Guide for Hydrological Modeling using QSWAT

PARADeS – Open Education Resource

Prepared by

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1. Introduction

1.1 The objectives and expectations from this training module

The objective of this module is to provide the potential audience with the basic skills and system steps for building a hydrological modeling, using the QSWAT tool. This training material is part of the aims of the PARADeS project to develop Open Education Resources for human capacity building, increase public awareness of flood disaster risks, and provide training materials on flood disaster management, using results and examples from project outcomes in Ghana. Overall, the OER serves as a valuable resource for learning about flood-related topics and research outcomes, while promoting knowledge exchange and awareness within both scientific and non-scientific communities. The White Volta River catchment in Ghana and Burkina Faso, West Africa, is used as an example.

What is the motivating factor to use this training material?

After going through this training module on hydrological modeling, the user is expected to gain knowledge and basic experience on building a hydrological model with QSWAT, its usefulness in flood and water resources management, and basic skills in model calibration and validation. This can then be a foundation for building advanced hydrological models for even more complex and large river catchments in any part of the globe and at varying scales.

1.2 Hydrological model

Hydrological models represent or simplify the complex interactions and movement of water within the water cycle of a watershed. It provides coordinated guidance for water resource management, river runoff, and flood forecasts based on return periods of river flow (observed and simulated) under climate change and land use scenarios (Marshall, 2014). Numerous Hydrologic models exist and have been widely adapted based on the expected outcome or the purpose of the modeling and the spatial conditions or scale of the catchment. The PARADeS project adopted the SWAT hydrologic model, due to its suitability for relatively large and data-scared catchments, such as the White Volta.

1.3 SWAT model

SWAT is a computer simulation hydrologic model, which uses the water-balanced approach or equation and has been widely applied in data-scared catchments. The Soil and Water Assessment Tool (SWAT) is a widely used hydrologic model for simulating the complex processes of the hydrologic cycle at the watershed scale. The SWAT model is a powerful tool for studying watershed-scale hydrology, land use planning, and water resource management. It allows for the assessment of various scenarios and the development of strategies to address water-related challenges and flood forecasting in a watershed. The SWAT model is integrated into GIS software (ArcGIS and QGIS) as a plugin to delineate watersheds, run simulations, and optimize the visualization of model outputs.

The input data for the SWAT model broadly include a digital elevation model (DEM), soil data, climate data, and land use. In catchments where dams or reservoirs exist, the dam management parameters are required as part of input data. The simulated results can be calibrated, using SWAT-CUP software. However, the calibration process requires observed data (e.g., river discharge data at either daily, monthly, or annual scale) using measured river discharge data with catchment-specific parameter ranges as input data. As part of the training materials, some basic data sets such as the DEM, soil, daily rainfall, and minimum and maximum temperature, and land use data for the White Volta catchment have been provided to be used as input data to set up the model and run the simulations.

1.4 Summary of SWAT hydrological modeling processes

1. **Data preparation**: Gather necessary data for the watershed, including topographic data (elevation, slope, aspect), land use/land cover, soil properties, climate data (precipitation, temperature, wind, solar radiation), and streamflow measurements. The historical climate data can be (e.g., daily precipitation, daily minimum and maximum temperature). SWAT requires daily weather data for simulation. Ensure that the data are in the required format and spatial resolution for the SWAT model. Climate data can be prepared, using SWAT Weather Generator
2. **Watershed Delineation:** Define the boundaries of the watershed of interest using digital elevation models (DEMs) and GIS software.
3. **Creation of Hydrological Response Units (HRUs):** Assigning land use and soil properties to each sub-basin based on their similarities. SWAT categorizes land use into various classes and soils into different soil types, each with specific hydrological properties.
4. **Hydrologic Simulation:** Set up the SWAT model by specifying input data, parameters, and model options. Run the SWAT model for specific time periods (e.g., annually, or monthly time steps) using the prepared input data. Depending on your objective and data availability, the SWAT model has the capability to simulate various hydrologic processes, including precipitation, runoff, infiltration, evapotranspiration, and groundwater flow.
5. **Running SWAT check and visualization of model outputs:** once the model simulation is complete, you can run SWAT check to see the water balance ratios of your model before you proceed to save your simulations output such as the *output.rch*, *output.hru*, *res*, or *output.sub*. After saving the simulation, you can then proceed to visualization of results.
6. **Calibration:** calibrate the model by adjusting various parameters to match observed streamflow and other hydrologic data.
7. **Validation:** validate the model's performance by comparing simulated results to independent datasets for different time periods.
8. **Output Analysis:** Analyze the model outputs, which may include streamflow, groundwater recharge, sediment yield, and nutrient loads.
9. **Evaluate the impact of land use and land management scenarios on water resources, using scenarios:** use the calibrated model to simulate different land use and management and climate change scenarios to assess their effects on the watershed's hydrology. Summarize the results and findings of the hydrologic modeling study in a clear and understandable manner, and communicate the findings to stakeholders, policymakers, and the public. This step is crucial for decision-making and water resource management, land-use planning, and flood risk management.
10. **Model Maintenance and Updating:** continue to monitor and collect new data to keep the model up to date. Periodically re-calibrate and re-validate the model as conditions change.

2. Setting the model using QSWAT

2.1 Computer/technical requirements

For your personal computer requirements, you can the important and updated requirements on the SWAT webpage (https://swat.tamu.edu/software/qswat/). Regarding the software requirements, you need not older software versions stated below:

- Microsoft Windows (32 or 64 bits) with free hard drive space of not less than 125 GB
- Microsoft .Net Framework 3.5
- Adobe Acrobat Reader version 7 or higher (Download Adobe Acrobat Reader: Free PDF viewer)
- You also need to download and install (Microsoft Access Data Engine Redistributable 2016) Remember to choose *accessdatabaseengine_X64.exe* if your PC is 64 bits. Otherwise, choose 32 bits version
- QGIS 3.16 or newer version such as 3.22. These are the long-term release versions

- SWAT Editor 2012
- QSWAT3_9 (or QSWAT3 the older version. Check the suitable version for Microsoft Operating system) (See Figure 1)
- SWAT Check 1.2.0.10
- You can download all the required software for QSWAT listed above from the main webpage: QSWAT | SWAT | Soil & Water Assessment Tool (tamu.edu)

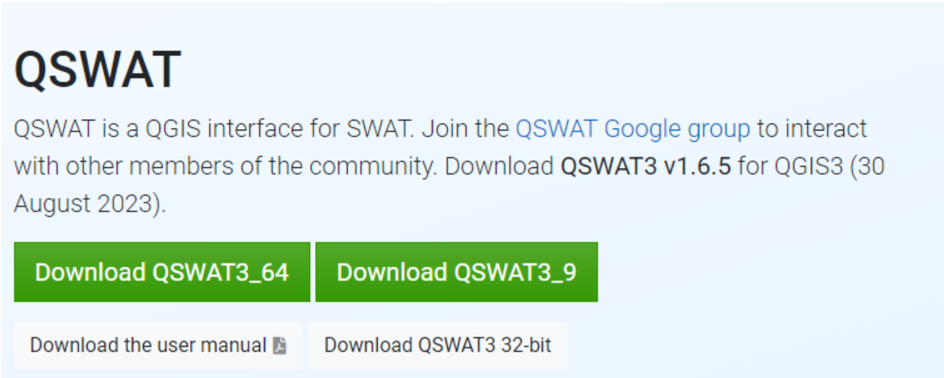

Figure 1. Interface of the QSWAT download site

2.2 Installation of QGIS and QSWAT

In the case of this training exercise, we are installing **QGIS 3.22 and QSWAT3_9 version** because the computer used for building this training material is **64 bits**.

After the installation, open QGIS and check for QSWAT plugin. On the QGIS menu bar, go to plugin and click on *Manage and Install Plugins.* Click on *"Installed"* and check the *QSWAT3_9* (figure 2)

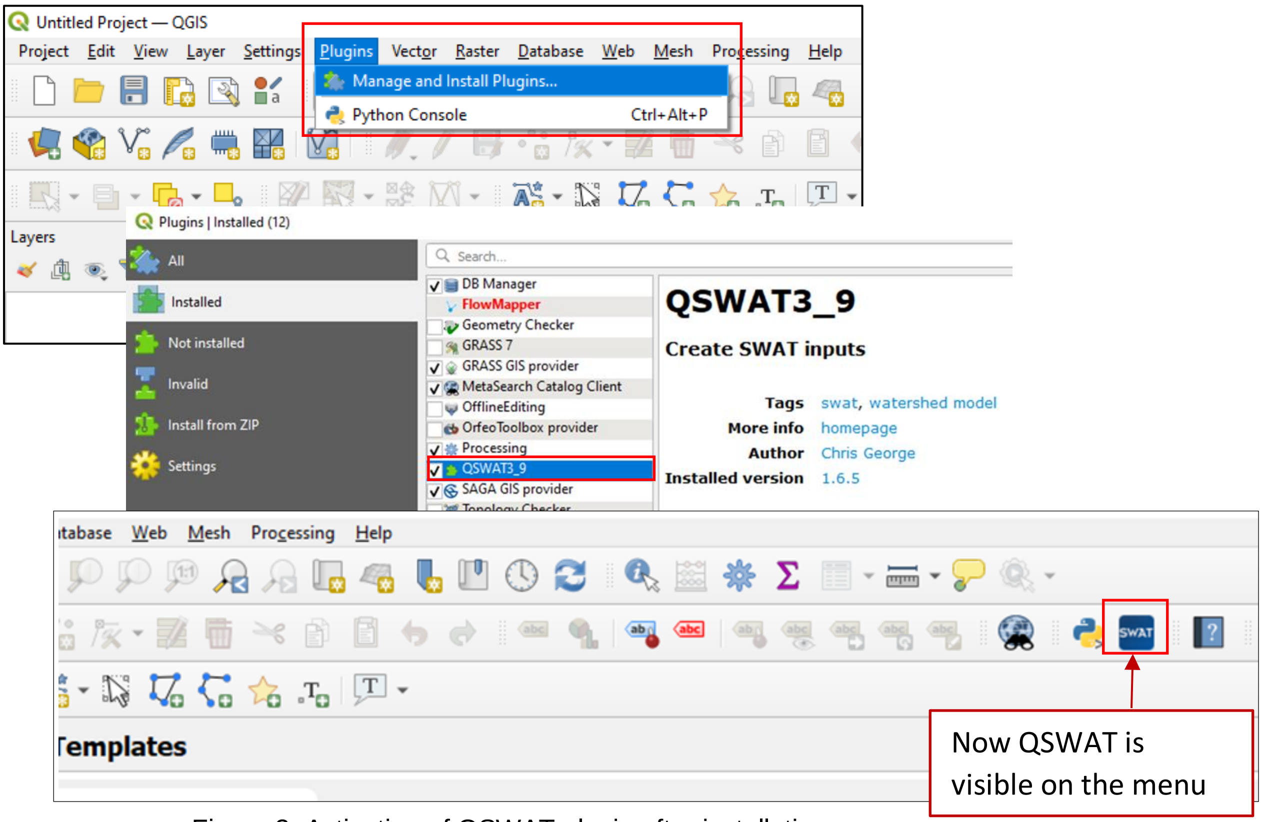

Figure 2. Activation of QSWAT plugin after installation

2.3 Input data requirement and organization

1. SWAT hydrological model requires (for this training, the input data has been provided for free)
   - DEM (grid or .tiff)
   - Soil (grid)
   - Climate data (daily rainfall, minimum and maximum temperature) (prepare with weather generator "WGEN")
   - land use data (raster format)
   - River outlet point (shapefile)

Please note that all the input data must have the same projections. For example, for Ghana it is ***WGS84 / UTM 30 N***

2. To start building a SWAT model, the input data must be prepared and organized into a single a folder, where you can easily gain access.
3. For help on how to prepare the input data, you may need support from various sources, including (the links and additional materials in the references section on Page 22).

