Thesis presentation

Degree:
Joint Master of Science in Hydroinformatics and Water Management

Tampere, August 21st, 2019

Urban sanitary sewer modelling in cold climate

Test case using automatic calibration and precipitation forecast in Finland

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Problem description

- Rainfall dependent **Inflow** and **infiltration (RDII).**
- Inflow – roof or foundation drain connections. Infiltration – pipe cracks, faulty manhole, etc.
- **Overflows** upstream caused by blockage or downstream by the WWTP bypass.
- Why model the RDII? Improve design, rehabilitation, operations.
- How can RDII be modeled in cold climates? Snow accumulation and **snowmelt**.

Root intrusion [1]

Infiltration through cracks [1]

Overflow: upstream [2]

Overflow: downstream [3]

Objectives of the thesis

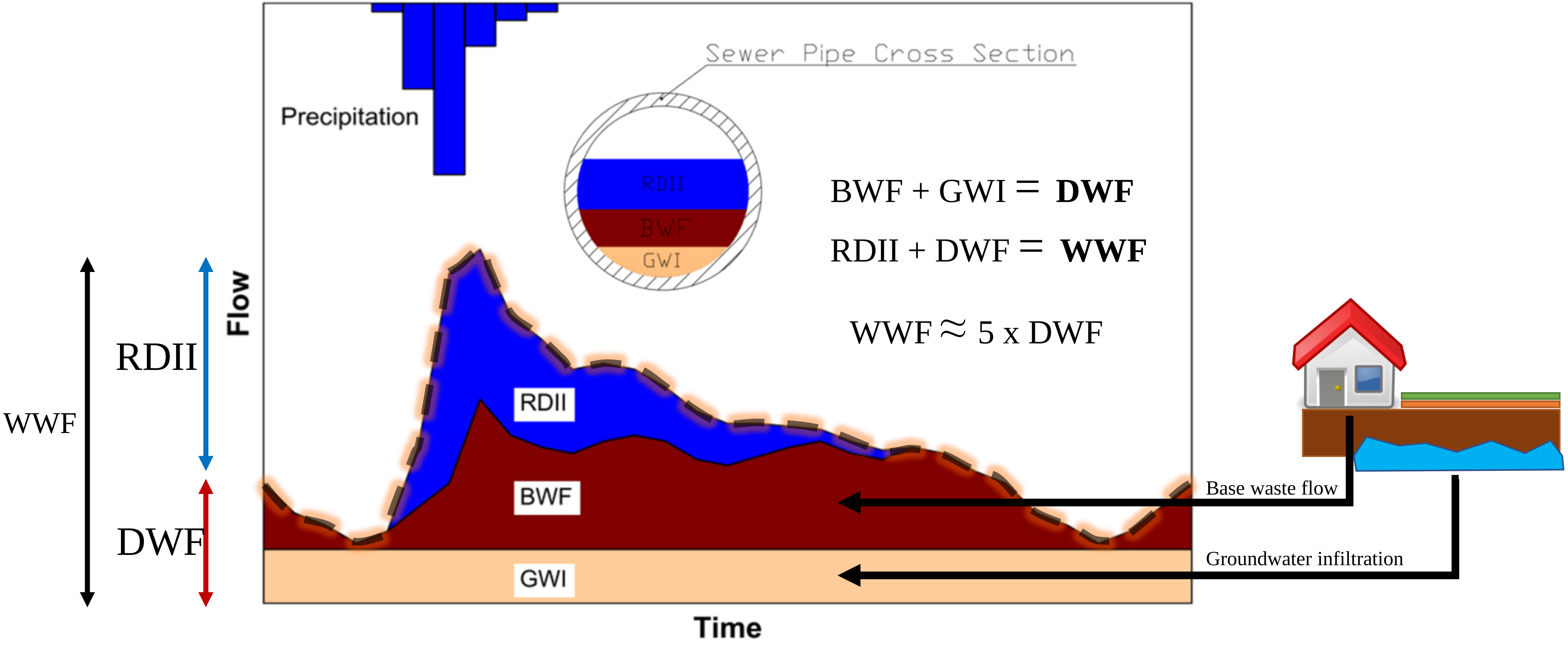
1. Use two different hydrological modeling approaches in SWMM to simulate RDII

2. Methodology for parameter estimation and calibration of the hydrological models.

3. Hydrological + hydraulic model for a case study of a town located in the south Finland.

4. Forecasted precipitation data and key aspects for a forecasting system.

Wet-weather flow components

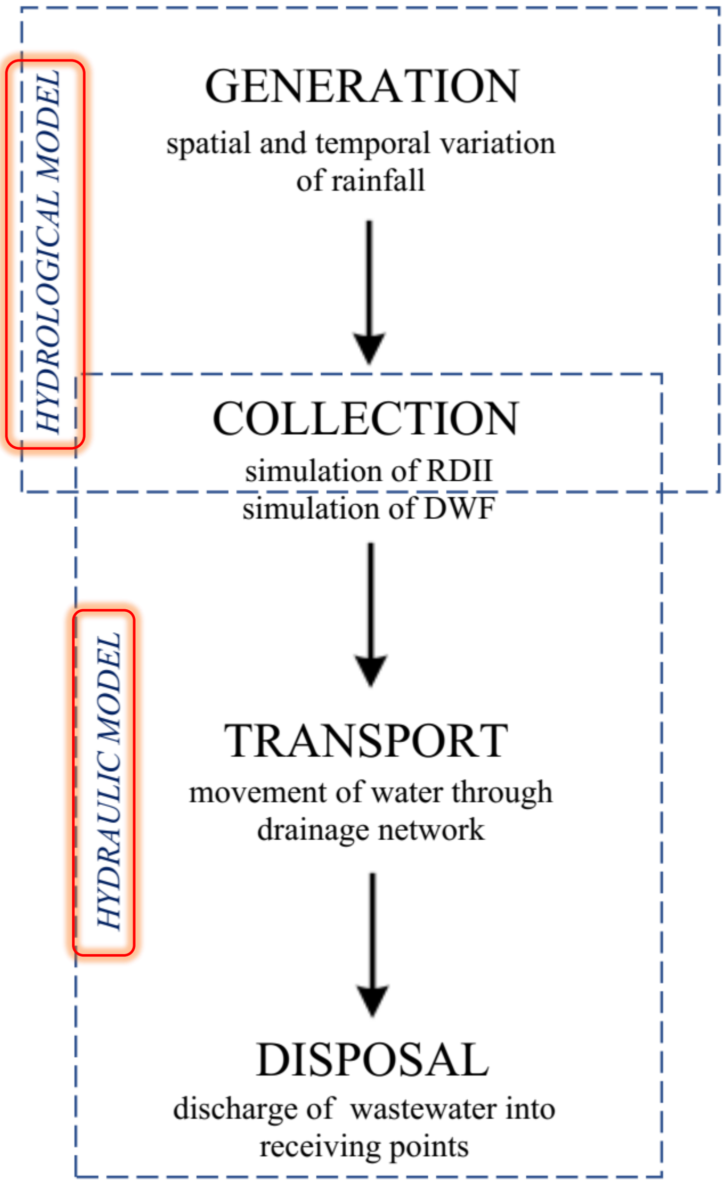


Wet-weather flow components in a sanitary sewer network. Modified from [5]

Methodology

Hydrological model

- Generation
- Collection → **RDII**



Conceptual components of a catchment modelling system. Modified from [4]

Hydraulic model

- Collection → **DWF**
- Transport
- Discharge to a disposal point

Division of the model set up

- Offline model set up
- Objectives 1, 2, and 3
- Choice of hydrological model
- Input data analysis
- Coupling with hydraulic model
- Parameter sensitivity and range
- Calibration and validation

- Online model set up
- Objective 4
- Routine for data acquisition
- Continuous simulation
- Routine for automatic calibration

Sewer model

- Methods to model the RDII
  Bennett et al. [5]

- Constant unit rate
- Percentage of stream flow
- Percentage of rainfall volume (R-value)
- Probabilistic methods

- Methods to model the RDII for a continuous simulation
  Bennett et al. [5]

