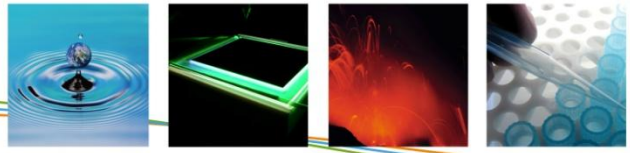
vito
vision on technology



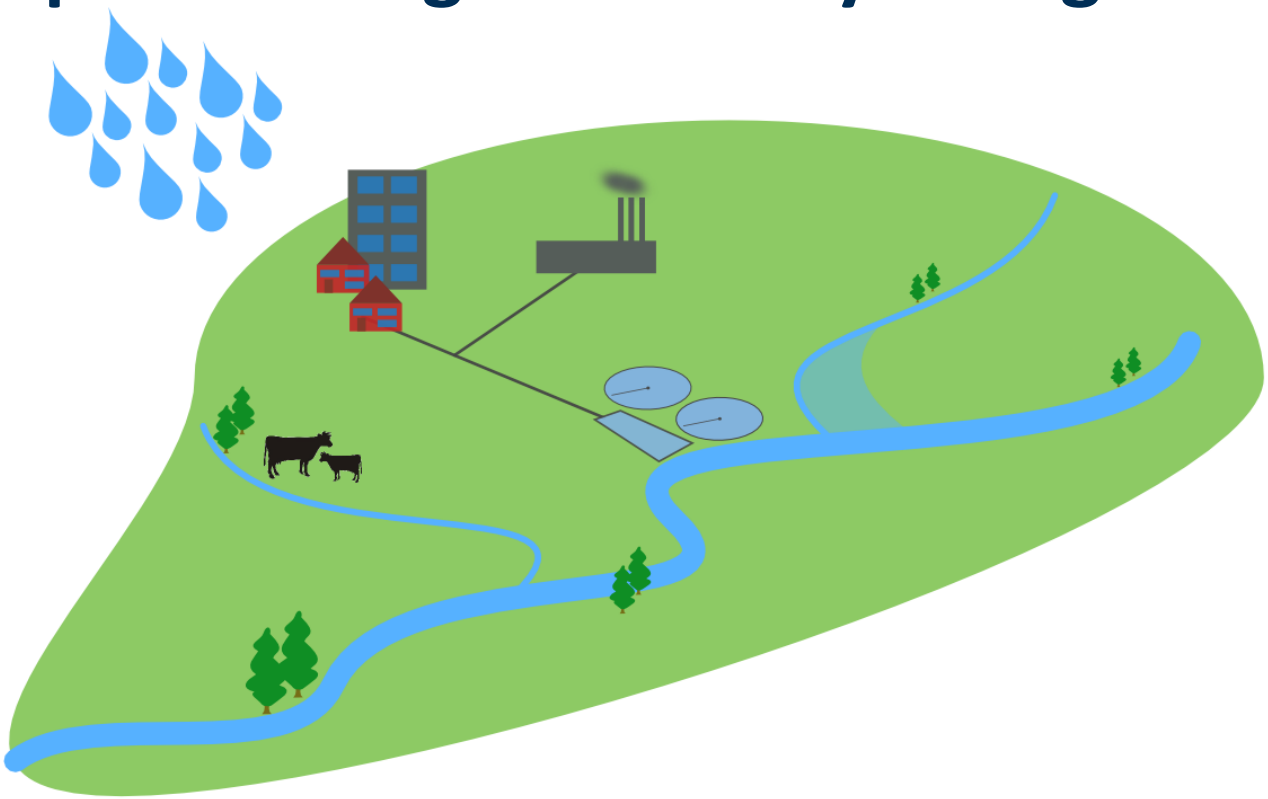
30/05/2012

Hydrological model structure evaluation

S. Van Hoey, J. Van der Kwast, I. Nopens, P. Seuntjens

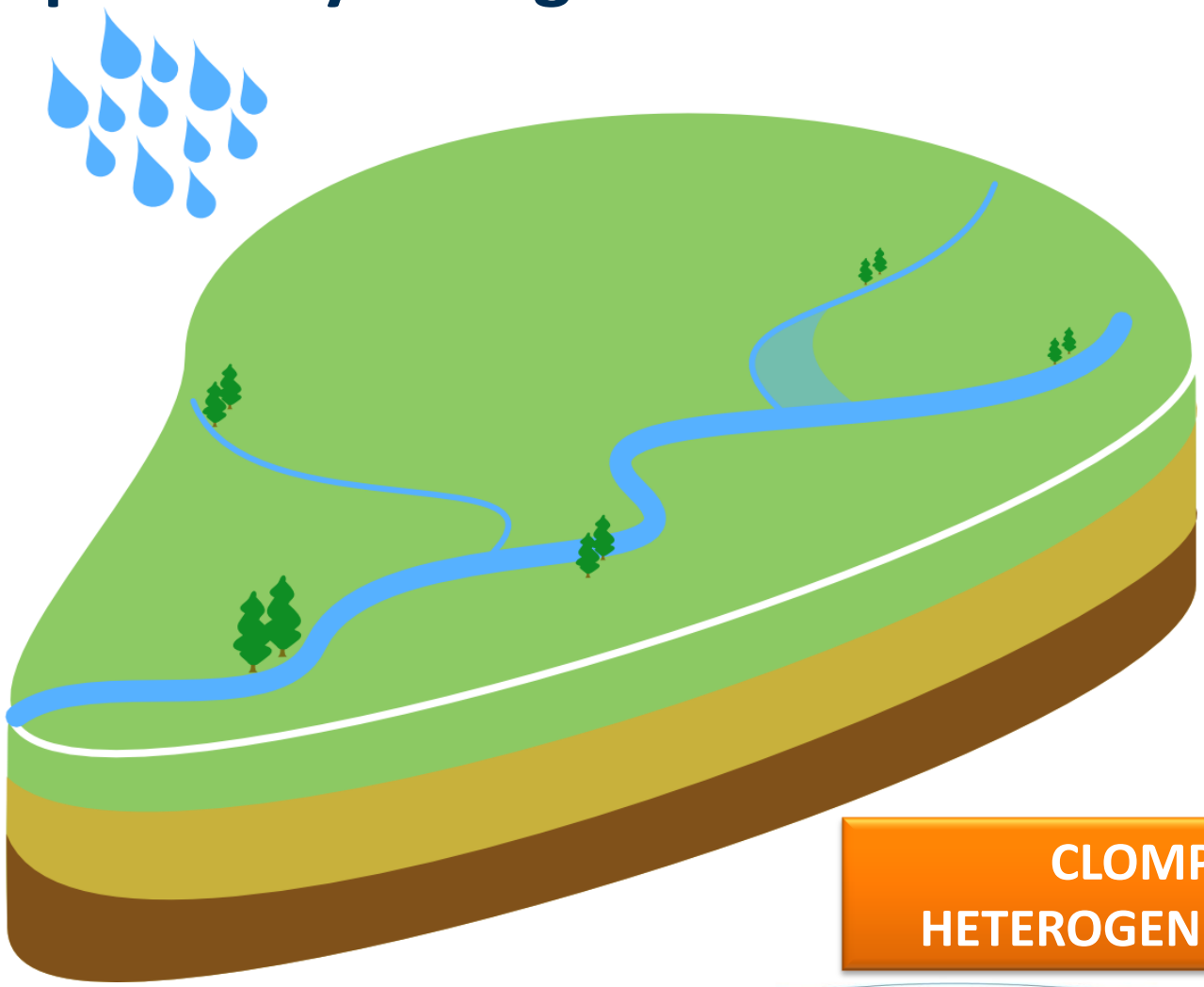
BIOMATH

A priori: Integrated <> Hydrological Modelling



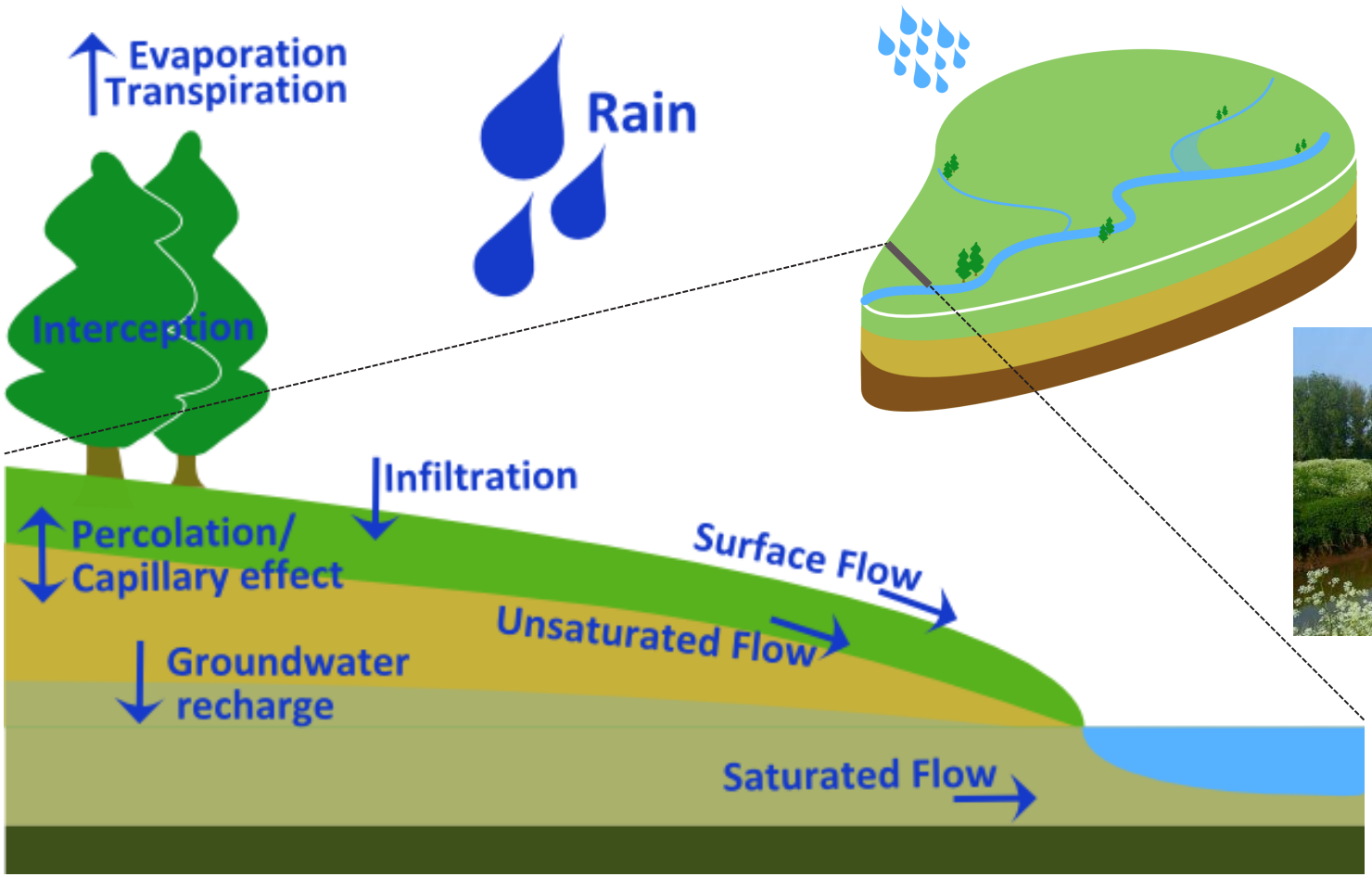
A priori: Integrated <> Hydrological Modelling

A priori: Hydrological Catchment Modelling



CLOMPEX AND HETEROGENEOUS SYSTEM

A priori: Hydrological Catchment Modelling



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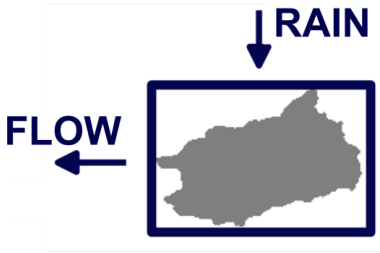
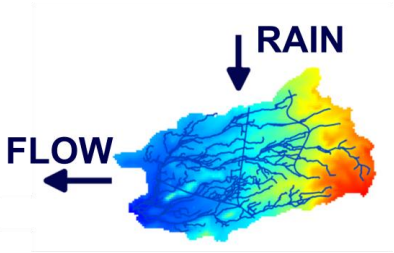


LUMPED

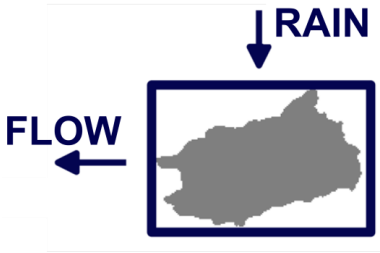
- No spatial component
- Set of ODE's
- Short computation time
- Describing *Dominant Processes* on catchment level
- Rainfall-runoff models



DISTRIBUTED

- Spatially explicit
- ODE/PDE options
- Long computation time
- Water balance on pixel-level + inter-pixel routing component
- Spatial data-inputs

A priori: Hydrological Catchment Modelling



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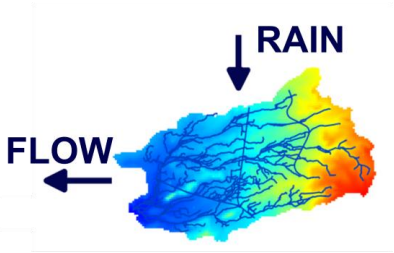

DISTRIBUTED

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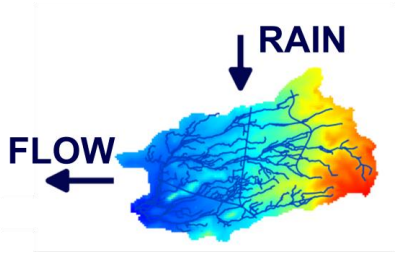
- Long computation time
- Water balance on pixel-level + inter-pixel routing component
- Spatial data-inputs

WHICH processes to include?
HOW to describe these processes?

