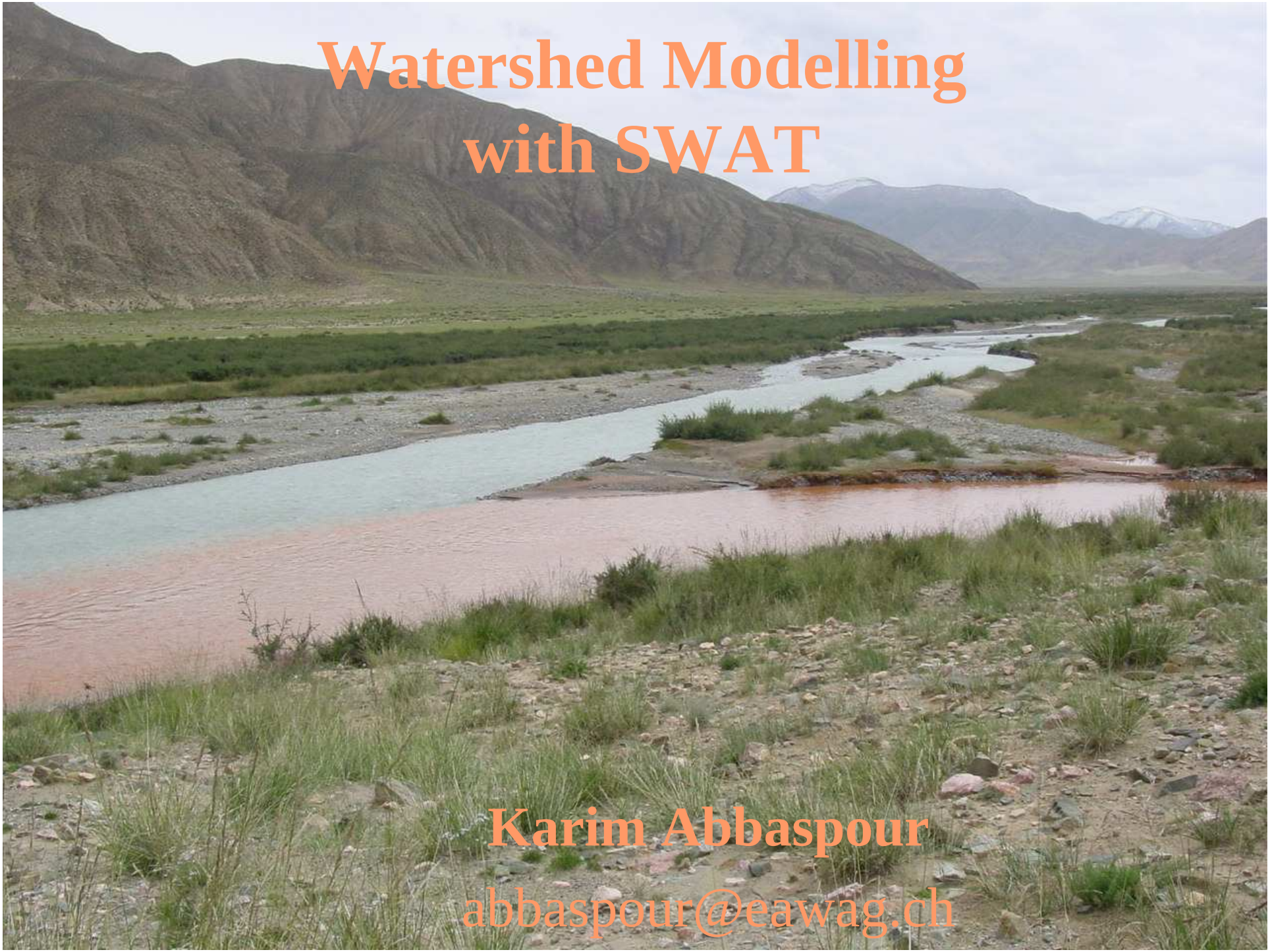

Watershed Modelling with SWAT

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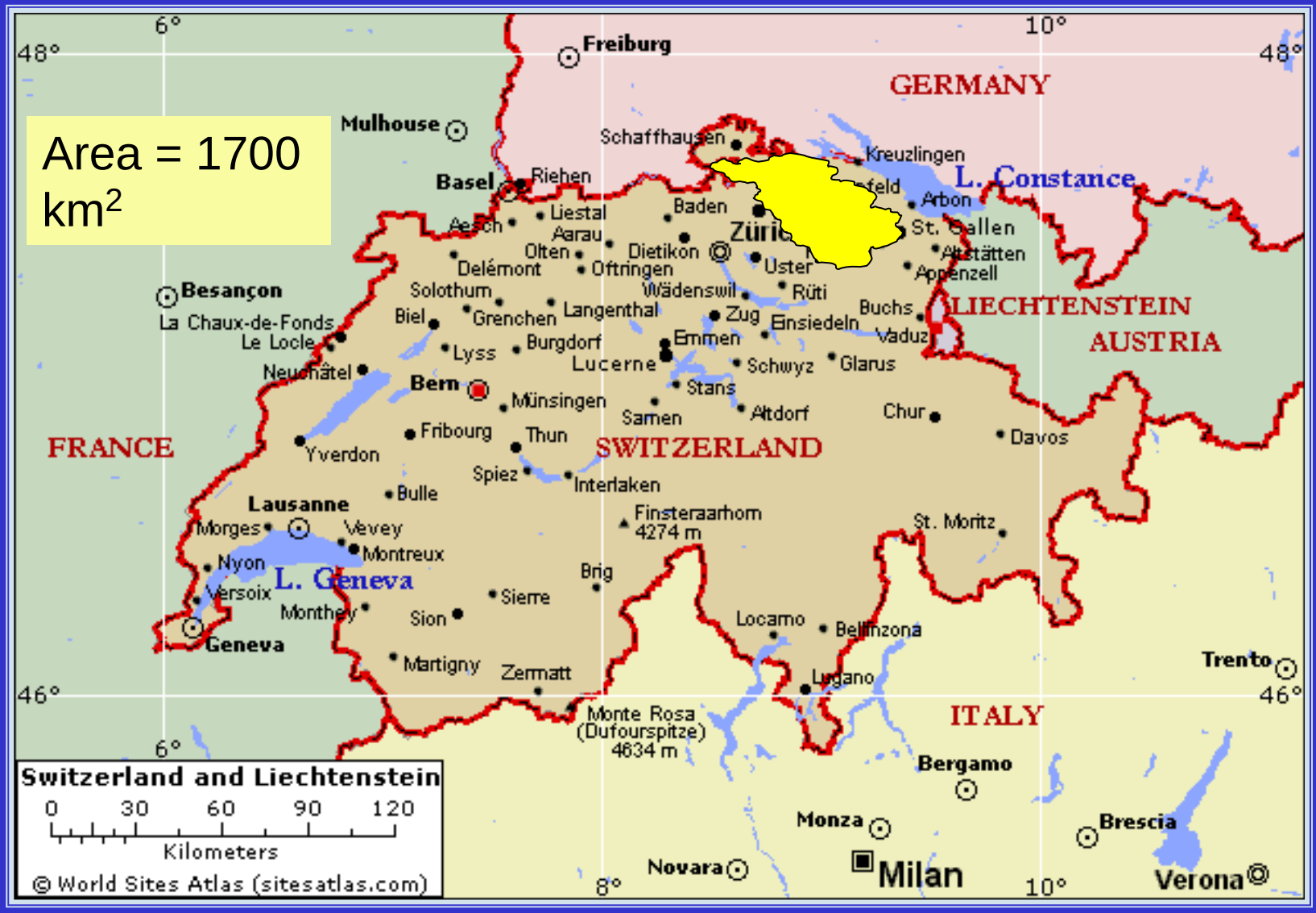
SWAT Applications

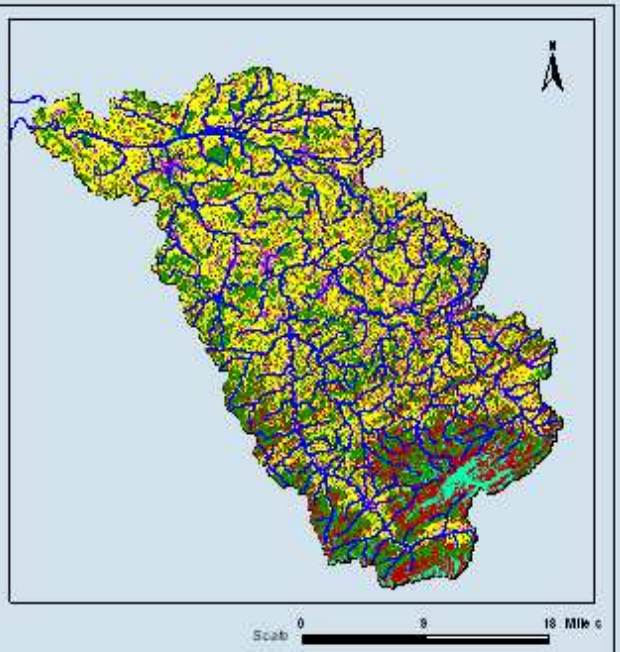
- Thur watershed, Switzerland (1,700 km^2)
- Chaobei River Basin, China (5,300 km^2)
- Iran application (1.6 million km^2)
- West Africa (4 million km^2)
- Entire Africa application (30 million km^2)