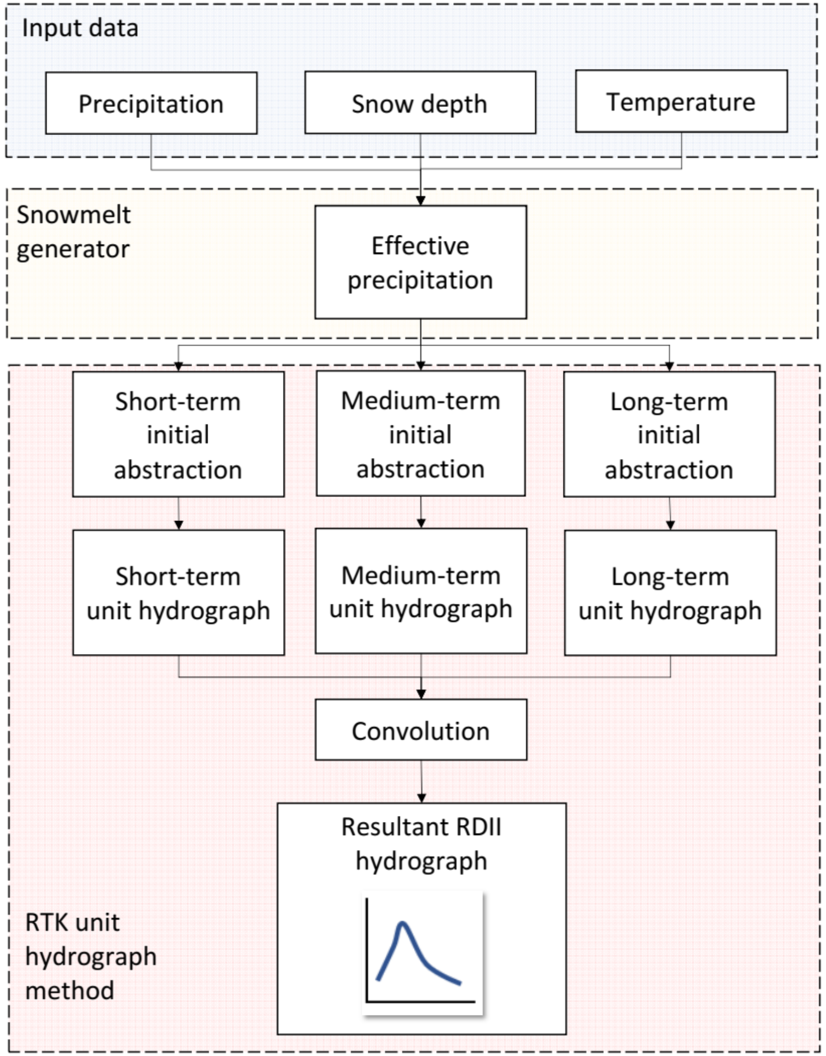
- Synthetic unit hydrograph
- Rainfall / flow regression (2 years of data)

- Methods chosen to model RDII in this study

- RTK unit hydrograph
- Physics-based model

SWMM

RTK unit hydrograph method



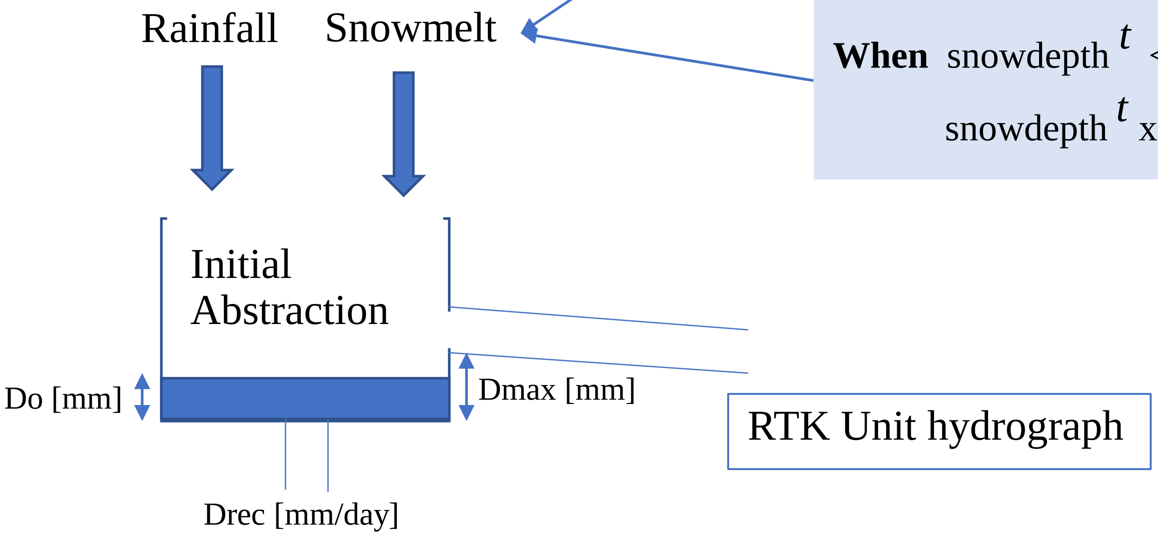
While precipitation = True

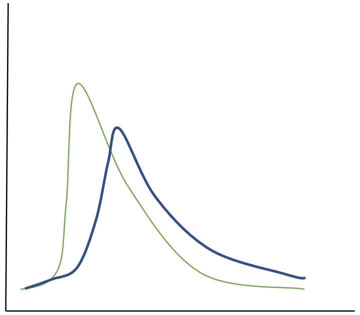
If (Temperature > 0,5°C):
Add rainfall to effective prec.

