User Guide (v1.0.0) for STARWARS Model Toolbox (SMTB) in ESRI ArcGIS Pro

1. Introduction

The STARWARS Model Toolbox (SMTB) in ArcGIS Pro is designed to simulate soil volumetric water content (VWC) based on the "Storage and Redistribution of Water on Agricultural and Re-vegetated Slopes" (STARWARS) model. This tool integrates multiple climatic and spatial datasets and model parameters to account for the amount of water content in varying soil profiles, climatic scenarios and time epochs. The toolbox is particularly beneficial for hydrological and agricultural applications, enabling spatially distributed simulations, visualizations, and outputs for effective water management decisions.

The toolbox features two tools i.e. the STARWARS Model Tool (SMT) and the VWC Averaging Tool (VAT). This User Guide provides a detailed description of the step-by-step procedure on how to use both tools including key considerations and recommendations.

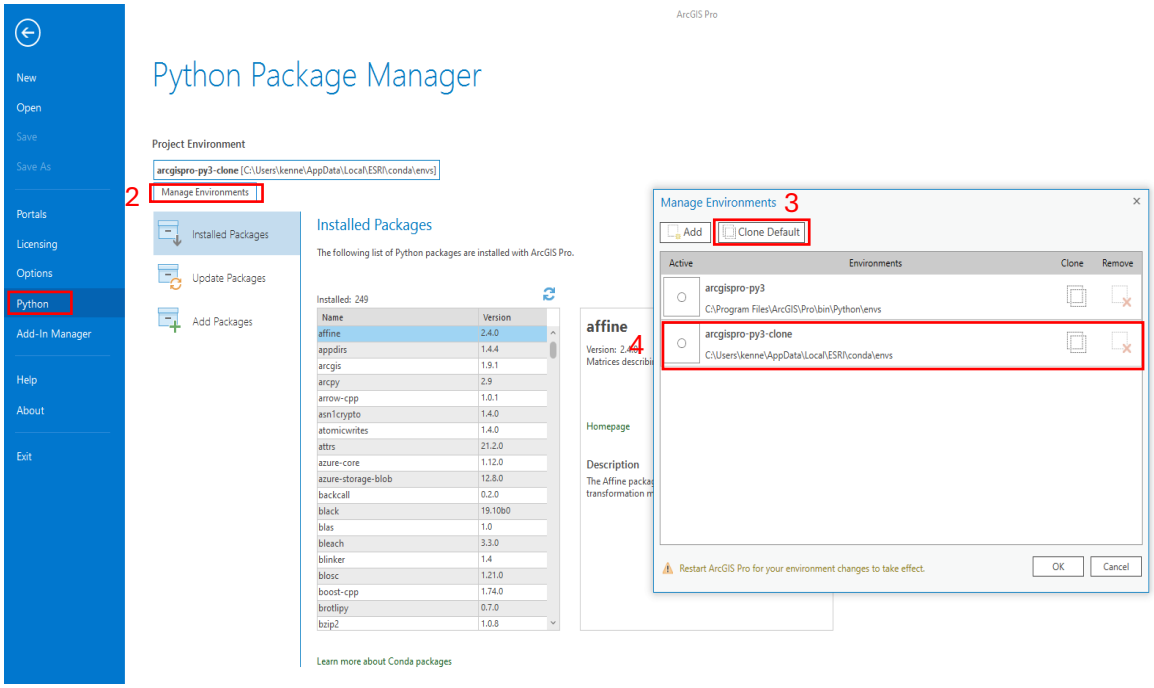
2. Prerequisites

The toolbox is scripted in Python and therefore requires a properly configured Python environment to execute it within ArcGIS Pro. Since the default ArcGIS Pro Python environment is read-only and does not allow additional package installations, a cloned environment is needed to allow installation of additionally required Python packages and modules.

2.1 Cloning the ArcGIS Pro Python Environment

The following steps should be followed to ensure a Python environment is created and updated with the necessary packages and modules.

i. Open **ArcGIS Pro** and navigate to **Settings**.
ii. Click on **Python** and select **Manage Environments** under **Project Environment**.
    By default, a single Python environment is listed, but there may be more depending on prior configurations.
iii. Click **Clone Default** to create a modifiable duplicate of the default environment.



