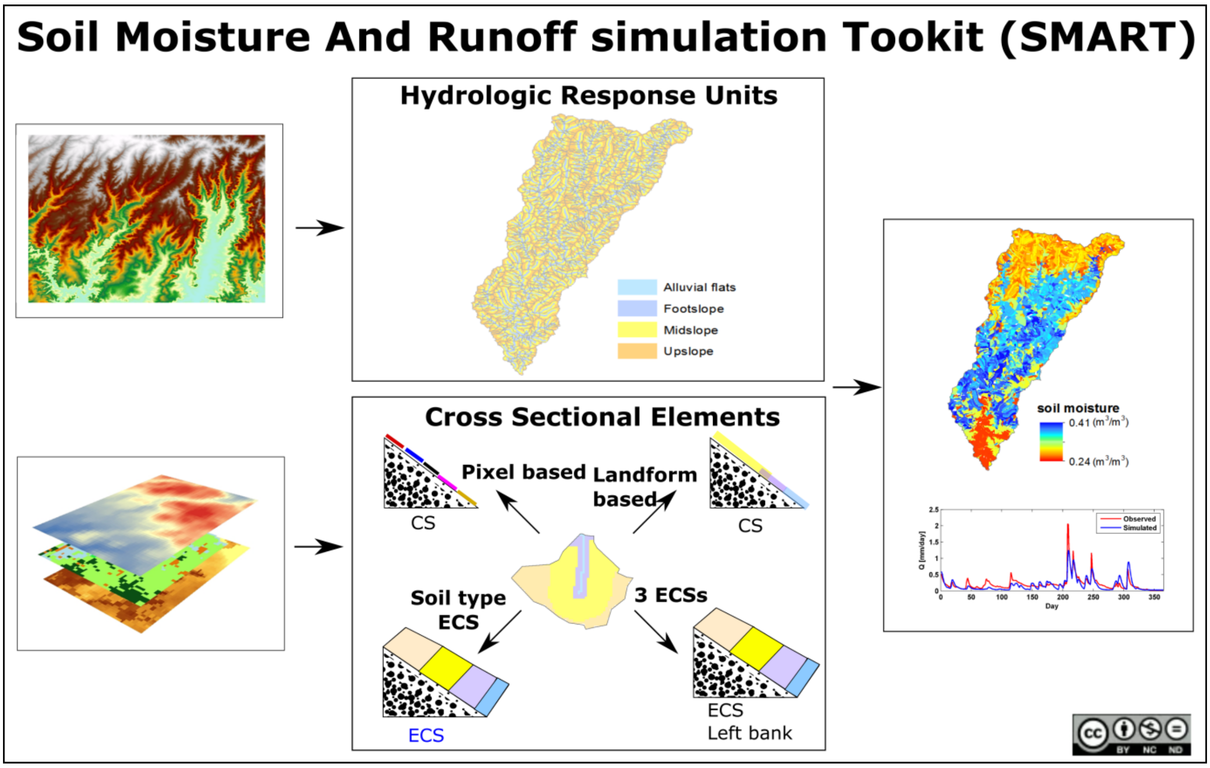
Semi-Distributed Hydrologic Modelling with Soil Moisture and Runoff simulation Toolkit (SMART)

User's Manual (Version 1.0)



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SMART Version 1.0

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Version 1.0, September 2016

https://github.com/hooriajami/SMART

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Disclaimer

The Soil Moisture and Runoff simulation Toolkit (SMART) is developed as a research software for semi-distributed hydrologic modelling. The software is provided without warranty. Authors, University of California Riverside, University of New South Wales and Australian Bureau of Meteorology are not liable for any claim in connection with the use of this software. Reference to specific commercial products and software does not necessarily constitute or imply its endorsement or recommendation by the authors or their institutions.

Abstract

The Soil Moisture and Runoff simulation Toolkit (SMART) is a GIS-based hydrological modelling framework designed for semi-distributed hydrologic modelling. The framework is based upon the delineation of contiguous and topographically connected Hydrologic Response Units (HRUs) that capture heterogeneity of catchment's topography and landforms (Khan et al., 2013). In SMART, simulations are performed across a series of perpendicular cross sections to a stream or equivalent cross sections (ECSs) in each first order sub-basin using a 2-dimensional Richards' equation based distributed hydrological model. Delineation of ECSs in SMART is performed by weighting the topographic and physiographic properties of a part or an entire first-order sub-basin and has the advantage of reducing computational time while maintaining reasonable accuracy in simulated hydrologic fluxes (e.g. evapotranspiration and runoff).

SMART pre- and post-processing scripts are written in MATLAB to automate the sub-basin, HRU and cross section delineations, model simulations across multiple cross sections, and to post-process model outputs. MATLAB Parallel Processing Toolbox is used for simultaneous simulations of cross sections and is further reduced computational time. SMART workflow consists of the following steps: 1) delineation of first order sub-basins of a catchment using a digital elevation model, 2) hillslope delineation, 3) landform delineation in every first order sub-basin based on topographic and geomorphic properties of a catchment, 4) formulation of cross sections as well as equivalent cross sections, and 5) extraction of vegetation and soil parameters using spatially distributed land cover and soil information for the 2-d distributed hydrological model. The post-processing tools generate streamflow at the outlet and spatially distributed evapotranspiration and soil moisture across the catchment. The current version of SMART has the Unsaturated Soil Moisture Movement Model (U3M-2D) (Tuteja et al., 2004) to solve the 2-dimensional Richards' equation. While SMART implements a particular hydrologic model, any hydrologic model can be incorporated in this framework. This manual provides an overview of the SMART software and contains a tutorial for setting up a catchment scale model using SMART in MATLAB.

Software Requirements:

- Microsoft Windows 7 operating system
- MATLAB 2014b or later release
- Terrain Analysis Using Digital Elevation Models (TauDEM) software developed by David G. Tarboton. The link to download the TauDEM package is (http://hydrology.usu.edu/**taudem**/). The command line version of TauDEM is used in SMART and users do not need ArcGIS license to use this software.

SMART Code Information:

- SMART is written in MATLAB. The terrain processing steps are performed using the command line version of the TauDEM.
- The unsaturated zone hydrologic model, U3M-2D, is written in C#. The compiled version of the model is provided with the toolkit.

Software Installation

MATLAB and TauDEM must be installed prior to using SMART.

Instructions for MATLAB installation can be found in (http://au.mathworks.com/support/install-matlab.html).

To install TauDEM manually on a 64-bit system:
1) Download the TauDEM 5.1.2 Zip file for customized installation
2) Unzip the TauDEM512.zip file. In the TauDEM512 folder, there are multiple executables.
3) Install mpi_x64.msi
4) Install vcredist_x64_2010.exe
5) Install TaudemSetup_x64.msi
6) Uninstall HPC Service Pack 2012 from the Control Panel
7) Download Microdoft MPI V5 or higher from http://www.microsoft.com/en-us/download/details.aspx?id=44990
8) Install MsMPiSetup.exe
9) Check the "Environmental Variables" in *Control Panel\System and Security\System\Advanced system settings* to make sure the "Path" variable in system variables has the following paths:
C:\Program Files\Microsoft MPI\Bin\;C:\Program Files\TauDEM\TauDEM5Exe\

For further instructions about TauDEM installation, please refer to http://hydrology.usu.edu/taudem/taudem5/downloads.html.

CHAPTER 1: Getting to Know the SMART

1. Overview of SMART

SMART is a GIS-based hydrological modelling framework designed for semi-distributed hydrologic modelling. The basis of this modeling framework is on the delineation of contiguous and topographically connected Hydrologic Response Units (HRUs) that capture heterogeneity of catchment's topography and landforms (Khan et al., 2013). Landforms are areas within a toposequence that represent macroscopic changes in land surface shape and pattern down and across the slope (Summerell et al., 2005; Khan et al., 2013). The HRU delineation methodology of Khan et al. (2013) is implemented in SMART and consists of delineating first order sub-basins (using digital terrain analysis) and landforms (using topographic and geomorphic properties of a catchment). Hydrologic modelling is performed across a series of cross sections or equivalent cross sections (ECSs) in each first order sub-basin using a 2-dimensional Richards' equation based distributed hydrological model. Simulated fluxes (e.g. runoff and evapotranspiration) from every cross section or an ECS are multiplied by the respective area from which the cross sections or ECSs are formulated to obtain the sub-basin scale fluxes.

SMART pre- and post-processing scripts are written in MATLAB to automate the sub-basin, HRU and cross section delineations, model simulations across multiple cross sections, and to post-process model outputs. MATLAB Parallel Processing Toolbox is used for simultaneous simulations of cross sections or ECSs and is further reduced computational time. SMART workflow consists of the following steps: 1) delineation of first order sub-basins of a catchment using a digital elevation model, 2) hillslope delineation, 3) landform delineation in every first order sub-basin based on topographic and geomorphic properties of a catchment, 4) formulation of cross sections as well as equivalent cross sections, and 5) extraction of vegetation and soil parameters using spatially distributed land cover and soil information for the 2-d distributed hydrological model (Figure 1). The Unsaturated Soil Moisture Movement Model (U3M-2D) is implemented in SMART 1.0. The U3M-2D is a 2-D physically based distributed hydrological model developed by Tuteja et al. (2004) based on an extended two-dimensional version of the U3M-1D (Vaze et al., 2004). The U3M-2D is written in C# and detailed descriptions of the model and equations are in the manual (http://www.toolkit.net.au/Tools/CLASS-U3M-1D/publications). Model inputs are daily rainfall and pan evaporation or potential evapotranspiration, soil hydraulic properties, land cover type, thickness of each soil material, root biomass distribution and monthly leaf area index (LAI). While a particular hydrologic model is implemented in SMART, any hydrologic model can be incorporated in this framework.

The post-processing tools of SMART generate daily, monthly and annual time series of streamflow, overstory and understory transpiration, soil evaporation, horizontal flow and deep drainage at a cross section and first order sub-basin scale. In addition, spatially distributed soil moisture and evapotranspiration are generated across the catchment (Figure 1). In SMART, spatial distribution of soil moisture is mapped at the scale of simulation units (pixels or landforms). Figure 1 outlines the SMART modelling framework. The terms pre- and post-processing refer to any processing steps for generating input files and processing of simulated outputs respectively.

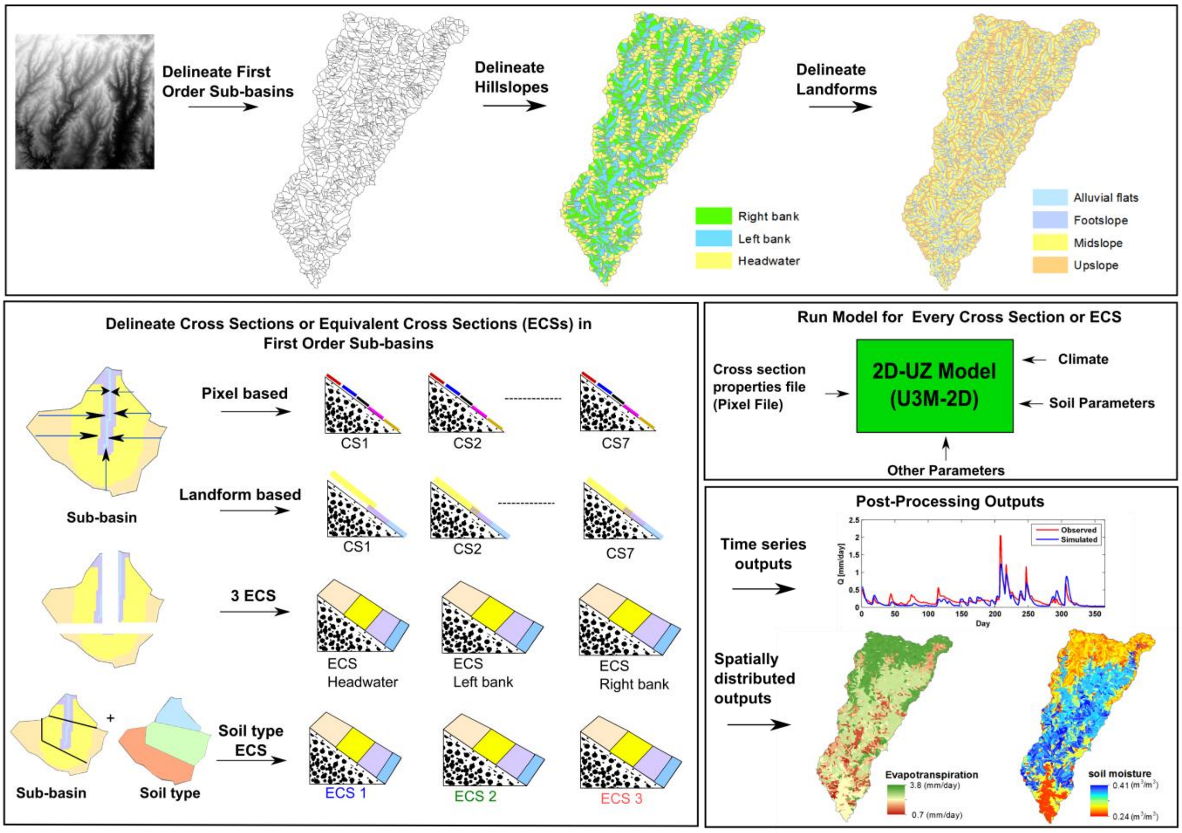


Figure 1. Overview of the SMART workflow. Hydrologic modelling with SMART consists of delineations of first order sub-basins, hillslopes, landforms and cross sections, and generation of model inputs (climate time series, cross section properties files, and soil parameter files). Once model simulations are completed, post-processing scripts generate time series of model outputs and spatiality distributed soil moisture and evapotranspiration.

1.1. First Order Sub-basin Delineation

The first step in the catchment modelling using the SMART software starts by delineating a catchment and its sub-basins from a Digital Elevation Model (DEM). Catchment delineation from a DEM involves multiple processing steps. The command line version of the Terrain Analysis Using Digital Elevation Models (TauDEM) toolbox is called from the MATLAB script in SMART to extract and analyse hydrologic information from a DEM (Tarboton 2013). The Stream Reach and Watershed tool of the TauDEM is particularly important for delineation of sub-watersheds across the stream network as it connects the sub-watersheds for accumulating and routing of stream flow (Tarboton 2013). Other catchment attributes such as slope, distance down the stream and topographic wetness index are generated as part of this step.

1.2. Hillslope Delineation for Every First Order Sub-basin

In this step, every sub-basin is partitioned to hillslopes. A given sub-basin, typically have two types of hillslopes: headwater and sideslopes (Fan and Bras, 1998). Headwater hillslopes are the zero-order basins that drain towards the channel head (Bogaart and Troch, 2006). Sideslopes are the lateral flow units to the left or right of a river segment that drain to the channel link (Noel et al., 2014) (Figure 2). The reasons for delineating the hillslopes in the toolkit are two folds. First, hillslope areas are used for calculating contributing areas of individual cross sections in the distributed cross section delineation approaches. Second, hillslopes are used for grouping of cross sections in the right bank, left bank and headwater hillslopes to formulate ECSs for the ECS delineation approach of SMART.

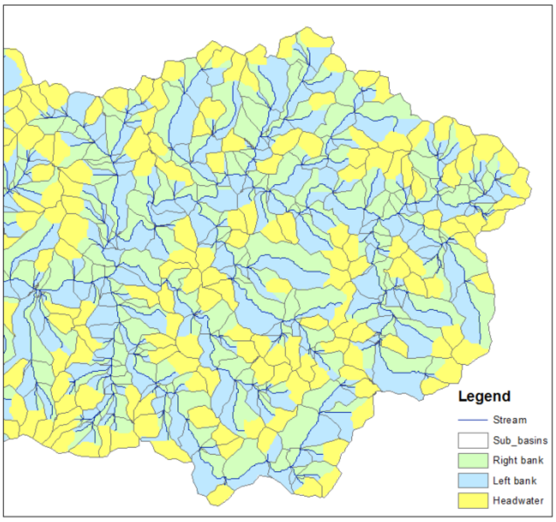


Figure 2. Delineated hillslopes in every sub-basin. Intermediate sub-basins only have the side slopes.

1.3. Landform Delineation in SMART

To delineate landforms, each first order sub-basin is divided into multiple contiguous landforms to transfer fluxes from the upper part of a hillslope to the lower regions. To obtain appropriate thresholds for the landform delineation, variation in topographic and geomorphologic descriptors of the entire catchment (Khan et al., 2013) in relation to distance from a stream is used. These thresholds correspond to areas within a certain distance from the stream where substantial changes in topographic properties such as slope are occurred (Khan et al., 2013). According to this approach a particular landform has a constant width across the catchment.

As can be seen in Figure 3, four landforms are delineated in each first order sub-basin. These landforms are named as alluvial flats, footslope, midslope and upslope according to their distance to a stream (Khan et al., 2013). Alluvial flats lie along the stream and the upslope landforms lie along the ridgeline. To obtain landform delineation thresholds in SMART, distance to a stream grid is calculated using the D-Infinity Distance Down tool of TauDEM. In the next step, the distance grid is classified to equal intervals based on the DEM resolution (i.e. 25 m in Figure 3) and average slope and distance of all pixels within a given interval are calculated (Figure 3 left) and plotted in SMART. Landform thresholds correspond to break points or inflection points along the slope-distance from the river curve. In SMART, the second derivative of the slope-distance from the stream curve is calculated using a finite difference scheme to derive landform delineation thresholds. Landform 1 in Figure 3 corresponds to the alluvial flats in the landform classification of Khan et al. (2013). This landform type consists of all the pixels in the catchment within a 0 to 25m (25 m is the DEM resolution) distance from a stream. The landform-footslope and landform-midslope correspond to all the pixels within a 25 to 86.6 m and 86.6-236.98 m distance from a stream respectively. Any pixel inside a catchment that is within a distance of 236.98 or larger from the stream is classified as the landform-upslope.

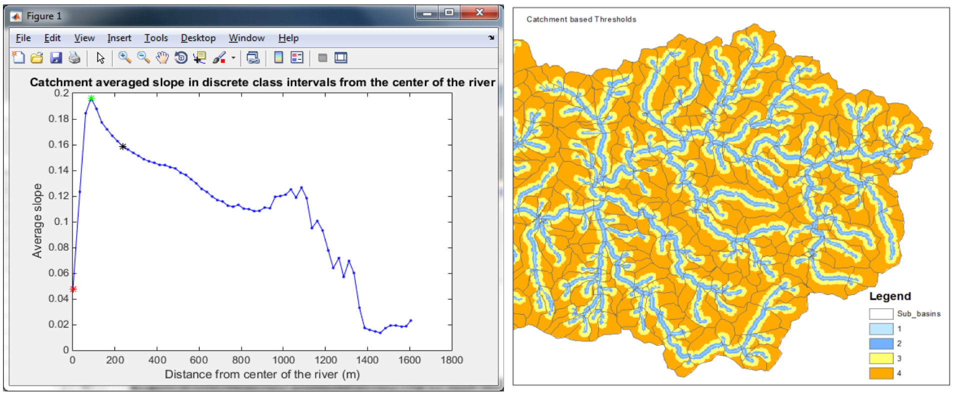


Figure 3. Landform thresholds (left) and delineated landforms (right) using SMART.

1.4. Cross Section Delineation Approaches in SMART

Modelling elements in SMART are series of cross sections or equivalent cross sections formulated for every first order sub-basin. To delineate cross sections, two main approaches are available in SMART using cross section formulation of Khan et al. (2014). These approaches differ in the cross section formulations and the scale at which cross section properties are obtained (pixel level or landform level).

1.4.1. Distributed Cross Section Delineation Approaches

In the distributed cross section delineation approaches, each hillslope is sub-divided to a series of cross sections perpendicular to a stream (Figure 1). Topographic, soil and land cover properties of each cross section are derived for individual pixels along a cross section (**Distributed pixel based approach**) or derived at the scale of each landform within a cross section (**Distributed landform based approach)**. For categorical data such as soil and land cover types, the dominant soil and land cover class is determined for each landform within a cross section in SMART. For slope and soil depth, average pixel values within a landform are considered.

1.4.2. Equivalent Cross Section Delineation Approaches

To further reduce the number of computational elements in the approaches outlined above, Khan et al. (2014) formulated the concept of “Equivalent cross sections”. In the equivalent cross section (ECS) approach, a sub-basin is subdivided to ECSs that are representative of a section or an entire area of a first-order sub-basin. Two ECS delineation approaches are available in SMART. In the first approach, one equivalent cross section is delineated for every hillslope within a sub-basin. In sub-basins with 1st order streams, three ECSs are delineated: one for the headwater hillslope, one for the right bank and one for the left bank hillslope. In sub-basins with stream orders greater than 1, two ECSs are delineated (one for the left bank and one for the right bank). This cross section delineation approach is referred to as the **three equivalent cross sections method** in the rest of this manual**.**

To delineate the right bank and left bank ECSs, a hillslope is divided into approximately uniformly spaced multiple cross sections along a stream segment in a first-order sub-basin and the topographic and physiographic properties of these cross sections are aggregated on a landform basis to formulate an ECS for each hillslope. For the headwater hillslope, three cross sections are delineated: one along the channel head and two cross sections within a 45 degree angle from each side of the channel head. In the ECS approach, instead of simulating water balance at the scale of every cross section in a sub-basin, model simulations are performed for every equivalent cross section (one for each hillslope insides a sub-basin). As an example, in a sub-basin with 43 cross sections (20 for the right bank, 20 for the left bank and three for the headwater hillslopes), properties of 20 cross sections in each side slopes are aggregated to delineate an ECS for each bank. For the headwater hillslope, properties of 3 cross sections are aggregated on a landform basis to delineate the headwater ECS. The right bank ECS length in this sub-basin is obtained by the arithmetic averaging of the length of 20 cross sections using equation (1). The slope and soil depth of each landform in the right bank ECS are obtained by the length-weighted averaging of slope and soil depth of 20 cross sections using equations (2) and (3) respectively (Khan et al., 2014).

$$\overline{L_J} = \frac{1}{n}\sum_{i=1}^{n} L_{i,j} \qquad (1)$$

$$\overline{S_J} = \frac{\sum_{i=1}^{n} S_{i,j} \times L_{i,j}}{\sum_{i=1}^{n} L_{i,j}} \qquad (2)$$

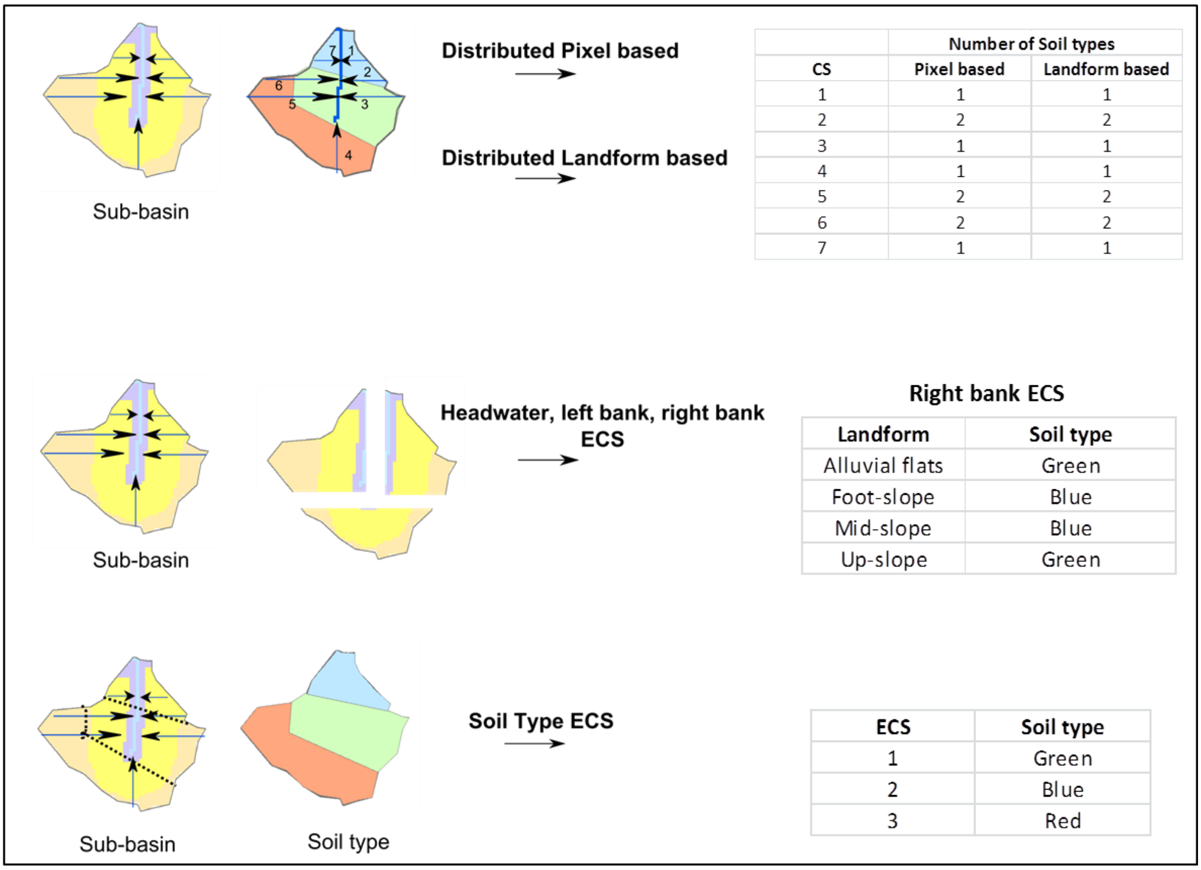
$$\overline{D_{J,k}} = \frac{\sum_{i=1}^{n} D_{i,j,k} \times L_{i,j}}{\sum_{i=1}^{n} L_{i,j}} \qquad (3)$$

where i is number of cross-sections (i = 1, 2, …, n); j is number of landforms (j = 1, 2, …, J), k is number of soil materials (k = l to 4), $L_{i,j}$ is length of landform j for cross section i, $\overline{L_J}$ is average length of landform J across all cross sections (n), $S_{i,j}$ is slope of landform j of cross section i, $\overline{S_J}$ is average slope of landform j across all cross sections (n), $D_{i,j,k}$ is depth of soil material k of landform j of cross section i, $\overline{D_{J,k}}$ is average depth of soil material k of landform j across all cross sections (n) (Khan et al., 2014).

The length-weighted averaging of slope and soil depth is not used for assigning the soil hydraulic properties of an ECS as the soil hydraulic properties are highly nonlinear. Instead, the dominant soil type in each landform is considered for an ECS. Spatial variability of soil hydraulic properties in the vertical direction is considered by assigning the dominant soil type for each soil horizon in a given landform. For land cover type, the dominant land cover class in each landform is selected and assigned to a given ECS.

In the second ECS delineation approach of SMART, the number of ECSs in a sub-basin depends on the number of **soil-types** within a first order sub-basin. Similar to the previous approach, series of cross sections are delineated in each first order sub-basin. However, cross section properties within a soil polygon are aggregated to delineate a soil type ECS using equations 1 to 3. Note that in the previous ECS delineation approach, cross section properties are aggregated for individual hillslopes rather than a soil polygon inside a sub-basin.

Figure 4 shows differences in which land surface properties such as soil type are assigned to each pixel of a cross section using four cross section delineation approaches of SMART.



CS	Number of Soil types Pixel based	Landform based
1	1	1
2	2	2
3	1	1
4	1	1
5	2	2
6	2	2
7	1	1

Right bank ECS

Landform	Soil type
Alluvial flats	Green
Foot-slope	Blue
Mid-slope	Blue
Up-slope	Green

ECS	Soil type
1	Green
2	Blue
3	Red

Figure 4. Assignment of soil types in four types of cross section delineations in SMART. In the distributed pixel based cross section delineation, soil types are written for every pixel of a cross section while in the distributed landform based option the dominant soil type of every landform is considered. In the three ECS delineation approach, the dominant soil type per landform in each hillslope is determined. In the ECS soil type, all landforms in a given ECS have the same soil type.

2. SMART Hydrologic Model

The Soil Moisture and Runoff simulation Toolkit (1.0) has the Unsaturated Soil Moisture Movement Model (U3M-2D) to simulate hydrologic fluxes across a cross section. The U3M-2D is a 2-D physically based distributed hydrologic model developed by Tuteja et al. (2004) based on an extended two-dimensional version of the U3M-1D (Vaze et al., 2004). Detailed descriptions of the model and equations are provided in the user's manual (http://www.toolkit.net.au/Tools/CLASS-U3M-1D/publications). The maximum unsaturated zone depth is set to 10.0 m in U3M-2D and the sub-surface is classified to a maximum of four horizons or materials based on soil hydraulic properties. Input data are daily meteorological data (rainfall and pan evaporation or potential evapotranspiration), soil hydraulic properties, land cover types (tree, crops, and pasture), thickness of each soil material, root biomass distribution in every soil layer, and monthly leaf area index (LAI). Model outputs are daily transpiration, soil evaporation, horizontal flow, deep drainage and soil moisture in the unsaturated zone.

In U3M-2D a modelling element consists of a 2-dimensional cross section that is perpendicular to a stream (Figure 5). Water balance calculations are performed for each pixel of a hillslope cross section along the vertical direction using the default vertical discretization of 0.1 m. Users can change vertical discretization in SMART to speed-up the calculations.

However, coarse vertical discretization will result in numerical instability and loss of accuracy. U3M-2D uses one-dimensional solution of Richards' equation in the vertical direction for each pixel on a hillslope cross section. Vertical water balance at a given pixel is calculated as:

$$\frac{\partial\theta(z,t)}{\partial t} = -\frac{\partial q_v}{\partial z} + S(z,t) \qquad (4)$$

where θ is volumetric water content (m^3m^{-3}), q_v is Darcy flux in the vertical direction (ms^{-1}), S is sum of the source and sink terms per unit control volume per time (s^{-1}).

Darcy flux in the vertical direction is written as follows:

$$q_v = -D(\theta)\frac{\partial\theta}{\partial z} - K_v(\theta),\ D(\theta) = K_v(\theta)\frac{\partial h}{\partial\theta} \qquad (5)$$

where $D(\theta)$ is hydraulic diffusivity (m^2s^{-1}) and $K_v(\theta)$ is unsaturated zone hydraulic conductivity (ms^{-1}). Substituting equation (5) in equation (4) will form the Richards' equation (Tuteja et al., 2004). After calculating the vertical flux, any moisture in excess of soil moisture holding capacity of each soil material is accumulated and transferred horizontally from the respective soil material to the downslope pixel using the unsaturated form of the Darcy's law. As stated earlier, the entire soil column is grouped into four soil horizons or soil materials and each soil material is further divided in thin soil layers for computation of vertical water balance in U3M-2D.

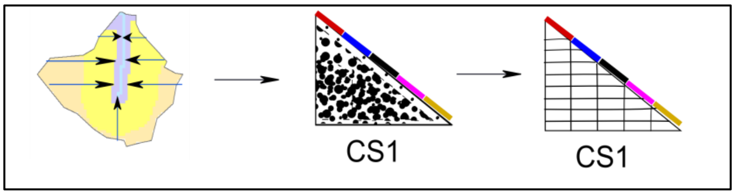


Figure 5. Conceptual diagram of a 2-dimensional hillslope cross section in SMART with the U3M-2D. First, perpendicular cross sections to a stream are delineated in a first order sub-basin. Then, hydraulic and land surface properties of each pixel in the horizontal and vertical directions are assigned.

The model time step is daily and it requires daily time series of rainfall and PET for water balance calculations. However, the time step is internally adjusted during the model simulations depending on the rainfall rate (See Chapter 2, Section 3.4). The model has parametrization for three main land cover types: tree, crop and pasture. Therefore, any other land cover types in the catchment should be assigned to one of these land cover classes.

In SMART, a set of scripts are provided to automate the pre- and post-processing steps of hydrologic modelling with U3M-2D (Figure 6). To perform U3M-2D simulations for each cross section, four model files are required:

1) PixelFile.txt. This file has properties of each pixel in a given cross section. Pixel properties are elevation, land cover type, soil type, and number of soil layers.

2) ClimateZone.txt. This file has climate zone identification number and time series of daily precipitation, potential understory and overstory transpiration and potential soil evaporation for three land cover classes (tree, pasture and crops) in U3M-2D.

3) InputSoilPar.txt. This file has soil hydraulic properties for each soil type in a cross section. These properties are used to solve the Richards' equation.

4) InputSHPTable.txt. This file has the tabulated pressure head values and corresponding soil water content, specific saturation and hydraulic diffusivity for each soil material in a cross section.

5) InputOtherData.txt. This file includes other model related parameters. Detailed description of U3M-2D input files are presented in Section 4.

