Introduction to Spatial Hydrologic Modeling in the US Army Corps of Engineers:

GSSHA Using the Watershed Modeling System

Tutorials – Volume 4

GSSHA Calibration

WMS 8.4 Compatible – Volume 4

The software *WMS* is a product of the Aquaveo, LLC. For more information about this software and related products, contact Aquaveo at:

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CHAPTER   1

Manual Calibration of GSSHA models

Creating a working GSSHA model is a preliminary step in hydrologic modeling. Such models can be used in analyzing different hydrologic problems only if the model developer has enough confidence in the model. Generally, such models should be calibrated.

In this tutorial, you will read a pre-existing GSSHA project for the Goodwin Creek watershed and perform a sensitivity analysis on the parameter in order to understand how parameters can be modified to calibrate the model. In this tutorial we will manually adjust parameters for a calibration, in the next tutorial we will use a series of batch or stochastic runs to calibrate the model and then finally we will use an automated shuffle, complex, evolution scheme to automate the calibration. In all cases a sensitivity analysis on the parameters is helpful in guiding the calibration.

1.1 Open an Existing GSSHA Project

Open the GSSHA model for the Goodwin Creek Watershed

1. In the *2D Grid Module* ⊞ select ***GSSHA | Open Project File…*** Browse and open the file ***C:\Training\Calibration\Manual\ goodwin.prj***

2. Select ***GSSHA | Save Project File*** to save the base project to a different location, so that the original project remains unchanged. Save your project as ***C:\Training\Personal\Calibration\Manual\ goodwin.prj***

3. Select ***GSSHA | Run GSSHA*** to compute the base model.

1.2 Replacing Parameters

Now you have seen that there are differences between your simulation results and the observed flow. You should have observed whether your model is under or over-predicting the flow (under-predicting in this case) which guides what you need to do next with the parameters so that the simulation results match up with the observed data.

Although there are several parameters that affect the outflow, there are a few which are more sensitive. We will investigate some of these.

- Increase and Decrease Hydraulic Conductivity
- Increase and Decrease Capillary head (infiltration tab)
- Increase and Decrease Initial Moisture (Initial Moisture tab)
- Increase and Decrease Overland Roughness (Roughness tab)
- Increase and Decrease Channel Roughness

Here are the steps that we will follow for the sensitivity analysis of each parameter:

Step I: Increase the value of the parameter by about 25%, run the model and copy the resulting hydrograph to: *C:\Training\Calibration\ManualCalib.xls* .

Step II: Decrease the value of the parameter by about 25% (from the original value), run the model again and copy the resulting hydrograph to *C:\Training\Calibration\ManualCalib.xls*.

Step III: Restore the value of the parameter to the original value and repeat the steps for the next parameter.

Note: For your convenience, a table is created in the same spreadsheet (*C:\Training\Calibration\ManualCalib.xls*) which has the original values of the parameters to begin with and places to enter the new values. You can compute the +25% and -25% in the spreadsheet and then cut/paste the values into the Mapping Tables dialog in WMS.

1. Select the *2D Grid Module*

2. Select **GSSHA| Map Tables…**

3. In the "*Infiltration*" tab change the hydraulic conductivity values.

4. *Save* and run the model (you can just overwrite the same GSSHA project).

5. Copy the hydrograph to the spreadsheet

6. Follow the same steps to adjust another parameter (1 at a time to see the sensitivity) for the following parameters:

- Capillary head (infiltration tab)
- Initial Moisture (Initial Moisture tab)
- Overland Roughness (Roughness tab)
- Channel Roughness (in the map module, click on *Select feature line branch* tool and double click on the most downstream channel segment).

7. With all these sensitivity analyses, you should have noticed how each of these parameter affect your model results. Now, instead of just playing with one parameter at a time, change a combination of parameters (with the values you think will best calibrate your model) and rerun GSSHA one more time.

8. Copy the hydrograph to the spreadsheet

9. Toggle through all different plots in the spreadsheet.

CHAPTER   2

Stochastic Simulations of GSSHA models

Manually updating parameters can become tedious as the size of the watershed and/or heterogeneity in the watershed increases. To facilitate this, WMS provides a way to generate a set of values for the parameters (of your choice) and have GSSHA make trial runs for a certain ranges of those parameters. This process is often called stochastic simulations or batch mode in WMS.

