

Creating SWAT Soil Database using FAO Soil and Terrain Database of East Africa (SOTER) Data

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Introduction:

SWAT is a very useful tool for hydrologists when modeling large watersheds. One of the main inputs the model needs is the soil properties for the basin. The soil data needed can be divided into physical characteristics (required) and chemical characteristics (optional). They play a large role in determining the movement of water and air within the HRU. To use FAO Soil and Terrain Database of East Africa (SOTER) data with SWAT, new soil characteristics will need to be appended into the existing SWAT database. Once a SWAT project is set up, the following steps will instruct how to use FAO SOTER soil data within the project.

SWAT Database:

To append the necessary data into the database, first locate the soil files within SWAT. Inside the SWAT database (ie SWAT2009.mlb) there is a table entitled "usersoil". This is the database that will be altered to include the FAO data.

The screenshot shows the Microsoft Access interface for a database named 'usersoil'. The 'Table Tools' ribbon is active, showing various options like 'New', 'Save', 'Delete', 'Filter', and 'Find'. The main area displays a Datasheet View of the 'usersoil' table. The table has the following columns: OBJECTID, MUID, SEQN, SNAM, S5ID, CMPPCT, and NLAYE. The data rows are as follows:

OBJECTID	MUID	SEQN	SNAM	S5ID	CMPPCT	NLAYE
1	VT060	8	POMFRET	VT0030		4
2	VT063	6	GLOVER	VT0072		5
3	VT065	4	HADLEY	MA0022		8
4	VT021	7	SCANTIC	ME0044		5
5	VT021	16	LORDSTOWN	NY0096		3
6	VT023	1	VERGENNES	VT0001		24
7	VT065	6	MERRIMAC	MA0026		7
8	VT065	8	WAITSFIELD	VT0044		6
9	VT065	12	LAMOINE	ME0108		2
10	VT017	13	COVINGTON	VT0012		1
11	VT017	16	PANTON	VT0019		1
12	VT021	6	ENOSBURG	VT0007		5
13	VT023	11	PALATINE	NY0006		3
14	VT023	13	SWANTON	ME0017		3
15	VT023	16	HINESBURG	VT0008		1
16	VT025	8	WINDSOR	CT0014		3
17	VT025	11	ADAMS	NY0025		3
18	VT025	17	HARTLAND	VT0011		3
19	VT002	12	BELGRADE	MA0076		3
20	VT002	18	FREDON	NJ0038		1
21	VT002		HERO	CT0047		1

Each column stands for the following:

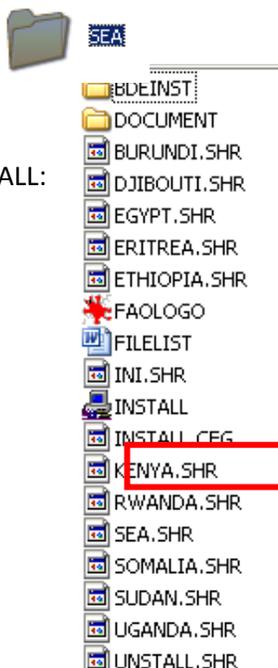
- SNAM:** Soil Name (printed in the HRU summary tables) [optional]
- HYDGRP:** Soil Hydraulic Group (A, B, C, or D) [required]
- SOL_ZMX:** Maximum rooting depth of soil profile (mm) [required]
- ANION_EXCL:** Fraction of porosity (void space) from which anions are excluded [optional]. If no value is entered, the model will set = 0.50
- SOL_CRK:** Potential or maximum crack volume of the soil profile [optional]
- TEXTURE:** Texture of soil layer [optional]
- SOL_Z(layer #):** Depth from soil surface to bottom of layer (mm) [required]
- SOL_BD(layer #):** Moist bulk density (Mg/m³ or g/cm³). Values should fall between 1.1 and 1.9 Mg/m³. [required]
- SOL_AWC(layer #):** Available water capacity of the soil layer (mm H₂O/mm soil) [required]
- SOL_K(layer#):** Saturated hydraulic conductivity (mm/hr) [required]
- SOL_CBN(layer #):** Organic carbon content (% soil weight) [required]
- SOL_CLAY(layer #):** Clay content (% soil weight) [required]
- SOL_SILT(layer #):** Silt content (% soil weight) [required]
- SOL_SAND(layer #):** Sand content (%s soil weight) [required]
- SOL_ROCK(layer #):** Rock fragment content (% total weight) [required]
- SOL_ALB(top layer):** Moist soil albedo [required]
- USLE_K(top layer):** USLE equation soil erodibility (K) factor (units: 0.013 (metric ton m² hr)/(m³-metric ton cm)). [required]