Today: Lumped Hydrological Modelling

LUMPED

- No spatial component
- Set of ODE's
- Short computation time
- Describing *Dominant Processes* on catchment level
- Rainfall-runoff models

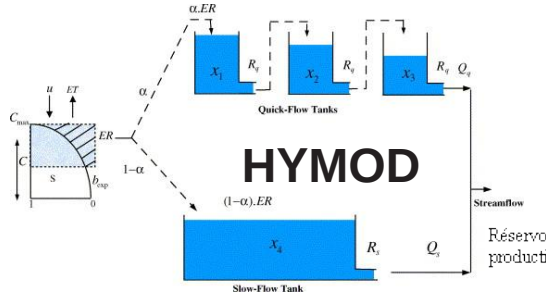


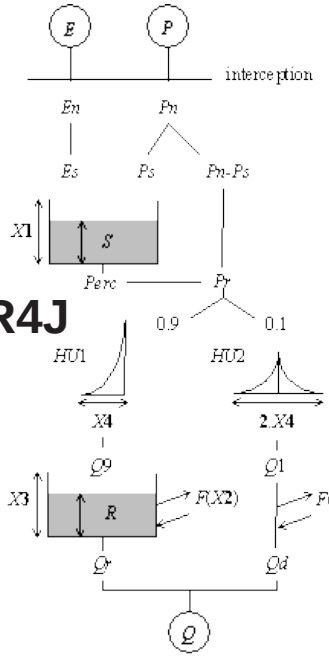
DISTRIBUTED

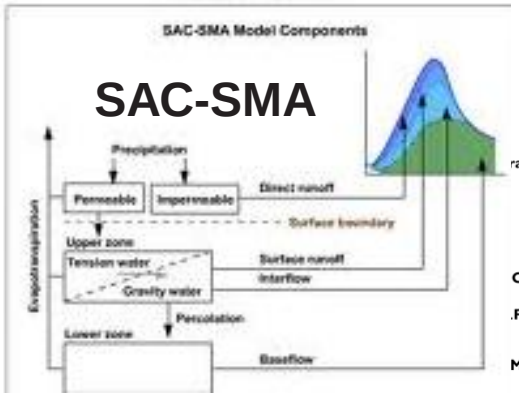
- Spatially explicit
- ODE/PDE options
- Long computation time
- Water balance on pixel-level + inter-pixel routing component
- Spatial data-inputs

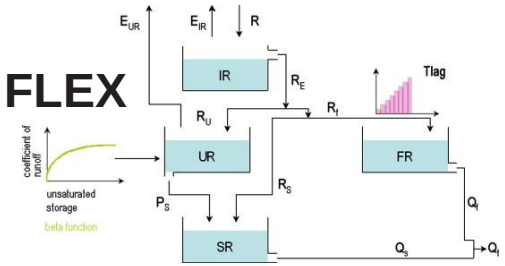
WHICH processes to include?
HOW to describe these processes?

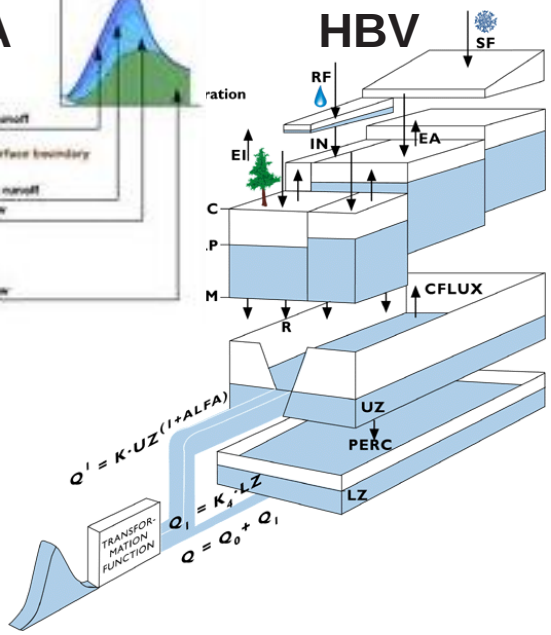
Lumped representations of the catchment

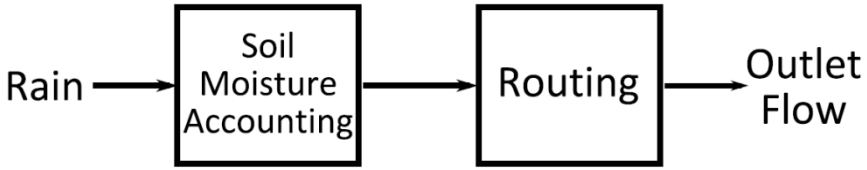




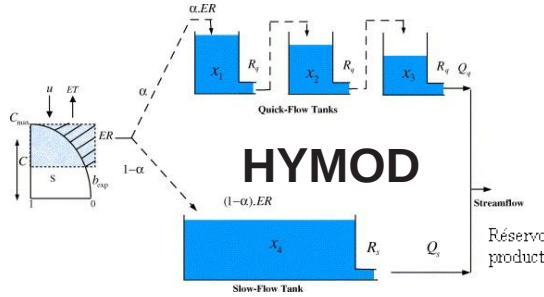


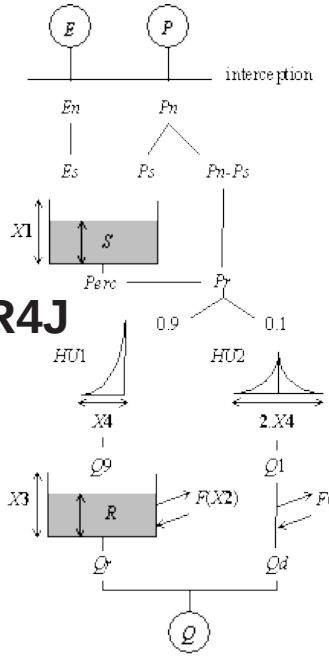


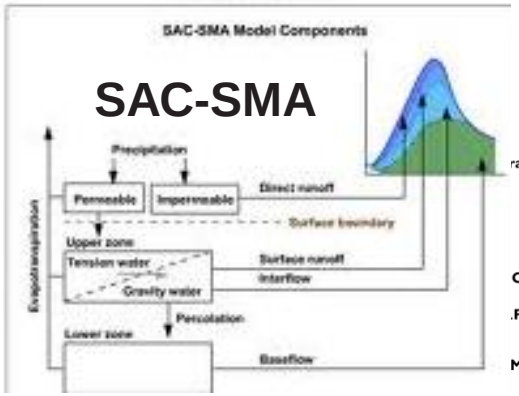


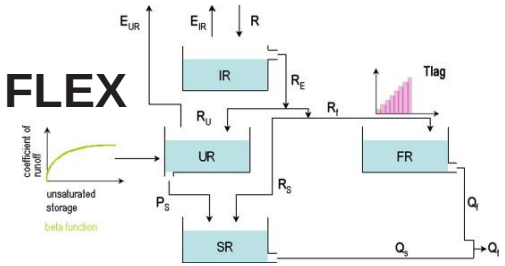


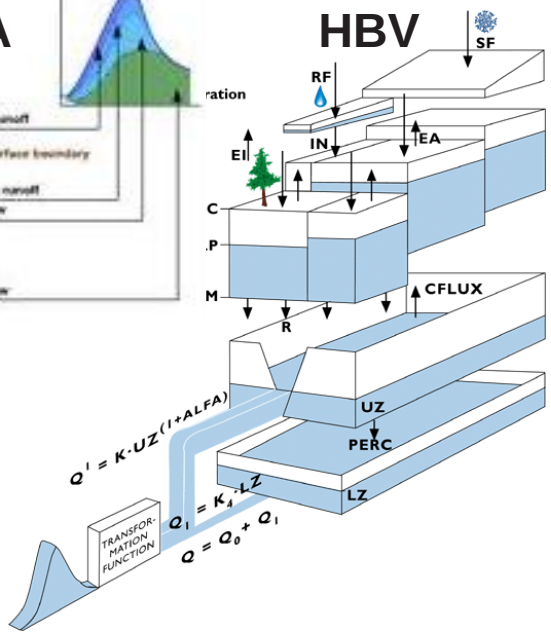
Lumped representations of the catchment

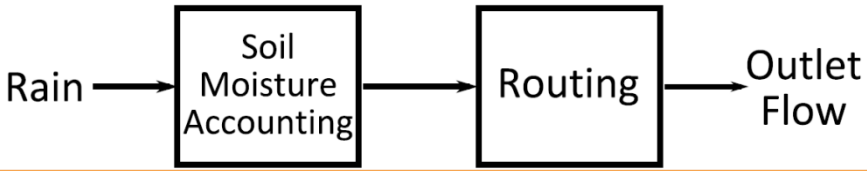






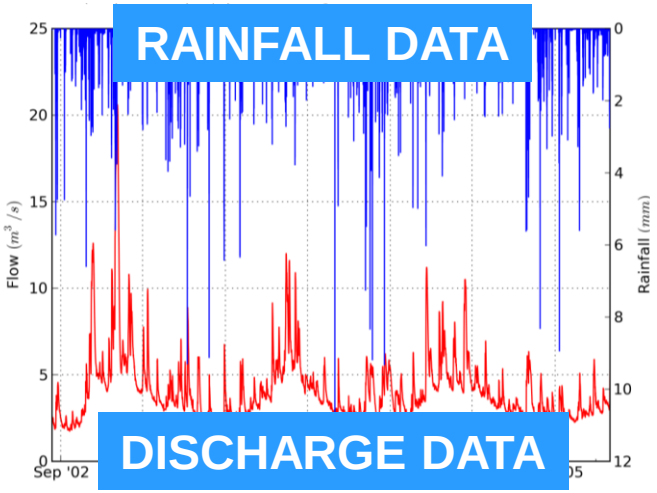




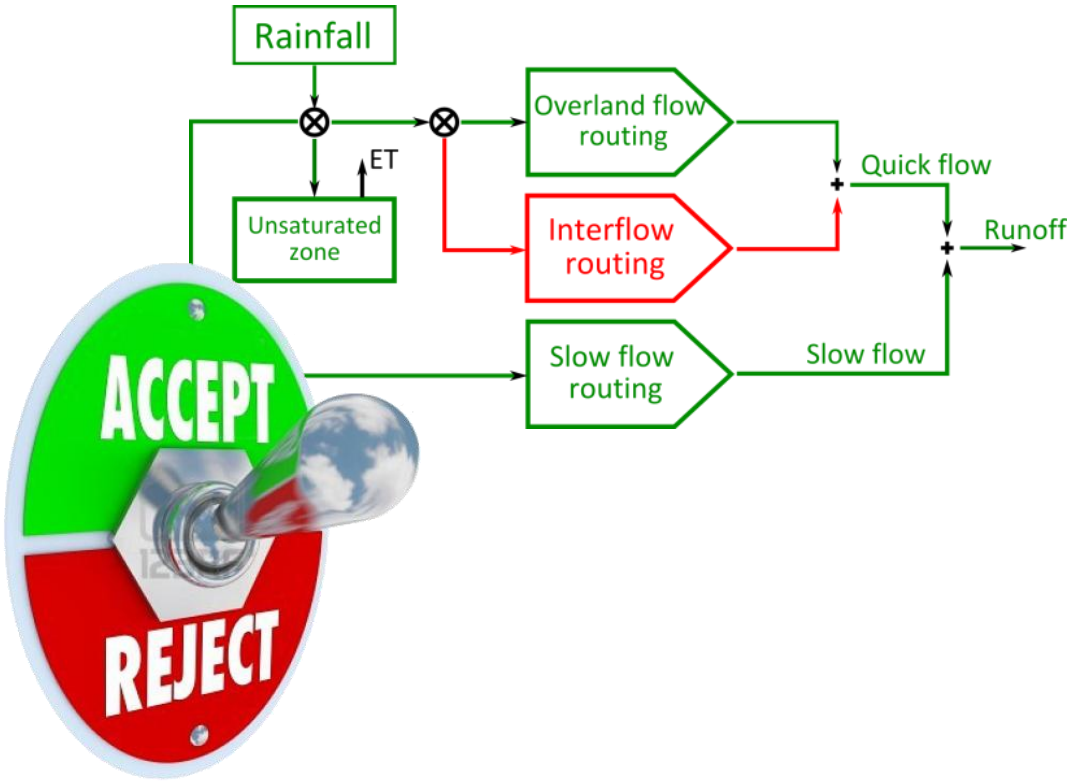


There is no 'one model fits all' -> need for flexibility!

Wishfull thinking…

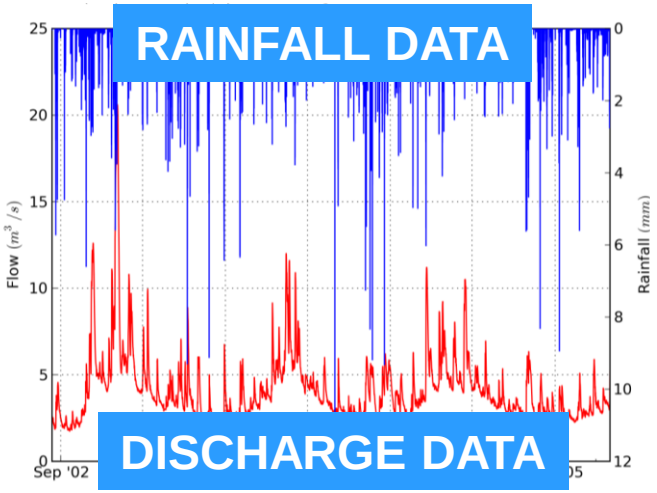


'EXPERT' KNOWLEDGE



No *one model fits all*, but *different models fit well*
=> We want *the right answer for the right reasons*

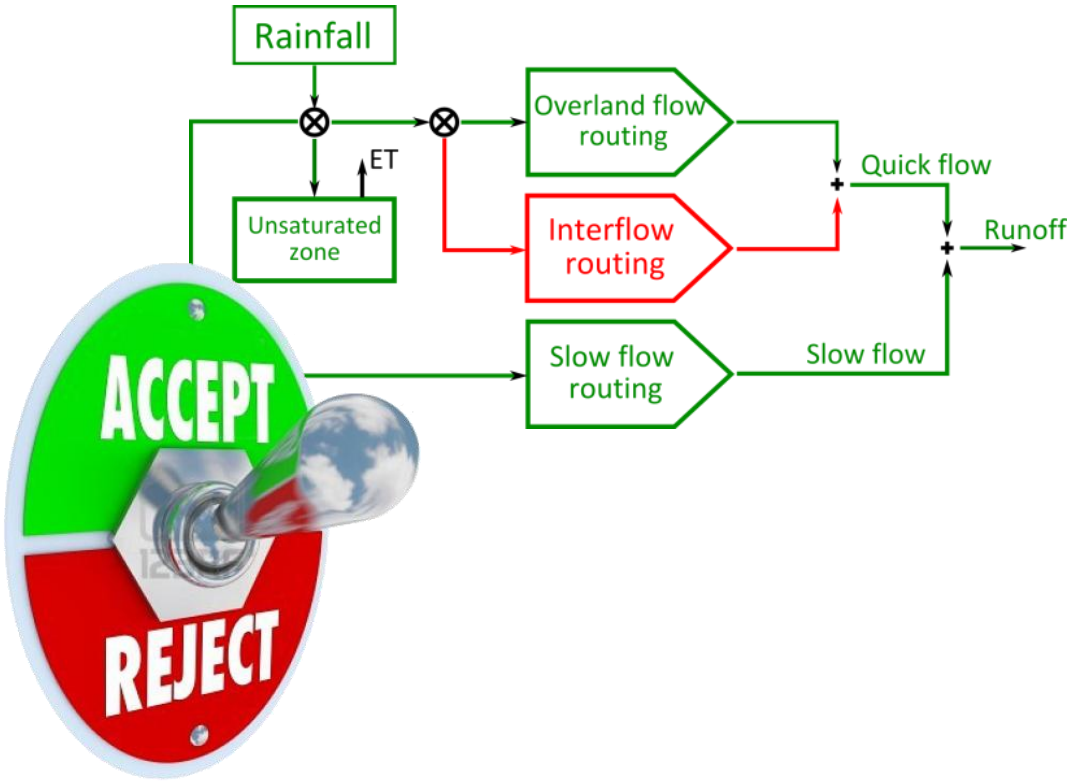
Wishfull thinking…



RAINFALL DATA

DISCHARGE DATA

'EXPERT' KNOWLEDGE



Can we identify the most suitable model structure?
Is this suitable structure conditioned by the performance criteria?

