A multiple hypotheses uncertainty analysis in hydrological modelling: about model structure, landscape parameterisation, and numerical integration

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Motivation

In Hydrology, a **large number of competing models** ranging from simple conceptual to complex process-based approaches has been developed. The lack of a community model is primarily the result of a **lack of a unified theory** in catchment hydrology due to **insufficient process understanding** and **uncertainties** related to model development and application. The **choice for a model** is based on the objective of the study, the temporal and spatial scale of interest, data availability, environmental characteristics, and personal preferences. However, there is a **high degree of ambiguity and subjectivity** during model selection. Moreover, the **vast sources of uncertainty** during model building and parameterisation and their impact on simulation results are **commonly acknowledged but rarely quantified**.

Objective

The goal of this study is to **analyse the uncertainty structure** of a process-based hydrological catchment model employing a **multiple hypotheses approach**.

Research questions:

1. What is the **impact of different sources of uncertainty** on runoff generation?
2. How important is an adequate **numerical approximation of Ordinary Differential Equations** in process-based hydrological modelling?

Model framework

LUMP

R Package: **L**andscape **U**nit **M**apping **P**rogram

- semi-automated delineation of landscape units (algorithm by Francke et al. (2008))
- connected to GRASS GIS
- creation and maintenance of a parameter database
- creation of model input files
- freely available via github: `https://github.com/tpilz/LUMP`

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ECHSE simulation environment (Kneis, 2015)

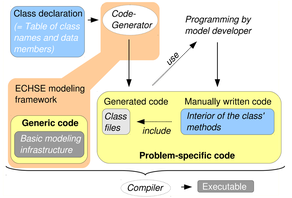

Figure 1: An ECHSE model consists of a generic part, i.e. the actual simulation environment (red), and a problem-specific model engine (yellow) based on code given by the user (blue). Graphic by David Kneis.

General model set-up

Model runs:

- 1 year spin-up, 1 year simulation (wet year 2004)
- model was run for an ensemble of hypotheses
- most plausible hypothesis defined as baseline for comparison

Example location:

- Benguê catchment, NE Brazil, 930 km^2
- semi-arid landscape, seasonal climate

Working hypothesis: The spread of model results is a measure for the model's structural uncertainty

Model hypotheses

Model hypothesis := f(landscape discretisation, process representation, numerical integration)

Landscape discretization

Hierarchical landscape discretisation scheme developed by Güntner & Bronstert (2004).

User decisions:

- number / size of sub-catchments
- number / size of elementary hillslope areas
- number of landscape units and importance of attributes during classification
- number of terrain components for each landscape unit
- soil and land-cover parameterisation

Figure 2: Schematic of landscape discretisation. Hatchures: sub-catchments, colors: landscape units with representative toposequence, polygons: elementary hillslope areas.

128 landscape classifications varying in detail and soil parameterisation

Process representation

Soil processes				Evapotranspiration			
Infiltration	**Percolation**	**Soil retention model**	**Approach**	**Bulk stomatal resistance of canopy**	**Roughness length**	**Displacement height**	**Clear sky radiation**
Philip's equation	Storage approach (SWAT)	Van Genuchten	Shuttleworth & Wallace (1985)	Shuttleworth & Wallace (1985)	SWAT	SWAT	Ångström
Green-Ampt two-stage approach	Richards' equation (simplified)	Brooks & Corey	Penman-Monteith	Saugier & Katerji (1991)	Shuttleworth & Gurney (1990)	Shuttleworth & Gurney (1990)	Allen et al. (2005)
–	–	Campbell	–	–	–	–	–

Table 1: Currently implemented user decisions in the ECHSE environment.

384 combinations of process representations based on possible user decisions

Numerical integration

Code of numerical solvers by open source GNU Scientific Library (**GSL**), `http://www.gnu.org/software/gsl/`

Explicit (each with and without sub-stepping)	**Implicit** (incl. sub-stepping)	**Linear multi-step**
Second order Runge-Kutta	Implicit Euler	Adams method in Nordsieck form
Fourth order Runge-Kutta	Implicit second order Runge-Kutta	Backward differentiation formula (BDF) method in Nordsieck form
Fourth order Runge-Kutta Fehlberg	Implicit fourth order Runge-Kutta	–
Fourth order Runge-Kutta Cash-Karp	Implicit Bulirsch-Stoer method of Bader and Deuflhard	–
Eigth order Runge-Kutta Prince-Dormand	–	–

Table 2: Currently implemented ODE solvers in the ECHSE environment.

16 ODE solvers

Results (preliminary)

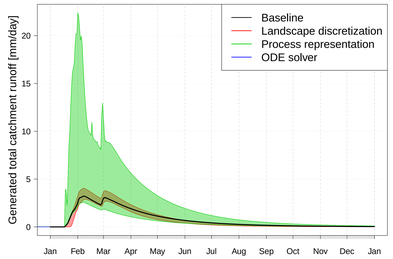

Figure 3: Ranges of generated daily total catchment runoff.

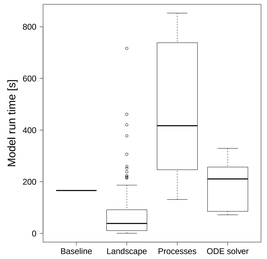

Figure 4: Boxplots of model run times for each class of model hypotheses.

Note on ODE solvers: Only some **explicit schemes with adaptive sub-stepping** and **linear multi-step** methods produced reasonable results! **Implicit methods did not converge** within defined limits. **Explicit** methods failed due to **unreasonable results** (oscillating or negative model states, etc.).

Conclusions

1. **sources of uncertainty**
   - process representation has the largest influence on runoff generation and largest span of model runtime
   - landscape discretisation of minor importance
2. **numerical approximation**
   - solvers that converge and are within plausible ranges produce similar results
   - solvers producing similar results differ greatly in model run time

Outlook

- **(in)dependence of results** from catchment and environmental properties?
- analysis of model **time step resolution**
- selection of **most adequate model structure**
- **data assimilation** framework based on uncertainty quantification

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