Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Discussions

Table 1. Description of streamflow characteristics used to calibrate the runoff model (adapted from Knight et al., 2014; U.S. Geological Survey, 2014) [mm d-1, millimeters per day; -, no units; a-1, per annum; %, percent]

Streamflow characteristic	Abbre-viation	Definition	Flow condition	Unit
Magnitude				
Mean annual runoff	MA41	Annual mean daily streamflow	mean-flow	[mm d^{-1}]
Maximum October runoff	MH10	Mean maximum October streamflow across the period of record	high-flow	[mm d^{-1}]
Lowest 15% of daily runoff	E85	85% exceedance of daily mean streamflow for the period of record	low-flow	[mm d^{-1}]
Rate of streamflow recession	RA7	Median change in log of streamflow for days in which the change is negative across the period of record	mean-flow	[mm d^{-1}]
Ratio				
Average 30-day maximum runoff	DH13	Mean annual maximum of a 30-day moving average streamflow divided by the median for the entire record	high-flow	[-]
Base flow	ML20	Ratio of total base flow to total flow. Base flow is the minimum flow in a 5-day window if 90% of that flow is less than the minimum of the 5 day-window before and after the considered block	low-flow	[-]
Stability of runof	TA1	Measure of the constancy of a flow regime by dividing daily flows into predetermined flow classes	mean-flow	[-]
Frequency				
Frequency of moderate floods	FH6	Average number of high-flow events per year that are equal to or greater than three times the median annual flow for the period of record	high-flow	[a^{-1}]
Frequency of moderate floods	FH7	Average number of high-flow events per year that are equal to or greater than seven times the median annual flow for the period of record	high-flow	[a^{-1}]
Variability				
Variability of March runoff	MA26	Standard deviation for March streamflow over the period of record divided by the mean streamflow for March over the period of record	mean-flow	[%]
Variability in high-flow pulse duration	DH16	Standard deviation for the yearly average high-flow pulse duration (daily flow greater than the 75th percentile) divided by the mean of the yearly average high-flow pulse duration multiplied by 100	high-flow	[%]
Variability of low-flow pulse count	FL2	Standard deviation for the average number of yearly low-flow pulses (daily flow less than the 25th percentile) divided by the mean low-flow pulse counts multiplied by 100	low-flow	[%]
Date				
Timing of annual minimum runoff	TL1	Julian date of annual minimum flow occurrence	low-flow	[Julian day]

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

Table 2. Objective functions used in model calibration. Objective functions were calculated with observed (obs) and simulated (sim) runoff (*Q*) or SFCs (*I*).

Objective function	Abbreviation	Definition	Optimal value
Nash-Sutcliffe efficiency	R_{eff}	$1-\frac{\sum(Q_{\mathrm{obs}}-Q_{\mathrm{sim}})^2}{\sum(Q_{\mathrm{obs}}-\overline{Q_{\mathrm{obs}}})^2}$	1
Efficiency for each individual SFC[1]	I_{Single}	$1-\frac{\lvert I_{\mathrm{obs}}-I_{\mathrm{sim}}\rvert}{I_{\mathrm{obs}}}$	1
SFC and Nash-Sutcliffe efficiency	$I_{\mathrm{Single_Reff}}$	$0.5\ (I_{\mathrm{Single}}+R_{\mathrm{eff}})$	1
Efficiency for the selected SFCs[2]	I_{Multi}	$0.25\ (I_{\mathrm{Single}_1}+\ldots+I_{\mathrm{Single_n}})$	1
SFCs and Nash-Sutcliffe efficiency	$I_{\mathrm{Multi_Reff}}$	$0.8\ I_{\mathrm{Multi}}+0.2\ R_{\mathrm{eff}}$	1

[1]For each of the 13 SFCs a specific I_{Single} exists.

[2]I_{Multi} consists of the *n* most robust and informative SFCs.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

Table 3. Performance measures used in model evaluation. Performance measures were calculated with observed (obs) and simulated (sim) runoff (*Q*) or SFCs (*I*).