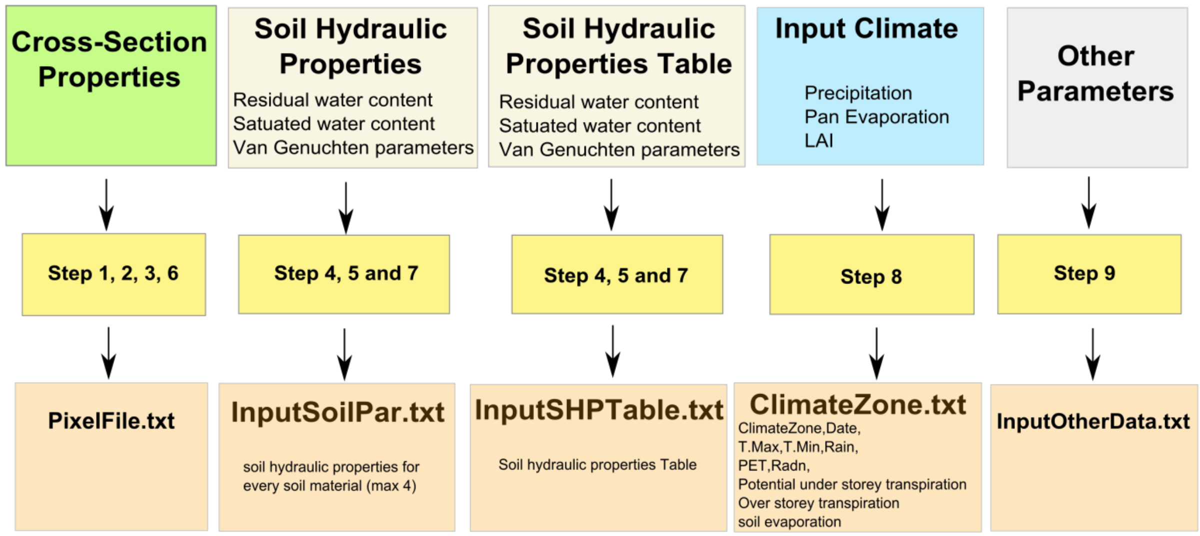


Figure 6. Summary of U3M-2D input files. Pre-processing scripts in SMART generate these files from a DEM, soil and land cover grids and climate time series data files. The step numbers in the yellow rectangles refer to the processing steps of the toolkit. For example, steps 1, 2, 3 and 6 of the Toolkit should be taken in order to generate a cross section properties file (PixelFile.txt).

3. SMART File Structure

The SMART folder contains six sub-folders (Figure 7). The contents of each folder are described in the following sections.

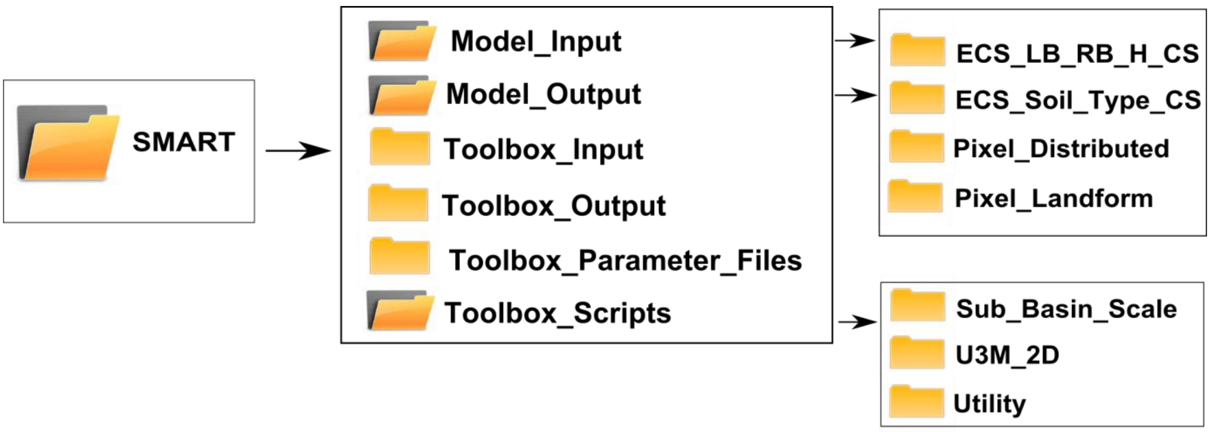


Figure 7. SMART folder structure

3.1. Toolbox_Input Folder

This folder contains the main input dataset for delineating sub-basins, HRUs, cross sections and U3M-2D input files. A summary of the toolkit input files are outlined in Table 1 and are described below:

- **A Digital Elevation Model (DEM) file (*.tif)**
  One of the main toolkit inputs is a DEM. The DEM is required for sub-basins, hillslopes and landform delineations. The DEM file format is Tiff (.tif) as this is the TauDEM requirement. As DEM files have different resolutions depending on the data source, users should specify the DEM resolution in the **UserRunInfo.m** script of SMART at the start of a simulation.

Table 1. Summary of SMART input files

Data	Format	Description
Digital Elevation Model	Geotiff format	Land surface elevation grid of a catchment
Catchment outlet	Shape File	Location of a discharge gage
Land cover class	Geotiff format	Reclassified to tree, grass and crops
Soil texture class or percent sand and clay	Geotiff format	USDA soil texture classes or percent sand and clay for every soil material
Soil thickness	Geotiff format	Thickness of four soil materials
Climate Zones	Geotiff format	Zones with the same climate inputs
Climate Input file	CSV format	Daily precipitation and potential evapotranspiration or pan evaporation

- **A catchment outlet file (*.shp)**
  A catchment outlet file is a point shapefile (ESRI format) that has the location of a discharge gage. The outlet file is used for catchment delineation in TauDEM.

⚠ **Note:** The catchment outlet file must contain one user defined attribute (“id”). Otherwise, an error will occur during the run time. Delete additional fields if your catchment outlet file has more than one user defined attribute (Figure 8).

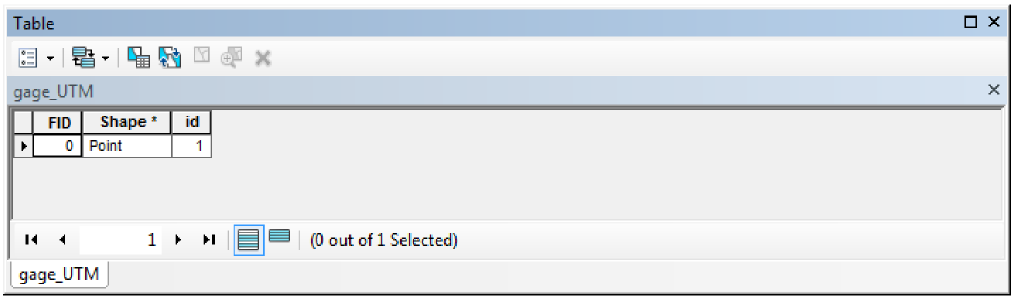


Figure 8. An attribute table of a shapefile in ArcGIS.

- **Soil textural class files (*.tif)**
  In U3M-2D, the soil zone can include up to four main soil materials to represent heterogeneity of soil hydraulic properties in the vertical direction of a cross section. In SMART, soil hydraulic properties are obtained using look up tables based on soil textural classes. If soil texture data are available for a catchment, users can use them directly in the toolkit. Otherwise, the toolkit derives soil texture classes from percentages of sand and clay data using the USDA soil texture classification scheme.

- **Percentages of sand in each soil material (*.tif)**
  If soil texture data is not available, percentages of sand at every grid cell for each soil material is required (four layers).

- **Percentages of clay in each soil material (*.tif)**
  Because the soil zone in the model can have up to four main soil materials, percentages of clay at every grid cell for each soil material is required (four layers).

- **Soil depth layer (*.tif)**
  The thickness of every soil material is required for every grid cell inside a catchment.

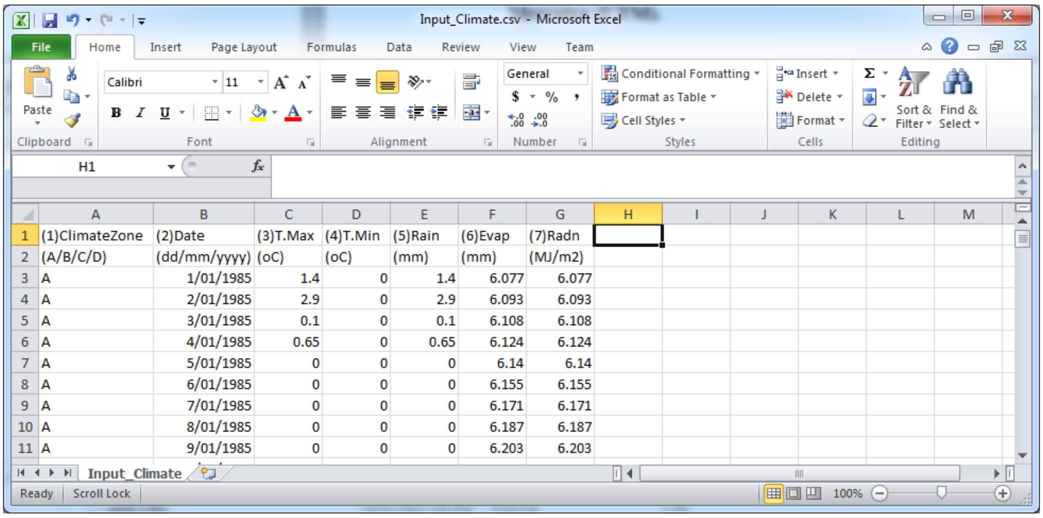
- **Land cover map of a catchment (*.tif)**
  The main land cover types in U3M-2D are tree, crop and pasture. The input land cover file in SMART should have the following codes for the land cover classes (1 = trees, 2 = pasture, 3 = crops).

⚠ **Note:** The current version of U3M-2D has parameterization for tree, pasture and crop land cover types.

⚠ **Note:** You should use the above codes in your land cover dataset.

- **A climate zone map of the catchment (*.tif)**
  A climate zone map has the climate zone identification values in a catchment. In SMART, class 1 is assigned to zone A, class 2 to zone B and so on. If there are multiple climatic zones in a catchment, climate times series files should be provided for each zone.

- **Input climate time series file(s) (*.csv**)
  To generate climate time series input file for the U3M-2D, a CSV file with the following information should be provided in the Toolbox_Input folder. Time series input file should contain 7 columns: climate zone identification key, Date, maximum temperature, minimum temperature, rain, potential evapotranspiration or pan evaporation and radiation (Figure 9). This version of the U3M-2D is only using **rainfall and potential evapotranspiration (PET) or pan evaporation** to compute actual evapotranspiration. The rest of variables will be used for the ecohydrological component of the model in later releases. If pan evaporation values are provided by the user instead of PET, the pan evaporation coefficient should be set to a value less than 1 to convert pan evaporation to PET (**UserRunInfo.m** script).



	A	B	C	D	E	F	G
1	(1)ClimateZone	(2)Date	(3)T.Max	(4)T.Min	(5)Rain	(6)Evap	(7)Radn
2	(A/B/C/D)	(dd/mm/yyyy)	(oC)	(oC)	(mm)	(mm)	(MJ/m2)
3	A	1/01/1985	1.4	0	1.4	6.077	6.077
4	A	2/01/1985	2.9	0	2.9	6.093	6.093
5	A	3/01/1985	0.1	0	0.1	6.108	6.108
6	A	4/01/1985	0.65	0	0.65	6.124	6.124
7	A	5/01/1985	0	0	0	6.14	6.14
8	A	6/01/1985	0	0	0	6.155	6.155
9	A	7/01/1985	0	0	0	6.171	6.171
10	A	8/01/1985	0	0	0	6.187	6.187
11	A	9/01/1985	0	0	0	6.203	6.203

Figure 9. A sample climate input file in SMART.

⚠ **Note:** Make sure all these seven files are located in your Toolbox_Input folder before starting your simulations.

⚠ **Note:** Use the Universal Transverse Mercator (UTM) projection system for all the spatial datasets.

⚠ **Note:** All spatial datasets should have the same resolution as the catchment's DEM.

3.2. Toolbox_Parameter_Files Folder

This folder contains three parameter files. The pre- processing scripts will access these files to derive relevant parameters for U3M-2D input files. These parameter files are:

- **Monthly_LAI.csv**: This file has the monthly LAI climatology for tree, crop and pasture land cover types. It also has the LAI coefficient Beta and canopy light extinction coefficients for the three land cover types (See U3M-1D manual for detailed explanation of these parameters). These parameters are also explained in Chapter 2, section 3.4 of this manual. A user defined file should have the same format as this file and should be stored in the Toolbox_Parameter_Files folder.

- **root_distribution.xlsx**: This file contains root distribution and soil evaporation parameters for the tree main land cover classes. For trees, relative root density of overstory and understory vegetation types is specified for every soil layer (default 100 layers). As there is no understory vegetation for crop and pasture, only relative root densities of main vegetation types are defined. The last column of **root_distribution.xlsx** file has the relative soil evaporation information for each soil layer (See section 3.4 in Chapter 2 or U3M-1D manual for detailed explanation of these parameters).

- **Soil_texture_ROSETTA_U3M.xlsx**: This file contains class average soil hydraulic properties for each USDA soil texture class using Rosetta pedotransfer functions (Schaap et al, 2001). There are 12 soil texture classes in this file and class codes in this table are used to link the soil texture maps of the create soil texture script of SMART to soil hydraulic properties. Soil hydraulic properties are for solving the

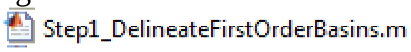
Richard's equation for unsaturated zone flow. A user defined hydraulic properties file should have the same format as this file and should be stored in the Toolbox_Parameter_Files folder.

3.3. Toolbox_Scripts Folder

This folder is the core of SMART software. All the MATLAB functions (Figure 10) and scripts (Figure 11 and 12) that generate model input files, perform U3M-2D simulations and process model results are located here. U3M-2D executable is stored in the U3M_2D sub-folder. Scripts for sub-basin scale simulations are in the **Sub_Basin_Scale** sub-folder (Figure 12). The Utility folder has additional scripts for data pre-processing (Figure 13).

MATLAB function files are called by other scripts in SMART (Figure 10) and they look like the image below in MATLAB Table of Contents:

MATLAB scripts (Figure 11 and 12) have the MATLAB logo ( ) and they look like the image below in MATLAB Table of Contents:



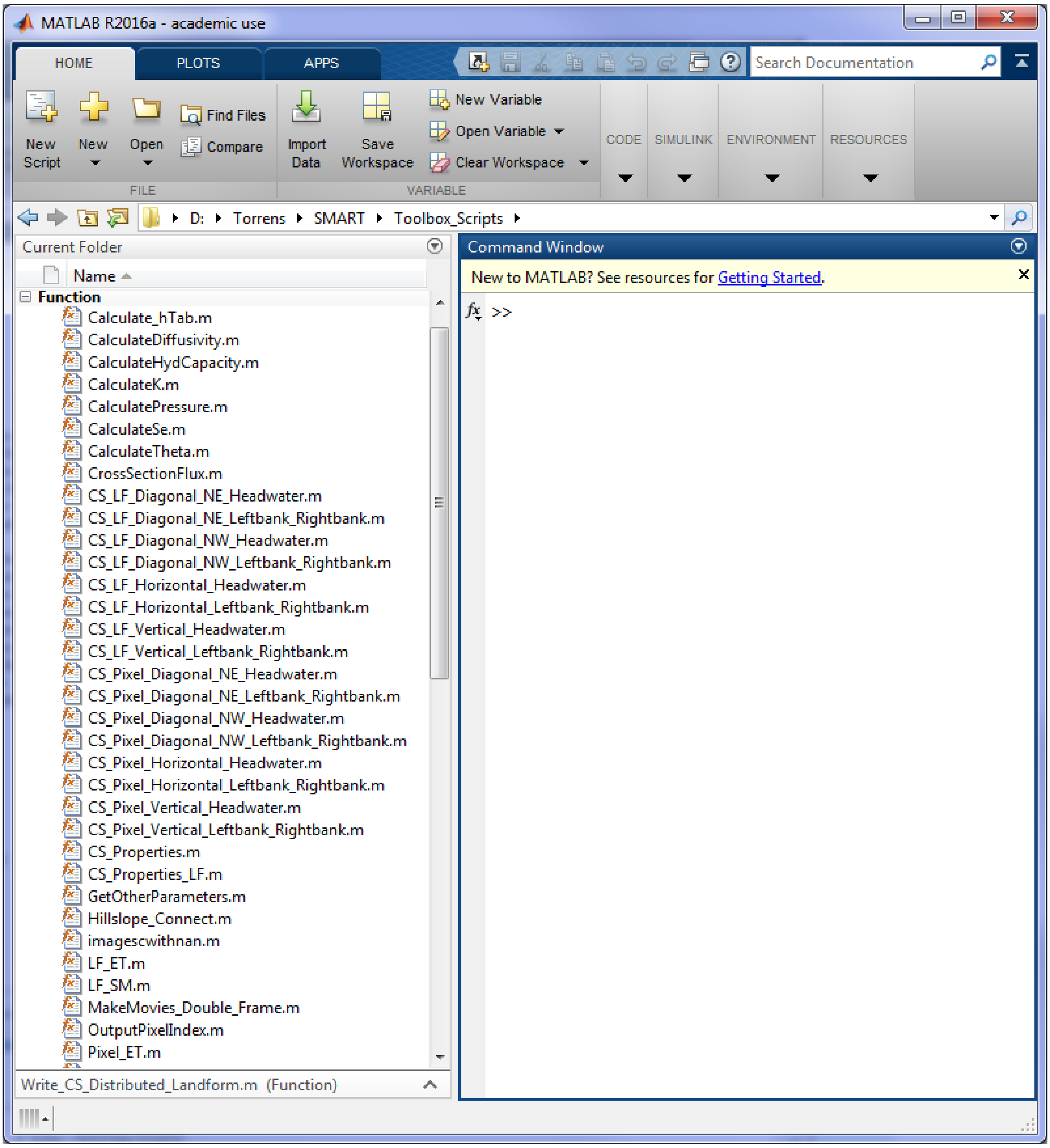


Figure 10. SMART MATLAB Functions

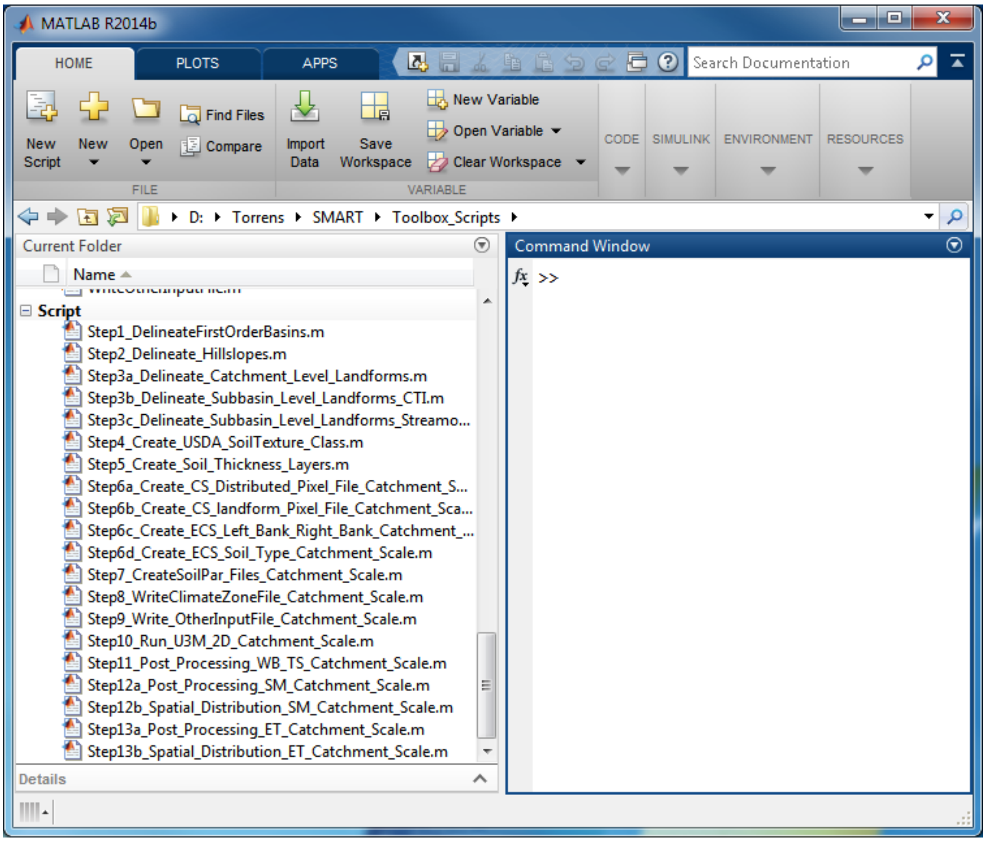


Figure 11. SMART MATLAB Scripts

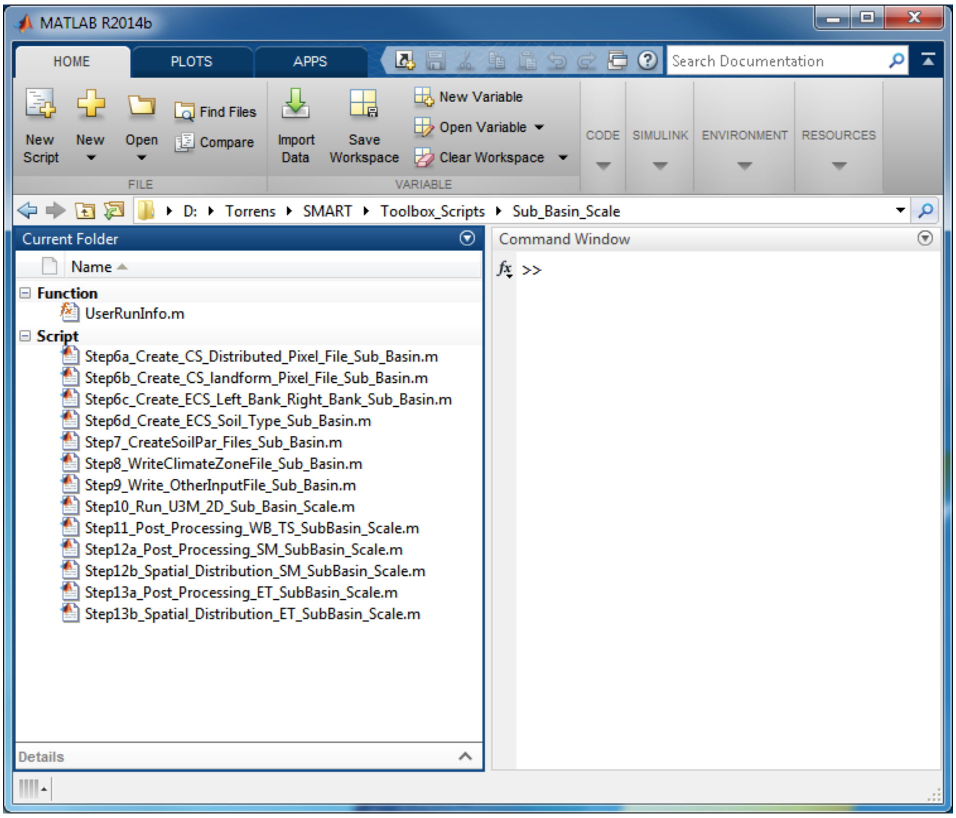


Figure 12. Sub-Basin Scale MATLAB scripts of SMART.

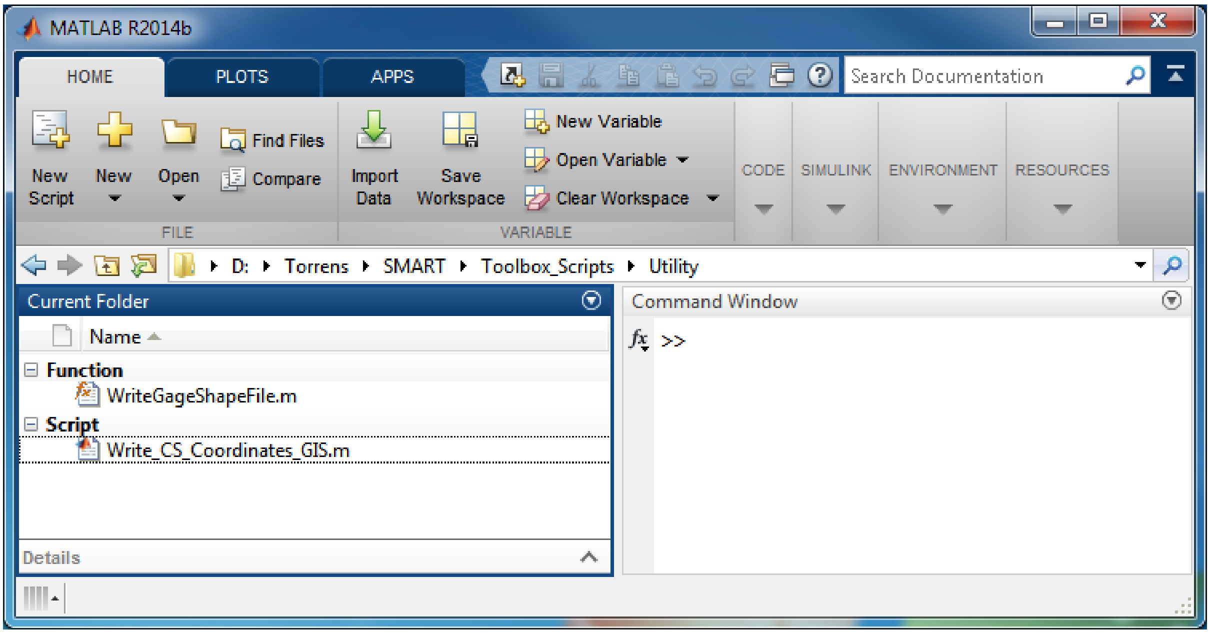


Figure 13. SMART utility Scripts

Tables 2 and 3 provide summary of SMART functions. Details of each processing script are described in Chapter 2.

Table 2. SMART Pre-Processing MATLAB Functions

Function Name	**Description**
UserRunInfo	User specified parameters and model path
WriteASCIIGrid	Writes ArcGIS or QGIS grid files
Hillslope_Connect	Checks hillslope connectivity
Soil_Classification	Performs USDA soil texture classification
CS_Properties	Obtains cross section properties on a pixel basis
CS_Pixel_Diagonal_NE_Headwater	Delineates 3 headwater cross sections in NE sub-basins
CS_Pixel_Diagonal_NE_Leftbank_Rightbank	Delineates left and right bank cross sections in NE sub-basins
CS_Pixel_Diagonal_NW_Headwater	Delineates 3 headwater cross sections in NW sub-basins
CS_Pixel_Diagonal_NW_Leftbank_Rightbank	Delineates left and right bank cross sections in NW sub-basins
CS_Pixel_Horizontal_Headwater	Delineates 3 headwater cross sections in horizontal sub-basins
CS_Pixel_Horizontal_Leftbank_Rightbank	Delineates left and right bank cross sections in horizontal sub-basins
CS_Pixel_Vertical_Headwater	Delineates 3 headwater cross sections for vertical sub-basins
CS_Pixel_Vertical_Leftbank_Rightbank	Delineates left and right bank cross sections in vertical sub-basins
Write_CS_Distributed_Pixel	Writes pixel files for the distributed pixel based cross section delineation
CS_Properties_LF	Obtains cross section properties on a landform basis
CS_LF_Diagonal_NE_Headwater	Delineates 3 headwater cross sections in NE sub-basins and obtains properties on a landform basis
CS_LF_Diagonal_NE_Leftbank_Rightbank	Delineates left and right bank cross sections in NE sub-basins and obtains properties on a landform basis
CS_LF_Diagonal_NW_Headwater	Delineates 3 headwater cross sections for NW sub-basins
CS_LF_Diagonal_NW_Leftbank_Rightbank	Delineates left and right bank cross sections in NW sub-basins and obtains properties on a landform basis
CS_LF_Horizontal_Headwater	Delineates 3 headwater cross sections in horizontal sub-basins and obtains properties on a landform basis
CS_LF_Horizontal_Leftbank_Rightbank	Delineates left and right bank cross sections in horizontal sub-basins and obtains properties on a landform basis
CS_LF_Vertical_Headwater	Delineates 3 headwater cross sections for vertical sub-basins and obtains properties on a landform basis
CS_LF_Vertical_Leftbank_Rightbank	Delineates left and right bank cross sections in vertical sub-basins and obtains properties on a landform basis
Write_CS_Distributed_Landform	Writes pixel files for the distributed landform based cross section delineation
Write_ECS_H_LB_RB_CS	Writes pixel files for the left bank, right bank and headwater ECS
Write_ECS_SoilType_CS	Writes pixel files for the ECS soil type delineation
WriteInputSoilPar	Writes input soil parameter files for U3M-2D
Calculate_hTab	Calculates pressure head values
CalculateDiffusivity	Calculates hydraulic diffusivity values
CalculateHydCapacity	Calculates hydraulic capacity
CalculateK	Calculates unsaturated zone hydraulic conductivity
CalculatePressure	Calculates pressure head
CalculateSe	Calculates saturation
CalculateTheta	Calculates volumetric water content
WriteInputSHPTable	Writes U3M-2D soil hydraulic properties file
WriteClimateZoneFile	Writes U3M-2D climate zone file
GetOtherParameters	Obtains parameters for the other input parameter file
WriteOtherInputFile	Writes U3M-2D other input parameter file

Table 3. SMART Post-Processing MATLAB Functions

Function Name	Description
OutputPixelIndex	Generates indices of U3M-2D cross sections and pixels from the cross section database files
CrossSectionFlux	Calculates time series of cross section and sub-basin scale fluxes for each cross section delineation type
Pixel_SM	Obtains time series of soil moisture for every pixel in a cross section using U3M-2D outputs
LF_SM	Calculates time series of landform averaged soil moisture from U3M-2D outputs
SM_Subbasin_Average	Calculates sub-basin average soil moisture and maps it to a grid
SM_LF_LB_RB_H	Distributes and maps landform average soil moisture of left bank, right bank and headwater hillslopes for the 3 ECS delineation option
SM_LF_LB_RB_H_T2	Distributes and maps landform average soil moisture of left bank, right bank and headwater hillslopes for the distributed landform based delineation
SM_LF_Soil_ECS_Soil_CS	Distributes and maps landform average soil moisture of each soil type ECS
SM_LF_CTI_ECS_Soil_1_CS	Distributes and maps landform average soil moisture of each ECS soil type using the relative wetness index
Pixel_ET	Obtains time series of pixel based overstory and understory transpiration and soil evaporation from U3M-2D output flux files
LF_ET	Calculates time series of landform average overstory and understory transpiration and soil evaporation from U3M-2D outputs
MakeMovies_Double_Frame	Makes animation of spatially distributed output files

3.4. Toolbox_Output Folder

Outputs of terrain analysis (delineate first order sub-basins, delineate hillslopes, and delineate landforms scripts), soil texture files (Create USDA Soil texture class script), soil thickness files (Create soil thickness layers script), and cross section database files (Chapter 2) are stored in this folder using SMART pre-processing scripts.

3.5. Model_Input Folder

Model input files for different cross section delineation options are stored in the respective folder inside the Model_Input folder. These folders are: **Pixel_Distributed, Pixel_LandForm, ECS_LB_RB_H_CS, and ECS_Soil_Type_CS.** Each folder will contain U3M-2D inputs files for every cross section.

3.6. Model_Output Folder

Model output files for different cross section delineation options are stored in the respective folder inside the Model_Output folder (**Pixel_Distributed, Pixel_LandForm, ECS_LB_RB_H_CS, and ECS_Soil_Type_CS).** During model simulations, a cross section simulation folder is generated for every cross section inside one of these folders depending on the cross section delineation method. Simulated output files as wells as the cross section input files are stored in the cross section simulation folder. Post-processing scripts store processed output files and movies in one of the Model_Output sub-folders depending on the cross section delineation method.

CHAPTER 2: Semi-Distributed Hydrologic Modelling with SMART

Setting up a distributed or a semi-distributed hydrologic model for catchment scale simulations involves multiple geospatial data processing steps. Development of a workflow based approach to automate the data processing tasks and guiding the user through several modelling steps are essential for reducing data processing time and error. Semi-distributed hydrologic modelling with SMART consists of four main tasks: 1) catchment scale topographic and geomorphic analysis, 2) cross sections or equivalent cross sections delineation and deriving model input parameters (soil, land cover and climate), 3) model simulation, and 4) post-processing of simulated outputs to create time series and spatially distributed outputs (Figure 1). While the first workflow task is performed using the entire catchment data, tasks 2 to 4 are performed for a single first order sub-basin or the entire catchment depending on the objectives.

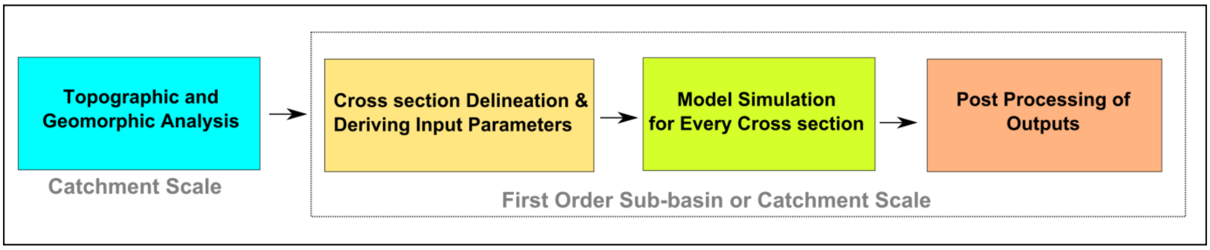


Figure 1. Summary of main workflow tasks in SMART

Each of the main workflow tasks in SMART is consisted of multiple steps or modules. A MATLAB script is written for every module to guide the user for semi-distributed hydrologic modelling with SMART. The modular structure is designed in a way to perform a particular aspect of the modelling at a time, and can be easily replaced with user custom functions. SMART has 13 modules. The first nine modules are for input data processing and they perform sub-basin, HRU and cross section delineations, and generate climate, soil and land cover properties files. The U3M-2D run time script manages cross sections simulations across multiple central processing units (CPUs) using MATLAB Parallel Processing Toolbox. Three modules are developed for post-processing of simulation results.