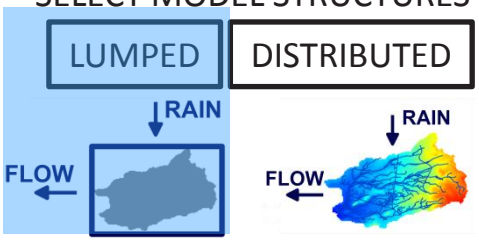
Methodology

CREATE

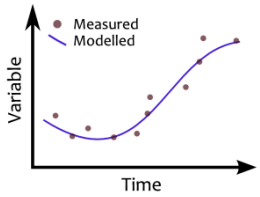
DIAGNOSE

CATCHMENT | OBJECTIVES | CONDITIONS | DATA

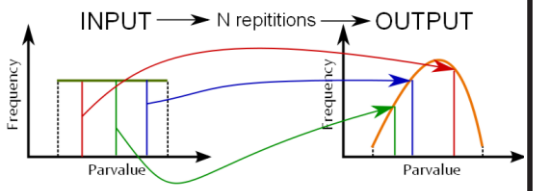
SELECT MODEL STRUCTURES



SELECT PERFORMANCE CRITERIA



UNCERTAINTY ASSESSMENT



SENSITIVITY ANALYSIS

OPTIMIZATION

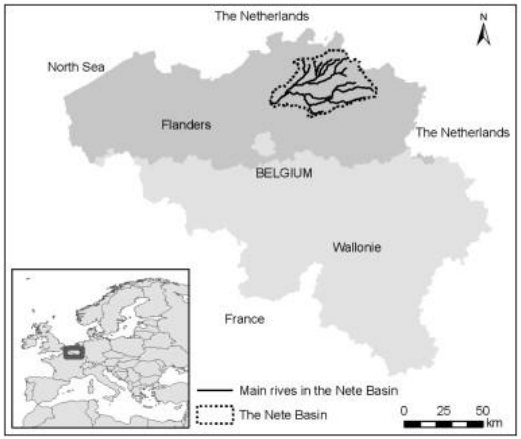
PARAMETER IDENTIFIABILITY

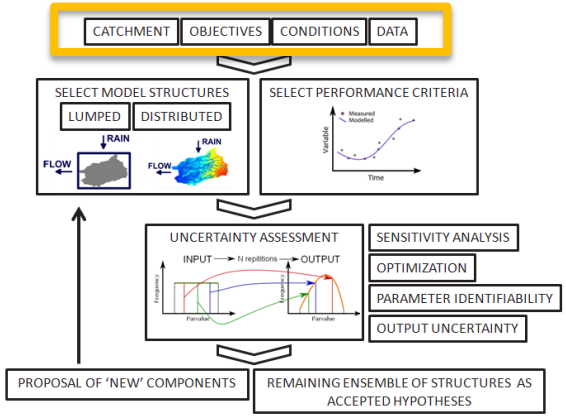
OUTPUT UNCERTAINTY

PROPOSAL OF 'NEW' COMPONENTS

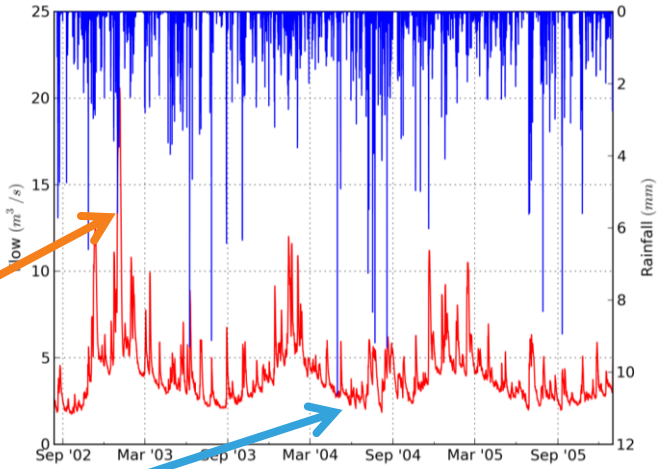
REMAINING ENSEMBLE OF STRUCTURES AS ACCEPTED HYPOTHESES

Application

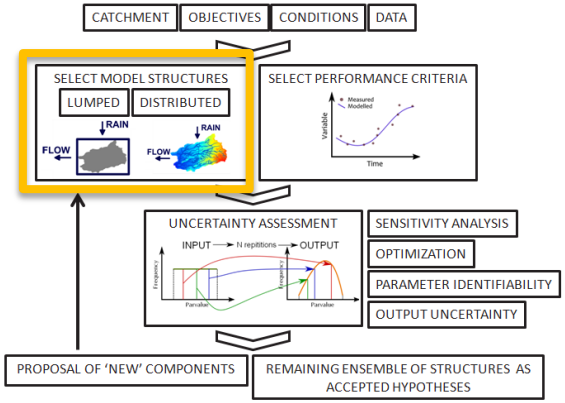




- Nete **catchment**
  - Belgium, 362km²
- **Data**
  - Rainfall (2002-2008, hourly timestep)
  - Flow at outlet (2002-2008, hourly timestep)
- **Objectives**: Understanding in dominant hydrological processes:
  - Flood risk in winter: peak discharges
  - Water availability in summer: baseflow reproduction

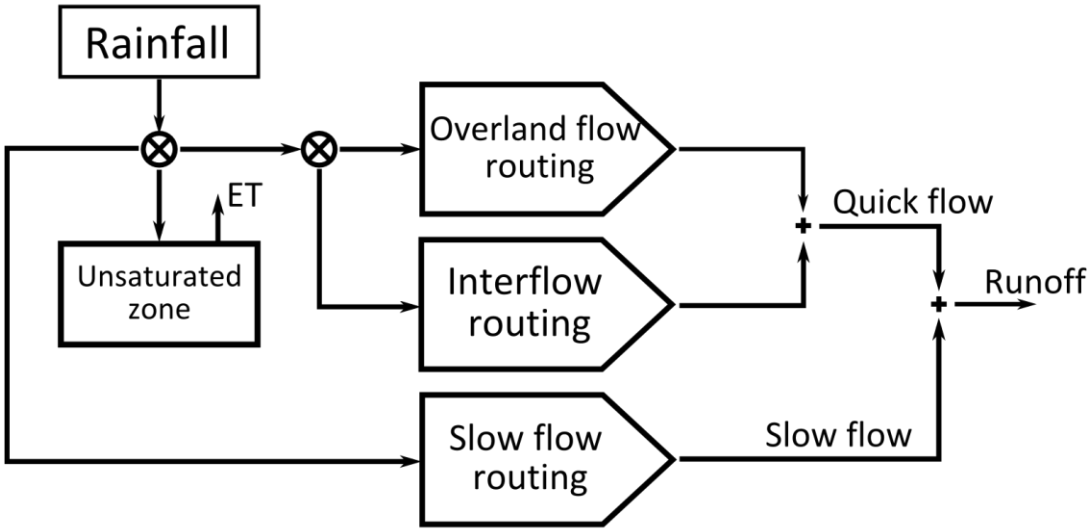


Model Structure Selection



LUMPED MODEL

Model structure variations based on VHM model (Willems, P.)

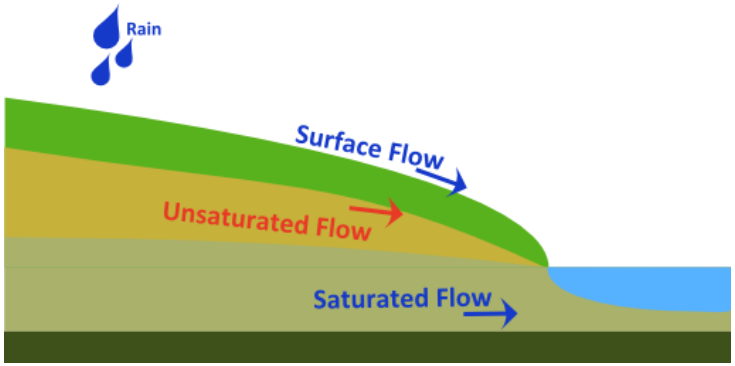


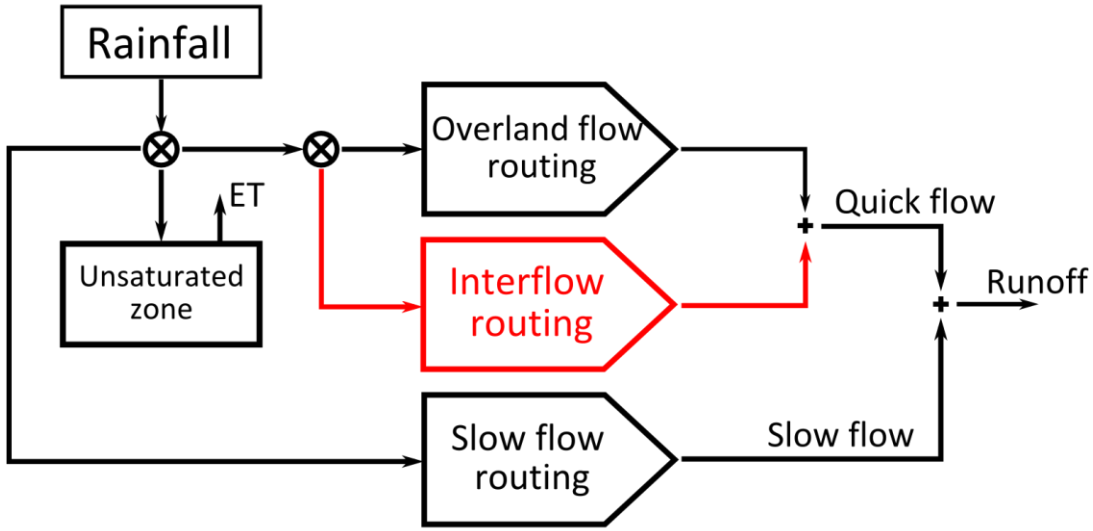
HYPOTHESES

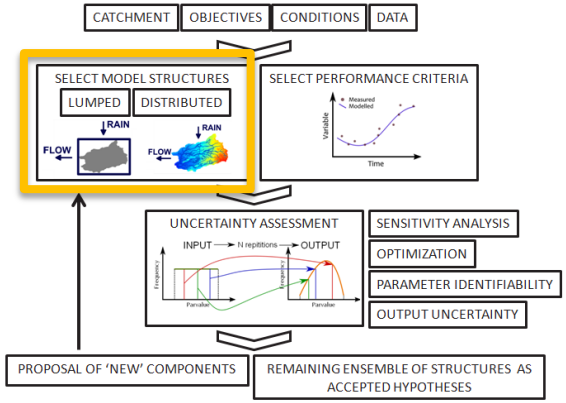
- Presence of Interflow?
- Unsaturated zone: Linear or non-linear?
- Which combination of linear reservoirs to represent routing?
- Infiltration excess overland flow dominant?

(Clark M.,2008; Willems P.,submitted)

Model Structure Selection







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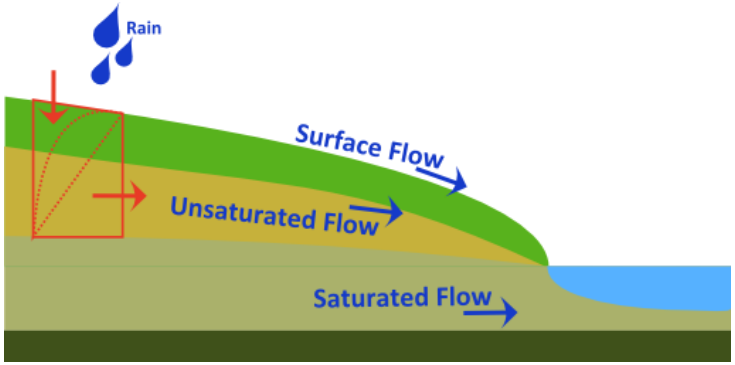

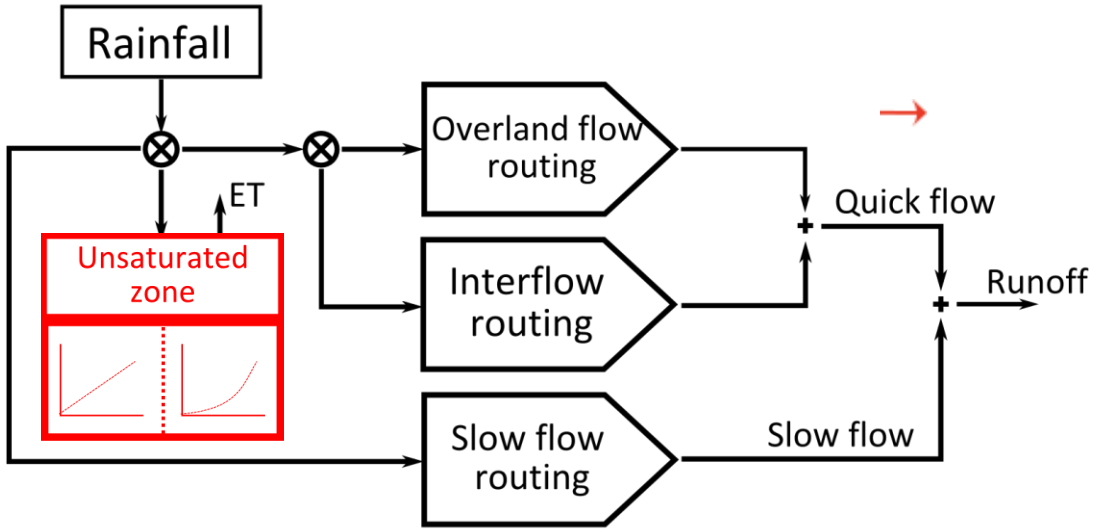

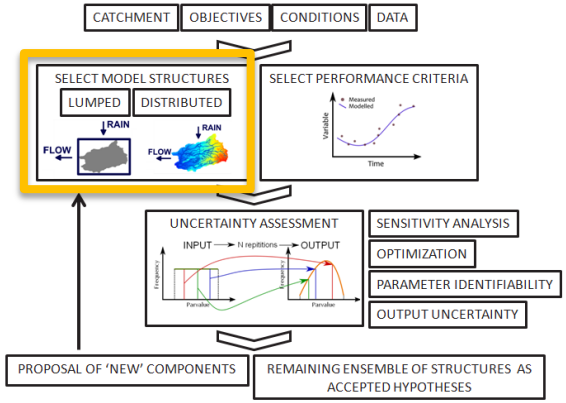

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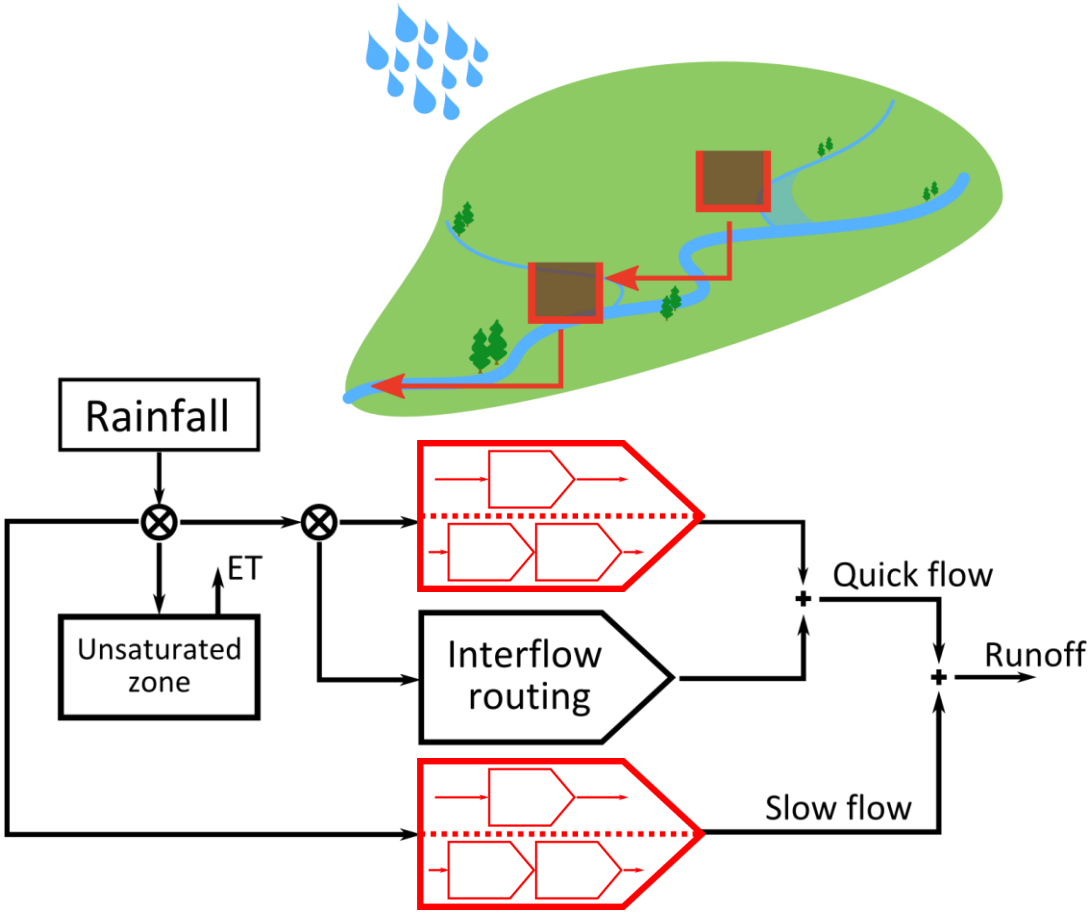