The FAO data contains textural soil information for up to 4 layers of soil; thus, the new table that will be appended will have SOL_Z1, SOL_Z2, SOL_Z3, SOL_4, etc. The next section will discuss how to access the data.

Accessing FAO Soil and Terrain Database of East Africa Data

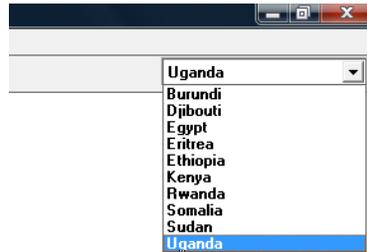
Extracting the necessary data from SOTER

- a. Open the file entitled SEA:

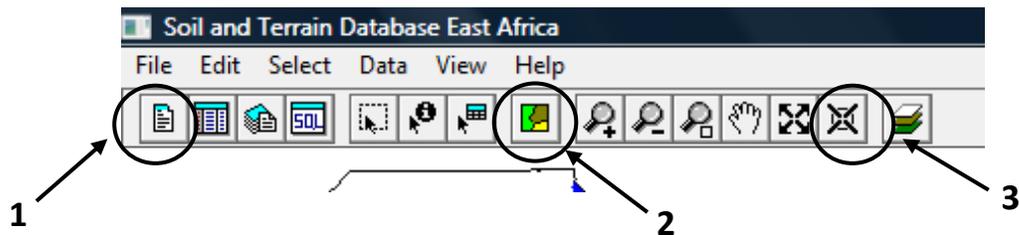


- b. Install the program called INSTALL:

c) Select the country of interest from the upper right drop-down menu

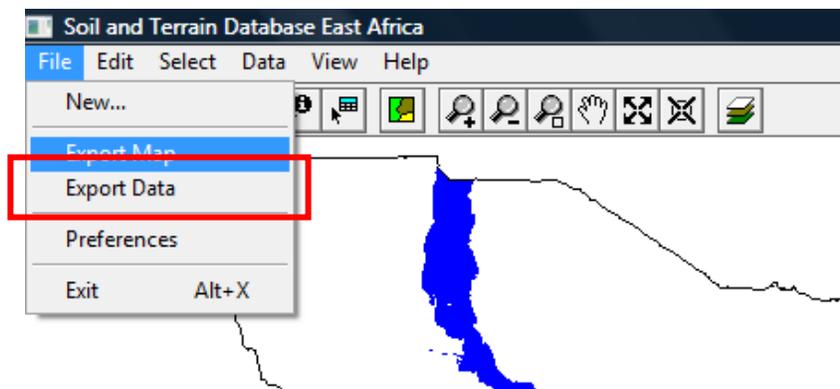


Below is the tool bar:

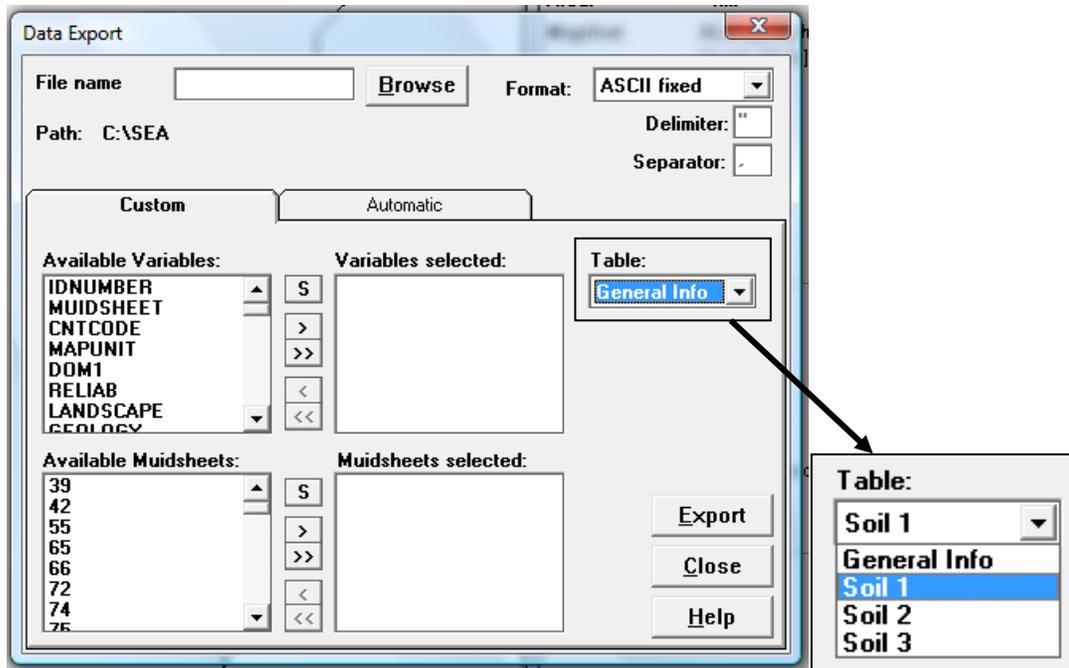


1. This button loads the data summary screen where you can browse through the muidsheets (data for each polygon within the country profile). This summary screen converts the class codes used in the database into full text.
2. This button displays the thematic map dialog box where you can choose variables, colors, classes etc. to display on the map (ie vegetation, landscape, geology, etc).
3. This icon simply redraws the map

To export the data into manageable files, go to file->Export Data



This will open the dialog box below. Click **Browse** to select where the file will be saved. Change the format to ASCII fixed or Dbase (to be opened in excel). Select the >> button to select all the variables as well as Muidsheets (these are the polygons that make up the entire country). From the **Table** drop down menu, there is the option of General Info, Soil 1, Soil 2, and Soil 3. It's necessary to export all 4 tables (they need to be exported individually).



Open these files in excel in order to manipulate them. SOTER gives soil data for up to 3 main soils within the polygon. Soil 1 represents the most dominant soil, Soil 1 represents the 2nd most dominant, and Soil 3 is the 3rd most dominant for the area. Use the dominant soil to characterize the entire polygon (in some cases there is no data for the dominant soil; in this case, use the subsequent soil data). In rare cases, no data for the soil is given. To characterize these polygons, use soil data from adjacent areas.

Finding SWAT Parameters

First, create a new excel file that contains the same column titles as the SWAT **usersoil** table. This will be the spreadsheet that is used to import the FAO data to the SWAT database. The FAO data gives a maximum of 5 layers of data. So the excel file only needs to extend to 5 soil profiles.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
1	MUID	SEQN	SNAM	SSID	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SIL

Soil textural and organic matter data are readily available for each soil/layer from the FAO data. Open the exported files in excel. It will be a large spreadsheet; the first row had headers that represent various characteristics of the polygons.

	B	C	D	E	F	G
1	MUIDSHEET	CNTCODE	MAPUNIT	DOM1	RELIAB	LANC
2	39	114	ALu.um/ALh.ch1-	ALu	H	U
3	42	114	CHl.or1-3ab	CHl	M	P
4	55	114	FRr.or8-4ab	FRr	H	P

Copy all of the MUID's over into the excel spreadsheet (if you are going to be using more than one country's MUID values, it is helpful to add a prefix to the MUID values to distinguish the different countries). Because the dominant soils are being used to define the polygons, open the Soil 1 exported

file. This contains the FAO data for the dominant soil of the polygon. Again, there will be headers for each column.