Application of SWAT-SUFI-2 to Thur watershed

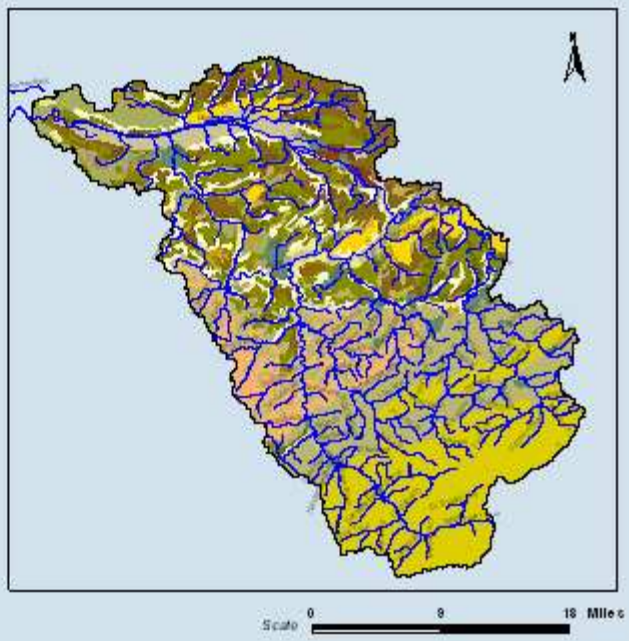


Thur Basin DEM

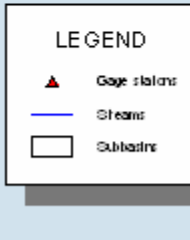
Thur Basin Land Use Map

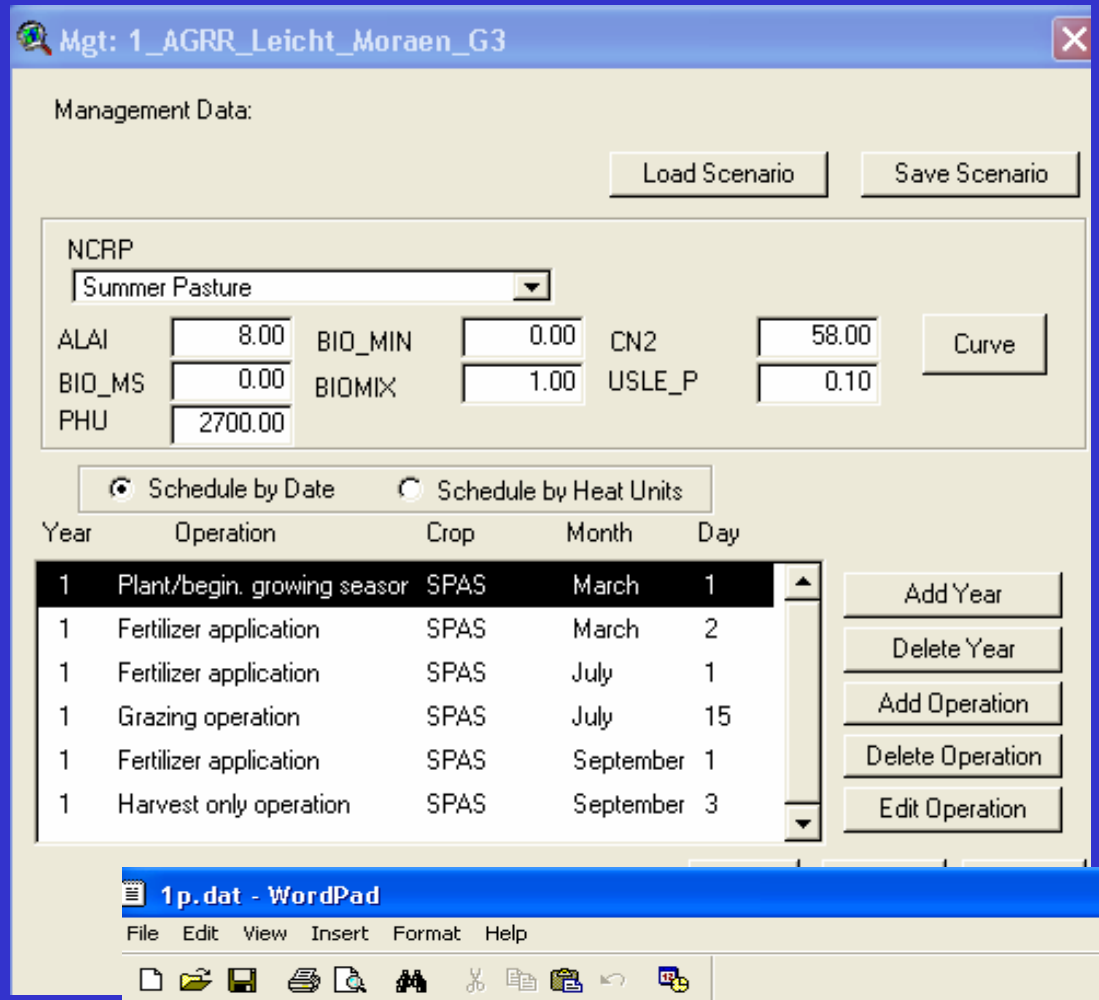


Thur Basin Soil Map



Delineation of the Thur River Basin (16 subchatchments)

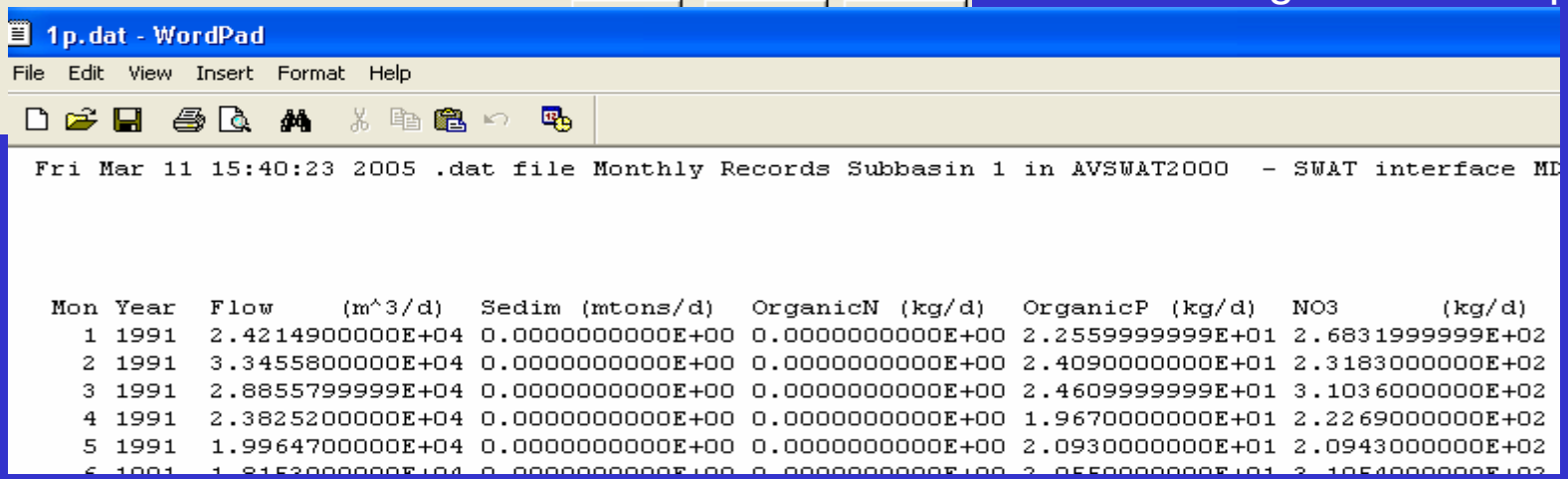




management

Point source discharge

Sewage treatment plants

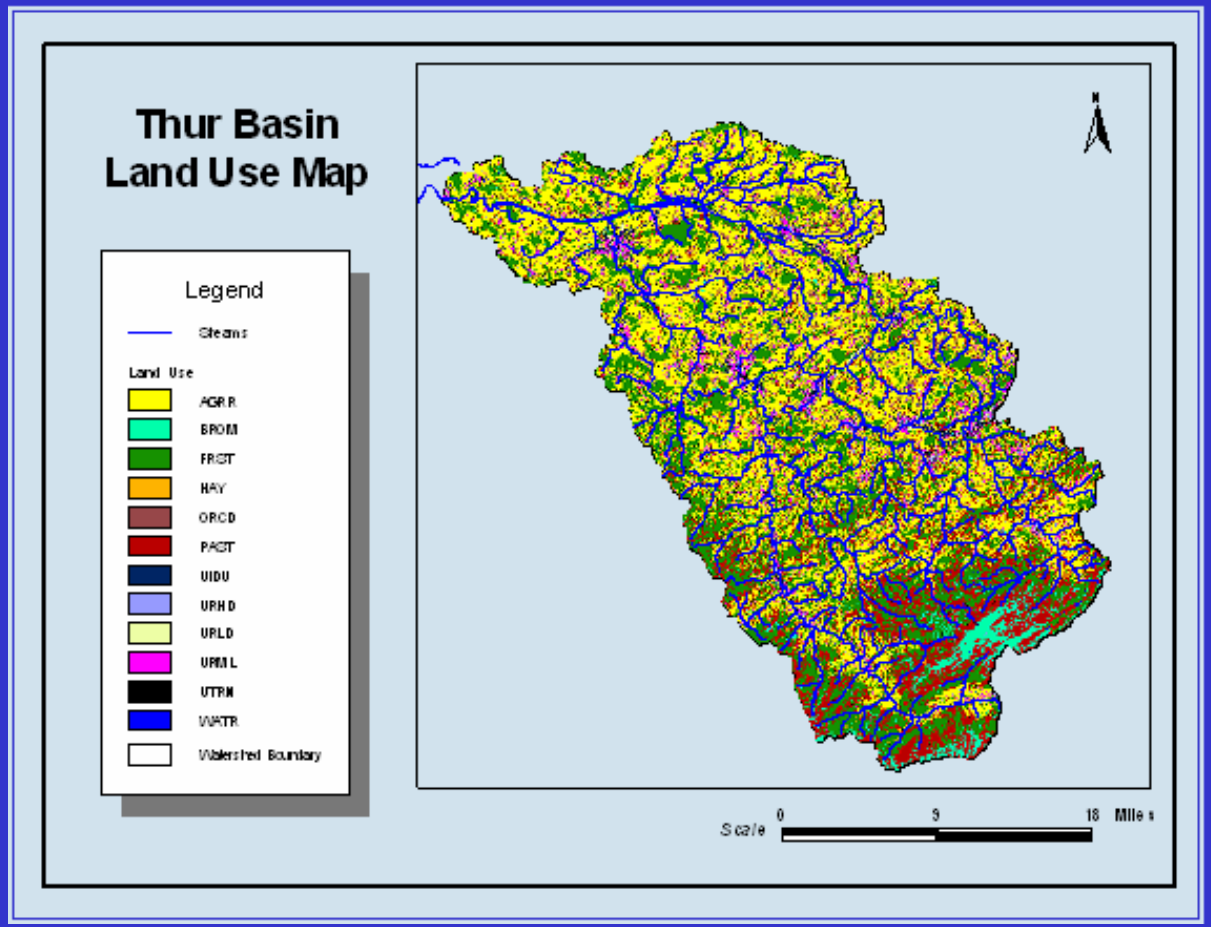


Objective function based on measured data at the watershed outlet:

$$g = \frac{1}{\sigma_{Q_m}^2}\sum_{i=1}^{130}\left(Q_m - Q_s\right)_i^2 + \frac{1}{\sigma_{S_m}^2}\sum_{i=1}^{130}\left(S_m - S_s\right)_i^2 + \frac{1}{\sigma_{N_m}^2}\sum_{i=1}^{130}\left(N_m - N_s\right)_i^2 + \frac{1}{\sigma_{P_m}^2}\sum_{i=1}^{130}\left(P_m - P_s\right)_i^2$$

