QGIS Interface for SWAT-MODFLOW (QSWATMOD)

Version 1.2

July 2019

Prepared by: Seonggyu Park[1], Ryan Bailey[2] and Katrin Bieger[1]

[1]Blackland Research & Extension Center,

Texas A&M AgriLife Research

seonggyu.park@brc.tamus.edu

[2]Dept. of Civil and Environmental Engineering

Colorado State University

In Association With:

Name of Software QSWATMOD	**Year First Available** 2018
Developers Seonggyu Park and Anders Nielsen	**Cost** Free
Contact Address Blackland Research & Extension Center, Texas A&M AgriLife Research, 808 E. Blackland Road Temple, TX 76502, United States	**Programming Language** Python 2.7
Email seonggyu.park@brc.tamus.edu	**Software required** QGIS (v 2.18.21 ~ 2.18.27)
	Availability Software (including SWAT-MODFLOW executable, and datasets for the Little River Experimental Watershed) and documentation can be downloaded from https://swat.tamu.edu/software/swat-modflow/

This version describes QSWATMOD version 1.2, which is compatible with SWAT-MODFLOW version 3.

How to cite

Citation for QSWATMOD

Park, S., Nielsen, A., Bailey, R.T., Trolle, D. and Bieger, K., 2019. A QGIS-based graphical user interface for application and evaluation of SWAT-MODFLOW models. Environmental modelling & software, 111, pp.493-497. https://doi.org/10.1016/j.envsoft.2018.10.017

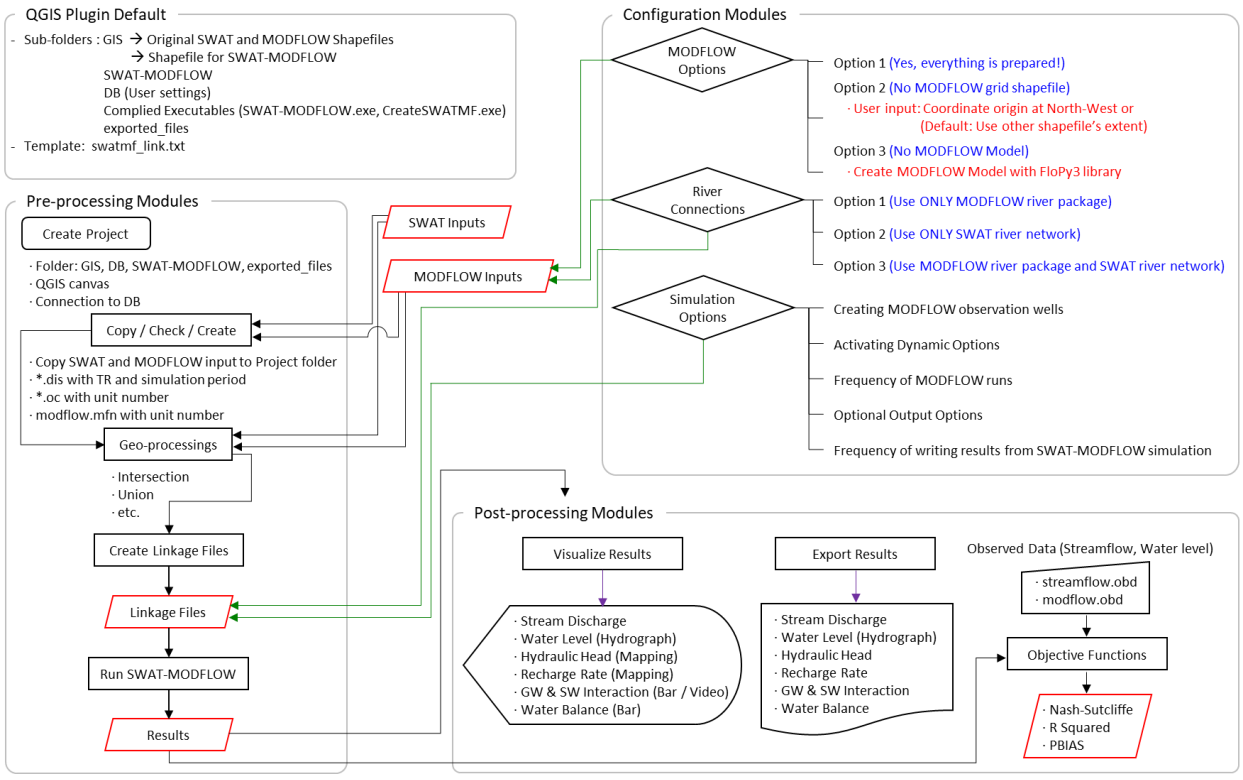
Citation for SWAT-MODFLOW

Bailey, R.T., Wible, T.C., Arabi, M., Records, R.M., Ditty, J., 2016. Assessing regional scale spatio-temporal patterns of groundwater-surface water interactions using a coupled SWAT-MODFLOW model. Hydrol. Process. 30 (23), 4420–4433. https://doi.org/10.1002/hyp.10933.

Contents

1. Overview of QSWATMOD

QSWATMOD is a QGIS-based GUI plugin that allows an existing SWAT model and a MODFLOW model to be linked within a geographical information system (GIS) setting, thus facilitating model preparation and model results viewing. The linkage is based on the SWAT-MODFLOW modeling code of Bailey et al. (2016), in which MODFLOW-NWT (Niswonger et al., 2011) is imbedded within the SWAT 2012 modeling code (Revision 591) to simulate groundwater flow and groundwater-surface water interactions. The tabs of QSWATMOD are "Pre-Processing", "Simulation", and "Post-Processing", which will be summarized in the next sections. All data processing is based on the pre-processing, configuration, and post-processing modules as outlined in the following figure. The current version of GUI handles a variety of scenarios for connecting MODFLOW river cells with SWAT subbasin channels for groundwater-surface water flow interactions. Besides the basic link between SWAT and MODFLOW (i.e. recharge, groundwater-surface water interactions), several other features have been included to allow more flexibility in applying SWAT-MODFLOW to managed watersheds. These features include linking MODFLOW groundwater pumping to SWAT irrigation and linking MODFLOW subsurface drains to SWAT channel flow.

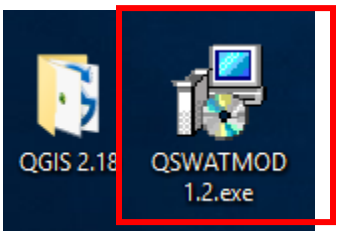


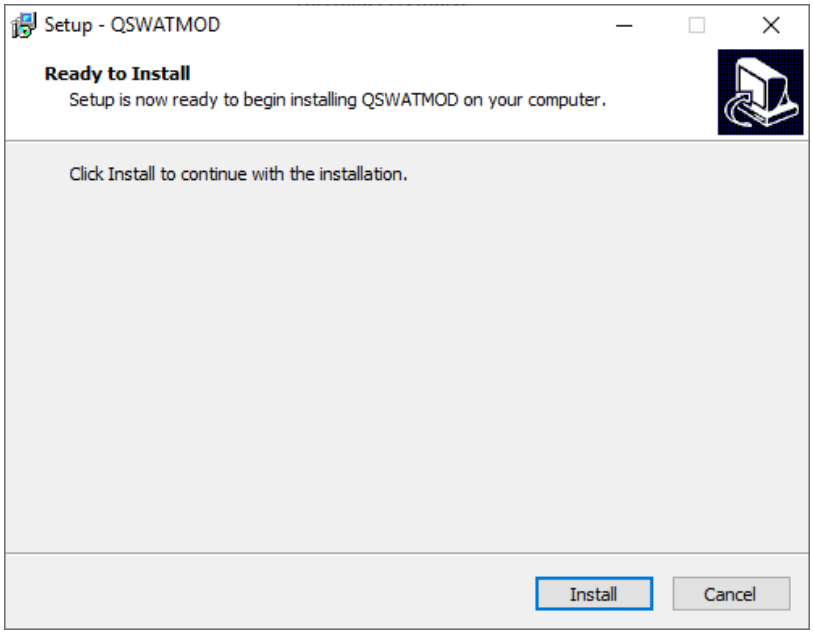
(Source: Park et al., 2018)

2. Installation

The QGIS software must be installed on the system prior to the installation of QSWATMOD. We recommend installing the latest “long term release (LTR)” version of QGIS (2.18.21 ~ 2.18.27)

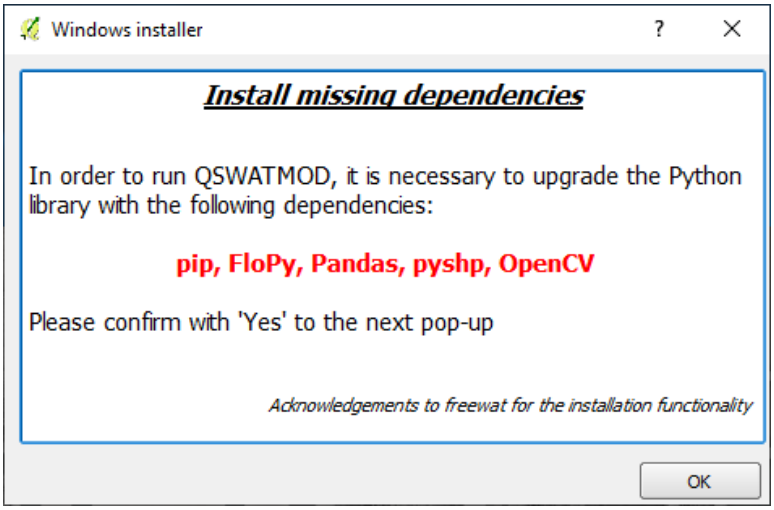
- Install QGIS by running QGIS-OSGeo4W-2.18.27-1-Setup-x86_64.exe. It can be downloaded from http://download.osgeo.org/qgis/win64/QGIS-OSGeo4W-2.18.27-1-Setup-x86_64.exe.
- Install QSWATMOD by running **QSWATMOD 1.2**.exe or a later version. The QSWATMOD is installed into the user's home directory (*~/.qgis2/python/plugins/QSWATMOD)*, which we will refer to as the *QSWATMOD plugin directory*. The latest version of QSWATMOD can be downloaded from the SWAT website https://swat.tamu.edu/software/swat-modflow.



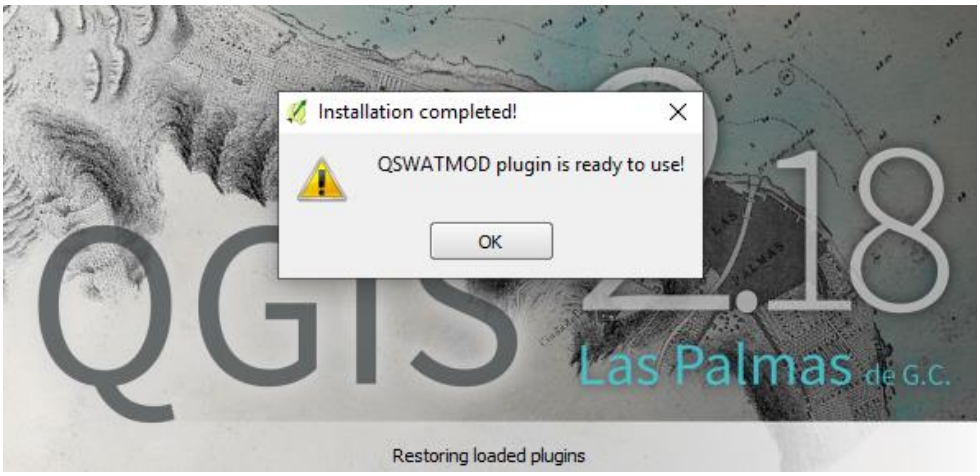


QSWATMOD has dependencies to third-party Python packages including FloPy3, Pandas, OpenCV, and pyshp. These packages will be installed automatically in the designated Python environment after QSWATMOD is activated in QGIS.

- Open QGIS after the installation of QSWATMOD is finished.
- Click the “Yes” button to install the dependencies.



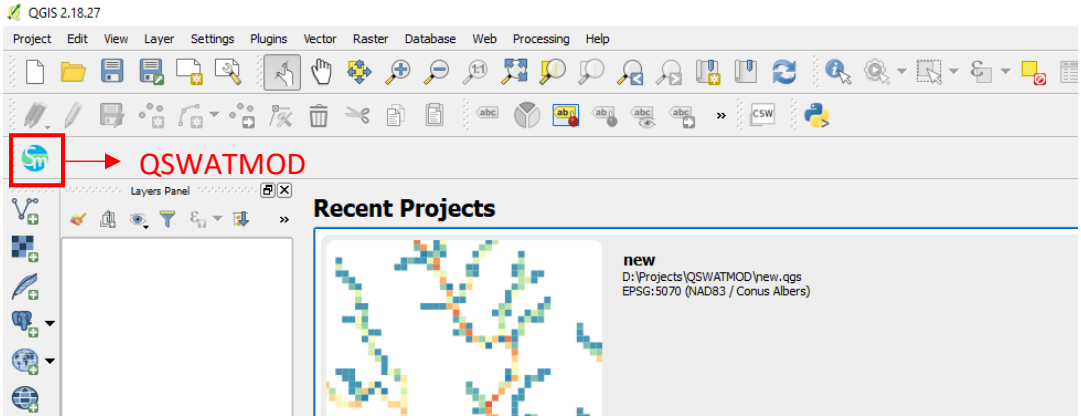
- After all the dependencies are installed, click the “OK” button. It will reopen QGIS automatically.



3. Setup for a New Project (LREW)

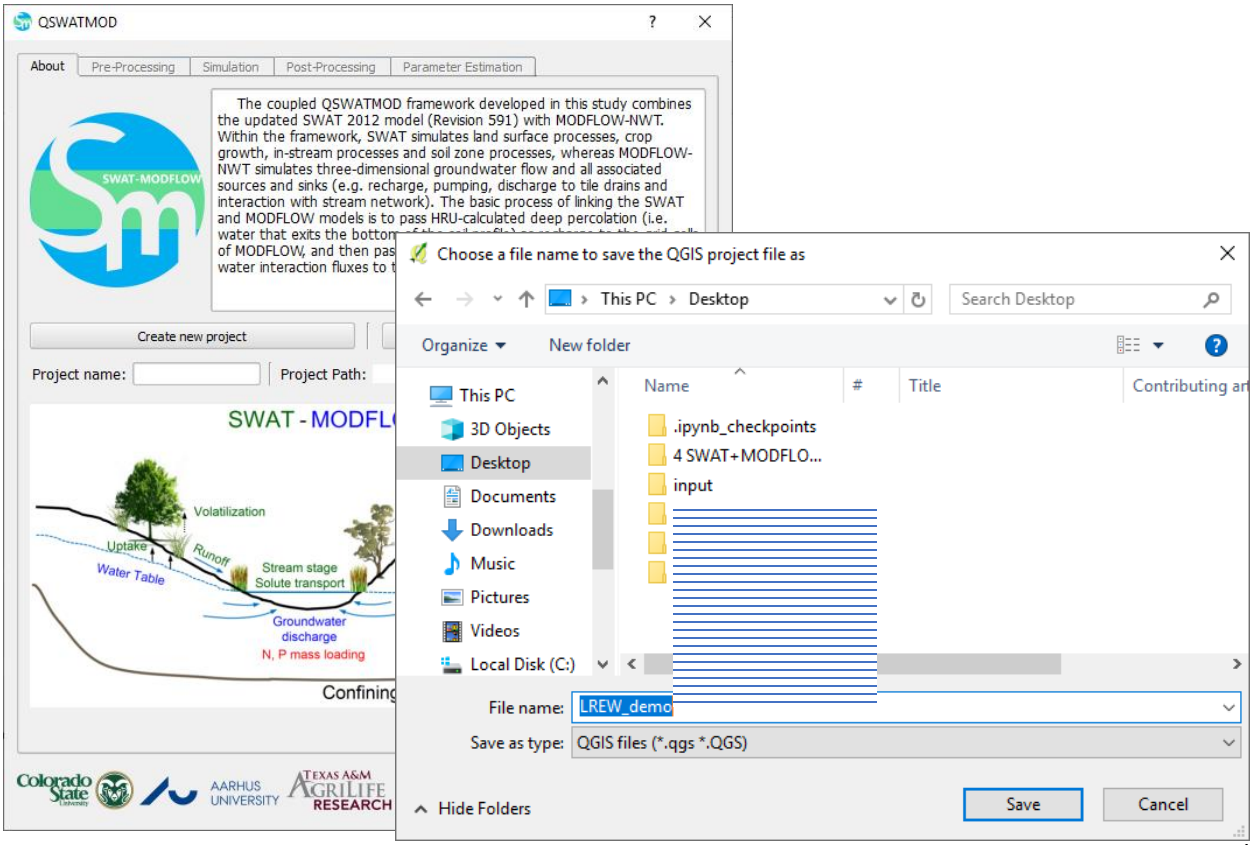
We are going to use the same dataset as the one used from Chapter 1 for a SWAT-MODFLOW simulation.

1) Click Plugins menu → Manage and Install Plugins and find QSWATMOD. Click its checkbox to activate. The QSWATMOD icon will appear in the toolbar.



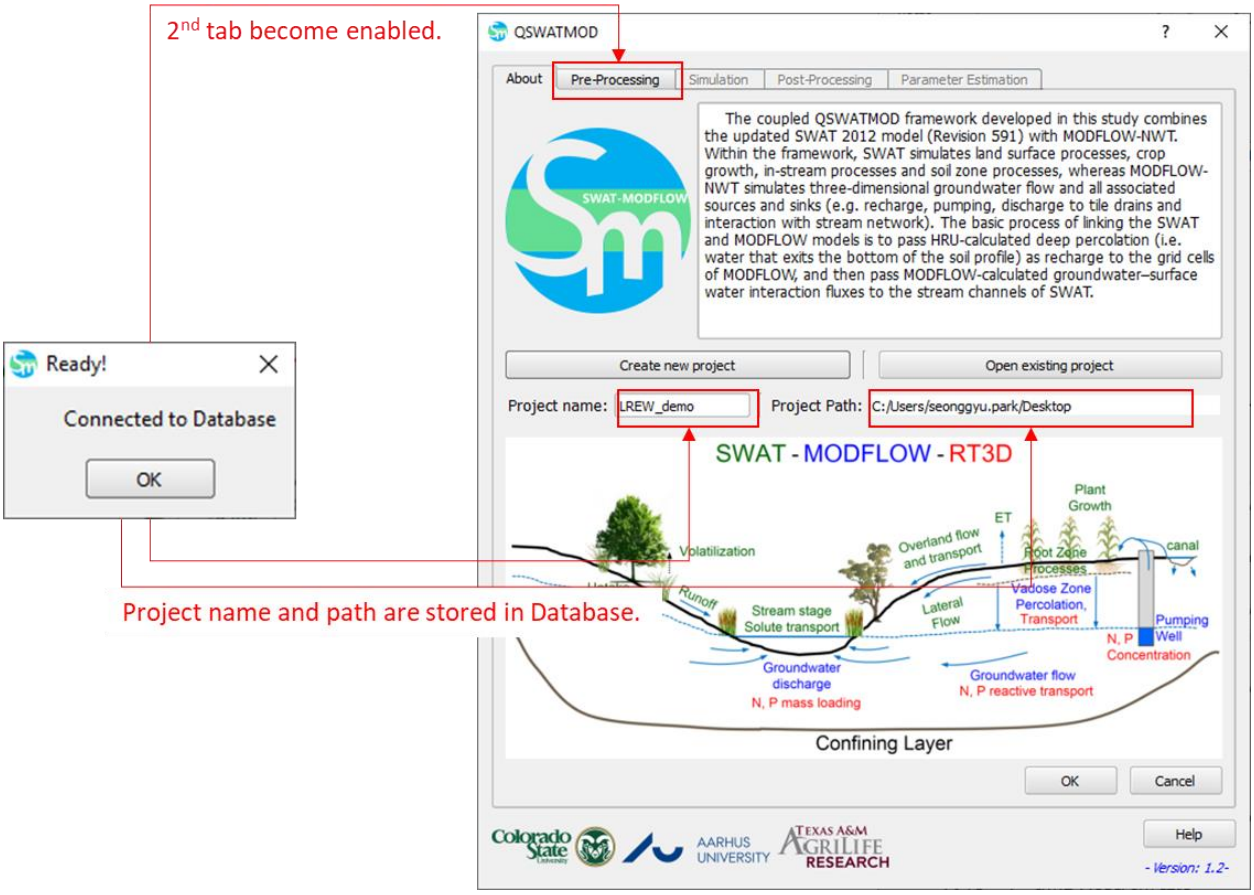
2) Open QSWATMOD by clicking its icon.