With stochastic simulations, you can select a few of the most sensitive parameters, define parameter ranges and have GSSHA run these several simulations in batch mode.

2.1 Open an Existing GSSHA Project

Open the GSSHA model for Goodwin Creek Watershed

1. In the *2D Grid Module* ⊞ select **GSSHA | Open Project File…** Browse and open the file **C:\Training\Calibration\Stochastic\ goodwin.prj**

2. Select **GSSHA | Save Project File** to save the base project with a different name, so that the original project remains unchanged. Save your project as **C:\Training\Personal\Calibration\Stochastic\sto.prj**

2.2 Creating Stochastic Runs

1. Select **GSSHA | Job Control…**and select the *Stochastic* Option (See the following figure)
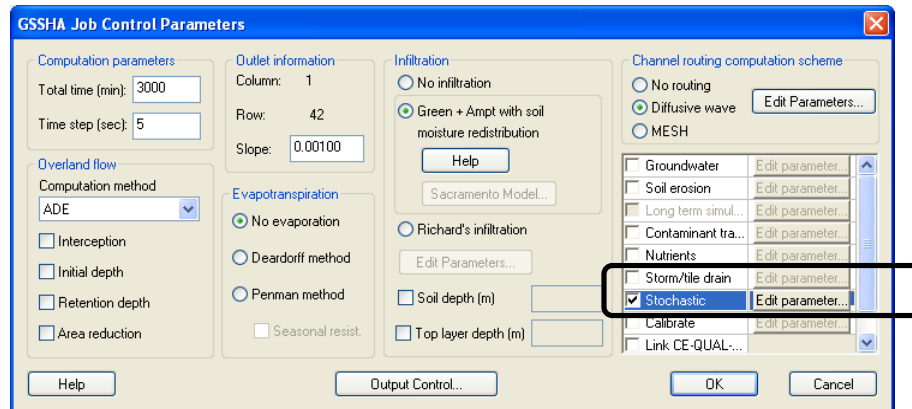
2. Click on the *Edit Parameter* button just to the right.

3. Enter 10 for *Number of Instances* which defines how many times we want to run GSSHA, thus that many sets of parameter values will be needed.

4. Make sure *GSSHA* is selected as the model to use.

5. Click on the *Add Parameter* button. Add two more parameters (for a total of three) to the *Parameter List.* You may resize the box so that all three parameters are visible.

6. Change the Key values on the very first row to -1, -2 and -3 for consecutive columns.

7. Select *Manning's Roughness, Hydraulic Conductivity and Initial Moisture* for the three parameters. Any of the parameters listed in the Type dropdown and any number of parameters can be defined in a similar fashion

8. Now you can see a list of values with each rows named Run1, Run2 and so on to Run 10 which means that GSSHA will be run ten times with each sequential run using one of the parameter sets for the three parameters we have added.

9. You can edit the max and min range of each parameter (You will have to change the mean value to do this).

10. Let us leave the values of Manning's n the same for now.

11. Change the standard deviation for hydraulic conductivity to 0.2, mean to 0.26, min to 0.01 and the max value to 0.5

12. Similarly, change the mean for Initial moisture to 0.2 and enter 0.4 for max. Do not change the standard deviation and the min values.

13. Once you change the range of these values, the list will update itself. You can generate another set of these values by clicking *Repopulate Runs* button.