Subject to:

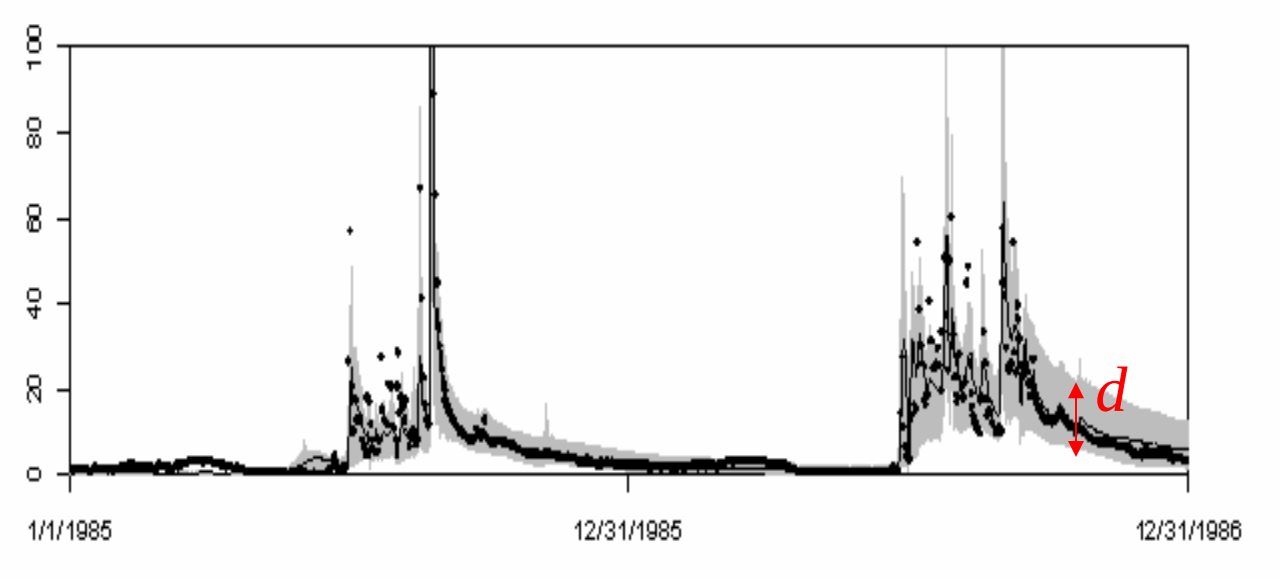
$$0.1 \le S_{\text{Forest}} \le 0.3$$
$$1.5 \le S_{\text{Agricultural}} \le 6$$
$$2.2 \le N_{\text{Forest}} \le 16$$
$$19 \le N_{\text{Agricultural}} \le 47$$
$$15 \le N_{\text{Pasture}} \le 25$$
$$0.02 \le P_{\text{Forest}} \le 0.1$$
$$0.5 \le P_{\text{Agricultural}} \le 2.4$$
$$0.3 \le P_{\text{Pasture}} \le 1.2$$