3) The main QSWATMOD GUI platform will be popped up. Click the "Create new project" button.



4) A browser will be shown requesting a name for the new project. As an example, create the project on the desktop naming “LREW_demo” and save it.

5) Click “OK”. It will get the 2nd tab (Pre-Processing) enabled and project name and its path will be stored in Database.

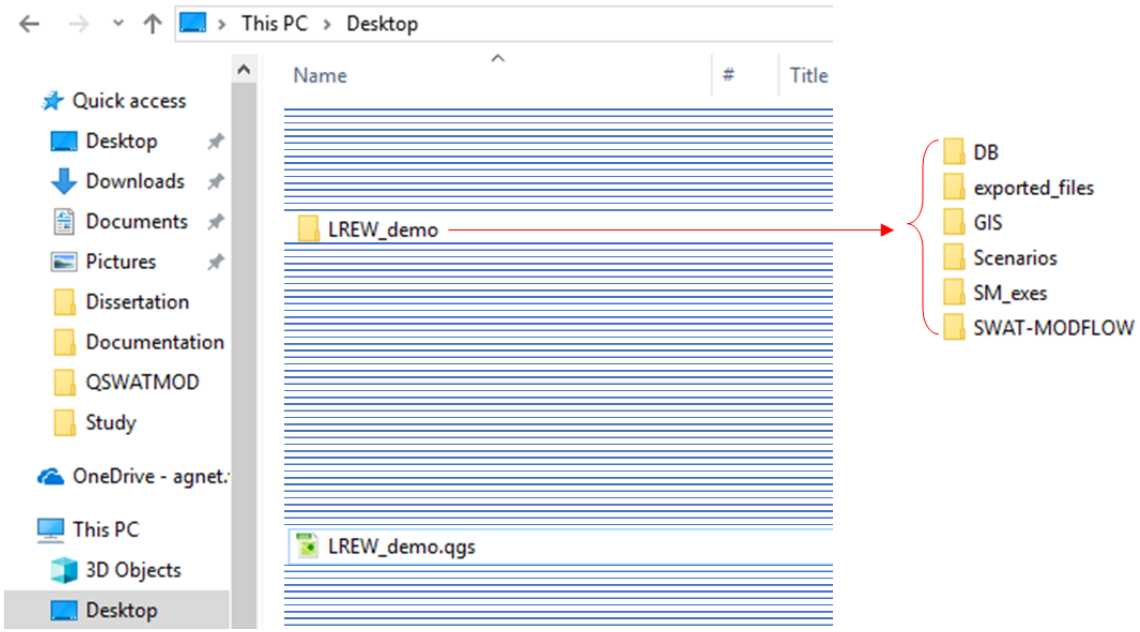


A project consists of a QGIS file (*.qgs), LREW_demo.qgis , which stores the information of QGIS status, loaded layers, user settings, and a project directory, which holds all project inputs and outputs.

Let’s exam the project directory (LREW_demo) on your desktop. The project directory contains 6 folders: DB, exported_files, GIS, Scenarios, SM_exes, and SWAT-MODFLOW.

- DB: contains *.db file holding project information, default user inputs and simulation settings.
- exported_files: simulation outputs (images, video, and text-formatted output files).

- GIS folder includes three sub-folders: org_shps (copies of original model shapefiles from SWAT and MODFLOW), SMshps (shapefiles used for creating linkage files and for visualizing simulation results), and Table (4 table files will be stored after the linking process is finished).
- Scenario folder will contain shapefiles used for creating additional hydrologic linkage files once this option become active.
- SM_exes includes the SWAT-MODFLOW3 and createSWATMF executables.
- SWAT-MODFLOW contains all the model input and output files.



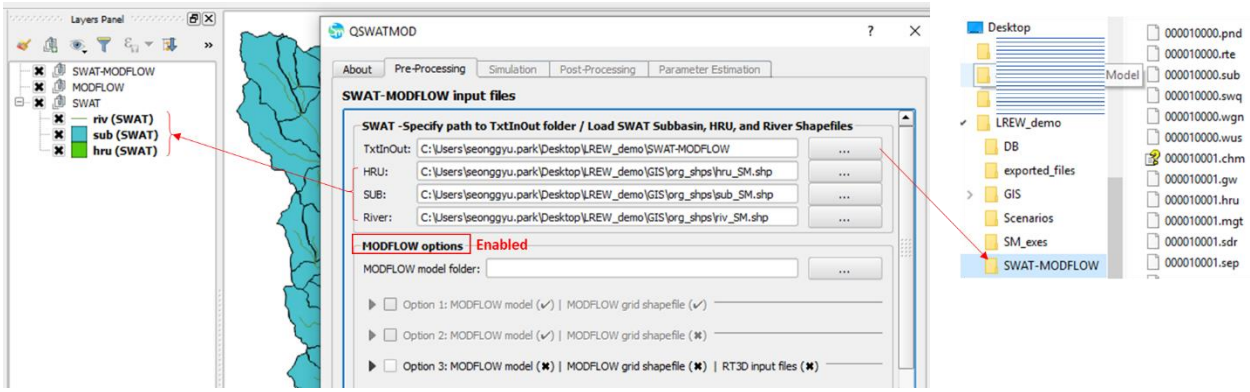
4. Pre-Processing Tab

4.1. SWAT Inputs

QSWATMOD creates copies of all SWAT model input files and associated GIS files (rasters, vectors) in the project folder and its sub-folders. For the tutorial,

1) Specify the path to the SWAT *TxtInOut* folder associated with the existing SWAT model *(…\Tutorial\SWAT-MODFLOW3\Files\1 SWAT LRW\SWAT Model\TxtInOut*).
2) Specify the paths to the HRU, sub-basin and river network shapefiles.

The copied HRU, sub-basin, and river network shapefiles are then imported to the QGIS canvas and shown in the SWAT layer tree. Once users provide all SWAT model input files and shapefiles, MODFLOW options become enabled.



4.2. MODFLOW options

QSWATMOD provides users with three options for MODFLOW:

a) MODFLOW model files and grid shapefile are available;

b) MODFLOW model files are available but there is no grid shapefile; and

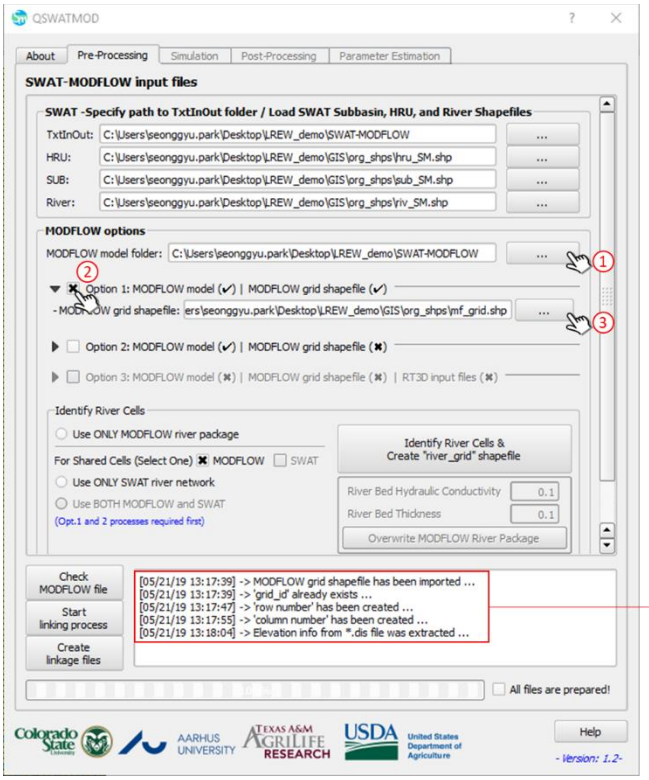
c) MODFLOW model has not yet been constructed.

4.2.1. MODFLOW model files and grid shapefile are available

This option guides users to specify the path to an existing MODFLOW model and MODFLOW grid shapefile, with the latter requiring the same projection as the SWAT shapefiles. For the tutorial,

1) Specify the path to the MODFLOW folder associated with the existing MODFLOW model *(…\Tutorial\SWAT-MODFLOW3\Files\2 MODFLOW LRW\MODFLOW model*).

2) Check the Option 1 and specify the path to the MODFLOW grid shapefile *(…\Tutorial\SWAT-MODFLOW3\Files\2 MODFLOW LRW\MODFLOW model shapefiles\MODFLOW_Grid.shp).*



* QSWATMOD creates or extracts information that can be used for creating linkage files or visualizing results.

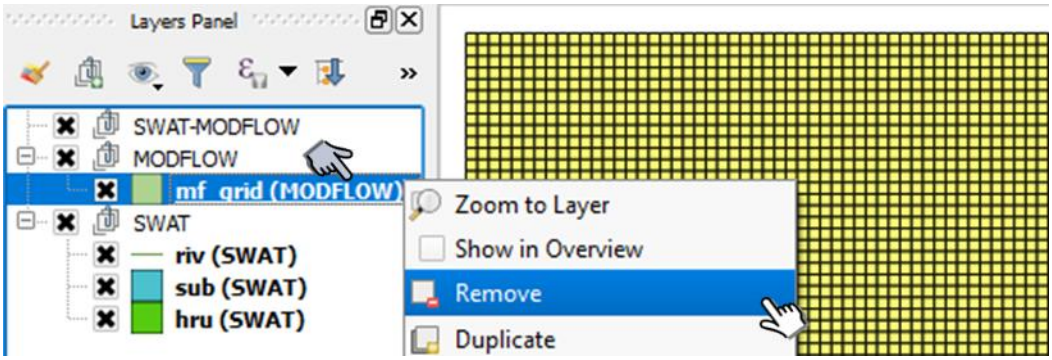
mf_grid (MODFLOW) :: Features total: 19176, filtered: 19176, selected: 0

	ID	GRIDCODE	grid_id	grid_area	row	col	elev_mf
11077	13392	5775	13392	40000	99	64	90.17000
11078	17795	1474	17795	40000	131	115	90.17000
11079	12593	6608	12593	40000	93	81	90.18000
11080	12319	6878	12319	40000	91	79	90.19000
11081	12852	6323	12852	40000	95	68	90.19000
11082	16406	2805	16406	40000	121	86	90.19000
11083	17511	1734	17511	40000	129	103	90.20000
11084	14100	5123	14100	40000	104	92	90.21000
11085	18608	655	18608	40000	137	112	90.21000
11086	11359	7822	11359	40000	84	71	90.22000
11087	17933	1340	17933	40000	132	117	90.22000
11088	12855	6326	12855	40000	95	71	90.23000
11089	13541	5652	13541	40000	100	77	90.23000

4.2.2. MODFLOW model files are available but there is no grid shapefile

For the second option, the user specifies the coordinate of the North-West corner of the MODFLOW boundary or, as default, the MODFLOW grid area can be created based on the extent of the SWAT subbasin shapefile, with both reading cell information (width, length, top elevation) from the MODFLOW discretization file (*.dis).

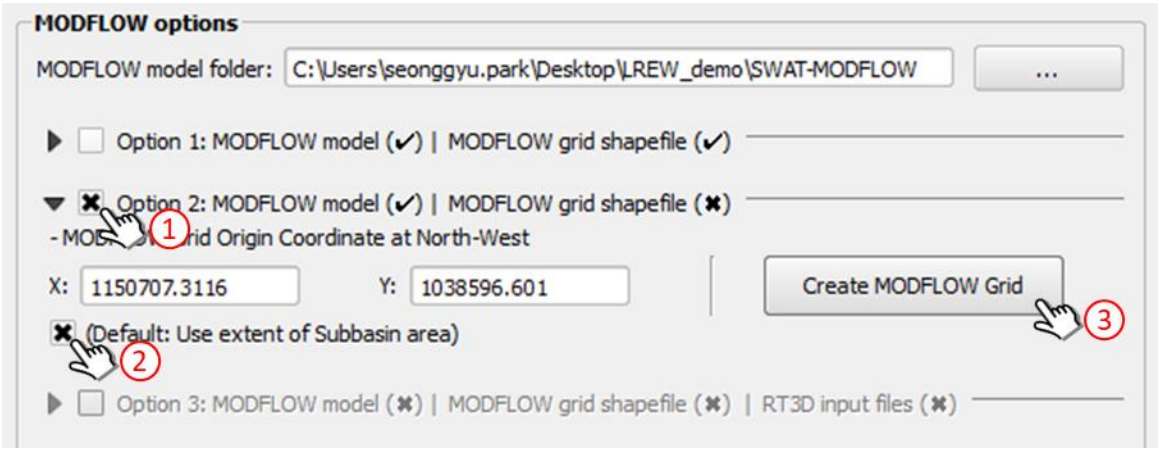
(If the "mf_grid (MODFLOW)" layer exists in Layer Panel, remove it first.)



1) Check the Option 2. If users want to create the MODFLOW grid area according to the extent of the SWAT subbasin shapefile, check the default check box (2) then the origin coordinates of the SWAT subbasin shapefile will appear.

   ** If users know specific values for MODFLOW origin coordinates at North-West, users need to provide X and Y coordinates that are expressed in the Universal Transverse Mercator (UTM) projection.*

2) Click the "Create MODFLOW Grid" button.



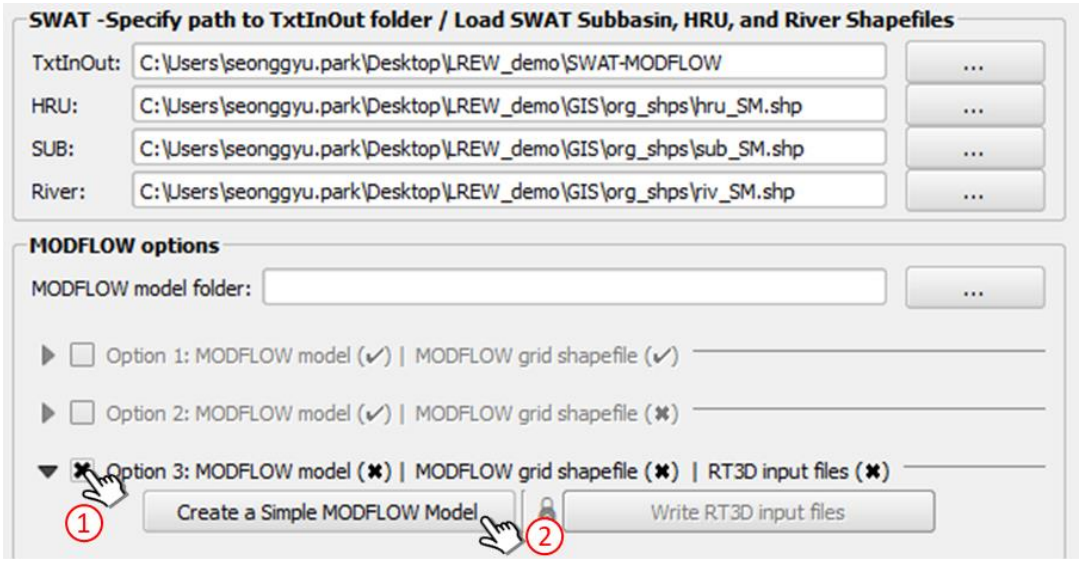
The MODFLOW grid shapefile (mf_grid.shp) is then created and the cell information is added to the attribute table of the MODFLOW grid shapefile.

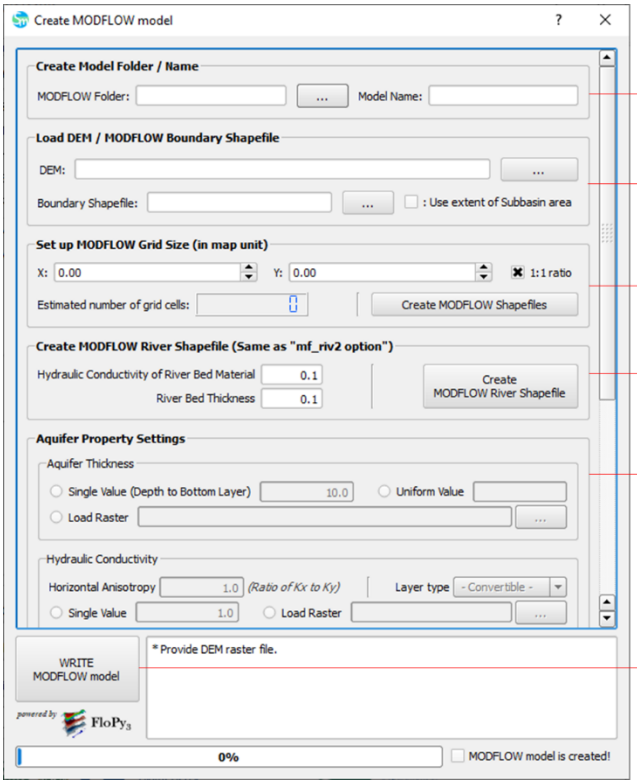
4.2.3. MODFLOW model has not yet been constructed

QSWATMOD provides an option for users to create a simple MODFLOW model, powered by the FloPy3 (Bakker et al., 2016) package.

If a MODFLOW model was not provided, only the 3rd option would be able to be checked.

1) Check the Option 3. Click the "Create a Simple MODFLOW model" button and the new window will pop up.





A folder to store MODFLOW input files is created. A model name is then created by the user and DEM and boundaries of the watershed are uploaded.

DEM and boundaries of the watershed are uploaded.

The MODFLOW grid is established using specified width (X) and length (Y) of grid cells.