3. Creating a new SWAT hydrological model

3.1 Create a new project

Click the SWAT icon (Labelled **#1**) in the toolbar (Figure 3). This will open a new window where you can either create a new project or select an existing project (in our case, we will create a new project). Click on *New Project* and name it as ***"SWAT_Volta"*** and save it in your working directory (the folder you created for the input data). After saving the project in the working directory, the next steps in "Select Project" frame will be activated. You will notice that Step 1 **(#2)** is now active and other two are still inactive.
Also, you will see location of your working directory in the bottom left corner.

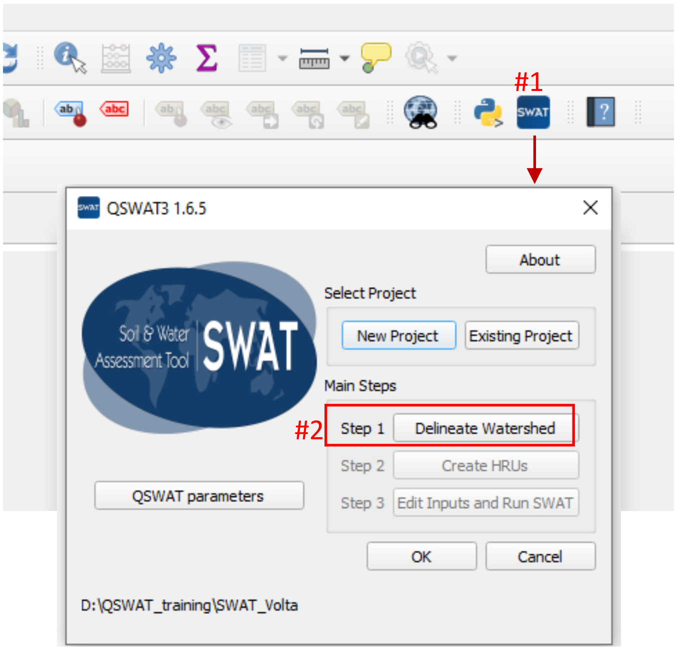

Figure 3. Creating a new SWAT project

3.2 Delineate Watershed

To delineate watershed, go to *Step 2* and click on *Delineate Watershed.* A new window will open for you to import the *DEM* **(#1)**. Next, we need to define threshold by specifying the number of cells (e.g., 470) (**#2**). Click on *create streams* **(#3)**.

Note! when you get warnings or messages related to firewall access, simply cancel those messages for the program to proceed

After creating the stream networks, the next step is creating the stream outlet to set the boundary of the catchment. In our case, the stream outlet points are provided so all you need is to import it to assist you locate the outlet. Click on *Draw inlets/outlets* **(#4)**. Zoom in to the outlet as much as possible to a place where you want to place the outlet point. Now, click on outlets **(#5)** and move to the map and place your outlet. Return to inlet/outlet window and press **OK**.

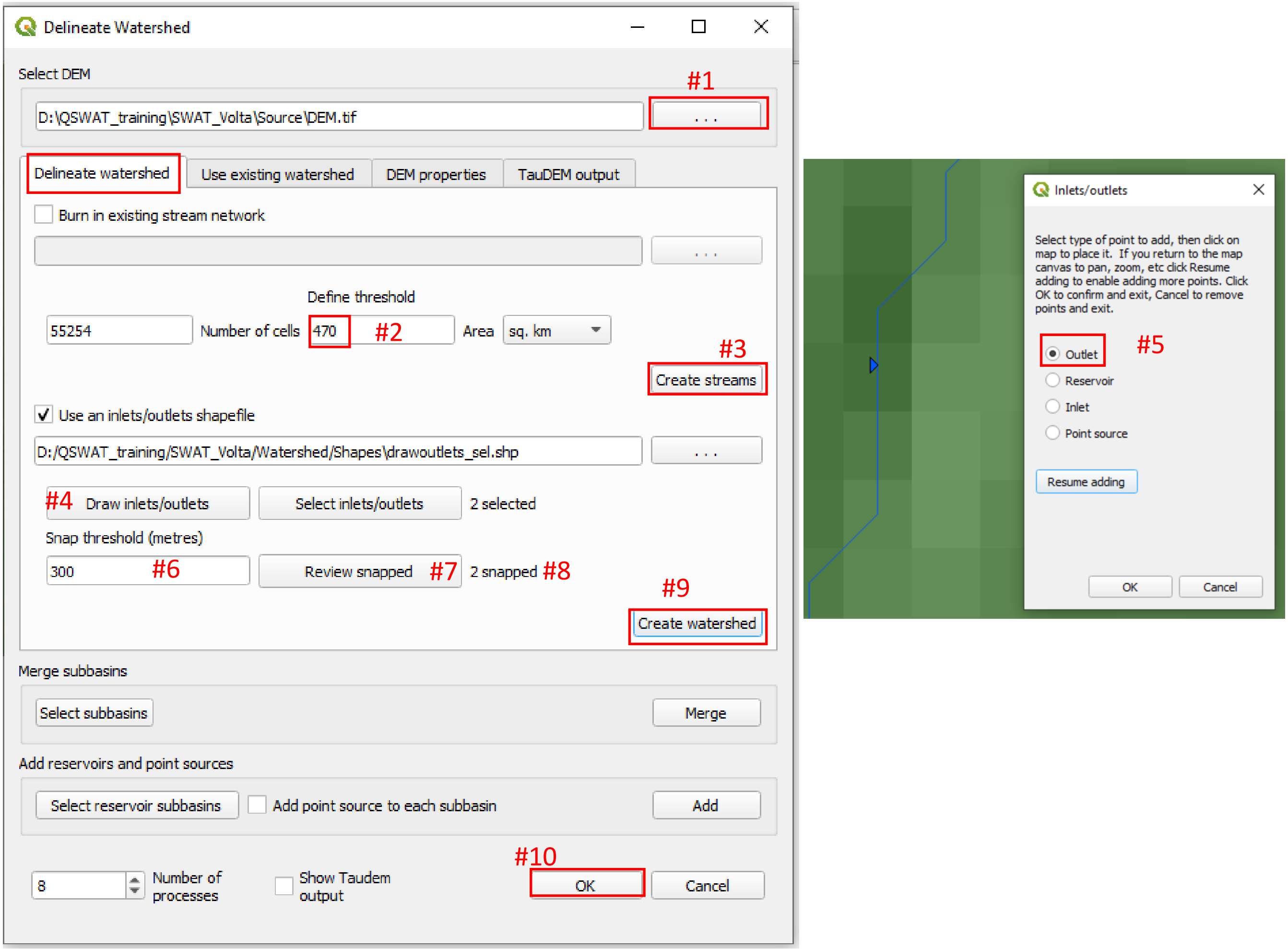

Figure 4. Steps for delineating watershed

When the outlet you have created is placed far from the main streamline, you can click on *Snap threshold* (meters). The default value is 300 meters **(#6)**. You can change it if appropriate. Click on Review *Snapped* **(#7).** A message *"2 snapped"* **(#8)** will show. Now go ahead and click on *"Create watershed"* **(#9).** Depending on the speed of your computer, it may take about 5 to 10 or more to create the watershed. Once the watershed is created, click on Ok (**#10**) to complete process under step 2.

3.3 Create the Hydrological Response Units (HRUs)

After the *Step 1* is completed, the *Step 2* will be activated for the creation of the HRUs. Land use, soil, and slope data are required to create the HRUs.

Figure 5. Step 2 frame is now activated for creating HRUs

Now click on *Create HRUs* (Figure 5), and a new window will open (Figure 6). Choosing land use **(#1)** and for the landuse table, select *csv file* **(#2)**. This will allow you to select the *landuse* table in the next steps. Next, select *soil map* **(#3)** and import the soil map provided (select the *hdr.adf* file). For the *Soil data section* click on *usersoil* **(#4)**, if not already selected by default. Next, for the *Soil Table* **(#5**), select *usersoil* and load soil data. This allows SWAT to communicate with the *usersoil* integrated in the database (*QSWATRef2012*).

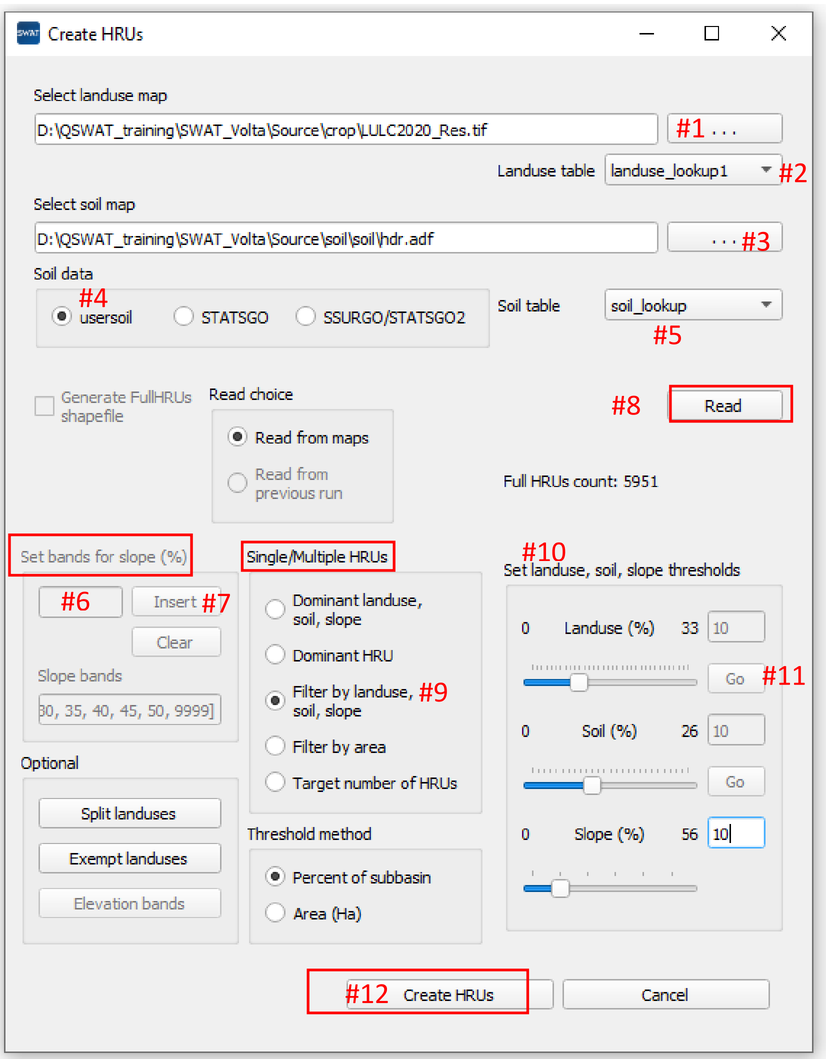

Figure 6. Illustration for creating HRUs

The next step is to define the slope (in %). Go to *Set bands for slope* and enter values (5, 10, 15, 20, 25, etc.) in the box **(#6).** You must enter the slope values one after the other. Once you enter e.g., 5, you must click on *Insert* (**#7**), and repeat the steps until you have completely defined all your preferred slope values. Once you click on *Read* **(#8)**, you will be prompted to choose the Landuse and soil lookup tables (then navigate to the SWAT training folder and select *Landuse lookup* file (repeat the steps to import the soil lookup table).