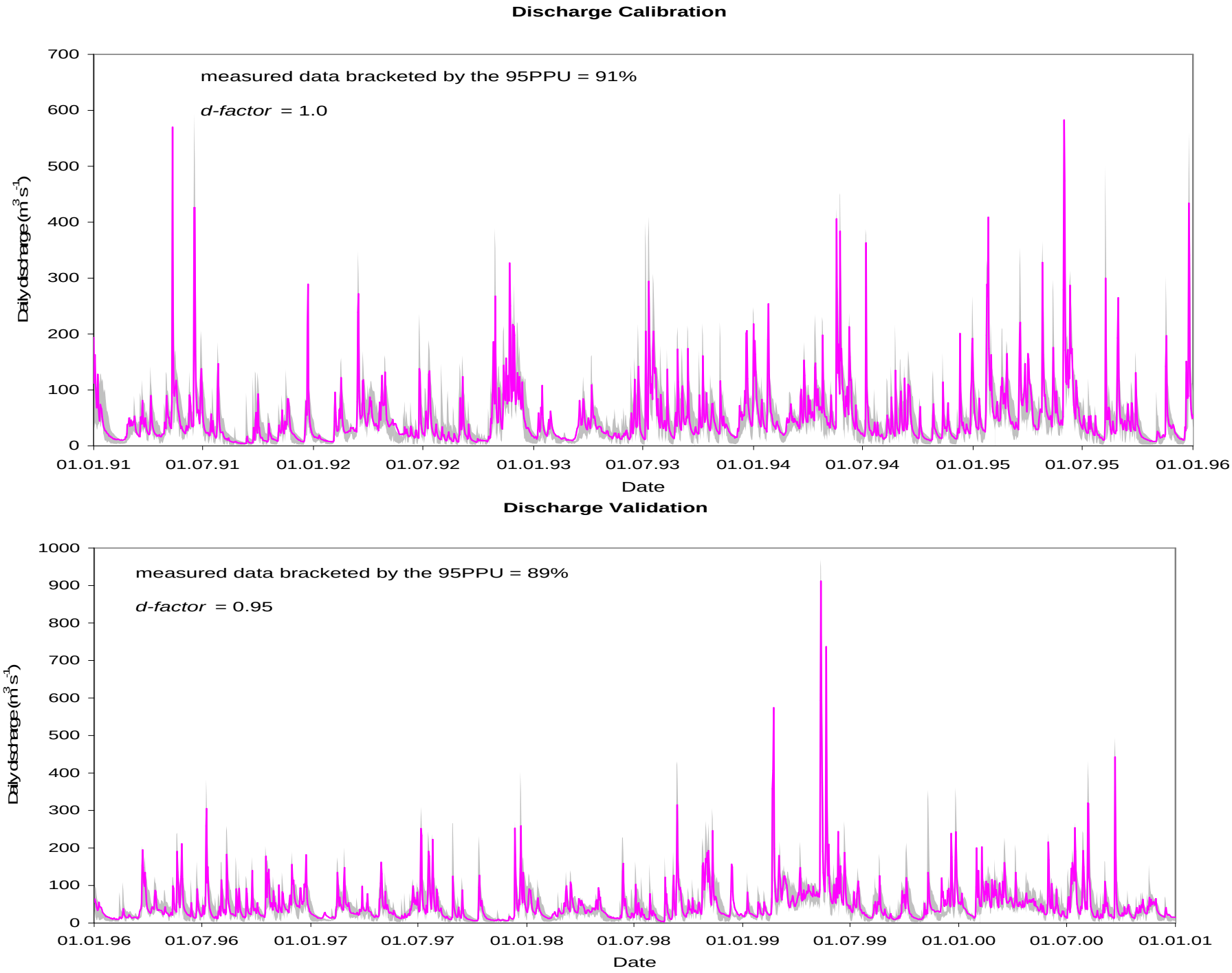


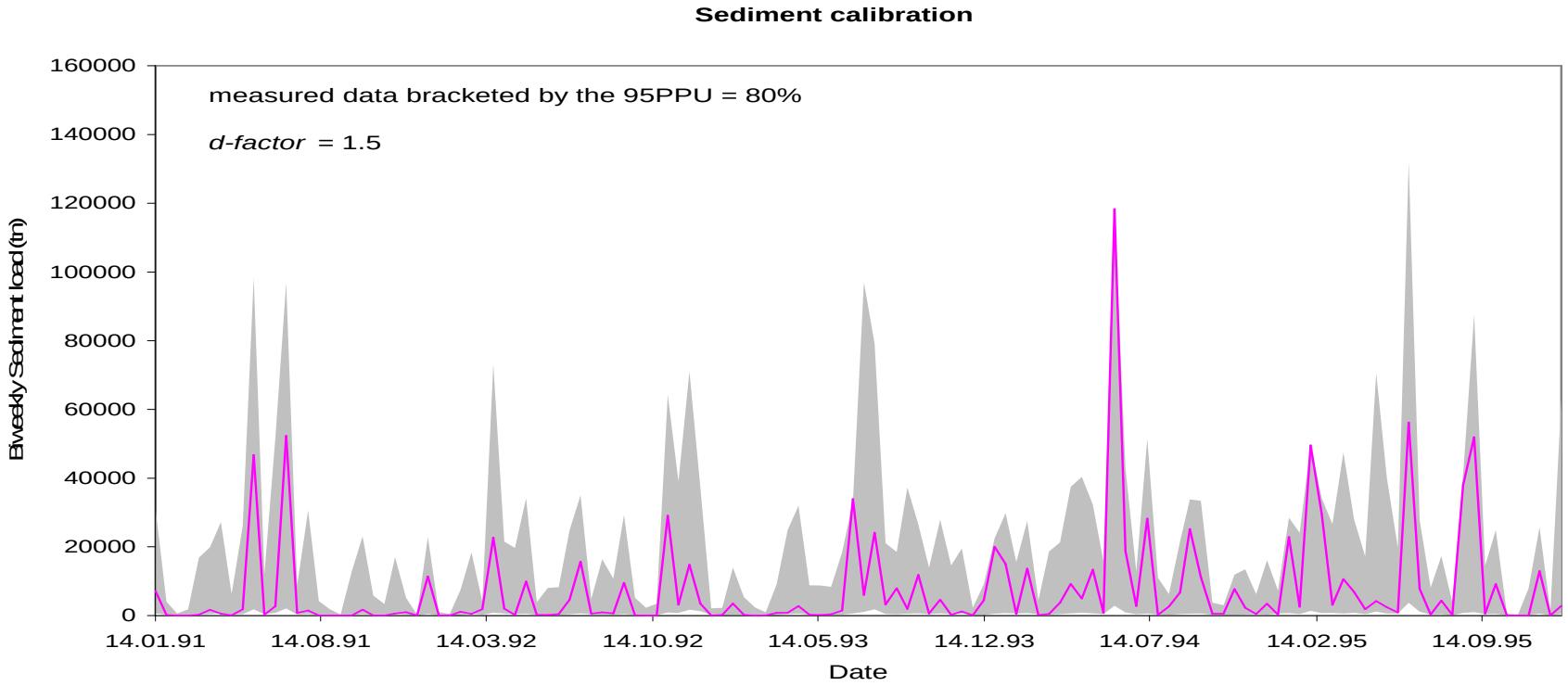
p-factor = 85%

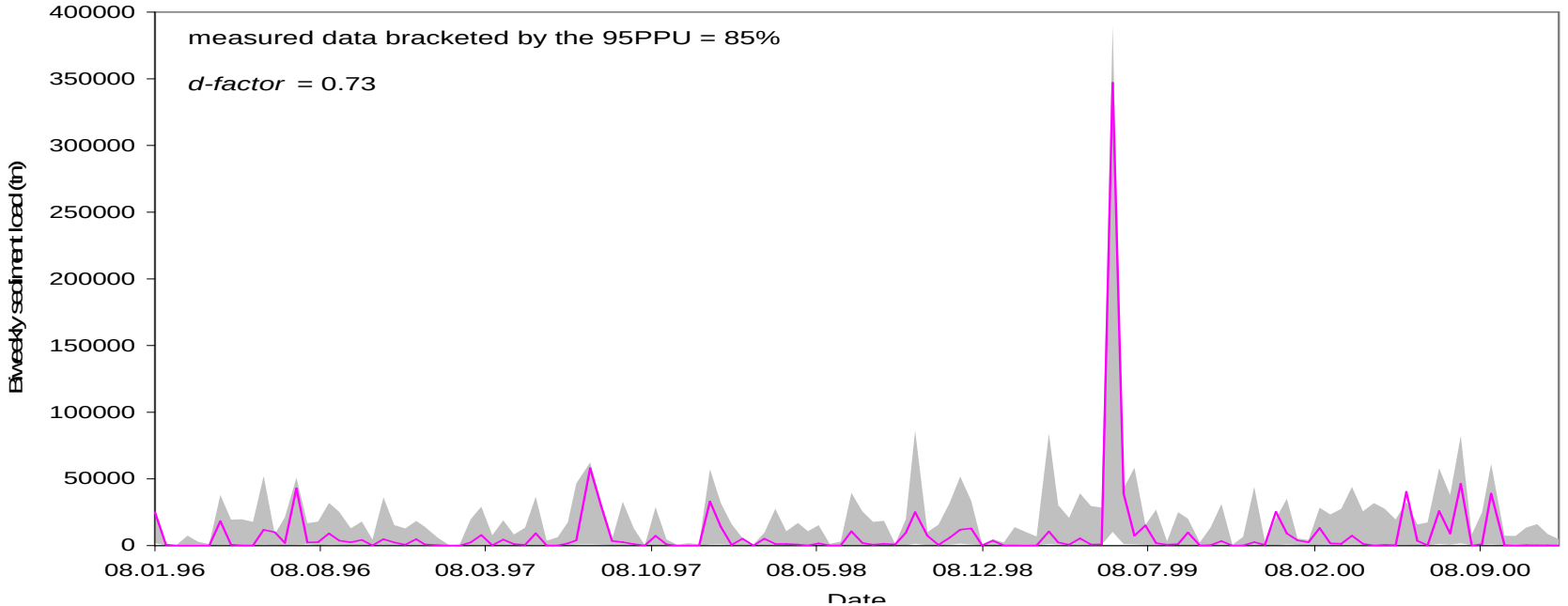
d-factor = 1.02

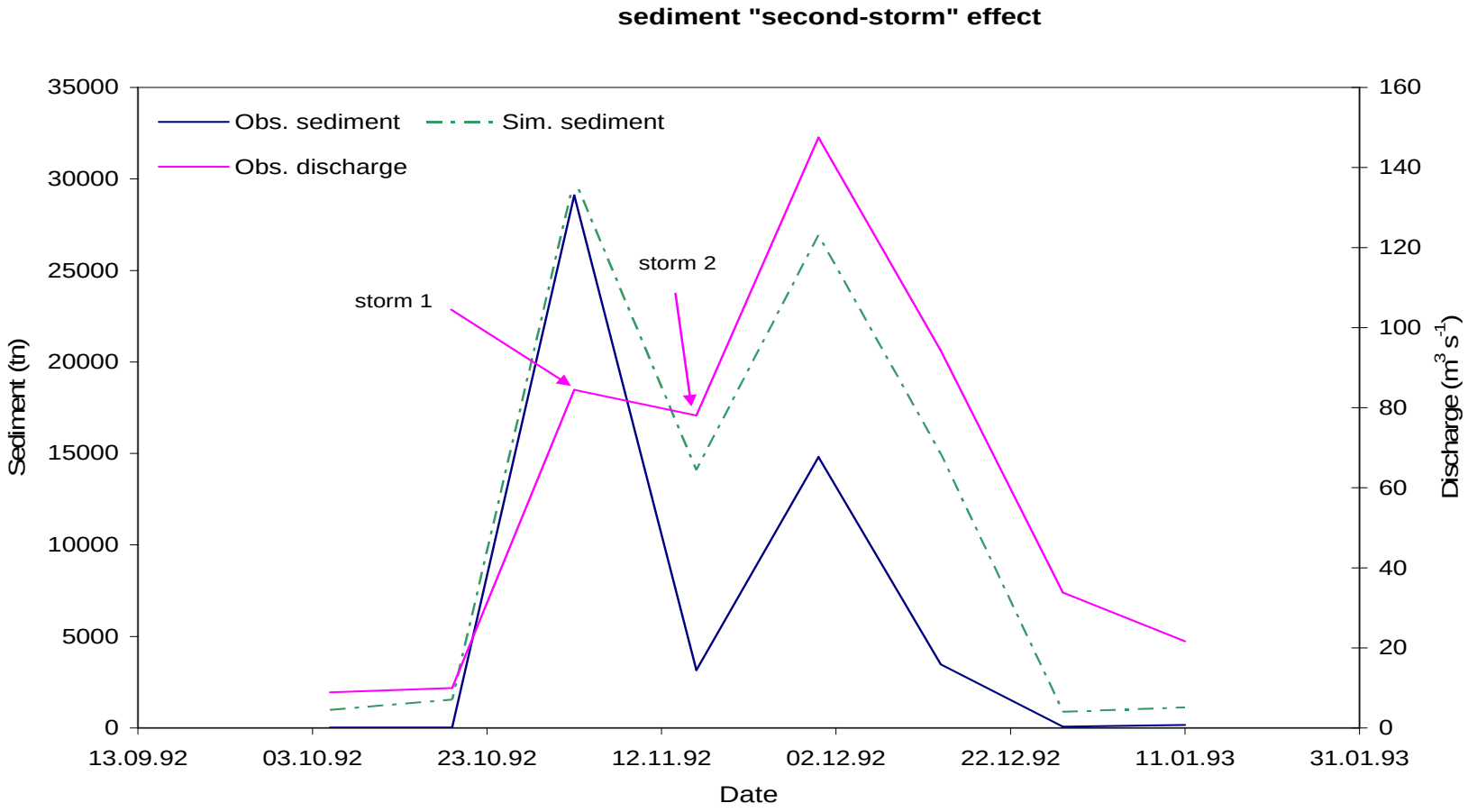
$$\bar{d} / \sigma^2$$

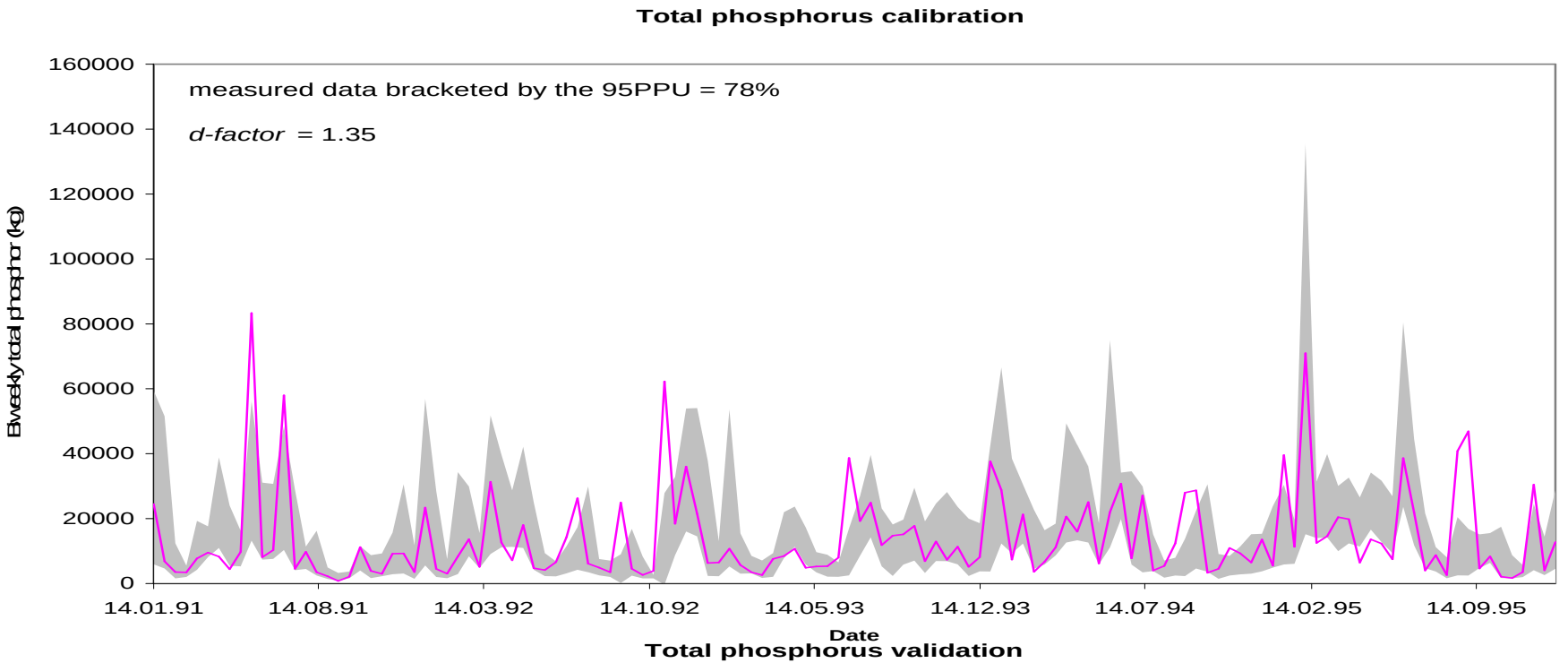


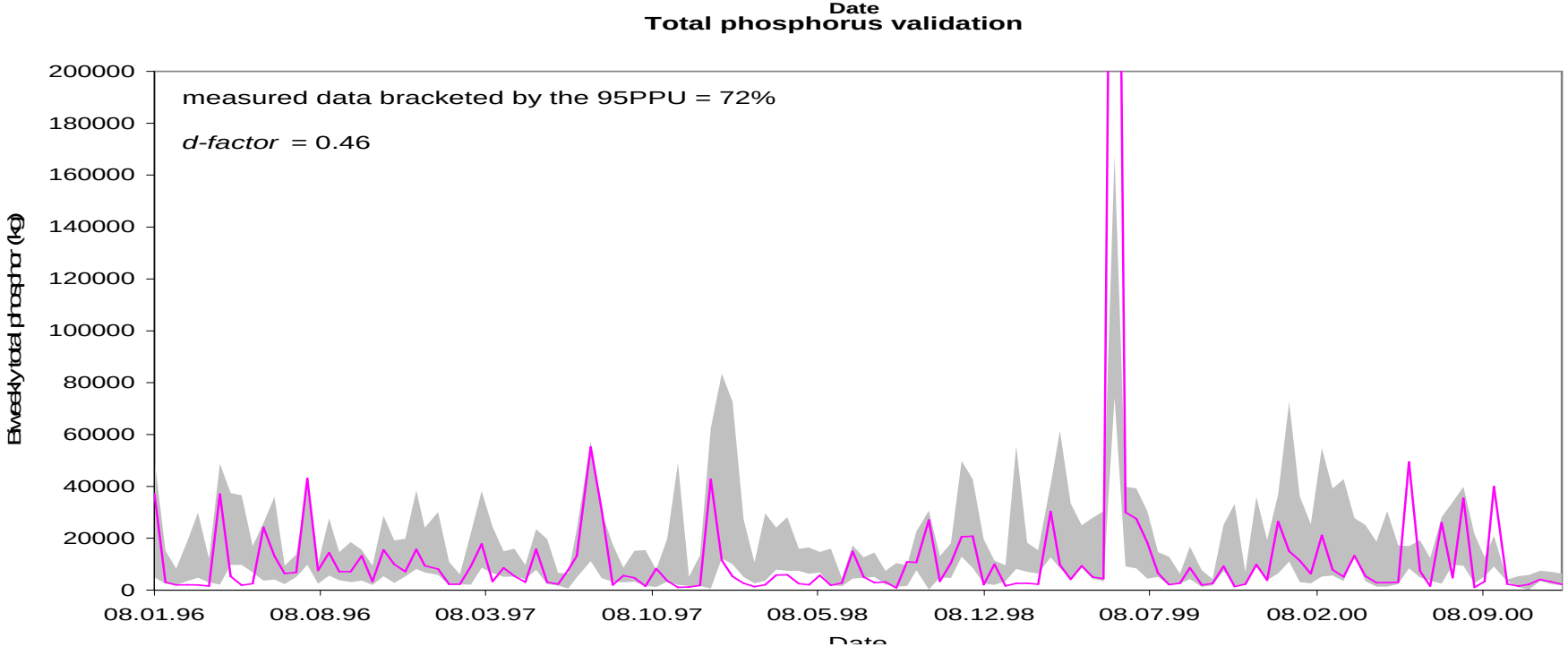

Discharge Calibration
measured data bracketed by the 95PPU = 91%
d-factor = 1.0
Daily discharge (m3 s-1)
0
100
200
300
400
500
600
700
01.01.91
01.07.91
01.01.92
01.07.92
01.01.93
01.07.93
01.01.94
01.07.94
01.01.95
01.07.95
01.01.96
Date
Discharge Validation
measured data bracketed by the 95PPU = 89%
d-factor = 0.95
Daily discharge (m3 s-1)
0
100
200
300
400
500
600
700
800
900
1000
01.01.96
01.07.96
01.01.97
01.07.97
01.01.98
01.07.98
01.01.99
01.07.99
01.01.00
01.07.00
01.01.01
Date

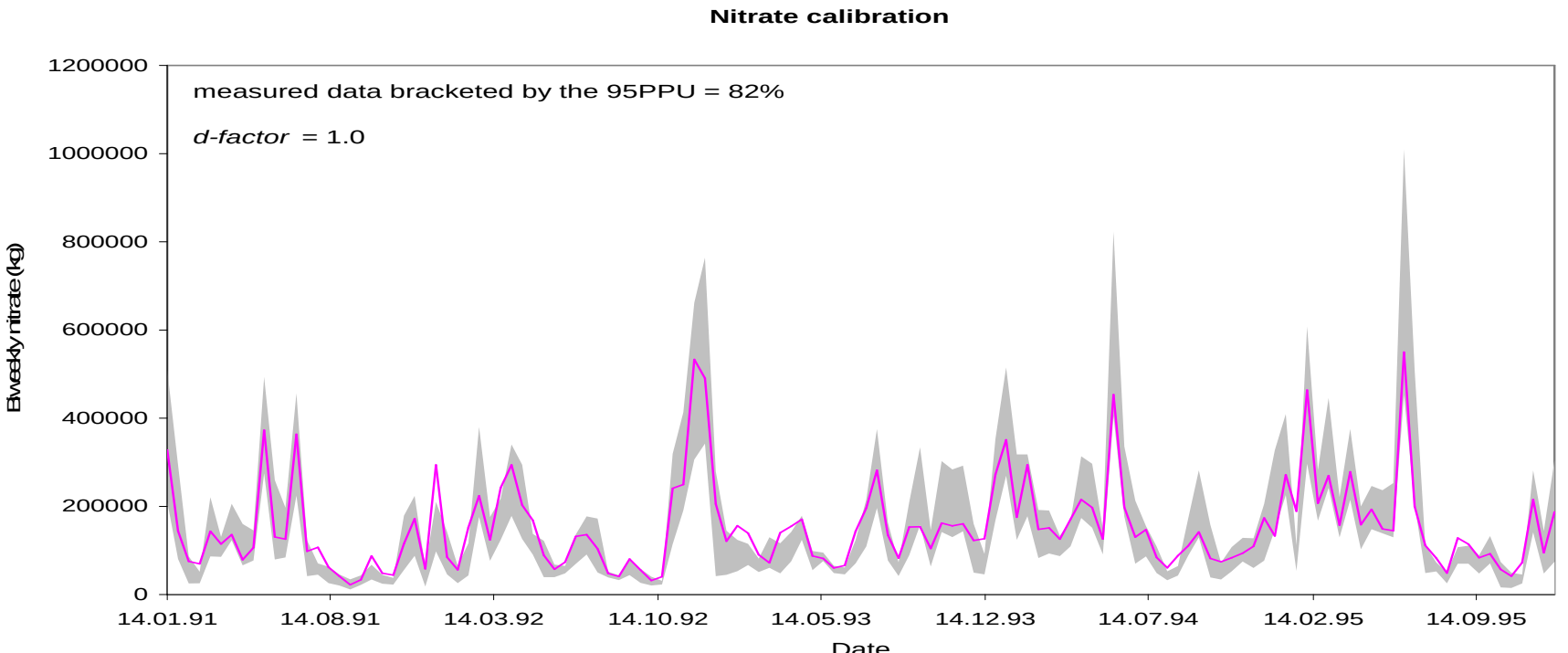