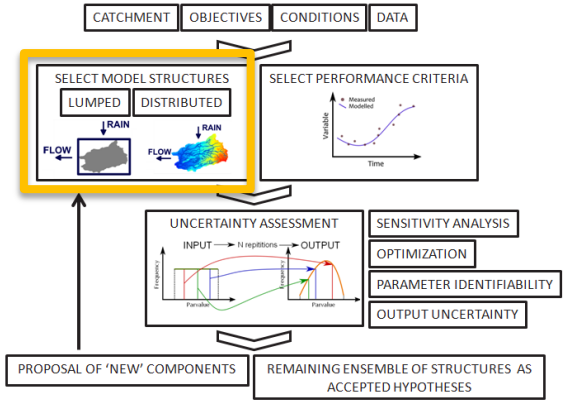

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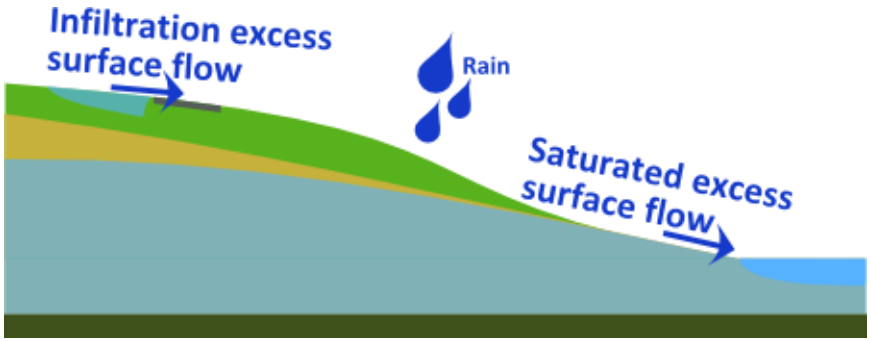

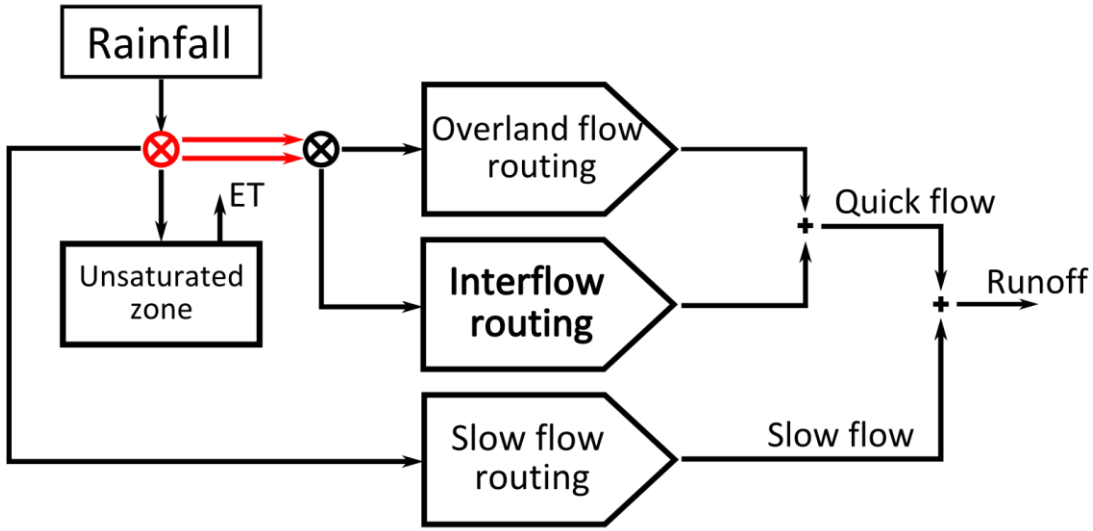

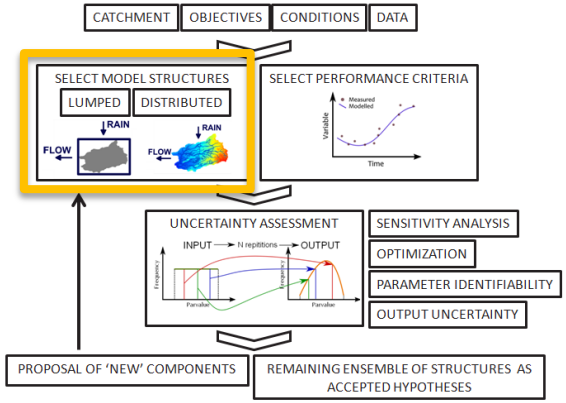

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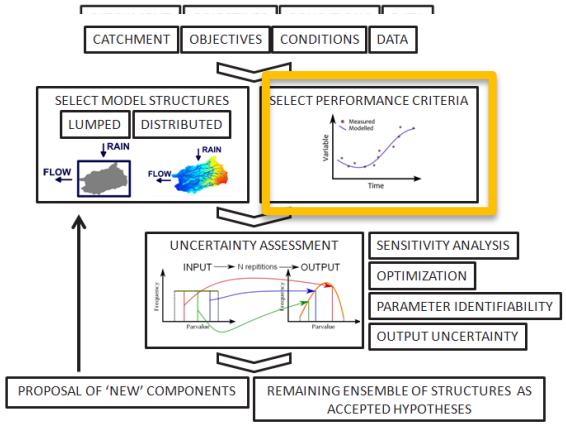
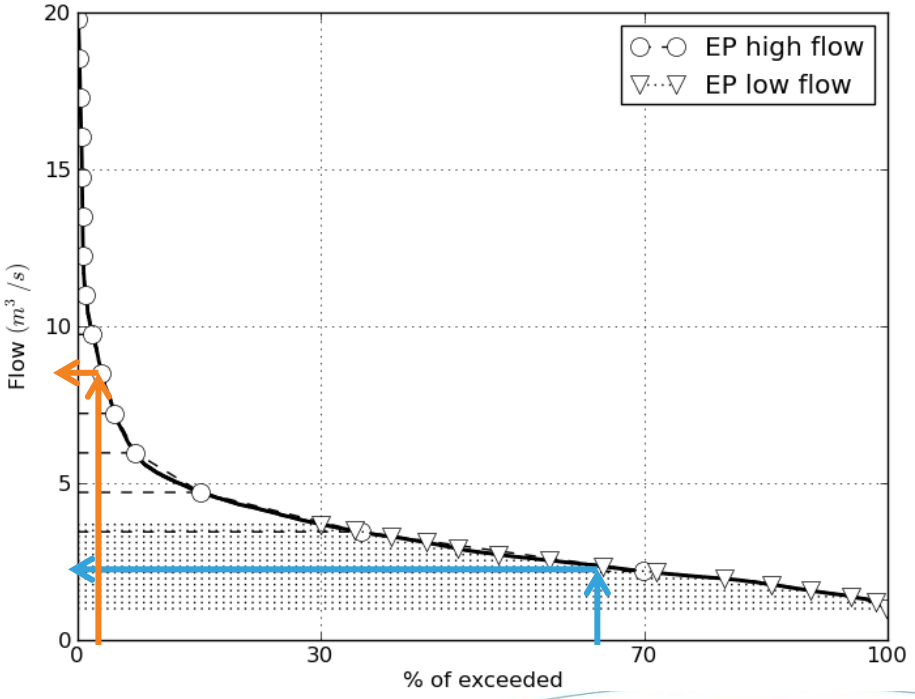
Performance criteria selection



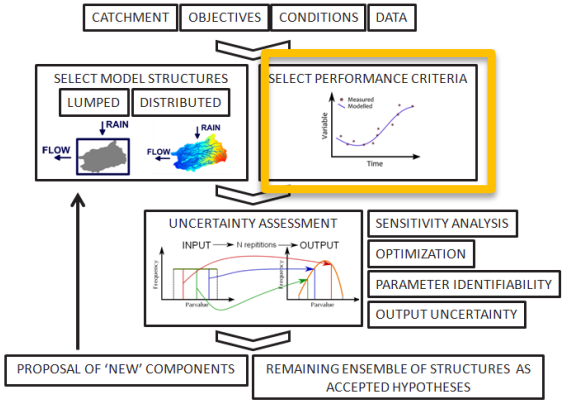
FLOW DURATION CURVE BASED

- **High flow** and **Low flow**
- In combination with Nash Sutcliffe (NS) criterium: : *W1****NS** + *W2** **FDC**$^{\mathbf{err}}$



$$NS = 1 - \frac{\sum_{i}^{N} (\hat{x}_i - x_i)^2}{\sum_{i}^{N} (x_i - \bar{x})^2}$$

Performance criteria selection



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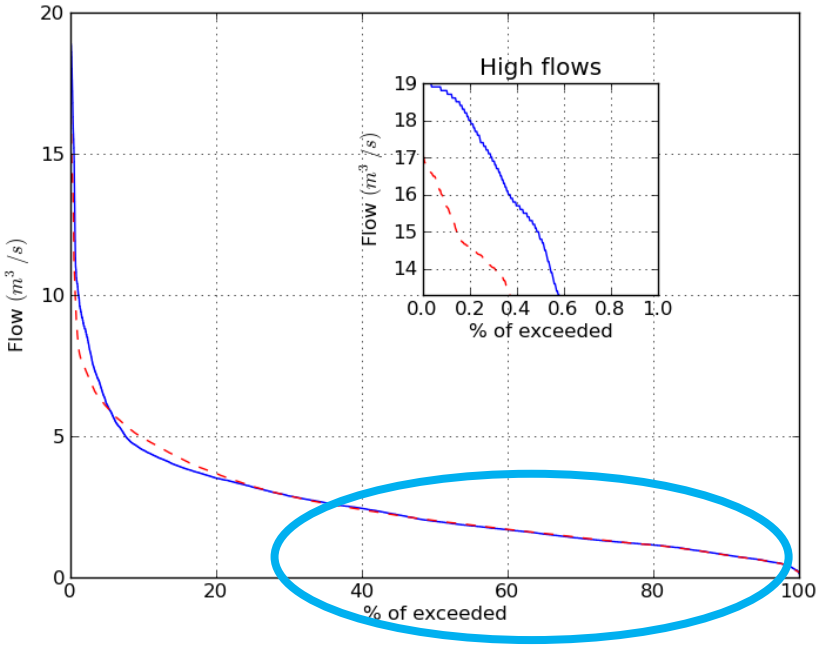
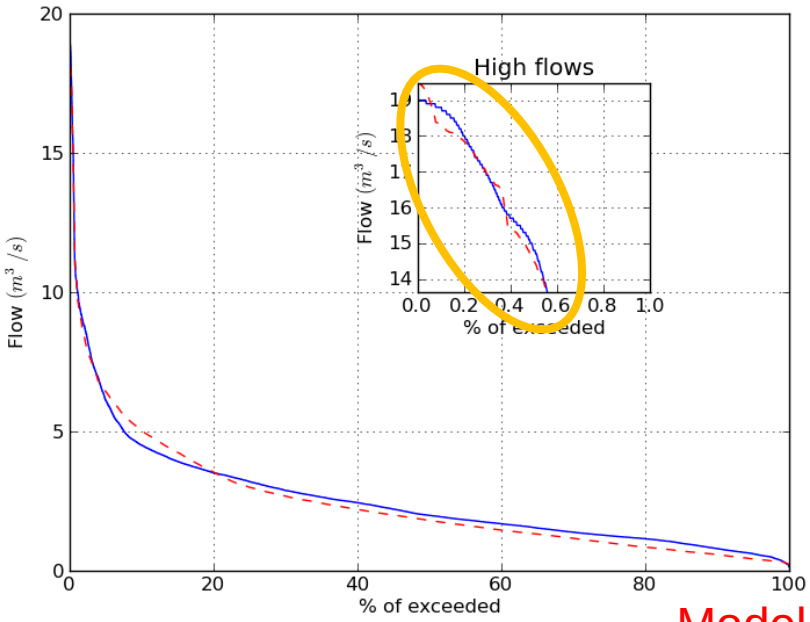
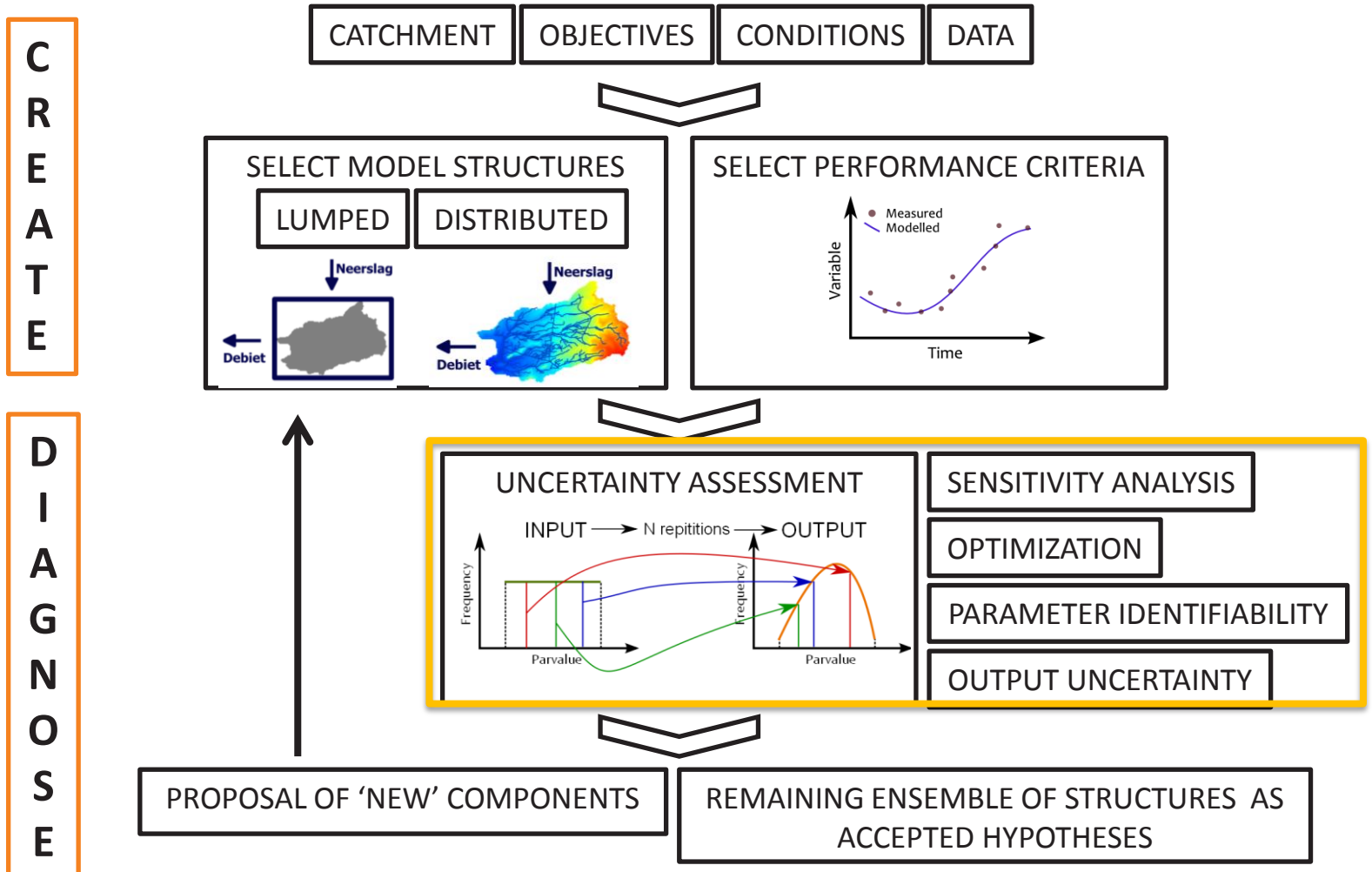




