Hydrological Modelling Using SWAT+ Training Manual (v1)

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1. Introduction

SWAT⁺ is a completely restructured version of SWAT, a time-continuous semi-distributed model that works on the principle of Hydrologic Response Units (HRUs). HRUs are areas of unique characteristics identified by land use, soil type, slope and catchment. Computations take place at HRU level and results are routed through stream connections to the outlet of the entire watershed.

SWAT⁺ uses similar equations to SWAT in estimating surface runoff/infiltration, evapotranspiration, plant growth, routing and many more. However, SWAT⁺ provides several benefits over SWAT (Table 1).



In this workshop, we will use SWAT⁺ to model robit catchment and calibrate the model. This training manual has task panels and challenge panels. The answers to the challenge panels are included at the end in the 'Answers to Challenges' section. Follow the tasks and make sure your results and answers to challenge panel questions match those in the answers at the end. There are also questions for discussion to help understanding some principles in SWAT+ Modelling.

2. Setting up SWAT+ Modelling Software

Before we can set up any model, we will need to make a number of installations of SWAT⁺ software. We will install (i) QGIS, (ii) SWAT⁺ tools and (iii) Microsoft MPI.

i. QGIS version 3.4

We start by installing QGIS version 3.4 (64-bit). Do this by completing Task 1.

	Task 1 Install QGIS 3.4
1.	Browse to <u>https://www.qgis.org/en/site/forusers/download.html</u> in your internet browser (Hint: if you press CTRL and click on the link, it will take you to the site).
2.	Under Long term release repository (most stable), Click on QGIS Standalone Installer Version 3.4 (64 bit) to download QGIS 3.4
3.	Double-click the downloaded file to install. You must use default settings (install in C:\Program Files\QGIS 3.4)

ii. SWAT+ tools

We also need to install SWAT+ tools. SWAT+ tools installation package has the following available for installation.

- QSWAT+ GIS interface, a QGIS plugin,
- SWAT+ Editor (includes SWAT+ model executable)
- SWAT+ datasets database
- Optional data downloads including global weather generator and US soil data.

Setup - SWAT+ Tools version 1.2.0	
Select Components Which components should be installed?	1
Select the components you want to install; dear the components you or install. Click Next when you are ready to continue.	lo not want to
Custom installation	~
✓ QSWAT+QGIS interface 1.2.2	29.0 MB
TauDEM executables. Not needed if you have QSWAT.	4.2 MB
	0.1 MB
QSWAT + user manual	3.9 MB
SWAT + Editor 1.2.0 (includes model rev. 59.3)	69.1 MB
Global weather generator data for SWAT+ (download)	334.3 MB
US SSURGO/STATSGO soil data for SWAT+ (download)	211.5 MB
L Current selection requires at least 433.0 MB of disk space.	
< Back Next >	 Cancel

Figure 1: SWAT+ tools setup window

Complete Task 2 to install SWAT+ tools.



- 1. Navigate to https://swatplus.gitbook.io/docs/installation in your browser
- 2. Click on Download SWAT+ Installer x.y.z where x, y, z are values for version identification. (at the time of writing: Download SWAT+ Installer 1.2.0)
- 3. Extract the contents of the downloaded zip file and start installation by doubleclicking the file, swatplustools-installer-1.2.0.exe
- 4. Check 'Global weather generator data for SWAT+ (download)' to download weather generator data (Figure 1)

iii. Microsoft MPI

Finally, we need to install the Microsoft MPI (Message Passing Interface). Modern personal computer processors allow running several tasks in parallel. We can use this to speed up the processing of raster files such as Digital Elevation Models (DEMs) by allowing QSWAT+ to take advantage of parallel processing. This is made possible with Microsoft MPI.

File Name	Size		
msmpisdk.msi	2.4 MB	Download Summary: KBMBGB	
msmpisetup.exe	7.5 MB	1. msmpisetup.exe	
		Total Size: 7.5 MB	

Figure 2: Downloading Microsoft MPI



iv. Activating QSWAT+ plugin

After restarting your computer, and opening QGIS 3.4, the QSWAT+ plugin is not available. It needs to be activated in order to make it available for use in QGIS.



Figure 3: Activation of SWAT+ plugin in QGIS 3.4



Figure 4: SWAT+ Icon after Activating QSWAT+

Now you will see the SWAT+ (S) button appear in one of the toolbars (Figure 4). You can open QSWAT+ and make sure that Use MPI is checked in the QSWAT+ Parameters (Figure 5). You are ready to start setting up your model.

QUINATE TO	anneters		
	SWATPlus directory		
C:\SWAT\SWAT	Plus		
V Use MPI	MPI bin directory		
C:\Program File:	\Microsoft MPI\Bin		
Channel widths a	ind depths		
Channel dep Slope and length	th multiplier 0.13 C multipliers	hannel depth exponent	0.4
Reach slopes Main channel length	1.0 Tributary slopes 1.0 Tributary channel length	1.0	bes 1.0 🗘
Stream burn-in d	epth 50	Upslope HRU drain %	90

Figure 5: QSWAT+ Parameters Window with 'Use MPI' Checked

3. Data

Our Case study is the robit catchment in Ethiopia. For this we have the following data for use with SWAT+ (Which comes with the SWAT+ tools installation).