14. Click OK and OK again.
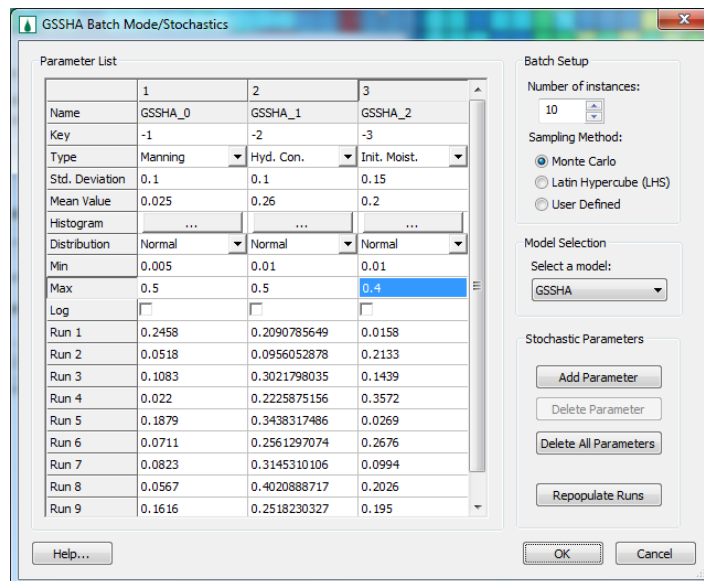
2.3 Changing the Mapping Tables

Once you defined the stochastic runs, you will need to tell GSSHA which parameters (Index ID's) you want to have these values substituted for. This is done in the mapping table.

1. Select **GSSHA | Map Tables…**

2. Enter -1 for the roughness value for ID 1 (Pine 27%) which sets this roughness as a parameter and links it with the stochastic parameters for ID -1 you created in the previous step.

3. Switch to the *Infiltration* tab and move to the last column. Enter -2 for hydraulic conductivity in column 9 (pasture-silt-loam 39%).

4. In the *Initial Moisture* tab, enter -3 for column 9 (pasture-silt-loam 39%) again.

5. Click *Done*

GSSHA will change the values of these three parameters in each consecutive run.

2.4 Save and Run the Model

1. Save the project as *C:\Training\Personal\Tutorial\Stochastic\ stochastic.prj*

2. Select *GSSHA/Run GSSHA*

3. GSSHA will now run for ten times and thus will take a while (a couple of minutes).

Once it completes, close the model wrapper. Double click the hydrograph icon which plots the simulation results for all these runs. You can compare all these simulations with the observed flow and chose the one that matches most closely. You may chose to change the set of parameters to make these simulation runs and see if that produces better result. For this tutorial, we will not make further runs.

4. Copy the hydrograph to the spreadsheet *C:\Training\Calibration\ Stochastic.xls*

2.5 Results

Your results might look something like the figure below.

CHAPTER 3
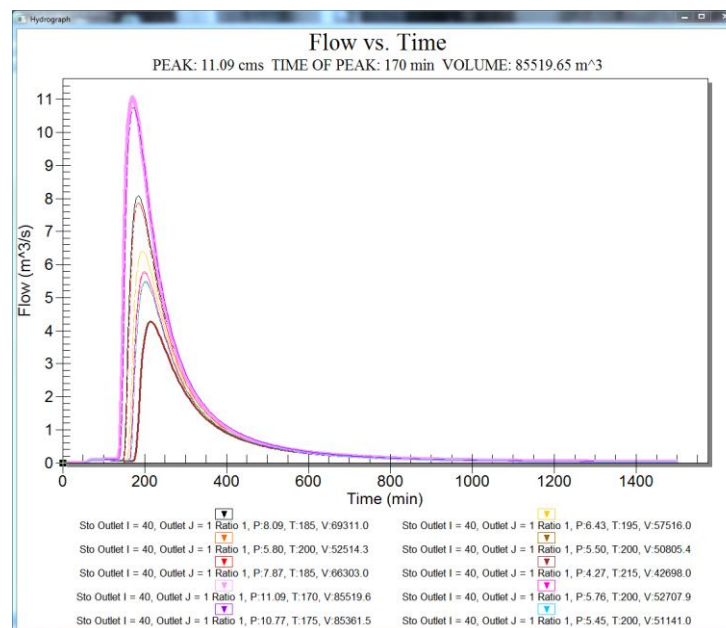
Automated Calibration of GSSHA models

There are several combinations of parameters that could be used in the stochastic simulation that we did in the previous exercise. If your selection of parameters was precise and the range of values you chose were very good, a well calibrated model could result. But, in many situations, you might need to make several trials to get your model calibrated. GSSHA has an automated calibration tool which looks though a wide parameter space for different combinations and keeps running the model until it meets the objective function requirement or it meets a maximum number of runs criteria.

Once, the calibration finishes, GSSHA will find the best set of parameters and produce a summary. GSSHA uses the Shuffle Complex Evolution (SCE) algorithm for automated calibration.

