SDMProjectBuilder

SWAT Simulation and Calibration for Nutrient Fate and Transport

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SUMMARY

This tutorial reviews screens, icons, and basic functions for downloading flow, sediment, and nutrient observations for a watershed of interest; how to prepare SWAT-CUP input files for SWAT parameter calibration; and how to perform SWAT parameter calibration with SWAT-CUP. It demonstrates how to

- Identify a USGS gaging station where flow, sediment, and nutrient data are available for a watershed of interest.
- Download flow, sediment, and nutrient observations associated with a USGS gage station.
- Prepare SWAT-CUP input files for SWAT parameter calibration.
- Calibrate SWAT parameters.
- View SWAT parameter calibration results with SWAT-CUP.

SWAT Simulation and Calibration for Nutrient Fate and Transport

PURPOSE

Automate SWAT parameter calibration, as much as possible, with SWAT-CUP.

OBJECTIVE

Prepare flow, sediment, and nutrient observation time series for SWAT parameter calibration; prepare SWAT-CUP input files for SWAT parameter calibration; and perform SWAT parameter calibration with SWAT-CUP

DEMONSTRATION

This tutorial reviews how to download flow, sediment, and nutrient observations for a watershed of interest; how to prepare SWAT-CUP input files for SWAT parameter calibration; and how to perform SWAT parameter calibration with SWAT-CUP. It demonstrates how to

- Identify a USGS gaging station where flow, sediment, and nutrient data are available for a watershed of interest.
- Download flow, sediment, and nutrient observations associated with a USGS gage station.
- Prepare SWAT-CUP input files for SWAT parameter calibration.
- Calibrate SWAT parameters.
- View SWAT parameter calibration results with SWAT-CUP.

TUTORIAL – TABLE OF CONTENTS

SOFTWARE ACCESS, RETRIEVAL, DOWNLOAD, AND INSTALLATION

Kim et al. (2016a) provide software access, retrieval, download, and installation instructions that must be implemented prior to executing the tutorial. The authors review screens, icons, and basic functions of the SDMProjectBuilder (SDMPB) and explain how to use SDMPB output to populate the Soil and Water Assessment Tool (SWAT) input files for nutrient fate and transport modeling in the Salt River Basin. They demonstrate how to choose and delineate a HUC-8 which includes the Salt River Basin; collect environmental data used in watershed modeling; address isolated subwatersheds which are disconnected from the waterbody network; modify a local data file to define an outlet point within a HUC-8; and develop input files necessary to execute SWAT successfully. By following Kim et al. (2016a) tutorial, appropriate folder structure and files associated with nutrient simulation and calibration are created and saved, including initial execution and results of SWAT for flow and nutrient fate and transport. SWAT-related software covered by Kim et al. (2016a) are summarized in Table 1.

Table 1. Summary of SWAT-related Software (after Kim et al., 2016a)

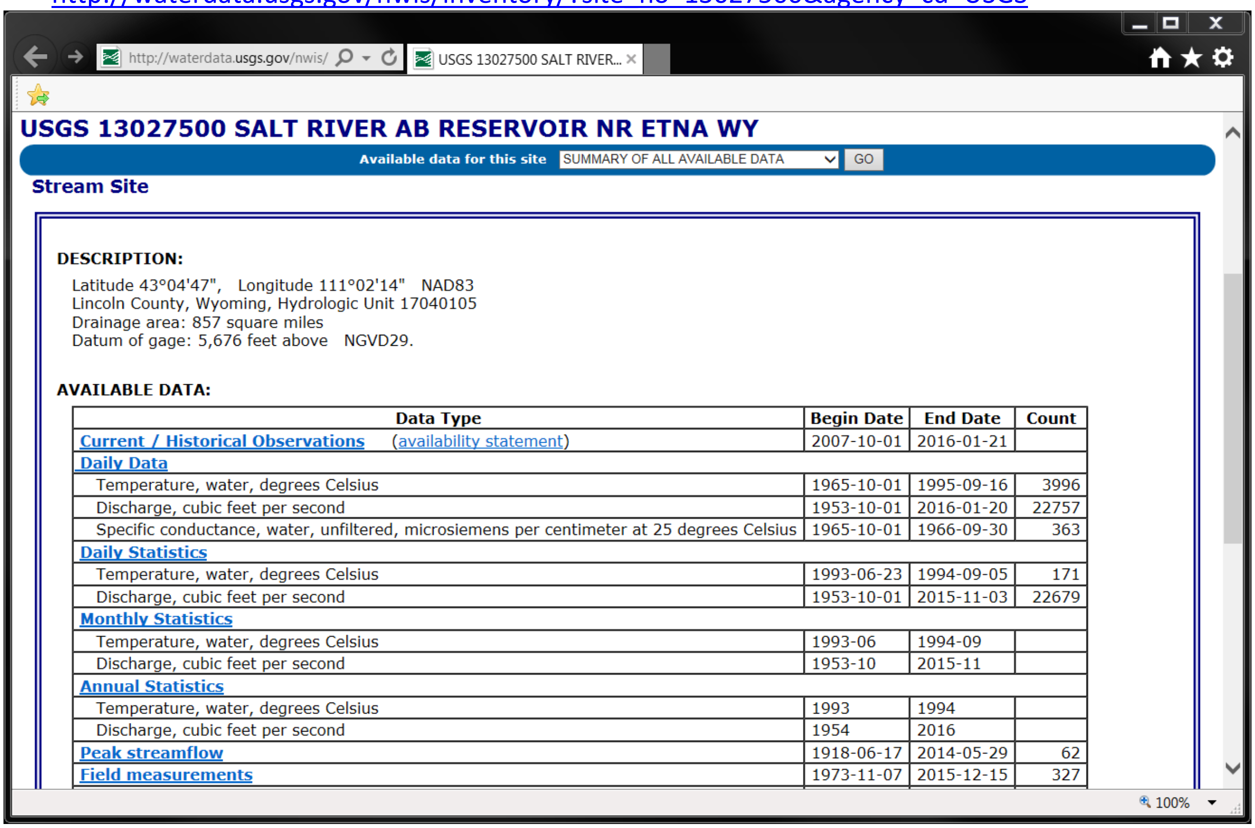
SOFTWARE	PURPOSE	SOURCE
SDMProjectBuilder	SWAT input file generator	O:\Public\QMRA\Software for Download\SDMPB
SWAT-CUP	SWAT parameter calibration	http://swat.tamu.edu/software/swat-cup/
SWAT_SWATCUP.exe	SWAT-CUP input file generator	Installed with SDMProjectBuilder
Input_SWAT.in	Default input file of "SWAT_SWATCUP.exe"	Installed with SDMProjectBuilder
Update_par_inf.exe	Updating "par_inf.txt" with new parameter ranges after each SWAT-CUP iteration	Installed with SDMProjectBuilder
FORTRAN Library	Library package for executing SWAT_SWATCUP.exe and Update_par_inf.exe	https://software.intel.com/en-us/articles/redistributable-libraries-of-the-intel-c-and-fortran-compiler-for-windows

DOWNLOADING FLOW, SEDIMENT, AND NUTRIENT OBSERVATION TIME SERIES

This section describes how to obtain flow, sediment, and nutrient observations for the calibration process. Kim et al. (2016b) describe how flow observations at USGS gage stations can be downloaded and exported through BASINS, although the example used is with the HSPF watershed model. For SWAT simulation and calibration, sediment and nutrient observations must be directly downloaded through the Internet. Here, a process is outlined that gathers data from sources which may differ slightly due to browser choice and its plug-in capabilities. The objective is to produce CSV-formatted files for use in SWAT-CUP. This may require steps to save the data in native formats, perform ancillary processes (e.g., un-zip), import the data into a spreadsheet (e.g., Excel), and save the data in a CSV format.

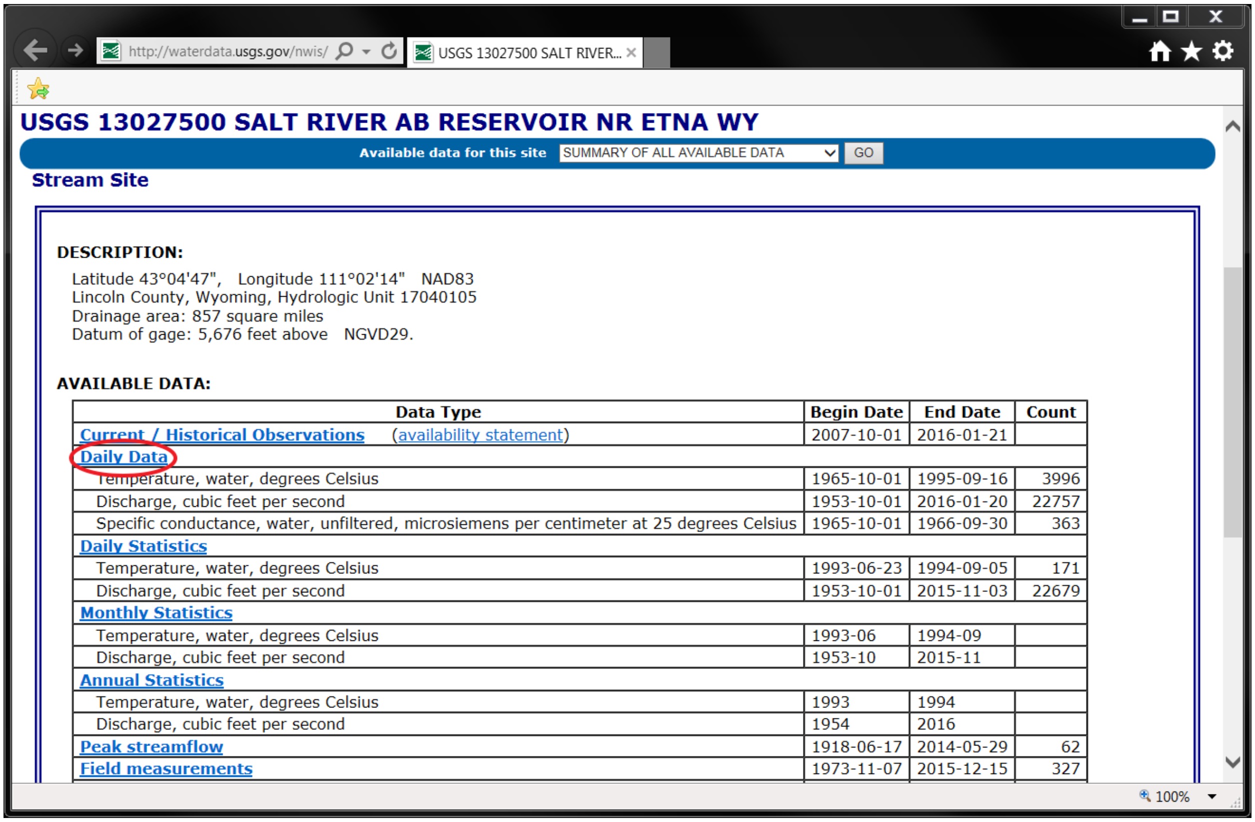
Daily Discharge Data

1. To download flow data at USGS Salt River ab Reservoir nr Etna WY gage station (13027500), click the following link to reach a USGS webpage: http://waterdata.usgs.gov/nwis/inventory/?site_no=13027500&agency_cd=USGS



Data Type	Begin Date	End Date	Count
Current / Historical Observations (availability statement)	2007-10-01	2016-01-21	
Daily Data			
Temperature, water, degrees Celsius	1965-10-01	1995-09-16	3996
Discharge, cubic feet per second	1953-10-01	2016-01-20	22757
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1965-10-01	1966-09-30	363
Daily Statistics			
Temperature, water, degrees Celsius	1993-06-23	1994-09-05	171
Discharge, cubic feet per second	1953-10-01	2015-11-03	22679
Monthly Statistics			
Temperature, water, degrees Celsius	1993-06	1994-09	
Discharge, cubic feet per second	1953-10	2015-11	
Annual Statistics			
Temperature, water, degrees Celsius	1993	1994	
Discharge, cubic feet per second	1954	2016	
Peak streamflow	1918-06-17	2014-05-29	62
Field measurements	1973-11-07	2015-12-15	327

2. Daily discharge data from 1953/10/01 to 2016/01/20 are available, including the simulation period specified in Kim et al. (2016a), which is the precursor to this tutorial. Click “Daily Data” in the “AVAILABLE DATA” table. The data at USGS gages are continuously updated, so more data may be available when users access this site.



http://waterdata.usgs.gov/nwis/ USGS 13027500 SALT RIVER...

USGS 13027500 SALT RIVER AB RESERVOIR NR ETNA WY

Available data for this site SUMMARY OF ALL AVAILABLE DATA GO

Stream Site

DESCRIPTION:

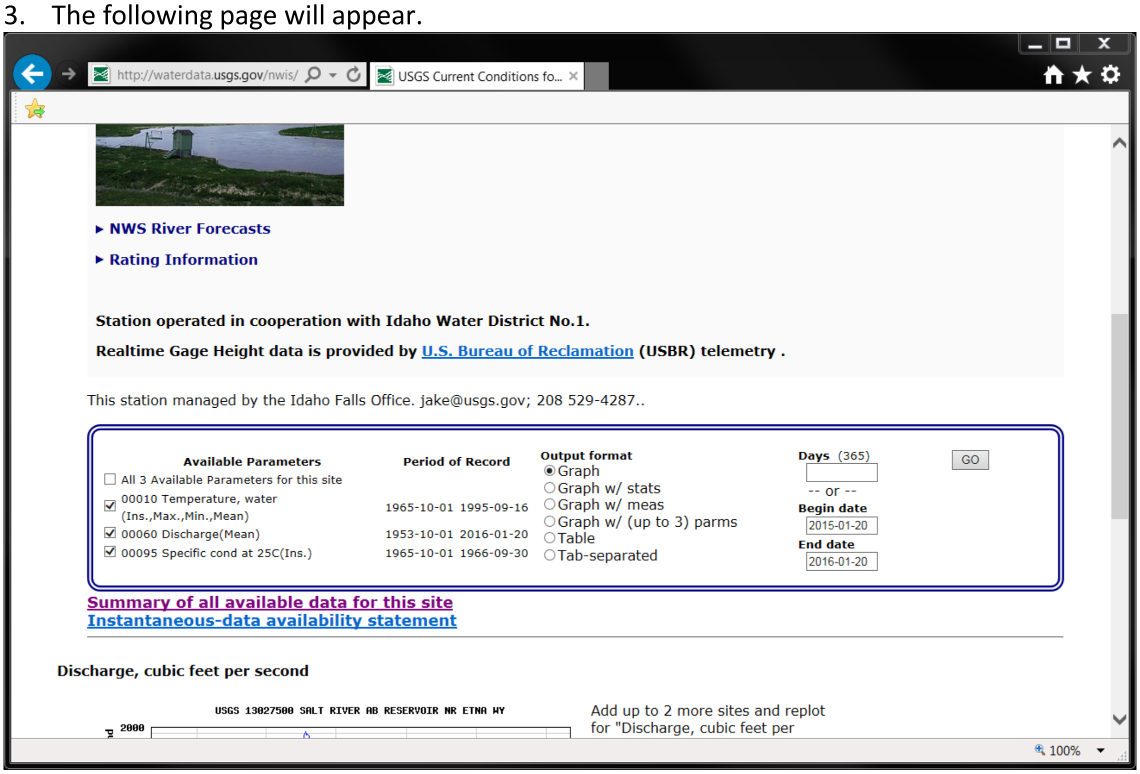
Latitude 43°04'47", Longitude 111°02'14" NAD83
Lincoln County, Wyoming, Hydrologic Unit 17040105
Drainage area: 857 square miles
Datum of gage: 5,676 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Current / Historical Observations (availability statement)	2007-10-01	2016-01-21	
Daily Data			
Temperature, water, degrees Celsius	1965-10-01	1995-09-16	3996
Discharge, cubic feet per second	1953-10-01	2016-01-20	22757
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1965-10-01	1966-09-30	363
Daily Statistics			
Temperature, water, degrees Celsius	1993-06-23	1994-09-05	171
Discharge, cubic feet per second	1953-10-01	2015-11-03	22679
Monthly Statistics			
Temperature, water, degrees Celsius	1993-06	1994-09	
Discharge, cubic feet per second	1953-10	2015-11	
Annual Statistics			
Temperature, water, degrees Celsius	1993	1994	
Discharge, cubic feet per second	1954	2016	
Peak streamflow	1918-06-17	2014-05-29	62
Field measurements	1973-11-07	2015-12-15	327

100%

3. The following page will appear.



http://waterdata.usgs.gov/nwis/ USGS Current Conditions fo...

▸ NWS River Forecasts

▸ Rating Information

Station operated in cooperation with Idaho Water District No.1.

Realtime Gage Height data is provided by U.S. Bureau of Reclamation (USBR) telemetry .

This station managed by the Idaho Falls Office. jake@usgs.gov; 208 529-4287..

Available Parameters	Period of Record	Output format	Days (365)
☐ All 3 Available Parameters for this site		◉ Graph	
☑ 00010 Temperature, water (Ins.,Max.,Min.,Mean)	1965-10-01 1995-09-16	○ Graph w/ stats	-- or --
☑ 00060 Discharge(Mean)	1953-10-01 2016-01-20	○ Graph w/ meas	Begin date 2015-01-20
☑ 00095 Specific cond at 25C(Ins.)	1965-10-01 1966-09-30	○ Graph w/ (up to 3) parms	End date 2016-01-20
		○ Table	
		○ Tab-separated	

GO

Summary of all available data for this site
Instantaneous-data availability statement

Discharge, cubic feet per second

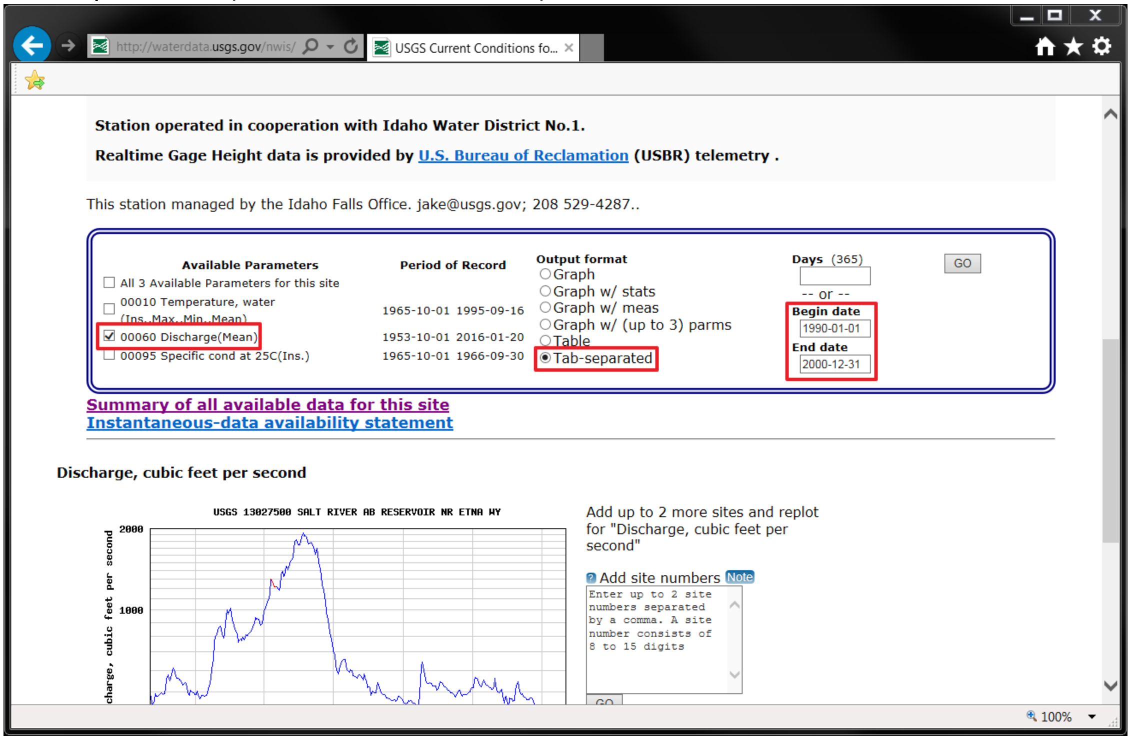
USGS 13027500 SALT RIVER AB RESERVOIR NR ETNA WY

2000

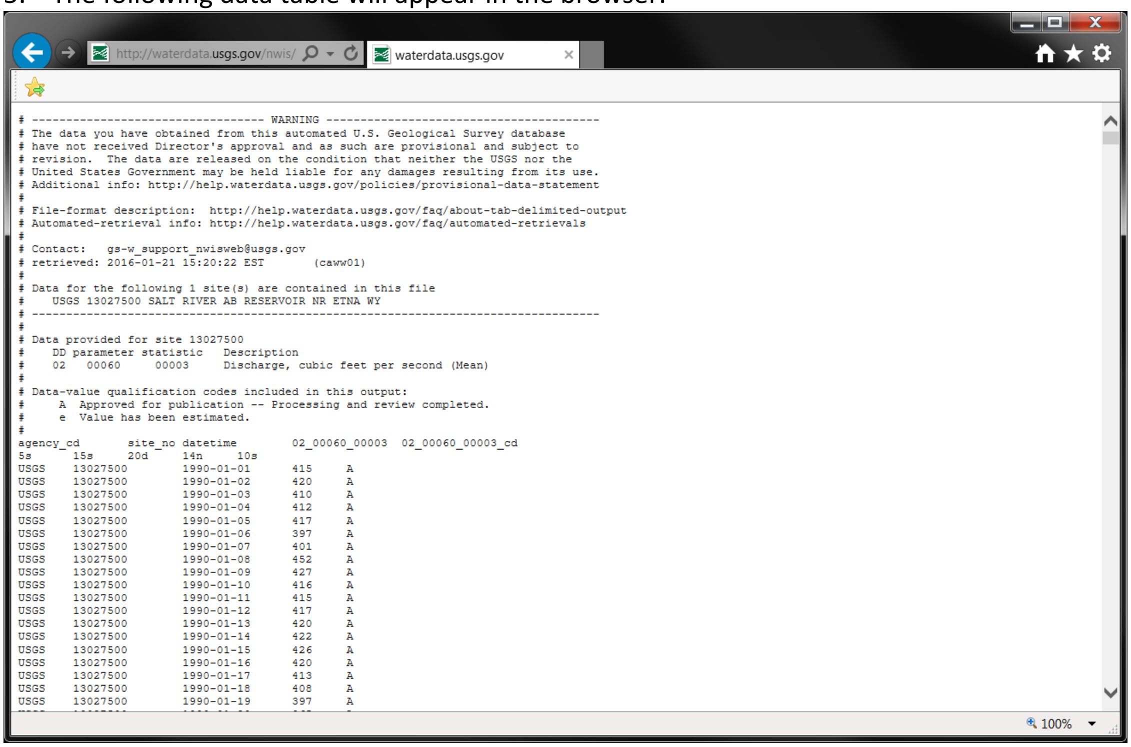
Add up to 2 more sites and replot for "Discharge, cubic feet per

100%

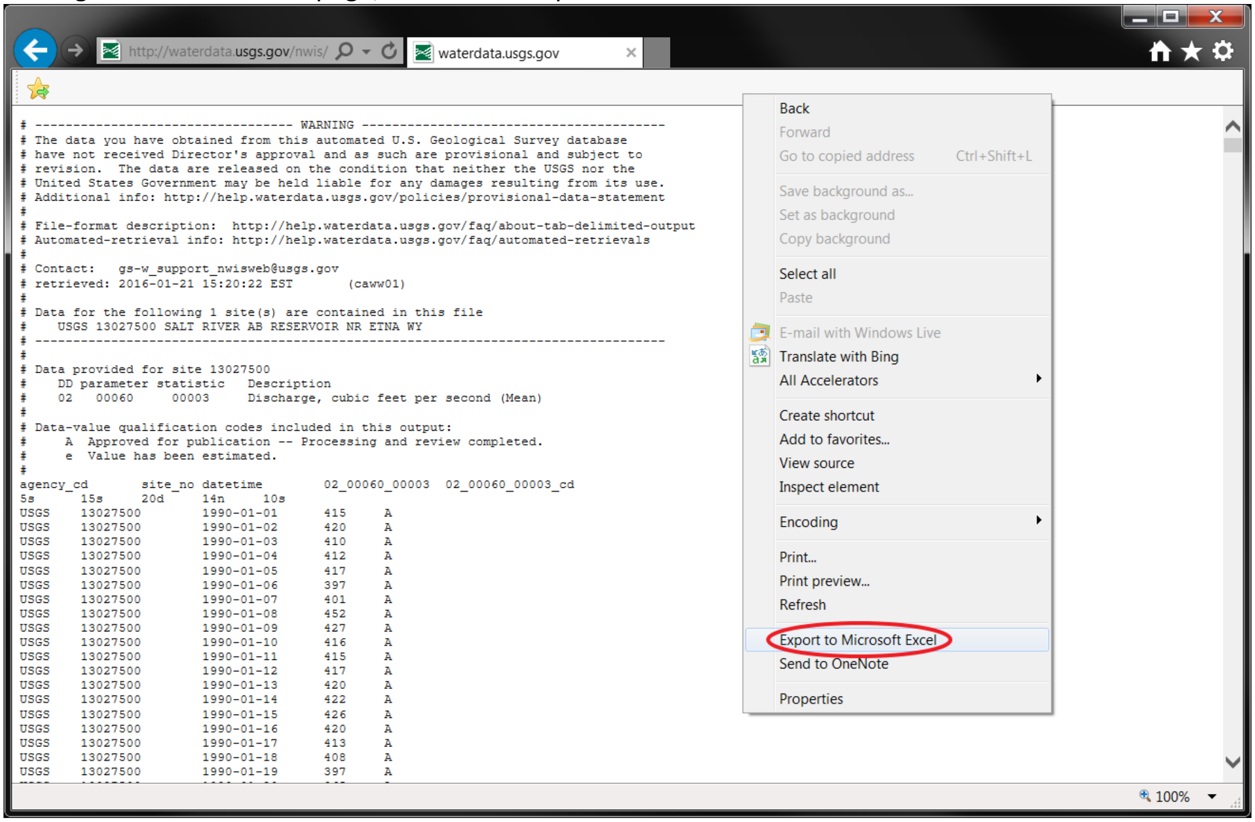
4. Ensure that “Discharge(Mean)” is checked and other variables are unchecked. Select “Tab-separated” for “Output format”, and set “Begin date” and “End date” as “1990-01-01” and “2000-12-31”, respectively. “Begin date” and “End date” can be outside the simulation period as long as they include it (1990-01-01 – 2000-12-31). Click “GO”.



