YALE SCHOOL OF FORESTRY AND ENVIRONMENTAL STUDIES (YALE FES)

Training Completion Report

Training workshop on ArcSWAT for Watershed Assessment
10 – 21 May 2010

by

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ArcSWAT Training Completion Report

Purpose of the Workshop

1. To briefly introduce Geographic Information System using ArcGIS
2. To introduce the use of hydrologic models in watershed assessment using the Soil Water Assessment Tool (SWAT)
3. To introduce the use of sensitivity analyses to identify dominant hydrological processes within a watershed using SWAT
4. To introduce calibration and validation of hydrological model using SWAT
5. To develop a hyrdolocal model for a watershed in Bhutan using SWAT and to predict or forecast the behavior of hydrological processes due to climate change, land cover change and other Anthropogenic changes

Content of the Workshop

1. Introduction to GIS

Geometry and Attributes of Geographic objects or Spatial objects which could be represented as point, line and polygon features in vector GIS or Grid cells in raster GIS – is discussed.

Spatial relationships of Geographic objects are discussed.

2. Introduction to hydrology process

The following concepts are discussed during the workshop.

a. Sun as the Energy source of light, heat, radiation and temperature
b. Precipitation as Rain and Snow as the source of moisture
c. Evapotranspiration
d. Interception
e. Root zones
f. Vadoze zones or unsaturated zones
g. Shallow Aquifer
h. Infiltration
i. Overland flow as one of the sources for stream flow
j. Baseflow or shallow aquifer recharge as one of the sources for stream flow
k. Stream flow contributions from overland flow and baseflow
l. Impervious layers
m. Deep aquifer

The following mathematical treatment, examples and procedures are documented as the reference for the participants.

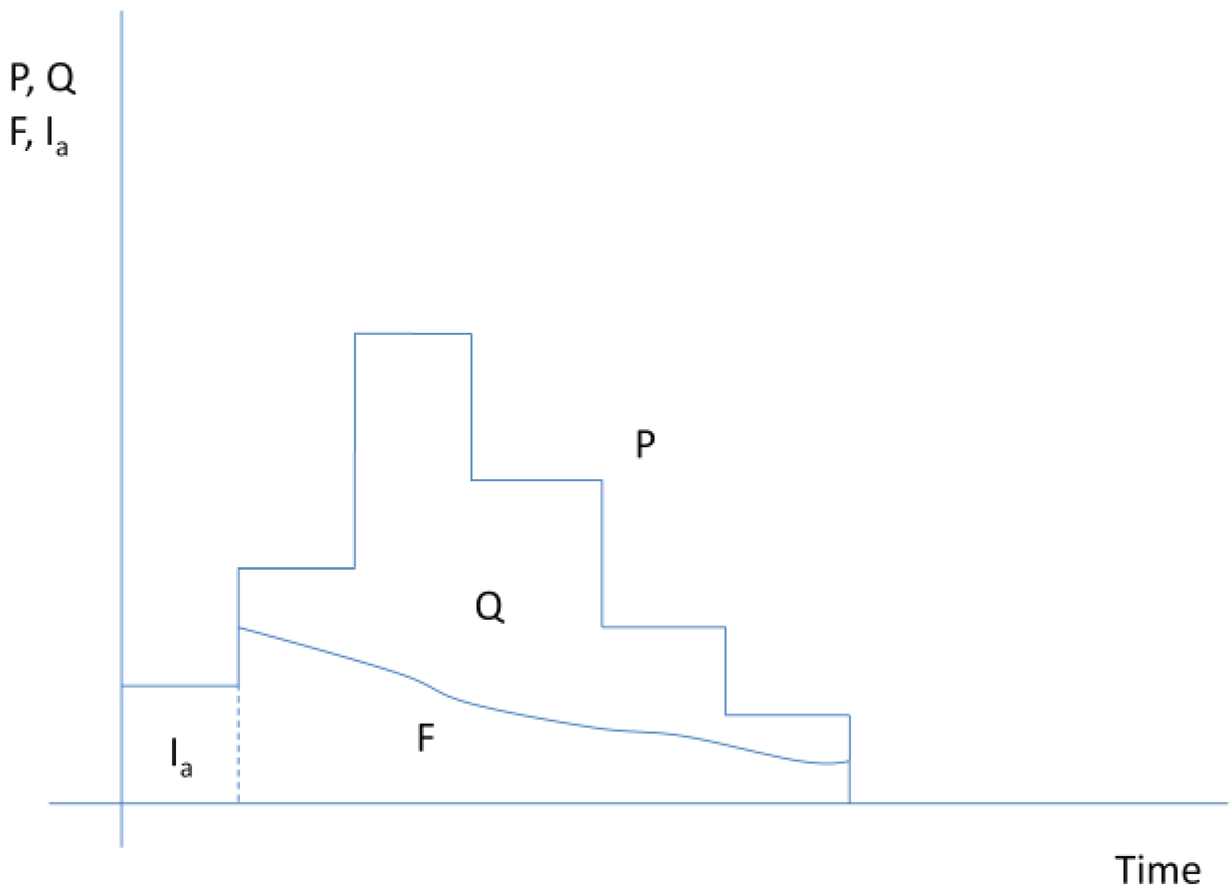
3. **Water balance equation**

$SW_t = SW_{t-1}{}^{+}\{R_t - Q_t - E_t - W_t - GWQ_t\}$

SW_t = Available water at time t, let's say today
SW_{t-1} = Available water at time t - 1, let's say yesterday
R_t = Rainfall of today
Q_t = Runoff of today
E_t =Evapotranspiration of today
W_t = Seepage loss of today
GWQ_t = Ground water runoff of today

4. **Mathematical formulation of water balance over time**

The surface runoff generation process was introduced using the Soil Conservation Service Curve Number method (SCS-CN) as described below,



P = Precipitation

Q = Surface Runoff

F = Actual Retention

I_a = Initial Abstraction

S = Potential Maximum Retention

P is known from the weather station data.

Three unknowns - Q?, F?, I_a?

Mathematically the following relationship can be developed,

$F/S = Q / (P - I_a)$

$F = (P - I_a) – Q$

Let, $(P - I_a) = X$ ➔ So $F = X-Q$

$F/S = Q/X$

$F = SQ / X$

$SQ / X = X-Q$

$SQ = X^2 – XQ$

$X^2 = SQ + XQ$

$X^2 = Q (S + X)$

$Q = X^2 / (S + X)$

$\mathbf{Q = (P - I_a)^2 / (P - I_a) + S}$

Now two unknowns

$\mathbf{I_a}$ and **S** unknown

Curve Numbers are introduced to solve the **S**.

Refer to the different Curve Numbers to the SWAT Theory document (Section 2 Chapter 1).