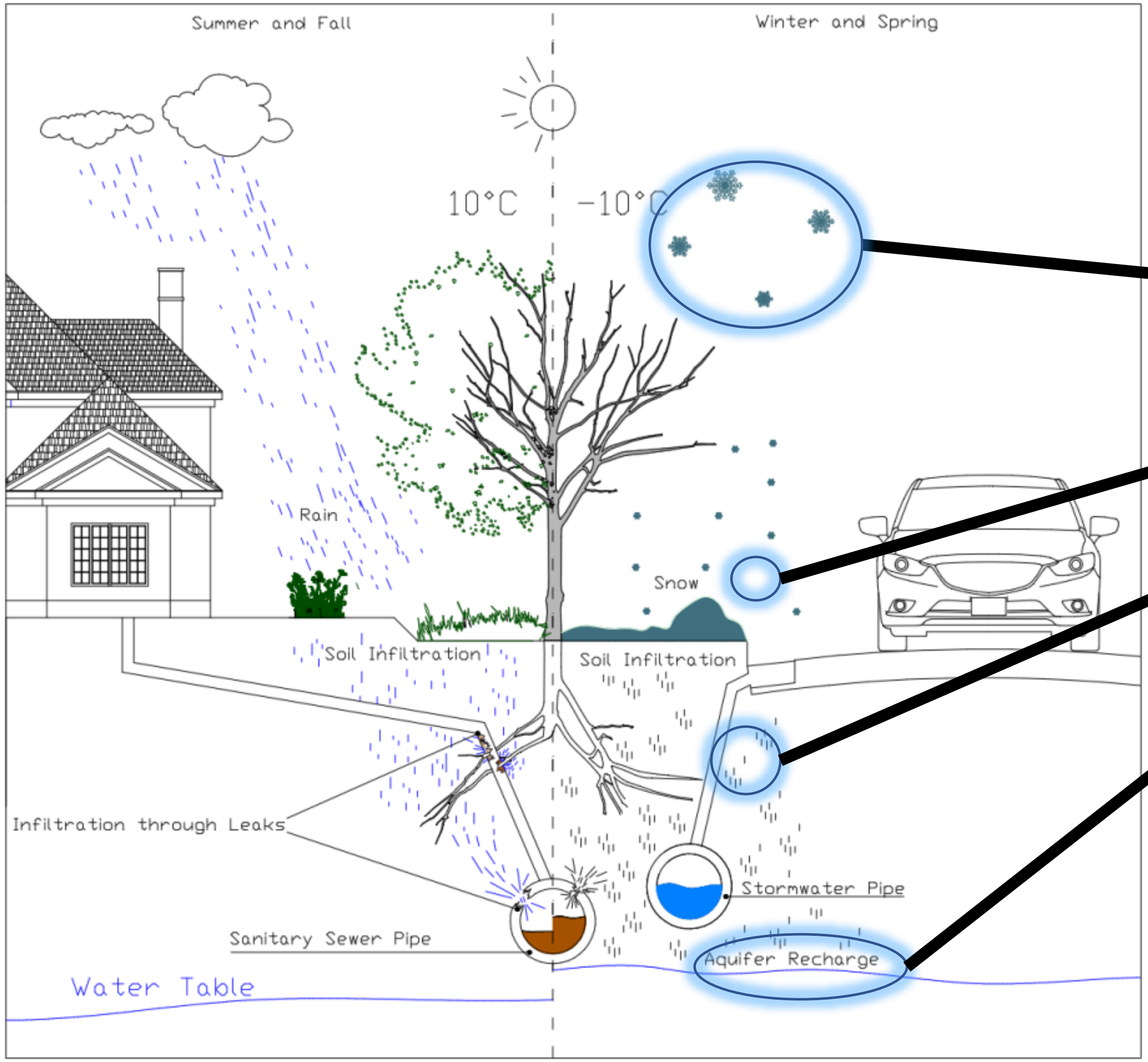
Else:
nothing *#snow accumulation*

When $\text{snowdepth}^{t} < \text{snowdepth}^{(t-1)}$:

$\text{snowdepth}^{t} \times 0{,}1$ *#1cm -> 10mm*



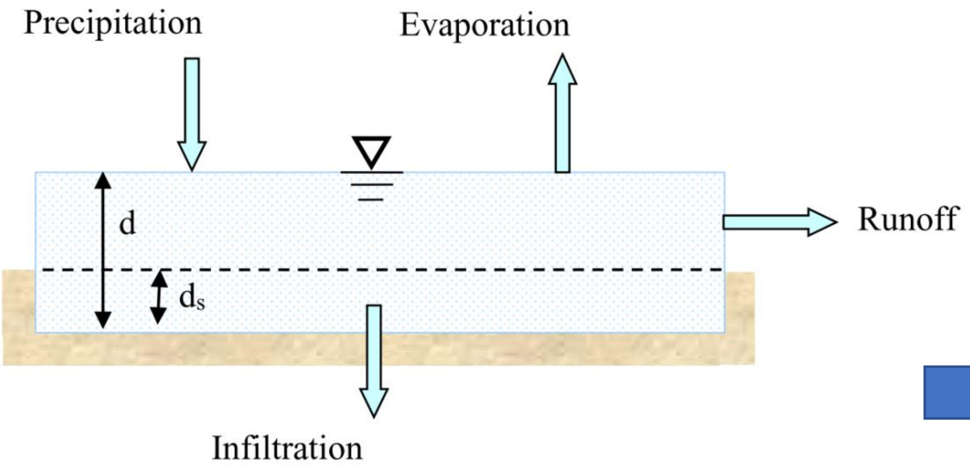


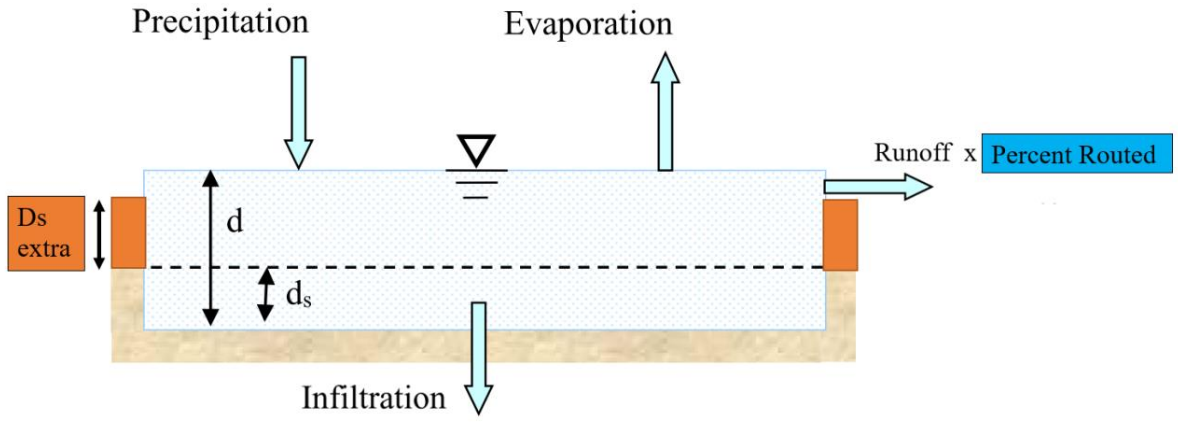


Physics-based model

- Snowpack and snowmelt
- Surface runoff
- Infiltration (modified Horton)
- Aquifer and groundwater flow

Physics-based model – conceptual adaptation for RDII Runoff



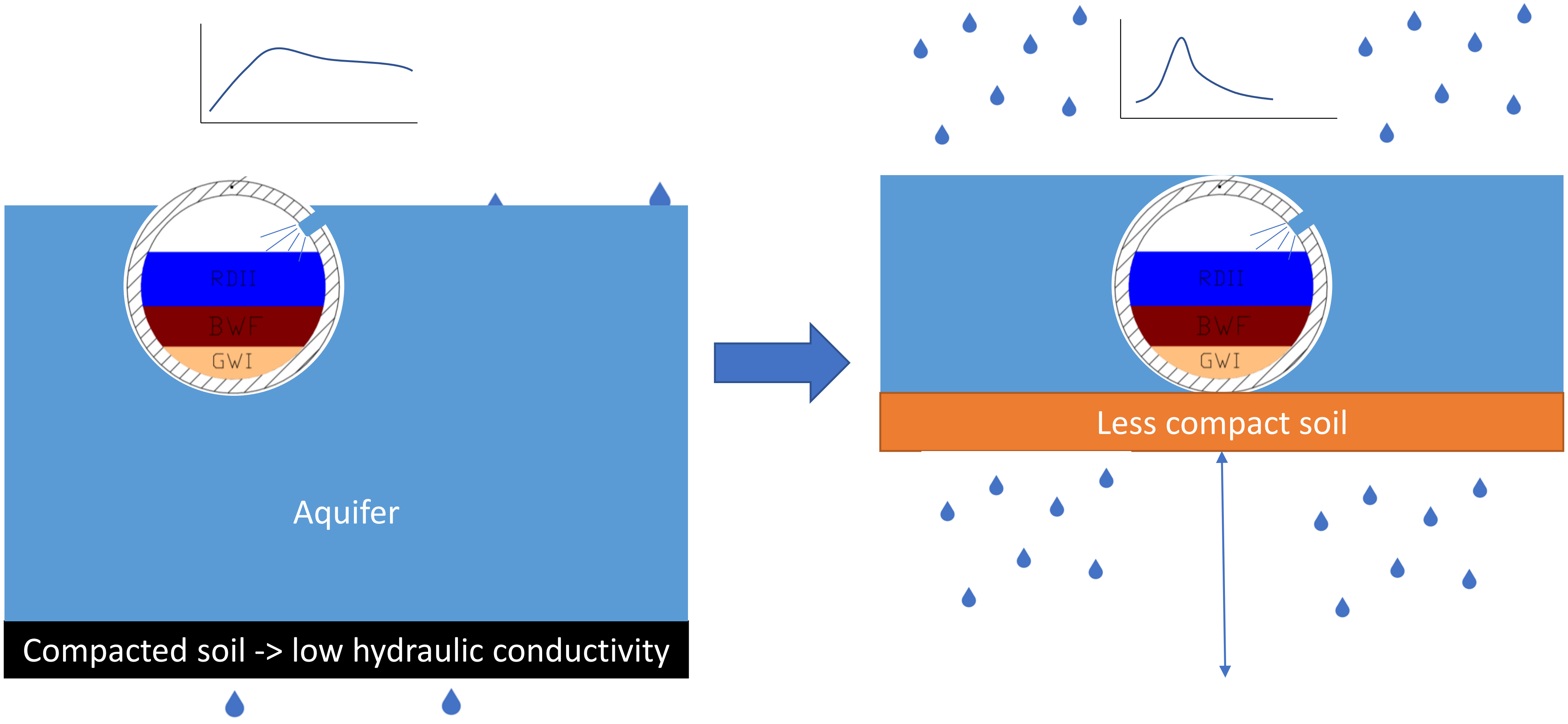


$$q = \frac{1.49 \cdot W \cdot S^{1/2}}{A \cdot n} \cdot (d - d_s)^{5/3} \cdot 0{,}05$$