Sediment calibration
measured data bracketed by the 95PPU = 80%
d-factor = 1.5
Biweekly Sediment load (tn)
160000
140000
120000
100000
80000
60000
40000
20000
0
14.01.91
14.08.91
14.03.92
14.10.92
14.05.93
14.12.93
14.07.94
14.02.95
14.09.95
Date

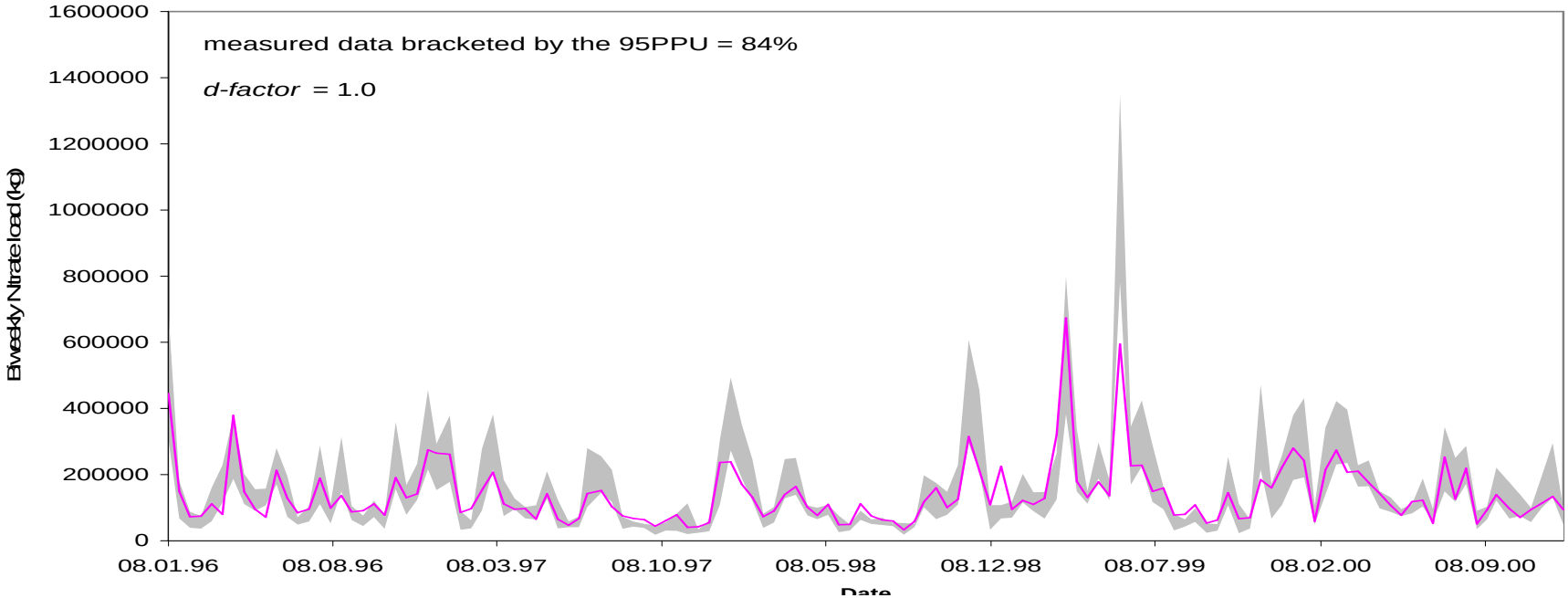

Sediment validation
measured data bracketed by the 95PPU = 85%
d-factor = 0.73
Biweekly sediment load (tn)
400000
350000
300000
250000
200000
150000
100000
50000
0
08.01.96
08.08.96
08.03.97
08.10.97
08.05.98
08.12.98
08.07.99
08.02.00
08.09.00
Date


sediment "second-storm" effect
Obs. sediment
Sim. sediment
Obs. discharge
storm 1
storm 2
Sediment (tn)
Discharge (m3 s-1)
Date
35000
30000
25000
20000
15000
10000
5000
0
160
140
120
100
80
60
40
20
0
13.09.92
03.10.92
23.10.92
12.11.92
02.12.92
22.12.92
11.01.93
31.01.93

