subjective modeling decisions on hydrological modeling

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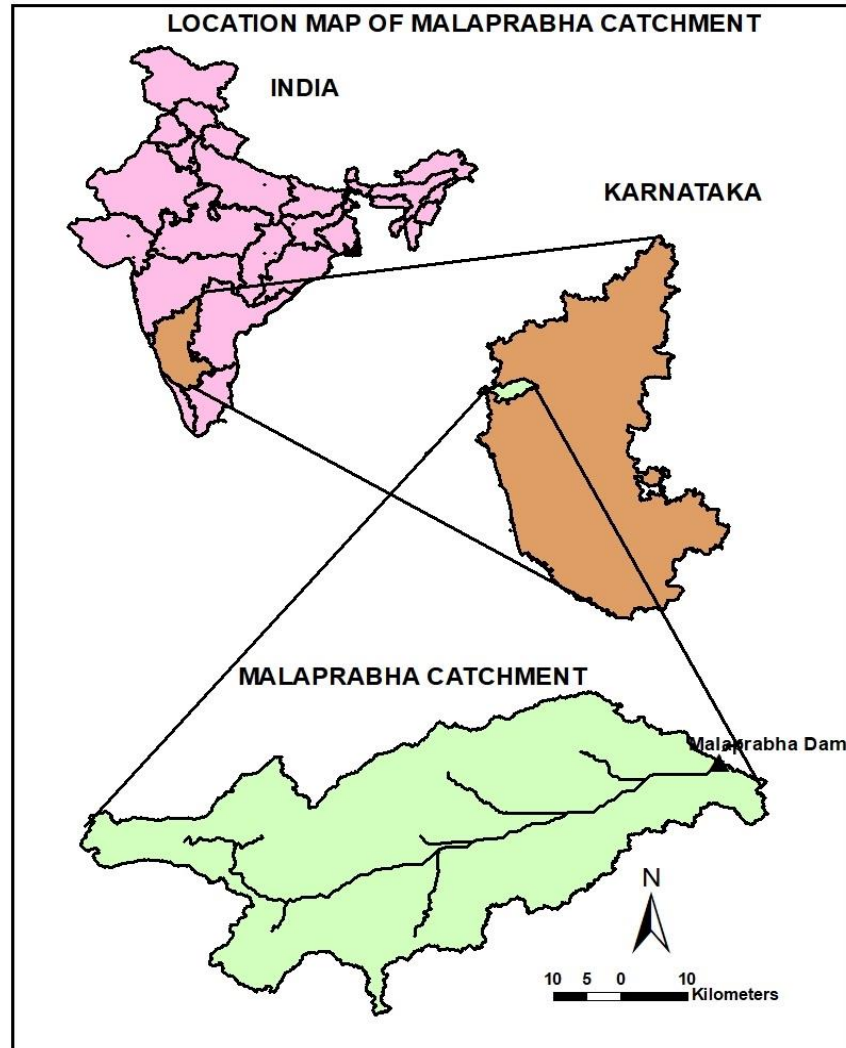
Motivation

- A wide range of models are developed which differ in many aspects in conceptualization and implementation
- A model developed for an environment setting need not necessarily be suitable for other environments
- Also, modeling decisions during model configuration introduce subjectivity from the modeler.
- Therefore, it is required to examine and evaluate the different model representations of hydrological processes and its impact on model simulations.
- This kind of study is important to understand if we are getting ‘right answers for the right reason’.
- In this study, we show that modeling decisions made during setting up of the model configuration, beyond the model choice, also impact the model results.

