SWAT-CUP

SWAT Calibration and Uncertainty Procedures

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eawag aquatic research

Content

- Issues in calibrating distributed models

- SWAT-CUP

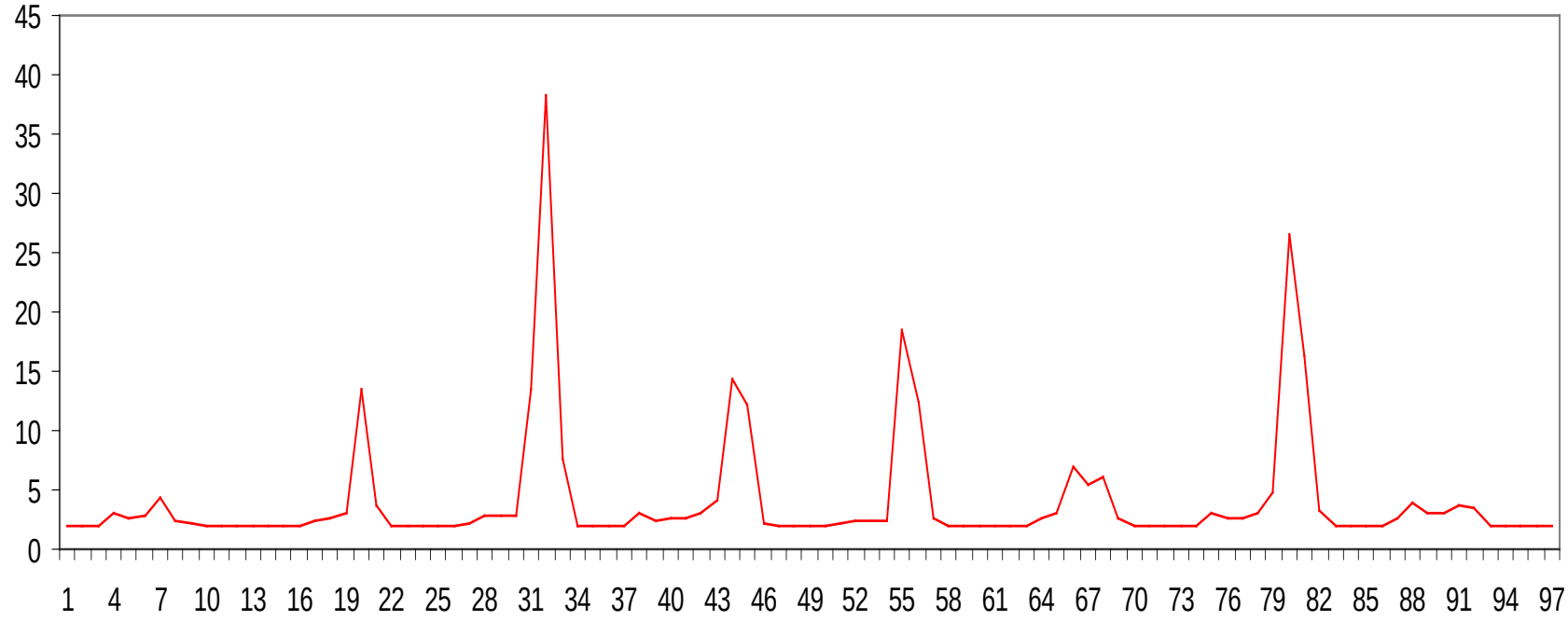
Modeling steps

- Calibration,
- Validation,
- Sensitivity analysis,
- Uncertainty analysis

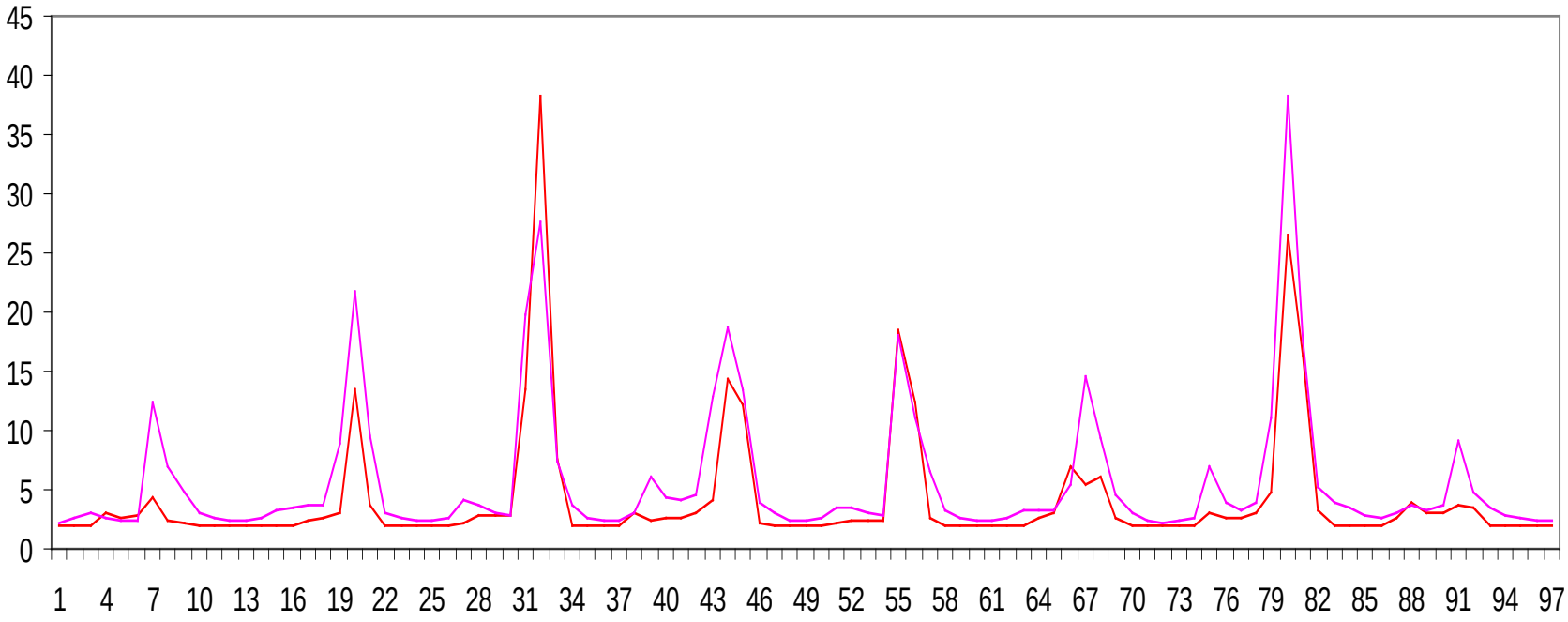
Modeling steps

- Calibration and uncertainty analysis
- Validation,
- Sensitivity analysis,

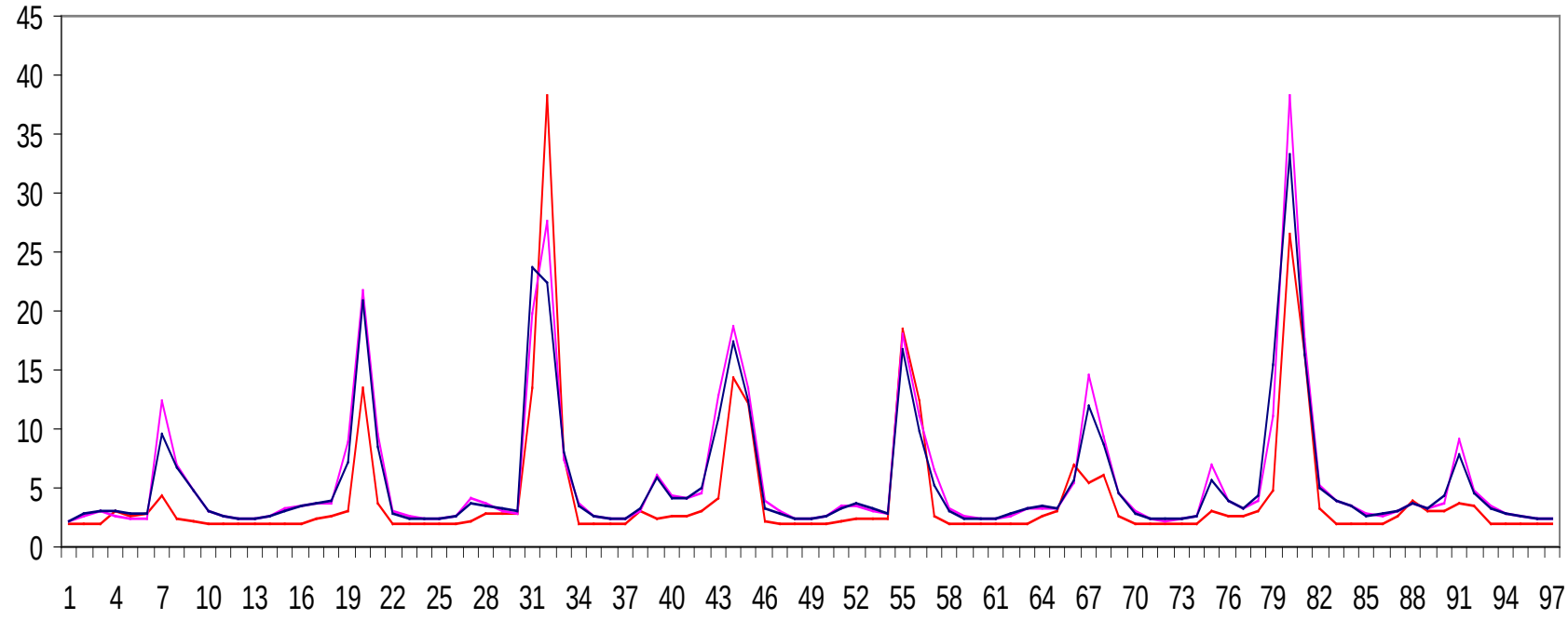
Calibration is subjective ……



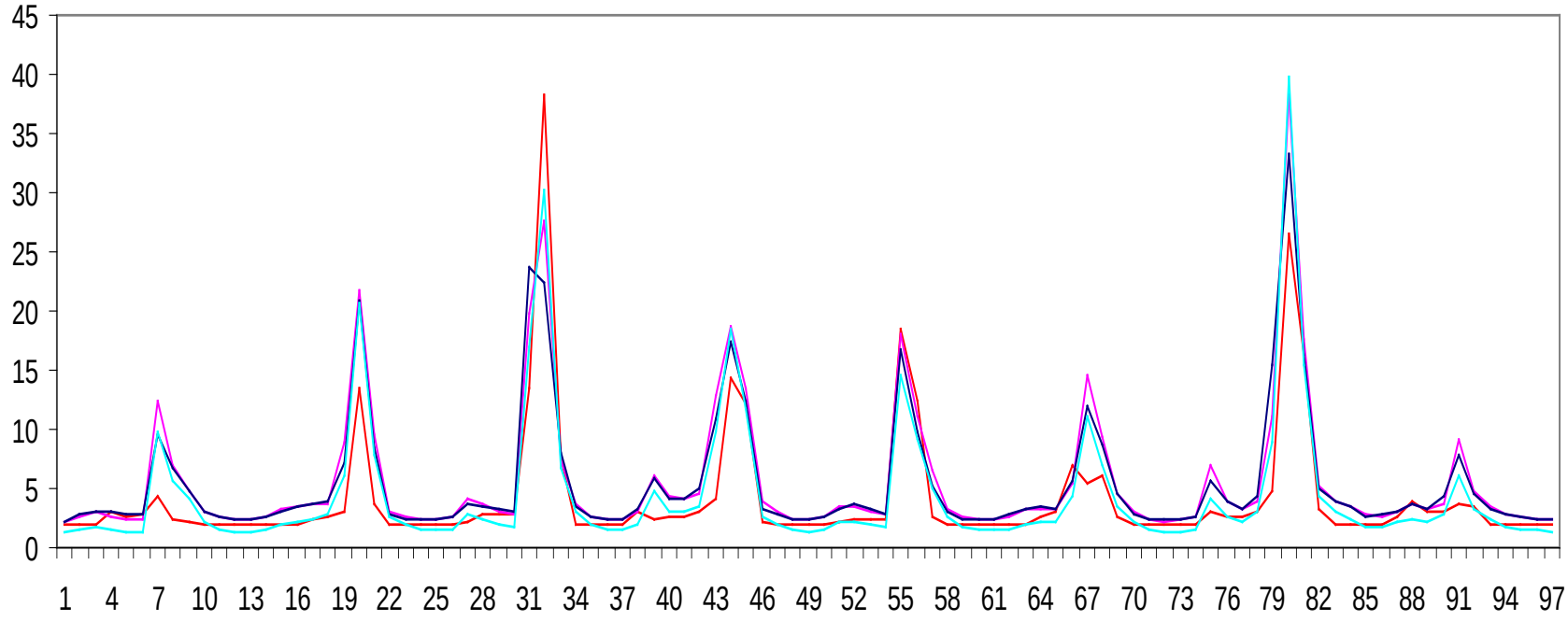
Calibration is subjective ……



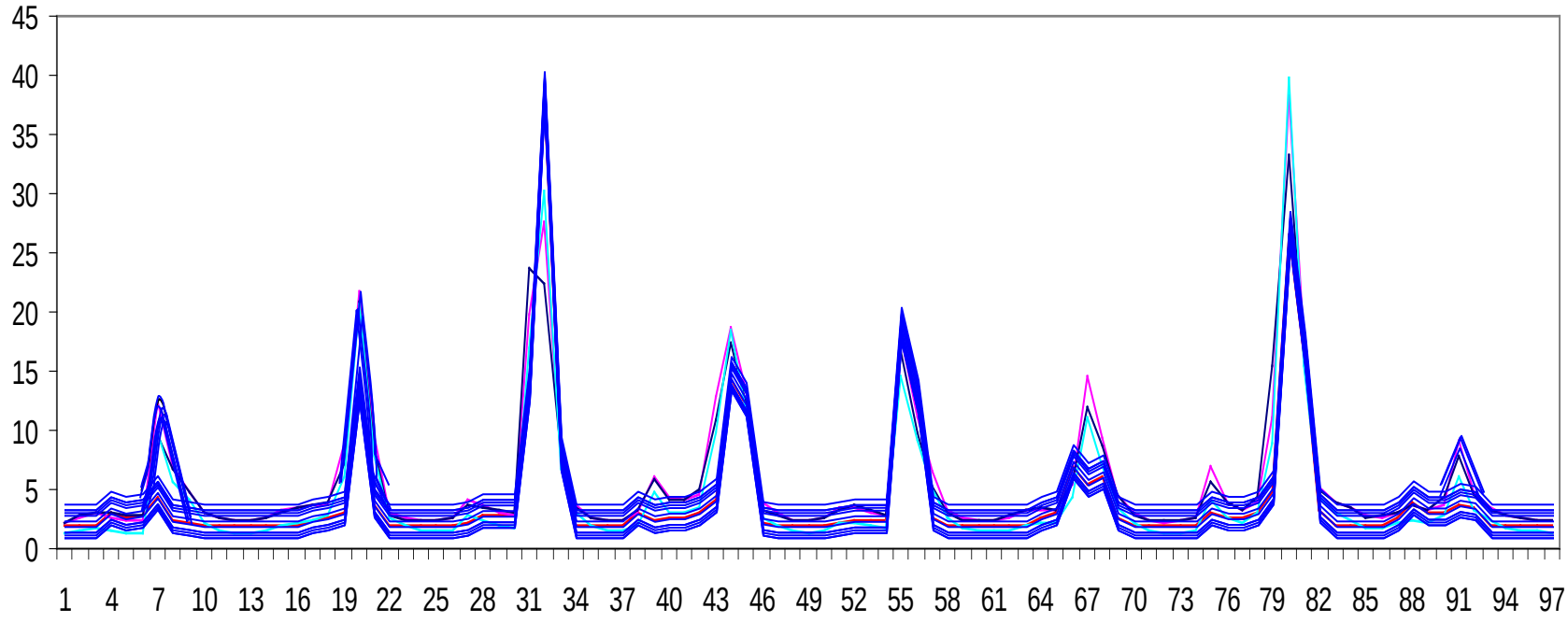
Calibration is subjective ……



Calibration is subjective ……



Calibration is subjective ……



Issues in Calibration of Distributed Models

1- Parameterization

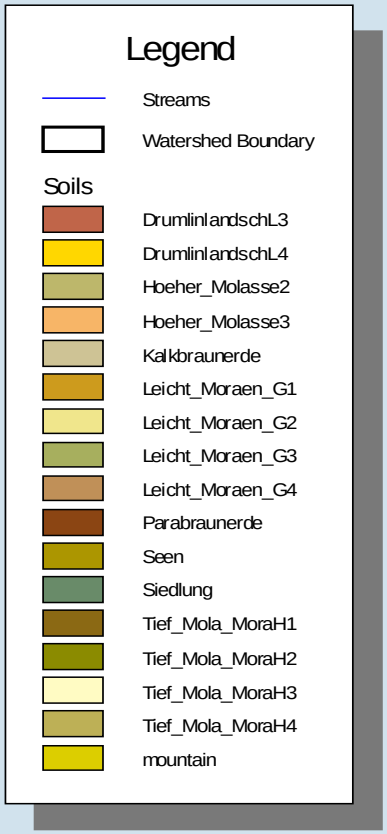
2- Objective function definition

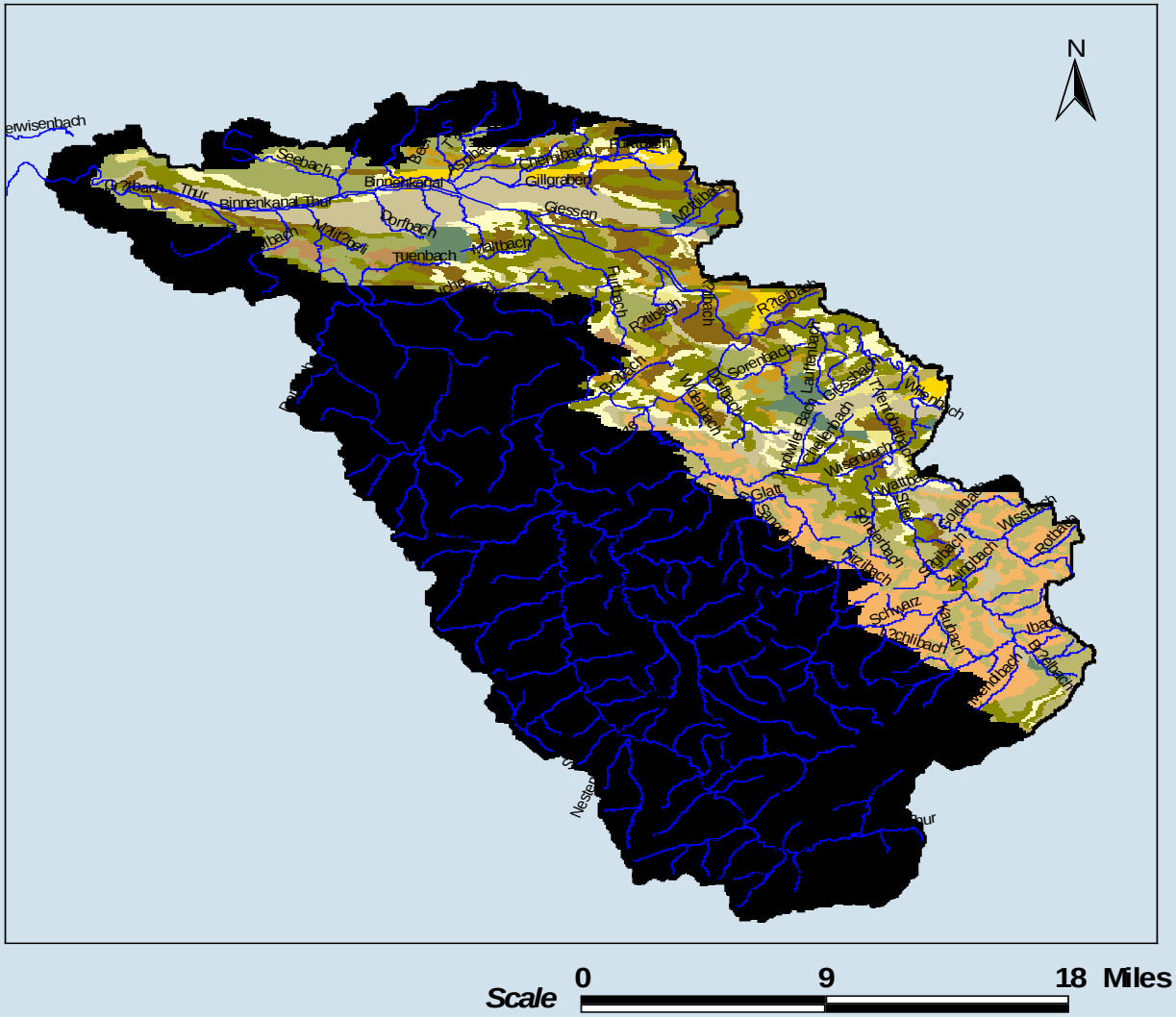
3- Uniqueness problem

4- Parameter conditionality

1. Parameterization

Thur Basin Soil Map





1. Parameterization

x__<parname>.<ext>__<hydrogrp>__<soltext>__<landuse>__<subbsn>__<Slope>

Where

x	= Code to indicate the type of change to be applied to the parameter: v – means the existing parameter value is replaced by a given value, a – means the given value is added to the existing parameter value, and r– means the existing parameter value is multiplied by (1+the given value);
<parname>	= SWAT parameter name;
<ext>	= SWAT file extension code for the file containing the parameter;
<hydrogrp>	= soil hydrological group (‘A’,’B’,’C’ or ‘D’);
<soltext>	= soil texture;
<landuse>	= name of the landuse category;
<subbsn>	= sub-basin number or crop index.

Soil Parameters

Parameter identifiers	Description
r__SOL_K(1).sol	K of Layer 1 of all HRUs
