Parallelizing SWAT Calibration in Windows using SUFI2 Program,

Lessons learned from Black Sea Catchment study

Elham Rouholahnejad
elham.rouholahnejad@eawag.ch

2012 International SWAT Conference
July 16-20, 2012, Delhi, India

Content

- Introduction to the Black sea project

- BSC SWAT model
  - model set up
  - complication regarding river flows

- Calibration
  - Claibration Set up
  - Iteration 1 (rough decisions)
  - Iteration 2
    - a) parallelization
    - b) parameterization

I. Black Sea Catchment

Black Sea


Black Sea Catchment
Moscow
Minsk
BELARUS
Bryansk
Berlin
GERMANY
Warsaw
POLAND
Homyel'
Pinsk
Kursk
Voronezh
RUSSIA
Praha
CZECH REPUBLIC
Kyiv
Kharkiv
Lviv
UKRAINE
Dnieper
Don
Munich
Bern
Zurich
Salzburg
Vienne
SLOVAKIA
Carpathian Mts.
Dniester
Donets'k
SWITZERLAND
Geneva
Alps
AUSTRIA
Bratislava
Budapest
Graz
Rostov-na-Donu
HUNGARY
Melitopol'
MOLDOVA
ITALY
SLOVENIA
Ljubljana
Cluj-Napoca
Bacau
Kishinev
Sea of Azov
Zagreb
CROATIA
ROMANIA
Odesa
Brasov
Kerch
Krasnodar
Ismail
Simferopol'
Novorossiysk
Caucasus
BOSNIA
and
HERZEGOVINA
Belgrade
Tulcea
Sevastopol'
Bucharest
SERBIA
Sarajevo
Danube
Constanta
Black Sea
Rome
MONTENEGRO
Varna
GEORGIA
Podgorica
Sofia
BULGARIA
Burgas
Tirana
Skopje
FYR
MACEDONIA
Samsun
Ordu
Trabzon
TURKEY
Kizilirmak
ALBANIA
Istanbul
Ankara
GREECE
Sources: ESRI, HydroSHEDS, GeoNames
©UNEP/DEWA/GRID-Europe

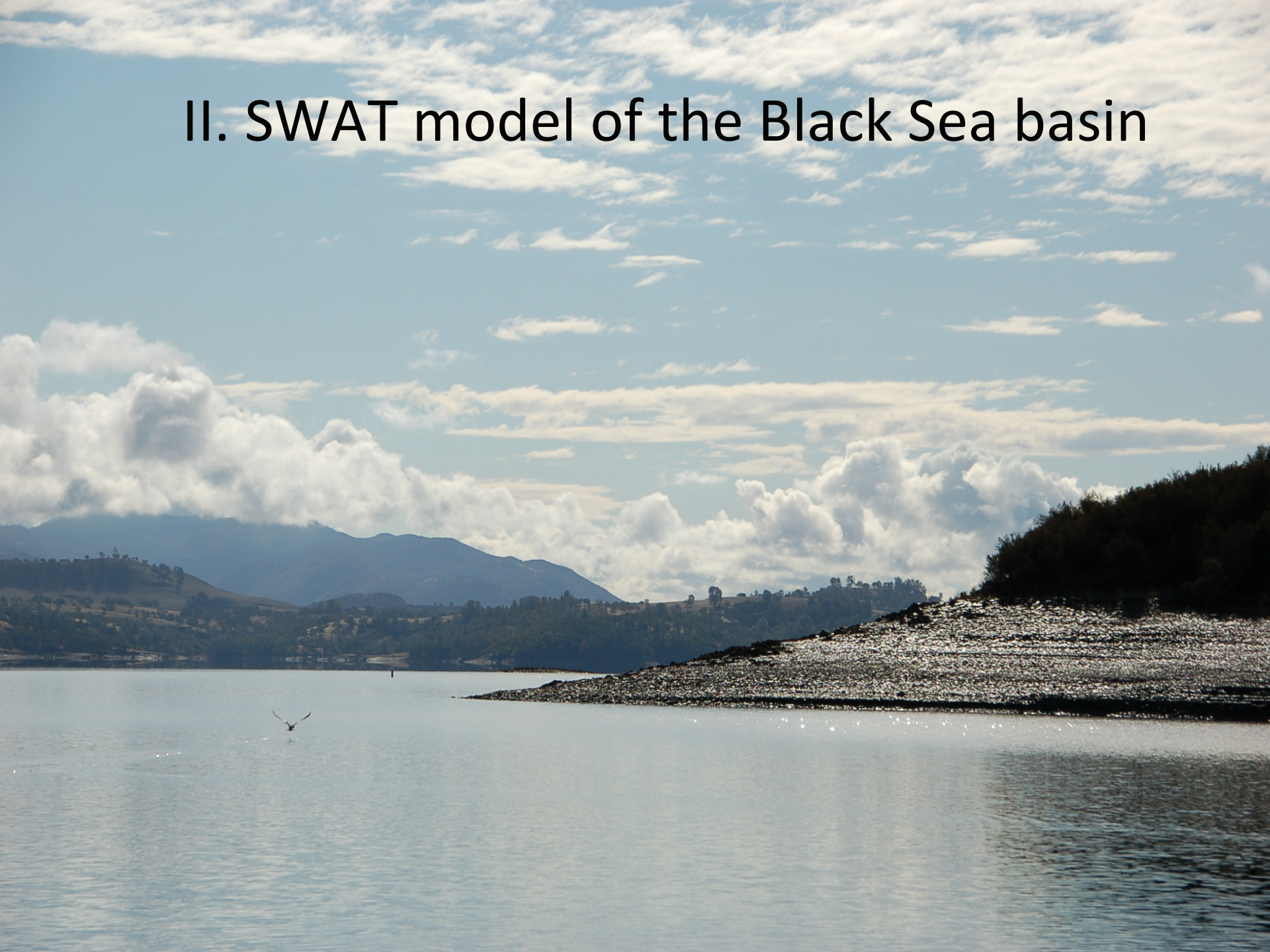
The project aims at building:

- A high resolution calibrated water quantity and water quality model for the entire region accounting for agricultural activities and point source pollutions using SWAT.

Black Sea Model

- **Major challenges in calibration process**
  - Lack of sufficient data
  - Large scale application
  - Calibration run time
  - Water managements in the basin
  - Inaccurate data (gauge locations)
  - Flow directions
  - Glacier and snow parameters

II. SWAT model of the Black Sea basin

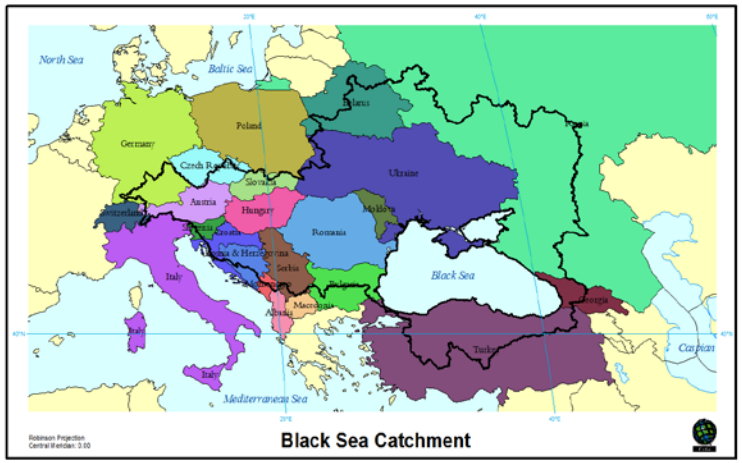


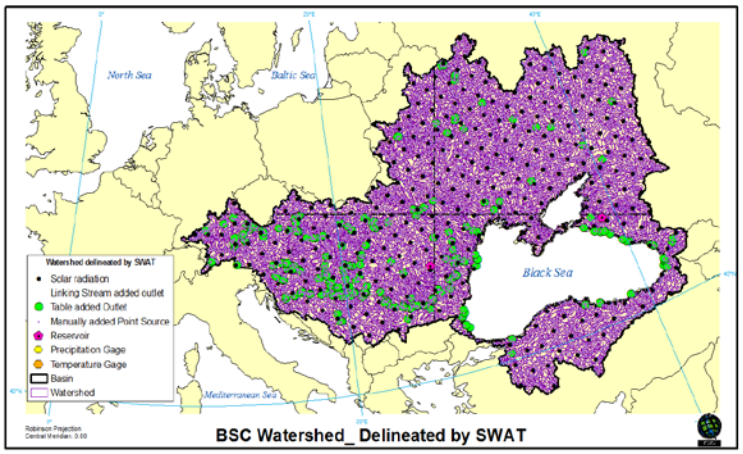
Black Sea SWAT Model set up

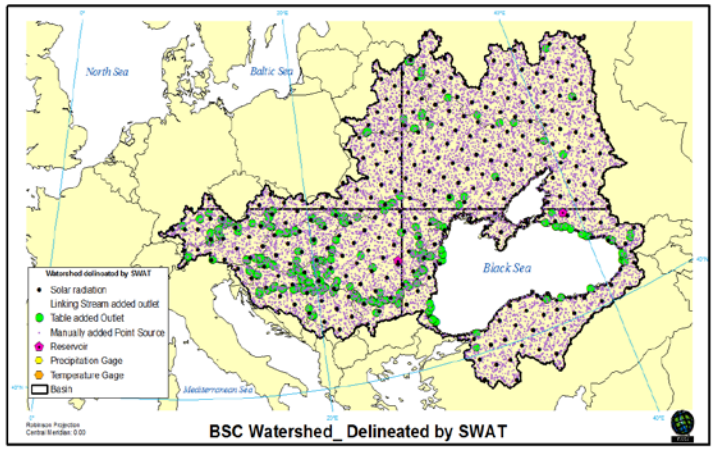
- Arc SWAT 2009.93.7 was used to parametraize the whole area
- 2 Mkm2 drainage area
- 12982 subbasins
- 89202 Hrus
- About 600,000 SWAT input files
- CRU data sets were used as weather data
- Agricultural management for three major crops: wheat, Maize and Barely.
- ET Calculation based on Hargreaves Method
- Daily step SWAT run
- 36 yrs of simulation, 3 yrs warm up period (1970-2006)