	B	C	D	E	F	G	H	I	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1	MUIDS	CNTCODE	MAPUNIT	SOIPR	HORIZ	DEPTHCM10	DEPTHPLU10	ORGCARBO10	TEXTURE10	NATBL	STRUS	STRUF	STRU5	COLWETA	COLWI	COLWI	COLDR	COLDR	COLDR	SCHORI	DEPTH
2	39	114	ALu.um/ALh.ch1-5c	1	0	0		B	C					0.0000	0.0	0	0.0	0.0	1	1	
3	42	114	CHL.or1-3ab	1	0	0			SL-L					0.0000	0.0	0	0.0	0.0	1	1	

Some attributes contain numbers after the header that corresponds to the soil profiles. For example, for ATTRIBUTExy, x is the soil number (1-5, 1 is the dominant soil) and y is the profile number (0-4). For the soil profile, 0 is for the complete profile (total soil, if no horizontal data area available) and 1-4 for the separate horizons.

The relevant columns from the exported Soil 1 table are the MUID, ORGCARBO##, TEXTURE##, and DEPTHCM## (it helps to hide the other columns). There are two scenarios for the data:

1. The MUID **does not** have any horizontal data. In this case, use organic carbon and texture data for the complete profile and the effective depth from the General Info export file (note: the depths given from the FAO data are in cm while SWAT requires them in mm).

	B	E	F	I	U	AF	AG	AH	AJ	AV
1	MUIDS	SOIPR	HORIZ	ORGCARBO10	TEXTURE10	SOIPR	HORIZ	DEPTHCM11	ORGCARBO11	TEXTURE11
2	39	1	0	B	C	1	1	25	B	
3	42	1	0		SL-L	1	1	0		
4	55	0	0			1	1	10	B	SL
5	65	1	0	E	L	0	0	0		
6	66	0	0			0	0	0		

	B	E	K	P	Y	AA	
1	MUIDSHEET	DOM1	AREAPER1	TEXTCLASS1	EDEPTHHIG1	FAOCLASS1	AREAF
2		39	ALu	35	5	150	ALu.um
3		42	CHL	60	3	150	CHL.or
4		55	FRr	100	4	150	FRr.or
5		65	HSs	85	3	100	HSs.dy
6		66	Prn	100		100	Prn

2. The MUID does have horizontal data. Use the individual layer DEPTHCM1#, ORGCARBO1#, and TEXTURE1#.

	B	E	F	I	U	AF	AG	AH	AJ	AV	BI	BK	BW	CI	CJ	CK
1	MUIDS	SOIPR	HORIZ	ORGCARBO10	TEXTURE10	SOIPR	HORIZ	DEPTHCM11	ORGCARBO11	TEXTURE11	DEPTHCM12	ORGCARBO12	TEXTURE12	DEPTHCM13	ORGCARBO13	TEXTURE13
2	39	1	0	B	C	1	1	25	B	C	0		0	0		
3	42	1	0		SL-L	1	1	0			0		0	0		
4	55	0	0			1	1	10	B	SL	25	A	SCL	3	60	A

The organic carbon is given in terms of A,B,C, and D while the texture data is given as C, L, Sa, Si, or a combination. The corresponding values are given in the tables below:

Table 1: FAO Textural Classifications*

FAO - Texture	% Clay	%Sand	% Silt
C – Clay	50	30	20
CL- Clay Loam	34	33	33
L – Loam	18	42	40
LS – Loamy Sand	6	82	12
Sa- Sand	5	92	3
SC- Sandy Clay	42	52	6
SCL – Sandy Clay Loam	28	60	12
SL- Sandy Loam	10	65	25
Si - Silt	6	7	87
SiC – Silty Clay	47	7	46
SiCL – Silty Clay Loam	34	10	56
SiL – Silty Loam	20	20	60

*in the cases where multiple textures are listed, the averages of each percentage were taken.