You can download the data here: http://download.snippet-code.com/robit_data.zip

```
i. Digital Elevation Model (DEM)
```

The resolution of the available DEM (srtm_30) is a 30m by 30m.

ii. Land use

The land use data includes a land use raster map (roblandusenew) at 30m by 30m resolution and a lookup table (landuse_lookup.csv). The lookup table identifies the land use which a value on the raster map represents. The lookup table often lists the land uses as 4-letter code (Figure 6) which is later matched to a land use and its properties. These properties are found in a database that comes with SWAT+ tools installer (swatplus_datasets.sqlite).

Ianduse_lookup.csv - Notepad
File Edit Format View Help
LANDUSE_ID, SWAT_CODE
0,AGRL
1,WATR
2,AGRL
3,PAST
4,FRST

Figure 6: Land Use Lookup table

iii. Soil

The soil data includes a soil raster map (mowr_soil90) and a lookup table (soils_lookup.csv). Just as with land use data, the lookup table identifies the soils from the raster. However, the user often needs to provide another file which contains the properties of the soils listed in the soil lookup table. In our case, the file is robit_usersoil.csv.

v. Weather Data

This includes precipitation, temperature, wind, solar radiation and relative humidity data. There is a station list file and timeseries files for each of the weather variables. The station file lists all the files that have timeseries data. Examples are given in Figure 7 and Figure 8.

```
I pepedi I
1 pcp.cli: Precipitation file names for robit
2 filename
3 robpcp.pcp
4
```

Figure 7: Weather station list file for precipitation

🔚 рср.(oli 🗵 🔚 rob	рср.рср 🔀			
1	robpcp	.pcp:	Precipitat	ion timeserie	s for robit
2	nbyr	tst	tep 1	at lon	elev
3	24		0 11.6	00 37.360	1790.000
4	1990	1	0.00000		
5	1990	2	0.00000		
6	1990	3	0.00000		
- 7	1990	4	0.00000		
8	1990	5	0.00000		
9	1990	6	0.00000		
10	1990	7	0.00000		
11	1990	8	0.00000		
12	1990	9	0.00000		
13	1990	10	0.00000		
14	1990	11	0.00000		
15	1990	12	0.00000		
16	1990	13	0.00000		
17	1990	14	0.00000		
18	1990	15	0.00000		
19	1990	16	0.00000		
20	1990	17	0.00000		
21	1990	18	0.00000		
22	1990	19	0.00000		
23	1000	20	0 00000		

Figure 8: Timeseries file listed in weather station file

vi. Shapefiles

There is a shapefile of rivers that are present in the robit catchment (robReach.shp) and another shapefile that has the main outlet of the catchment (MainOutlet.shp).

vii. Data Directory Structure

Figure 9 summarises how the data is organised in this exercise.



Figure 9: Structure of data directory.

4. Model Setup

To set up the model, you need to (i) create a project and save it in a specified directory. Then go through (ii) catchment delineation, (iii) HRU definition and (iv) SWAT+ editor. We will go through the process step by step.

i. Create a project

Task 5 will create a default project structure (Figure 10) with its own project database where project information is saved (for this workshop, it will be named robit.sqlite). A reference database (which has default parameters for the model) is also copied to the project directory.



After completing Task 5, the QSWAT+ interface shows the three main steps (Figure 11). Step 2 and Step 3 are unavailable because we first nseed to complete Step 1.

🔇 *robit ·	- QGIS		
Project	<u>E</u> dit <u>V</u> iew <u>Layer</u> <u>S</u> etti	ngs <u>P</u> lugins Vect <u>o</u> r <u>R</u> aster <u>D</u> atabase <u>W</u> eb Pro <u>c</u> essing <u>H</u> elp	
	- 8 8 6) R Q Q 👯 🔍 🗢 🗲 🔅 🕐 I	A 🖪 🕂 🕐 🌫 🔍 🔍 - 🔜 - 🚽 🛅 🗉
	🎕 Vi 🌈 🖷	// · · · · k · Z 🖬 🛪 🖻 🕻 😽	🔿 🚳 🖣 🌉 🚳 🕸 🕷 🚳 🚳 🛃 🛃
v	Layers 💐 💽 🔻 🖇	88 	
	Animations Animations Animations Animations Animations Animations	S QSWAT+ 1.2.1 - X	
7	✓ ഈ Watershed ✓ ഈ Landuse	About	
P	✓ ⓓ Soil	Select Project	
	V III Slope		
V.		Assessment Tool SWAT New Project Existing Project	
@		Main Steps	
·		Step 1 Delineate Watershed	
		QSWAT+ Parameters Step 3 Edit Inputs and Run SWAT	
- 💱		Export Table OK Cancel	
V		C:/swat_projects/robit	

Figure 11: QSWAT+ interface showing the three main steps for SWAT+ model setup

ii. Delineate Watershed

Create Watershed

At this stage, we create sub-basins from the DEM by specifying area thresholds and outlet(s). We have an option to use an existing stream network to assist in the delineation, especially in relatively flat topography. The interface allows you to draw outlets for your catchment, but for this exercise, we will use an already existing shapefile.

