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Application of the new grid-based SWAT landscape model in a small mountainous watershed in Germany

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DRESDEN concept Exzellenz aus Wissenschaft und Kultur

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Objective

To test whether the application of the SWAT-Grid version achieves comparable results to SWAT 2012 for a small mountainous watershed in Germany.

Due to shallow soils over bedrock, lateral sub-surface flow is the dominant runoff-generation process.

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Development of a grid-based version of the SWAT landscape model

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Abstract:

Integrated river basin models should provide a spatially distributed representation of basin hydrology and transport processes to allow for spatially implementing specific management and conservation measures. To accomplish this, the Soil and Water Assessment Tool (SWAT) was modified by integrating a landscape routing model to simulate water flow across discretized routing units. This paper presents a grid-based version of the SWAT landscape model that has been developed to enhance the spatial representation of hydrology and transport processes. The modified model uses a new flow separation index that considers topographic features and soil properties to capture channel and landscape flow processes related to specific landscape positions. The resulting model is spatially fully distributed and includes surface, lateral and groundwater fluxes in each grid cell of the watershed. Furthermore, it more closely represents the spatially heterogeneous distributed flow and transport processes in a watershed. The model was calibrated and validated for the Little River Watershed (LRW) near Tifton, Georgia (USA). Water balance simulations as well as the spatial distribution of surface runoff, subsurface flow and evapotranspiration are examined. Model results indicate that groundwater flow is the dominant landscape process in the LRW. Results are promising, and satisfactory output was obtained with the presented grid-based SWAT landscape model. Nash–Sutcliffe model efficiencies for daily stream flow were 0.59 and 0.63 for calibration and validation periods, and the model reasonably simulates the impact of the landscape position on surface runoff, subsurface flow and evapotranspiration. Additional revision of the model will likely be necessary to adequately represent temporal variations of transport and flow processes in a watershed.

KEY WORDS raster-based simulation; watershed modeling; discretization scheme; SWATgrid; landscape routing

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INTRODUCTION

River basin models are valuable tools for examining the impact of land use and management on landscape hydrology, sediment transport and water quality. The Soil and Water Assessment Tool (SWAT) has proven to be a suitable tool under many landscape conditions, and in most applications the prediction accuracy was satisfactory for obtaining knowledge of the hydrologic system and the watershed processes (Arnold and Fohrer, 2005; Gassman *et al.*, 2007). However, previous studies showed that the assessment of the effects of conservation practices on watershed-scale water quality relies strongly on the flow and transport models used (e.g. Mausbach and Dedrick, 2004). The SWAT model typically utilizes a hydrologic response unit (HRU) approach. The watershed is divided into sub-watersheds which are further subdivided into HRUs. However, the SWAT routing command language enables the model to use an HRU, a representative hillslope or a grid cell configuration, alone or in combination, to model a watershed (Arnold *et al.*, 1994, 2013). Nevertheless, SWAT uses the HRU configuration as the primary discretization scheme (Gassman *et al.*, 2007; Arnold *et al.*, 2013), and all geographic information system (GIS) input interfaces use the computationally efficient HRU discretization. Thus, there are only few SWAT applications and studies which actually have used a different discretization approach (e.g. Manguerra and Engel, 1998; White *et al.*, 2009; Arnold *et al.*, 2010; Rathjens and Oppelt, 2012a,b).

Within the HRU approach, all areas in a sub-watershed with the same combination of soil, topography and land use are lumped to form an HRU. The HRUs represent percentages of the sub-watershed area and are not spatially

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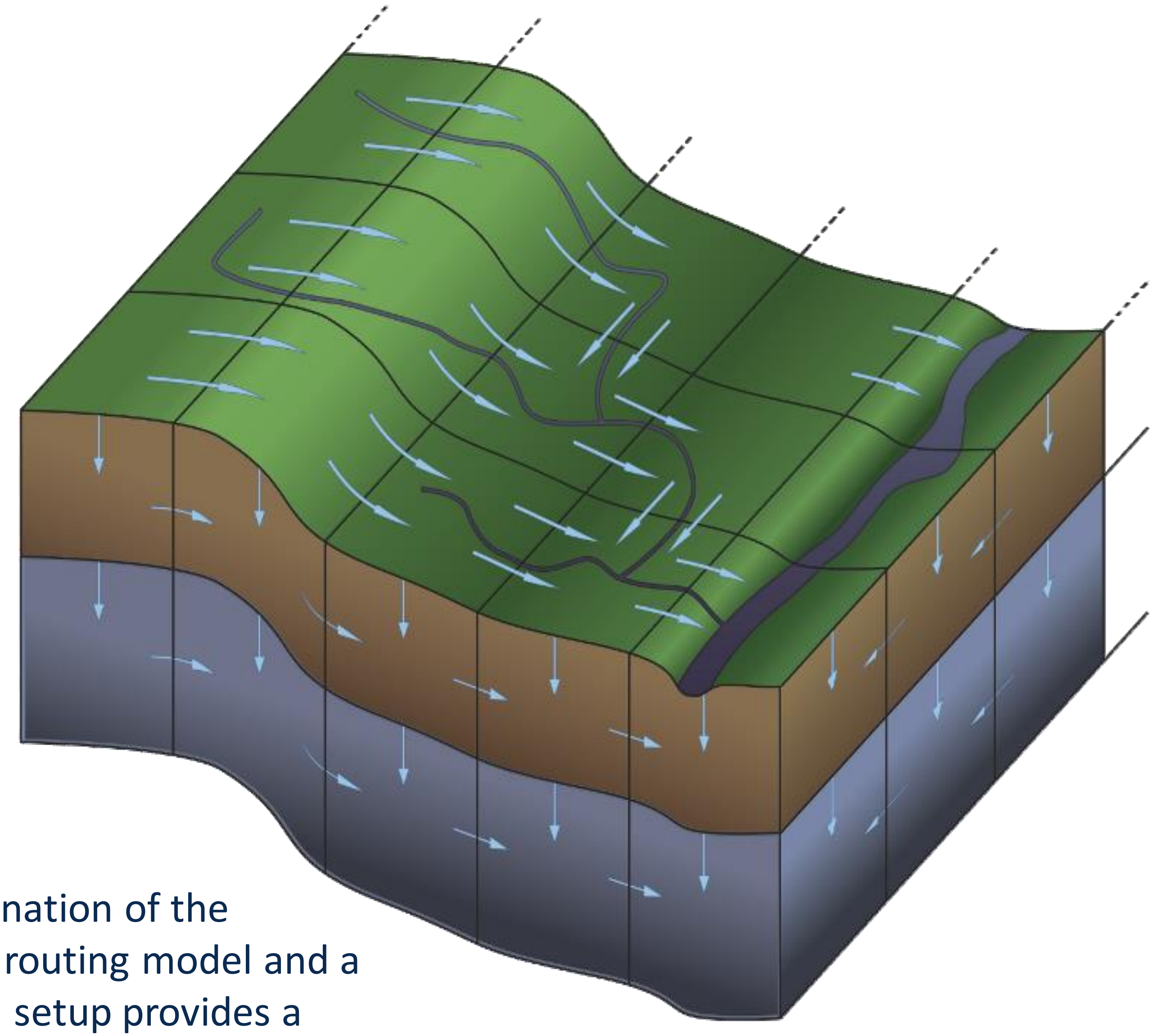
Grid-based SWAT landscape model