$\mathbf{S = 25.4 [(1000/CN) – 10]}$

CN = Curve number

I_a = 0.1 S for Urban or developed area

I_a = 0.2 S Other area

So

$Q = (P-0.2S)^2 / (P+0.8S)$ for vegetative area

$Q = (P-0.1S)^2 / (P+0.9S)$ for Urban or developed area

Conceptually –

For Vegetative Areas -

If P = 0.2S then Q = 0 ➔ It means no surface water flow

If P < 0.25 then Q is Negative ➔ Meaningless

Therefore, the equation is valid for P >= 0.2S ➔ **$Q = (P-0.2S)^2 / (P+0.8S)$ for vegetative area**

Otherwise **Q = 0 for vegetative area**

For Urban and Developed area -

If P = 0.1S then Q = 0 ➔ It means no surface water flow

If P < 0.1S then Q is Negative ➔ Meaningless

Therefore, the equation is valid for P >= 0.1S ➔ **$Q = (P-0.1S)^2 / (P+0.9S)$ for Urban and developed areas**

Otherwise **Q = 0 for urban and developed areas**

5. Examples on Q (surface runoff) calculations

Example (1) application of the Q calculation

24 hours Rainfall = 100 mm

Soil Group = D

Land use land cover Type = Small Grain Contours and Terraced – Good condition

So CN value = 81 based on the paper provided at the workshop

Estimate Q?

Calculate S First.

S = 25.4 [(1000/CN) – 10]

= 25.4 [1000/81) – 10]

= 25400/81 -254

S = 59.58

Vegetative Area

$Q = (P-0.2S)^2 / (P+0.8S)$

$Q = (100- (0.2*29.58))^2 / (100 + (0.8*59.58))$

Q = 52.544 mm

Example (2) Application of Q Calculation on different land use and soil types

							Area	1		
							Forest	10	%	
land use	soil group Area	Area	CN	S	Q(mm)		Residential	90	%	
Forest	B	0.03	58.00	183.93	0.89					
	D	0.07	79.00	67.52	12.81		Soil Group B	30	%	
Residential	B	0.27	74.00	89.24	12.95		Soil Group D	70	%	
	D	0.63	86.00	41.35	24.12					
							Rainfall	50	mm	24 hours rainfall
	Watershed Runoff		19.61							

Total Runoff Q = Area1 * Q1 + Area2 * Q2 + Area3 * Q3 + Area4 * Q4

Area1 = 1 * 10/100 * 30/100 = 0.03 ➔ Forest and Soil Type B

(Total Area = 1, 10% of Forest and 30% of Soil Type B)

S1 = 25.4 [(1000/58) – 10]

= 25.4 [1000/58) – 10]

= 25400/58 -254

S 1= 189.93

$Q1 = (50 – (0.2 * 189.93))^2 / (50 + (0.8 * 189.93)) = 0.89$

Similar way the following items are calculated.

Area2, S2, Q2 ➔ Forest and Soil Type D

Area3, S3, Q3 ➔ Residential and Soil Type B

Area4, S4, Q4 ➔ Residential and Soil Type D

The Total Q = 0.03 * 0.89 + 0.07 * 12.81 + 0.27 * 12.95 + 0.63 * 24.12 = 19.61 mm is calculated.

Example (3) Application of Q Calculation for land use changes impact on surface water

In this example, forests are changed to agriculture based on the Example -3.

Then water runoff increases to 59.27 mm. Calculation is illustrated as below.

							Area	1	
							Agriculture	10	%
land use	soil group Area	Area	CN	S	Q(mm)		Residential	90	%
Agriculture	B	0.03	70.00	108.86	32.71				
	D	0.07	81.00	59.58	52.54		Soil Group B	30	%
Residential	B	0.27	74.00	89.24	46.00		Soil Group D	70	%
	D	0.63	86.00	41.35	66.98				
							Rainfall	100	mm
	Watershed Runoff		59.27						

6. Simple Precipitation and Runoff Model (P-R Model)

R = c +b **P**

R = Surface runoff ➔ Output

P= Precipitation ➔ Input

It is regression model - c and b have to be estimated.

Nash efficiency (NS) and Percentage Bias (PBIAS) are calculated to calibrate and validate the regression model or P-R model.

NS = $\sum(\text{obs.flow} - \text{sim.flow})^2 / \sum(\text{obs.flow} - \text{avg.obs.flow})^2$

PBIAS = $100 * (\sum(\text{obs.flow} - \text{sim.flow}) / \sum(\text{obs.flow}))$

NS value >= 0.5 is good indicator of model calibration and validation.

PBIAS value within the range of ± 10% is a good indicator of model calibration and validation.

Example of Calibration of Model

The following dataset illustrated precipitation (inches), observed flow and simulated flow for calculation of NS and PBIAS.

In the following example, c value is 0.04 and b value is 0.25.

year	prcp (in)	obs.flow	sim.Runoff	avg.obs.flow	(obs-sim)^2	(obs-avg.obs)^2	(obs-sim)
1960	1.95	0.46	0.528	1.349	0.005	0.790	-0.067
1961	10.82	2.85	2.745	1.349	0.011	2.254	0.105
1962	3.22	0.99	0.845	1.349	0.021	0.129	0.145
1963	4.51	1.4	1.168	1.349	0.054	0.003	0.233
1964	6.71	1.98	1.718	1.349	0.069	0.399	0.263
1965	1.18	0.45	0.335	1.349	0.013	0.807	0.115
1966	4.82	1.31	1.245	1.349	0.004	0.001	0.065

The NS value is 0.96 and PBIAS is 9.08.

The target NS value is to maximize to 1 and the PBIAS is to be within +-10%. Theoretically, if the observed value and simulated values are the same, PBIAS will be 0. Practically, PBIAS value is +- 10% and NS is greater than or equal 0.5, it is acceptable calibration.

The different groups tried to calibrate the model manually by trying c values from 0.01 to 1 and b value from 0.1 to 0.5. The followings are the result of simulations of different groups.

Simulation	c	b	NS	PBIAS
1	0.010	0.282	0.975	0.000
2	0.010	0.280	0.980	0.700
3	0.080	0.250	0.970	6.100
4	0.100	0.250	0.980	2.970
5	0.070	0.270	0.980	-0.170
6	0.070	0.270	0.980	-0.180
7	0.080	0.250	0.978	6.118
8	0.020	0.270	0.980	0.940
9	0.029	0.278	0.980	0.001
10	0.085	0.250	0.970	5.700
11	0.080	0.260	0.980	2.600
12	0.020	0.280	0.980	0.000
13	0.029	0.278	0.980	0.000
14	0.040	0.250	0.800	9.080
15	0.030	0.300	0.940	-7.760
16	0.020	0.300	0.950	-7.020
	c	b	NS	PBIAS
Average	0.048	0.270	0.963	1.192
median	0.035	0.270	0.980	0.351
max	0.100	0.300	0.980	9.080
min	0.010	0.250	0.800	-7.760
st.dev	0.0310	0.0171	0.0450	4.4222
variance	0.0010	0.0003	0.0020	19.5560

Then calculate the Average, median, maximum, minimum, standard deviation and variance of simulated results. Then compare the NS and PBIAS values. According to the table above, median performs the best. So the group decided to use the c value 0.035 and b value 0.27.

Then **recalibrate** the model with **new c and b value**, 0.035 and 0.27 respectively.

