Supplementary Material

S1. Protocol

Experiment: The evolution of root zone moisture capacities after land use change

Partners: SMHI, Bristol

Lead: TUD

Formal protocol

Execution

i. Data requirements and formatting

   Required data: Long-term hydrological data (i.e. daily precipitation, runoff and potential evaporation) for at least 20 years for at least one and temporally well documented, land use change (ideally deforestation). Selected catchments are Hubbard Brook WS2 and WS5, and HJ Andrews WS1.

ii. Experiment execution steps

   a. TUD: Determine time series of root zone moisture capacity based on water-balance.

   b. SMHI, Bristol, TUD: Randomly run models with a moving time window of 2 years. Compute Kling-Gupta Efficiency, log Kling-Gupta Efficiency and Volume Error for each model run.

   c. TUD: Adjust model with a more dynamic formulation of the root zone storage capacity. Randomly run adjusted model and original model for a longer time series including deforestation. Compute hydrological signatures.

iii. Result reporting

   a. Mat-files with the used parameter combinations and performance metrics for each window.

Analysis

i. Trend analysis for the water balance derived root zone storage capacities

ii. Derive posterior distributions for window-based model runs for the root zone storage capacity or the equivalent parameter for each model.

iii. Calculate probability of improvement and ranked probability score for each hydrological signature for the adjusted model with time-varying root zone storage capacity and the original model.

iv. Analyse/interpret findings.

S2. Model descriptions

2.1 FLEX

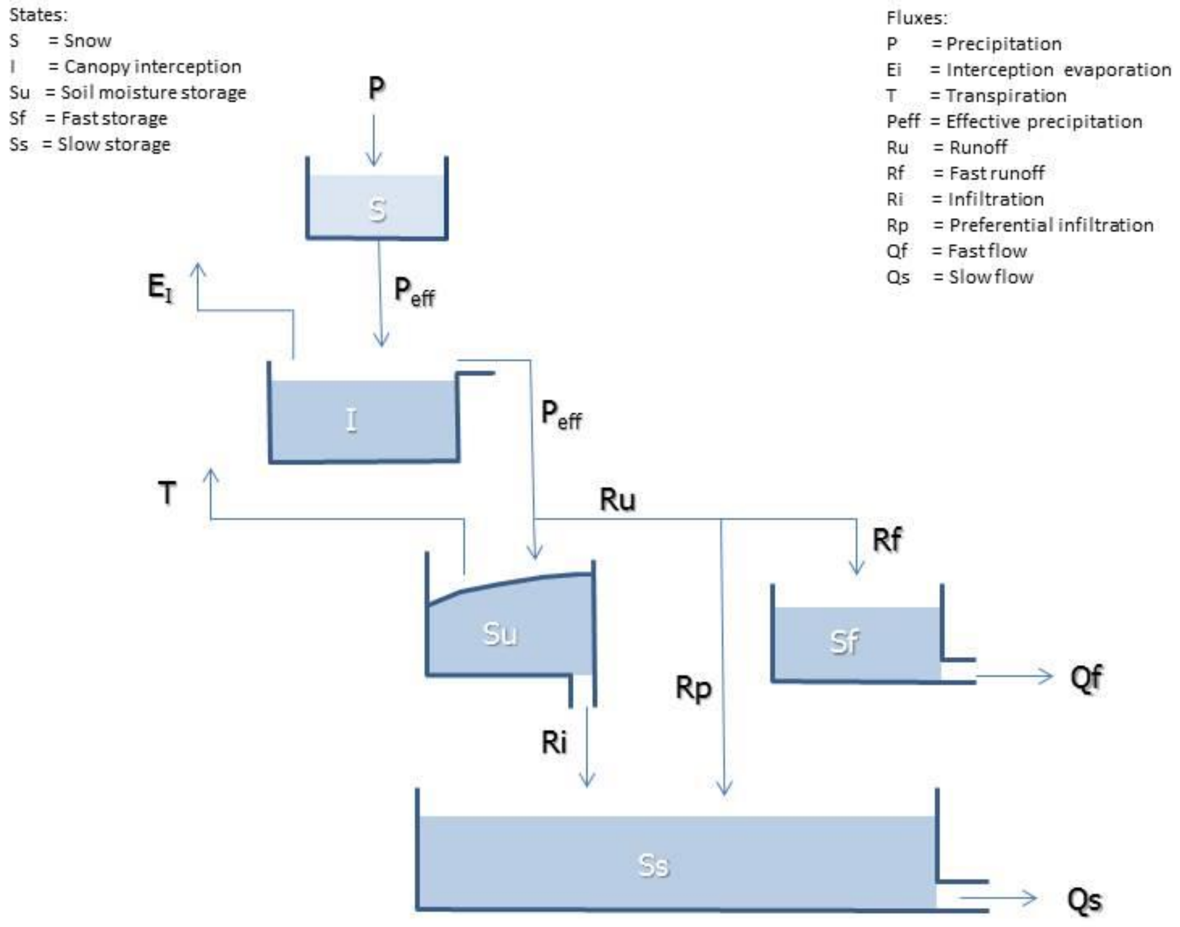

Figure S1. FLEX model structure.

Table S1. Parameters with descriptions and prior ranges for the FLEX model

Parameters	**Unit**	**Min**	**Max**	**Description**
Meltfactor	mm/ ^{o}C	4	5	Water released with a degree change temperature
Tthresh	^{o}C	-1	0	Threshold temperature to separate rain from snow
Imax	mm	0.0	0	Maximum interception capacity
Sumax	mm	1.0	1000	Maximum soil moisture storage
Beta	-	0.01	3	Shape factor soil moisture function
Kf	days	1	10	Recession coefficient fast reservoir
Ks	days	60	65	Recession coefficient slow reservoir
D	-	0.0	1.0	Partition of runoff that preferentially percolates to the groundwater
Pmax	mm/d	0.0	10	Maximum percolation to the groundwater

Table S2. Water balance and constitutive relations applied in the FLEX model

Reservoir	**Water balance equation**	**Constitutive relation**
Snow	$\frac{dS_{Snow}}{dt} = P - M$	$P_{e,s} = \begin{cases} Meltfactor * (T_a - T_{thresh}) & if\ T_a > T_{thresh} \\ 0 & if\ T_a \leq T_{thresh} \end{cases}$
Interception	$\frac{dS_I}{dt} = P_{e,s} - E_i - P_{eff}$	$P_{eff} = \max(0, S_i + P_{e,s} - I_{\max})$ $E_i = \min(E_p, \quad S_i - P_{eff})$ $S_{i,new} = S_{i,old} + P_{e,s} - P_{eff} - E_i$
Soil moisture	$\frac{dS_u}{dt} = P_{eff} - E_t - R - P$	$S_{u,m} = (1+\beta)\, S_{u,max} \left(1 - \left(1 - \frac{S_u}{S_{u,max}}\right)^{1/(1+\beta)}\right)$ $R = P_{eff} - S_{u,max} + S_u + S_{u,max} * \left(1 - \frac{P_{eff} + S_{u,m}}{(1+\beta)\, S_{u,max}}\right)^{1+}$ $E_t = \begin{cases} E_p \frac{S_u}{0.5 * S_{u,max}} & if\ S_u \leq 0.5 * S_{u,max} \\ \min(E_p, \quad S_u) & if\ S_u > 0.5 * S_{u,max} \end{cases}$ $P = P_{max} \frac{S_u}{S_{u,max}}$ $S_{u,new} = S_{u,old} + P_{eff} - R - E_t - P$
Fast reservoir	$\frac{dS_f}{dt} = (1-D) * R - Q_f$	$Q_f = K * S_f$ $S_{f,new} = S_{f,old} + (1-D) * R - Q_f$

Slow reservoir	$\frac{dS_s}{dt} = D * R + P - Q_s$	$Q_s = K * S_s$ $S_{s,new} = S_{s,old} + D * R - Q_s$

2.2 HYPE

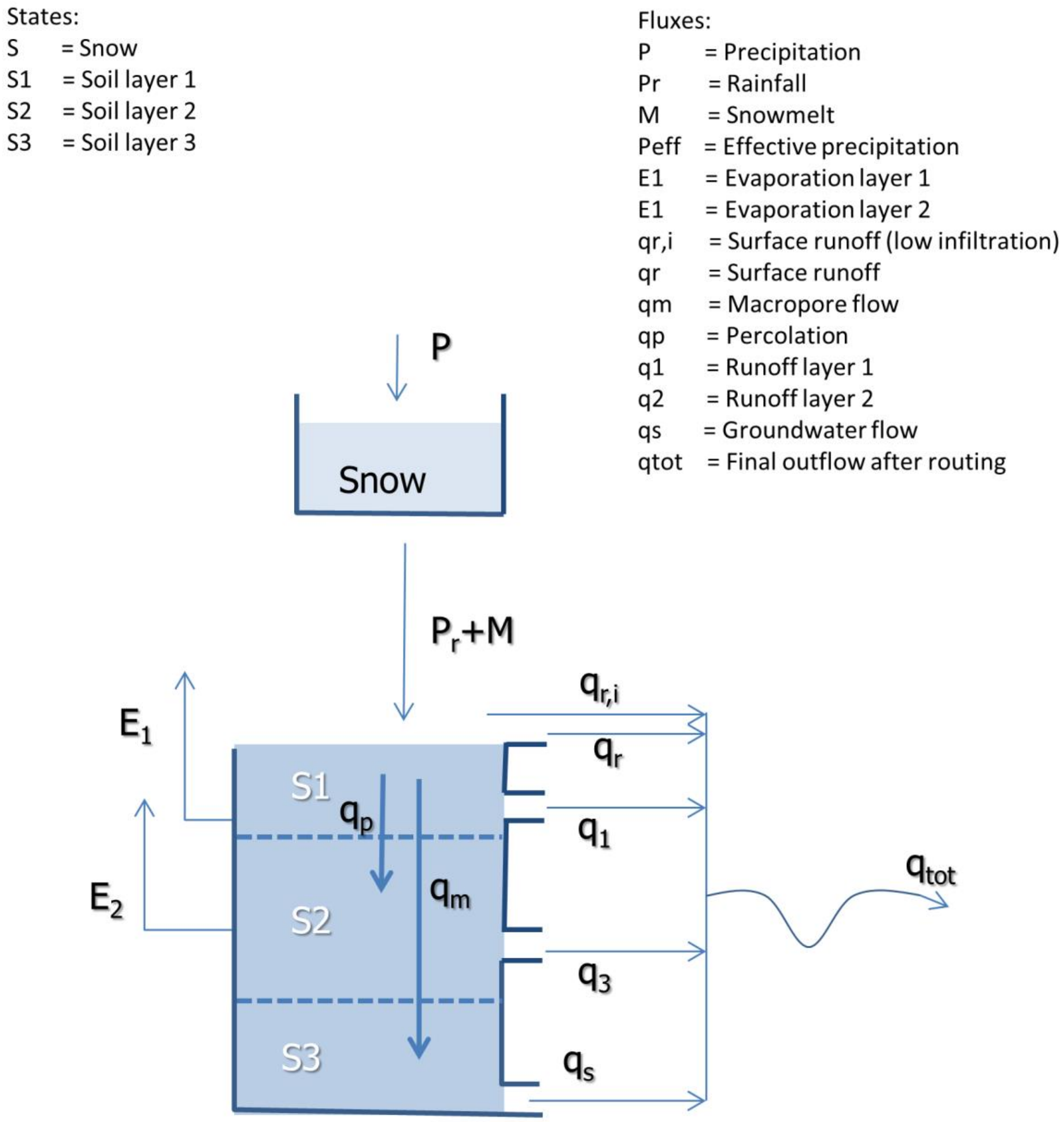

Figure S2. HYPE model structure.