To use MPI, set number of processes to a positive value. For most computers, 8 can be used. However, in order to have the same numbering of channels across all workshop participants, set it to 0.

How do you decide what values to use as thresholds for delineation?



S* Delineate Watershed Select DEM C:/swat_projects/robit\Watershed\Rasters\DEM\srtm 30m.tif 2 Delineate watershed Use existing watershed DEM properties TauDEM output ✓ Burn in existing stream network C:/swat_projects/robit\Watershed\Shapes\robReach.shp Channel threshold 100 Cells 0.09 Area sq. km 💌 Create streams Stream threshold 1000 Cells 0.9 Area ✓ Use an inlets/outlets shapefile C:/swat projects/robit/Watershed/Shapes\MainOutlet sel.shp 5.. Draw inlets/outlets Select inlets/outlets 1 selected Snap threshold (metres) 300 Review snapped 1 snapped Grid size Make grid 1 Create watershed Merge subbasins Add Lakes Create landscape Create landscape Create 0 \$ Number Show Taudem ОК Cancel

Figure 12: Watershed Delineation Window (reference for Task 6)



QSWAT+ allows you to merge sub-basins. However, that is not necessary for this case study.

After completing Task 6, channels, sub-catchment and landscape unit shapefiles are created and added to the project (Figure 13).



Figure 13: Delineated Sub-catchments

Create floodplain and upslope

QSWAT+ allows you to separate floodplain and upslope areas. This makes sure that HRUs

are in the correct Landscape unit to separate upland processes and floodplain. There are three options for creating floodplains. In this exercise, we will use DEM inversion. In this method, the values in the DEM are inverted in such a way that ridges become streams and streams become ridges.

Complete Task 7 to create a floodplain map.

S* Landscape analysis —			
Buffer streams	DEM inversion	Branch len	gth
Use an inverted [DEM to calculate ri	dges	
	Ridge thres	nold	
1000 Number of 0.9 Area sq. km •			
0.10 🗘 Slope position threshold			
	Ci	eate	Done

<u>S1</u>



1. Click on Create under Create Landscape. Landscape Analysis window Create Appears (Figure 14).

2. Do not change the default values, accept defaults in the DEM inversion tab by Clicking on Create. A floodplain layer is added to the map, Click Done to exit the landscape analysis window.

It is important to note that QSWAT+ has an option to add lakes. For more information on adding lakes, refer to the QSWAT+ manual.

Click Ok to close the Watershed Delineation Window.

Task 7

5* QSWAT+ 1.2.1	— C	X C
- 47	Select Project	About
Sol & Water Assessment Tool	New Project Existing	g Project
	Main Steps	
	Done Delineate Wate	rshed
QSWAT+ Parameters	Done Create HRL	Js
Export Table	Step 3 Edit Inputs and Ru	IN SWAT
Reports	Step 4 Visualise	
Select report to view	ОК	Cancel

Figure 15: Step 4 activated after importing results in SWAT+ Editor

iii. Create HRU

This step creates units of unique combinations of landscape unit, land use, soil, and topography (slope classes). To identify land uses in the study area, lookup

The QSWAT+ interface now shows Step 2: Create HRUs enabled (Figure 15).



Figure 16: Layers that are overlain to create HRUs

tables are used to match values in the land use map with land use type in the databases. Soils are also identified in a similar way. However, there is often a need to provide a table (usersoil) with soil properties for each soil present in the lookup table.

In Task 8, we will load land use map, soil map, lookup tables and usersoil. We will also specify slope classes and thresholds for defining HRUs. Refer to Figure 17 for Task 8. Remember, all raster maps should have the same projection as the DEM.

- 1. Open Create HRUs Window (Figure 17) by clicking on the Create Arask 8 HRUs button.
- 2. Load land use map and soil map using buttons 1 and 2 in Figure 17 respectively
- 3. Import land use lookup (landuse_lookup.csv) and soil lookup (soil_lookup.csv) tables to the project database using Landuse table and Soil table dropdown menus respectively (below buttons 1 and 2). You will have to select Use csv file to do this.
- 4. Import the usersoil table, robit_usersoil.csv, in the same manner as above (dropdown menu 3 in Figure 17).
- 5. To use slope classes 0-10 and 10-9999, enter 10 in box 4 as seen in Figure 17 and click Insert.
- 6. Select the floodplain map generated during watershed delineation using the select floodplain map dropdown menu.
- 7. Check Generate FullHRUs shapefile (checkbox 5 in Figure 17) to allow mapping at HRU level during visualisation.
- 8. Click Read to read data into memory. Potential HRUs are created at this stage.
- 9. To filter out small HRUs, there are many options provided (section 6 in Figure 17). Chose Filter by Area and use 0 to keep all potential HRUs
- 10. Click Create HRUs to save potential HRUs data as final HRUs to project database.