Performance measure	Abbreviation	Definition	Optimal value
Nash-Sutcliffe	R_{eff}	$1-\frac{\sum(Q_{\mathrm{obs}}-Q_{\mathrm{sim}})^2}{\sum(Q_{\mathrm{obs}}-\overline{Q_{\mathrm{obs}}})^2}$	1
Mean absolute relative error[1]	MARE	$1-\frac{1}{n}\sum\frac{\lvert Q_{\mathrm{obs}}-Q_{\mathrm{sim}}\rvert}{Q_{\mathrm{obs}}}$	1
Normalized SFC error[2]	nSFC	$\frac{I_{\mathrm{obs}}-I_{\mathrm{sim}}}{R_{\mathrm{obs}}}$	0

[1] *n* is the number of days.

[2] *R* is the range of possible values of a SFC for the respective catchment.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

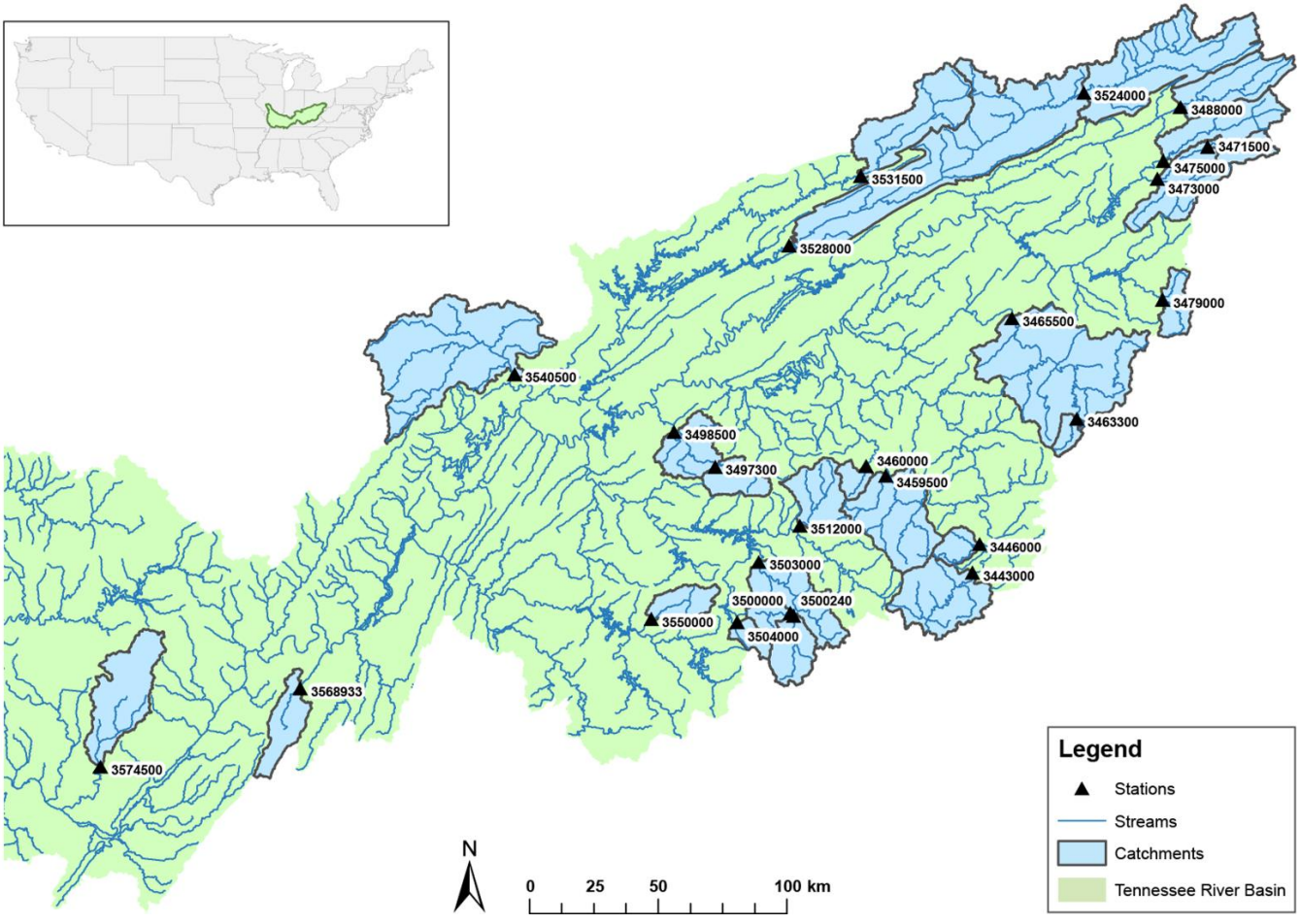


Figure 1. Location of the 25 study catchments in the Tennessee River basin (Table 1 in Vis et al. (2015) for more information).