Data sources

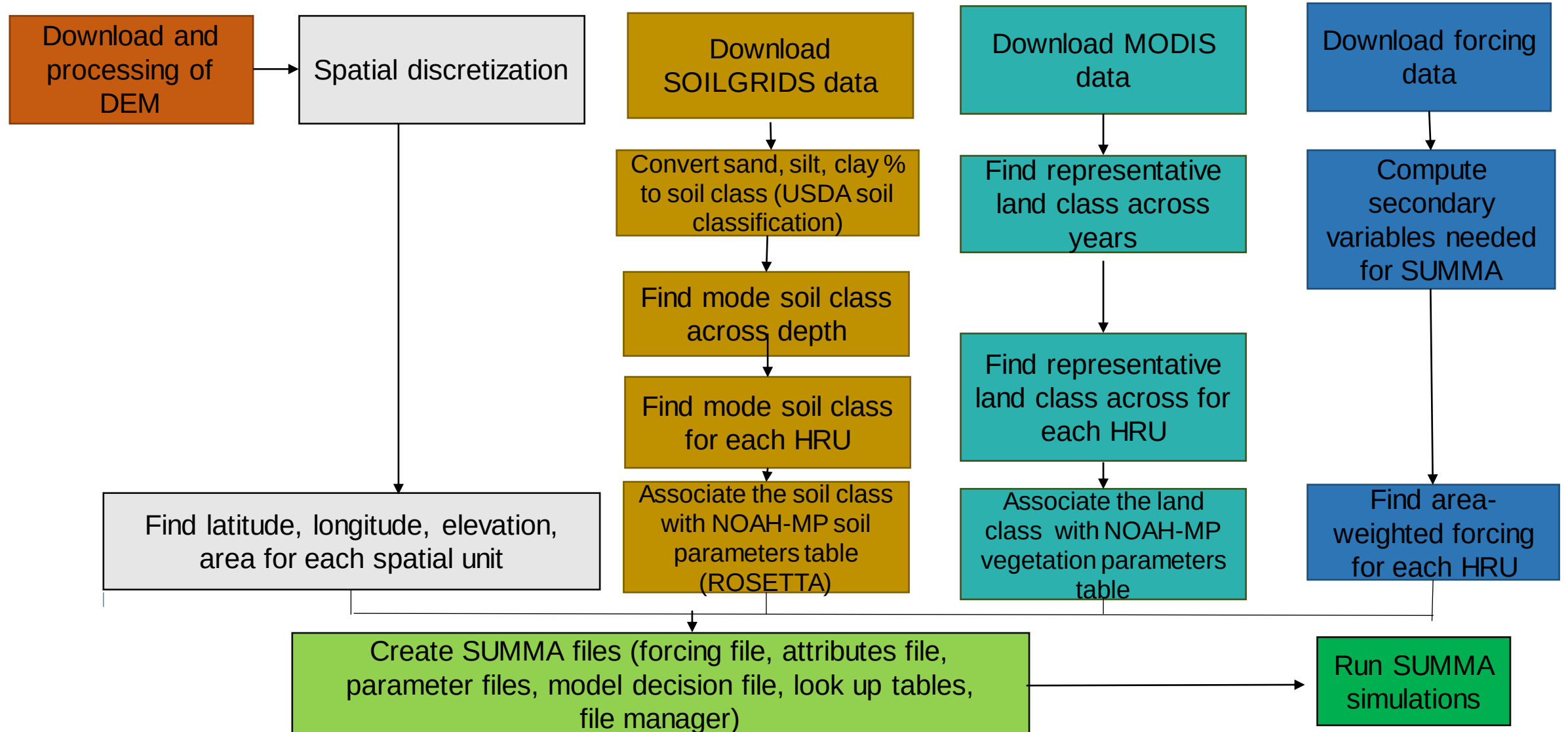
Data	Source
DEM	The Shuttle Radar Topography Mission (SRTM), 30m resolution
LULC	MODIS global 500m resolution
Soil	SOILGRIDS 250m resolution
Forcing data	The Indian Monsoon Data Assimilation and Analysis (IMDAA) 12km hourly gridded data (2006-2017)
Observed streamflow (Inflow to Malaprabha reservoir)	Water Resources Development Organization, Bangalore (obtained from KWRIS) / daily data (2006 – 2017)

Study area



1. Name of the Catchment	Malaprabha Catchment
3. Study area	Area drained by Malaprabha river and its tributaries up to Malaprabha dam
4. Total catchment area	2227 km ²
5. Location of study area	
a. Towns in and around	Khanapur, Belgaum, Baihongal, Hubli
b. Latitude	15 ⁰ 28' N – 15 ⁰ 55' N
c. Longitude	74 ⁰ 12' E – 75 ⁰ 10' E
6. Location of Malaprabha Dam	15 ⁰ 49' N, 75 ⁰ 06' E