Channel flow

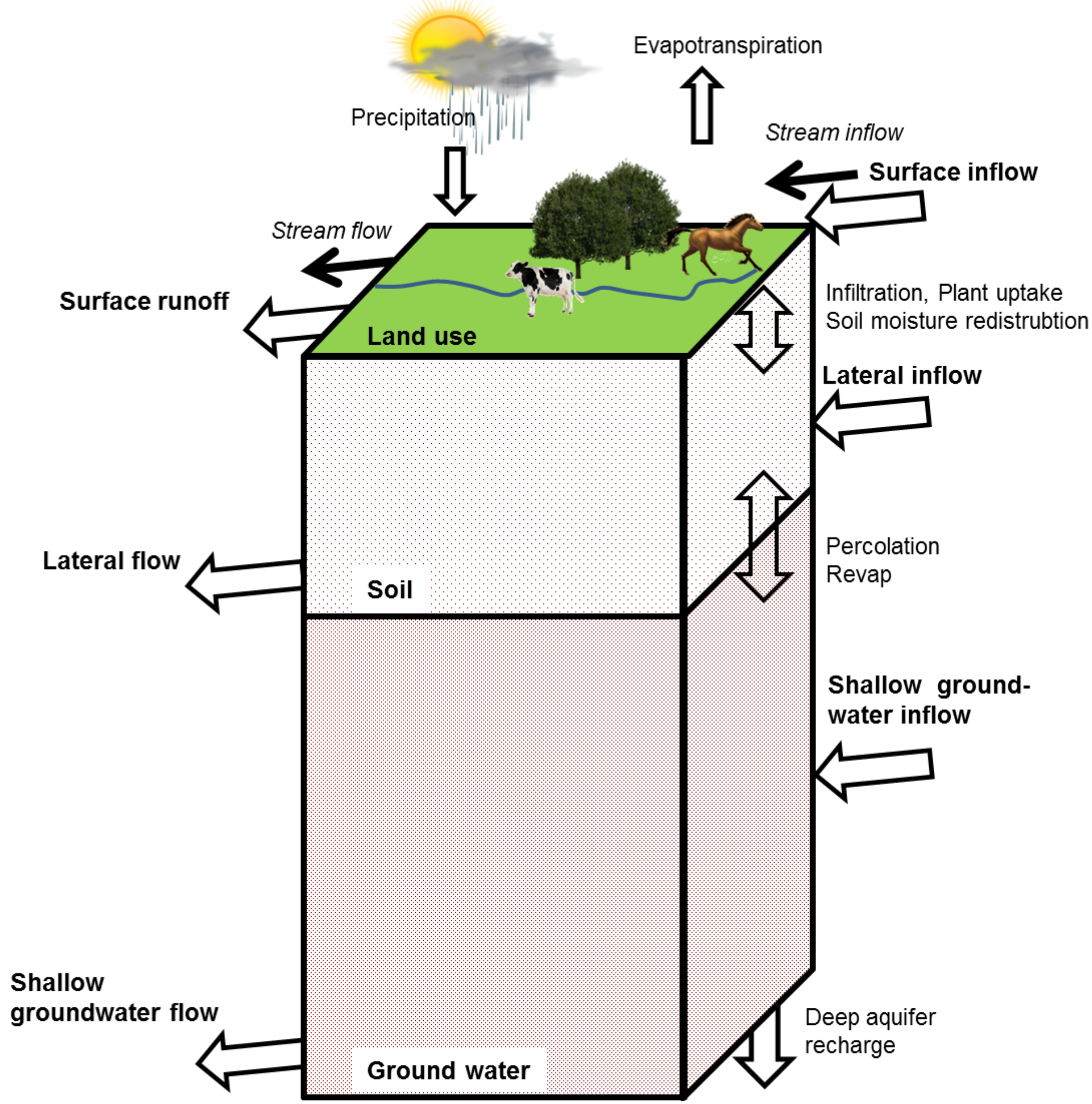
Landscape flow

- Surface runoff
- Lateral flow
- Shallow groundwater flow



The combination of the landscape routing model and a grid-based setup provides a spatially fully distributed model.