2.2 Required Python Packages

After cloning the environment, the following essential Python modules must be installed to ensure full functionality of the toolbox:

Package	Purpose
PCRaster (version 4.3.0) *	Package for PCRaster specific functions
imageio_ffmpeg	Enables video processing and visualization for simulation outputs.
psycopg2	Facilitates interaction with PostgreSQL databases, ensuring compatibility with spatial data storage.

* This PCRaster Python Package version works seamlessly with ArcGIS Pro environment

Packages' Installation:

```
conda install -c conda-forge --override-channels -y pcraster==4.3.0 imageio_ffmpeg psycopg2
```

3. STARWARS Model Tool (SMT)

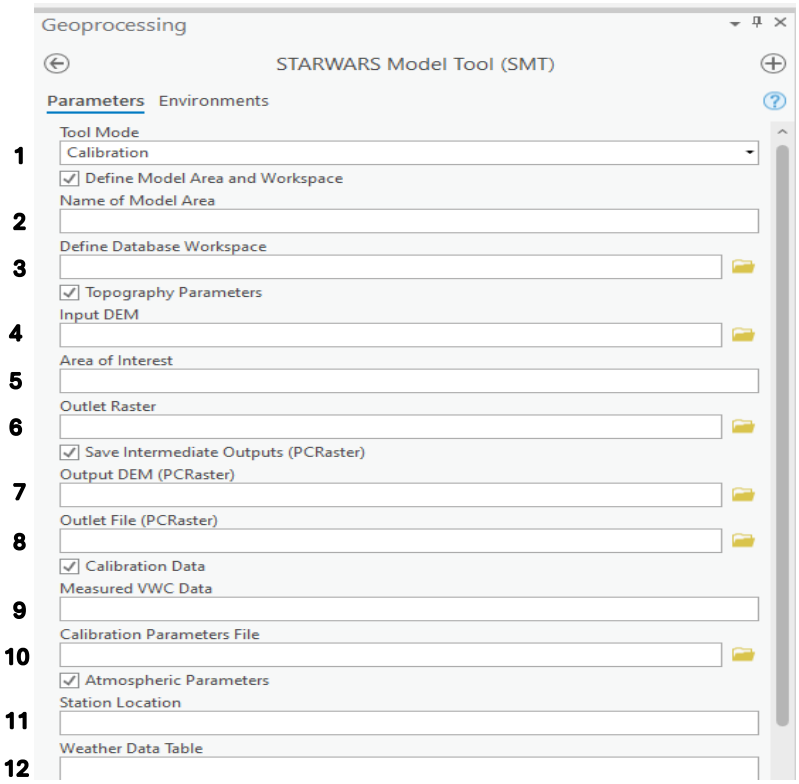
The SMT interface offers you with a single and unified interface to execute model tasks based on the STARWARS Model. The tool supports three main modes, specifically calibration, Modeling and Validation.

