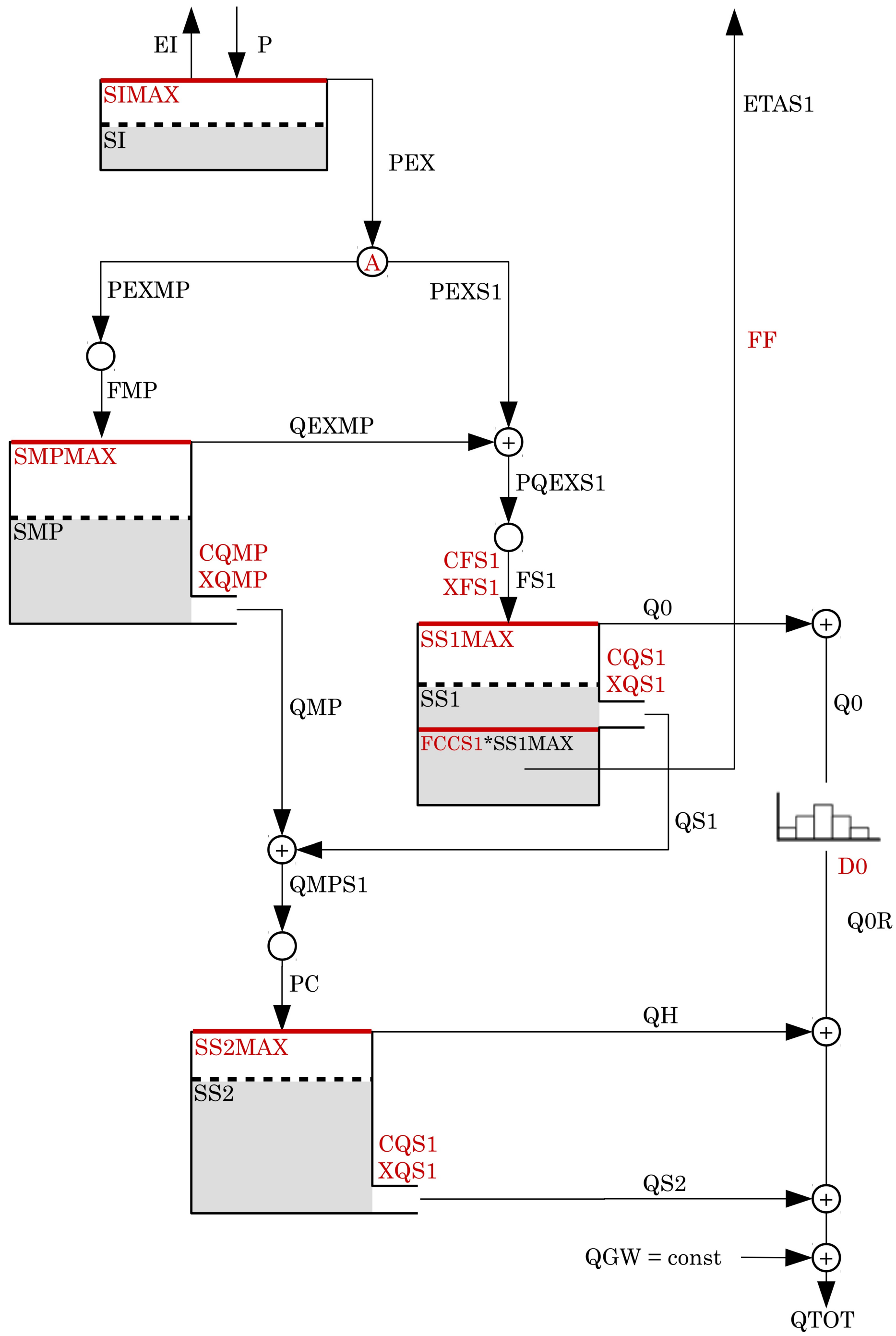

Fig. 1: Structure of IHM19 Model

0.1 IHM19 MODEL (MODEL ID: 47)

The IHM19 model was created in a master's thesis at the Institute for Hydrology and Meteorology at the Technical University of Dresden (Germany) for a small catchment in the Bavarian Forest National Park. The Forellenbach basin was originally covered by a spruce forest, where the tree population dramatically declined due to a bark beetle infestation in the 1990ies and 2000s. The model was developed to test the previously identified main features of the catchment that influence the unique flood reaction with a lumped approach. One very important factor is the increase in macropores, due to root channels, which formed after 60% of the forest cover perished.
This conceptual model is the first addition to the 46 original models of the finished MARRMoT Toolbox.

- Interception
- Separate macropore storage
- Combined soil and vegetation evapotranspiration
- Interflow when soil moisture exceeds storage capacity
- Percolation to a lower soil storage with baseflow

0.2 FILE NAMES

Model: m_47_ihm19_16p_4s
Parameter ranges: m_47_ihm19_16p_4s_parameter_ranges

0.3 MODEL EQUATIONS

$$\frac{dSI}{dt} = P - EI - PEX \tag{1}$$

$$EI = evap\_1 = \begin{cases} E_P & \text{, if } SI > 0 \\ 0 & \text{, otherwise} \end{cases} \tag{2}$$

$$EI \leq SI$$

$$\mathrm{PEX} = \mathrm{interception\_1} = \begin{cases} \mathrm{P} & \text{, if SI} \geq \text{SIMAX} \\ 0 & \text{, otherwise} \end{cases} \tag{3}$$

$$\mathrm{PEXMP} \ = \ \mathrm{split\_2} \ = \ (1 - \mathrm{A}) \ \cdot \ \mathrm{PEX} \tag{4}$$

$$\mathrm{PEXS1} \ = \ \mathrm{split\_1} \ = \ \mathrm{A} \cdot \ \mathrm{PEX} \tag{5}$$