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Discussions

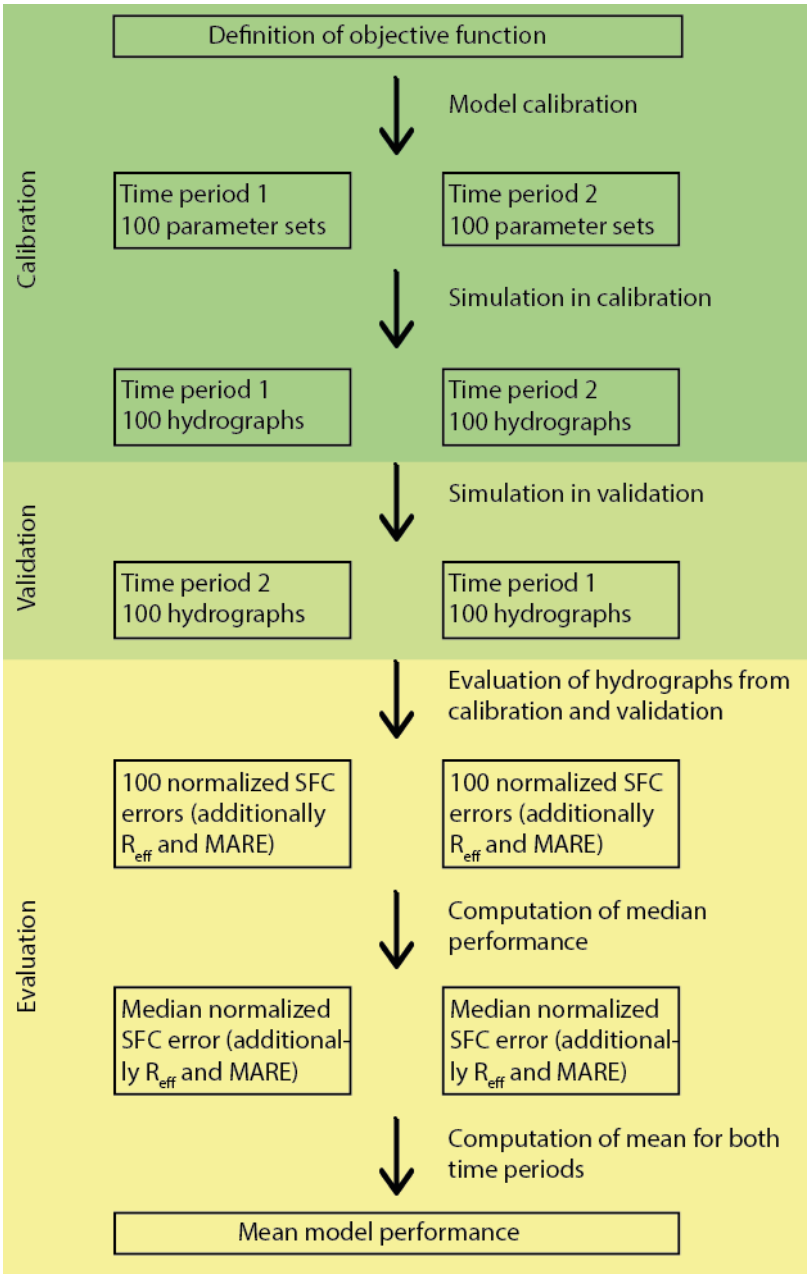
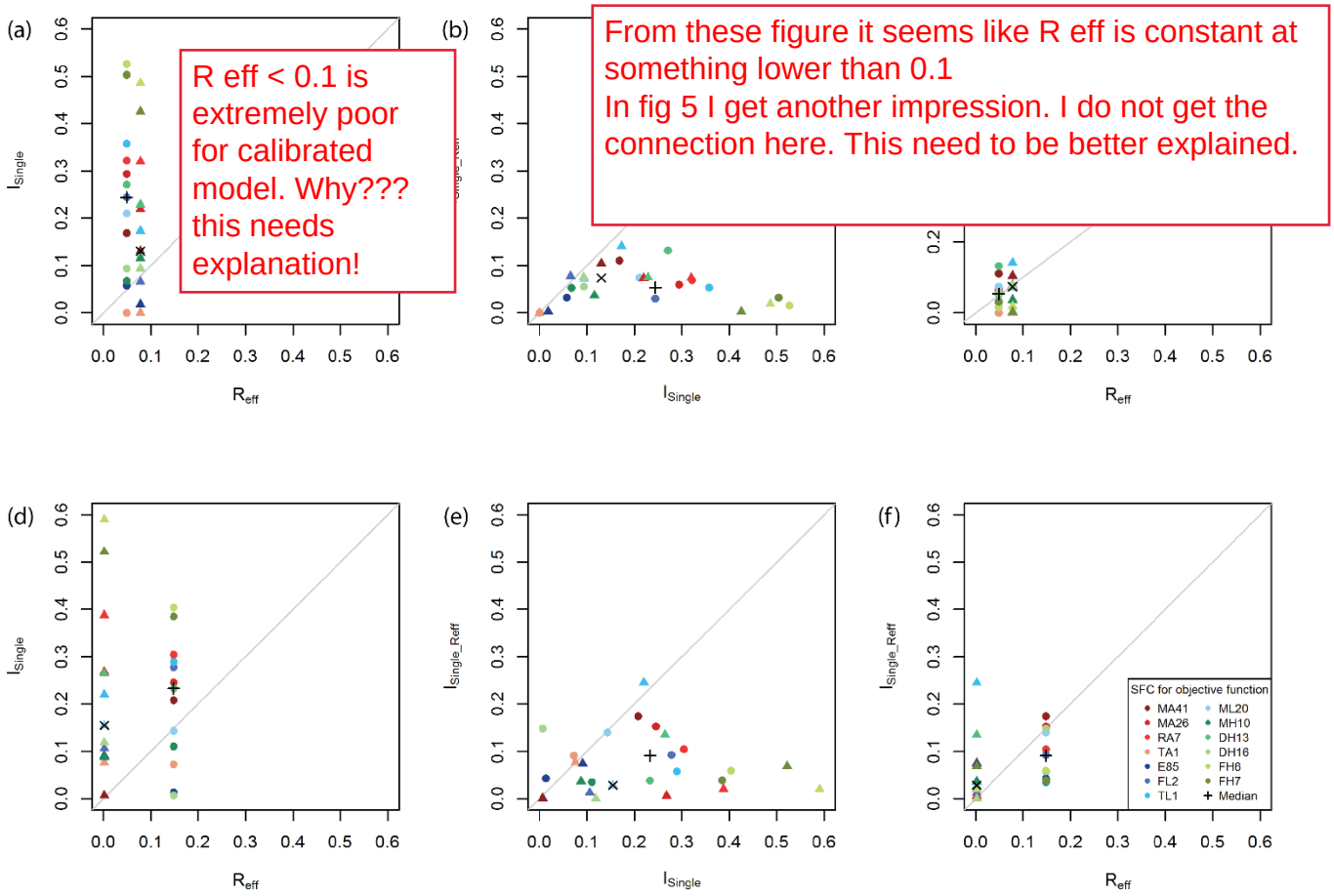