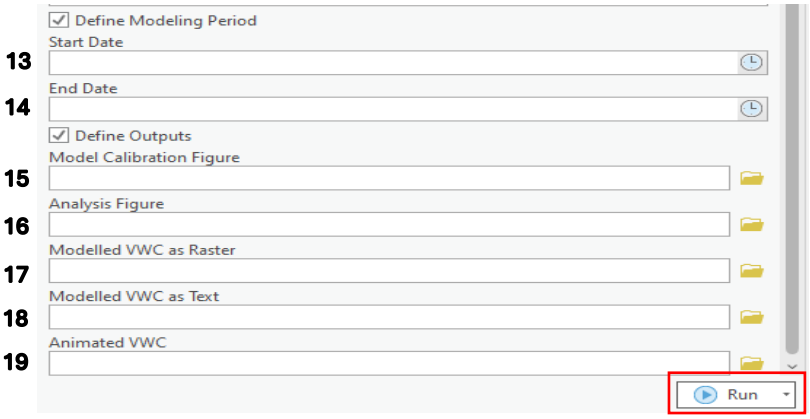
3.1 Use Cases of SMT

- Calibration Mode – Used for a location in an area where field measurements have been made and the user is interested in configuring the tool so that it can be used to simulate volumetric water content (VWC)for other locations in the area, in which filed measurements of VWC have not been made.
- Modeling Mode – It is used to simulate VWC for an area where there is no measured VWC, but the tool calibration has already been done.
- Validation Mode – It is used to assess and quantify the accuracy of the tool's simulations. Taking measured VWC and modelled VWC as inputs, the tool is applicable in situations where measured VWC of a location is available, and the user would want to assess how the tool's simulations. Ideally, the results from the Modeling Mode are compared with field measurements and the accuracy quantified using root mean square error (RMSE) and normalized Nash-Sutcliffe Efficiency (NNSE) metrics.

3.2 SMT Modes

3.2.1 Calibration Mode





Parameter Definition

1. Define the Tool Mode

This is the mode in which you want to run the tool. You can select Calibration, Modeling or Validation Mode. You can only run the tool one mode at a time. It is a required parameter.

Model Area and Workspace

2. Name of Model Area

Give a name of the area you are working with. It is a required parameter. Even though there are no restrictions on what you can put here, note that this name will appear on the plots generated automatically by the tool. Therefore, for readability, keep it short.

Recommended: At most 3 words or less than 20 characters

Example: Canevino Calib Area

3. Define Database Workspace

Specify the path to the workspace database in. sde format. It is a required parameter.

Example: starwars_model.sde.

Topography Parameters

4. Input DEM

Add the Digital Elevation Model (DEM) (in GeoTIFF format) of the area to be simulated. The DEM must be georeferenced and acts as the main input dataset on which all other spatial datasets are based on.

Example: Canevino_dem.tif.

5. Area of Interest

Provide a Feature Class that defines the boundary of the area to be modelled. The tool will automatically match the coordinate reference system to that of the DEM, and the area used to clip the DEM if need be. It is required and must be a Feature Class, meaning the source has to be a Database, either that define in Parameter 3, a File Geodatabase or any other connected Database in ArcGIS Pro.

Example: Canevino_watershed

6. Outlet Raster

Specify the output raster file (as TIFF) for the outlet point of the area DEM. This is a binary raster file where the output point has one (1) value, and the rest is assigned zeros (0). It is a required parameter.
Example: canevino_outlet.tiff

Intermediate Outputs in PCRaster

7. Output DEM (PCRaster)

The processed DEM is saved in a PCRaster format i.e. *.map* extension. This is an optional parameter.
Example: canevino_dem.map

8. Outlet File (PCRaster)

Provide an output location and file name for the outlet raster in PCRaster Format (.map). This is the same file in Parameter 6 in the PCRaster format. It is an optional parameter.
Example: outlet_raster.map

Calibration Parameters

9. Measured VWC

A valid database workspace (define in Parameter 3) will populate this field with existing tables in the database. Select the hypertable that contains the measured volumetric water content data for the area of interest. It is a required parameter.
Example: project_data.canevino.measured_vwc i.e. *database.schema.table_name*

10. Calibration Parameters File

Define the file (in .txt format) containing the various calibration parameters. It is a required parameter.
Example: Canevino_calibfile.txt.

Atmospheric Parameters

11. Station Location

Select from the list of database tables, the spatial table containing the location of the station being analysed. Taking point or polygon, this is the location where the measured VWC data was taken and is the point at which the tool will be calibrated. It is a required parameter.
Example: project_data.canevino.station_point i.e. *database.schema.table_name*

12. Weather Data Table: Select from the list of database tables, the hypertable containing the climatic and weather parameters i.e. rainfall, evapotranspiration, temperature, solar radiation, and wind.
Example: project_data.canevino.weather_data *database.schema.table_name*

Modeling Period

13. Start Date

Specify the start date (without time) of the calibration and will be used to query the measured VWC and weather hypertables. This will be validated during execution. It is a required parameter.

14. End Date

Specify the end date (without time) of the calibration and will be used to query the measured VWC and weather hypertables. This will be validated during execution. It is a required parameter.

Outputs

15. Model Calibration Figure

Define the path to save the calibration plot in JPG format. The plot shows a comparison between measured VWC and modelled VWC using Nush Sutcliffe Efficiency and RMSE metrics. It is a required parameter

Example: canevino_calib.jpg.