1. SMART Workflow

SMART workflow for a catchment scale semi-distributed hydrologic modelling is illustrated in Figure 2. SMART workflow steps are series of MATLAB scripts organized in a logical manner. Workflow steps should be performed in a sequential manner as the outputs of a particular step are inputs of the subsequent steps or modules. Each workflow step calls multiple custom functions that are specifically written for SMART. Main inputs and outputs of each workflow step are shown in Figure 2. Detailed description of each workflow step with its inputs and outputs are described below. Steps 1 to 5 in Figure 2 are for topographic and geomorphic analysis of a catchment (Figure 1). The rest of workflow steps are designed for two scales of simulations depending on the modelling objectives: 1) individual sub-basin simulation or 2) a catchment scale simulation. Separating sub-basin from catchment scale simulation will save data processing time when the focus of the modelling is on a single or a few first order sub-basins.

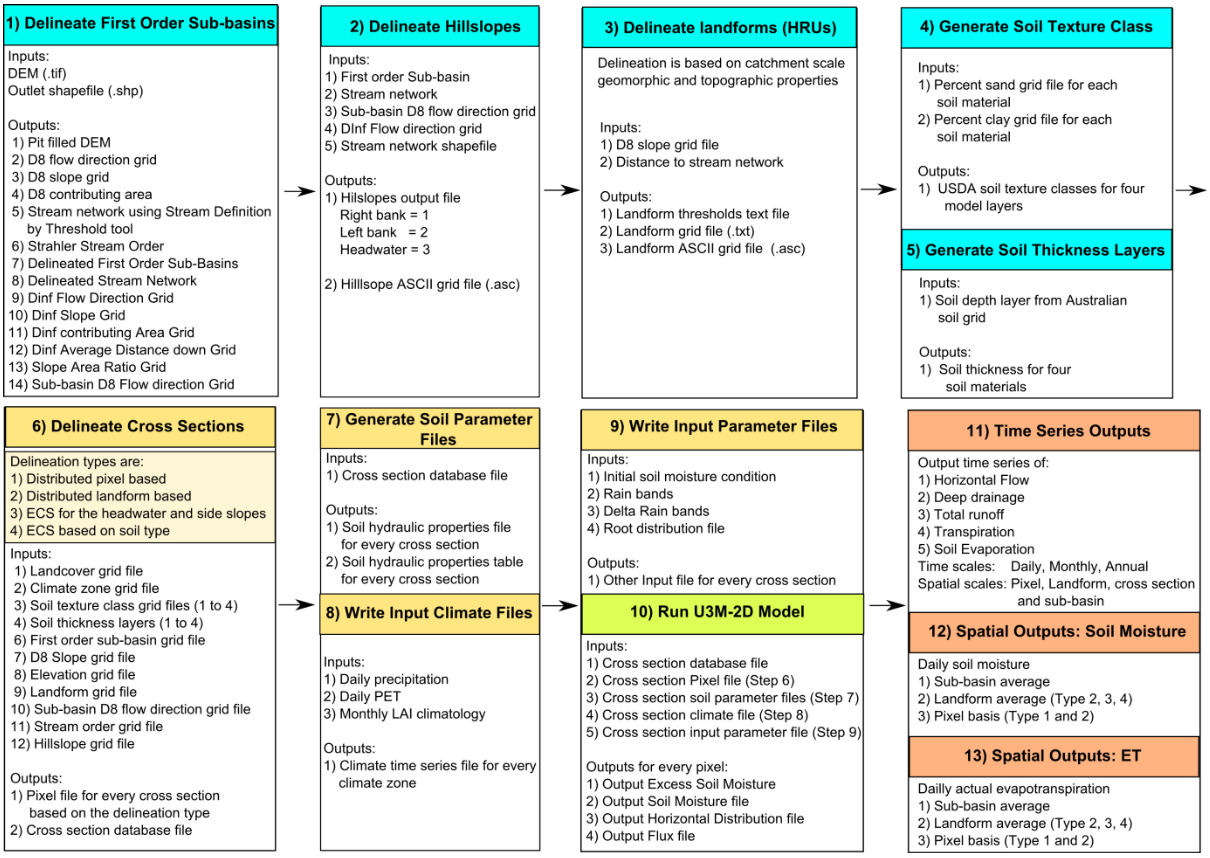


Figure 2. SMART workflow for catchment scale semi-distributed hydrologic modelling. Date processing in steps 1 through 5 is performed for the entire catchment. Steps 6 through 13 can be performed for a single sub-basin or all the sub-basins of a catchment.

2. Topographic and Geomorphic Analysis of a Catchment

Topographic and geomorphic analysis of a catchment in SMART includes catchment scale analysis of topographic data (DEM) to delineate first order sub-basins and hydrologic response units. This workflow task consists of five steps:

1) First order sub-basins delineation
2) Hillslope delineation
3) Landform or hydrologic response units (HRUs) delineation
4) Soil texture classification
5) Calculation of soil thickness for individual soil horizons.

2.1. Delineate First Order Sub-basins

The first step in catchment modelling with SMART starts by delineating a catchment from a DEM. To delineate a catchment and first order sub-basins, the DEM and catchment outlet shapefile are required. The ***"Step1_DelineateFirstOrderBasins.m"*** script calls various executables from the TauDEM toolbox to process a DEM and delineate first order sub-basins. In this step, additional outputs are generated such as a slope grid file, a Strahler's stream order file (Figure 3), a sub-basin flow direction grid file, a distance to stream grid file, and a slope to area ratio grid file (inverse of the topographic wetness index) (Figure 2). These outputs are used in the subsequent tasks. Summary of inputs and outputs of this script are outlined below:

Inputs (…\SMART\Toolbox_Input):
- A Digital Elevation Model (DEM) file (*.tif)
- A catchment outlet file (*.shp)
- Number of processors for parallel processing
- Stream delineation threshold

Outputs (*.tif) (…\SMART\Toolbox_Output):
- Pit filled DEM (*fel.tif)
- D8 flow direction grid (*p.tif)
- D8 slope grid (*sd8.tif)
- D8 contributing area (*ad8.tif)
- Stream network using Stream Definition by Threshold (*src.tif)
- Strahler Stream Order (*ord.tif)
- Delineated First Order Sub-Basins (*w.tif)
- Delineated Stream Network (*.net.shp)
- Dinf Flow Direction Grid (*ang.tif)
- Dinf Slope Grid (*slp.tif)
- Dinf contributing Area Grid (*sca.tif)
- Dinf Average Distance down Grid (*dd.tif)
- Slope Area Ratio Grid (*sar.tif)

Outputs (*.txt) (…\SMART\Toolbox_Output):
- Elevation.txt: filled DEM
- Sloped8Grid.txt: D8slope grid
- SubBasinGrid.txt: First order sub-basins
- StrOrdGrid.txt: Strahler stream order grid
- DisDownGrid.txt: Horizontal distance towards the stream network in meter
- SlpAreaGrid.txt: Slope/area grid
- StreamGrid.txt: Stream network grid
- FlowDirBasinGrid.txt: Major flow direction of first order sub-basins
- ArcGIS_Header.asc: a header file for ASCII grid files

This workflow step can take advantage of the parallel processing of the TauDEM tools. For detailed description of the TauDEM algorithms and functionalities, please refer to the TauDEM manual (Tarboton 2013).

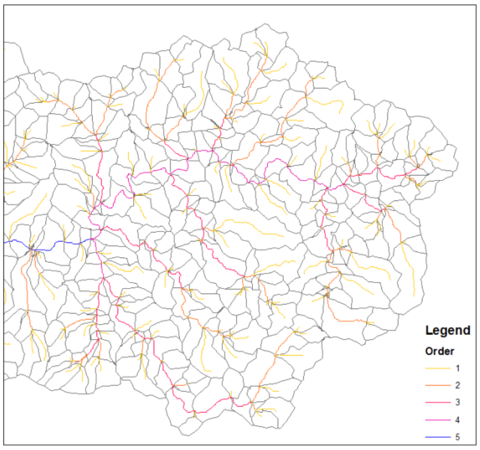


Figure 3. Illustration of the Strahler's stream order classification. In the Strahler method, all the exterior stream links have an order of 1 and the downstream reach from the confluence of two first order streams gets an order of 2.

2.2. Delineate Hillslopes for Each First Order Sub-basin

In this step, every sub-basin is partitioned to hillslopes. For each sub-basin, two types of hillslopes are delineated: headwater and sideslopes (Fan and Bras, 1998). Headwater hillslopes are the zero-order basins that drain towards the channel head (Bogaart and Troch, 2006). Sideslopes are the lateral flow units to the left or right of a river segment that drain to the channel link (Noel et al., 2014). To delineate a headwater hillslope, the delineated stream network shapefile from the TauDEM tool is processed to obtain channel head nodes. In sub-basins with a first order stream, the headwater contributing areas are delineated using the DInf contributing area tool of TauDEM and location of the channel heads. The rest of a sub-basin's area is then partitioned to the right and left bank hillslopes using the stream network location. For intermediate sub-basins (stream order >= 2), only sideslopes are delineated (Figure 4). Summary of inputs and outputs of this script are outlined below:

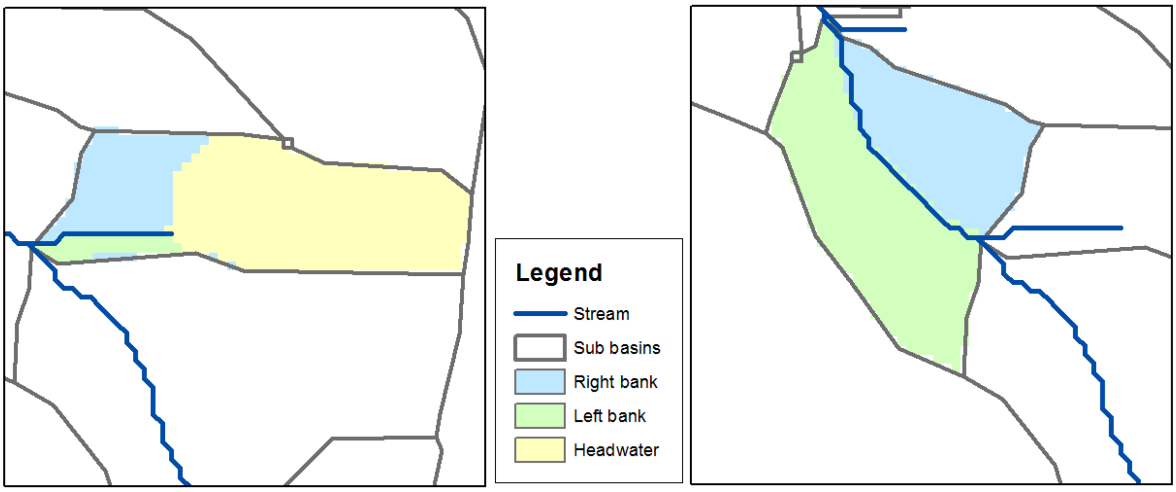


Figure 4. Delineated hillslopes in a first-order (left) and an intermediate (right) sub-basin.

Inputs (…\SMART\Toolbox_Input):

- The DEM file name (using the DEM file name, the script accesses the TauDEM outputs from step 1 including sub-basin grid, stream grid, major flow direction grid of first order sub-basins and stream network shapefile).

Outputs (…\SMART\Toolbox_Output):

- Hillslopes_Final.mat: delineated hillslopes file in MATLAB *.mat format
- Hillslopes.txt: delineated hillslopes in ASCII format
- Hillslopes_gis.asc: An ASCII grid file for ArcGIS or QGIS

2.3. Delineate Landforms

The methodology of Khan et al. (2013) is implemented for landform delineation in SMART. In Khan et al. (2013), an entire catchment is sub-divided into four contiguous major landforms based upon variations in topographic and geomorphologic descriptors of a catchment. These landforms transfer fluxes from the upper part of a hillslope to the lower regions. While in Khan et al. (2013) various topographic and geomorphic descriptors are examined to define landform delineation thresholds, in SMART variations in land surface slope in relation to distance down the stream is used as the main descriptor for landform delineation. However, users can use any topographic variable to obtain landform delineation thresholds using SMART scripts.

"***Step3_Delineate_Catchment_Level_Landforms.m***": In this approach, the relationship between the average slope and distance from the stream is used to determine cut-off values for delineating landforms. The script uses the D8 slope file and the distance to the stream file generated in step 2.1 to delineate landforms. This delineation approach derives one set of thresholds for the entire catchment as shown in Figure 5.

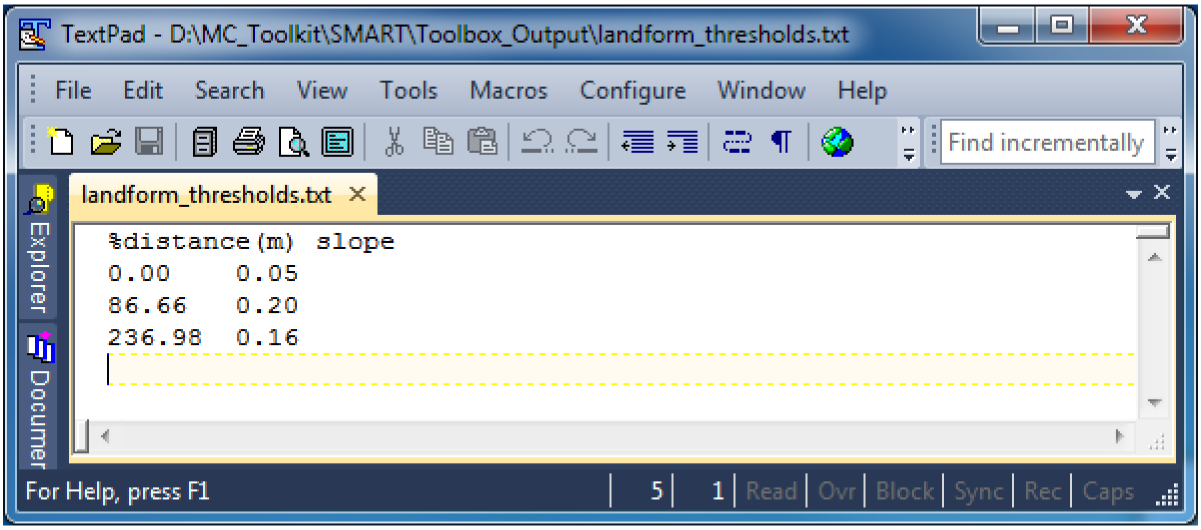


Figure 5. Threshold values obtained for landform delineation using catchment level data.

Summary of inputs and outputs of this script are outlined below:

Inputs (...\SMART\Toolbox_Output\):
The following inputs from step 1 are used: Sloped8Grid.txt; DisDownGrid.txt; DEM resolution.

Outputs (...\SMART\Toolbox_Output\):

- landform_thresholds.txt: This file contains information about landform thresholds including distance from the centre of a stream and an average slope value for each threshold.

- landform.txt: This is a text file that contains delineated landforms across the catchment. Numerical codes in this file range from 1 to 4 and indicate landform classification of Khan et al. (2013): 1 = alluvial flats, 2 = footslope, 3 = midslope, 4 = upslope.

- landform_gis.asc: This is an ASCII grid file for ArcGIS or QGIS

2.4. Create USDA Soil Texture Classes

If soil textural classes are not available for a catchment, the "***Step4_Create_USDA_SoilTexture_Class.m***" script determines soil texture classes based on the USDA soil texture classification scheme. Inputs for this script are percentages of sand and clay values for every grid cell of a catchment. As U3M-2D can have up to four soil materials or horizons for representing variability of vertical soil hydraulic properties in the vadose zone, percentages of sand and clay data are required for all the soil materials. CSIRO's Digital soil maps of Australia website (http://www.clw.csiro.au/aclep/soilandlandscapegrid/) provides gridded data of percentages of sand and clay for the following depths: 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm, and 100-200 cm.

In the USA, NRCS Geo-Spatial Data Gateway (https://gdg.sc.egov.usda.gov/) provides soil textural dataset across the USA. Summary of inputs and outputs of this script are outlined below:

Inputs (...\SMART\Toolbox_Input\):

- Percentages of sand and clay files for every soil material in tiff format (*.tif). User enters names of these files during the runtime. The input files should be stored in ...\SMART\Toolbox_Input folder.

Outputs (...\SMART\Toolbox_Output\):

- soiltype_usda1.txt: USDA soil texture classes of layer 1 (top layer)
- soiltype_usda2.txt: USDA soil texture classes of layer 2
- soiltype_usda3.txt: USDA soil texture classes of layer 3
- soiltype_usda4.txt: USDA soil texture classes of layer 4 (bottom layer)
- soiltype_usda1_gis.asc: layer 1 soil texture in ASCII grid for ArcGIS or QGIS
- soiltype_usda2_gis.asc: layer 2 soil texture in ASCII grid for ArcGIS or QGIS
- soiltype_usda3_gis.asc: layer 3 soil texture in ASCII grid for ArcGIS or QGIS
- soiltype_usda4_gis.asc: layer 4 soil texture in ASCII grid for ArcGIS or QGIS

⚠ **Note**: If users have soil texture class files, they should skip this workflow step. User defined soil texture class files should be stored in (…\SMART\Toolbox_Output) folder and should be in text format. These files should have the same name as outlined in section 2.4 outputs.

2.5. Generate Soil Thickness Layers

The U3M-2D model can have up to four soil materials in the unsaturated zone for representing sub-surface heterogeneity. Thickness of these four soil materials should be provided by the user in meter. Pixels along a single cross section can have different thickness for individual soil materials. However, total maximum soil profile depth cannot exceed 10.0 m in U3M-2D.

⚠ **Note:** Contact the developers if you want to reset the total soil depth of U3M-2D to a value greater than 10.0 m.

The ***"Step5_Create_Soil_Thickness_Layers.m"*** script generates thickness of soil materials for the following intervals 0-0.3 m, 0.3-0.6 m, 0.6-1.0 m, and 1.0-2.0 m from the soil depth layer provided by the CSIRO. These depth intervals are arbitrary and users can change these in the script. Summary of inputs and outputs of this script are outlined below:

Inputs (...\SMART\Toolbox_Input\):

- A catchment soil depth layer file from CSIRO (*.tif). This file should be stored in the Toolbox_Input folder.

Outputs (...\SMART\Toolbox_Output\)**:**

- soil_depth1.tif: Thickness of the top soil material (0-0.3 m depth)
- soil_depth2.tif: Thickness of the second soil material (0.3-0.6 m depth)
- soil_depth3.tif: Thickness of the third soil material (0.6-1.0 m depth)
- soil_depth4.tif: Thickness of the bottom soil material (1.0-2.0 m depth)
- soil_depth1_gis.asc: Thickness of the top soil material (0-0.3 m depth)
- soil_depth2_gis.asc: Thickness of the second soil material (0.3-0.6 m depth)
- soil_depth3_gis.asc: Thickness of the third soil material (0.6-1.0 m depth)
- soil_depth4_gis.asc: Thickness of the bottom soil material (1.0-2.0 m depth)

⚠ **Note:** If users have soil thickness layer files, they should skip this workflow step. User defined soil thickness files should be stored in (…\SMART\Toolbox_Output) folder. Soil thickness files should be in text format, and have the same name as outlined in section 2.5 outputs.

3. Cross Section Delineation and Deriving Input Model Parameters

Following the landform delineation and processing of soil data, delineation of modelling elements (cross sections) are performed. In SMART, cross section delineation and generation of U3M-2D input parameter files can be performed for a selected set of first order sub-basins in a catchment or all the sub-basins depending on the modelling objectives. There are two sets of scripts in SMART for this purpose. Scripts for select sub-basin simulations are in (…\SMART\Toolbox_Scripts\Sub_Basin_Scale) folder. These scripts allow users to generate model parameter files, perform simulations and analyse results for a select first order sub-basin. Implementation of this approach in the workflow will reduce computational time in situations where the focus of the modelling study is on a particular sub-basin inside a larger catchment. Scripts for catchment scale and sub-basin scale analysis and simulation have the Catchment_Scale and SubBasin_Scale suffix respectively. For the sub-basin scale scripts, a sub-basin identification number must be provided by the user at runtime.

3.1. Cross Section Delineations in SMART

SMART has four options for cross section delineations in a first order sub-basin. To automate cross section delineations, the algorithm in SMART classifies a first order sub-basin based on its dominant flow direction along the sub-basin stream segment (Figure 6). The D8 flow direction grid from TauDEM is used to identify eight types of sub-basins in SMART. This classification will ensure that at every location along a stream, delineated cross sections are almost perpendicular to the stream.

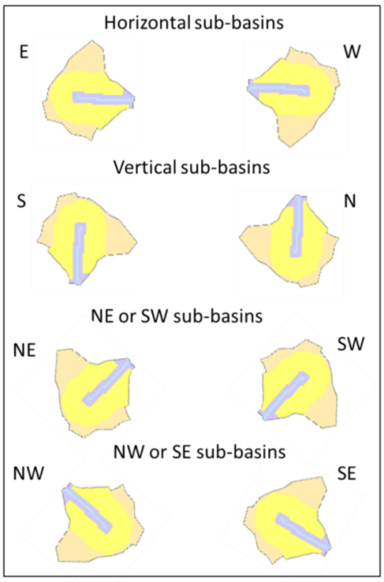


Figure 6. Delineation of cross sections in SMART based on the principal flow direction of a stream in every sub-basin. These eight principal directions are identified using the D8 flow direction algorithm of TauDEM.

As outlined in Chapter 1, SMART has two main cross section delineation methods:

1) In the distributed cross section delineations, each hillslope is sub-divided to a series of cross sections perpendicular to a stream. Topographic, soil and land cover properties of each cross section is derived at a pixel (**Distributed pixel based approach**) or a landform scale (**Distributed landform based approach)** along a cross section.

2) In the equivalent cross section delineations, a sub-basin is subdivided to ECSs that are representative of a section or an entire area of a first-order sub-basin. Two ECS delineation approaches are available in SMART. In the first approach, one ECS is delineated for every hillslope within a sub-basin. In sub-basins with 1st order streams, three ECSs are delineated: one for the headwater, one for the right bank and one for the left bank hillslope. In sub-basins with a Strahler's stream order greater than 1, two ECSs are delineated (one for the left bank and one for the right bank). This cross section delineation approach is referred to as the **three equivalent cross sections method** in the rest of this manual**.** The second ECS delineation approach is based on the number of soil types in each first order sub-basin, and it is referred to as the **ECS Soil Type method**.

Workflow steps for cross section delineations in SMART are:

1. Step6a_Create_CS_Distributed_Pixel_File*.m: This script sub-divides every first order sub-basin to a series of almost perpendicular cross sections to a stream. Cross section properties (land cover type, soil type, soil depth, climate zones, elevation and slope) are obtained for every pixel from geospatial data during the delineation process (Figure 7). A cross section properties file (Pixel File) is written for individual cross sections in (…\SMART\Model_Input\Pixel_Distributed) folder. The script also generates the cross section database file in MATLAB .mat format (data_CS_Distributed_Pixel*.mat) and stores it in (…\SMART\Toolbox_Output) folder. The database file is used in the rest of pre- and post-processing tasks of SMART.

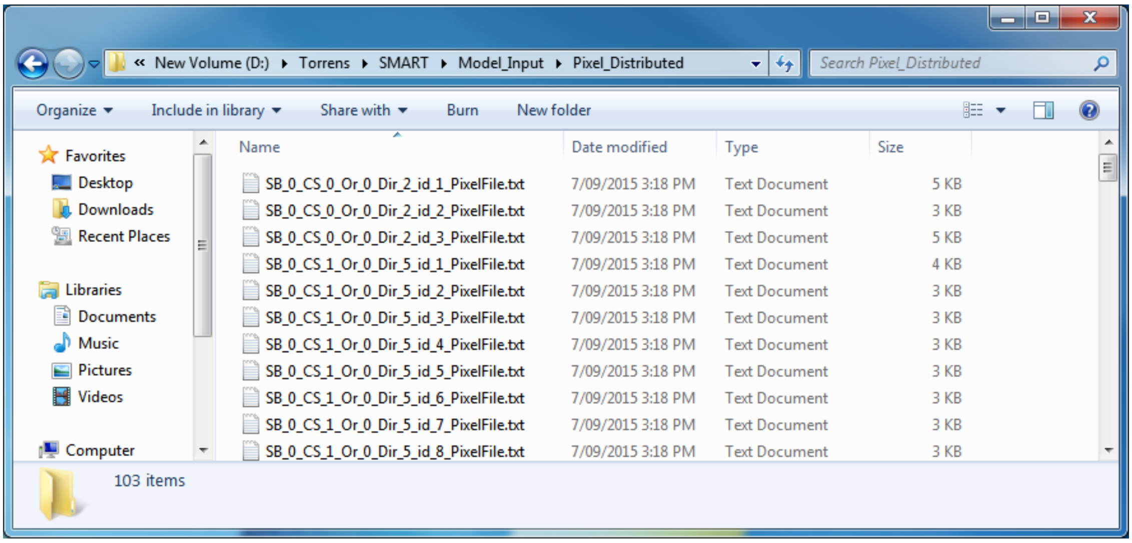


Figure 7. Cross section properties files for every cross section in a catchment. The file naming is as follows: SB (sub-basin), 0 (sub-basin unique number), CS (cross section), 1 (cross section type 0 = headwater, 1 = right bank, 2 = left bank), Or (Orientation of the sub-basin), 0 (0 = Horizontal orientation, 1 = vertical, 2 = northeast or southwest, 3 = northwest or southeast), Dir (stream direction), 2 (stream drains from west to east, 1 = east to west, 3 = north to south, 4 = south to north, 5 = northeast to southwest, 6 = southwest to northeast, 7 = northwest to southeast, 8 = southeast to northwest), id, 1 (cross section number).

Input files for this script should be stored in (…\SMART\Toolbox_Input) folder. At run time, a user enters the names of the following input files in the MATLAB command window. The rest of inputs for this script are generated in previous steps and are read during the run time from the (...\SMART\Toolbox_Output\) folder. Summary of inputs and outputs of this script are outlined below:

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number if the sub-basin script is used.

Outputs (…\SMART\Model_Input\Pixel_Distributed):

- *_PixelFile.txt: The file naming is as follows: SB (sub-basin)_(sub-basin unique number)_CS (cross section)_(cross section type 0 = headwater, 1 = right bank, 2 = left bank)_Or (Orientation of the sub-basin)_(0 = Horizontal orientation, 1 = vertical, 2 = northeast or southwest, 3 = northwest or southeast)_Dir (stream direction)_ (2 = stream drains from west to east, 1 = east to west, 3 = north to south, 4 = south to north, 5 = northeast to southwest, 6 = southwest to northeast, 7 = northwest to southeast, 8 = southeast to northwest)_id_(cross section number)_PixelFile.txt. A sample pixel file is shown in Figure 8.

- data_CS_Distributed_Pixel*.mat in (…\SMART\Toolbox_Output) folder. If the sub-basin scale script is used, the database file has the identification number of a selected sub-basin.

- CS_Coordinates.txt in (…\SMART\Toolbox_Output) folder has the coordinates of cross sections.

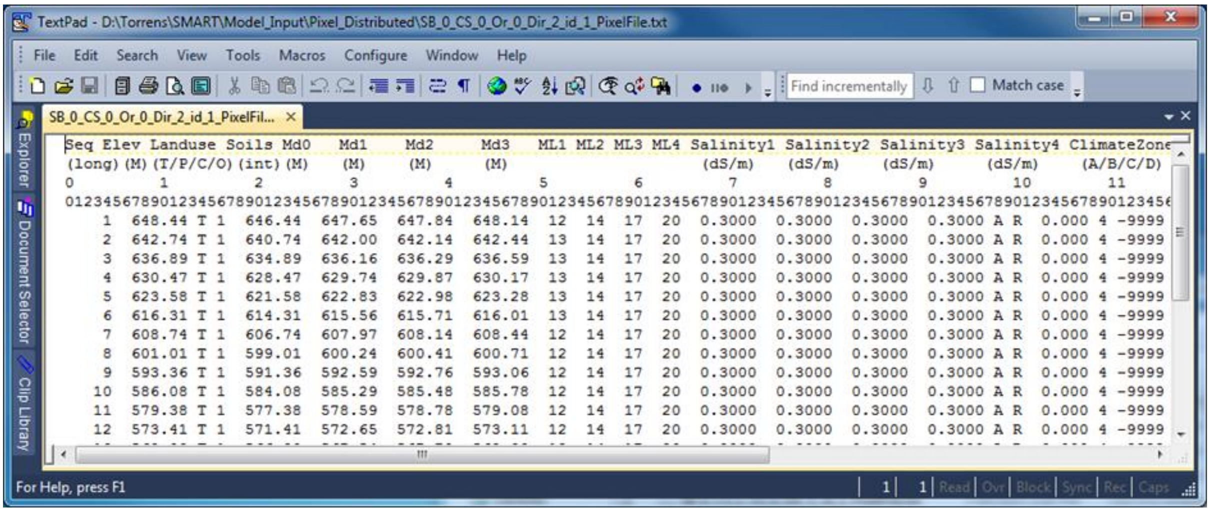


Figure 8. A sample cross section properties file (U3M-2D Pixel File). Sequence number is the sequence number of pixels in a cross section from the ridgeline to a stream. The rest of columns are: elevation, land cover type (T=tree, C= crop, P=pasture), Soils (Soil type code), Md0 to Md4 (elevation of four soil materials), ML1 to ML4 (cumulative number of vertical layers in each soil material). Default thickness of soil layers is 0.1 m.

2. Step6b_Create_CS_Landform_Pixel_File*.m: This script sub-divides every first order sub-basin to a number of almost perpendicular cross sections to a stream and derives cross section properties (soil type, land cover, elevation and slope) on a landform basis from input files. This means that if a landform upslope in a first order sub-basin consists of 12 pixels (based on the DEM resolution), the dominant land cover, soil type and climate zone of these 12 pixels are identified and assigned to that particular landform or HRU in a cross section properties file. For slope and soil depth mean values of those 12 pixels are calculated and assigned to every pixel of HRU. Compared to the previous cross section delineation approach where 12 slope values are written for the upslope segment of a cross section, in this formulation one slope value is assigned to each landform. This script generates cross section properties files (Pixel File) for every cross section in (…\SMART\Model_Input\Pixel_Landform) folder. It also generates the cross section database file in MATLAB .mat format (data_CS_Landform*.mat) in (…\SMART\Toolbox_Output) folder. The database file is used in the rest of pre- and post-processing scripts of SMART.

Input files for this script should be stored in (…\SMART\Toolbox_Input) folder. At run time, a user enters the names of the following input files in the MATLAB command window. The rest of inputs for this script are generated in previous steps and are read during run time from the (...\SMART\Toolbox_Output\) folder. Summary of inputs and outputs of this script are outlined below:

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number if the sub-basin script is used.

Outputs (…\SMART\Model_Input\Pixel_Landform):

- *_PixelFile.txt: SB_(sub-basin unique number)_CS_(Delineation type 1 = pixel distributed)_Or_(orientation of the sub-basin)_Dir_(stream direction)_id_(cross section number)_PixelFile.txt

- data_CS_Landform*.mat (…\SMART\Toolbox_Output). If the sub-basin scale script is used, the database file has the name of a selected sub-basin.

- CS_Coordinates_LF_T2.txt in (…\SMART\Toolbox_Output) folder has the coordinates of cross sections.

⚠ **Note:** As horizontal discretization in U3M-2D is constant, number of pixels to represent a particular landform depends on the landform length. Therefore, the number of pixels in the pixel files for this approach is exactly equal to the number of pixels in the distributed cross section delineation approach. Future modification of the U3M-2D code will include variable horizontal discretization. This can further reduce the number of computational elements.

3.Step6c_Create_ECS_Left_Bank_Right_Bank*.m: This script delineates three equivalent cross sections for every sub-basin using the cross sectional properties of the headwater, and side slopes. Assignment of cross section properties for the ECS approach is explained in Chapter 1. In summary, the ECS delineation approach starts by delineating individual cross sections in each first order sub-basin and assigning cross section properties on a landform basis. In the second step, properties of all cross sections inside a hillslope are aggregated according to equations 1 to 3 (Chapter 1) to derive an ECS for the hillslope. This script generates a cross section properties file (Pixel File) for every equivalent cross section in the

(…\SMART\Model_Input\ECS_LB_RB_H_CS) folder (Figure 9). It also generates a cross section database file in MATLAB .mat format (data_ECS_LB_RB_H_CS*.mat) in (…\SMART\Toolbox_Output) folder. The database file is used in the rest of pre- and post-processing scripts of SMART.

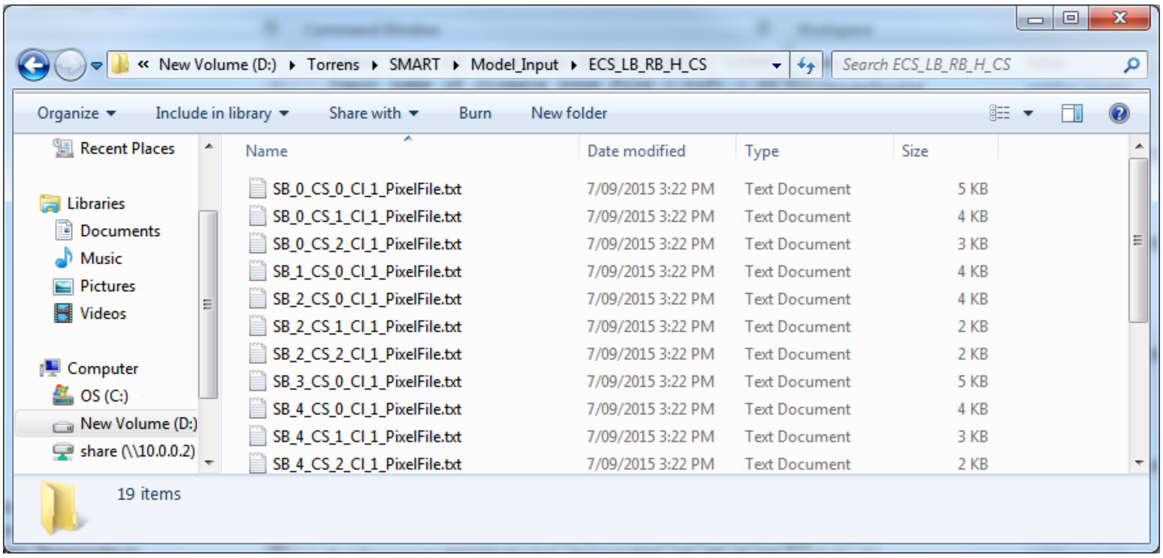


Figure 9. Cross section properties files of ECSs. The file naming is as follows: SB (sub-basin), 0 (sub-basin unique number), CS (cross section), 0 (cross section type 0 = headwater, 1 = right bank, 2 = left bank), Cl (climate), 1 (climate zone number). As you can see, three ECSs are generated for the sub-basin 2.