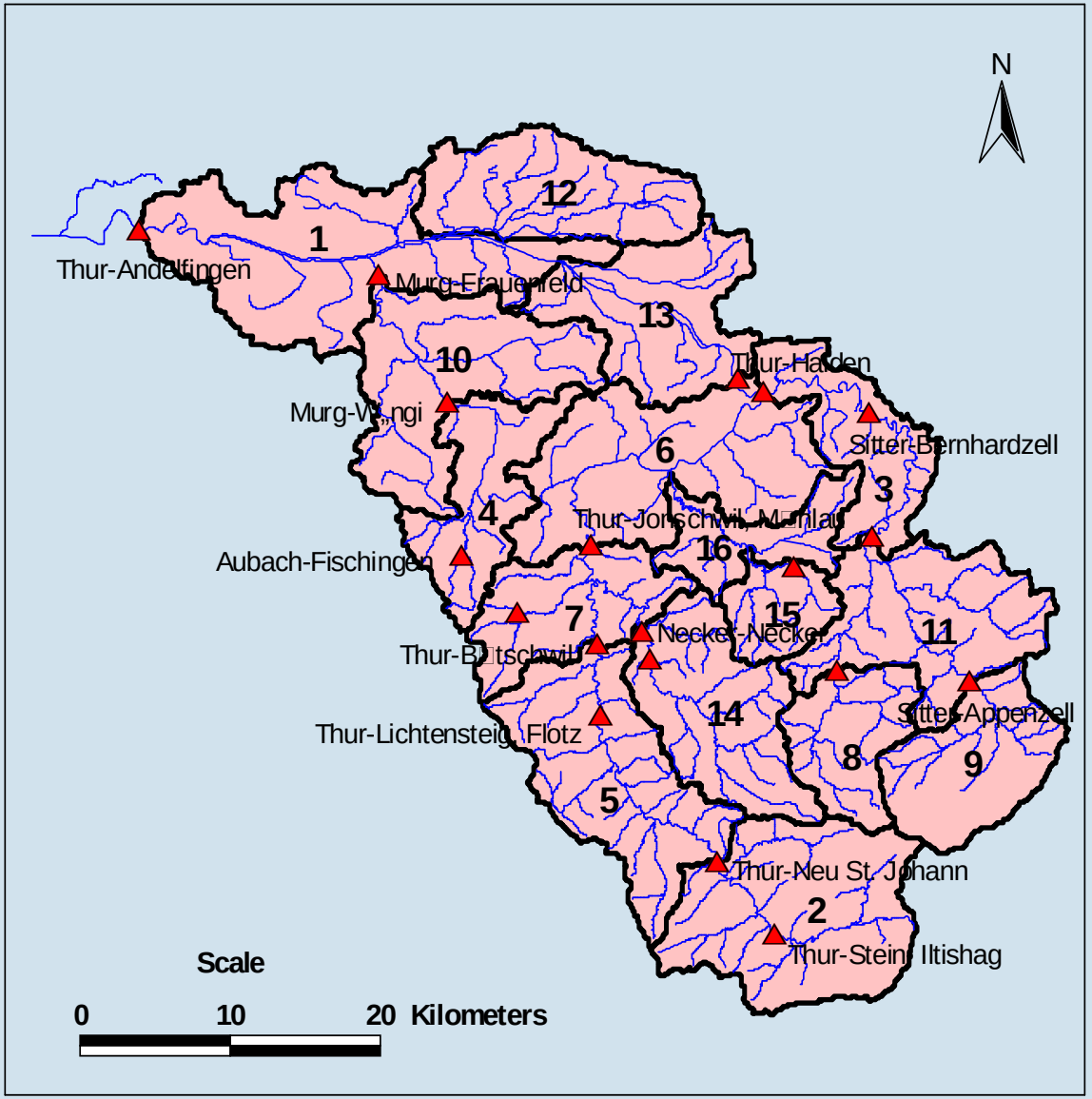

Total phosphorus calibration
measured data bracketed by the 95PPU = 78%
d-factor = 1.35
Bweekly total phosphor (kg)
160000
140000
120000
100000
80000
60000
40000
20000
0
14.01.91
14.08.91
14.03.92
14.10.92
14.05.93
14.12.93
14.07.94
14.02.95
14.09.95
Date


Total phosphorus validation
measured data bracketed by the 95PPU = 72%
d-factor = 0.46
Bweekly total phosphor (kg)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
08.01.96
08.08.96
08.03.97
08.10.97
08.05.98
08.12.98
08.07.99
08.02.00
08.09.00
Date


Nitrate calibration
measured data bracketed by the 95PPU = 82%
d-factor = 1.0
Biweekly nitrate (kg)
1200000
1000000
800000
600000
400000
200000
0
14.01.91
14.08.91
14.03.92
14.10.92
14.05.93
14.12.93
14.07.94
14.02.95
14.09.95
Date

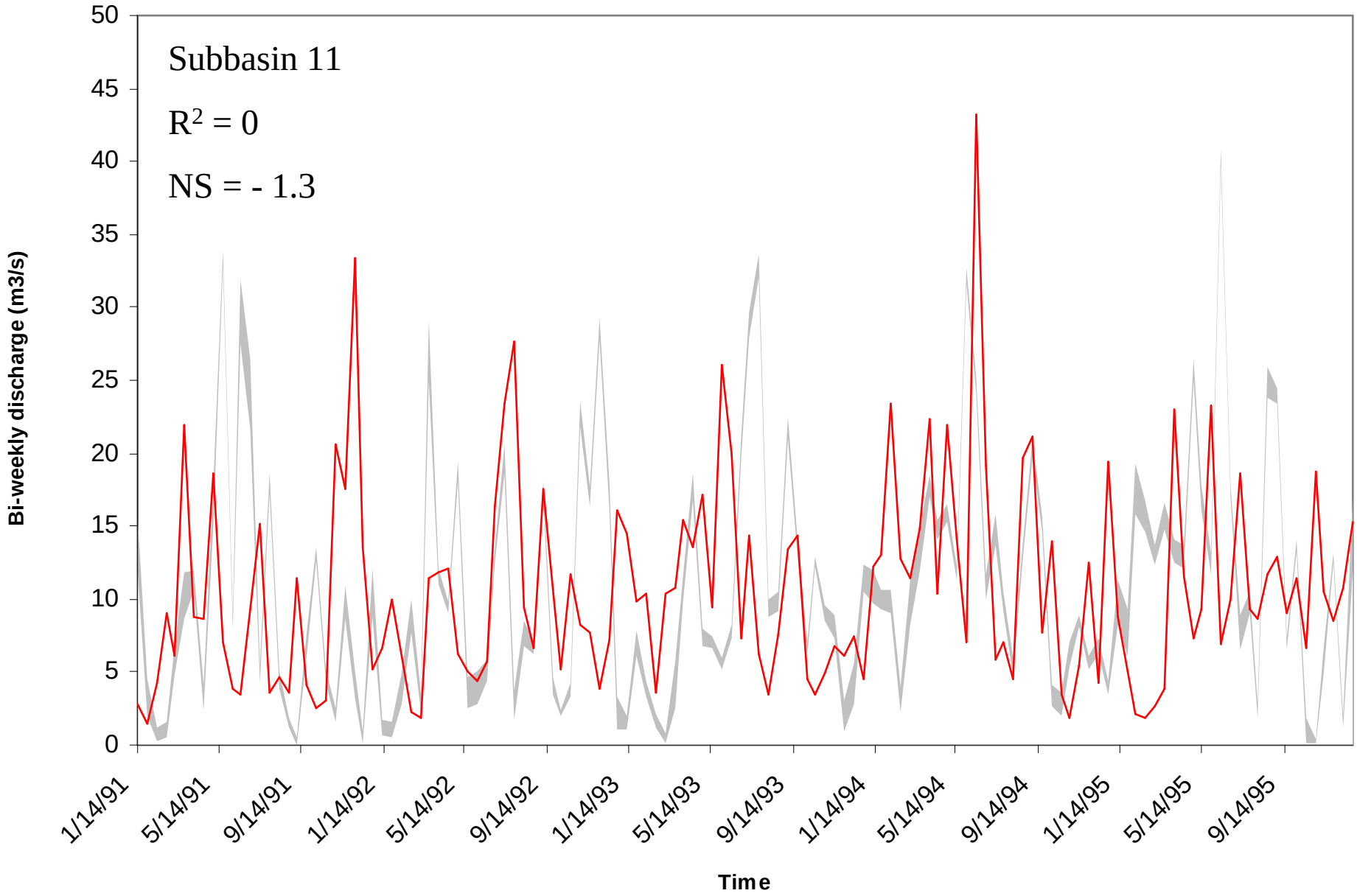

Nitrate validation
measured data bracketed by the 95PPU = 84%
d-factor = 1.0
Biweekly Nitrate load (kg)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
08.01.96
08.08.96
08.03.97
08.10.97
08.05.98
08.12.98
08.07.99
08.02.00
08.09.00
Date