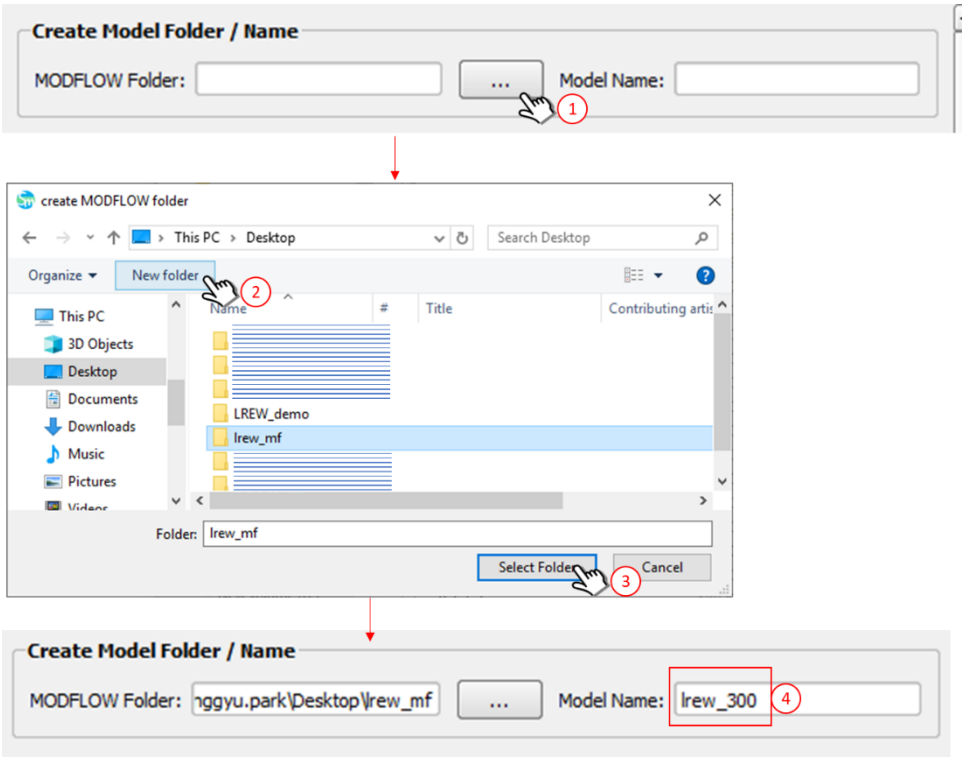
The cells are intersected with the SWAT river network to establish River cells (2nd option in Identify River Cells).

The aquifer properties can be specified by a single value or a raster. The ratio of horizontal K to vertical K (horizontal anisotropy) and layer type are also specified.

The "Write MODFLOW Information" button is selected to write input files to the model folder.

2) Click the browse (1) button to create a MODFLOW model folder.

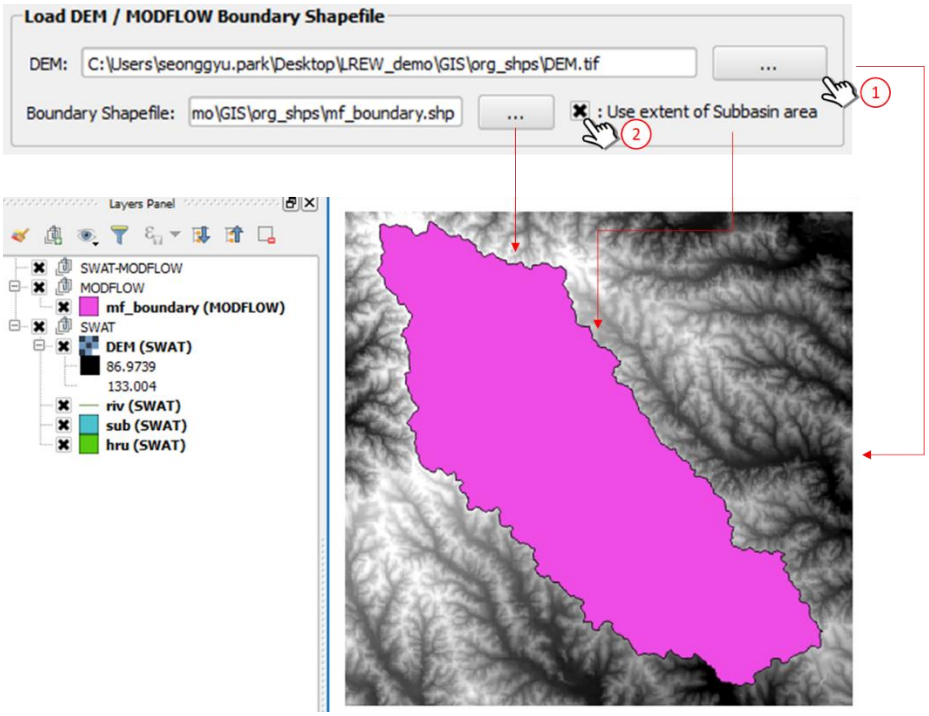
3) Type a model name.



MODFLOW needs the ground surface elevation for the grid cell, which will be used as the top of the layer

4) Click the browse (1) button to load DEM. Set the path to the DEM that has been used during the initial SWAT setup *(…\Tutorial\SWAT-MODFLOW3\Files\1 SWAT LRW\SWAT Model shapefiles\ groundeleveation30.tif).*

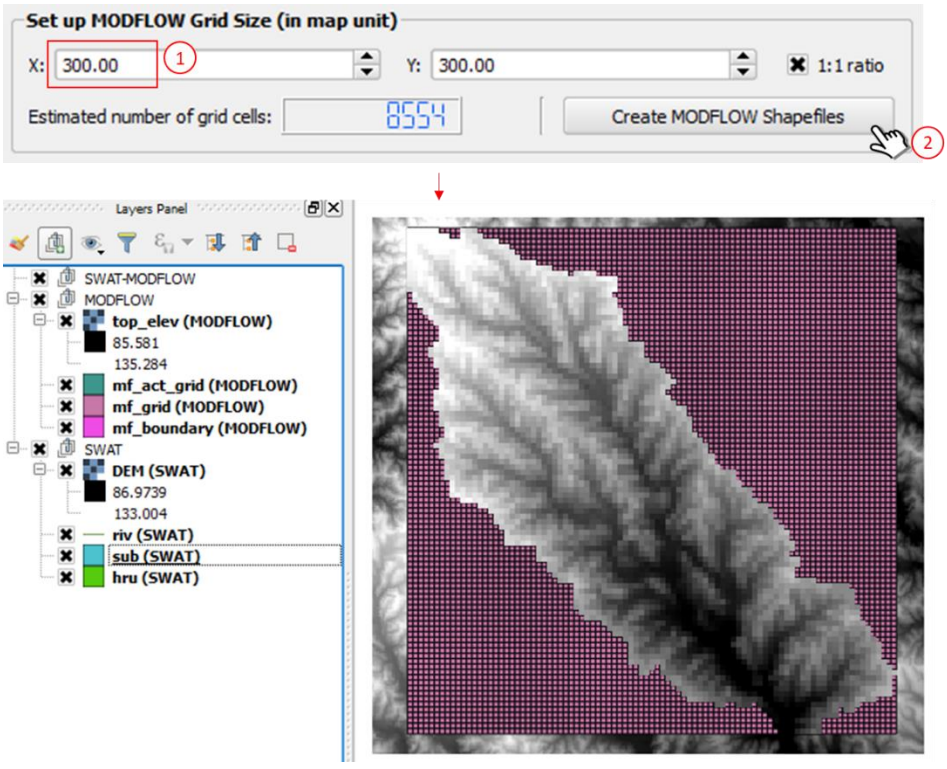
5) Check the “Use extent of Subbasin area” box to set its area to the MODFLOW model boundary.



Users can choose MODFLOW grid sizes and even different width (X) and length (Y) dimensions.

6) Type 300 in X dimension field.

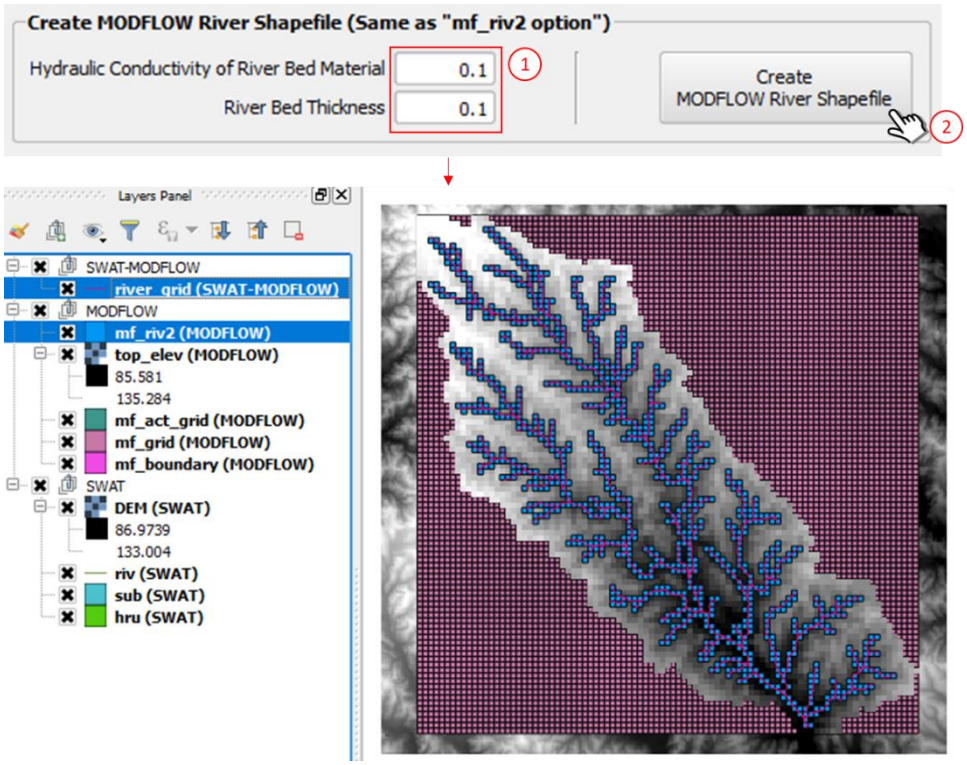
7) Click the “Create MODFLOW shapefiles” button



Riverbed properties are specified by the user to estimate conductance values for each river cell (4.3 section for details).

8) Use default values or type different ones.

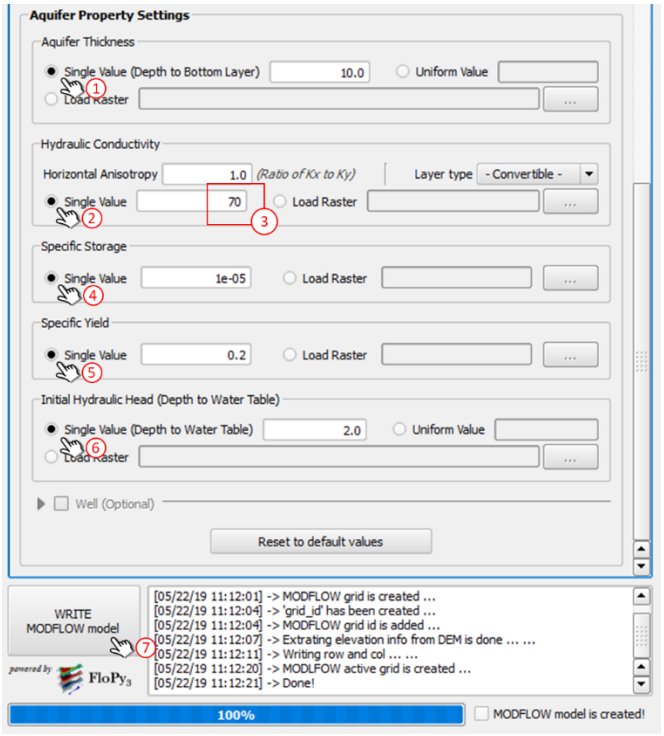
9) Click the “Create MODFLOW River Shapefile” button.

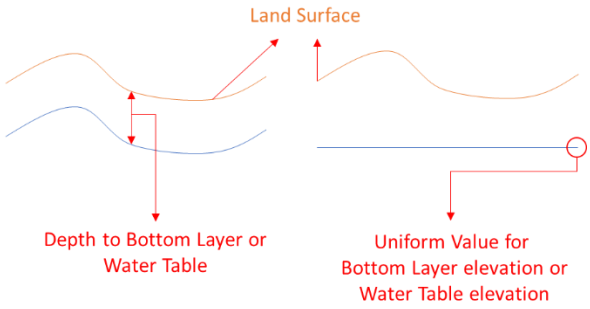


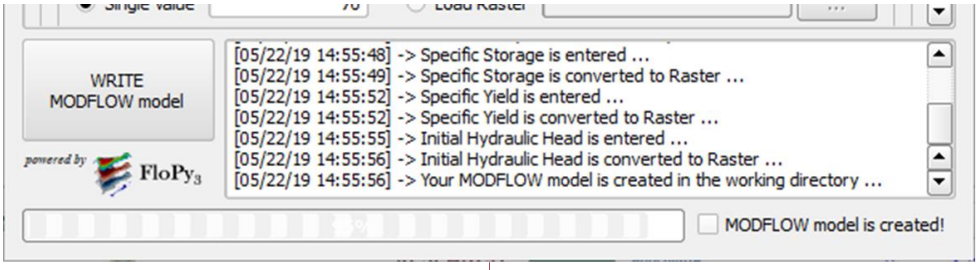
Users can provide either a single value for the entire watershed or specify the path to a raster representing the aquifer properties: aquifer thickness, hydraulic conductivity, specific storage, specific yield, and initial hydraulic head. For the tutorial,

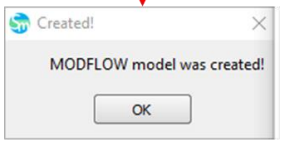
10) Set a single value for each aquifer property (See the following figure).

11) Click the “WRITE MODFLOW model” button.

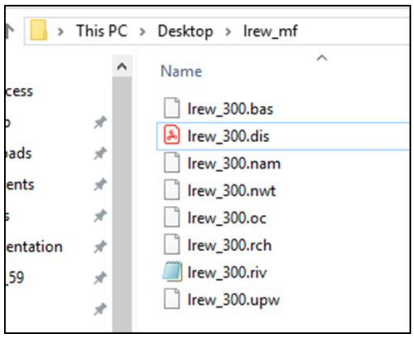








Open the MODFLOW model folder to confirm whether MODFLOW input files have been created.

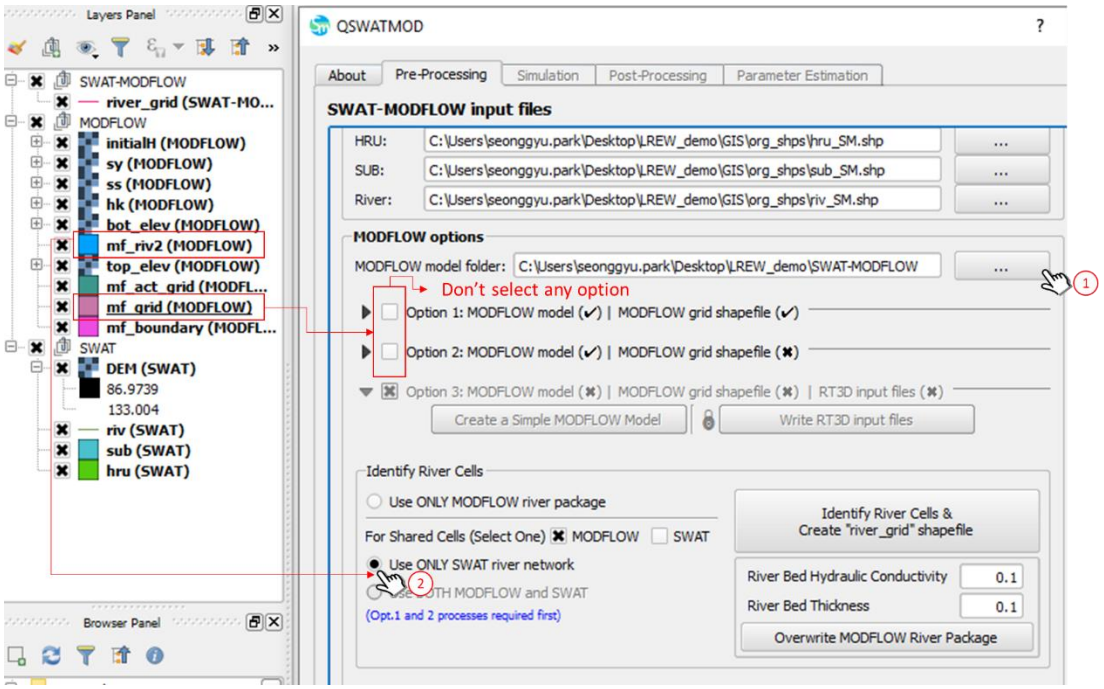


Now users can provide the MODFLOW model and its grid shapefile to the main QSWATMOD window, which is the same condition as the option "(4.2.1)". For the tutorial,

12) Specify the path to the MODFLOW you just created *(…C:\Users\seonggyu.park\Desktop\lrew_mf*).

13) No need to Check neither the Option 1 nor Option 2 because the "mf_grid (MODFLOW)" layer already exists.

14) Select the "Use ONLY SWAT river network" from the "Identify River Cells" option because we used the SWAT river network (shapefile) to create the MODFLOW river package (See Section 4.3 for details).

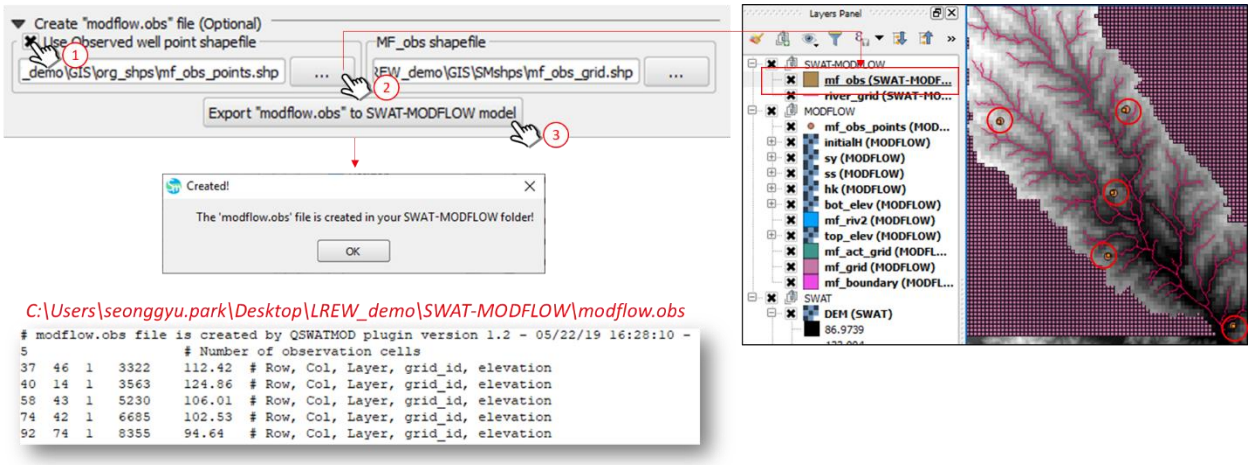


Now, it's ready for linking!