Input files for this script should be stored in (…\SMART\Toolbox_Input) folder. At run time, a user enters the names of the following inputs in the MATLAB command window. The rest of inputs for this script are generated in previous steps and are read during run time from the (...\SMART\Toolbox_Output\) folder. Summary of inputs and outputs of this script are outlined below:

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number if the sub-basin scale script is used.

Outputs (…\SMART\Model_Input\ECS_LB_RB_H_CS):

- *_PixelFile.txt: SB_(sub-basin unique number)_CS_(cross section type 0 = headwater, 1 = right bank, 2 = left bank)_Cl_(climate zone number)_PixelFile.txt.

- data_ECS_LB_RB_H_CS*.mat in (…\SMART\Toolbox_Output) folder. If the sub-basin scale script is used, the database file has the name of a selected sub-basin.

- CS_Coordinates_LF_T3.txt in (…\SMART\Toolbox_Output) folder has the coordinates of cross sections.

4. Step6d_Create_ECS_SoilType*.m: This script delineates the ECSs for every sub-basin using the ECS soil type delineation option. In summary, the ECS delineation approach starts by delineating individual cross sections for each first order sub-basin and assigning cross section properties on a landform basis. In the second step, properties of all cross sections in a given soil type are aggregated according to equations 1 to 3 (Chapter 1) to derive an ECS for individual soil polygons in a sub-basin. This script generates a cross section properties file (Pixel File) for every equivalent cross section in the (…\SMART\Model_Input\ECS_Soil_Type_CS) folder (Figure 10). It also generates a cross section database file in MATLAB .mat format (data_ECS_SoilType_CS*.mat) in the (…\SMART\Toolbox_Output) folder.

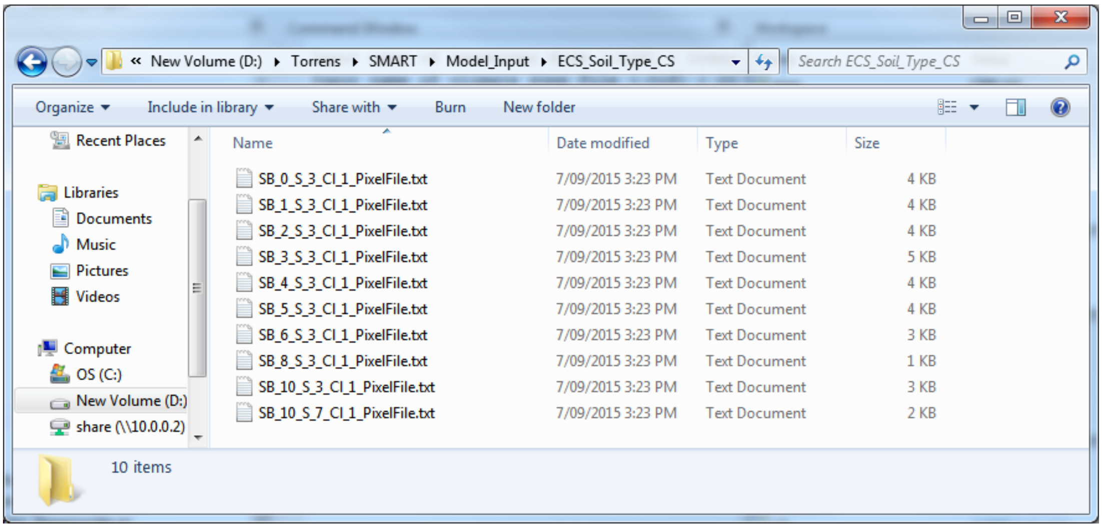


Figure 10. Cross section properties files of ECSs for the ECS soil type delineation. The file naming is as follows: SB (sub-basin)_(sub-basin unique number)_S (Soil type)_(soil type code)_Cl(climate)_(climate zone number). As you can see, sub-basin 10 has two soil types and 2 ECSs are generated for this sub-basin.

Input files for this script should be stored in (…\SMART\Toolbox_Input) folder. At run time, a user enters the names of the following inputs in the MATLAB command window. The rest of inputs for this script are generated in previous steps and are read during run time from the (...\SMART\Toolbox_Output\) folder. Summary of inputs and outputs of this script are outlined below:

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)

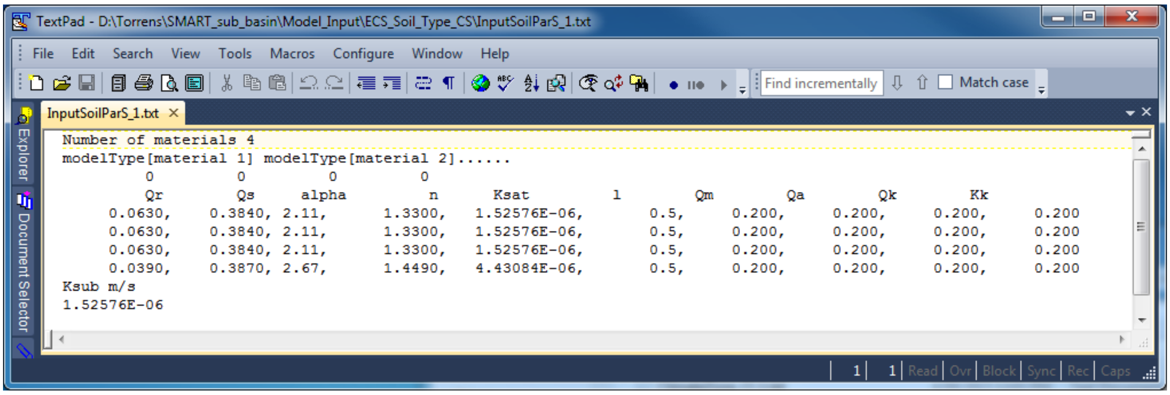
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number if the sub-basin script is used.

Outputs (…\SMART\Model_Input\ECS_Soil_Type_CS):

- *_PixelFile.txt: SB_(sub-basin unique number)_S_(soil type code)_Cl_(climate zone number)_PixelFile.txt
- data_ECS_SoilType_CS*.mat in (…\SMART\Toolbox_Output) folder. If the sub-basin scale script is used, the database file has the name of a selected sub-basin.
- ECS_Soil_CS_Area*.mat in (…\SMART\Toolbox_Output). This file contains an ECS contributing area.
- CS_Coordinates_LF_T4.txt in (…\SMART\Toolbox_Output) folder has the coordinates of cross sections.

3.2. Create U3M-2D Soil Parameter Files

To solve the Richards' equation in U3M-2D, two input files related to soil hydraulic properties are required for every cross section. The InputSoilPar.txt file has the soil hydraulic properties for each soil material in a cross section. In this version of SMART, soil hydraulic properties are based on the van Genuchten soil hydraulic model. These properties are residual volumetric water content [m^3/m^3], saturated volumetric water content [m^3/m^3], alpha (soil water retention function parameter) [L^{-1}], n (soil water retention function parameter) [-], saturated hydraulic conductivity [LT^{-1}], and statistical pore size distribution parameter [-]. As can be seen in Figure 11, these properties are specified for four soil materials in a given cross section. In the InputSoilPar.txt file, the first row of soil hydraulic properties corresponds to the properties of the bottom soil layer. The Ksub parameter is the lower boundary condition of the soil profile and is set to the saturated hydraulic conductivity of the bottom soil layer in SMART.

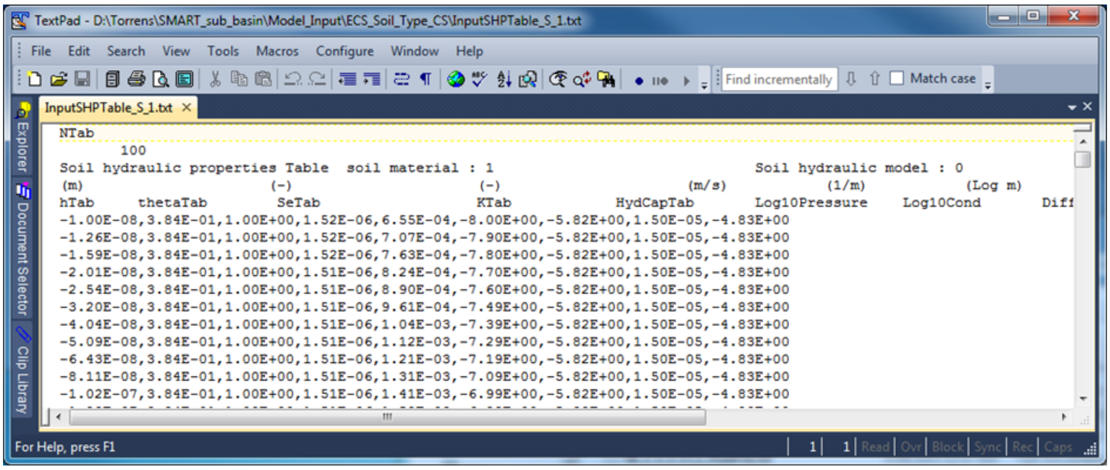


```
Number of materials 4
modelType[material 1] modelType[material 2]......
          0          0          0
          Qr         Qs      alpha          n       Ksat           l         Qm         Qa         Qk         Kk
      0.0630,    0.3840, 2.11,      1.3300,   1.52576E-06,      0.5,       0.200,     0.200,     0.200,     0.200
      0.0630,    0.3840, 2.11,      1.3300,   1.52576E-06,      0.5,       0.200,     0.200,     0.200,     0.200
      0.0630,    0.3840, 2.11,      1.3300,   1.52576E-06,      0.5,       0.200,     0.200,     0.200,     0.200
      0.0390,    0.3870, 2.67,      1.4490,   4.43084E-06,      0.5,       0.200,     0.200,     0.200,     0.200
Ksub m/s
1.52576E-06
```

Figure 11. An input soil parameter file

The second input file is the soil hydraulic properties table and it includes tabulated pressure head values for user defined pressure heads (hTab1 and hTabN below), tabulated volumetric water content (thetaTab), specific saturation ($\frac{\theta}{\theta_s}$) (SeTab), unsaturated hydraulic conductivity (KTab), hydraulic capacity or dθ/dh (HydCapTab), and hydraulic diffusivity for all the tabulated pressure heads (Figure 12). To compute these properties in SMART, the user should specify the following parameters. The *default parameter values* in SMART are:

- Soil hydraulic model (Van Genuchten model),
- Number of values in the SHP table (NTab = 100),
- First pressure head value in the SHP table (m) (hTab1 = -1.00E-08),
- Last pressure head value in the SHP table (m) (hTabN = -100.0).



```
NTab
        100
Soil hydraulic properties Table  soil material : 1                    Soil hydraulic model : 0
(m)                    (-)                    (-)                    (m/s)           (1/m)           (Log m)
hTab      thetaTab        SeTab                   KTab            HydCapTab       Log10Pressure    Log10Cond        Diff
-1.00E-08,3.84E-01,1.00E+00,1.52E-06,6.55E-04,-8.00E+00,-5.82E+00,1.50E-05,-4.83E+00
-1.26E-08,3.84E-01,1.00E+00,1.52E-06,7.07E-04,-7.90E+00,-5.82E+00,1.50E-05,-4.83E+00
-1.59E-08,3.84E-01,1.00E+00,1.52E-06,7.63E-04,-7.80E+00,-5.82E+00,1.50E-05,-4.83E+00
-2.01E-08,3.84E-01,1.00E+00,1.51E-06,8.24E-04,-7.70E+00,-5.82E+00,1.50E-05,-4.83E+00
-2.54E-08,3.84E-01,1.00E+00,1.51E-06,8.90E-04,-7.60E+00,-5.82E+00,1.50E-05,-4.83E+00
-3.20E-08,3.84E-01,1.00E+00,1.51E-06,9.61E-04,-7.49E+00,-5.82E+00,1.50E-05,-4.83E+00
-4.04E-08,3.84E-01,1.00E+00,1.51E-06,1.04E-03,-7.39E+00,-5.82E+00,1.50E-05,-4.83E+00
-5.09E-08,3.84E-01,1.00E+00,1.51E-06,1.12E-03,-7.29E+00,-5.82E+00,1.50E-05,-4.83E+00
-6.43E-08,3.84E-01,1.00E+00,1.51E-06,1.21E-03,-7.19E+00,-5.82E+00,1.50E-05,-4.83E+00
-8.11E-08,3.84E-01,1.00E+00,1.51E-06,1.31E-03,-7.09E+00,-5.82E+00,1.50E-05,-4.83E+00
-1.02E-07,3.84E-01,1.00E+00,1.51E-06,1.41E-03,-6.99E+00,-5.82E+00,1.50E-05,-4.83E+00
```

Figure 12. A soil hydraulic properties table file.

In SMART, **"Step7_CreateSoilPar_Files*.m"** script generates soil hydraulic properties files. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Soil hydraulic properties model name (van Genuchten = 0; Brooks and Corey =1; Vogel and Cislerova=2). This version of SMART only supports the "van Genuchten" soil hydraulic model.

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type).

Depending on the cross section delineation option, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.

- **Soil_texture_ROSETTA_U3M.xlsx**: This file contains soil hydraulic properties for each USDA soil texture class (12 classes). The code for each class in this table is used to link the soil texture maps generated in previous steps to soil hydraulic properties. A user defined soil hydraulic properties file should have the same format as this file and should be stored in (…\SMART\Toolbox_Parameter_Files\) folder.

- Sub-basin identification number if the sub-basin script is used.

Outputs (...\SMART\Model_Input\DEL TYPE[1])**:**
- Cross section soil parameter file: InputSoilParS_(cross section id).txt in (...\SMART \Model_Input\DEL TYPE)
- Cross section soil hydraulic properties table: InputSHPTable_S_(cross section id).txt in (...\SMART\Model_Input\DEL TYPE)

[1] refers to the delineation type folders (**Pixel_Distributed, Pixel_LandForm, ECS_LB_RB_H_CS, and ECS_Soil_Type_CS**).

3.3. Write Climate Zone Files

To generate a U3M-2D climate input file, a CSV file with the following information should be provided by the user in the Toolbox_Input folder for each climatic zone in a catchment. The user time series input file should contain 7 columns: climate zone identification key, date, maximum temperature, minimum temperature, rain, potential evapotranspiration or pan evaporation and radiation. This version of the U3M-2D is only using **rainfall and potential evapotranspiration (PET) or pan evaporation** to compute actual evapotranspiration. The rest of variables will be used for the ecohydrological component of the model in later releases. If pan evaporation values are provided by the user instead of PET, the pan evaporation coefficient should be set to a value less than 1 to convert pan evaporation values to PET (**UserRunInfo.m** script).

The **Step8_WriteClimateZoneFile*.m** script writes the climatezone.txt file for every climate zone in a catchment depending on the delineation approach. The ClimateZone.txt file includes information about the climate zone, daily precipitation, potential understory and overstory transpiration and potential soil evaporation. Potential transpiration demands for tree, crop and pasture land cover types are calculated based on the monthly LAI values. Monthly LAI data are provided by the user or default values are used by SMART. Equations for computing potential evapotranspiration demands are presented in (Vaze et al., 2004) and are outlined below:

$PET = K_0 * \text{Pan evaporation}$ (1)

Tree:
$ET_o = PET * (1 - \exp(-K\_light * LAI));$ (2)
$ET_g = PET * \exp(-K\_light * LAI);$ (3)
$ET_u = 0$ (4)

Crop:
ET_u = PET * (1 – exp (-K_light * LAI)); (5)
ET_g = PET * exp (-K_light * LAI); (6)
ET_o = 0 (7)

Pasture:
ET_u = PET * (1 – exp (-K_light * LAI)); (8)
ET_g = PET * exp (-K_light * LAI); (9)
ET_o = 0 (10)
LAI month = LAI average month * (monthly rainfall / mean monthly rainfall) ^{Beta} (11)

PET is potential evapotranspiration; ET_o is overstory transpiration; ET_u is understory transpiration; ET_g is soil evaporation; K_light is canopy light extinction coefficient that controls partitioning of PET to potential plant transpiration and soil evaporation. Trees with horizontal leaves transmit less light through the canopy compared to crops and have higher light extinction coefficient (default value of 0.8 for trees and 0.6 for crop and pasture). LAI is Leaf area index; K_0 is pan evaporation coefficient; LAI average month is user defined mean monthly LAI, LAI month is scaled LAI for the month based on average LAI and monthly rainfall; and Beta is the scaling factor to scale mean monthly LAI based on the ratio of monthly rainfall to mean monthly rainfall over the simulation period. This means that in months wetter than the average condition, mean LAI is scaled up to indicate higher growth than average condition (default Beta value is 1).

The **Step8_WriteClimateZoneFile*.m** script writes the climatezone.txt file for every climate zone in a catchment depending on the delineation approach. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Monthly LAI climatology for tree, crop and pasture land cover classes (*.csv). The data file should be stored in the (…\SMART\Toolbox_Parameter_Files\) folder.

- Climate time series input file (…\SMART\Toolbox_Input)

  ⚠ **Note:** If you are using pan evaporation data instead of PET, set the pan evaporation coefficient in **UserRunInfo.m** script to a value in the range of 0.8 to 0.9 (Vaze et al., 2004).

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECS); 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.

- Sub-basin identification number if the sub-basin script is used.

Outputs (...\SMART\Model_Input\DEL TYPE)**:**

- Climate zone file for every climate zone in a catchment. The file name is ClimateZone_Cl_(zone number).txt and is stored in (...\SMART\Model_Input\DEL TYPE) (Figure 13).

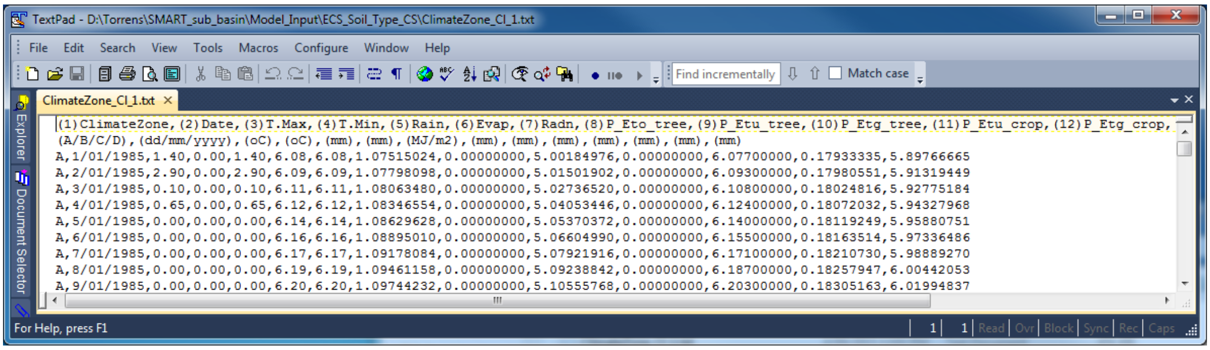


Figure 13. A U3M-2D sample climate zone input file.

3.4. Write Other Input Parameter File

The Other input parameter file contains time step related parameters, root distribution and soil evaporation parameters for U3M-2D. Time step related parameters are:

- **Vertical water balance time step (deltatdash (sec)):** A user defined time step parameter to solve the explicit solution of the Richards' equation. The default value in SMART is set to 3600 (s). Any values less than 1 hour will increase computational time and it is not recommended (Vaze et al., 2004).

- **Number of vertical water balance time step bands (-):** The number of time step bands depends on the number of rainfall bands defined below. The default value in SMART is 5.

- **Rainfall bands (mm/day) and time step bands (sec):** These parameters are used to specify a time step for a given daily rainfall that belongs to a particular rainfall band. Actual time step is the minimum of deltatdash times previous day time step and the respective time step corresponding to the rainfall band. The default values of rainfall bands are: 5, 10, 20, 40, 1000 (mm/day) and default corresponding time step bands are 3600, 2400, 1560, 600, 300.

- **Time step multiplier:** The multiplier is used to change the internal calculation time step based on the rainfall amount using the rainfall bands and time step band parameter values defined above. Based on the above values for a rainfall between 5 and 10 mm/day, the minimum time step band (2400 s) is selected. The model time step is the minimum of 2400 s or the previous day time step multiplied by the time step multiplier (Vaze et al., 2004). The default value of the time step multiplier is 1.3.

- **Moisture stress threshold multiplier (gamRecharge (-)):** This is a parameter for calculating moisture content at recharge point. Recharge point is the amount of moisture content at which a plant experiences water stress (Vaze et al., 2004). The default value of this parameter is 0.5.

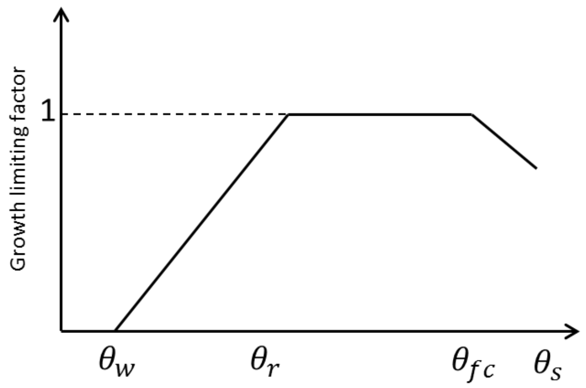


Figure 14: Growth limiting factor parameter in relation to soil water content.
θ_w is wilting point, θ_r is recharge point (gamrecharge (θ_w+θ_{fc}), θ_{fc} is field capacity, θ_s is saturated water content (Vaze et al., 2004)).

- **Transpiration compensation parameter (Transp_sigma) for overstory and understory vegetation**: This is the compensation factor for plants in case of water stress in the rooting layer to get water from other layers. The default value of this parameter is zero, and it means that no compensation for water limitation in dry layers is considered. Value of 1 means that the water limitation in dry layers is compensated by layers that might have abundant water. Please see definition of these parameters in (Sections 3.3.4 and 3.3.5 of Vaze et al., 2004).

- **Number of overstory root distribution values:** This parameter is set to the number of soil layers (default value is 100 in SMART).

- **Relative root density of overstory and understory vegetation:** For trees, relative root density of overstory and understory vegetation types is defined for every soil layer (default 100 layers). For crop and pasture, only the relative root density of understory vegetation is defined. For soil evaporation, relative soil evaporation information for each soil layer is required.

- **Horizontal re-distribution time step (DELTAT (s)):** User defined time step for horizontal redistribution. Default value is 1 day in seconds (86400 s).

- **Horizontal flow factor (range 0.5-1):** This parameter controls hydraulic conductivity calculations. The horizontal flow factor is is set to 1 for fast horizontal flow and 0.5 for slow horizontal flow.

- **Preferential flow factor (range 0-1)**: This parameter controls proportion of excess soil moisture that is passed downslope as preferential flow (1: all excess water is transferred as preferential flow and 0: no preferential flow is considered and all horizontal flow is matrix flow).

- **Arithmetic geometric mean cutoff** (>= 1 for making this parameter ineffective)

- **Horizontal transfer equation (1 or 2):** This parameter is set to 1 for unsaturated Darcy's law and is set to 2 for saturated Darcy's law.

In SMART default parameters values are used for the above parameters, but users can change these values if desired. Users have to specify initial soil moisture content parameter for every soil material in a given cross section. If the initial condition parameter is set to 1, it means that a particular soil material is at saturation and the value of 0 corresponds to residual water content. For parameter values between zero and 1, the initial water content is calculated as follows in U3M-2D:

$$\theta_i = \theta_r + p\,(\theta_s - \theta_r) \quad (12)$$

where θ_i is initial volumetric water content, θ_r is residual water content, θ_s is saturated water content and p is a parameter value between zero and 1.

The **Step9_Write_OtherInputFile*.m** script writes the other input parameter file for every cross section, and it stores the file in the respective folder in Model_Input directory depending on the delineation option. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.

- Initial soil moisture condition

- Rainfall bands (mm/day) and time step bands (s), otherwise default values are used.

- Root distribution data file provided in the parameter files folder (…\SMART\Toolbox_Parameter_Files\). User defined values should be stored in the same directory and the name of a user defined file should be entered in **UserRunInfo.m** script.

- Sub-basin identification number if the sub-basin script is used.

Outputs (...\SMART\Model_Input\DEL TYPE)**:**

- Other Input file (InputOtherData_S_(cross section id)_(SB_sub-basin id).txt) for all the cross sections.

4. Perform Hydrologic Model Simulations

There are two options for 2-dimensional unsaturated zone modelling of cross sections in SAMRT. Users can either perform simulations for cross sections in a single sub-basin by identifying the sub-basin identification number or simulations are performed for all the cross sections in a given catchment. The **Step10_Run_U3M_2D_Sub_Basin_Scale.m** and **Step10_Run_U3M_2D_Catchment_Scale.m** scripts control model simulations across a single sub-basin or all the sub-basins in a catchment respectively.

The user needs to enter the cross section delineation option upon running the **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script. The script first generates a cross section simulation folder in (...\SMART\Model_Output\DEL TYPE) and the folder name is CS_(cross section number)_SB(sub-basin number).

In the next step, model files for every cross is accessed and copied from (...\SMART\Model_Input\DEL TYPE) folder to the cross section simulation folder in Model_Output folder. The U3M-2D executable is also copied to the cross section simulation folder. SMART uses MATLAB Parallel Processing toolbox to perform simultaneous simulations of multiple cross sections depending on the number of available CPU cores in a computer.

⚠ **Note:** If simulation for a specific sub-basin is desired**,** users need to enter the sub-basin identification number upon running the **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script.

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.
- Number of processors for parallel processing
- Sub-Basin identification number if simulations for a specific sub-basin are desired.

Outputs:

- For every cross section, a folder is generated in (...\SMART\Model_Output\DEL TYPE). The folder name is CS_(cross section number)_SB(sub-basin number).
- Within each simulation folder, four sets of output files are generated. The number of output files for each set depends on the number of pixels in a given cross section. The following files are generated by U3M-2D:

  OutputExcessSoilMoisture_(Pixel_number).txt
  OutputFlux_(Pixel_number).txt
  OutputHorizontalDistribution_(Pixel_number).txt
  OutputSoilMoisture_(Pixel_number).txt

5. Post Processing of Simulation Results

U3M-2D hydrologic model produces four output files for every simulated pixel in a given cross section. Therefore, post processing of large amounts of outputs is required to obtain simulated discharge at a sub-basin outlet, or produce spatially distributed soil moisture and evapotranspiration across a sub-basin or the entire catchment. This section describes available post processing tools in SMART.

In general, post processing tools are classified to two main groups:

1) Time series outputs

Time series outputs are generated by **Step11a_Post_Processing_WB_TS_SubBasin_Scale.m** and **Step11b_Post_Processing_WB_TS_Catchment_Scale.m** scripts depending on whether simulations are performed for a given sub-basin or across the entire catchment. These scripts generate time series of horizontal flow, deep drainage, total runoff, overstory and understory transpiration, and soil evaporation at multiple time scales. Spatial aggregation units are cross section and sub-basin scales.

- Time scales: Daily, Monthly, Annual
- Spatial scales: Cross section and sub-basin scales

2) Spatially distributed soil moisture outputs
As model simulations are performed across a series of cross sections in a first order sub-basin, there is a need to map soil moisture distribution at the scale of modelling elements. SMART has tools for producing time series of daily and monthly soil moisture at the smallest conceptual modelling element scale (pixel or landform). Mapping of soil moisture at the smallest conceptual modelling element scale depends on the cross section delineation approach. For the distributed pixel based and distributed landform based delineations, soil moisture is mapped for every pixel of a cross section. For the left bank/right bank/headwater ECS, ECS soil type and distributed landform based delineations, soil moisture is mapped at the landform scale. This means that all pixels within a given landform of a hillslope or a soil type have a uniform soil moisture value. Sub-basin averaged soil moisture values are also generated.

3) Spatially distributed evapotranspiration outputs
Mapping of actual evapotranspiration are performed at the scale of modelling elements in SMART. For the distributed pixel based and distributed landform based cross section delineations, ET is mapped for every pixel of a cross section. For the left bank/right bank/headwater ECSs, ECS soil type and distributed landform based delineations, ET is mapped at a landform scale. This means that all pixels within a given landform of a hillslope or a soil type have a uniform ET value. Sub-basin averaged ET values are also generated.

5.1. Generating Time Series Output Files

Two scripts are available in SMART to generate time series output files. The **Step11a_Post_Processing_WB_TS_SubBasin_Scale.m** script generates outputs for a particular sub-basin while **Step11a_Post_Processing_WB_TS_Catchment_Scale.m** script processes simulated data from all the sub-basins in a catchment. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank); and 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.

- Sub-Basin identification number if results of a specific sub-basin are desired (**Step11a_Post_Processing_WB_TS_SubBasin_Scale.m).**

Outputs:

- In (...\SMART\Model_Output\DEL TYPE) folder, four MATLAB .mat files are generated. These files are:
  CS_Daily_Type(Delineation type code)_*.mat
  Sub_Basin_Daily_Type(Delineation type code)_*.mat
  Sub_Basin_Monthly_Type(Delineation type code)_*.mat

Sub_Basin_Yearly_Type(Delineation type code)_*.mat

The following variables are stored in each file:
Horizontal Flow
Deep drainage
Total runoff (Horizontal Flow + Deep drainage) for sub-basin files only
Overstory transpiration
Understory transpiration
Soil Evaporation

5.2. Generating Spatially Distributed Soil Moisture Outputs

To generate spatially distributed soil moisture outputs, two steps should be taken.

5.2.1. Processing at the Smallest Conceptual Modelling Element Scale

To process simulated soil moisture data at the smallest conceptual modelling element scale, **Step12a_Post_Processing_SM_SubBasin_Scale.m** script or **Step12a_Post_Processing_SM_Catchment_Scale.m** script is used depending on whether outputs from a single sub-basin or all the sub-basins are required respectively. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); and 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from (…\SMART\Toolbox_Output) folder.

- Sub-Basin identification number if results for a specific sub-basin are desired (**Step12a_Post_Processing_SM_SubBasin_Scale.m).**

Outputs:

- In (...\SMART\Model_Output\DEL TYPE) folder, these MATLAB .mat files are generated:

  Pixel_Soil_Moisture_Daily_Type*.mat for delineation type 1 and 2
  Pixel_Soil_Moisture_Monthly_Type*.mat for delineation type 1 and 2

  LF_Soil_Moisture_Daily_Type*.mat for delineation type 2, 3 and 4
  LF_Soil_Moisture_Monthly_Type*.mat for delineation type 2, 3 and 4
  LF_Soil_Moisture_Annual_Type*.mat for delineation type 2, 3 and 4

Soil moisture values from three different depths: top layer, 0-30 cm and 0-50 cm are stored in a structure in the above files. Users can generate soil moisture for any particular model layer by modifying these codes.

5.2.2. Mapping Daily Soil Moisture

Using data from the step above, soil moisture is mapped in SMART using **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** or **Step12b_Spatial_Distribution_SM_Catchment_Scale.m** script depending on the sub-basin or catchment scale simulations.

For the distributed pixel based and distributed landform based cross section delineations, soil moisture values are mapped for every pixel of a cross section. For the left bank, right bank and headwater ECSs delineation, soil moisture per landform per each hillslope is mapped. For the ECS soil type, soil moisture is mapped per landform within a soil type polygon. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from (…\SMART\Toolbox_Output) folder.

- Sub-Basin identification number if results for a specific sub-basin are desired (**Step12b_Spatial_Distribution_SM_SubBasin_Scale.m).**

- Start and end dates of data processing period. These dates should be within the simulation period.

Outputs:

- In (...\SMART\Model_Output\DEL TYPE) folder, MATLAB *.mat files with multi-dimensional arrays are stored that have spatial distribution of soil moisture for every time step. These files are:

- Map_Pixel_Soil_Moisture_Daily_Type*.mat: This file has soil moisture for every pixel in a cross section for selected time steps. This output is only generated for the distributed cross section delineations.

- Map_subbasin_Soil_Moisture_Daily_Type*.mat: The file has sub-basin averaged soil moisture for selected time steps. Average soil moisture is assigned to all pixels in a first order sub-basin. This option is available for all the cross section delineations.

- Map_LF_Soil_Moisture_Daily_Type*.mat: In this file, landform average soil moisture for selected time steps is distributed to all pixels of that landform. This option is available for the distributed landform, 3 ECSs and ECS soil type cross section delineations. In the 3 ECSs delineation, landform soil moisture distribution is done separately for each ECS in left bank, right bank and headwater ECSs. For the ECS soil type, all the pixels within a particular landform in a given soil type have the same values.