Black Sea SWAT Model

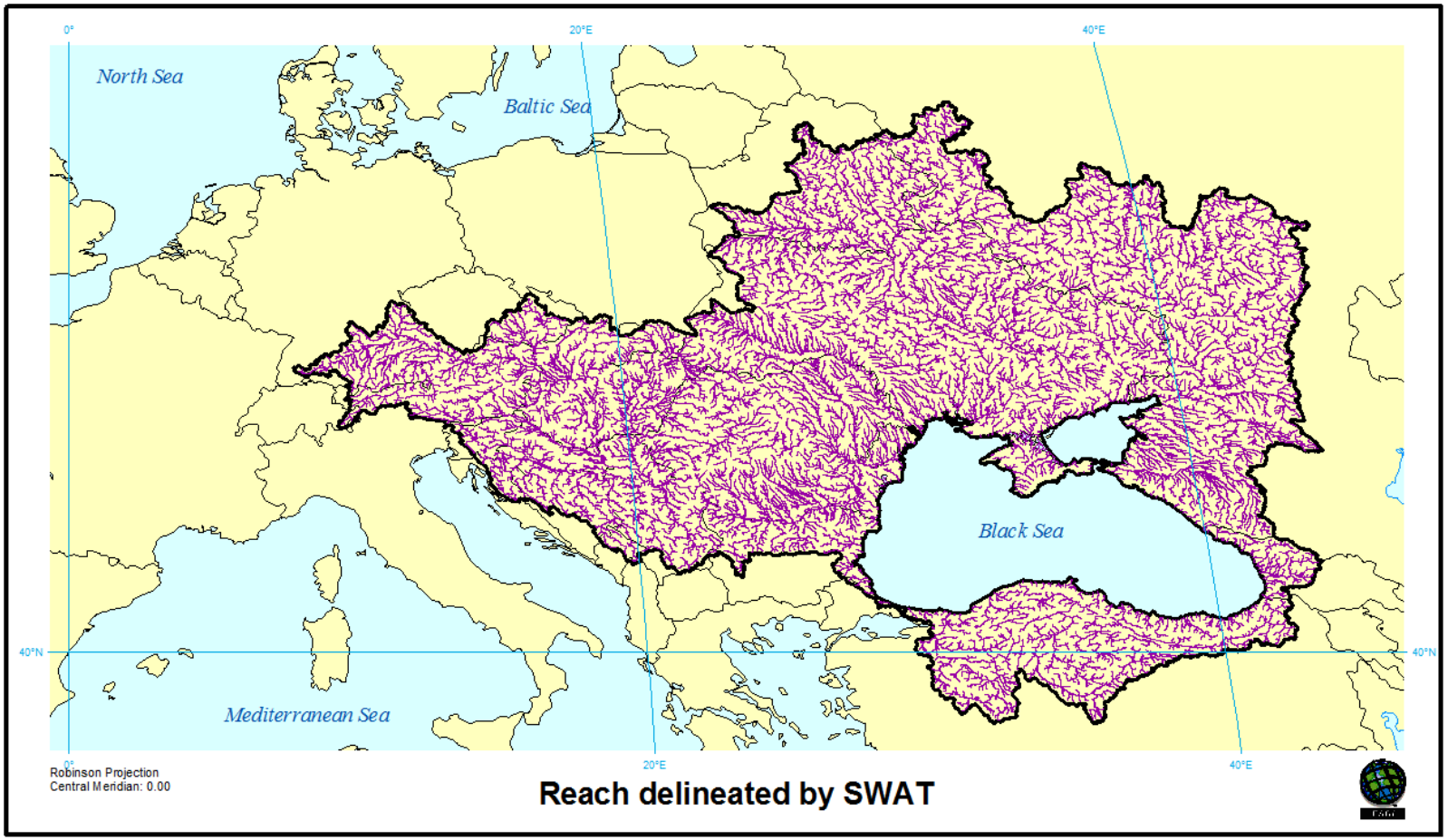
Basin, Subbasin, Hrus





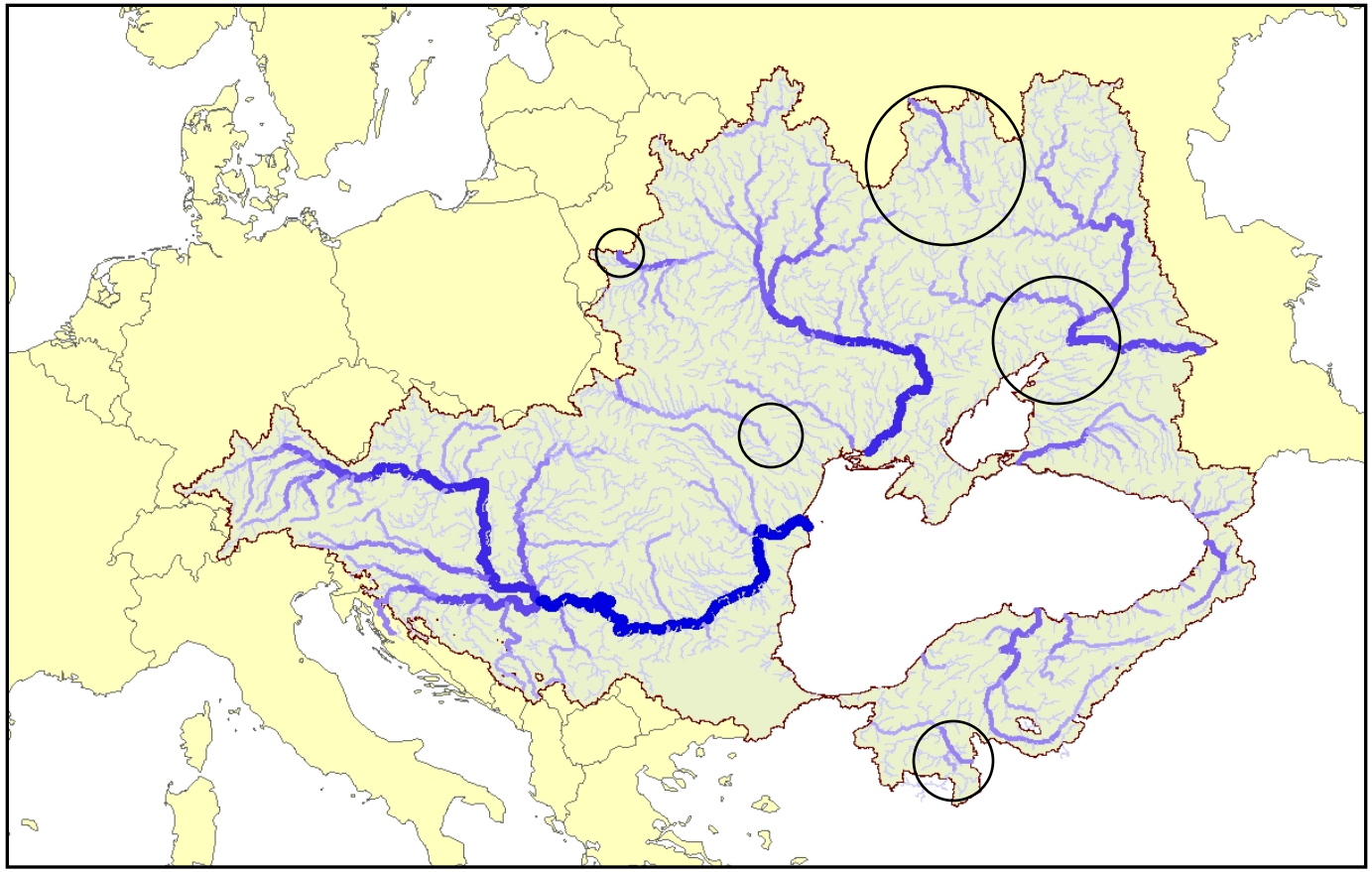


Black Sea SWAT Model

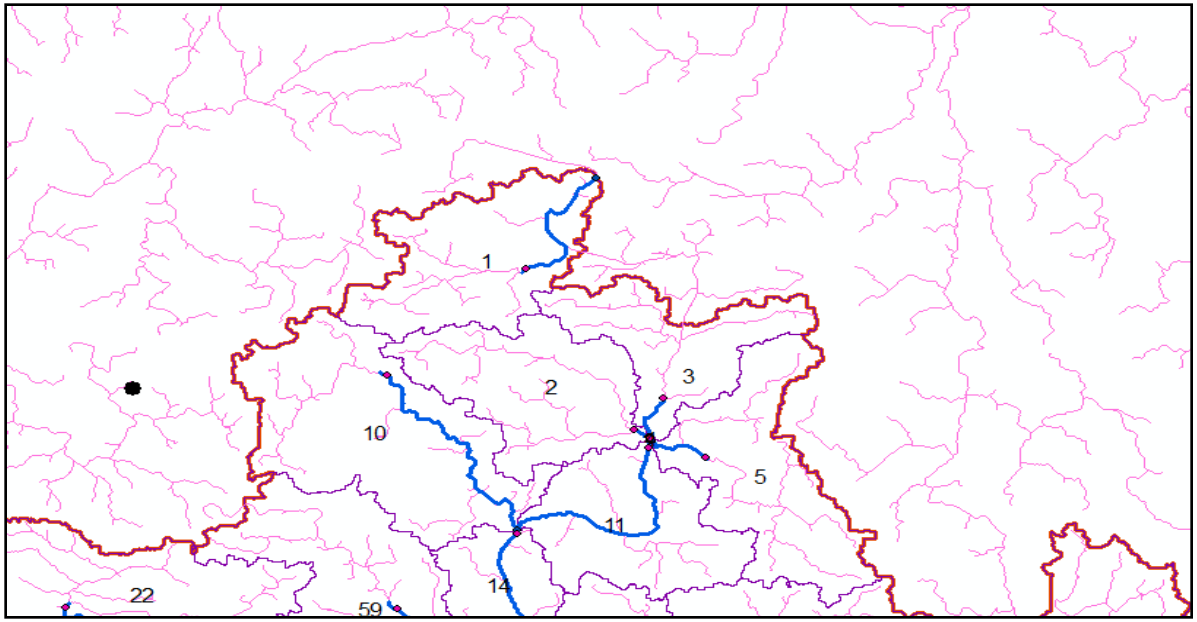


Reach delineated by SWAT

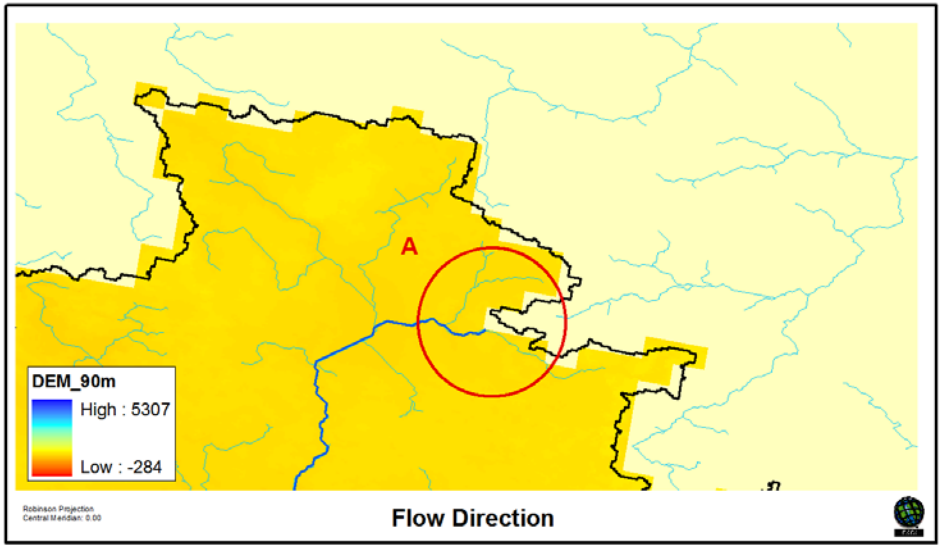
- Complication in flow directions

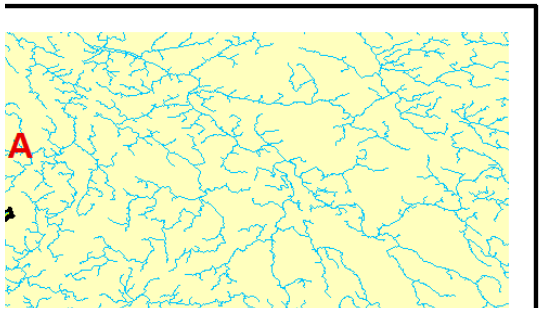


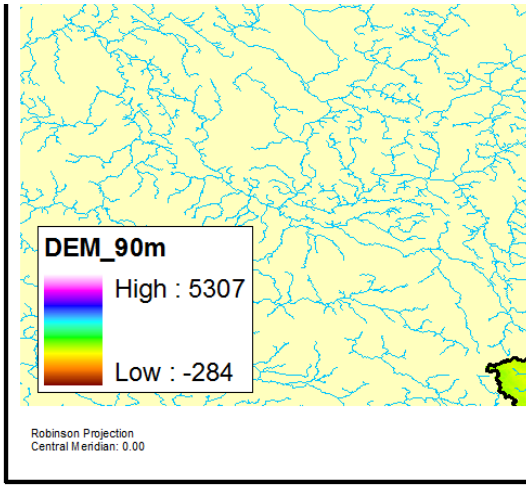
- Imprisice Basin mask or wrong rivers!

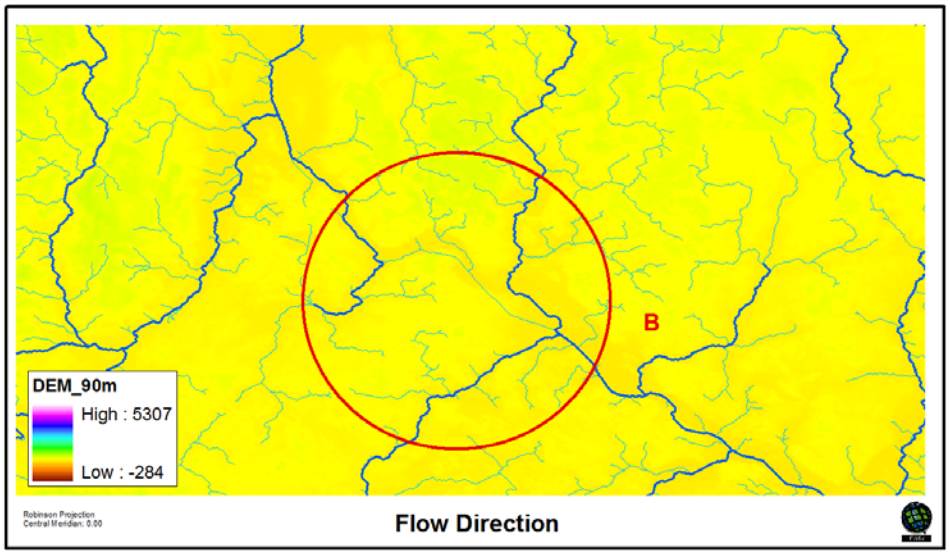


- DEM

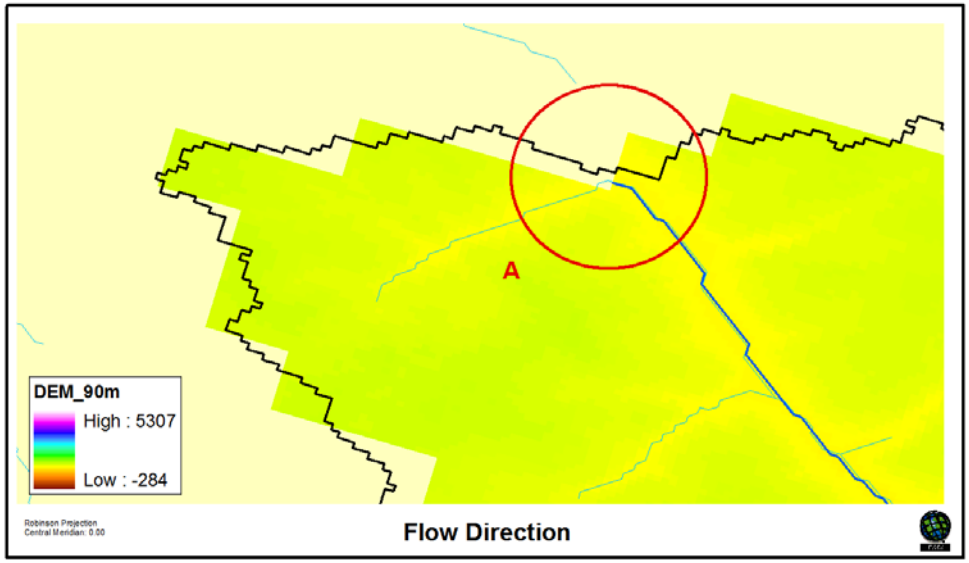

A
DEM_90m
High : 5307
Low : -284
Robinson Projection
Central Meridian: 0.00
Flow Direction