Pre-processing steps



Spatial discretization

- In semi-distributed models, the goal is to use as much information as possible while minimizing the additional computational burden from a fully distributed model.
- To serve this purpose, the catchment is divided into Grouped Response Units (GRUs) and Hydrologic Response Units (HRUs).
- GRUs (Grouped Response Units) and HRUs (Hydrologic Response Units) define a typical hierarchical spatial organization where HRUs are nested within GRUs.
- GRUs represent sub-basin and HRUs represent hydrologically similar areas within the sub-basin.
- **Key characteristics of GRUs:**
 - GRUs can be of any shape and size
 - The area of each GRU must be spatially contiguous
- **Key characteristics of HRUs:**
 - A GRU is composed of one or more HRUs
 - HRUs can be of any shape and size
 - HRUs need not be spatially contiguous (HRU can lump together hydrological similar areas from different parts of the landscape)

Delineation of GRUs and HRUs

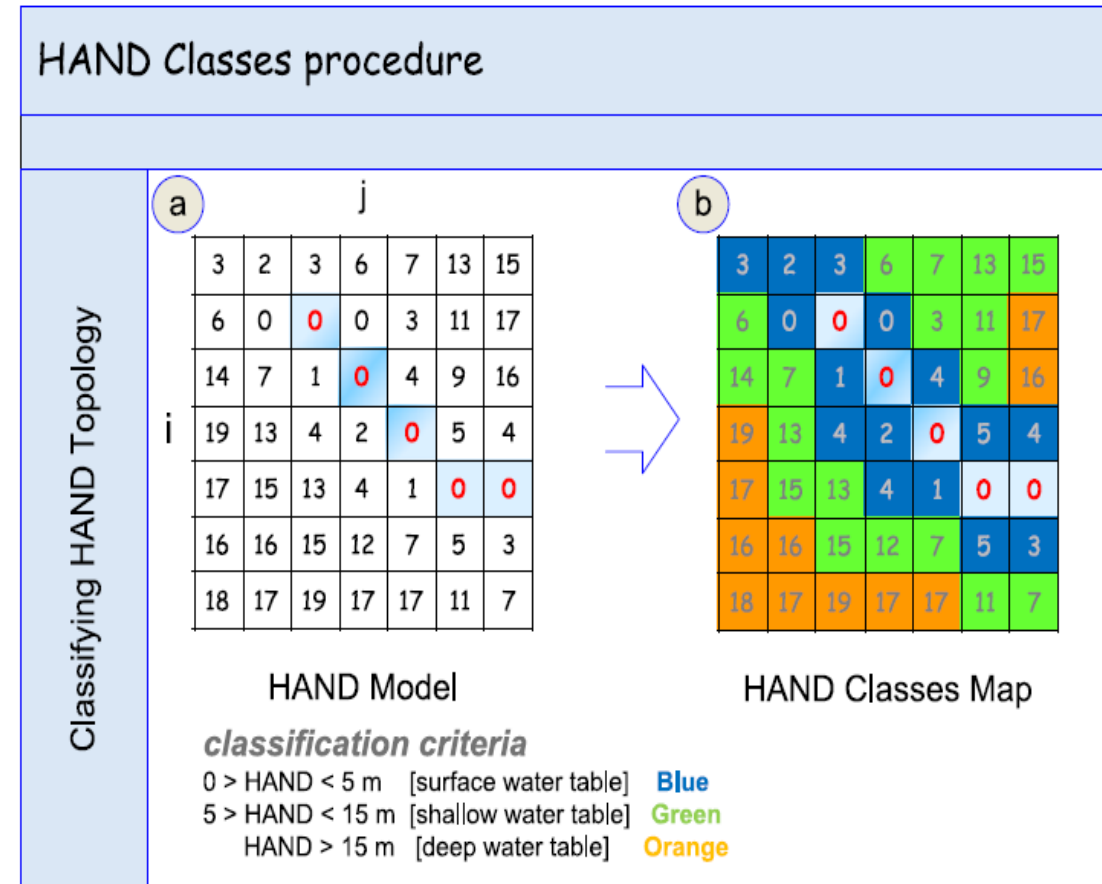
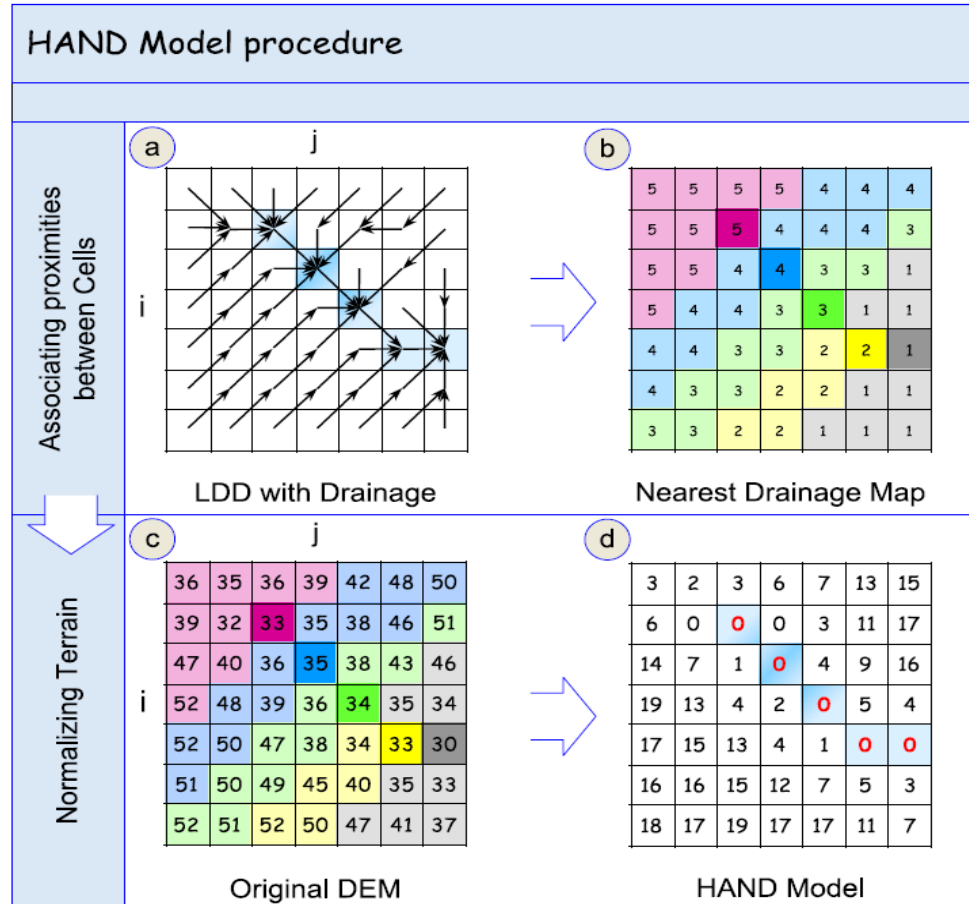
- **GRU delineation (by terrain analysis)**