QSWAT+ provides a way to eliminate short channels that often occur when there are channel junctions to the same channel close to each other. If used, LSUs that are bigger than the

specified threshold in the short channel merge section (box 8 in Figure 17) are merged with the one downstream of them as long as they are in the same subbasin.

There are is an option to split and exempt land uses. Refer to the QSWAT+ user manual for more information on these options.

What does each of the HRU filtering options do?

The next time you come back to this stage to create HRUs, you do not have to read from maps again. Data read from the previous session can be loaded quickly by checking the Read from previous run option in the Read choice section.

When Task 8 is complete, Step 3 in the Main QSWAT+ window becomes available. New shapefiles are also created as shown in Figure 18 below. Use the Select report to view button to see the information on HRUs.



Figure 17: Create HRUs window



Figure 18: Edit Inputs and Run SWAT option becomes available after creating HRUs

Based on the HRU report.

- a) How many HRUs are in LSU 501?
- b) What percentage of the watershed area are FRST and AGRL land cover areas?
- c) Which slope class is the most dominant in the area?
- d) What is the Land Use present in HRU 448 in LSU 292?

iv. Run SWAT+ model in SWAT+ Editor

We are ready to use SWAT+ editor after Task 8. SWAT+ Editor allows you to change the options for running the model including routing, ET calculation methods, land use management practices etc.. SWAT+ also allows you to import climate data and read results for visualisation. Task 9 will take us through SWAT+ Editor to run the model.

S* SWA	VAT+ Editor - robit —		<
File Edit	dit View Help		
	CURRENT PROJECT		Ê
ľ	SWAT + Editor Project from QSWAT +		
Ø	If this is the first time opening your QSWAT+ project in SWAT+ Editor, we will need to import your GIS data into SWAT+ objects. This may take a few seconds to several minutes depending on the size of your project.		
	Select your project/GIS SQLite database file		
.~	C:/swat_projects/robit.sqlite Browse		
	Project name		
	robit		
	SWAT+ datasets database file		
	C:\swat_projects\robit\swatplus_datasets.sqlite Browse	,	
9	If you do not have an existing dataset, download the newest version online.		
0	Note: SWAT+ Ite is not an option for this project because you have reservoirs or point source/inlet data.	ject: robit	Ŧ

Figure 19: SWAT+ Editor: import project window

- Click on Edit Inputs and Run SWAT button to open SWAT+ Editor. A window shown in Figure 19 will open.
 Click Start Import to accept defaults. This will create tables with default parameters and options which can be changed within the SWAT+ Editor interface.
- 3. Click Start Editing SWAT+ Inputs. You will see navigation sections on the left pane of the interface (Figure 20)

Challenge 1



Figure 20: SWAT+ Editor sections

- 4. Click Weather Generator under the Climate section.
- 5. As stated earlier, we are using the weather generator created from cfsr world data which we added as an option during installation. Click Import Data, and check "Using observed weather data?...". This prevents SWAT+ Editor from creating stations based on weather generator data. make sure wgn_cfsr_world is selected as table name in the wgn database. Click Start Import.
- 6. Select Weather Stations and click Import Data. A window for importing weather data files appears. We will use SWAT+ format for weather change data format to SWAT+.
- 7. Click Browse and select the directory containing weather data (weather_swat_plus). Click Start Import. You will see one station showing (Figure 22)
- 8. Go to Time under simulation section and set the starting year to 1990 and the ending year to 2000. Click Save Changes.
- 9. Click Print in the Simulation section. Notice the warmup period (top-most value) is set to 1 year. Set it to 3.
- 10. Under Print Objects you can select the timestep for printing each object. Select monthly output for Channel Output and Water balance HRUoutput (Figure 23). Click Save button.
- 11. Click the Write file icon (↗) then Save & Write Files (Confirm by Start Writing Files) to write files to Default Scenario TxtInOut (more in input and output files).
- 12. Click on Run the model (\triangleright) button and Run SWAT.

Import Weather Generator Data
Click the Start Import button to add weather generator data from the selected database to your project. If you have routing units defined, it will only import wgns within the boundaries of your watershed. Otherwise, it will import all from the selected database table.
Select your data format
Database \$
Database file
C:/SWAT/SWATPlus/Databases/swatplus_wgn.sqlite Browse
Table name in database
wgn_cfsr_world
Using observed weather data ? Check to not create weather stations based on wgns and import them from observed data in the next step.
Start Import Cancel

Figure 21:Import Weather Generator Window

ru	Routing unit output		
hyd	Hydrology in/out output		
recall	Point Source (recall) output		~
reservoir	Reservoir output		~
aquifer	Aquifer output		~
channel_sd	Channel output		~
hru_pw	Plant weather HRU output		~
hru_ls	Losses HRU output		~
hru_nb	Nutrient balance HRU output		~
hru_wb	Water balance HRU output		~
lsunit_pw	Plant weather routing unit output		~

We	ather	Statio	ons			
Crea	ate new ecord	E simu da	dit Ilation ates		Type a name to s	search
	Name	Ļ	Wgn	1	Precipitation 1	Temperature \updownarrow
<	sta1160n	3736e	117n37	5e	robpcp.pcp	robtmp.tmp
						SWAT+ Edite



Figure 23: Select Monthly Channel Output.

v. More Options in SWAT Editor

Task 8 has led us through SWAT Editor and running the model without making many adaptations to our model. However, many times, you may want to change specific options based on your case study. This section highlights important adaptations that you can make in SWAT+ Editor.