3.1 Open an Existing GSSHA Project

Open the GSSHA model for Goodwin Creek Watershed

1. In the *2D Grid Module* select *GSSHA | Open Project File…* Browse and open the file *C:\Training\Calibration\Automated\ goodwin.prj*

2. Select *GSSHA | Save Project File* to save the base project with a different name, so that the original project remains unchanged. Save your project as *C:\Training\Personal\Calibration\Automated\ autocalib.prj*

3. Turn off the display of all the coverages except the *GSSHA coverage.*

3.2 Creating Calibration Runs

Here you will select the parameters that you want to calibrate and also define the SCE calibration parameters.

1. Select **GSSHA | Job Control…**and select the *Calibrate* Option (See the following figure)
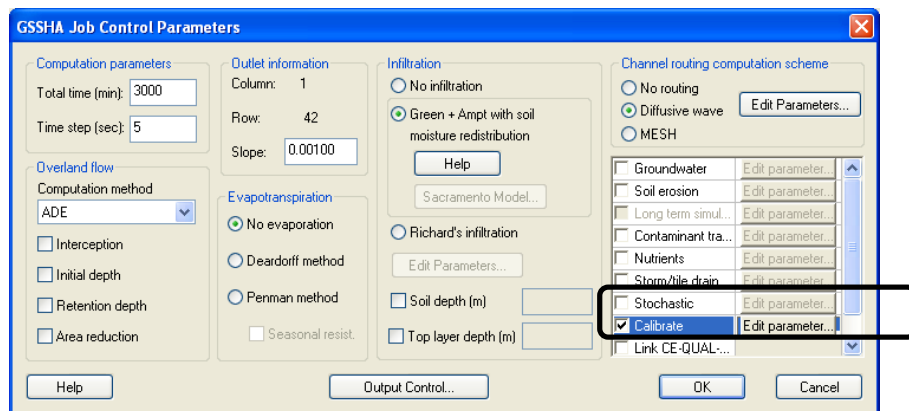
3.2.1 Defining calibration parameters

We need to setup the parameters whose values can vary during the calibration run. Generally, the calibration parameters are those which involve uncertainty in measurement or the ones that affect the outflow hydrograph the most.

1. In the *Job Control* dialog, click on the *Edit Parameter* button for calibration option.

2. Select the *Add Parameter* button 18 times so that you have 18 parameters in the list.

3. Define the parameter names from the drop down boxes for each parameter. See the following figure for reference.

4. Similarly, enter the *Starting, Minimum and Maximum* values shown in the following figure or copy and paste from this file *C:\Training\Calibration\Automated\InitialParams.txt.*

5. Do not close this dialog yet.

Parameter		Key	Start Value	Min	Max
Roughness	▼	-1	0.0595	0.0238	0.1488
Roughness	▼	-2	0.4071	0.1628	1.0178
Roughness	▼	-3	0.1051	0.042	0.2628
Roughness	▼	-4	0.8408	0.3363	2.1019
Retention depth (mm)	▼	-5	1.3094	0.5237	3.2734
Retention depth (mm)	▼	-6	1.2854	0.5142	3.2135
Retention depth (mm)	▼	-7	0.8503	0.3401	2.1258
Retention depth (mm)	▼	-8	1.8644	0.7458	4.6611
Hydraulic conductivit...	▼	-9	2.1891	0.8756	5.4727
Hydraulic conductivit...	▼	-10	0.0158	0.0063	0.0395
Hydraulic conductivit...	▼	-11	0.2925	0.117	0.7313
Hydraulic conductivit...	▼	-12	0.1965	0.0786	0.4912
Hydraulic conductivit...	▼	-13	1.3196	0.5279	3.2991
Hydraulic conductivit...	▼	-14	1.9421	0.7769	4.8554
Hydraulic conductivit...	▼	-15	0.2443	0.0977	0.6106
Channel roughness	▼	-16	0.0371	0.0148	0.0927
Soil moisture depth (m)	▼	-17	0.4184	0.2	1.0459
Top layer depth (m)	▼	-18	0.0784	0.0313	0.1959

Add Parameter   Delete Parameter   Delete All

SCE Parameters...   Observed Data...   Done

3.2.2 Defining the Observed Flow Data

GSSHA needs observed peak and volume flow data to compare calibration runs for a closeness of fit. A cost function is computed for each calibration run to check how close to the observed flow GSSHA computes in the simulation results. The best set of parameters corresponds to a the lowest cost function, which should be close to zero.