- 1) Fill the DEM.
- 2) Generation of flow direction map (D8 approach)
- 3) Flow accumulation map
- 4) Generation of river network by defining a threshold drainage area (tda) from flow accumulation map
- 5) Sub-basin delineated from river network

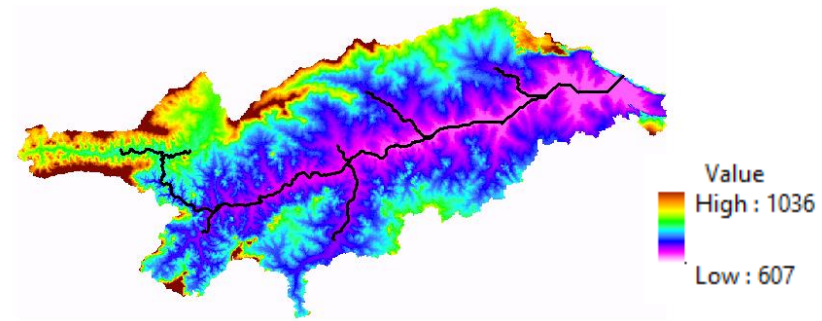
- **HRU delineation (by Height above nearest drainage concept)**

- 1) Within the sub-basin, we can compute the relative elevation difference between a given pixel and the channel into which it flows.
- 2) Height above nearest drainage (HAND) model (Nobre et al., 2011) is used to discretize area into HAND bands by defining a threshold value for height difference, dh .