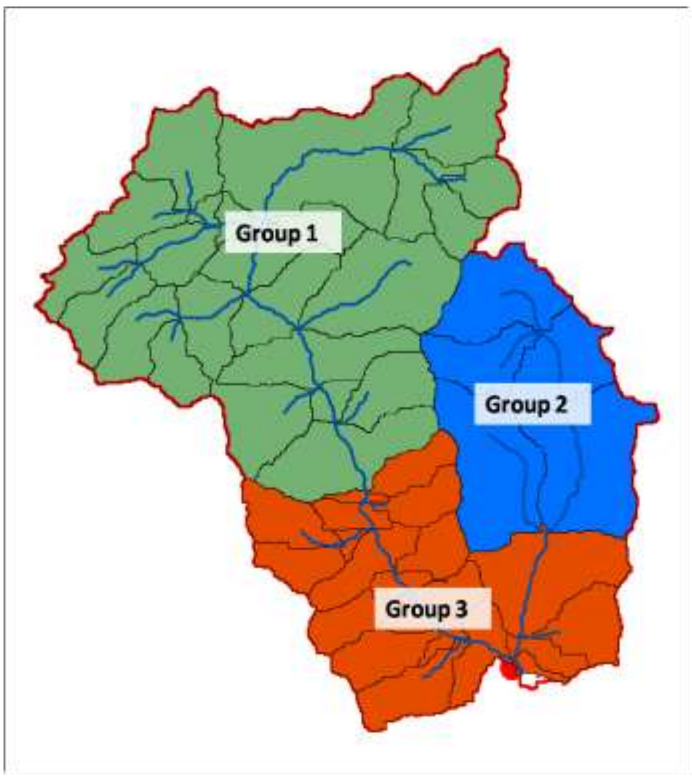
year	prcp (in)	obs.flow	sim.Runoff	avg.obs.flow	(obs-sim)^2	(obs-avg.obs)^2	(obs-sim)
1960	1.95	0.46	0.562	1.349	0.010	0.790	-0.102
1961	10.82	2.85	2.956	1.349	0.011	2.254	-0.106
1962	3.22	0.99	0.904	1.349	0.007	0.129	0.086
1963	4.51	1.4	1.253	1.349	0.022	0.003	0.147
1964	6.71	1.98	1.847	1.349	0.018	0.399	0.133
1965	1.18	0.45	0.354	1.349	0.009	0.807	0.096
1966	4.82	1.31	1.336	1.349	0.001	0.001	-0.026

The NS value is 0.99 and PBIAS is 2.42.

With the new c and b values, the NS value improved from 0.96 to 0.98 and PBIAS value improved from 9.08 to 2.42.

The aforementioned process is called Model Calibration. ArcSWAT or SWAT does this calibration process for you in similar but more sophisticated way.

Distributed watershed-scale hydrologic models, such as SWAT, simulate several hydrologic processes. Each process is represented by a mathematical formulation for which appropriate parameter values have to be estimated. Watershed response varies based on various physical characteristics. For example, the Paro watershed's stream flow producing areas are dominated by forest cover on western part and snow/glacier cover on the eastern part. A good practice is to group sub-watersheds into groups and calibrate each group separately. Observed data such as stream flows should be available at each one of these group outlets. For example, consider the Paro river basin is grouped into three as shown in the figure below. The group 1 watershed parameters can be calibrated using the stream flow observation available at the group 1 outlet while keeping the group 2 and group 3 parameters unchanged (only if such observations are available). Similary group 2 and group 3 can be calibrated. This procedure will take longer time and more computer resources, but will results in a well-calibrated watershed model.



Example of Validation of Model

Through the calibration process, we have estimated the best possible **c** and **b** parameters using 1960-1966 information on observed flow and simulated flow.

Then add the 1966-1969 data for validation purpose. The data is green highlighted.

Then calculate the simulated flow for the 1967-69 data using the new c value 0.035 and new b value 0.27.

Then calculate the NS and PBIAS for the 1967-69 data. The NS value is 0.49 and PBIAS is 2.04 for the 1967-69 data. The NS value is approximately 0.5 and PBIAS is still within 10%. So, the calibration could be useful for validation of the model.

The aforementioned process is called Model validation.

7. ArcSWAT Procedures and Steps to apply the concepts

Create a directory Model. Then create Input, Output, and Analyses sub folders. Create Climate and Spatial sub folders within Input.

DEM Processing and Automated Watershed Delineation

Projected DEM, Mask Boundary
DEM Processing for flow direction and flow Accumulation
Stream Definition
Watershed delineation
Writing sub watershed parameters
Exit the module to write the output files to the Geodatabase

Remember the **last sub watershed number** which is before the outlet or flow monitoring station.

HRU (Hydrological Response Unit) Analyses

Prepare Land use data, LUT and Reclassification
Prepare Soil data, LUT and Reclassification
Prepare Slope data, LUT and Reclassification
Assign the definition of landuse, soil and slope for HRU
Overlay and create HRUs

Write Tables

Prepare the weather generator stations text file. Give the name wgnstns.txt.
Prepare the precipitation station text file. Give the name prcp_stns.txt.
Prepare the temperature station text file. Give the name tmp_stns.txt.

Create the temperature observations data text files. Give the names of the file illustrated in tmp_stns.txt.

Create the precipitation observations data text files. Give the names of the file illustrated in prcp_stns.txt .

If you have Relative Humidity, Wind Speed and Solar Radiation data, create the files accordingly.

Write All.

Edit SWAT Input

Prepare the User soils database to add the customized soil data for Bhutan.
Prepare the User weather stations database to add the customized weather generator parameters.
Prepare the Land Cover / Plant Growth database to add the customized land cover data for Bhutan.

8. Sensitivity Analyses

In the aforementioned model calibration (section -5 Examples), only two parameters (c, b) are estimated. In reality different parameters related to overland flow, base flows such as Alpha_Bf, CanMx, CN2, Gwqmn, Revamp, Surleg and Soil_AWC etc. are calculated.

Prepare the observed flow data for daily and monthly values. The following is the example of 2006 monthly flow data. Column width for year is 5, column width for month is 5 and column width for the flow is 14.

```
 2006    1          6.51
 2006    2          5.69
 2006    3          5.87
 2006    4          7.89
 2006    5         13.51
 2006    6         32.97
 2006    7         64.03
 2006    8         77.42
 2006    9         50.18
 2006   10         27.89
 2006   11         13.21
 2006   12          8.70
```

The following is the example of 2006 daily flow data. Column width for year is 5, column width for day is 5 and column width for the flow is 14.