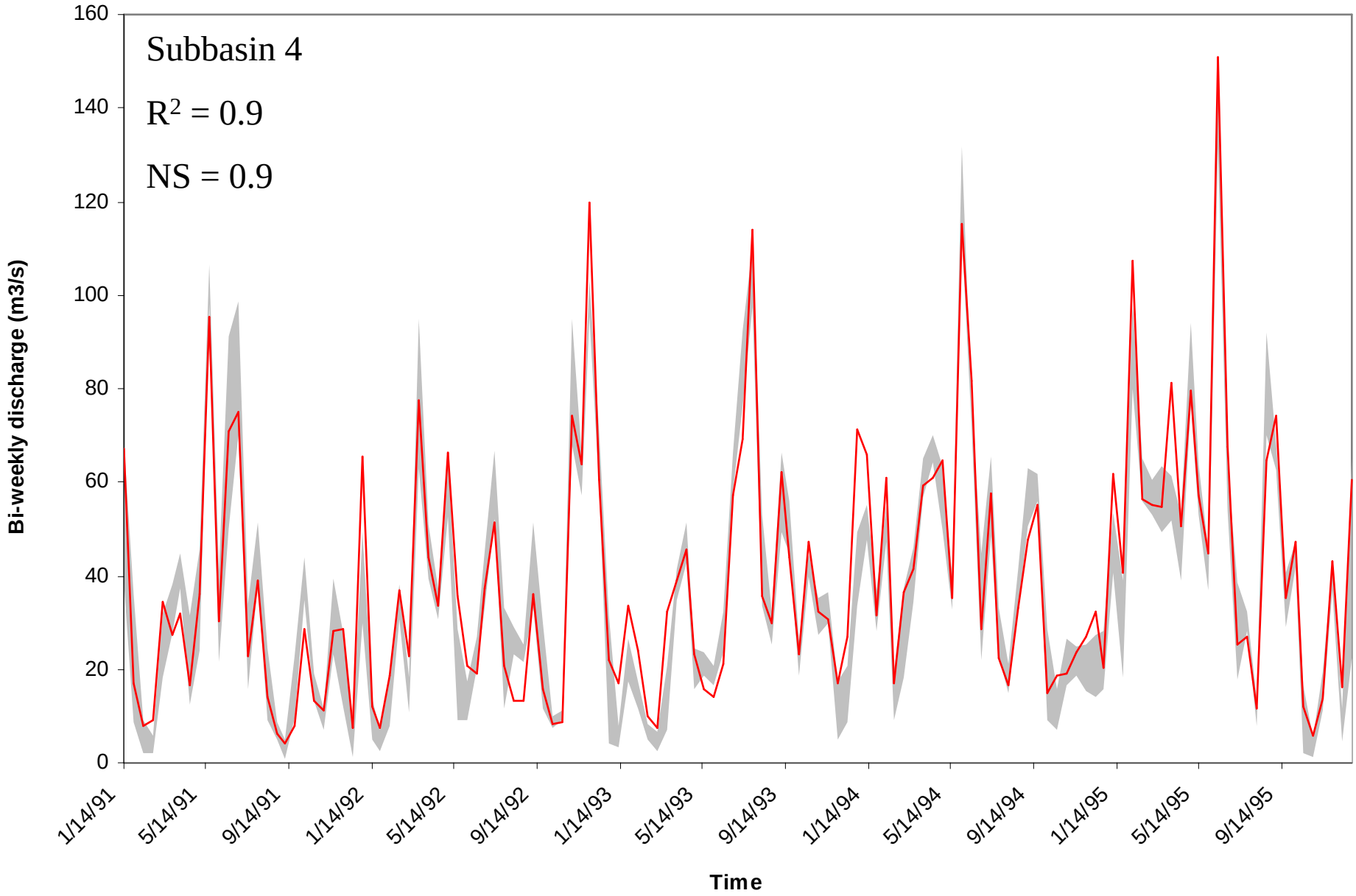
Delineation of the Thur River Basin (16 subchatchments)



LEGEND

- Gage stations
- Streams
- Subbasins


Subbasin 11
R2 = 0
NS = - 1.3
Bi-weekly discharge (m3/s)
Time
0
5
10
15
20
25
30
35
40
45
50
1/14/91
5/14/91
9/14/91
1/14/92
5/14/92
9/14/92
1/14/93
5/14/93
9/14/93
1/14/94
5/14/94
9/14/94
1/14/95
5/14/95
9/14/95


Subbasin 4
R2 = 0.9
NS = 0.9
Bi-weekly discharge (m3/s)
0
20
40
60
80
100
120
140
160
1/14/91
5/14/91
9/14/91
1/14/92
5/14/92
9/14/92
1/14/93
5/14/93
9/14/93
1/14/94
5/14/94
9/14/94
1/14/95
5/14/95
9/14/95
Time

What is a calibrated model?

- Models are always conditionally calibrated
- There are different degrees of calibration
- Not every “calibrated” model can be applied to every analysis

Application to Chaohe watershed in China

5,300 km^2

a__CN2.mgt

v__ESCO.hru

v__EPCO.hru

r__SOL_K.sol

a__SOL_AWC.sol

v__ALPHA_BF.gw

r__SLSUBBSN.hru

a__CH_K2.rte

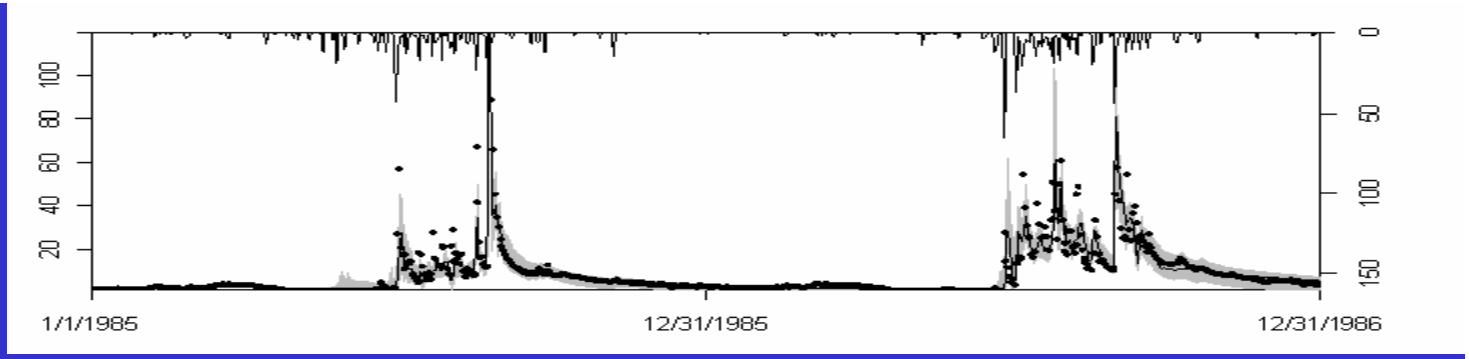
a__OV_N.hru

v__GW_DELAY.gw

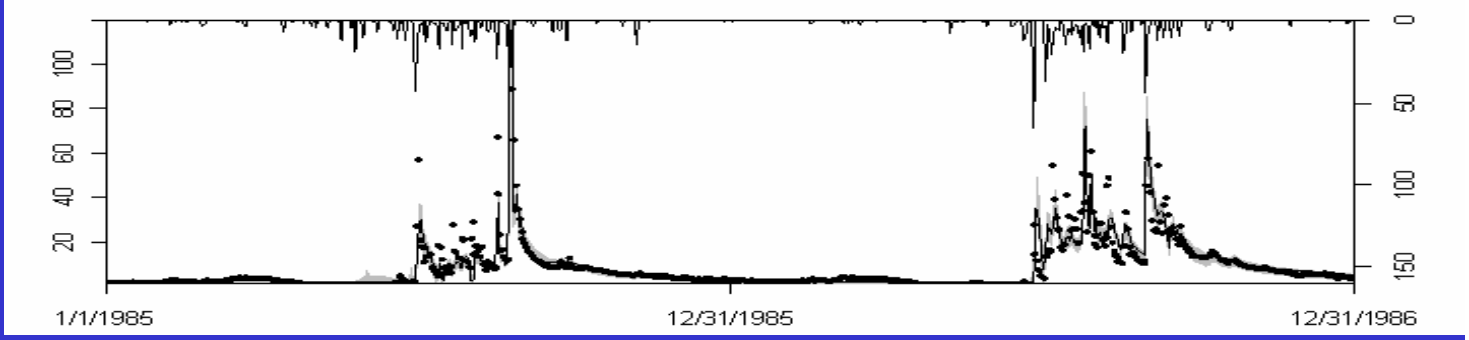
Calibration and Uncertainty Procedures

1. Markov Chain Monte Carlo (MCMC)
2. Importance Sampling (IS)
3. Sequential Uncertainty FItting algorithm (SUFI-2)
4. Generalized Likelihood Uncertainty Estimation (GLUE)
5. Parameter Solution (ParaSol)