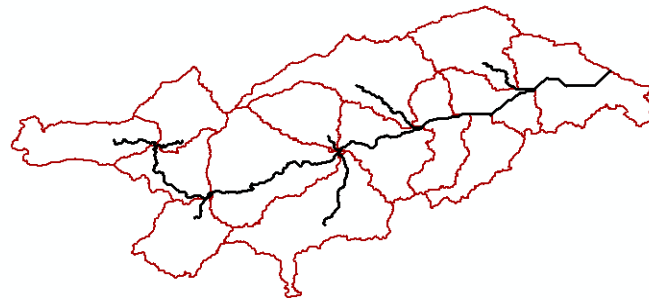
HAND procedure



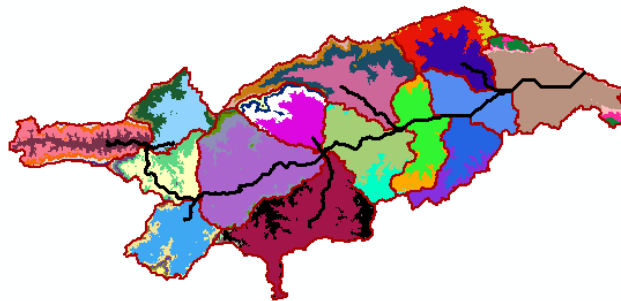
Procedure to generate HAND maps
[Source: Nobre et al. (2011)]



River network overlaid on DEM



Grouped Response Units (Total: 15)
Delineated based on the threshold drainage area of 100 km²