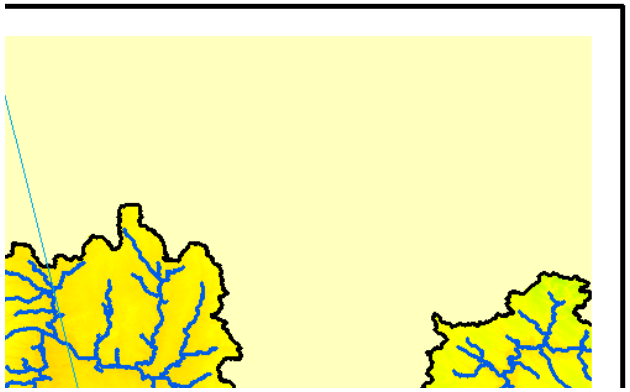

A

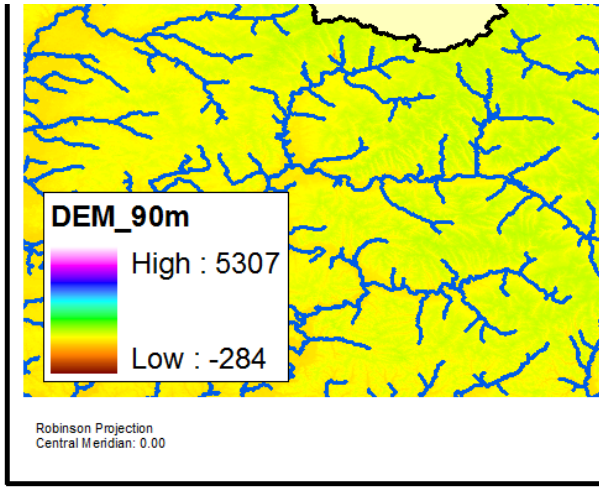

DEM_90m
High : 5307
Low : -284
Robinson Projection
Central Meridian: 0.00

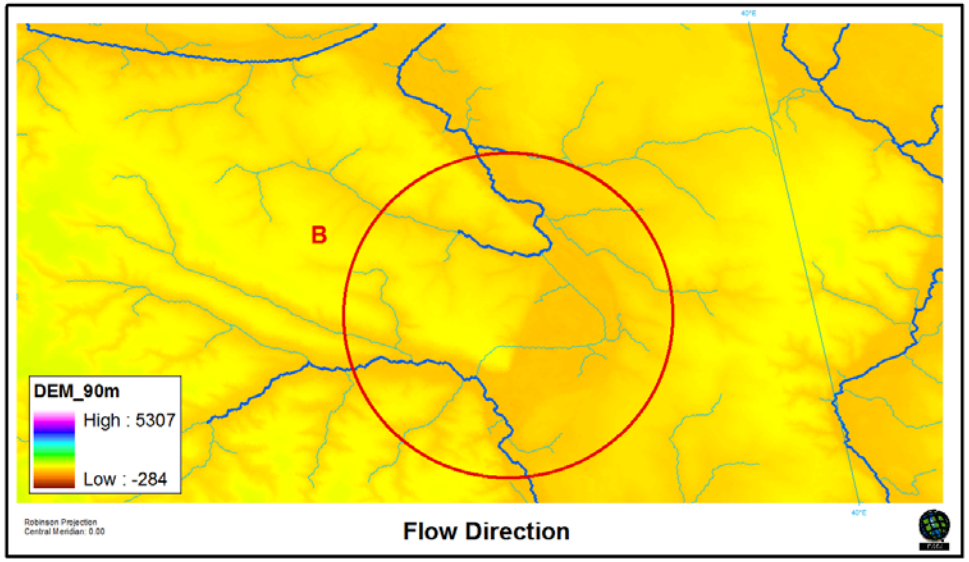

B
DEM_90m
High : 5307
Low : -284
Robinson Projection
Central Meridian: 0.00
Flow Direction

- DEM

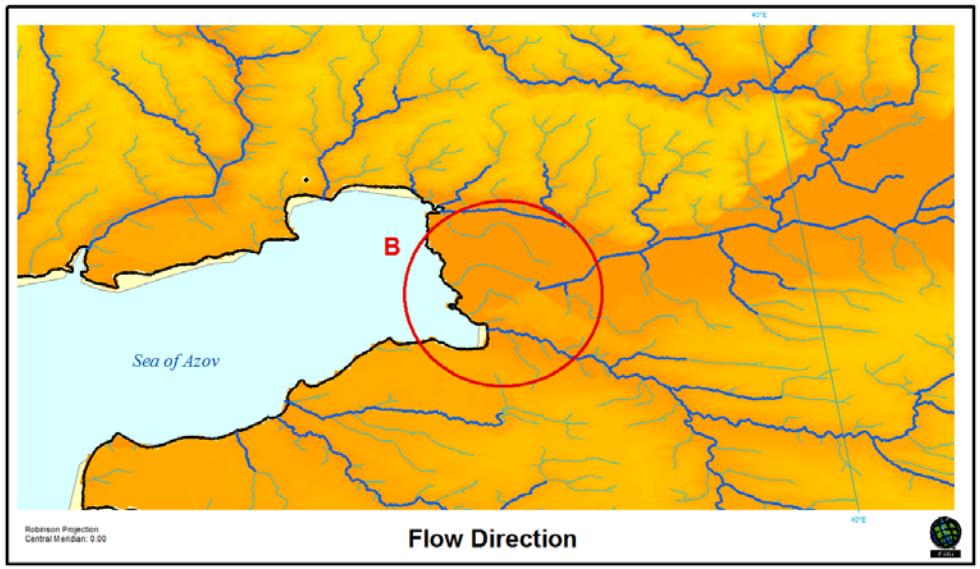

A
DEM_90m
High : 5307
Low : -284
Robinson Projection
Central Meridian: 0.00
Flow Direction

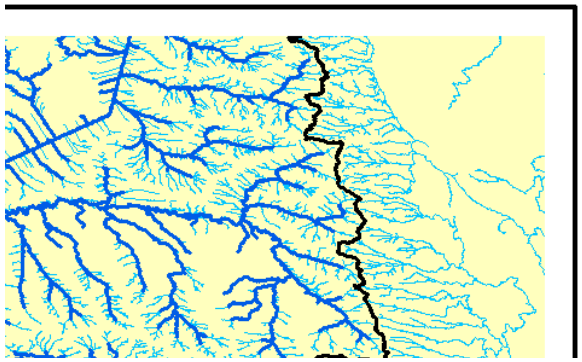


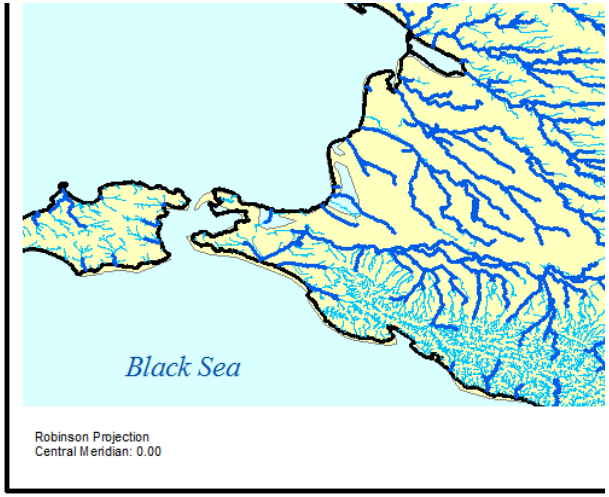

DEM_90m
High : 5307
Low : -284
Robinson Projection
Central Meridian: 0.00

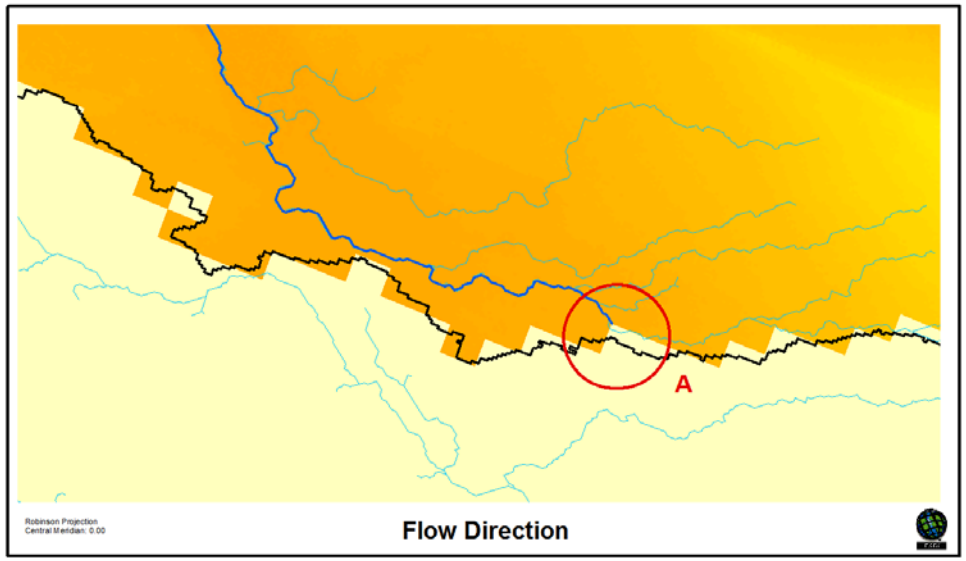

B
DEM_90m
High : 5307
Low : -284
Robinson Projection
Central Meridian: 0.00
Flow Direction