Since we are calibrating the model for a long term event, there are multiple storm events and corresponding peak flows and volumes.

1. In the *Parameters* dialog, click on the *Observed Data…* button to bring up the *GSSHA Observations* dialog.

2. Click *Setup All Precip Events* button which will populate all storm events (there are 14 defined in this model). These events are read from the precipitation data that was already defined for this simulation.
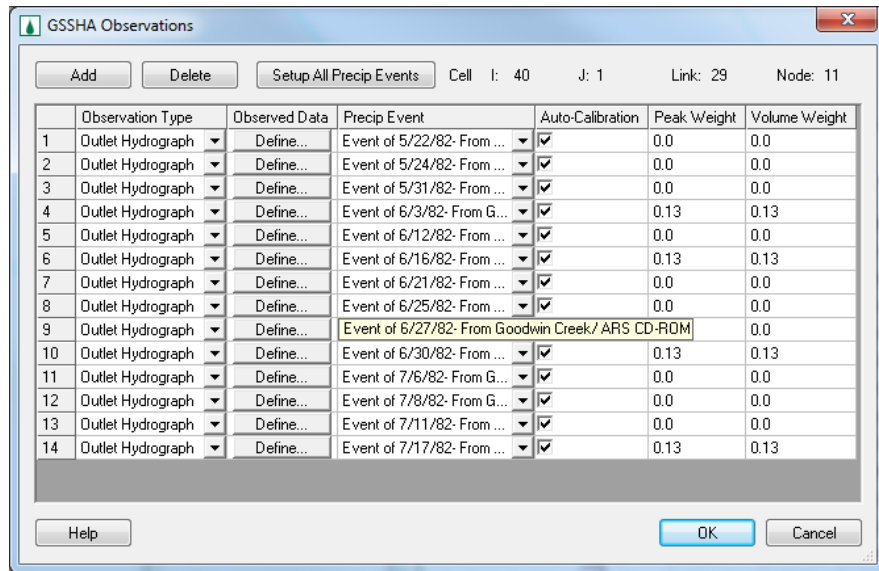
3. Click on the *Define* button under the *Observed Data* column and enter the following peak and flow volumes.

    Note: You do not have to define the peak and volumes
    -   **If the values are 0 for both peak and volume as they are zero by default.**
    -   **If the weights for both peak and volumes are zero**

S No	Peak Flow (cms)	Volume (m³)	Peak Weight	Volume Weight
1	0	0	0	0
2	23.818	202577	0	0
3	0	0	0	0
4	12.925	271593	0.125	0.125
5	0	0.1	0	0
6	0.9796	17956	0.125	0.125
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	15.772	119761	0.125	0.125
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	6.06	35419.2	0.125	0.125

Note: The observed flow data can also be defined as a hydrograph by selecting *Use XY Data* option and then clicking *Define Series* button.

4. Once you are done defining the peak flows and volumes, enter the Peak and Volume Weights using the above table. Make sure that the sum of the peak and volume weights is equal to 1.0.

3.2.3 Defining SCE (Shuffle Complex Evolution) Flow data

1. In the *Parameter* dialog, click on the *SCE Parameters…* button which will open the *Shuffle Complex Evolution* dialog.

2. Change the *Maximum number of iterations* to 500.

3. Click OK.

4. Click *Done* to close the *Parameters* dialog.

5. Click OK to close the *Job Control*.

Note: GSSHA might not calibrate well within 500 runs, but we will see how the automated calibration works

3.3 Changing the map tables

Once you defined the SCE parameters, you will need to tell GSSHA (mapping table) which parameters you want to use as the calibration parameters. This is done in the mapping table.

1. Select **GSSHA | map Tables…** and switch to the *Roughness* tab.

2. Enter the keys -1, -2, -3 and -4 for the following roughness. Entering a negative numbers tells WMS that these are the calibration parameters. WMS then associates the values we defined in the calibration dialog (previous step) with these parameters.