Where SI is the current interception storage (equation 1) which is refilled through Precipitation P an emptied by interception evaporation EI (equation 2)occuring at potential rate when possible.
When the maximum capacity of the interception storage SIMAX is exceeded throughfall PEX forms and drips to the soil surface.
Throughfall PEX is divided into macropore excess precipitation PEXMP which forms the possible inflow into macropore storage SMP and excess precipitation for the soil storage PEXSI, by multiplying a splitting factor A (equation 4 & 5).

$$\frac{\mathrm{dSMP}}{\mathrm{dt}} \ = \mathrm{FMP} \ - \ \mathrm{QMP} \tag{6}$$

$$\mathrm{FMP} = \mathrm{infiltration\_8} = \begin{cases} \mathrm{PEXMP} & \text{, if SMP} < \text{SMPMAX} \\ 0 & \text{, otherwise} \end{cases} \tag{7}$$

$$\mathrm{QMP} = \ \mathrm{interflow\_3} \ = \ \mathrm{CQMP} \ \cdot \mathrm{SMP}^{\mathrm{XQMP}} \tag{8}$$

$$\mathrm{QEXMP} \ = \ \mathrm{subtraction\_2} \ = \ \mathrm{PEXMP} \ - \ \mathrm{FMP} \tag{9}$$

$$\mathrm{PQEXS1} \ = \ \mathrm{addition\_2} \ = \ \mathrm{PEXS1} \ + \ \mathrm{QEXMP} \tag{10}$$

Macropore storage SMP (equation 6) is refilled by macropore infiltration FMP (equation 7), that is equal to PEXMP until maximum macropore storage SMPMAX is reached. The runoff from the macropore storage QMP (equation 8) depends on current storage SMP, time-parameter CQMP an scaling-parameter XQMP (equation 8). When the macopore storage is filled SMPMAX macropore excess flow QEXMP forms on the soil surface. PEXS1 and QEXMP (equation 9) together form the possible flow to the first soil layer PQEXS1 (equation 10).