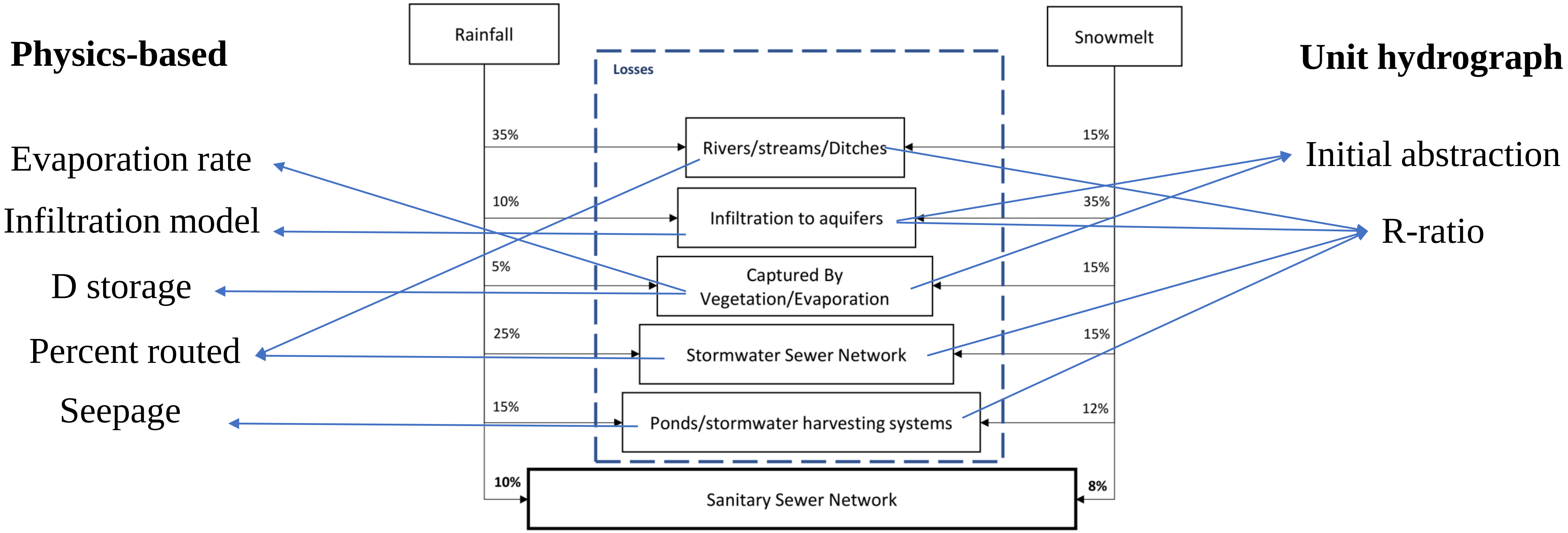
The other 95% is routed to the pervious area

Gauckler–Manning–Strickler formula

Physics-based model – conceptual adaptation for RDII
Aquifer and groundwater flow



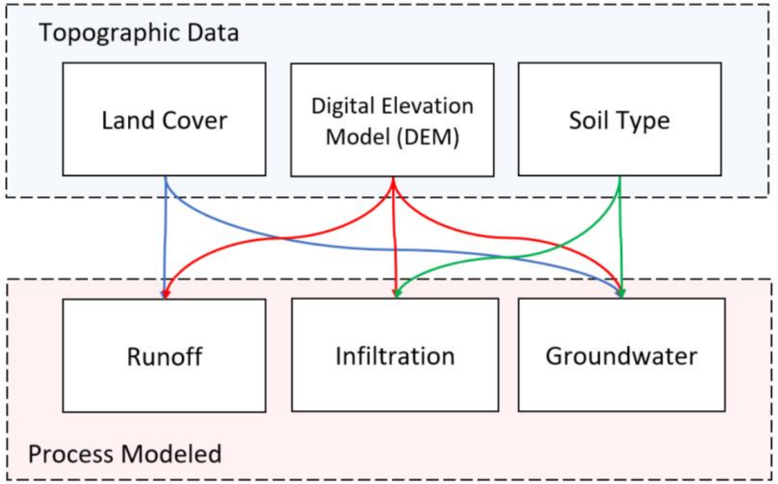
Losses



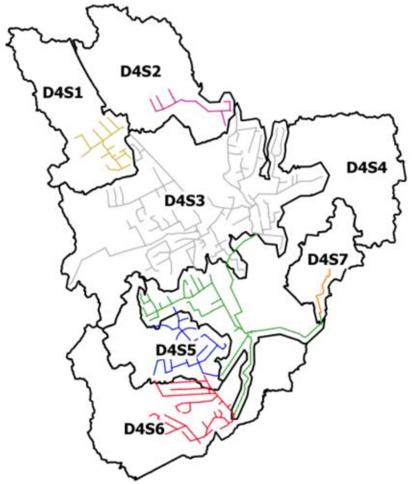
Losses relative to a sanitary sewer network

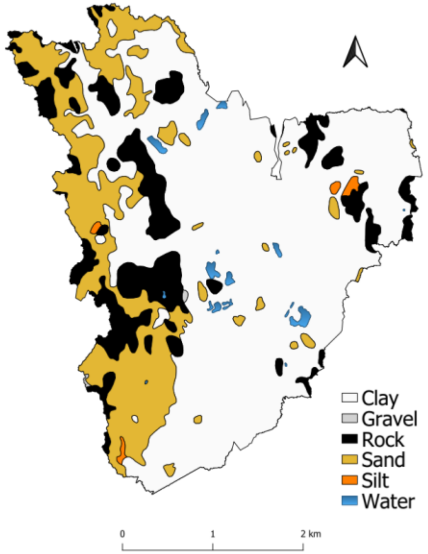
Topographic data and parameter estimation

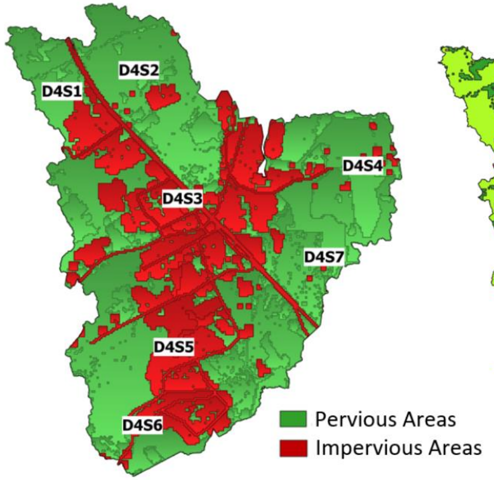
- 6500 residents and 1550 DWF
- 3% average slope
- Delineated area of 1355 ha

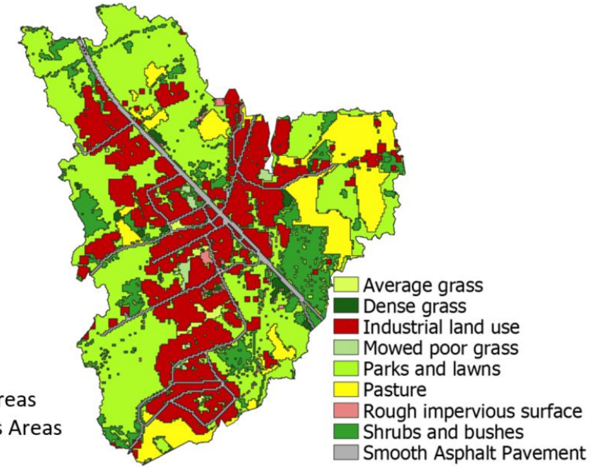


- Soil type: Clay and sand (86%)
- Land use: ~ 30% impervious
- ~ 47 km of network