Table S2. Parameters with descriptions and prior ranges for the HYPE model

Parameters	**Unit**	**Min**	**Max**	**Description**
wcfc	-	0.05	0.35	fraction of soil available for evapotranspiration but not for runoff, same for all soil layers
wcep	-	0.05	0.4	effective porosity as a fraction, same for all soil layers
wcwp	-	0.05	0.5	wilting point as a fraction, same for all soil layers
rrcs1	-	0.05	0.6	recession coefficient for uppermost soil layer
rrcs2	-	0.05	0.6	recession coefficient for lowest soil layer
mperc1	-	5	100	maximum percolation capacity from soil layer 1 to soil layer 2
mperc2	-	5	100	maximum percolation capacity from soil layer 2 to soil layer 3
mactrsm	-	0.2	0.9	threshold soil water for macro-pore flow and surface runoff
macrate	-	0.1	0.5	fraction for macro-pore flow
mactrinf	mm/d	10	45	threshold for macro-pore flow
srrcs	-	0.01	0.2	recession coefficient for surface runoff
cmlt	mm/^{o}/d	2	5	melting parameter for snow
ttmp	^{o}C	0	1	threshold temperature for snow melt and evapotranspiration
lp	-	0.7	1	limit for potential evapotranspiration

rivvel	m/s	0.5	2	celerity of flood in watercourse

2.3 TUW

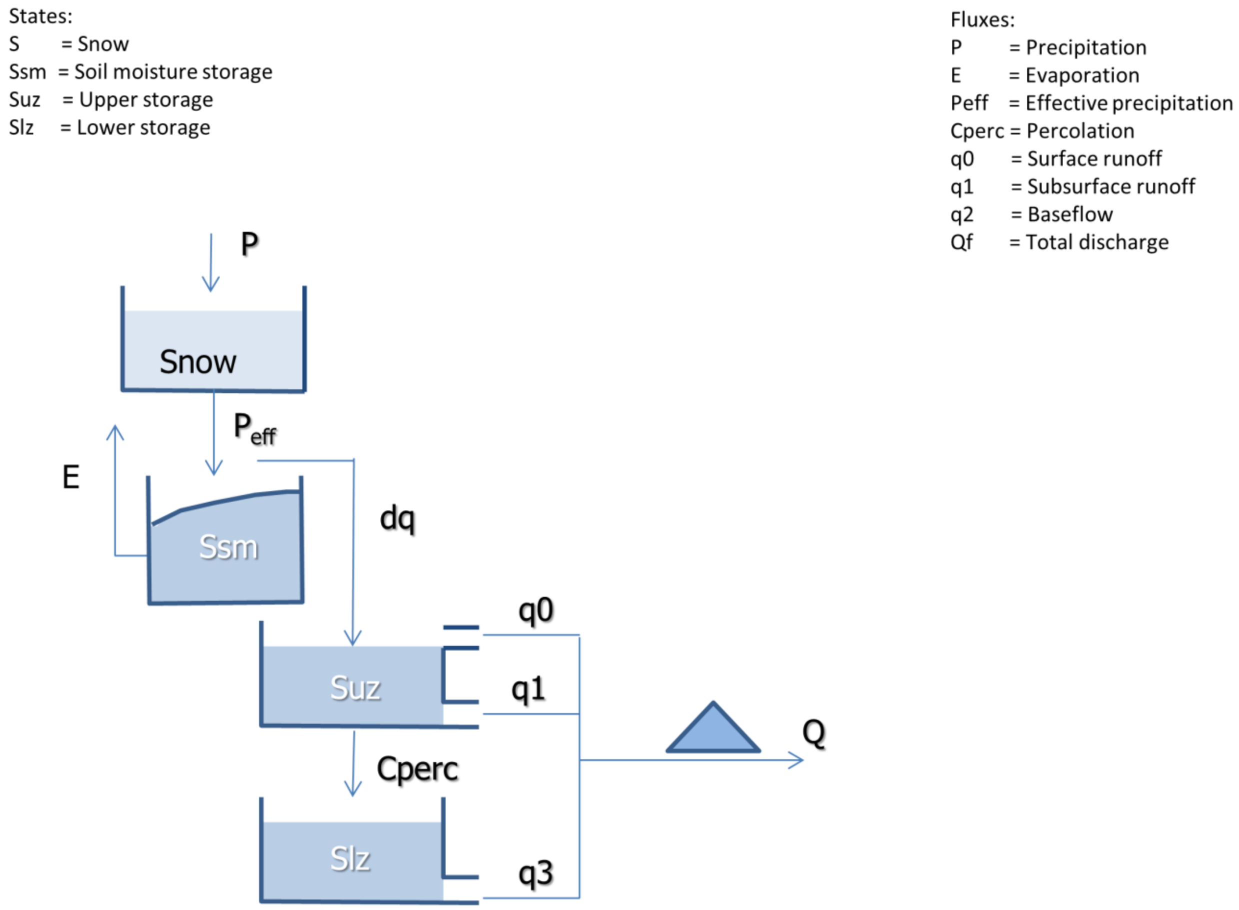

Figure S3. TUW model structure.

Table S3. Parameters with descriptions and prior ranges for the TUW model

Parameters	**Unit**	**Min**	**Max**	**Description**
SCF	-	0.9	1.5	Snow correction factor
DDF	Mm/^{o}C /d	0	6	Degree day factor
Tr	mm	1.0	3.0	Threshold temperature above which precipitation is rain
Ts	mm	-3.0	1	Threshold temperature below which precipitation is snow
Tm	-	-2.0	2	Threshold temperature above which melt starts
LPrat	days	0	1	Parameter related to the limit for potential evaporation
FC	mm	0.0	1000	field capacity, i.e., max soil moisture storage
Beta	-	0.0	20.0	the non linear parameter for runoff production
k0	days	0.0	2	storage coefficient for very fast response
k1	days	2.0	5	storage coefficient for fast response
k2	days	5.0	30	storage coefficient for slow response
lsuz	mm	1.0	100.0	threshold storage state, i.e., the very fast response start if exceeded
Cperc	mm/d	0.0	8.0	constant percolation rate
bmax	days	0.0	10.0	maximum base at low flows
croute	day2/mm	0.0	50.0	free scaling parameter

2.4 HYMOD

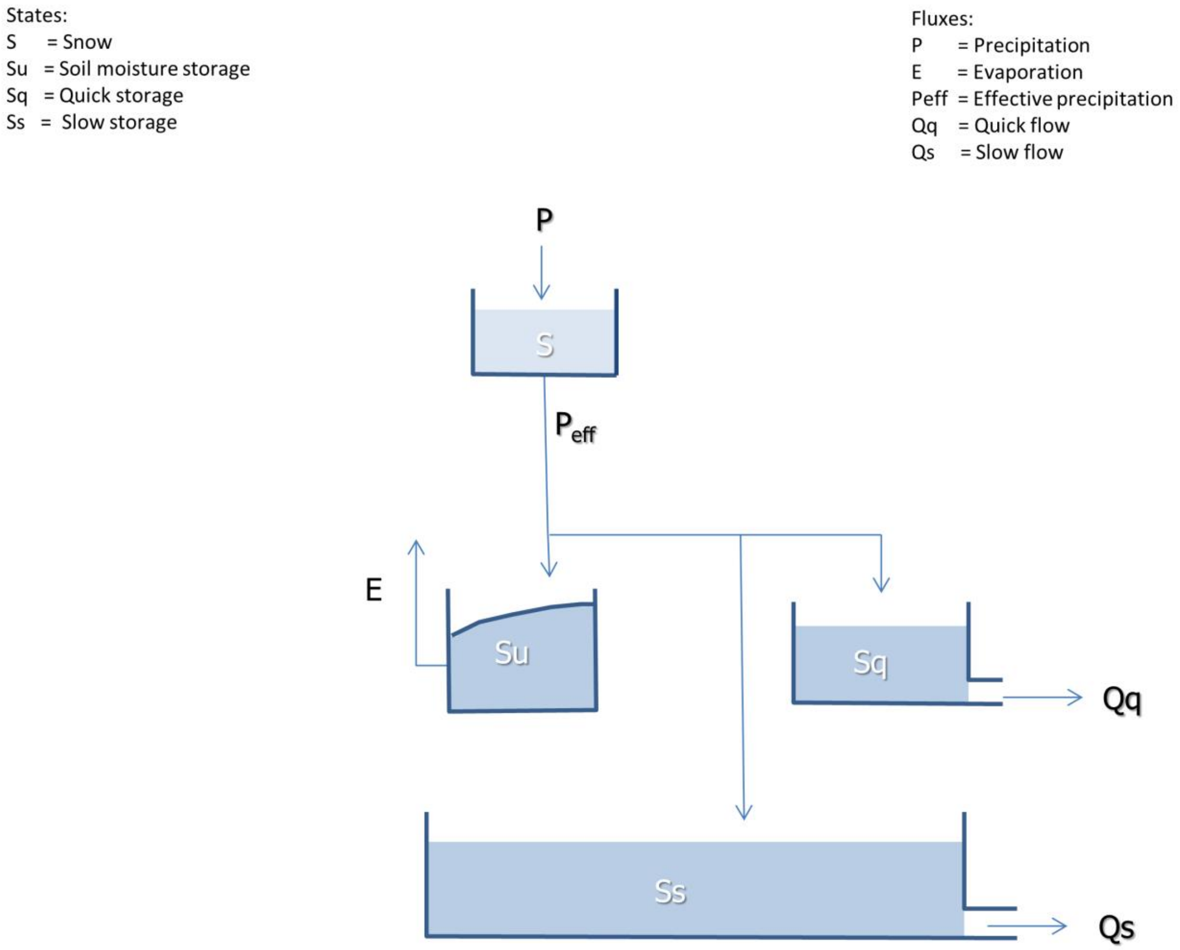

Figure S4. HYMOD model structure.

Table S4. Parameters with descriptions and prior ranges for the HYMOD model

Parameters	**Unit**	**Min**	**Max**	**Description**
DDF	Mm/^{o}C /d	0	6	Degree day factor
Tb	^{o}C	-3.0	3.0	Threshold temperature above which precipitation is rain
Tth	^{o}C	-2.0	2	Threshold temperature below which precipitation is snow
alpha	-	0.0	1	Parameter determining separation between fast and slow runoff
Cmax	Mm	0	1000	max soil moisture storage
Beta	-	0.01	3.0	the non linear parameter for runoff production
Kq	Days	1.0	3.0	storage coefficient for fast response
Ks	Days	1.0	20	storage coefficient for slow response

S3. Objective function values

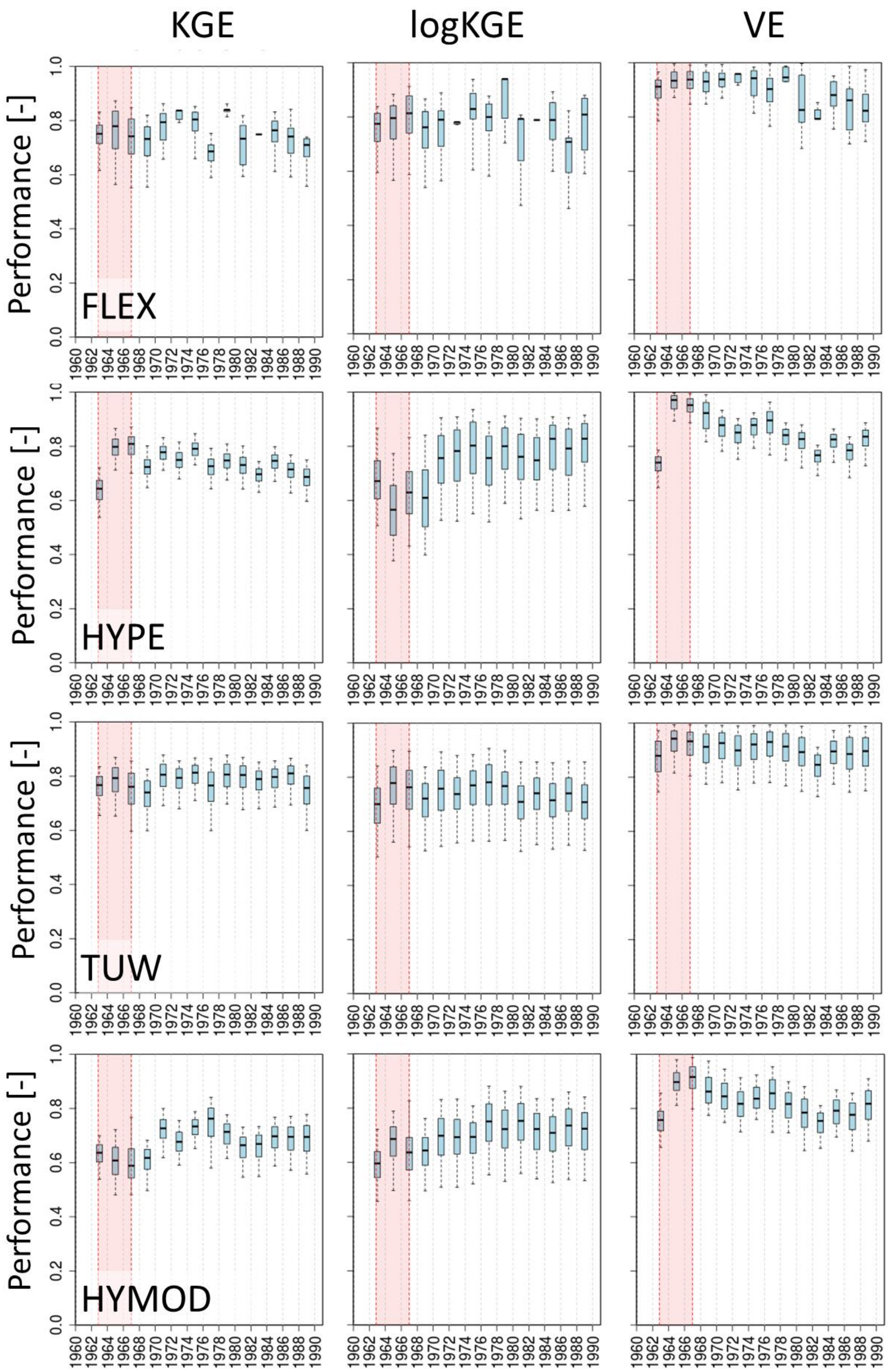

Figure S5. Objective function values of Kling-Gupta Efficiency (KGE), log Kling-Gupta Efficiency (logKGE) and volume error (VE) for HJ Andrews WS1 resulting from the calibration for each time window.