_					
File Edit	View Help				
	CLIMATE	✓ [▲]			
	Weather Generator		Basin Codes		
	Weather Stations				
			Value	Description	SW/AT+ Variable
	SIMULATION	•	value	Description	SWATE Valiable
Ø	Time			Potential ET	pet_file
	Print			filename	
				Watershed stream	
	BASIN	•		water quality	wq_file
<u>∽</u>	Codes			filename	
	Parameters		0 - Priestley-Taylor 🖨	Potential ET	pet
			o mestej lajtor v	method code	,
	CONNECTIONS	•	0 - Priestley-Taylor metho	ent code	event
	Channels	<	1 - Penman/Monteith me	thod	
	HRUs	<	2 - Hargreaves method	ack flow code	crack
	Routing Units	<	2 Pood in potential ET w	aluar	
•	Aquifers	<	0 - Do not calculate €	bbasin water	rtu wa
	Reconvoirs			quality code	
0	Reservoirs Deserv	Ì	0. Conorato daily 🔺	Max half-hour	sod dat
v	кесан	¢	o - Generate daily V 🗸	rainfall frac calc	seu_uet
	Export Coefficients	< *			

Potential

Evapotranspiration (PET)

Figure 24: Changing PET calculation method to Penman/Montheith Method

Ś

Task 9

Depending on the available

data you may want to use a different PET calculation method. For Example, if you only have Temperature data, you may choose the Hargreaves method instead of the Penman/Monteith method. In Task 9, we will change the PET calculation method to Penman/Monteith.

- 1. Under the Basin section, click on Codes (Figure 24).
- 2. On Potential method code combo-box, select
- 1 Penman/Montheith method
- 3. Scroll down and click Save Changes

Do not navigate away from this page.

Routing

There are two methods for routing available in SWAT, Variable Storage and Muskingum. We will use the Muskingum method. You can change this on the same page you changed the PET calculation method under Water routing method.

You can change more routing parameters such as Manning's n and time of concentration for each channel in the Hydrology & Sediment under channels in the connections section.

S* SWAT	+ Editor - robit												- 0
File Edit	View Help												
	Parameters		^	new	multip	le s							Data 📥
	CONNECTIONS	*		recor									
	Channels Properties	*			Name ↓	Order 🕽	Wd ≎	Dp∶	Slp 🕽	Len 🕽	Mann (Kţ	Erod_fa
ø	Initial			ľ	hydcha01	first	5.308	0.334	0	1.666	0.050	1	0.0
	Nutrients			Ľ	hydcha02	first	5.049	0.323	0	0.602	0.050	1	0.0
0	HRUs Routing Units	۲ ۲		ľ	hydcha03	first	4.881	0.316	0.023	0.302	0.050	1	0.0
~	Aquifers	<		4	_	_							

Figure 25: Parameters for Hydrology and Sediment for channels

Land Use Management

Each HRU is assigned a Land Use Management (LUM) practice. You can change the LUM for any HRU in properties under HRUs in the connections section. In this example, there are three LUM practices: frst_lum, agrl_lum and past_lum (Figure 26).

A LUM practice is associated with Plant Communities, Management Schedule, Conservation Practice, Curve number, etc

Plant communities

Plant communities list which crops are grown under the specified LUM practice. The corresponding file name is plant.ini

	a) What plan	t is gr	owir	ng in HRU 14			Challenge
Edit	View Help						
	Recall Export Coefficients Delivery Ratio	< < <	La	nd Use Mana	agement		landuse.lum 目
•	REGIONS	< •	Cre	Name L Calibration Gr	IType a name to search	Sch † CN2	
•	Land Use Management			Hume : Cambration of			ţ construct ţ
	Management Schedules		ø	agrl_lum	agrl_comm agrl_rot	rc_strow	_g cross_slope
!	Operations Databases Curve Numbers	۲.	ø	frst_lum	frst_comm	wood_f	up_down_slope
	Conservation Practices		ø	past_lum	past_comm	pastg_f	up_down_slope

Figure 26: Land Use Management

Management Schedule

The Management Schedule tells what time of the year events such as planting, harvest, irrigation applications, nutrient applications, pesticide applications, and tillage operations happen in the HRU.

There are two methods of specifying operations in Management Schedule. You can enter an operation directly in the Management Schedule or Add a reference to a schedule that already

S* SWAT	+ Editor - robit_model				- 🗆 ×
File Edit	View Help				
► ()	Recall Export Coefficients Delivery Ratio	< < <	Management Sche	dules / Edit	management.sch 🗏
<u>a</u> r		۲ ۲	Schedule name agrl_rot		
	Land Use Management		Automatic schedules	Operations	
M	Management Schedule Operations Databases Curve Numbers	s <	☑ pl_hv_agrl ×	Add an operation	l
	Conservation Practices Manning's n		Add an automatic schedule 😯 Start typing to search Ad	d	
	DECISION TABLES	<			

Figure 27: Adding Operations to Management Schedules

exists in the land use management decision table (lum.dtl) (Figure 27). Currently, SWAT+ Editor does not support editing of decision tables. However, you can import and export decision tables to and from CSV files. We will discuss decision tables in Part 6 (i).