r__SOL_K(1,2,4-6).sol	K of Layer 1,2,4,5, and 6 of all HRUs
r__SOL_K().sol	K of All layers and all HRUs
r__SOL_K(1).sol__D	K of layer 1 of HRUs with hydrologic group D
r__SOL_K(1).sol____FSL	K of layer 1 of HRUs with soil texture FSL
r__SOL_K(1).sol____FSL__PAST	K of layer 1 of HRUs with soil texture FSL and landuse PAST
r__SOL_K(1).sol____FSL__PAST__1-3	K of layer 1 of subbasin 1,2, and 3 with HRUs containing soil texture FSL and landuse PAST

Management Parameters

Parameter identifiers	Description
v__HEAT_UNITS{rotation no,operation no}	Management parameters that are subject to operation/rotation must have both specified

Crop Parameters

Parameter identifiers	Description
v__T_OPT{30}.CROP.DAT	Parameter T_OPT for crop number 30 in the crop.dat file
v__PLTNFR(1){3}.CROP.DAT	Nitrogen uptake parameter #1 for crop number 3 in crop.dat file

Rainfall Parameters

Parameter identifiers	Description
v__precipitation(1){1977300}.pcp	(1) means column number 1 in the pcp file {1977300} specifies year and day
v__precipitation(1-3){1977300}.pcp	(1-3) means column 1, 2, and3 {1977300} specifies year and day
v__precipitation( ){1977300,1977301}.pcp	( ) means all columns (all stations) {1977300,1977301} means 1977 days 300 and 301
v__precipitation( ){1977001-1977361,1978001-1978365,1979003}.pcp	( ) means all columns from day 1 to day 361 of 1977, and from day 1 to day 365 of 1978, and day 3 of 1979

2. Objective function definition

Different objective functions produce different calibration results

S-MSR

$$g(\mathbf{B}) = w_1 \sum_{i=1}^{n_1} \left(Q_o - Q_s\right)_i^2 + w_2 \sum_{i=1}^{n_2} \left(S_o - S_s\right)_i^2 + \ldots\ldots$$

M-MSR

$$g(\mathrm{B}) = \sum_{i=1}^{n_1} \left(Q_o - Q_s\right)_i^2 * \sum_{i=1}^{n_2} \left(S_o - S_s\right)_i^2 * \ldots\ldots$$

NS