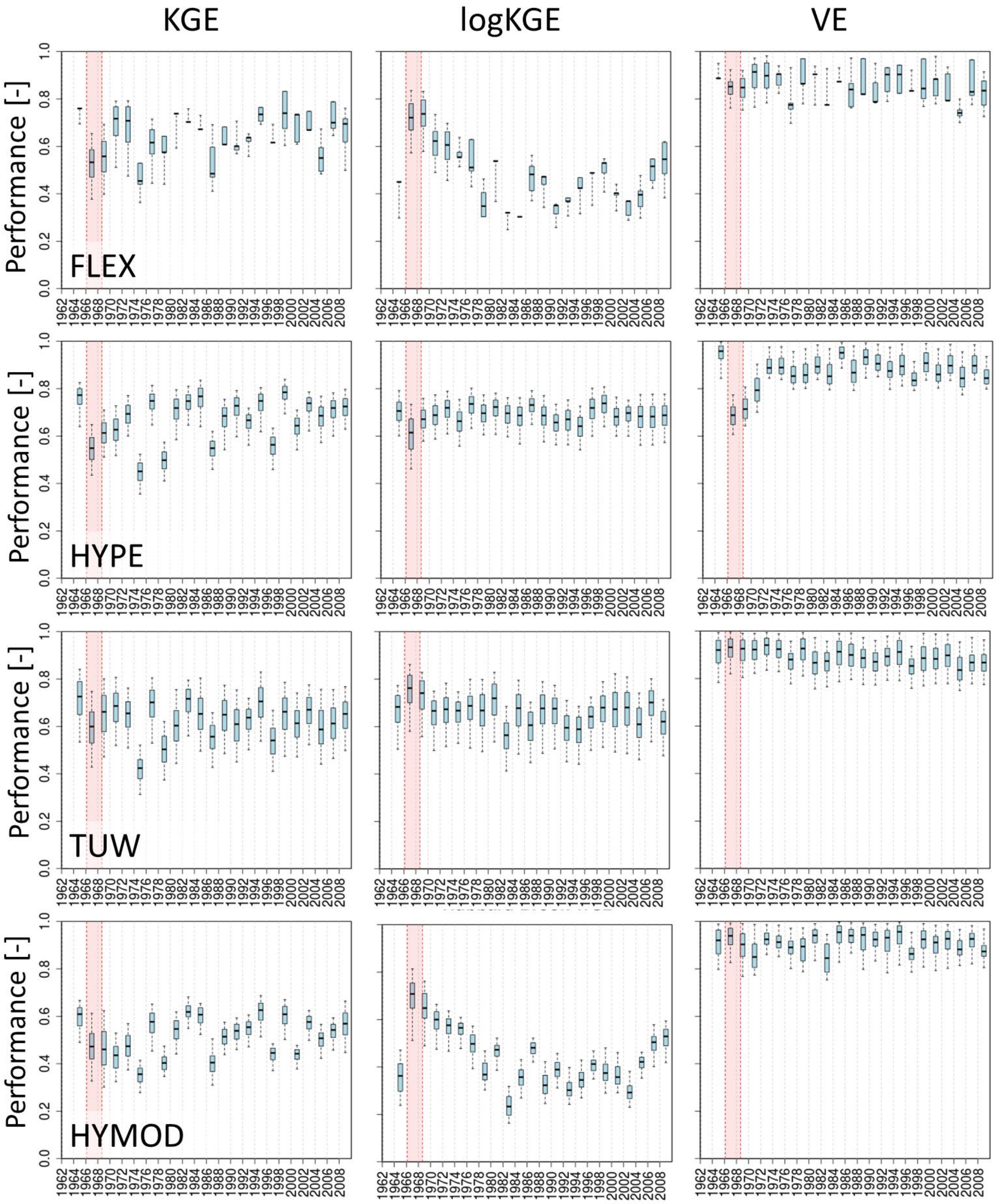

Figure S6. Objective function values of Kling-Gupta Efficiency (KGE), log Kling-Gupta Efficiency (logKGE) and volume error (VE) for Hubbard Brook WS2 resulting from the calibration for each time window.

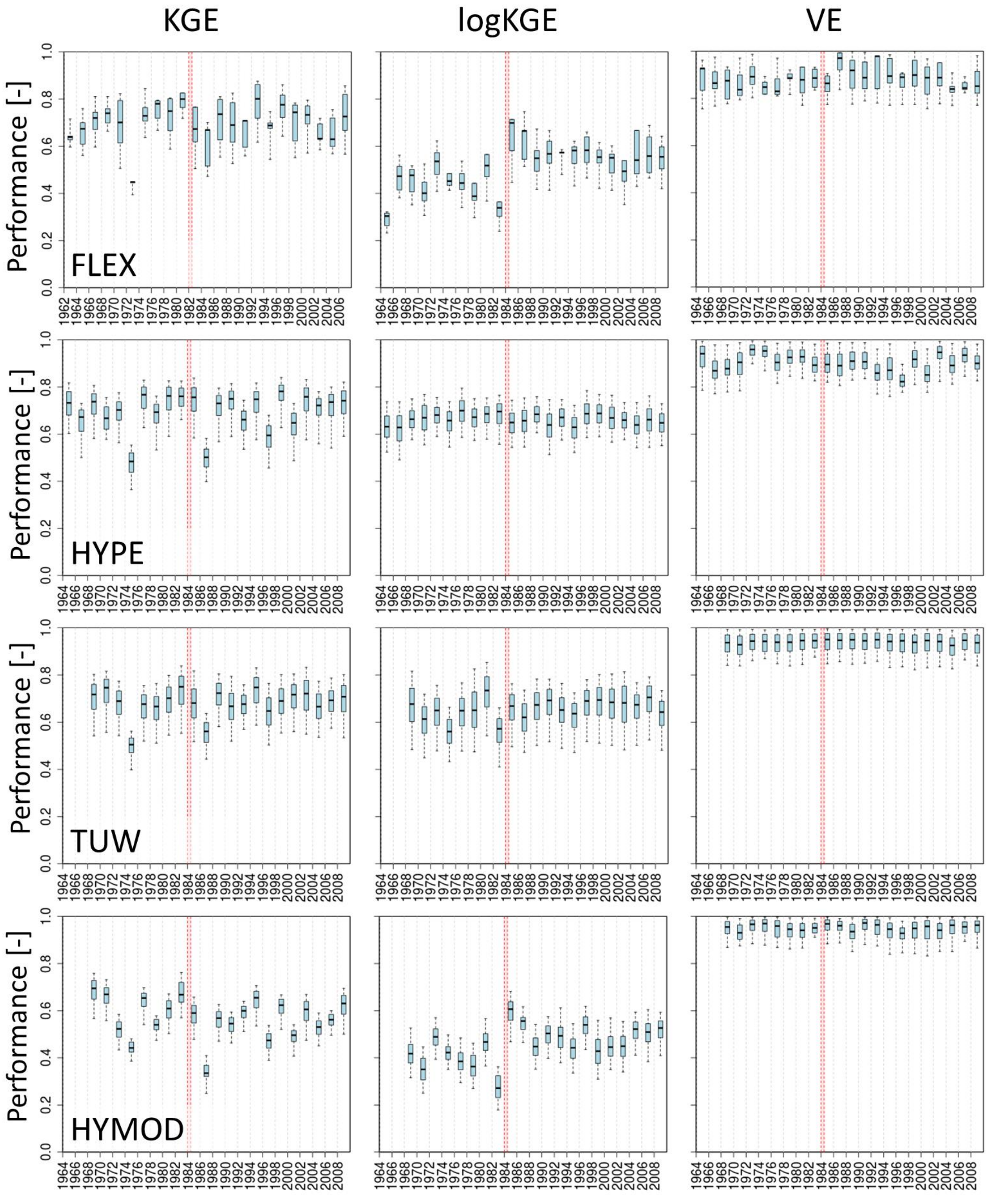

Figure S7. Objective function values of Kling-Gupta Efficiency (KGE), log Kling-Gupta Efficiency (logKGE) and volume error (VE) for Hubbard Brook WS5 resulting from the calibration for each time window.

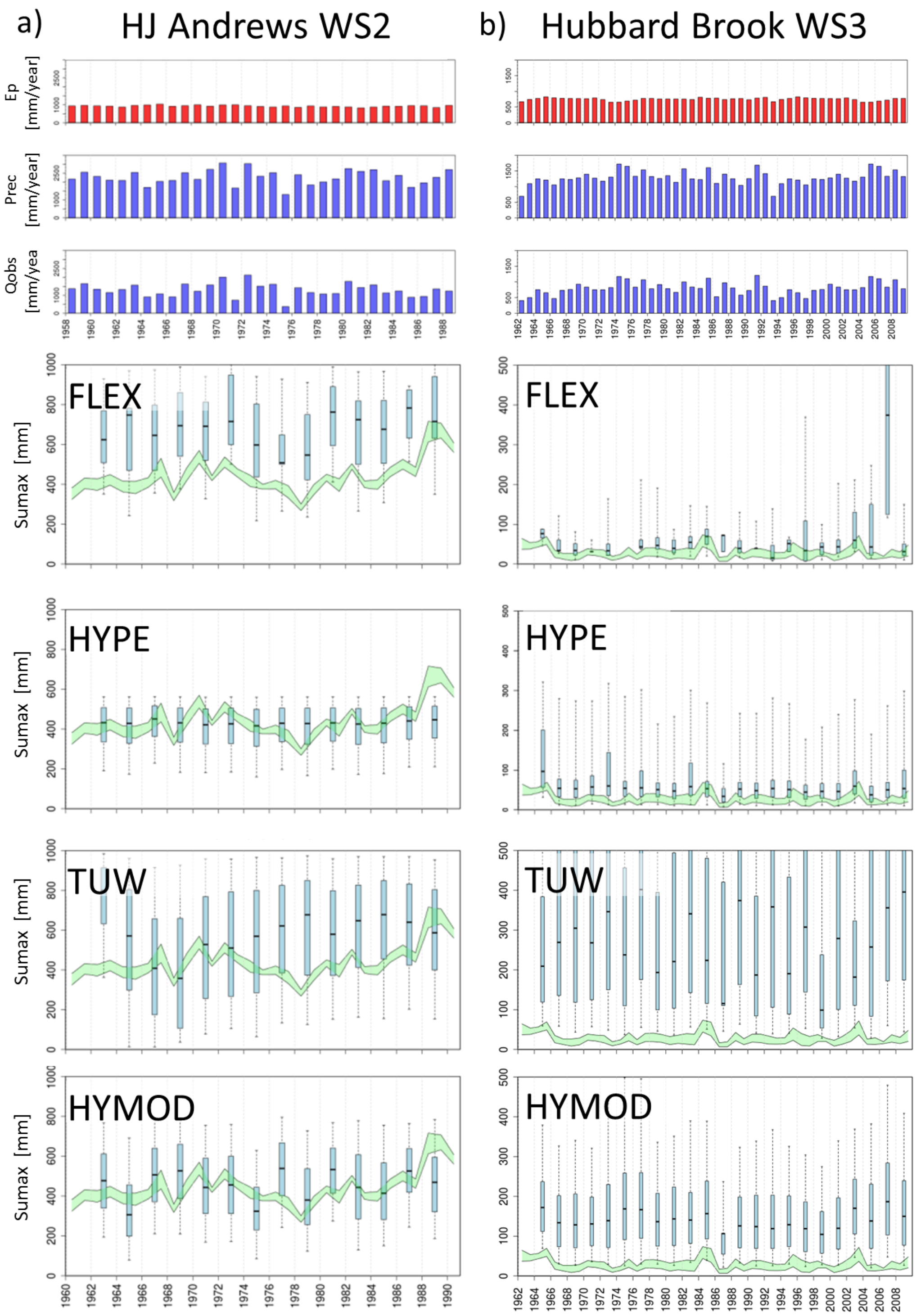

Figure S8. Evolution of root zone storage capacity $S_{R,1yr}$ from water balance-based estimation (green shaded area, a range of solutions due to the sampling of the unknown interception capacity) compared with $S_{u,max,2yr}$ estimates obtained from the calibration of four models (FLEX, HYPE, TUW, HYMOD; blue boxplots) for a) HJ Andrews WS2, b) Hubbard Brook WS3.

S4. Posterior parameter distributions

4.1 FLEX

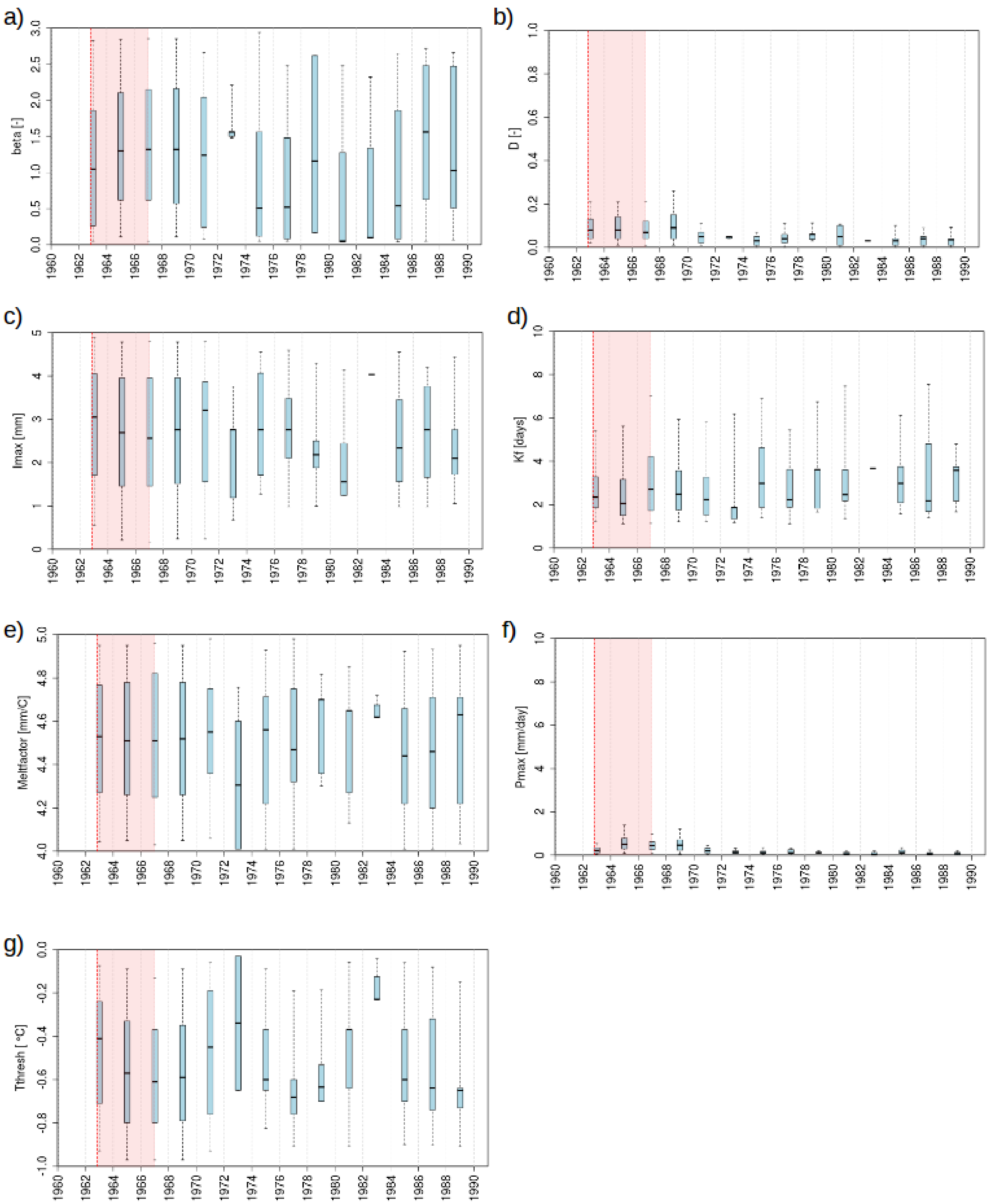

Figure S9. Posterior parameter distributions for the FLEX model in HJ Andrews WS1.