Figure 2. Flow chart of the modelling approach consisting of calibration, validation and evaluation in time period 1 (1984 - 1996) and time period 2 (1997 - 2009) and completed for each of the five objective function types R_{eff}, I_{Sinlge}, I_{Single_Reff}, I_{Multi}, I_{Multi_Reff}.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions



R eff < 0.1 is extremely poor for calibrated model. Why??? this needs explanation!

From these figure it seems like R eff is constant at something lower than 0.1
In fig 5 I get another impression. I do not get the connection here. This need to be better explained.

Figure 3. Comparison of absolute normalized TA1 error (nSFC) in calibration (a-c) and validation (d-f) calculated from model calibrations with the objective functions R_{eff}, I_{Single} and I_{Single_Reff}. Absolute normalized SFC errors correspond to the median of the 25 catchments and are shown separately for both modelling time periods (triangles for period 1 (1984 - 1996) and circles for period 2 (1997 - 2009)). The x and plus symbols represent the median of period 1 and period 2 respectively.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Discussions

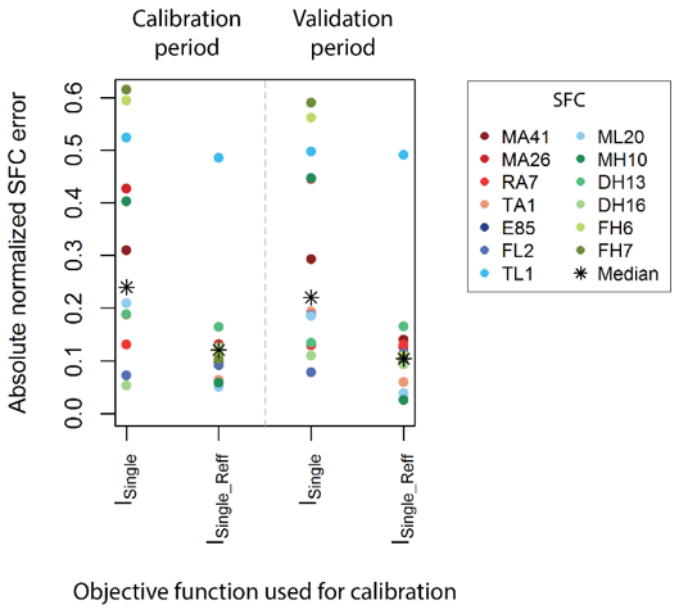


Figure 4. Absolute normalized SFC error (nSFC) for the model calibration (left side) and model validation periods (right side) calculated from model calibrations with the objective functions I_{Single} and I_{Single_Reff}. Values correspond to the median error of all 13 objective function versions and were calculated from the median of the 25 catchments and the mean of both modelling time periods.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