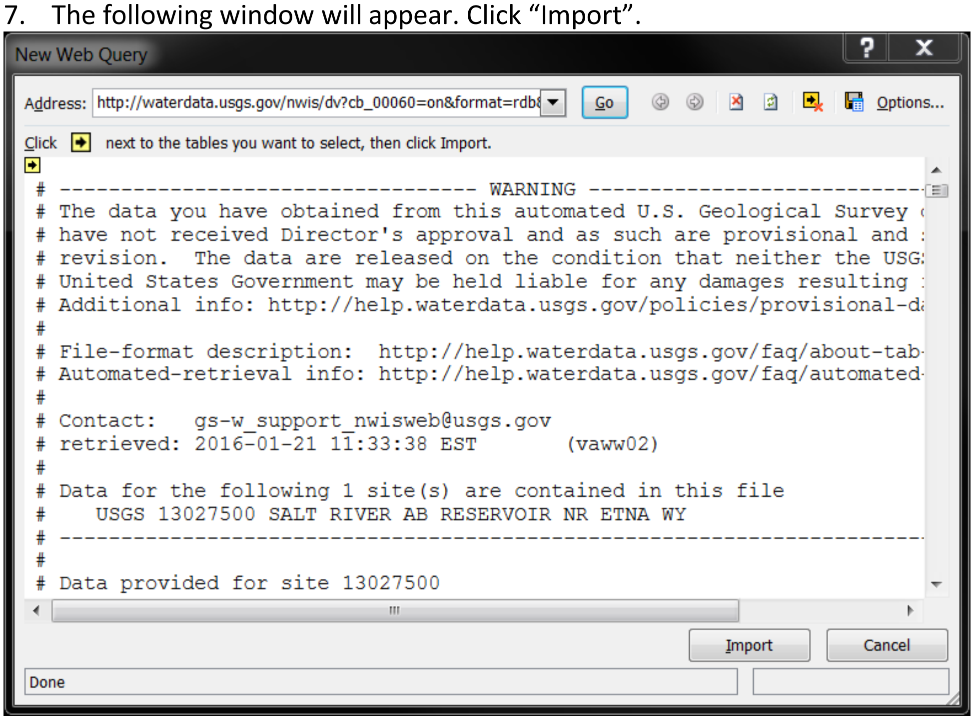
5. The following data table will appear in the browser.



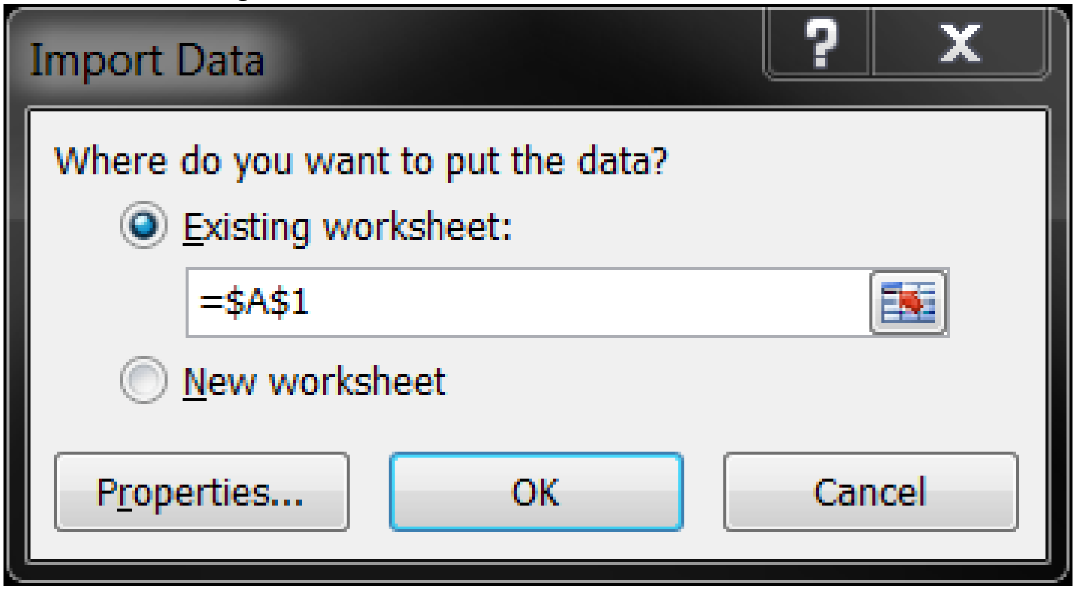
6. Right-click on the webpage, and select “Export to Microsoft Excel”.



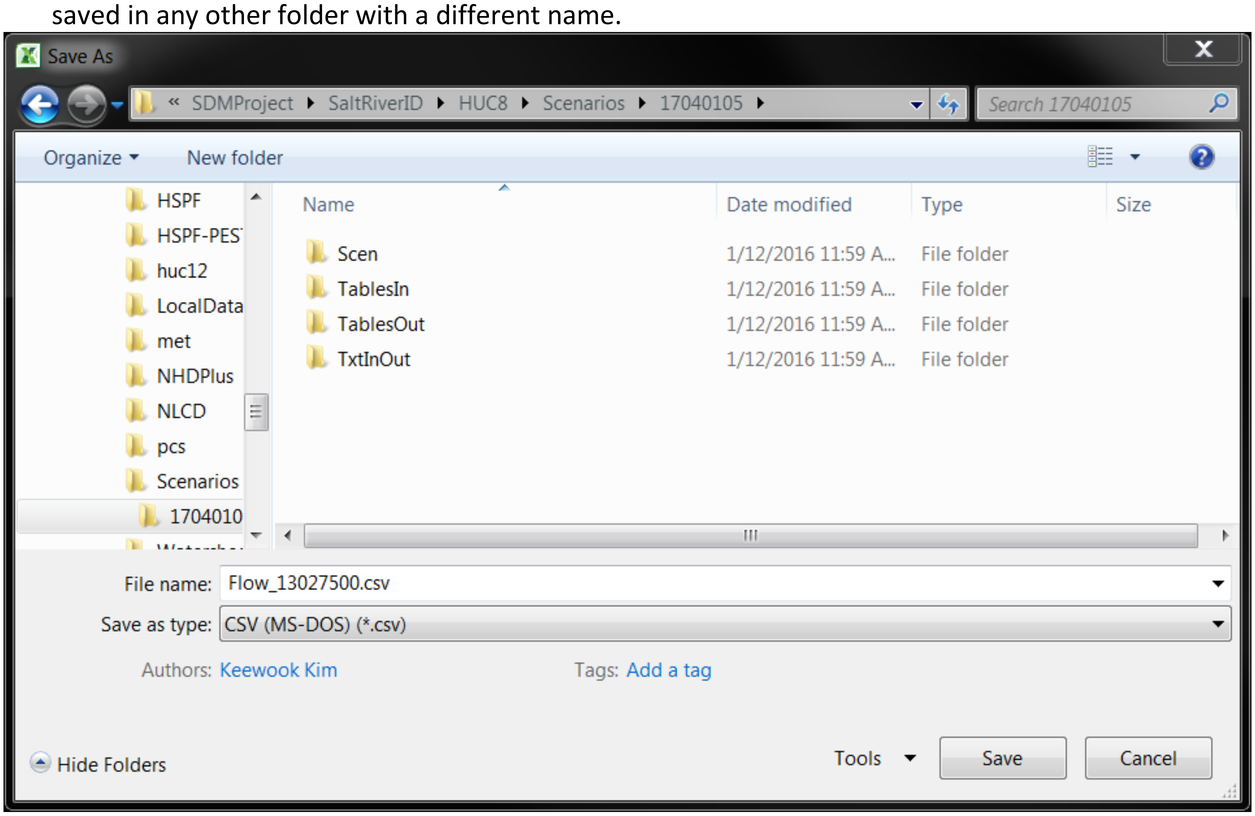
7. The following window will appear. Click “Import”.



8. On the following window, click “OK”.

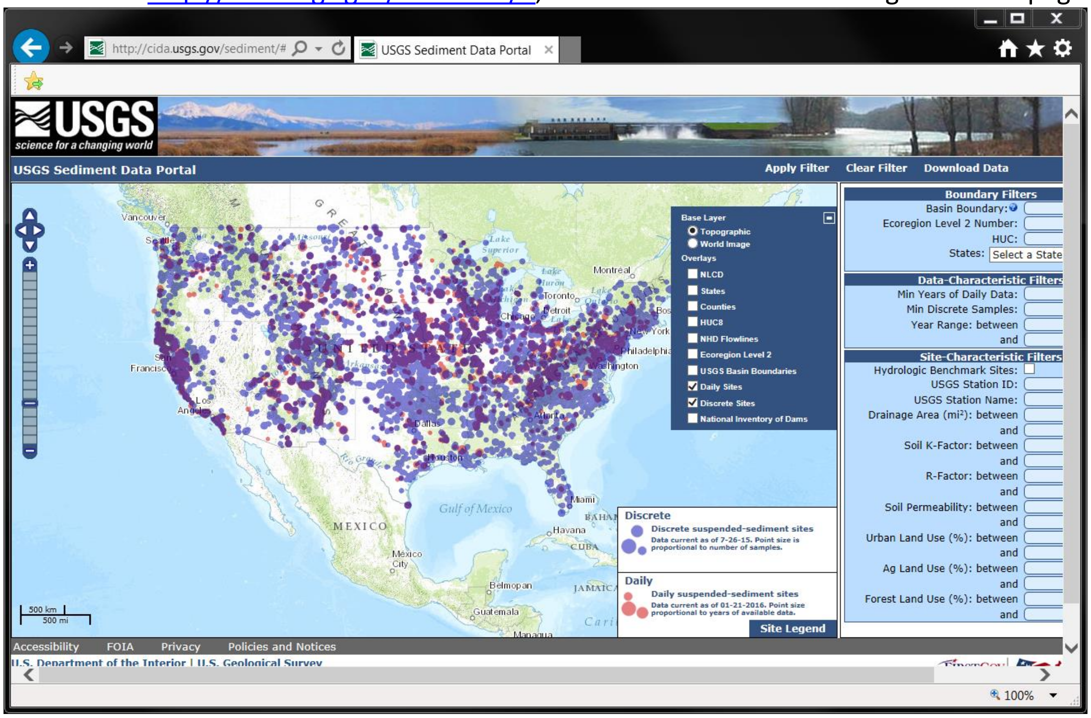


9. These data must be imported into an Excel spreadsheet. If the “Export to Microsoft Excel” menu is not available in the browser, data must be manually copied from the webpage and pasted to the spreadsheet. Now save the Excel file. In this example, the file is saved as “C:\Temp\SDMProject\SaltRiverID\HUC8\Scenarios\17040105\Flow_13027500.csv”. The file can be saved in any other folder with a different name.

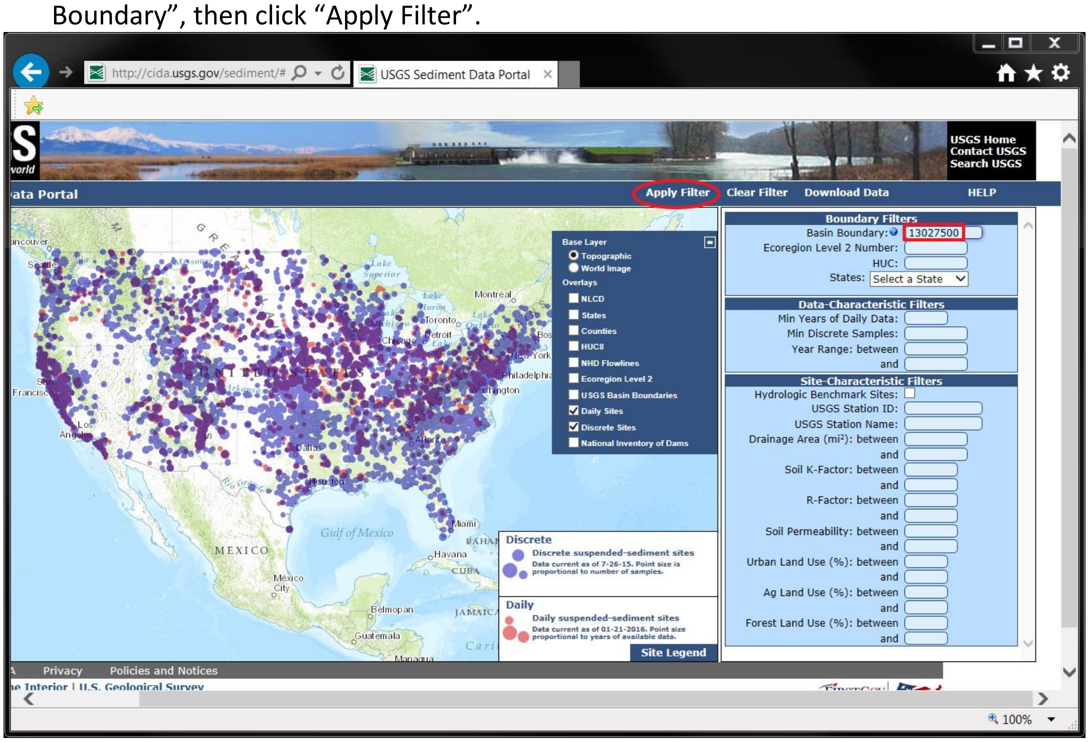


Sediment Data

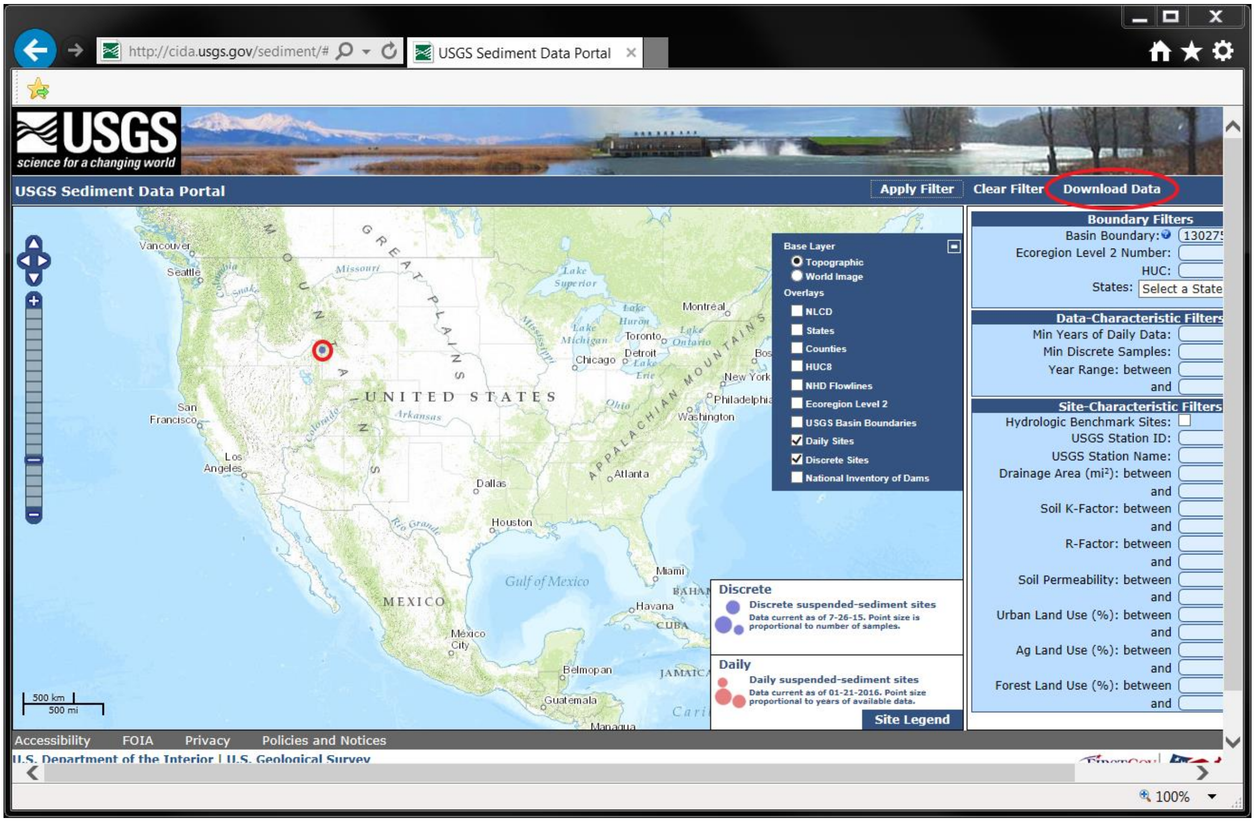
10. To download sediment data at USGS Salt River ab Reservoir nr Etna WY gage station (13027500), click on http://cida.usgs.gov/sediment/#, which results in the following USGS webpage.



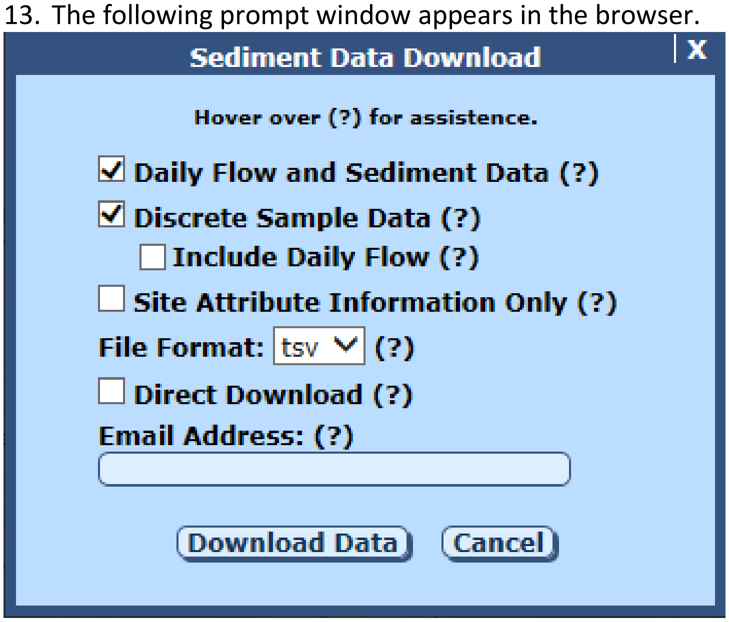
11. Within the "Boundary Filters" section, type the USGS gage station ID "13027500" for the "Basin Boundary", then click "Apply Filter".



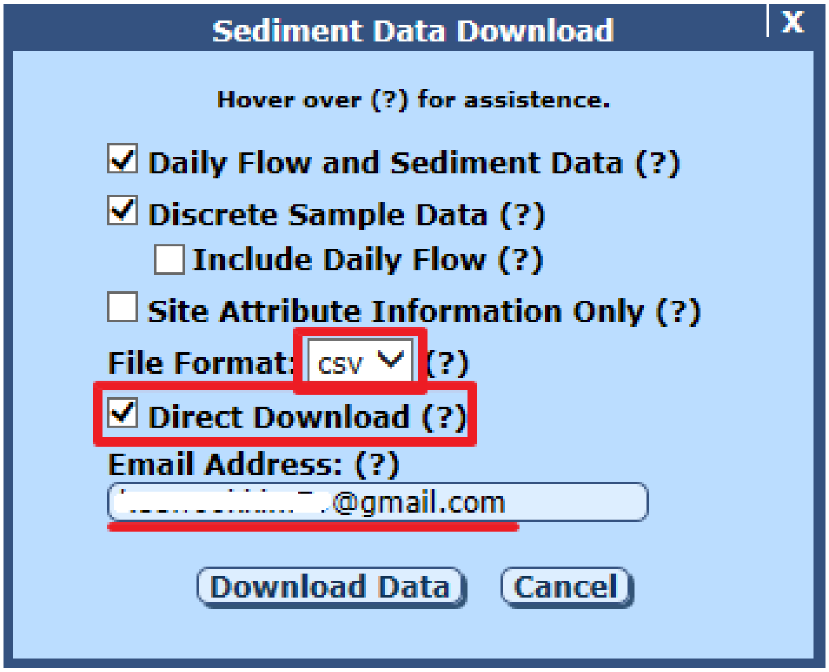
12. A purple circle (highlighted with a red open circle in the picture below) will appear at the gage station's location. Click "Download Data".



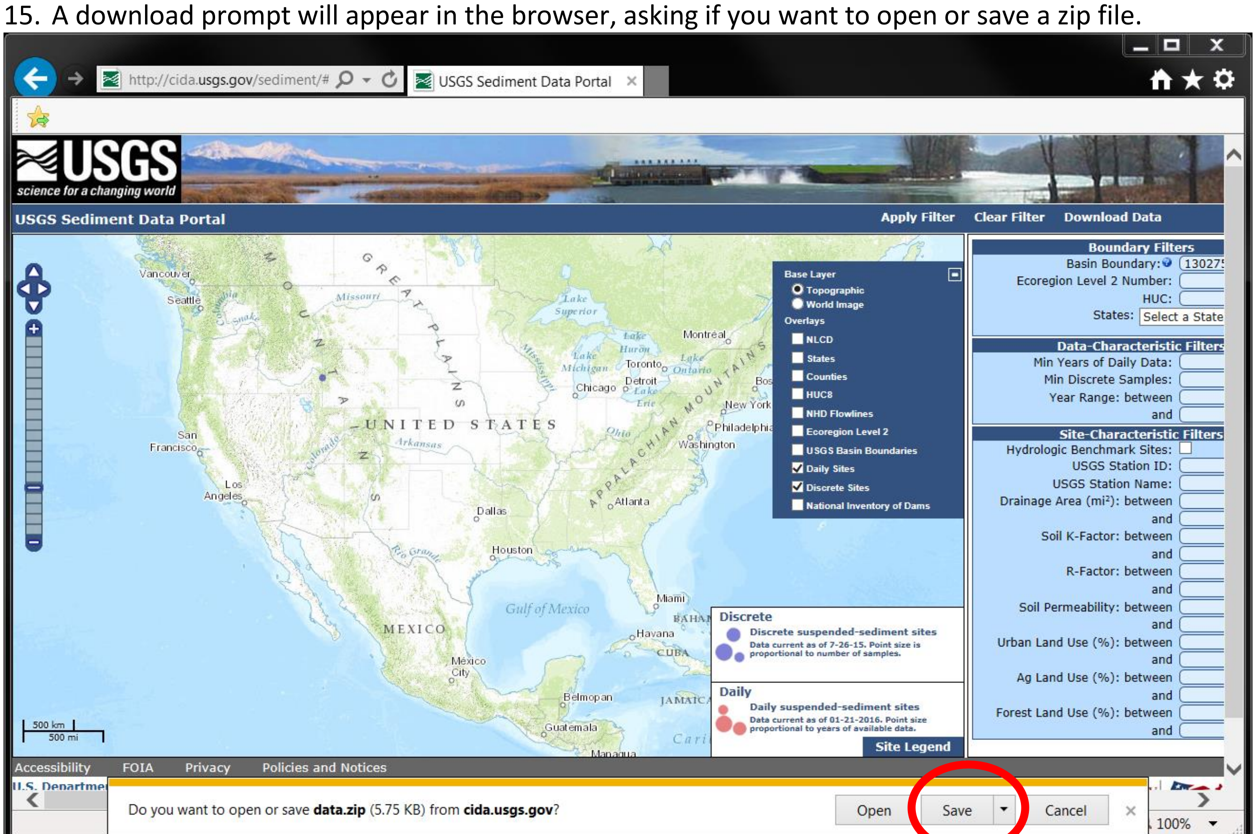
13. The following prompt window appears in the browser.



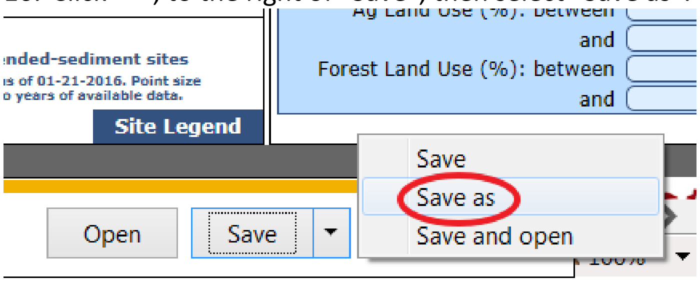
14. Select “csv” for “File Format”, check “Direct Download”, and include your Email address in the text box for “Email Address”. Click “Download Data”.