16. Analysis Figure

Define the path to save analysis plot. The plot visualizes the modelled VWC in comparison to key weather parameters i.e. precipitation and evapotranspiration while also calculating a correlation between the parameters and the simulated VWC.

Example: canevino_analysis.jpg.

17. Modeled VWC as Raster

Define a folder destination where the modeled VWC will be saved as raster format i.e. in GeoTIFF format.

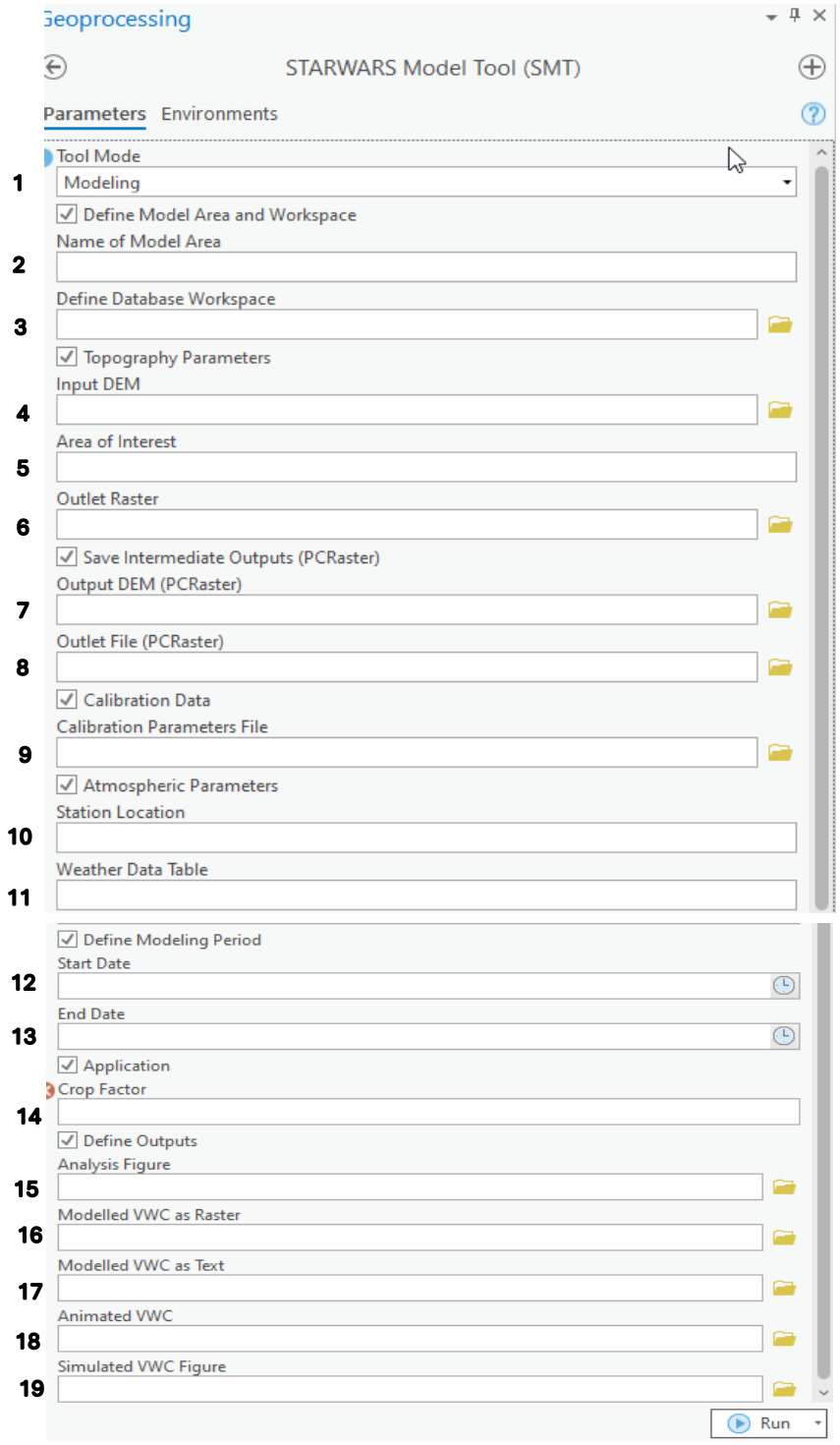
18. Modeled VWC as Text

Define the folder destination for text-based for the modeled VWC for the station. Separate text files are available for the different soil layers as defined in the calibration file.

