Multi-variable and multi-site calibration and validation of SWAT for water quality in the Kaskaskia River watershed

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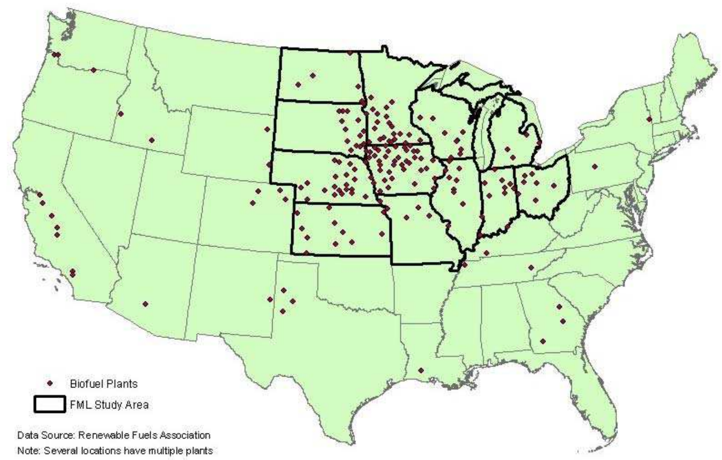
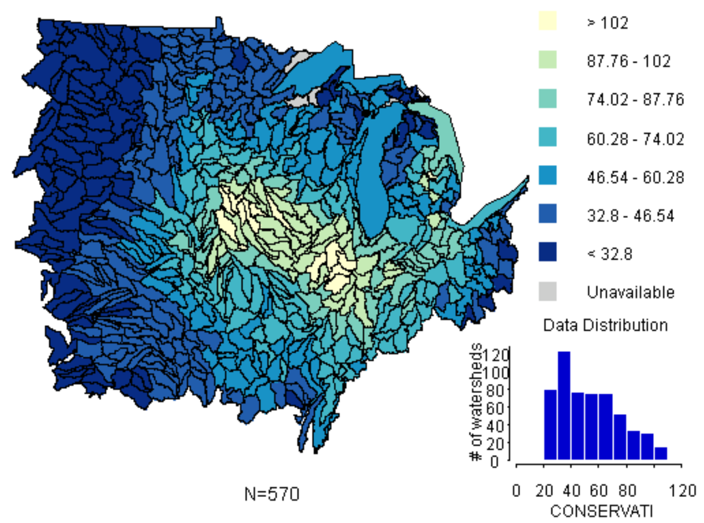
Introduction

- Part of EPA's Ecological Services Research Program (ESRP)
- Two change drivers of interest for FML study:

- Biofuels
- Agricultural conservation practices



Locations of ethanol biorefineries and FML boundary



Conservation program participation (\$/acre)

Objectives & Hypothesis

- Evaluate the effects of different HRU definition in SWAT model on simulation results (flow, sediment and nutrients)
- Calibrate and validate the model which can mostly represent the current land characteristics, and simulate the impact of BT land use change

Hypothesis:

- A more detailed HRU definition can better represent the real landscape characteristics, thus simulation results are closer to observations

Study area: Kaskaskia River Basin

- Located in the downstream of Upper Mississippi River Basin

- Excessive nutrient loadings from the Mississippi River Basin resulted in hypoxia in the Gulf of Mexico

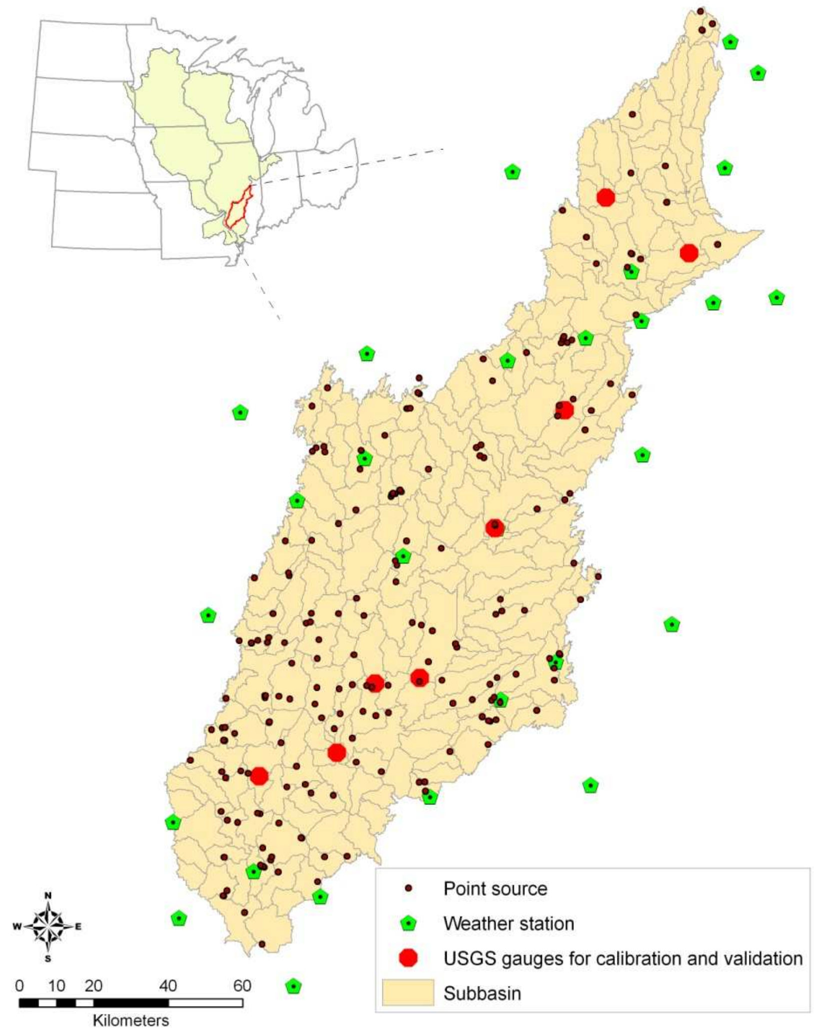
- Area: 14,152.63 km^2 (218 subbasins)

- Available measured data:

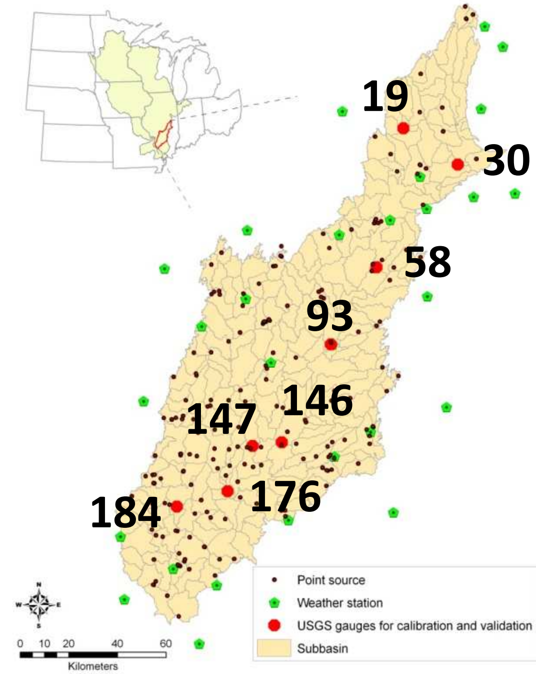
- USGS gauges: 8 out of 22 are used for model calibration and validation (1960 - 2009)
- Weather station: 28 pre-processed using PRISM dataset and IDW method (1960 - 2007)
- Point source: 265 (1998 - 2007)