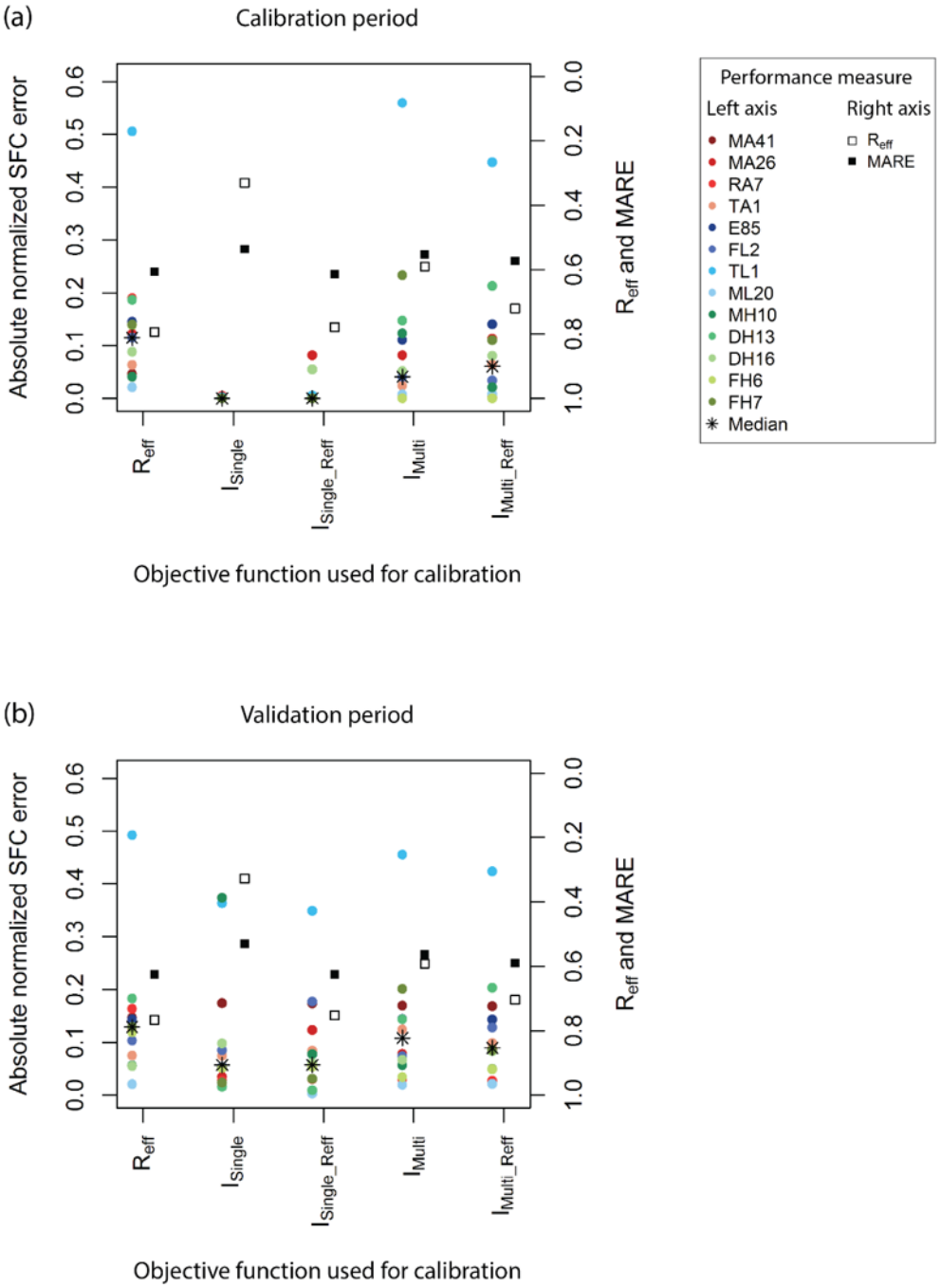


Figure 5. Model performance in a) calibration and b) validation for absolute normalized SFC errors (nSFC) as well as R_{eff} and MARE depending on the the objective function used in calibration (optimal value is one for R_{eff} and MARE and zero for all SFC related performance measures). Model performance values correspond to the median of the 25 catchments and the mean of both modelling time periods. R_{eff} and MARE values for the objective functions I_{Single} and I_{Single_Reff} were calculated as the median over all 13 versions. Note that in calibration with I_{Single} and I_{Single_Reff} the values of all or most absolute normalized SFCs plot at the same value.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

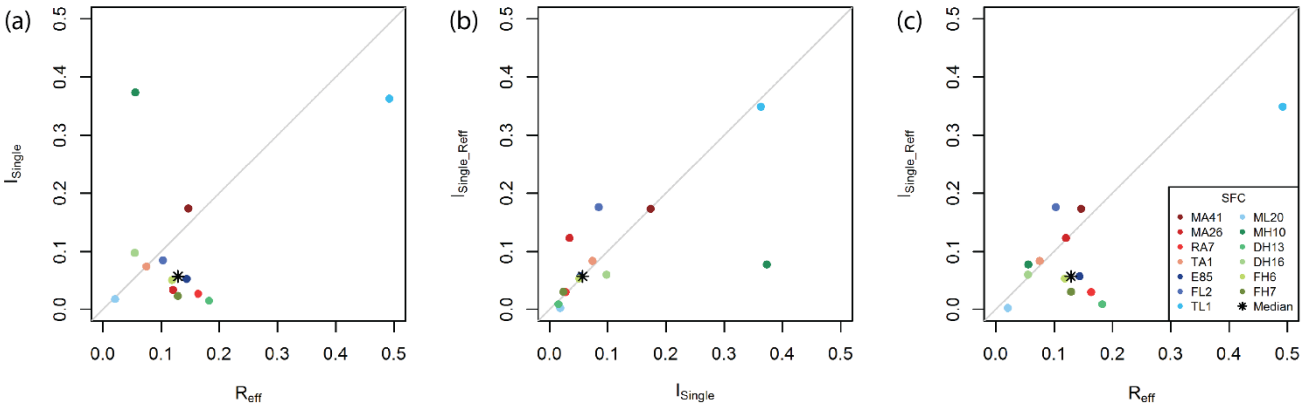


Figure 6. Comparison of absolute normalized SFC errors (nSFC) in validation calculated from model calibrations with the objective functions R_{eff}, I_{Single} and I_{Single_Reff}. Absolute normalized SFC errors correspond to the median of the 25 catchments and the mean of both modelling time periods.