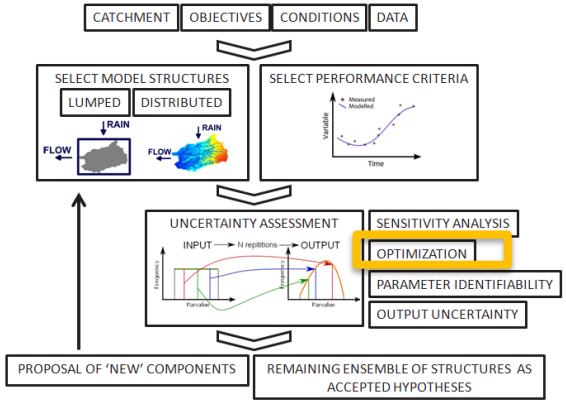
- Model
- Measured

Methodology

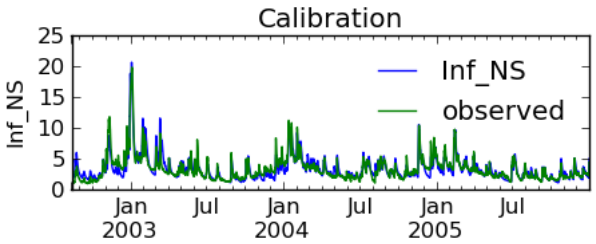


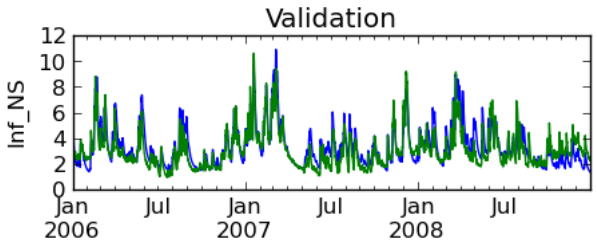
Optimization results: 1 structure

	Calibration period					Validation Period				
	NS	lowflow	highflow	NS – FDClow	NS – FDChigh	NS	lowflow	highflow	NS – FDClow	NS – FDChigh
NS	0.85	0.57	0.75	0.85	0.84	0.7	0.51	0.61	0.69	0.67

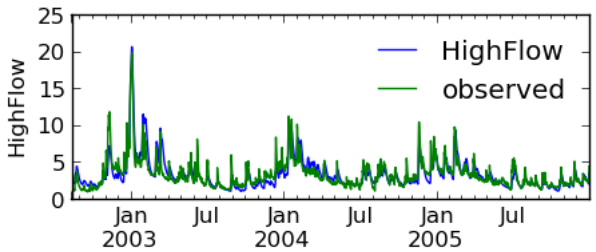


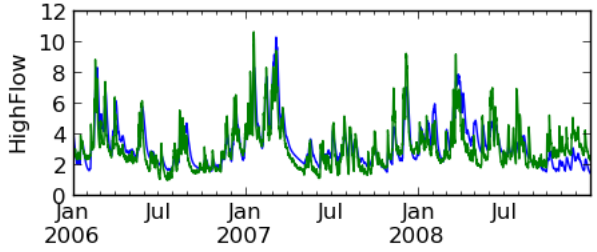
Optimization method used: *Shuffled Complex Evolution*



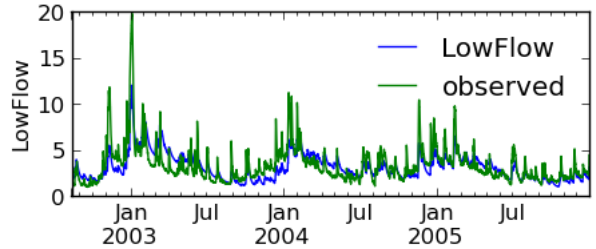


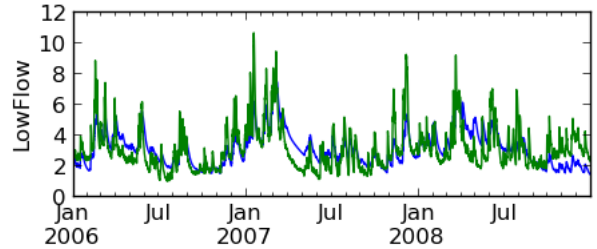
NS





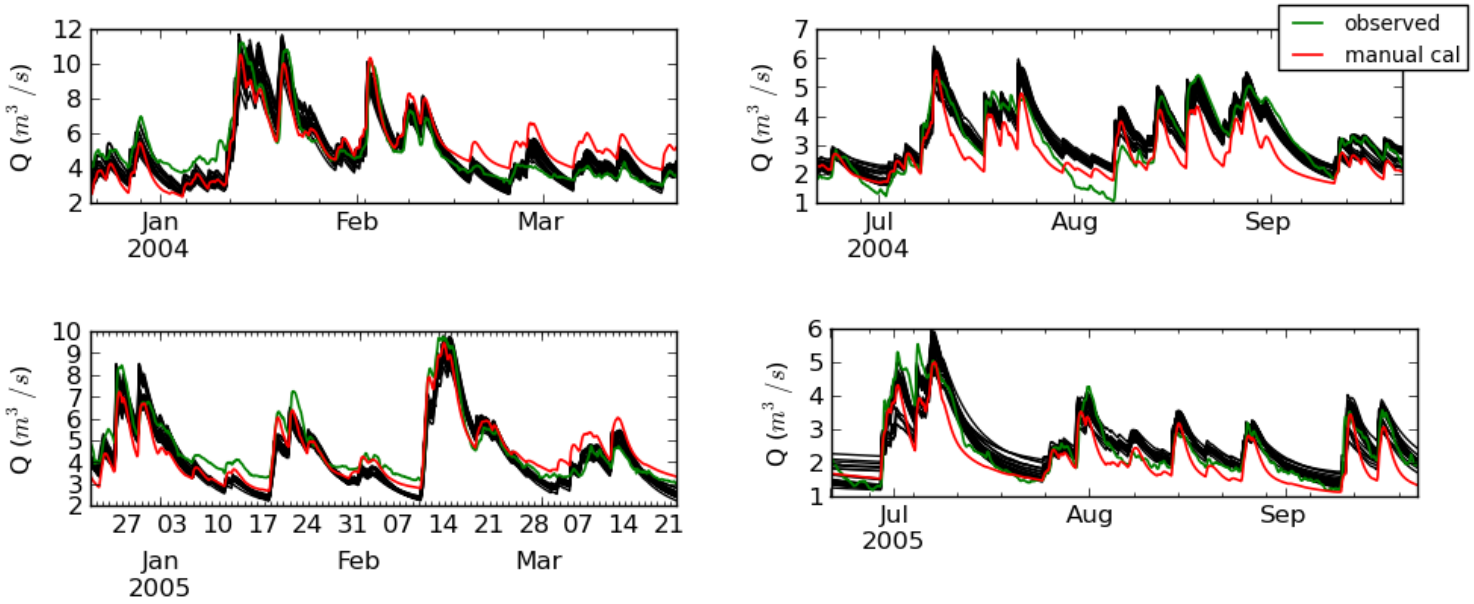
FDC^{err}_{high}





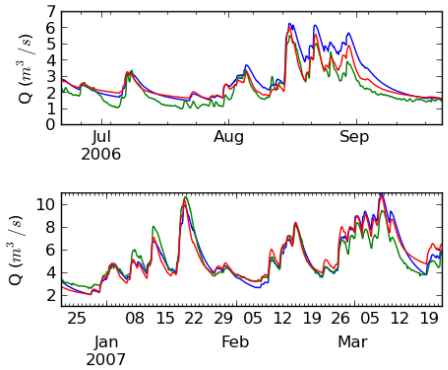
FDC^{err}_{low}

Optimization results: ensemble



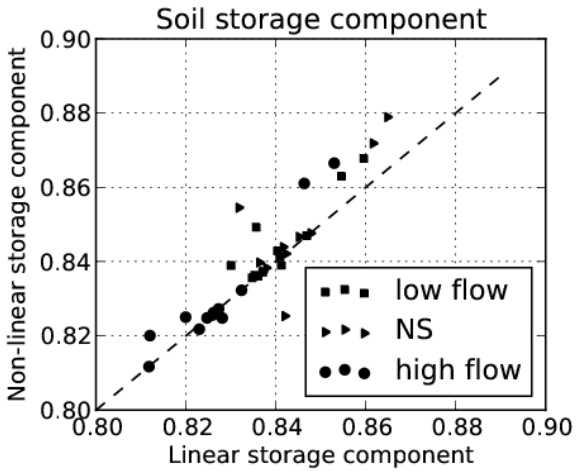
	Mean of ensemble performance on calibration period
NSE	0.86
R^2	0.93
MAE	0.56
RMSE	0.77

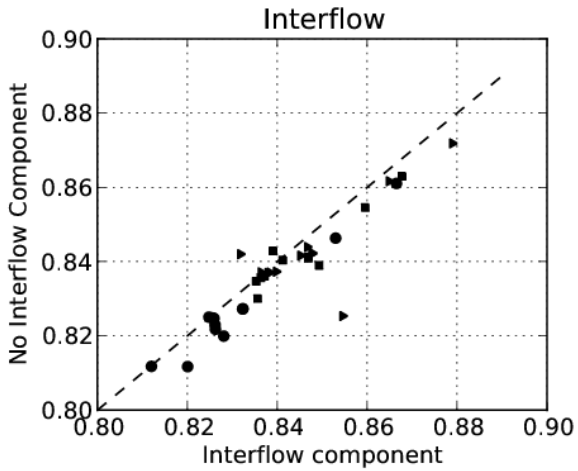
Validation events

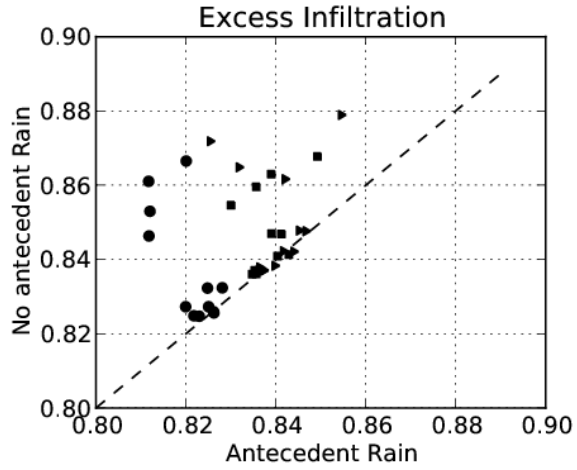


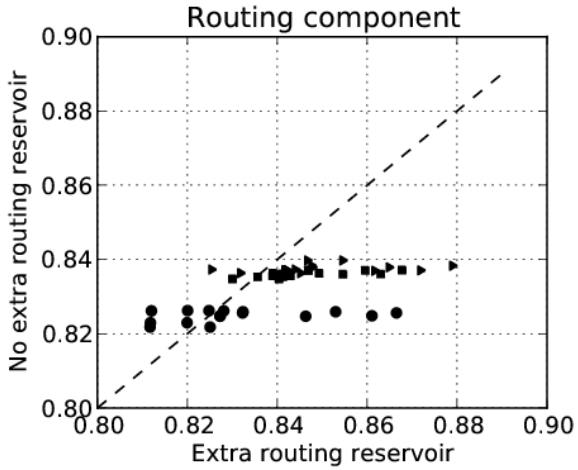
Manual calibration by Vansteenkiste T.
Based on 'general calibration methodology' used at Hydraulics Laboratorium