19. Animated VWC

Define the folder destination to save the animations for the modeled VWC for the station. Separate animations, in .mp4 format, will be created for the different soil layers as defined in the calibration file.

3.2.2 Modeling Mode



Parameter Definition

1. Define the Tool Mode

This is the mode in which you want to run the tool. You can select Calibration, Modeling or Validation Mode. You can only run the tool one mode at a time. It is a required parameter.

Model Area and Workspace

2. Name of Model Area

Give a name of the area you are working with. It is a required parameter. Even though there are no restrictions on what you can put here, note that this name will appear on the plots generated automatically by the tool. Therefore, for readability, keep it short.
Recommended: At most 3 words or less than 20 characters
Example: Canevino Calib Area

3. Define Database Workspace

Specify the path to the workspace database in .sde format. It is a required parameter.
Example: starwars_model.sde.

Topography Parameters

4. Input DEM

Add the Digital Elevation Model (DEM) (in GeoTIFF format) of the area to be simulated. The DEM must be georeferenced and acts as the main input dataset on which all other spatial datasets are based on.
Example: Canevino_dem.tif.

5. Area of Interest

Provide a Feature Class that defines the boundary of the area to be modelled. The tool will automatically match the coordinate reference system to that of the DEM, and the area used to clip the DEM if need be. It is required and must be a Feature Class, meaning the source has to be a Database, either that define in Parameter 3, a File Geodatabase or any other connected Database in ArcGIS Pro.
Example: Canevino_watershed

6. Outlet Raster

Specify the output raster file (as TIFF) for the outlet point of the area DEM. This is a binary raster file where the output point has one (1) value, and the rest is assigned zeros (0). It is a required parameter.
Example: canevino_outlet.tiff

Intermediate Outputs in PCRaster

7. Output DEM (PCRaster)

The processed DEM is saved in a PCRaster format i.e. .map extension. This is an optional parameter.
Example: canevino_dem.map

8. Outlet File (PCRaster)

Provide an output location and file name for the outlet raster in PCRaster Format (.map). This is the same file in Parameter 6 in the PCRaster format. It is an optional parameter.
Example: outlet_raster.map

Calibration Parameters

9. Calibration Parameters File

Define the file (in .txt format) containing the various calibration parameters. It is a required parameter.
Example: canevino_calibfile.txt.

Atmospheric Parameters

10. Station Location

Select from the list of database tables, the spatial table containing the location of the station being analysed. Taking point or polygon, this is the location where the measured VWC data was taken and is the point at which the tool will be calibrated. It is a required parameter.
Example: project_data.canevino.station_point i.e. *database.schema.table_name*

11. Weather Data Table

Select from the list of database tables, the hypertable containing the climatic and weather parameters i.e. rainfall, evapotranspiration, temperature, solar radiation, and wind.
Example: project_data.canevino.weather_data *database.schema.table_name*

Modeling Period

12. Start Date

Specify the start date (without time) of the calibration and will be used to query the measured VWC and weather hypertables. This will be validated during execution. It is a required parameter.

13. End Date

Specify the end date (without time) of the calibration and will be used to query the measured VWC and weather hypertables. This will be validated during execution. It is a required parameter.

Application

14. Crop Factor

Select from the list of database tables, the hypertable containing the crop coefficients to assess the impact of different land management practices on the simulated volumetric water content.
Example: project_data.canevino.humusfert i.e. *database.schema.table_name*

Outputs

15. Analysis Figure

Define the path to save analysis plot. The plot visualizes the modelled VWC in comparison to key weather parameters i.e. precipitation and evapotranspiration while also calculating a correlation between the parameters and the simulated VWC.
Example: canevino_analysis.jpg.