Grid-based SWAT landscape model



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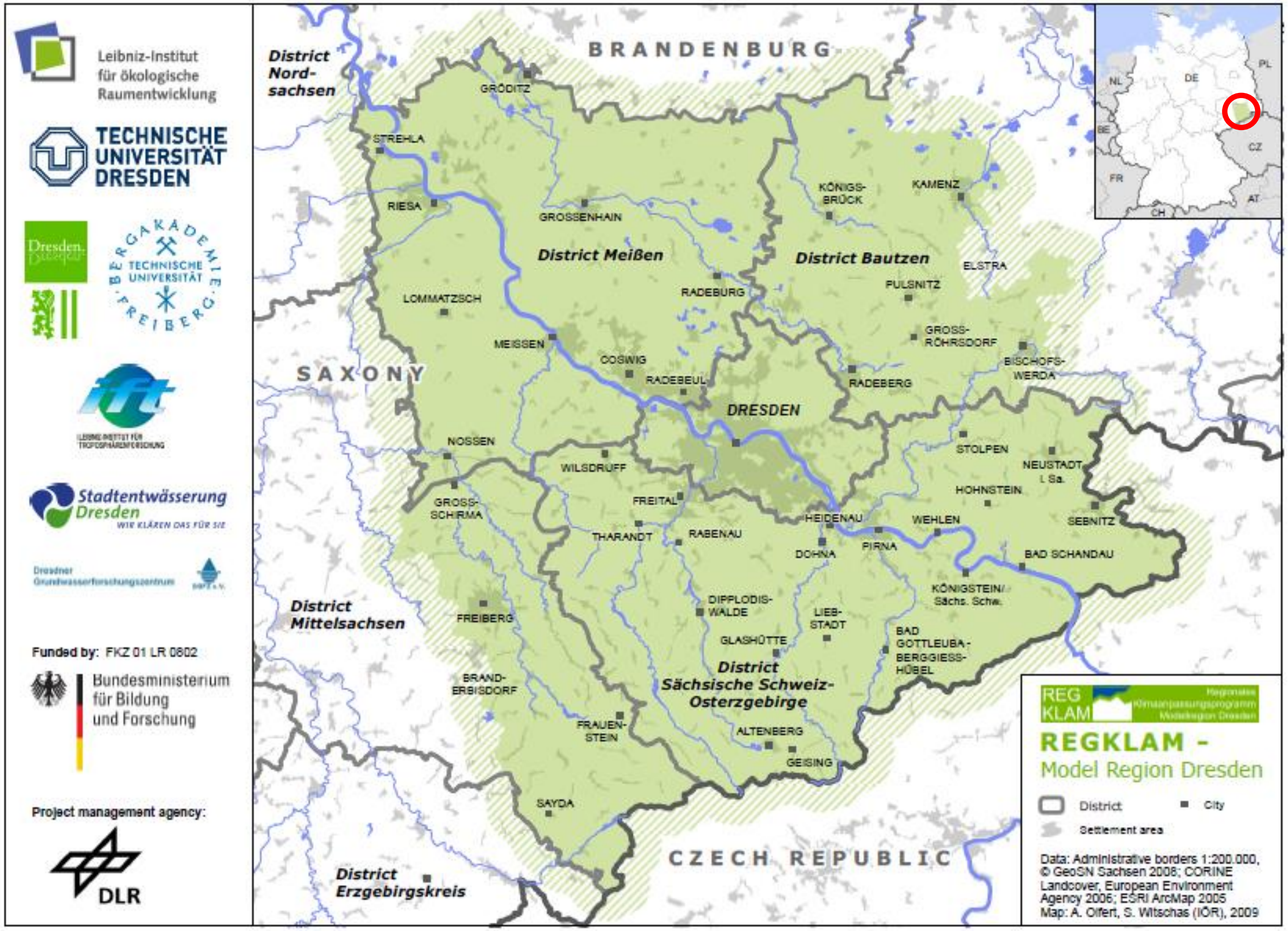
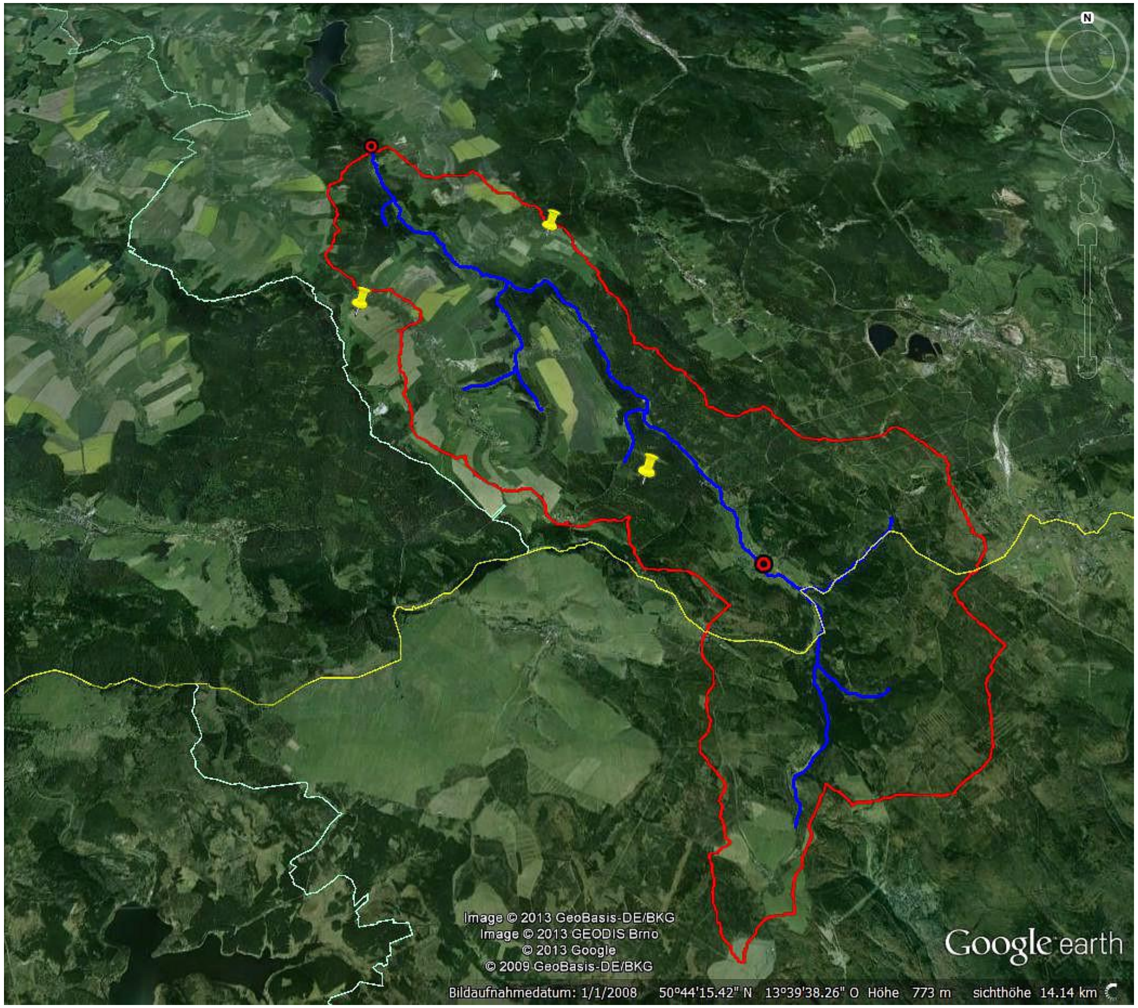
Study Site



Study Site

Research area - Ammelsdorf catchment



Climate

(period 1961 – 1990)