$$g(\mathbf{B}) = \left[1 - \frac{\sum_{1}^{n_1} \left(O_i - P_i\right)^2}{\sum_{1}^{n_1} \left(O_i - \overline{O}\right)^2} \right]$$

2. Objective function definition

R^2

$$g(\mathbf{B}) = \left[\frac{\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \overline{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \overline{P})^2}} \right]^2$$

Chi^2

$$\chi^2 = \frac{\sum_i (Q_m - Q_s)_i^2}{\sigma_Q^2}$$

bR^2

$$g(\mathbf{B}) = \begin{cases} |b| . R^2 & for \quad b \leq 1 \\ |b|^{-1} . R^2 & for \quad b > 1 \end{cases}$$

2. Objective function definition

The SSQR method aims at the fitting of the frequency distributions of the observed and the simulated series. After independent ranking of the measured and the simulated values, new pairs are formed and the SSQR is calculated as

SSQR

$$SSQR = \sum_{j=1,n} \left[Q_{j,measured} - Q_{j,simulated} \right]^2$$

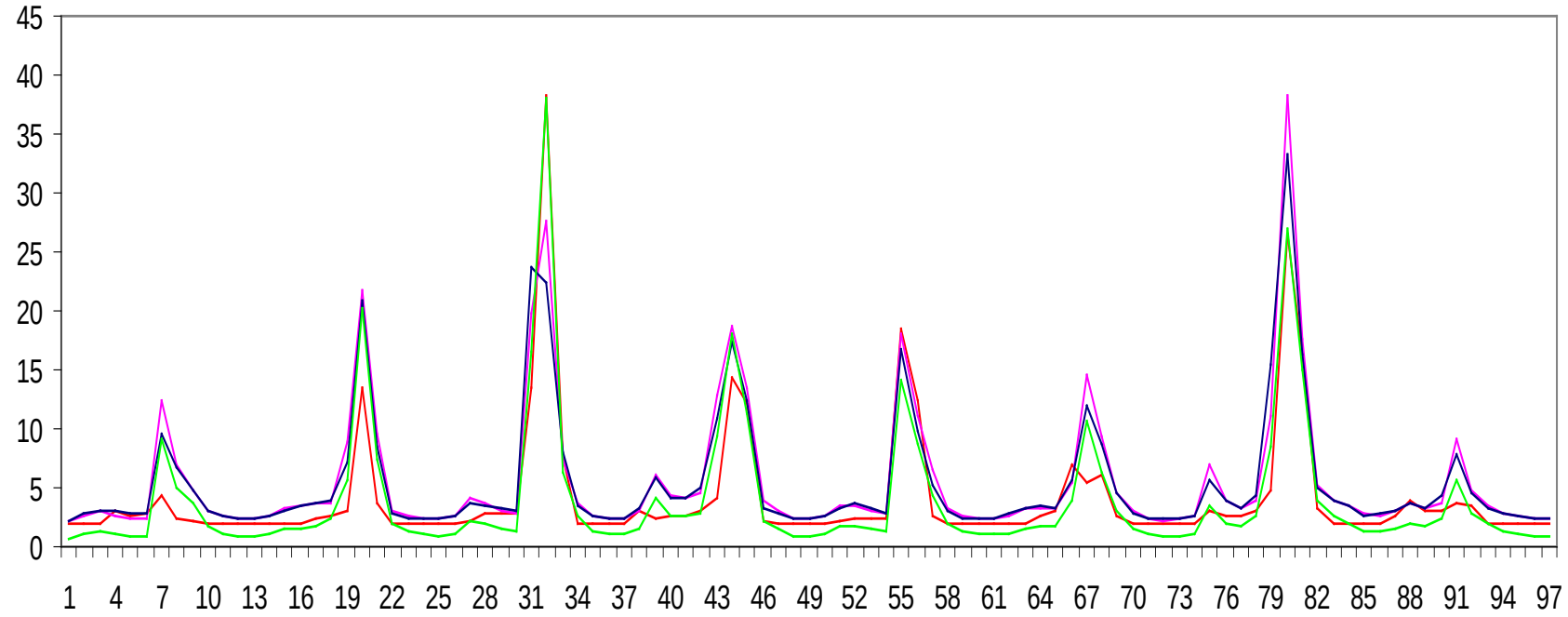
2. Objective function definition

Likelihood function in a Bayesian inference using Box-Cox transformation and continuous time auto regressive function:

$$f_{\mathbf{Y}^M|\boldsymbol{\Theta}}(\mathbf{y}|\boldsymbol{\theta}) = \frac{1}{\sqrt{2\pi}}\frac{1}{\sigma}\exp\left(-\frac{1}{2}\frac{\left[g(y_{t_0}) - g\left(y_{t_0}^M(\boldsymbol{\theta})\right)\right]^2}{\sigma^2}\right)\cdot\left|\frac{dg}{dy}\right|_{y=y_{t_0}}\left|\cdot\prod_{i=1}^{n}\left[\frac{1}{\sqrt{2\pi}}\frac{1}{\sigma\sqrt{1-\exp\left(-2\frac{t_i-t_{i-1}}{\tau}\right)}}\exp\left(-\frac{1}{2}\frac{\left[\begin{array}{l} g(y_{t_i}) - g\left(y_{t_i}^M(\boldsymbol{\theta})\right) \\ -\left[g(y_{t_{i-1}}) - g\left(y_{t_{i-1}}^M(\boldsymbol{\theta})\right)\right]\exp\left(-\frac{t_i-t_{i-1}}{\tau}\right)\end{array}\right]^2}{\sigma^2\left(1-\exp\left(-2\frac{t_i-t_{i-1}}{\tau}\right)\right)}\right)\cdot\left|\frac{dg}{dy}\right|_{y=y_{t_i}}\right]\right|$$