Roughness					
ID	1	2	3	4	5
Description1	pine 27% ...	water 0.3% ...	cotton 14% ...	pasture 42%...	gullied land ...
Description2	...	...	...	...	...
Surface roughness	-1.000000	0.358000	-2.000000	-3.000000	-4.000000

3. In the *Retention* tab, enter the following keys

| Retention					
ID	1	2	3	4	5
Description1	Pine 27% ...	Water 0.3% ...	Cotton 14% ...	Pasture 42%...	Gullied land ...
Description2	...	...	...	...	...
Retention depth (mm)	-5.000000	1.300000	-6.000000	-7.000000	-8.000000
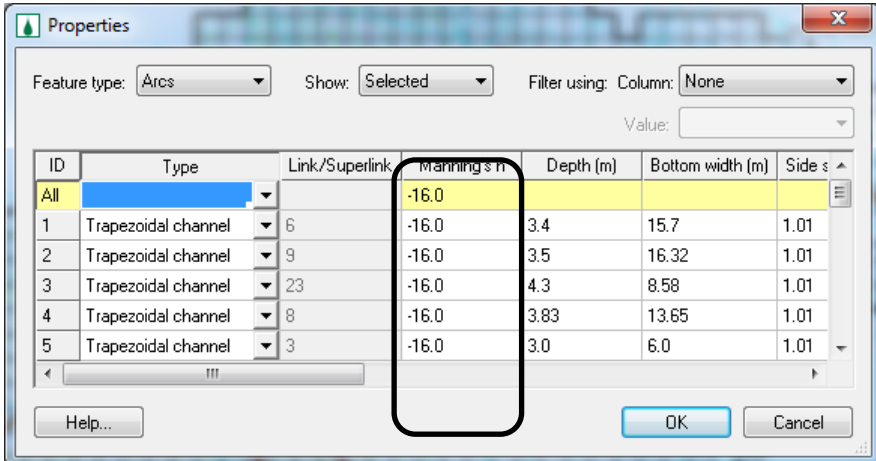
4. Switch to the *Infiltration* tab and enter the following keys for *Hydraulic Conductivity*.

Infiltration									
ID	1	2	3	4	5	6	7	8	9
Description1	gullied-land-...	gullied-land-...	water-.3%	pasture-clay...	cotton-clay-l...	pine-clay-loa...	pine-silt-loa...	cotton-silt-lo...	pasture-silt-l...
Description2	...	...	...	...	...	...	...	...	...
Hydraulic conductivity (cm/hr)	-9.000000	1.410000	0.003000	10.000000	-11.000000	-12.000000	-13.000000	-14.000000	-15.000000
Capillary head (cm)	16.680000	4.950000	0.003000	20.880000	20.880000	20.880000	16.680000	16.680000	16.680000
Porosity (m^3/m^3)	0.486000	0.437000	0.582000	0.464000	0.464000	0.464000	0.486000	0.486000	0.486000
Pore distribution index (cm/cm)	0.234000	0.694000	0.001000	0.242000	0.242000	0.242000	0.234000	0.234000	0.234000
Residual saturation (m^3/m^3)	0.015000	0.020000	0.015000	0.075000	0.075000	0.075000	0.015000	0.015000	0.015000
Field capacity (m^3/m^3)	0.330000	0.091000	0.436500	0.318000	0.318000	0.318000	0.330000	0.330000	0.330000
Wilting point (m^3/m^3)	0.133300	0.033000	0.133300	0.133300	0.133300	0.133300	0.197000	0.133000	0.133000