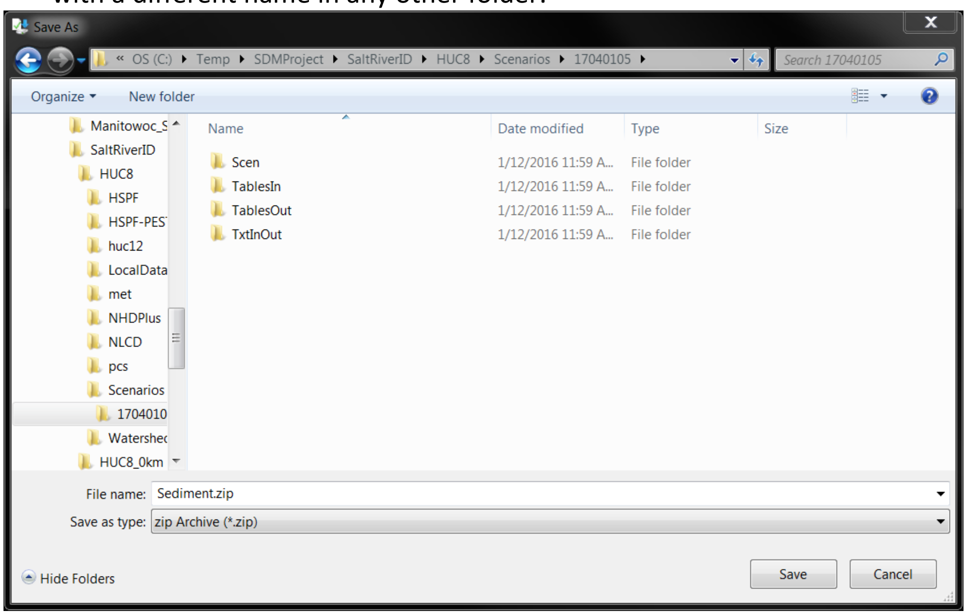
15. A download prompt will appear in the browser, asking if you want to open or save a zip file.



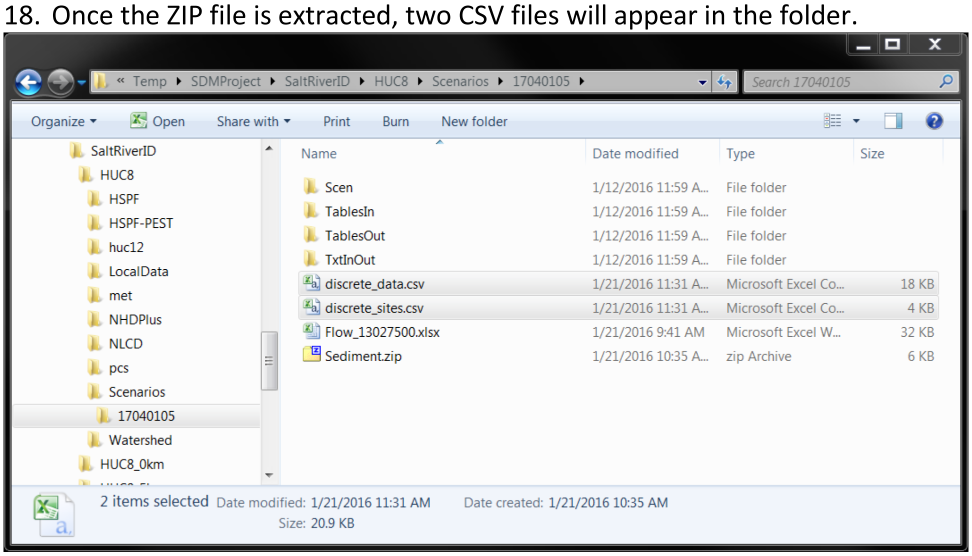
16. Click , to the right of “Save”, then select “Save as”.



17. Here, the file is saved as “C:\Temp\SDMProject\SaltRiverID\HUC8\Scenarios\17040105\Sediment.zip”. The file can be saved with a different name in any other folder.

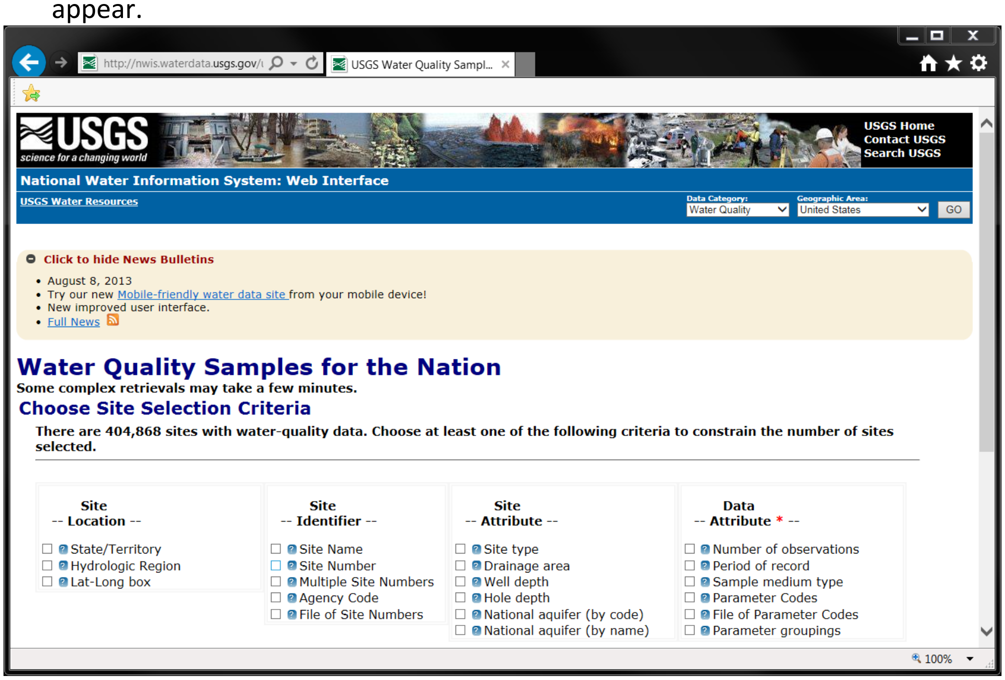


18. Once the ZIP file is extracted, two CSV files will appear in the folder.

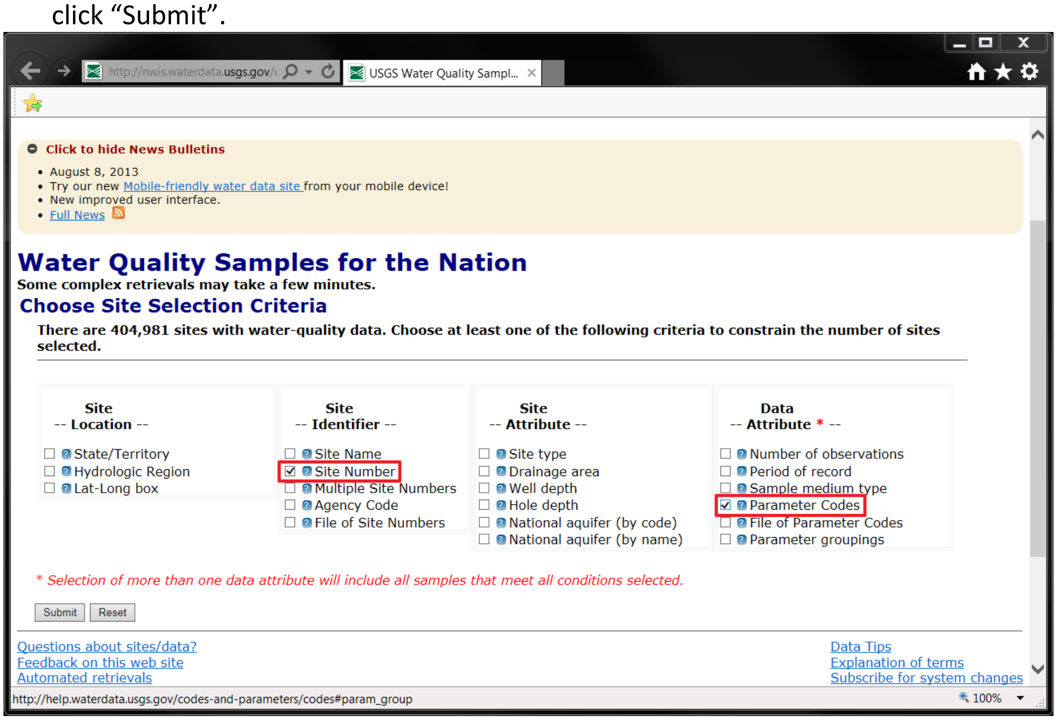


Nutrient Data

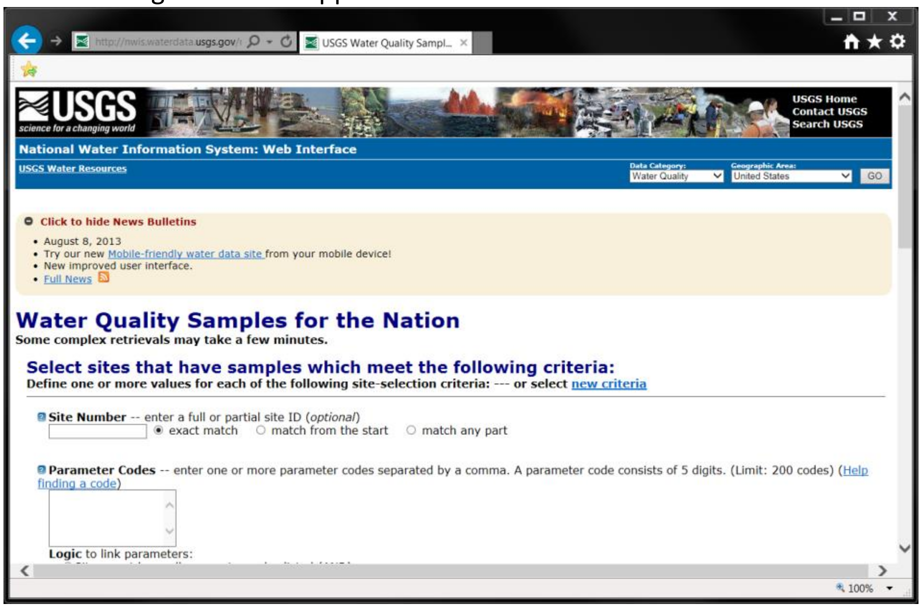
19. To download nutrient data at the USGS Salt River ab Reservoir nr Etna WY gage station (13027500), click http://nwis.waterdata.usgs.gov/usa/nwis/qwdata, and the following USGS webpage will appear.



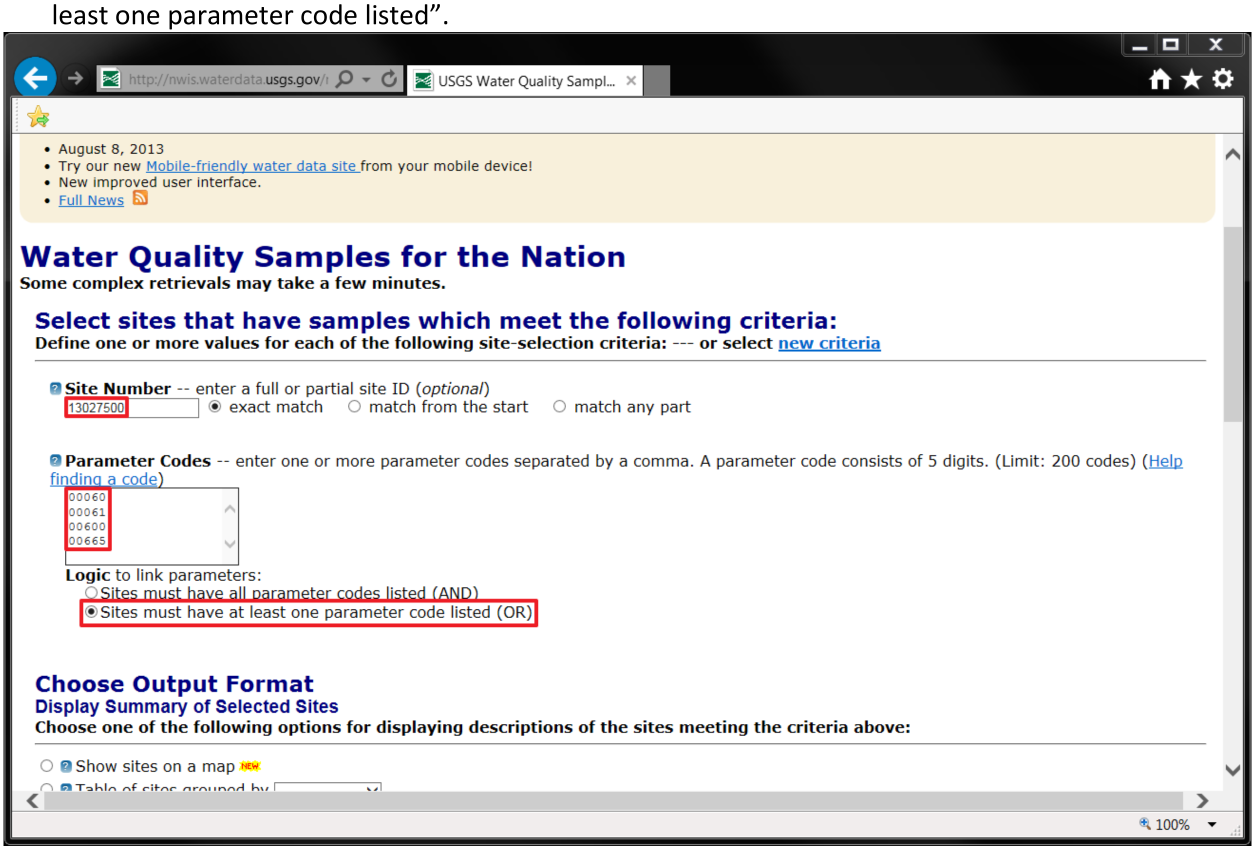
20. Check "Site Number" under "Site Identifier" and "Parameter Codes" under "Data Attribute", and click "Submit".



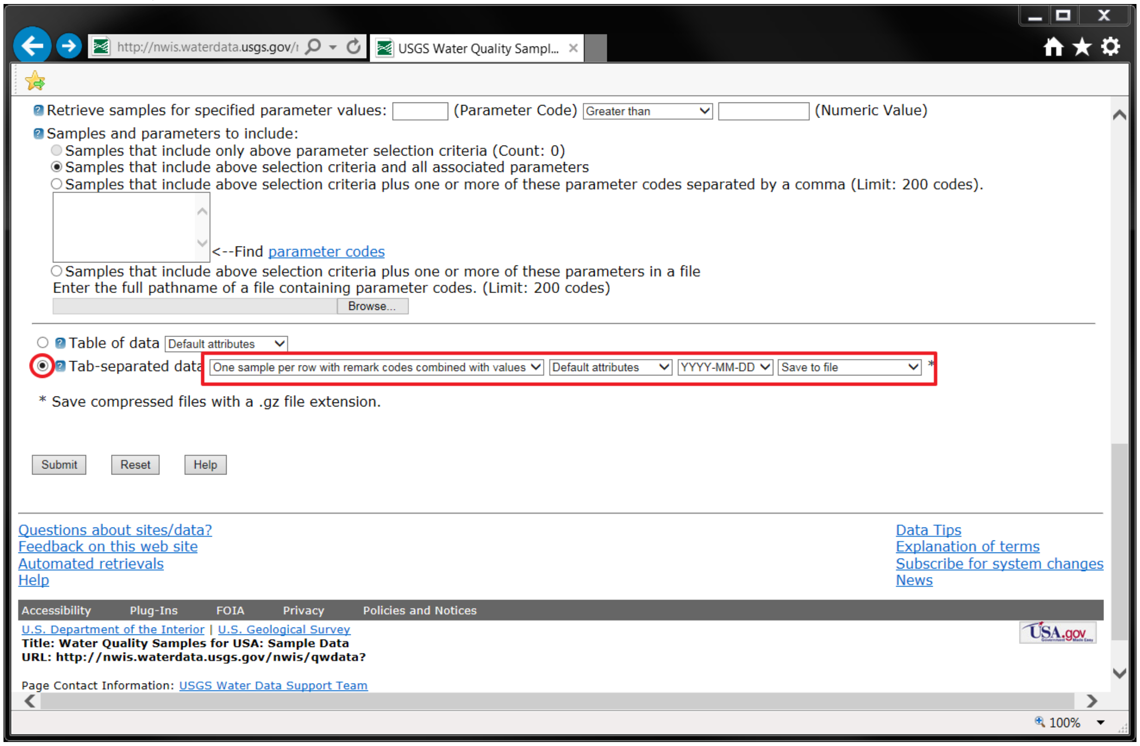
21. The following screen will appear.



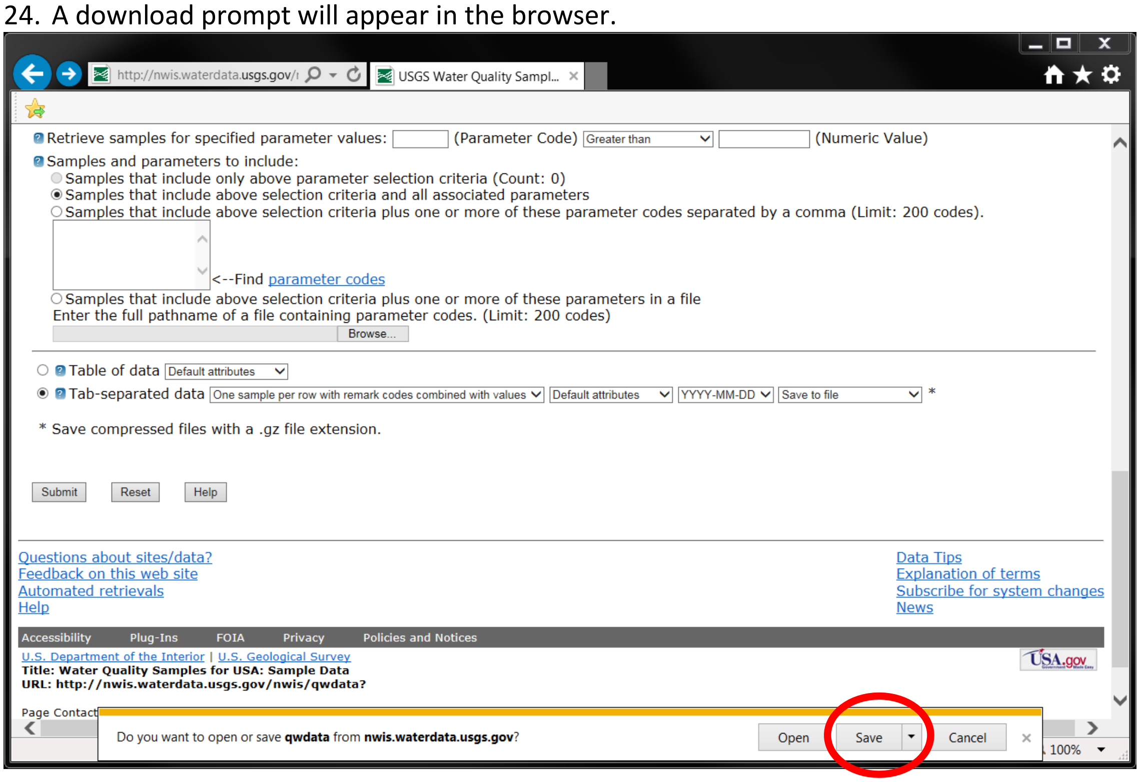
22. Place the USGS gage station ID (i.e., 13027500) in the blank for “Site Number”; place parameter codes “00060” for discharge, “00061” for instantaneous discharge, “00600” for total nitrogen, and “00665” for total phosphorus in the text box for “Parameter Codes”; and select “Sites must have at least one parameter code listed”.



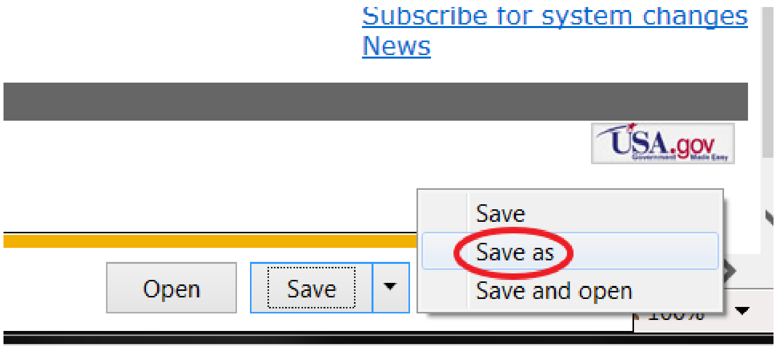
23. Scroll down, and select “Tab-separated data”, then click “Submit”. Ensure that pull-down menus are selected, as shown below.



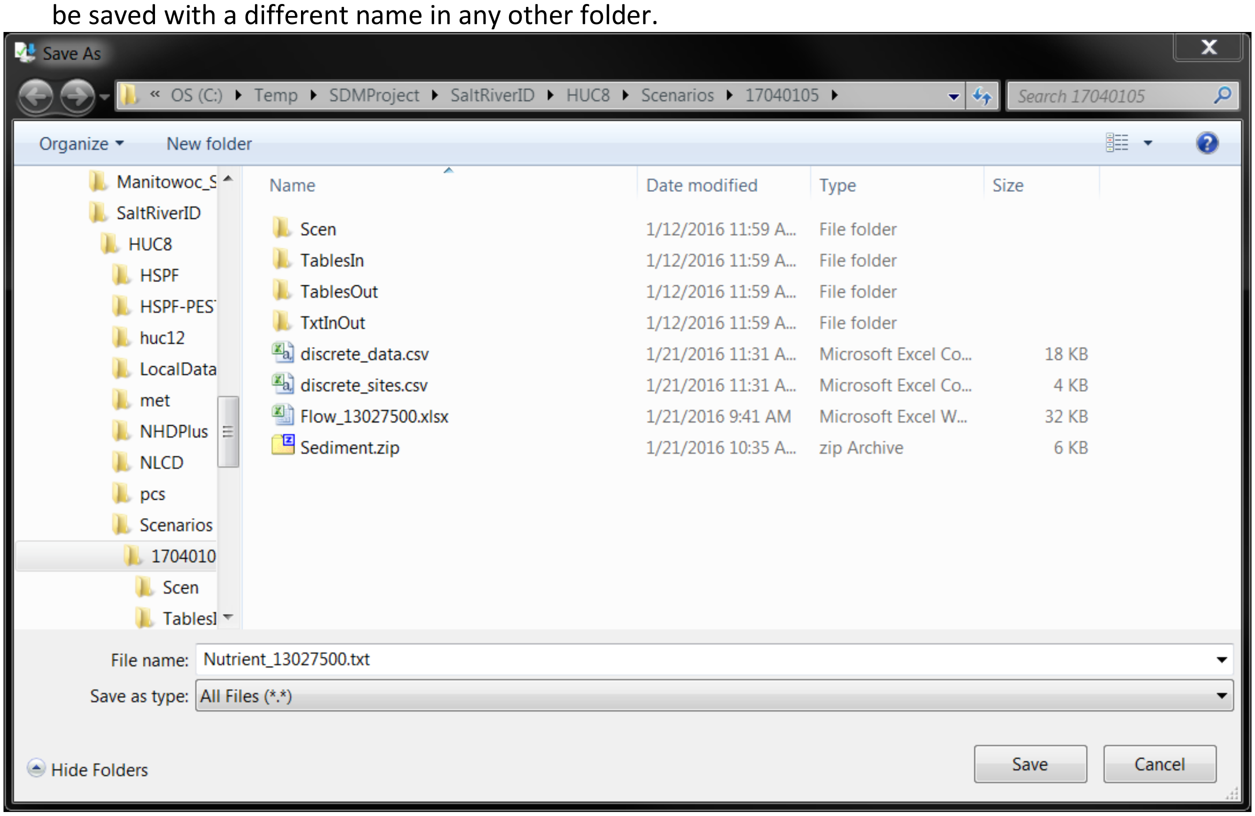
24. A download prompt will appear in the browser.



25. Click , to the right of “Save”, then select “Save as”.



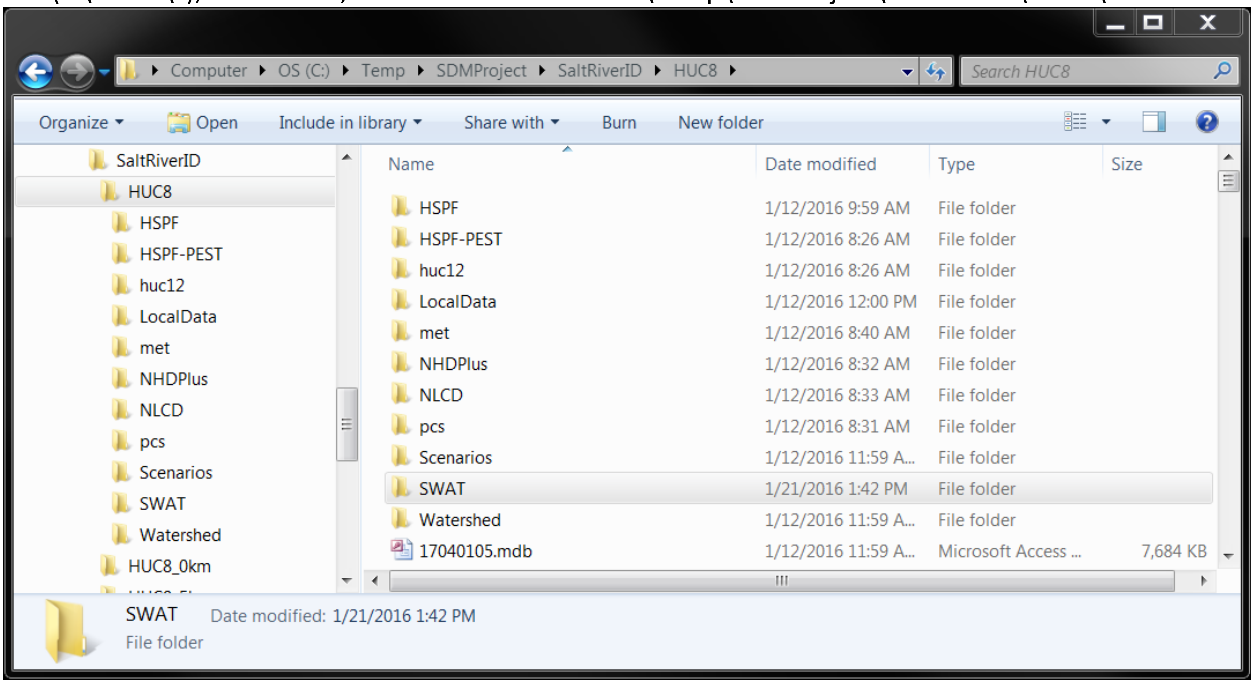
26. In this example, the file is saved as “C:\Temp\SDMProject\SaltRiverID\HUC8\Scenarios\17040105\Nutrient_13027500.txt”. The file can be saved with a different name in any other folder.