Table 4. Available options in SMART for soil moisture (SM) mapping

Soil Moisture Distribution in SMART	Type 1	Type 2	Type 3	Type 4
Pixel level SM for every pixel in a cross section	x	x		
Sub-basin averaged SM is assigned to all pixels of a sub-basin	x	x	x	x
Landform averaged SM is distributed to all pixels of a landform in left bank, right bank and headwater hillslopes		x	x	
Landform averaged SM is distributed to all pixels of a landform in a given soil type				x

Type refers to cross section delineation option in SMART (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type).

5.3. Generating Spatially Distributed Evapotranspiration Outputs

To generate spatially distributed evapotranspiration (ET) outputs, two steps should be taken.

5.3.1. Processing at the Smallest Conceptual Modelling Element Scale

The first step is to process simulated ET data at the smallest conceptual modelling element scale (pixel or landform). To do this **Step13a_Post_Processing_ET_SubBasin_Scale.m** script or **Step13a_Post_Processing_ET_Catchment_Scale.m** script is used depending on whether output data from a single sub-basin or all sub-basins are required respectively. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from …\SMART\Toolbox_Output folder.

- Sub-Basin identification number if results for a specific sub-basin are desired (**Step12a_Post_Processing_ET_SubBasin_Scale.m).**

Outputs:

- In (...\SMART\Model_Output\DEL TYPE) folder, these MATLAB .mat files are generated:

  Pixel_ET_Daily_Type*.mat for delineation type 1 and 2
  Pixel_ET_Monthly_Type*.mat for delineation type 1 and 2
  Pixel_ET_Yearly_Type*.mat for delineation type 1 and 2

  LF_ET_Daily_Type*.mat for delineation type 2, 3 and 4
  LF_ET_Monthly_Type*.mat for delineation type 2, 3 and 4
  LF_ET_Yearly_Type*.mat for delineation type 2, 3 and 4

These files have overstory transpiration, undersotry transpiration and soil evaporation.

5.3.2. Mapping Daily Evapotranspiration

Using data from the step above, ET maps are generated in SMART using **Step13b_Spatial_Distribution_ET_SubBasin_Scale.m** or **Step13b_Spatial_Distribution_ET_Catchment_Scale.m** depending on the simulation scale.

For the distributed pixel based and distributed landform based delineations, ET values are mapped for every pixel in a cross section (Table 5). For the left bank, right bank and headwater ECSs delineation, ET per landform per each hillslope is mapped to the associated pixels. For the ECS soil type delineation, ET per landform per soil type is mapped to the associated pixels. For all the cross section delineation approaches, sub-basin averaged ET is mapped to every pixel. Summary of inputs and outputs of this script are outlined below:

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from (…\SMART\Toolbox_Output) folder.

- Sub-Basin identification number if results for a specific sub-basin are desired (**Step13b_Spatial_Distribution_ET_SubBasin_Scale.m).**

- Start and end dates of data processing period. These dates should be within the simulation period.

Outputs:

- In (...\SMART\Model_Output\DEL TYPE) folder, MATLAB *.mat files with multi-dimensional arrays are stored that have spatial distribution of soil moisture for every time step. These files are:

- Map_Pixel_ET_Daily_Type*.mat: This file has ET values for every pixel in a cross section for selected time steps. This output is only generated for the distributed cross section delineations.

- Map_subbasin_ET_Daily_Type*.mat: In this file, sub-basin averaged ET for selected time steps are assigned to all pixels in a sub-basin. This option is available for all the cross section delineations in SMART.

- Map_LF_ET_Daily_Type*.mat: In this file landform averaged ET for selected time steps are distributed to all pixels in a given landform per ECS. This option is available for the distributed landform, 3 ECSs and ECS soil type cross section delineations. In the 3 ECSs delineation, landform ET distribution is done separately for each ECS in left bank, right bank and headwater hillslopes. For the ECS soil type, all the pixels within a particular landform in a given soil type have the same values.

Table 5. Available options in SMART for ET mapping

ET spatial distribution in SMART	Type 1	Type 2	Type 3	Type 4
Pixel level ET for every pixel in a cross section	x	x		
Sub-basin average ET is assigned to all pixels of a sub-basin	x	x	x	x
Landform averaged ET is distributed to all pixels of a landform in left bank, right bank and headwater hillslopes		x	x	
Landform averaged ET is distributed to all pixels of a landform in a given soil type				x

Type refers to cross section delineation option in SMART (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); 4 = ECS soil type).

CHAPTER 3: Tutorial Instructions

The objective of this tutorial is to set-up a catchment scale model using the SMART software in MATLAB. In this tutorial, you will perform catchment scale topographic and geomorphic analysis. However, you will generate U3M-2D input files for a single sub-basin using four cross section delineation approaches of SMART. Once the model simulations are completed for each cross section delineation option, you will post-process and visualize model simulations results. As part of this tutorial, you will compare the simulation results of four cross section delineation approaches for a first order sub-basin.

The tutorial is organized as follows. The first section provides detailed information about the input files. This is followed by a brief overview of MATLAB software and the SMART toolkit. Finally, step by step instructions are provided for generating input files and performing model simulations.

Dataset:
Download the latest version of the software and tutorial dataset from SMART website on GitHub (https://github.com/hooriajami/SMART/). The tutorial data is from the First Creek at Waterfall Gully catchment in South Australia. This catchment is part of the Bureau of Meteorology Hydrologic Reference Station network (http://www.bom.gov.au/water/hrs/).

1. Setting up the Workspace

Step 1.1. Unzip the SMART.zip file that you downloaded from the SMART webpage. Copy the SMART folder to **My Documents** or any other folders that you have read and write access.

⚠ **Note**: Make sure there are no special characters or spaces in your folder names. Otherwise, SMART functions won't work.

Step 1.2. Open the **SMART** folder in windows explorer and look at the folder structure.

Step 1.3. Open the **SMART>Toolbox_Input** folder and check if all the input files are there. There are 14 files in this folder:

1. **A Digital Elevation Model (DEM) file (*.tif): *dem_clip.tif***
   The DEM is one of the main toolkit inputs. The DEM resolution is 30 m.

2. **A catchment outlet file (*.shp): *gage_UTM.shp***
   The catchment outlet shapefile contains location of the discharge gage. This file is used for catchment delineation in TauDEM.

3. **Percentages of sand in each soil material (*.tif): *sand_1.tif, sand_2.tif, sand_3.tif, sand_4.tif***
   Because soil zone can have up to four soil materials, percentage of sand at every pixel for each soil material is required. For this tutorial, there are four tiff files that correspond to the percentage of sand in every soil material at each pixel. These files are numbered from 1 to 4 (1 = top layer and 4 = bottom soil layer). Layer 1 data

corresponds to depth 0-0.3 m, layer 2: 0.3-0.6 m, layer 3: 0.6-1.0 m and layer 4: 1.0-2.0 m.

4. **Percentages of clay in each soil material (*.tif): *clay_1.tif, clay_2.tif, clay_3.tif, clay_4.tif***
   Because soil zone in the model can have up to four soil materials, percentage of clay at every pixel for each soil material is required. In this tutorial, there are four tiff files that correspond to the percentage of clay in every soil material at each pixel. These files are numbered from 1 to 4 (1 = top layer and 4 = bottom soil layer). Layer 1 data corresponds to depth 0-0.3 m, layer 2: 0.3-0.6 m, layer 3: 0.6-1.0 m and layer 4: 1.0-2.0 m.

5. **A soil depth layer file (*.tif): *Soil_depth.tif***
   This file contains total thickness of soil zone at each pixel.

6. **A land cover map of the catchment (*.tif): *trees.tif***
   The codes in the land cover file correspond to the following land cover classes (1 = trees, 2 = pasture, 3 = crops). Because this catchment is covered by trees, all pixels in the land cover map have value of 1.

7. **A climate zone map of the catchment (*.tif): *climate_zones.tif***
   Pixel values in the climate zone map correspond to catchment's climate zones. There is only one climate zone in this catchment, so all the pixels have the same value.

8. **Input climate time series (*.csv): *Input_Climate.csv***
   This file contains 7 columns including climate zone identification key, date, maximum temperature, minimum temperature, rain, potential evapotranspiration and radiation. Keep in mind that this version of U3M-2D is only using daily rainfall and potential evapotranspiration or pan evaporation, and the rest of variables will be used for the ecohydrological component of the model in later releases. You can view the content of this file in EXCEL.

⚠ **Note**: We have potential evapotranspiration values in the Input_Climate.csv file. So, set the pan evaporation coefficient in **UserRunInfo.m** script should be set to 1. We will set this value later in the tutorial.

Step 1.4. Click on **Start> All Programs> MATLAB 2014b** to open MATLAB.

MATLAB desktop has three panels (Figure 1):

- **Current Folder:** to access your files and scripts.
- **Command Window:** to type commands at the command line. The command window is indicated by the prompt (>>).
- **Workspace:** to explore variables that you created or imported from files.

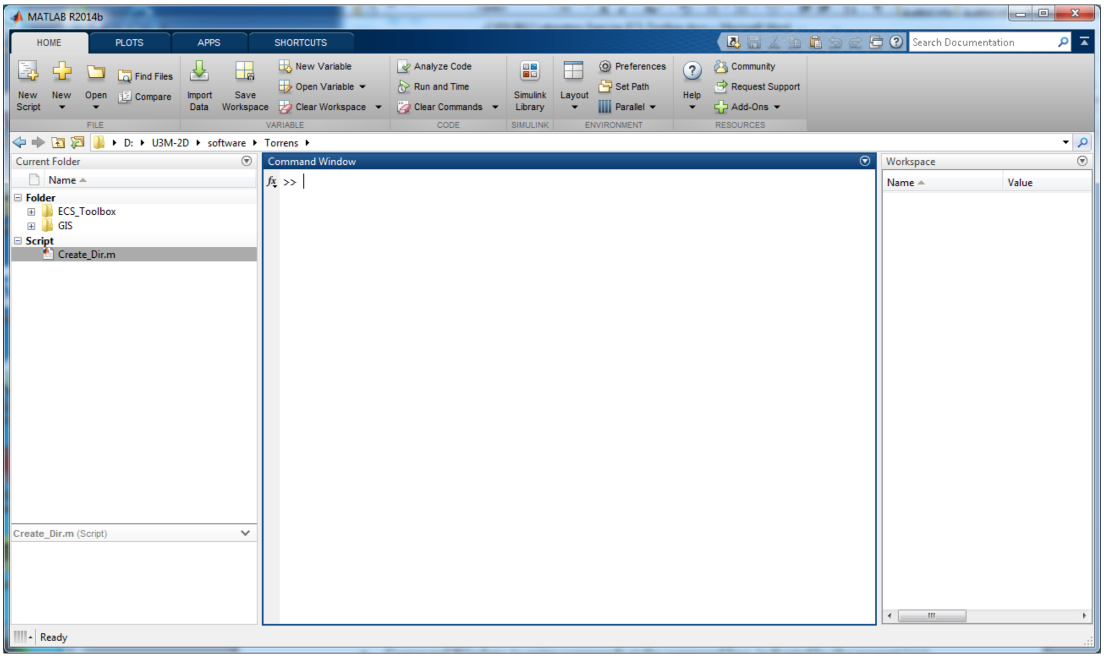


Figure 1. MATLAB desktop

Step 1.5. To create a MATLAB variable and assign it to a value, type x = 2 in the command window (Figure 2). You can see the content of the variable in the workspace window.

To create a one dimensional array or a vector in MATLAB, type v = [1 2 3 4 5].

To create a 3 by 3 matrix (3 rows and 3 columns) in MATLAB, type m = [1 2 3; 4 5 6].
To create a Structure, use MATLAB **struct** command. To get more details about MATLAB commands, type **doc** at the command prompt to access MATLAB help files.

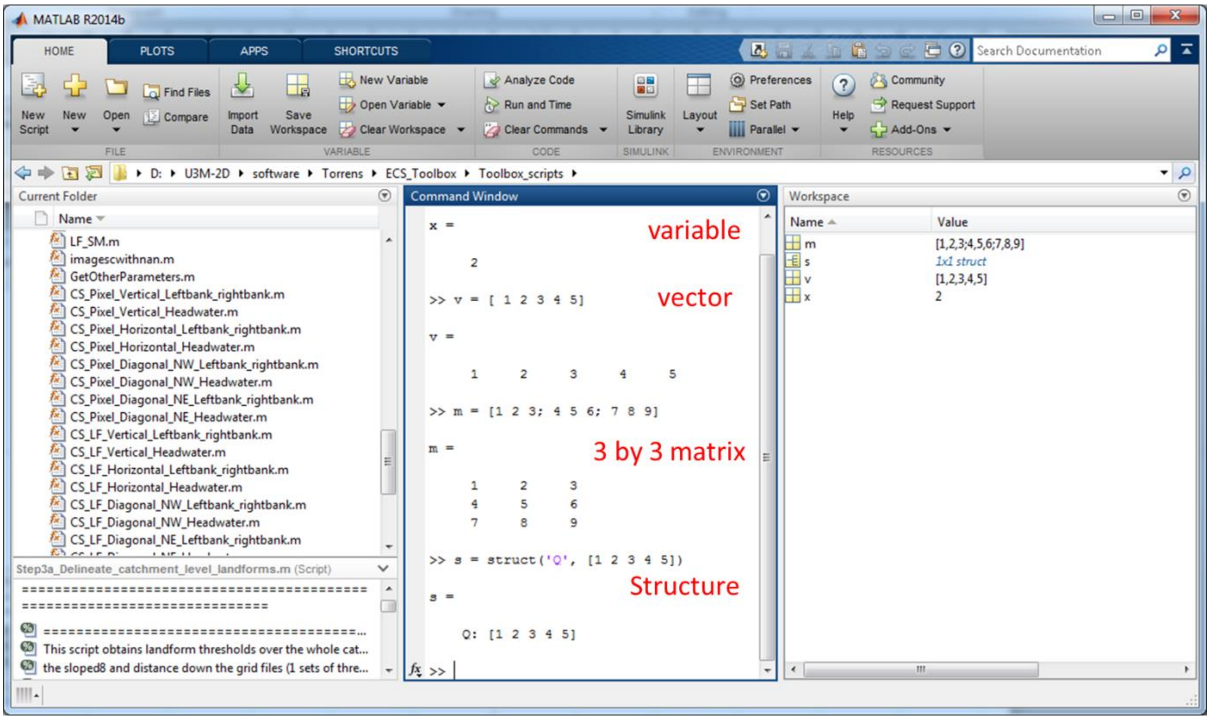


Figure 2. MATLAB variable (x), vector (v, one dimensional array), matrix (m), structure (s) with one field Q. To access values in Q type S.Q.

To delete a MATLAB variable like x, type at the command prompt >> clear x

To delete all MATLAB variables in the workspace, type at the command prompt>> clear all

To clean up the command history, type at the command prompt >> clc

To close all open figures, type at the command prompt >> close all

Step 1.6. In MATLAB, navigate to the directory where you copied the SMART folder. Click on the **Toolbox_Scripts** folder in MATLAB to view MATLAB scripts and functions (Figure 3).

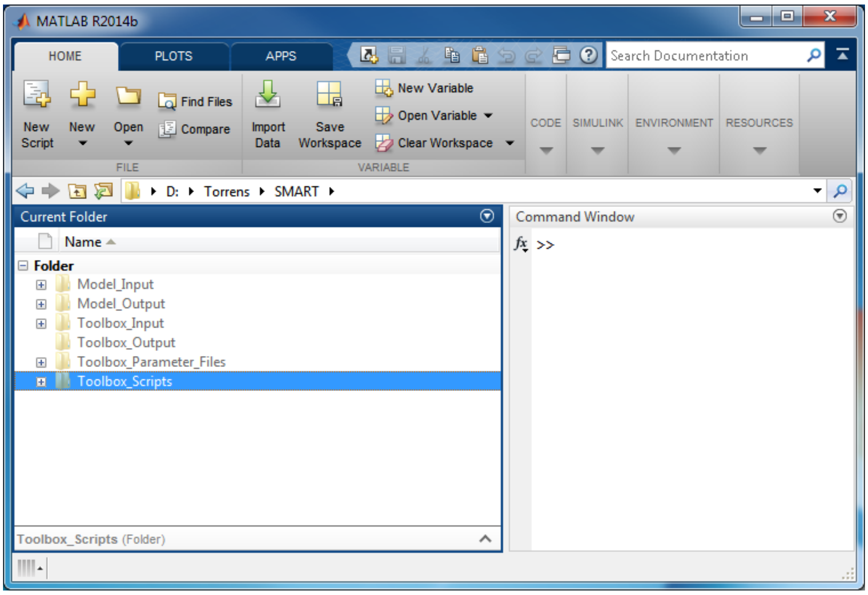


Figure 3. Navigate and open the **Toolbox_Scripts** folder

Step 1.7. Open the **UserRunInfo.m** script by double clicking on the script name (Figure 4).

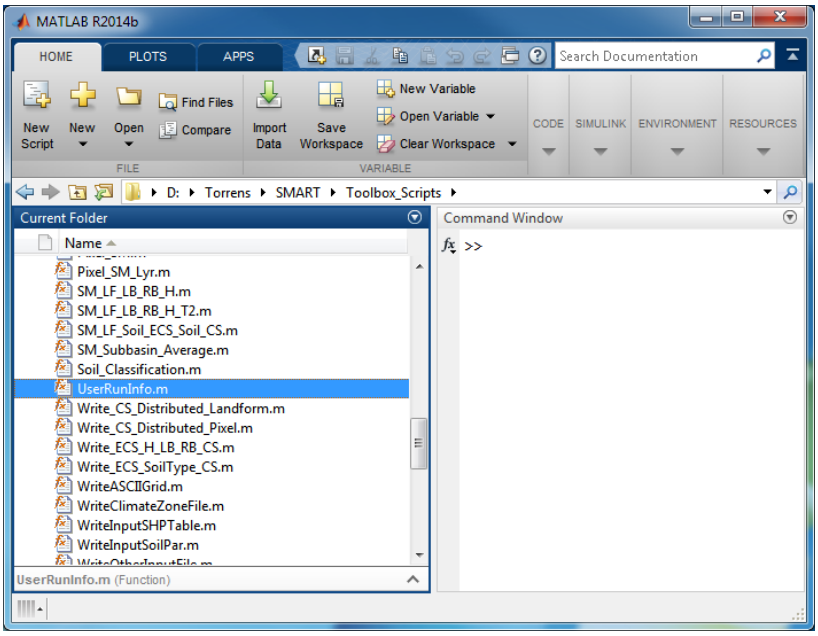


Figure 4. Find and open the **UserRunInfo.m** script to set user and parameter settings.

Step 1.8. In the **UserRunInfo.m** script, write the folder path where you copied the SMART folder (Figure 5).

RunInfo.UserPath = 'D:\Torrens\SMART' (Make sure to write your own path.Yours might be different than this!)

⚠ **Note**: Make sure to type the correct path. Otherwise the toolkit does not work!

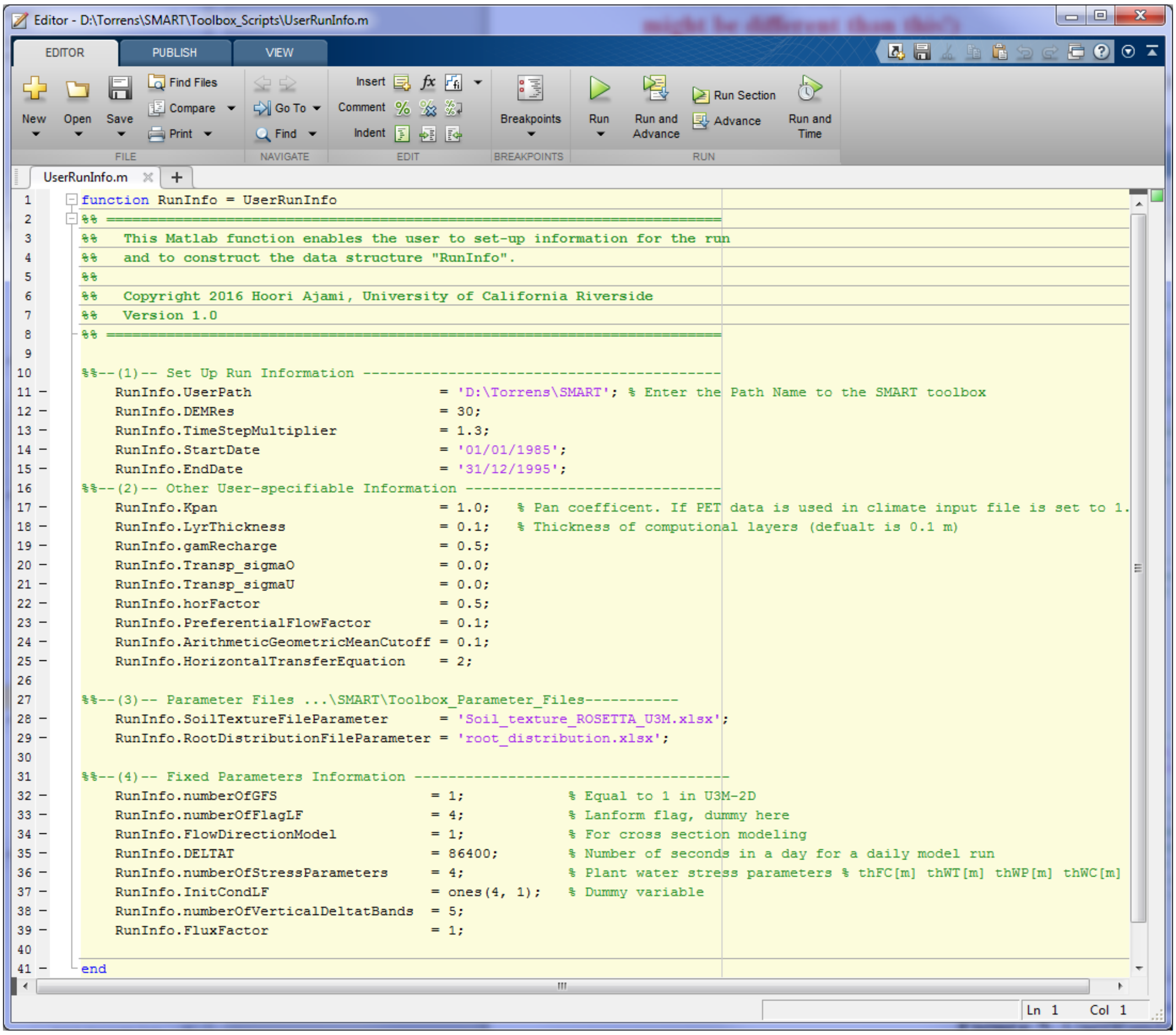


Figure 5. UserRunInfo.m script.

Step 1.9. In the **UserRunInfo.m** script, write the resolution of the DEM file for the RunInfo.DEMRes variable.

RunInfo.DEMRes = 30;

Step 1.10. In the **UserRunInfo.m** script, write the start and end date of model simulations.

RunInfo.StartDate = ‘01/01/1985’
RunInfo.EndDate = ‘31/12/1995’

Step 1.11. Because we are using potential evapotranipration values in the climate data time series file, set the pan coefficient to 1.0 in the **UserRunInfo.m** script.

RunInfo.Kpan = 1.0;

Step 1.12. Default vertical discritization of each computional layer is 0.1 m. If you want to increase or decrease the vertical discritization, change **RunInfo.LyrThickness** parameter in the **UserRunInfo.m** script. Keep in mind that decreasing the vertical discritization will result in increases in the computional time.

RunInfo.LyrThickness = 0.1;

Step 1.13. If you want to use user defined values for soil hydraulic properties and root distributions, enter the name of the files here. We will skip this step, as we are using the default parameter files stored in the (…\SMART\Toolbox_Parameter_Files) folder.

RunInfo.SoilTextureFileParameter = 'Soil_texture_ROSETTA_U3M.xlsx';
RunInfo.RootDistributionFileParameter = 'root_distribution.xlsx';

Step 1.14. Keep default parameter values for the rest of the parameters in sections 2 and 4 of the **UserRunInfo.m** script. Description of these parameters are provided in Chapter 2 of this user manual.

Let's start building the U3M-2D input files!

2. Topographic and Geomorphic Analysis of a Catchment

The first step in building input files is to perform topographic and geomorphic analysis of a catchment. Topographic and geomorphic analysis of a catchment consists of 5 main steps. To do this, we will use scripts in (…\SMART\Toolbox_Scripts) folder.

2.1. Delineate First Order Sub-basins

Open the **Step1_DelineateFirstOrderBasins.m** script and click on the 

button on the menu bar (Figure 6).

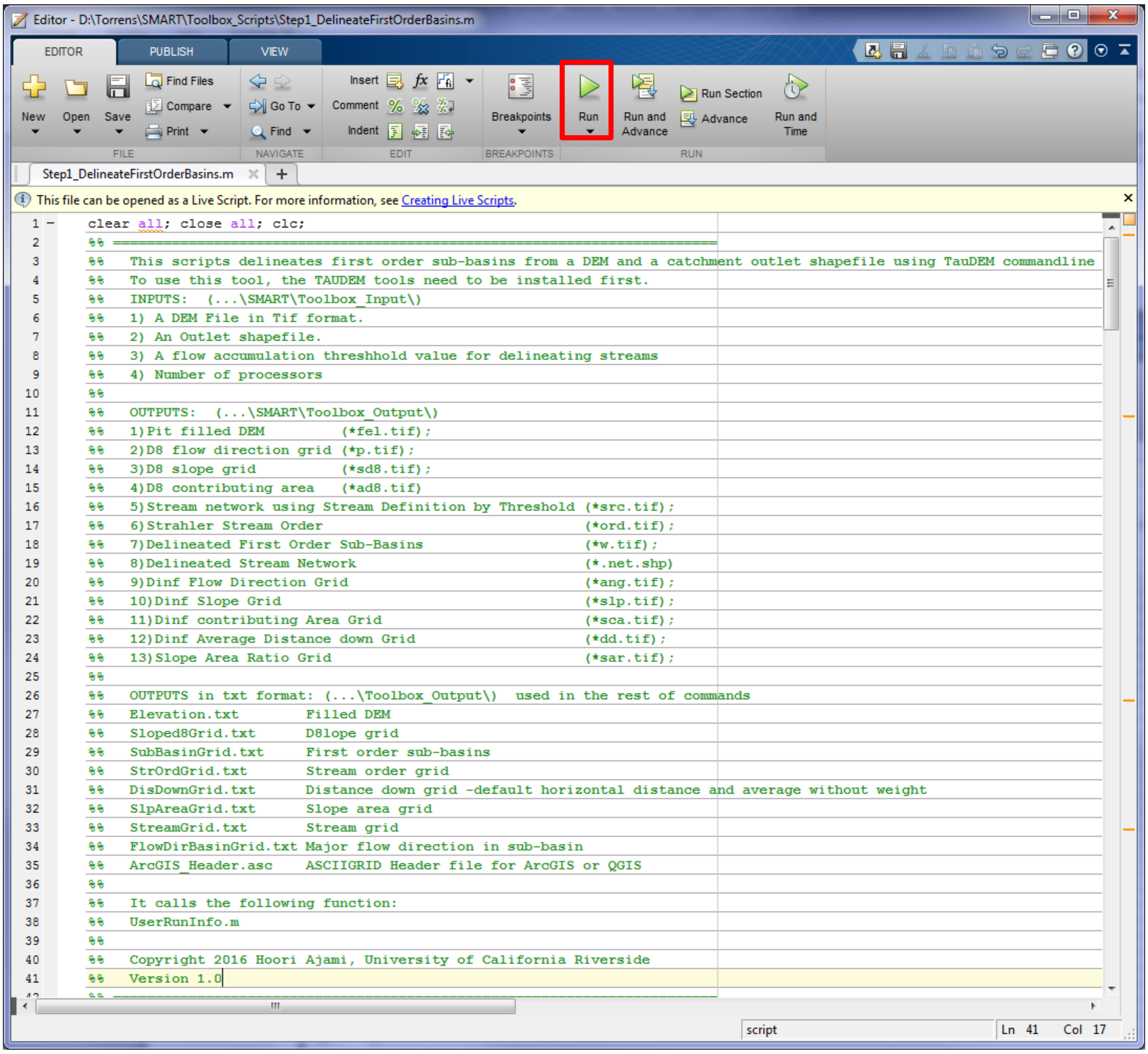


Figure 6. **Step1_DelineateFirstOrderBasins.m** script.

Upon clicking on the Run button, the following input line will appear on the command window (Figure 7). Type the name of the DEM file in the command window and click 

.

Enter the name of a DEM File (.tif): *dem_clip.tif*

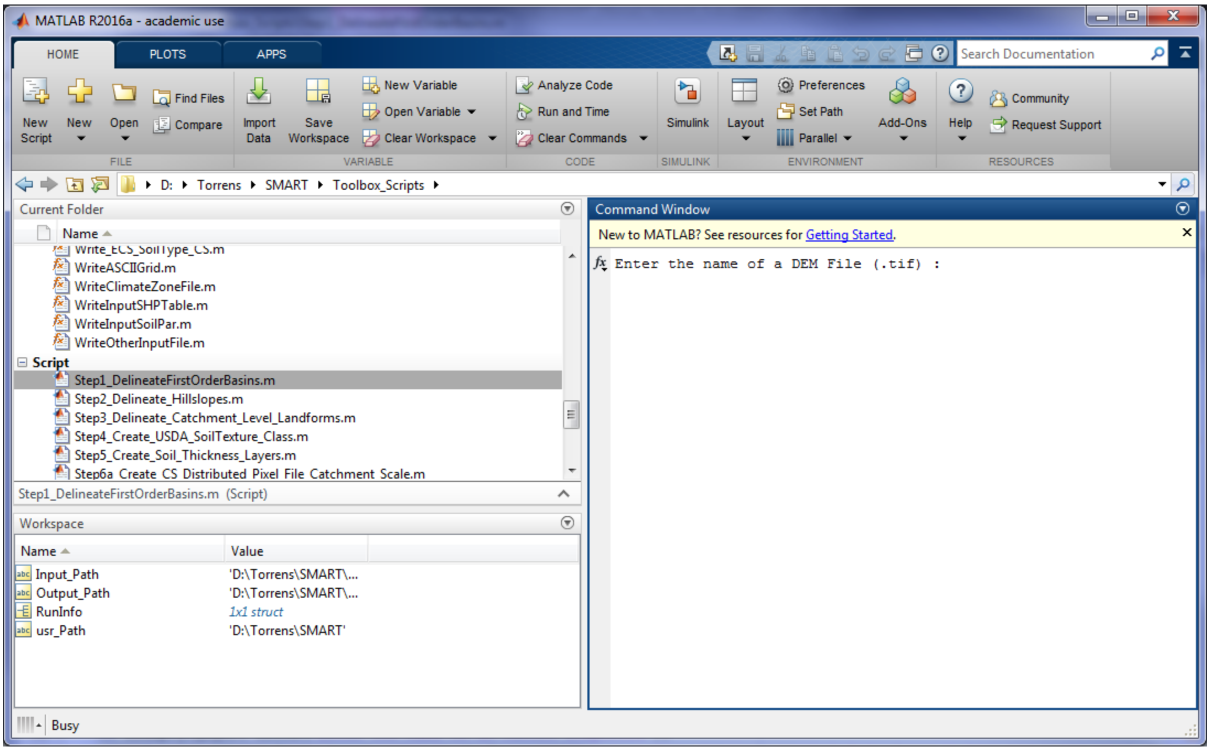
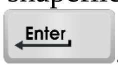


Figure 7. Enter the name of a DEM file in the command window.

In the next step, the script asks for the name of an outlet shapefile (Figure 8). Type the name of the outlet shapefile in the command window and click 

.

Enter the name of an outlet shapefile (.shp): ***gage_UTM.shp***

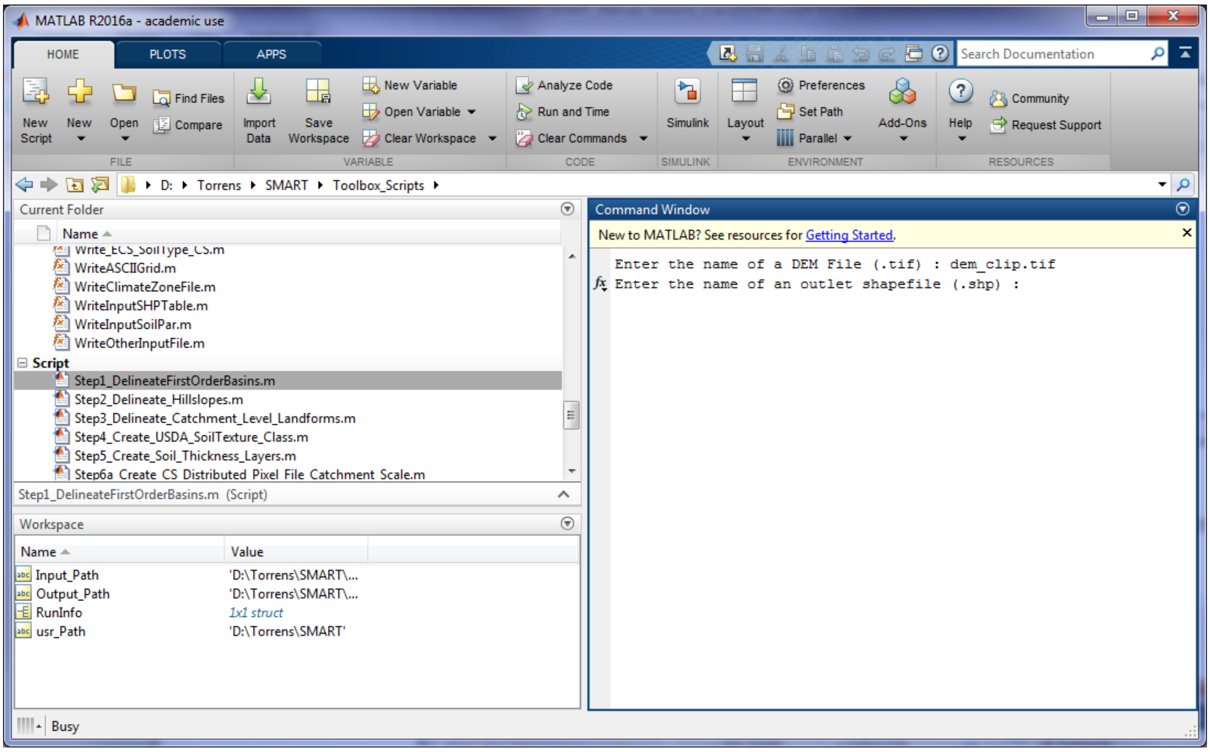


Figure 8. Enter the name of an outlet shapefile in the command window

In the next step, the script asks for the number of processors to use for parallel processing of the DEM (Figure 9). Here we are using 2 processors. However, this number depends on the number of available cores in your computer. Type 2 and click 
.