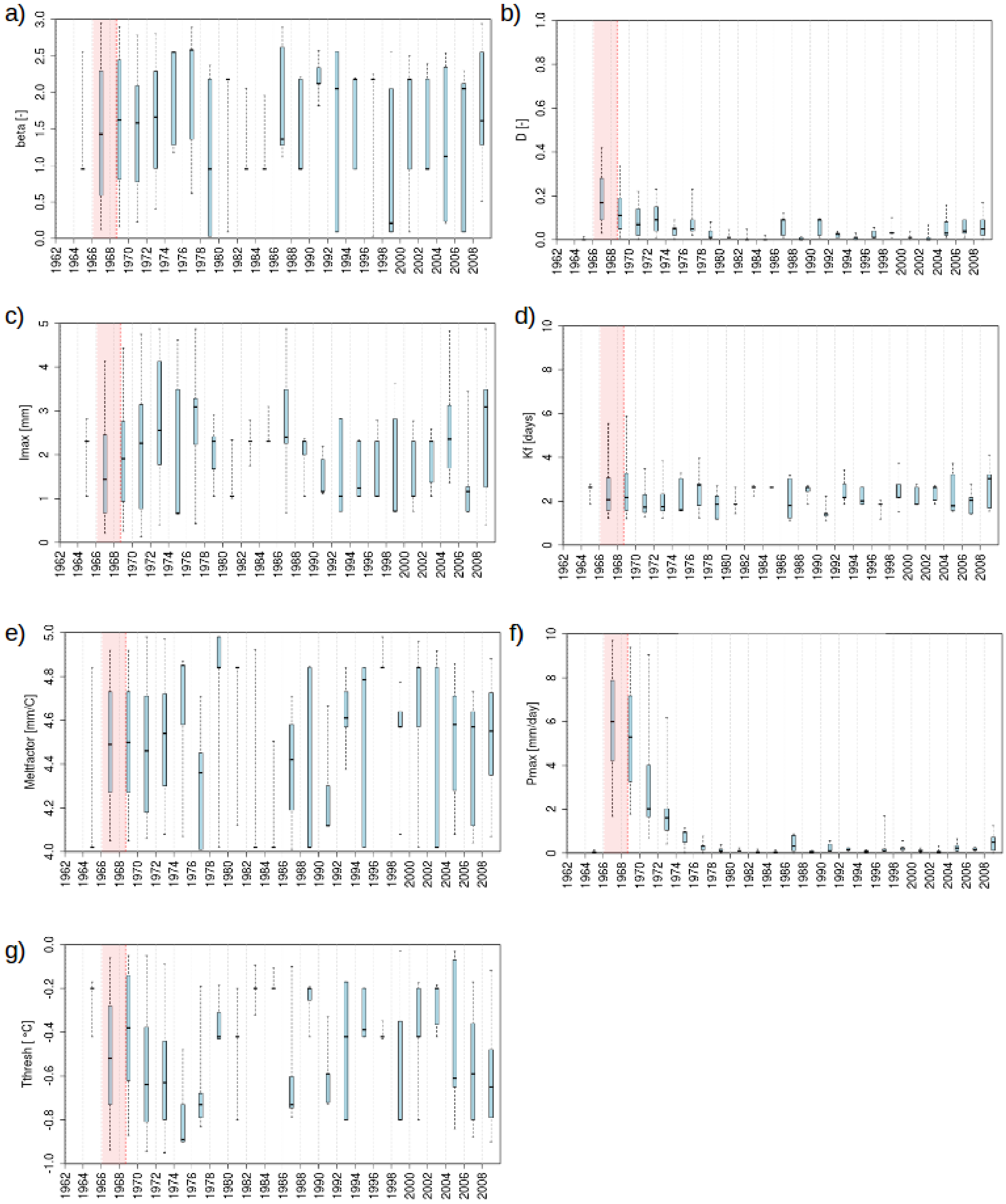

Figure S10. Posterior parameter distributions for the FLEX model in Hubbard Brook WS2.

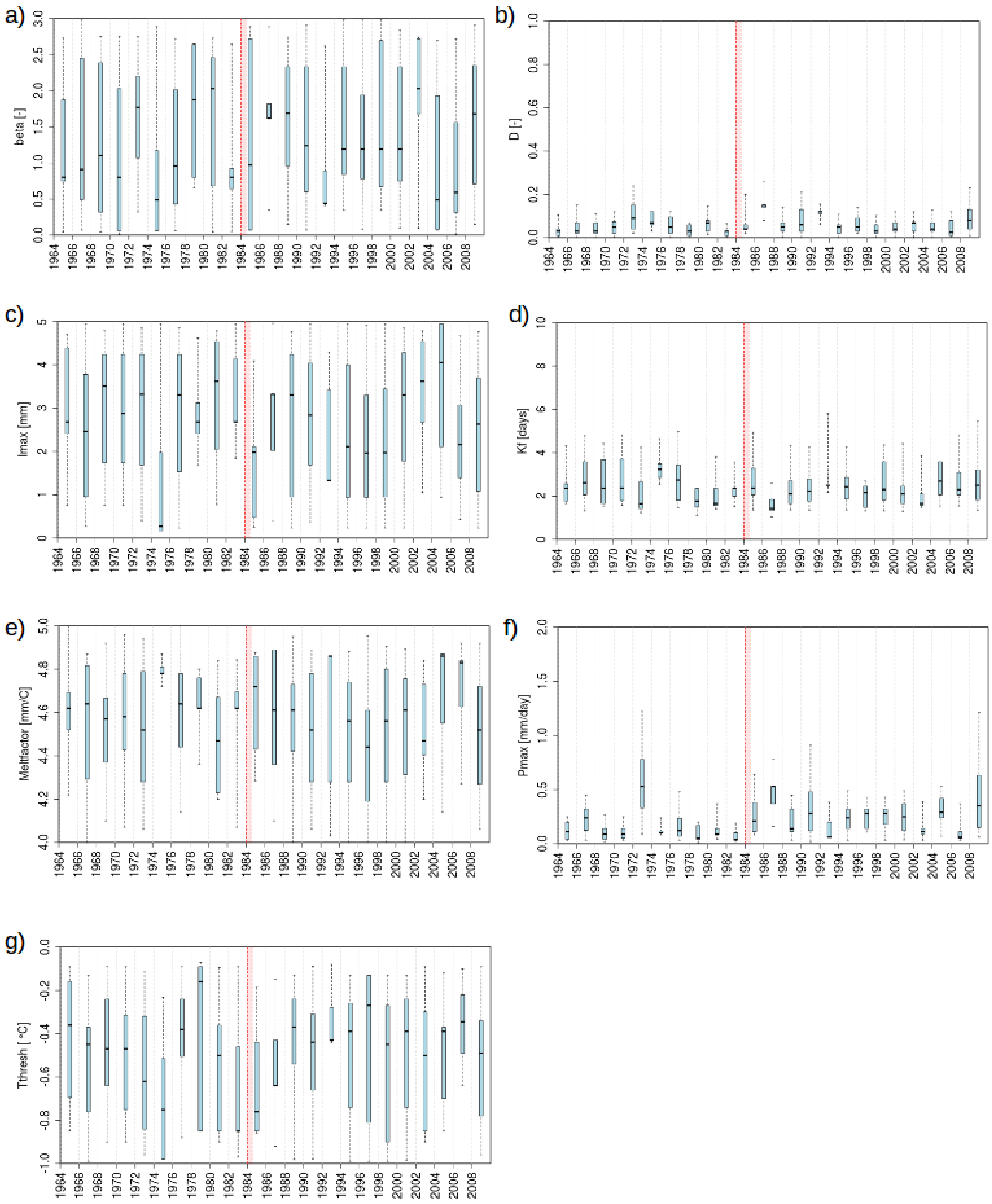

Figure S11. Posterior parameter distributions for the FLEX model in Hubbard Brook WS2.

4.2 HYPE

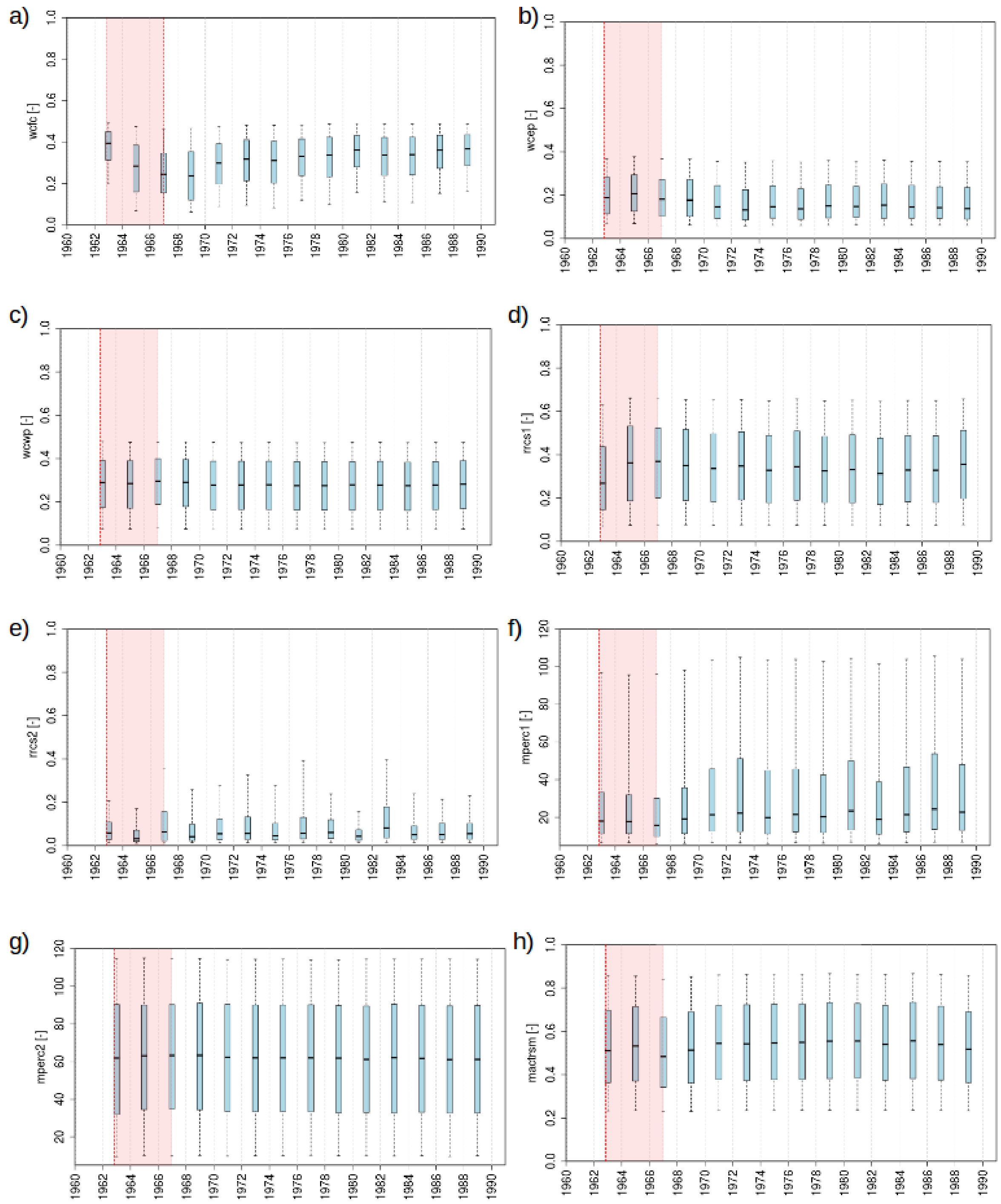

Figure S12. Posterior parameter distributions for the HYPE model in HJ Andrews WS1.