Table 2: FAO Organic Matter Data

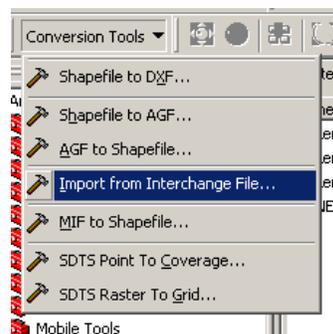
FAO – OM code	Organic Carbon in % weight	OC used in SWAT/SPAW %
A	0 - 0.6	0.3
AB	0 – 2	1
B	0.6 - 2	1.3
C	2 - 3	2.5
D	3 - 8	5.5
E	8+	8
MISSING DATA**	N/A	0.1

**Missing data was given a value of 0.1% because the region isn't known to have fertile soil [1]

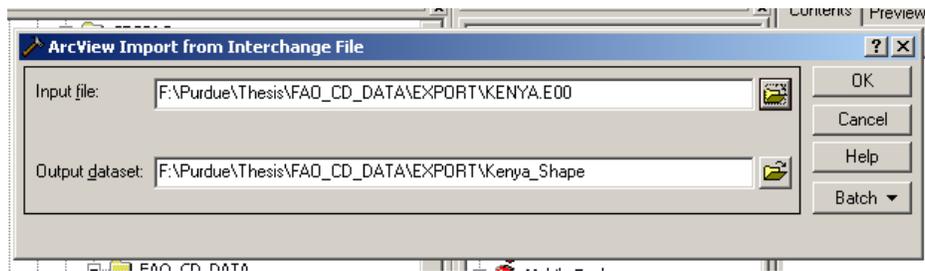
Exporting Shapefiles

In order to link the MUID data into SWAT, the country shapefiles will need to be exported and used in ArcMap. The ten countries and their corresponding ARC/INFO EXPORT files are in the EXPORT files (from the FAO CD) and are .E00 files. To do this, open ArcCatalog. Go into **TOOLS->Customize** and make sure the **ArcView 8x Tools** box is checked.

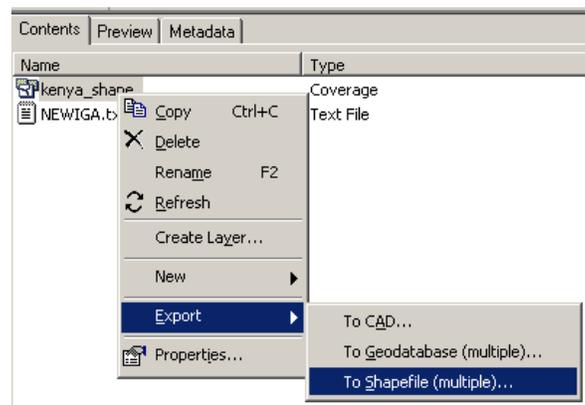
Now click the **Conversation Tools** button and select **Import from Interchange File...**



The input file is the SOTER export file of each country. Choose the file with the ending of .E00. The output dataset should have a corresponding name. Then press **OK**.



Now the dataset will be visible in ArcCatalog. Right click the data set and select **Export->to Shapefile**



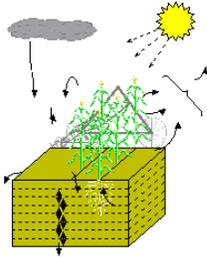
The input features will automatically be added. Select the location of an output folder for the shapefile to be saved and press **OK**. The polygon shapefile is what will be used in ArcMap. It may also be necessary to add a coordinate system to the shapefile that matches the projection of the SWAT project. This is done in ArcCatalog by right clicking the file and selecting **properties**. Then under the **XY coordinate system** tab, a coordinate system can be selected for the shapefile.

SPAW Pedotransfer Functions

Using the textural data and organic matter data from FAO, the available water content (SOL_AWC), saturated hydraulic conductivity (SOL_K), and bulk density (SOL_BD) can be determined using a downloadable program called SPAW (available free from the following website:

<http://hrsl.arsusda.gov/SPAW/Index.html>).