Before visualisation Write files and Run the model again to apply the adaptations that we have made since the last time we run the model.

5. Visualisation of results

The main QSWAT+ Window has Step 4 for visualisation, but it becomes visible after importing results to the database.

i. Map Static Data

Different variables from the results can be mapped at the landscape unit level or HRU level. Note that you can map results at HRU level only if you created the HRU shapefile during HRU creation. Follow Task 10 to visualise annual evapotranspiration results at HRU level.

- 1. Click on Analyse model output icon () and select Import Output to read model run results to the database.
- 2. Close SWAT+ Editor. Now, the QSWAT+ shows Visualise as Step 4.
- 3. Click Visualise in Main QSWAT+ Window. This will show Visualise Results window.
- 4. The Default Scenario is selected. Chose SWAT+ output table hru_wb_yr.
- 5. In the Chose Variables section, select et in the dropdown menu and Annual means in Chose summary section, then click Add.
- 6. Select et in the 'selection box' and click create. A new layer showing ET annual means appears.
- 7. If you do not like the lines separating HRUs, Follow step 8 and 9.



Figure 28: Main QSWAT+ Window, now with Step 4.

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Print

Task 10

	Create Static ET Map
alise Results	- 🗆 X
se scenario	Choose SWAT+ output table
efault 👻	hru_wb_yr *
se period	
Start date	Finish date
* January * 1993	31 - December - 2000
ay Month Year	Day Month Year
tatic data Animation Pl	ot Post processing
hoose results shapefile	
cenarios\Default\Results\hru_	_wb_yrresults.shp
hoose variables	Choose summary
et	▼ Annual means ▼
Add et	
All	
Del	

Create

Figure 29: Visualise Results Window

Landscape O Portrait Number of m 1
 Print

- 8. Double-click on the layer Default et Annual means and go to Symbology. Click Change along the Symbol line and select Simple fill.
- 9. Select No Pen on Stroke Style then click OK to close the box. Click Apply and then OK to close the layer properties window.

After completing Task 10, you will have a map that is clear as shown in Figure 30. You can print this view to file or paper using the Print button in the Visualise Results window.



Figure 30: Default Annual ET map

i. Animations

The Visualise Results window also allows you to Animate how different variables in the watershed change over time. These animations can be exported to a file for presentations.

Task 11 will guide us through animating the evolution of Surface Runoff at LSU scale.



You can save an animation by using the record function as described in Task 12.

- 1. Click the rewind button to rewind the animation
- 2. Click Start Recording and click the arrow to start the animation
- 3. When it reaches the end, Click Stop recording.
- 4. You can find the animation in Scenarios\Default\Results\ in GIF format Open and view it

Task 12

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Plots ii.

QSWAT+ also allows you to plot results on a graph and add observed data. We are going to plot both simulated and observed flow for the main outlet in Task 13.



QSWAT+ plots the graphs and also calculates some statistics to check how good is the fit of the simulated data to observations (Figure 32).

Close Figure 31: Using the plot tab in visualisation window of QSWAT+



Figure 32: Simulated (Default Scenario) and observed hydrographs at the main outlet of the Robit Case

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6. Evaluate Inputs and outputs

There are a number of files that we will look at found in the TxtInOut Directory (Refer to Figure 10). It is possible to modify these files and run the model using an executable file from the SWAT Website. However, you need to be careful not to change the format. These files help us understand model inputs and outputs better. You can open all these files using notepad, notepad++ or Visual Studio Code.

• time.sim

Defines the beginning and ending year of simulation

print.prt

Set warmup period and which output to print you can change the options between 'y' for yes and 'n' for no. If you want to print results as comma-separated values (CSV), you can change the csvout output (line 7 in the file, print.prt) option to yes.

chandeg.con

Shows connections between channels. The column out_tot (fifth from the last) shows the number of objects that the channel is routing flow into. If it is 0, it means that is a main outlet of the watershed.

Based	on the time.sim, print.prt and channel.con files.	Challenge 3
a)	How many years were simulated in the model?	
b)	Can we get flows for the year 1991?	
c)	For how many simulation years will the model skip printing	of results?
d)	Which channel is the main outlet channel?	

- channel_sd_[tstep].txt (where [tstep] is timestep mon, day, yr, aa)
 This file shows mass balance in each channel for specified timestep. This includes, water balance, nutrient balance, sediments.
- basin_wb_[tstep].txt (where [tstep] is timestep mon, day, yr, aa)

This file shows the water balance of the entire catchment at the given timestep. This is important in checking potential problems with the model.

Based on the basin_wb_yr.txt file.	Challenge 4
a) How much was the evapotranspiration in the year 1995?	
b) How much was the precipitation in the year 1995?	
c) How much was the surface runoff in the year 1997?	