  Collected at EPA's Envirofacts Website

  http://www.epa.gov/enviro/html/pcs/adhoc.html



Measured streamflow and WQ data



USGS	Sub	drainage area(mi2)	Flow	TSScon	Ammonia	orgN	Nitrate	TN	solP	TP	covered year
05591200	30	473	10/1/1970 - 12/31/2009	1979-1992 (218)	-	1977-1997 (104)	1976-1980 (45)	1980-1997 (137)	1978-1997 (166)	1977-1997 (175)	1976-1997
05591700	19	112	2/20/1980 - 12/31/2009	just 1 point	3/1980-1997 (129)	3/1980-1996 (56)	-	3/1980-1997 (113)	3/1980-1997 (125)	3/1980-1997 (131)	3/1980-1997
05592100	58	1330	7/1/1970 - 12/31/2009	-	1977-1997 (174)	1977-1997 (97)	5 points	1977-1997 (164)	1980-1998 (144)	1977-1997 (173)	1977-1998
05592500	93	1940	1/1/1960 - 12/31/2009	-	1977-1997 (169)	1979-1997 (98)	-	1979-1997 (144)	1979-1997 (150)	1977-1997 (167)	1977-1997
05593000	146	2719	1/1/1960 - 12/31/2009	-	-	-	-	-	-	-	-
05594000	147	735	1/1/1960 - 12/31/2009	-	1978-1997 (161)	just 1 point	5 points	4 points	1982-1998 (111)	1982-1997 (110)	1978-1998
05594100	176	4393	10/1/1969- 12/31/2009	1975-1992 (213)	1977-1997 (155)	1977-1997 (131)	4 points	1974-1997 (196)	1977-1997 (178)	1974-1997 (214)	1974-1997
05594800	184	464	10/1/1970 - 12/31/2009	5 points	1978-1997 (163)	just 1 point	-	5 points	1982-1997 (113)	1982-1997 (114)	1978-1997

Methodology

- Soil and Water Assessment Tool (SWAT) model

- Can predict long-term impacts of land use/ land management on water, sediment and agricultural chemical yields at different temporal and spatial scales in a complex watershed
- Key GIS input files: DEM, land use/land cover, soil data
- HRU (hydrologic response unit): a homogeneous unit in a subbasin that shares the same land use and soil type

Threshold for land use

Threshold for soil type

	1/0	**5**	**10**	**15**
1	1_1	1_5	1_10	1_15
5	5_0	5_5	5_10	5_15
10	10_0	10_5	10_10	10_15
15	15_0	15_5	15_10	15_15

- Simulation period: 1960 – 2007 (1960-62: warming-up; 1963-1985: calibration; 1986 – 2007: validation)

- Load Estimation Tool (LOADEST)

- Given a time series of streamflow, constituent concentration, LOADEST can estimate constituent concentration over a user-specified time interval using various regression models

Compared to the exact land use (0/0 thresholds)

	Soil	0 0	1 1	1 5	1 10	1 15	5 0	5 5	5 10	5 15	10 0	10 5	10 10	10 15	15 0	15 5	15 10	15 15
HRU no.		20327	13731	11849	10222	8969	7039	5464	4659	4069	3075	2354	1998	1754	2220	1698	1424	1256
Land Use																		
	B	2.52	2.60	2.60	2.58	2.62	2.53	2.53	2.52	2.55	1.00	1.01	1.01	1.04	0.48	0.48	0.48	0.49
CORN	C	1.89	1.96	1.95	1.96	1.90	1.02	1.01	1.00	0.95	0.14	0.12	0.12	0.07	0.01	0.01	0.01	0.00
	D	0.99	1.02	1.03	1.04	1.06	0.96	0.97	0.99	1.02	0.27	0.28	0.28	0.29	0.05	0.06	0.06	0.06
	Total	5.40	5.58	5.58	5.58	5.58	4.51	4.51	4.51	4.51	1.41	1.41	1.41	1.41	0.54	0.54	0.54	0.54
	B	20.19	20.81	20.78	20.77	20.86	24.00	23.97	23.96	24.08	28.52	28.47	28.46	28.66	31.27	31.21	31.18	31.41
CnSo	C	17.41	18.10	18.04	17.84	17.49	21.72	21.65	21.40	21.00	28.57	28.48	28.15	27.59	32.76	32.65	32.30	31.68
	D	8.16	8.45	8.53	8.75	9.00	9.95	10.05	10.31	10.59	13.58	13.72	14.07	14.43	15.16	15.33	15.71	16.11
	Total	45.76	47.36	47.36	47.36	47.36	55.67	55.67	55.67	55.67	70.68	70.68	70.68	70.68	79.19	79.19	79.19	79.19
	B	0.38	0.11	0.11	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn+Other	C	0.74	0.17	0.17	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.30	0.13	0.13	0.13	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	1.41	0.41	0.41	0.41	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOYB	C	0.21	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	0.33	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	2.08	2.06	2.04	1.99	2.03	1.63	1.62	1.55	1.59	0.51	0.51	0.47	0.49	0.08	0.08	0.08	0.08
Soyb+Other	C	6.17	6.23	6.24	6.28	6.23	5.58	5.59	5.66	5.60	1.33	1.33	1.39	1.38	0.54	0.54	0.54	0.53
	D	2.08	2.11	2.12	2.13	2.13	2.05	2.05	2.05	2.06	0.41	0.40	0.38	0.38	0.11	0.10	0.10	0.11
	Total	10.34	10.40	10.40	10.40	10.40	9.26	9.26	9.26	9.26	2.24	2.24	2.24	2.24	0.72	0.72	0.72	0.72
	B	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WWHT	C	0.25	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.08	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	0.39	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	2.92	2.94	2.89	2.84	2.76	3.09	3.02	2.96	2.87	2.98	2.89	2.82	2.75	2.41	2.34	2.27	2.16
FRST	C	13.90	14.39	14.51	14.70	14.97	15.93	16.08	16.29	16.59	17.35	17.53	17.76	18.02	13.96	14.12	14.31	14.59
	D	1.48	1.51	1.44	1.30	1.11	1.62	1.54	1.40	1.18	1.76	1.67	1.51	1.32	1.29	1.20	1.08	0.92
	Total	18.30	18.84	18.84	18.84	18.84	20.64	20.64	20.64	20.64	22.09	22.09	22.09	22.09	17.66	17.66	17.66	17.66
	B	1.88	1.68	1.66	1.67	1.67	0.62	0.61	0.62	0.61	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.00
PAST	C	4.19	4.03	4.04	4.06	4.11	1.43	1.44	1.45	1.47	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00
	D	0.92	0.87	0.87	0.84	0.80	0.28	0.28	0.26	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	7.00	6.57	6.57	6.57	6.57	2.32	2.32	2.32	2.32	0.11	0.11	0.11	0.11	0.00	0.00	0.00	0.00
	B	3.58	3.54	3.54	3.55	3.57	2.07	2.06	2.07	2.10	1.12	1.12	1.13	1.14	0.78	0.78	0.78	0.78
URBN	C	4.30	4.25	4.26	4.26	4.23	3.18	3.19	3.19	3.16	0.56	0.55	0.55	0.53	0.00	0.00	0.00	0.00
	D	1.23	1.19	1.18	1.17	1.18	0.69	0.69	0.68	0.68	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
	Total	9.11	8.98	8.98	8.98	8.98	5.94	5.94	5.94	5.94	1.70	1.70	1.70	1.70	0.78	0.78	0.78	0.78
Wetland	Total	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WATR	Total	1.95	1.77	1.77	1.77	1.77	1.65	1.65	1.65	1.65	1.78	1.78	1.78	1.78	1.10	1.10	1.10	1.10
Total		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Fertilizer input preparation