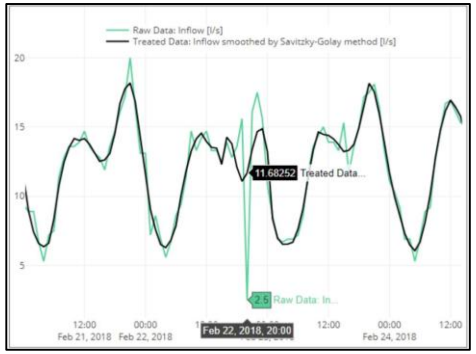


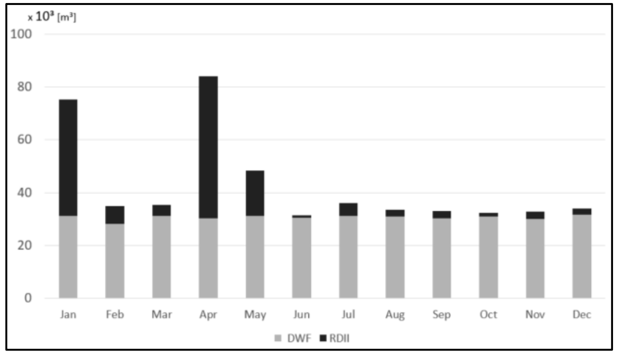


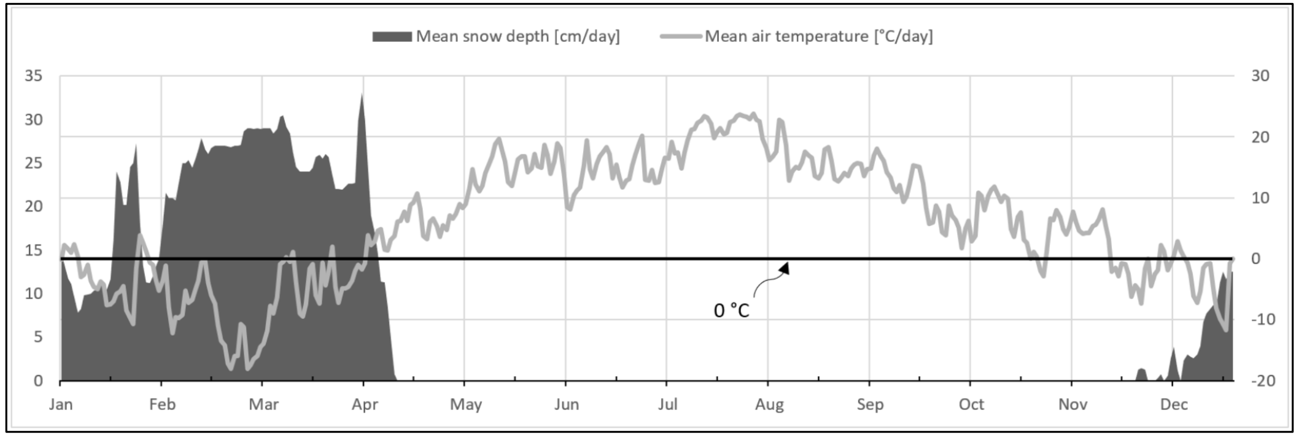


Meteorological and flow data

- Python script to treat the sanitary sewer flow data
- EPA SSOAP tool to estimate RDII
  30% of RDII and 50% of RDII + GWI
  88% of annual RDII between January and May of 2018
- Historical meteorological data used:
  Precipitation, temperature, snow depth, evaporation, wind speed
- Python script to fetch and parse forecast data from FMI's and TMFG's APIs







Calibration

- Two seasons:
  Dormant and growth. One set of parameters calibrated for each season.

Physics-based

- **Eight sensitive parameters found**

Runoff:
Percent routed
Width

Aquifer:
Seepage rate
Hydraulic conductivity
Hydr. Conduct. Slope
A1 GWF coefficient

Snowpack:
Min. melt coefficient
Max. melt coefficient

From ~51 to 8

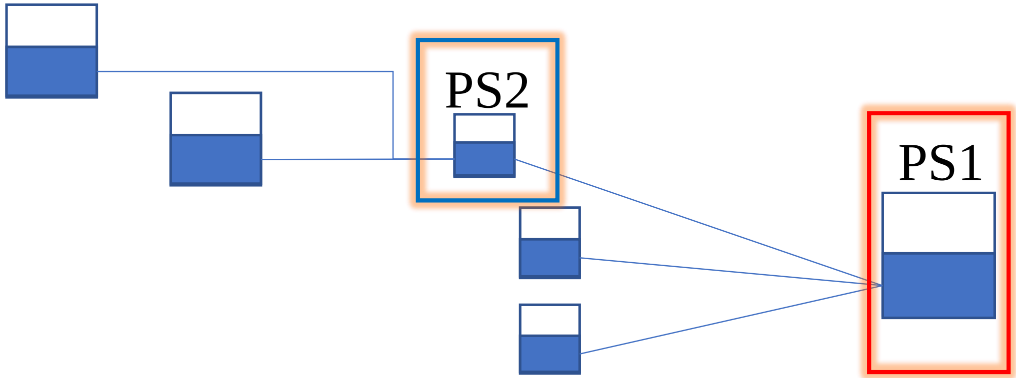
Unit hydrograph

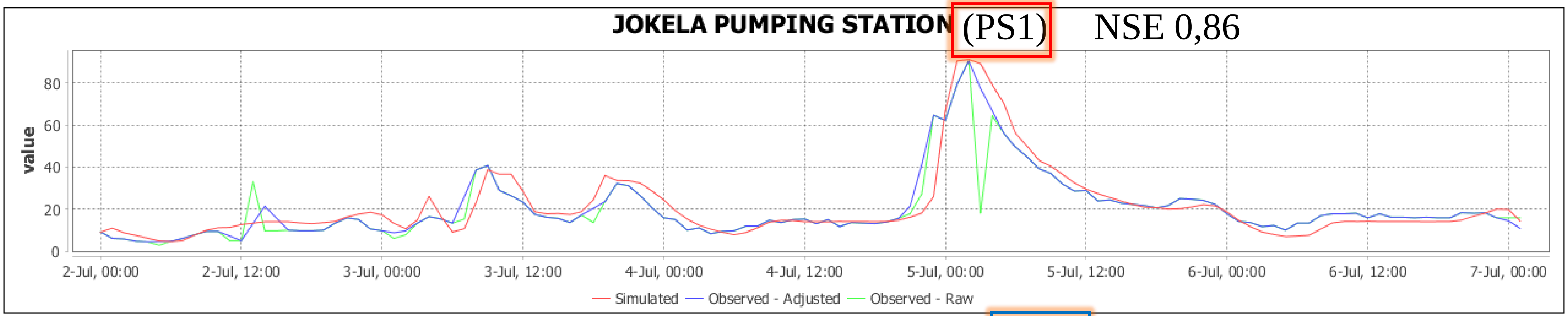
- Calibration using an optimization algorithm.

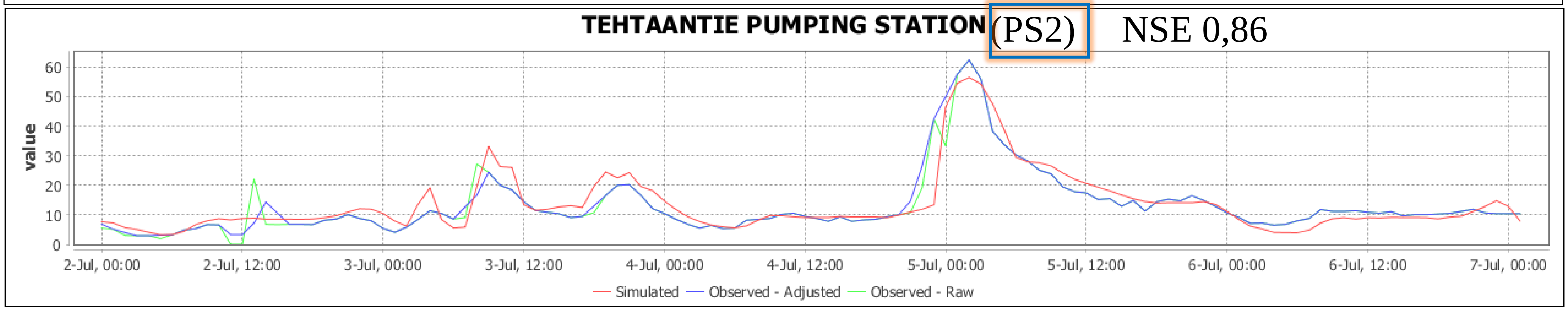
- **Dormant and growth season**:
  - Event-based calibration.
  - Calibrated parameters averaged for each season

