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The importance of hydrological uncertainty assessment methods in climate change impact studies

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Index of Contents

Table SM-1. Process Matrix of the applied hydrological model[a]

Process	Symbol	Rate	Affected storage[b]					
			h_{snow}	h_c	h_s	h_{gw}	h_p	h_q
snowfall	P_{snow}	$\left\{\begin{array}{ll} P & \text{if } T < T_{crit} \\ 0 & \text{otherwise} \end{array}\right\}$	+					
snowmelt	P_{melt}	$\left\{\begin{array}{ll} k_{melt}\,(T - T_{melt}) & \text{if } T > T_{melt} \\ 0 & \text{otherwise} \end{array}\right\}$	−	+			+	
rainfall	P_{rain}	$\left\{\begin{array}{ll} P & \text{if } T \geq T_{crit} \\ 0 & \text{otherwise} \end{array}\right\}$		+			+	
throughfall	$P_{through}$	$(1 - k_{capt})\,(P_{melt} + P_{rain})$		−	+			
canopy evapotr.	E_c	$k_{ce} E_{pot} \left\{\begin{array}{ll} \frac{h_c}{h_{c,sat}} & \text{if } h_c \leq h_{c,sat} \\ 1 & \text{otherwise} \end{array}\right\}$		−				
dripping	P_{drip}	$k_{drip} \left\{\begin{array}{ll} h_c - h_{c,sat} & \text{if } h_c \geq h_{c,sat} \\ 0 & \text{otherwise} \end{array}\right\}$		−	+			
ground evapotr.	E	$E_{pot}\, f_{et}$			−			
sat. excess runoff	Q_r	$f_{sat}\,\left(P_{drip} + P_{through}\right)$			−			+
groundwater rech.	Q_{rge}	$k_{rge}\, f_{sat}\, q_{seep}^{max}$			−	+		
subsurface flow	Q_{ssf}	$(1 - k_{rge})\, f_{sat}\, q_{seep}^{max}$			−			+
baseflow	Q_{bf}	$k_{bf}\, h_{gw}$				−		+
paved evapor.	E_p	$k_{p,e}\, E_{pot}\, \frac{h_p}{h_p + h_{p,e}}$					−	
paved runoff	Q_p	$\left\{\begin{array}{ll} k_{p,r}\,(h_p - h_{p,sat}) & \text{if } h_p \geq h_{p,sat} \\ 0 & \text{otherwise} \end{array}\right\}$					−	+
stream discharge	Q_q	$k_q h_q$						−

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[a] All storages are in [mm] while processes are in [mm d^{-1}]. f_{sat} and f_{et} are defined in equations (1) and (2), respectively.

[b] Storages: h_{snow}: snow; h_c: canopy; h_s: soil; h_{gw}: groundwater; h_p: paved area; h_q: stream.

Table SM-2. Prior distributions of snow and canopy parameters

Parameter [Unit]	**Description** Values[a]	Reference	Applied distribution[b]
T_{crit}	**Critical temperature for snowfall**		N(1, 0.5)
[$^\circ$C]	+1.0 – +1.6	(Kokkonen et al., 2006)	
T_{melt}	**Threshold temperature for snowmelt**		N(0, 1)
[$^\circ$C]	-1.8 – +0.6	(Kokkonen et al., 2006)	
	0 (without calibration)	(Martinec and Rango, 1981)	
k_{melt}	**Temperature-specific snowmelt rate constant**		LN(3, 1.2)
[$\frac{\text{mm}}{^\circ\text{C d}}$]	1.5 – 4.0 (Sweden)	(Bergström, 1990)	
	1.2 – 6.0 (Finnland)	(Kokkonen et al., 2006)	
k_{capt}	**Precipitation capturing efficiency of fully developed canopy**		B(0.7, 0.15)
[–]	0.72 – 0.94 (Douglas fir)	(Vrugt et al., 2003)	
	0.68 – 0.74 (Scots pine)	(Gash, 1979)	
	0.44 – 0.71 (dense Spruce forest)	(Alavil et al., 2001)	
$k_{e,c}$	**Evaporation multiplier of canopy**		LN(1, 0.1) grass
[–]	0.69 – 1.26 (Douglas fir)	(Vrugt et al., 2003)	LN(0.8, 0.1) forest
k_{drip}	**Dripping rate from canopy storage**		δ(400)
[d^{-1}]	120 – 880 (Douglas fir)	(Vrugt et al., 2003)	
$h_{c,sat}$	**Storage in fully wetted canopy**		LN(1.2, 0.2) forest
[mm]	1.01 – 1.13 (black pine)	(Rutter et al., 1971)	LN(1.0, 0.2) grass
	0.8±0.08 (Scots pine)	(Gash, 1979)	
	2.7±1.3 (European crops)	(Breuer et al., 2003)	
	1.4±0.9 (European grasses)	(Breuer et al., 2003)	
	1.5±1.2 (European coniferous trees)	(Breuer et al., 2003)	
	1.0±0.9 (European deciduous trees)	(Breuer et al., 2003)	
	1.8 – 2.6 (Douglas fir)	(Vrugt et al., 2003)	
	2.0 (dense Spruce forest)	(Alavil et al., 2001)	
	1.7 – 2.3 (forest floor debris)	(Putuhena and Cordery, 1996)	
$k_{LAI_{min}}$	**Relative winter leaf area index**		
[–]	5 – 15% (grassland)	estimation	B(0.1, 0.05) grass
	10 – 30% (forest)	estimation	B(0.2, 0.1) forest

[a] Values are represented by range (min – max) or mean±standard deviation.