Yang et al., 2007, WRR, JHydrol

2. Objective function definition



RMSE	R2	NS	bR2
29.90	0.79	0.67	0.54
29.70	0.75	0.67	0.42
23.50	0.84	0.83	0.45
21.10	0.90	0.80	0.62
23.30	0.84	0.80	0.75

3. Uniqueness problem

Direct (deterministic) Modelling:

Inverse Modelling:

3. Uniqueness problem

So, different parameter sets can give you equally good calibration results

CN2	ALPHA_BF	REVAPMN	GW_REVAP	RCHRG_DP	SOL_AWC	SOL_K	SOL_BD
-0.20	0.25	83.4	0.05	0.09	-0.19	0.57	-0.13
0.11	0.59	66.0	0.05	0.19	-0.25	0.45	-0.19
0.33	0.35	86.1	0.07	0.19	-0.04	0.30	0.08
0.29	0.50	32.8	0.07	0.29	-0.16	0.29	-0.07

4. Parameter Conditionality

(B)

- watershed parameterization
- type of the objective function
- weights in the objective function
- conceptual model (model structure)
- experimental procedure (to collect the calibrating data)
- input (driving or forcing) data
- number and type of variables (in the objective function)
- location of outlets
- ……

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SWAT-CUP

SWAT-CUP

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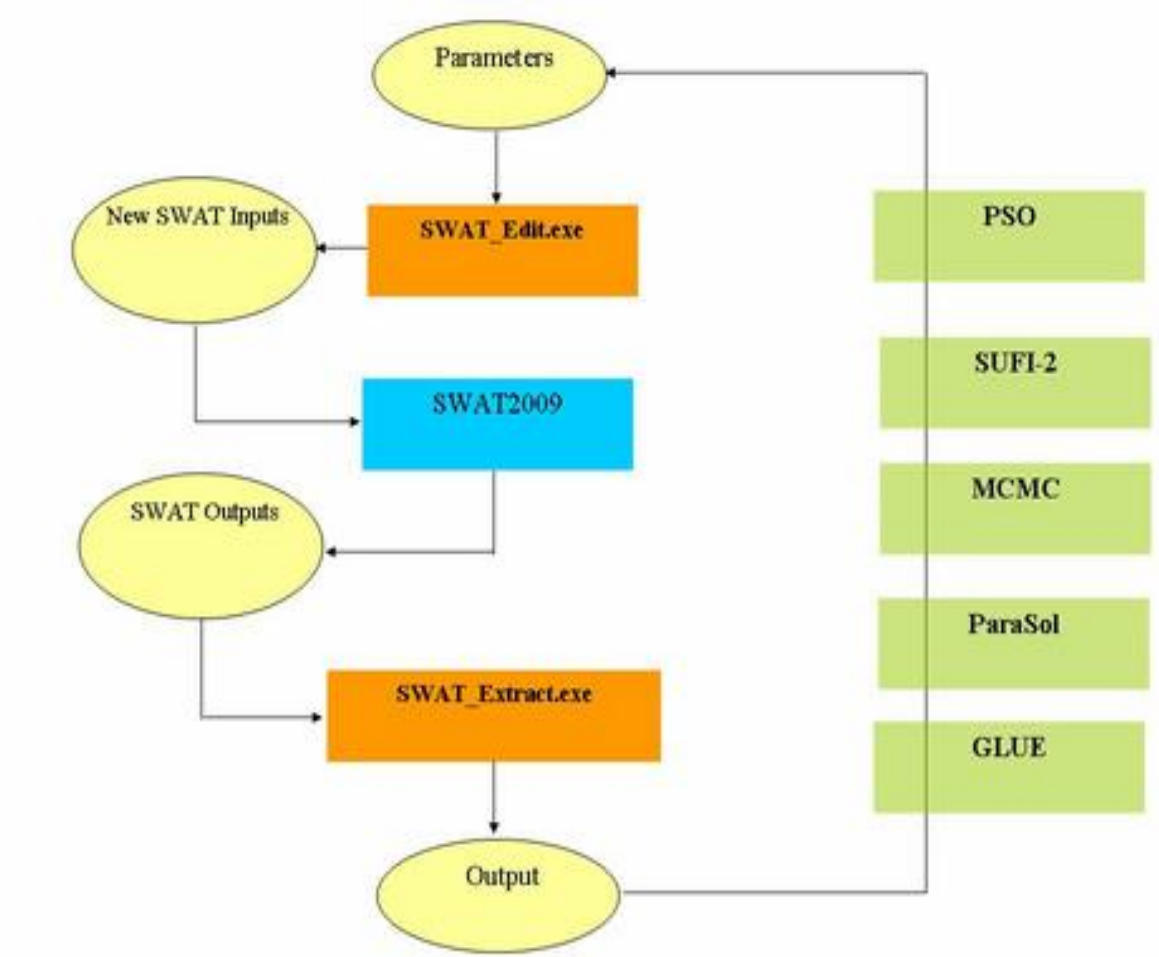
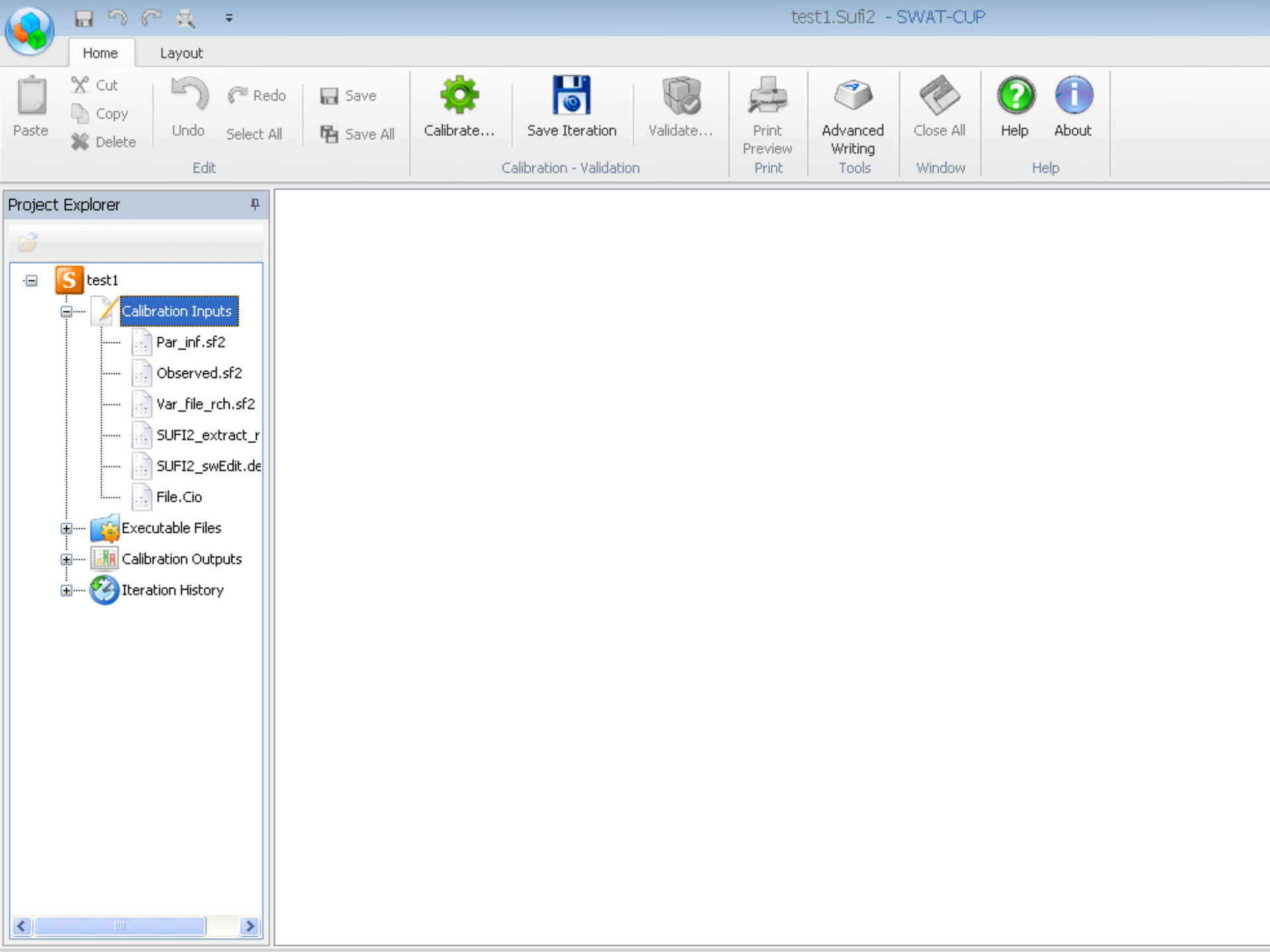
SWAT-CUP is a computer program for calibration of SWAT models. SWAT-CUP is a public domain program, and as such may be used and copied freely. The program links GLUE, ParaSol, SUFI2, MCMC, and PSO procedures to SWAT. It enables sensitivity analysis, calibration, validation, and uncertainty analysis of a SWAT model. The overall program structure is as shown in the Figure below.