Calibration

Unit hydrograph
600 iterations





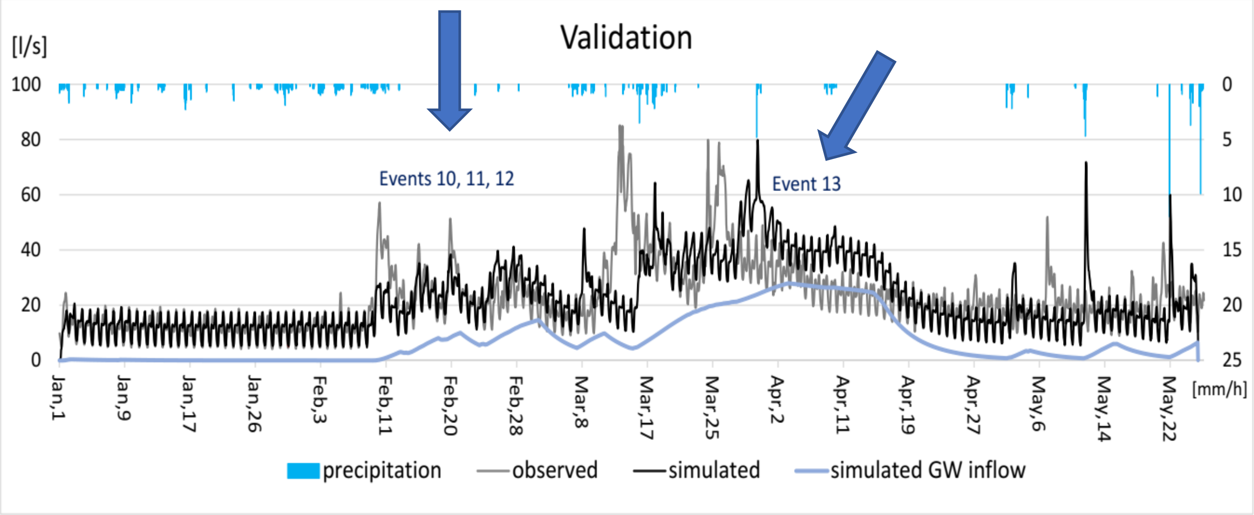


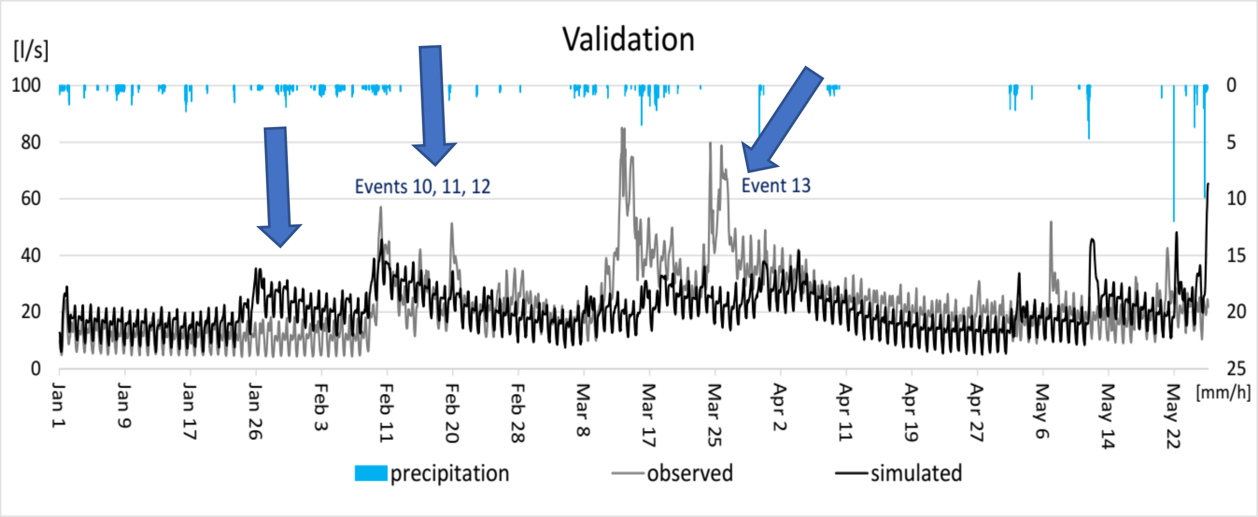
Dormant season – calibration and validation

Physics-based **Unit hydrograph**

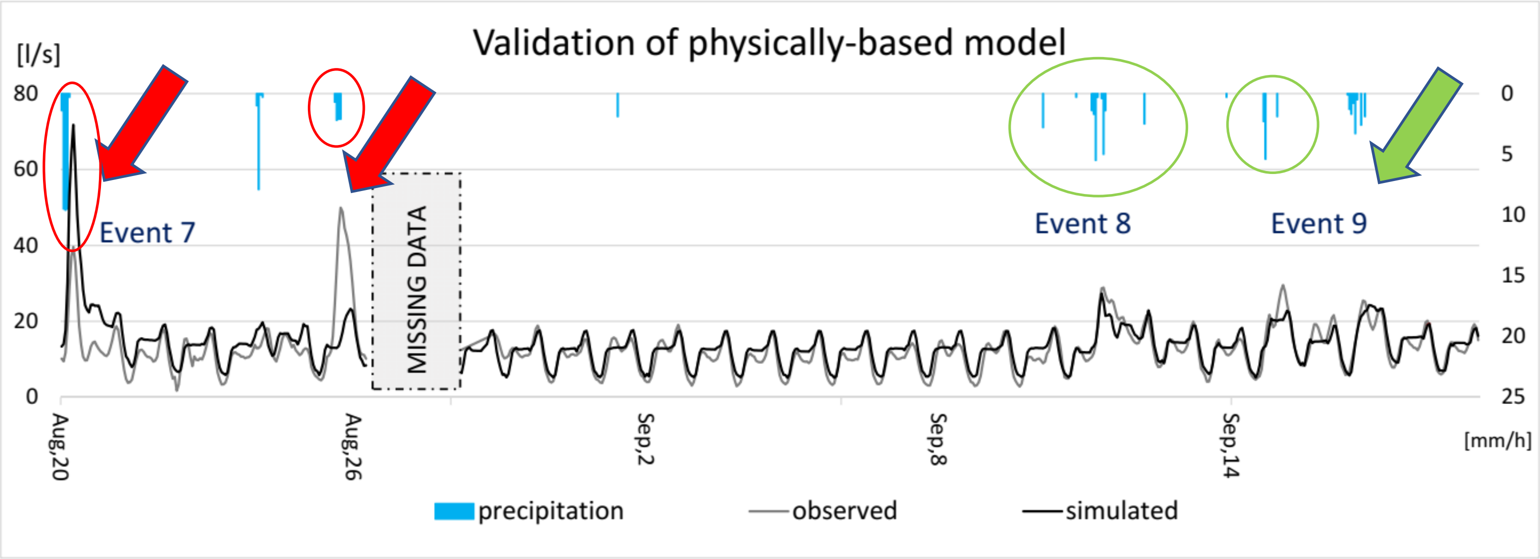
Table 5.8.: Season-based validation results of proposed hydrological models