Now move to the next stage under *Single/Multiple HRUs* frame and click on *Filter by landuse, soil, slope* **(#9)**. To create HRU by using the combined land use, soil and slope data, we have to input the threshold in either percentage or area. Define the threshold for land use, soil and slope **(#10)**, as shown in Figure (6). Proceed by entering "*10*" each for land use, soil, and slope, which are widely and usually preferred in SWAT models. Depending on the version of QSWAT, you may be required to push the *Go* button **(#11)** after specifying one threshold and then move to another. This process must be repeated for soil and slope. After the thresholds are specified, push the *Create HRUs button* **(#12)**.

***Note**! The HRUs window may automatically close when the process is successful*

Once *Step 2* is completed, you may see it marked "*done*"

3.4 Editing Input Files and Running SWAT

The *Step 3* allows you to edit inputs and run the SWAT model. When you click on the *SWAT Editor* a window will open for you to connect your SWAT project to the Database. If your working directory is saved on a different Disk Drive, you must copy the path in **(#1)** and paste it in **(#2**) (this will connect to your local soil database). If not done, the default soil from the USA will be used. Now click on connect to database **(#3)**. This step allows input of Weather/climate data.

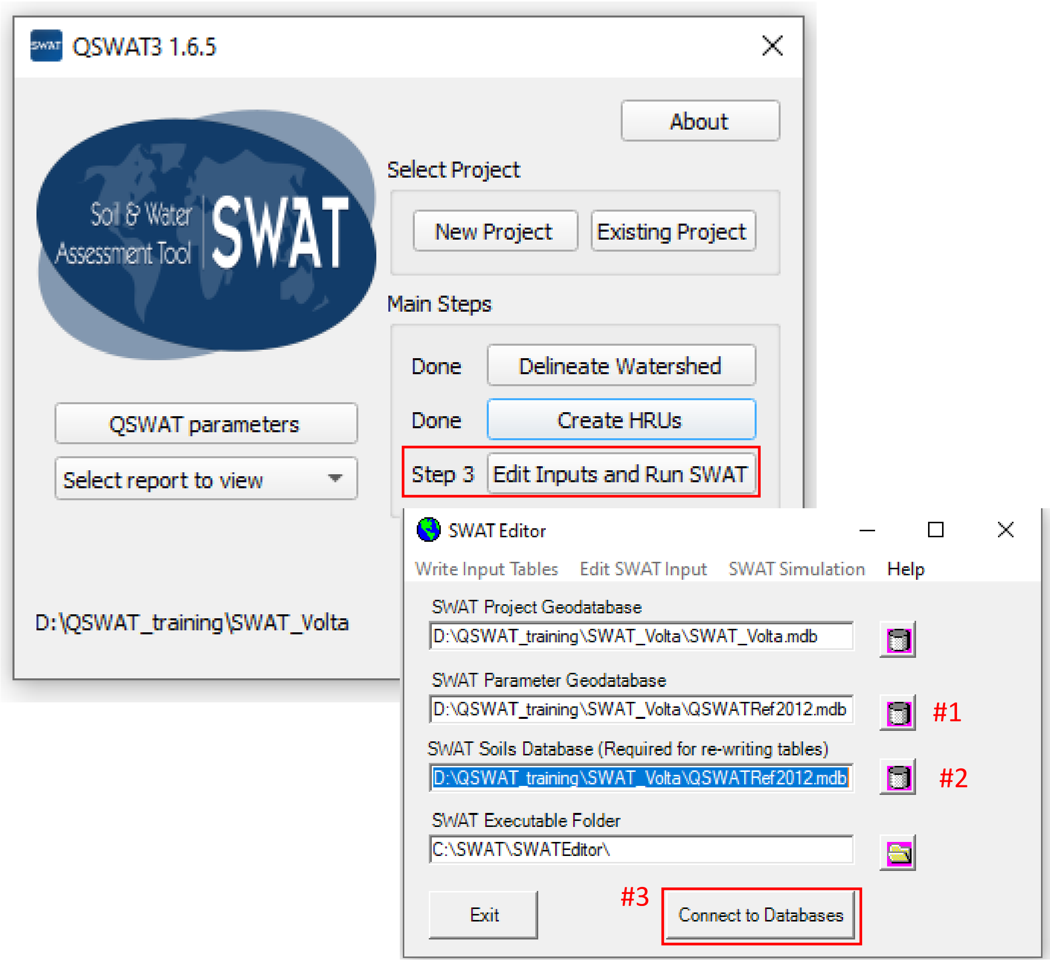

Figure 7. Steps to creating input tables

Before creating SWAT input tables, remember to integrate your Weather generator (*WGEN_Volta.xlsx*) (which is provided in the *QSWAT_training* folder) file into the Q*SWATRef2012 dabase*. This database contains the weather data you created. For support on how import these files into the database, see appendix (page 19).

Now go to *Write Input Tables* (Figure 8) and load the weather geodatabase ("*WGEN_Volta.xlsx*") **(#4)** from the dataset provided. Next, load the *Rainfall Data* but you must choose *Dailly* for the *Precip Timestep* in **figure 9** (because the data provided was on daily time scale), but check the *Raingages* box (In case the measured data is missing, you can choose *simulation option*). Go to the *QSWAT_training* folder, open the "swat-weatherdatabase" folder, further open the PCP folder, and select the *StPCP.txt file* for Rainfall **(#5)***.* Repeat the same step in figure 9 for Temperature Data **(#6)**, by selecting the *StTMP.txt. file and* check the *Climate stations* box ***(#7)*** (figure 9*)*.

Finally, click OK **(#8)**. This will create a weather database for the study area.
Then, you will get a message that *processing complete* **(#9)**. Now, click OK **(#10)** on the dialogue box. Now, click on *Cancel* on the *Weather Data Definition* window **(#11)**.

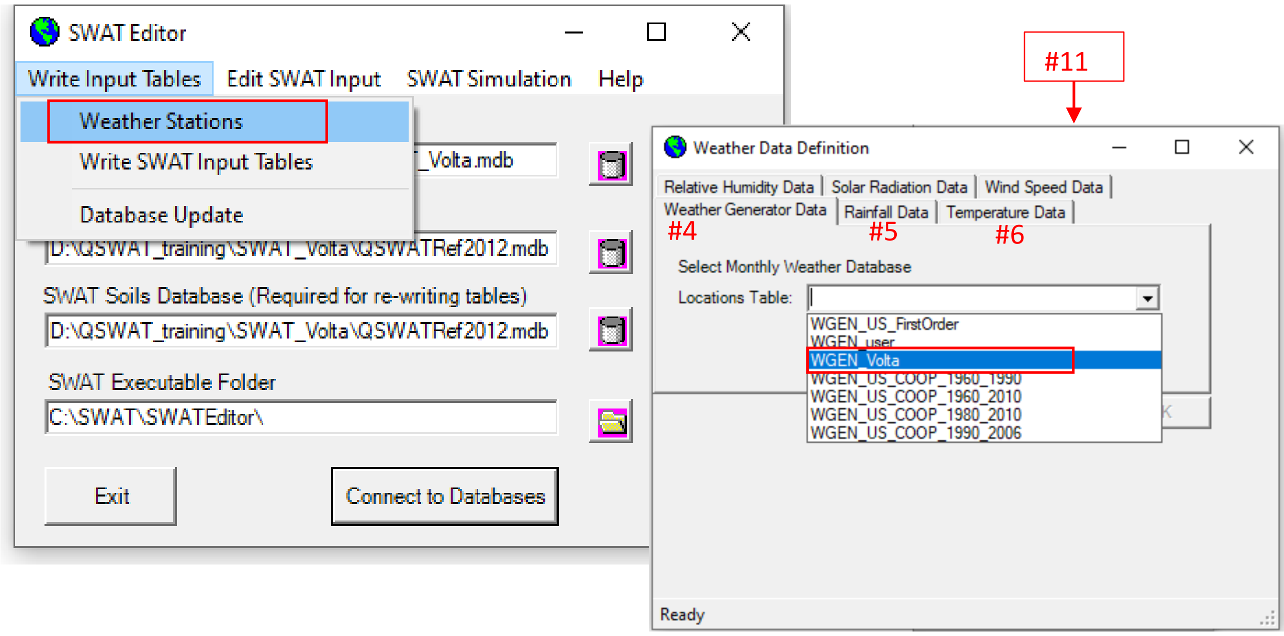

Figure 8. Steps for importing input data

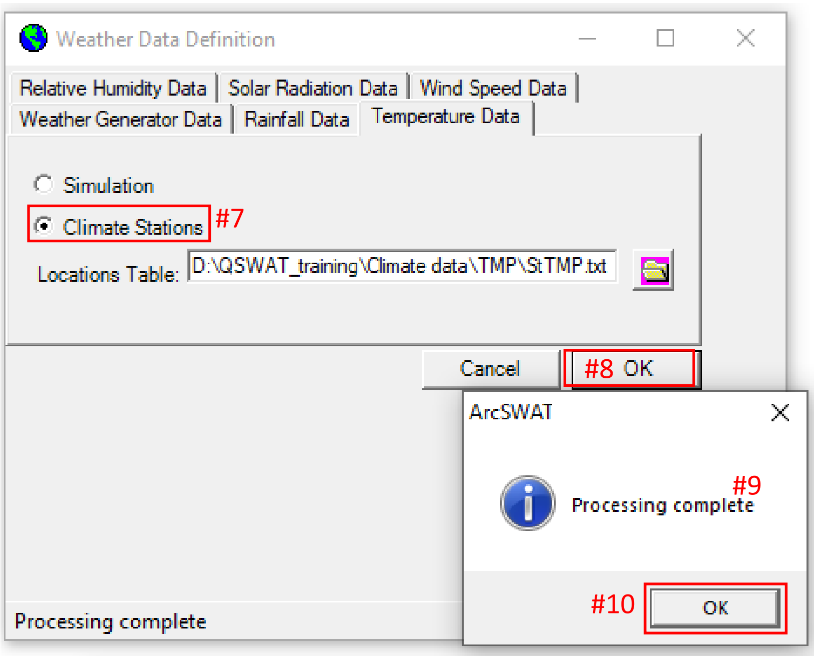

Figure 9. Further steps for importing input data

A. Write Input Tables

After generating weather database, create all input files by selecting *Write Input Tables* **(#1)** in figure 10. A new window named *Write SWAT Database Tables* will be displayed. Click on *Select All* **(#2)** and then click on *Create Tables* **(#3)**. The order of the steps are labelled A, B, and C in figure 10.