- DEM


B
Sea of Azov
Robinson Projection
Central Meridian: 0.00
Flow Direction



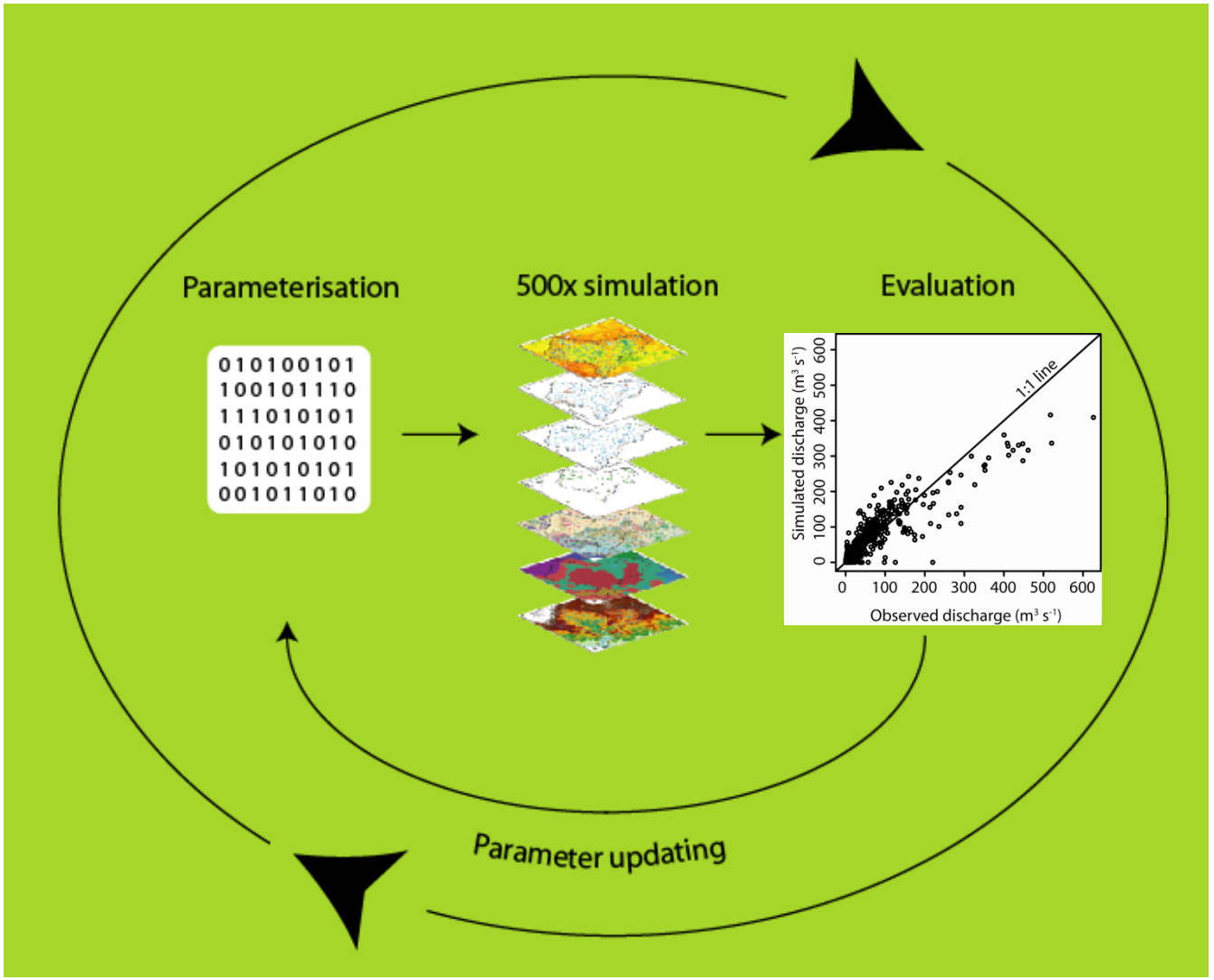

Black Sea
Robinson Projection
Central Meridian: 0.00


A
Robinson Projection
Central Meridian: 0.00
Flow Direction

III. Calibration Of the hydrologic model of the Black sea basin

Calibration_ SUFI2 algorithm

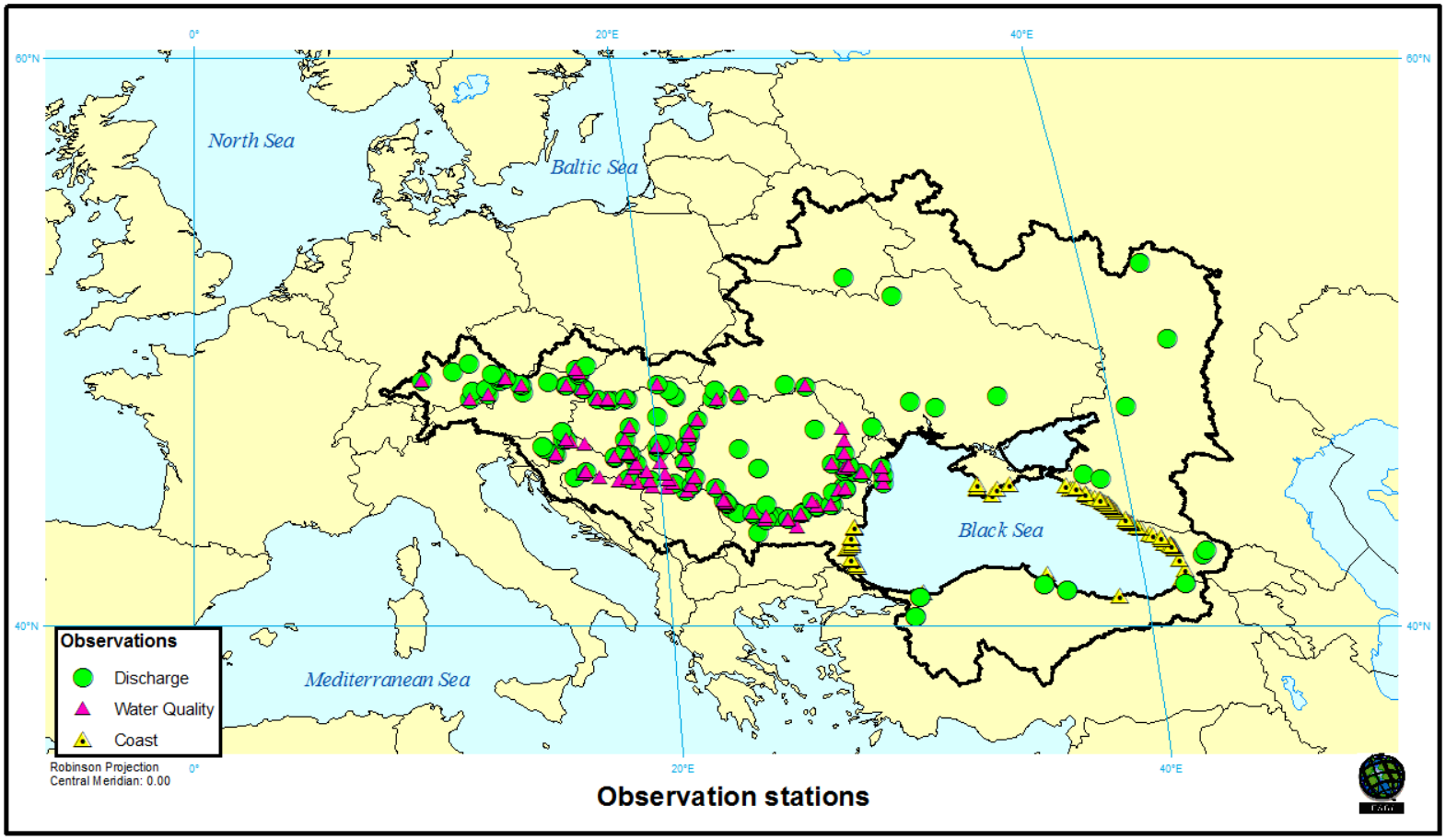
- SWAT Cup, SUFI2



SUFI-2 algorithm

- Uncertainty
  - Attributed to parameters
  - Obtained by calibrating a set of parameter ranges against observed data (priors → posteriors)
  - Characterised by 95 % prediction uncertainty (95PPU)
- Dual aim:
  - Maximise P-factor
  - Minimise R-factor
- Process for each calibration iteration
  - Latin hypercube sampling of parameter space, model simulations, objective function evaluation and parameter updating

- Observation stations



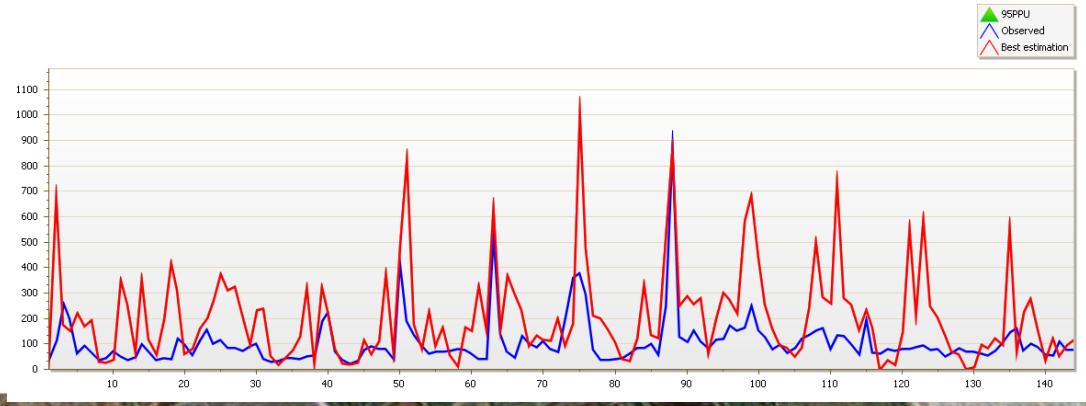
First run

- 1970- 2006, 3 years warm up period (34 years)
- Discharge (monthly, 125 stations)
- Default parameter
- 1 run- 37 hours