2006	1	7.42
2006	2	7.24
2006	3	7.07
2006	4	7.10
2006	5	6.94
2006	6	6.97
2006	7	6.76
2006	8	6.86
2006	9	6.74
2006	10	6.88
2006	11	6.75
2006	12	6.64
2006	13	6.49
2006	14	6.54
2006	15	6.46
2006	16	6.35
2006	17	6.28
2006	18	6.39
2006	19	6.27
2006	20	6.26
2006	21	6.23
2006	22	6.21

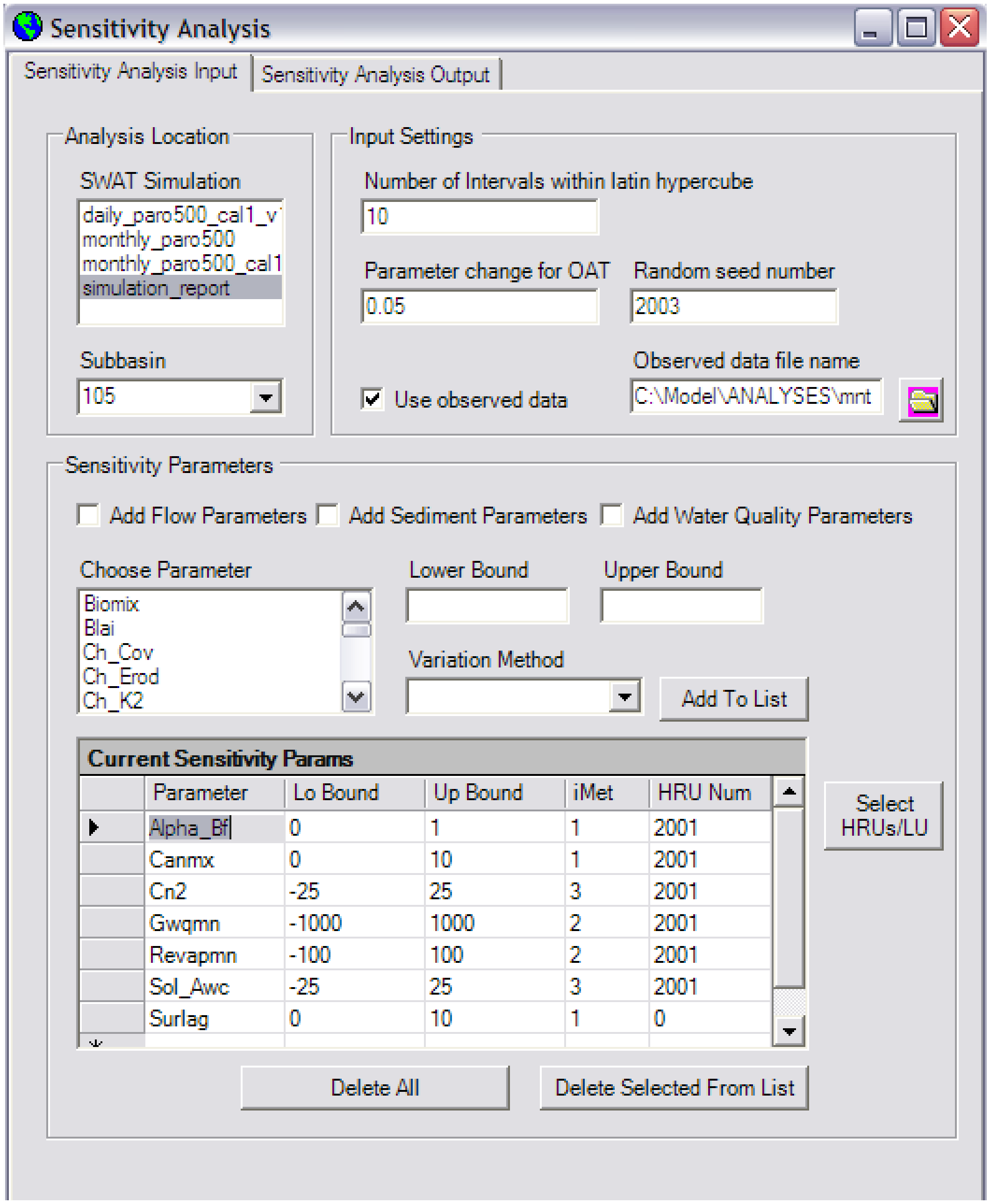
2006	356	8.16
2006	357	8.03
2006	358	7.83
2006	359	7.78
2006	360	7.75
2006	361	7.60
2006	362	7.54
2006	363	7.54
2006	364	7.53
2006	365	7.47

In SWAT and ArcSWAT, Sensitivity Analyses menu could assist to Rank the parameters.

The observation monthly or daily flow data should be logically named such as mnthlyflw.txt or dlyflow.txt.

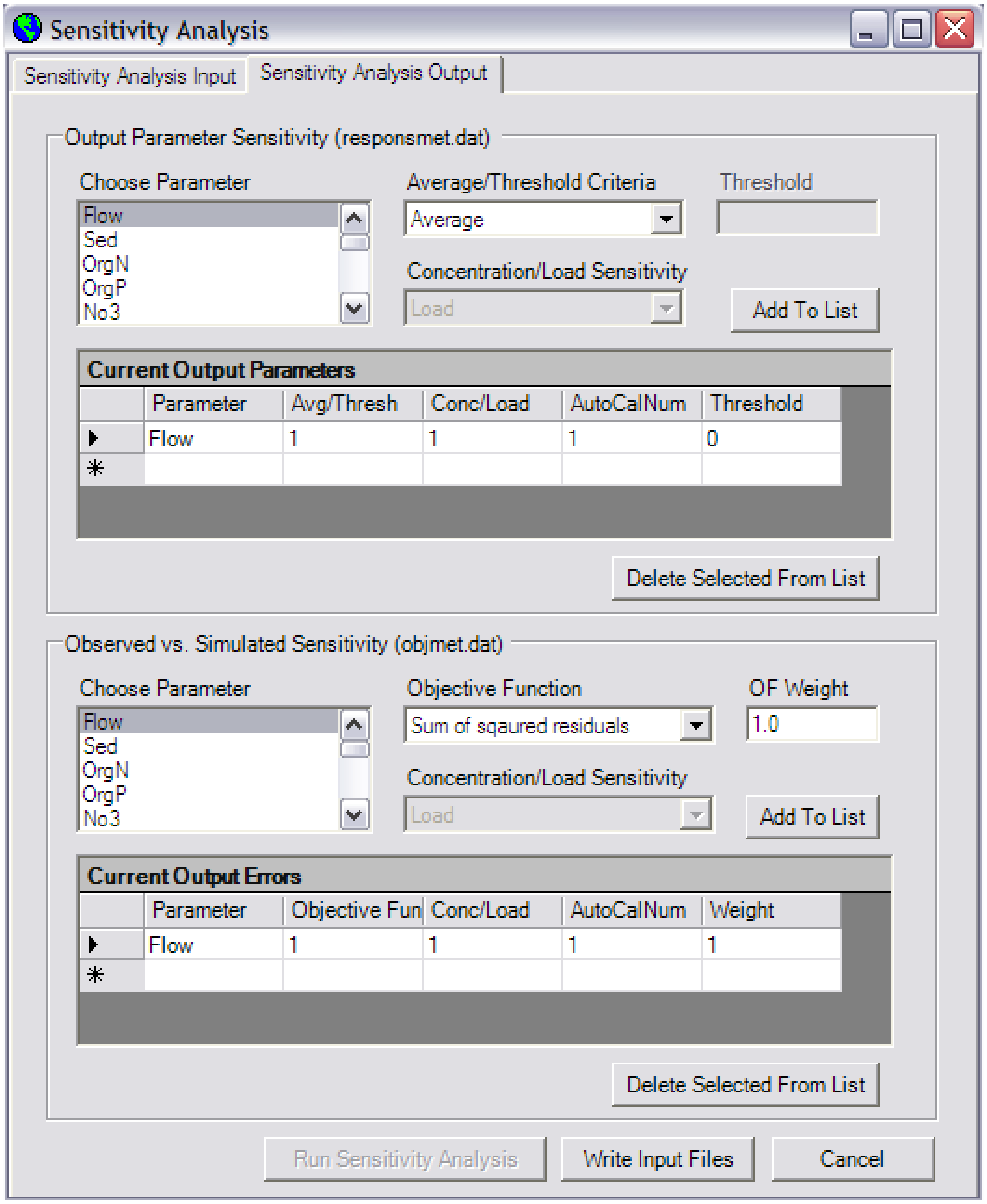
Before the following steps, model should be run once for monthly or daily and save the simulation. Moreover, set the model to the Default.