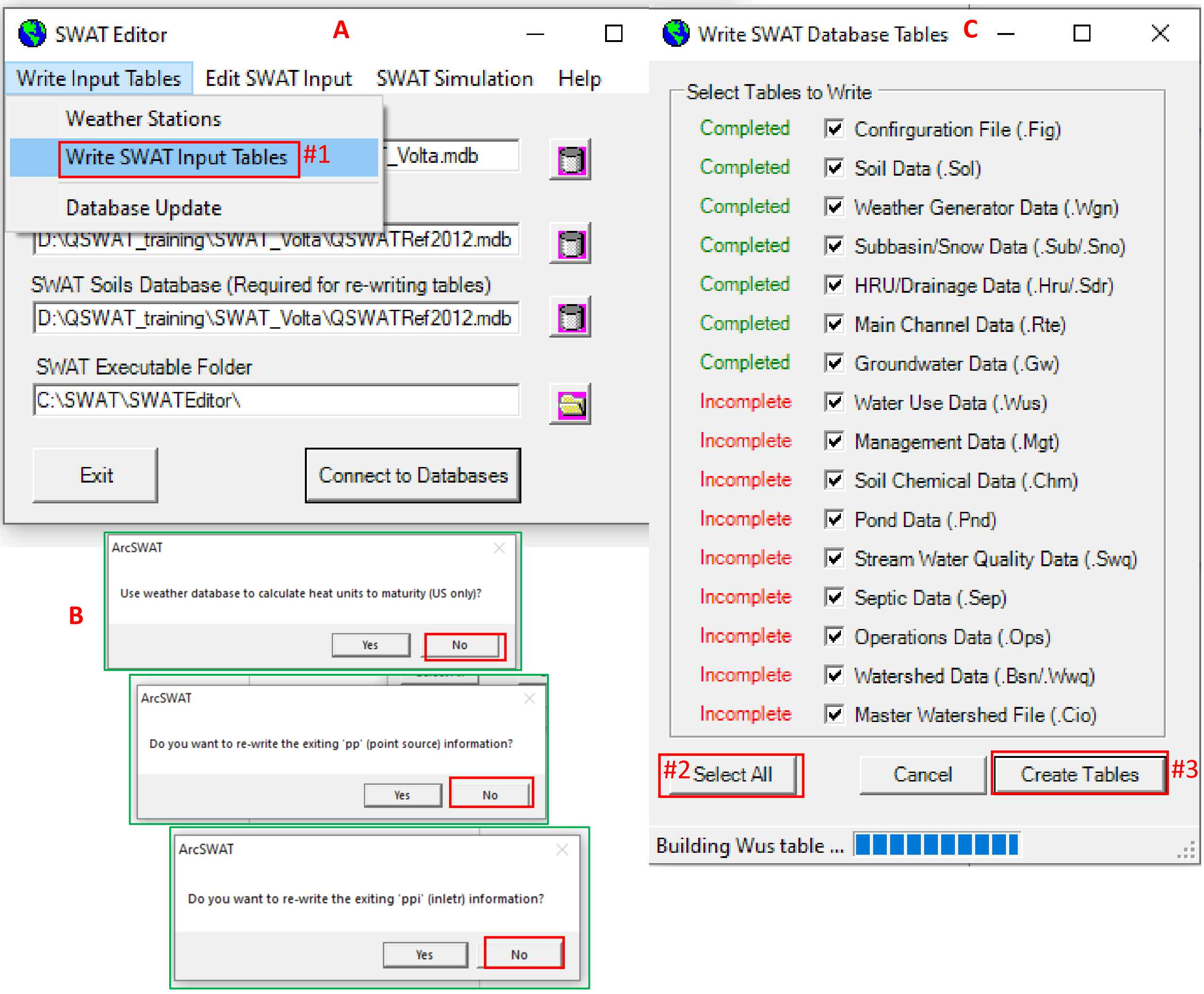

Figure 10. Writing Input Tables

A series of queries will pop up (see **B**) click no to all, and click yes to write new inlet tables, because our study area is different from the default SWAT study area which is in the USA.

B. Database updates

The next step is to update the SWAT database (See Figure 11). Select all the components **(#1)** and click on Update database **(#2)**. Once complete, you will receive a success message. Click Ok **(#3)** to exit. Now close that frame.

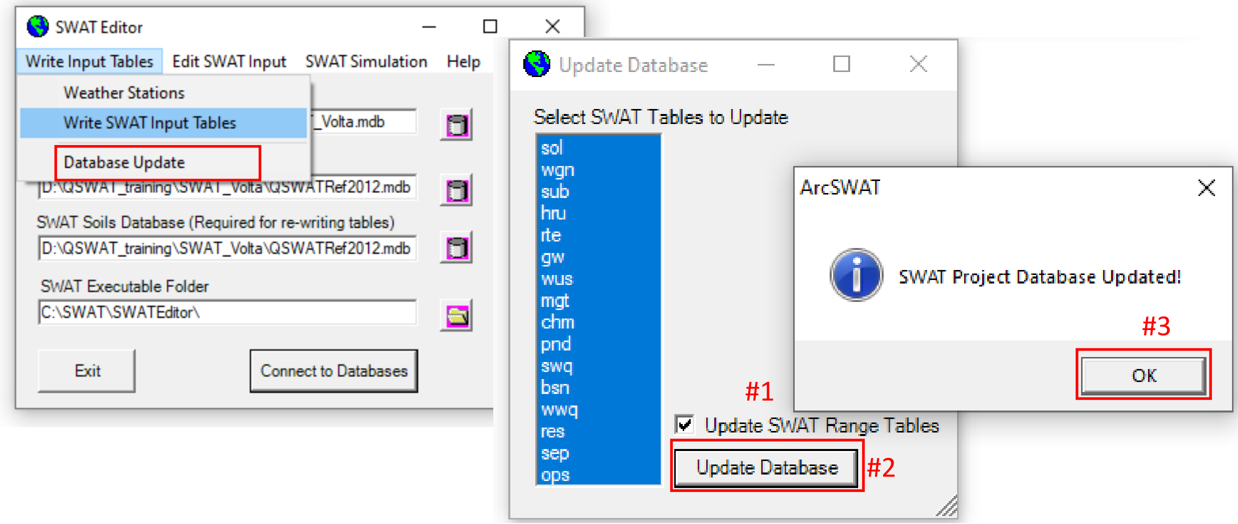

Figure 11. Steps to update SWAT database

C. Edit SWAT Input

Next, go to *Edit SWAT Input* and choose the *PET* mothed **(#2)** that can help simulate the missing PET for our study area (White Volta). Hargreaves method is the best for estimating PET when measured data is unavailable for your catchment. Start from **(#1)**, **(#2)**, and **(#3)** to open and choose the PET method as illustrated in figure 12.

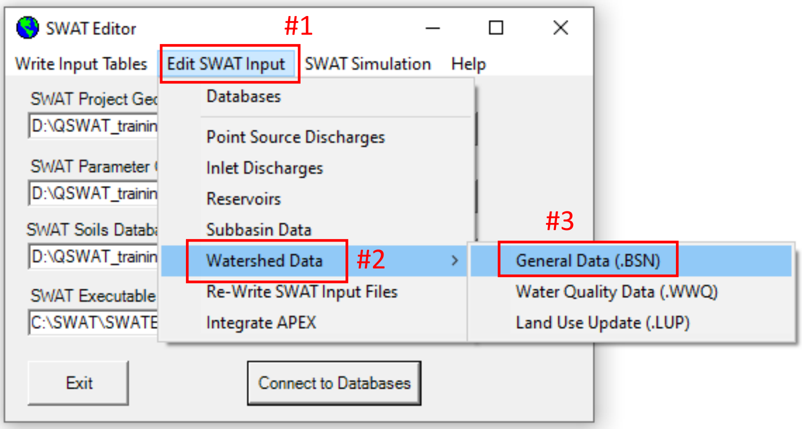

Figure 12. Editing the SWAT input

Selecting the Potential evaporation (PET) method

Once the *General Data (.BSN)* frame is open, click on *Edit Data* **(#4)** to activate the frame for editing. Nex, locate the *PET Method* section **(#5)** and click on it. You will find a number of methods among which you can choose the ***Hargreaves***. After choosing the PET method, click on *Save Edits* **(#6),** and then *Exit.*

Return to *Editing SWAT* frame and click on the *Re-write SWAT input files*. This will allow you to select all **(#7)** the components and write tables **(#8)** once again, due to new PET data that was generated by the Hargreaves method (see figure 13 for illustrations).

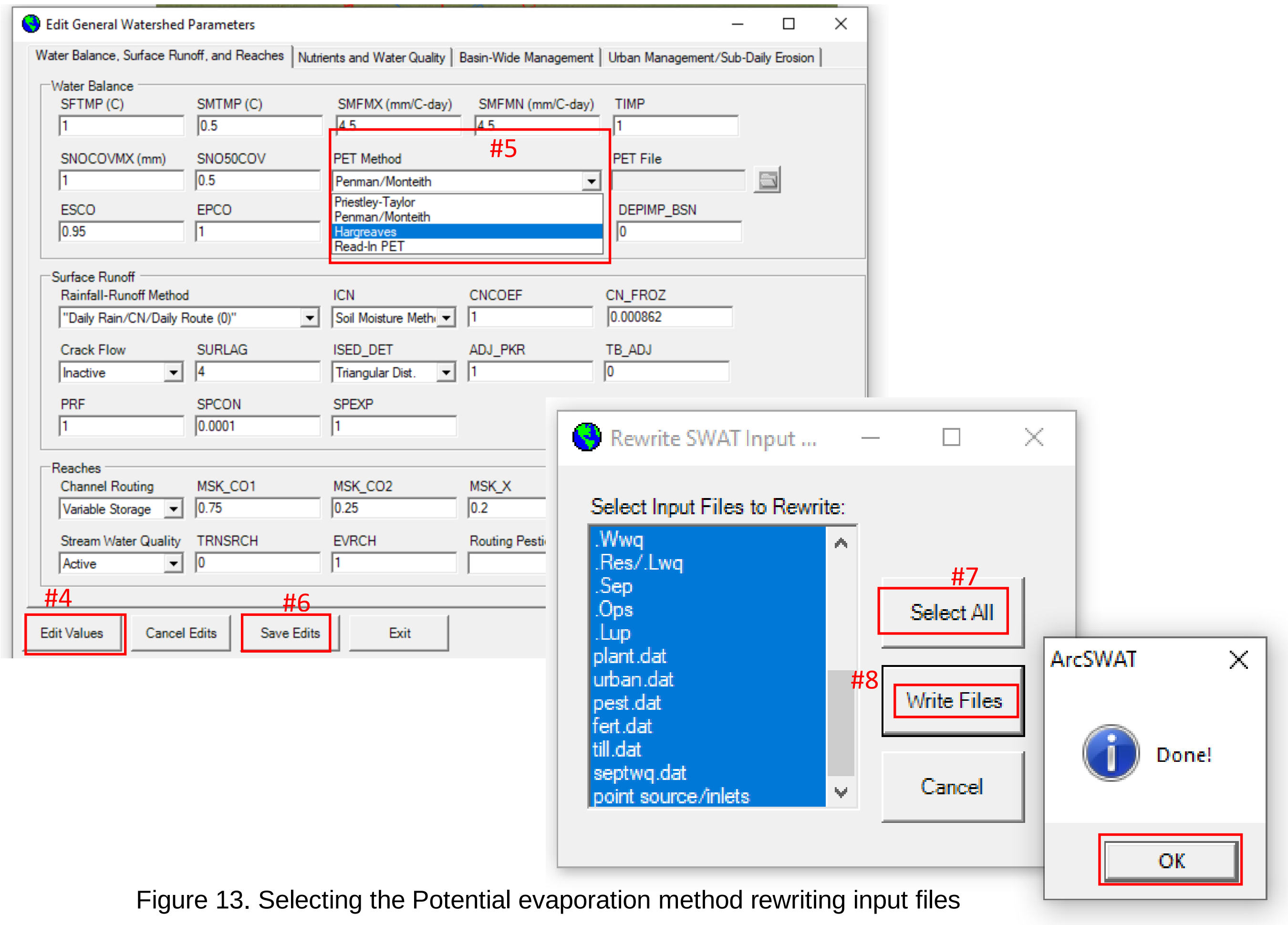

Figure 13. Selecting the Potential evaporation method rewriting input files

D. Running SWAT Simulation

Click on *SWAT Simulation* and chose *Run SWAT* as illustrated in figure 14.