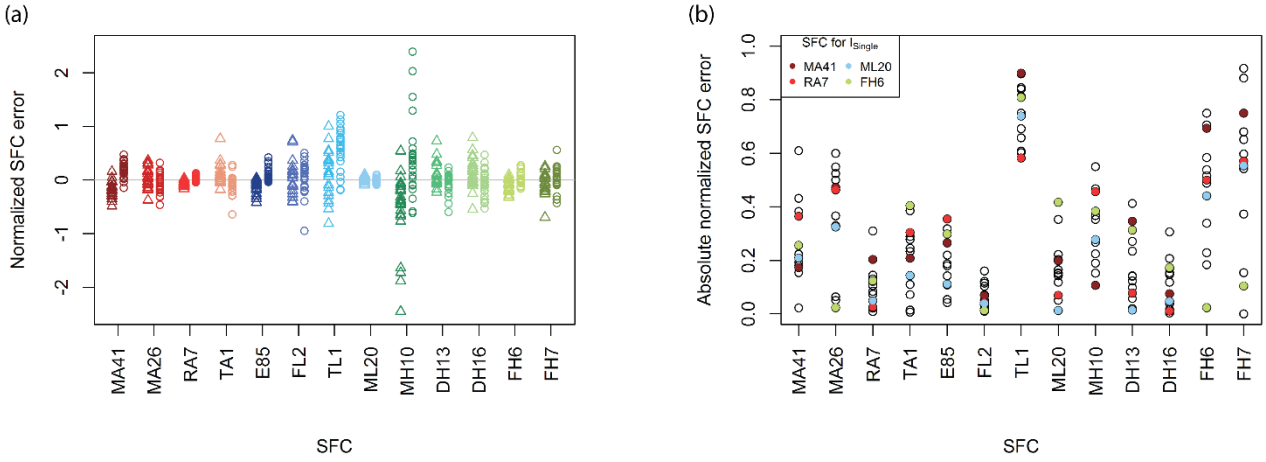


Figure 7. a) Robustness: normalized SFC errors (nSFC) in validation calculated from model calibrations with the objective function I_{Single} for the respective SFC. Values are shown for all 25 catchments and both modelling time periods (triangles for period 1 (1984 - 1996) and circles for period 2 (1997 - 2009)). b) Information value: absolute normalized SFC errors (nSFC) in validation calculated from model calibrations with all 13 objective functions I_{Single}. Model performance values correspond to the median of the 25 catchments and the mean of both modelling time periods. Each circle represents a SFC used for I_{Single}. The coloured circles show the information value of the final selection of SFCs for the objective function I_{Multi}.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

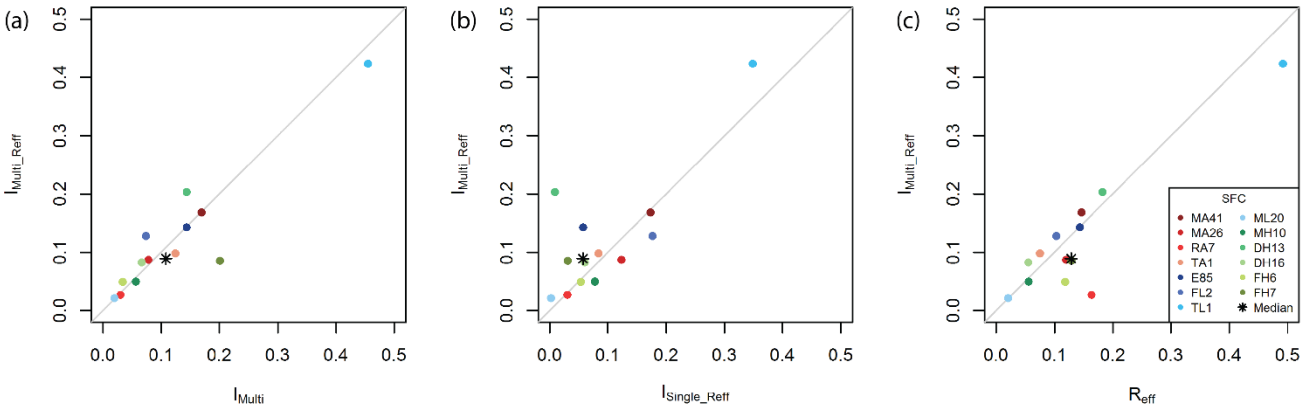


Figure 8. Comparison of absolute normalized SFC errors (nSFC) in validation calculated from model calibrations with the objective functions R_{eff}, I_{Single_Reff}, I_{Multi} and I_{Multi_Reff}. Absolute normalized SFC errors correspond to the median of the 25 catchments and the mean of both modelling time periods.