Precipitation

1096 mm a^{-1}

Mean annual temperature

4,3 °C

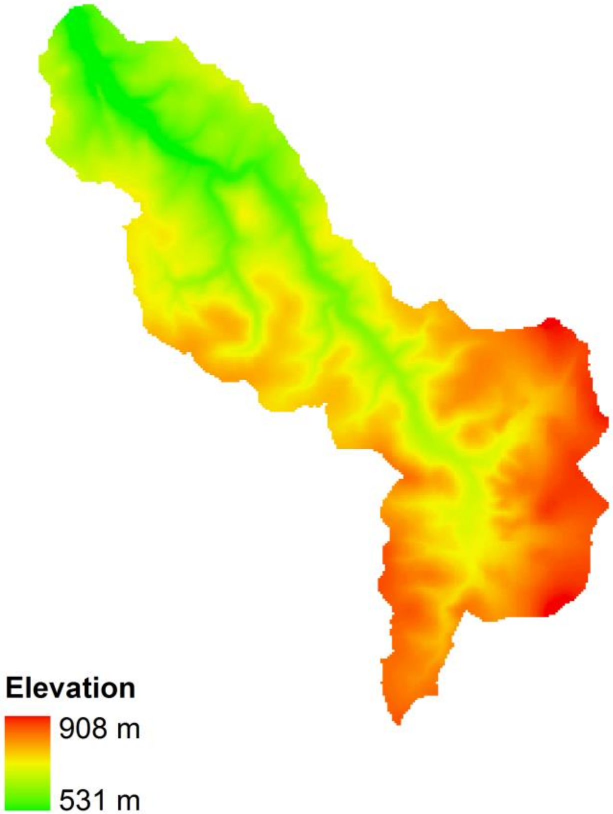
(Bernhofer et al., 2009)

Size

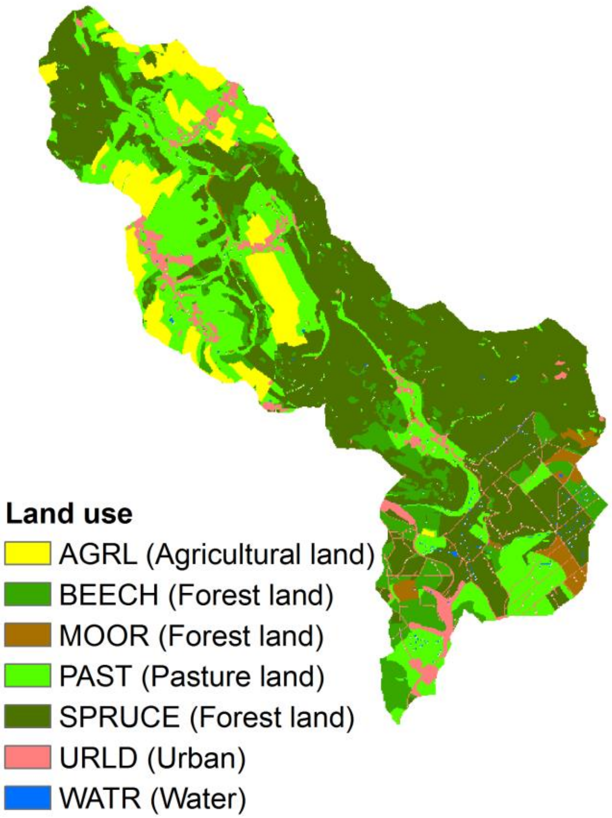
51 km²

Study Site

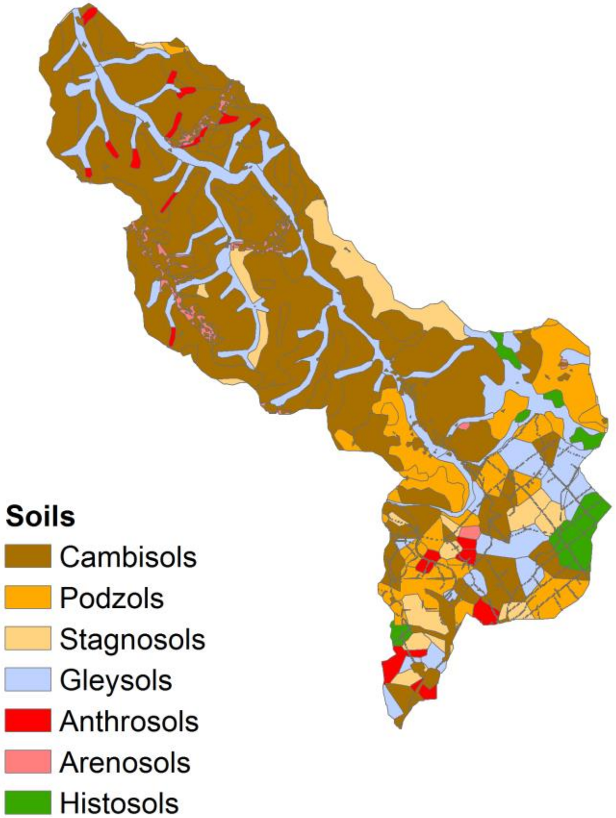
Input data for Ammelsdorf catchment



20 m resolution DEM
(GeoSN, 2010)



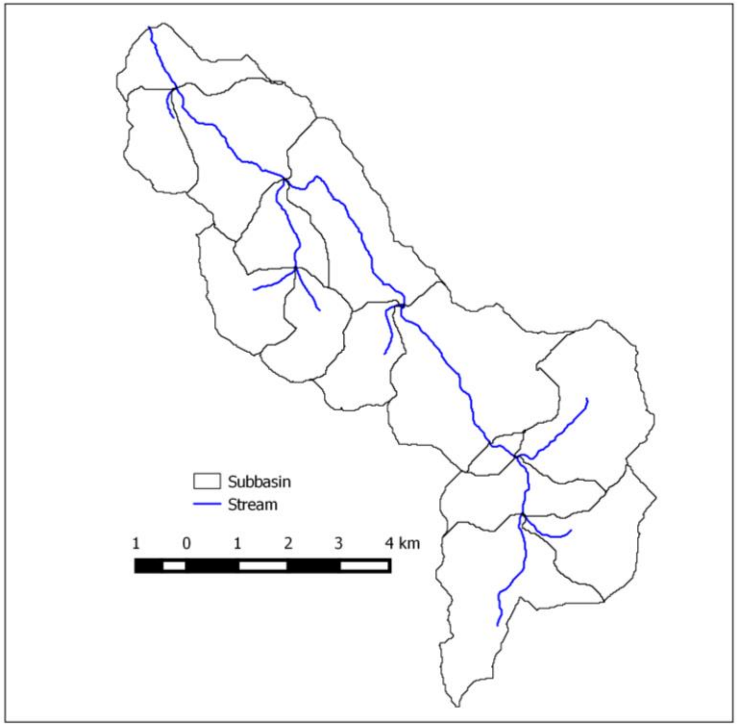
Land use, CIR 2005
(LfULG, 2010)