Optimization: structures are doing well…



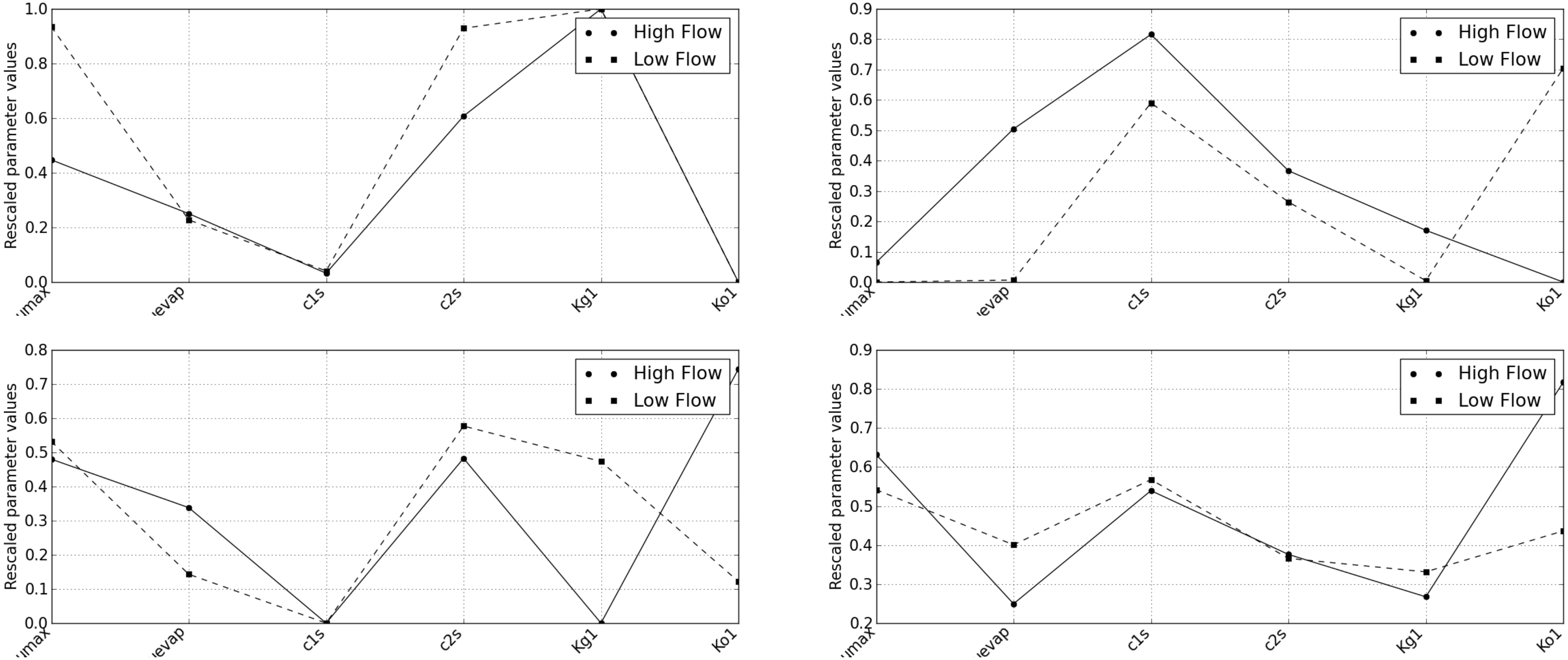






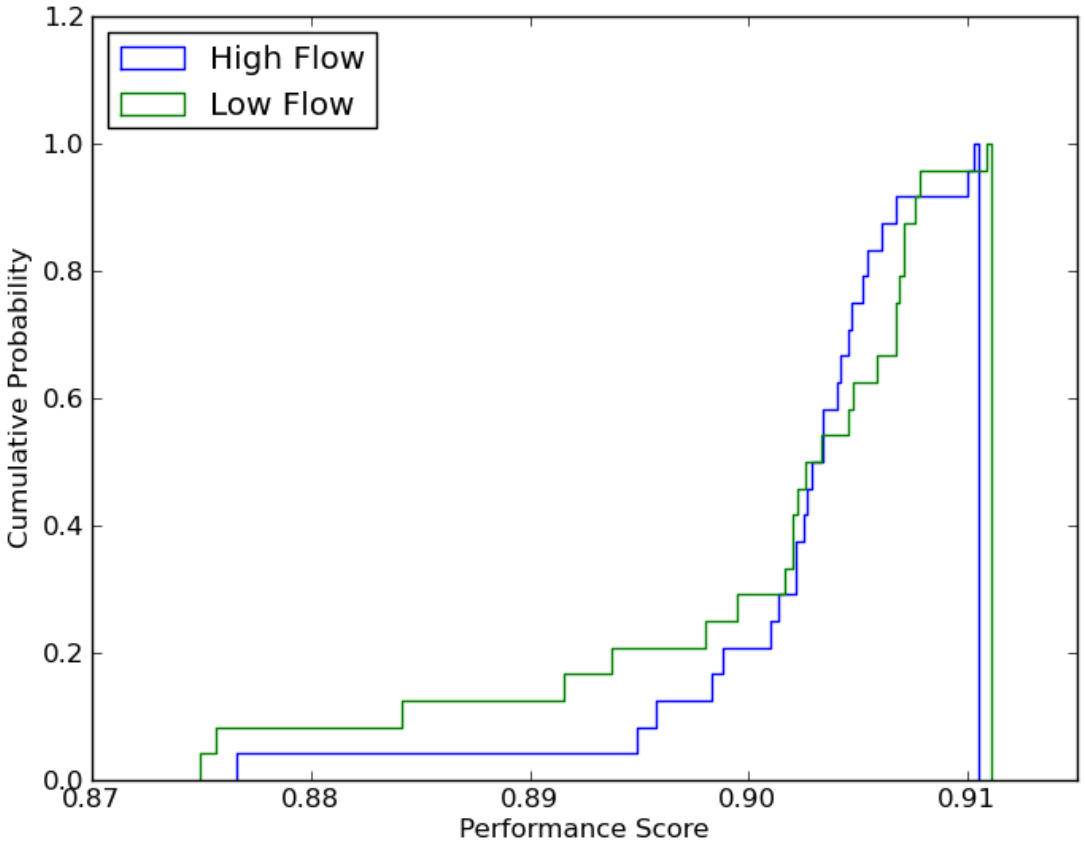
… with very different parameter sets.

» Structures able to ‘fit’ the model -> *overparameterization?, equifinality*?



Optimal parameter set is dependent from the objective used.
Enough degrees of freedom to ‘fit’ – overparameterization?

Objective criteria not conditioning the structure

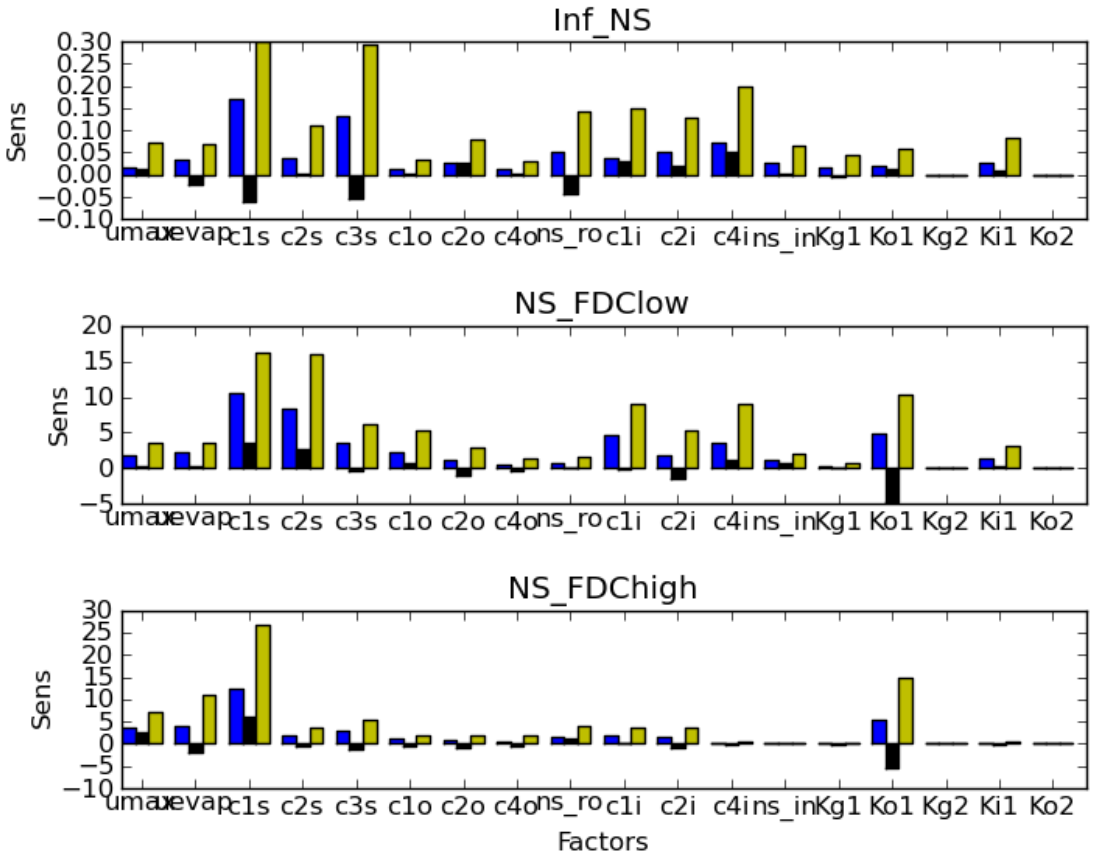


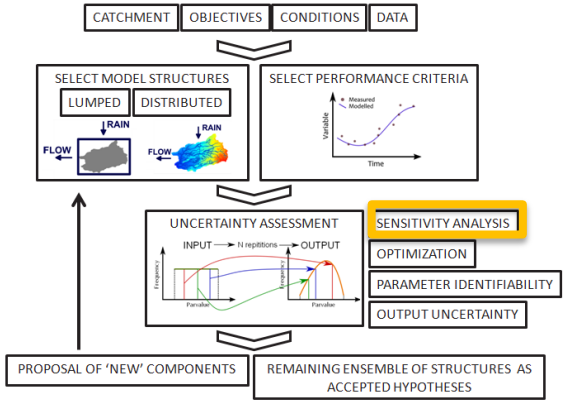
- CDF of 24 structures
- Spread of performance score is measure of discriminating power

- TWO POSSIBILITIES:
  1. Objective measures not well selected
  2. High similarity of model structures

Sensitivity Analysis (qualitive)

Based on distribution of Elementary Effects (EE)



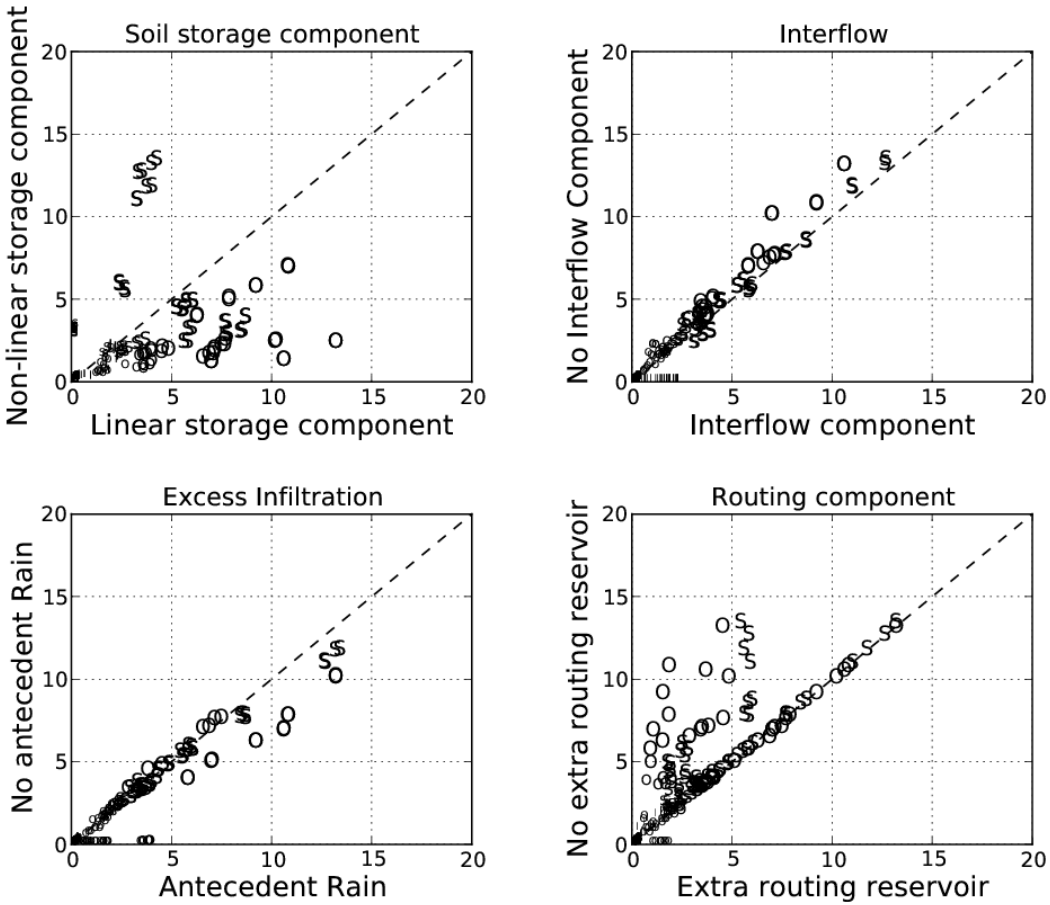


Sensitivity method used:
Morris screening method

- INFLUENCE ON OUTPUT:
  - **Blue**: mean of the absolute values of EE
  - **Black**: mean of the EE
- PARAMETER INTERDEPENDENCE:
  - **Yellow**: standard deviation of EE
  - High interactions is inherent to the VHM structure used!

Different parameters sensitive to different objective criteria

Sensitivity Analysis (qualitive)

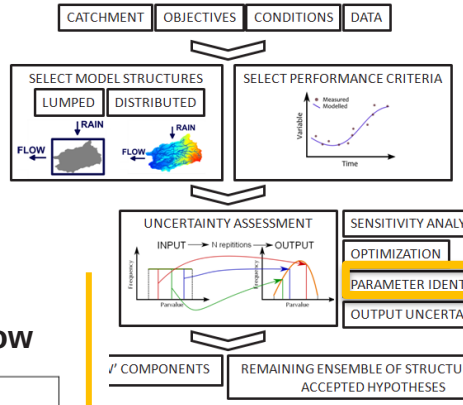


Comparison for **HIGH FLOW** criterium

- Parameters present in the **overland component** and the **unsaturated soil** always most sensitive
- When going from **linear to non-linear soil** component the variation in the output is mainly described by the unsaturated zone parameters instead of overland flow parameters **–>** *both sensitive*
- **Interflow** and **excess infiltration** -> *limited effect*
- **More complex routing** decreases sensitivity + no benefit in performance **->** *exclude*

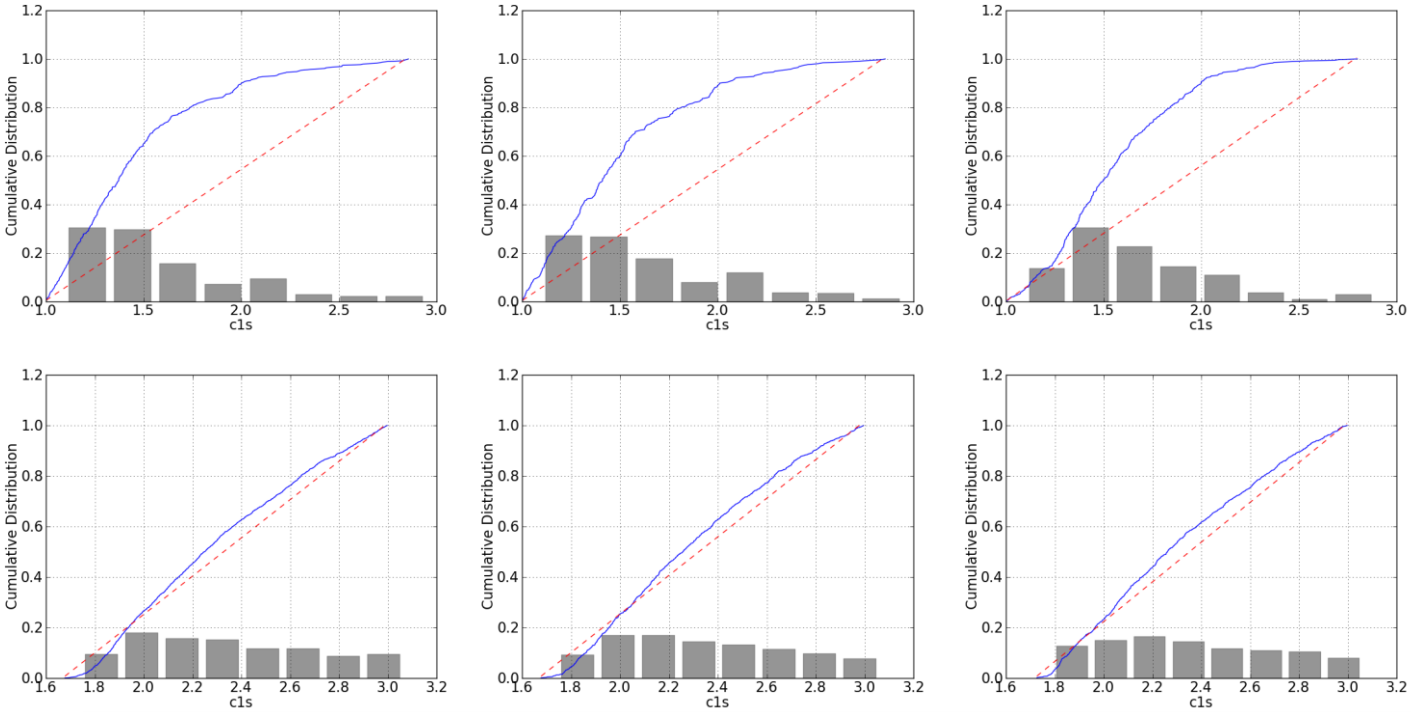
Model structures not diverse enough!