Enter number of processors: 2

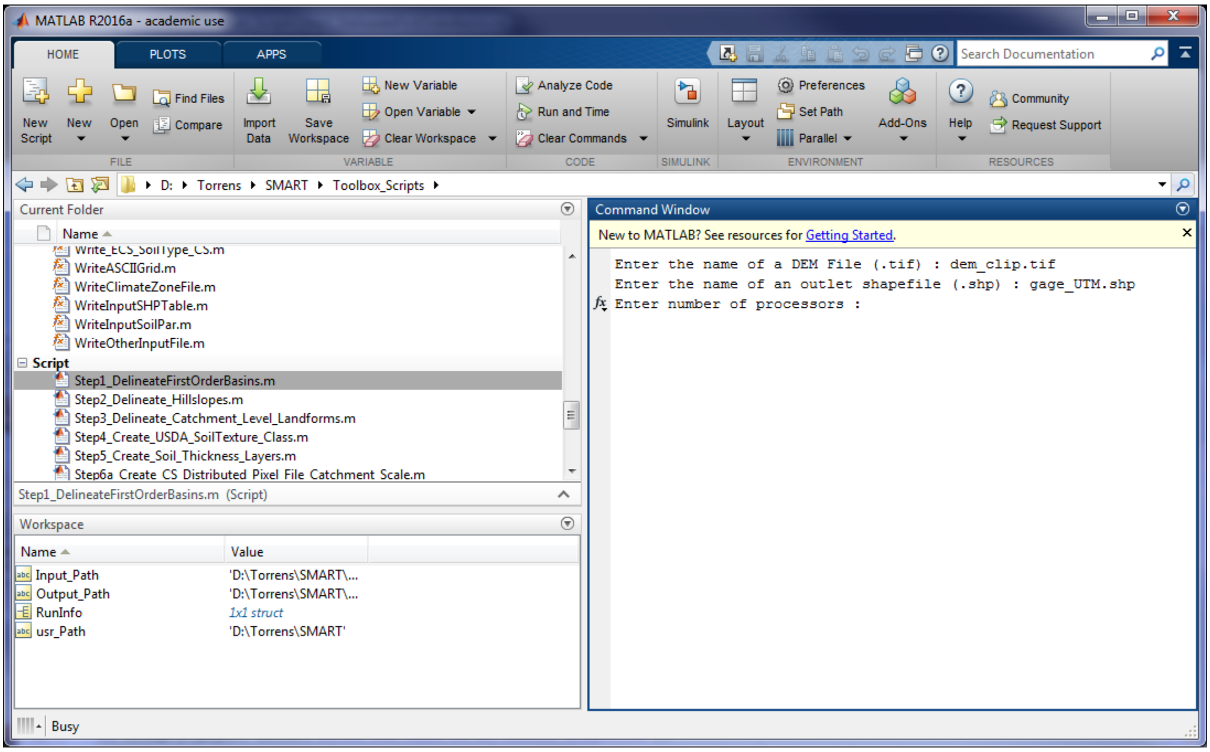


Figure 9. Enter the number of processors in the command window

In the next step, the script asks for the stream delineation threshold. We are going to use the threshold value of 330. Type 330 and click 
.

Enter stream delineation threshold: 330

⚠ If you enter name of a file that does not exist in (…\SMART\Toolbox_Input) folder, the following error will appear and you need to run the script again and enter the correct file name (Figure 10).

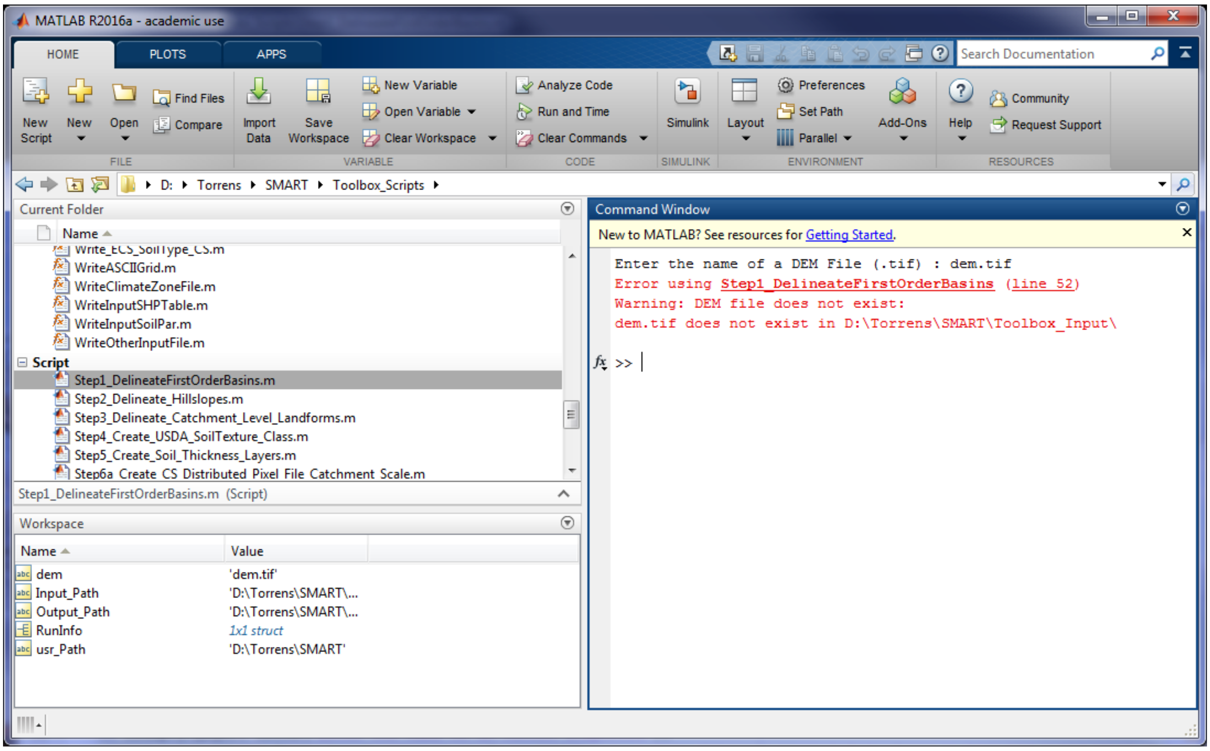


Figure 10. SMART Error Message

Upon successful execution of the script, the following output files are generated:

Outputs (…\SMART\Toolbox_Output):

- Pit filled DEM (dem_clipfel.tif)
- D8 flow direction grid (dem_clipp.tif)
- D8 slope grid (dem_clipsd8.tif)
- D8 contributing area (dem_clipad8.tif)
- Stream network using Stream Definition by Threshold (dem_clipsrc.tif)
- Strahler Stream Order (dem_clipord.tif)
- Delineated First Order Sub-Basins (*w.tif)
- Delineated Stream Network (dem_clipnet.shp)
- Dinf Flow Direction Grid (dem_clipang.tif)
- Dinf Slope Grid (dem_clipslp.tif)
- Dinf contributing Area Grid (dem_clipsca.tif)
- Dinf Average Distance down Grid (dem_clipdd.tif)
- Slope Area Ratio Grid (dem_clipsar.tif)
- Elevation.txt: filled DEM
- Sloped8Grid.txt: D8slope grid
- SubBasinGrid.txt: First order sub-basins
- StrOrdGrid.txt: Stream order grid
- DisDownGrid.txt: Horizontal distance towards the stream network
- SlpAreaGrid.txt: slope area grid
- StreamGrid.txt: stream grid
- FlowDirBasinGrid.txt: major flow direction in first order sub-basins

As the script executes the TauDEM tools, it generates series of MATLAB Figures. For example, Figure 11 shows Strahler's stream order, first order sub-basins and stream network.

Use MATLAB data cursor button  to identify the identification number of delineated sub-basins.

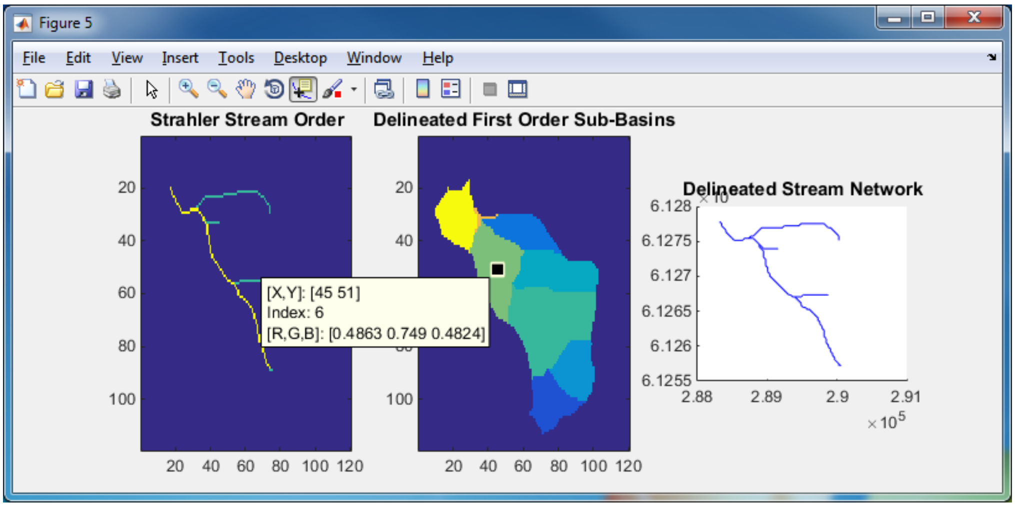


Figure 11. Delineated stream network and sub-basins in the catchment

2.2. Delineate Hillslopes

Open the **Step2_Delineate_Hillslopes.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the following input line will appear on the command window (Figure 12). Type the DEM file name and click .

Enter the name of the DEM File (.tif): *dem_clip.tif*

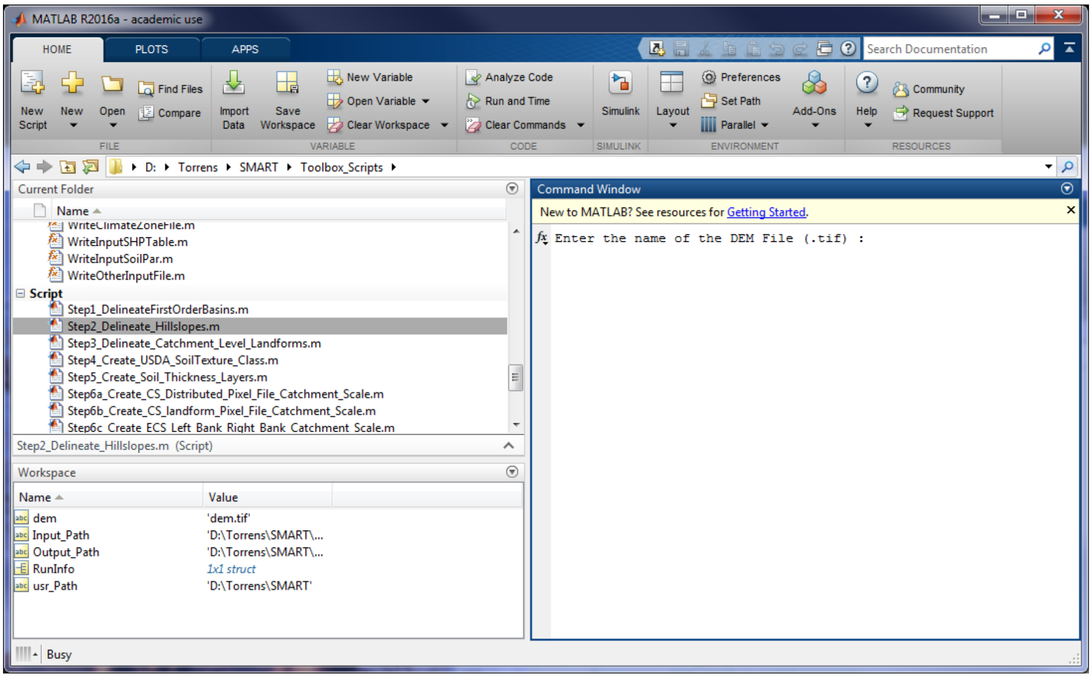


Figure 12. Enter the name of the DEM file in the command window upon running the **Step2_Delineate_Hillslopes.m** script

The script will generate the “temp” folder in (…\SMART\Toolbox_Output) folder for storing delineated headwater hillslopes and a channel head shapefile (river_nodes_end.shp). These are intermediate files and you do not need to work with these files.

Upon successful execution of the script a figure is generated (Figure 13) and the following output files are stored in the (…\SMART\Toolbox_Output) folder:

Outputs (…\SMART\Toolbox_Output):

- Hillslopes_Final.mat: delineated hillslopes in MATLAB format.
- Hillslopes.txt: delineated hillslopes in ASCII format.
- Hillslopes_gis.asc: delineated hillslopes in ASCII Grid format for ArcGIS or QGIS.

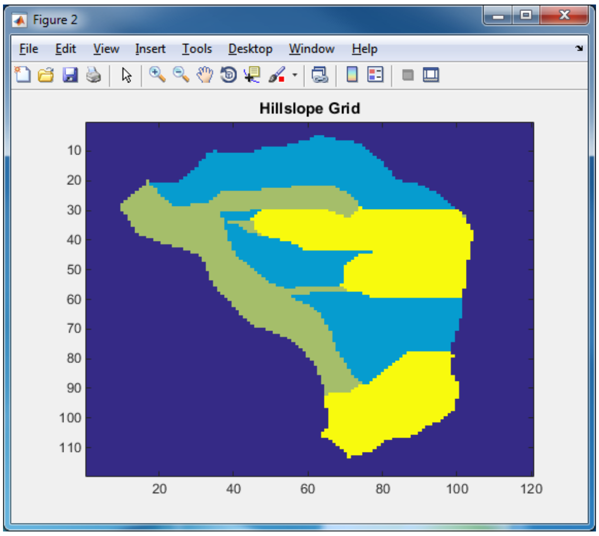


Figure 13. Delineated hillslopes. Headwater pixels have the value of 3, right bank pixels have the value of 1 and left bank pixels have the value of 2.

2.3. Delineate Landforms

In this tutorial, we derive catchment level thresholds for delineating landforms. To delineate catchment level landforms, open the **Step3_Delineate_Catchment_Level_Landforms.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script reads Sloped8Grid.txt and DisDownGrid.txt files from step 1 and generates three output files.

Outputs (...\SMART\Toolbox_Output\):

- landform_thresholds.txt: This file contains landform delineation thresholds including distance from the centre of a stream and an average slope for each landform.

- landform.txt: This is a text file that contains delineated landforms across the catchment. Numerical codes in this file range from 1 to 4 and indicate the landform classification of Khan et al. (2013): 1 = alluvial flats, 2 = footslope, 3 = midslope, 4 = upslope.

- landform_gis.asc: This is an ASCII grid file for ArcGIS or QGIS

Upon successful execution of the script, two figures are generated. Figure 14 shows catchment level slope-distance from the centre of the river curve as well as the landform delineation thresholds. In Figure 15, delineated landforms across the catchment are presented.

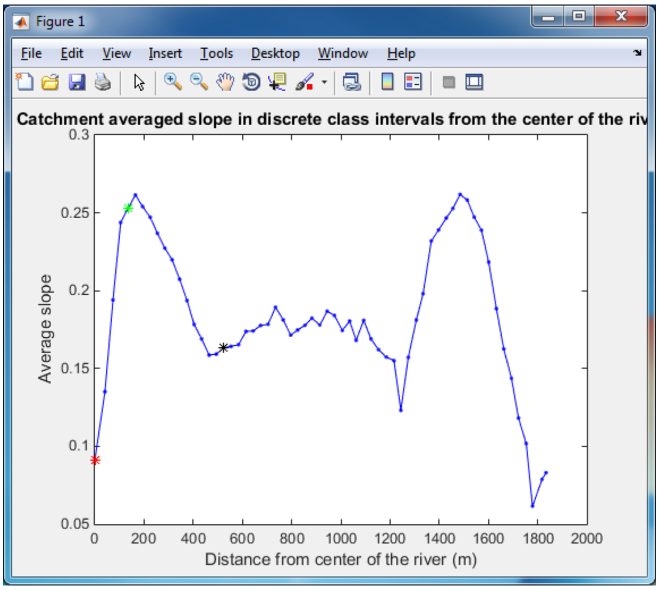


Figure 14. Delineated thresholds for landform delineation.

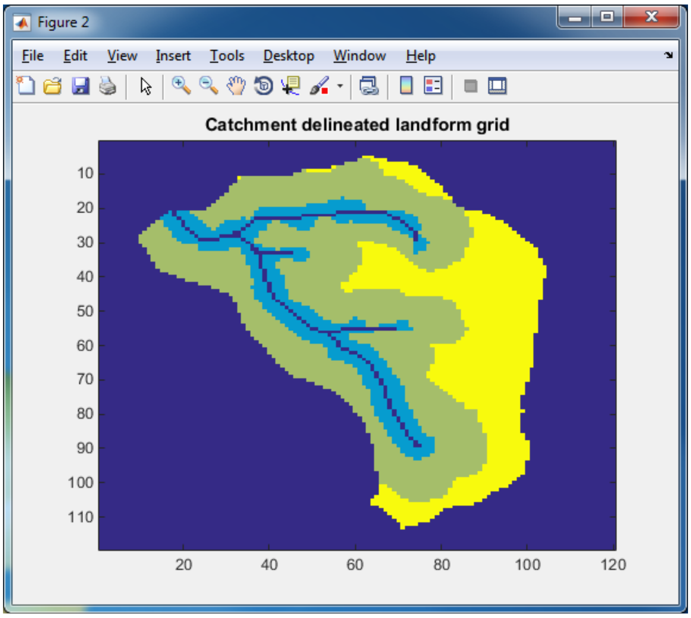


Figure 15. Delineated landforms in the catchment.

2.4. Create USDA Soil Texture Classes

Because soil textural classes are not available for the catchment, we need to generate soil texture classes for every soil material using the "***Step4_Create_USDA_SoilTexture_Class.m***" script. To use this script, percentage of sand and clay values for every grid cell in the domain is provided in four files in the (...\SMART\Toolbox_Input\) folder: ***sand_1.tif, sand_2.tif, sand_3.tif, sand_4.tif and clay_1.tif, clay_2.tif, clay_3.tif, clay_4.tif***

Open the **Step4_Create_USDA_SoilTexture_Class.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the **“Enter the name of %Sand file for Layer--1(.tif)**:”. Type the file name sand_1.tif at the command prompt (Figure 16) and click 

.

Enter the name of %Sand file for Layer--1(.tif): sand_1.tif

In the next step, the script asks to enter the **“Enter the name of %Clay file for Layer--1(.tif)**:”. Type the file name clay_1.tif and click 

(Figure 16).

Enter the name of %Clay file for Layer--1(.tif): clay_1.tif

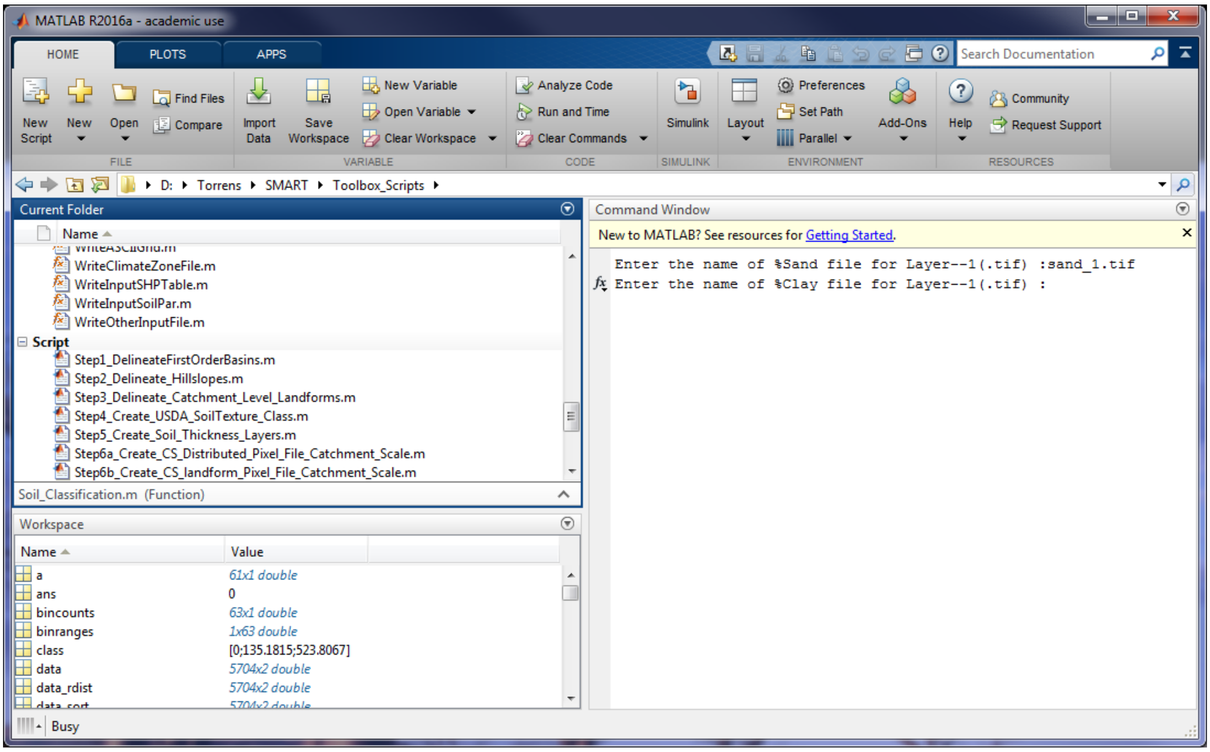


Figure 16. Step4_Create_USDA_SoilTexture_Class.m dialog for entering file names for the top soil layer.

After entering the file names, the script generates the soil texture class for layer 1 (top layer) and asks the user to enter the name of sand and clay layers for the second soil material (Figure 17).

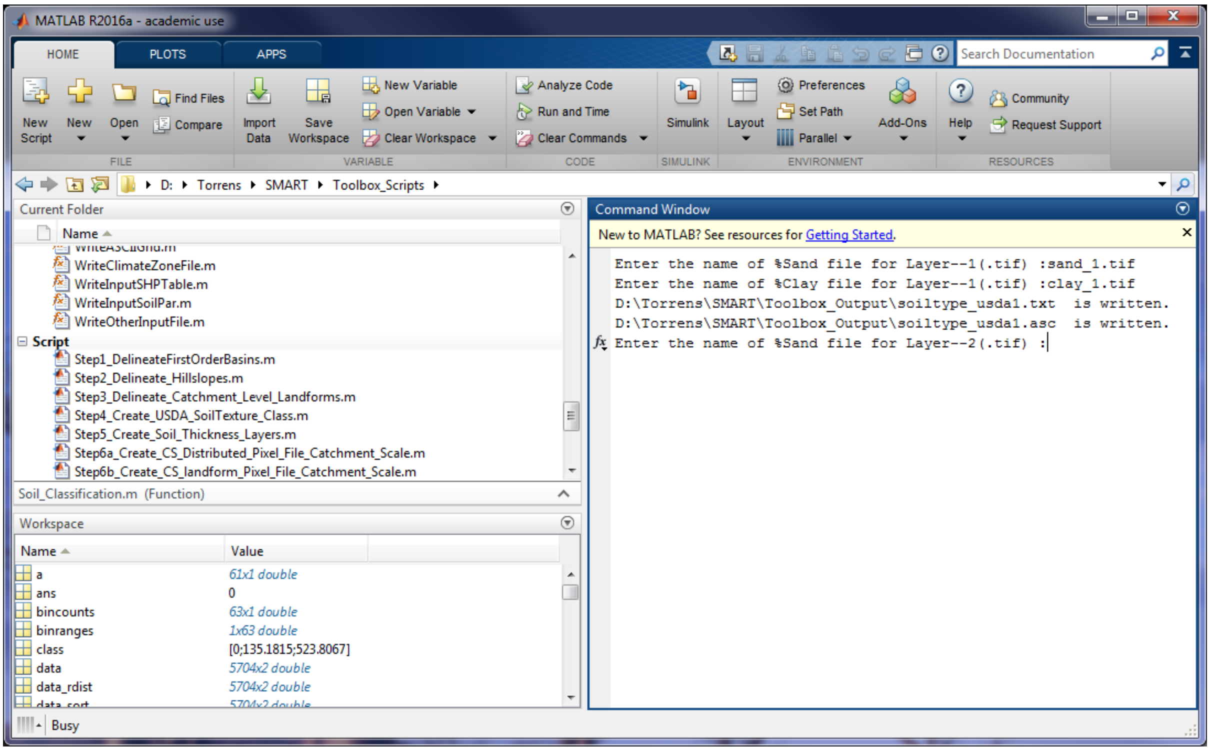


Figure 17. **Step4_Create_USDA_SoilTexture_Class.m** dialog to enter file names for the second soil layer.

Repeat the above steps for layers 3 and 4. Upon successful execution of this script, the following output files are generated in the (…\SMART\Toolbox_Output) folder.

Outputs (...\SMART\Toolbox_Output\):

- soiltype_usda1.txt: USDA soil texture classes of layer 1 (top layer)
- soiltype_usda2.txt: USDA soil texture classes of layer 2
- soiltype_usda3.txt: USDA soil texture classes of layer 3
- soiltype_usda4.txt: USDA soil texture classes of layer 4 (bottom layer)
- soiltype_usda1_gis.asc: layer 1 soil texture in ASCII grid for ArcGIS or QGIS
- soiltype_usda2_gis.asc: layer 2 soil texture in ASCII grid for ArcGIS or QGIS
- soiltype_usda3_gis.asc: layer 3 soil texture in ASCII grid for ArcGIS or QGIS
- soiltype_usda4_gis.asc: layer 4 soil texture in ASCII grid for ArcGIS or QGIS

2.5. Generate Soil Thickness Layers

As mentioned in Chapter 1, U3M-2D uses up to four soil materials or horizons to represent variability of soil hydraulic properties in the sub-surface. The **Step5_Create_Soil_Thickness_Layers.m** script generates thickness of soil materials for the following intervals 0-0.3 m, 0.3-0.6 m, 0.6-1.0 m, and 1.0-2.0 m from the soil depth layer downloaded from the CSIRO website. These intervals correspond to the percentages of sand and clay data used in the previous step.

Open the **Step5_Create_Soil_Thickness_Layers.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the **"Enter the name of a soil depth file (.tif)** :" (Figure 18). Type soil_depth.tif and click 

. The script will access this file in the (…\SMART\Toolbox_Input) folder.

Enter the name of a soil depth file (.tif): soil_depth.tif

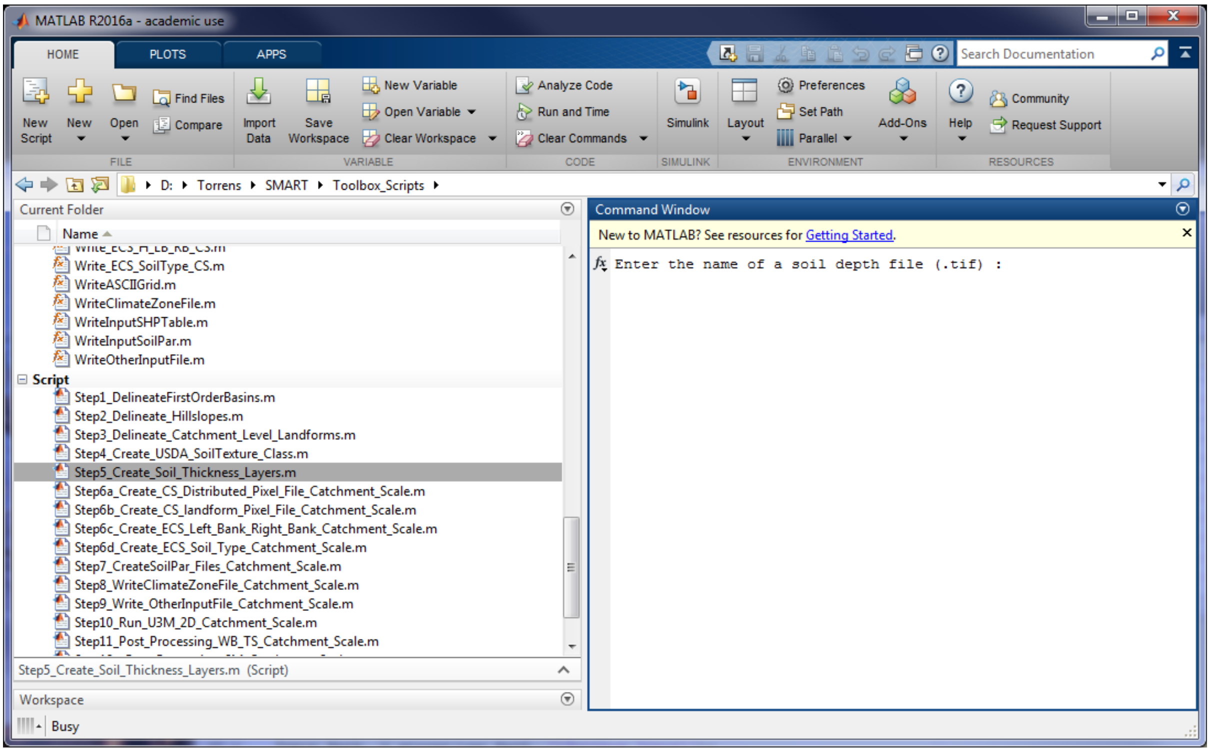


Figure 18. **Step5_Create_Soil_Thickness_Layers.m** dialog to enter the soil depth file name.

Upon successful execution of the script, the following soil thickness files are generated in the (…\SMART\Toolbox_Output) folder.

Outputs (...\SMART\Toolbox_Output\)**:**

- soil_depth1.tif: Thickness of top soil material (0-0.3 m)
- soil_depth2.tif: Thickness of second soil material (0.3-0.6 m)
- soil_depth3.tif: Thickness of third soil material (0.6-1.0 m)
- soil_depth4.tif: Thickness of bottom soil material (1.0-2.0 m)
- soil_depth1_gis.asc: Thickness of top soil material (0-0.3 m)
- soil_depth2_gis.asc: Thickness of second soil material (0.3-0.6 m)
- soil_depth3_gis.asc: Thickness of third soil material (0.6-1.0 m)
- soil_depth4_gis.asc: Thickness of bottom soil material (1.0-2.0 m)

3. Cross Section Delineation and Deriving Input Model Parameters

As our goal is to perform model simulations for a single sub-basin, we will delineate cross sections and model parameters files using SMART scripts designed for a single sub-basin simulation. These scripts are in **(...\SMART\Toolbox_Scripts\Sub_Basin_Scale)** folder.
For the entire catchment scale simulations, use scripts in (...\SMART\Toolbox_Scripts) folder.

3.1. Cross Section Delineation

SMART has four options for cross section delineations. We are going to delineate all four types of cross sections in this tutorial for a select sub-basin.

3.1.1. Step6a_Create_CS_Distributed_Pixel_File_Sub_Basin.m

This script sub-divides a select first order sub-basin to a number of cross sections that are almost perpendicular to the sub-basin's stream. Cross section properties (land cover type, soil type, soil depth, climate zone, elevation and slope) are obtained for every pixel of a cross section and are written to the cross section properties file (Pixel File). This script also generates the cross section database table in MATLAB .mat format (data_CS_Distributed_Pixel_Subbasin_*.mat) and stores it in the (…\SMART\Toolbox_Output) folder. This database file is used in the rest of pre- and post-processing scripts of SMART.

Input dataset to run this script should be stored in the (…\SMART\Toolbox_Input) folder.

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number.

⚠ **Note:** Make sure to set the path in the **UserRunInfo.m** script in the …\SMART\Toolbox_Scripts\Sub_Basin_Scale folder since you are using the sub-basin scale scripts.

Open the **Step6a_Create_CS_Distributed_Pixel_File_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the name of the land cover file. For this simulation, we are using trees.tif file. Type trees.tif and click 

.

Enter the name of a landcover file (.tif):" trees.tif

In the next step, the script asks to enter the name of a climate zone file (Figure 19). Type climate_zones.tif and click .