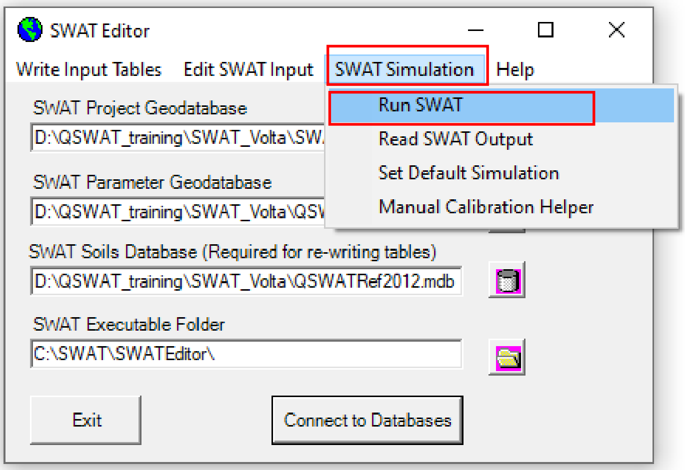

Figure 14. Step to defining and runing the SWAT simulation

Set the period of simulation *Starting Date* **(#1)** 01/01/2004 and *Ending Date* 12/31/2010 **(#2)** (These time frames will show by default because the datasets provided for this training exercise falls within that period). Change the printout settings to *daily* **(#3)** and leave other default options unchanged. NYSKIP means model simulation warm-up period (the period used to train the model) and for this training, we will use *NYSKIP as 2 years* **(#4)**. For the *SWAT extension version*, can choose the *64-bit, release* **(#5)** because it is faster for running simulations. Click on *Setup SWAT Run* **(#6)**. You will get a message indicating SWAT Setup is finished. Now, click on *Run SWAT* **(#7).**

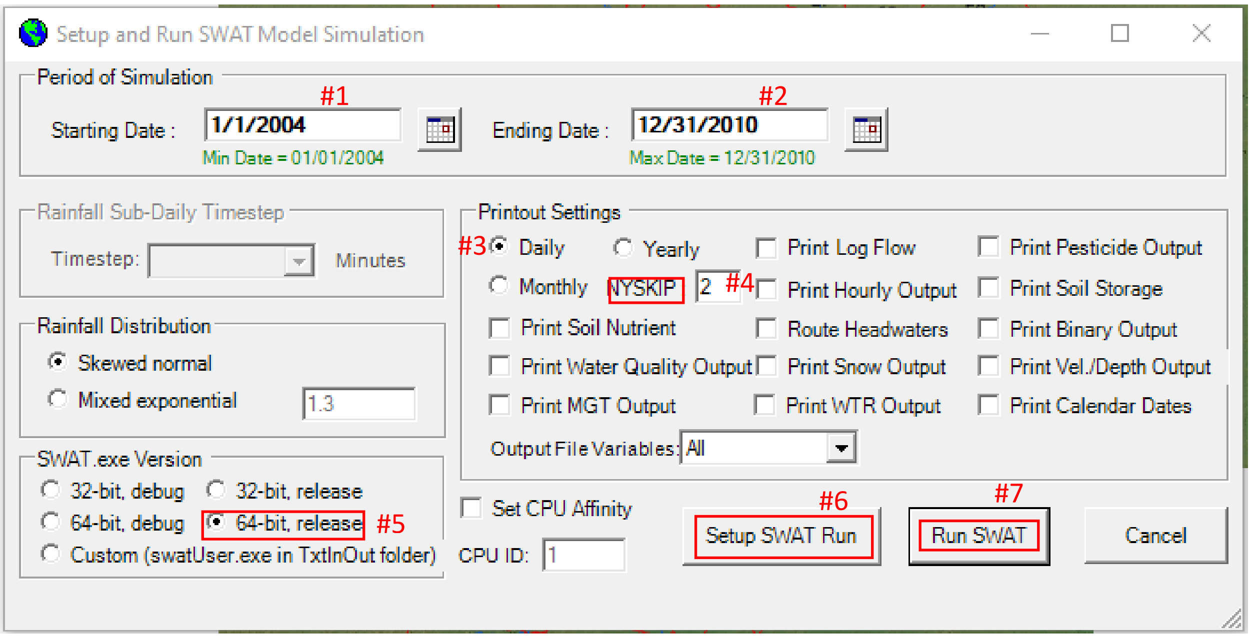

Figure 15. Defining the simulation periods and running SWAT

While SWAT is running (see figure 16), you will see a DOS window showing the progress, and when the simulation is done, you will get a final completion message and click Ok.

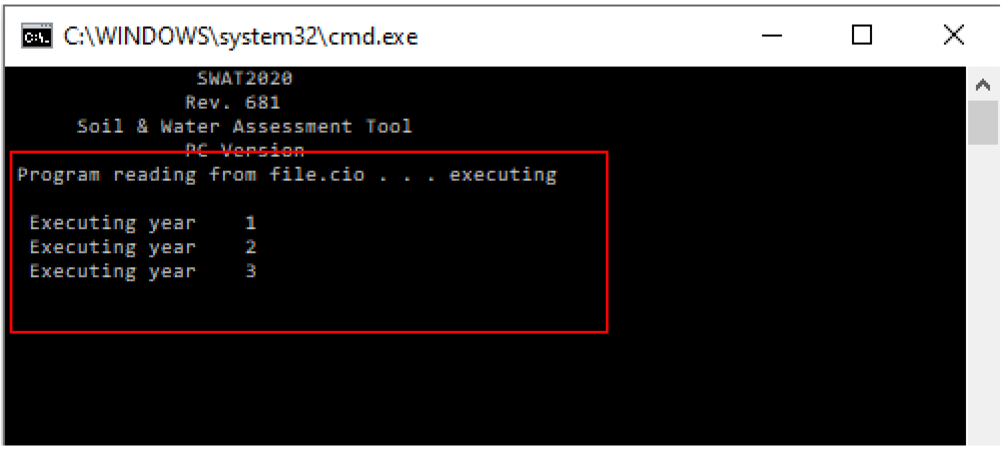

Figure 16. SWAT simulation in progress

When the simulation is successful, close the SWAT simulation setup window. You are now ready to *Read SWAT Output* (see figure 17) and visualize the model output.

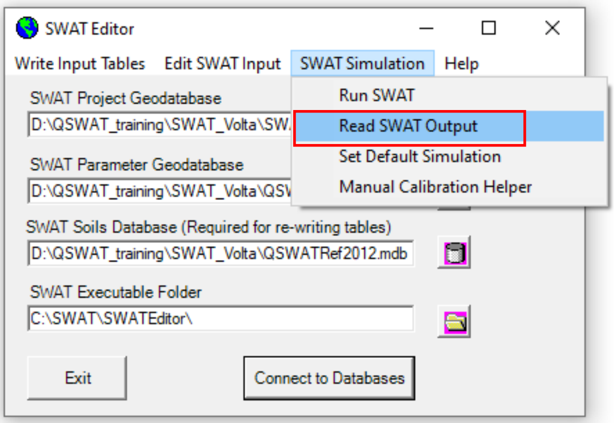

Figure 17. Steps to reading SWAT output

E. Checking the simulation for Errors

The SWAT Error Check tool is used to find out issues with the modeling in the early stage. It enables us to find out any hidden problems and reduce the time in regenerating or recalibrating the model at a later stage. SWAT Check performs three operations; i). it reads the output and notify the users if the values lie outside the possible limits, ii). it produces process-based figures for quick visualization, and iii). also find and notify the common model errors. In figure 18, illustrations show how to select the *output.rch* file **(#1)** and import files to database **(#2)**. Also, SWAT simulations can be saved using the *Save SWAT Simulation* with a user input name. Type simulation name as *Volta Simulation* **(#3)** and save *the* Simulation **(#4)**. You will receive a message indicating that your simulation has been saved. You can find saved simulation in your SWAT folder (in the Scenarios folder). Finally, click on Run *SwatCheck* option **(#5)**.

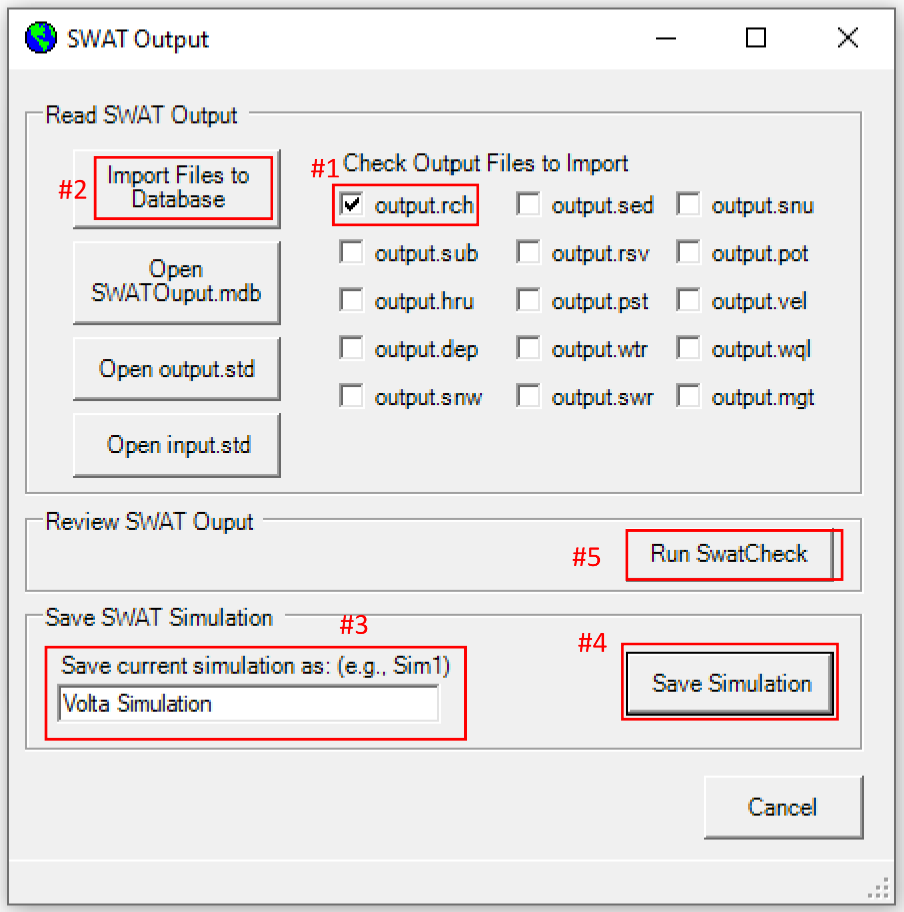

Figure 18. Selecting, saving model output, and running SWAT check

The SWAT check window will open, and you can now continue with the steps to run the *SWAT check*, as illustrated in figure 19. Click on the *Examine model output* **(#6)**. When the SWAT check is complete, you can now assess the results, the watershed characteristics **(#7)**, and read the warning messages **(#8)**.