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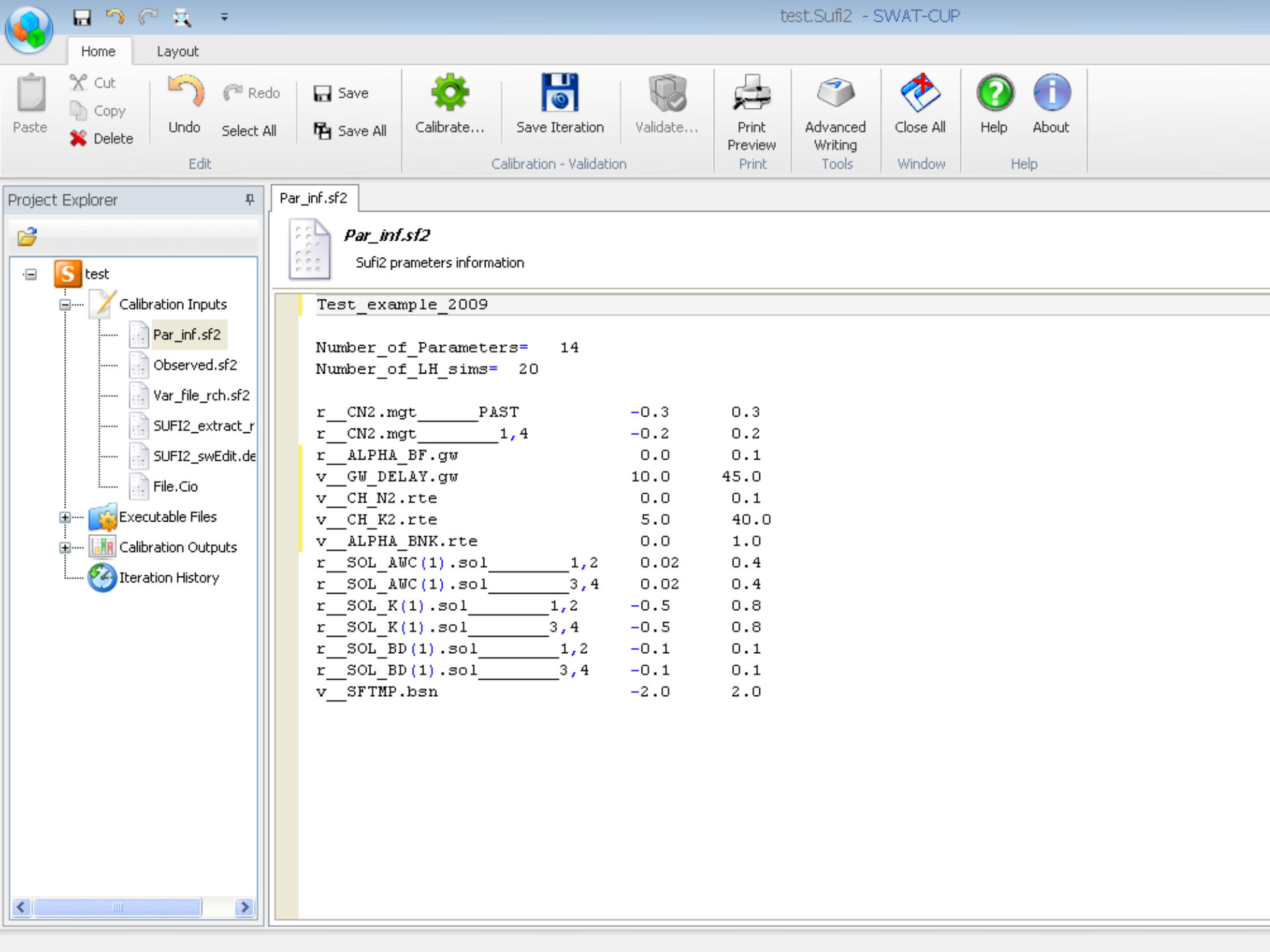
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Par_inf.sf2
Par_inf.sf2
Sufi2 prameters information
Test_example_2009
Number_of_Parameters= 14
Number_of_LH_sims= 20
r__CN2.mgt_____PAST -0.3 0.3
r__CN2.mgt_____1,4 -0.2 0.2
r__ALPHA_BF.gw 0.0 0.1
v__GW_DELAY.gw 10.0 45.0
v__CH_N2.rte 0.0 0.1
v__CH_K2.rte 5.0 40.0
v__ALPHA_BNK.rte 0.0 1.0
r__SOL_AWC(1).sol_____1,2 0.02 0.4
r__SOL_AWC(1).sol_____3,4 0.02 0.4
r__SOL_K(1).sol_____1,2 -0.5 0.8
r__SOL_K(1).sol_____3,4 -0.5 0.8
r__SOL_BD(1).sol_____1,2 -0.1 0.1
r__SOL_BD(1).sol_____3,4 -0.1 0.1
v__SFTMP.bsn -2.0 2.0

```
V__GW_DELAY.gw_____45        29.813421     40.136478
v__ALPHA_BF.gw_____45         0.320068      0.579920
v__GW_REVAP.gw_____45         0.0      0.163754
v__RCHRG_DP.gw_____45         0.038500      0.233160
r__SOL_K().sol_____45        -0.300590      0.512008
v__ESCO.hru_____45          0.391444      0.749038
v__SLSUBBSN.hru_____45        18.260817     40.833183
v__CH_K2.rte_____45         0.0      6.095049
r__HRU_SLP.hru_____45         0.263282      0.633366

r__CN2.mgt_____61         0.556328      1.020978
v__REVAPMN.gw_____61         5.263700     10.631983
v__GW_REVAP.gw_____61         0.083167      0.249507
v__RCHRG_DP.gw_____61         0.264409      0.532161
r__SOL_K().sol_____61        -0.927616      0.049724
r__SOL_BD().sol_____61         0.356627      1.013543
v__ESCO.hru_____61         0.02     0.235157
v__SLSUBBSN.hru_____61         0.0     19.965151
v__OV_N.hru_____61         0.287933      0.670415
r__CH_N2.rte_____61        -0.066399      0.582939
v__ALPHA_BNK.rte_____61         0.0      0.221242

 r__CN2.mgt_____5-11,13,14,16,18,22,23,27-30,33-35,39-41,44,47,48,50-57,59,60,63         0.348061      0.5437
 r__CN2.mgt_____12,15,24        -0.002354      0.682160
 r__CN2.mgt_____1,2,3,4        -0.081239      0.245297
 r__CN2.mgt_____17,22,31,32,36         0.435100      0.610310
 r__CN2.mgt_____27,42,49,46,43         0.127156      0.425522
 r__CN2.mgt_____52        -0.324336      0.006194

 v__GW_REVAP.gw_____1,2,3,4         0.129748      0.389252
 v__GW_REVAP.gw_____17,22,31,32,36         0.059568      0.217864
 v__GW_REVAP.gw_____52         0.0      0.087147

 r__SOL_AWC().sol_____5-16,18-25,26-30,33-35,37-41,44,47,48,50-57,59,60,63         0.070241      0.280667
 r__SOL_AWC().sol_____1,2,3,4        -0.118537      0.181741
 r__SOL_AWC().sol_____27,42,49,46,43         0.100708      0.336324
 r__SOL_AWC().sol_____52        -0.007669      0.250197

 v__ALPHA_BNK.rte_____5-16,18-25,26-30,33-35,37-41,44,47,48,50-57,59,60,63         0.321167      0.628545
 v__SMTMP.bsn         2.482387      5.280932
```

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Par_inf.sf2 | Observed.sf2

Observed.sf2

Observed Data

```
no_obs_vars=         5
Obj_Fn_Type(1=mult,2=sum,3=r2,4=chi2,5=NS,6=br2,7=Ssqr)=         5
behavioral_threshold=   .45

q_1
var_weight=      1
var_Threshold=       -1
wt_below_threshold=      1
wt_above_threshold=      1
pcnt_Error=      10
NO_Data=         21
4    q_1_1977.4  0.5913
5    q_1_1977.5  0.8188
6    q_1_1977.6  0.3899
7    q_1_1977.7  0.2955
8    q_1_1977.8  0.1019
9    q_1_1977.9  0.2147
10   q_1_1977.10 1.906
11   q_1_1977.11 0.4995
12   q_1_1977.12 0.3348
13   q_1_1978.1  0.5686
14   q_1_1978.2  0.7132
15   q_1_1978.3  0.4877
16   q_1_1978.4  0.5748
17   q_1_1978.5  2.199
18   q_1_1978.6  0.5848
19   q_1_1978.7  0.1127
20   q_1_1978.8  0.0012
21   q_1_1978.9  0.8347
```

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Par_inf.sf2 | Observed.sf2 | SUFI2_extract_rch.def

SUFI2_extract_rch.def

```
swat_output_file=    output.rch


no_vars_to_get=    3
var_column_no[no_vars_to_get]=       7   11   18

reaches_for_each_variable[no_vars_to_get]
no_reaches_to_get=    2
reach_no=            1  2

no_reaches_to_get=    2
reach_no=            1  3

no_reaches_to_get=    1
reach_no=            4


total_reaches_in_project=       4

beg_year=            1977
end_year=            1978

time_step(1d,2m,3y)= 2



/**** Remark
column_no=  7    discharge   (m3/s)
column_no=  11   sed out     (tn)
```