Identifiability Analysis



OBJECTIVE CRITERIA

NS | **NS & FDC$^{err}_{high}$** | **NS & FDC$^{err}_{low}$**



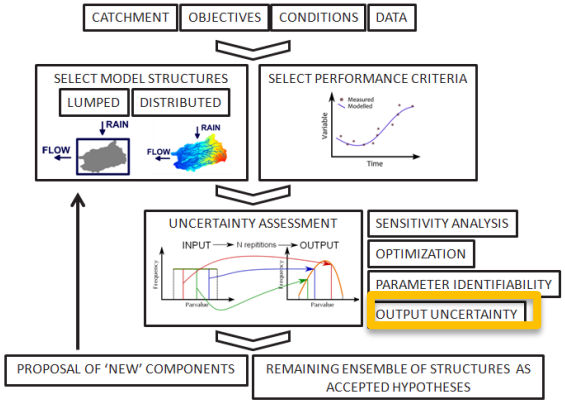
STRUCTURES

Identifiability method used:
GLUE-based identifiability index (Wagener, 2007)

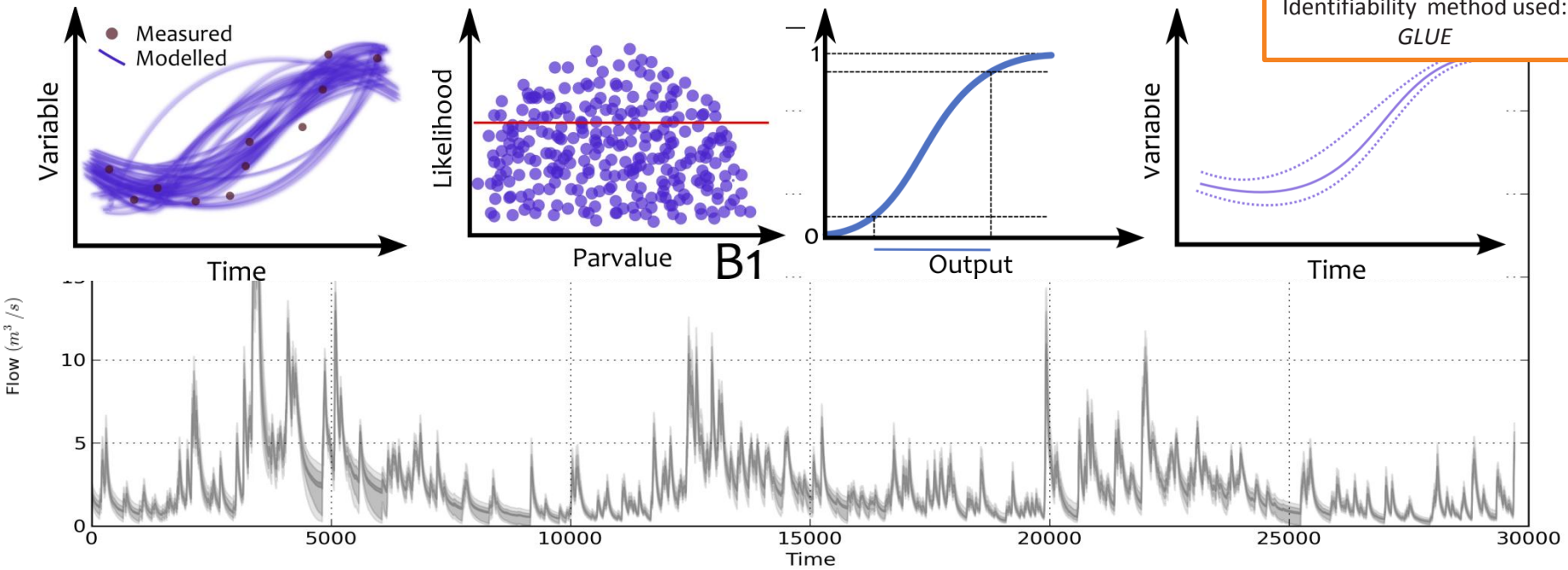
Parameter identifiability can be applied as model selection criterion

Uncertainty Analysis (not in detail)

- Ensemble of accepted **parameter sets** based on limits of acceptance
- Ensemble of accepted **structures** used based on limits of acceptance
- Every accepted run weighted by objective criteria

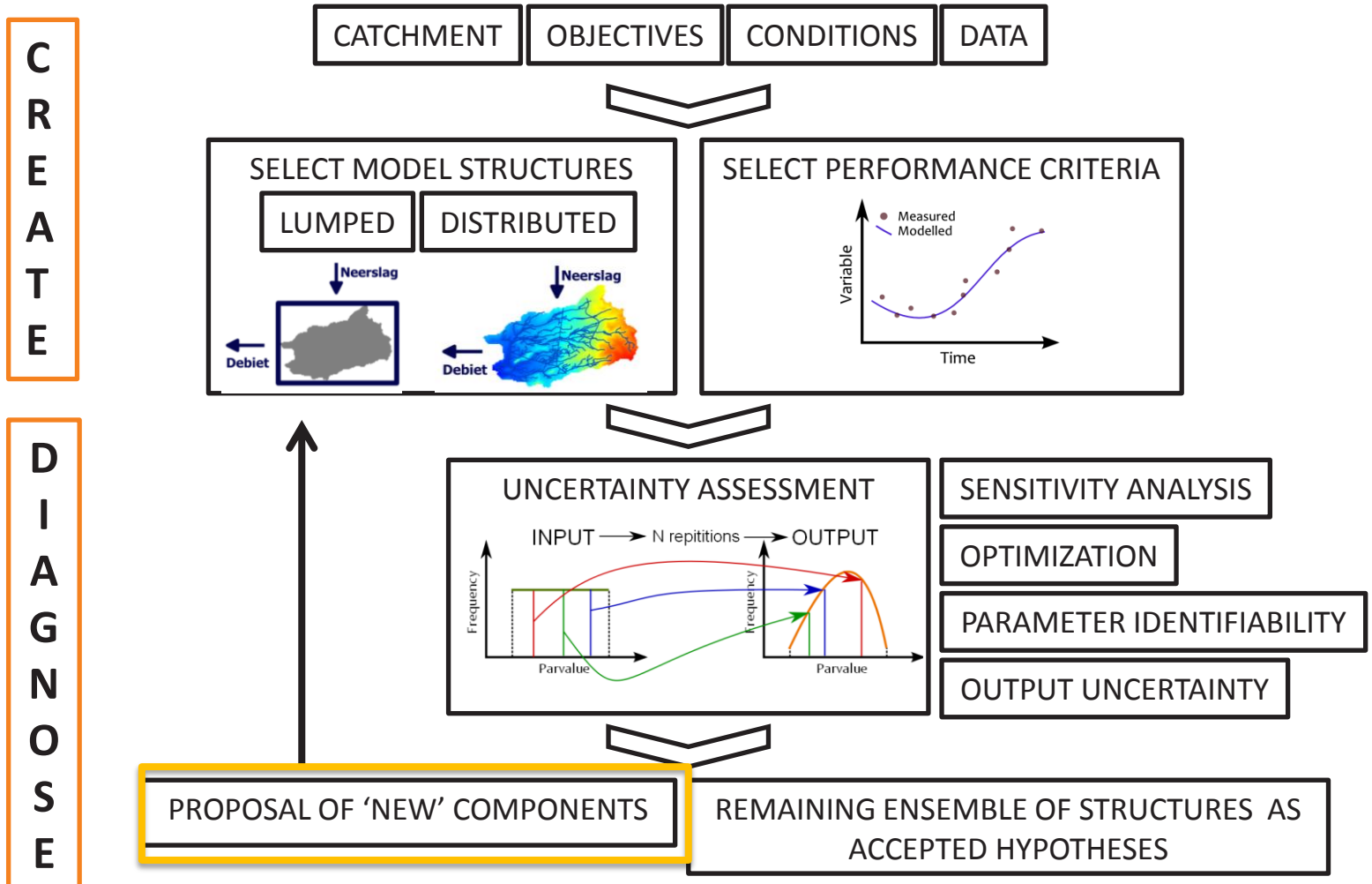


Identifiability method used: *GLUE*



Model structures not diverse enough!

Methodology



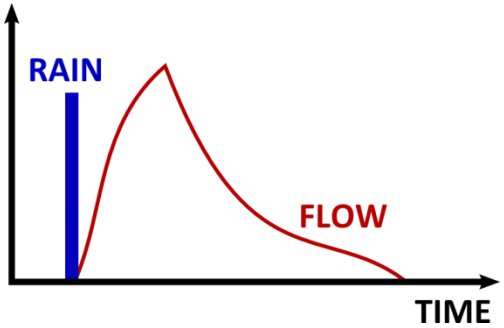
What have we learned? -> next steps

More diversity needed in model structures

- NEW STRUCTURES: PDM and NAM model with completely different configuratons compared to VHM-alternatives

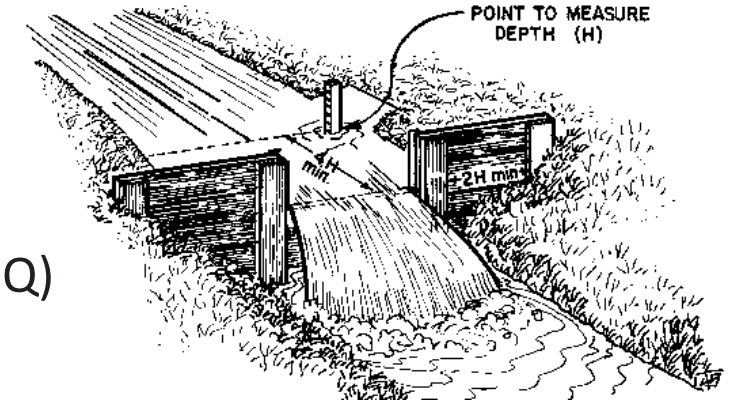
More diversity needed in objective measures

- CHECK SPECIFIC PROPERTIES OF THE HYDROGRAPH: check how the structure behaves in rising limb versus falling limb of flow after rain event