Calibration_First Run

- Observation station check_deleted

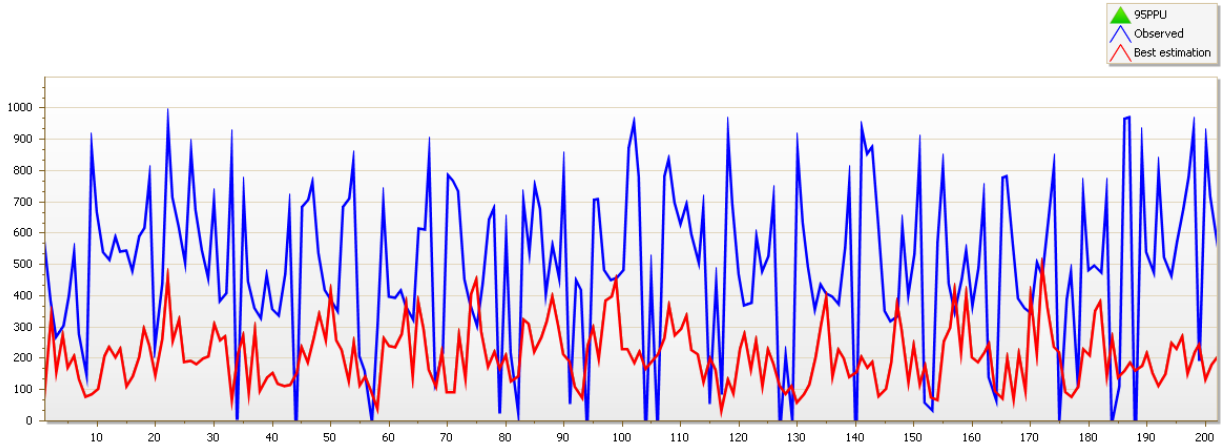
q_5842



Calibration_First Run

- Observation station check_deleted

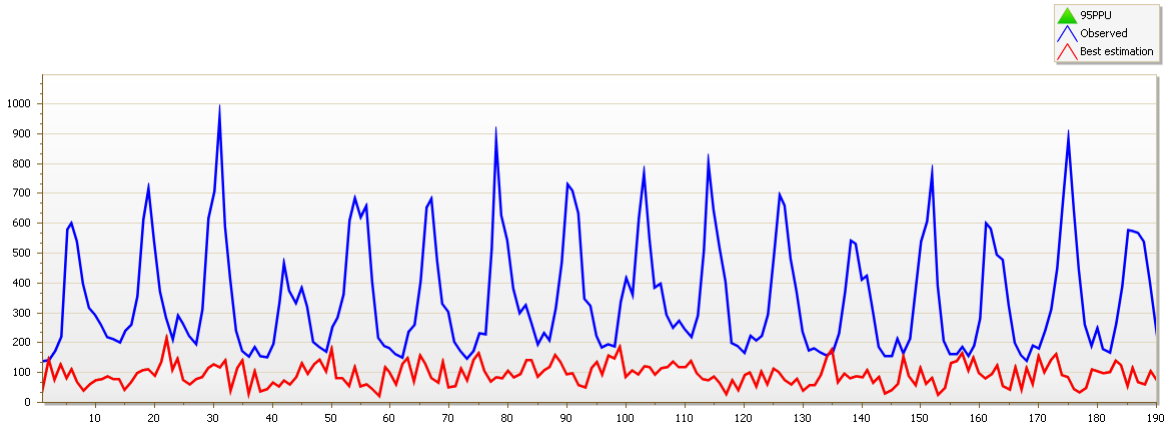
q_7460



Calibration_First Run

- Observation station check_deleted

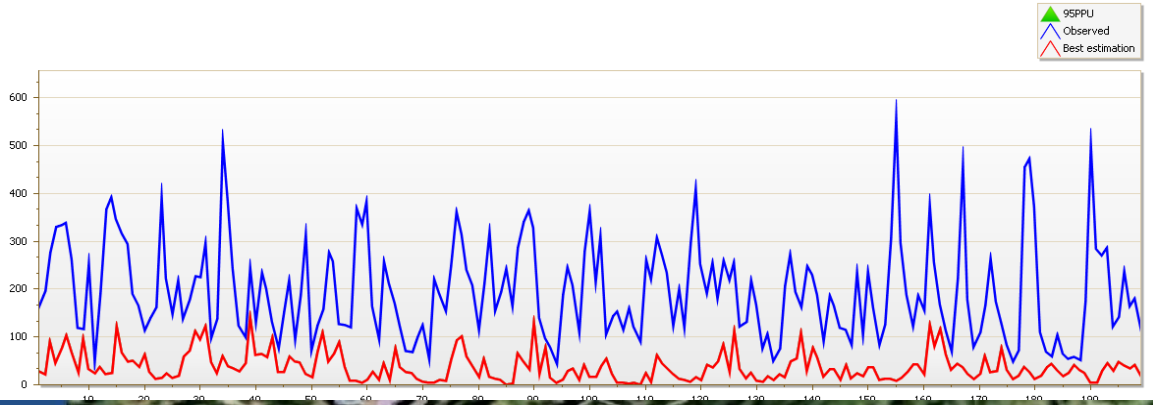
q_8136

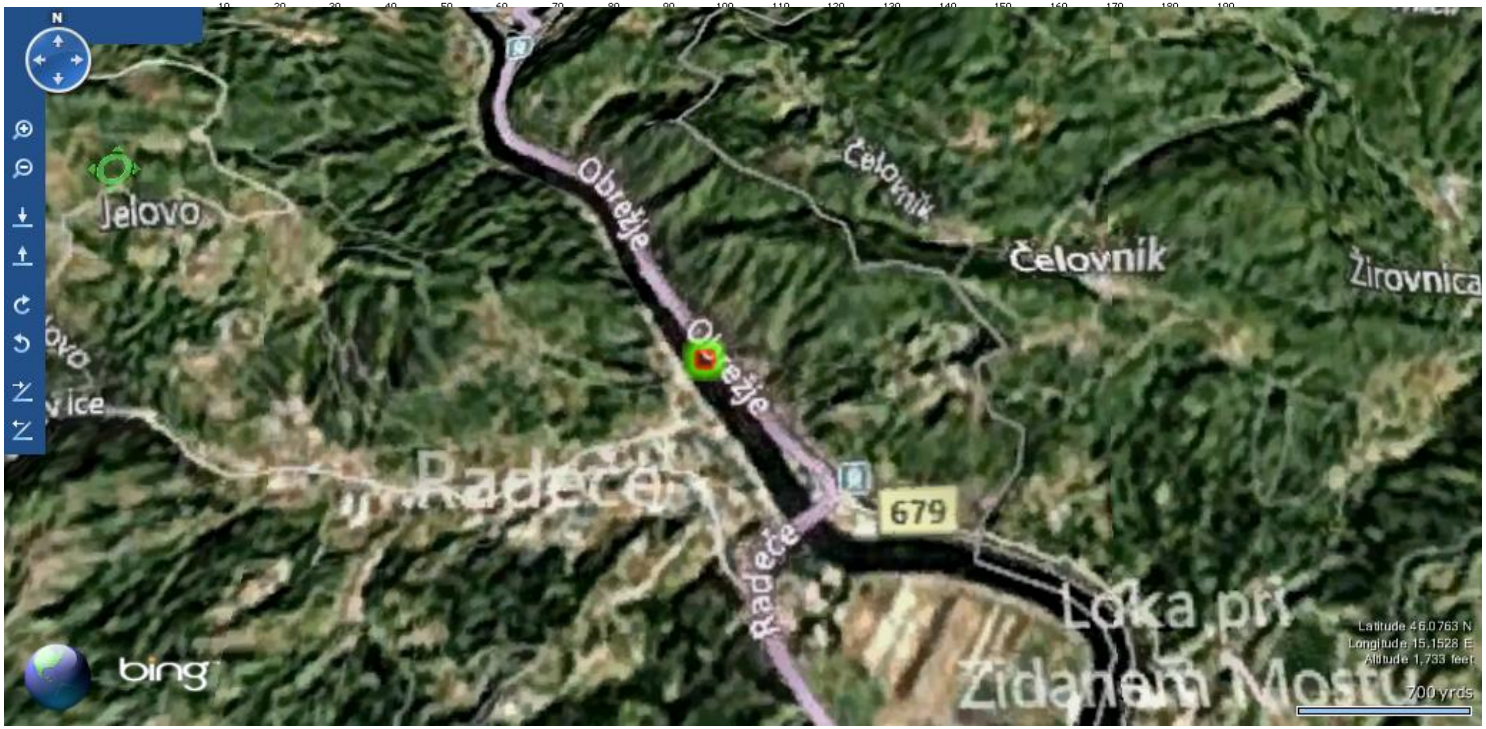


Calibration_First Run

- Observation station check_
  kept to apply Elev band

q_9883

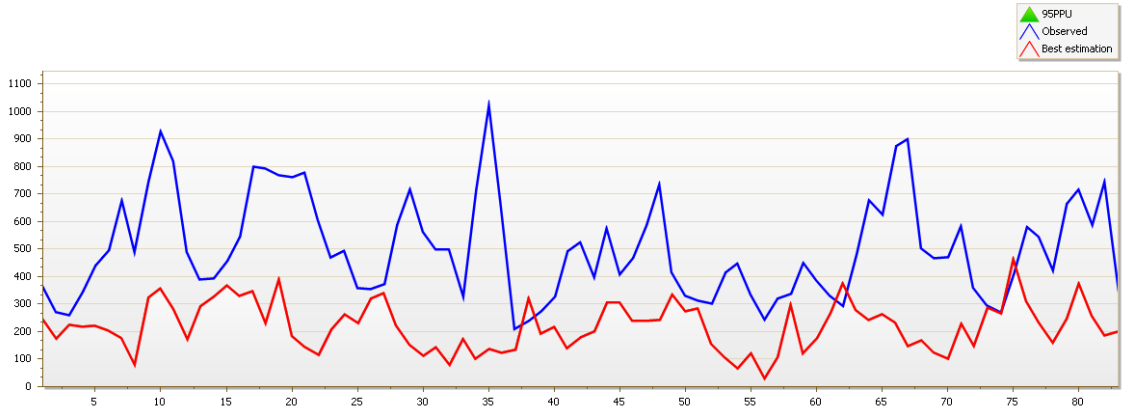




Calibration_First Run

- Observation station check_deleted

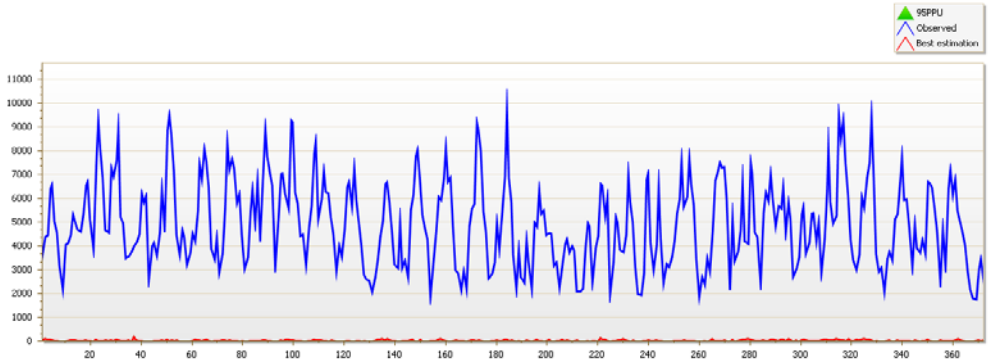
q_9977

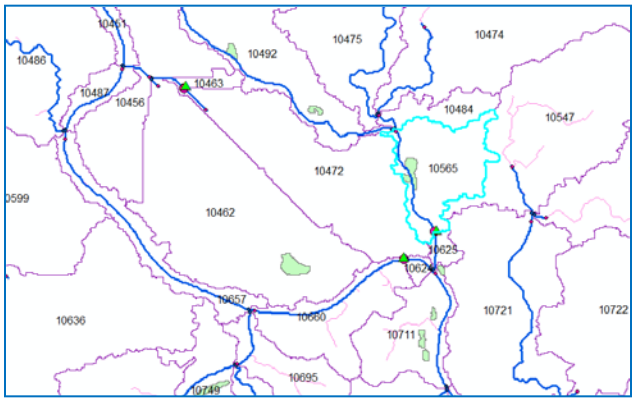


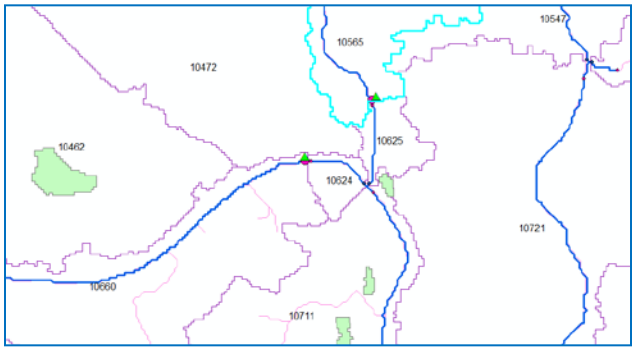
Calibration_First Run

- Observation station check_dislocation

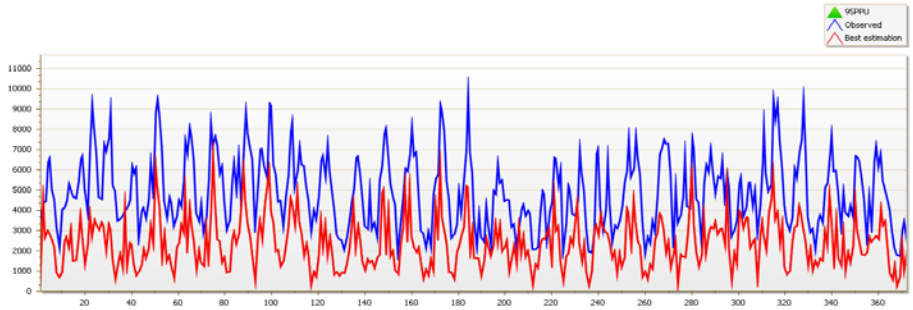
q_10565







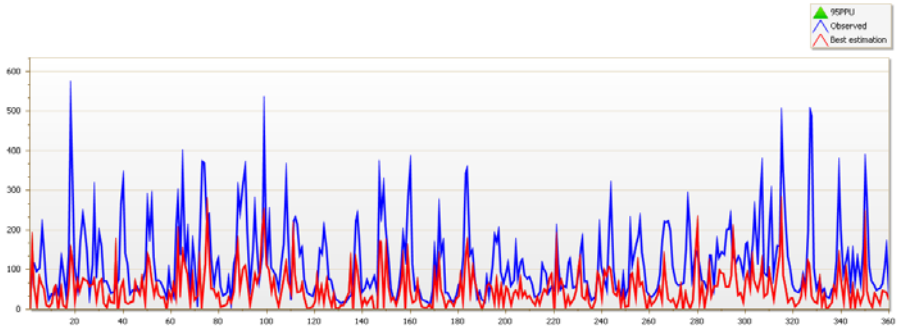
q_10624



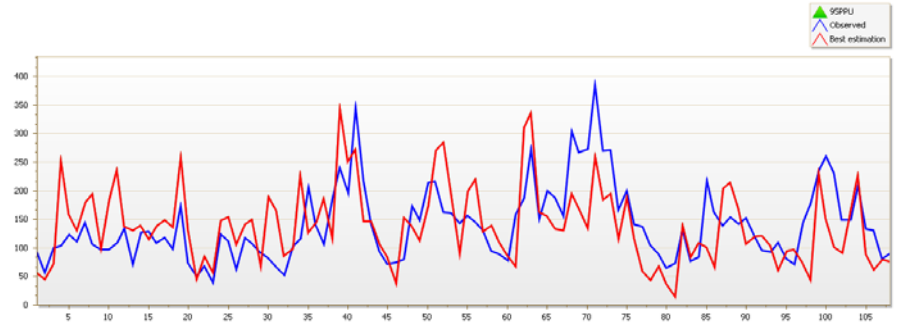
Calibration_First Run

A few good satations

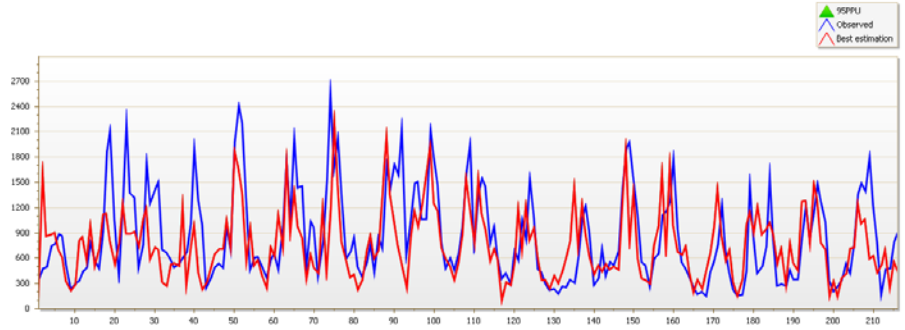
q_7477



q_7635



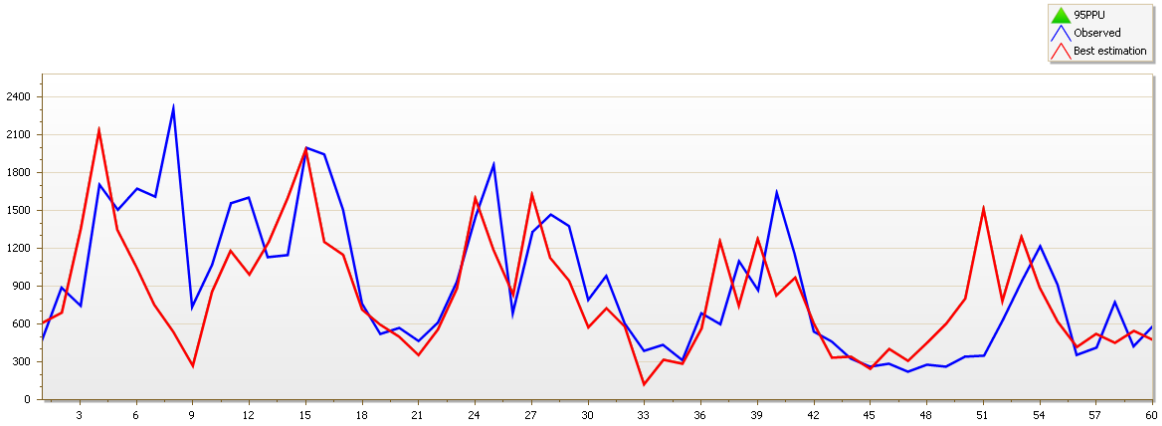
q_9393



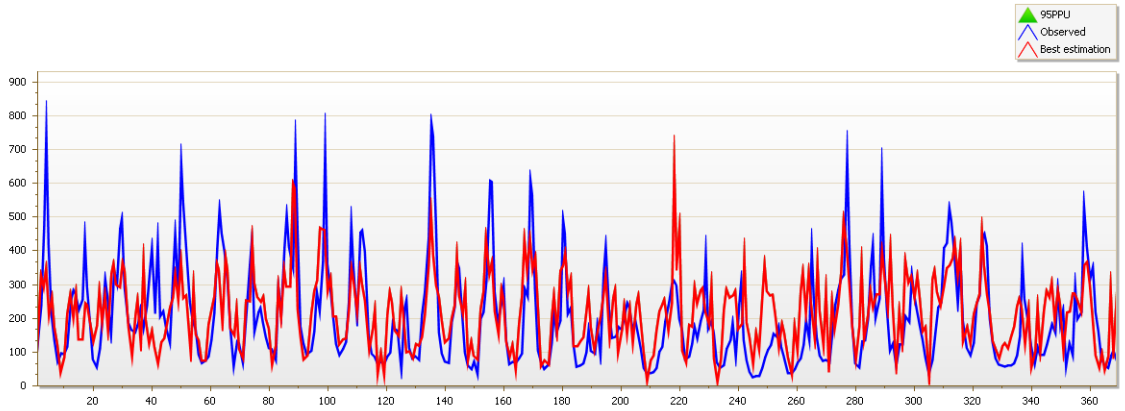
Calibration_First Run

A few good satations

q_9687



q_11021



Iteration 1

- Calibration and evaluation
  - 1970- 2006, 3 years warm up period,
  - 34 years calibration
  - Discharge (monthly, 87)
- Parameter selected based on sensitivity
  → 23 parameters sensetive to flow_ glo
- Initial parameter ranges from physically
- New ranges based on parameterisation v