- State level (NASS): Annual chemical application rates and acres treated for field crops (corn, soybeans, cotton, potatoes, wheat) by major producing states
- Available at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1560
- Data were collected from 1990 to 2009 for corn, soybean and wheat in Illinois

- County level: Annual acres on which used commercial fertilizer for each county (Census of agriculture)
- Available at http://www.agcensus.usda.gov/Publications/
- Data were collected for 1987, 1992, 1997, 2002, 2007 for the counties within the Kaskaskia River Basin
- Calculate the annual average fertilizer usage during 1990 – 2009 for each county

6-year average crop area at subbasin level

(1990-2009)	Year	CORN	CnSo	SoOt	CrWh	CrOt	SoWh	WWHT	SOYB	SoFl	WhOt
Area in 1_1 model (ha)		79014.54	670258.95	91311.31	3728.85	2026.00	53771.13	365.35	908.23	2068.54	54.50
1990	1	Corn	Corn	corn	Corn/ Wheat	Corn/ Wheat	corn	wheat	soybean	soybean	wheat
1991	2	Corn	soybean	soybean/ wheat	wheat harvest	wheat harvest & soybean	soybean/ wheat	wheat harvest	soybean	soybean	wheat harvest
1992	3	Corn	Corn	soybean	Corn/ Wheat	Corn/ Wheat	soybean	wheat	soybean	soybean	soybean
1993	4	Corn	soybean	corn	wheat harvest	wheat harvest & soybean	corn	wheat harvest	soybean	soybean	wheat
1994	5	Corn	Corn	soybean/ wheat	Corn/ Wheat	Corn/ Wheat	soybean/ wheat	wheat	soybean	soybean	wheat harvest
1995	6	Corn	soybean	soybean	wheat harvest	wheat harvest & soybean	soybean	wheat harvest	soybean	soybean	soybean

Example:

<u>Year1:</u>

Corn: CORN, CnSo, SoOt, CrWh, CrOt, SoWh

Soybean: SOYB, SoFl

Wheat: CrWh, CrOt, WWHT, WhOt

- Subbasin level:

$$R_{corn,s} = \sum_i \left(F_{corn,i} * \frac{A_{corn,s} * P_{s,i}}{\sum_s (A_{corn,s} * P_{s,i})} \right)$$

$R_{corn,s}$ = Fertilizer application rate on *corn* fields in subbasin *s* (kg/ha).

$P_{s,i}$ = Percentage of area of subbasin *s* is covered by county *i*, and $\sum_i P_{s,i} = 1$

$F_{corn,i}$ = Fertilizer usage on *corn* fields in county *i* (kg).

$A_{corn,s}$ = *Corn* area of subbasin *s* (ha).

		Average rate (kg/ha)	Min. rate (kg/ha)	Max. rate (kg/ha)	Illinois state app. rate in 1990
corn	N	187.60	134.73	296.4	183.77
	P	78.77	56.52	124.5	82.58
soybean	N	3.21	2.55	4.9	4.51
	P	13.66	10.85	20.82	17.54
wheat	N	98.1065	37.29	1811.16	94.39
	P	66.6517	25.45	1227.22	73.74

Methodology

- Model evaluation statistics
- Coefficient of determination (R^2)
- Nash-Sutcliff efficiency (NSE)
- Percent bias (PBIAS)
- RMSE-observations standard deviation ratio (RSR)
- Relative error (RE)

$$R^2 = [\frac{\sum_{i=1}^{n}(O_i - O_{avg})(P_i - P_{avg})}{[\sum_{i=1}^{n}(O_i - O_{avg})^2 \sum_{i=1}^{n}(P_i - P_{avg})^2]^{0.5}}]^2$$

$$NSE = 1 - [\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}]$$

$$PBIAS = [\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) * 100}{\sum_{i=1}^{n}(Y_i^{obs})}]$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}]}{[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}]}$$

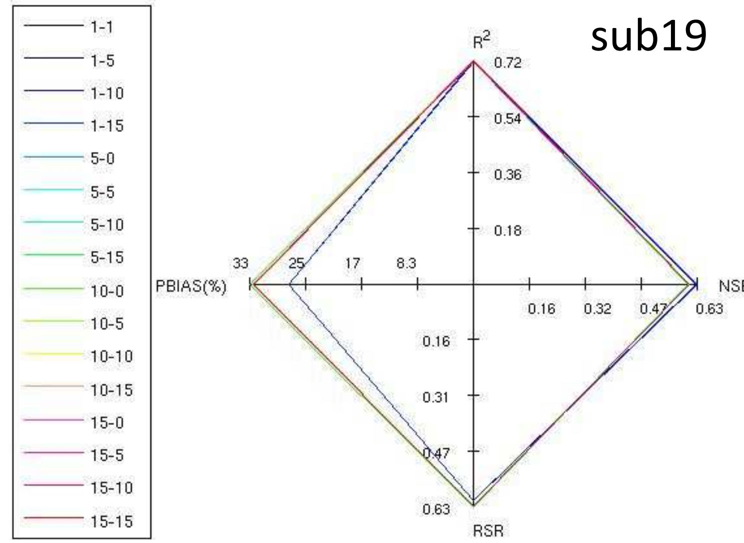
$$RE(\%) = \left|\frac{(O - P)}{O}\right| * 100$$