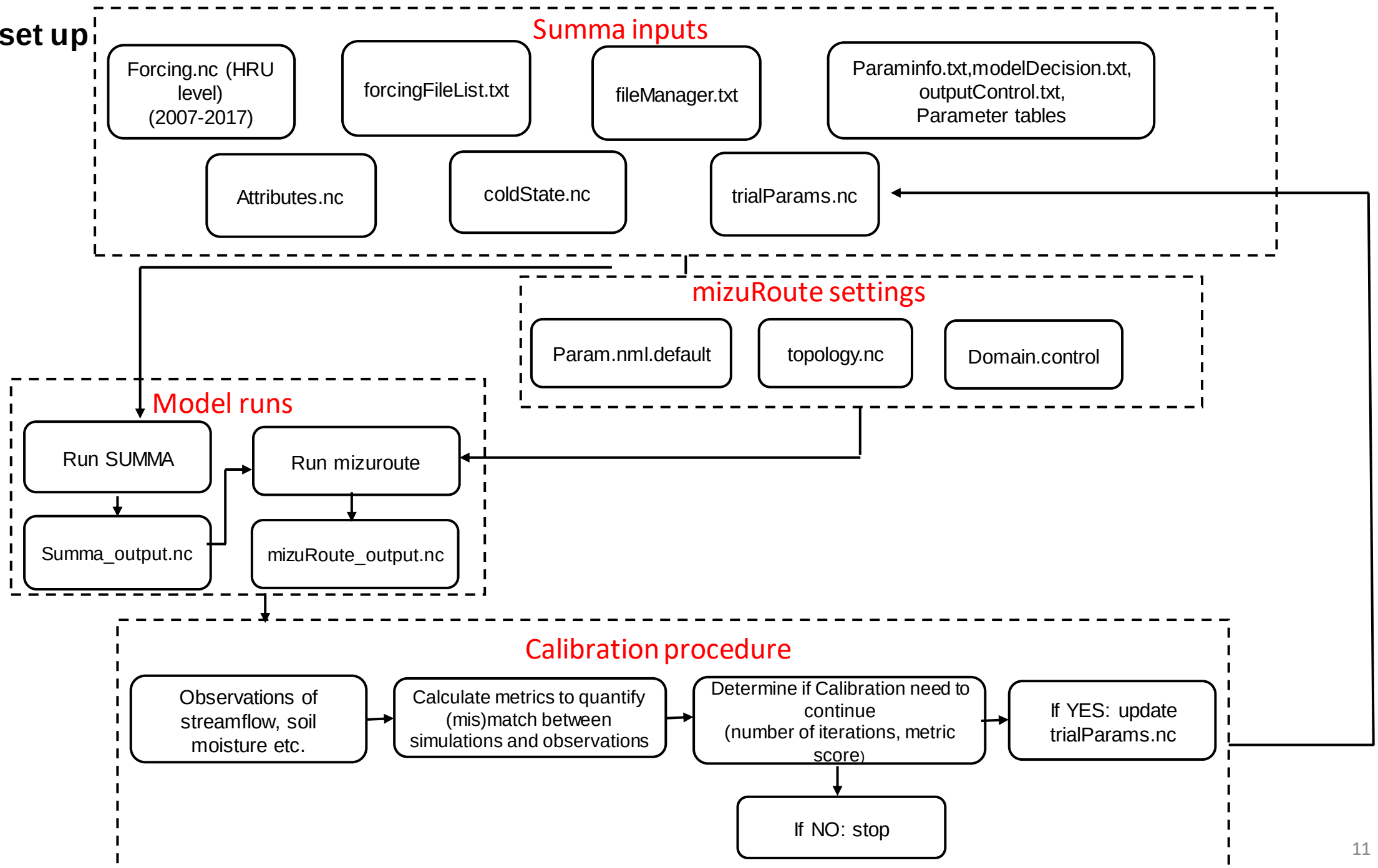


Hydrologic Response Units (Total: 61).
HRUs are delineated within each GRUs based on HAND's concept for a threshold elevation difference of 50m

Overview of the study

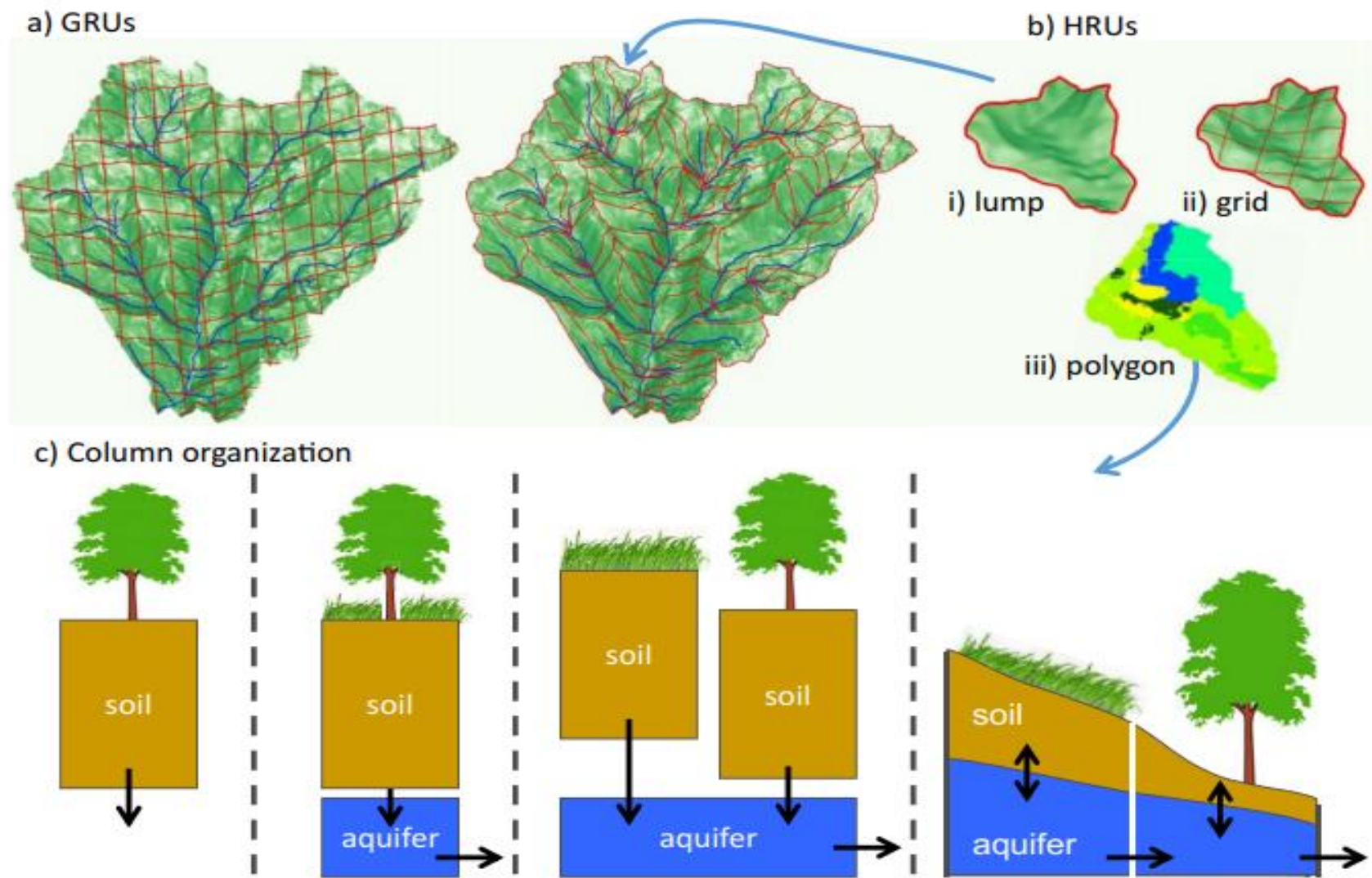
- Hydrologic simulations are carried out using the hydrologic framework, SUMMA (Structure for Unifying Multiple Modeling Alternatives) [Clark et al.,2015 a,b)
- Routing is performed using mizuRoute [Mizukami et al., 2016]
- Studied the impact of lateral flow parameterizations on the basin runoff using 1D Richards' and topmodel configuration