Field Hydrologic Processes

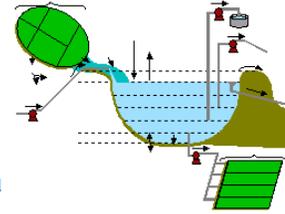


SPA W

SOIL - PLANT - ATMOSPHERE - WATER FIELD & POND HYDROLOGY

SPA W is a daily hydrologic budget model for agricultural fields and ponds (wetlands, lagoons, ponds and reservoirs). Included are irrigation scheduling and soil nitrogen. Data input and results are graphical screens.

Pond Hydrologic Processes (Wetland / Lagoon / Reservoir)



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[DVD Training: Hydrology and the SPA W simulation model](#)

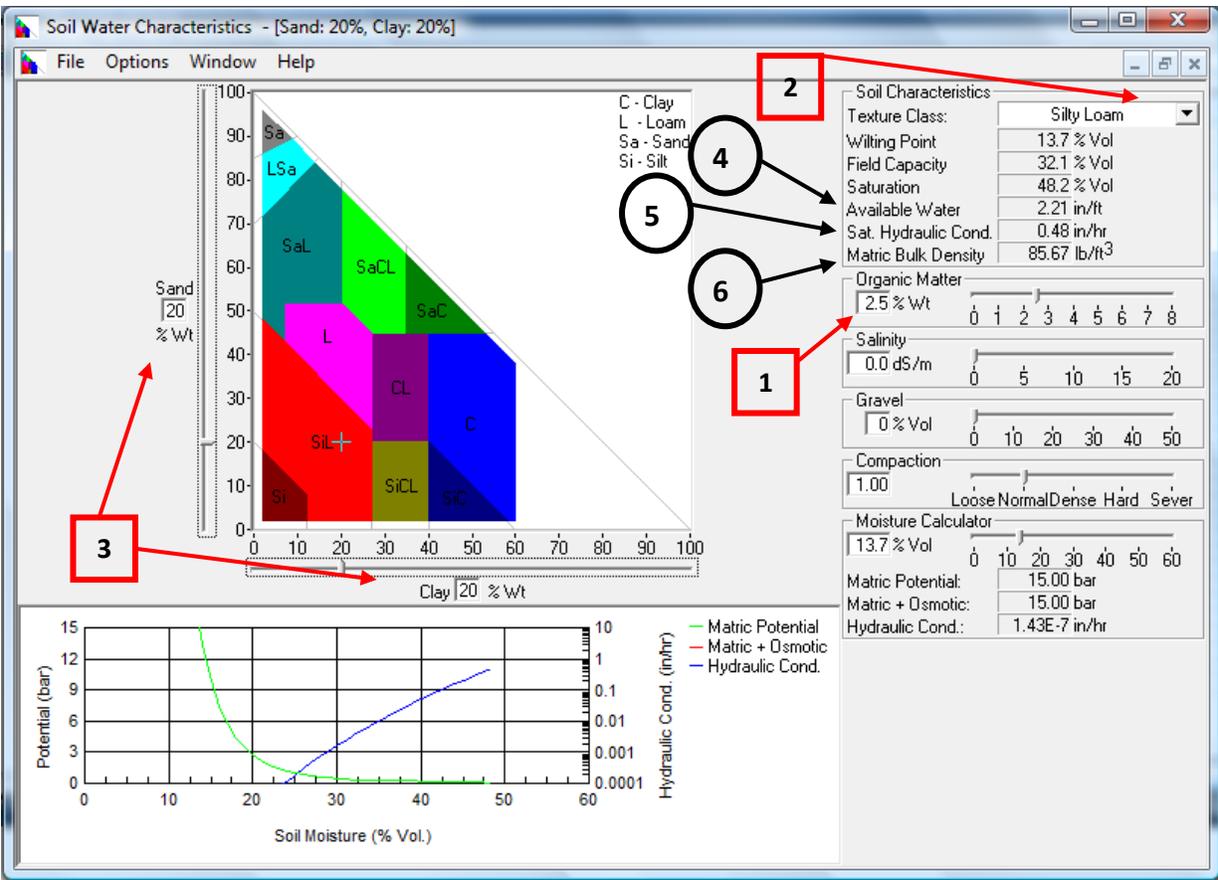
[Register and Download SPA W](#)

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Install and open SPA W. The SPA W program used to calculate the SWAT variable is the Soil Water Characteristics program. Make sure the values are in metric units (under options).