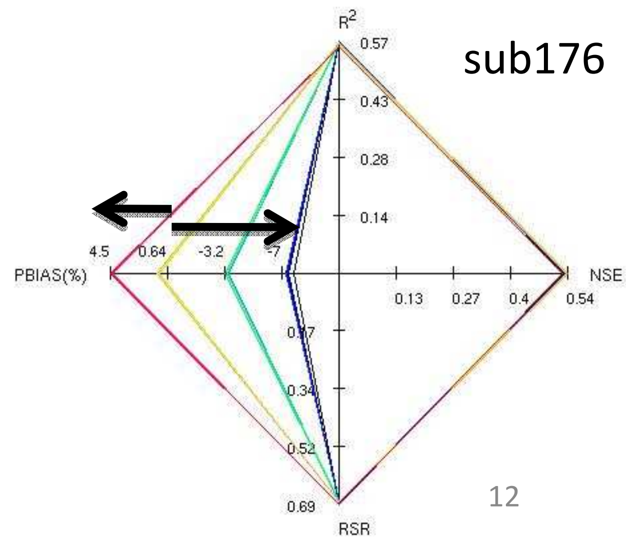
*Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. of ASABE. 50(3):885-900

Ranges of R^2, NSE, PBIAS and RSR values for different HRU definitions for streamflow

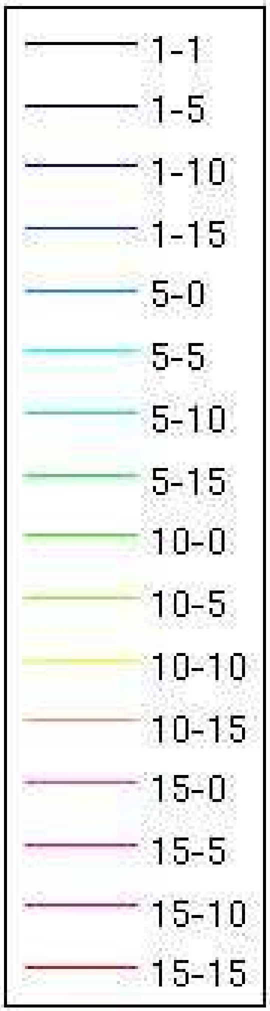
Satisfactory: $R^2 \geq 0.6$
NSE $\geq$ 0.5
RSR $\leq$ 0.7
PBIAS$\leq \pm$25%

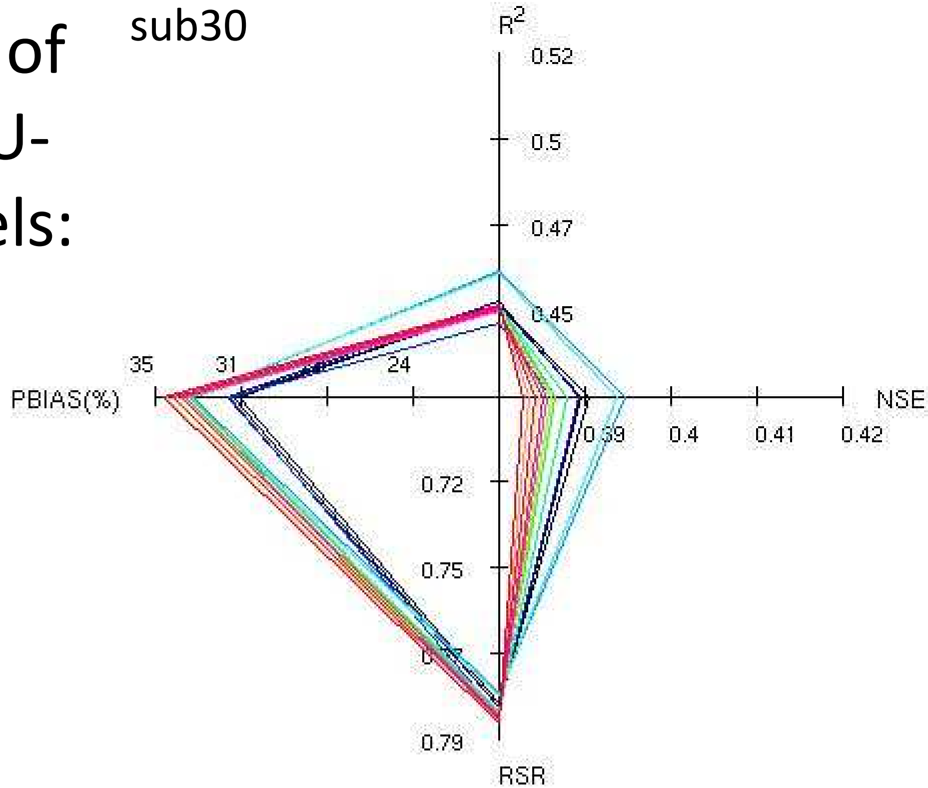
	min				max			
	R^2	NSE	PBIAS	RSR	R^2	NSE	PBIAS	RSR
1_1	0.39	0.25	-20.01	0.57	0.72	0.68	27.60	0.86
1_5	0.39	0.25	-19.71	0.57	0.72	0.68	27.60	0.86
1_10	0.39	0.26	-19.74	0.57	0.72	0.68	27.60	0.86
1_15	0.39	0.26	-19.61	0.56	0.72	0.68	27.60	0.86
5_0	0.38	0.26	-17.10	0.58	0.72	0.67	33.26	0.86
5_5	0.39	0.26	-16.97	0.58	0.72	0.67	33.26	0.86
5_10	0.39	0.26	-17.02	0.58	0.72	0.67	33.27	0.86
5_15	0.39	0.26	-16.82	0.58	0.72	0.67	33.27	0.86
10_0	0.38	0.26	-7.85	0.58	0.72	0.66	32.88	0.86
10_5	0.38	0.26	-7.68	0.58	0.72	0.66	32.88	0.86
10_10	0.38	0.26	-7.80	0.58	0.72	0.66	32.89	0.86
10_15	0.38	0.26	-7.53	0.58	0.72	0.67	32.90	0.86
15_0	0.37	0.25	-5.45	0.58	0.72	0.66	32.80	0.87
15_5	0.37	0.25	-5.52	0.58	0.72	0.66	32.80	0.87
15_10	0.37	0.25	-5.57	0.58	0.72	0.67	32.81	0.87
15_15	0.37	0.25	-5.66	0.58	0.72	0.67	32.82	0.87