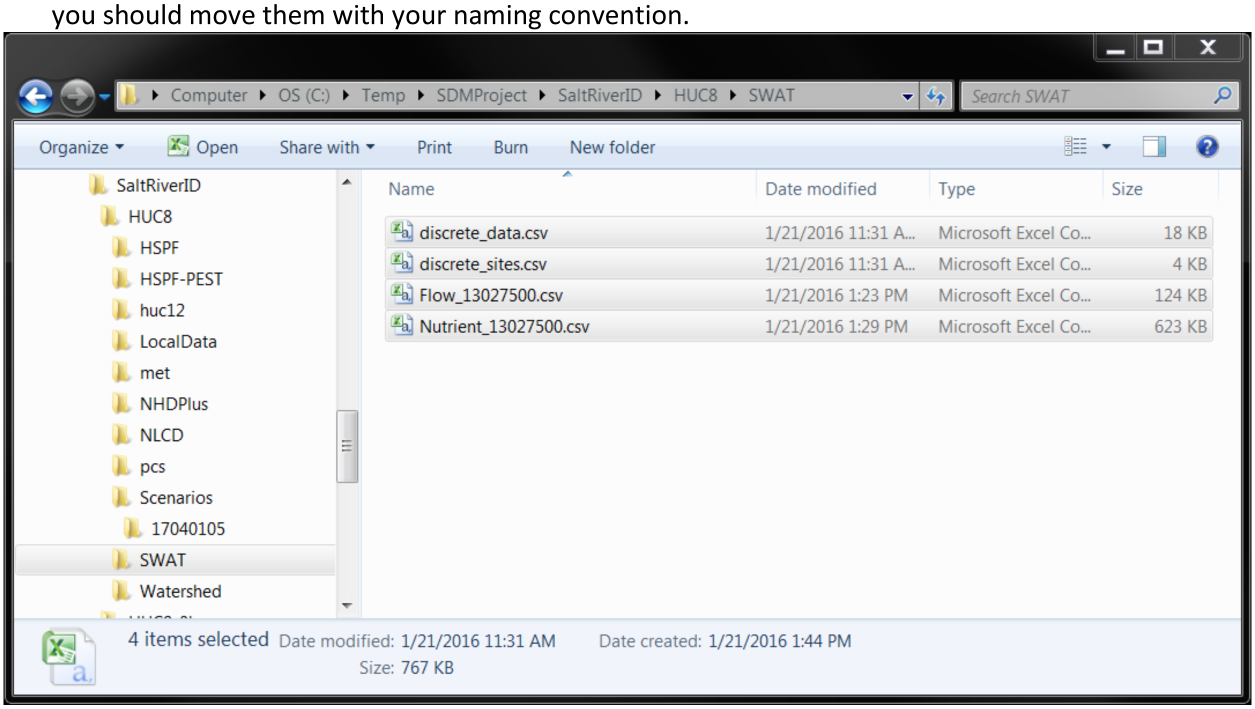
27. Open “Nutrient_13027500.txt” in Excel, and save it as “Nutrient_13027500.csv”.

PREPARING SWAT-CUP INPUT FILES FOR SWAT PARAMETER CALIBRATION

28. Parameter calibration will be performed using daily observations. For this, create a new folder ("\.\SWAT\"); in this case, it was created under "C:\Temp\SDMProject\SaltRiverID\HUC8\".



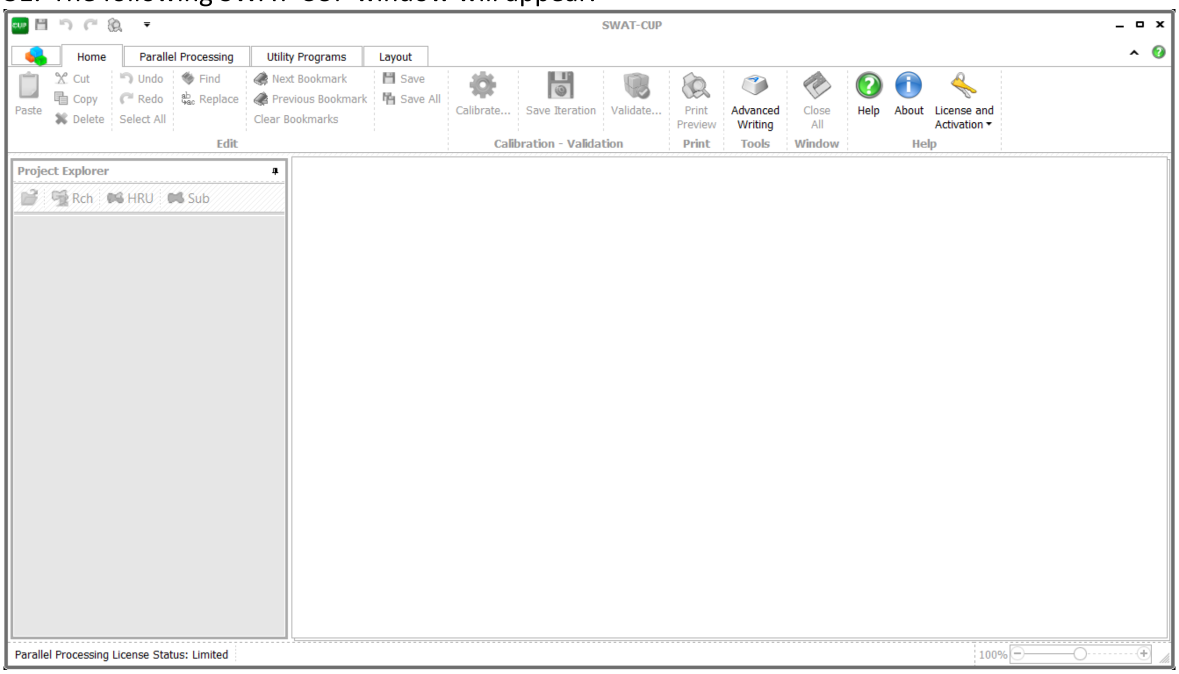
29. Move the following files, including observations, to "C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\". If you saved these files under different names, you should move them with your naming convention.



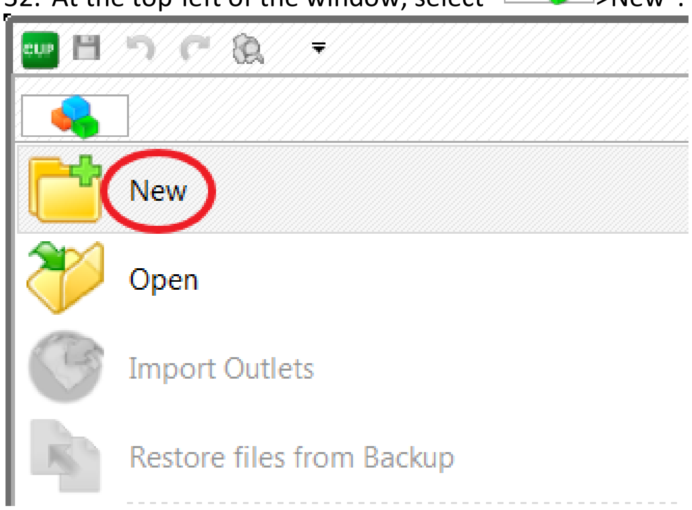
Generate a New SWAT-CUP Project

30. A new SWAT-CUP project must be generated, so open SWAT-CUP by double-clicking (left) on the icon. If the icon cannot be found on the Desktop screen, locate SwatCup.exe on the hard drive, typically in C:\SWAT\SWAT-CUP\.

31. The following SWAT-CUP window will appear.

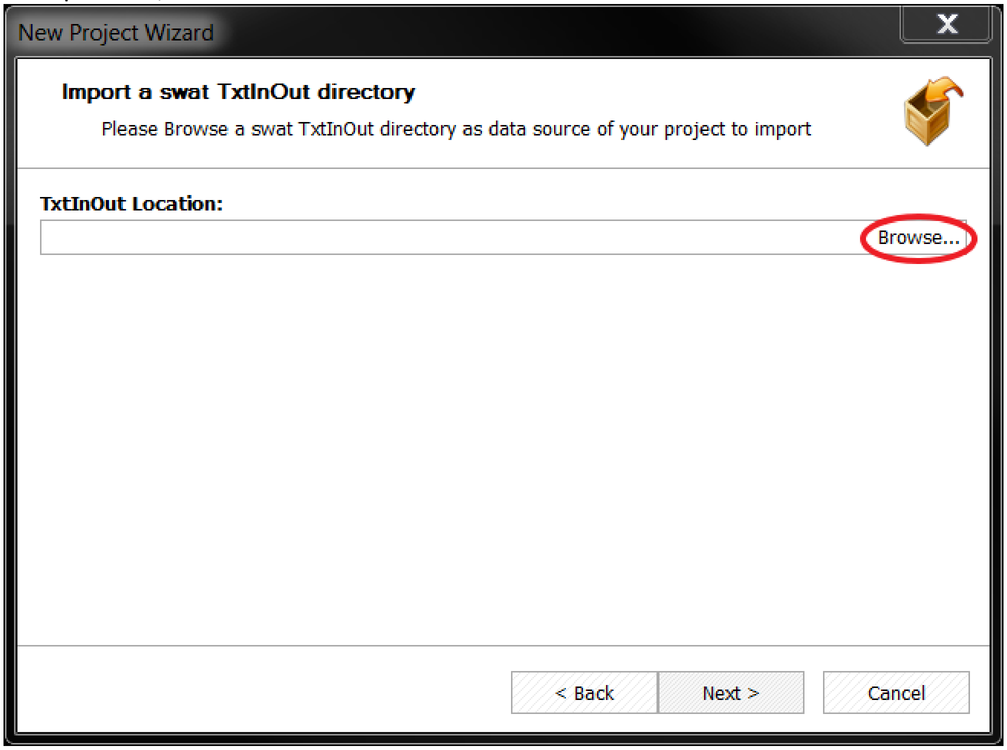


32. At the top-left of the window, select ">New".

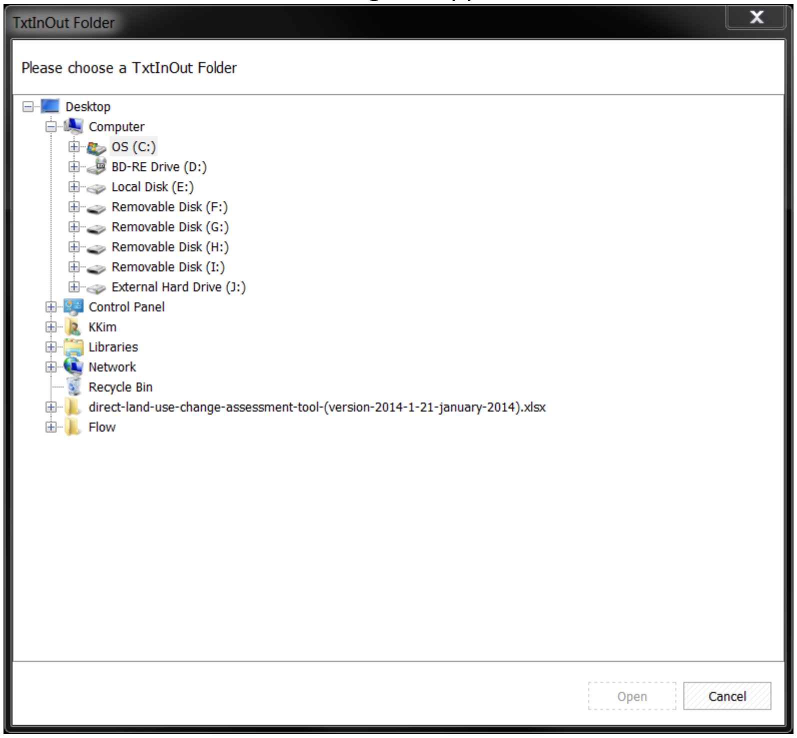


33. The “New Project Wizard” window will appear. Click “Next”.

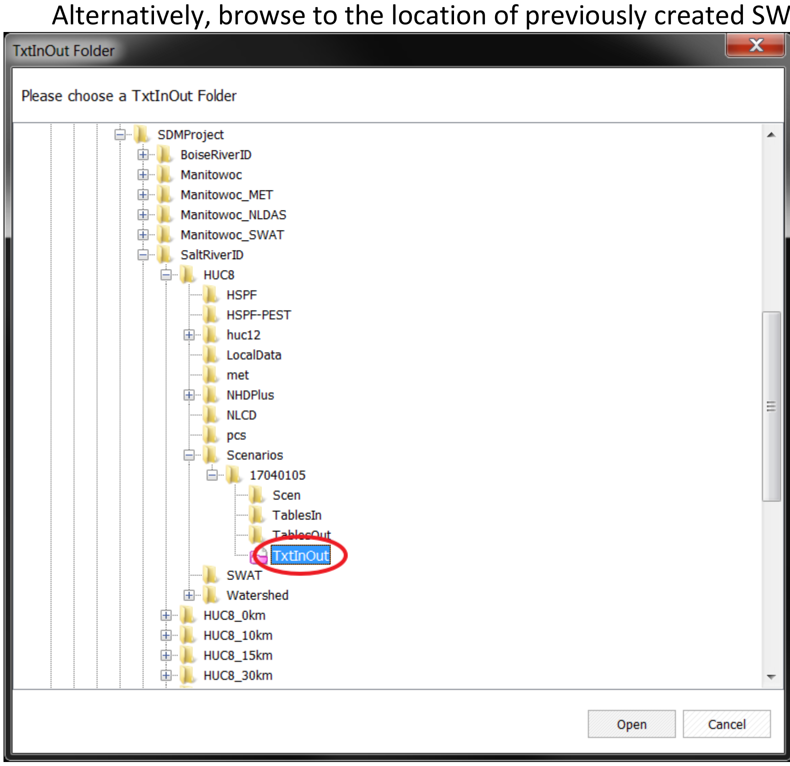
34. The screen below appears. SWAT input files are located at “TxtInOut Location”; this location must be specified, so click “Browse…”.



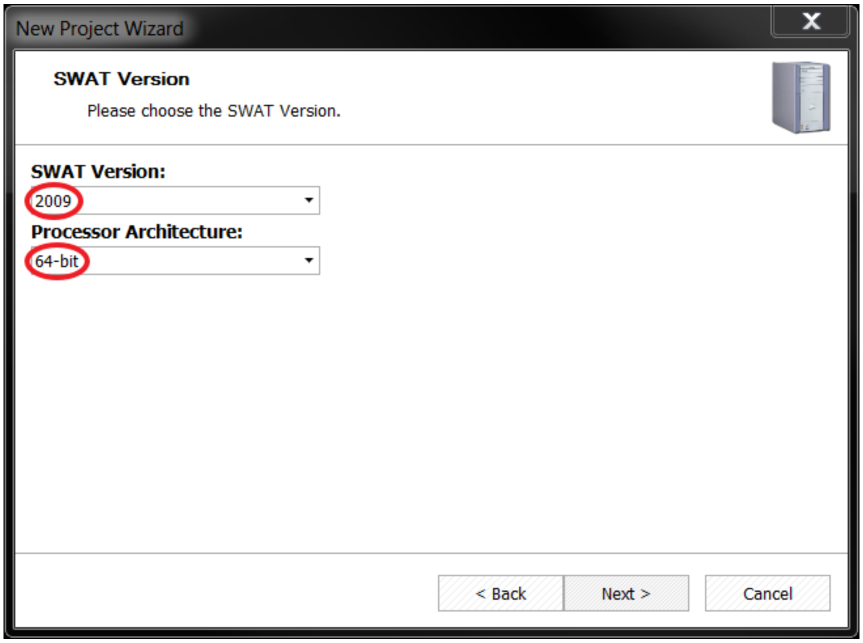
35. A window like the following will appear.



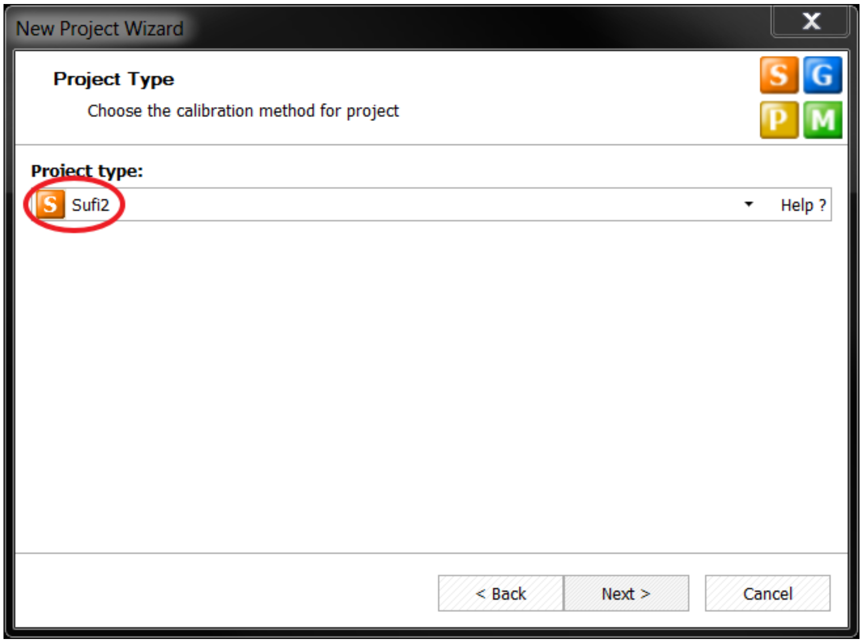
36. In this example, browse to "C:\Temp\SDMProject\SaltRiverID\HUC8\Scenarios\17040105\TxtInOut\", then click "Open". Alternatively, browse to the location of previously created SWAT TxtInOut directory.



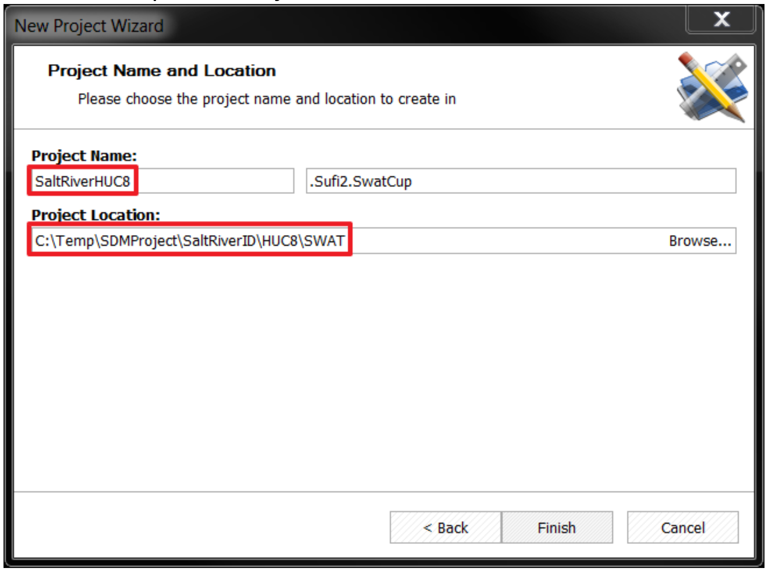
37. The SDMProjectBuilder was originally designed to prepare input files for SWAT 2005, but SWAT 2005 is also compatible with SWAT 2009; therefore, select “2009” for “SWAT Version” and “64-bit” for “Processor Architecture”. “32-bit” can be selected, if using a 32-bit Operating System (OS). Click “Next”. Note that SWAT input files generated by the SDMProjectBuilder are not compatible with SWAT2012.



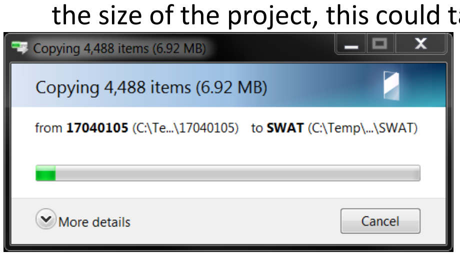
38. The following window appears. There are different calibration algorithms that can be used within SWAT-CUP; for the purpose of this tutorial, we will only use Sufi2 for calibration of SWAT. Select “Sufi2” for “Project type”. Details of project types in SWAT-CUP can be found in Abbaspour (2014). Click “Next”.



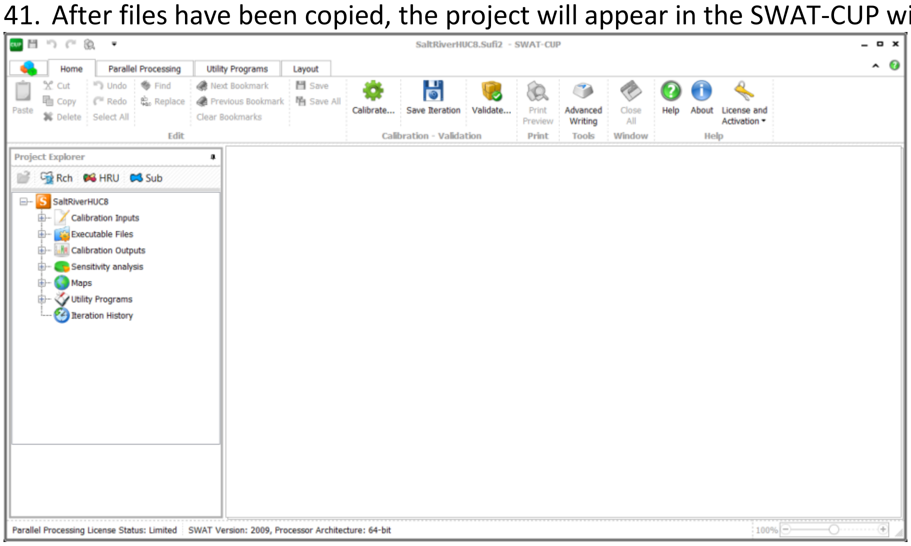
39. The following screen appears. Define “Project Name” (in this case, “SaltRiverHUC8”), and browse to the “Project Location” of “C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\. SWAT-CUP generates a new folder with the “Project Name” in the “Project Location”. Here, the project will be generated in “C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\SaltRiverHUC8.Sufi2.SwatCup\”. Click “Finish”.



40. SWAT-CUP will copy SWAT input files from the “TxtInOut” folder to the project folder. Depending on the size of the project, this could take minutes to hours. This example took only a few minutes.



41. After files have been copied, the project will appear in the SWAT-CUP window.



Prepare SWAT-CUP Input Files

42. SWAT-CUP input files need additional preparation, but must be copied from "C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT-SWATCUP\" to "C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\"
    - "SWAT_SWATCUP.exe"
    - "Input_SWAT.in"
    - "Update_par_inf.exe"

    Descriptions of these and related files are provided in Table 2.