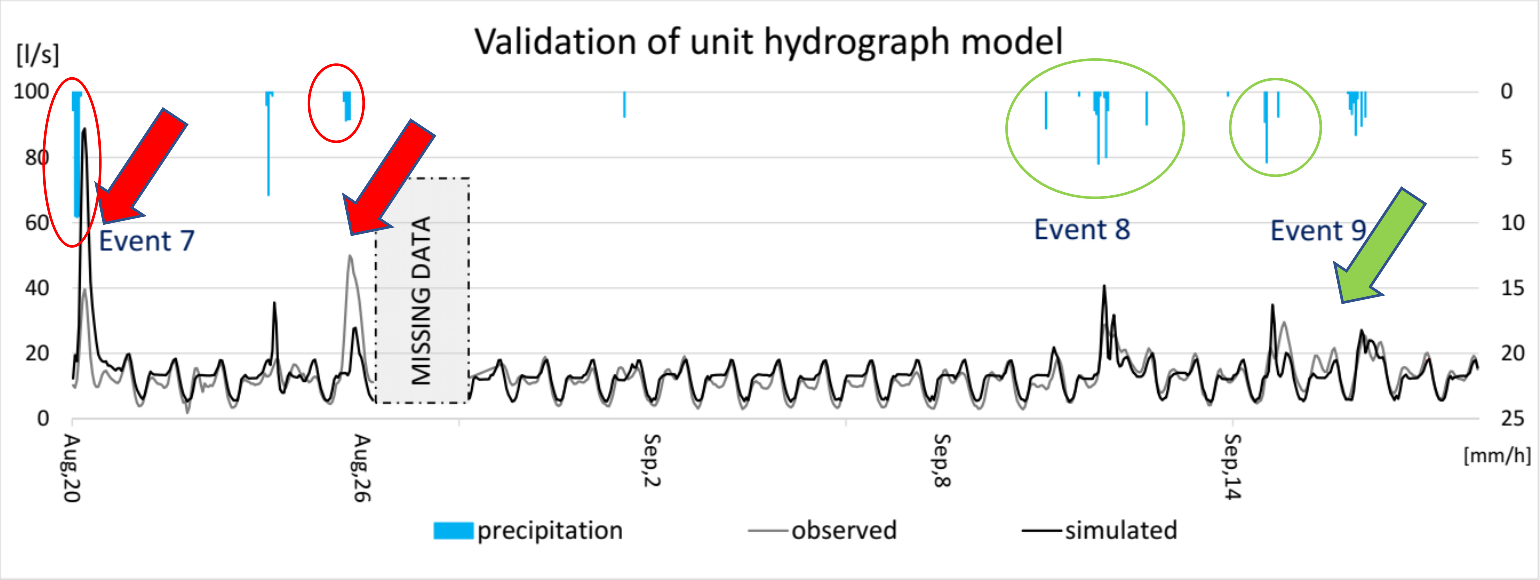
model	season	event	NSE	volume error [%]
physics-based	dormant	10, 11, 12; 13	0,20	+1,53
	growth	7, 8, 9	0,40	+8,94
unit hydrograph	dormant	10, 11, 12, 13	0,12	-8,40
	growth	7, 8, 9	0,18	+6,51





Growth season – validation





	event	NSE	Volume Error [/%]	Peak Error[/%]	Peak shifted [h]
Physics-based	7	-1,79	+45,3	+46,0	0
	8	0,64	+0,688	-5,93	0
	9	0,55	-4,02	-40,92 ; -8,436	+3 ; +3
Unit hydrograph	7	-4,24	+48,2	+56,2	0
	8	0,44	-4,74	+28,5	-1
	9	0,50	-10,6	+15,2 ; +6,04	-7 ; -2

- Event 7 overestimated
- Peak after event 7 underestimated
- Events 8 and 9 better simulated

Hypothesis with validation results

- Complete simulated snowmelt occurred even before than the observed

- Depth of snow measured different than the real snow cover within the catchment?
  Was the temperature the same?

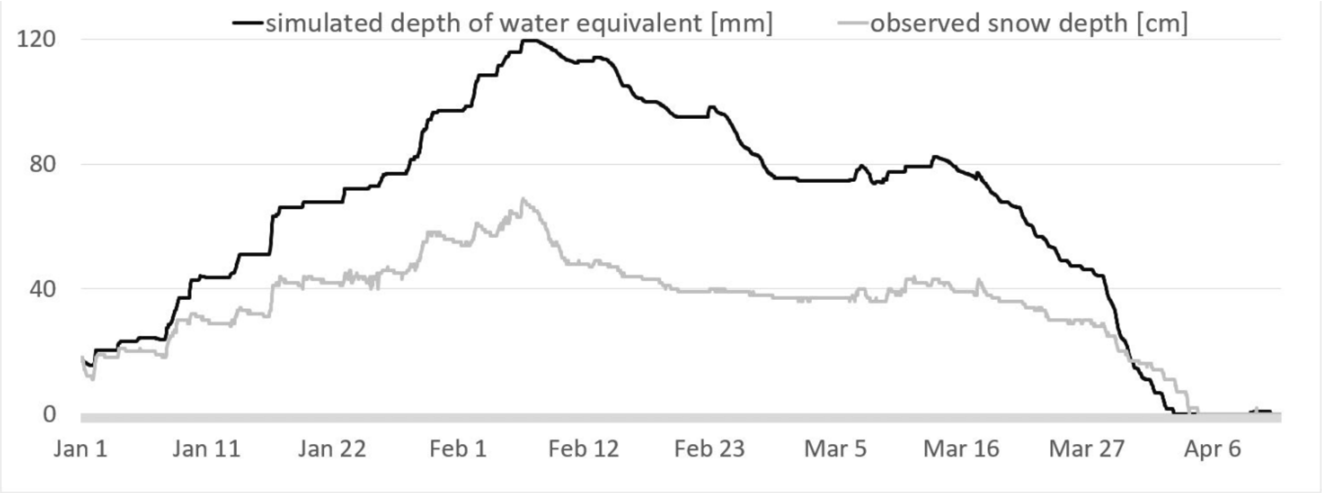
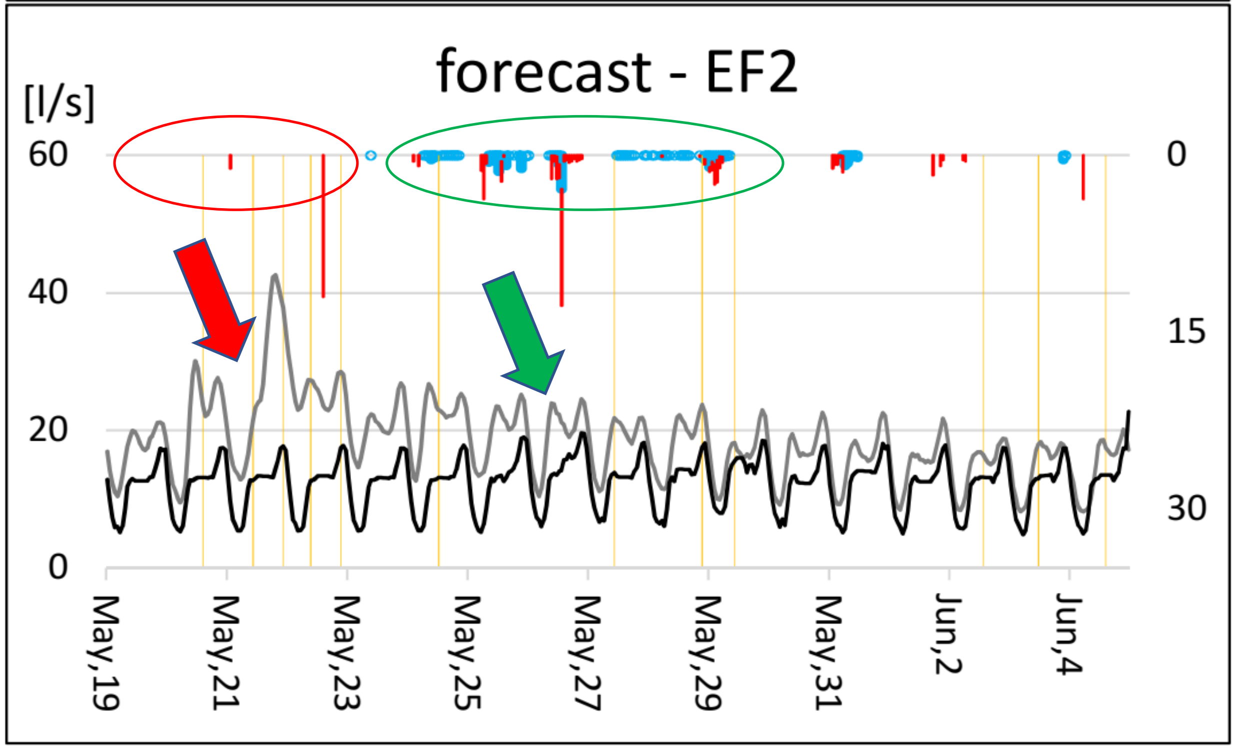