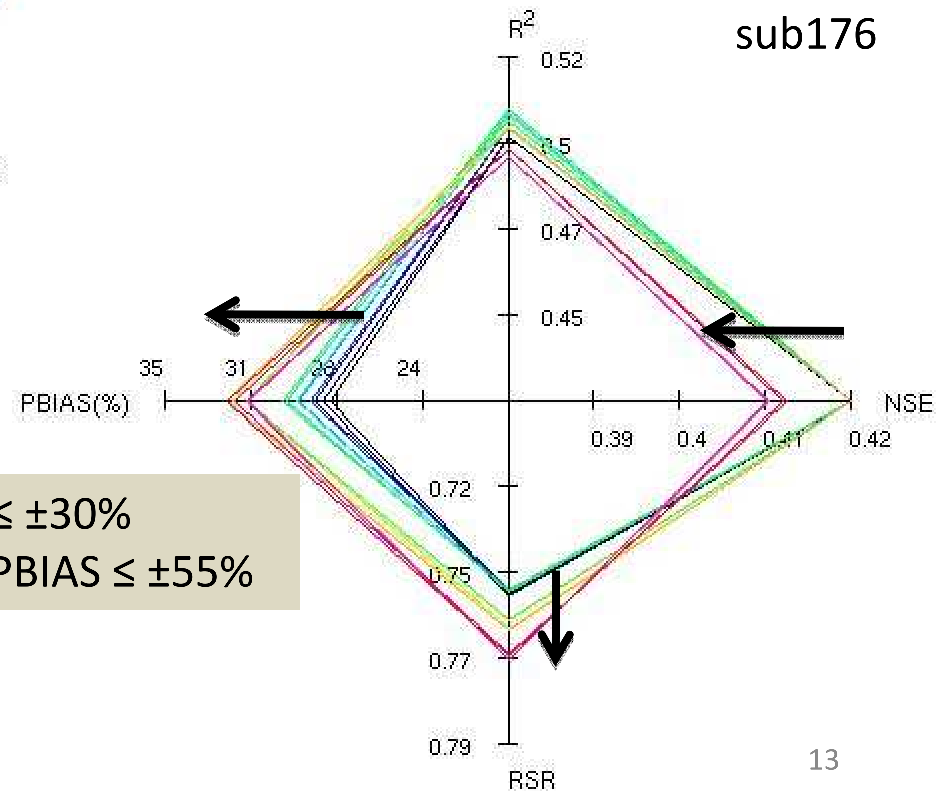




Performance of different HRU-defined models: TSS

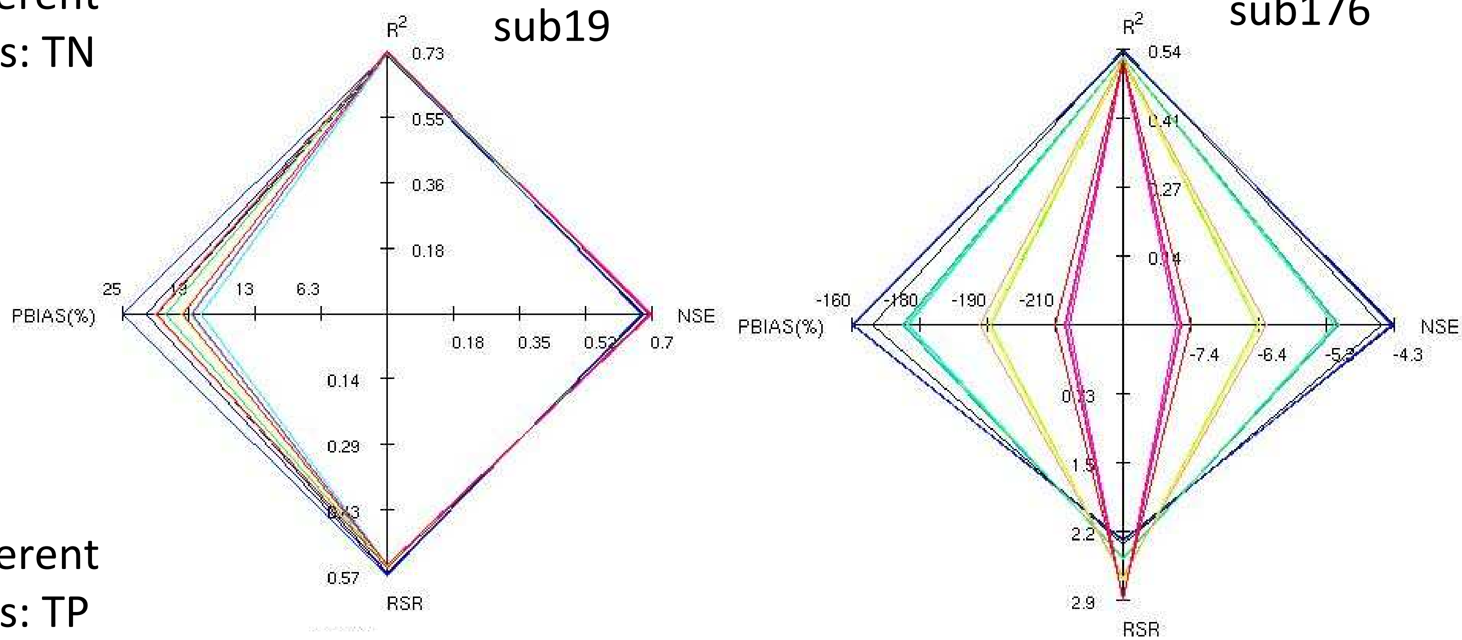




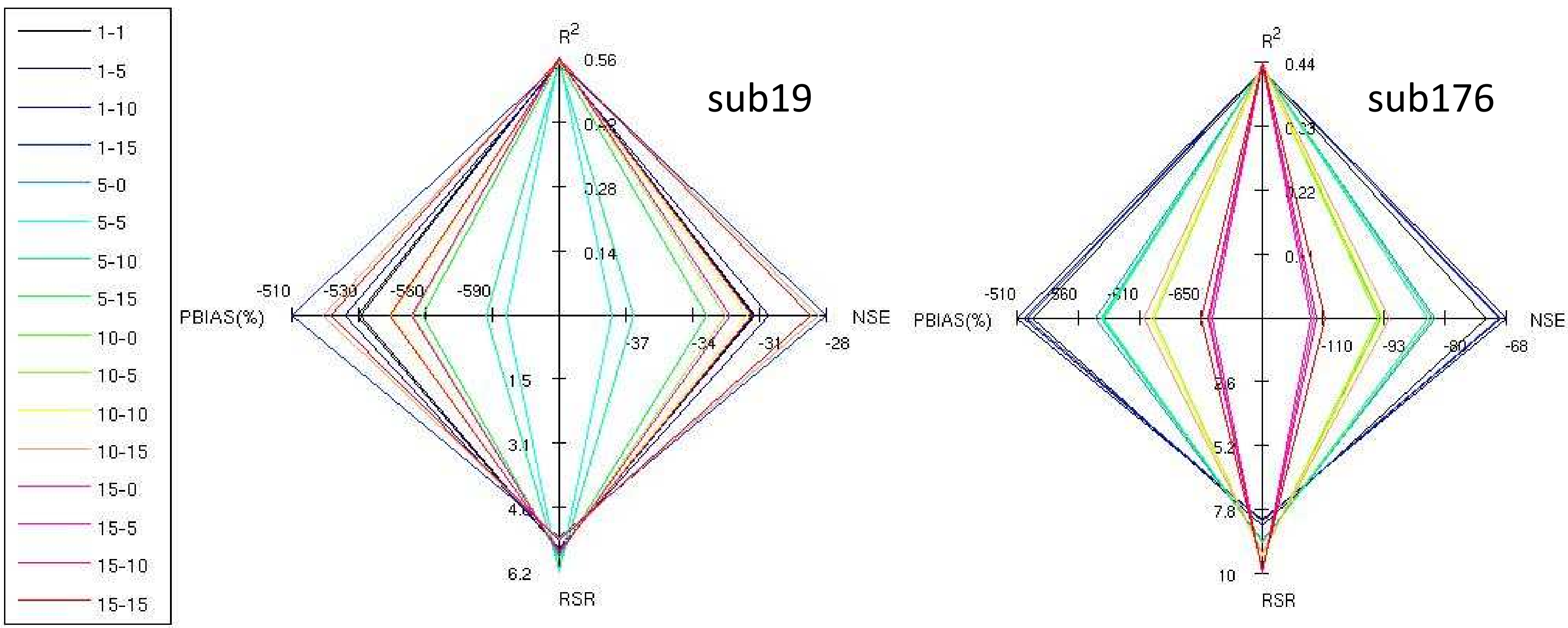


Good: ±15% ≤ PBIAS ≤ ±30%
Satisfactory: ±30% ≤ PBIAS ≤ ±55%

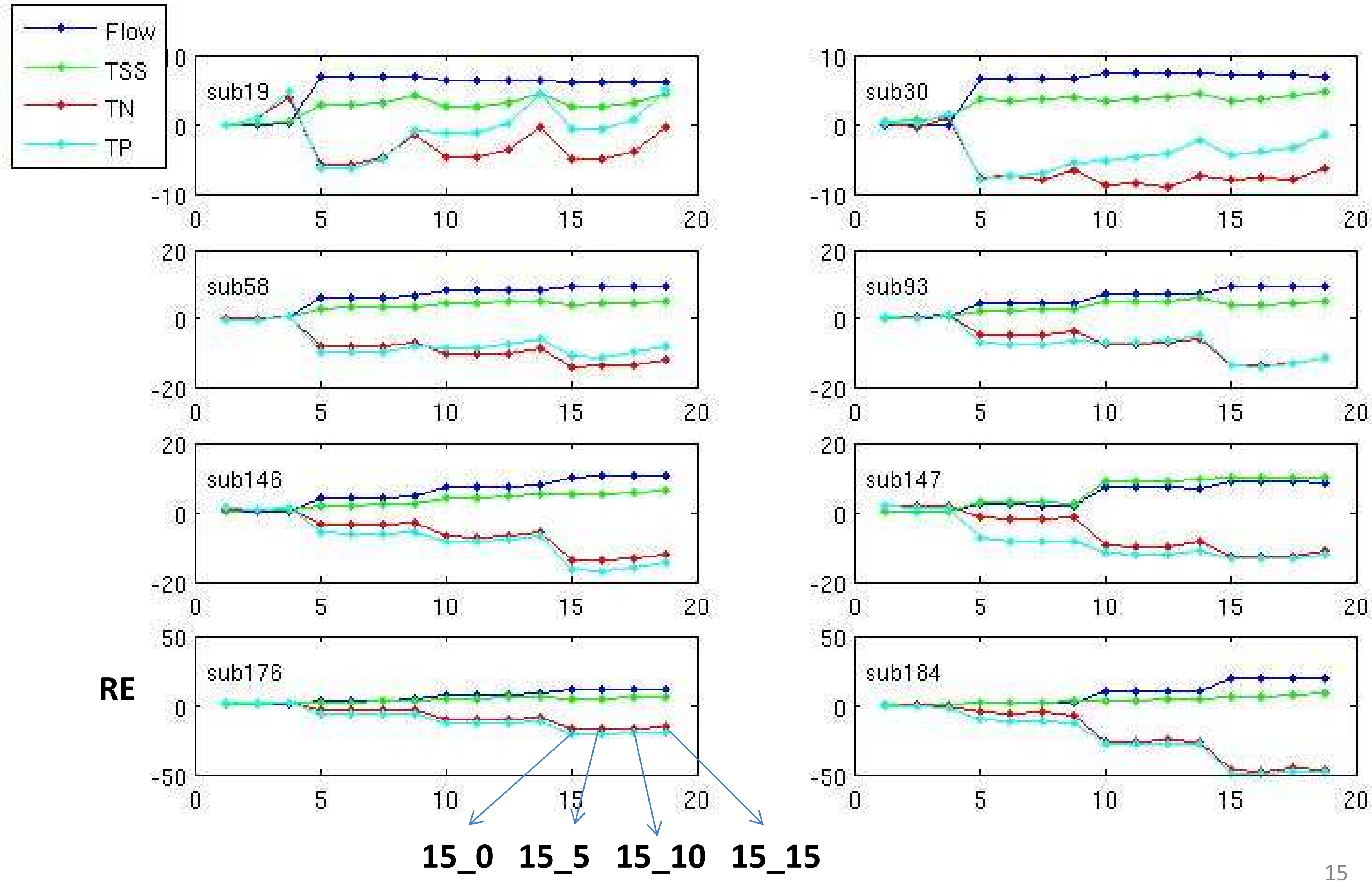
Performance of different
HRU-defined models: TN



Performance of different
HRU-defined models: TP



Compared to the best model (1/1 thresholds)



SWAT parameters for calibration

Output	Parameters	Short Description	Units	Default	Calibrated
Flow	CN (%)	Initial SCS runoff curve number	-	30-98	-30%
	ALPHA_BF	Baseflow alpha factor	-	0.048	0.4
TSS	SPEXP (-)	Exponenet coefficient for sediment routing	-	1	2
TN	NPERCO (-)	Nitrogen percolation coefficient	-	0.2	0.001
	CMN (-)	Rate factor for mineralization of active organic nutrients	-	0.0003	0.003
	CNYLD	Fraction of nitrogen in yield	kg N/kg yield	0.014 - 0.065	20%
	BIOMIX	Biological mixing efficiency	-	0.2	0.8
	RS4	Organic N settling rate in the reach at 20℃	1/day	0. 05	0.1
	RHOQ	Algal respiration rate at 20℃	1/day	0.3	0.05
	MUMAX	Maximum specific algal growth rate at 20℃	1/day	2	3
	SOL_CBN	Organic carbon content	% soil weight	1.16 - 0.26	-30%
TP	CPYLD	Fraction of phosphorus in yield	kg P/kg yield	0.0016 - 0.0091	20%
	PSP	Phosphorus availability index	-	0.4	0.9
	RS2	Benthic (sediment) source rate for dissolved P	mg P/m^2-day	0.05	0.001
	RS5	Organic P settling rate in the reach at 20℃	1/day	0. 05	0.1
	P_UPDIS	Phosphorus uptake distribution parameter	-	20	60
	AI2	Fraction of algal biomass that is phosphorus	mg P/mg alg	0.015	0.02
	BC4	Rate constant for mineralization of P to dissolved P	1/day	0.35	0.01-0.6