$$\frac{\mathrm{dSS1}}{\mathrm{dt}} = \mathrm{FS1} - \mathrm{ETAS1} - \mathrm{QS1} \tag{11}$$

$$\mathrm{FS1} = \mathrm{infiltration\_7} = \begin{cases} \mathrm{CFS1} \cdot \exp\left(-\mathrm{XFS1} \cdot \frac{\mathrm{SS1}}{\mathrm{SS1MAX}}\right) & \text{, if } \mathrm{SS1} < \mathrm{SS1MAX} \\ 0 & \text{, otherwise} \end{cases} \tag{12}$$

$$\mathrm{FS1} \leq \mathrm{PQEXS1}$$

$$\mathrm{ETAS1} = \mathrm{evap\_24} = \begin{cases} \mathrm{FF} \cdot \mathrm{E_P} + (1 - \mathrm{FF}) \cdot \frac{\mathrm{SS1}}{\mathrm{SS1MAX}} \cdot \mathrm{E_P} & \text{, if } \mathrm{SS1} > \mathrm{FCCS1} \cdot \mathrm{SS1MAX} \\ \mathrm{FF} \cdot \frac{\mathrm{SS1}}{\mathrm{FCCS1} \cdot \mathrm{SS1MAX}} \cdot \mathrm{E_P} + (1 - \mathrm{FF}) \cdot \frac{\mathrm{SS1}}{\mathrm{SS1MAX}} \cdot \mathrm{E_P} & \text{, otherwise} \end{cases} \tag{13}$$

$$\mathrm{ETAS1} \leq \mathrm{SS1}$$

$$\mathrm{QS1} = \mathrm{interflow\_12} = \begin{cases} \mathrm{CQS1} \cdot (\mathrm{SS1} - (\mathrm{FCCS1} \cdot \mathrm{SS1MAX}))^{\mathrm{XQS1}} & \text{, if } \mathrm{SS1} > \mathrm{FCCS1} \cdot \mathrm{SS1MAX} \\ 0 & \text{, otherwise} \end{cases} \tag{14}$$

$$\mathrm{Q0} = \mathrm{subtraction\_2} = \mathrm{PQEXS1} - \mathrm{FS1} \tag{15}$$

$$\mathrm{Q0R} = \mathrm{uh\_4\_full}(\mathrm{Q0}, \mathrm{D0}, \mathrm{delta\_t}) \tag{16}$$

$$\mathrm{QMPS1} = \mathrm{addition\_2} = \mathrm{QMP} + \mathrm{QS1} \tag{17}$$

The upper soil storage SS1 is filled by Soil Infiltration FS1 and drained by soil runoff QS1, as well as evapotranspiration ETAS1 (equation 11). The soil infiltration rate FS1 is calculated with an exponentially declining function with maximum infiltration rate CFS1 and a loss exponent XFS1, it is also dependent on the current soil storage and becomes zero as soon as SS1 reaches SS1MAX. The runoff QSI (equation 14) is calculated with a non-linear function, depending on a time-and scaling-Parameters CQS1 and XQS1. It only occurs when the current soil storage SS1 exceeds the field capacity of soil FCCS1·SS1MAX, where

FCCS1 is a value between 0 and 1. This ensures that the field capacity is always smaller than maximum storage SS1MAX.

When the current storage of SS1 is smaller than the field capacity it is emptied only by evapotranspiration ETAS1 (equation 13). Parameters for the actual evapotranspiration ETAS1 are the forest fraction FF (Transpiration), maximum soil storage SS1MAX (Soil Evaporation) and the field capacity FCCS1 $\cdot$ SS1MAX.

If the soil storage of the first layer is filled completely and potential inflow still occures through PQEXS1 surface runoff Q0 forms (equation 15).

The surface runoff is routed with the full triangular routing-function included in the framework, which is one of the frequently used routing-functions. It uses only one additional parameter D0 which is the time base of routing delay (equation 16).