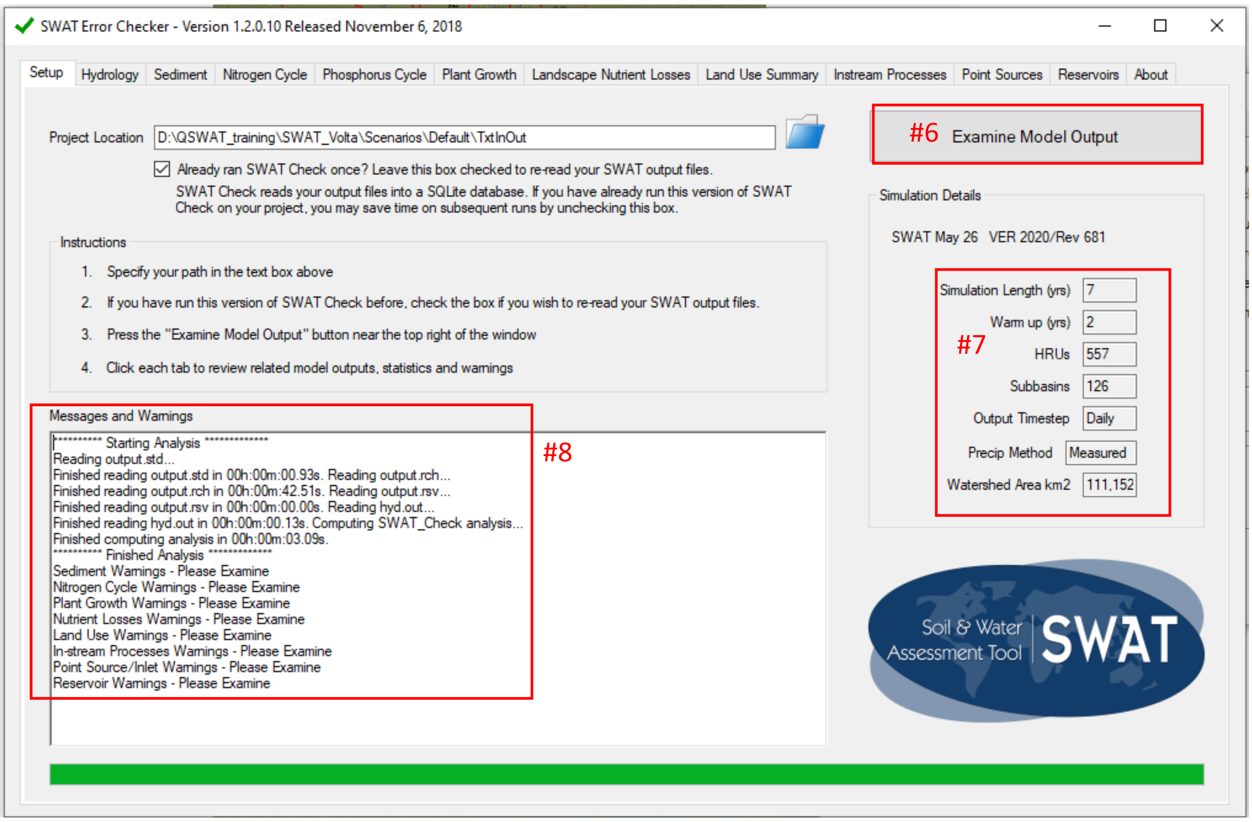

Figure 19. Steps to running SWAT checks

Assessment of the hydrology and water balance ratios **(#10)** in figure 20. You can click on each of the components **(#11)** to view the results that are important for your analysis **(#12)**.

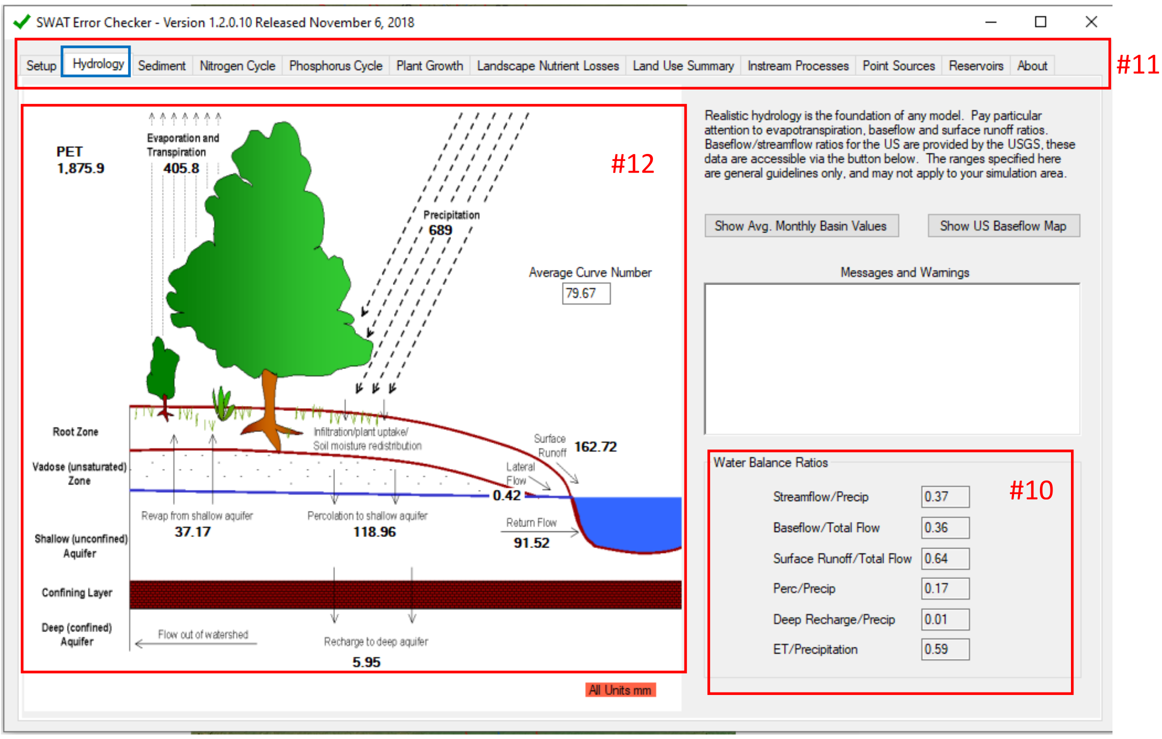

Figure 20. Display of SWAT check outcome with the water balance ratios

3.5 Visualize model result or outputs

After running the model and error checks, *Step 4 Visualize* will be activated on the QSWAT main form. Click on *Step 4 Visualise* as shown in figure 21.

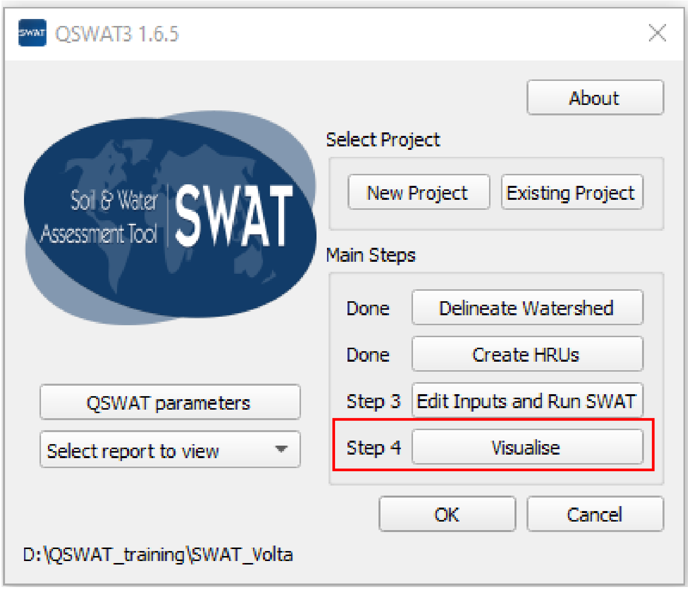

Figure 21. Visualization of model results

There are three possibilities for visualization: *Static data*, *Animation* and *Plot*. For Static data option, a single summary value is calculated for each sub-basin, reach, or HRU and displayed as a map. For Animation option, we can view the animated display of the value in each sub-basin, reach, or HRU at each time step in the map display. Plot option supports the creation and display of plots of selected variables. First, let us look at Static data option.

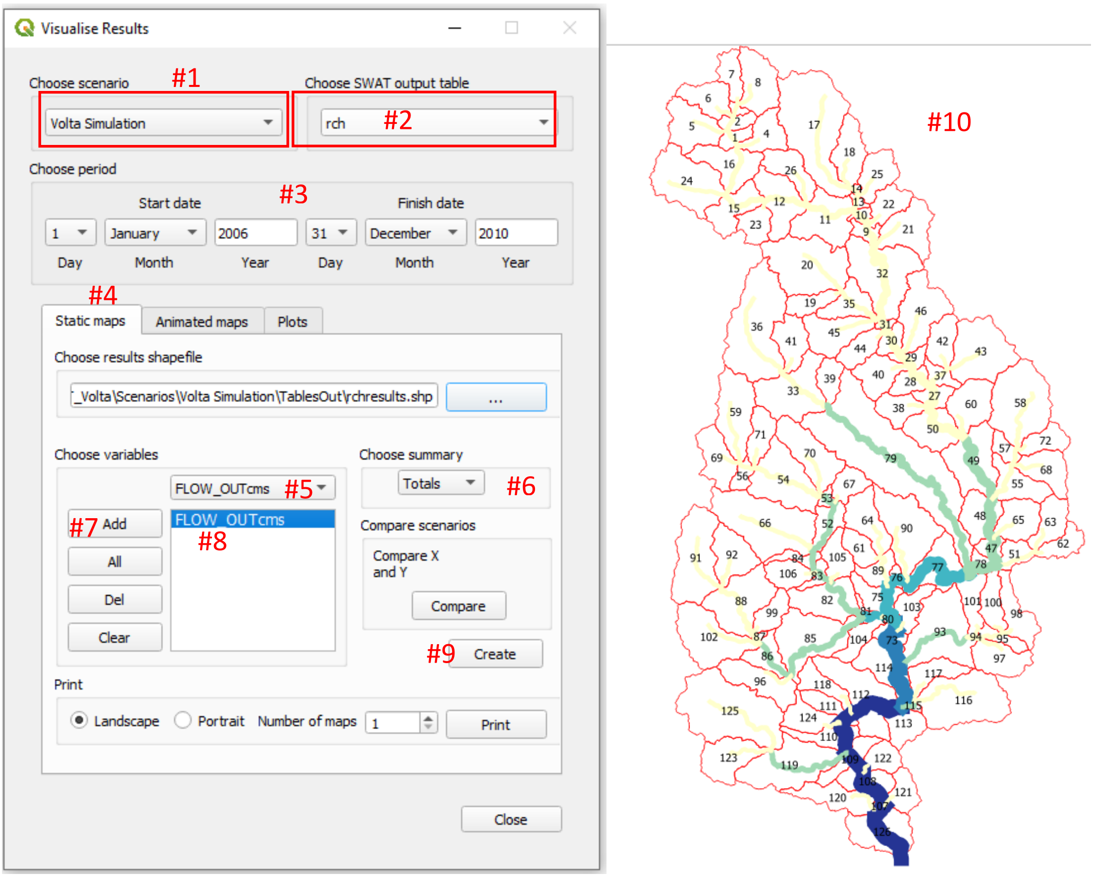

Figure 22. Visualization of model results

To visualize your simulated results, click on the box under the *Scenarios frame* **(#1).** This will provide you all the saved simulations in the scenarios folder in your working folder (*SWAT_Volta*), including the ones saved by default. Now select *Volta Simulation*. For the SWAT output table **(#2)**, select the "*rch*" file because that is the only one you imported into the database. The *Start date* and the *Finish Date* **(#3)** will remain the same as displayed in figure 23. In the *Static maps* section **(#4)** go to the variable you want to display and choose "*FLOW_OUTcms*" **(#5)** and click on *Add* **(#6)**. Now choose the results *Summary* **(#7)** you want to visualize and select *"Totals"*. You can also explore all other options such as the daily means, annual means, etc. Select the variable you want to display by clicking on "*FLOW_OUTcms*" **(#8)**. Finally, click on *Create* **(#9).** The results of river flow within each sub-catchment will be displayed in **(#10)**.