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95ppu.sf2

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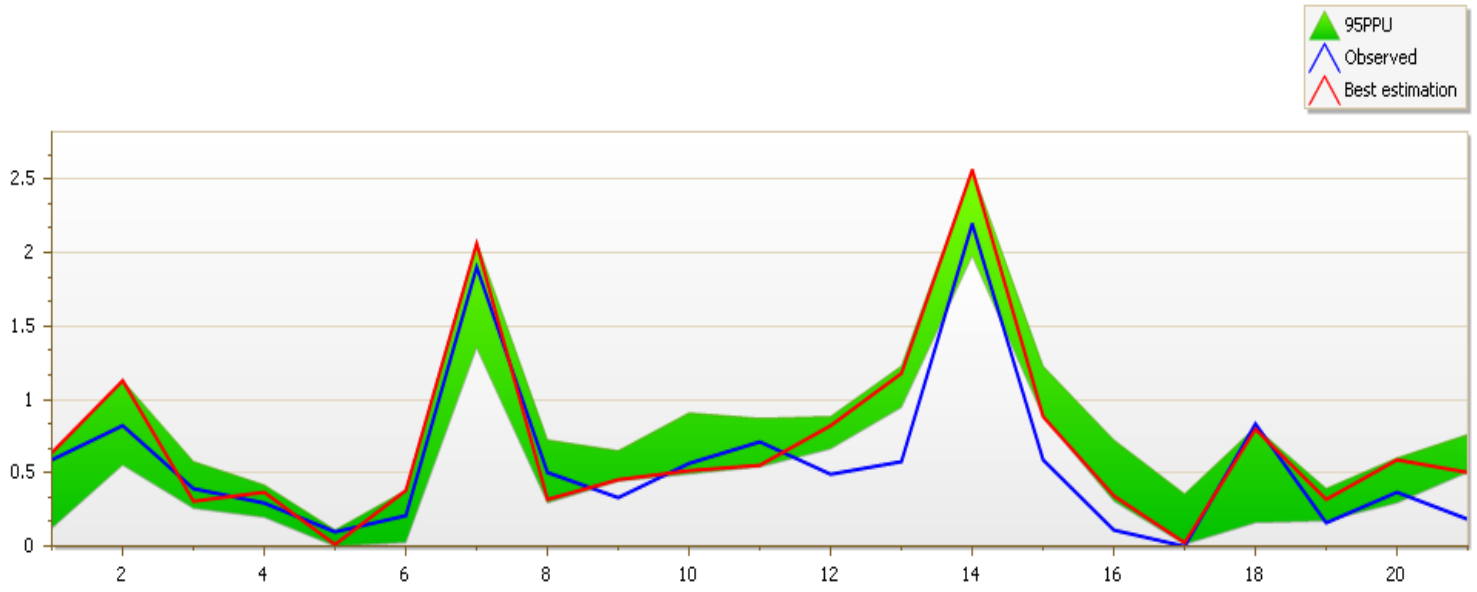

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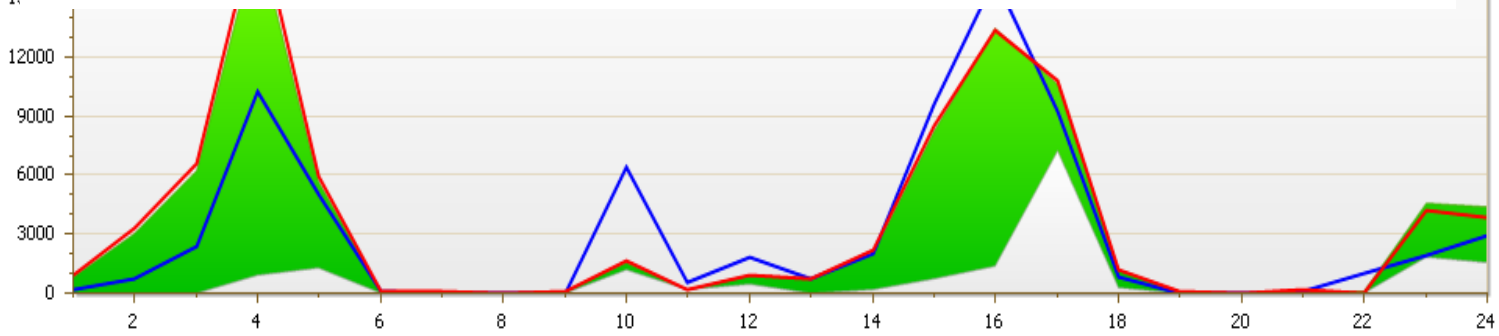
95ppu.sf2

P-factor = % observed data bracketet by the 95PPU

R-factor= avg. thickness of the 95PPU band



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Par_inf.sf2 | Observed.sf2 | SUFI2_extract_rch.def | 95ppu.sf2 | Dotty Plots

Dotty Plots

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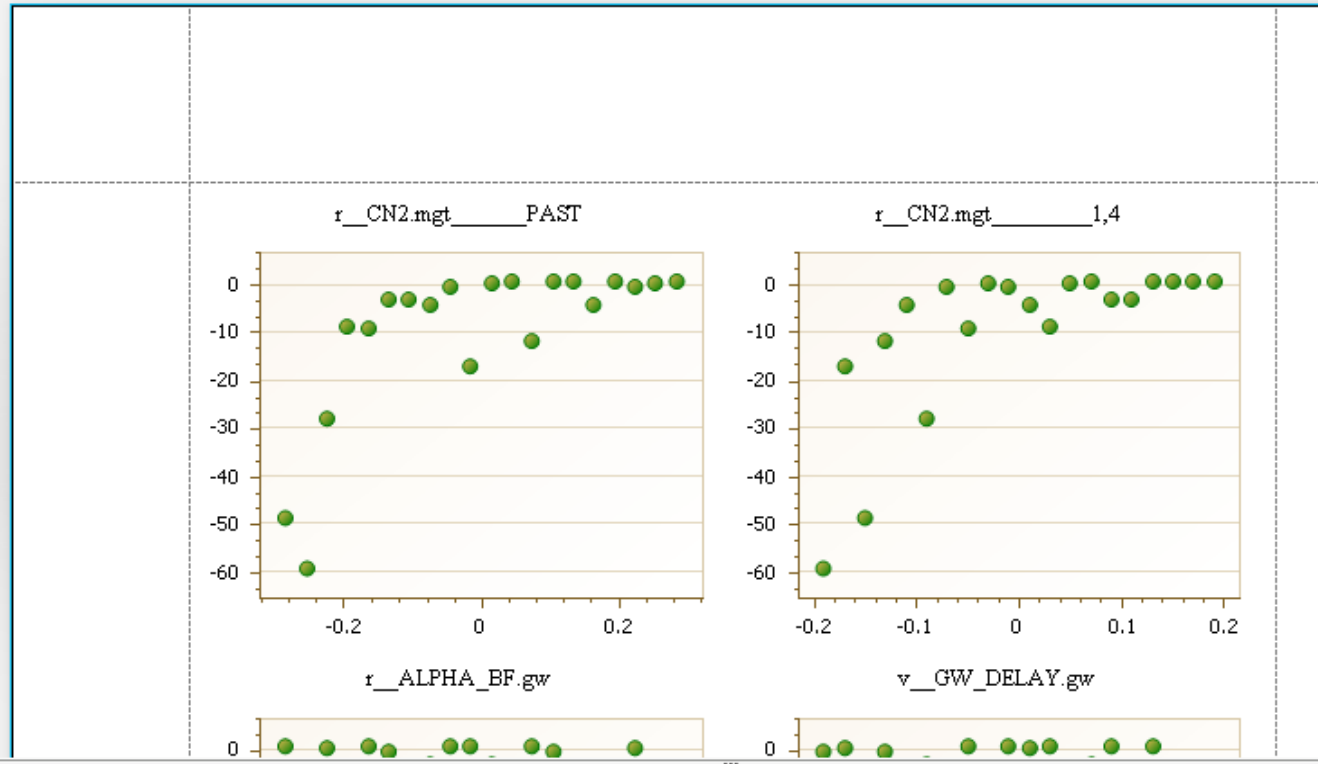

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    - Observed.sf2
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    - Dotty Plots
    - Best_Par.Sf2
    - Best_Sim.Sf2
    - Goal.Sf2
    - New_pars.sf2
    - Summary_Stat.S
    - Sensitivity
  - Iteration History

Par_inf.sf2 | Observed.sf2 | SUFI2_extract_rch.def | 95ppu.sf2 | Dotty Plots | Goal.Sf2

Goal.Sf2

```
no_pars=  14
no_Sims=  20
type_of_goal_fn=  Nash_Sutcliff
```

Sim_No.	r__CN2.mgt_____PAST	r__CN2.mgt_____1,4	r__ALPHA_BF.gw	v__GW_DELAY.gw	v__CH_N2.rte	v__CH_K2.rt
1	0.255000	-0.030000	0.087500	12.625000	0.007500	9.375000	0.175000	0.333500	0.048500	-0
2	0.045000	0.190000	0.002500	30.125000	0.022500	26.875000	0.825000	0.181500	0.105500	0
3	-0.285000	-0.150000	0.097500	17.875000	0.027500	12.875000	0.725000	0.371500	0.029500	0
4	-0.225000	-0.090000	0.057500	31.875000	0.052500	16.375000	0.225000	0.200500	0.219500	-0
5	0.285000	0.150000	0.022500	35.375000	0.072500	14.625000	0.875000	0.314500	0.086500	-0
6	0.225000	-0.070000	0.067500	10.875000	0.097500	21.625000	0.425000	0.219500	0.181500	-0
7	-0.075000	0.010000	0.007500	42.375000	0.087500	35.625000	0.675000	0.029500	0.333500	0
8	0.075000	-0.130000	0.072500	21.375000	0.092500	28.625000	0.275000	0.105500	0.162500	0
9	0.105000	0.130000	0.062500	23.125000	0.047500	30.375000	0.475000	0.295500	0.295500	-0
10	-0.105000	0.090000	0.052500	33.625000	0.002500	23.375000	0.575000	0.086500	0.238500	0
11	-0.015000	-0.170000	0.077500	14.375000	0.032500	32.125000	0.125000	0.067500	0.390500	-0
12	-0.165000	-0.050000	0.032500	24.875000	0.067500	7.625000	0.325000	0.352500	0.314500	-0
13	0.165000	-0.110000	0.092500	44.125000	0.057500	25.125000	0.375000	0.162500	0.200500	0
14	-0.135000	0.110000	0.037500	19.625000	0.042500	19.875000	0.025000	0.238500	0.352500	0
15	-0.195000	0.030000	0.017500	40.625000	0.082500	5.875000	0.775000	0.143500	0.276500	0
16	-0.255000	-0.190000	0.082500	37.125000	0.037500	33.875000	0.625000	0.124500	0.257500	0
17	0.195000	0.170000	0.047500	38.875000	0.017500	37.375000	0.075000	0.257500	0.371500	0
18	-0.045000	-0.010000	0.027500	16.125000	0.012500	39.125000	0.925000	0.390500	0.067500	0
19	0.135000	0.070000	0.042500	26.625000	0.062500	18.125000	0.525000	0.276500	0.143500	0
20	0.015000	0.050000	0.012500	28.375000	0.077500	11.125000	0.975000	0.048500	0.124500	-0