5. The last column in the *Hydraulic Conductivity* field should be -15. Click *Done* to close the *Job Control* dialog.
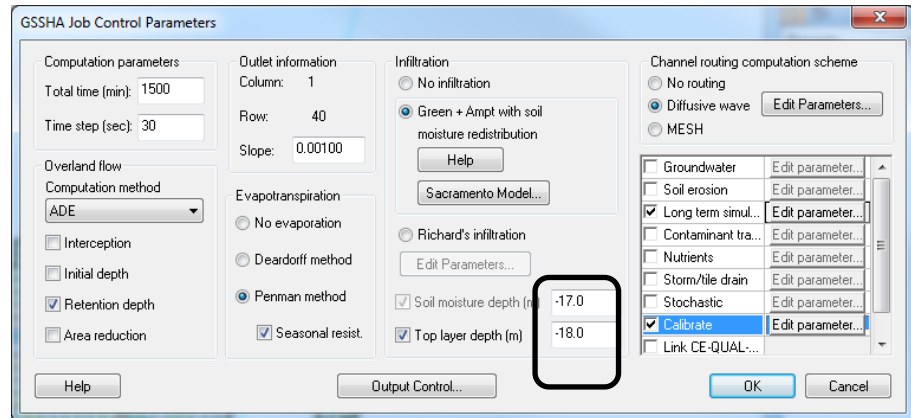
6. In the *Map module* , click on the *Select feature line branch tool* and double click on the downstream most channel arc (the one closest to the watershed outlet) which will open the *Properties* dialog.

7. Enter -16 for Manning's n for all arcs and click OK.

8. Click *OK*.

9. Select **GSSHA | Job Control**, and enter -17 for *Soil Depth* and -18 for *Top Layer Depth*.

So, altogether there are 18 parameters that will be used in the automated calibration, we have 14 storm events and we will let GSSHA run a maximum of 500 simulations. The model is all set up to run an automated calibration.

3.4 Save and Run the Model

1. Save the project as *C:\Training\Personal\Calibration/Automated/ autocalib.prj*

2. Select *GSSHA|Run GSSHA…*

3. This will take about 12-14 hours to finish!!!!!

3.5 Run the Forward Simulation with the Optimized Parameters

Once the calibration completes, GSSHA writes the best set of parameters (the set of parameters which produce minimum cost function). WMS can read the best parameters, plug in back to GSSHA input files and perform a forward simulation. Doing that helps you see the results of your calibration.

1. The model wrapper displays the results of the calibration. It indicates if the maximum number of iterations was met or if the cost function converged first.

2. Close the model wrapper as the calibration completes which will open the *GSSHA Calibration Output* dialog.
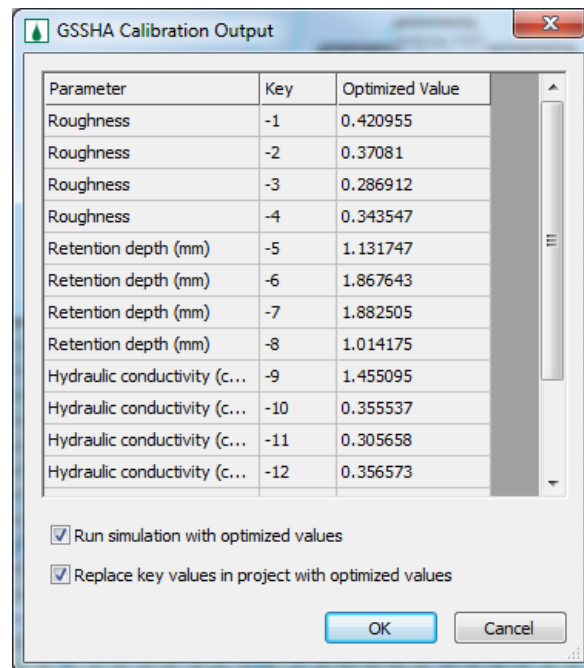
3. Click OK to replace the key values for calibration (all the negative numbers) with the optimized parameters and run GSSHA.

4. Once done, view the model results.

3.6 Observe the Full Calibration Results

GSSHA writes several files during and after a calibration run. Here are a few files that we will look at:

1. **best.out**: Browse and open file **C:\Training\Personal\Calibration\ Automated\best.out.** This file populates the best set of values for the calibration parameters.

2. **sce_output.out:** Browse and open file **C:\Training\Personal\ Calibration\Automated\sce_output.out:** This file populates the all the SCE parameters that were used during the calibration runs.

3. **0000_log_file.txt:** Browse and open file **C:\Training\Personal\ Calibration\Automated\000_log_file.txt.** This file populates the results from all the calibration runs. You can access this file even when the calibration is running and check the progress of the calibration.