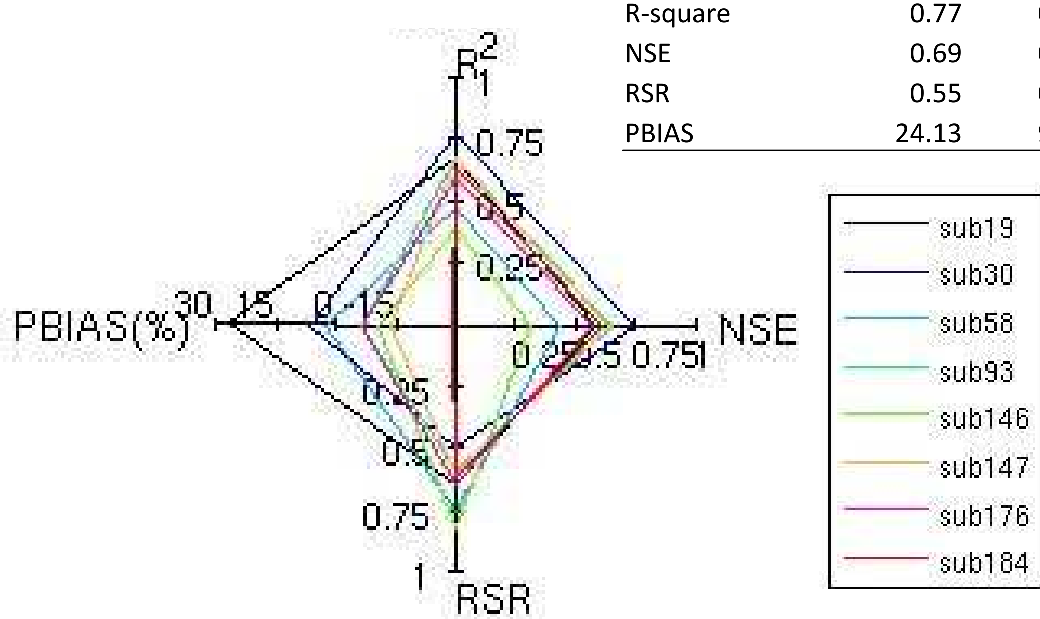
Calibration and validation results: streamflow

Calibration

Subbasin	19	30	58	93	146	147	176	184
Gauge no.	5591700	5591200	5592100	5592500	5593000	5594000	5594100	5594800
Observed Mean	119.36	413.01	1084.93	1435.52	1908.34	495.98	3427.85	319.34
Predicted Mean	87.30	383.96	1060.25	1525.41	2100.61	563.34	3375.12	368.97
R-square	0.68	0.77	0.47	0.67	0.39	0.67	0.58	0.63
NSE	0.58	0.75	0.44	0.66	0.31	0.64	0.58	0.62
RSR	0.65	0.50	0.75	0.59	0.83	0.60	0.65	0.62
PBIAS	26.86	7.03	2.27	-6.26	-10.08	-13.58	-6.24	-29.55

Validation

Subbasin	19	30	58	93	146	147	176	184
Gauge no.	5591700	5591200	5592100	5592500	5593000	5594000	5594100	5594800
Observed Mean	89.58	366.62	905.68	1343.98	1727.01	446.37	2901.17	301.88
Predicted Mean	67.97	330.04	960.96	1520.34	2121.89	568.05	3431.42	392.56
R-square	0.77	0.72	0.56	0.70	0.51	0.78	0.68	0.73
NSE	0.69	0.71	0.48	0.66	0.35	0.73	0.63	0.68
RSR	0.55	0.54	0.72	0.58	0.81	0.52	0.61	0.56
PBIAS	24.13	9.98	-6.10	-13.12	-22.87	-27.26	-18.28	-30.04



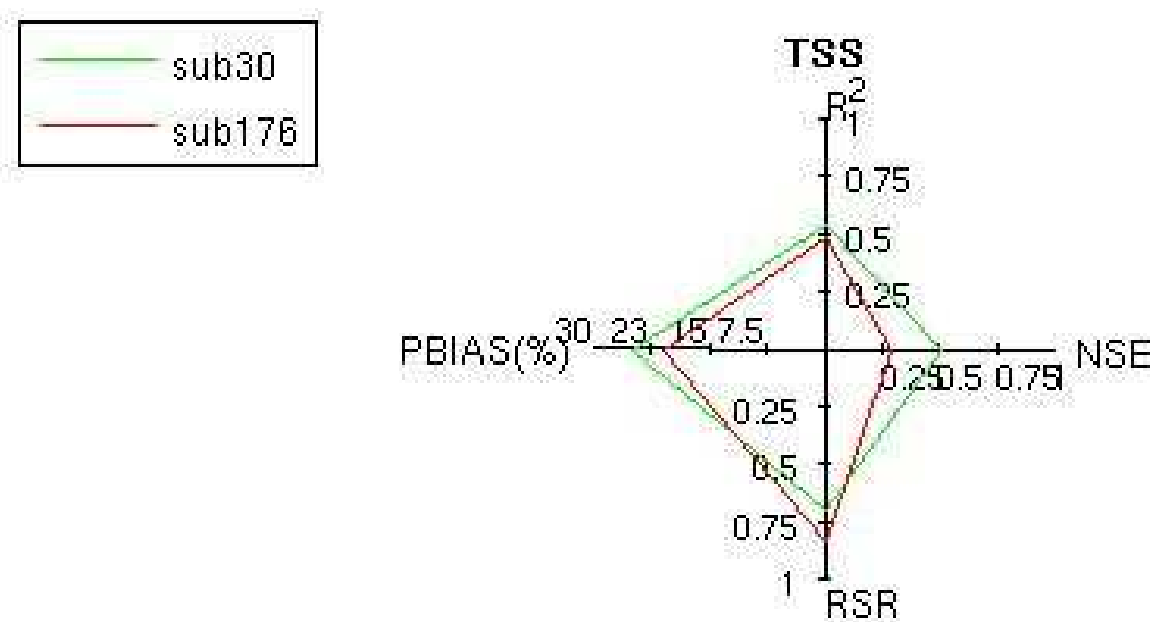
Calibration and validation results: TSS

Calibration

Subbasin	30	176
Gauge no.	5591200	5594800
Observed Mean	41.98	54.82
Predicted Mean	31.45	43.30
R-square	0.54	0.49
NSE	0.50	0.29
RSR	0.70	0.84
PBIAS	25.09	21.02

Validation

Subbasin	30	176
Gauge no.	5591200	5594100
Observed Mean	27.85	27.86
Predicted Mean	22.96	28.48
R-square	0.31	0.61
NSE	0.27	0.06
RSR	0.86	0.97
PBIAS	17.59	-2.20