The following files (hru-data.hru, landuse.lum, plant.ini and management.sch) are important to understand the land use, crops and management practices in waterched.

hru-data.hru

This file contains a list of all hrus and their properties such as soil and landuse management. The landuse management codes (e.g. agrl_lum) are listed in the file, landuse.lum.

Ianduse.lum

This file provides more information on the landuse management practices assigned to each HRU in the hru-data.hru. Note that it also lists plant communities (column 3) for each management practice.



plant.ini

This file lists plant communities. A plant community comprises of plants that grow together in the same area. This file also has the state of each of the listed plants at the beginning of the simulation. This file, along with management.sch, can be used to specify mixed cropping and crop rotation patterns.

management.sch

Management.sch shows a sequence of operations in each schedule. The operations are either listed in the file or a reference to lum.dtl.

decision table files (files ending with '.dtl')

Decision tables list sets of actions that take place in the model when specific conditions are met (Figure 33). This gives the user more flexibility when timing operations in the model such as reservoir release.

name harvest grain	conds 2	alts 1	acts 1				
var	obj	obj num	lim var	lim op	lim const	alt1	
soil water	hru	0	fcap fr	*	0.90000	<	
phu_plant	hru	0	phu mat	-	1.15000	>	
act_typ	obj	obj_num	name	type	const	application	outcome
harvest_kill	hru	0	grain_harv	all	0.00000	grain	У

Figure 33: Decision table extract

To better understand the structure of decision tables in SWAT+ refer to Figure 34. The decision table can be visualised as having 4 quadrants.



Quadrant 1 has conditions which is a list of variables, objects and specified limits. For example, referring to Figure 33, the first condition can be broken down as follows:



you can read the above condition as:

"If [the soil_water in current hru is [alternative comes here] (fcap_fr * 0.9)]"

As you can see, the above condition is incomplete without an alternative.

Quadrant 2 lists alternatives such as '=', '>' '<', e.t.c. From Figure 33, there is one alternative: '<'

The condition now reads:

"If [the soil_water in current hru is less than (fcap_fr * 0.9)]"

Quadrant 3 shows which actions are performed when the condition is satisfied. 'y' means the current action gets performed if the condition is satisfied. The actions are listed in Quadrant 4. In this example, once the condition is satisfied, crops in the current HRU are going to be harvested (harvest_kill).

7. Calibration

i. Manual Calibration

Unlike in the previous version of SWAT (SWAT 2012), only one file is used and changed during the calibration of parameters. The default name of this file is calibration.cal and it has to be listed in the file.cio in order to have the parameters applied before running the model.

SWAT+ Editor can be used in conjunction with QSWAT interface to perform manual calibration. Parameters can be added or changed in the Hard Calibration under Change Section and plots can be made in QSWAT after importing results. Remember that NSE is automatically calculated when you plot simulated and observed flows. This can be used to evaluate the progress of the calibration process. Complete Task 14 to change a parameter for the model.

1.	Select Hard Calibration under Change section and click	🖄 Task 14
	Create New Record	Calibrate a parameter
2.	Enter cn2 in Calibration Parameter, Select Change the value by sp	ecified percent under
	Type of Change, Enter 12 as Value of Change.	
3.	Click Save Changes, Do not select any HRUs. This means that t	the parameter will be
	changed in all HRUs, Click Back and Back again.	-
4.	Write the files. You can now check the new file calibration.cal	inside the TxtInOut
	directory with the parameter we added. It has also been listed in	the file cio

- 5. Run the model and import results ready for visualisation.
- 6. Plot the flows for the main outlet before and after parameter change on the same plot as the observed flows.

You can specify more conditions for an object to be calibrated. For example, you can set the parameter change to only be applied to HRUs that have frst lum.

ge to only be applied to s that have frst_lum.	<i>I</i>	Operations Databases Curve Numbers Conservation Practices Manning's n	<	Calibration Parameter 3	Type of Change Change the value b 🕈	Value of Change
	.	DECISION TABLES	۲.	You will be able to set condi	tions and objects to which to a	apply the calibration af
1:55		CHANGE	~	clicking save changes below		
nere any different in ws after changing the		Hard Calibration Parameters	¥	Save Changes Back		
ameter?		Soft Calibration	٢			
		INITIALIZATION DATA	٢			
		HYDROLOGY	۲			
	8	SOILS	۲.			
88		DATABASES	¢			
	0	STRUCTURAL	¢			
			Y		SWAT+ Ec	ditor 1.2.0 Project: robit_

Hard Calibration /

Create

5* SWAT+ Editor - robit_mod

Land Use Management

Management Schedule

ile Edit View Help

Figure 35: Selecting Parameters for Hard Calibration

ii. Soft Calibration

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For calibrating flows, hard calibration focuses on getting simulated and observed hydrographs as close as possible. However, soft calibration focuses on mass balance. Thus, it focuses on matching the components of the hydrological cycle to observed long term averages. For more information on soft calibration, refer to the SWAT+ Editor manual.

iii. Automatic Calibration with IPEAT+

SWAT+ is relatively new and as discussed in the introduction, there are not many tools available for calibration and checking for potential errors. IPEAT+ is one of the first

calibration tools created for calibrating SWAT+ models. The IPEAT+ interface has 5 main steps that are shown on the navigation pane on the left of the main window. On start-up, the project page is selected (Figure 36). This is where you start.