Plot the graph

Now, we will use *Plot* option **(#11)**, illustrated in figure 23 and follow the steps. Choose your preferred graph type **(#12)** and select the *Subbasin* **(#13)** you wish to visualize. Under the *variable* section, select "*FLOW_OUTcms*" **(#14)**. Next, click on the *Add plot* **(#15)** and go ahead to select the scenario **(#16)** you want to display. Finally, click on *Plot* **(#17)**. At this stage, you will be prompted to save the flow time series in your *Volta Simulation* folder.

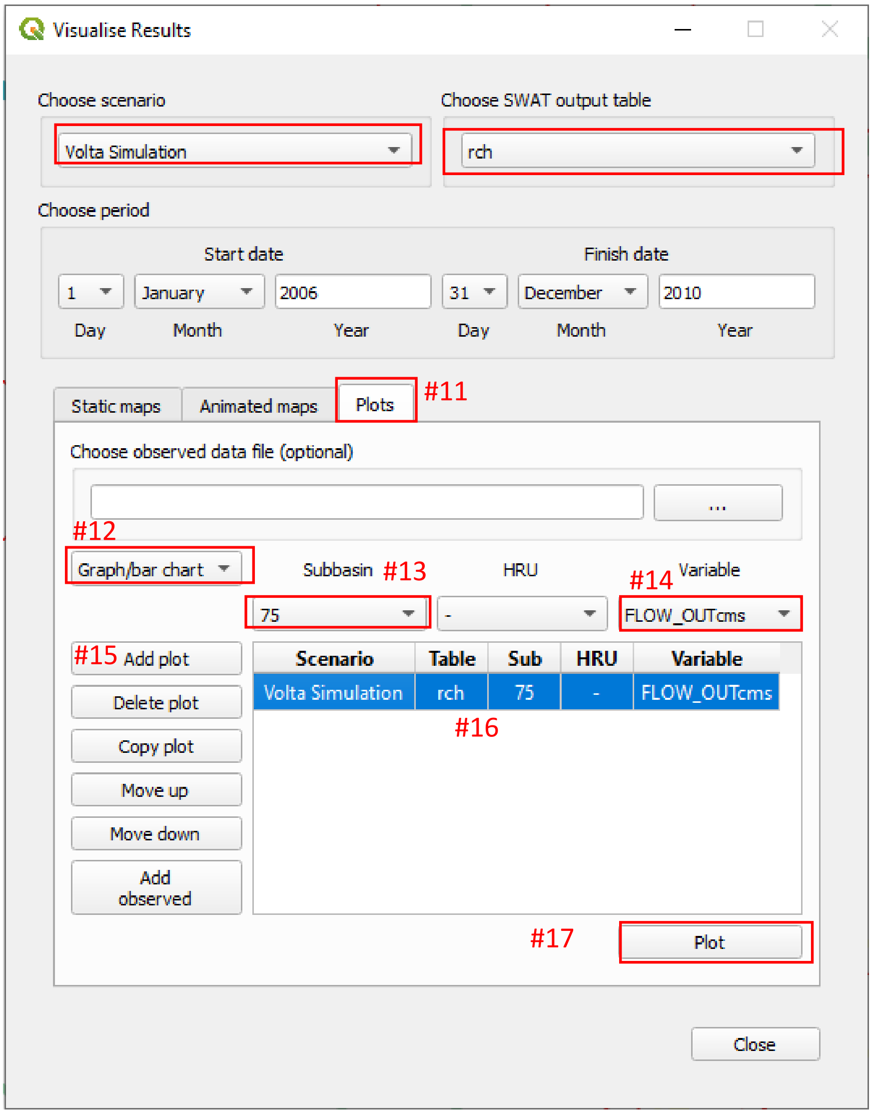

Figure 23. Illustration to plot hydrographs

The graph for the exercise would look like figure 24. If you have observed data for your watershed, you can include it in *Choose observed data file* option. Also, you can use the Save button to save the plot in different formats with a suitable name

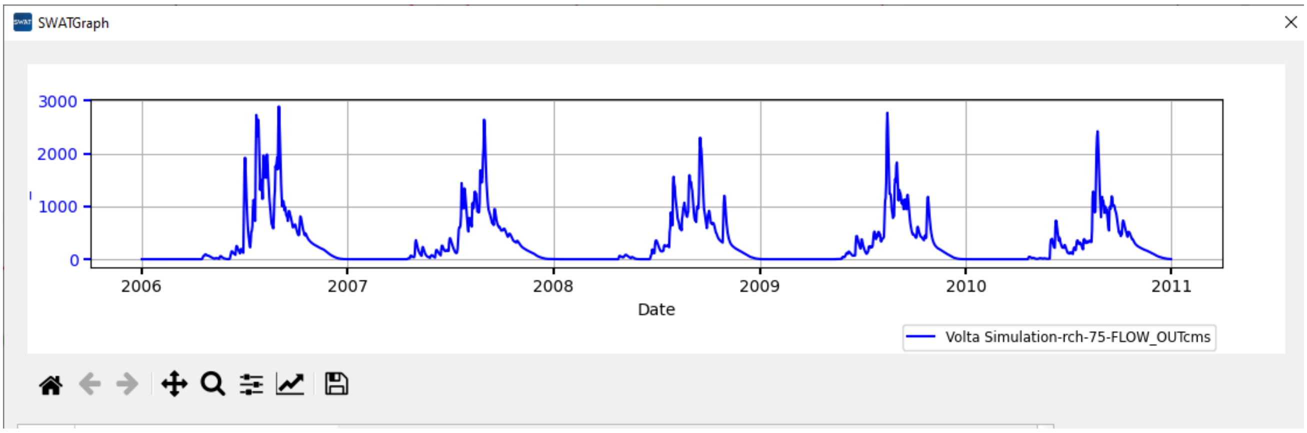

Figure 24. Hydrograph showing river flow at an outlet (75)

Next step

Calibration and validation of the model

Requirement

1. SWAT CUP (SUFI2 software)
2. River discharge data

4. Appendix

Adding table into SWAT project database

To be able run SWAT simulations, the table containing the climate data must be integrated into SWAT database (Microsoft database file). In our case, we need to import the table containing the weather stations, daily rainfall, and daily minimum and maximum temperature. To import tables into the SWAT database, navigate to your working folder *QSWAT_training* and open the *SWAT_Volta* folder (see illustrations in figure 25). Next, open the *QSWATRef2012.mdb* as indicated in figure 25.

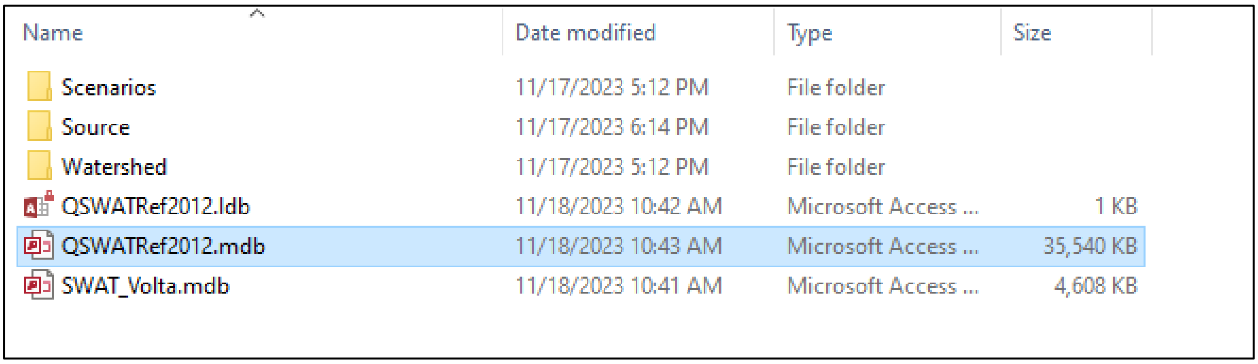

Figure 25

Once the Microsoft database file is open, under the Tables, locate the *WGEN_user* and righ-click on it. Now you will have many options so click on *Import* and choose Excel. This will open the windows explorer for you select the table you want to import. In this case, navigate to your working folder *QSWAT_training, climate data folder,* select *WGEN_Volta.xlsx* file, and click on open (see figure 26).