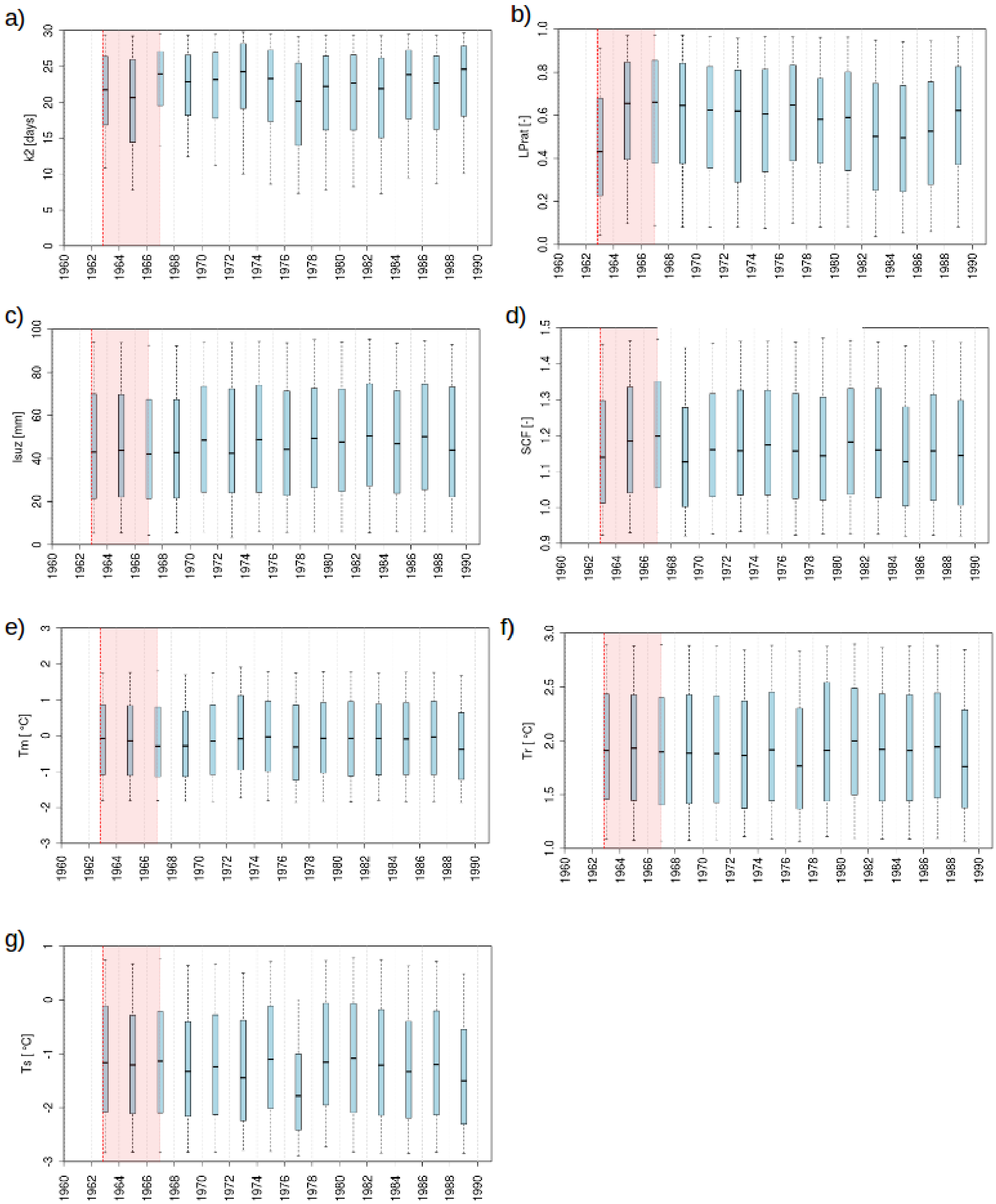

Figure S13. Continued posterior parameter distributions for the HYPE model in HJ Andrews WS1.

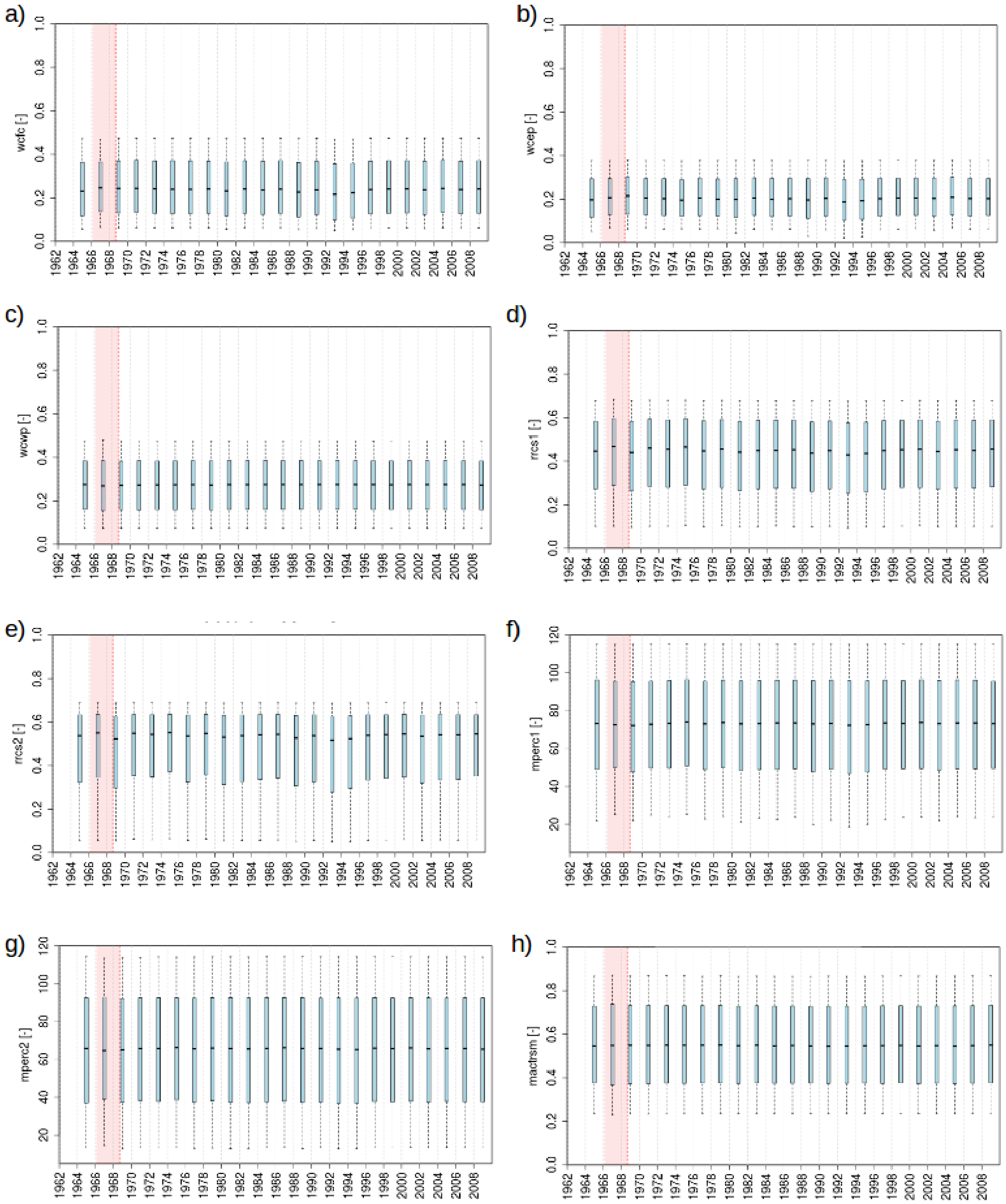

Figure S14. Posterior parameter distributions for the HYPE model in Hubbard Brook WS2.

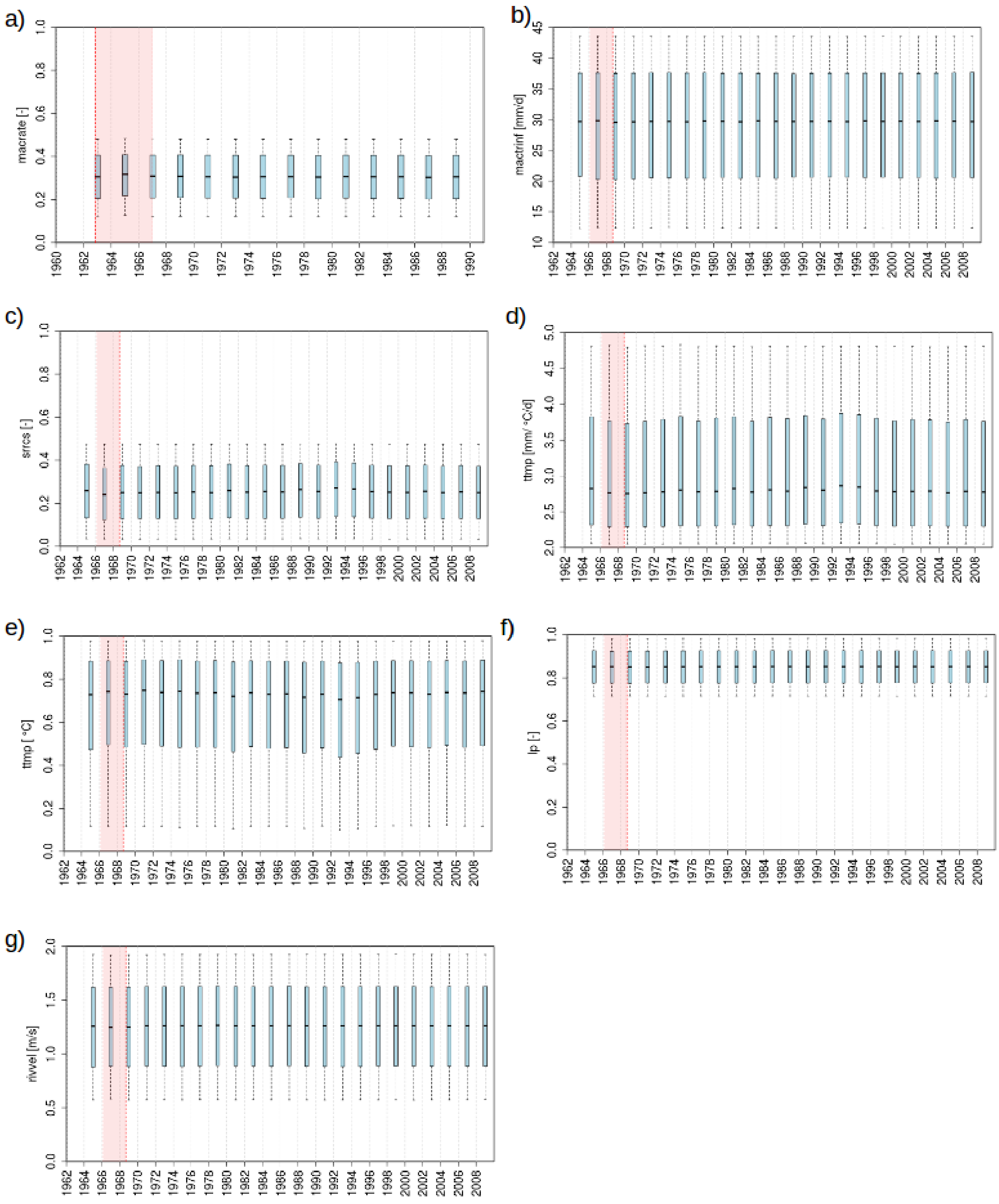

Figure S15. Continued posterior parameter distributions for the HYPE model in Hubbard Brook WS2.

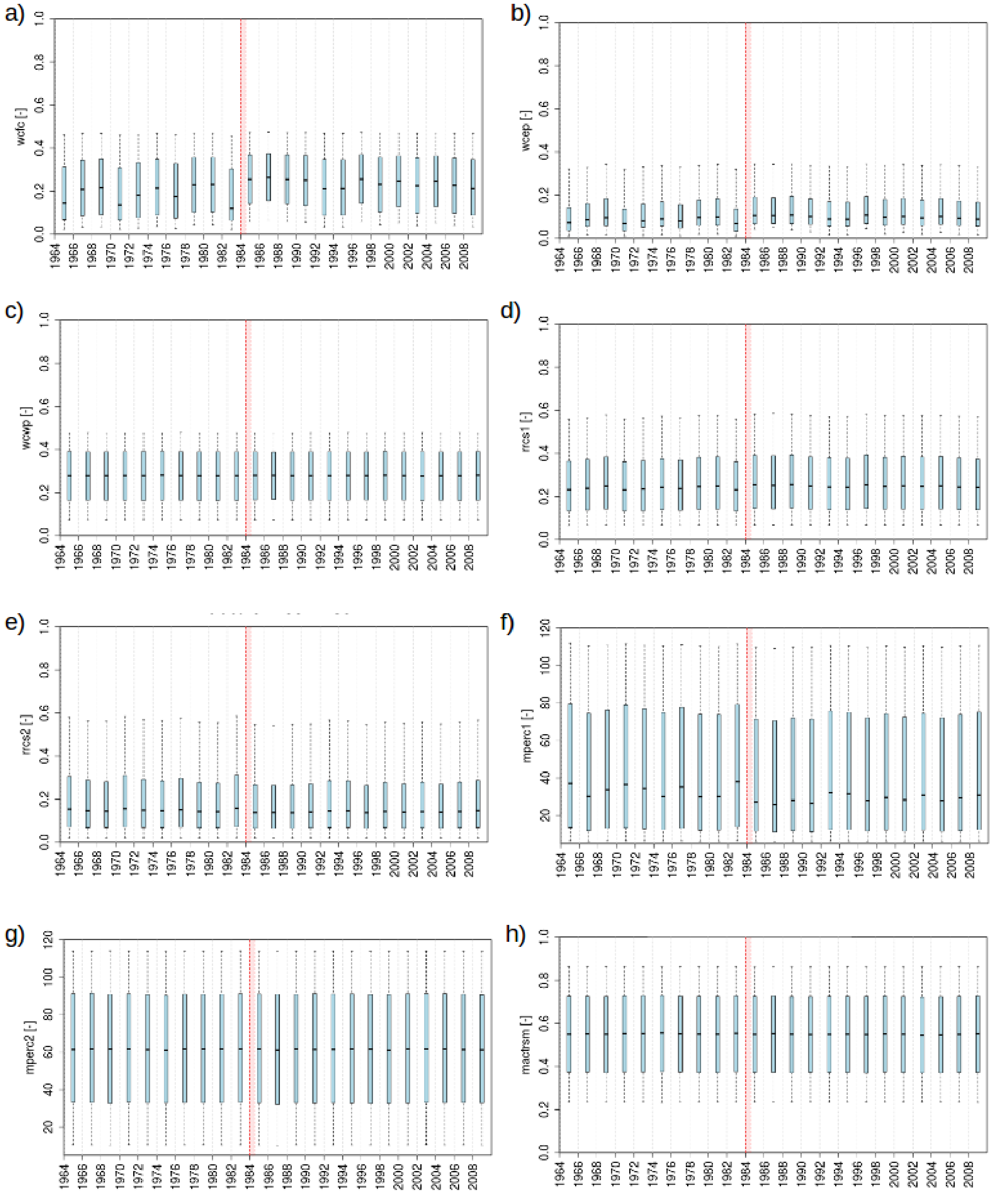

Figure S16. Posterior parameter distributions for the HYPE model in Hubbard Brook WS5.