For each MUID, plug in the FAO data for organic carbon (1), and texture (using the drop down menu (2) or the manual inputs for % sand and % clay (3)). Once these values are filled in, press ENTER and the values of Available Water content (4), Saturated Hydraulic Conductivity (5), and Bulk Density (6) will be calculated. These values will need to be inputted into the new excel file under their respective headers.

This needs to be done for each layer of soil. While doing this, make sure to fill in the **NLAYERS** column for each MUID. This represents the number of layers of soil within the MUID. It will range from 1-4 depending on the data available.



Hydrologic Group (HYDGRP)

Soil hydrologic groups are classified by four categories: A, B, C, and D based on infiltration characteristics. Using the definitions in the SWAT user manual and in the paper by Gijsman et. al.⁽²⁾ distinctions between the groups based on soil texture were computed. Sandier, deeper soils were given a value of A (% sand > 86, depth >= 1500 mm), fairly sandy, middepth soils were given a value of B (% sand > 50, % clay < 35, and depth > 500 mm), soils that were slightly more clayey than sandy and fairly shallow were given a value of C (% clay >= 28, % sand <= 44, and depth <= 800 mm), and very clayey soils were given a value of D (% clay >= 50). If the soil wasn't a definite fit for one of these categories, it was given the default value of B.

Rock (SOL_ROCK)

The FAO data doesn't have a value for rockiness pertaining to each layer. A value of "stoniness" is even for each MUID (high and low). Use the low value as the rockiness for the first layer of soil.

	R	S	T	U	V	W
JPAE		STONELOW1		STONEHIGH1	STONEPLUS1	CRE
CXW		0		0		
JHW		0		0		5

Soil Albedo (SOL_ALB(top layer))

Soil albedo is the ratio of the amount of solar radiation reflected by a body to the amount incident upon it, expressed as a fraction. It can be calculated from a linear regression between albedo and the Chroma Meter Munsell color value⁽³⁾. The FAO data contains a Munsell color value for each MUID in the Soil 1 export file under **COLWETC10**. It is given in the format #/# where the first number is the medium value (lightness) and the second number is the chroma value. The value used for determining the soil albedo is the first (lightness) number. It is used in the following equation⁽²⁾:

X	Y	Z	AA	AB	AC	AD
0	0	7.5000 YR	3/2	0	0	0
0	0	0.0000	0.0	0	0	0
0	0	5.0000 YR	4/3	0	0	0
0	0	7.5000 YR	3/4	0	0	0
0	0	0.0000	0.0	0	0	0

$$\text{Soil Albedo} = 0.069 * (\text{color value}) - 0.114$$

For soil MUIDs that are missing a Munsell color value, use a default value of 0.13 (classified as brown by Gijssman et al⁽²⁾).

USLE (USLE_K)

The USLE factor has to do with soil erodibility; some soils erode more easily than others even when all other factors are the same. The SWAT Input/Output documentation describes the factors that affect the USLE K value. Using textural data and organic carbon data from above, the USLE K value was found using the following equations from the SWAT documentation:

$$K_{USLE} = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand}$$

$$f_{csand} = \left(.2 + .3 * \exp \left(-0.256 * m_s * \left(1 - \frac{m_{silt}}{100} \right) \right) \right)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^3$$

$$f_{orgc} = \left(1 - \frac{0.0256 * orgC}{orgC + \exp \left(-5.51 + 22.9 * \left(1 - \frac{m_s}{100} \right) \right)} \right)$$

$$f_{hisand} = \left(1 - \frac{0.7 * \left(1 - \frac{m_s}{100} \right)}{\left(1 - \frac{m_s}{100} \right) + \exp \left[-5.51 + 22.9 * \left(1 - \frac{m_s}{100} \right) \right]} \right)$$

with m_s = percent sand, m_{silt} = percent silt, m_c = percent clay, $orgC$ = percent organic carbon of layer

Remaining SWAT Parameters:

At this point there are only 5 more columns to fill; any other empty spaces/columns are either optional or will be left as a 0.