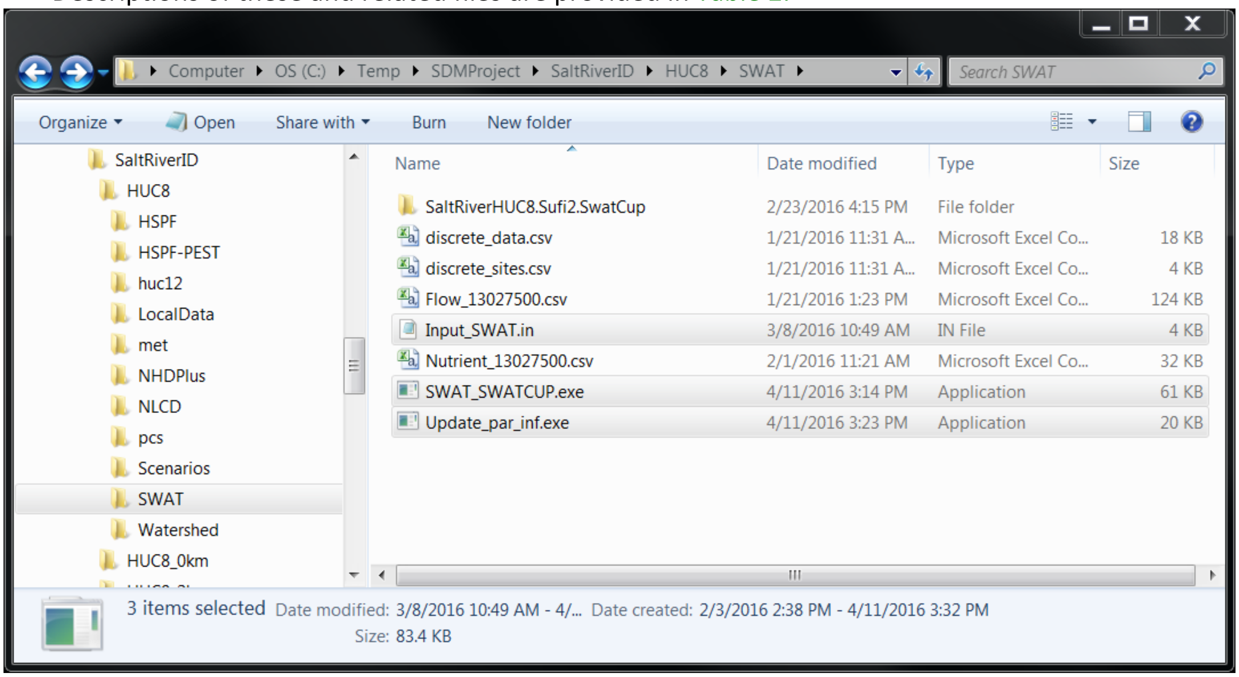
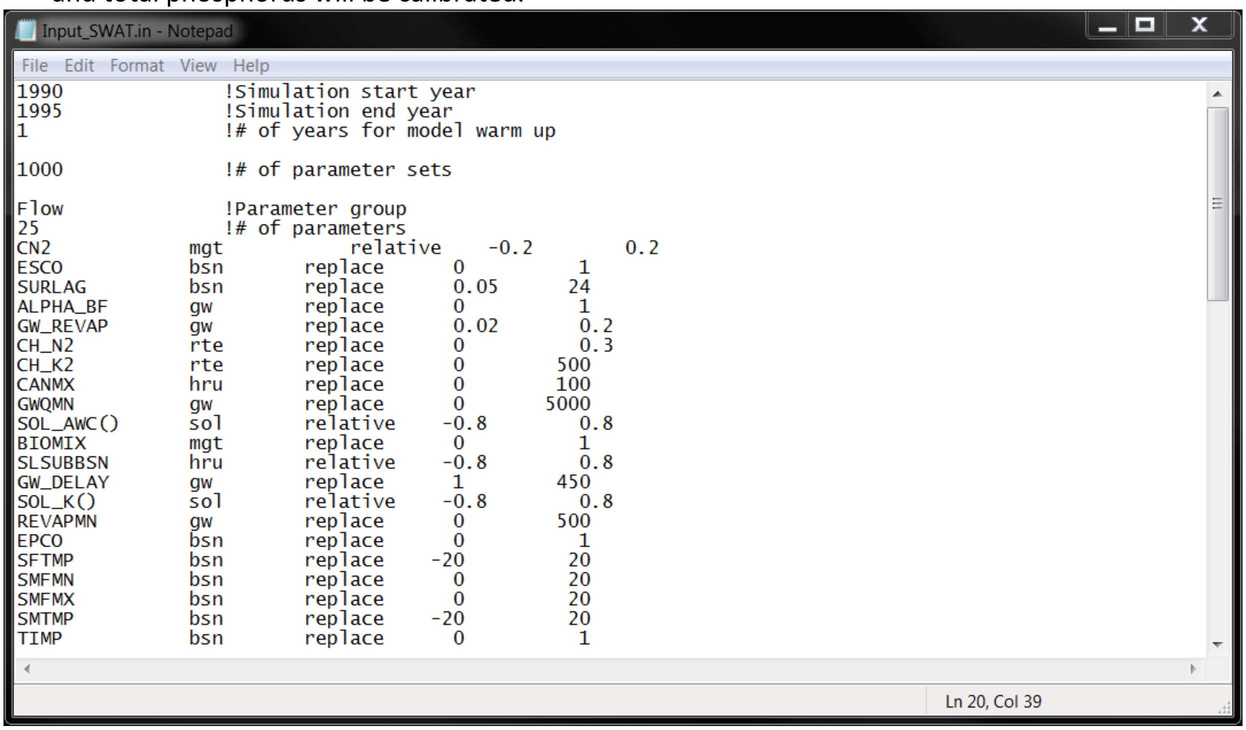


Table 2. Descriptions of Selected Files

FILE	DESCRIPTION
par_inf.txt	is the file used in the calibration process and contains ranges in parameter values that are within acceptable minimum and maximum values
new_pars.txt	contains suggested updated ranges in parameter values computed by SWAT-CUP without considering whether the values are outside of the minimums and maximums defined in "Absolute_SWAT_Values.txt"
Absolute_SWAT_Values.txt	identifies acceptable minimum and maximum value ranges for all SWAT parameters and is a part of SWAT-CUP
SWAT_SWATCUP.exe	prepares SWAT-CUP input files
Input_SWAT.in	is a default input file of "SWAT_SWATCUP.exe", includes acceptable ranges for calibration parameters (i.e., subset of "Absolute_SWAT_Values.txt"), and are the same as those included in "Absolute_SWAT_Values.txt"

Update_par_inf.exe	reads suggested parameter ranges, compares them to acceptable minimums and maximums, modifies suggested parameter ranges within acceptable bounds, and stores updated ranges in “par_inf.txt” for the next iteration
par_inf_init.txt	Is created by “Update_par_inf.exe”, and stores the original acceptable ranges defined in “Input_SWAT.in” for use after the first calibration iteration

43. Save a copy of “Input_SWAT.in” to another folder for future use. Open “Input_SWAT.in” with a text editor, since it needs to be reviewed and updated. In this example, parameters for flow, sediment, and total phosphorus will be calibrated.




```
1990            !Simulation start year
1995            !Simulation end year
1               !# of years for model warm up

1000            !# of parameter sets

Flow            !Parameter group
25              !# of parameters
CN2         mgt      relative    -0.2     0.2
ESCO        bsn      replace     0        1
SURLAG      bsn      replace     0.05     24
ALPHA_BF    gw       replace     0        1
GW_REVAP    gw       replace     0.02     0.2
CH_N2       rte      replace     0        0.3
CH_K2       rte      replace     0        500
CANMX       hru      replace     0        100
GWQMN       gw       replace     0        5000
SOL_AWC()   sol      relative    -0.8     0.8
BIOMIX      mgt      replace     0        1
SLSUBBSN    hru      relative    -0.8     0.8
GW_DELAY    gw       replace     1        450
SOL_K()     sol      relative    -0.8     0.8
REVAPMN     gw       replace     0        500
EPCO        bsn      replace     0        1
SFTMP       bsn      replace     -20      20
SMFMN       bsn      replace     0        20
SMFMX       bsn      replace     0        20
SMTMP       bsn      replace     -20      20
TIMP        bsn      replace     0        1
```

44. Under the “Nutrient” parameter group,
    - change “TNTP” in line 50 to “TP”
    - remove parameters for nitrogen
    - update the “# of parameters” to “13”.

    Save and close “Input_SWAT.in”. Parameter definitions can be found in the SWAT Input/Output Documentation (Arnold et al., 2012) or in the “Absolute_SWAT_Values.txt” file, generated in the SWAT-CUP project folder.

```
LAT_SED        hru       replace     0        5000
RSDIN          hru       replace     0       10000
ADJ_PKR        bsn       replace     0.5         2
PRF_BSN        bsn       replace     0           2
USLE_C{1-121}  plant.dat relative   -0.5         0.5
USLE_P         mgt       replace     0           1
USLE_K()       sol       relative   -0.8         0.8
SPCON          bsn       replace     0.0001      0.01
SPEXP          bsn       replace     1           1.5
CH_COV1        rte       replace     0.05        0.6
CH_COV2        rte       replace     0.001       1

Nutrient                 !Parameter group
TP                       !TN or TP
13                       !# of parameters
PPERCO         bsn       replace     10         17.5
RSDCO          bsn       replace     0.02        0.1
PHOSKD         bsn       replace    100        200
P_UPDIS        bsn       replace     0         100
PSP            bsn       replace     0.01        0.7
BC4            swq       replace     0.01        0.7
ERORGP         hru       replace     0           5
SOL_LABP()     chm       replace     0         100
SOL_ORGP()     chm       replace     0         100
SOL_CBN()      sol       relative   -0.5         0.5
BC1            swq       replace     0.1         1
BC2            swq       replace     0.2         2
RS3            swq       replace     0           1
```

SWAT-CUP input files are prepared by executing “SWAT_SWATCUP.exe” with its input file “Input_SWAT.in”. “SWAT_SWATCUP.exe” prepares:

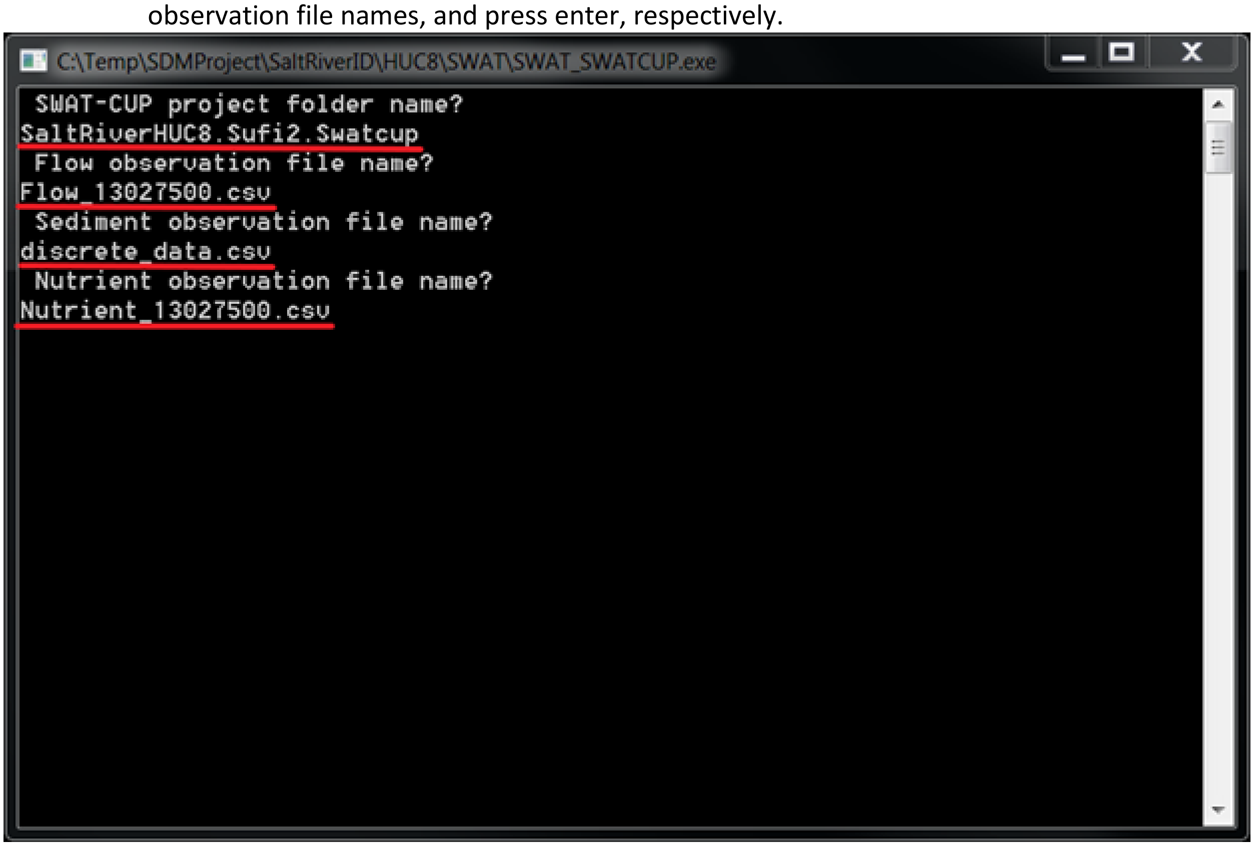
A. A SWAT input file
    a. Master watershed file (file.cio): Beginning year of SWAT simulation, number of years simulated, and number of years to skip output printing (model warm up period) are modified, as defined in “Input_SWAT.in”. A description of “Input_SWAT.in” is provided in Appendix A. “Input_SWAT.in”, the default input file of “SWAT_SWATCUP.exe”, contains details for preparing SWAT-CUP input files, including:
        i. Simulation start and end year
        ii. Number of years for model warm up
        iii. Number of parameter sets in each iteration for the parameter calibration process
        iv. Parameter group name (i.e., Flow, Sediment, or Nutrient), number of parameters to be calibrated in each group, names of parameters to be calibrated in each group, and ranges.
B. Seven SWAT-CUP input files
    a. “SUFI2_swEdit.def”: A file including starting and ending simulation numbers.
    b. “SUFI2_extract_rch.def”: A file defining how to extract modeling results for estimating the objective function (e.g., Nash-Sutcliffe statistic).
    c. “par_inf.txt”: A file defining the number and names of parameters to be calibrated and their ranges, and number of model runs for calibration.

d. "observed.txt": A file including the objective function of the calibration, observed data, etc.
e. "observed_rch.txt": A file including the number of observations and observed data in reaches.
f. "var_file_name.txt": A file including all variable names in the estimation of the objective function.
g. "var_file_rch.txt": A file including all variable names in reaches that should be included in estimation of the objective function.

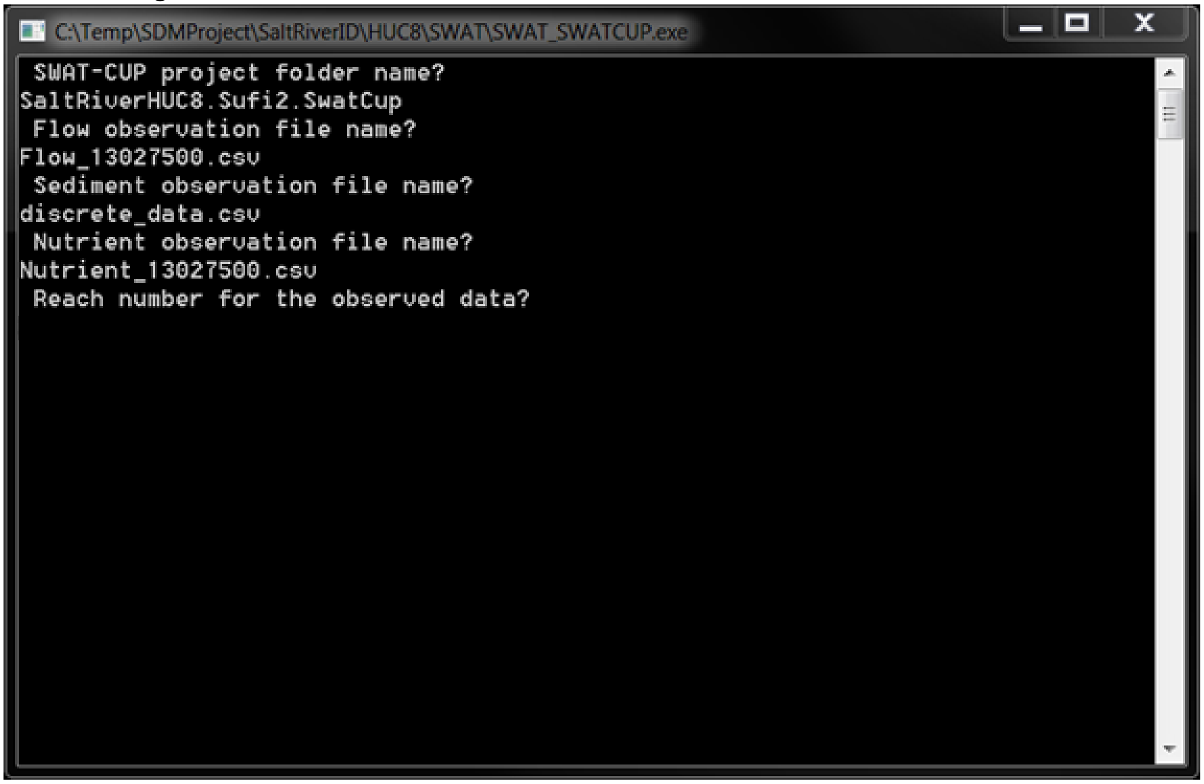
C. Input file for "Update_par_inf.exe"
   a. "projectfolder.txt": Includes a name of the SWAT-CUP project folder.

D. An extra output file
   a. "observed_data.txt": Includes all observed data in the parameter calibration. This can be used for drawing graphs and parameter validation with another period.

45. In "C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\", execute "SWAT_SWATCUP.exe" by double-clicking on the icon. The Command window shown below will appear.
    a. Type in the SWAT-CUP project folder name, where the SWAT-CUP project was generated: "SaltRiverHUC8.Sufi2.SwatCup". Press enter.
    b. Type in "Flow_13027500.csv" for the flow observation file name. Press enter.
    c. Type in "discrete_data.csv" and "Nutrient_13027500.csv" for sediment and nutrient observation file names, and press enter, respectively.



46. The following screen will appear, but the "Reach number for the observed data" must first be determined for the observed data where the USGS gage is located, which will be determined by executing BASINS.

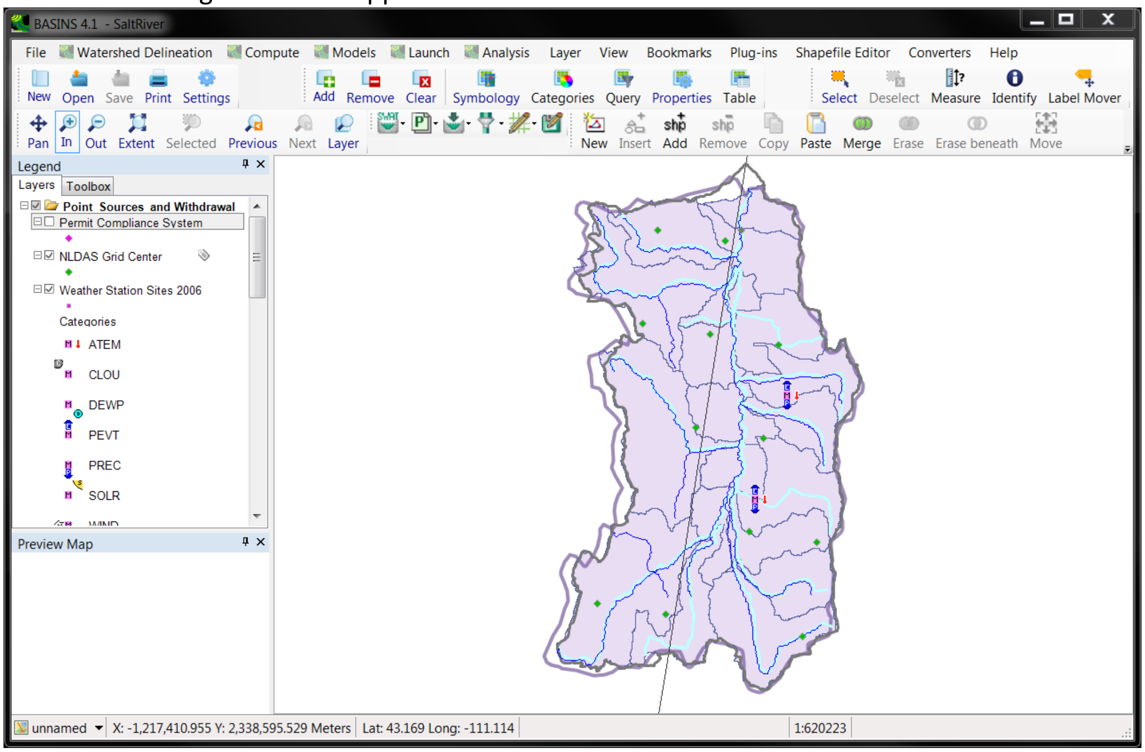


47. Without exiting the current screen, start BASINS from the BASINS 4.1 icon on the desktop:

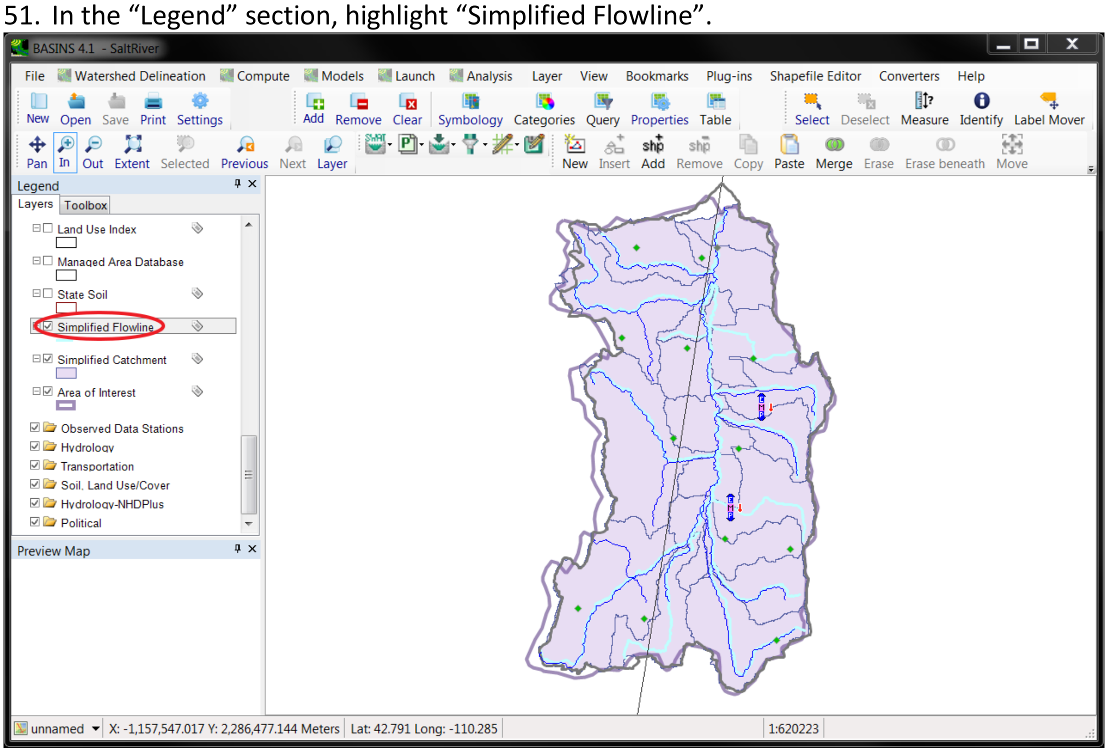
48. At the "Welcome" window, choose "Open Existing Project".

49. Navigate to the project folder (e.g., "C:\Temp\SDMProject\SaltRiverID\HUC8\), with the MapWindow project file (*.mwpj), and select "SaltRiver.mwprj". Click "Open".

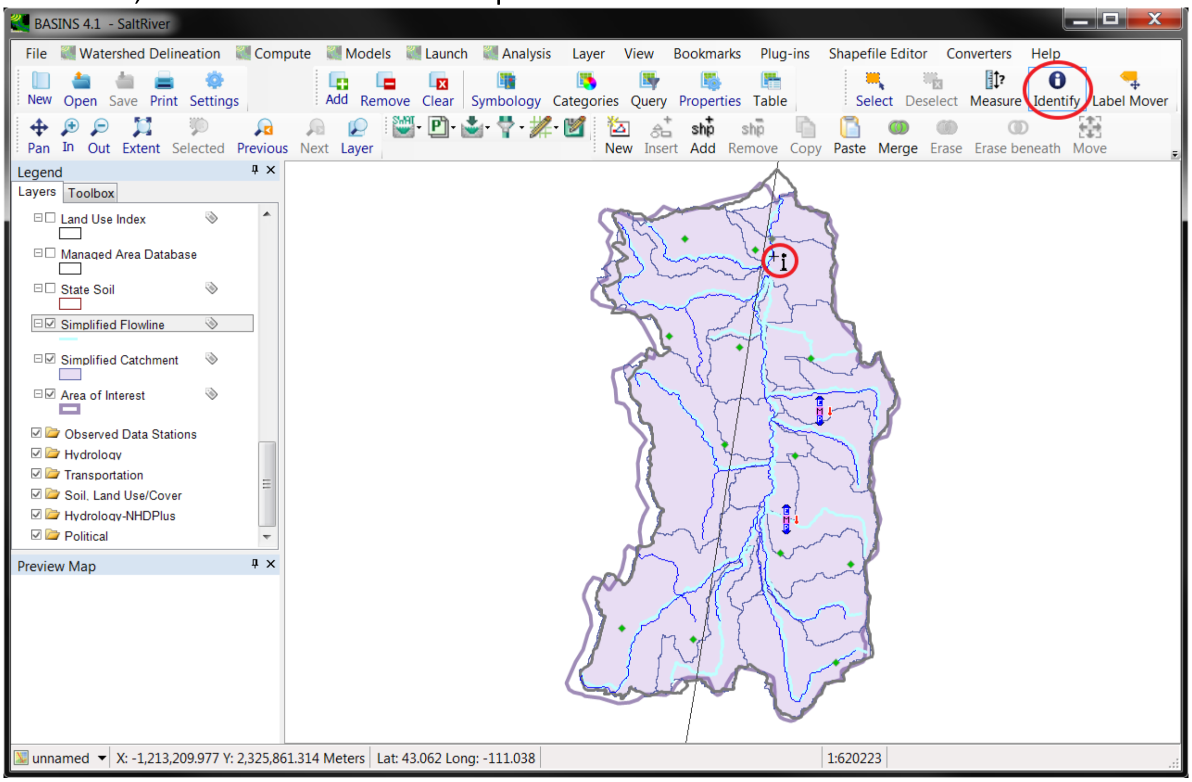
50. The following screen will appear.



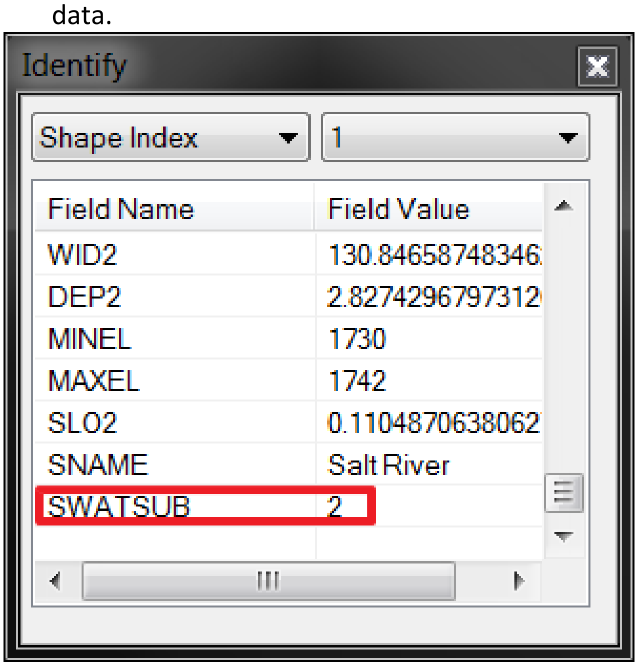
51. In the "Legend" section, highlight "Simplified Flowline".