4.2.4. Create the “modflow.obs” file

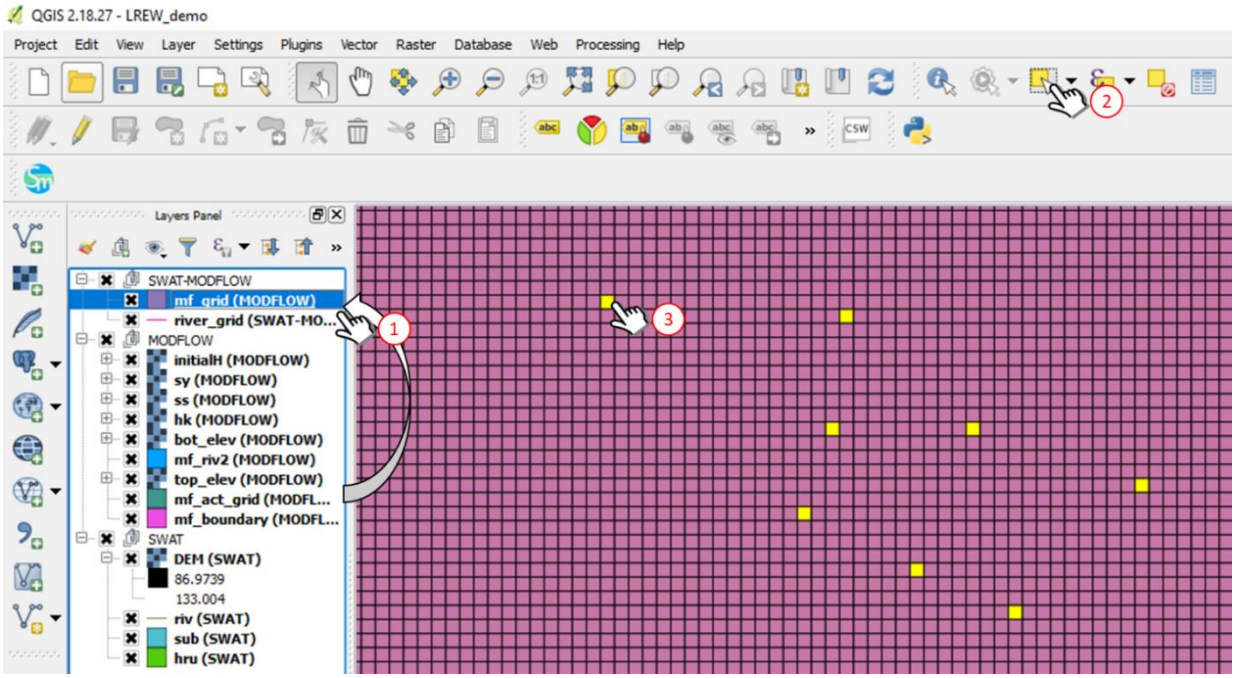
Locations for comparing model results (groundwater head) with observation data can be established by either an observation well shapefile or through the user selecting cells on the generated MODFLOW grid shapefile on the QGIS canvas (see Figure S1 in Supplementary Material). For the tutorial,

1) Check the “Use Observed well point shapefile” box.
2) Specify the path to the observed well point” shapefile *(…\Tutorial\SWAT-MODFLOW3\Files\2 MODFLOW LRW\MODFLOW model shapefiles\well_obs_pts.shp*).
3) Click the “Export” button.



- If the well point shapefile is not available, the “mf_grid (MODFLOW)” layer can be used to create the “modflow.obs” file.

1) Drag the “mf_grid (MODFLOW)” layer to the top of the layer panel (easier to select a grid cell).
2) Click the “Select features” button.
3) Select a grid cell or press Ctrl key + click to select multiple grid cells.

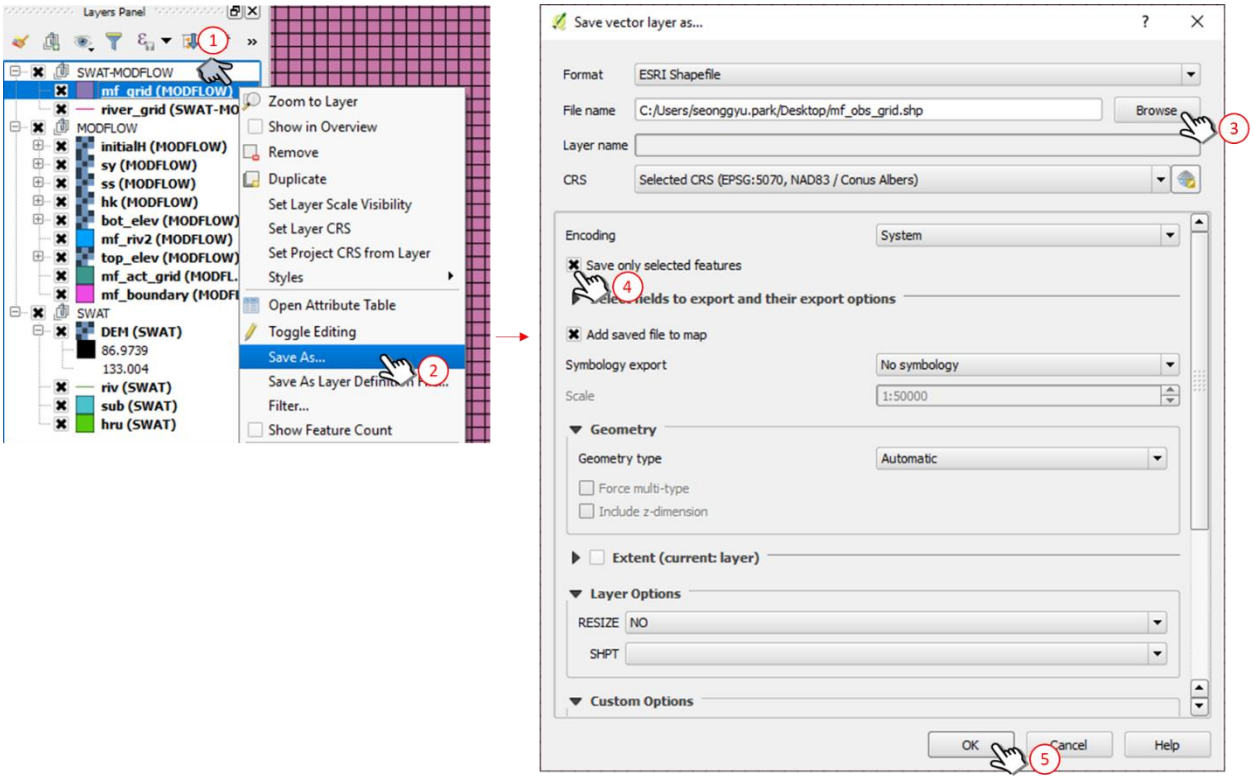


4) Right click on the “mf_grid (MODFLOW)” layer (1).

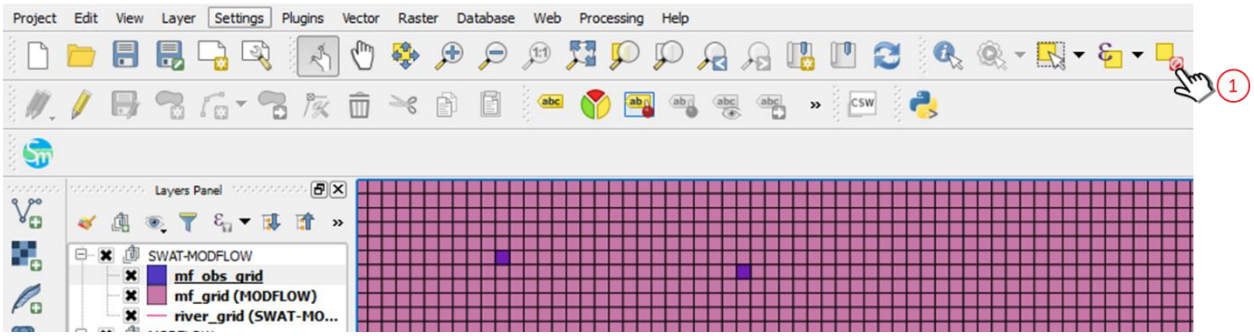
5) Click Save As..(2)

6) Click Browse button to save a vector layer as a shapefile (3).

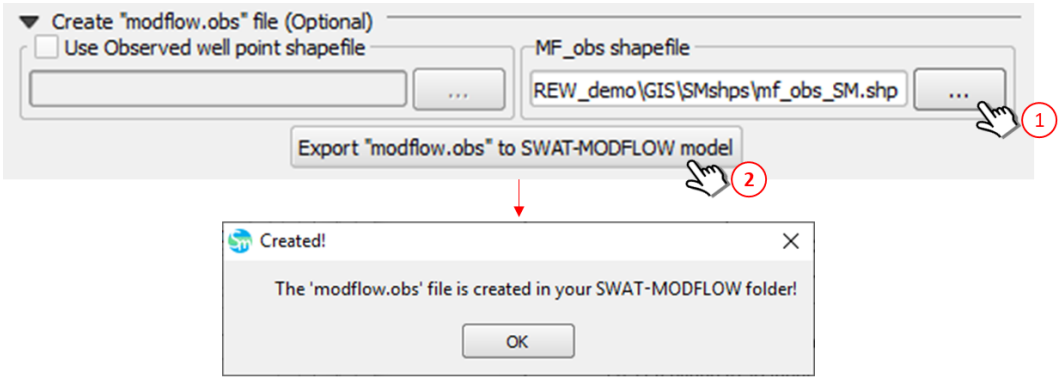
7) Check the “Save only selected features” box (4) then Click OK (5).



8) Click the “Deselect Features from All Layers” button.



9) Specify the path to the mf_obs_grid shapefile and click Export button.

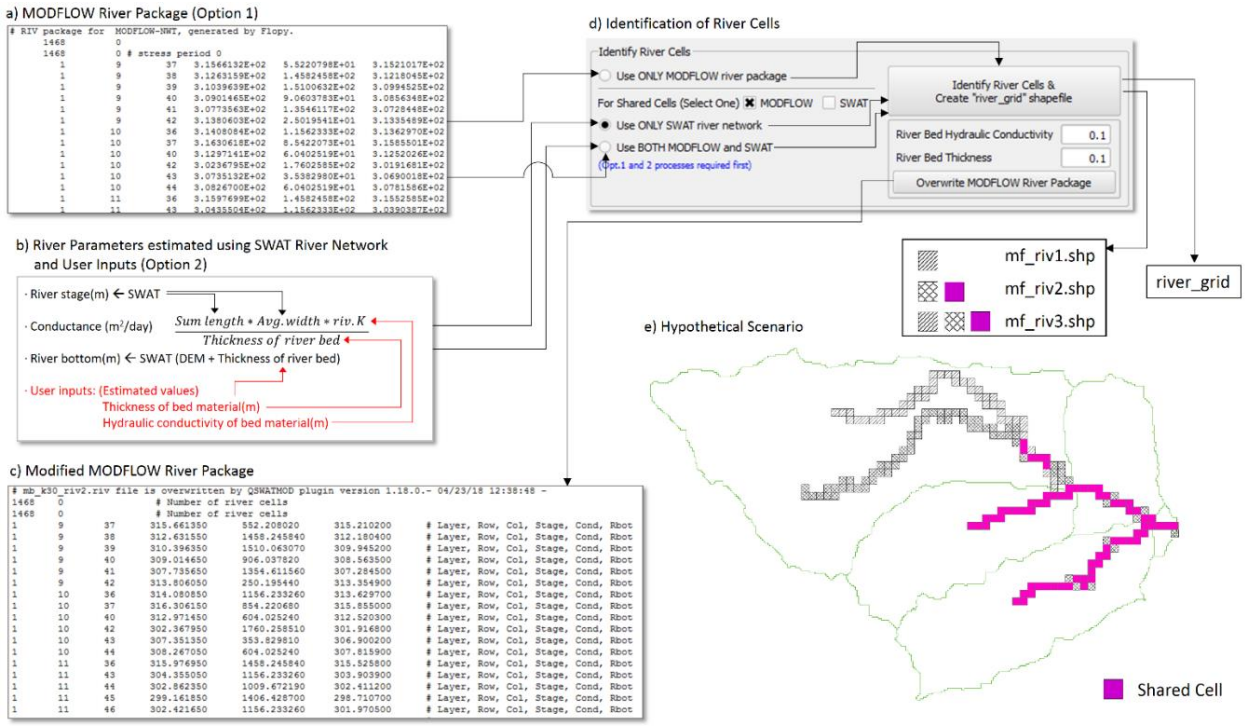


C:\Users\seonggyu.park\Desktop\LREW_demo\SWAT-MODFLOW\modflow.obs

```
# modflow.obs file is created by QSWATMOD plugin version 1.2 - 05/23/19 10:38:40 -
11                  # Number of observation cells
21  19  1   1839    117.53  # Row, Col, Layer, grid_id, elevation
22  36  1   1947    124.94  # Row, Col, Layer, grid_id, elevation
30  35  1   2674    102.07  # Row, Col, Layer, grid_id, elevation
30  45  1   2684    109.25  # Row, Col, Layer, grid_id, elevation
34  57  1   3060    106.14  # Row, Col, Layer, grid_id, elevation
36  33  1   3218    106.69  # Row, Col, Layer, grid_id, elevation
40  41  1   3590    100.07  # Row, Col, Layer, grid_id, elevation
43  48  1   3870    110.09  # Row, Col, Layer, grid_id, elevation
51  46  1   4596    100.32  # Row, Col, Layer, grid_id, elevation
55  55  1   4969    113.03  # Row, Col, Layer, grid_id, elevation
67  52  1   6058    89.73   # Row, Col, Layer, grid_id, elevation
```

4.3. River Connections

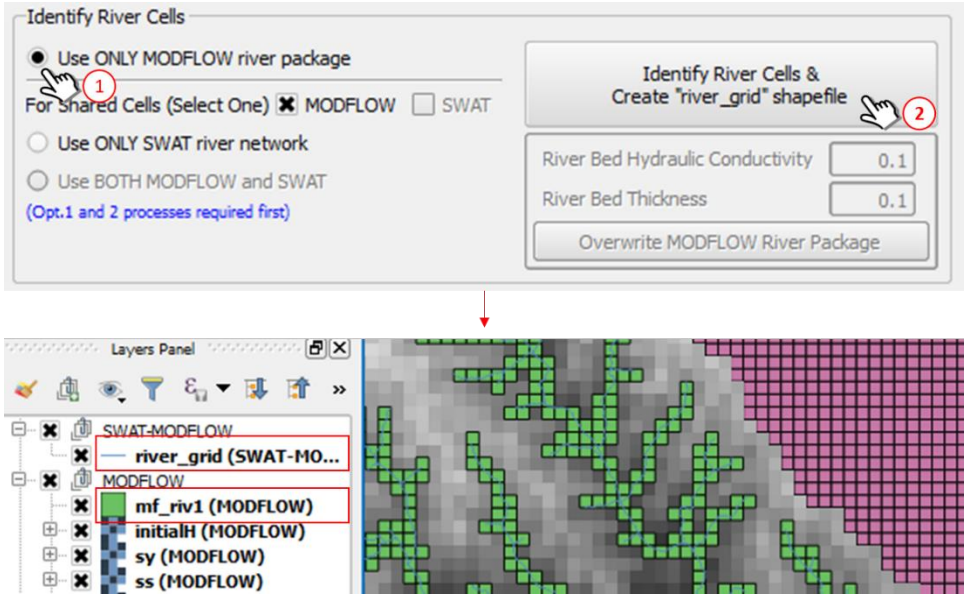
Linking the cells in the MODFLOW River package with the SWAT river network is required to simulate groundwater-surface water interactions. QSWATMOD provides three options: 1) Use Only MODFLOW river package, 2) Use Only SWAT river network, and 3) Use Both MODFLOW and SWAT. For the first option, QSWATMOD extracts river cell values (river stage, river bed conductance, river bottom elevation) from the MODFLOW River package file (*.riv), and then writes these values into the attribute table of a new "mf_riv1.shp" shapefile. For the second option, QSWATMOD creates the "mf_riv2.shp" by intersecting the MODFLOW grid with the SWAT river network shapefile and then calculates the river cell parameters for each river cell based on information provided by the SWAT river network (DEM, stream length and width) and user inputs (thickness and hydraulic conductivity of river bed material). For the third option, the existing MODFLOW river cells are compared to the SWAT river network to determine if river cells should be added. The user then decides which information will be used for the new cells (mf_riv3.shp).



(Source: Park et al., 2018)

4.3.1. Use Only MODFLOW river

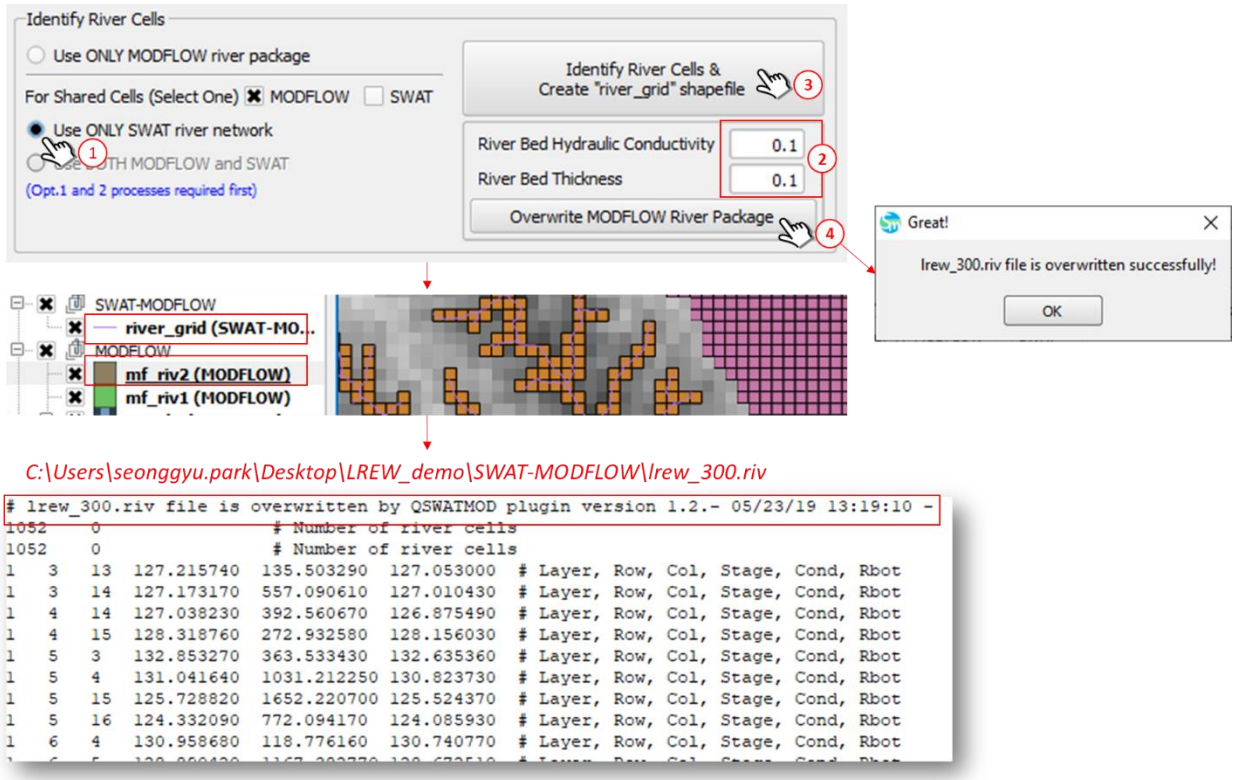
1) Select the first option.
2) Click the “Identify River Cells & Create ‘river_grid’ shapefile” button.



4.3.2. Use Only SWAT river network

(Note: this option creates a new MODFLOW River Package and overwrites an existing one.)

1) Select the second option.
2) Set riverbed properties.
3) Click the “Identify River Cells & Create ‘river_grid’ shapefile” button.
4) Click the “Overwrite MODFLOW River Package” button.