- 200 runs (Estimated run time in a si

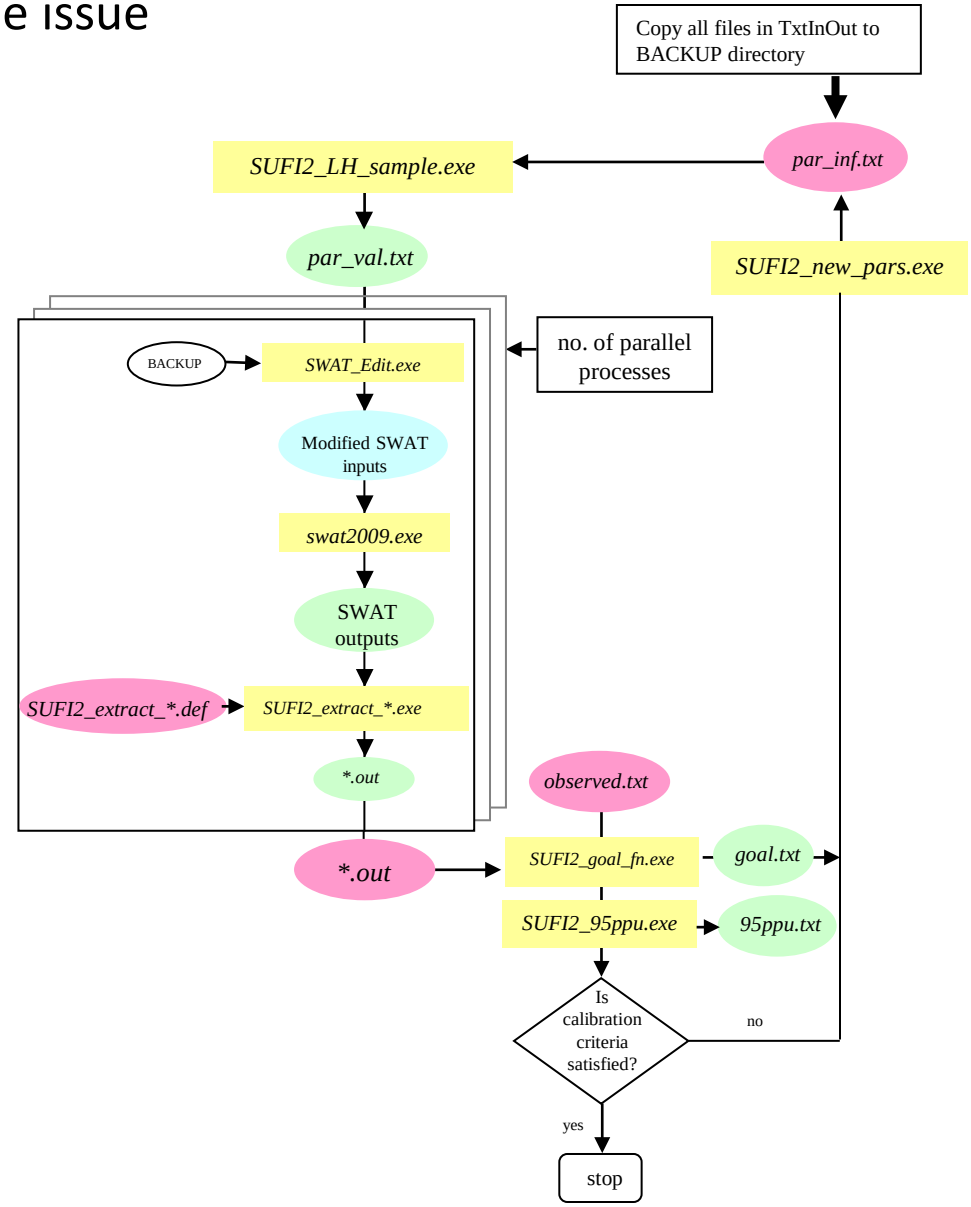
par_inf.txt - WordPad

File Edit View Insert Format Help

```
23      : Number of Parameters
200     : number of simulations

r__CN2.mgt                    0.0    0.4
r__SOL_AWC(1).sol            -0.4    0.2
v__ESCO.hru                   0.5    0.8
v__GWQMN.gw                 500.0 1000
v__GW_REVAP.gw                0.0    0.1
v__REVAPMN.gw                 200    500

v__EPCO.hru          0.0      0.5
v__ALPHA_BF.gw       0.0      1.0
v__GW_DELAY.gw      30.0    160.0
v__CH_N2.rte         0.0      0.3
v__CH_K2.rte         5.0    130.0
v__ALPHA_BNK.rte     0.0      1.0
r__SOL_K(1).sol     -0.8      0.8
r__SOL_BD(1).sol    -0.5      0.6
v__SFTMP.bsn        -5.0      5.0
v__SMTMP.bsn        -5.0      5.0
v__SMFMX.bsn         0.0     10.0
v__SMFMN.bsn         0.0     10.0

v__PLAPS.sub         1        10
v__TLAPS.sub       -10        -6

r__OV_N.hru         -0.1     0.3
r__HRU_SLP.hru             -0.2    0.0
r__SLSUBBSN.hru             0.0    0.1
```

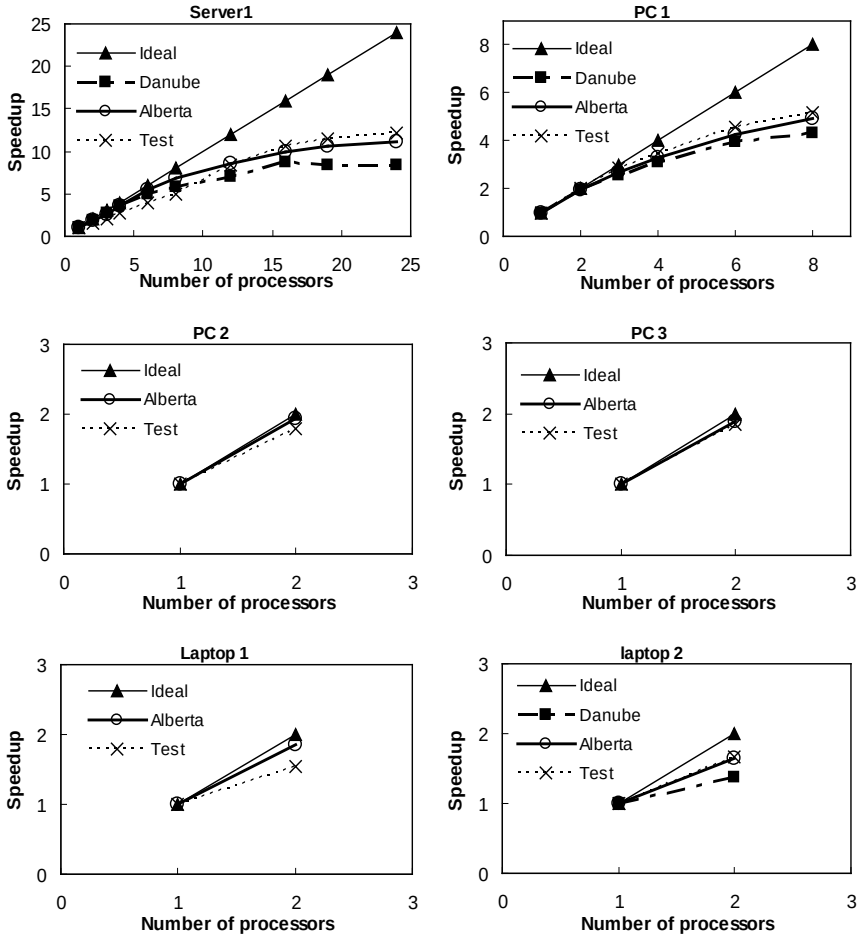
Calibration_SUFI2 paralelization

Running time issue



Calibration_SUFI2 paralelization

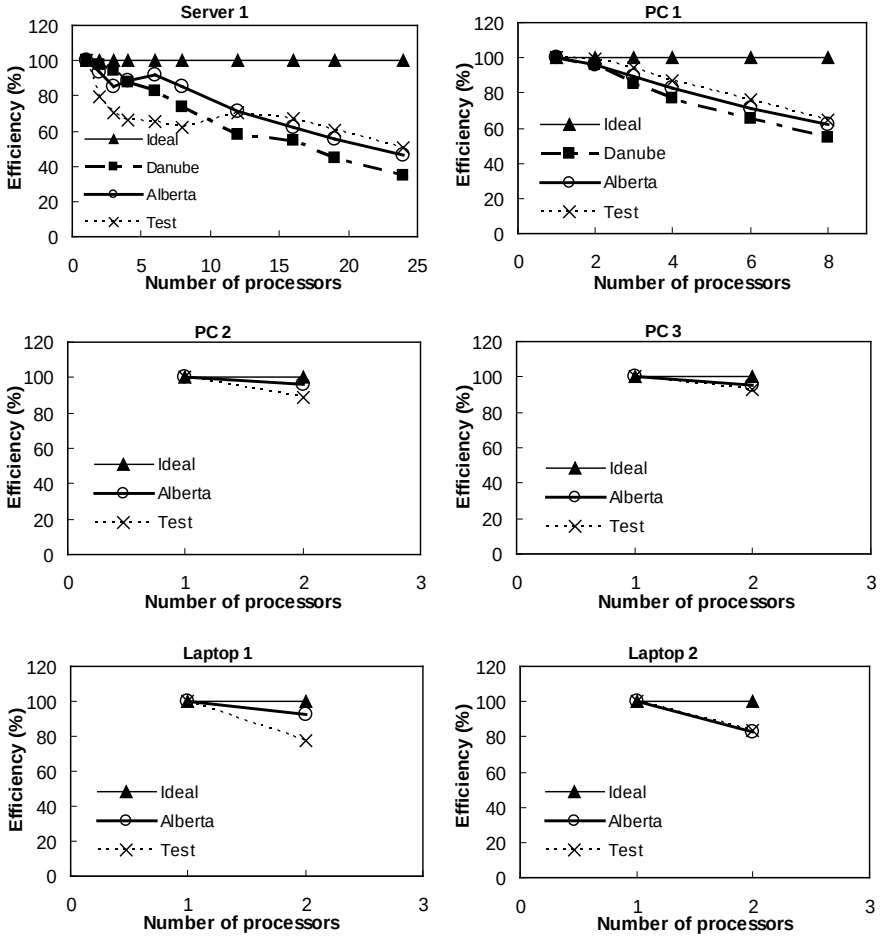
o parallel Sufi2 Spead up tested in Different projects



More details:
E. Rouholahnejada, K.C. Abbaspoura, M. Vejdanib, R. Srinivasanc, R. Schulind, A. Lehmanne: A parallelization framework for calibration of hydrological models *Environmental Modelling and Software*, 2011.