Soil map BK50
(LfULG, 2011)

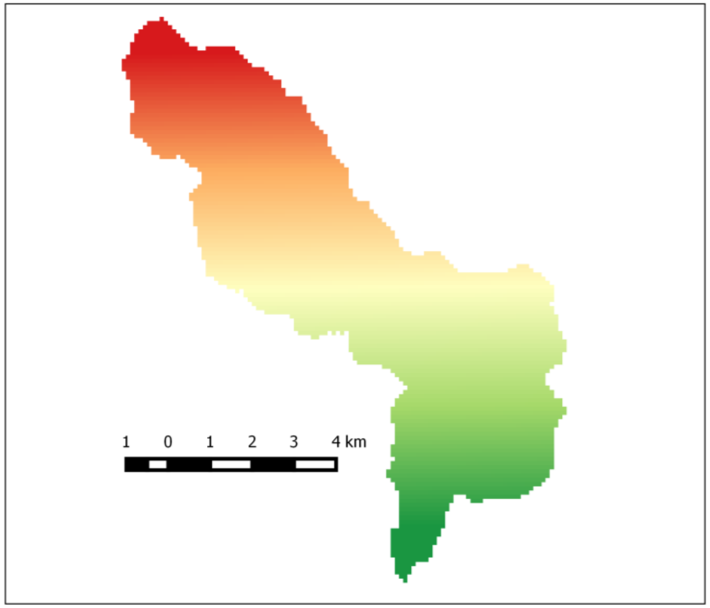
Model Set-Up

SWAT2012



13 Subbasins
1312 HRU'S
5 min 5 years

SWAT-dis



13000 Gridcells
100mx100m
11 min 5 years

Calibration – SWAT-Grid

Parameter	Min	Max
SURLAG [days]	0	3
SFTMP [°C]	-1.5	1.5
SMTMP [°C]	0	2
SMFMX [°C]	1	6
SMFMN [°C]	1	6
SNOCOVMX [°C]	0.5	3
SNO50COV [°C]	0.01	0.99
TIMP [-]	0	1
AWC * [mm/mm]	-0.15	0.15
k_norock* [mm/h]	-0.15	0.15
k_rock [mm/h]	0	200
ALPHA_BF [-]	0.001	0.99
GW_DELAY [days]	0	50
GW_REVAP [-]	0.02	0.2
GW_QMN [mm]	0	100
Depth impervious layer* [mm]	-0.3	0.3

* Relative to initial value

- 500 Parameter Sets
- Two year warm up
- Calibration 2010-211
- Validation 2012

Objective function:
Average of NSE and NSE-log @ all available gaging station

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

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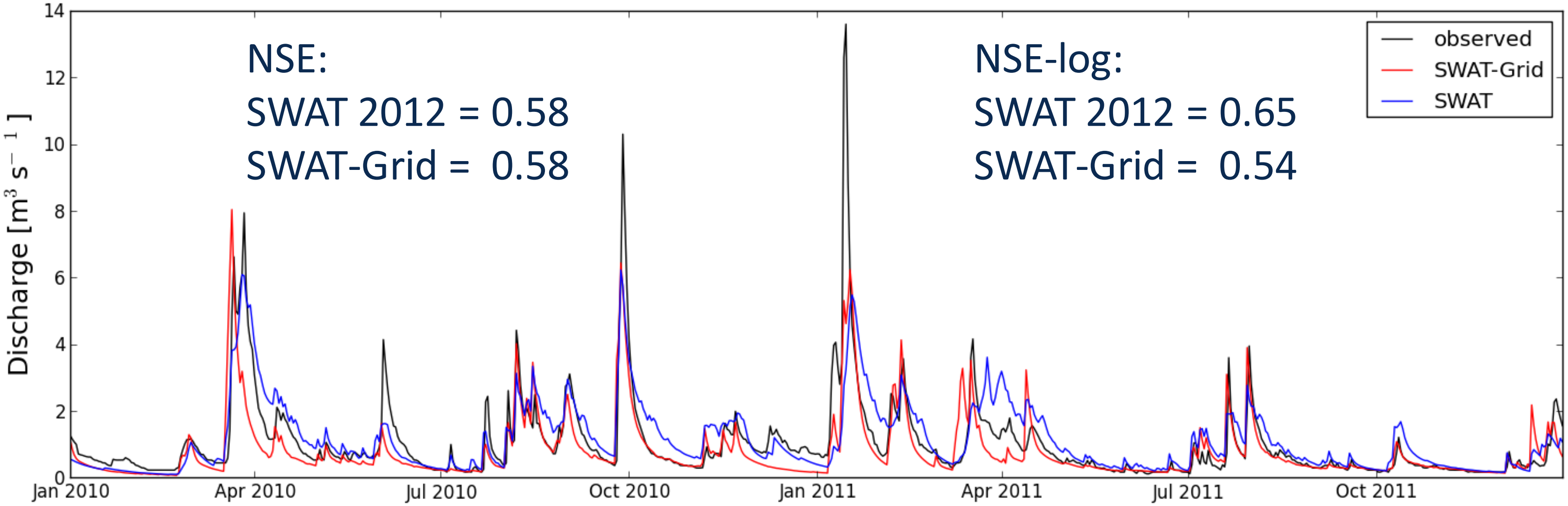
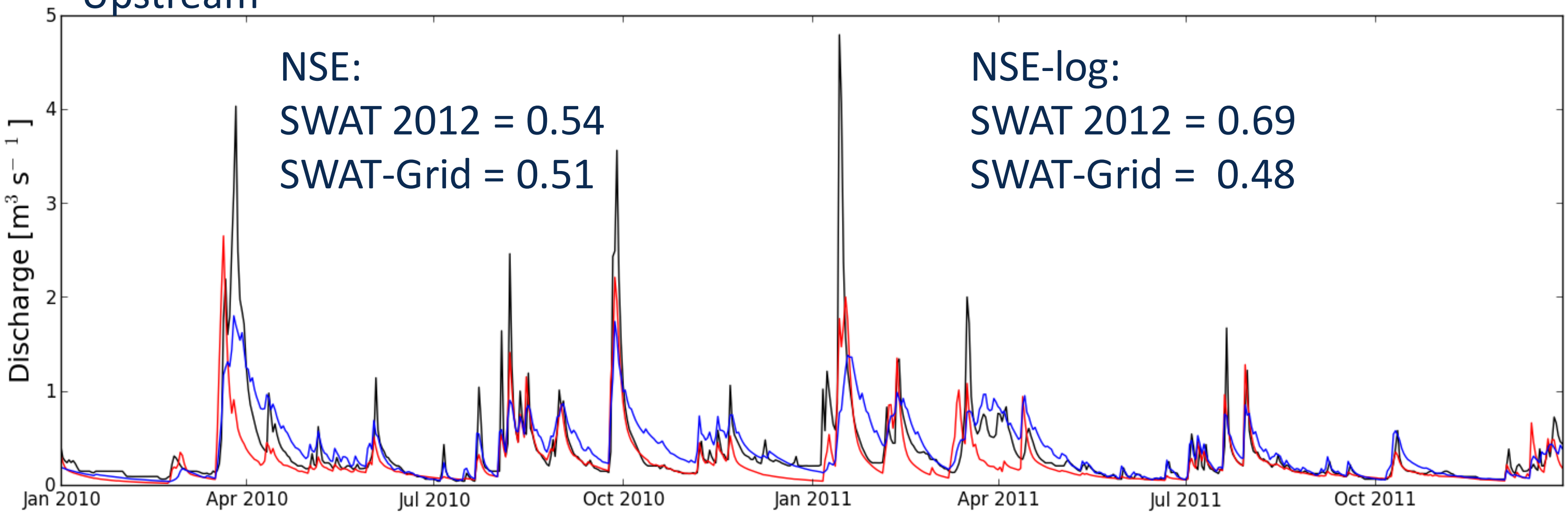
Calibration