Then run the sensitivity analyses. Add the sensitivity analyses input parameters. Consider the following input screen as the reference and the paper provided during the workshop for the parameter list.



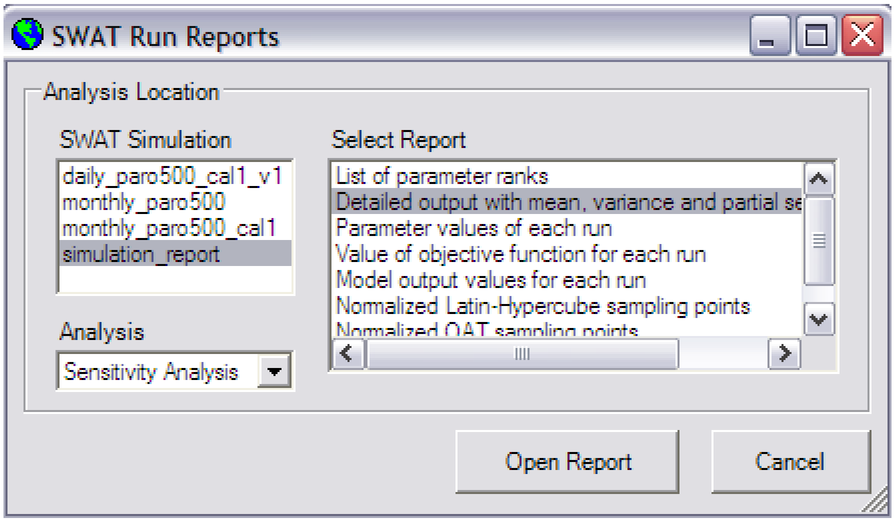
Then select the Sensitivity Analyses Output Tab.

Use the following screen for the reference.



Then click Write Input Files. Then Run Sensitivity Analyses.

Then check the report of the sensitivity analyses – Detailed output with mean, variance and partial sensitivities.



The following pieces of information are important.

```
        INITIAL PARAMETER VALUES AND PARAMETER BOUNDS
        =============================================

  PARAMETER     INITIAL VALUE     LOWER BOUND     UPPER BOUND
  ---------     -------------     -----------     -----------
   1    0.00000   1.00000     1     1 2001   Alpha_Bf
   2    0.00000  10.00000     7     1 2001      Canmx
   3  -25.00000  25.00000    10     3 2001        Cn2
   4**********1000.00000     6     2 2001      Gwqmn
   5-100.00000 100.00000     5     2 2001    Revapmn
   6  -25.00000  25.00000    17     3 2001    Sol_Awc
   7    0.00000  10.00000    33     1    0     Surlag
```

```
  parname    rank       mean
  Alpha_Bf      1    0.126E+01
     Canmx      4    0.113E+00
       Cn2      5    0.442E-01
     Gwqmn      3    0.145E+00
   Revapmn      8    0.000E+00
   Sol_Awc      2    0.373E+00
    Surlag      6    0.296E-01
```

```
       par #       mean
  Alpha_Bf      4    0.445E-01
     Canmx      2    0.711E-01
       Cn2      5    0.771E-02
     Gwqmn      1    0.146E+00
   Revapmn      8    0.000E+00
   Sol_Awc      3    0.520E-01
    Surlag      6    0.112E-02
```

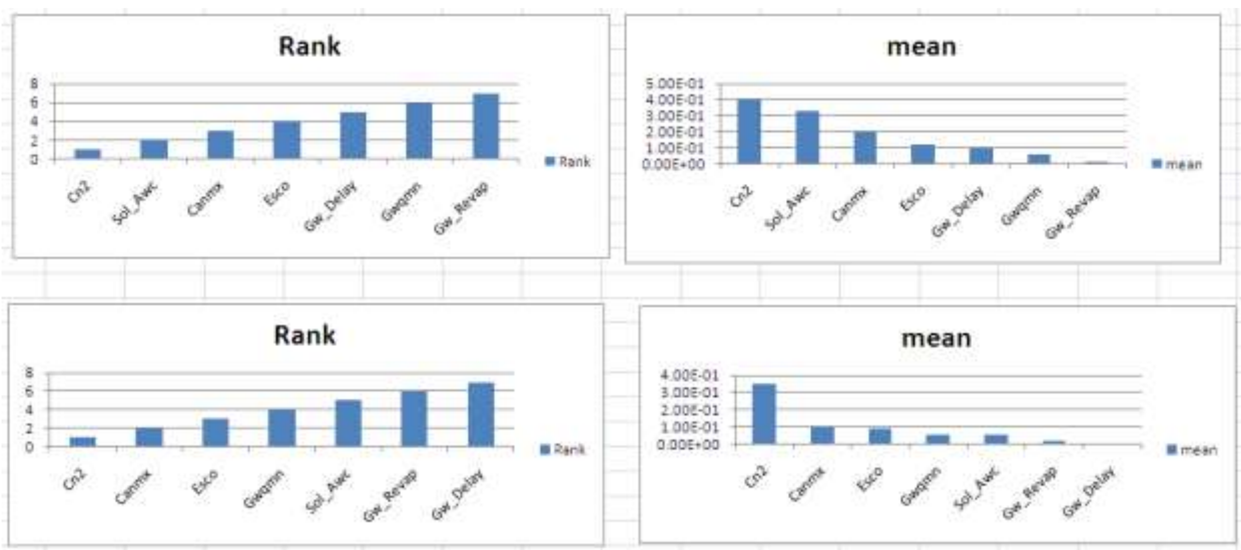
In the first block of information, 1 = Replace, 2 = Add value and 3 = Multiply by %. It illustrated how to change the parameter values.

In the second block of information, it report the sensitivity analyses result **with** observation data. Rank column represents the sensitivity of parameters by rank. Rank 1 is the highest sensitivity.

In the third block of information, it report the sensitivity analyses result **without** observation data. Rank column represents the sensitivity of parameters by rank. Rank 1 is the highest sensitivity.