100%

C:\My Documents\Workshops\2010 Turkey

start | C:\My Docu... | C:\My Docu... | C:\SWAT-C... | C:\My Docu... | (0 unread) ... | Windows M... | upgradeSW... | Microsoft P... | test.Sufi2 -... | DE

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    - Summary_Stat.S
    - Sensitivity
  - Iteration History

Par_inf.sf2 | Observed.sf2 | SUFI2_extract_rch.def | 95ppu.sf2 | Dotty Plots | Goal.Sf2 | Summary_Stat.Sf2

Summary_Stat.Sf2

Goal_type= Nash_Sutcliffe (type 5) Best_sim_no= 5 Best_goal = 7.658981e-001

Variable	p_factor	r-factor	R2	NS	br2	MSE
q_1	0.62	0.70	0.90	0.80	0.8397	0.0561
q_2	0.58	0.63	0.94	0.86	0.9317	0.0977
S_1	0.50	0.31	0.74	0.70	0.4481	764768
s_3	0.63	0.65	0.75	0.65	0.7433	611138
N_4	0.52	9.31	0.82	0.82	0.6819	256179

-- Results for bevavoral parameters

Variable	p_factor	r-factor	R2	NS	br2	MSE
q_1	0.52	0.35	0.90	0.80	0.8397	0.0561
q_2	0.29	0.22	0.94	0.86	0.9317	0.0977
S_1	0.29	0.19	0.74	0.70	0.4481	764768
s_3	0.29	0.23	0.75	0.65	0.7433	611138
N_4	0.48	0.73	0.82	0.82	0.6819	256179

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    - Best_Sim.Sf2
    - Goal.Sf2
    - New_pars.sf2
    - Summary_Stat.S
    - Sensitivity
  - Iteration History

Par_inf.sf2 | Observed.sf2 | SUFI2_extract_rch.def | 95ppu.sf2 | Dotty Plots | Goal.Sf2 | Summary_Stat.Sf2 | Sensitivity

Sensitivity

Parameter Name	t-Stat	P-Value
r__ALPHA_BF.gw	-1.570698190	0.177052024
v__CH_K2.rte	-0.884914156	0.416722277
v__GW_DELAY.gw	-0.685187837	0.523692215
v__CH_N2.rte	-0.410948069	0.698130054
r__SOL_AWC(1).sol____...	-0.279574449	0.791000307
r__SOL_K(1).sol_____...	-0.160762679	0.878573818
v__SFTMP.bsn	-0.160692450	0.878626319
v__ALPHA_BNK.rte	-0.145360643	0.890104276
r__CN2.mgt_____1,4	-0.007925449	0.993982968
r__SOL_AWC(1).sol____...	0.119566045	0.909482520
r__SOL_BD(1).sol_____...	0.446672588	0.673793633
r__SOL_BD(1).sol_____...	0.792913927	0.463773734
r__SOL_K(1).sol_____...	1.076260875	0.330977237
r__CN2.mgt_____PAST	2.717782435	0.041885535

Sensitivity Analysis

1. Global sensitivity analysis

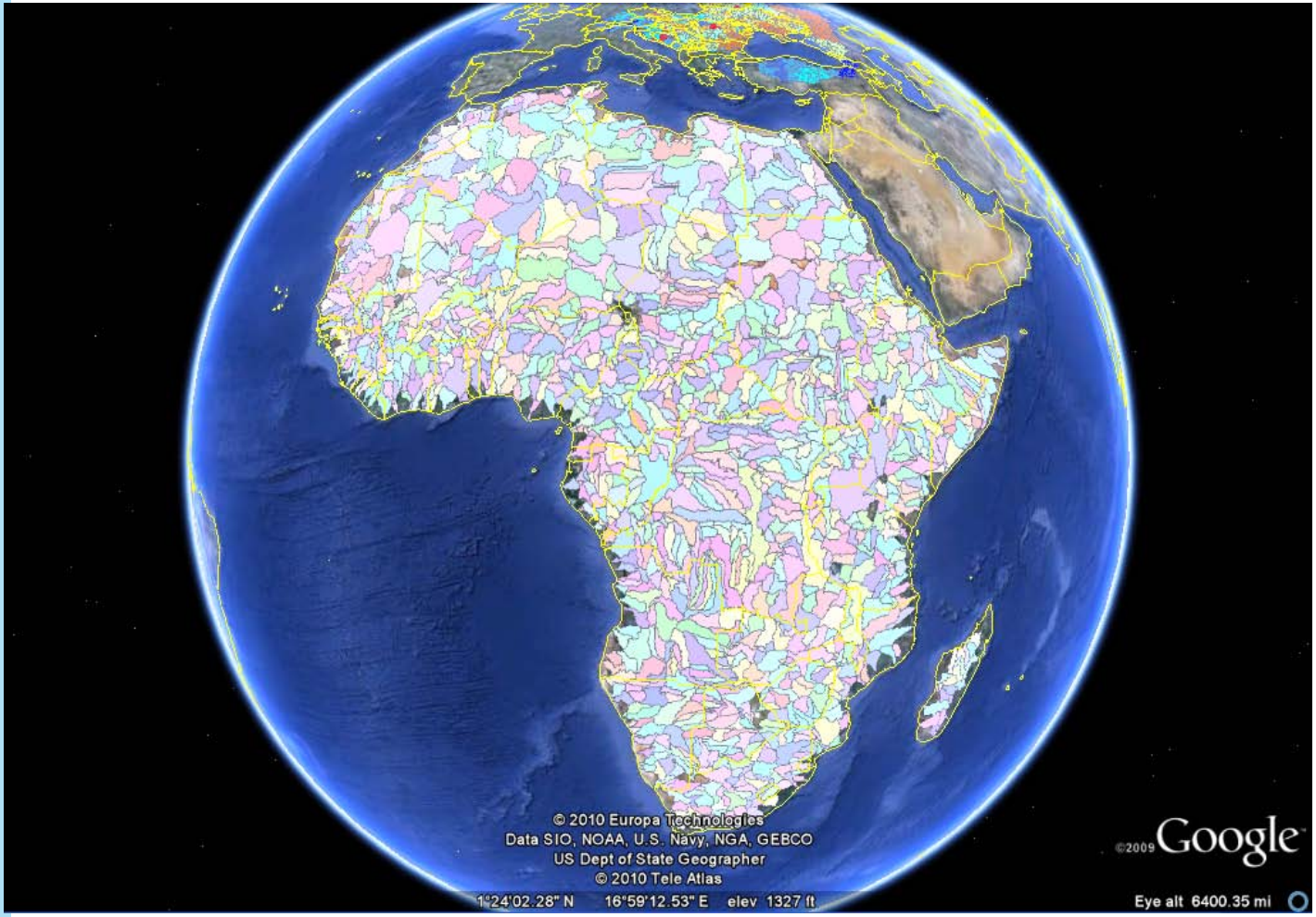
$$g_n = \alpha + \sum_{j=1}^{m} \beta_j b_j$$