Enter the name of a climate zone file (.tif):" climate_zones.tif

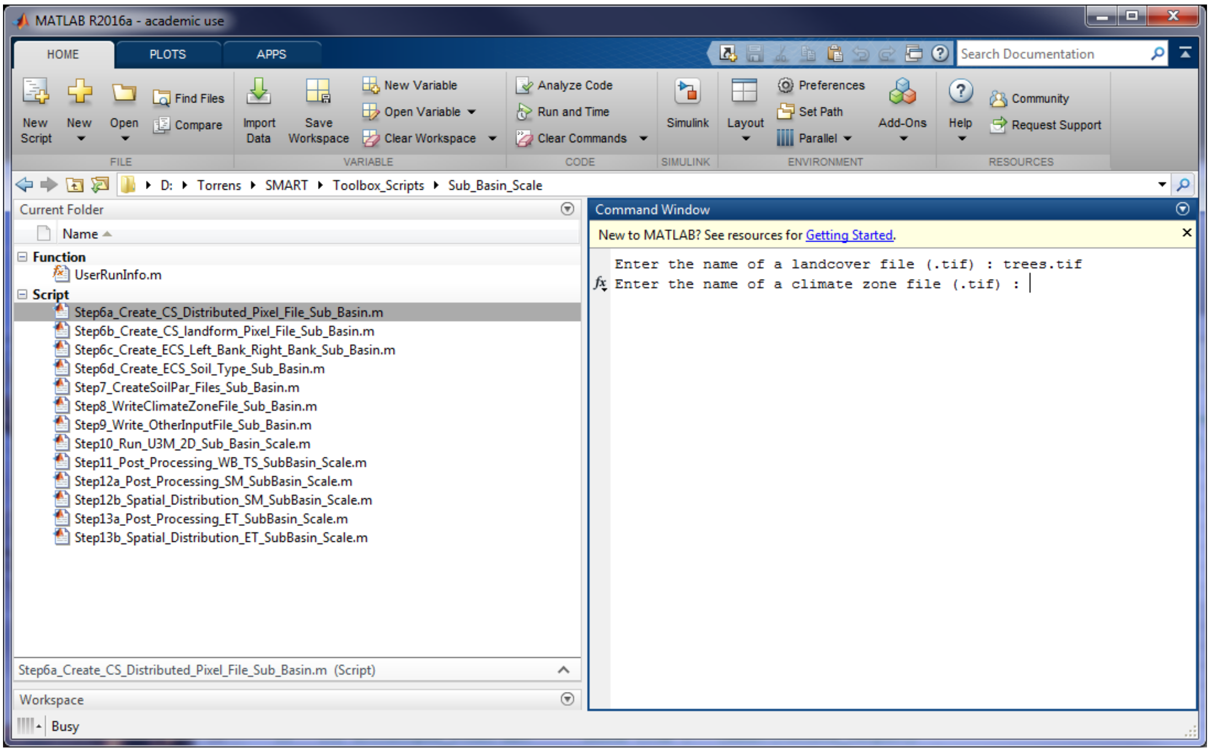
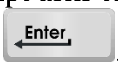


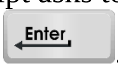
Figure 19. **Step6a_Create_CS_Distributed_Pixel_File_Sub_Basin.m** dialog to enter the climate zone file name.

In the next step, the script asks to enter the name of the soil depth layer 1 which is the top soil layer. Type soil_depth1.tif and click .

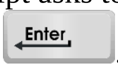
Enter the name of the soil depth layer 1 (.tif):" soil_depth1.tif

In the next step, the script asks to enter the name of the soil depth layer 2. Type soil_depth2.tif and click .

Enter the name of the soil depth layer 2 (.tif):" soil_depth2.tif

In the next step, the script asks to enter the name of the soil depth layer 3. Type soil_depth3.tif and click .

Enter the name of the soil depth layer 3 (.tif):" soil_depth3.tif

In the next step, the script asks to enter the name of the soil depth layer 4. Type soil_depth4.tif and click .

Enter the name of the soil depth layer 4 (.tif) :" soil_depth4.tif

In the next step, the script asks to enter the name of a landform file. Type landform.txt and click .

Enter the name of the landform file (.txt): landform.txt

In the next step, the script generates a Figure so you can select a sub-basin that you are interested to perform model simulations. Click on the tool in the Figure (Figure 20) and select a sub-basin to view its identification number.

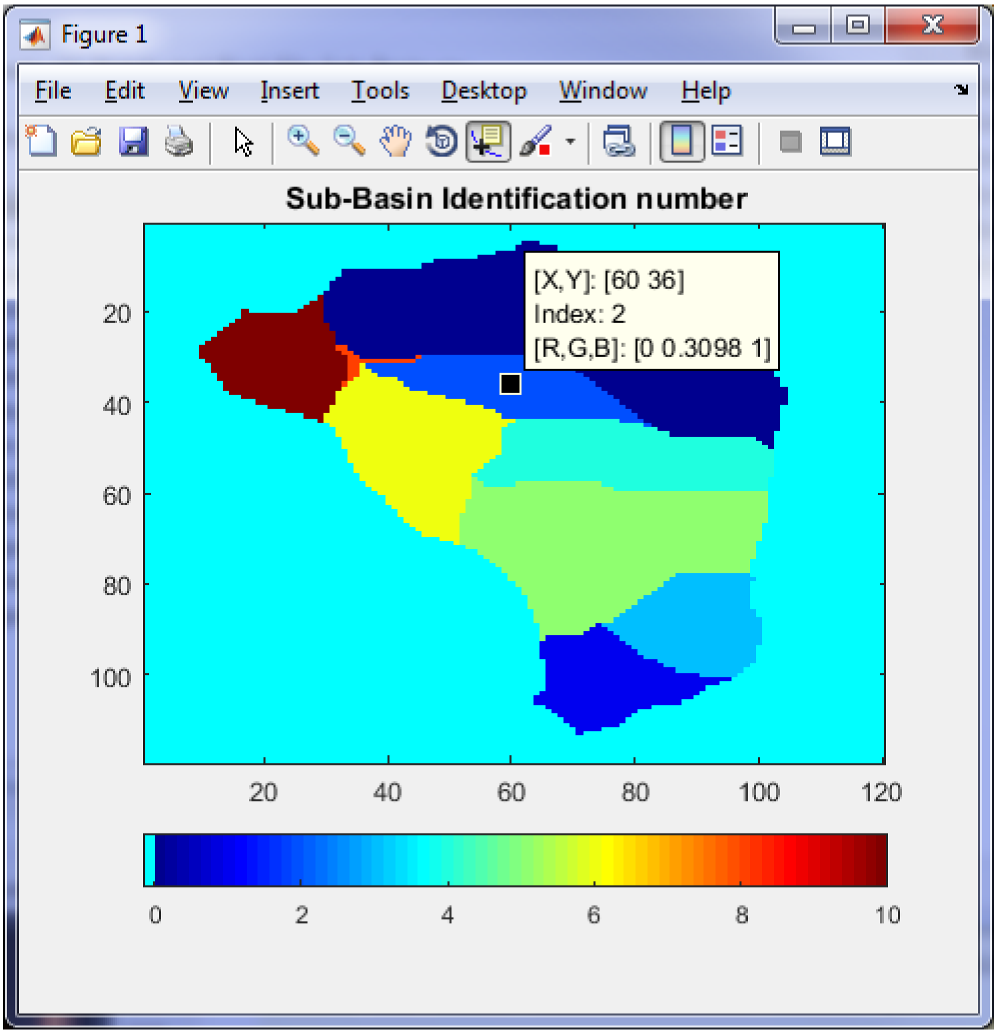


Figure 20. Sub-basin identification number. Use the identify tool to select the sub-basin that you want to perform model simulations.

Since we are interested to simulate fluxes for the sub-basin 2, click and the script asks you to enter the sub-basin identification number (Figure 21). Type 2 and click .

Select the Sub-basin ID for model simulation: 2

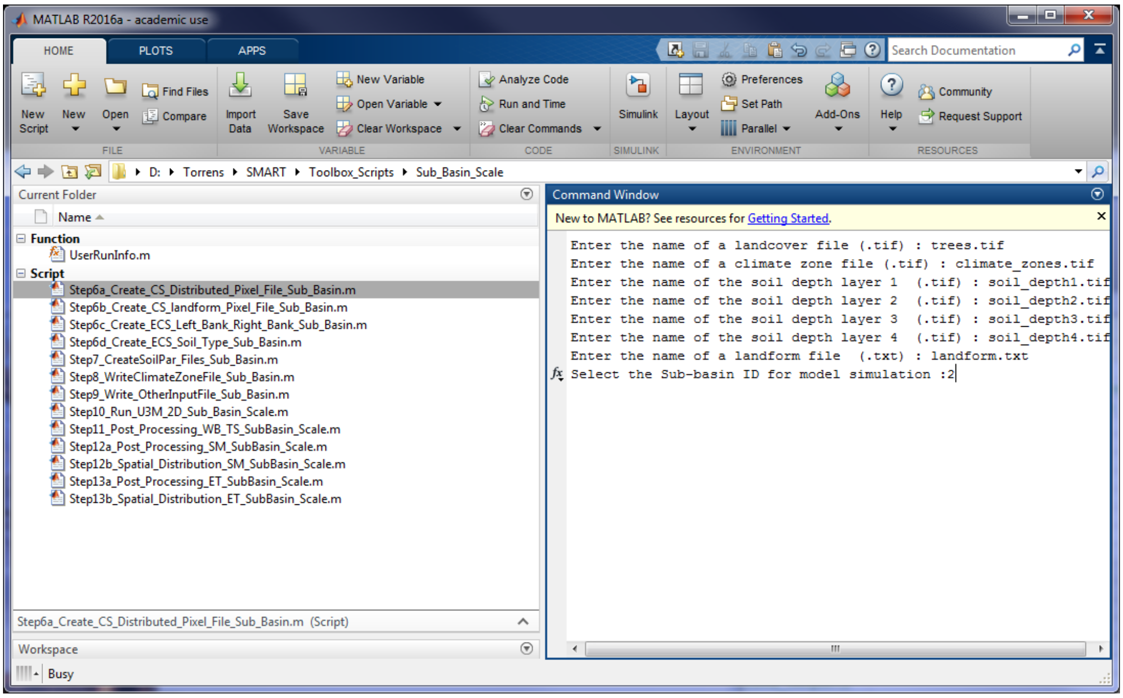


Figure 21. Step6a_Create_CS_Distributed_Pixel_File_Sub_Basin.m dialog to enter a sub-basin ID for cross section delineation.

The names of output files are printed in the MATLAB command window during the execution of the script (Figure 22). Upon successful execution of the script, nine pixel files are generated for the sub-basin 2.

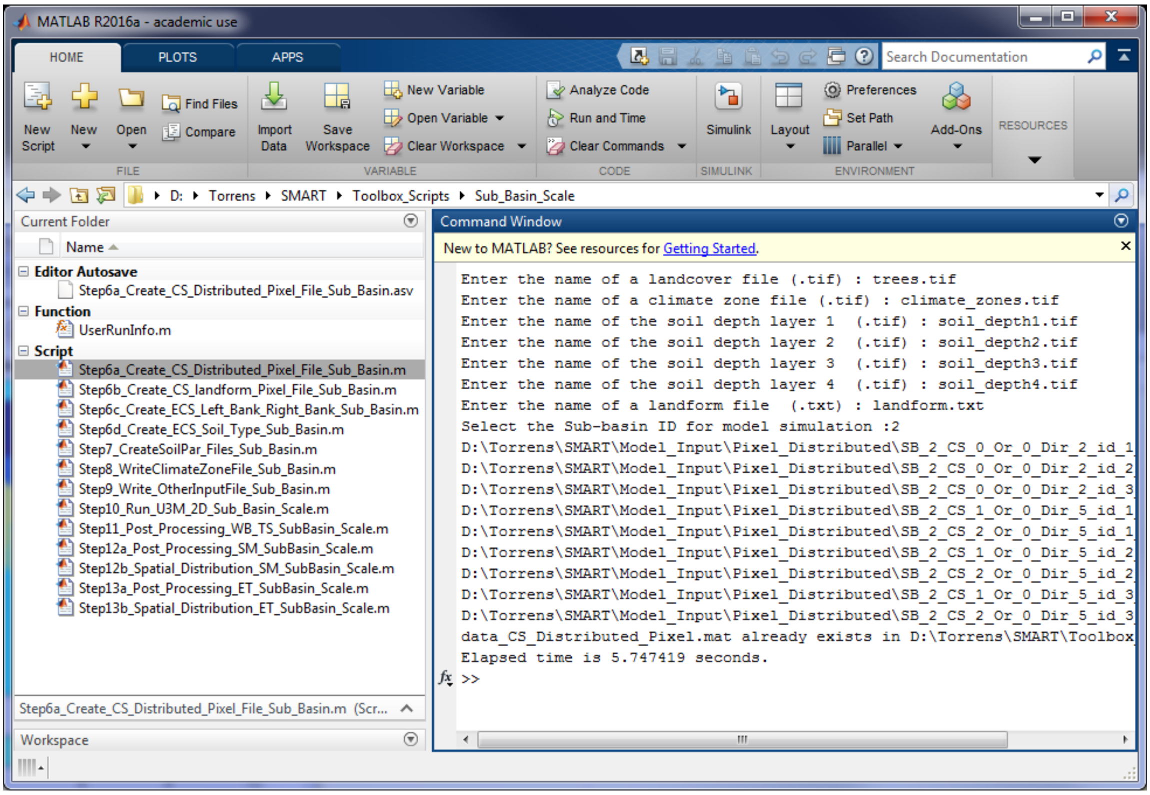


Figure 22. Execution of the **Step6a_Create_CS_Distributed_Pixel_File_Sub_Basin.m** script for the sub-basin 2.

Outputs (…\SMART\Model_Input\Pixel_Distributed):

- *_PixelFile.txt for every cross section in the selected sub-basin. The file naming is as follows: SB (sub-basin)_(sub-basin unique number)_CS (cross section)_(cross section type 0 = headwater, 1 = right bank, 2 = left bank)_Or (Orientation of the sub-basin)_(0 = Horizontal orientation, 1 = vertical, 2 = northeast or southwest, 3 = northwest or southeast)_Dir (stream direction)_(2 = stream drains from west to east, 1 = east to west, 3 = north to south, 4 = south to north, 5 = northeast to southwest, 6 = southwest to northeast, 7 = northwest to southeast, 8 = southeast to northwest)_id_(cross section number)_PixelFile.txt.

- data_CS_Distributed_Pixel_Subbasin_2.mat in the (…\SMART\Toolbox_Output) folder where 2 is the sub-basin identification number.

- CS_coordinates_Subbasin_2.txt in (…\SMART\Toolbox_Output) folder.

3.1.2. Step6b_Create_CS_landform_Pixel_File_Sub_Basin.m

This script sub-divides a select first order sub-basin to a number of cross sections and cross section properties are obtained on a landform basis. A cross section properties file (Pixel File) for every cross section is stored in the (…\SMART\Model_Input\Pixel_Landform) folder. The cross sections database table is saved in MATLAB .mat format (data_CS_Landform_Subbasin_*.mat) in the (…\SMART\Toolbox_Output) folder.

Input dataset to run this script should be stored in the (…\SMART\Toolbox_Input) folder.

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number.

Open the **Step6b_Create_CS_Landform_Pixel_File_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the name of the land cover file. For this simulation, we are using trees.tif file. Type trees.tif and click .

Enter the name of a landcover file (.tif):" trees.tif

In the next step, the script asks to enter the name of a climate zone file. Type climate_zones.tif and click .

Enter the name of a climate zone file (.tif):" climate_zones.tif

In the next step, the script asks to enter the name of the soil depth layer 1 which is the top soil layer. Type soil_depth1.tif and click .

Enter the name of the soil depth layer 1 (.tif):" soil_depth1.tif

In the next step, the script asks to enter the name of the soil depth layer 2. Type soil_depth2.tif and click .

Enter the name of the soil depth layer 2 (.tif):" soil_depth2.tif

In the next step, the script asks to enter the name of the soil depth layer 3. Type soil_depth3.tif and click .

Enter the name of the soil depth layer 3 (.tif):" soil_depth3.tif

In the next step, the script asks to enter the name of the soil depth layer 4. Type soil_depth4.tif and click .

Enter the name of the soil depth layer 4 (.tif):" soil_depth4.tif

In the next step, the script asks to enter the name of a landform file. Type landform.txt and click .

Enter the name of a landform file (.txt): landform.txt

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure (Figure 20) and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click and the script asks you to enter the sub-basin identification number. Type 2 and click .

Select the Sub-basin ID for model simulation: 2

The names of output files are printed in the MATLAB command window during the execution of the script (Figure 23). Upon successful execution of the script, nine pixel files are generated for the sub-basin 2.

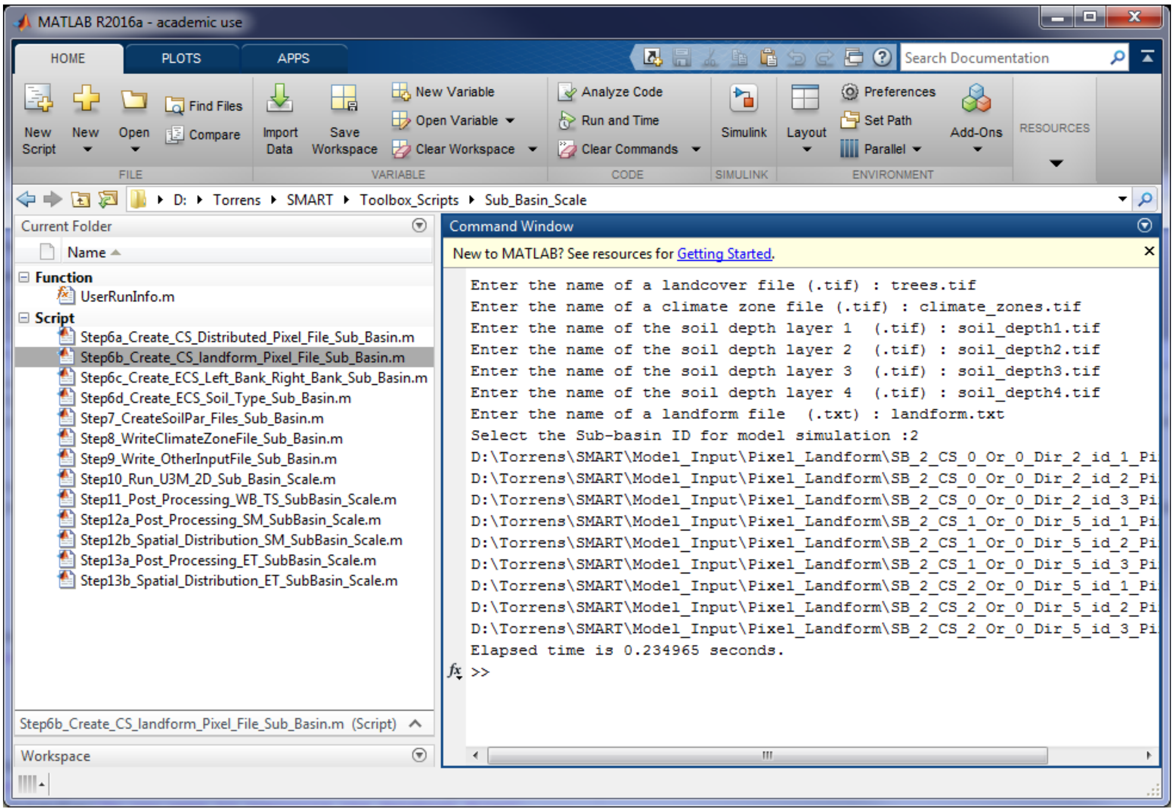


Figure 23. Execution of the **Step6b_Create_CS_Landform_Pixel_File_Sub_Basin.m** script for the sub-basin 2.

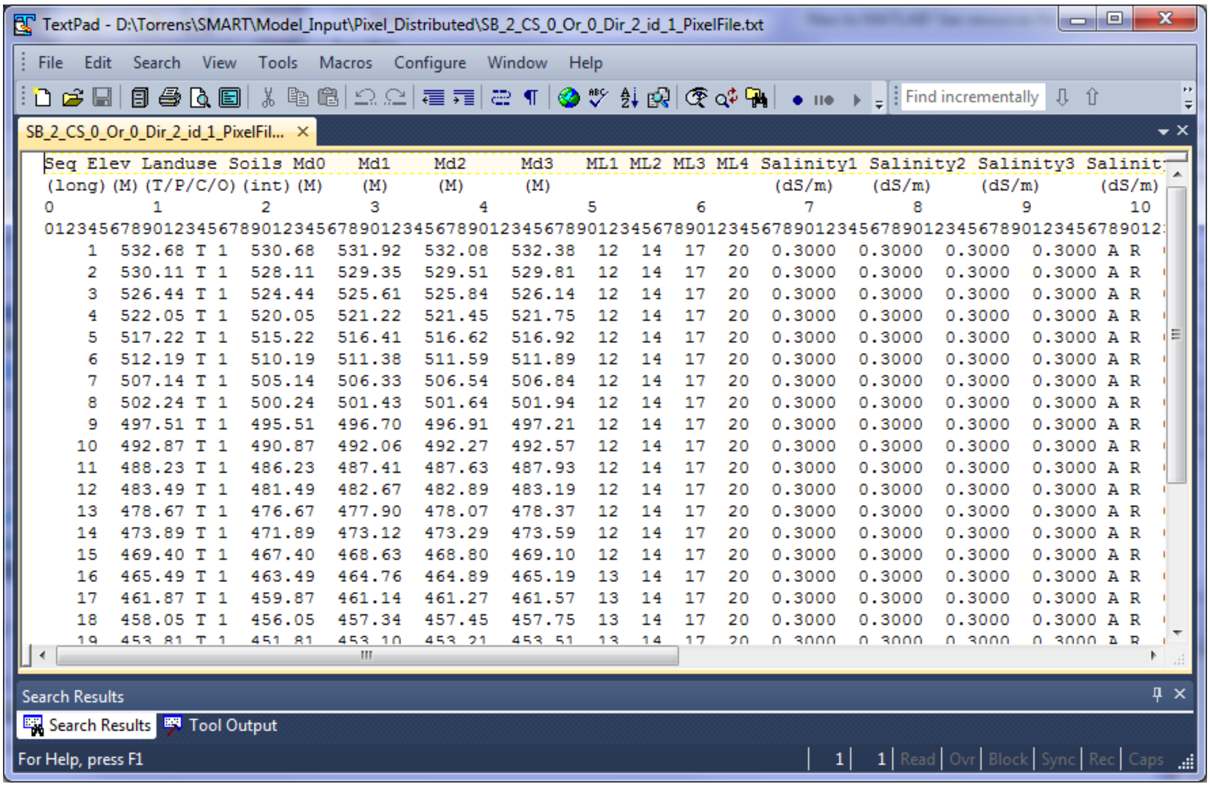
Outputs (…\SMART\Model_Input\Pixel_Landform):

- *_PixelFile.txt for every cross section in the selected sub-basin. The file naming is as follows: SB_(sub-basin unique number)_CS_(hillslope type 0 = headwater, 1 = right bank, 2 = left bank)_Or_ (orientation of the sub-basin)_Dir_(stream direction)_id_(cross section number)_PixelFile.txt

- data_CS_Landform_Subbasin_2.mat in the (…\SMART\Toolbox_Output) folder where 2 is the sub-basin identification number.

- CS_coordinates_LF_T2_Subbasin2.txt in the (…\SMART\Toolbox_Output) folder

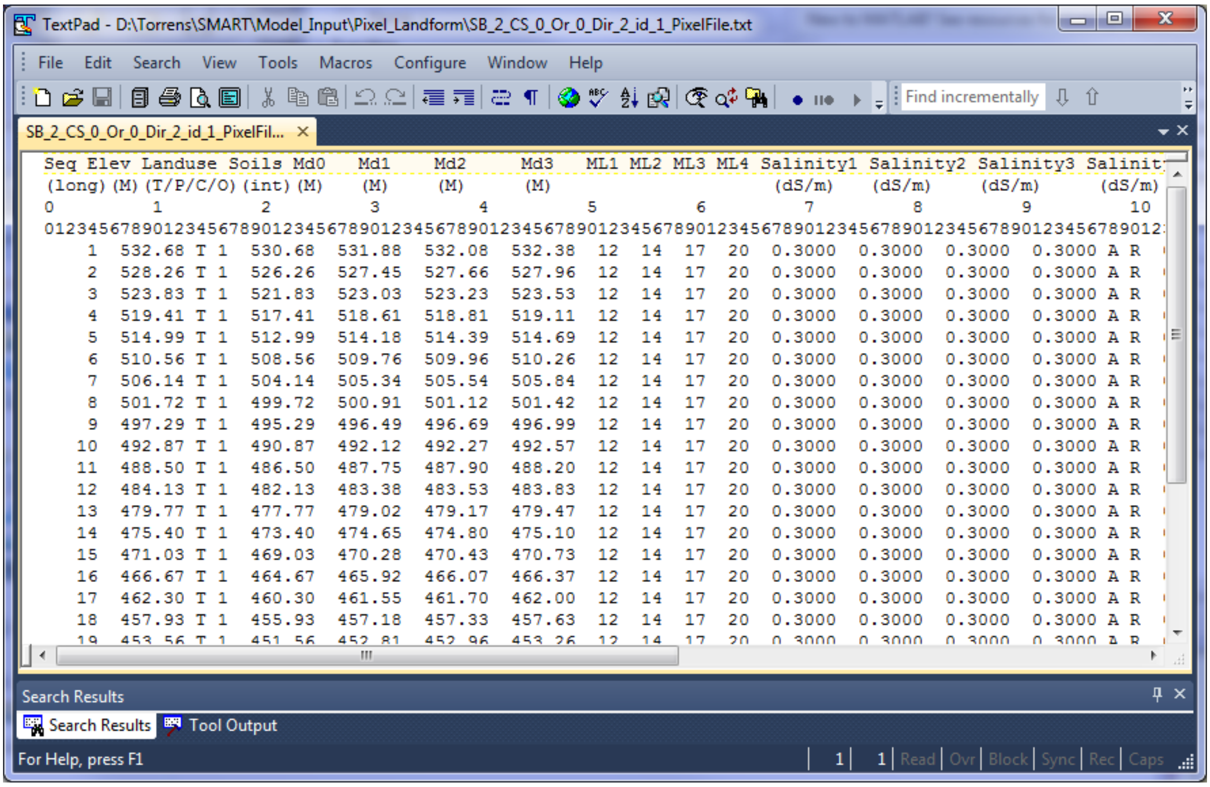
Figures 24 and 25 show cross section properties files (Pixel Files) for a select cross section in sub-basin 2 based on the distributed pixel and distributed landform based cross section delineation respectively.



TextPad - D:\Torrens\SMART\Model_Input\Pixel_Distributed\SB_2_CS_0_Or_0_Dir_2_id_1_PixelFile.txt

```
Seq Elev Landuse Soils Md0    Md1     Md2      Md3    ML1 ML2 ML3 ML4 Salinity1 Salinity2 Salinity3 Salinit
(long) (M) (T/P/C/O) (int) (M)    (M)     (M)      (M)                    (dS/m)    (dS/m)     (dS/m)     (dS/m)
0         1         2         3         4         5         6         7         8         9         10
01234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
    1  532.68 T 1  530.68  531.92  532.08  532.38  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    2  530.11 T 1  528.11  529.35  529.51  529.81  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    3  526.44 T 1  524.44  525.61  525.84  526.14  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    4  522.05 T 1  520.05  521.22  521.45  521.75  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    5  517.22 T 1  515.22  516.41  516.62  516.92  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    6  512.19 T 1  510.19  511.38  511.59  511.89  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    7  507.14 T 1  505.14  506.33  506.54  506.84  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    8  502.24 T 1  500.24  501.43  501.64  501.94  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    9  497.51 T 1  495.51  496.70  496.91  497.21  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   10  492.87 T 1  490.87  492.06  492.27  492.57  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   11  488.23 T 1  486.23  487.41  487.63  487.93  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   12  483.49 T 1  481.49  482.67  482.89  483.19  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   13  478.67 T 1  476.67  477.90  478.07  478.37  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   14  473.89 T 1  471.89  473.12  473.29  473.59  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   15  469.40 T 1  467.40  468.63  468.80  469.10  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   16  465.49 T 1  463.49  464.76  464.89  465.19  13  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   17  461.87 T 1  459.87  461.14  461.27  461.57  13  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   18  458.05 T 1  456.05  457.34  457.45  457.75  13  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   19  453.81 T 1  451.81  453.10  453.21  453.51  13  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
```

Figure 24. One of the Pixel files of the sub-basin 2 delineated using the distributed pixel based cross section delineation.



TextPad - D:\Torrens\SMART\Model_Input\Pixel_Landform\SB_2_CS_0_Or_0_Dir_2_id_1_PixelFile.txt

```
Seq Elev Landuse Soils Md0    Md1     Md2      Md3    ML1 ML2 ML3 ML4 Salinity1 Salinity2 Salinity3 Salinit
(long) (M) (T/P/C/O) (int) (M)    (M)     (M)      (M)                    (dS/m)    (dS/m)     (dS/m)     (dS/m)
0         1         2         3         4         5         6         7         8         9         10
01234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
    1  532.68 T 1  530.68  531.88  532.08  532.38  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    2  528.26 T 1  526.26  527.45  527.66  527.96  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    3  523.83 T 1  521.83  523.03  523.23  523.53  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    4  519.41 T 1  517.41  518.61  518.81  519.11  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    5  514.99 T 1  512.99  514.18  514.39  514.69  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    6  510.56 T 1  508.56  509.76  509.96  510.26  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    7  506.14 T 1  504.14  505.34  505.54  505.84  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    8  501.72 T 1  499.72  500.91  501.12  501.42  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
    9  497.29 T 1  495.29  496.49  496.69  496.99  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   10  492.87 T 1  490.87  492.12  492.27  492.57  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   11  488.50 T 1  486.50  487.75  487.90  488.20  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   12  484.13 T 1  482.13  483.38  483.53  483.83  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   13  479.77 T 1  477.77  479.02  479.17  479.47  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   14  475.40 T 1  473.40  474.65  474.80  475.10  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   15  471.03 T 1  469.03  470.28  470.43  470.73  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   16  466.67 T 1  464.67  465.92  466.07  466.37  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   17  462.30 T 1  460.30  461.55  461.70  462.00  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   18  457.93 T 1  455.93  457.18  457.33  457.63  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
   19  453.56 T 1  451.56  452.81  452.96  453.26  12  14  17  20  0.3000  0.3000  0.3000  0.3000 A R
```

Figure 25. One of the Pixel files of the sub-basin 2 delineated using the distributed landform based cross section delineation.

3.1.3. Step6c_Create_ECS_Left_Bank_Right_Bank_Sub_Basin.m

This script delineates three equivalent cross sections for a select sub-basin using properties of cross sections in the headwater and side slopes. A cross section properties file (Pixel File) for every equivalent cross section is stored in the (…\SMART\Model_Input\ECS_LB_RB_H_CS) folder. The cross sections database file is in MATLAB .mat format (data_ECS_LB_RB_H_CS_Subbasin*.mat) and it is saved in the (…\SMART\Toolbox_Output) folder.

Input dataset to run this script should be stored in the (…\SMART\Toolbox_Input) folder.

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number.

Open the **Step6c_Create_ECS_Left_Bank_Right_Bank_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the name of the landcover file. For this simulation, we are using trees.tif file. Type trees.tif and click 

.

Enter the name of a landcover file (.tif):” trees.tif

In the next step, the script asks to enter the name of a climate zone file. Type climate_zones.tif and click 

.

Enter the name of a climate zone file (.tif):” climate_zones.tif

In the next step, the script asks to enter the name of the soil depth layer 1 which is the top soil layer. Type soil_depth1.tif and click 

.

Enter the name of the soil depth layer 1 (.tif):” soil_depth1.tif

In the next step, the script asks to enter the name of the soil depth layer 2. Type soil_depth2.tif and click .

Enter the name of the soil depth layer 2 (.tif):" soil_depth2.tif

In the next step, the script asks to enter the name of the soil depth layer 3. Type soil_depth3.tif and click .

Enter the name of the soil depth layer 3 (.tif):" soil_depth3.tif

In the next step, the script asks to enter the name of the soil depth layer 4. Type soil_depth4.tif and click .

Enter the name of the soil depth layer 4 (.tif):" soil_depth4.tif

In the next step, the script asks to enter the name of a landform file. Type landform.txt and click .

Enter the name of a landform file (.txt): landform.txt

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click and the script asks you to enter the sub-basin identification number. Type 2 and click .

Select the Sub-basin ID for model simulation: 2

The names of output files are printed in the MATLAB command window during the execution of the script (Figure 26). Upon successful execution of the script, three pixel files are generated for the sub-basin 2 (Figure 27).