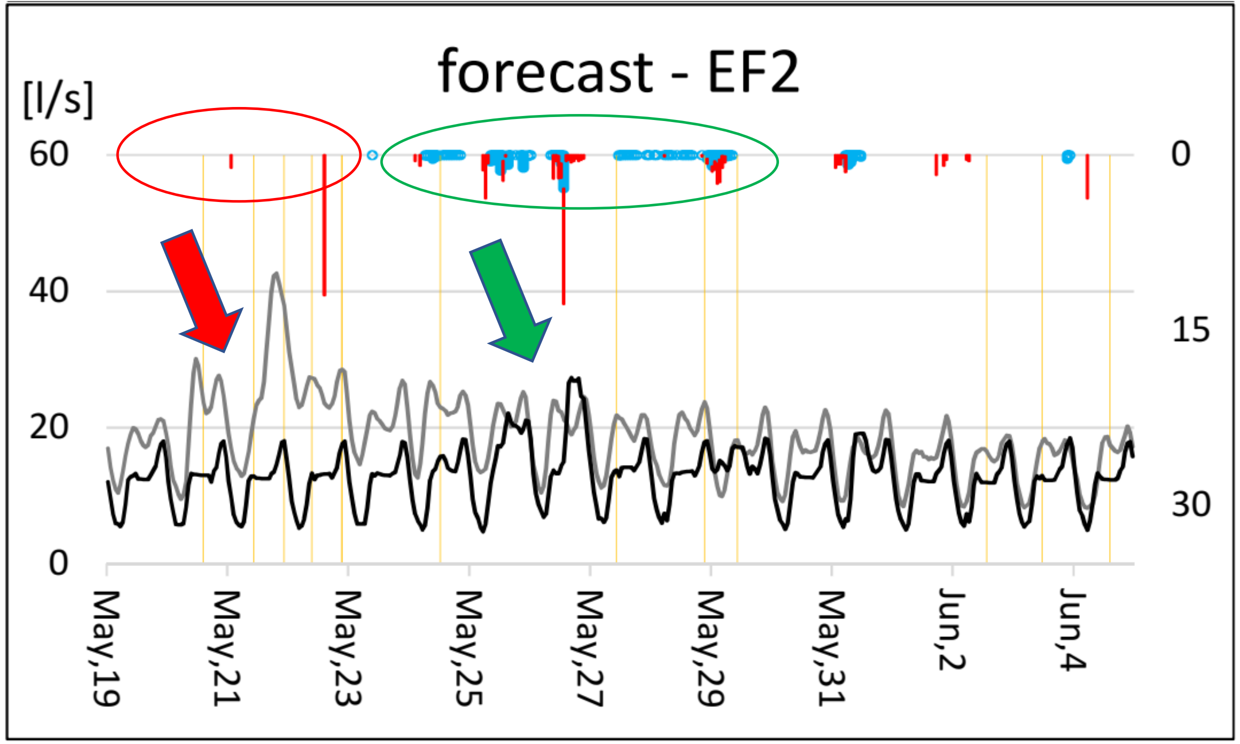
Figure 5.5.: Observed snow depth versus simulated depth of water equivalent of 2019

Preliminary results with forecasted precipitation

Physics-based

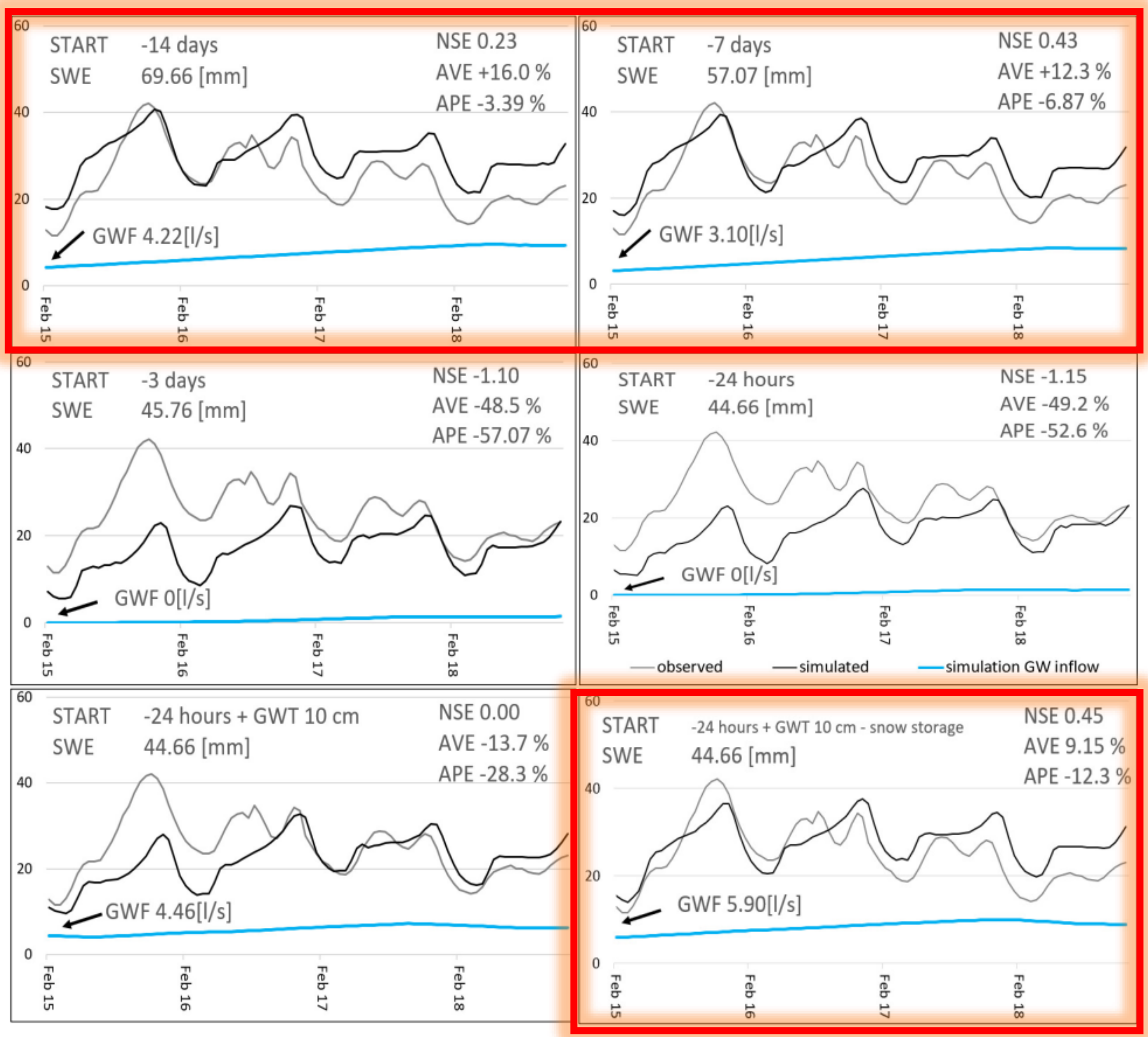


Unit hydrograph



forecast rain gauge forecast update

observed simulated - PB



- Six simulations with different initial conditions
- Snow storage and groundwater table
- **For a forecasting system:** Use of a hot-start file or a routine updating the initial conditions

Conclusions

- Both hydrological models can be used to simulate RDII in cold climates. The physics-based model performed better than the RTK model proposed in this study during the dormant season.
- Methodology for estimation of parameters and their range seems to facilitate the model set up, calibration, and application for a near to real-time forecasting system.
- The proposed snowmelt routine for the unit hydrograph underestimates the snowmelt volume. Variable ratio of snow depth and depth of water equivalent should be introduced.
- The results are highly sensible to the meteorological inputs. Spatial distribution of the measurements affects the simulation results.
- Reducing the number of parameters to be calibrated in the physics-based model can be considered an important step towards the utilization of an optimization algorithm.
- Hot-start file or the update of initial conditions are also key aspects when implementing a forecasting system.

References

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Thank you

Questions?