Model set up



Modeling the impact of lateral flow parameterizations on basin runoff

Method	1D Richards model	Topmodel
Groundwater Parameterization	No explicit (Hydrologically disconnected)	Hydrologically connected between HRUs
Hydraulic conductivity profile	constant hydraulic conductivity with depth	power-law profile
Lower boundary condition for soil hydrology	Free drainage to river networks	lateral flux
Thermal conductivity representation for soil	Volumetric fraction of different constituents	Function of soil wetness



Spatial organization of SUMMA, showing: (a) GRUs (grid or polygon), (b) HRUs (single unit, grid, polygon), and (c) the connection among soil columns and the aquifer. The horizontal footprint of each vertical soil column corresponds to a single HRU, and there can be multiple soil columns (HRUs) embedded within a GRU.

[Source: Clark et al. 2015 a]

Lateral flux from the soil profile

- The soil columns can be hydrologically connected or hydrologically disconnected
- When hydrologically connected the lateral flux from upslope soil columns is the inflow to downslope soil columns
- When hydrologically disconnected, lateral flux of water from soil columns is assumed to flow directly into river network.
- The conservation equation for soil hydrology can be written as :

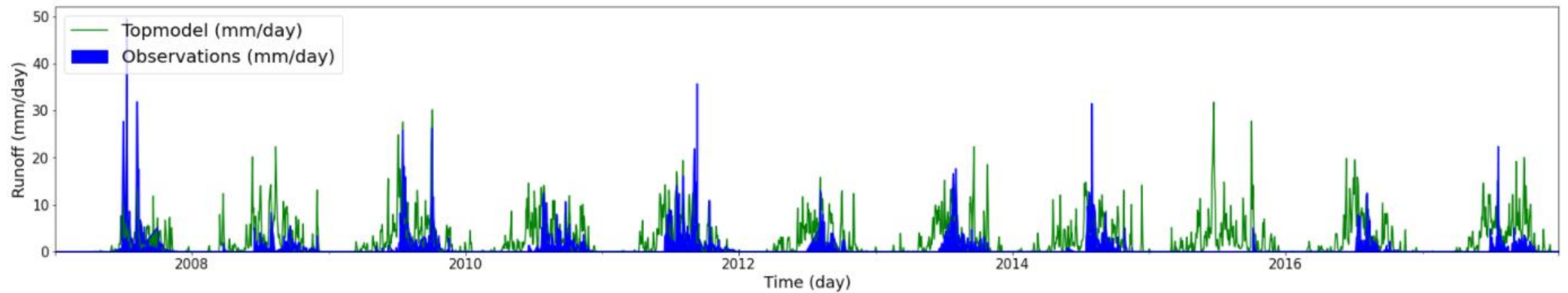
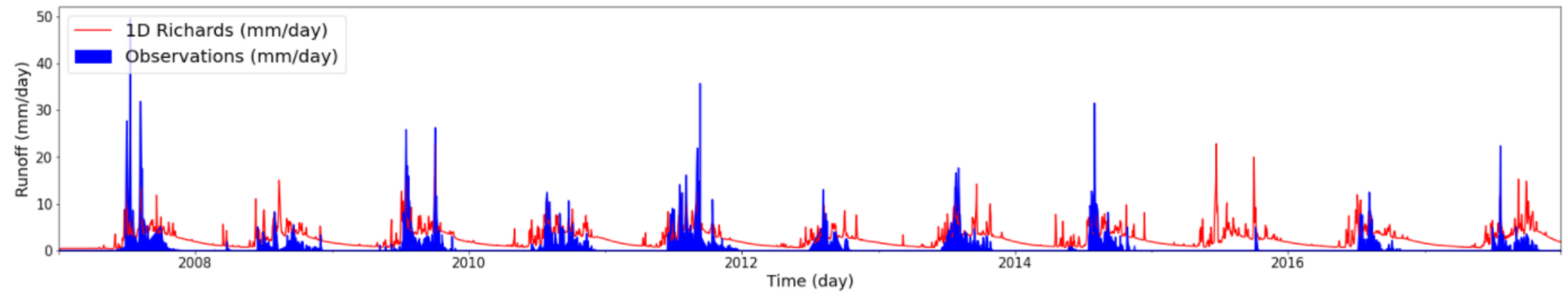
$$\frac{\partial \theta_m^{soil}}{\partial t} = \frac{\partial q_{liq,x}^{soil}}{\partial x} + \frac{\partial q_{so^{illiq},y}}{\partial y} + \frac{\partial q_{so^{illiq},z}}{\partial z} + \frac{E_{evap}^{soil} + E_{trans}^{soil}}{\rho_{liq}}$$