16. Modeled VWC as Raster

Define a folder destination where the modeled VWC will be saved as raster format i.e. in GeoTIFF format.

17. Modeled VWC as Text

Define the folder destination for text-based for the modeled VWC for the station. Separate text files are available for the different soil layers as defined in the calibration file.

18. Animated VWC

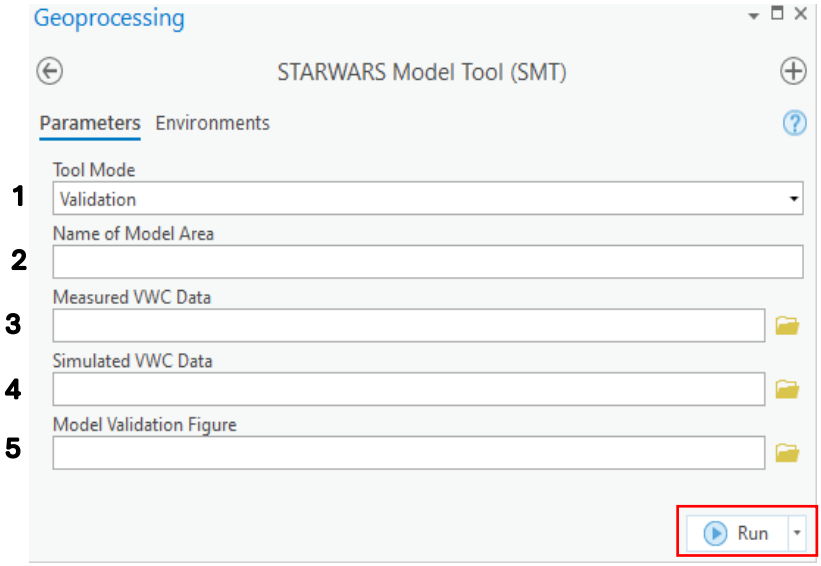
Define the folder destination to save the animations for the modeled VWC for the station. Separate animations, in .mp4 format, will be created for the different soil layers as defined in the calibration file.

19. Model Calibration Figure

Define the path to save the analysis plot in JPG format. The plot shows the trend of the simulated VWC for the defined soil layers.

Example: canevino_simulation.jpg.

3.2.3 Validation Mode



<u>Parameter Definition</u>

All parameters are required.

1. Define the Tool Mode

This is the mode in which you want to run the tool. You can select Calibration, Modeling or Validation Mode. You can only run the tool one mode at a time.

2. Name of Model Area

Give a name of the area you are working with. Even though there are no restrictions on what you can put here, note that this name will appear on the plots generated automatically by the tool. Therefore, for readability, keep it short.

Recommended: At most 3 words or less than 20 characters

Example: Validation Area

3. Measured VWC Data

Provide an input folder containing the text files for the measured VWC for all the soil layers.

4. Simulated VWC Data

Provide an input folder containing the text files for the simulated VWC for all the soil layers.

Soil layers in measured VWC should be the same as simulated VWC data.

5. Model Validation Figure

Define the path to save the validation plot in JPG format. The plot shows a comparison between measured VWC and modelled VWC using Nush Sutcliffe Efficiency and RMSE metrics. It is a required parameter.