To begin, download and Install IPEAT+

IPEAT * v 0.8.8	
A Project	
🕜 Edit Parameters	IPEAI
🔀 Observation Data	FORTRAN Based Auto-Calibration Tool for SWAT+
😣 Calibration Settings	New Project Open Existing
່ Calibrate Model	
	Recent Projects
â	
*	N

from http://download.snippet-code.com/ipeat_plus.zip

We will now perform automatic calibration of the robit model Using IPEAT+.

calibration.cal

Create Project

To perform calibration using IPEAT+, we will need to create a project. Task 15, takes us through the process.

- 1. Open IPEAT+ interface (Figure 36).
- 2. Click on New Project.
- 3. Click Browse and select the TxtInOut directory, click Ok
- 4. Enter robit_model as project name and Click Save. A Save as window will appear.
- 5. Browse to the desktop and click Save to save the project.
- 6. A message confirming that the project has been created successfully will briefly appear at the bottom of the main window.

Add Parameters

In Task 16. We will add parameters.

1. Click Next to navigate to Edit Parameters window



<u>S1</u>

Task 15

- 2. Check cn2, esco and alpha and enter limits and change types shown in Figure 37. Note that you can add any parameter that is not listed on the Edit Parameters Page by clicking More Parameters.
- 3. Click Save and click Next

IPEAT + v 0.8.8	Chose Parameters and Set Ranges			- x
 ✔ Edit Parameters ▲ Observation Data ▲ Callibration Settings ↑↑ Calibrate Model 	<pre>Parameter Selection</pre>	cn2 esco alpha	Change Type Percent Percent Percent	Minimum Maximum 20 20 0.3 0.3 - 10 10
\$	More Parameters Saved parameter settings			Save Next

Figure 37: Edit Parameters Page

Add Observation Data

IPEAT+ accepts observations in CSV format with date and value fields. Dates should be in dd/mm/yyyy format and any negative number represents missing data. Task 17 will get us through adding monthly observation data for calibration.

IPEAT * v 0.8.8	- x Import Observation Data
 Project ✓ Edit Parameters ✓ Observation Data ✓ Callibration Settings ☆ Calibrate Model 	Object Type Number Observation File Observation Type + Reach 1 C:\Users\james\Desktop\SWAT_plus Flow
10	Save Next

Figure 38: Adding Observation File for Channel 1

 On the Observation Data page, leave Reach as the Object Type (Figure 38).
 The observations we have are for channel 1, which is the main outlet channel. Enter channel number 1.
 Leave Observation Type as flow and click the browse button.
 Select observedFlow.csv and click Open
 Click Save.

IPEAT+ will read the observation data into memory.

Set Calibration Settings and Run Calibration

To perform automatic calibration, objective functions such as the Nash-Sutcliffe Efficiency (NSE) and Coefficient of Determination (\mathbb{R}^2) are used. IPEAT+ allows the use of one of the 5 objective functions as shown in Figure 39. Other settings that need to be specified include calibration period and timestep of calibration data. Complete Task 18 to set calibration settings.

1. Click on Calibration Settings on the navigation pane. A page appears that lets you specify calibration settings (Figure 39)

Task 18 Add Calibration Parameters

- 2. Leave NSE selected.
- 3. Enter 7 years as Total simulated years and enter 1990 as the start year with 3 years of warmup period.
- 4. Select Monthly time-step to perform the calibration using monthly flows.
- 5. Click Save and then Next.
- 6. Click Finish Setup to write calibration files and Run

IPEAT * v 0.8.8 Project Edit Parameters Observation Data Callibration Settings Calibrate Model 	Specify Callibration Settings Objective Functions Calibration Period \Big NSE Total Simulated : 10 Years R R ² Start Year : 1990 RMSE Warm Up : 3 Years PBIAS Time-step : Monthly \vee MAE Starting Parameters : Random Parameters \vee Perturbation Factor : 02 Number of Runs : 100	ĸ
\$	Vumber of Runs : 100 Upon Interuption : Continue Calibration v	

Figure 39: Calibration Settings page

During Calibration, IPEAT+ shows the progress of the calibration in real time (Figure 40).



Figure 40: IPEAT+ shows calibration progress in realtime.

8. Answers to Challenges

- i. Challenge 1:
 - a) There are 2 HRUs in LSU 501
 - b) FRST and AGRL cover 1.79% and 88.93% of the watershed respectively
 - c) 0%-10% slope class
 - d) AGRL

ii. Challenge 2:

a) past (\rightarrow Pasture)

iii. Challenge 3:

- a) 11 years
- b) No, because warm up period was set to 3 years.
- c) 3 years
- d) Channel 1

iv. Challenge 4:

- a) 508.59 mm
- b) 1175.8 mm
- c) 535.36 mm

v. Challenge 5:

a) cross_slope