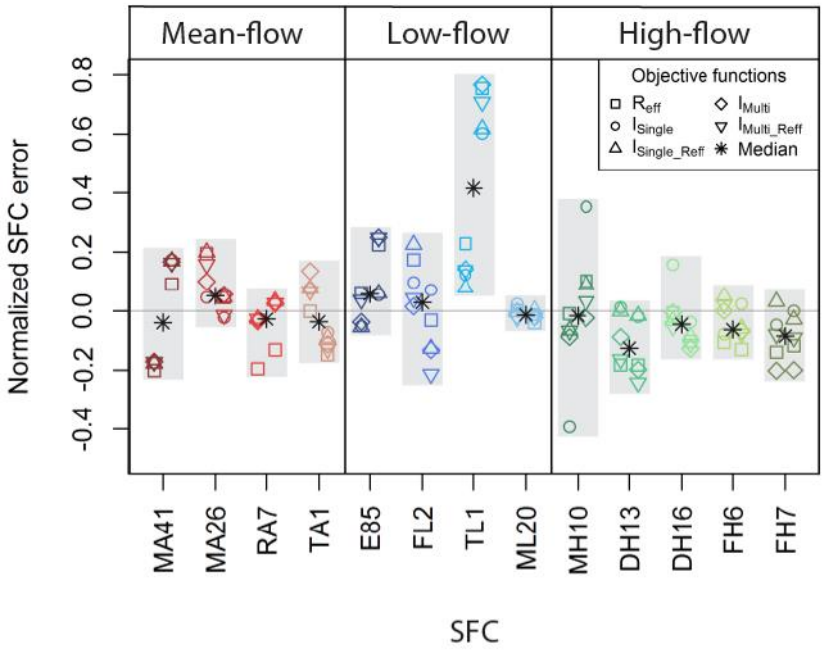


Figure 9. Normalized SFC errors (nSFC) in validation depending on the objective function used in calibration. Model performance values correspond to the median of the 25 catchments and are shown for both modelling time periods (period 1 (1984 - 1996) on the left side and period 2 (1997 - 2009) on the right side).

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-546, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 19 October 2016
© Author(s) 2016. CC-BY 3.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

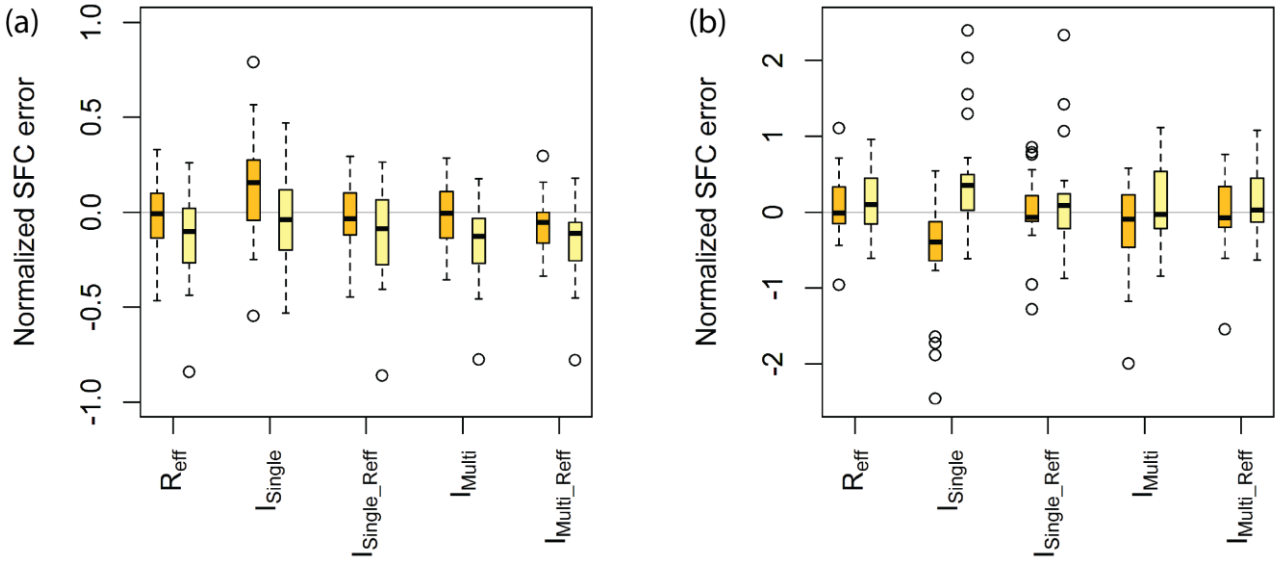


Figure 10. a) Normalized DH16 errors (nSFC) and b) normalized MH10 errors (nSFC) in validation depending on the objective function used in calibration. Absolute normalized SFC errors are shown for all 25 catchments and for both modelling time periods (period 1 (1984 - 1996) in orange on the left side and period 2 (1997 - 2009) in yellow on the right side). Note the difference in y-axis.