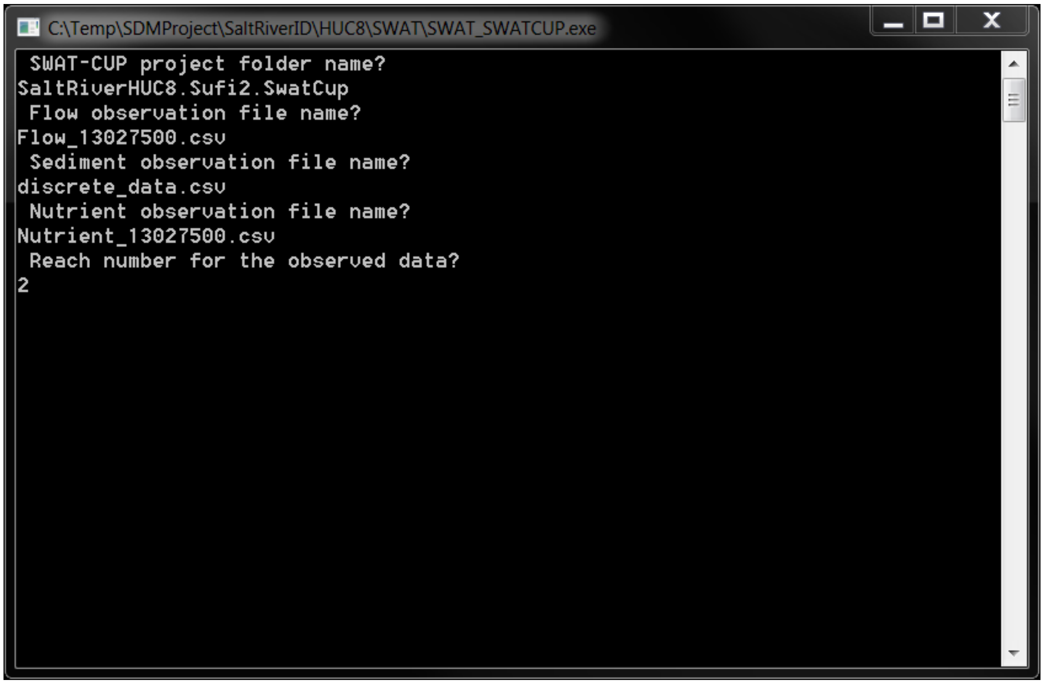
52. From the Tool bar, click  , and select the stream line directly upstream from the USGS gaging station, as illustrated in the screen capture below.



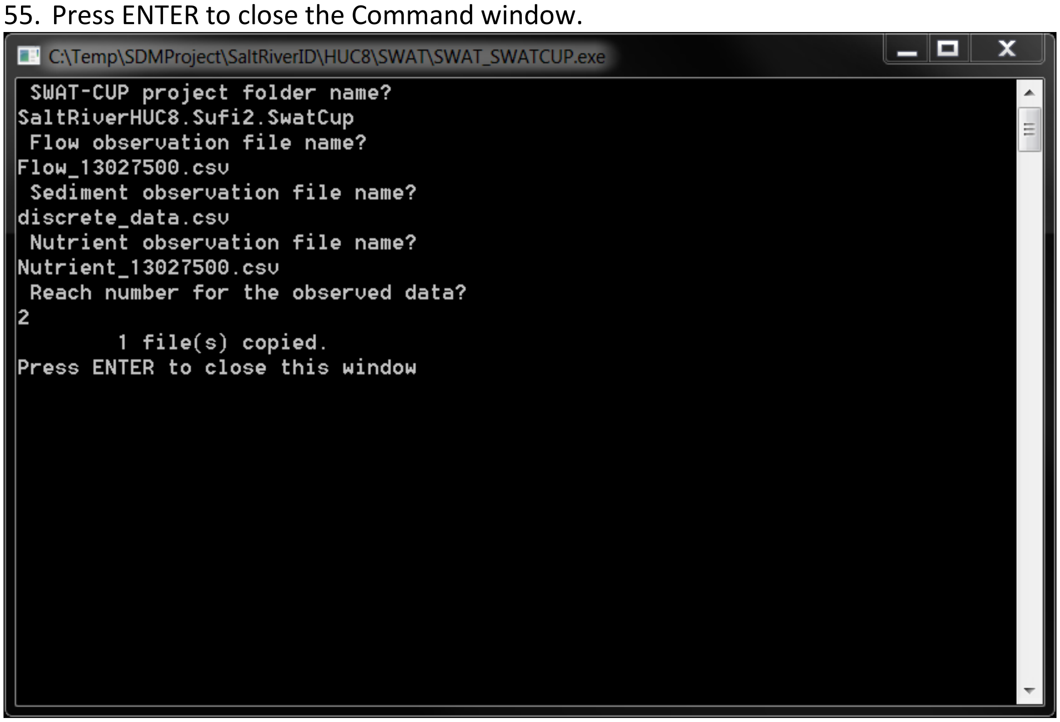
53. In the "Identify" window, read the value for "SWATSUB"; this is the reach number for the observed data.



54. “SWAT_SWATCUP.exe” only works for a single outlet. If the user wants to include multiple outlets for parameter calibration, the user needs to manually modify SWAT-CUP input files (i.e., SUFI2_extract_rch.def, observed.txt, observed_rch.txt, var_file_name.txt, var_file_rch.txt). Close BASINS, then type in “2” in the Command window for the “Reach number for the observed data”. Press enter.

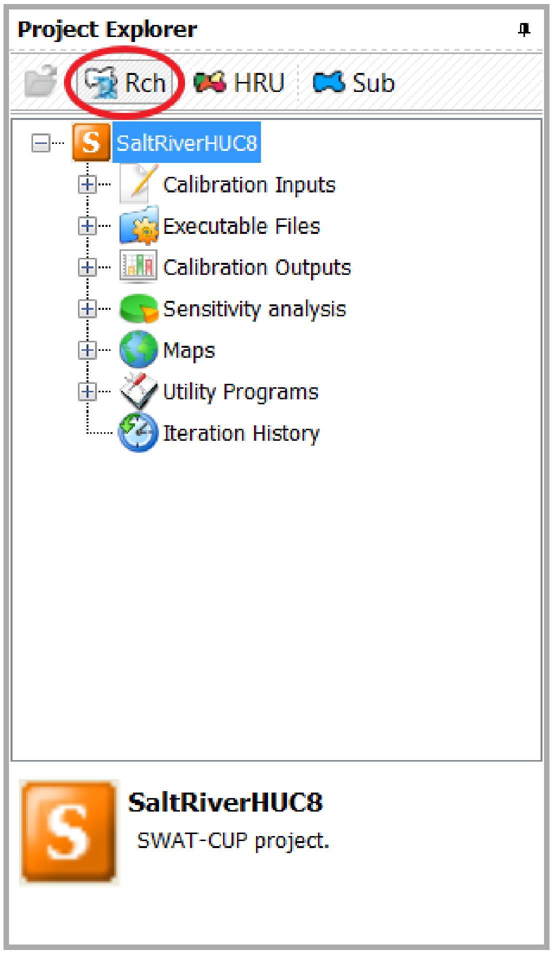


55. Press ENTER to close the Command window.

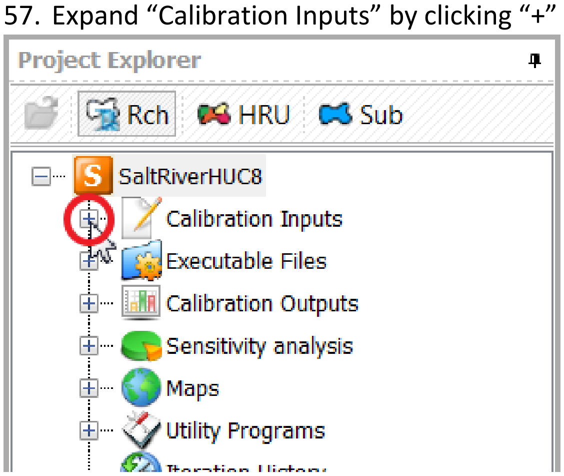


Inspect SWAT-CUP Input Files

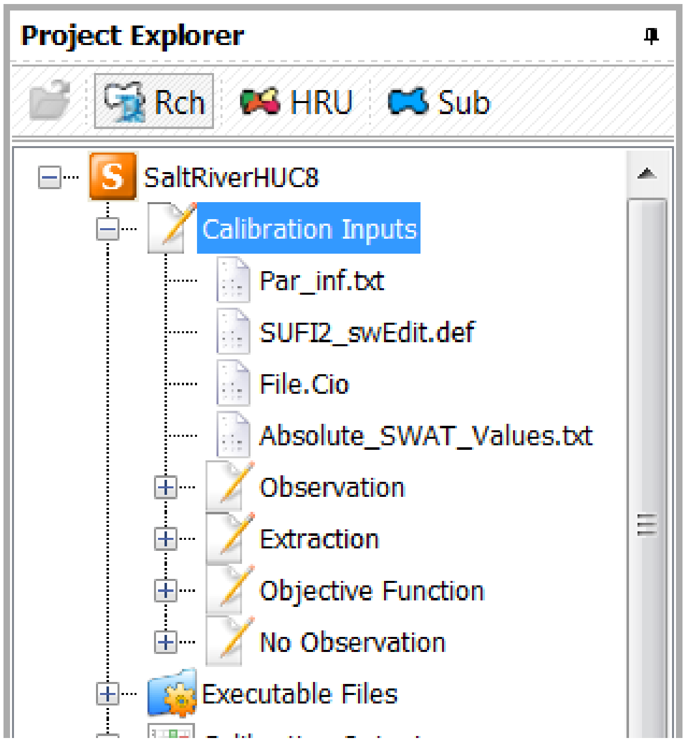
56. To inspect the SWAT-CUP input files prepared by “SWAT_SWATCUP.exe”, activate reaches in SWAT-CUP window by clicking  in the “Project Explorer” section.



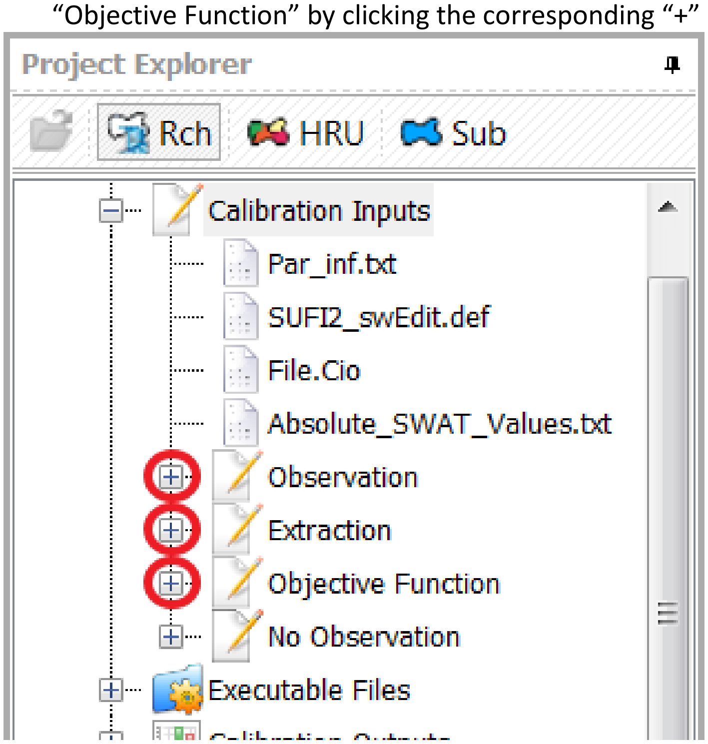
57. Expand “Calibration Inputs” by clicking “+” at the left of “Calibration Inputs”.



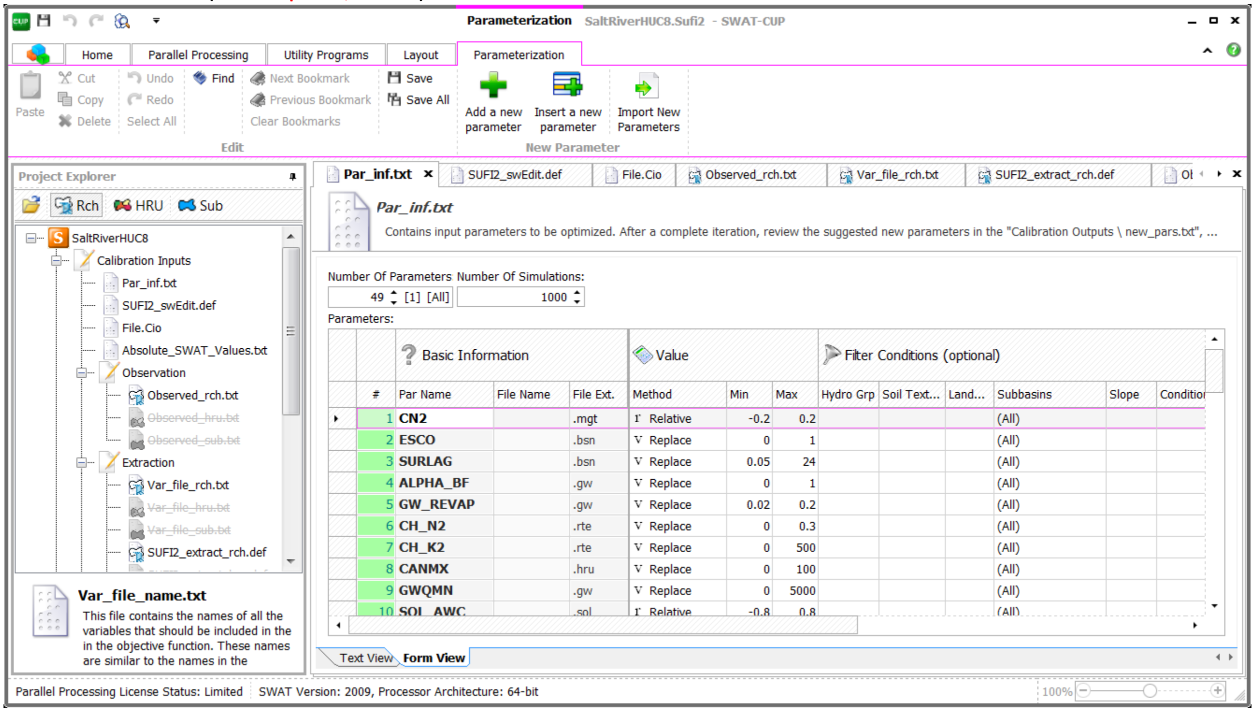
58. Sub-items of “Calibration Inputs” will be shown.



59. Among the sub-items within “Calibration Inputs”, expand “Observation”, “Extraction”, and “Objective Function” by clicking the corresponding “+” signs.



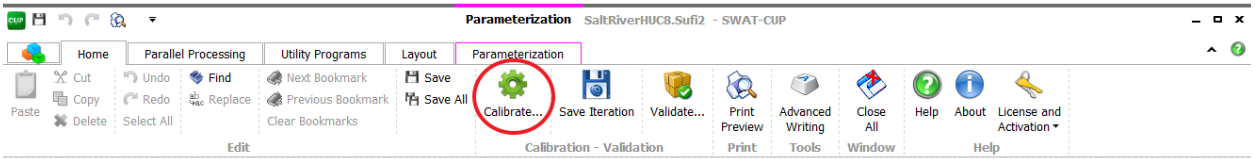
60. Open “Par_inf.txt”, “SUFI2_swEdit.def”, “File.Cio”, “Observed_rch.txt”, “Var_file_rch.txt”, “SUFI2_extract_rch.def”, “Observed.txt”, and “Var_file_name.txt” by double-clicking on the file names. The files will be shown in the main section of the SWAT-CUP window. They can be directly modified in the SWAT-CUP window, if desired. Details of the files can be found in the SWAT-CUP user manual (Abbaspour, 2014).



CALIBRATING SWAT PARAMETERS WITH SWAT-CUP

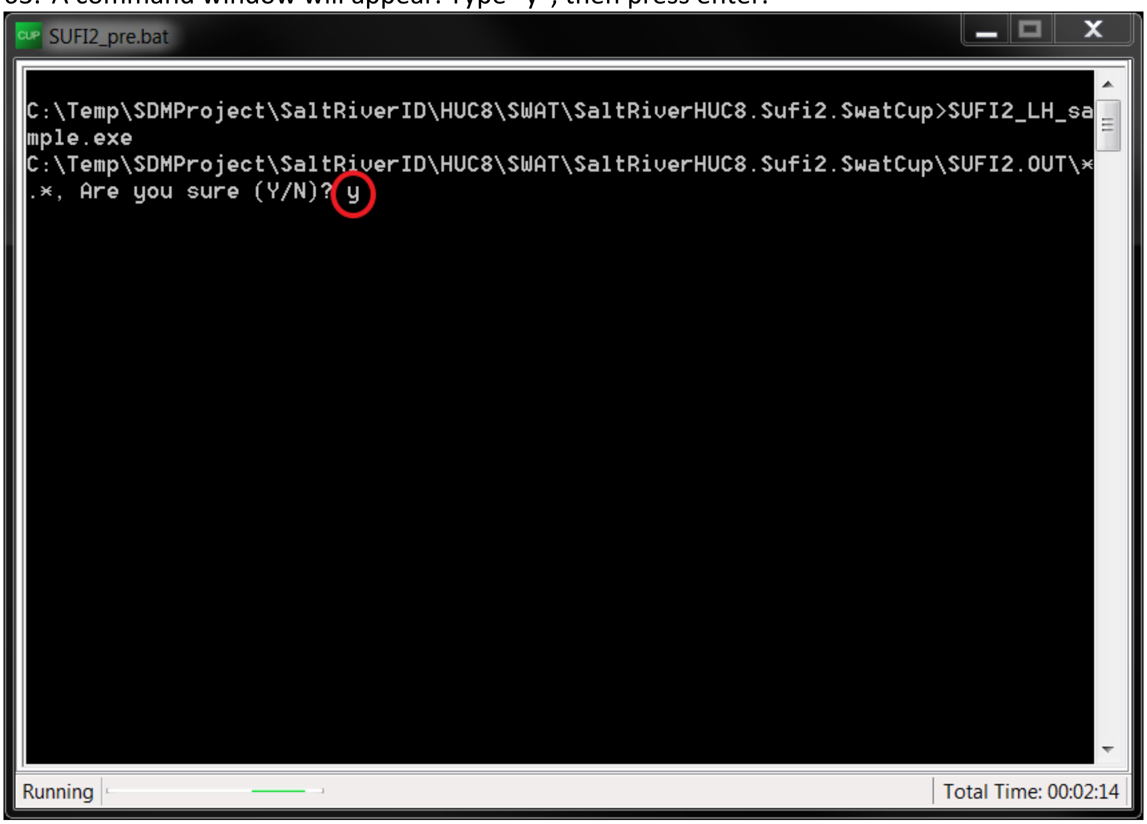
Calibration, Iteration 1

61. Go to the “Home” tab in the SWAT-CUP window, and click the “Calibrate” button.

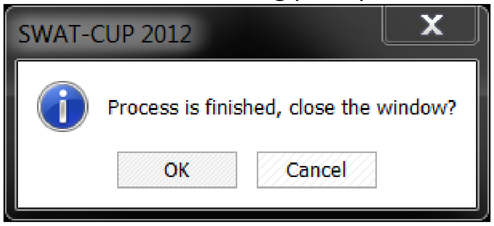


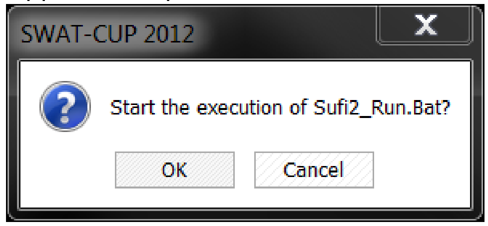
62. The following “Execute Calibration” window will appear. Click “Execute all”.

63. A command window will appear. Type “y”, then press enter.

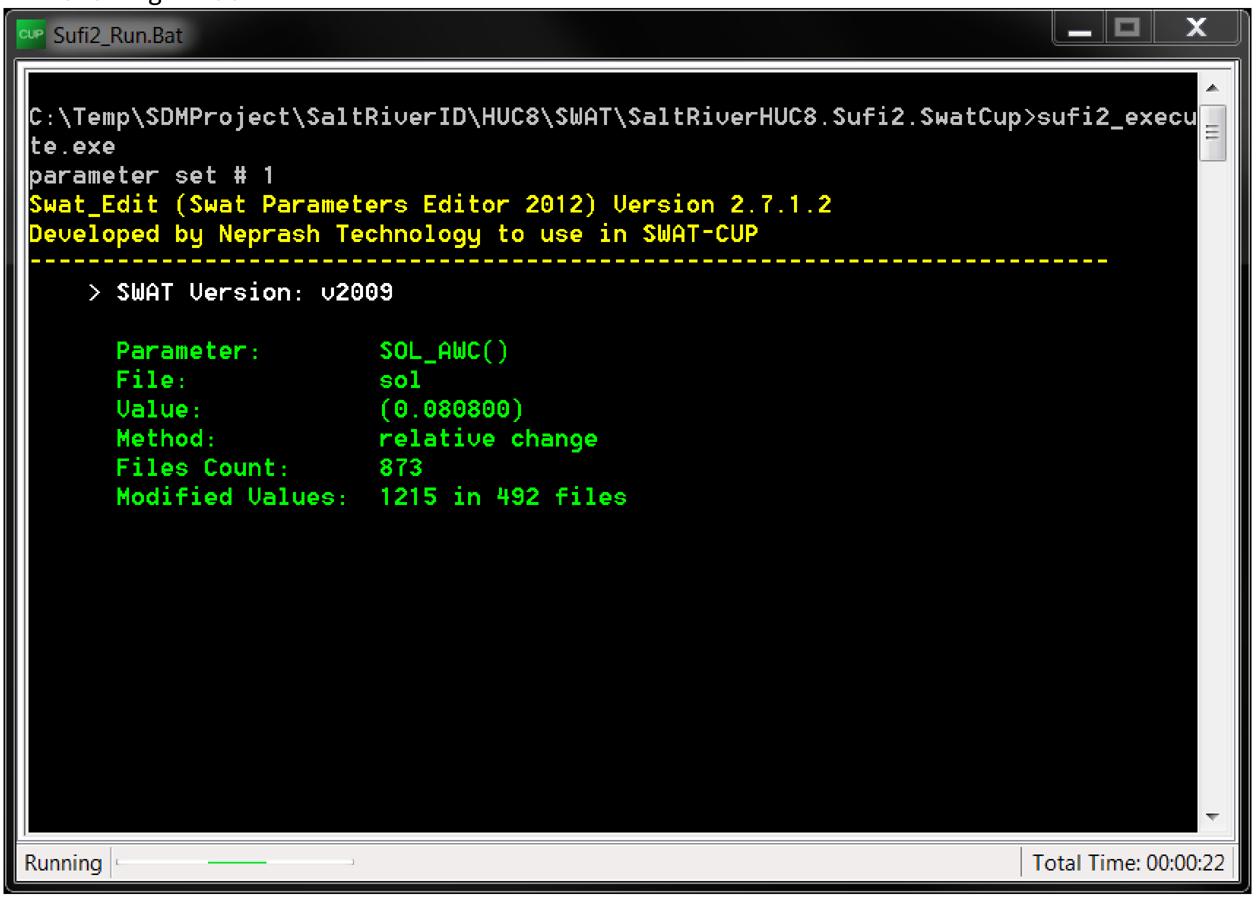


64. When the following prompt windows appear in sequence, click “OK”.

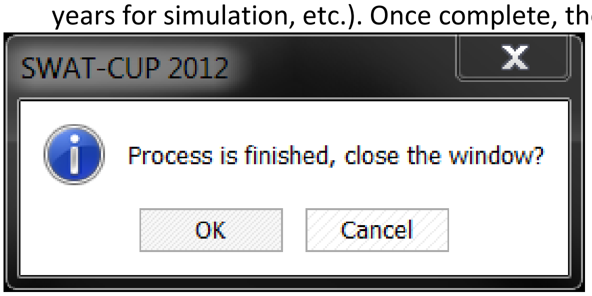




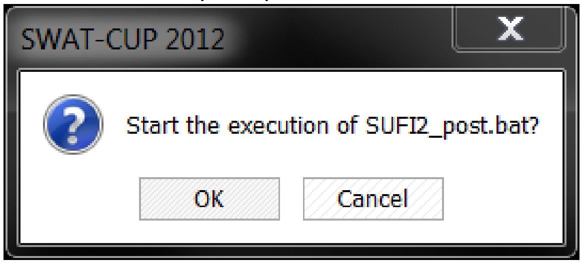
65. Execution of SWAT-CUP will begin, and it will run SWAT with multiple parameter sets in the following window.