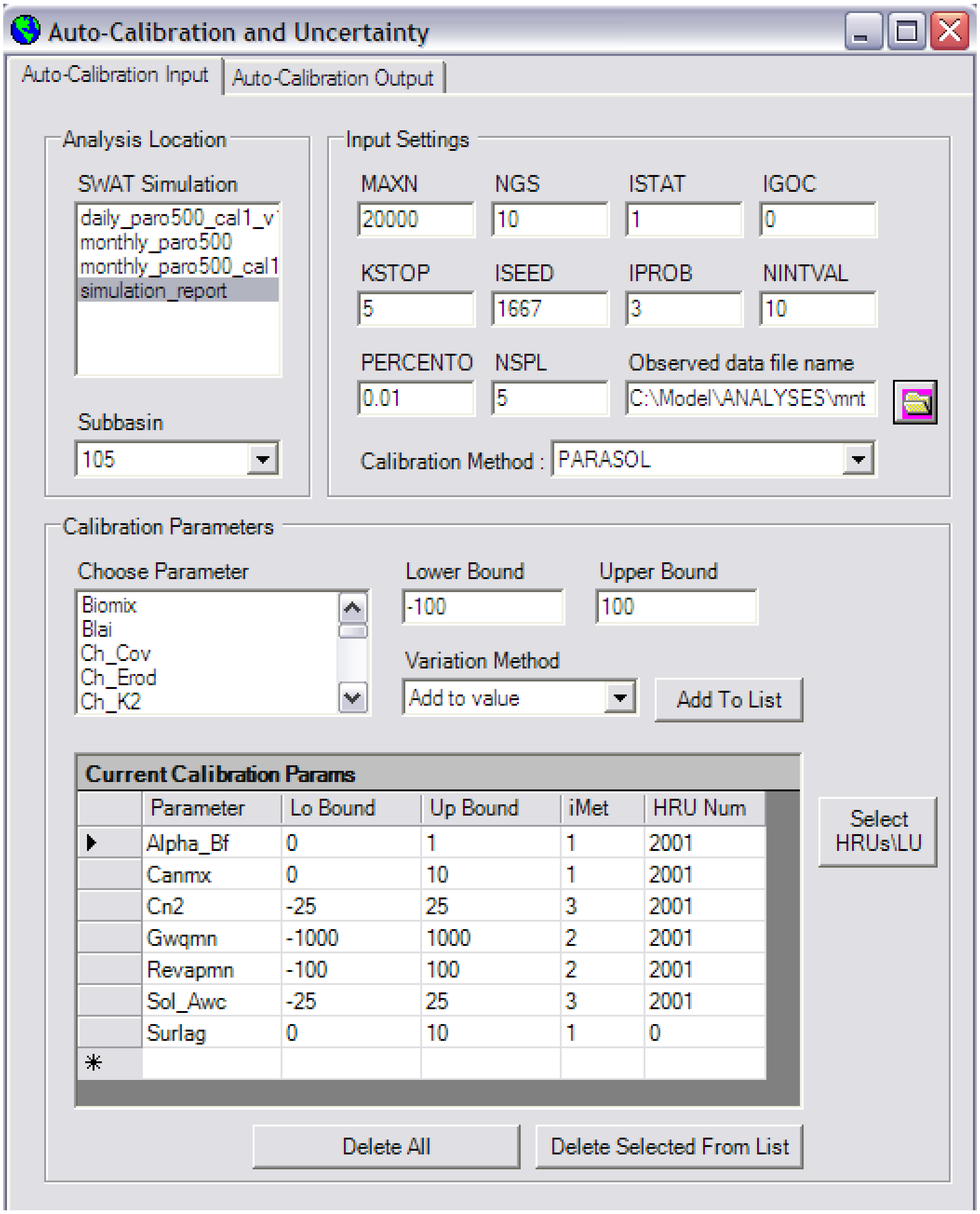
Draw the graphs on Parameters Vs Ranks and Parameters vs. Mean. Then select the most sensitive parameters for **model calibration and uncertainty analyses**, as the following example.

Ation

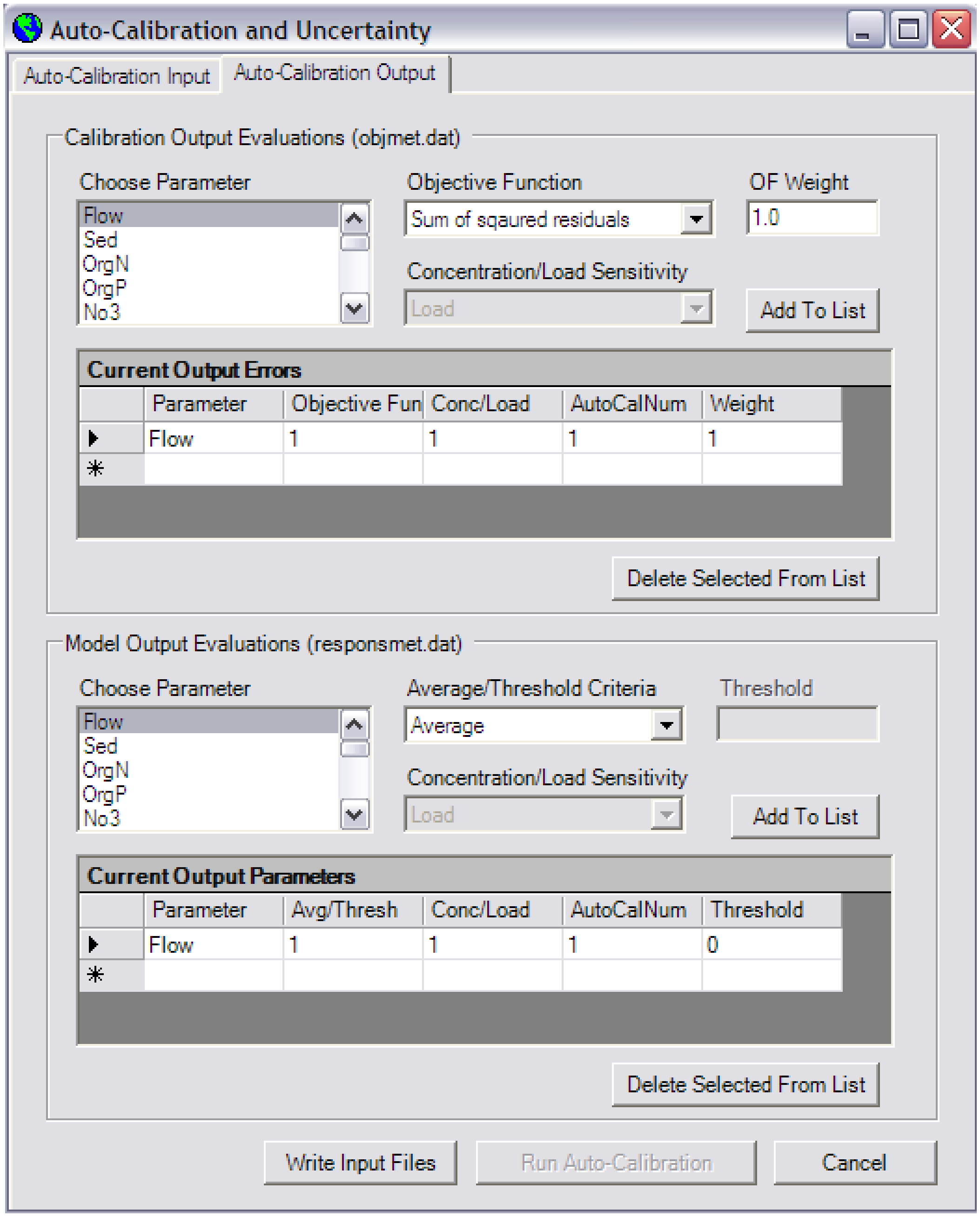


9. Auto Calibration and Uncertainty Analyses

Run the Auto calibration and Uncertainty Analyses. Select the parameters recommended and use the default value. Use the following figure as the reference.