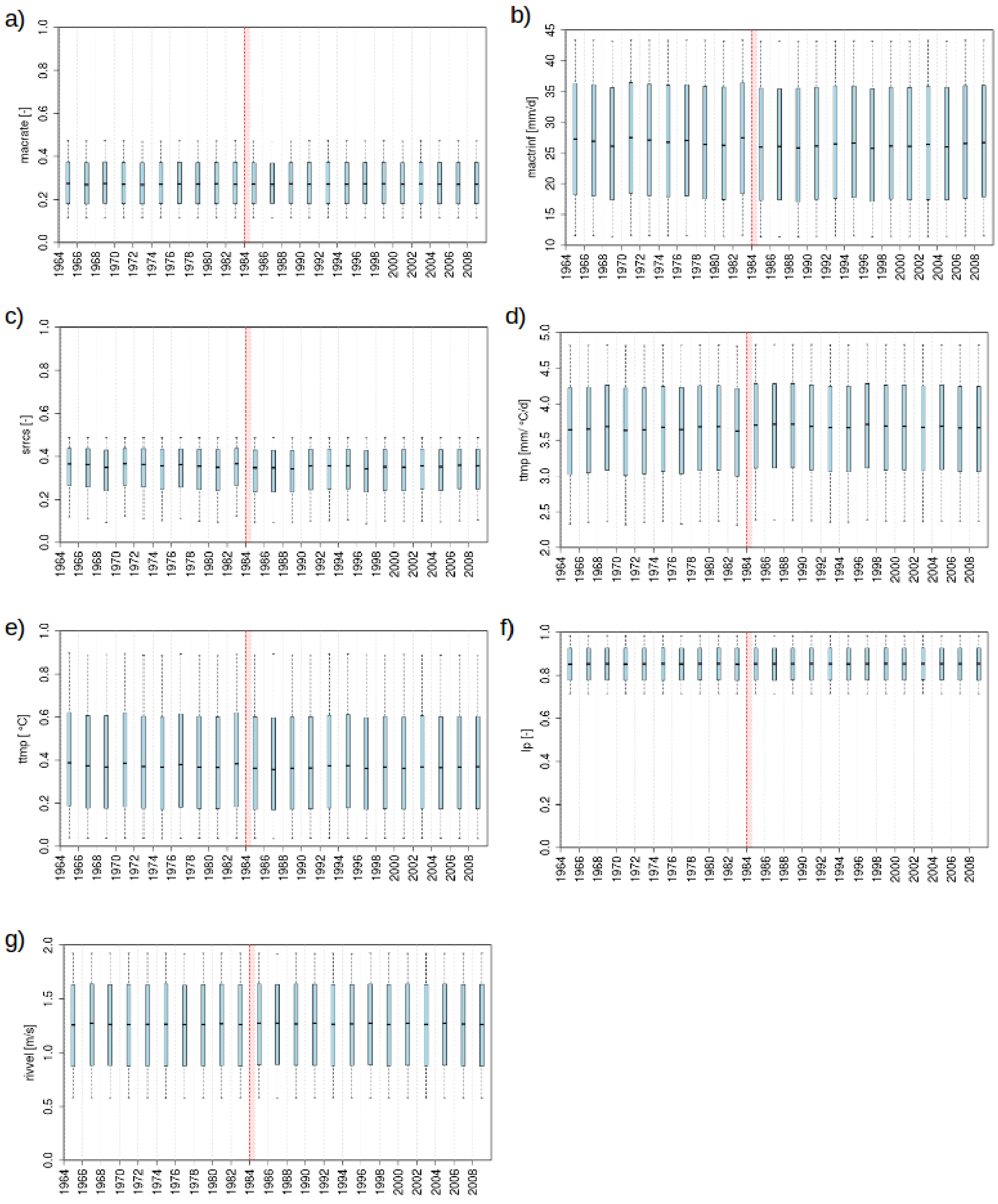

Figure S17. Continued posterior parameter distributions for the HYPE model in Hubbard Brook WS5.

4.3 HYMOD

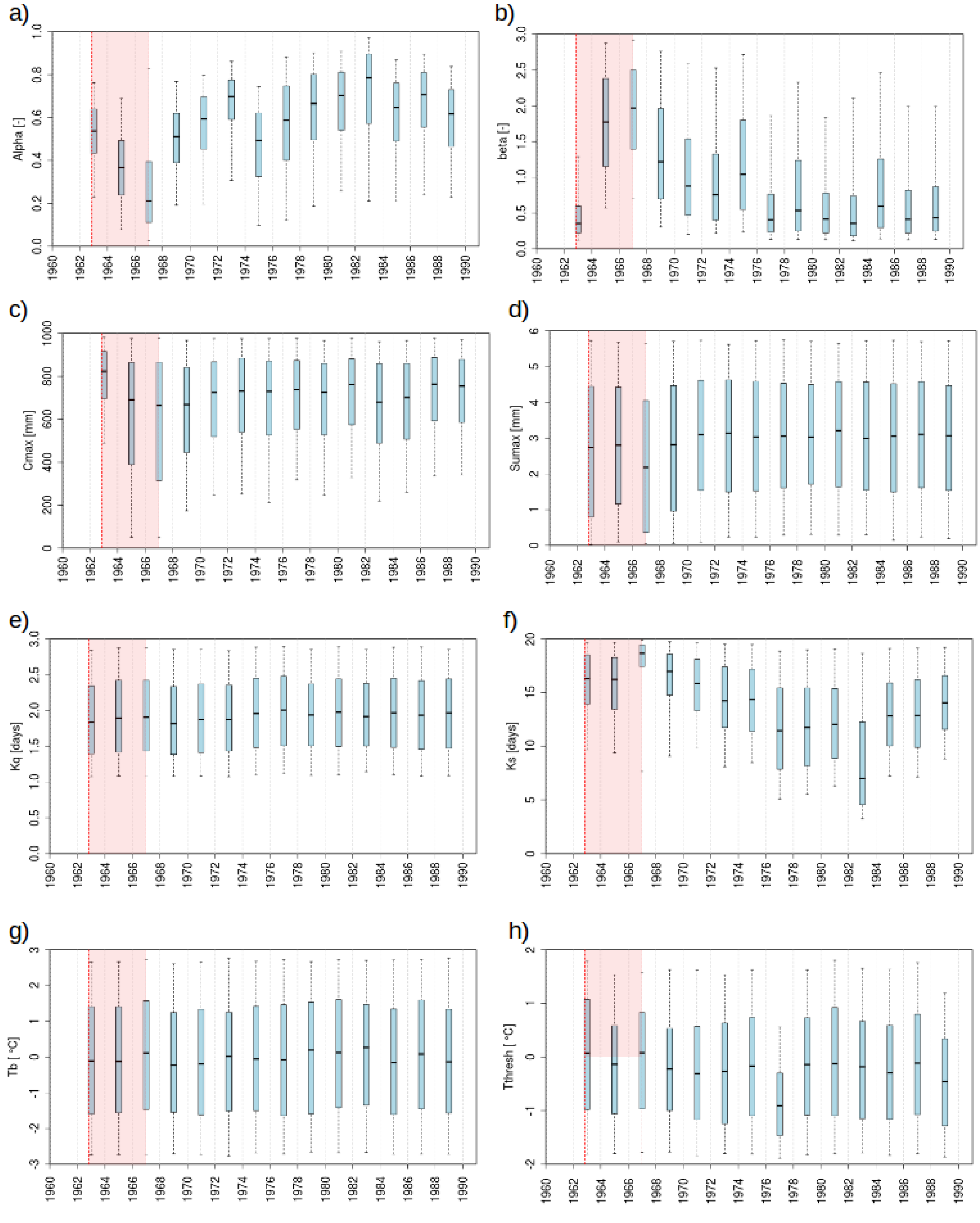

Figure S18. Posterior parameter distributions for the HYMOD model in HJ Andrews WS1.

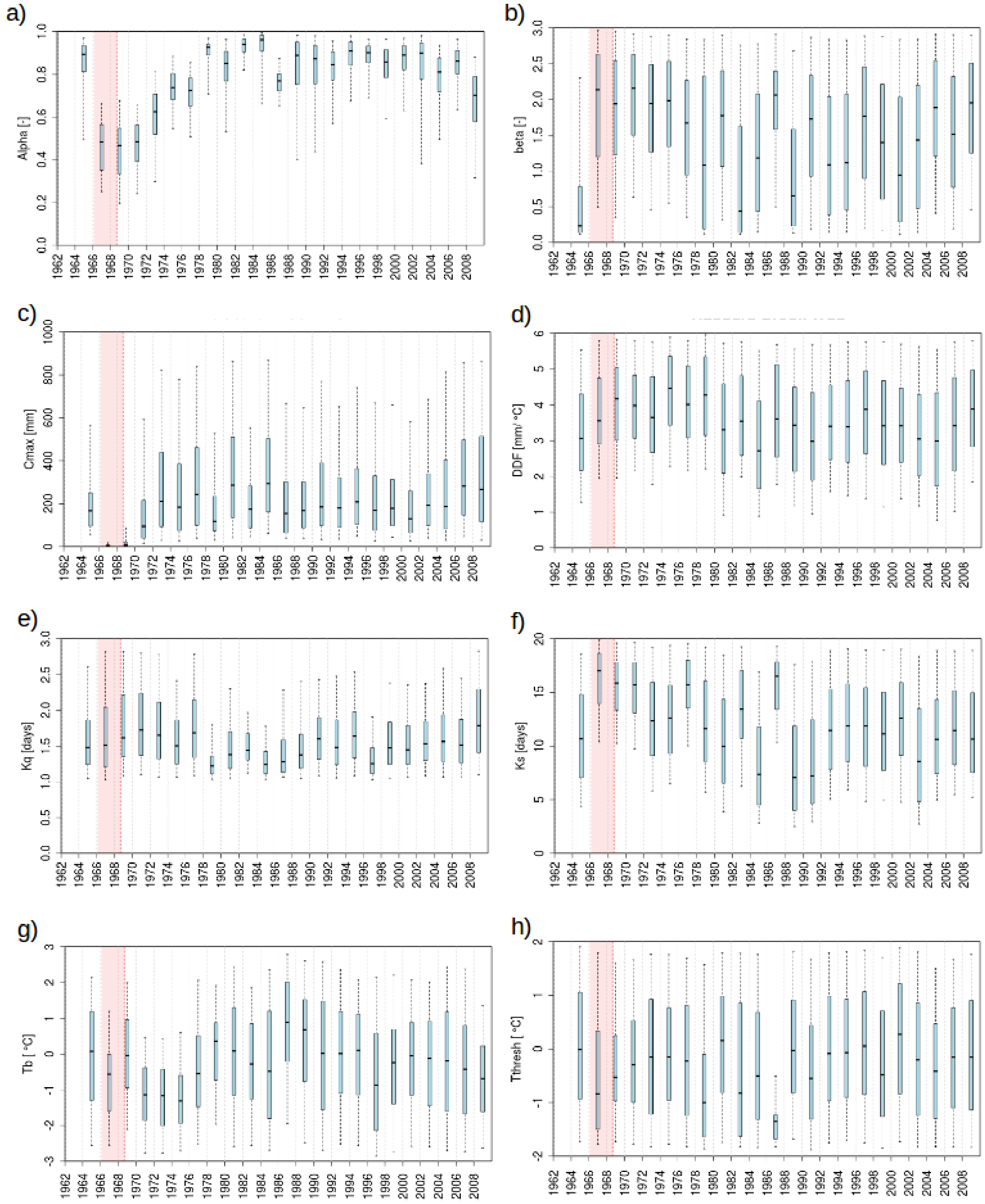

Figure S19. Posterior parameter distributions for the HYMOD model in Hubbard Brook WS2.