Outlet

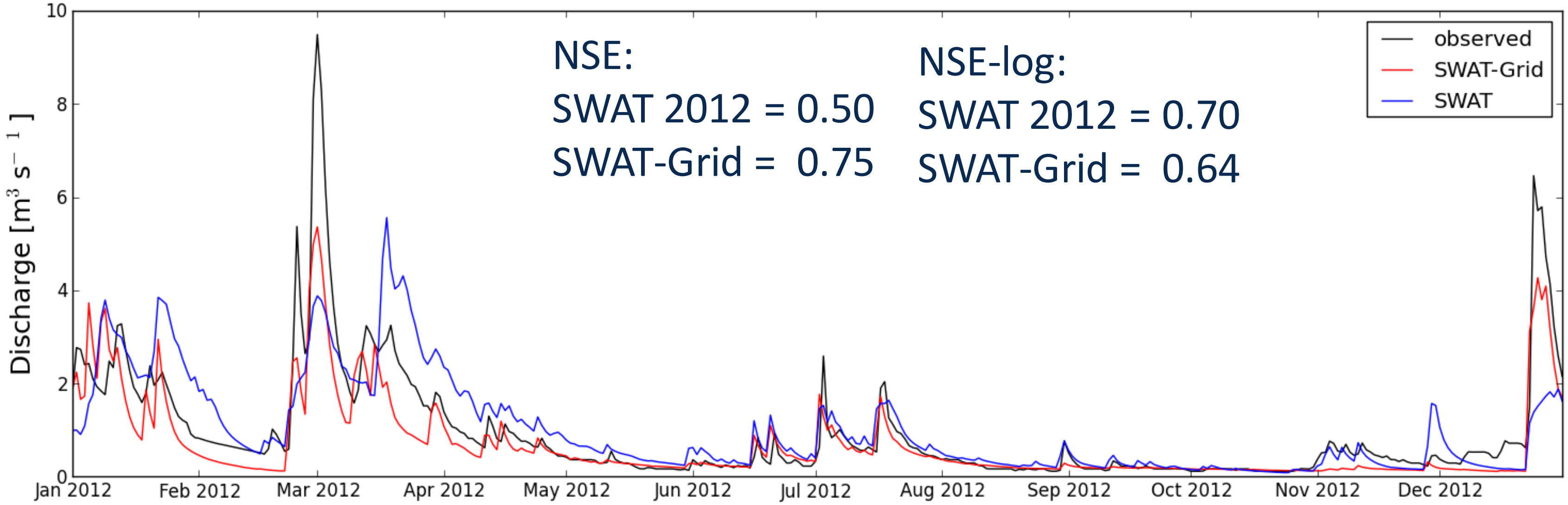


Upstream

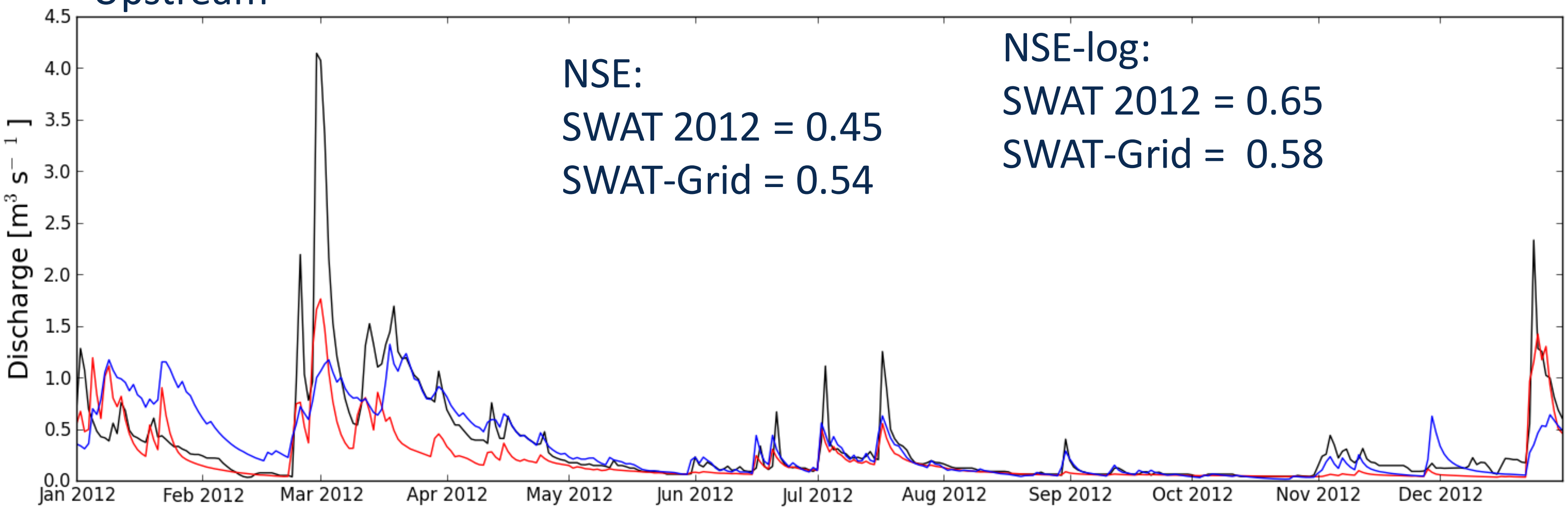


Validation

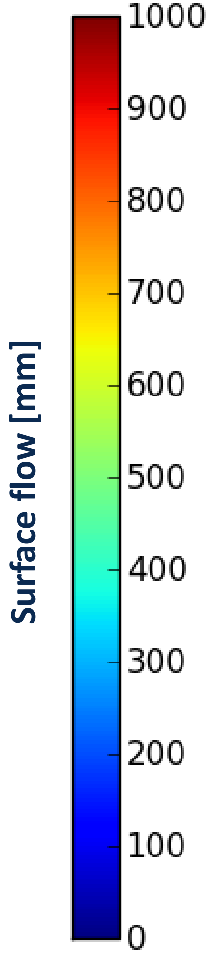
Outlet

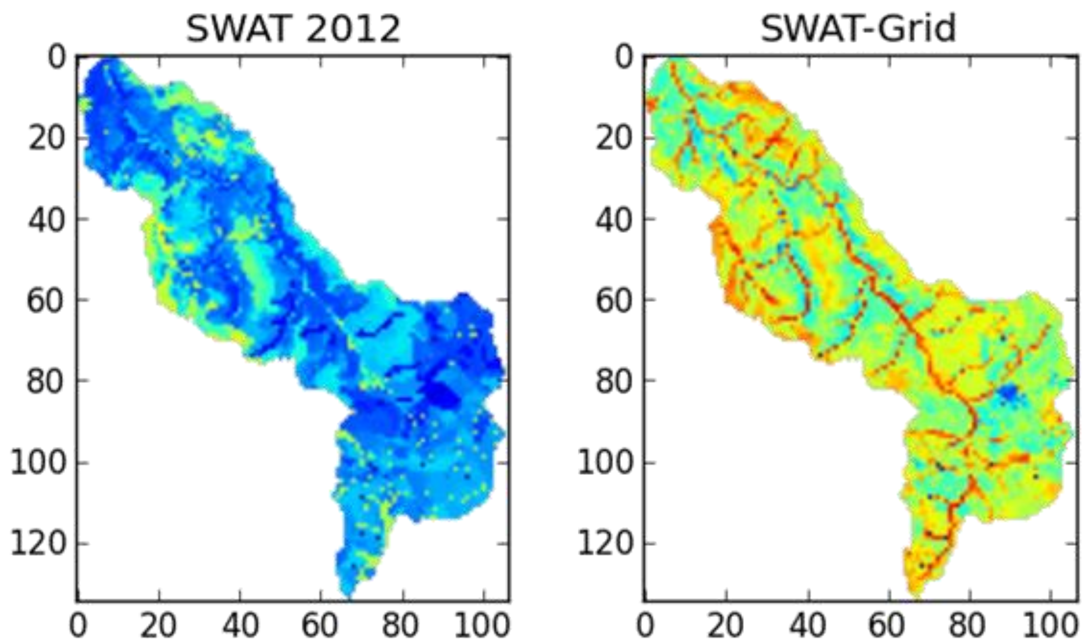


Upstream



Spatial analysis – surface flow





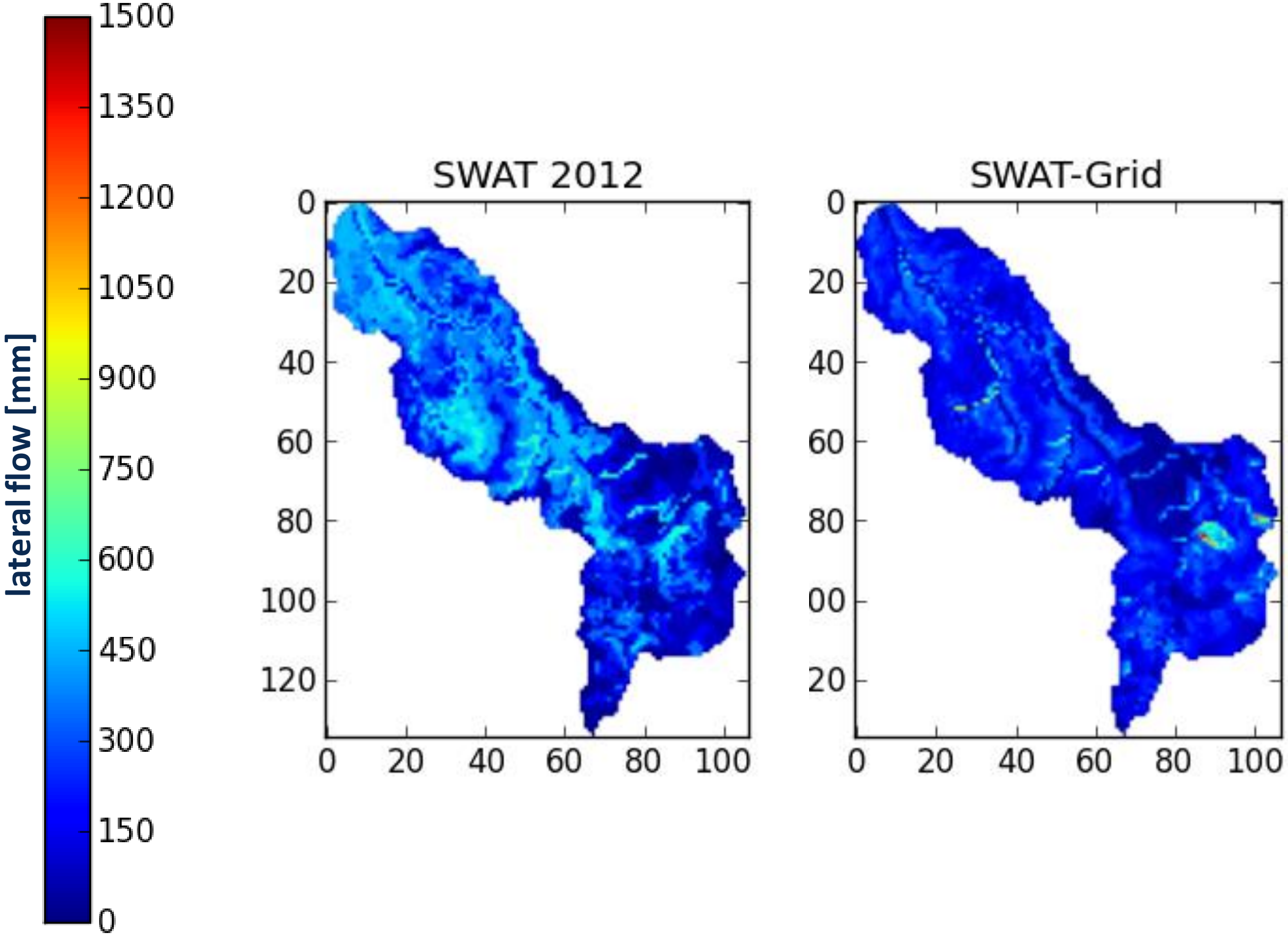
SWAT AVE MONTHLY BASIN VALUES

MON	RAIN (MM)	SNOW FALL (MM)	SURF Q (MM)	LAT Q (MM)	WATER YIELD (MM)
1	144.97	48.73	98.08	0.71	91.50
2	68.77	33.72	57.01	0.09	51.45
3	67.32	14.51	62.60	47.47	123.37
4	64.25	0.91	4.26	43.82	83.95
5	91.12	0.00	1.41	15.15	32.01