4.3.3. Use Both MODFLOW and SWAT river network

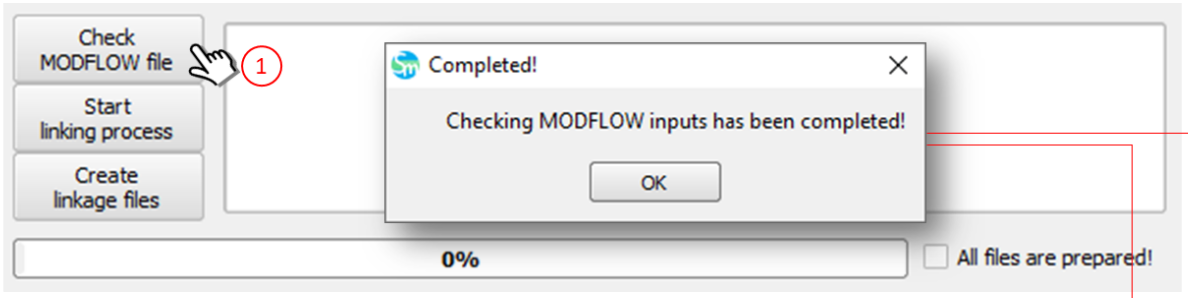
Once the "mf_riv1" and "mf_riv2" have been created, the 3rd option will be activated. The main purpose of this option is to make the best use of insufficient river data from both MODFLOW and SWAT models.

IMPORTANT: This option has not been tested extensively. Please contact the SWAT-MODFLOW authors if you plan to use this option.

4.4. Linking Process

Through the linking process, the HRUs are disaggregated to create DHRUs, which are then intersected with MODFLOW grid cells. MODFLOW river cells are identified using the SWAT stream network or other river connection options (see Section 4.3), and the set of river cells within each subbasin are identified for mapping groundwater-surface water exchange rates from river cells to SWAT subbasin channels. These generated shapefiles are used to create the four required SWAT-MODFLOW linkage files ("swatmf_dhru2hru.txt", "swatmf_dhru2grid.txt", "swatmf_grid2dhru.txt", and "swatmf_river2grid.txt"), which are stored in the project folder.

(1) Click the "Check MODFLOW file" button to create the "modflow.mfn" file, modifying unit numbers in its own and the *.oc file, and checking *.dis file (simulation period and model state). All the modifications made are stored in the "modflow_EditLog.txt" file.



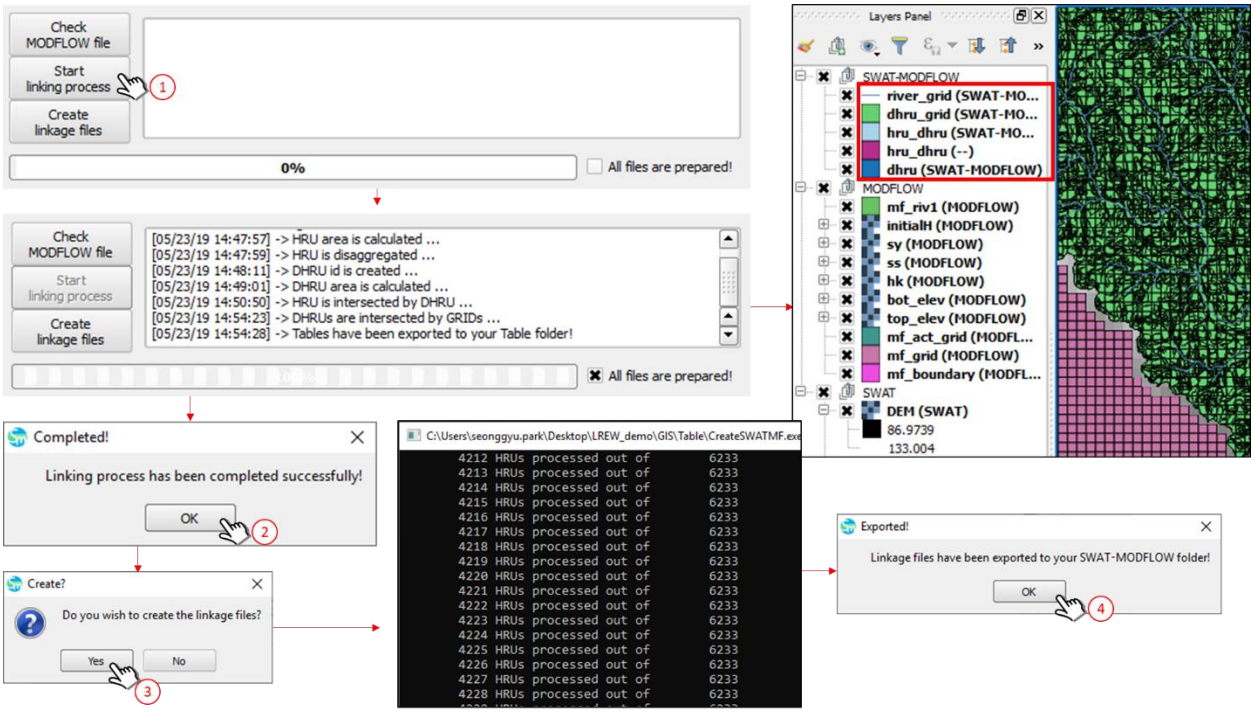
C:\Users\seonggyu.park\Desktop\LREW_demo\SWAT-MODFLOW\modflow.mfn

```
# modflow.mfn file, generated by QSWATMOD plugin version 1.2. - 05/23/19 13:35:19 -
# Name file for MODFLOW-NWT, generated by Flopy version 3.2.11.
#xll:0; yll:0; rotation:0; proj4_str:EPSG:4326; units:meters; lenuni:2; length_multipl
LIST    5002    lrew_300.list
DIS 5011    lrew_300.dis
BAS6    5013    lrew_300.bas
NWT 5032    lrew_300.nwt
UPW 5031    lrew_300.upw
RIV 5018    lrew_300.riv
RCH 5019    lrew_300.rch
OC  5014    lrew_300.oc
DATA(BINARY)    5051    lrew_300.hds    REPLACE
```

C:\Users\seonggyu.park\Desktop\LREW_demo\SWAT-MODFLOW\modflow_EditLog.txt

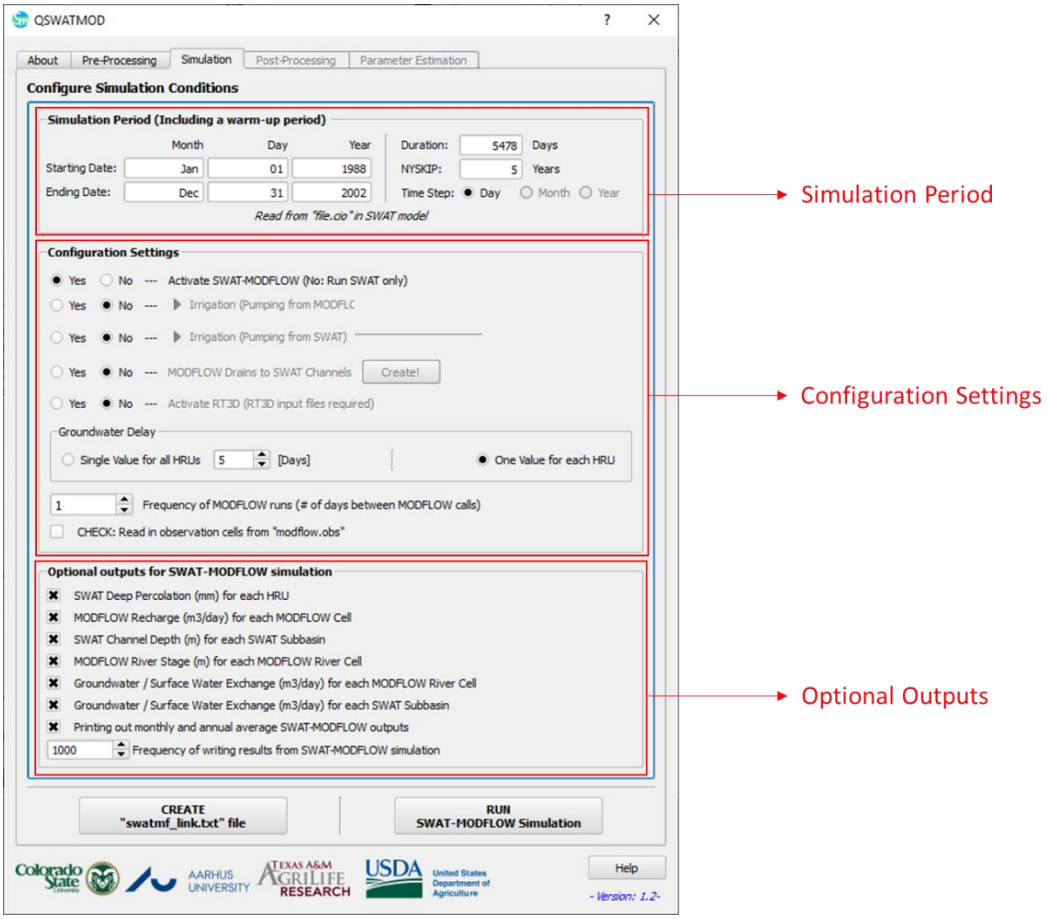
```
[05/23/19 13:35:19] -> modflow.mfn: Unit number 2 -> 5002
[05/23/19 13:35:19] -> modflow.mfn: Unit number 11 -> 5011
[05/23/19 13:35:19] -> modflow.mfn: Unit number 13 -> 5013
[05/23/19 13:35:19] -> modflow.mfn: Unit number 32 -> 5032
[05/23/19 13:35:19] -> modflow.mfn: Unit number 31 -> 5031
[05/23/19 13:35:19] -> modflow.mfn: Unit number 18 -> 5018
[05/23/19 13:35:19] -> modflow.mfn: Unit number 19 -> 5019
[05/23/19 13:35:19] -> modflow.mfn: Unit number 14 -> 5014
[05/23/19 13:35:19] -> modflow.mfn: Unit number 51 -> 5051
[05/23/19 13:35:19] -> lrew_300.oc: Unit number 51 -> 5051
```

(2) Click the “Start linking process” button. *(It takes around 10 mins, but the processing time depends on computer specifications, the number of HRUs and of MODFLOW grids.)*



5. Simulation Tab

The “Simulation” tab includes three frames: Simulation Period, Configuration Settings, and Optional outputs for SWAT-MODFLOW simulation.



In the “Simulation Period” frame, starting date, ending date, warm-up period, and time step of the simulation are provided based on information in the SWAT input file “file.cio” and used for synchronizing the MODFLOW model time and writing simulation results. In the “Configuration Settings” frame, besides the basic link between SWAT and MODFLOW, several other features have been included to allow more flexibility in applying SWAT-MODFLOW to managed watersheds. These features are described in the following sections. The optional model output (HRU deep percolation, MODFLOW cell-by-cell recharge, subbasins channel depth, MODFLOW river cell stage, groundwater/surface water exchange rates for each SWAT sub-basin, groundwater/surface water exchange rates for each MODFLOW river cell) is also specified. Due to the potentially large output files (> 1 GB), the current version of SWAT-MODFLOW adds two functionalities: writing monthly and annual average SWAT-MODFLOW results, and setting the frequency of writing SWAT-MODFLOW results. Finally, the “Create ‘swatmf_link.txt’ file” button is selected to export the configuration settings to the project folder

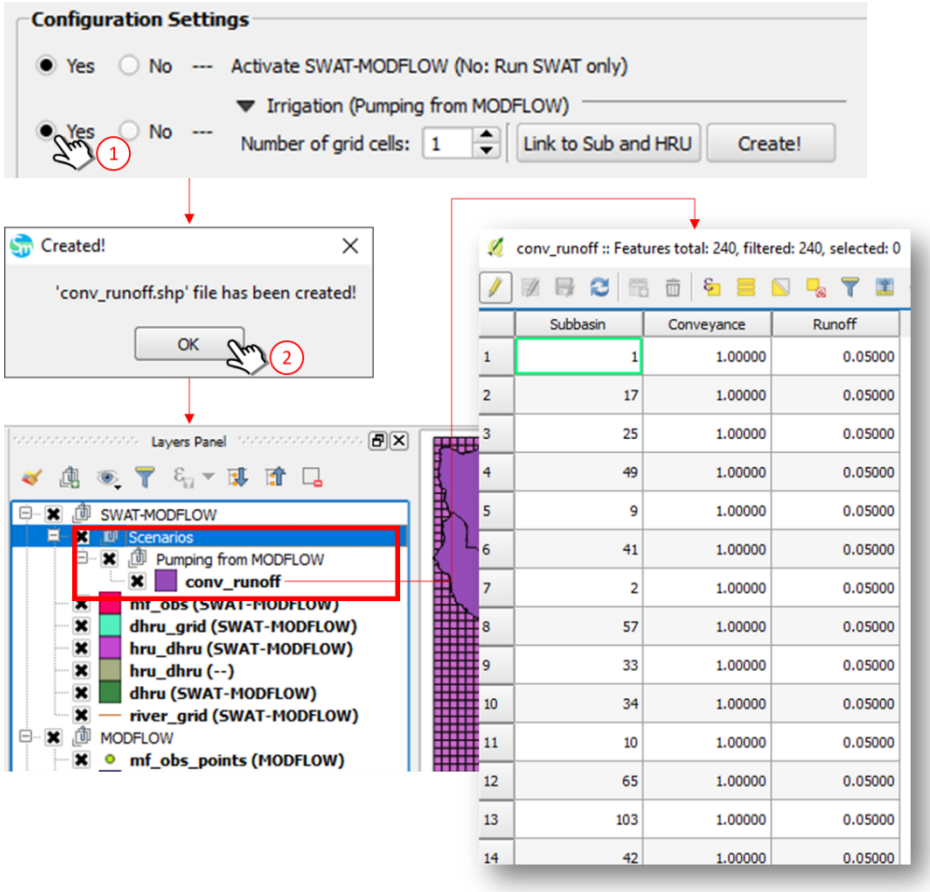
and the “Run Simulation” button is selected to call the SWAT-MODFLOW executable and run the simulation.

*IMPORTANT: the current QSWATMOD version doesn’t support options for creating the WEL and DRN packages. Thus, to perform the following sections, an existing MODFLOW model should include those packages or users need to provide them.

5.1. Pumping Rate Dictated by MODFLOW

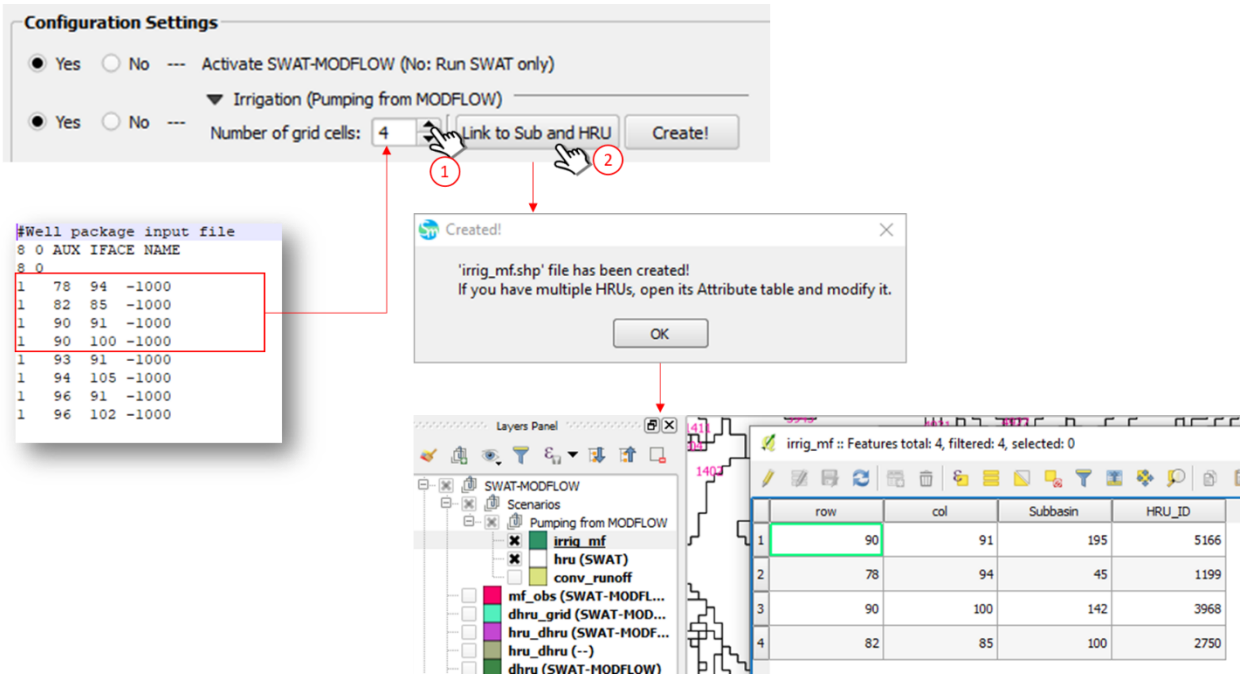
For the tutorial, it is assumed that the top 4 wells from the MODFLOW WEL package provide irrigation water.

(1) Check the “Yes” button to activate linking MODFLOW pumping to SWAT irrigation (Pumping rate dictated by MODFLOW). Once activated, the “conv_runoff” shapefile is created including the conveyance efficiency and runoff ratio for each subbasin. Users can modify the conveyance efficiency and runoff ratio for each subbasin from the its attribute table.

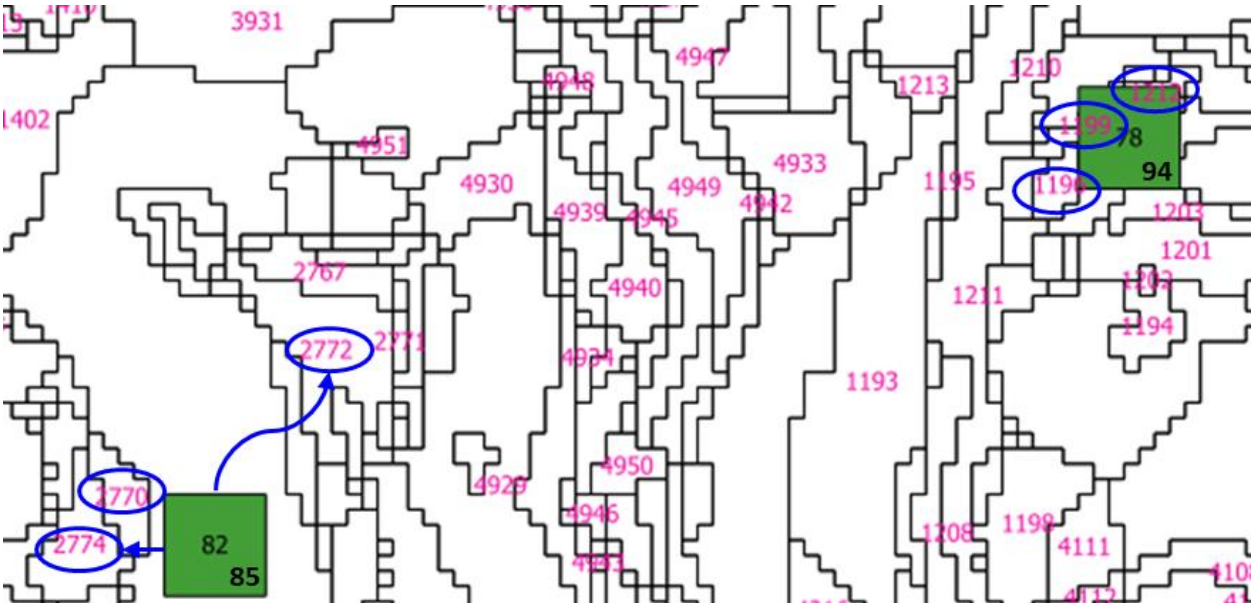


(2) Set the “Number of grid cells” that provide irrigation water.