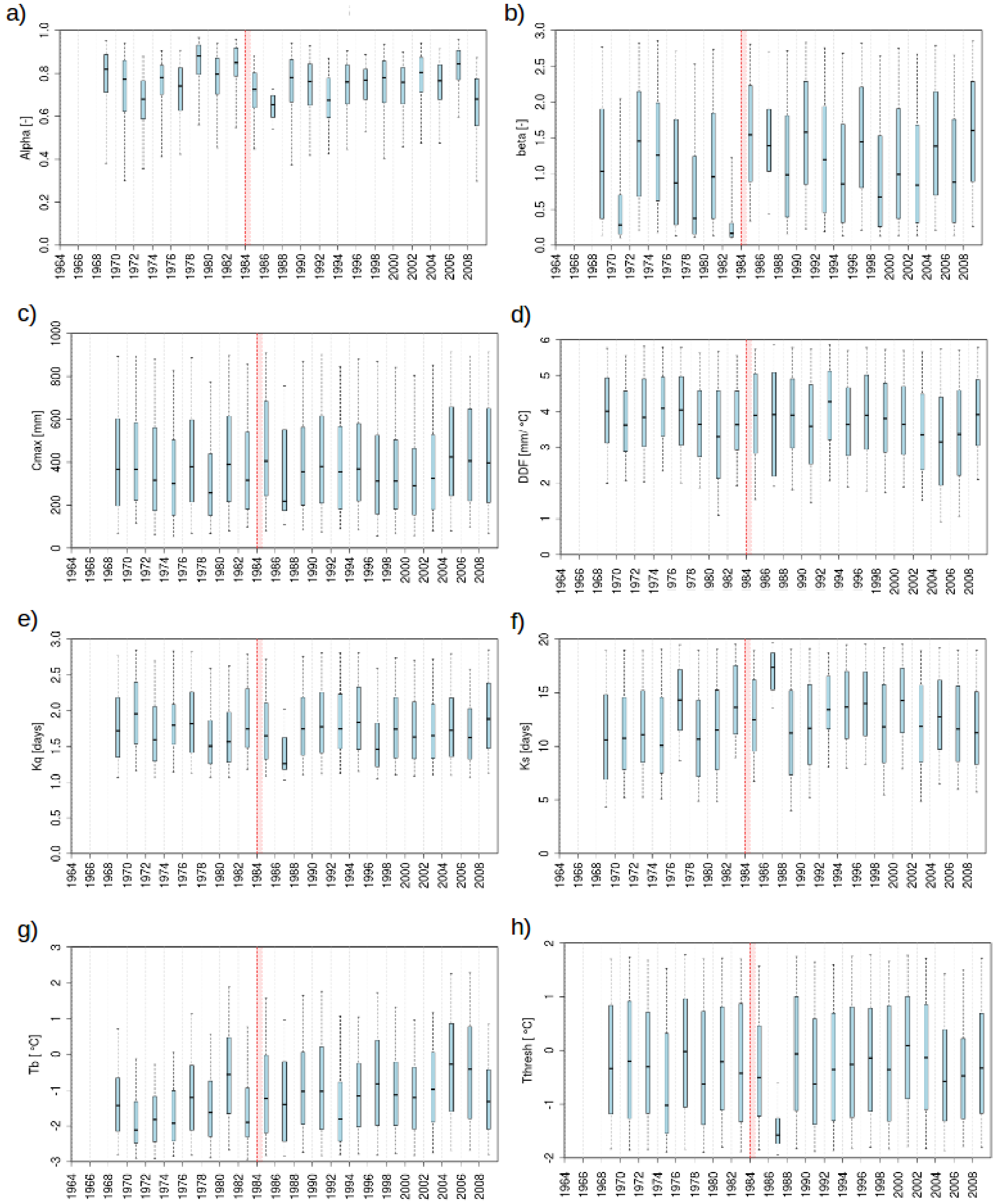

Figure S20. Posterior parameter distributions for the HYMOD model in Hubbard Brook WS5.

4.4 TUW

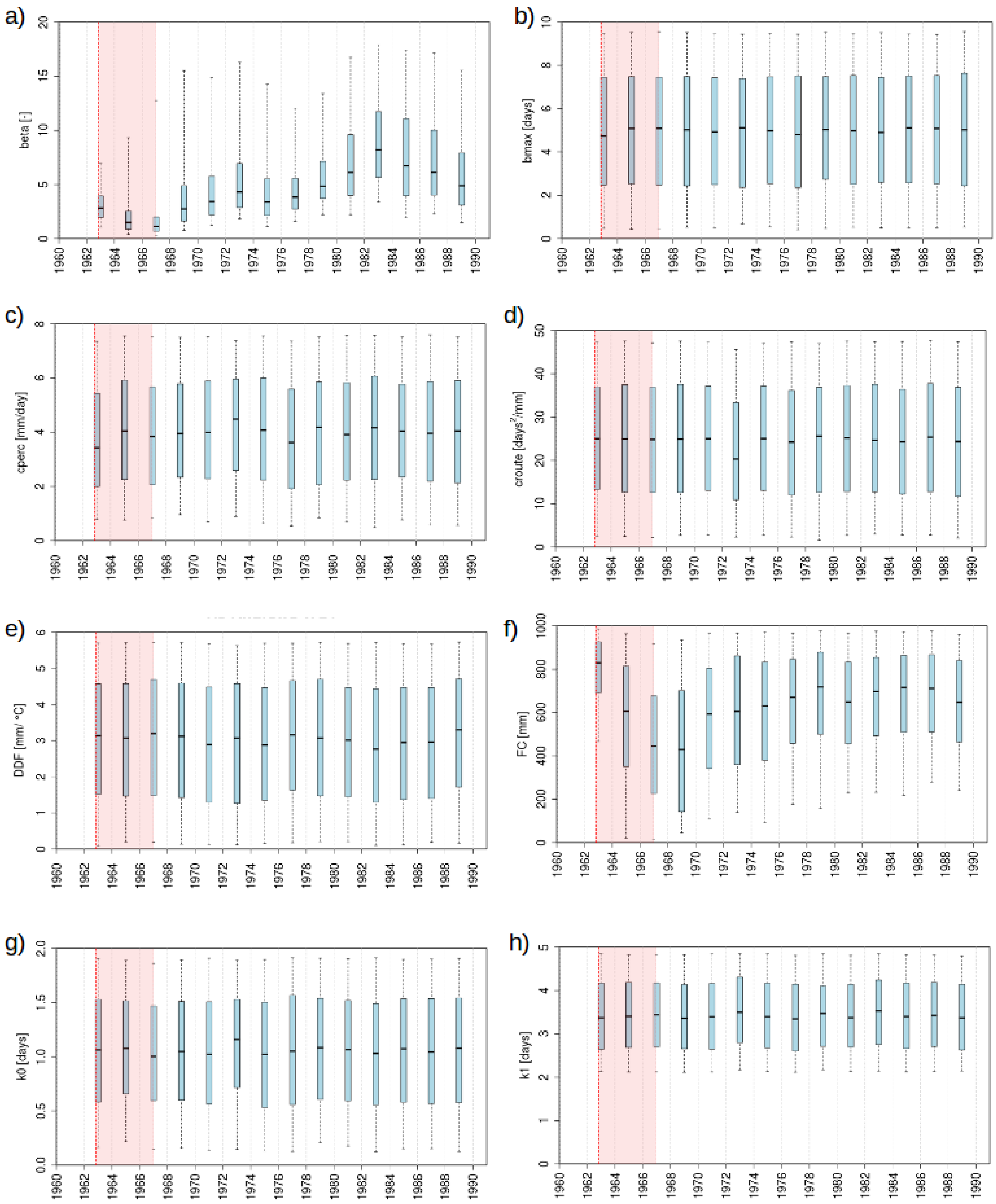

Figure S21. Posterior parameter distributions for the TUW model in HJ Andrews WS1.

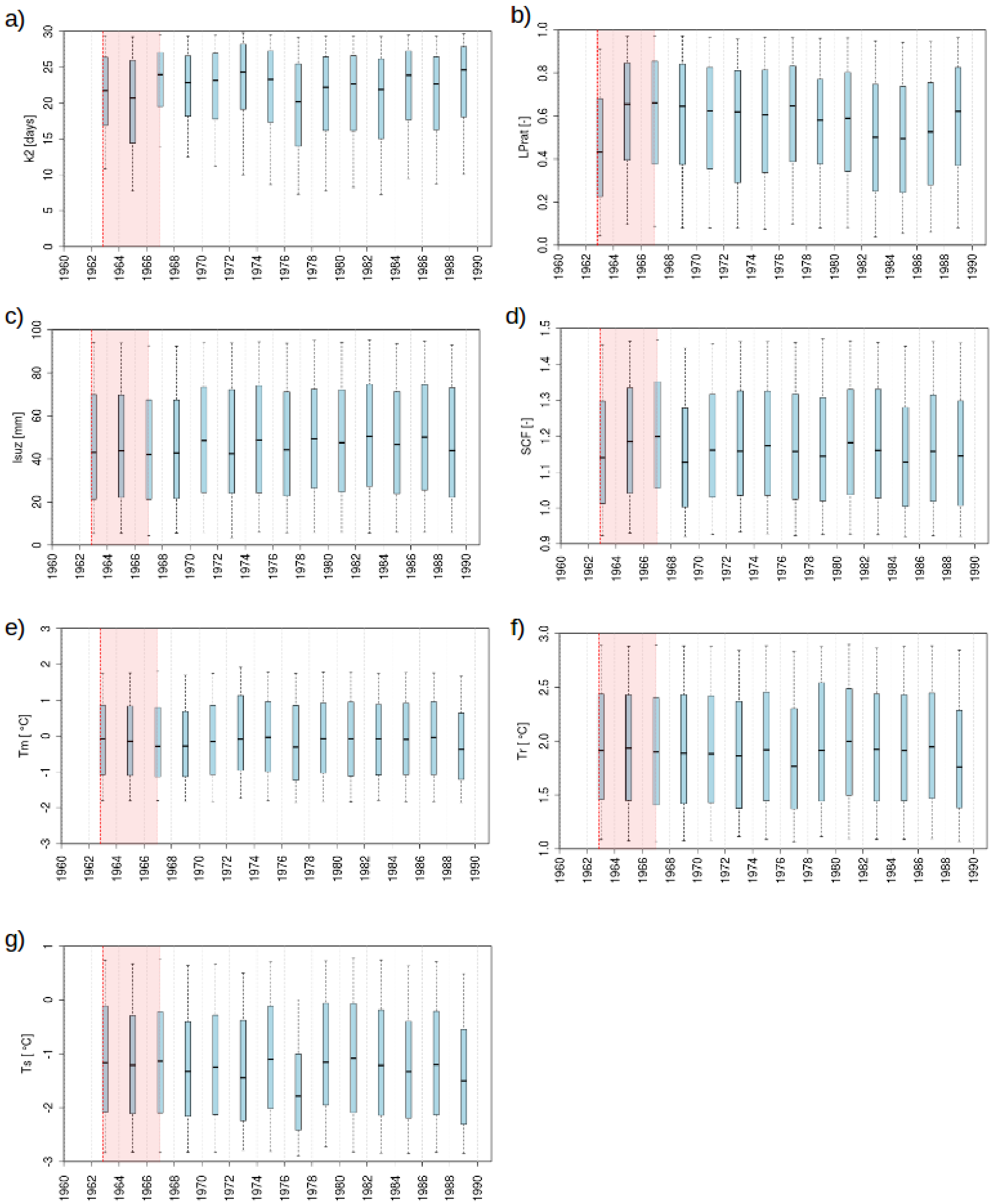

Figure S22. Continued posterior parameter distributions for the TUW model in HJ Andrews WS1.

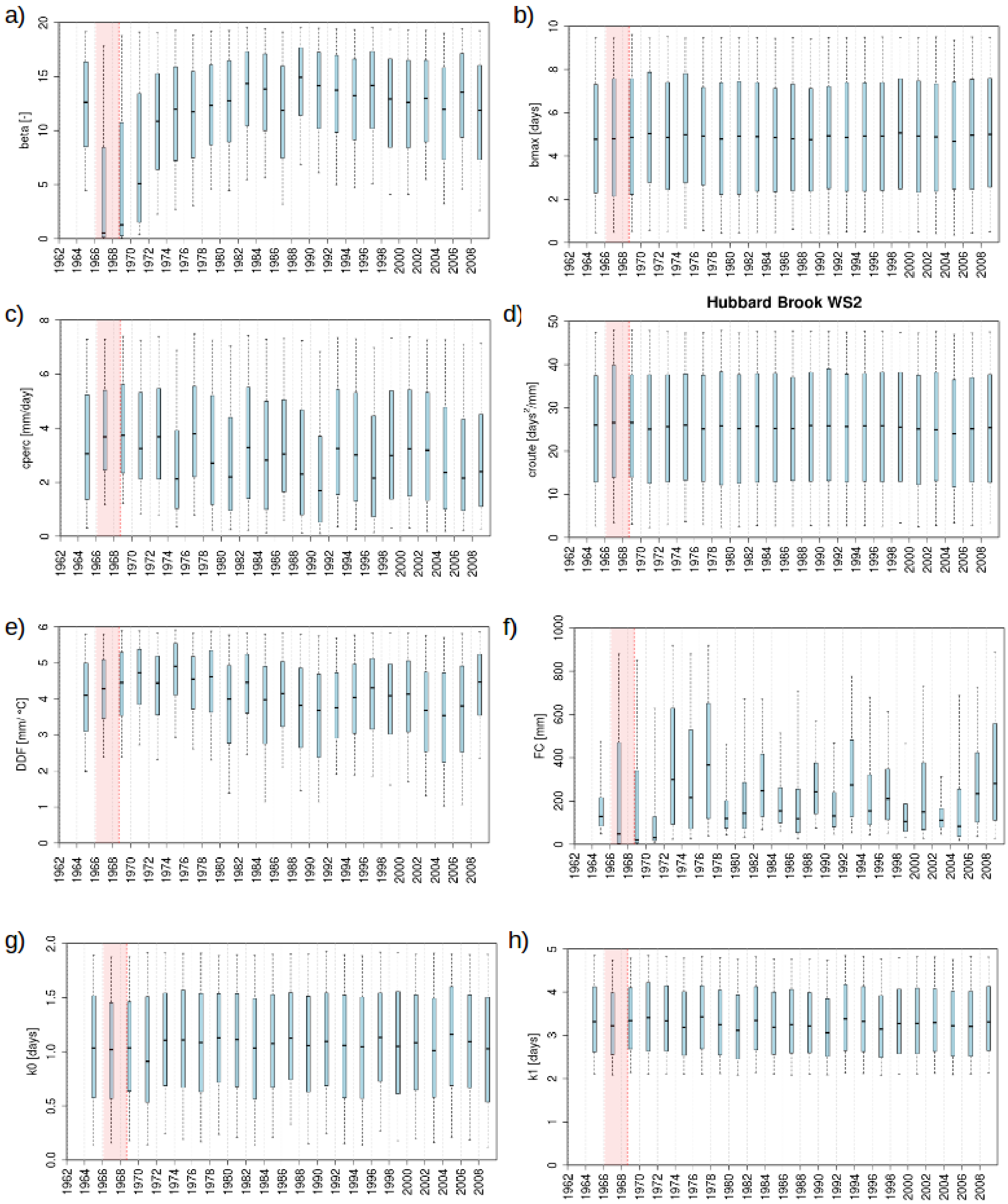

Figure S23. Posterior parameter distributions for the TUW model in Hubbard Brook WS2.