6	95.68	0.00	2.28	16.04	26.49
7	198.36	0.00	10.28	33.78	48.73
8	150.41	0.00	8.53	35.21	57.89
9	104.87	0.00	9.84	28.09	47.17
10	48.02	1.58	0.79	18.34	39.80
11	84.63	10.91	3.88	20.66	34.91
12	166.98	72.34	39.03	3.62	36.32

SWAT-Grid AVE MONTHLY BASIN VALUES

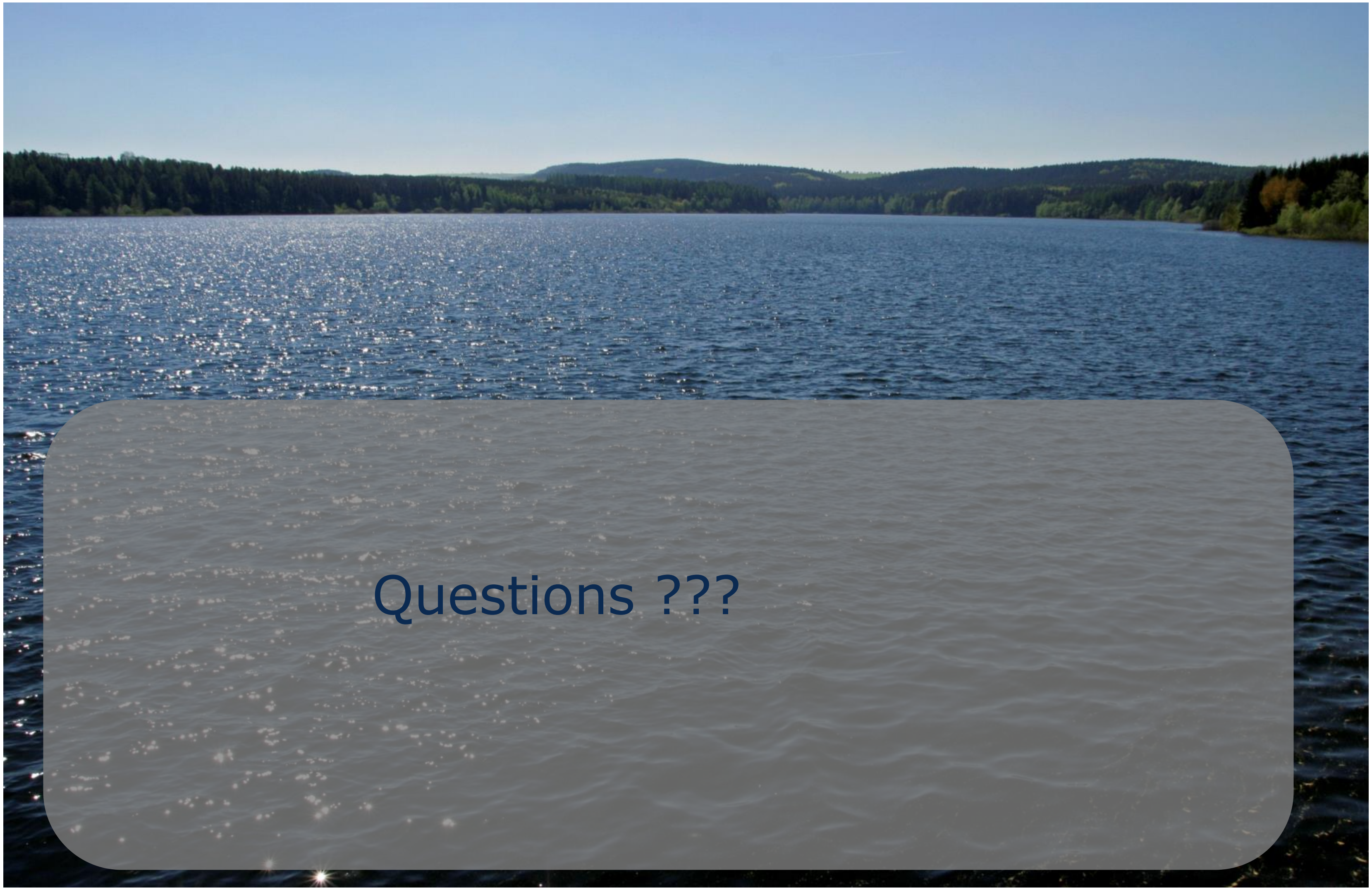
MON	RAIN (MM)	SNOW FALL (MM)	SURF Q (MM)	LAT Q (MM)	WATER YIELD (MM)
1	146.01	86.62	98.65	6.71	109.17
2	69.47	41.81	78.37	3.69	66.43
3	67.90	23.95	113.47	5.49	131.22
4	64.77	1.30	30.51	19.80	52.72
5	91.84	0.73	16.48	21.36	34.89
6	96.37	0.00	15.46	19.02	36.69
7	199.18	0.00	58.57	20.51	73.10
8	151.21	0.00	49.32	22.99	73.30
9	105.41	0.00	41.61	21.75	63.41
10	48.67	2.59	7.08	21.50	33.69
11	85.34	26.28	20.42	16.86	36.97
12	168.14	116.75	59.42	9.52	66.87

Spatial analysis – lateral flow



conclusions

- The application of SWAT-Grid leads to similar results as SWAT2012 in regards of model efficiency
- Differences in spatial output of both versions
- Both versions →difficulties in snow melt periods
- More data than measured discharge needed →for validation of the model …


Questions ???