[b] Distribution types: N(μ, σ): normal, LN(μ, σ): lognormal, B(μ, σ): beta, $\delta(\mu)$: Dirac-delta. μ and σ are the mean and the standard deviation of the distributions, respectively.

Table SM-3. Prior distributions of paved area parameters

Parameter [Unit]	**Description** Values[a]	Reference	Applied distribution[b]
$h_{p,sat}$	**Paved area storage**		LN (1, 0.3)
[mm]	0.1 – 1.1	(Falk and Niemczynowicz, 1979)	
	0.1 – 1.5	(Kidd, 1978)	
	1.5	(Heaney et al., 1976)	
	0.4 – 0.7	(Arnell, 1982)	
$k_{p,r}$	**Paved area runoff rate**		LN (20, 1)
[d^{-1}]	18 – 22	estimation	

[a] Values are represented by range (min – max).

[b] Distribution types: LN(μ, σ): lognormal. μ and σ are the mean and the standard deviation of the distribution, respectively.

Table SM-4. Prior distributions of catchment and stream parameters

Parameter [Unit]	**Description** Values[a]	Reference	Applied distribution[b]
h_{FS}	**Catchment-scale equivalent of full saturation ($f_{\mathsf{sat}} = 98\%$)**		LN(430, 20) for loamy soils
[mm]	387 – 440 for clay-loam/loam/sandy loam	(Schaap et al., 2001)[c]	LN(382, 3) for sandy soils
	390 – 430 for clay-loam/loam/sandy loam	(Carsel and Parrish, 1988)[c]	
	375 – 390 for sand/loamy sand	(Schaap et al., 2001)[c]	
	440 – 490 for silt/silt-loam/silt-clay-loam	(Schaap et al., 2001)[c]	
h_{FC}	**Catchment-scale equivalent of field capacity ($f_{\mathsf{sat}} = 2\%$)**		LN(220, 25) for loamy soils
[mm]	168 – 255 for clay-loam/loam/sandy loam	(Schaap et al., 2001)[c]	LN(75, 9) for sandy soils
	85 – 270 for clay-loam/loam/sandy loam	(Carsel and Parrish, 1988)[c]	
	55 – 105 for sand/loamy sand	(Schaap et al., 2001)[c]	
	280 – 305 for silt/silt-loam/silt-clay-loam	(Schaap et al., 2001)[c]	
h_{WP}	**Catchment-scale equivalent of wilting point (E is 5% of E_{pot})**		LN(90, 10) for loamy soils
[mm]	60 – 150 for clay-loam/loam/sandy loam	(Schaap et al., 2001)[c]	LN(52.5, 1) for sandy soils
	65 – 150 for clay-loam/loam/sandy loam	(Carsel and Parrish, 1988)[c]	
	52 – 53 for sand/loamy sand	(Schaap et al., 2001)[c]	
	70 – 120 for silt/silt-loam/silt-clay-loam	(Schaap et al., 2001)[c]	
k_{rge}	**Proportion of groundwater recharge from seepage**		B(0.7, 0.1)
[–]	40 – 90%	estimation	
q_{seep}^{max}	**Maximal seepage rate**		LN(100, 50)
$[\frac{\mathsf{mm}}{\mathsf{d}}]$	50 – 200	estimation	
k_{bf}	**Baseflow constant**		LN(0.0005, 0.0005)
[d^{-1}]	10^{-5} – 10^{-3}	estimation[d]	
k_q	**Stream constant**		LN(10, 5)
[d^{-1}]	3 – 30	estimation	

[a] Values are represented by range (min – max).

[b] Distribution types: LN(μ, σ): lognormal, B(μ, σ): beta. μ and σ are the mean and the standard deviation of the distribution, respectively.

[c] Full saturation (FS), field capacity (FC) or wilting point (WP) moisture content of homogenous soils of the given type with 1 m thickness.

[d] Groundwater residence time is estimated to be between 180 days and about 30 years.

Table SM-5. ENSEMBLES model chains included in this study

Institution	Code	GCM	RCM
CNRM	cnrm	Arpege	Aladin
DMI	dmi	ECHAM5	HIRHAM
ETHZ	ethz	HadCM3Q0[a]	CLM
ICTP	ictp	ECHAM5	RegCM
KNMI	knmi	ECHAM5	RACMO
MetOffice-HC	hadley	HadCM3Q0[a]	HadRM3Q0
MPI	mpi	ECHAM5	REMO
SMHI	smhi_bcm	BCM	RCA
	smhi_echam	ECHAM5	RCA
	smhi_had	HadCM3Q3[b]	RCA

[a] Normal sensitivity

[b] Low sensitivity

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