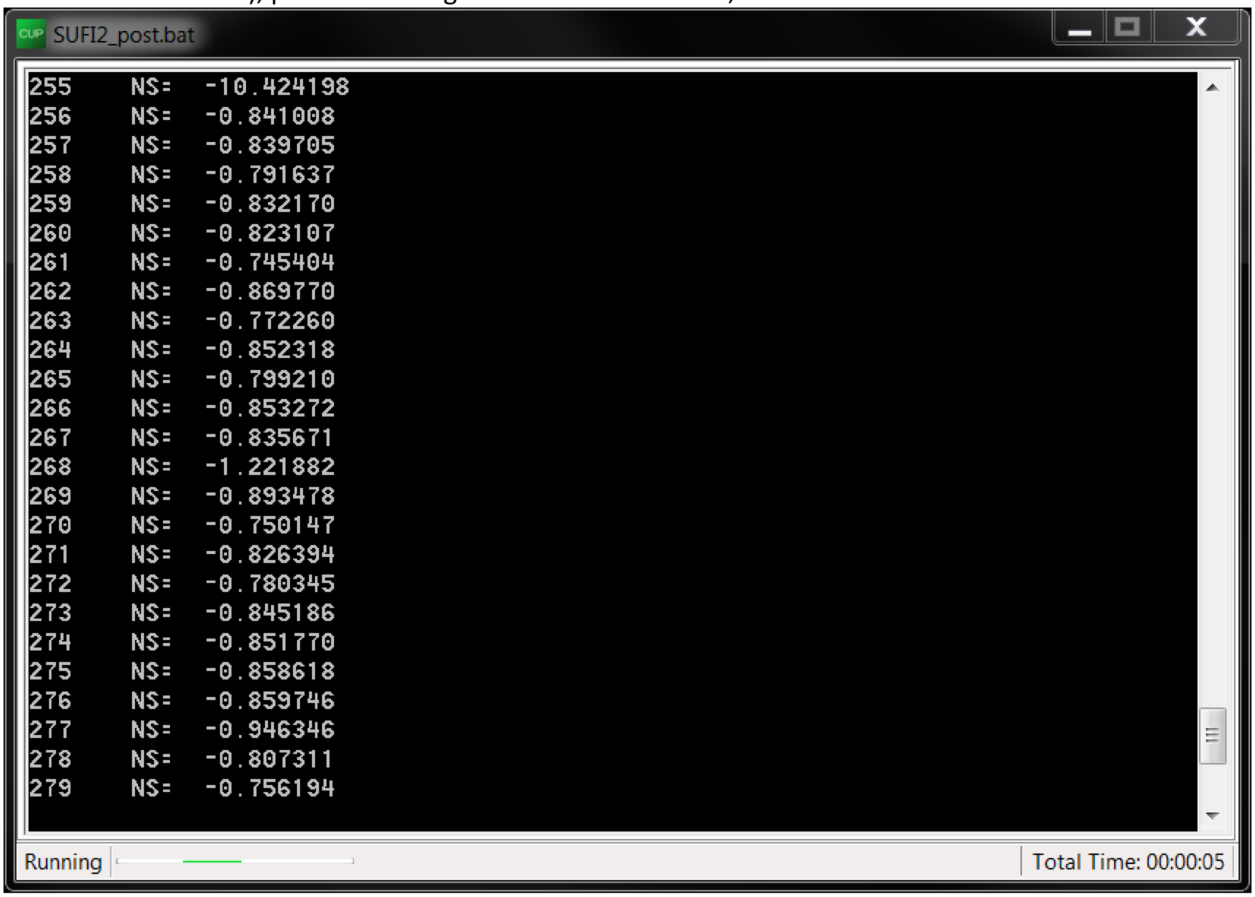
66. This execution may take hours to days depending on the project (e.g., number of HRUs, subbasins, years for simulation, etc.). Once complete, the following prompt window will appear. Click “OK”.



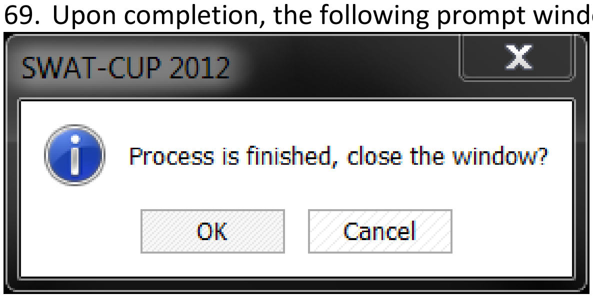
67. On the next prompt window, click "OK".



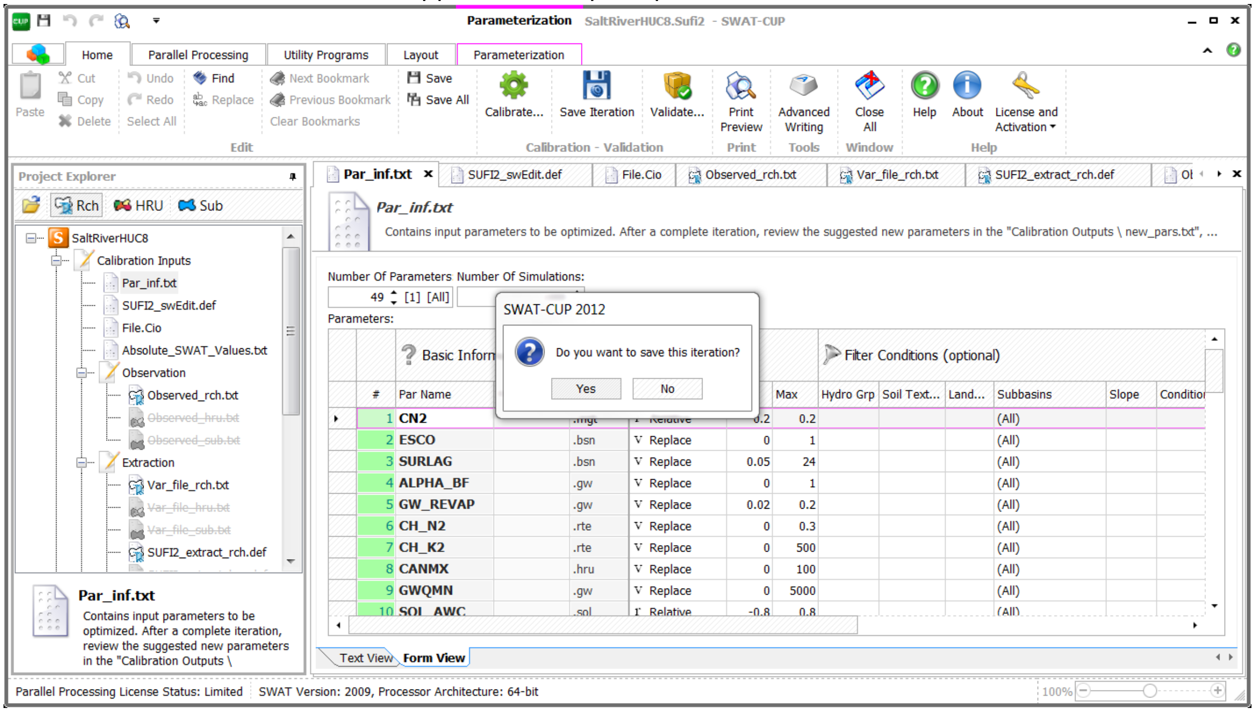
68. SWAT-CUP will perform post processing, including calculating the objective function (i.e., Nash-Sutcliffe statistic), parameter range for the next iteration, etc.



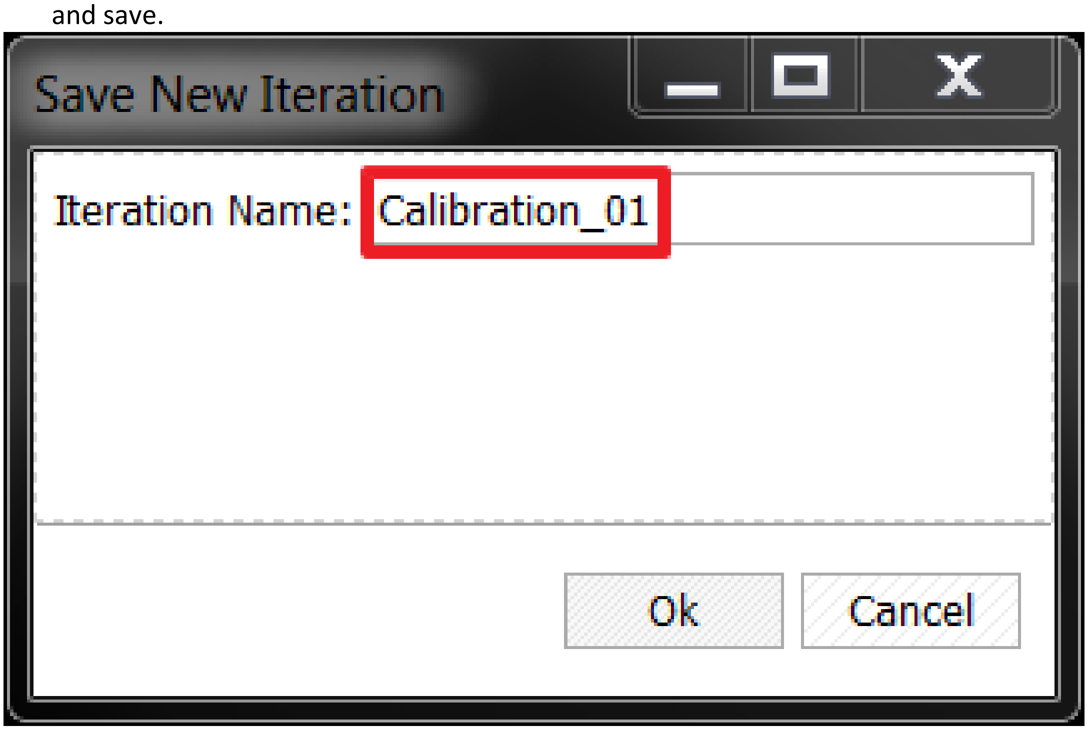
69. Upon completion, the following prompt window will appear. Click "OK".



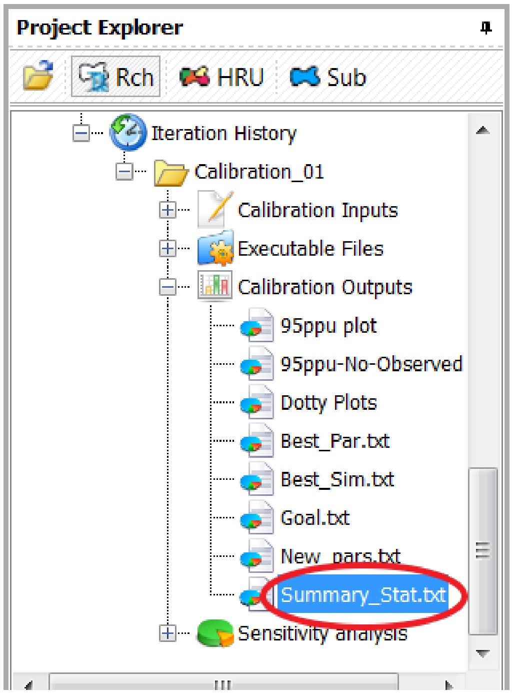
70. The main SWAT-CUP window appears with a prompt window. Click “Yes”.



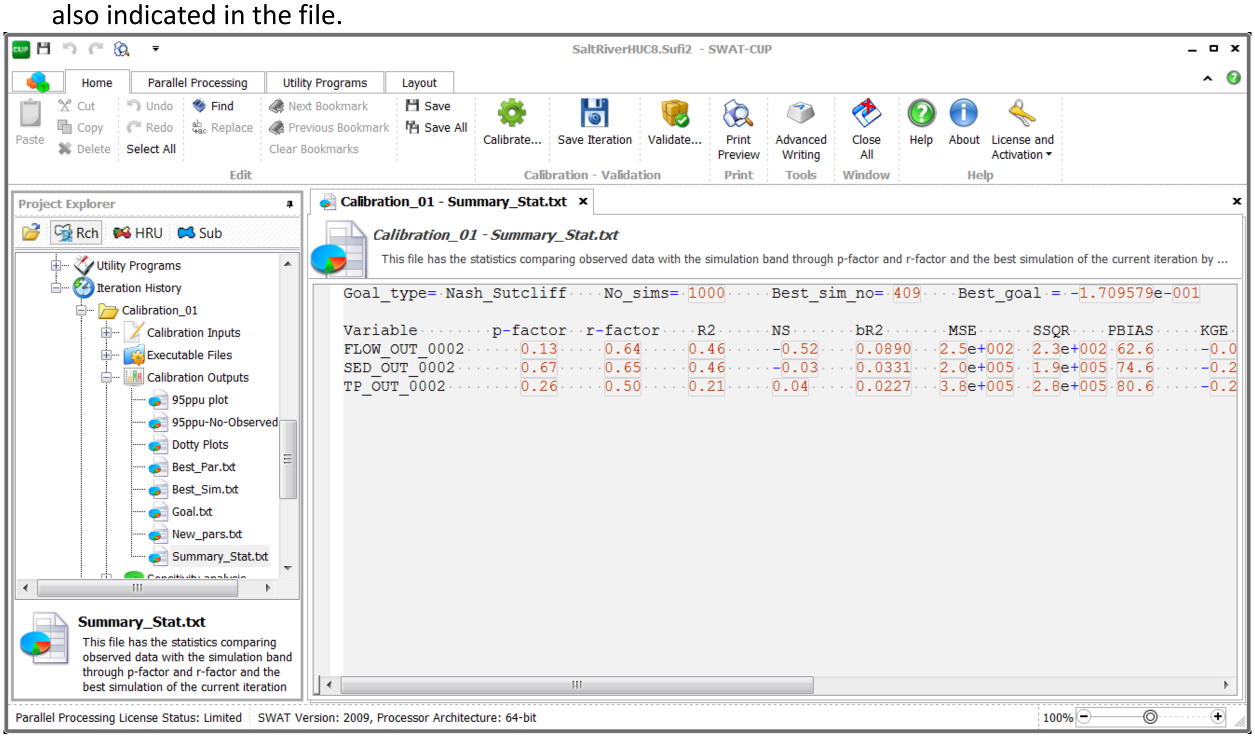
71. The following window appears. In this example, “Iteration Name” is “Calibration_01”. Click “Ok”, and save.



72. The first iteration of the parameter calibration is complete. To view results, open “Iteration History>Calibration Outputs>Summary_Stat.txt” in the “Project Explorer” section by double-clicking on “Summary_Stat.txt”.



73. The file will open to the SWAT-CUP window. In the “Summary_Stat.txt”, results of the best objective function for the SWAT simulation are shown for each variable. Other goodness-of-fit statistics are also indicated in the file.



74. Results of the goodness-of-fit statistics do not indicate good performance of the SWAT model: -0.52, -0.03, and 0.04 of Nash-Sutcliffe for flow, sediment, and total phosphorus, respectively. Because Iteration 1 may not be acceptable, additional calibrations iterations may be required.

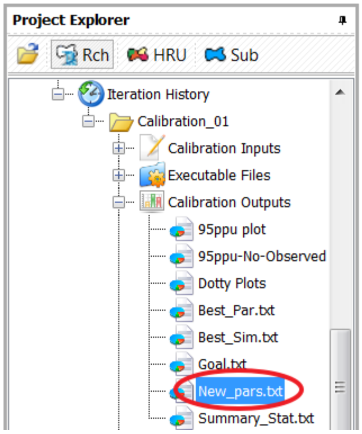
A summary of key folder locations associated with the example calibration is presented in Table 3.

Table 3. Folder Locations of Key Files for this Example Calibration

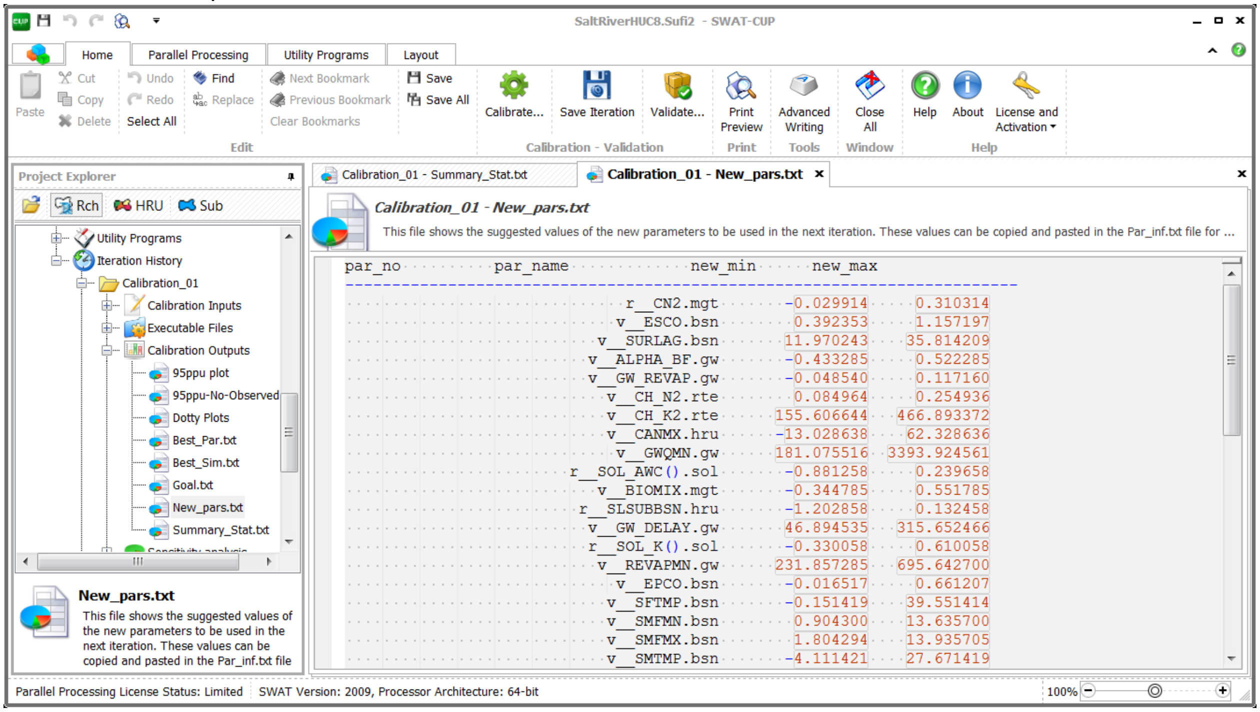
FILE	FOLDER LOCATION
par_inf.txt	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\SaltRiverHUC8.Sufi2.SwatCup\SUFI2.IN\
New_pars.txt	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\SaltRiverHUC8.Sufi2.SwatCup\SUFI2.OUT\
Absolute_SWAT_Values.txt	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\SaltRiverHUC8.Sufi2.SwatCup\ [Note that this file is a part of SWAT-CUP.]
SWAT_SWATCUP.exe	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\ [Note that this file is included with the SDMPB install and copied to C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT-SWATCUP\ when a new SDMPB project is generated.]
Input_SWAT.in	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\ [Note that this file is included with the SDMPB install and copied to C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT-SWATCUP\ when a new SDMPB project is generated.]
Update_par_inf.exe	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\ [Note that this file is included with the SDMPB install and copied to C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT-SWATCUP\ when a new SDMPB project is generated.]
par_inf_init.txt	C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\SaltRiverHUC8.Sufi2.SwatCup\SUFI2.IN\ [Note that this file is generated by "Update_par_inf.txt", when it is executed after the first iteration.]

Additional Calibration Iterations

75. To improve performance statistics, additional calibration iterations can be implemented by repeating steps outlined previously for calibration Iteration 1. With new iterations, parameter ranges, which can be supplied by SWAT-CUP, must be updated. To view, open "Iteration History>Calibration_01>Calibration Outputs>New_pars.txt" in the "Project Explorer" section by double-clicking the name.

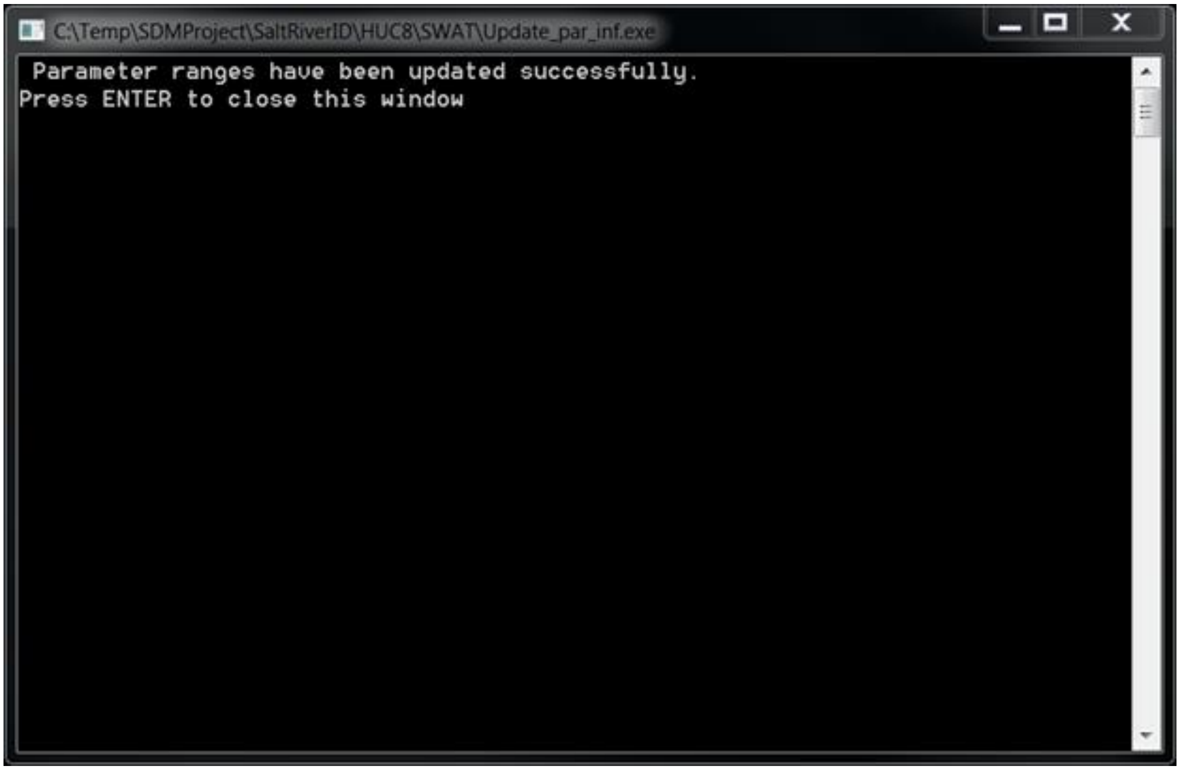


76. The file will open to the SWAT-CUP window.

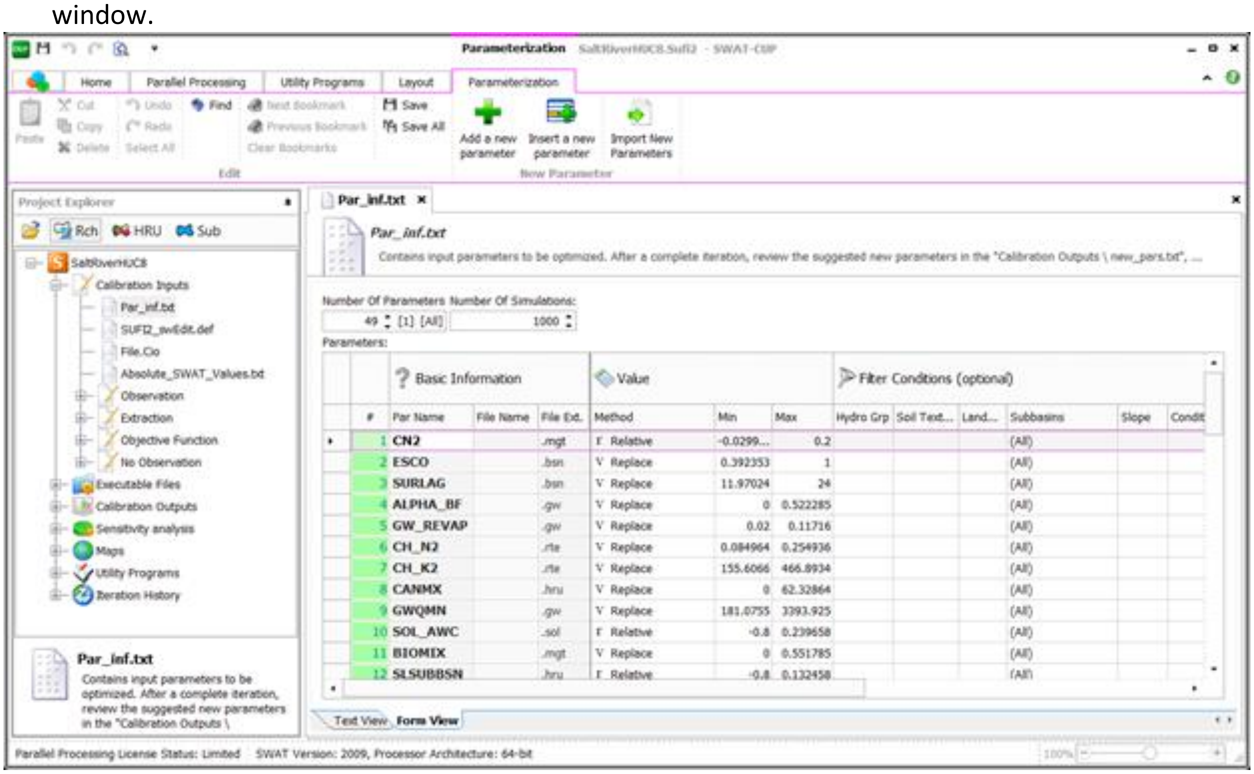


Because SWAT-CUP does not consider acceptable minimum and maximum values identified in par_inf_init.txt (which contains the same ranges as in "Absolute_SWAT_Values.txt") when it suggests ranges in "New_pars.txt", those ranges must be reviewed and revised, then copied to "par_inf.txt" for use in the calibration. For example, in the above window, the new range for "ALPHA_BF" is calculated as -0.43 – 0.52, and the acceptable range is 0 – 1. In this case, the new range needs to be revised to 0 – 0.52. Although these ranges can be modified manually by copying the revised ranges to "par_inf.txt" (located in "C:\Temp\SDMProject\SaltRiverID\HUC8\SWAT\SaltRiverHUC8.Sufi2.SwatCup\SUFI2.IN\"), a module ("Update_par_inf.exe") has been developed to automatically check and revise ranges and copy them to "par_inf.txt" for use in the calibration process.