(3) Click the “Link to Sub and HRU” button



For the tutorial, the pumping grid (row 82, col 85) provides irrigation water to HRU id 2750, 2770, 2774, and 2772. The pumping grid (78, 94) provides irrigation water to HRU id 1199, 1212, and 1196. The pumping grid (90, 91) and (90, 100) provide irrigation water to HRU id 5166 and 3968, respectively.

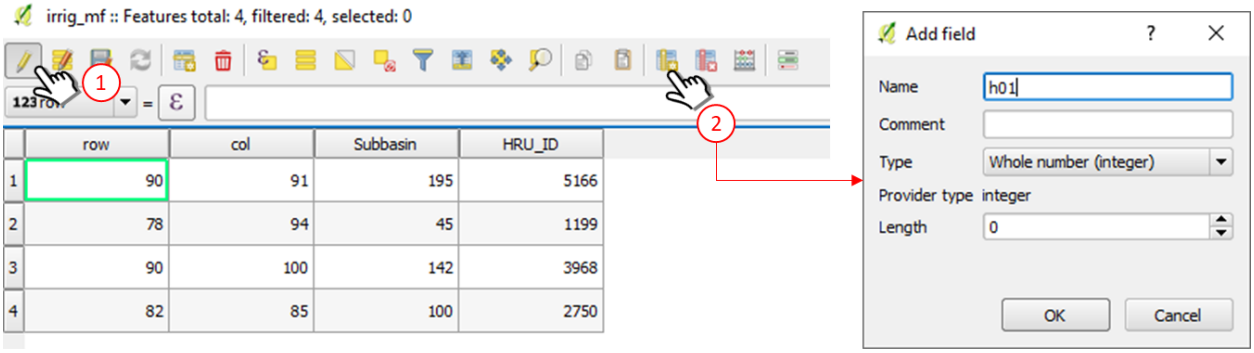


In this case, the maximum number of HRUs that a pumping grid provides water to is 4 (from the grid (82, 85)). Thus, users need to add 3 new fields.

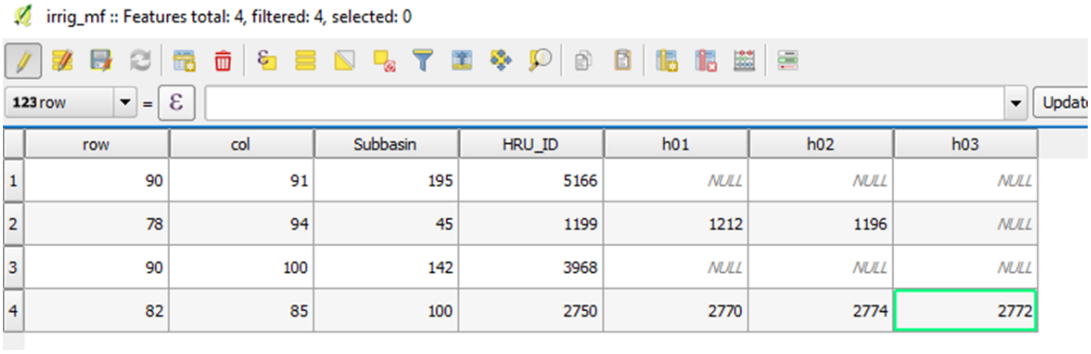
(1) Open the attribute table of the “irrig_mf” layer.

(2) Click the “Toggle edit mode” and then “New field” button.

(3) Add HRU numbers and modify it.

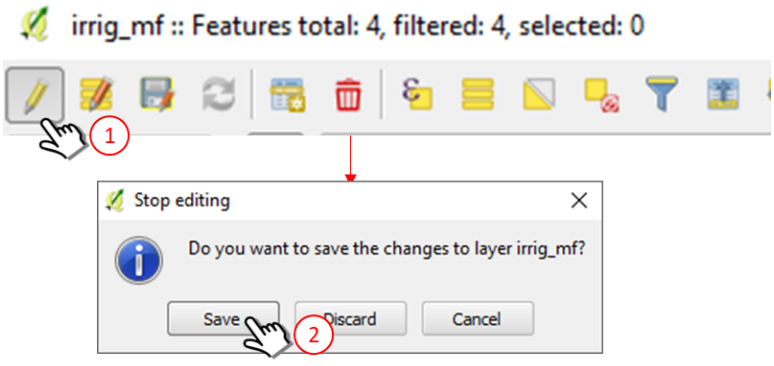


	row	col	Subbasin	HRU_ID
1	90	91	195	5166
2	78	94	45	1199
3	90	100	142	3968
4	82	85	100	2750

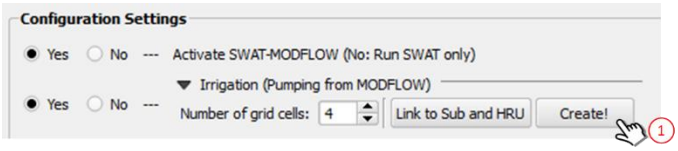


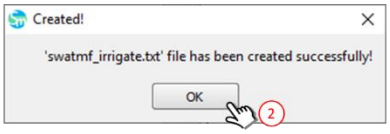
	row	col	Subbasin	HRU_ID	h01	h02	h03
1	90	91	195	5166	NULL	NULL	NULL
2	78	94	45	1199	1212	1196	NULL
3	90	100	142	3968	NULL	NULL	NULL
4	82	85	100	2750	2770	2774	2772

(4) After updating HRU ids, turn off the “Toggle edit mode” by clicking its button and then save button.



(5) Click the “Create!” button to create the “swatmf_irrigate.txt” file.






```
# This file contains a listing of MODFLOW grid cells, and their associated SWAT sub-basins,
4       # Number of grid cells that provide irrigation water
# Conveyance efficiency, Runoff Ratio for each sub-basin
1.0 0.05
1.0 0.05
1.0 0.05
1.0 0.05
                                                    :
                                                    :
1.0 0.05
# Sub     Row     Col     HRU_ID
195 90   91   5166
45  78   94   1199
142 90   100 3968
100 82   85   2750
# HRUs that receive irrigation water (Subbasin, HRU ID)
9
195 5166
45  1199
45  1212
45  1196
142 3968
100 2750
100 2770
100 2774
100 2772
```

5.2. Pumping Rate Dictated by SWAT

- With an existing MODFLOW WELL package

  If users have an existing *.wel package and activate this function, the additional wells dictated by SWAT will be added to the existing wells. Thus, QSWATMOD will modify the number of wells at the start of the WELL package input file (for example, if there are 10 original pumping wells, and then SWAT dictates the operation of 5 additional wells, the total number in the WELL package should be 15, since the array needs to eventually handle up to 15 during the simulation).

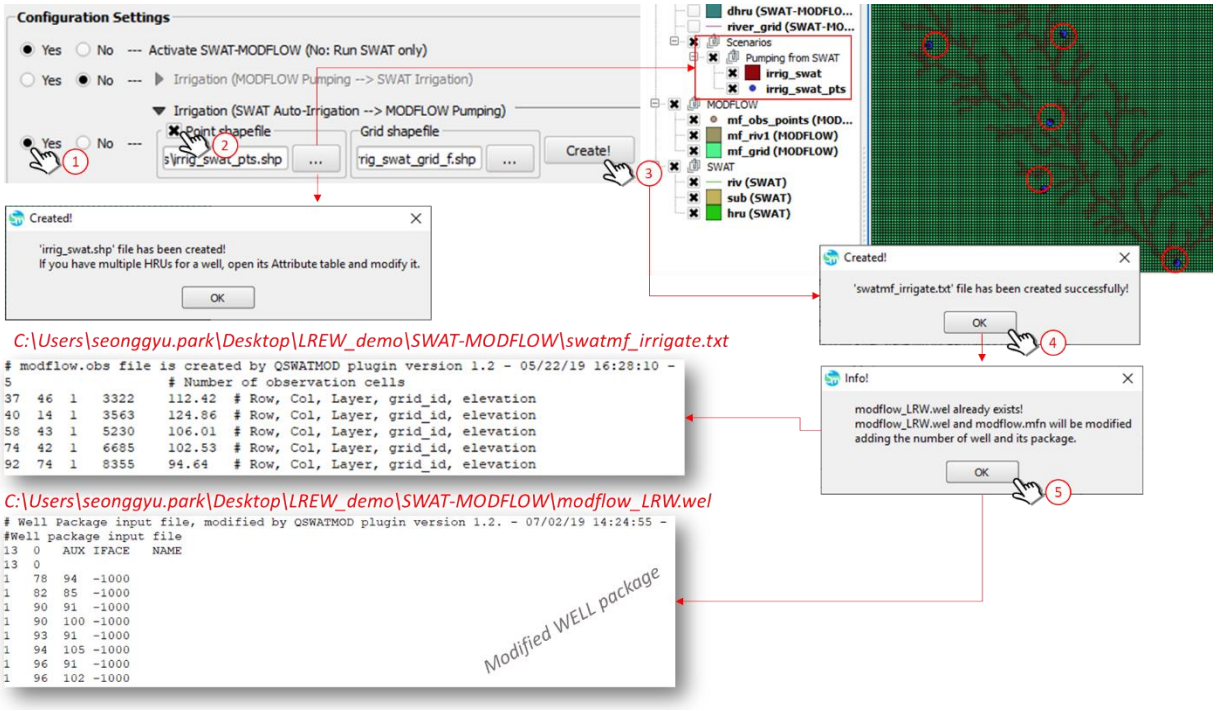
For the tutorial, the WELL package contains 8 pumping wells and we are going to use the same point shapefile “*well_obs_pts.shp”* that we used for the section 4.2.4 which has 5 observation wells.

(1) Check the “Yes” button to activate linking MODFLOW pumping to SWAT irrigation (Pumping rate dictated by SWAT).

(2) Check the “Use Point shapefile” box. (Users also can use a grid shapefile in the same way one is created using the “mf_grid.shp” file. See section 4.2.4. for details.)

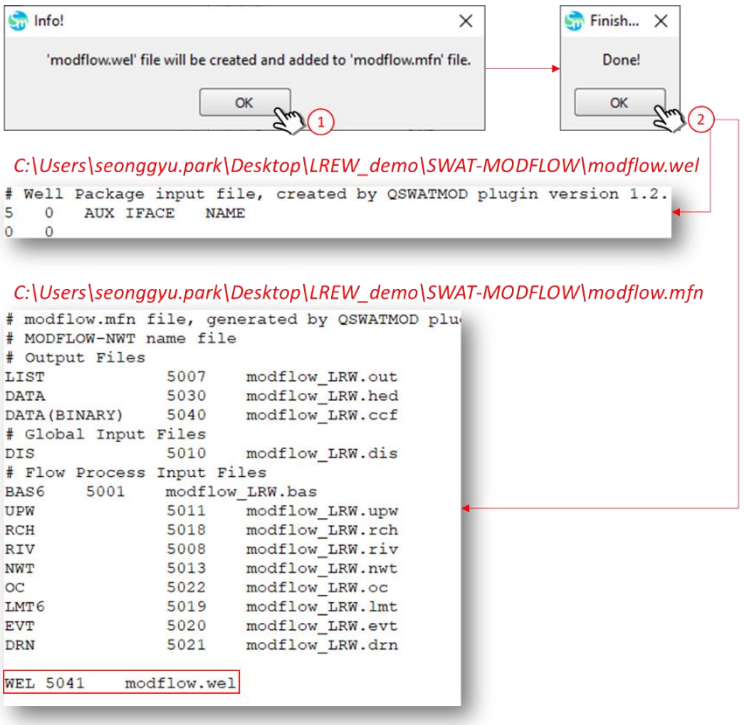
(3) Specify the path to the observed well point” shapefile *(…\Tutorial\SWAT-MODFLOW3\Files\2 MODFLOW LRW\MODFLOW model shapefiles\well_obs_pts.shp*). Users can modify the number of HRUs and their ids HRU ids that receive water from the pumping wells (see Section 5.1 for details).

(4) Click the “Create!” button.



- With **NO** MODFLOW WELL package

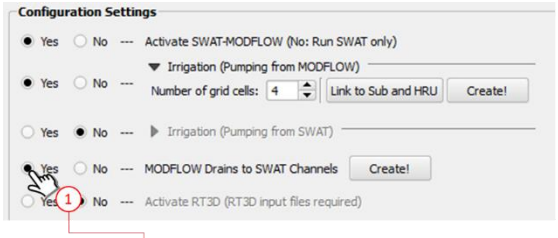
  If users activate this function without a WELL package, QSWATMOD will generate the “modflow.wel” file with the number of wells dictated by SWAT and modify the “modflow.mfn” file, adding the file name to the package list.



5.3. MODFLOW DRAIN cells to SWAT Subbasin Channels

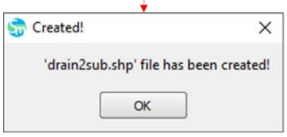
For the tutorial, the Drain Package from MODFLOW model contains 162 drain cells.

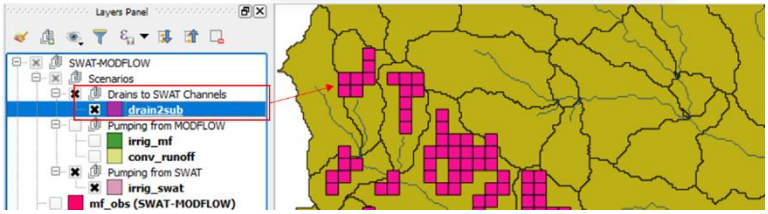
(1) Check the “Yes” button to activate linking MODFLOW drains to SWAT channels.



C:\Users\seonggyu.park\Desktop\LREW_demo\SWAT-MODFLOW\modflow_LRW.drn

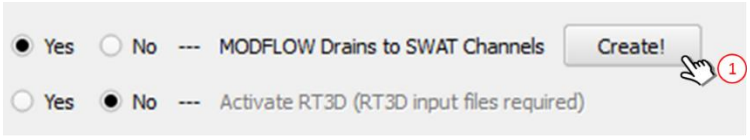
```
#Drain package input file
162 0                                   Number of t
162 0                                   Number of a
1   34  15  134.27  100.00  0
1   36  19  133.34  100.00  0
1   37  19  130.56  100.00  0
1   34  15  134.27  100.00  0
1   35  15  131.34  100.00  0
1   36  13  133.35  100.00  0
1   36  14  128.83  100.00  0
```

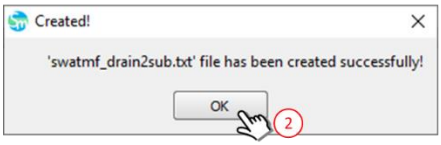




If users need to modify subbasin numbers, open the attribute table of the drain2sub layer and edit subbasin numbers then save the changes.

(2) Click the “Create!” button to create the “swatmf_drain2sub.txt” file.





C:\Users\seonggyu.park\Desktop\LREW_demo\SWAT-MODFLOW\swatmf_drain2sub.txt

```
146  # Number of MODFLOW DRAIN cells t
# Row    Column    Subbasin
65  35  93
52  11  86
52  12  86
65  43  236
50  31  74
35  15  19
50  32  74
37  13  19
37  14  19
52  33  12
52  34  12
37  18  43
37  19  43
54  33  12
54  34  12
39  18  43
56  21  164
54  36  12
56  22  164
39  21  122
 .
 .
 .
```

5.4. RT3D Option

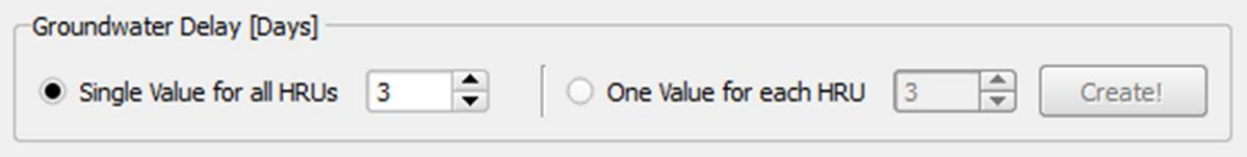
*IMPORTANT: the current QSWATMOD version doesn't support creating RT3D input files. Thus, to perform this option, users need to create and provide them to the SWAT-MODFLOW folder manually.

If users have prepared RT3D input files, activate the RT3D option by selecting the "Yes" check box.

5.5. Groundwater Delay

Transport of groundwater and associate mass of N and P from the bottom of the soil profile to the water table is simulated using a groundwater delay function. For the tutorial,

(1) A single value of 3 for all HRUs is selected.



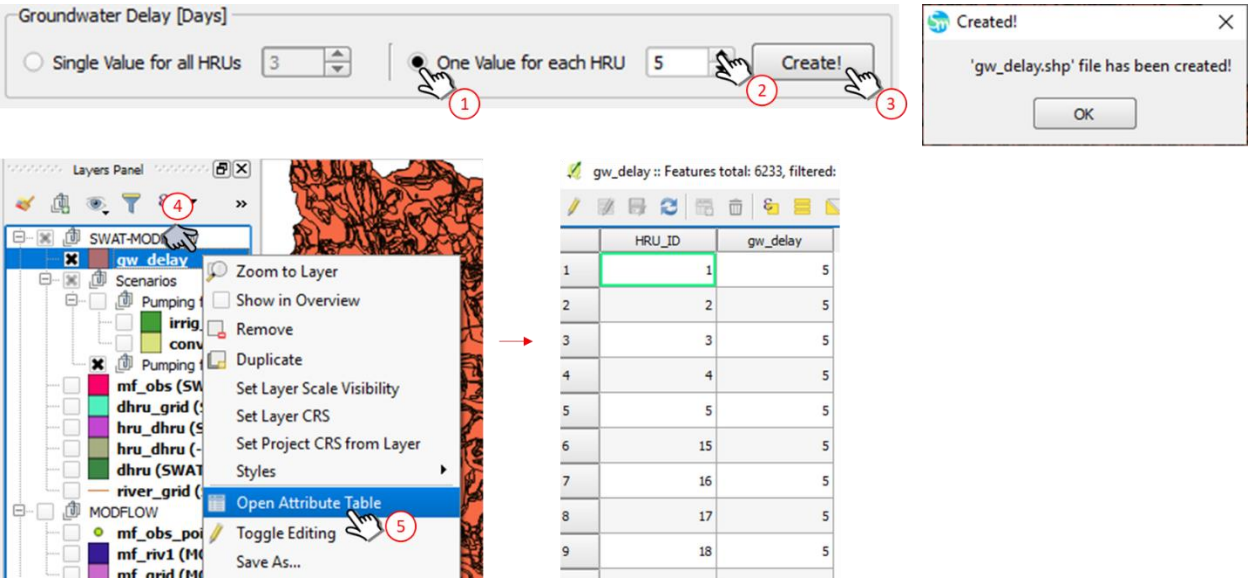
To use one value for each HRU,

(1) Check the "One Value for each HRU" option.