	A	B	C	D	E	F	G	H	I	J	K
1	MUID	SEQN	SNAM	S5ID	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_E	SOL_CRK	TEXTURE
2	K0039	1	K0039	KEN	100	1	D	1500	0.5		C
3	K0042	1	K0042	KEN	100	1	B	1500	0.5		SL/L

SEQN and **CMPPCT** mean sequence number and soil component percent, respectively. Because the data used is for the one soil component (dominant soil) for each polygon, CMPPCT should not be an important factor in the SWAT modeling; it can be filled with 100 values. SEQN looks to be an identification number for manipulation of the soil layers; it may not be directly related to simulation⁽⁴⁾; fill this column with values of 1.

SNAM and **S5ID** have to do with naming and identifying the different soils. The **SNAM** is the identifier SWAT will use to print in the HRU summary tables; using the MUID values will suffice. S5ID is described in the SWAT User Guide as:

“The user may also link the soils map to the database via Soils5ID number. When the “S5ID” option is chosen, data for the specified soil series is used to represent the map unit. In order to use the “S5ID” option, the soil database for the entire US must be installed”⁽⁵⁾

Because the soils are not from within the US, this is not an option. Instead, insert a prefix for the country to further identify the soil.

Importing to SWAT Database/Model

Save the new excel file and reopen the SWAT Access Database. In Microsoft Access, click the **External Data** tab and then on the right (above import) select **Excel**. Browse for the excel file that was created using the FAO soil data, then select **Append a copy of the records to the table:** and select the **usersoil** table and press okay. Make sure all of your headers line up with the existing table and Finish.

Look Up Table

When loading the soil data into SWAT, a look up table will need to be used. Do this in Excel by creating a column of MUIDs corresponding to the country shapefile in ArcMap and another column matching to the MUIDs of the new SWAT soils appendage. They should have the headers “VALUE” and “NAME” respectively.

Using the country shapefile exported earlier, open the layer to the SWAT project in ArcMap. Make sure that there is an attribute column in the shapefile that matches up with the "VALUE" column of the look up table (if not add one).

With the shapefile, the look up table, and the appended SWAT database, SWAT soil analysis can be run.

Following the steps to Land Use/Soils/Slope Definition in SWAT, the new soils database can now be accessed.

References

- [1] Woodwell, G. M. "Chapter 3: Organic Carbon in Soils of the World." *The Role of Terrestrial Vegetation in the Global Carbon Cycle: Measurement by Remote Sensing*. Chichester [West Sussex: Published on Behalf of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) by Wiley, 1984. 91-109.
- [2] Gijsman, A., P. Thornton, and G. Hoogenboom. "Using the WISE Database to Parameterize Soil Inputs for Crop Simulation Models." *Computers and Electronics in Agriculture* 56.2 (2007): 85-100.
- [3] Post, D. F., A. Fimbres, A. D. Matthias, E. E. Sano, L. Accioly, A. K. Batchily, and L. G. Ferreira. "Predicting Soil Albedo from Soil Color and Spectral Reflectance Data." *Soil Science Society American Journal* 64 (2000): 1027-034.
- [4] Peschel, Joshua M., Patricia K. Haan, and Ronald E. Lacey. *A SSURGO Pre-Processing Extension for the ArcView Soil and Water Assessment Tool*. Tech. no. 032123. N.p.: ASAE, n.d.
- [5] Winchell, M., R. Srinivasan, M. Di Luzio, and J. Arnold. *ArcSWAT Interface For SWAT2005: User's Guide*. Publication. Temple, Texas: Blackland Research Center, 2007.