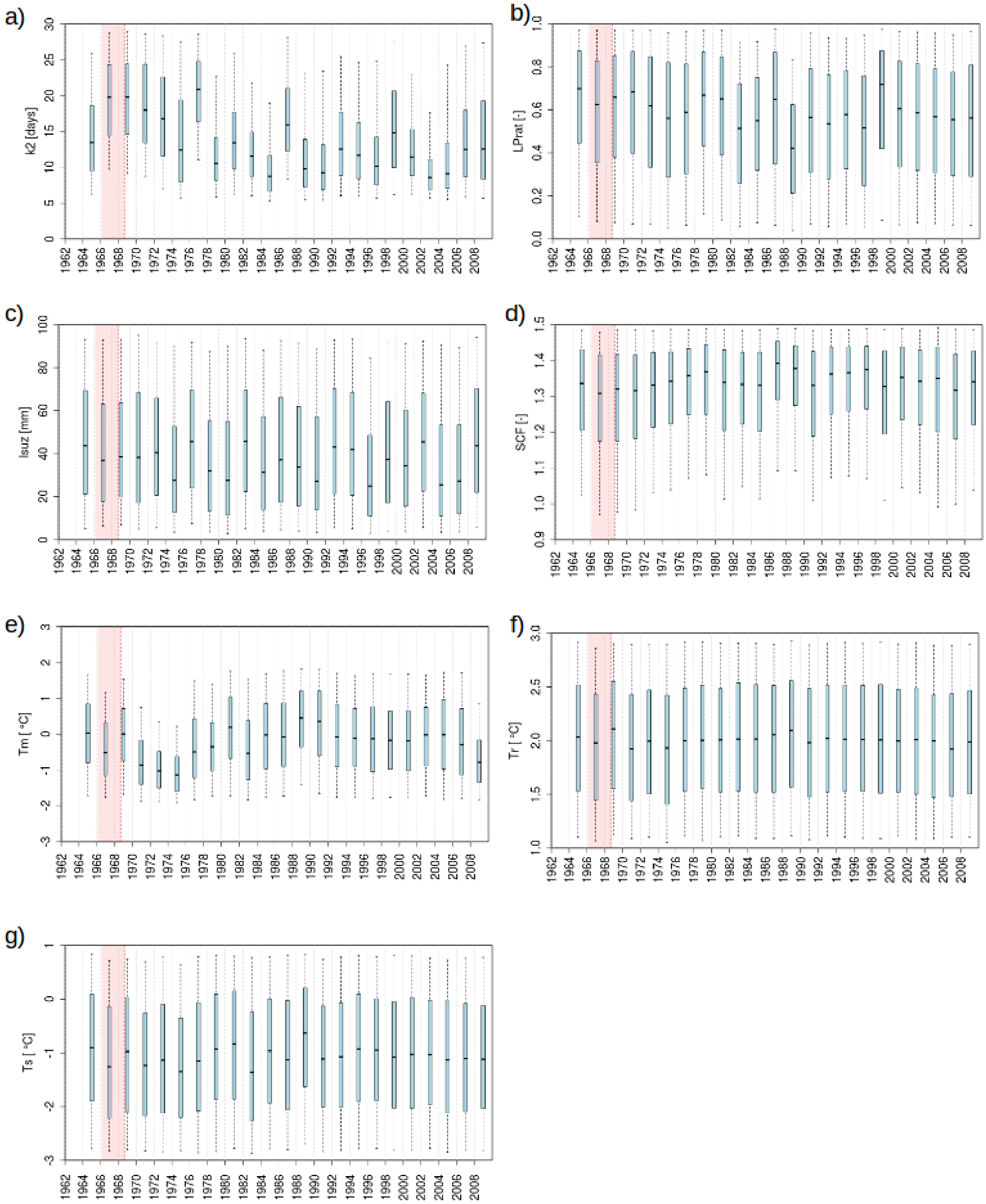

Figure S24. Continued posterior parameter distributions for the HYMOD model in Hubbard Brook WS2.

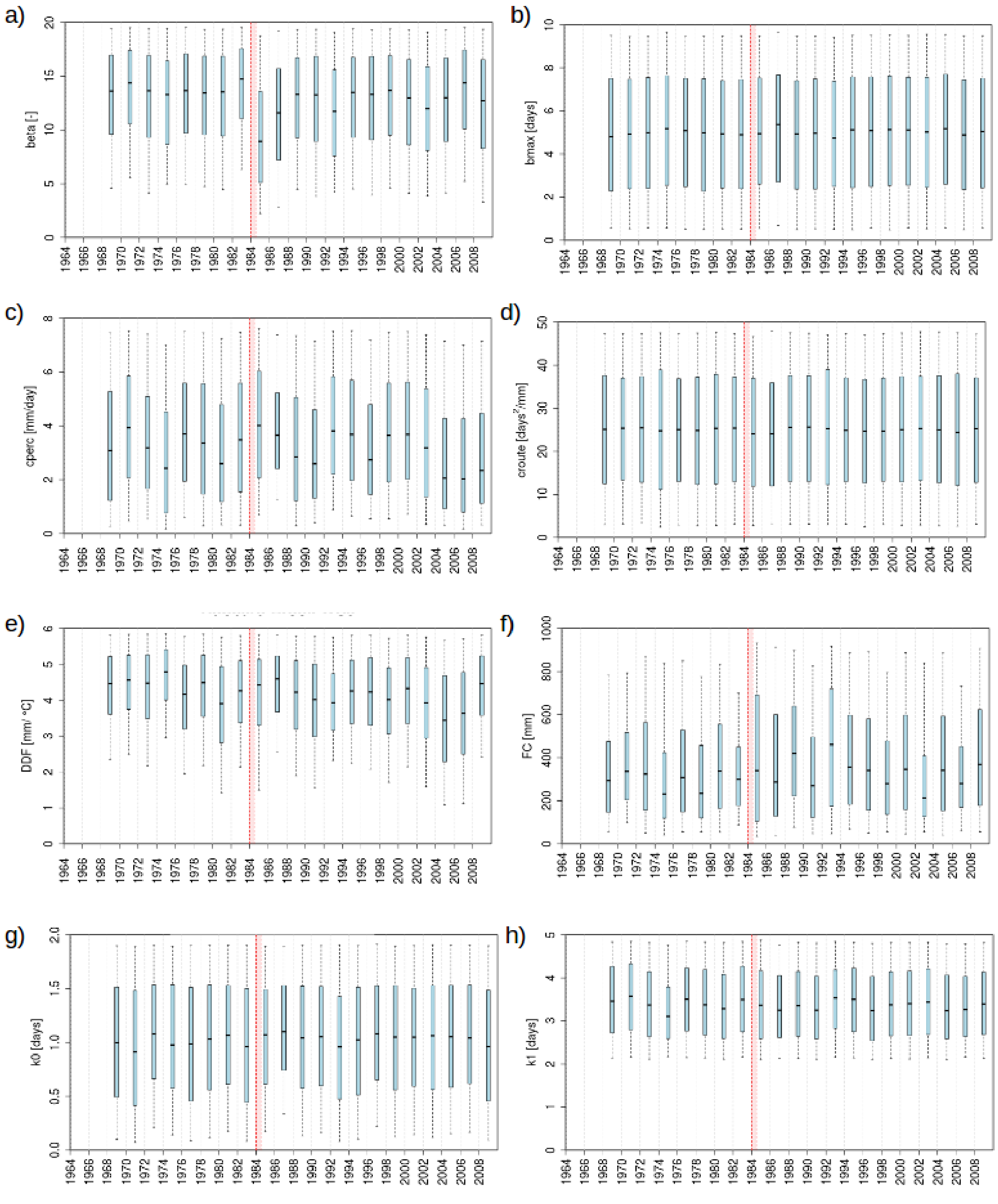

Figure S25. Posterior parameter distributions for the HYMOD model in Hubbard Brook WS5.

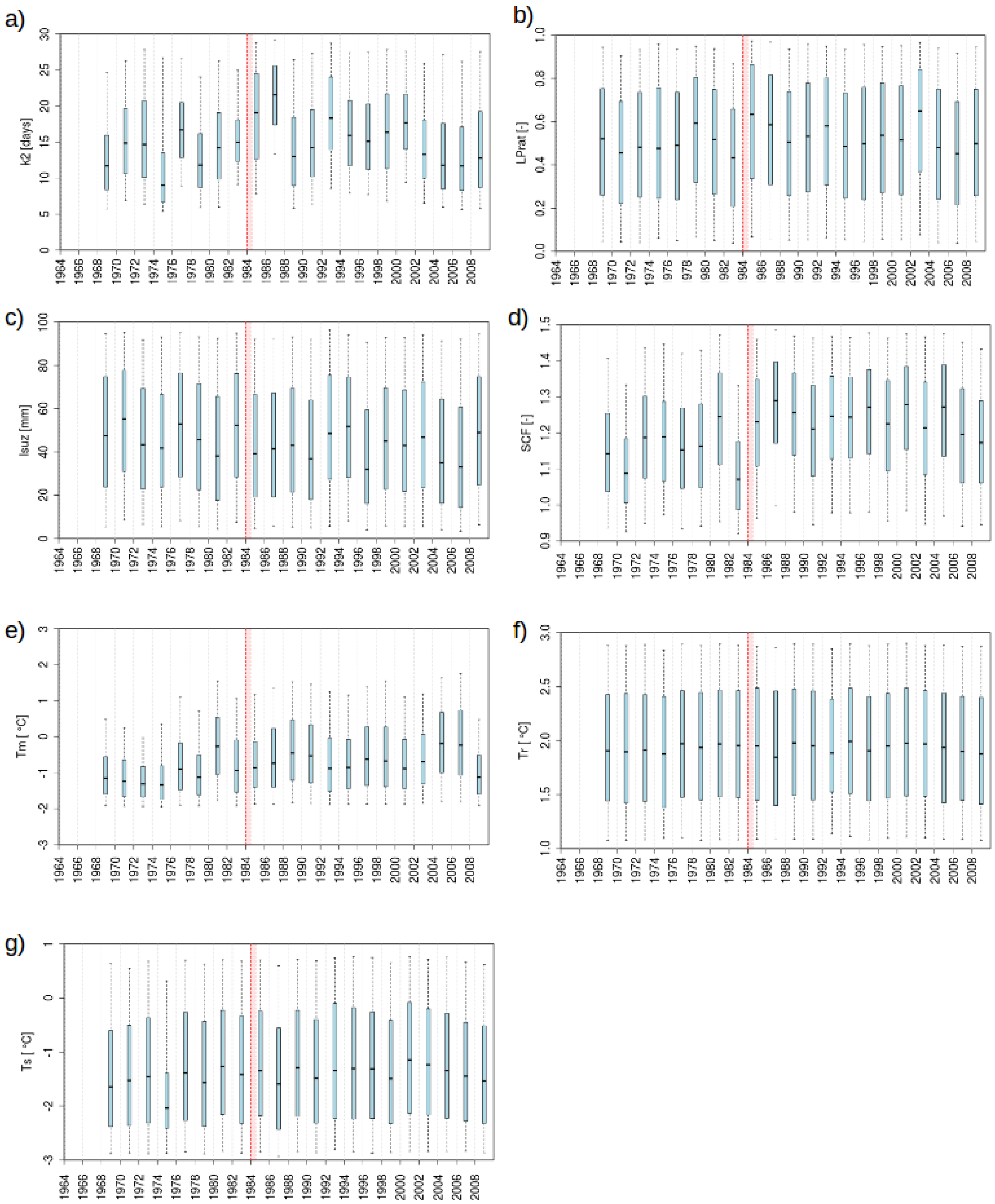

Figure S26. Continued posterior parameter distributions for the HYMOD model in Hubbard Brook WS5.