(2) Change the "Groundwater Delay" by clicking or typing a number.

(3) Click the "Create" button.

(4) Open the "gw_delay" layer's attribute table then modify values.



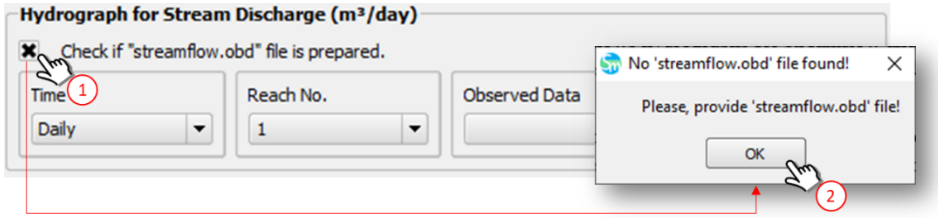
6. Post-Processing

QSWATMOD has three types of post-processing modules: plotting, mapping, and exporting results.

6.1. Hydrographs for streamflow and hydraulic head

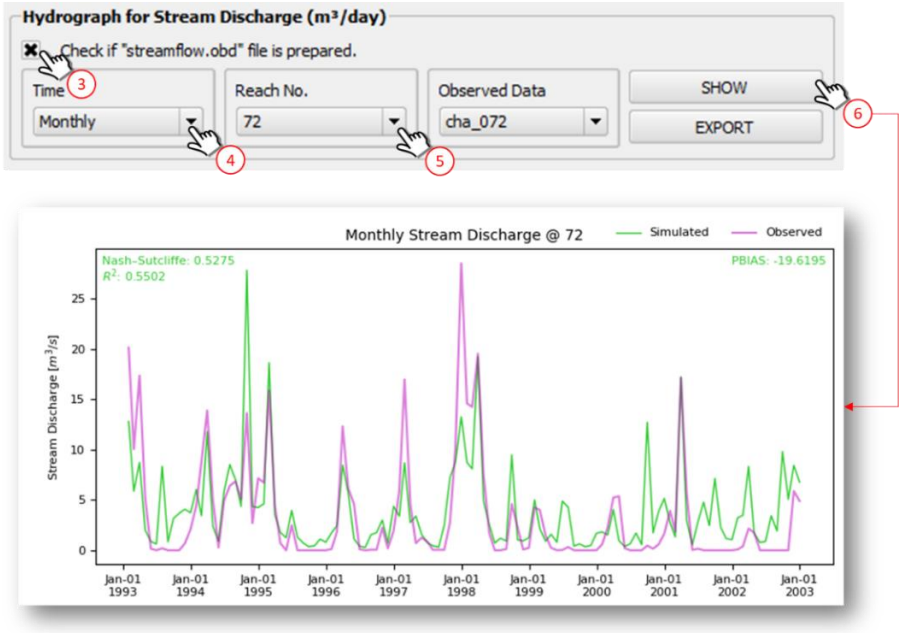
The plot function shows hydrographs for streamflow and groundwater head and is intended mainly for comparisons between simulated and observed results for each reach or observation well location. Once the observation data from streamflow and hydraulic head are provided in the formats "streamflow.obd" (see Figure S2a in Supplementary Material) and "modflow.obd" (see Figure S2b in Supplementary Material), objective function summary values such as Nash-Sutcliffe Efficiency (NSE), Percent bias (PBIAS), and R-squared (R2) will be displayed on the figures. For the tutorial, the outlet reach number of LREW is 72.

(1) Check the box for the "streamflow.obd" box and it will ask you provide the "streamflow.obd" file.



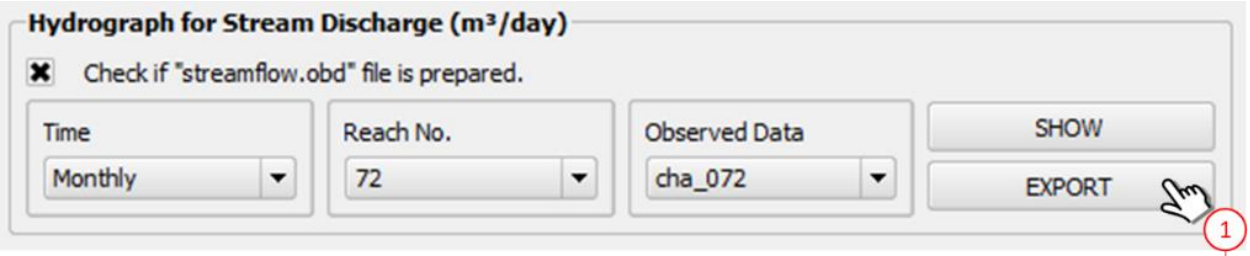
(2) Copy the "streamflow.obd" file from the workshop folder and past it to the "SWAT-MODFLOW" folder in your project directory. Now, you will be able to check that box.

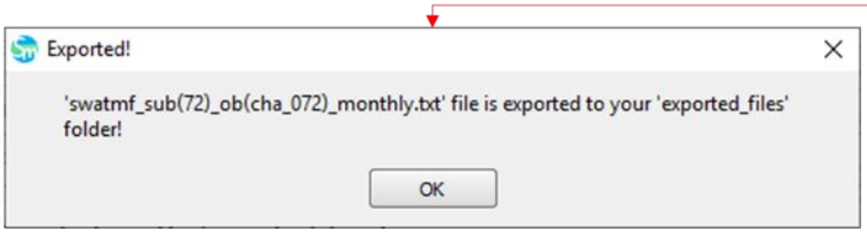
(3) Change Time to "Monthly" and Reach No. to 72. Click the "SHOW" button (6).



Users can also export a data used for the above plot by clicking the “EXPORT” button. QSWATMOD will store an exported file in a sub-folder named “exported_files” in the project directory.

(1) Click the “EXPORT” button.



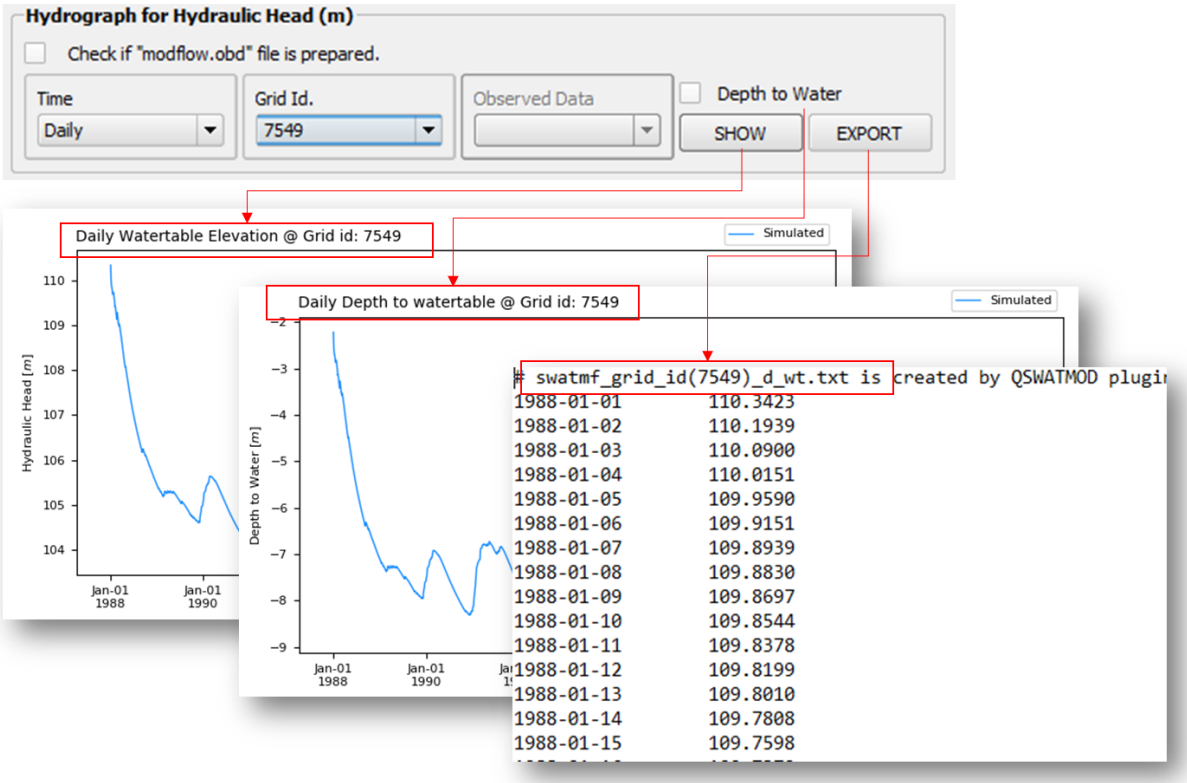


C:\Users\seonggyu.park\Desktop\LREW_demo\exported_files

```
# swatmf_reach(72)_ob(cha_072)_monthly.txt is created by QSWATMOD plugin
Date     streamflow_sim  cha_072
1993-01-31      12.7837      20.1129
1993-02-28       5.8707      10.0507
1993-03-31       8.7162      17.3432
1993-04-30       1.9977       5.2170
1993-05-31       0.8668       0.1535
1993-06-30       0.6252       0.0013
1993-07-31       8.3258       0.1881
1993-08-31       0.8392       0.0000
              .
              .
              .
2002-11-30       8.4217       5.8700
2002-12-31       6.7560       4.8903

# Statistics
Nash-Sutcliffe: 0.5275
R-squared: 0.5502
PBIAS: -19.6195
```

Once users provided the “modflow.obs” file, the “Hydrograph for Hydraulic Head” frame would be activated. Like hydrograph for streamflow, users can plot hydrographs of hydraulic head for each observation well and depth to water graphs and export data.


Hydrograph for Hydraulic Head (m)
Check if "modflow.obd" file is prepared.
Time
Daily
Grid Id.
7549
Observed Data
Depth to Water
SHOW
EXPORT
Daily Watertable Elevation @ Grid id: 7549
Simulated
Hydraulic Head [m]
Daily Depth to watertable @ Grid id: 7549
Depth to Water [m]
Jan-01 1988
Jan-01 1990
swatmf_grid_id(7549)_d_wt.txt is created by QSWATMOD plugi
1988-01-01 110.3423
1988-01-02 110.1939
1988-01-03 110.0900
1988-01-04 110.0151
1988-01-05 109.9590
1988-01-06 109.9151
1988-01-07 109.8939
1988-01-08 109.8830
1988-01-09 109.8697
1988-01-10 109.8544
1988-01-11 109.8378
1988-01-12 109.8199
1988-01-13 109.8010
1988-01-14 109.7808
1988-01-15 109.7598

6.2. Mapping Hydraulic Head and Recharge

The mapping function is designed to show maps of hydraulic head and recharge via assigned shapefiles on the QGIS canvas. After users specify the period of visualization, the data are exported to a shapefile and stored in its attribute table.

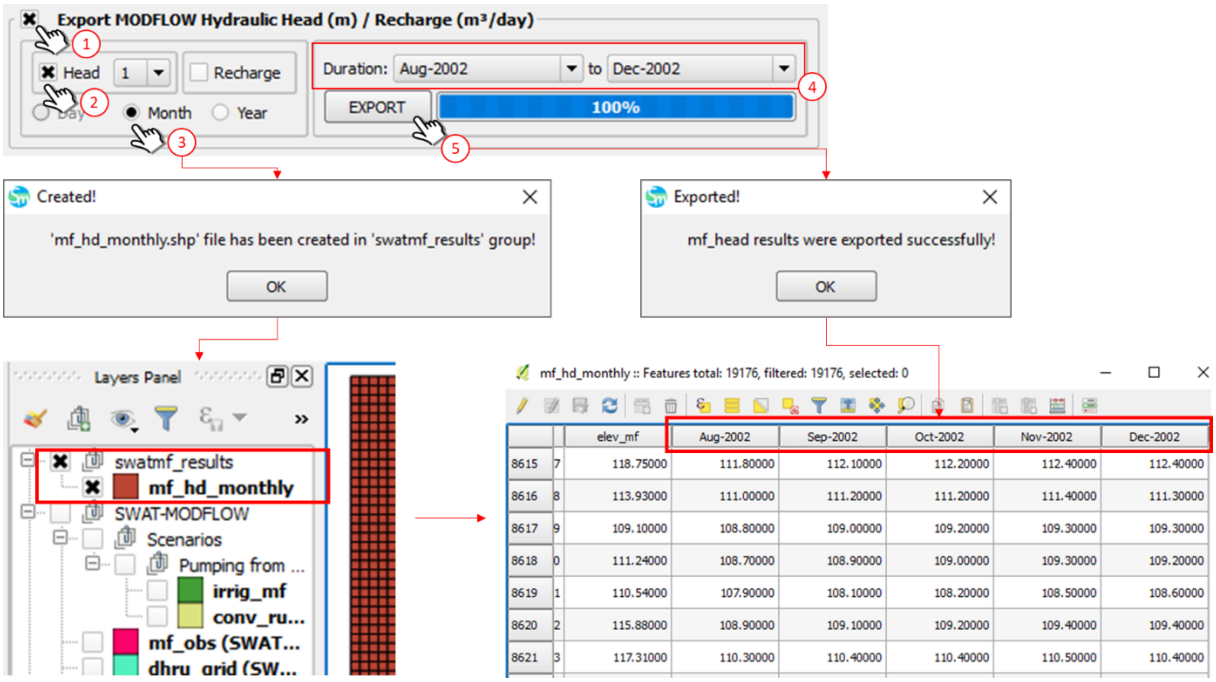
1) Check the box, Head, and Month. (Users will see the "mf_hd_monthly" shapefile is created under the "swatmf_results" tree.)

- *Note: The current version doesn't support mapping daily hydraulic head from *.hed, or *.fhd file.*

2) Select the layer number. (LREW MODFLOW model has a single layer.)

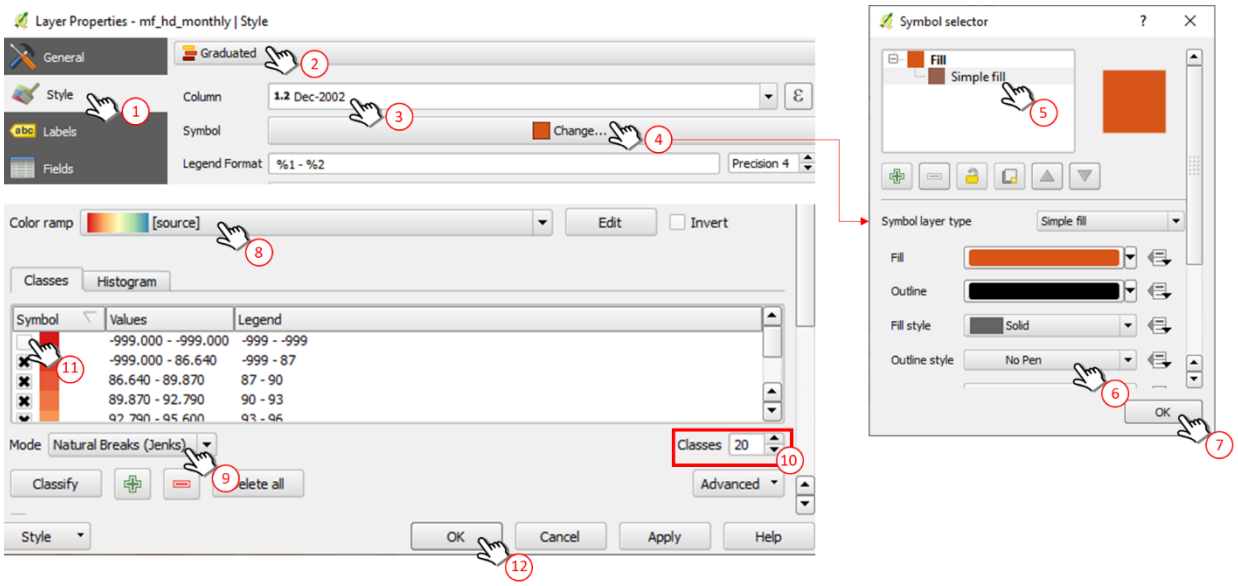
3) Specify the period of visualization.

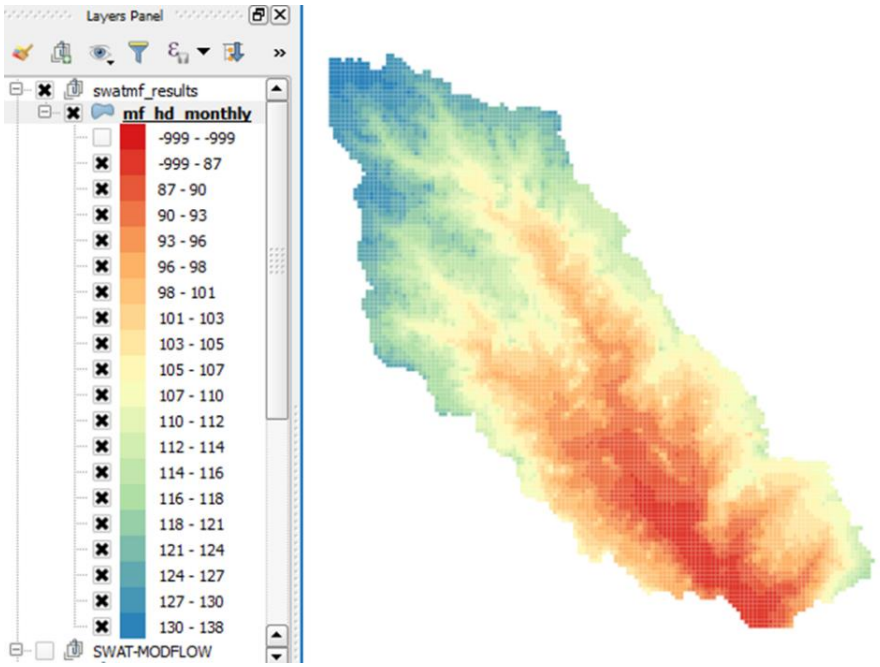
4) Click the "EXPORT" button.