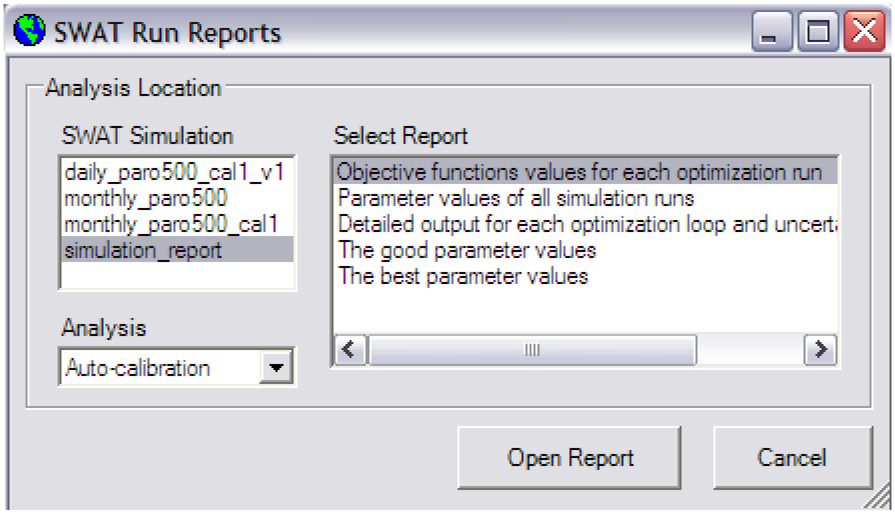


Then select the Auto Calibration Output Tab. Then select the flow parameters. Use the following figure as the reference.



Then click Write Input Files.

Run the Auto calibration and Uncertainty Analyses based on the selected parameters from the rank analyses and observed data (monthly or daily). It may take long time. Then see the Sensitivity analyses report – objective functions and simulations.



Copy the values from Objective function values for each simulation to the excel sheet, run# and OF values. Plot it in excel. Calculate the minimum value. Plot the simulation number and OF values.

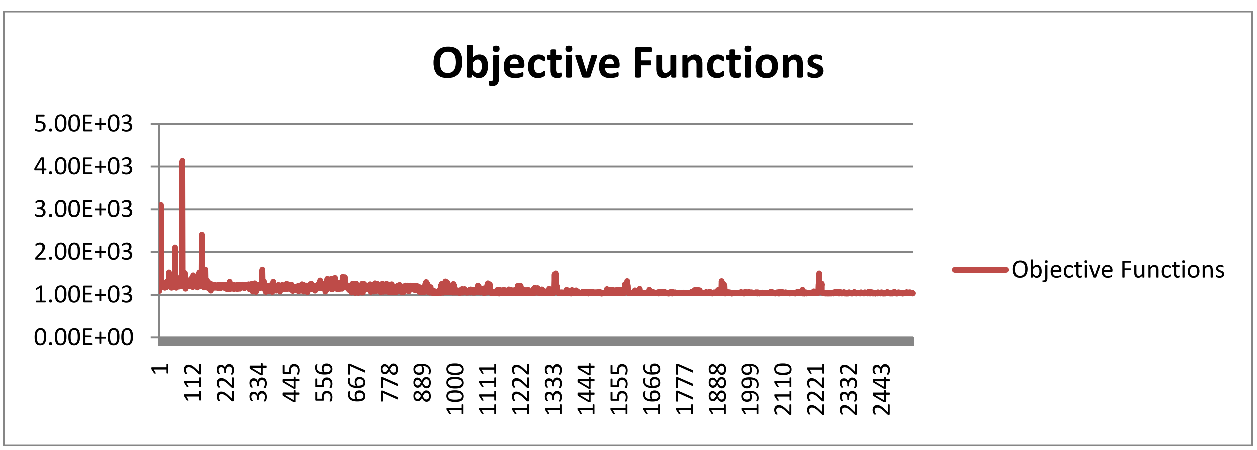
In this example run#1939 has the following best parameter values.

Open the best parameter values. Note down the best parameter values for each parameter. More over - note the values for Replace (item 1), added by (item 2) multiply by (item 3) for each parameter. (Note the best parameter values for calibration using parasolout.out and bestpar.out).

1939 0.99055E+00 0.42628E-01 0.88580E+01 -0.77154E+03 0.23307E+02 -0.14925E+02 0.00000E+00

There are 7 color highlighted values above.

In this example, the chart is similar to the following.



The following paragraph from detail output instructed on – what to do with the best values – to replace

(1) or to multiply (2) by or added by (3). There are also 7 parameter values for each parameter.

```
          INITIAL  PARAMETER  VALUES  AND  PARAMETER  BOUNDS
          ==============================================

 PARAMETER       INITIAL  VALUE      LOWER  BOUND      UPPER  BOUND
 ---------       -------------       -----------       -----------
  1    0.00000   1.00000     1     1  2001   Alpha_Bf
  2    0.00000  10.00000     7     1  2001      Canmx
  3  -25.00000  25.00000    10     3  2001        Cn2
  4**********1000.00000      6     2  2001      Gwqmn
  5-100.00000 100.00000      5     2  2001    Revapmn
  6  -25.00000  25.00000    17     3  2001    Sol_Awc
  7    0.00000  10.00000    33     1     0     Surlag
```

In this example,

Alpha_Bf is suggested to be **replaced by** 0.99055E+00.
Canmx is suggested to be **replaced by** 0.42628E-01.
Cn2 is suggested to be ***multiplied by*** a factor (1.08858) calculated based on 0.88580E+01.
Gwqmn is suggested to be **added by** -0.77154E+03.
Revapmn is suggested to be **added by** 0.23307E+02.
Sol_Awc is suggested to be ***multiplied by*** a factor (0.85075) calculated based on -0.14925E+02.
Surlag is suggested to be **replaced by** 0.00000E+00.

Note that the calculation of factor value for multiply by (item 3) is calculated as follows.