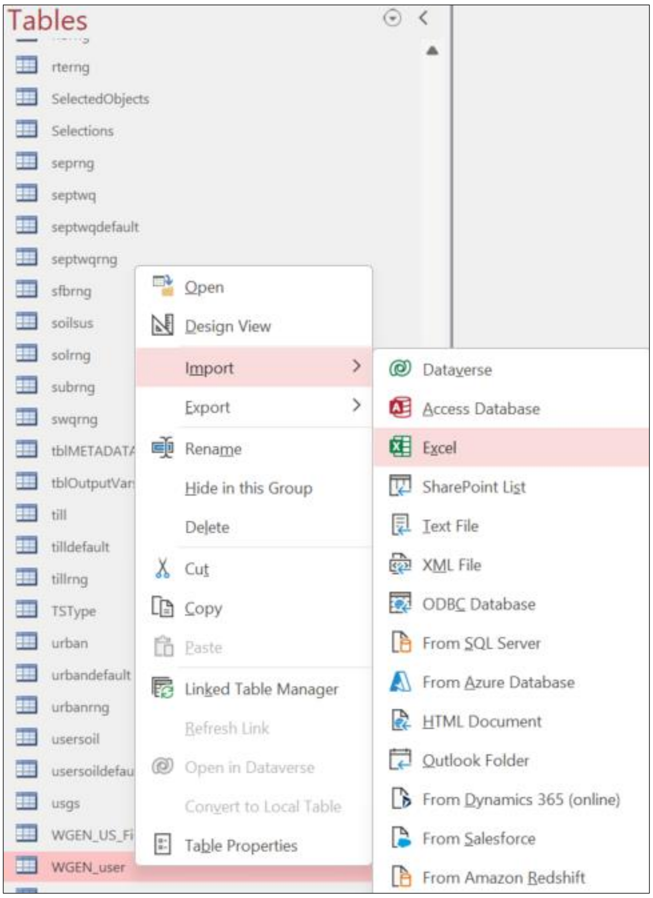

Figure 26. Importing the WGEN_Volta table into SWAT database

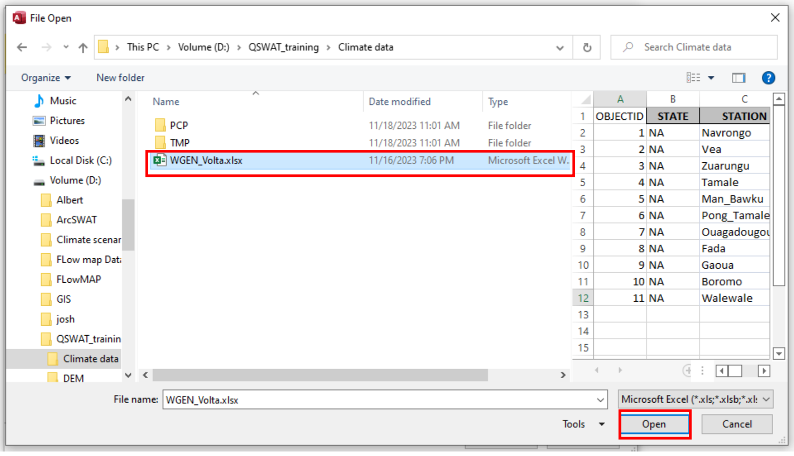

Figure 27

Figure 27 shows the next steps, where you need to only click *Ok* to proceed to the next steps. In figure 28, select *No primary key* and click on next. In the next steps, under the *Import to Table*, rename it as *WGEN_Volta* as indicated in figure 29. You can also use a different name, but it must begin with WGEN…… Now click on *Finish* to complete the table importation

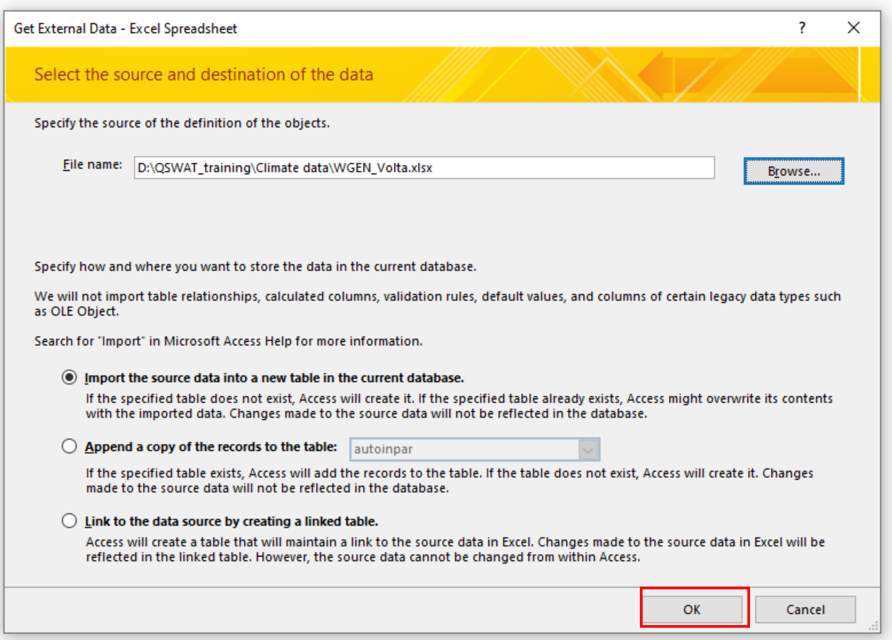

Figure 28. Importing the *WGEN_Volta* table into SWAT database

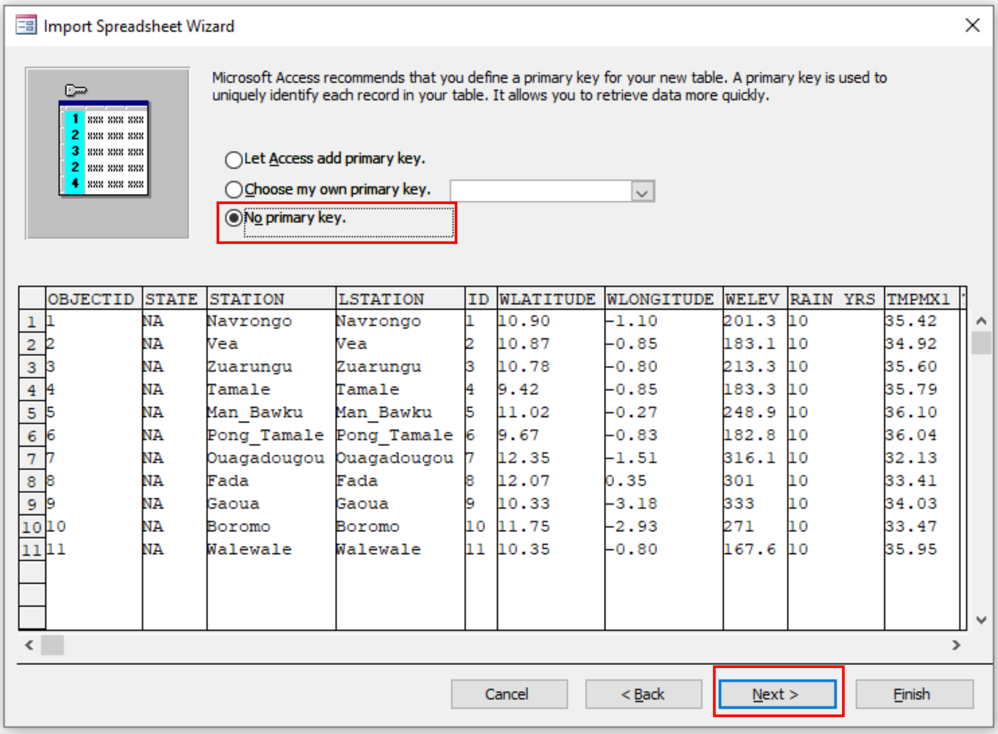

Figure 29. Further steps to import the WGEN_Volta table into SWAT database

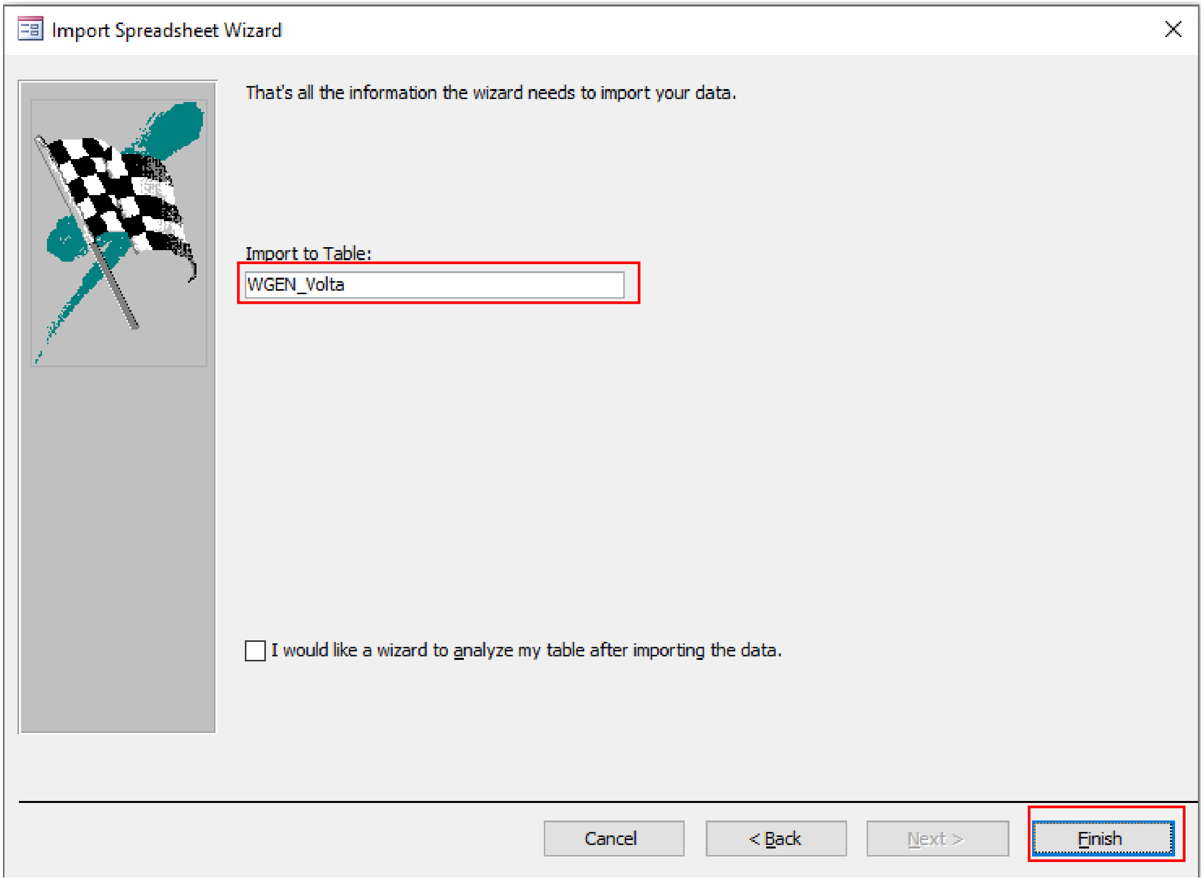

Figure 30. The final steps to import the SWAT tables into database

5. Reference and links to additional support

Basic understanding on SWAT and how it works
SWAT literature database https://www.card.iastate.edu/swat_articles/
YouTube video support: https://www.youtube.com/watch?v=2YW0ZDNfdlU&t=711s

Data preparation
George, C. (2015). *Preparing global DEM data for QSWAT Chris George*. *March*, 12.
YouTube video support: https://www.youtube.com/watch?v=EafZcQp-Has&t=590s
YouTube video on soil data preparation: https://www.youtube.com/watch?v=ztPitjNici8
YouTube video on Weather data preparations: https://www.youtube.com/watch?v=OGrlYxUh67g

SWAT model setup
Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R., Haney, E. B., & Neitsch, S. L. (2013). Soil & Water Assessment Tool: Input/output documentation. version 2012. *Texas Water Resources Institute, TR-439*, 650. http://swat.tamu.edu/media/69296/SWAT-IO-Documentation-2012.pdf
Srinivasan, R., & George, C. (2015). *QGIS Interface for SWAT (QSWAT) QSWAT (QGIS SWAT) Step by Step Setup for the Robit Watershed, Lake Tana basin Ethiopia Contents*. *May*.
https://swat.tamu.edu/media/114676/qswat-manual.pdf
Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., Griensven, a. van, VanLiew, M. W., Kannan, N., & Jha, M. K. (2012). Swat: Model Use, Calibration, and Validation. *Asabe*, *55*(4), 1491–1508. https://doi.org/ISSN 2151-0032

SWAT group
You can one of the groups created to provide support SWAT modeling. For example:
https://groups.google.com/g/qswat

Project Partners

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