Calibration_SUFI2 paralelization

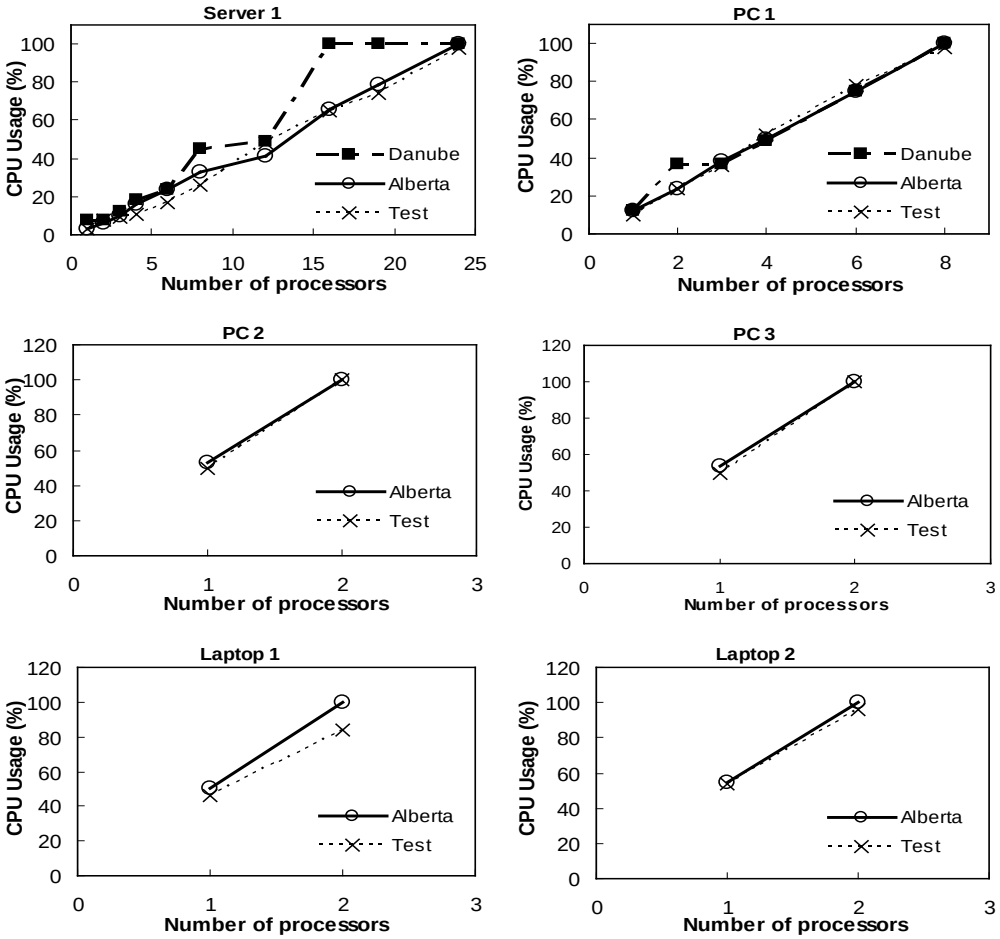
o parallel Sufi2 Efficiency tested in Different projects



More details:
E. Rouholahnejada, K.C. Abbaspoura, M. Vejdanib, R. Srinivasanc, R. Schulind, A. Lehmanne: A parallelization framework for calibration of hydrological models *Environmental Modelling and Software*, 2011.

Calibration_SUFI2 paralelization

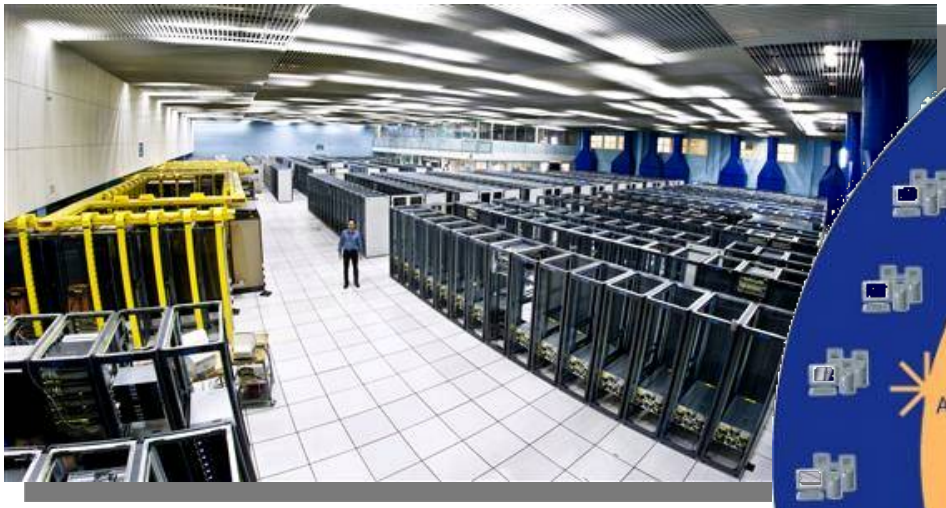
o parallel Sufi2 Efficiency tested in Different projects

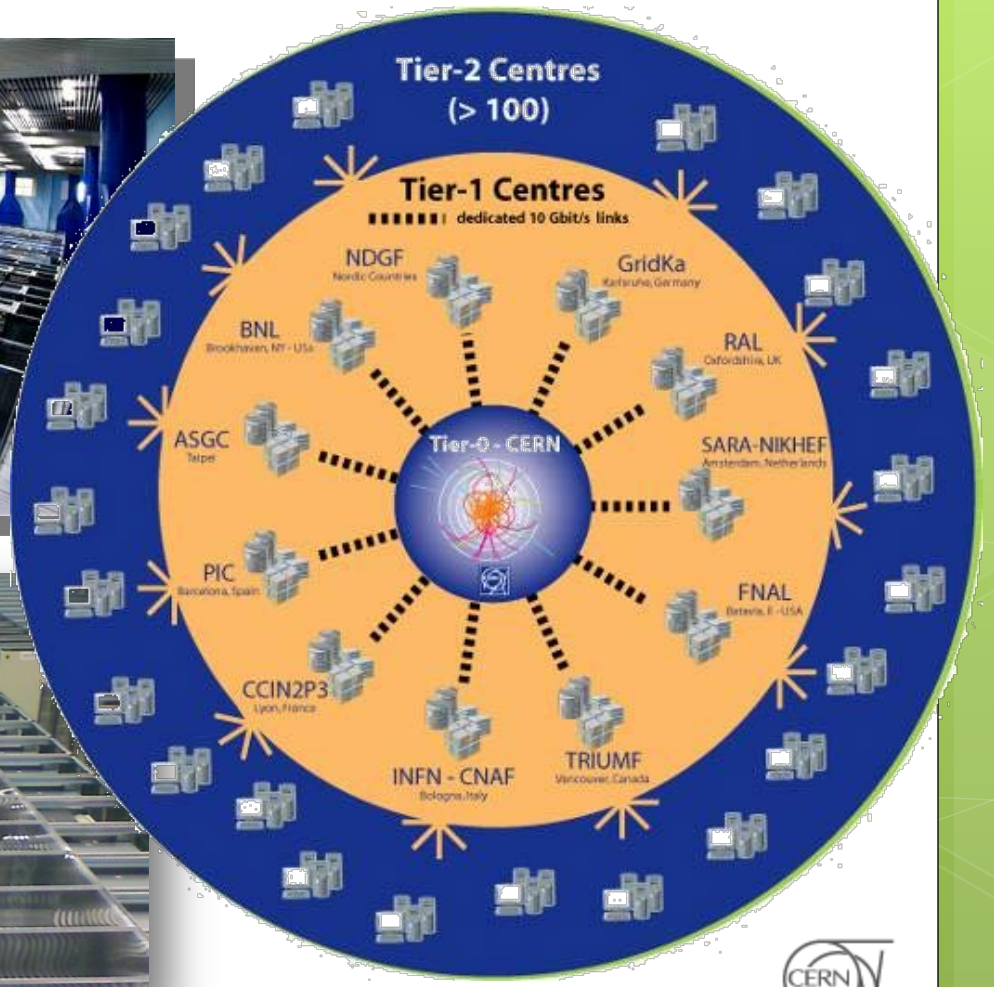


More details:
E. Rouholahnejada, K.C. Abbaspoura, M. Vejdanib, R. Srinivasanc, R. Schulind, A. Lehmanne: A parallelization framework for calibration of hydrological models *Environmental Modelling and Software*, 2011.