2. Local sensitivity analysis

One-at-a-time sensitivity analysis

Future addition to SWAT-CUP

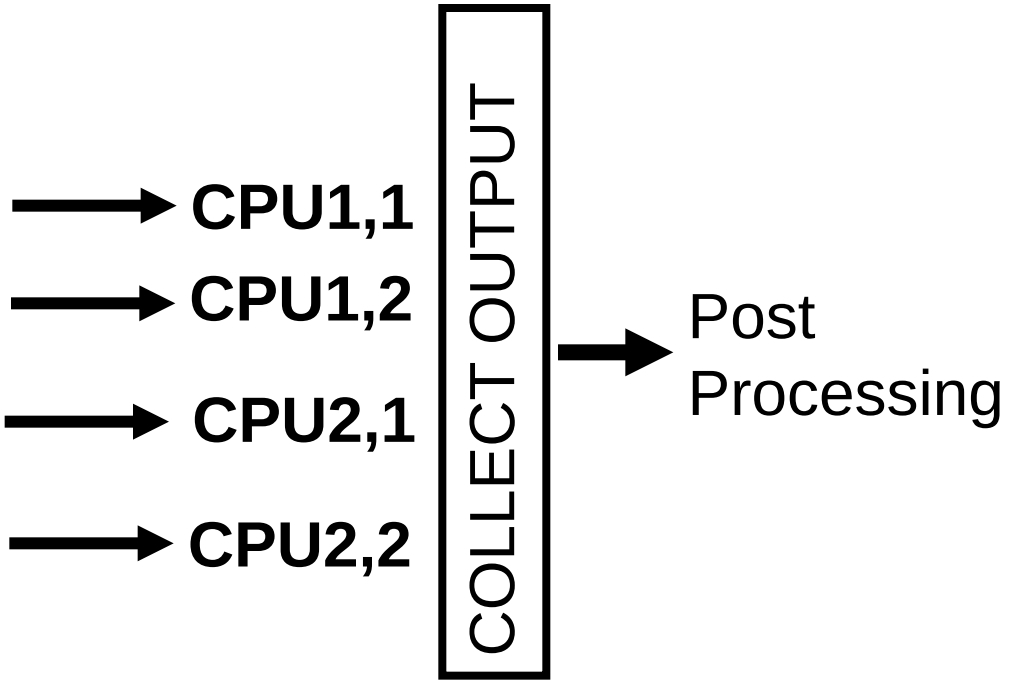
Visualization of the calibrated outputs



Future addition to SWAT-CUP

Parallelization of calibration runs

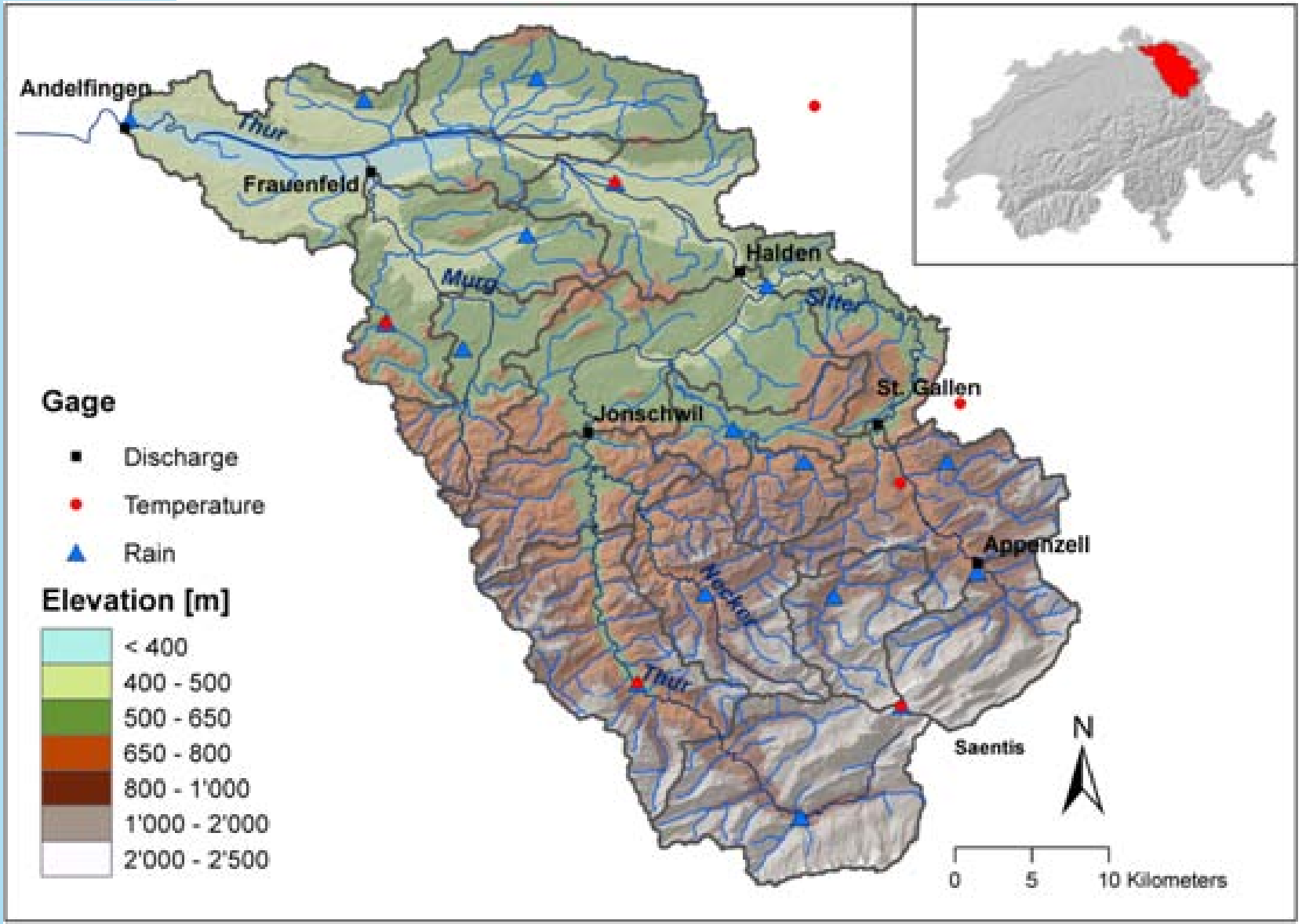
1	0.600000	0.066667	38.033333	0.029333
2	-0.066667	0.024000	36.566666	0.056000
3	0.133333	0.018667	39.500000	0.013333
4	0.333333	0.008000	43.166668	0.045333
5	0.533333	0.029333	34.366665	0.066667
6	0.400000	0.050667	35.833332	0.024000
7	0.066667	0.077333	42.433334	0.061333
8	0.266667	0.002667	37.299999	0.077333
9	0.800000	0.072000	41.700001	0.050667
10	-0.000000	0.013333	43.900002	0.034667
11	0.200000	0.034667	44.633335	0.008000
12	0.466667	0.045333	35.099998	0.040000
13	0.666667	0.056000	40.966667	0.072000
14	0.866667	0.061333	38.766666	0.002667
15	0.733333	0.040000	40.233334	0.018667



eawag
aquatic research

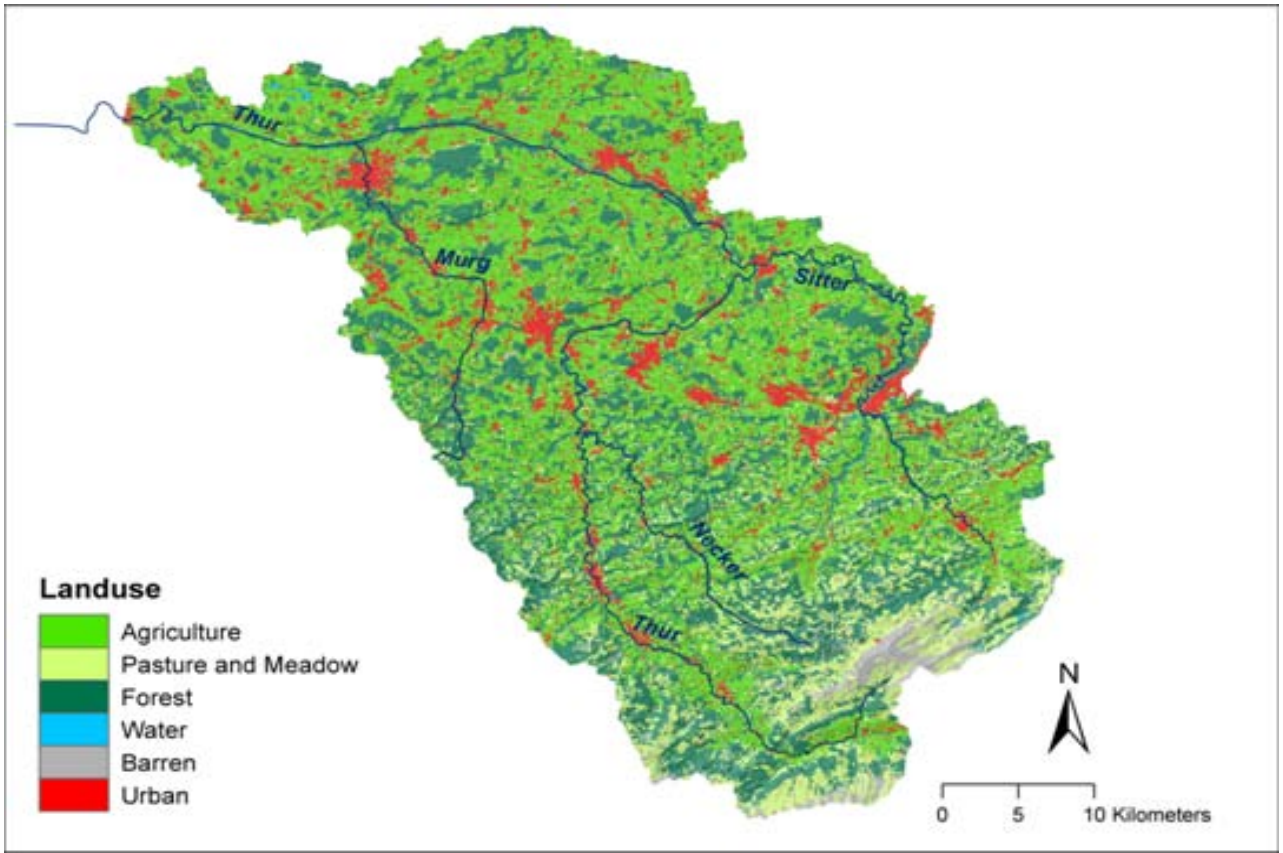
Thank you for your attention!

Thur Watershed Application



Objective Function

$$g = w_1 \sum_{i=1}^{n} \left(Q_m - Q_s\right)_i^2 + w_2 \sum_{i=1}^{n} \left(S_m - S_s\right)_i^2 + w_3 \sum_{i=1}^{n} \left(N_m - N_s\right)_i^2 + w_4 \sum_{i=1}^{n} \left(P_m - P_s\right)_i^2$$



Constrained Objective Function

$$g = w_1 \sum_{i=1}^{n} \left(Q_m - Q_s\right)_i^2 + w_2 \sum_{i=1}^{n} \left(S_m - S_s\right)_i^2 + w_3 \sum_{i=1}^{n} \left(N_m - N_s\right)_i^2 + w_4 \sum_{i=1}^{n} \left(P_m - P_s\right)_i^2$$

$2.2 < N_{forest} < 16$

$19 < N_{agricultural} < 47$

$15 < N_{pasture} < 25$

.....

Conditionality of Calibrated Models

A calibrated model is always conditioned on the situation that it was calibrated for and care must be taken to apply it to outside this boundary