The sum of the runoffs from macropore and fist soil storage QMPS1 is the potential inflow for the lower soil storage SS2.

$$\frac{\mathrm{dSS2}}{\mathrm{dt}} = \mathrm{PC} - \mathrm{QS2} \tag{18}$$

$$\mathrm{PC} = \mathrm{infiltration\_8} = \begin{cases} \mathrm{QMPS1} & \text{, if SS2} < \text{SS2MAX} \\ 0 & \text{, otherwise} \end{cases} \tag{19}$$

$$\mathrm{QS2} = \mathrm{interflow\_3} = \mathrm{CQS2} \cdot \mathrm{SS2}^{\mathrm{XQS2}} \tag{20}$$

$$\mathrm{QH} = \mathrm{subtraction\_2} = \mathrm{QMPS1} - \mathrm{PC} \tag{21}$$

$$\mathrm{QTOT} = \mathrm{addition\_3} = \mathrm{Q0} + \mathrm{QH} + \mathrm{QS2} \tag{22}$$

The second, lower soil layer SS2 is filled by percolation PC (equation 19), which is equal to the runoff from the upper soil storages QMPS1, as long as the second soil layer is not saturated. If SS2MAX is reached and there is still runoff from above interflow QH is created between the soil layers (equation 21).

The runoff from the second soil layer QS2 is the baseflow of the model (equation 20) and is calculated similarly to the Macropore-runoff with a non-linear function and two parameters for time and scaling CQS2 & XQS2.

The total runoff QTOT is calculated as an addition of the routed surface runoff Q0R, interflow QH and the baseflow QS2 (equation 22).

Tab. 1: Jacobian Matrix for dependencies of Storages

			Jacobian Matrix			
Storage	Description	Storage Number	S1	S2	S3	S4
SI	Interception Storage	S1	1	0	0	0
SMP	Macropore Storage	S2	1	1	0	0
SS1	Upper Soil Storage	S3	1	1	1	0
SS2	Lower Soil Storage	S4	0	1	1	1

Tab. 2: Flux Overview

Flux	Description
P	precipitation
EI	interception evaporation
PEX	excess precipitation
PEXMP	excess precipitation macropore storage
FMP	infiltration macropore storage
QMP	runoff macropore storage
QEXMP	excess runoff macropore storage
PEXS1	excess precipitation soil storage 1
PQEXS1	excess influx soil storage 1
FS1	infiltration soil storage 1
ETAS1	actual evapotranspiration soil storage 1
QS1	runoff soil storage 1
Q0	surface runoff
Q0R	routed surface runoff
QMPS1	runoff macropore storage and soil storage 1
PC	percolation
QS2	runoff soil storage 2
QH	interflow
QTOT	total runoff

Tab. 3: Parameter overview

Nr.	Parameter Description	Unit	Min	Max
1	SIMAX, maximum interception storage	[mm]	2	5
2	A, splitting coeffcient for excess precipitation	[-]	0,9	1
3	FF, forest fraction	[-]	0,4	0,95
4	SMPMAX, maximum storage macropores	[mm]	0,05	5
5	CQMP, runoff time parameter (fast/slow runnoff) first soil layer	[1/d]	0	1
6	XQMP, runoff scale parameter first soil layer	[-]	1	5
7	SS1MAX, maximum soil moisture storage first soil layer	[mm]	400	600
8	FCCS1, field capacity coefficient fist soil layer	[-]	0,3	0,7
9	CFS1, maximum infiltration rate first soil layer	[mm/d]	0	1000
10	XFS1, infiltration loss exponent first soil layer	[-]	0	15
11	CQS1, runoff time parameter for (fast/slow runnoff) first soil layer	[1/d]	0	1
12	XQS1, runoff scale parameter first soil layer	[-]	1	5
13	SS2MAX, maximum soil moisture storage second soil layer	[mm]	300	500
14	CQS2, runoff time parameter for (fast/slow runnoff) second soil layer	[1/d]	0	1
15	XQS2, runoff scale parameter second soil layer	[-]	1	5
16	D0, Flow delay before surface runoff	[d]	0,01	5