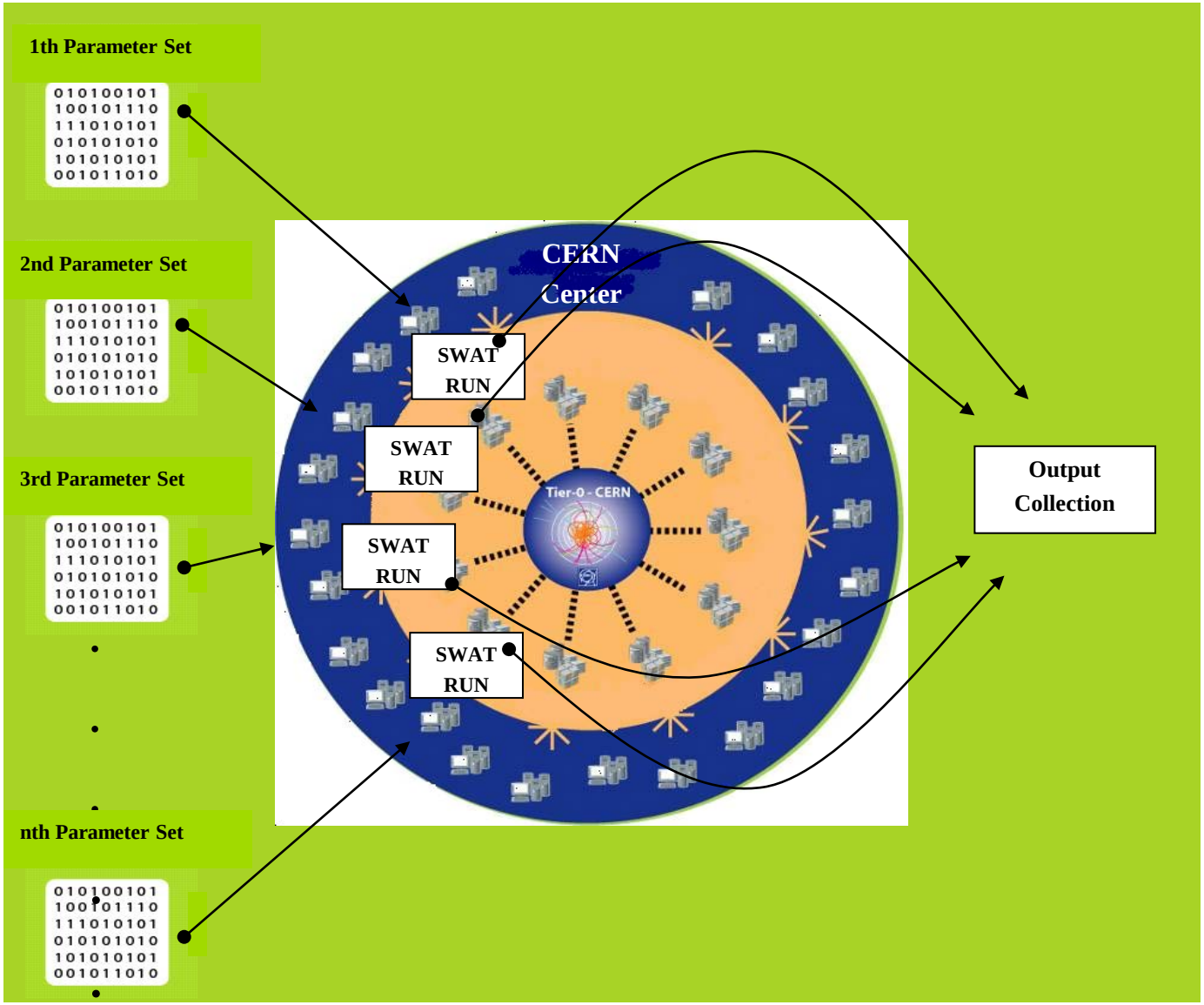
Calibration_Gridification

CERN super computer center



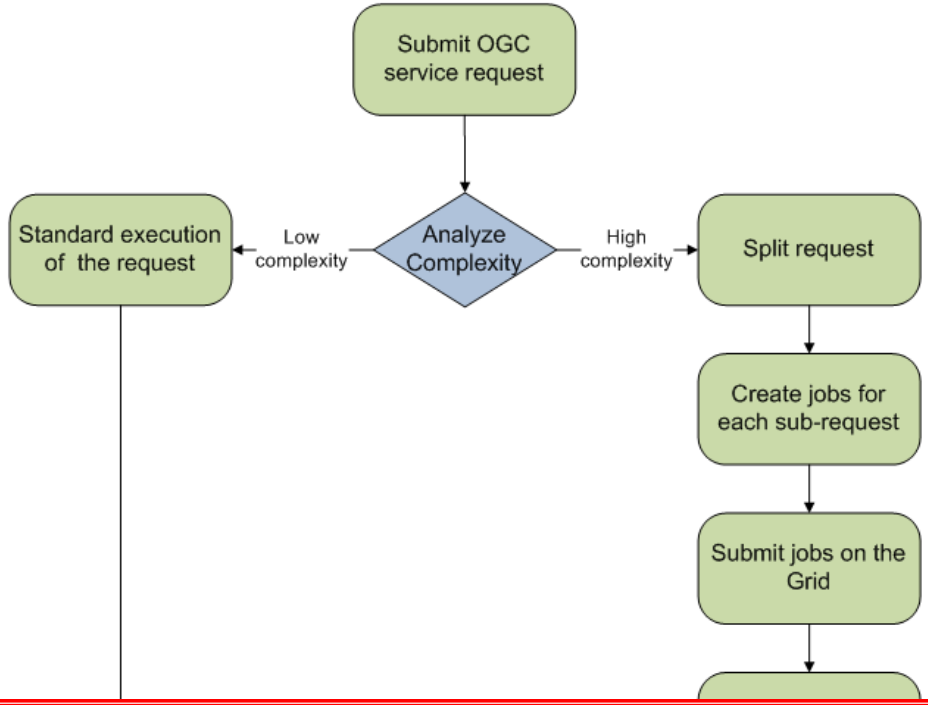


Gridification on CERN Grids



Calibration_Gridification

Gridification scheme



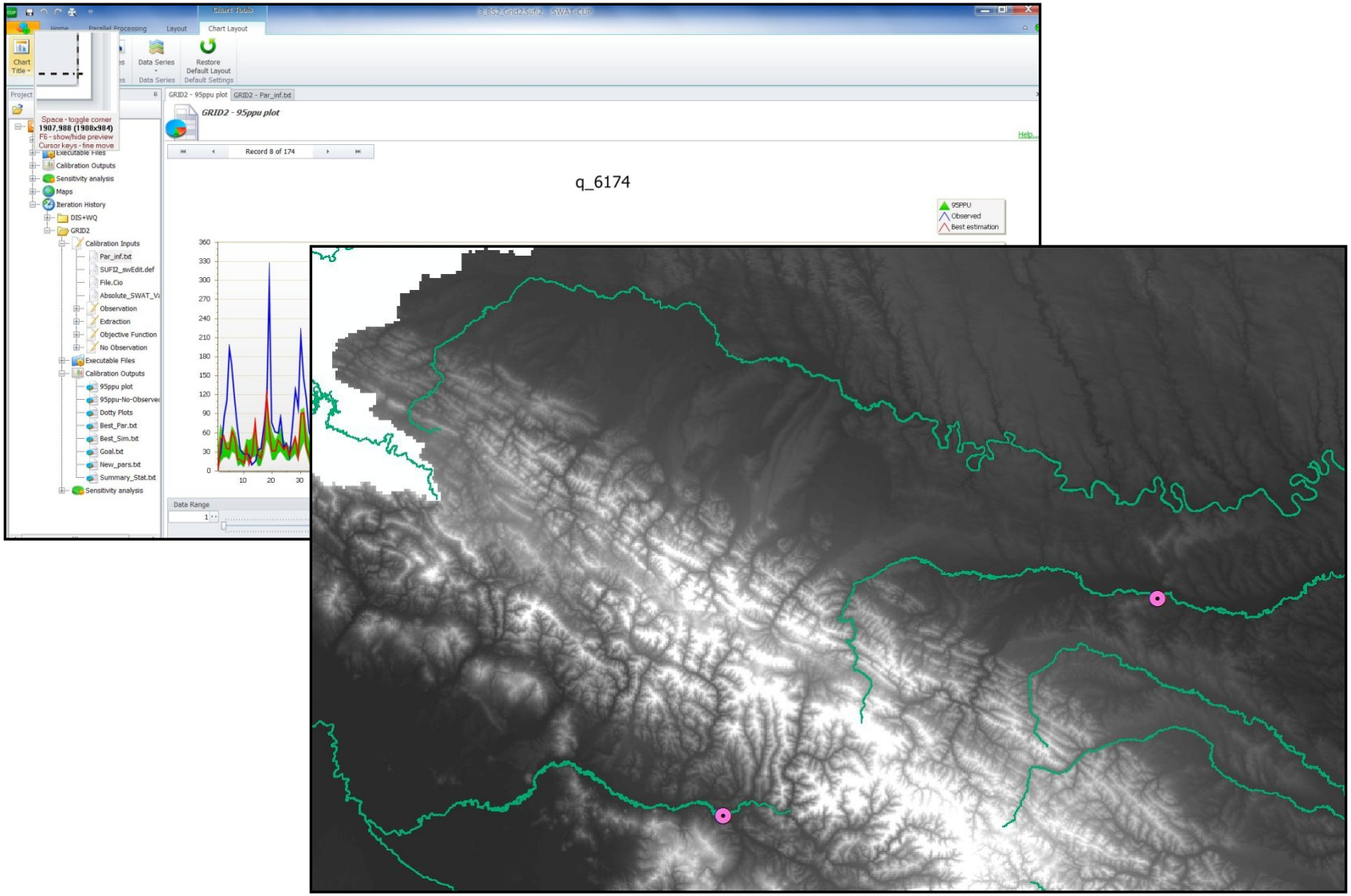
200 runs_Estimated run time in a single machine → **350 days!!**

200 runs using the parallel processing and Grid infrastracture → **8days!!**

(4 blocks of 50 worker node)

Calibration_Parameterization

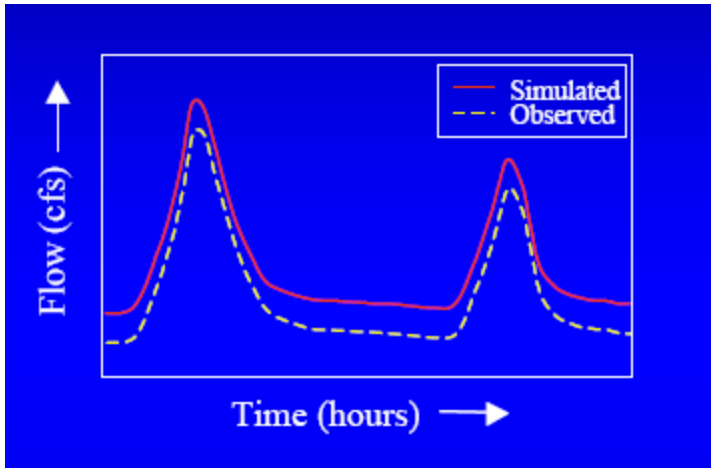
Snow melt, glaciers, elevation band



Calibration_Parameterization

Model consistently over pridicts the flow

- High Surface flow



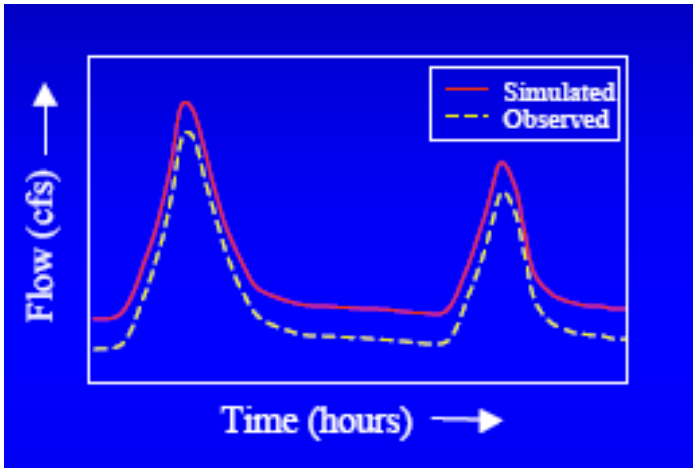
- Solutions

- Curve number for different land uses- decrease (CN in *.mgt)
- Soil available water- increase (SOL_AWC in *.sol)
- Soil evaporation compensation factor- increase up to 1.0 (ESCO in *.sub

Calibration_Parameterization

Model consistently over pridicts the flow

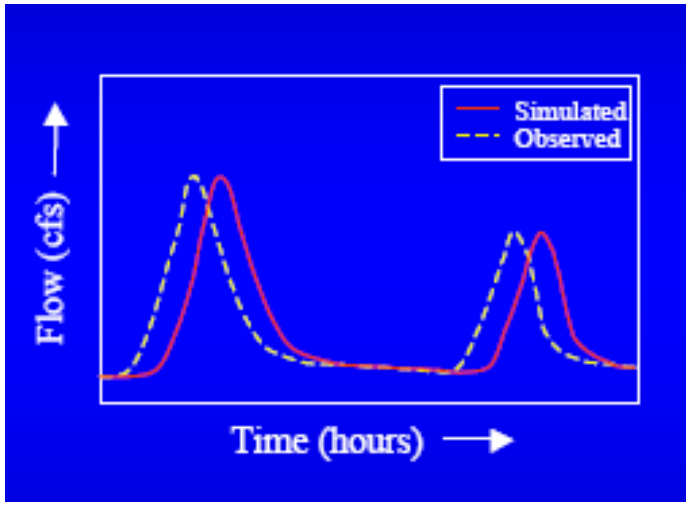
- High base flow
- Too little evapotranspiration



- Solutions
- Increase deep percolation loss (adjust threshold depth of water in shallow aquifer required for the base flow to occur) (max 100 mm, GWQMN in *.gw)
- Increase grouindwater revap coefficient (max of 0.4, GW_Revap in *in.gw)
- Decrease threshold depth of water in shallow aquifer for revap tp occur (min of 0.0, REVAPMN in.gw)

Simulated flow follows the observed pattern but lags the actual flow consistently

- Time of concentration is too long
- Less than actual slope for overland flow
- Over estimated surface roughness
- Snow melt parameters
- Flood routing coefficients



Solutions:

- Increase slope (up to 20%) for overland flow (SLOPE)
- Lower Manning`s roughness coefficient (OV_N)
- Lower the value of overland flow length to 4-10 m, if necessary (SLSUBBSN)

Calibration_Parameterization

New parameter set

Par_inf.txt

Par_inf.txt

Sufi2 prameters information

```
440      : Number of Parameters
500      : number of simulations

                              r__CN2.mgt          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                    r__SOL_AWC(1).sol             1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                             v__ESCO.hru          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                             v__GWQMN.gw          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                           v__GW_REVAP.gw         1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                           v__REVAPMN.gw          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                             v__EPCO.hru          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                           v__ALPHA_BF.gw         1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                           v__GW_DELAY.gw         1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                            r__SOL_K(1).sol       1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                           r__SOL_BD(1).sol       1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,18
                             v__SUB_SFTMP().sno          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,
                             v__SUB_SMTMP().sno          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,
                             v__SUB_SMFMX().sno          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,
                             v__SUB_SMFMN().sno          1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,

                              r__CN2.mgt          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                             v__GWQMN.gw          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                           v__GW_REVAP.gw         5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                           v__REVAPMN.gw          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                             v__ESCO.hru          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                      v__EPCO.hru          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,82,83,90
                           v__ALPHA_BF.gw         5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                           v__GW_DELAY.gw         5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                            r__SOL_K(1).sol       5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                           r__SOL_BD(1).sol       5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                          r__SOL_AWC(1).sol       5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,
                      v__SUB_SFTMP().sno          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77,8
                             v__SUB_SMTMP().sno          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,
                             v__SUB_SMFMX().sno          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,
                             v__SUB_SMFMN().sno          5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,

                              r__CN2.mgt          6174,6069,6073,6075,6076,6081,6091,6094,6101,6102,6104,6105,6115,6149,6158,6159,6168,61
```

What comes next?

Once the model is calibrated, the impcat of climate change and landuse change on water resources will be evaluated.

Acknowledgments
This project has been funded by the European Commission's Seventh Research Framework through the enviroGRIDS project (Grant Agreement n 226740).