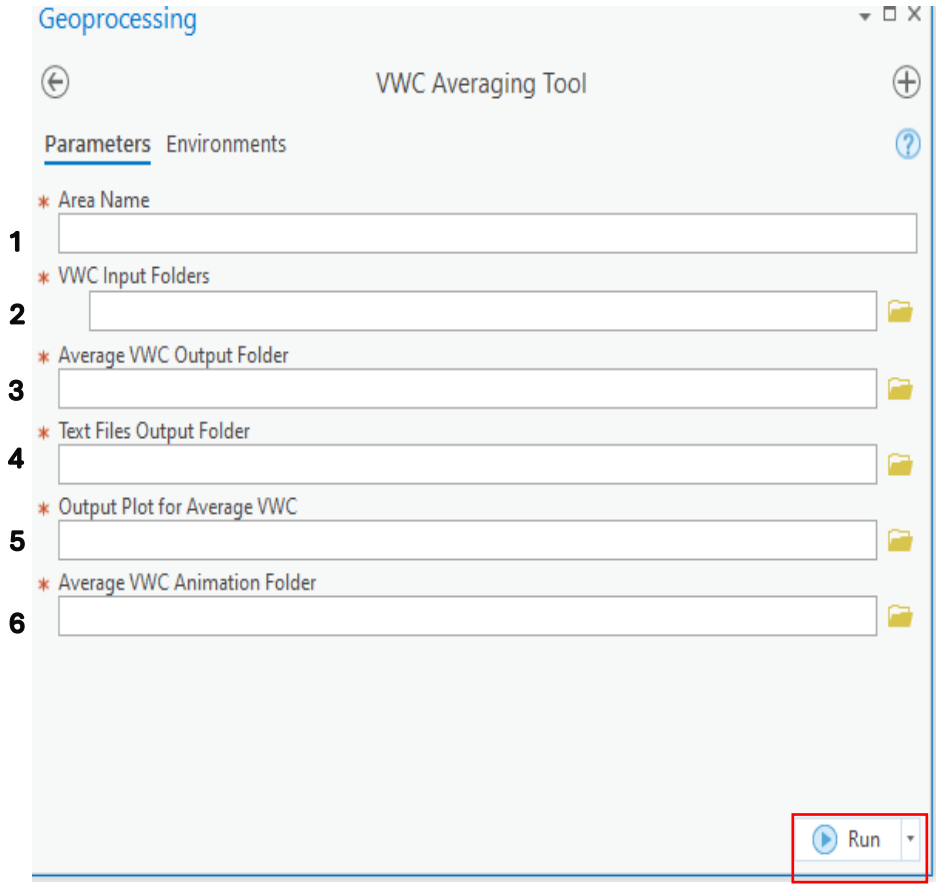
Example: canevino_validation.jpg.

4. VWC Averaging Tool (VAT)

4.1 Use Case of VAT

As the SMT works on a station-by-station basis, the VWC Averaging Tool (VAT) is used to calculate the average VWC of the outputs from the various stations in the same area making it more applicable in areas where there is data from more than one (1) location i.e. more than 1 weather station for weather data, or more than one station location.

4.2 Tool Interface



Parameter Definition

All parameters are required.

1. Area Name

Give a name of the area you are working with. It is a required parameter. Even though there are no restrictions on what you can put here, note that this name will appear on the plots generated automatically by the tool. Therefore, for readability, keep it short.
Recommended: At most 3 words or less than 20 characters
Example: Canevino Average VWC

2. VWC Input Folders

Provide the folders containing the raster files for the measured VWC for the different locations that have been modelled in the Area of Interest. It accepts multiple folders and at least two input folders are required to run the tool.

3. Average VWC Output Folder

Provide an output folder where the average raster files for the soil layers will be saved.

4. Output Plot for Average VWC

The plot of the average VWC for the different soil layers as JPG format.

5. Average VWC Animation Folder

Provide an output folder where the average animation files for the soil layers will be saved.

5. Useful Links and Resources

- ✓ GitHub Tool Code: https://github.com/KiemaKennedy/starwars_model_toolbox/tree/main/Toolbox
- ✓ Data Input Templates: https://github.com/KiemaKennedy/starwars_model_toolbox/tree/main/Data%20Input%20Templates
- ✓ Tutorials:
- ✓ Scripts: https://github.com/KiemaKennedy/starwars_model_toolbox/tree/main/Scripts

Disclaimer:

The STARWARS Model Toolbox (SMTB) was developed on ESRI ArcGIS Pro 2.9.0.
While the SMTB was tested on ESRI ArcGIS Pro 3.3.0, and ran error-free implying forward compatibility, there is no guarantee that it will run in any other existing or future versions of the ESRI ArcGIS Pro software.
This User Guide version 1.0 is based on ESRI ArcGIS Pro 2.9.0.

Please Note:

This document serves **only** as a guide to configuring and operating the STARWARS Model Toolbox (SMTB) in ArcGIS Pro effectively. For additional details or troubleshooting, contact with the developer through kennedykiema46@gmail.com or raise an issue with via GitHub.