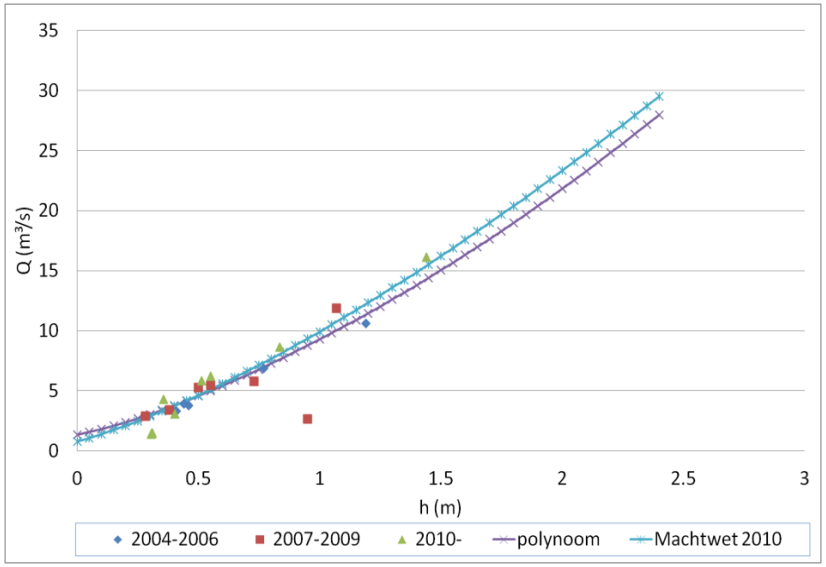


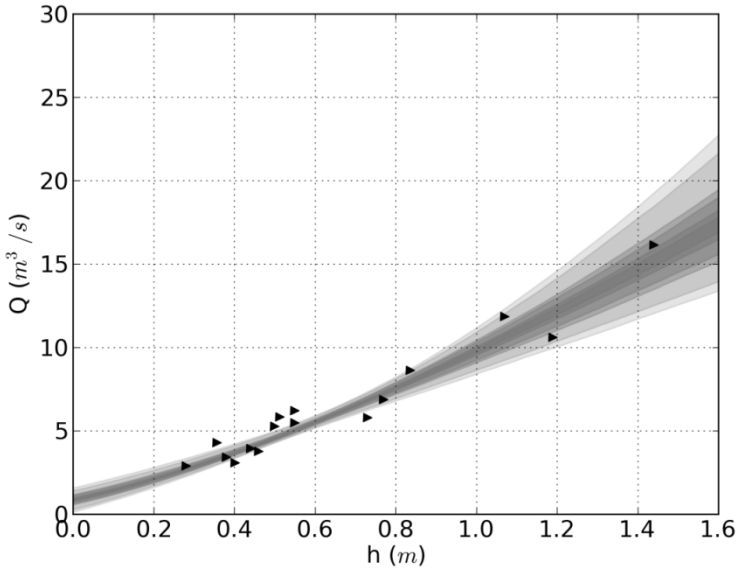
- INCORPORATE FLOW DATA UNCERTAINTY

Flow data uncertainty

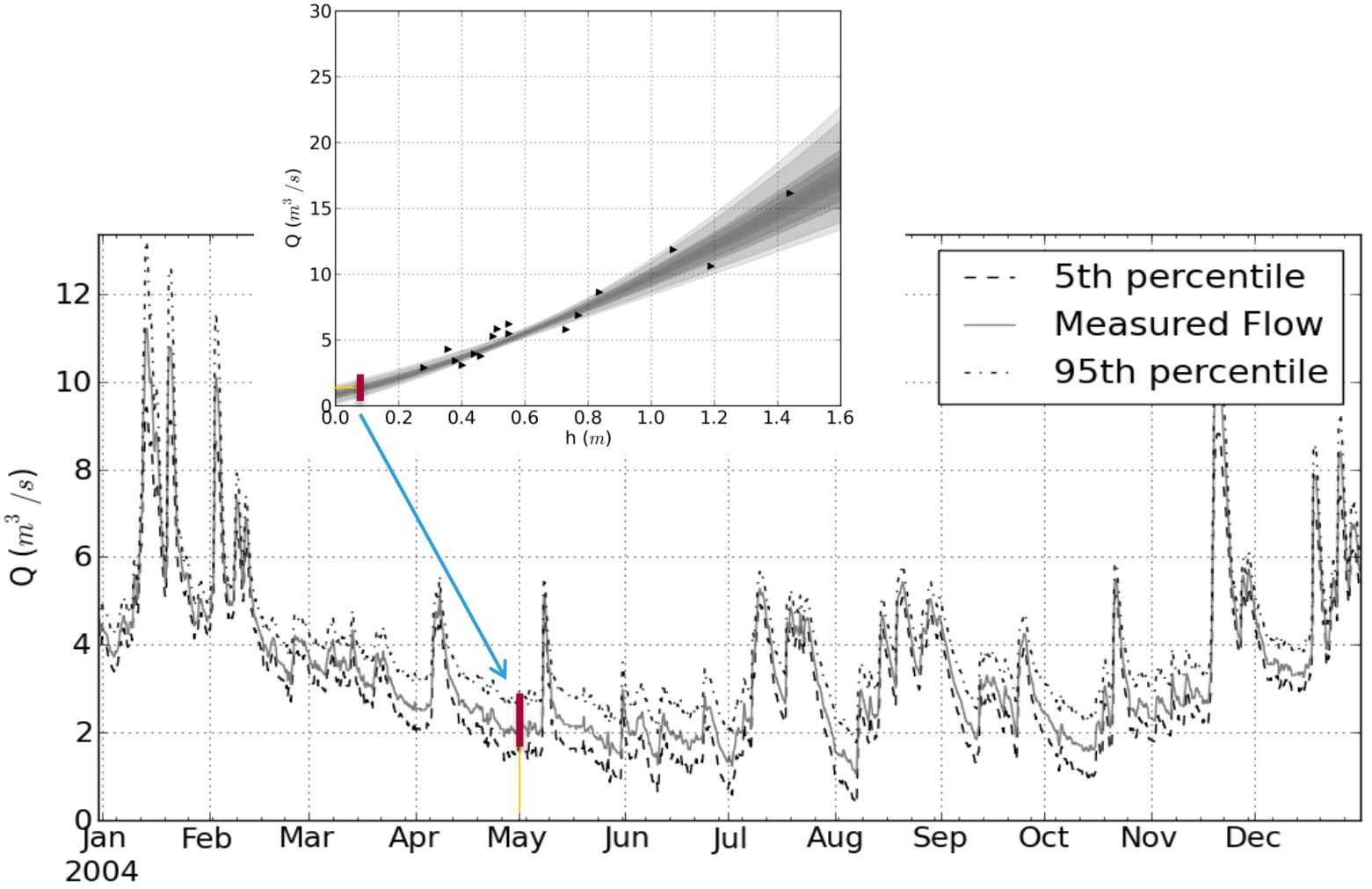


- Flow measured by weir
- Need control measurements to find relation between measured height (h) and discharge (Q)
- Power-law: $Q = a(h+b)^c$
- Uncertainty enveloppe derived based on subset of measurements



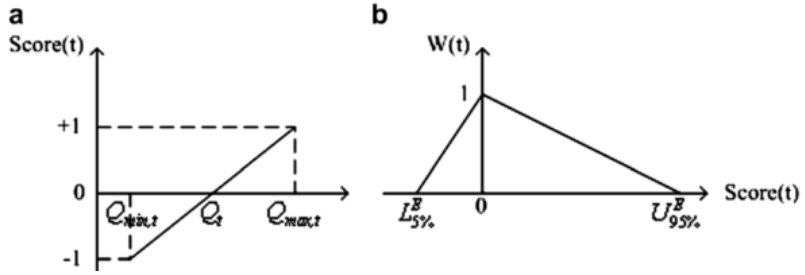


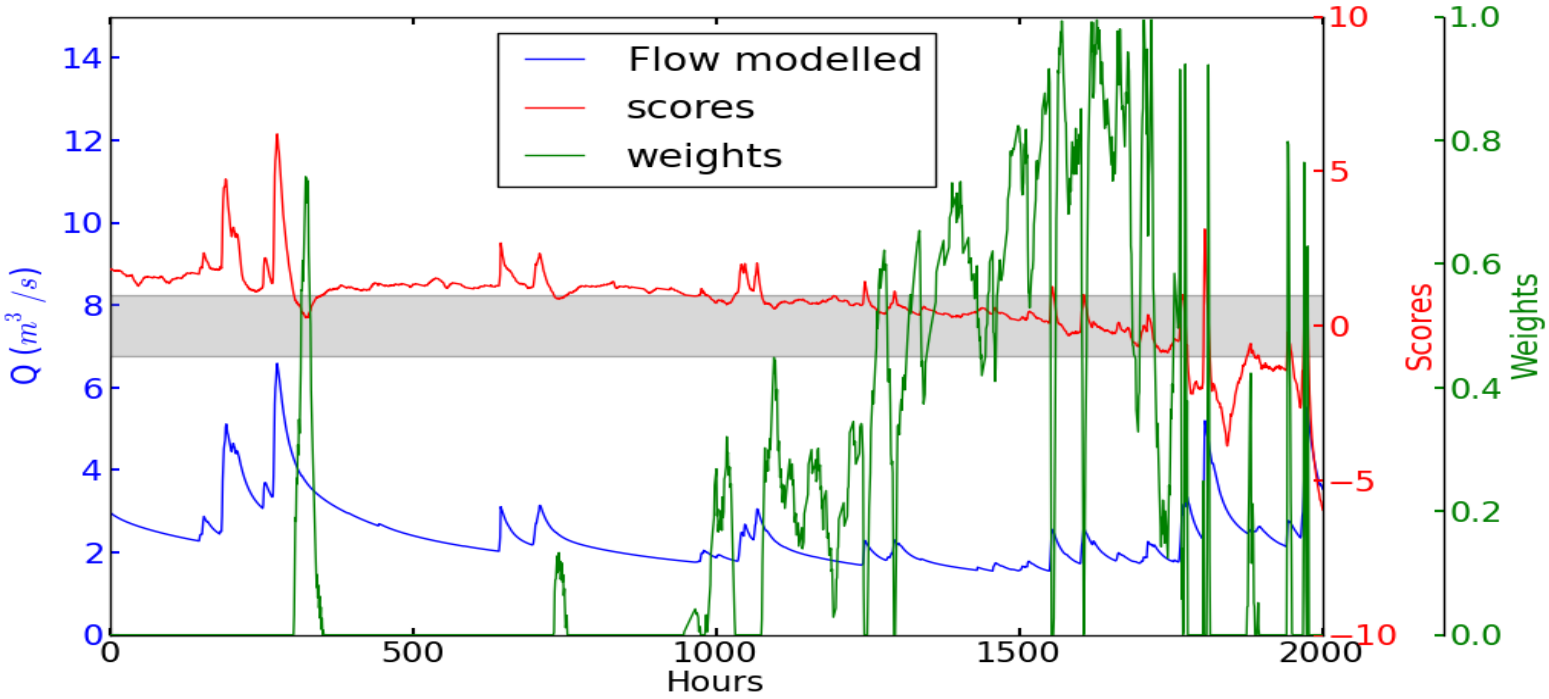
Q-h uncertainty to Q timeserie uncertainty



Q timeserie uncertainty as objective criterion

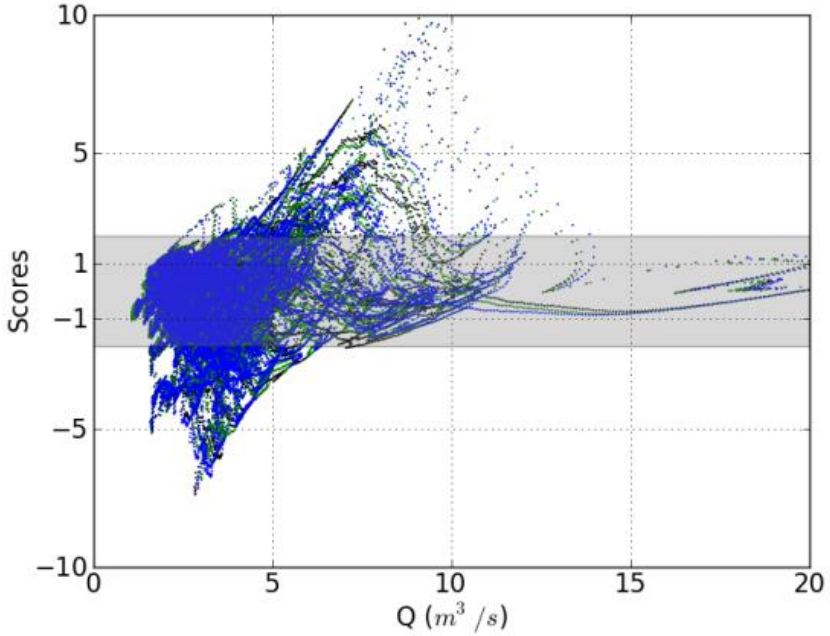
- Data uncertainty bounds to evaluate model outputs and weight simulations



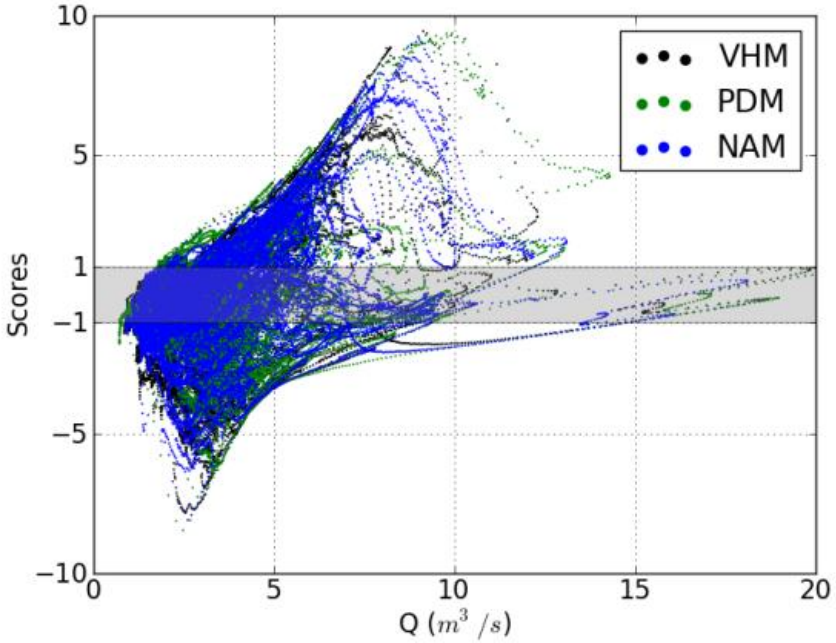


NAM, PDM and VHM similar failures

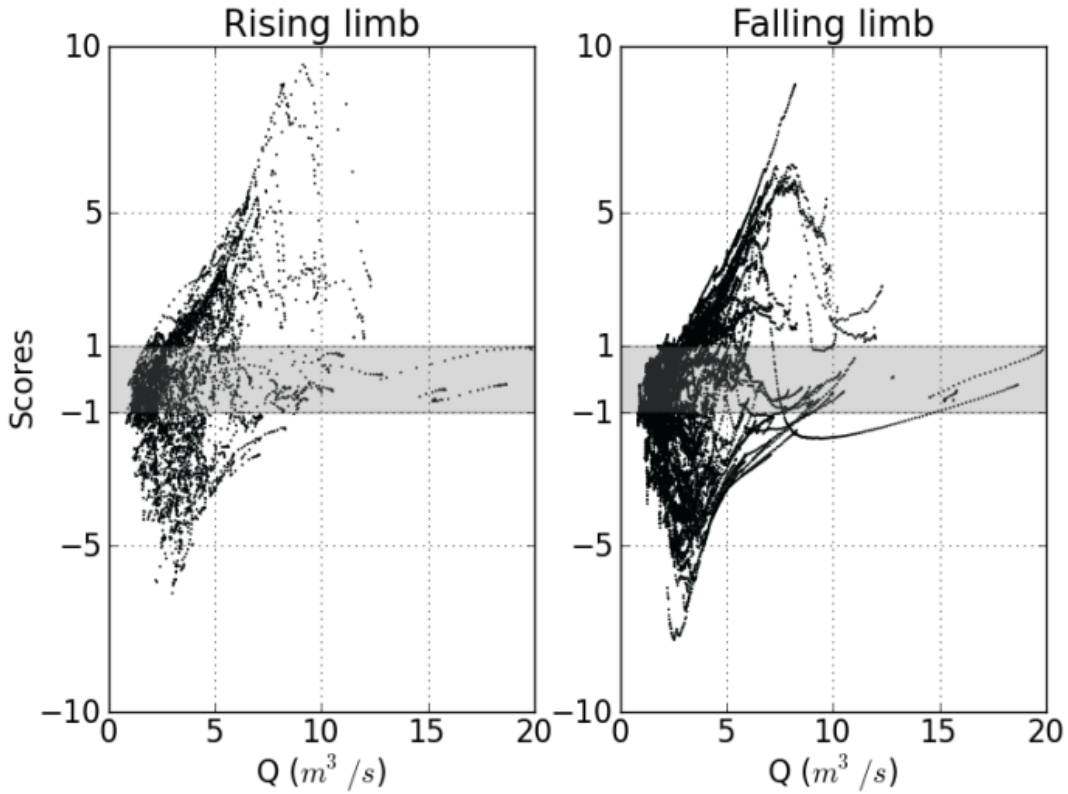
VHM alternatives

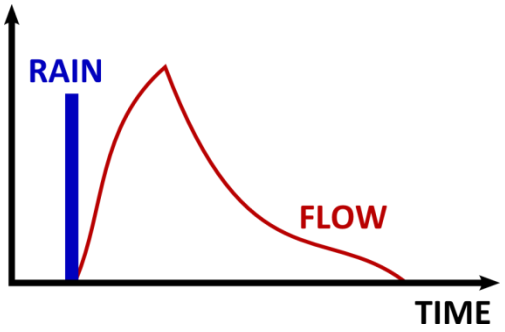


cfr. PDM, NAM en VHM



Failure in rising and falling limb very similar





To be continued…

Conclusions

- Shift from *on the shelf* fixed model structure towards case-specific ensemble of behavioural model structures
- Shift from *classic* (observed-simulated)^2 evaluation towards more rigorous analysis of model outcome
  - Improvement needed in *discriminating criteria*
- Model identification *a combined effort* of parameterization and structure identification in uncertainty assessment
- NOT *Push the button for success* – > tools to interpret model structures!
  - Learning by modelling!
- Difficult to discriminate structures as *optimal model structure* based on single streamflow output signal
- Implementation in **Python** (open source) => open and extendable!