77. Execute "Update_par_inf.exe". The Command window below appears. Press "Enter" to exit.



78. Updated parameter ranges in “Par_inf.txt” can be checked by opening the file in the SWAT-CUP window.



79. For additional iterations, repeat steps outlined in “Calibration, Iteration 1” until the desired objective function (e.g., Nash-Sutcliffe statistic) is obtained. A summary of calibration steps is presented in Table 4. For this example, flow, sediment, and nutrient have been calibrated simultaneously, so there is only one calibration with 10 iterations.

80. This example performed 10 iterations, and a summary of the results for the 10th iteration can be found in “Iteration History>Calibration_10>Calibration Outputs>Summary_Stat.txt”

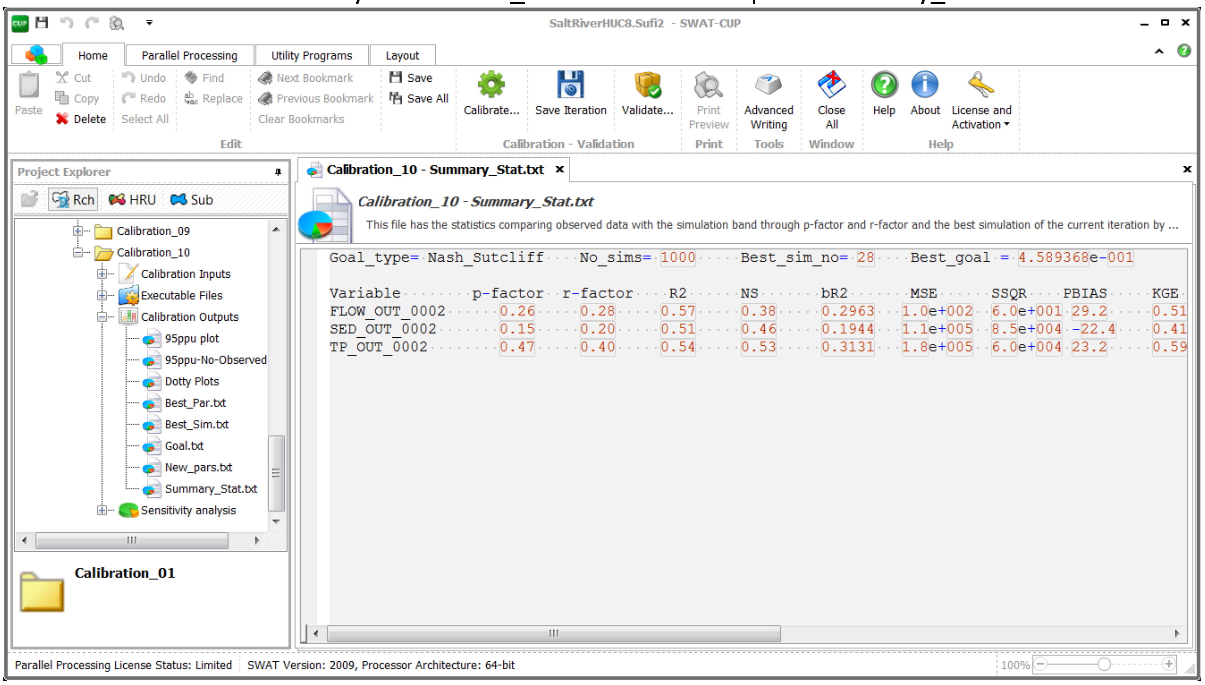


Table 4. Summary of Calibration Steps

CALIBRATION 1
1. Manually update “Input_SWAT.in” with a text editor
2. Execute “SWAT_SWATCUP.exe”
First iteration of calibration 1
3. Go to the “Home” tab in the SWAT-CUP window and click “Calibrate” button.
4. Click the “Execute all” button.
5. Answer command line questions and prompt windows
6. Save first iteration of calibration 1
• When the iteration is saved, it copies files (file.cio, SUFI2_extract_rch.def, etc.) from the SWAT-CUP project folder and subfolders (“.\SUFI2.IN\” and “.\SUFI2.OUT\”) to the “.\Iterations\(*Iteration Name*)\” folder. Saved files for the first and subsequent iterations are different. For example, parameter ranges in “par_inf.txt” are different, and resulting files in .\SUFI2.OUT\ are different.
7. Execute “Update_par_inf.exe”, where the first iteration is based on the original “par_inf.txt” (i.e., prior to modification), and the following automated steps (i.e., invisible to the user) occur:
• reads “new_pars.txt”

- reads the original “par_inf.txt” file [For the first iteration, parameter ranges are the same as those in “Input_SWAT.in”.]
  saves the “par_inf.txt” ranges to “par_inf_init.txt”. [This only happens after the first iteration, so “par_inf_init.txt” records possible parameter ranges throughout the iterations for this calibration cycle.]
- compares new ranges with acceptable ranges
- updates new ranges in “par_inf.txt”

Second iteration of calibration 1

8. Go to the “Home” tab in the SWAT-CUP window and click the “Calibrate” button.
9. Click the “Execute all” button.
10. Answer command line questions and prompt windows
11. Save second iteration of calibration 1
12. Execute the “Update_par_inf.exe”; the following automated steps (i.e., invisible to the user) occur:
    - reads “new_pars.txt”
    - reads “par_inf_init.txt” to obtain the possible ranges. [Note that ranges in “par_inf_init.txt” and “Input_SWAT.in” are the same].
    - compares new ranges with acceptable ranges
    - updates the new ranges in “par_inf.txt”

Third iteration of calibration 1

●
●
●

Tenth iteration of calibration 1

etc.

[Note: The total number of iterations depends on goodness-of-fit statistics]

CALIBRATION 2

13. Update “Input_SWAT.in” manually with a text editor
14. Execute “SWAT_SWATCUP.exe”

First iteration of calibration 2

15. Go to the “Home” tab in the SWAT-CUP window and click “Calibrate” button.
16. Click “Execute all” button.
17. Answer command line questions and prompt windows
18. Save the first iteration of calibration 2
19. Execute “Update_par_inf.exe” (see Step 7)

Second iteration of calibration 2

20. Go to the “Home” tab in the SWAT-CUP window and click “Calibrate” button.
21. Click the “Execute all” button.
22. Answer command line questions and prompt windows
23. Save the second iteration of calibration 2
24. Execute “Update_par_inf.exe”(see Step 12)

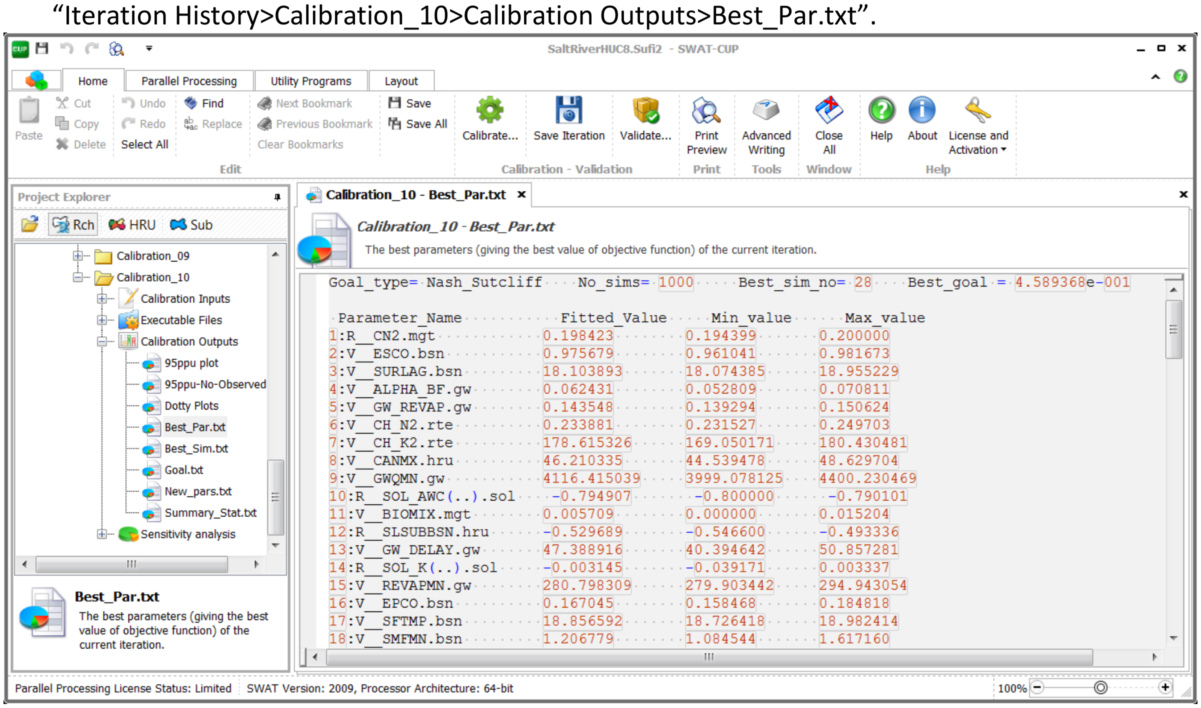
Third iteration of calibration 2

●
●
●

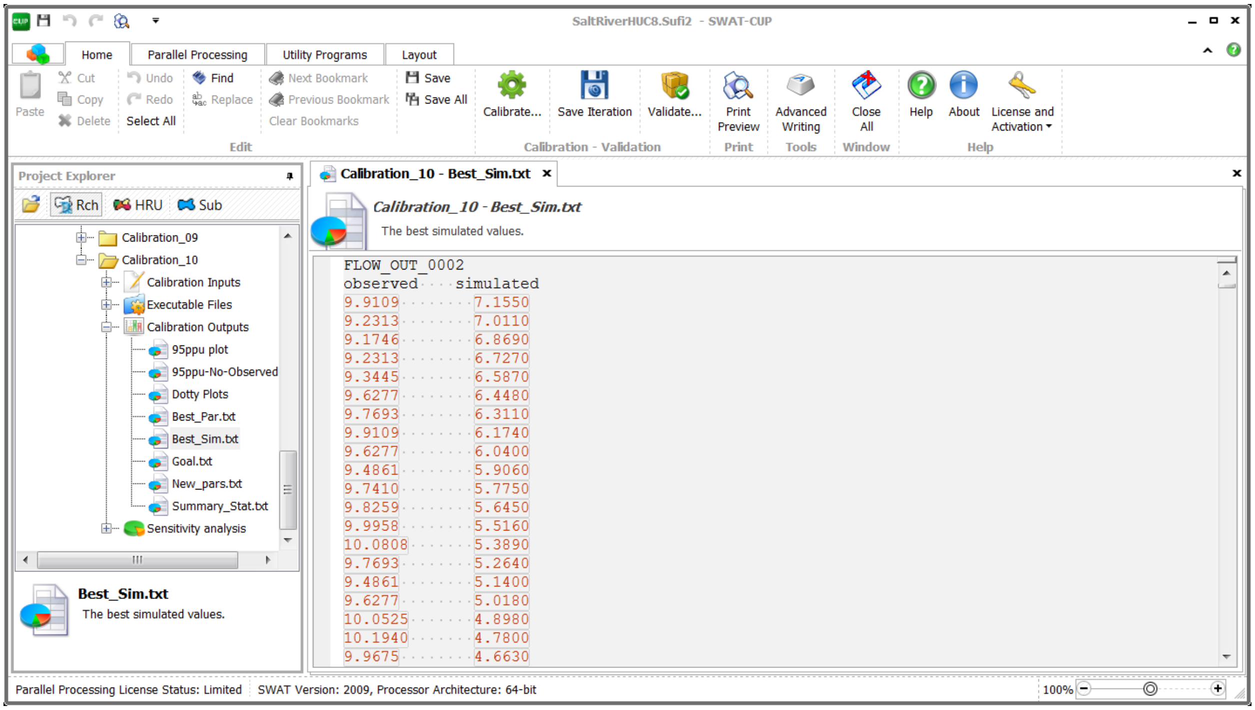
Tenth iteration of calibration 2
•
•
•
CALIBRATION 3
•
•
•

81. After the 10th iteration, Nash-Sutcliffe statistics have improved to 0.38, 0.46, and 0.53 for flow, sediment, and total phosphorus, respectively. This example calibrates the three parameters simultaneously to illustrate the calibration process. It is strongly recommended to calibrate parameters for flow, sediment, and nutrients separately when performing SWAT parameter calibrations. Appendix B provides example "Input_SWAT.in" files for independent calibrations of flow, sediment, and nutrients. One can modify "Input_SWAT.in" and repeat steps outlined in "Calibration, Iteration 1" and "Additional Calibration Iterations". Additional calibration steps are summarized in Table 4, including steps for Calibrations 2 and 3.

82. The parameters sets with the best Nash-Sutcliffe statistic can be found in "Iteration History>Calibration_10>Calibration Outputs>Best_Par.txt".



83. A comparison of observations and simulations can be found in History>Calibration_10>Calibration Outputs>Best_Sim.txt". No specific software can generate plots for SWAT modeling results. One may import the results to BASINS and generate plots, similarly to those reported by Kim et al. (2016c), or use spreadsheet software such as Microsoft Excel.



DISCLAIMER

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APPENDIX A
Details of "SWAT_SWATCUP.exe" and "Input_SWAT.in"

The purpose is to provide details of the FORTRAN code for preparing SWAT parameter calibration with SWAT-CUP (i.e., SWAT_SWATCUP.exe). "SWAT_SWATCUP.exe" is designed to

- consume data from observation files downloaded by the user and the user input file "Input_SWAT.in"
- modify the SWAT input file "file.cio"
- prepare SWAT-CUP input files (i.e., SUFI2_swEdit.def, SUFI2_extract_rch.def, par_inf.txt, observed.txt, observed_rch.txt, var_file_name.txt, var_file_rch.txt) and an extra file including observed data with missing values (i.e., observed_data.txt).

Input files include:

- Observed data for flow, sediment, or nutrient for the parameter calibration, downloaded by user. The user must download data as instructed in this document. The time series in this file can include missing data.
- A User input file ("Input_SWAT.in") containing information for generating SWAT-CUP input files

```
startyear
endyear
ny_warm

nparaset

paragroup
(TNTP)
npara
para   parafile    change    lower    upper
  ⋮

paragroup
(TNTP)
npara
para   parafile    change    lower    upper
  ⋮
```

Figure A.1. Construction of user input file ("Input_SWAT.in")

Figure A.1 presents the format of the "Input_SWAT.in". Descriptions of input data are:

- *startyear*: simulation start year including model warm-up period
- *endyear*: simulation end year
- *ny_warm*: number of years for model warm-up from start of the simulation (i.e., *startyear*)
- *nparaset*: number of parameter sets to be generated by SWAT-CUP for parameter calibration
- *paragroup*: name of parameter group, which needs to be defined as "Flow", "Sediment", or "Nutrient"

- *(TNTP)*: names of nutrient to be calibrated ("TN", "TP", or "TNTP" for total nitrogen, total phosphorus, or both, respectively). This variable is only needed when the *paragroup* is "Nutrient". With another *paragroup* (Flow or Sediment), the line including *TNTP* must be removed.
- *npara*: number of parameters to be calibrated in the corresponding *paragroup*
- *para*: name of each parameter. Names can be identified from the SWAT input/output documentation (Arnold et al., 2012) or "Absolute_SWAT_Values.txt", generated in the SWAT-CUP project folder.
- *parafile*: extension of SWAT input file where the corresponding parameter will be located. The file extension can be identified from SWAT input/output documentation (Arnold et al., 2012) or "Absolute_SWAT_Values.txt".
- *change*: a variable that defines how parameter values should be changed. SWAT-CUP supports three change types: replace, relative, and additive. Among these, "SWAT_SWATCUP.exe" only supports two types: replace and relative, excluding additive change type; therefore, one of the following variables must be selected:
    - replace: parameter value is replaced
    - relative: parameter value is changed proportionally to the original value in the SWAT input file. This is generally done if the parameter is defined differently by landuses, soils, subbasins, etc.
- *lower* and *upper*: minimum and maximum values of each parameter used in the calibration process. Parameter ranges can be identified from "Absolute_SWAT_Values.txt".

Figure A.2 illustrates an example user input file "Input_SWAT.in". It defines three parameter groups for simultaneously calibrating flow, sediment, and nutrients (TN and TP for total nitrogen and total phosphorus, respectively). The following assumptions apply when constructing the file:

- A daily time step is assumed for calibrating parameters with observed data.
- Instantaneous observations of constituent concentrations are assumed to represent daily values.
- Instantaneous flow observation are used to estimate daily constituent loadings from concentrations. Daily flow observations always have to be prepared even when flow parameters are not calibrated. For example, when only sediment or nutrient parameters are calibrated, "SWAT_SWATCUP.exe" always asks for the flow observation file.
- To obtain total number of reaches in the SWAT project, software reads "fig.fig". The SWAT input file "fig.fig" defines channel connectivity and provides the total number of reaches.
- The objective function for parameter calibration uses the Nash-Sutcliffe Modeling Efficiency. The objective function can be modified through the "observed.txt" file.

```
1990          !Simulation start year
1995          !Simulation end year
1             !# of years for model warm up

1000          !# of parameter sets

Flow          !Parameter group
9             !# of parameters
CN2           mgt      relative   -0.2     0.2
ESCO          bsn      replace     0       1
SURLAG        bsn      replace     0.05    24
ALPHA_BF      gw       replace     0       1
GW_REVAP      gw       replace     0.02    0.2
CH_N2         rte      replace     0       0.3
CH_K2         rte      replace     0       500
CANMX         hru      replace     0       100
GWQMN         gw       replace     0       5000

Sediment      !Parameter group
11            !# of parameters
LAT_SED       hru      replace     0       5000
RSDIN         hru      replace     0       10000
ADJ_PKR       bsn      replace     0.5     2
PRF           bsn      replace     0       2
USLE_C{1-108} crop.dat relative   -0.5     0.5
USLE_P        mgt      replace     0       1
USLE_K()      sol      relative   -0.8     0.8
SPCON         bsn      replace     0.0001  0.01
SPEXP         bsn      replace     1       1.5
CH_COV1       rte      replace     0.05    0.6
CH_COV2       rte      replace     0.001   1

Nutrient      !Parameter group
TNTP          !TN or TP
7             !# of parameters
CMN           bsn      replace     0.001   0.003
CDN           bsn      replace     0       3
NPERCO        bsn      replace     0       1
PPERCO        bsn      replace     10      17.5
SDNCO         bsn      replace     0       1
RSDCO         bsn      replace     0.02    0.1
PHOSKD        bsn      replace     100     200
```

Figure A.2. Example user input file (“Input_SWAT.in”), which defines the three parameter groups for calibrating flow, sediment, and nutrient (TN and TP) parameters simultaneously

APPENDIX B

Example "Input_SWAT.in" Files for Independent Calibrations of Flow, Sediment, and Nutrients

```
Input_SWAT.in - Notepad
File  Edit  Format  View  Help
1990              !Simulation start year
1995              !Simulation end year
1                 !# of years for model warm up

1000              !# of parameter sets

Flow              !Parameter group
25                !# of parameters
CN2          mgt          relative    -0.2        0.2
ESCO         bsn      replace      0.01       1
SURLAG       bsn      replace      0.05      24
ALPHA_BF     gw       replace      0          1
GW_REVAP     gw       replace      0.02       0.2
CH_N2        rte      replace      0          0.3
CH_K2        rte      replace      0        500
CANMX        hru      replace      0        100
GWQMN        gw       replace      0       5000
SOL_AWC()    sol      relative    -0.8        0.8
BIOMIX       mgt      replace      0          1
SLSUBBSN     hru      relative    -0.8        0.8
GW_DELAY     gw       replace      1        450
SOL_K()      sol      relative    -0.8        0.8
REVAPMN      gw       replace      0        500
EPCO         bsn      replace      0.01       1
SFTMP        bsn      replace    -20         20
SMFMN        bsn      replace      0         20
SMFMX        bsn      replace      0         20
SMTMP        bsn      replace    -20         20
TIMP         bsn      replace      0          1
TLAPS        sub      replace    -10         10
SLSOIL       hru      replace      0        150
SOL_ALB()    sol      relative    -0.8        0.8
RCHRG_DP     gw       replace      0          1

Ln 1, Col 1
```

Figure B.1. Example user input file ("Input_SWAT.in"), which defines the setup of Flow for calibration

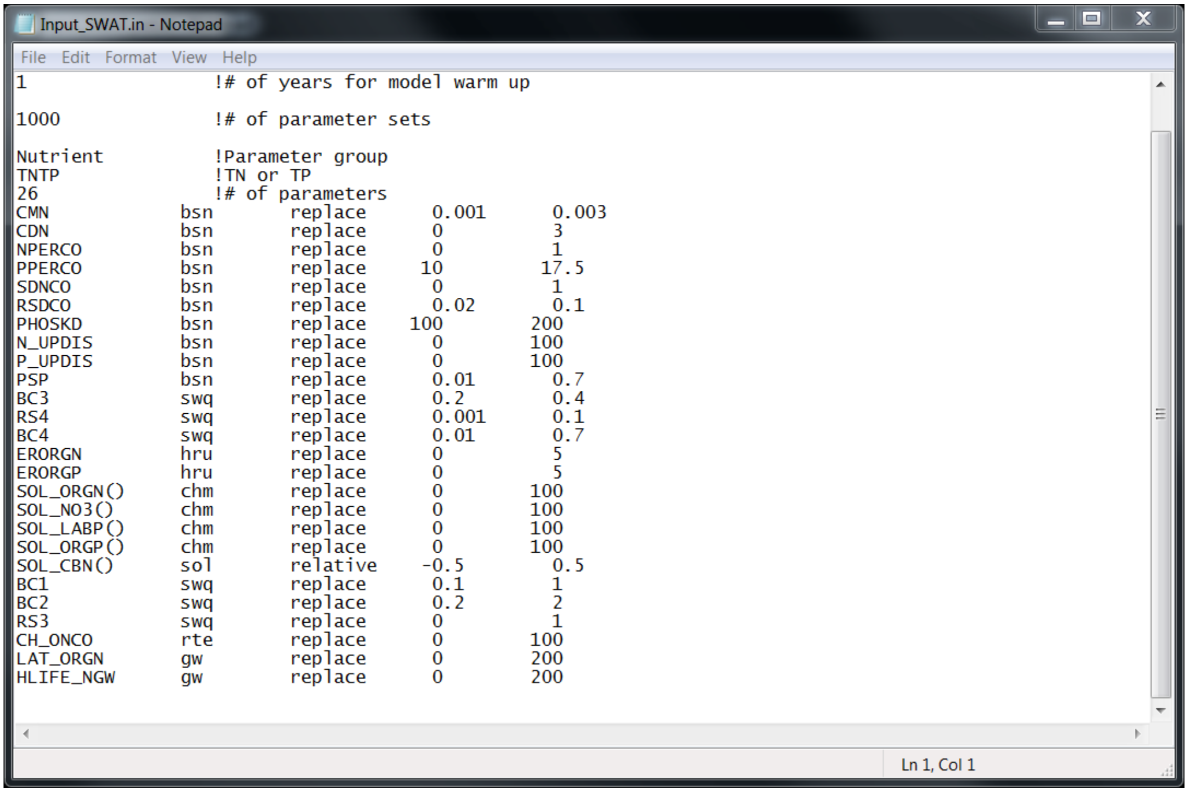
```
Input_SWAT.in - Notepad
File  Edit  Format  View  Help
1990              !Simulation start year
1995              !Simulation end year
1                 !# of years for model warm up

1000              !# of parameter sets

Sediment          !Parameter group
11                !# of parameters
LAT_SED      hru       replace      0        5000
RSDIN        hru       replace      0       10000
ADJ_PKR      bsn       replace      0.5         2
PRF          bsn       replace      0           2
USLE_C{1-108} crop.dat relative    -0.5         0.5
USLE_P       mgt       replace      0           1
USLE_K()     sol       relative    -0.8         0.8
SPCON        bsn       replace      0.0001      0.01
SPEXP        bsn       replace      1           1.5
CH_COV1      rte       replace      0.05        0.6
CH_COV2      rte       replace      0.001       1

Ln 1, Col 1
```

Figure B.2. Example user input file ("Input_SWAT.in"), which defines the setup of Sediment for calibration



```
1                  !# of years for model warm up

1000               !# of parameter sets

Nutrient           !Parameter group
TNTP               !TN or TP
26                 !# of parameters
CMN            bsn       replace      0.001      0.003
CDN            bsn       replace      0          3
NPERCO         bsn       replace      0          1
PPERCO         bsn       replace     10          17.5
SDNCO          bsn       replace      0          1
RSDCO          bsn       replace      0.02       0.1
PHOSKD         bsn       replace    100         200
N_UPDIS        bsn       replace      0         100
P_UPDIS        bsn       replace      0         100
PSP            bsn       replace      0.01       0.7
BC3            swq       replace      0.2        0.4
RS4            swq       replace      0.001      0.1
BC4            swq       replace      0.01       0.7
ERORGN         hru       replace      0          5
ERORGP         hru       replace      0          5
SOL_ORGN()     chm       replace      0         100
SOL_NO3()      chm       replace      0         100
SOL_LABP()     chm       replace      0         100
SOL_ORGP()     chm       replace      0         100
SOL_CBN()      sol       relative    -0.5        0.5
BC1            swq       replace      0.1        1
BC2            swq       replace      0.2        2
RS3            swq       replace      0          1
CH_ONCO        rte       replace      0         100
LAT_ORGN       gw        replace      0         200
HLIFE_NGW      gw        replace      0         200
```

Figure B.3. Example user input file ("Input_SWAT.in"), which defines the setup of Nutrients for calibration