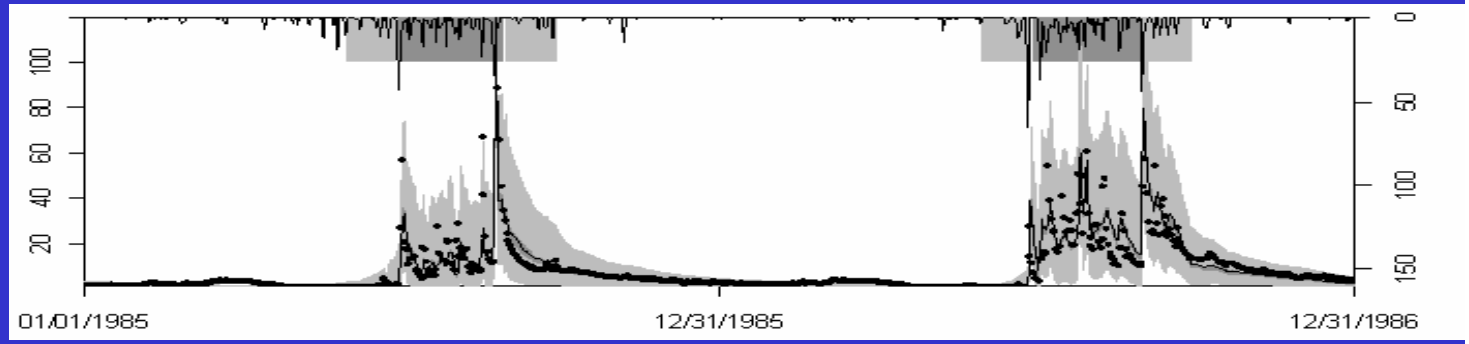
GLUE



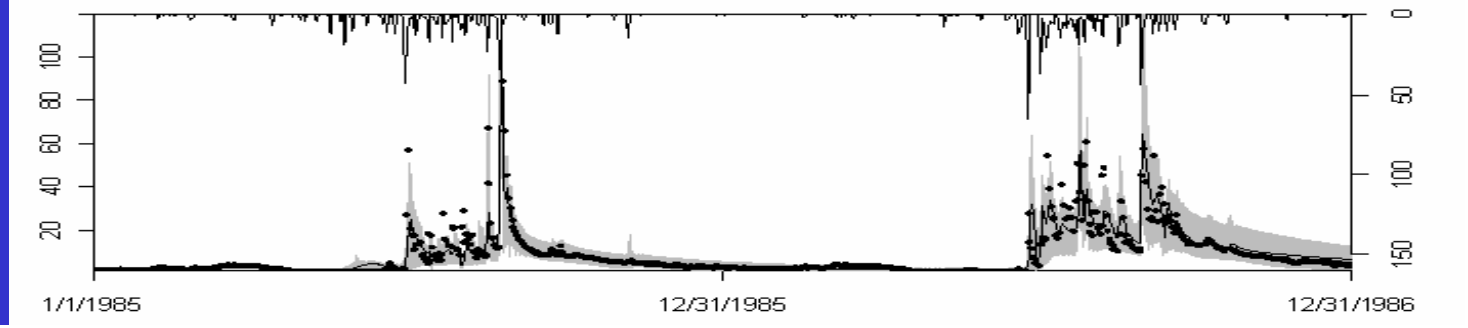
ParaSol



MCMC



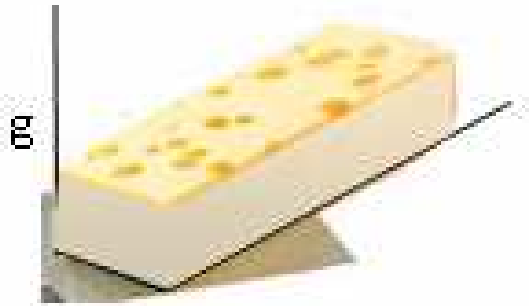
SUFI-2

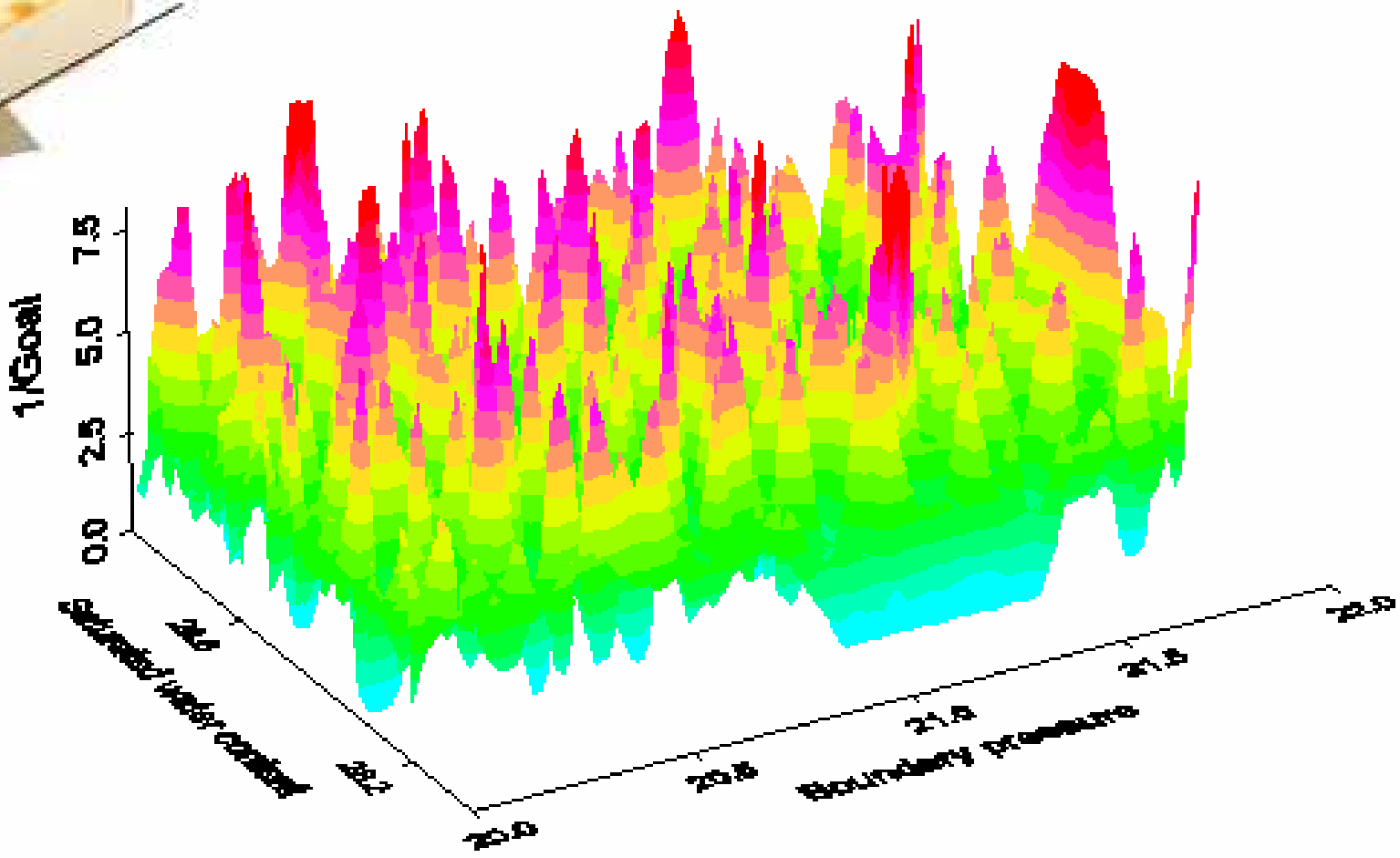


[5]Parameter	GLUE	ParaSol	SUFI-2	MCMC
a__CN2.mgt	(-29.58, -9.84)[1]	(-21.93, -20.08)	(-30.00, -7.23)	(-16.85,-11.62)
v__ESCO.hru	(0.02, 0.97)	(0.65, 0.69)	(0.43, 1.00)	(0.63, 0.75)
v__EPCO.hru	(0.04, 0.90)	(0.13, 0.20)	(0.34, 1.00)	(0.39, 0.98)
r__SOL_K.sol	(-0.36, 0.78)	(-0.41, -0.34)	(-0.58, 0.34)	(-0.31, 0.78)
a__SOL_AWC.sol	(0.01, 0.15)	(0.08, 0.08)	(0.05, 0.15)	(0.1, 0.13)
v__ALPHA_BF.gw	(0.06, 0.97)	(0.08, 0.13)	(0.23, 0.74)	(0.11, 0.15)
v__GW_DELAY.gw	(9.72, 289.29)	(91.23, 115.20)	(100.24, 300.00)	(17.78, 33.34)
r__SLSUBBSN.hru	(-0.56, 0.46)	(-0.60, -0.58)	(-0.60, 0.03)	(-0.56, 0.15)
a__CH_K2.rte	(6.01, 144.82)	(27.72, 37.67)	(69.42, 150.00)	(68.03, 86.23)
a__OV_N.hru	(0.00, 0.20)	(0.07, 0.10)	(0.00, 0.11)	(0.00, 0.19)
[2]σ_{dry}	-	-	-	(0.81, 1.10)
[2]σ_{wet}	-	-	-	(2.44, 3.95)
[2]τ_{dry}	-	-	-	(29.5, 53.84)
[2]τ_{wet}	-	-	-	(2.4, 8.02)
MS cal (val)	0.80 (0.78)	0.82 (0.81)	0.80 (0.75)	0.77 (0.77)
R^2 cal (val)	0.80 (0.84)	0.82 (0.85)	0.81 (0.81)	0.78 (0.81)
[3]*p-factor* cal (val)	79% (69%)	18% (20%)	84% (82%)	85% (84%)
[4]*d-factor* cal (val)	0.65 (0.51)	0.08 (0.07)	1.03 (0.82)	1.47 (1.19)
Uncertainty described	All sources of uncertainty	Parameter uncertainty only	All sources of uncertainty	Parameter uncertainty only
Implementation	easy	easy	easy	complicated
Number of runs	10000	7500	3000	45000

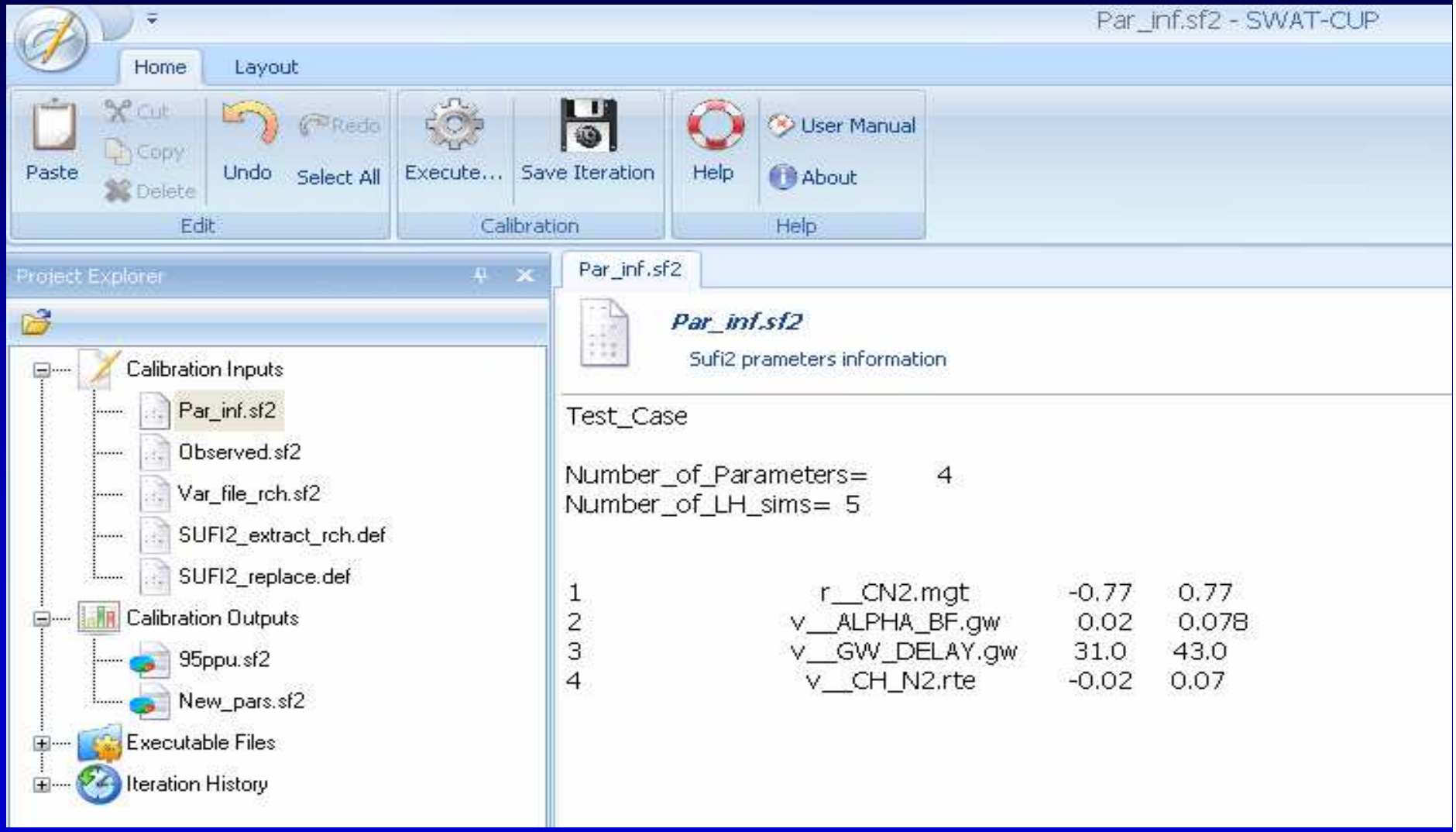
Multimodality of the objective function

(the Swiss cheese effect)





SWAT Calibration and Uncertainty Procedures (SWAT-CUP)



SWAT Calibration and Uncertainty Procedures (SWAT-CUP)