(100 + X)/100 where X is the Percentage value provided by the multiply by (item-3)

Example

CN2	0.88580E+01	3	Multiply by % value
Sol_AWC	-0.14925E+02.	3	Multiply by % value

Factor value for CN2 = (100 + 8.858) / 100 = 1.08858

Factor value for Sol_AWC = (100 – 14.925) / 100 = 0.85075

At Swat simulations menu, Run model one more time for monthly or daily but do not save it.

Open the detailed output for each optimization loop and uncertainty.

At Swat simulations menu, Run model one more time for monthly or daily but do not save it.

Set the default simulation. For example - monthly_ver3

10. Manual calibration helper

Replace, or add or multiply values recommended by the Simulations.

For example --

Select parameter Alpha_Bf – replace 0.99055E+00 for
All Watershed
All land use
All soil
All slope
and Update Parameters ONCE for each parameter.

Select parameter CanMx – **replaced by** 0.42628E-01.
All Watershed
All land use
All soil
All slope
and Update Parameters ONCE for each parameter.

Select parameter Cn2 – multiplied by 1.08858.
All Watershed
All land use
All soil
All slope
and Update Parameters ONCE for each parameter.

Select parameter Gwqmn – added by -0.77154E+03.
All Watershed
All land use
All soil
All slope
and Update Parameters ONCE for each parameter.

Select parameter Revapmn – **added by** 0.23307E+02.
All Watershed
All land use
All soil
All slope
and Update Parameters ONCE for each parameter.

Select parameter Sol_Awc - ***multiplied by*** a factor (0.85075)
All Watershed
All land use
All soil
All slope

and Update Parameters ONCE for each parameter.

Select parameter Surlag– replace 0.00000E+00. for
All Watershed
All land use
All soil
All slope
and Update Parameters ONCE for each parameter.

Then Re-Write SWAT Input Files

Edit swat input >> Rewrite swat input files >> select all >> write files

In the Default folder >> TxtInOut – open 0000**000**.mgt file in order to check the changes of related parameters.

Then run the simulations for monthly or daily.

Save the simulation (e.g.: "Simulation monthly_ver3_cal1").

Open the Microsoft Access database in C:\Model\ Simulation monthly_ver3_cal1\Scenario\tablesout\SWAToutput.mdb

Then open the RCH table.

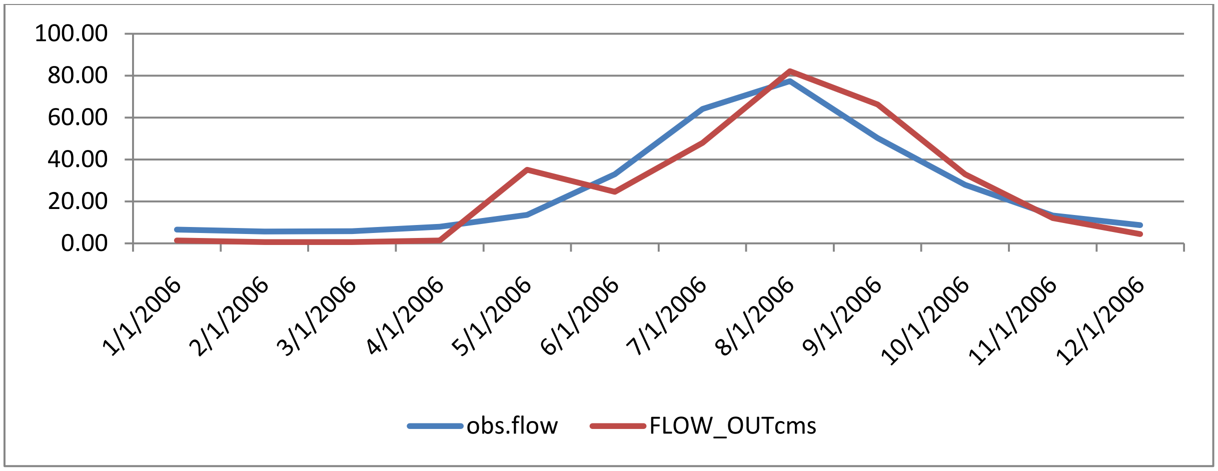
Make sure to select SUB, YEAR and MON columns. Then sort ascending order.

Copy the last 12 values of the **last** watershed for monthly simulation or 365 values of last watershed for the last watershed for daily simulation.

Paste it to the excel sheet.

Then calculate the NS and PBIAS values against the daily observed flow or monthly observed flow.

Validate the observed flow graph and simulated flow graphs.



NS value is 0.82 and PBIAS is 1.48 in this example.

Resource Persons of the Workshop

1. Dr. Moe Myint, Research Scientist, Yale School of Forestry and Environmental Studies (Yale FES)
2. Mr. Noel Aloysius, Doctoral Student, Yale FES
3. Mr. Karma Tshering, Watershed Management Division

Participants of the Workshop

1. Mr. Sonam Penjor
2. Mrs. Deki Wangmo
3. Mr. Pema Thinley
4. **…………**

List to be added by Sonam Chodan.

Key Points of the Workshop for the Participants to remember

1. 1 m^3/sec = 601,344 m^3/day
2. If the Basin Area is 834.37 Ha, it will be 0.7207 mm/day

   (601344 / (834.37 * 1000 * 1000)) * 1000 = 0.7207 mm/day

Recommendations

Immediate Application of knowledge to Watershed Management using the land use, soil, topographic, climatic and hydrological station data to the selected watershed

Quality control procedures of climatic data is required.

Integration of soil map which is being produced by the National Soil Service Center

Integration of Land use and land cover map which is being produced by the LCMP/SLMP Project.

Filling the data gap using the available tools such as PCPSTAT

Future Directions

Advanced hydrological modeling workshop should be organized when the participants have the enough experience on application of knowledge gained during this workshop. The advanced workshop shall consist of three major components,

I. Train the WMD officers of observed climate and hydrologic data analysis and presentation of data
II. Advanced model calibration and validation techniques including the selection of appropriate parameter groups, multi-site calibration and parameter transferability within similar watersheds
III. Watershed assessment and reporting protocols so that the WMD officers can systematically collect and analyze the relevant data, develop, calibrate and validate hydrological models, and prepare assessment reports.

The WMD may also explore the possibility of setting up an "experimental watershed" which can be fully instrumented to monitor different hydrologic processes. The following two links provide examples of such experimental watershed in the United States,

Kings River Experimental Watershed - http://www.fs.fed.us/psw/programs/snrc/water/kingsriver/

Little River Experimental Watershed - http://www.nrcs.usda.gov/Technical/nri/ceap/watershed.html

Conclusion

The ArcSWAT training provided the new applicable knowledge on hydrology and geographic information system to the participants who have the diverse background in academic and work experience.

Some participants, who have the GIS background, learned the hydrology as the new knowledge.

Some participants, who have the hydrology background, learned how to apply hydrology within GIS environment.

Some participants learned both hydrology and GIS as the new knowledge.

All participants learned ArcSWAT, SWAT and ArcGIS as the tools to assist hydrological modeling and watershed management using land use, soil, temperature data, precipitation data and recorded flow data in an integrated way.

Participants also learned how to calculate the impact on water flow for the landuse or climatic changes scenarios.

It is a successful workshop.