$$q_{liq,z}^{soil} = \begin{cases} q_{rain} - q_{ix} - q_{sx} ; z=0 \\ -k^{soil} \frac{\partial \phi}{\partial z} + K^{soil} ; z>0 \end{cases}$$

$$\frac{\partial (\theta_m^{soil})_j}{\partial t} = \frac{(q_{liq,z}^{soil})_{j+0.5} - (q_{liq,z}^{soil})_{j-0.5}}{(\Delta Z)_j} + (S_{et})_j - (S_{lf})_j$$

Variables	Description
θ_m^{soil}	Total liquid water content (kg/m ³)
$q_{liq,x}^{soil}, q_{liq,y}^{soil}, q_{liq,z}^{soil}$	Liquid fluxes in x,y, z directions (m/s)
E_{evap}^{soil}	Loss due to evaporation (kg m ⁻³ s ⁻¹)
E_{trans}^{soil}	Loss due to transpiration (kg m ⁻³ s ⁻¹)
q_{rain}	Rainfall (m/s)
q_{ix}	Infiltration excess runoff (m/s)
q_{sx}	Saturation excess runoff (m/s)
$(S_{et})_j$	Sink term defining evapotranspiration losses from the j th layer (s ⁻¹)
$(S_{lf})_j$	Source/sink term defining net lateral flux of water in/out of j th layer (s ⁻¹)
Z	Depth of soil layer from surface (m)
ϕ	Liquid water matric potential (m)

Results and discussion



Comparison of modeling configurations

Method	Nash-Sutcliffe Efficiency	Kling-Gupta Efficiency
1D Richards	0.5	0.5
Topmodel	0.7	0.6

Hydrologic signatures	Observed	1D Richards	Topmodel
5 th quantile flow (mm/day)	0.0	0.03	0.0
Mean daily discharge (mm/day)	0.9	0.7	0.8
95 th quantile flow (mm/day)	5.0	3.4	4.2

Conclusions

- The subset of model options is selected to illustrate the different types of model behavior, rather than provide an exhaustive analysis of all modeling alternatives.
- The above figure illustrates that simulations of basin-wide runoff strongly depends on the model representation of lateral flow.
- In 1D Richards' approach, which is common in traditional land-surface models there is no explicit representation of lateral flow – i.e., the source/sink term for lateral subsurface flow is set to zero – and vertical drainage from the bottom of the soil profile is delivered immediately to the stream.
- The exceedingly spiky behavior occurs because the model does not include the longer residence times present in natural systems.
- Topmodel simulations represent the observations reasonably well.

References

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