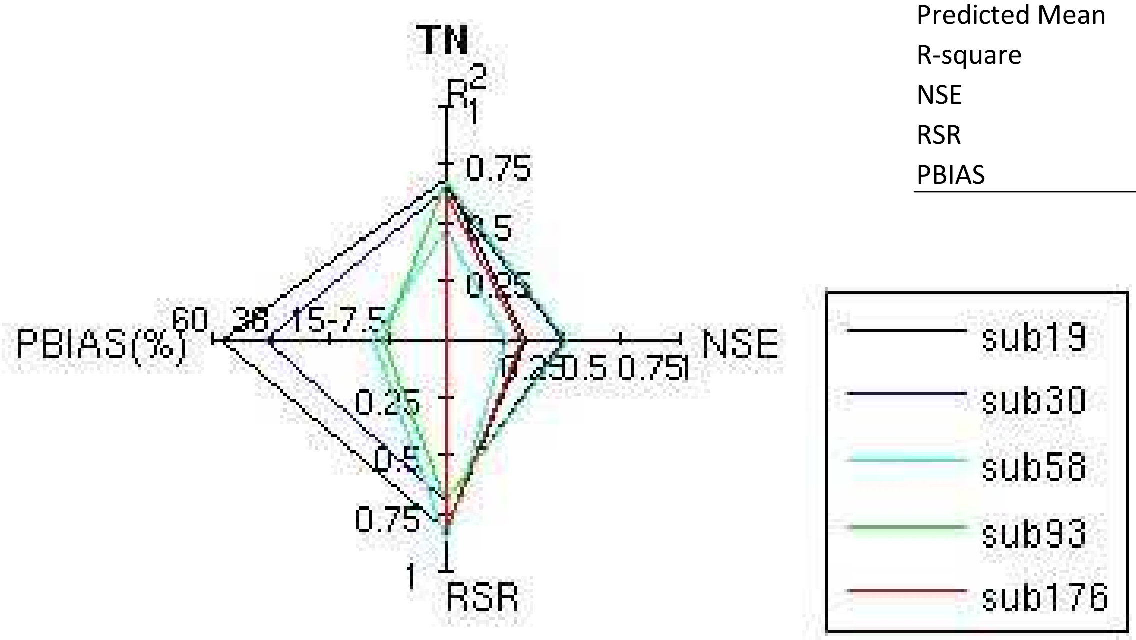
Calibration and validation results: TN

Calibration

Subbasin	19	30	58	93	176
Gauge no.	5591700	5591200	5592100	5592500	5594100
Observed Mean	5.10	3.43	1.71	1.44	0.78
Predicted Mean	2.21	2.09	1.73	1.52	1.02
R-square	0.68	0.64	0.47	0.67	0.61
NSE	0.33	0.50	0.26	0.52	0.32
RSR	0.82	0.71	0.86	0.69	0.82
PBIAS	56.58	39.21	-1.35	-5.17	-30.30

Validation

Subbasin	19	30	58	93	176
Gauge no.	5591700	5591200	5592100	5592500	5594100
Observed Mean	3.63	2.71	1.24	1.18	0.62
Predicted Mean	1.55	1.60	1.19	1.00	0.74
R-square	0.77	0.65	0.39	0.61	0.60
NSE	0.46	0.52	-0.05	0.54	0.40
RSR	0.74	0.69	1.03	0.68	0.77
PBIAS	57.19	41.01	3.62	15.15	-19.67



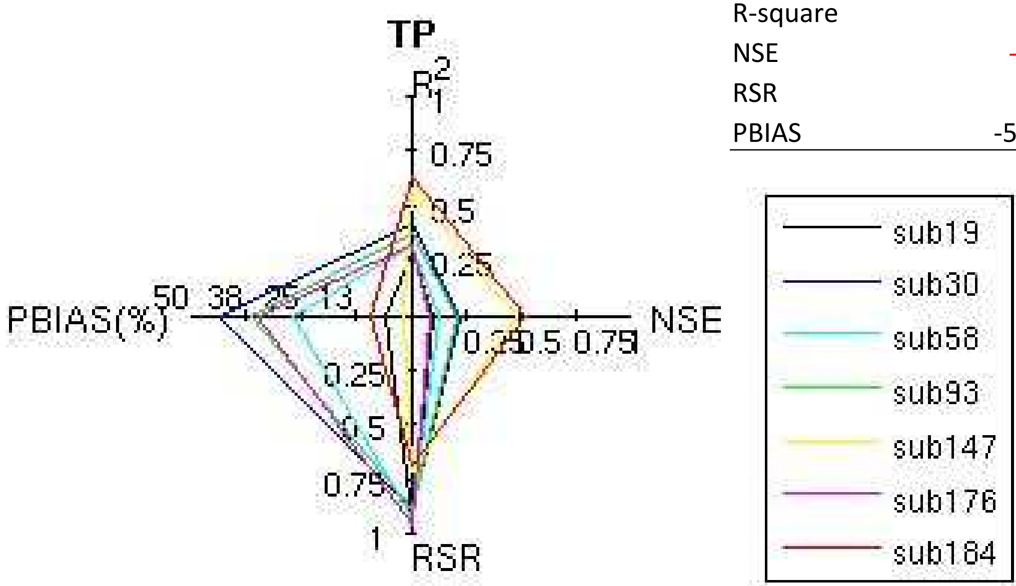
Calibration and validation results: TP

Calibration

Subbasin	19	30	58	93	147	176	184
Gauge no.	5591700	5591200	5592100	5592500	5594000	5594100	5594800
Observed Mean	0.06	0.09	0.05	0.07	0.19	0.07	0.17
Predicted Mean	0.05	0.05	0.03	0.04	0.19	0.05	0.16
R-square	0.30	0.42	0.33	0.38	0.58	0.32	0.63
NSE	0.10	0.22	0.13	0.21	0.49	0.09	0.52
RSR	0.95	0.88	0.93	0.89	0.72	0.95	0.69
PBIAS	5.81	43.85	26.88	36.66	1.99	34.85	9.36

Validation

Subbasin	19	30	58	93	147	176	184
Gauge no.	5591700	5591200	5592100	5592500	5594000	5594100	5594800
Observed Mean	0.04	0.06	0.04	0.05	0.11	0.08	0.16
Predicted Mean	0.06	0.06	0.04	0.05	0.13	0.05	0.10
R-square	0.34	0.42	0.29	0.34	0.32	0.28	0.45
NSE	-0.32	-0.17	-0.80	-0.12	0.09	0.01	0.36
RSR	1.15	1.08	1.34	1.06	0.95	0.99	0.80
PBIAS	-50.69	-4.26	-5.37	4.72	-19.72	30.07	39.70



Conclusions

- The greater thresholds of land use and soil type resulted in less reliable HRU distribution.
- Different model performance at the subwatershed level among the models with various HRU definition, indicating that a constant HRU definition applied on all subbasins may not fully represent the characteristics of a subbasin.
- Usage of multi-variable and multi-site calibration and validation, various ranges of model performances indicating that more efforts are needed to better simulate the complex hydrological process in a large watershed.

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