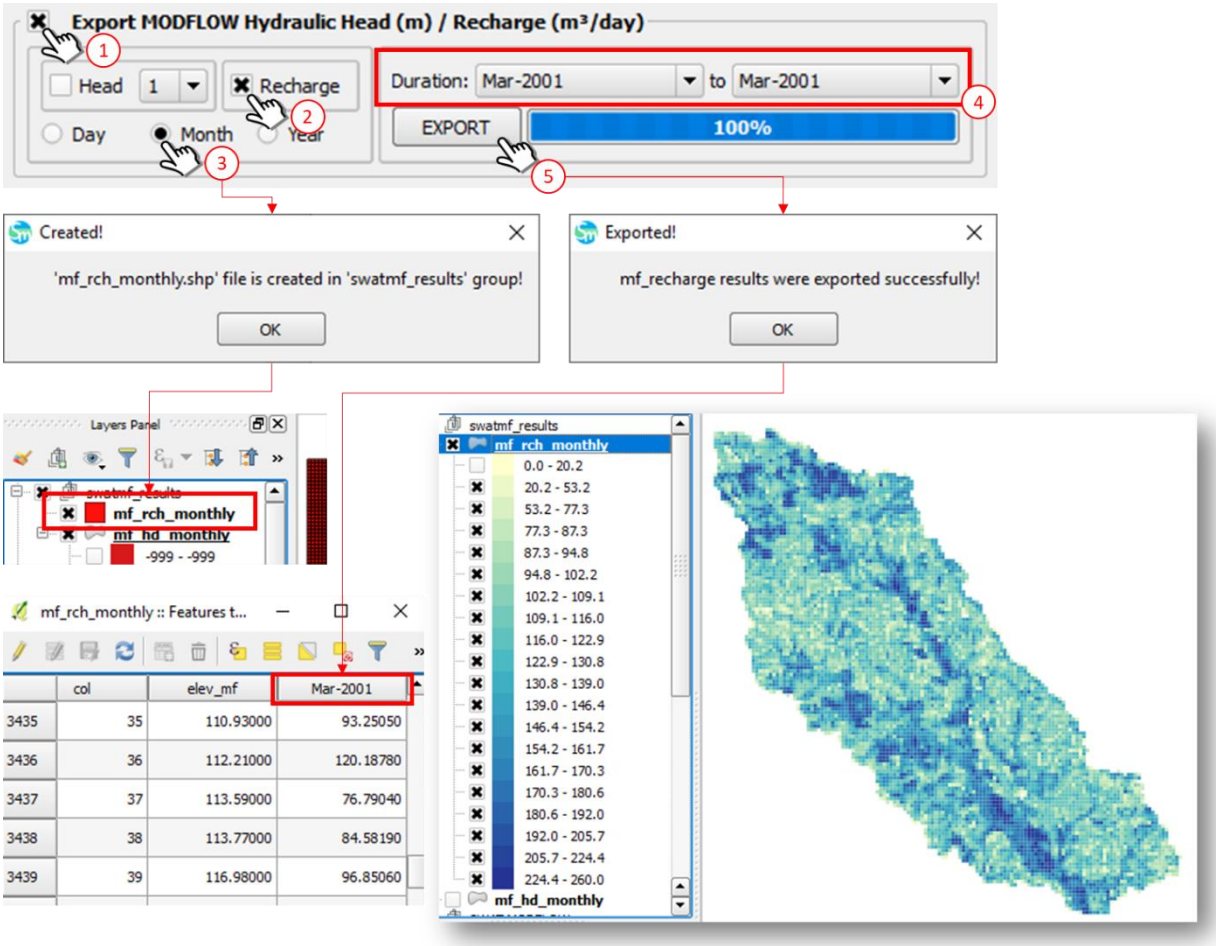
Now users can visualize the exported hydraulic head on the QGIS canvas. For the tutorial, let's map the hydraulic head of Dec-2002.

1) Open the "mf_hd_monthly" layer's property and click the "Style" tab (1).
2) Change Symbol Option to Graduated (2).
3) Choose Dec-2002 field (Column) (3).
4) Click Change button (4) and change Outline style to No Pen.
5) Choose Color ramp (8), set Class Mode to Natural Breaks (9), and the number of Classes (10)
6) Uncheck a symbol range for MODFLOW inactive cells.





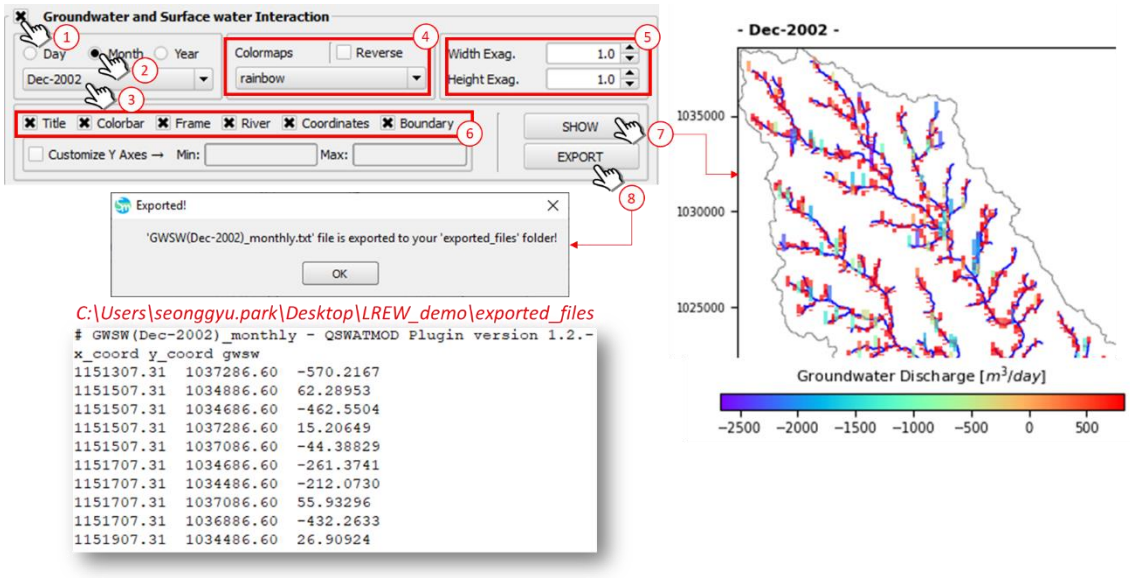
For mapping recharge, it would be the same procedure as mapping hydraulic head.



6.3. Visualizing Surface and Groundwater Interaction

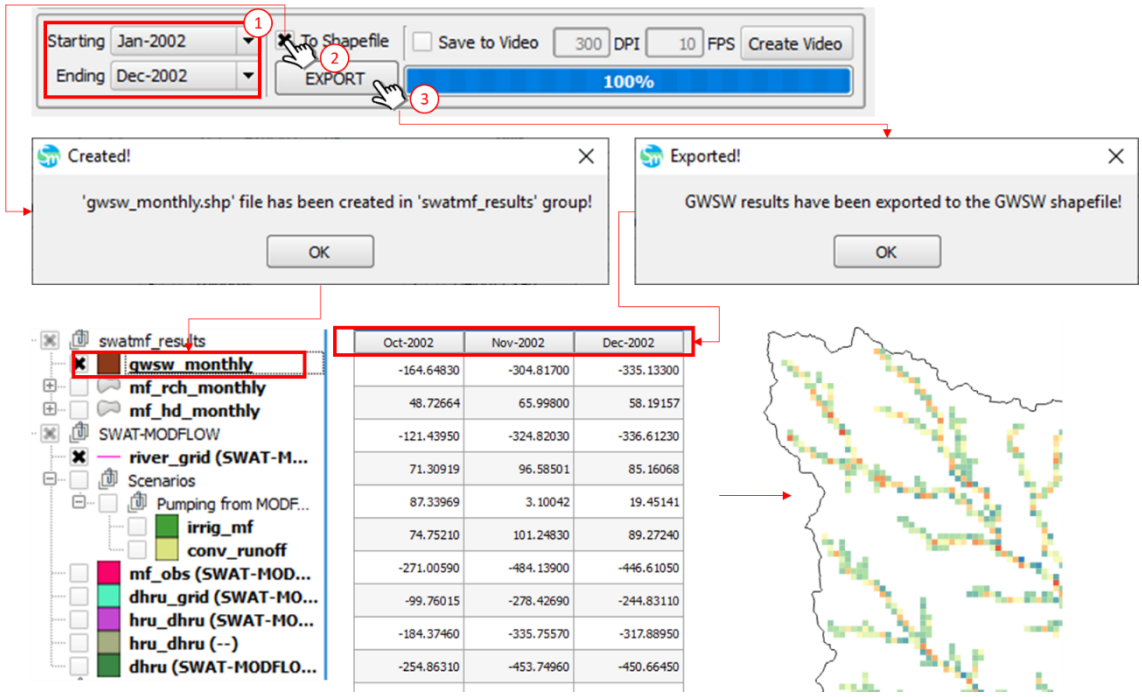
The SWAT-MODFLOW simulation provides output for groundwater-surface water interaction and QSWATMOD reads the output files (swatmf_out_MF_gwsw -daily, monthly, and yearly), draw plots, export them to shapefiles and create a video for timeseries outputs.

1) Check the “Groundwater and Surface water Interaction” box (1).
2) Check Month (2) and Choose Dec-2002 (3).
3) Select Color ramp (4)
4) Users can set width and height exaggeration option for changing bar shapes (5).
5) Check the objects you want to display on the plot (6).
6) Click the “SHOW” button (7).
7) Users can store selected data in a text-formatted file by clicking the “EXPORT” button (8).



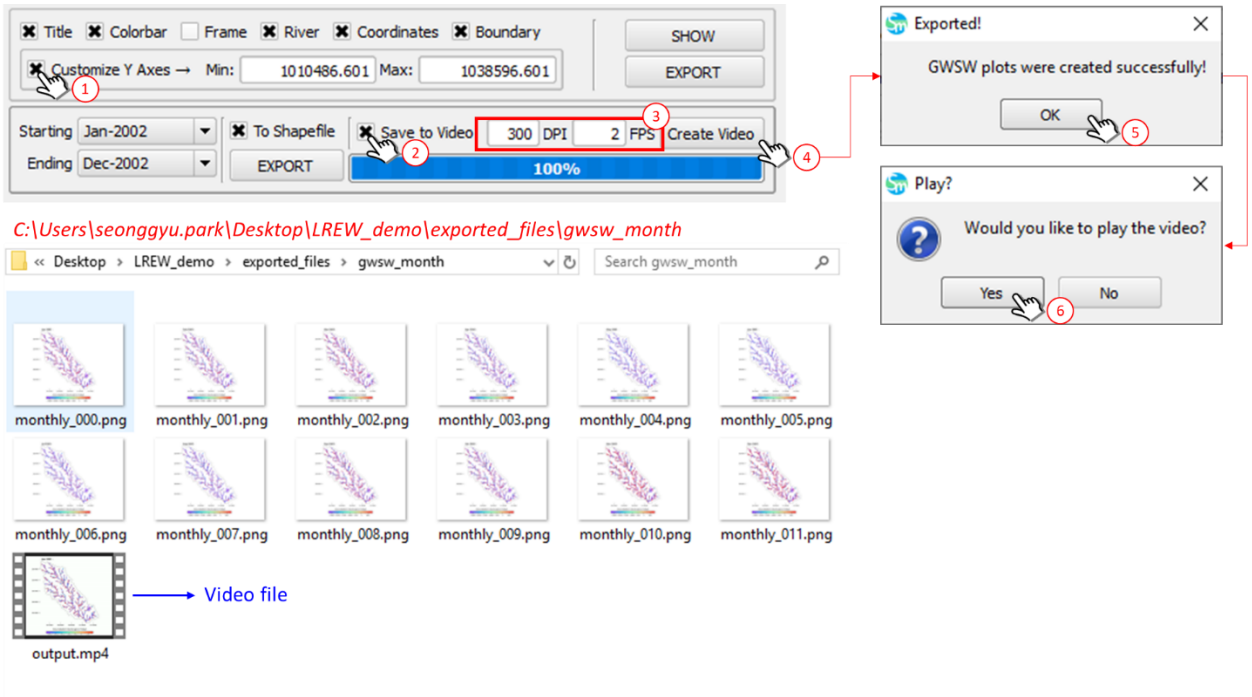
Users can also use the mapping function showing the map of groundwater and surface water interaction. After users specify the period of visualization, the data are exported to a shapefile and stored in its attribute table.

1) Specify the period of visualization (1).
2) Check the “To Shapefile” box (2).
3) Click the “EXPORT” button (3).



Once users create the figures for the period of visualization, the figures can be converted to a single video clip by selecting the “Save to Video” icon, according to the “DPI” and “FPS” settings (see Video https://ars.els-cdn.com/content/image/1-s2.0-S1364815218307710-mmc3.mp4).

1) Check the “Customize Y Axes” box to have constant Y min and max values through a visualization period (1).
2) Check Save to Video and set DPI and FPS values (2)(3).
   ** DPI: Pixels Per Inch / FPS: Frames Per Second*
3) Click the “Create Video” button (4).
4) Images and a video will be stored in a sub-folder (gwsw) of the exported_files folder.

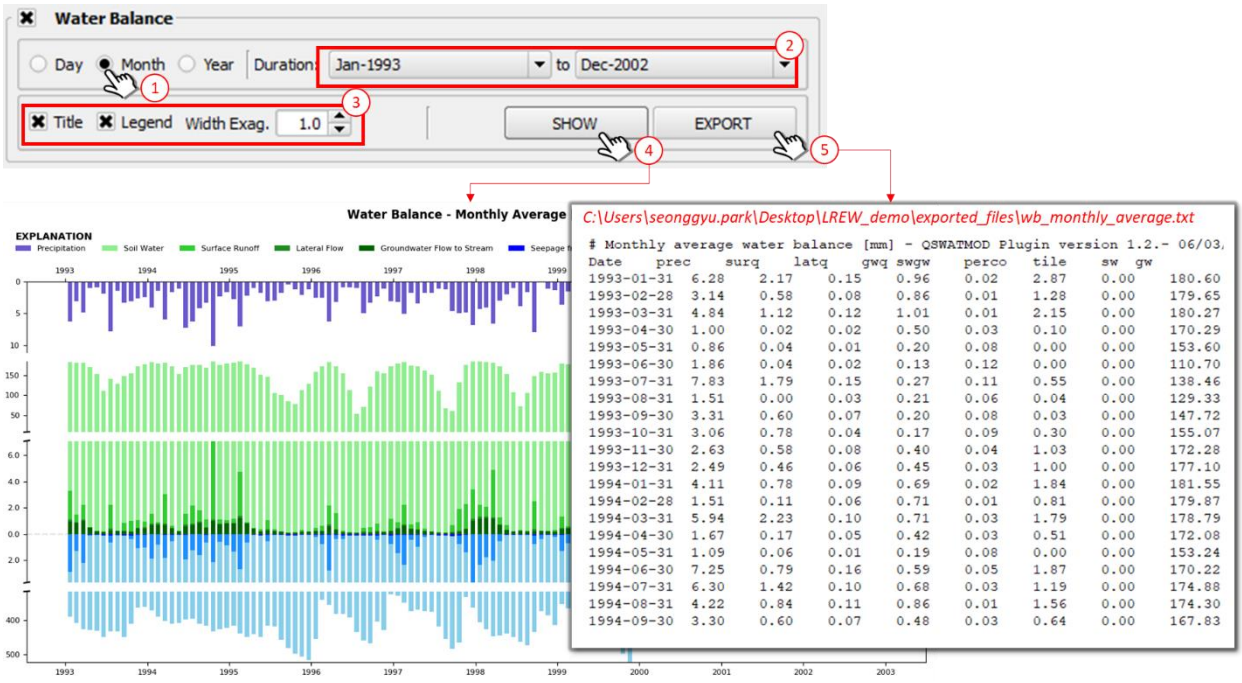


6.4. Water Balance Chart

The water balance option reads the SWAT “output.std” file and uses precipitation, surface runoff, lateral flow, groundwater flow to streams, recharge to the water table, soil water, seepage from streams to the aquifer, and groundwater volume to display a time series of water balance components.

1) Select one of time options (1).
2) Specify the period of visualization (2).
3) Check the objects you want to display on the chart and set width exaggeration (3).
4) Click the “SHOW” button (4).

Users can store a selected data in a text-formatted file by clicking the “EXPORT” button (5).



Supplementary Material

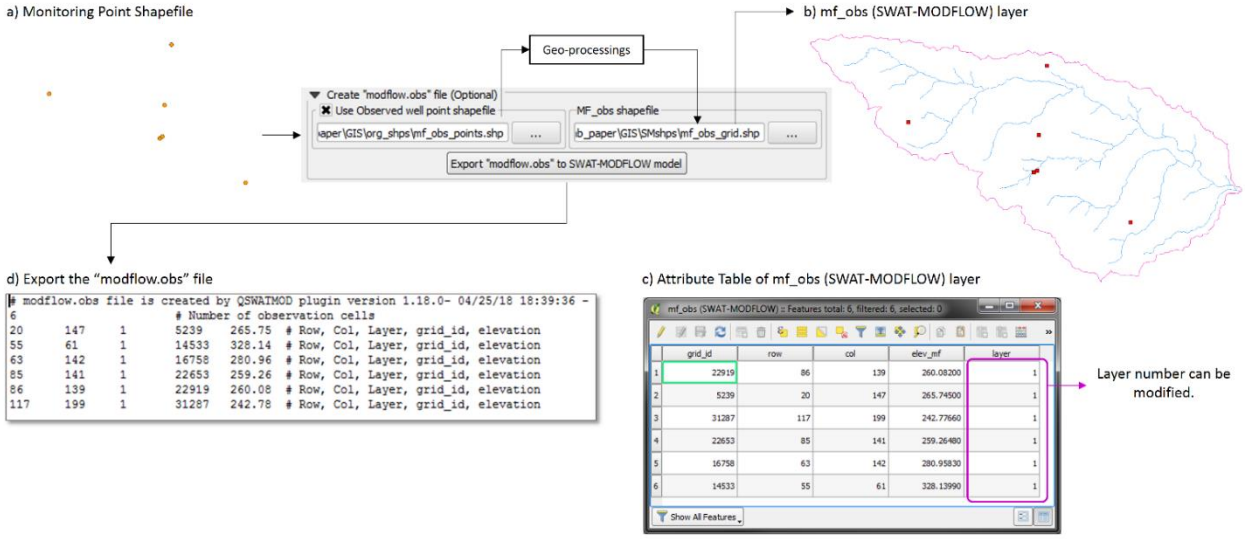


Figure S1. Creating "modflow.obs" file using either a) Monitoring point; or b) "mf_grid.shp" shapefile.

a) "streamflow.obd" file

Date	sub_58	sub_56	sub_1	sub_3
2/1/1993	5.88		1.93	5.88
2/2/1993	5.31		3.5	5.31
2/3/1993	11.3		3.2	11.3
2/4/1993	41.56		2.64	41.56
2/5/1993	14.79		2.64	14.79
2/6/1993	9.44		2.3	9.44
2/7/1993	6.97		2.22	6.97
2/8/1993	6.03		2.22	
2/9/1993	5.31		2.15	
2/10/1993	12.7		2.07	
2/11/1993	8.04		2.07	
2/12/1993	5.31		2	
2/13/1993	4.78		3.1	
2/14/1993	4.53		2.73	
2/15/1993	18.75		2.3	
2/16/1993	11.3		2.22	
2/17/1993	6.49		1.93	

b) "modflow.obd" file

Date	C01L_22919_wt	C02D_22653_wt	C01L_22919
10/21/1985	259.503644		-0.85344
10/22/1985	259.412204		-0.94488
10/23/1985	259.320764		-1.03632
10/24/1985	259.229324		-1.12776
10/25/1985	259.107404		-1.24968
10/26/1985	258.894044		-1.46304
10/27/1985	258.680684		-1.6764
10/28/1985	258.589244		-1.76784
10/29/1985	258.528284		-1.8288
10/30/1985	258.436844		-1.92024
10/31/1985	258.375884		-1.9812
11/1/1985	258.314924		-2.04216
11/2/1985	258.253964		-2.10312
11/3/1985	258.208244		-2.14884
11/4/1985	258.162524		-2.19456
11/5/1985	258.071084		-2.286
11/6/1985	258.040604		-2.31648
11/7/1985	258.010124		-2.34696
11/8/1985	257.979644		-2.37744

Figure S2. Observation file formats (Tab delimited) for a) "streamflow.obd"; and b) "modflow.obd" files. These data will be compared to SWAT-MODFLOW output once the simulation has finished.