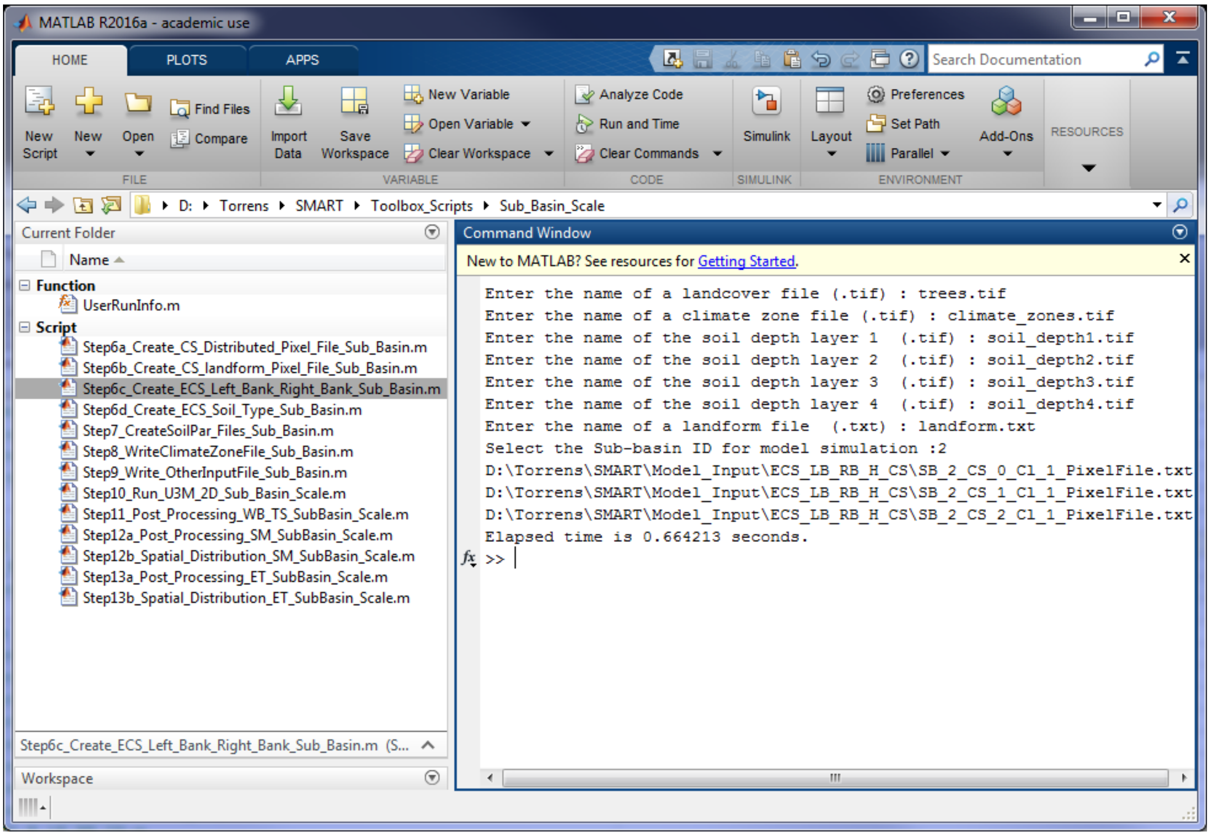


Figure 26. Execution of the **Step6c_Create_ECS_Left_Bank_Right_Bank_Sub_Basin.m** script for the sub-basin 2 using the 3 ECSs delineation option.

Outputs (…\SMART\Model_Input\ECS_LB_RB_H_CS)**:**

- *_PixelFile.txt for every cross section in the selected sub-basin. The file naming is as follows: SB_(sub-basin unique number)_ CS_(cross section type 0 = headwater, 1 = right bank, 2 = left bank)_Cl_(climate zone number)_PixelFile.txt.

- data_ECS_LB_RB_H_Subbasin_2.mat in the (…\SMART\Toolbox_Output) folder where 2 is the sub-basin identification number.

- CS_coordinates_LF_T3_Subbasin2.txt in the (…\SMART\Toolbox_Output) folder

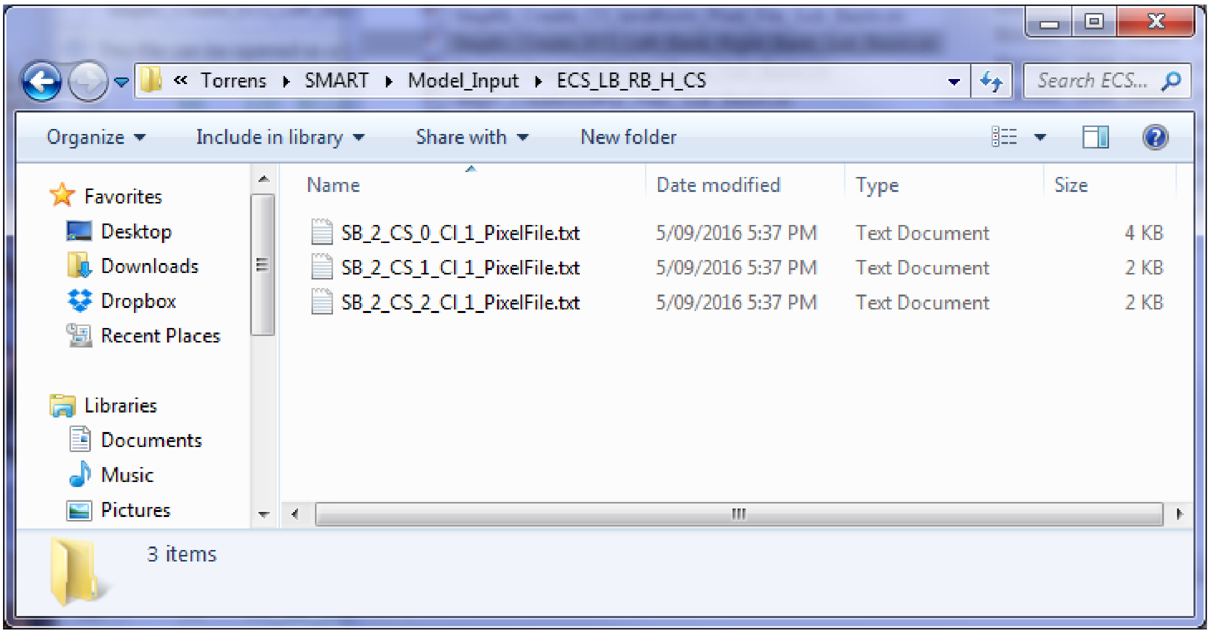


Figure 27. Generated pixel files for sub-basin 2 using the 3 ECSs delineation approach.

3.1.4. Step6d_Create_ECS_Soil_Type_Sub_Basin.m

This script delineates equivalent cross sections for a select sub-basin using the ECS soil type delineation option. A cross section properties file (Pixel File) is written for every equivalent cross section in the (…\SMART\Model_Input\ECS_Soil_Type_CS) folder. The cross sections database table is in MATLAB .mat format (data_ECS_SoilType_CS_Subbasin*.mat) and it is saved in (…\SMART\Toolbox_Output) folder.

Input dataset to run this script should be stored in the (…\SMART\Toolbox_Input) folder.

Inputs (…\SMART\Toolbox_Input):

- Land cover file (*.tif)
- Climate zone file (*.tif)
- Soil thickness for top layer (*.tif)
- Soil thickness for layer 2 (*.tif)
- Soil thickness for layer 3 (*.tif)
- Soil thickness for layer 4 (*.tif)
- Landform file (*.txt)
- Soil texture class files (soiltype_usda*.txt) (Reads from ...\SMART\Toolbox_Output\)
- SubBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sloped8Grid.txt (Reads from ...\SMART\Toolbox_Output\)
- Elevation.txt (Reads from ...\SMART\Toolbox_Output\)
- FlowDirBasinGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Hillslopes_Final.mat (Reads from ...\SMART\Toolbox_Output\)
- StrOrdGrid.txt (Reads from ...\SMART\Toolbox_Output\)
- Sub-basin identification number.

Open the **Step6c_Create_ECS_Left_Bank_Right_Bank_Sub_Basin.m** script and click on the button on the menu bar.

Upon clicking on the Run button, the script asks to enter the name of the landcover file. For this simulation, we are using trees.tif file. Type trees.tif and click .

Enter the name of a landcover file (.tif):" trees.tif

In the next step, the script asks to enter the name of a climate zone file. Type climate_zones.tif and click .

Enter the name of a climate zone file (.tif):" climate_zones.tif

In the next step, the script asks to enter the name of the soil depth layer 1 which is the top soil layer. Type soil_depth1.tif and click .

Enter the name of the soil depth layer 1 (.tif):" soil_depth1.tif

In the next step, the script asks to enter the name of the soil depth layer 2. Type soil_depth2.tif and click .

Enter the name of the soil depth layer 2 (.tif):" soil_depth2.tif

In the next step, the script asks to enter the name of the soil depth layer 3. Type soil_depth3.tif and click .

Enter the name of the soil depth layer 3 (.tif):" soil_depth3.tif

In the next step, the script asks to enter the name of the soil depth layer 4. Type soil_depth4.tif and click .

Enter the name of the soil depth layer 4 (.tif):" soil_depth4.tif

In the next step, the script asks to enter the name of a landform file. Type landform.txt and click .

Enter the name of a landform file (.txt): landform.txt

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click and the script asks you to enter the sub-basin identification number. Type 2 and click .

Select the Sub-basin ID for model simulation: 2

The names of output files are printed in the MATLAB command window during the execution of the script (Figure 28). Upon successful execution of the script, one pixel file is generated for the sub-basin 2 (Figure 29).

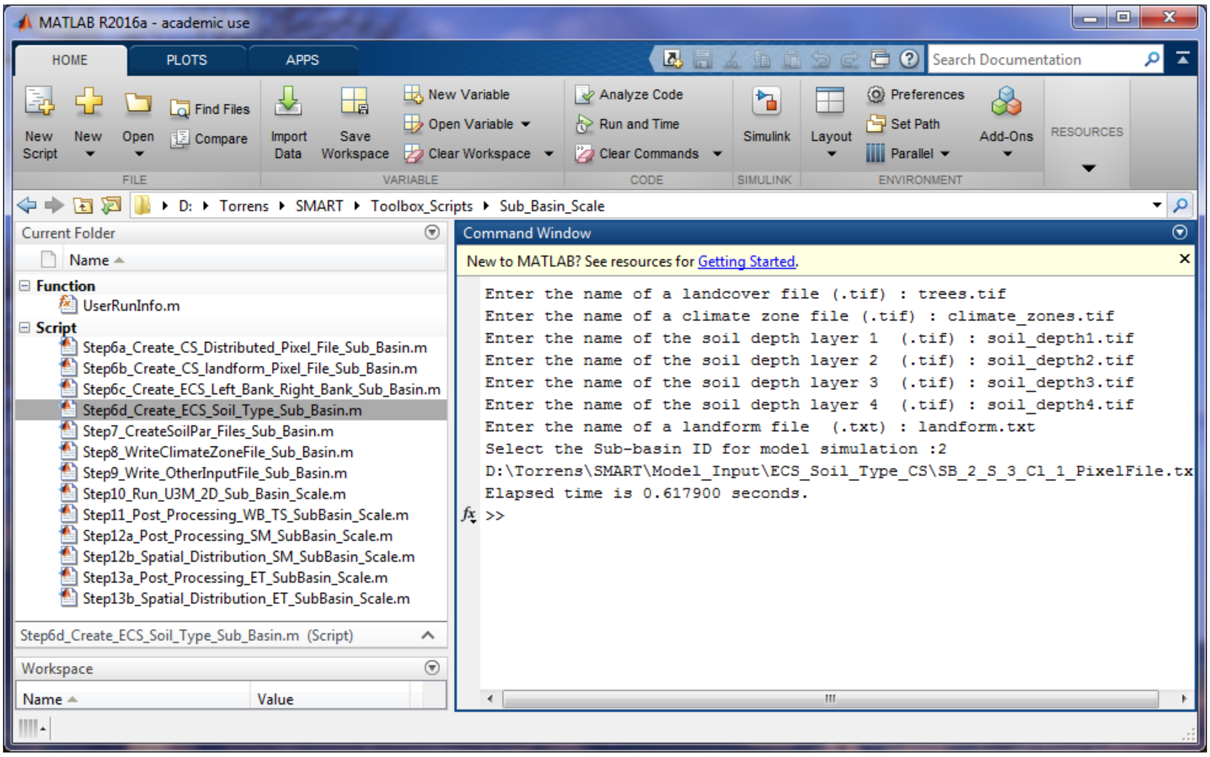


Figure 28. Execution of the **Create_ECS_Left_Bank_Right_Bank_Sub_Basin.m** script for the sub-basin 2.

Outputs (…\SMART\Model_Input\ECS_Soil_Type_CS):

- *_PixelFile.txt for every cross section in the selected sub-basin. The file naming is as follows: SB_(sub-basin unique number)_S_(soil type code)_Cl_(climate zone number)_PixelFile.txt
- data_ECS_SoilType_CS_Subbasin_2.mat in the (…\SMART\Toolbox_Output) folder where 2 is the sub-basin identification number.
- ECS_Soil_CS_Area_Subbasin_2.mat in the (…\SMART\Toolbox_Output) folder where 2 is the sub-basin identification number.
- CS_coordinates_LF_T4_Subbasin2.txt in the (…\SMART\Toolbox_Output) folder

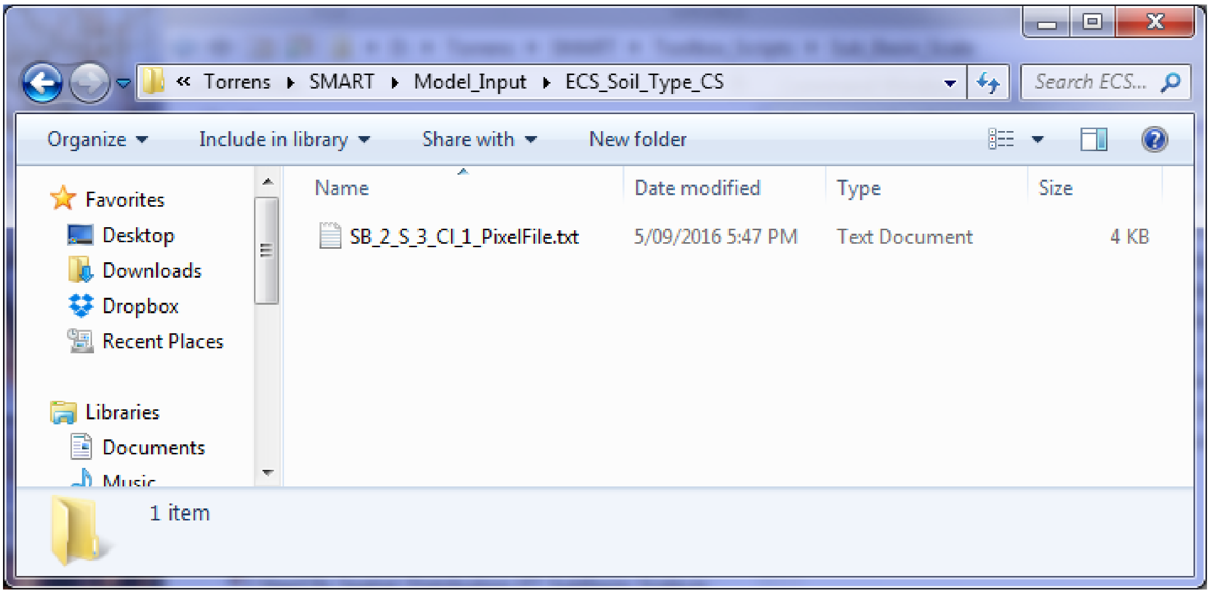


Figure 29. Generated pixel file for sub-basin 2 using the ECS Soil type delineation approach.

3.2. Create U3M-2D Soil Parameter Files

To perform model simulations using the U3M-2D model for every cross section, two soil parameters files are required. The InputSoilPar.txt file includes soil hydraulic properties for each soil material in a cross section. In this version of SMART, soil hydraulic properties are based on the van Genuchten soil hydraulic model. These properties are residual water content [-], saturated water content [-], alpha is a parameter in the soil water retention function [L^{-1}], n is a parameter in the soil water retention function [-], saturated hydraulic conductivity [LT^{-1}], and statistical pore size distribution parameter [-].

The second input file is the soil hydraulic properties table that includes tabulated pressure head values corresponding to user defined pressure head values (hTab1 and hTabN below), tabulated volumetric water content (thetaTab), specific saturation ($\frac{\theta}{\theta_s}$) (SeTab), unsaturated hydraulic conductivity (KTab), hydraulic capacity or $d\theta/dh$ (HydCapTab), and hydraulic diffusivity corresponding to tabulated pressure head values. To compute these values, the user should specify the following parameters. The ***Default parameter values*** in SMART are:

- Soil hydraulic model (Van Genuchten model),
- Number of values in the SHP table (NTab = 100),
- First pressure head value in the SHP table (m) (hTab1 = -1.00E-08),
- Last pressure head value in the SHP table (m) (hTabN = -100.0).

3.2.1. Generate Soil Parameter Files for the Distributed Pixel based Cross Section Delineation

Open the **Step7_CreateSoilPar_Files_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to select a soil hydraulic model. Here, we are using the van Genuchten soil hydraulic model. Therefore, type 0 at the command prompt and click Enter.

Select Hydraulic Model (van Genuchten = 0; Brooks and Corey =1; Vogel and Cislerova=2: 0

In the next step, the script asks to select the cross section delineation option. The value codes for cross section delineations are: 1 = Distributed Pixel based, 2 = Distributed landform based, 3 = 3 ECSs (headwater, left bank and right bank ECSs), and 4 = ECS Soil type. To generate soil parameter files for the distributed pixel based cross section delineation option, type 1 at the command prompt and click Enter (Figure 30).

Select Cross Section Delineation Type (1 to 4): 1

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click Enter and the script asks you to enter the sub-basin identification number. Type 2 and click Enter.

Select the Sub-basin ID for model simulation: 2

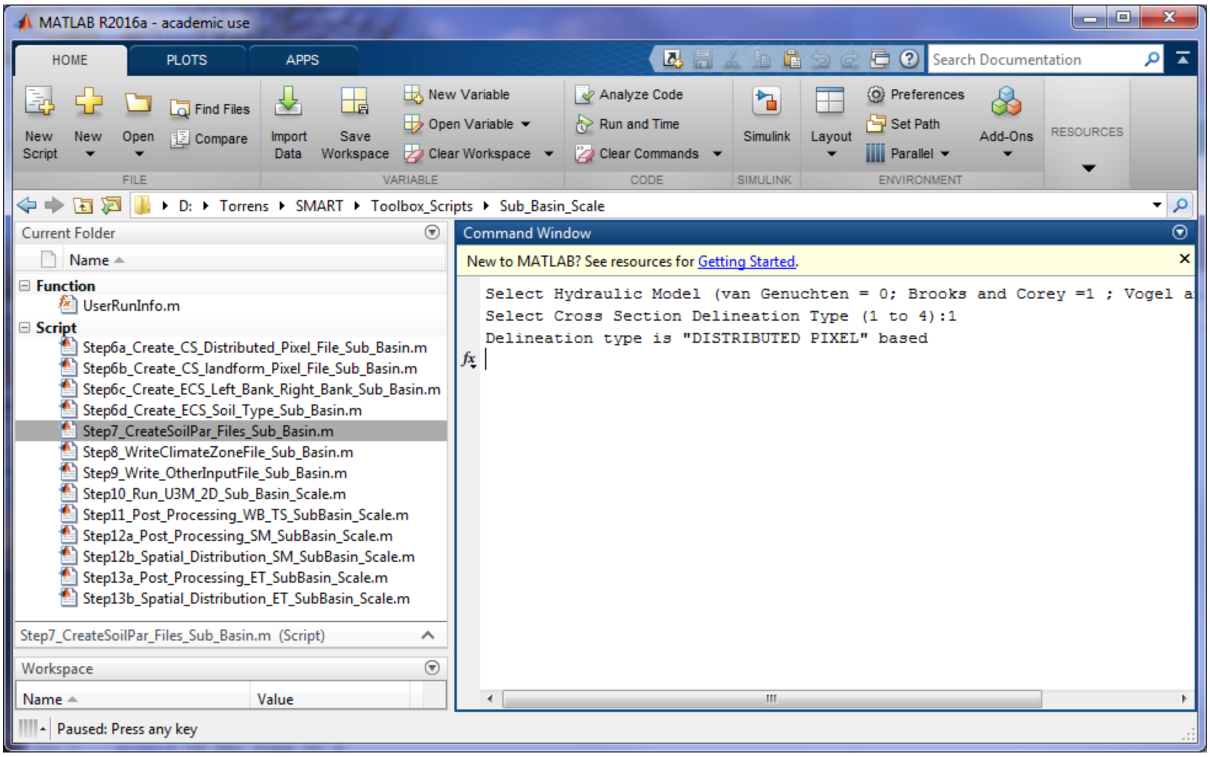


Figure 30. **Step7_CreateSoilPar_Files_Sub_Basin.m** script dialog for the distributed pixel based cross section delineation option

Outputs (...\SMART\Model_Input\Pixel_Distributed):

- A cross section soil parameter file, InputSoilParS_(cross section id)_SB_(sub-basin unique number).txt, is generated in the (...\SMART\Model_Input\ Pixel_Distributed) folder for every cross section in the selected sub-basin.

- A cross section soil hydraulic properties table file, InputSHPTable_S_(cross section id)_SB_(sub-basin unique number).txt, is generated in the (...\SMART\Model_Input\ Pixel_Distributed) folder for every cross section in the selected sub-basin.

Upon successful execution of the script, nine InputSHPTable_S_*.txt and nine InputSoilParS_*.txt are generated for the sub-basin 2 (Figure 31).

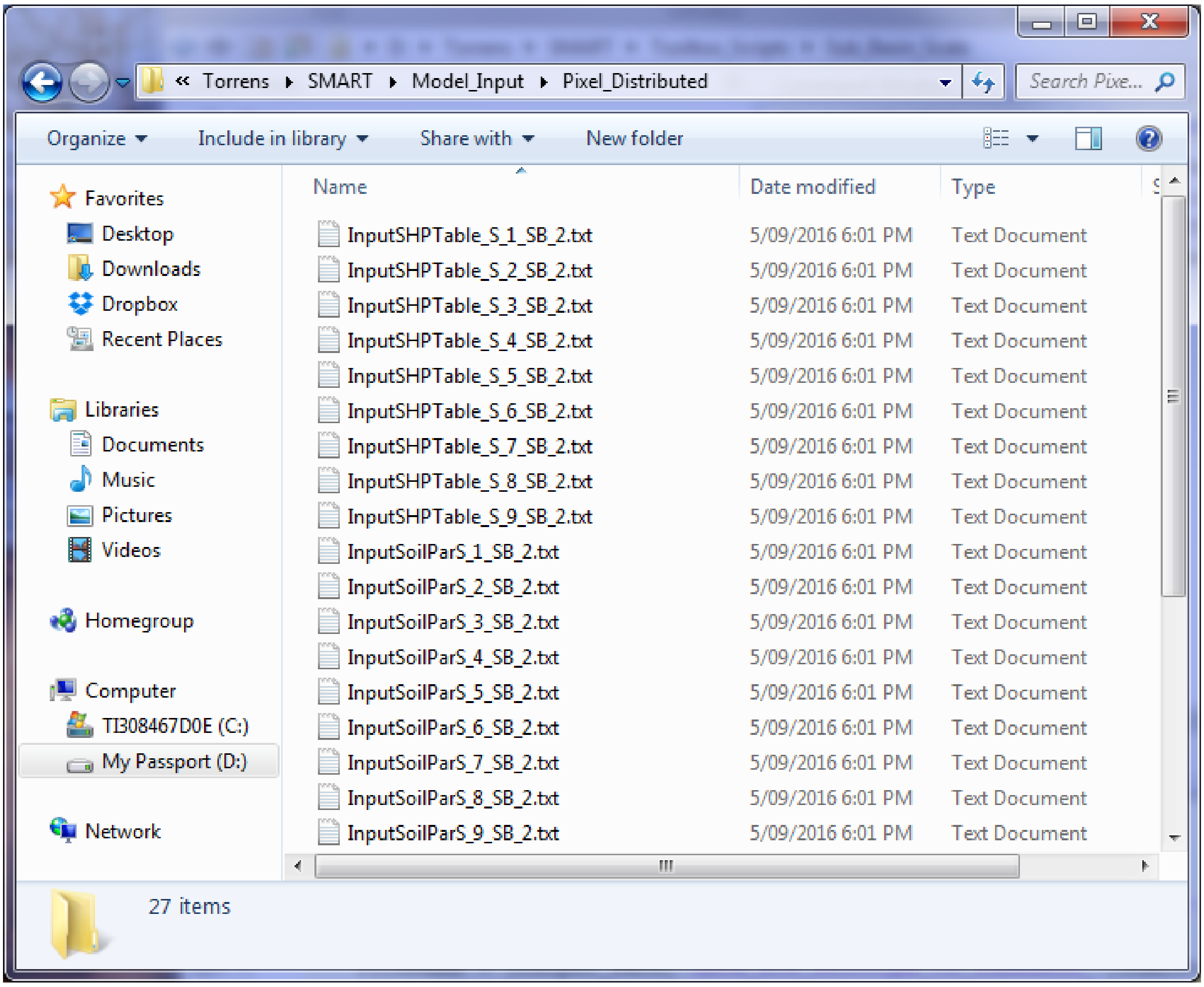


Figure 31. Soil hydraulic properties files for the distributed pixel based cross section delineation. Nine (InputSHPTable_S_(cross section number)_SB_(sub-basin unique number).txt) and nine InputSoilParS_(cross section number)_SB_(sub-basin unique number).txt files are generated for the sub-basin 2. The number of soil parameter files should be equal to the number of pixel files for a particular sub-basin.

3.2.2. Generate Soil Parameter Files for the Distributed Landform Cross Section Delineation

Open the **Step7_CreateSoilPar_Files_Sub_Basin.m** script and click on the button on the menu bar.

Upon clicking on the Run button, the script asks to select a soil hydraulic model. Here, we are using the van Genuchten hydraulic model. Therefore, type 0 at the command prompt and click .

Select Hydraulic Model (van Genuchten = 0; Brooks and Corey =1; Vogel and Cislerova=2: 0

In the next step, the script asks to select the cross section delineation option. The value codes for cross section delineations are: 1 = Distributed Pixel based, 2 = Distributed landform based, 3 = 3 ECSs (headwater, left bank and right bank ECSs), and 4 = ECS Soil type. To generate soil parameter files for the distributed landform based cross section delineation, type 2 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 2

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click and the script asks you to enter the sub-basin identification number. Type 2 and click (Figure 32).

Select the Sub-basin ID for model simulation: 2

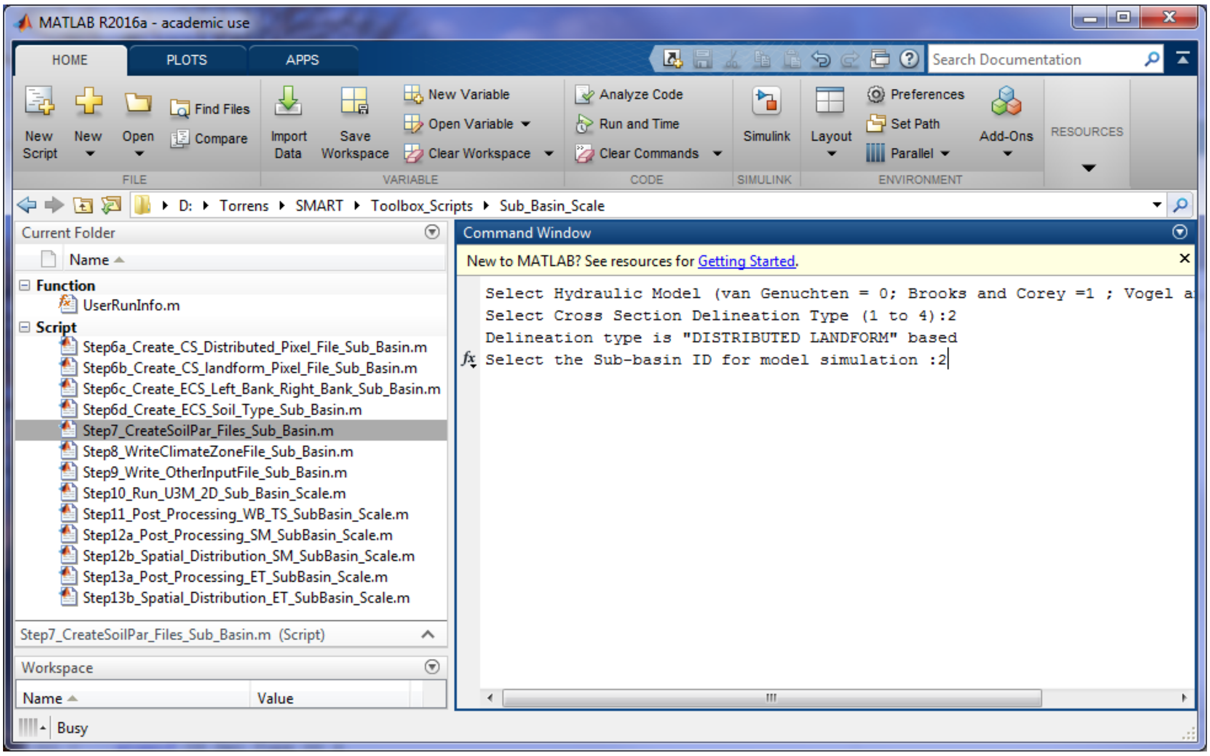


Figure 32. **Step7_CreateSoilPar_Files_Sub_Basin.m** dialog for creating soil parameter files for the distributed landform cross section delineation option.

Upon successful execution of the script, nine InputSHPTable_S_*_SB_(sub-basin unique number).txt and nine InputSoilParS_*_SB_(sub-basin unique number).txt are generated for the sub-basin 2 (Figure 33).

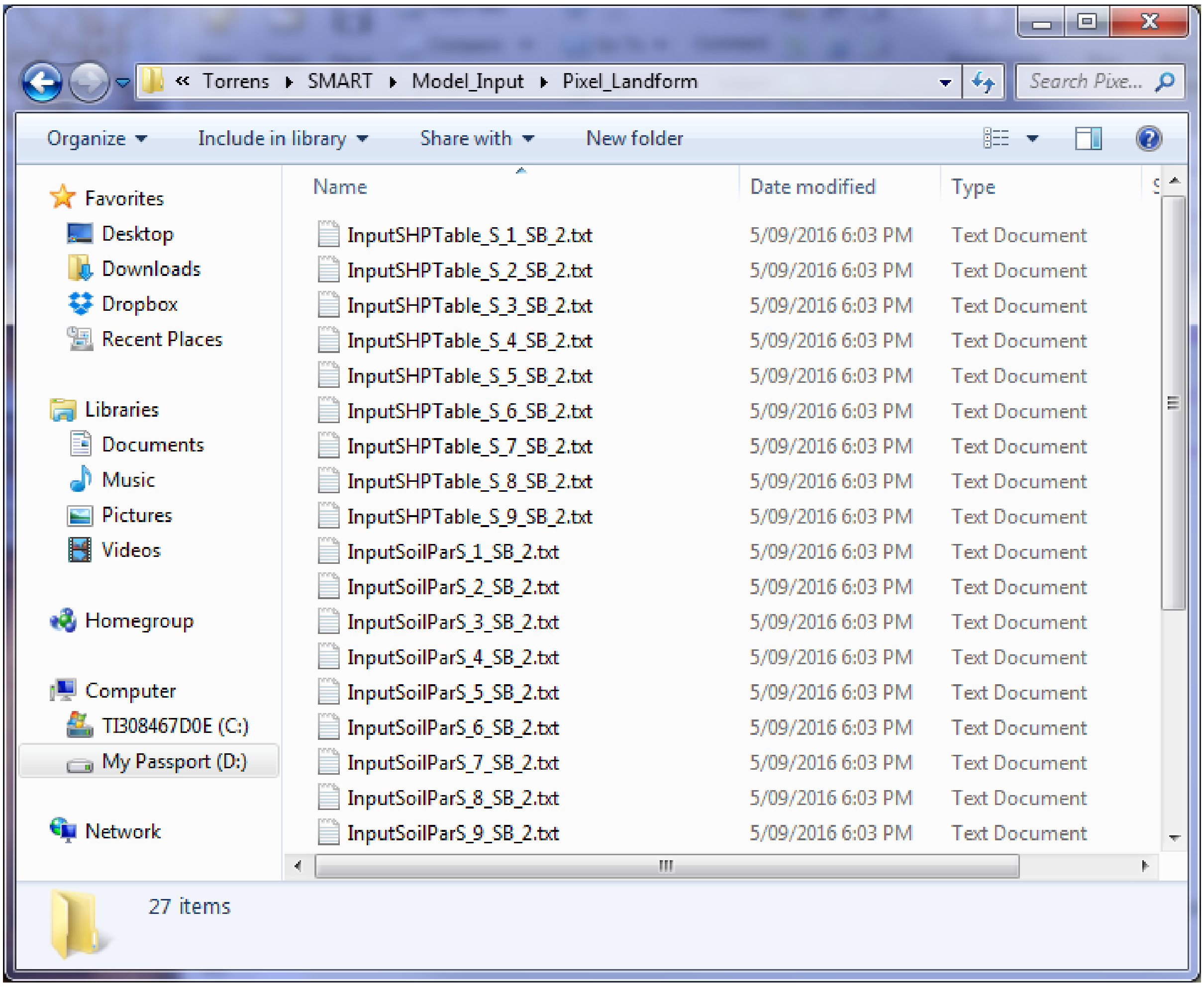


Figure 33. Soil hydraulic properties files for the distributed landform cross section delineation. Nine (InputSHPTable_S_*_SB_(sub-basin unique number).txt) and nine (InputSoilParS_*_SB_(sub-basin unique number).txt) files are generated for the sub-basin 2.

3.2.3. Generate Soil Parameter Files for the Headwater/Left Bank/Right Bank ECSs Delineation

Open the **Step7_CreateSoilPar_Files_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to select a soil hydraulic model. Here, we are using the van Genuchten hydraulic model. Therefore, type 0 at the command prompt and click 

.

Select Hydraulic Model (van Genuchten = 0; Brooks and Corey =1; Vogel and Cislerova=2: 0

In the next step, the script asks to select the cross section delineation option. The value codes for cross section delineations are: 1 = Distributed Pixel based, 2 = Distributed landform based, 3 = 3 ECSs (headwater, left bank and right bank ECSs), and 4 = ECS Soil type. To generate soil parameter files for the 3 ECSs delineation option, type 3 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 3

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 34).

Select the Sub-basin ID for model simulation: 2

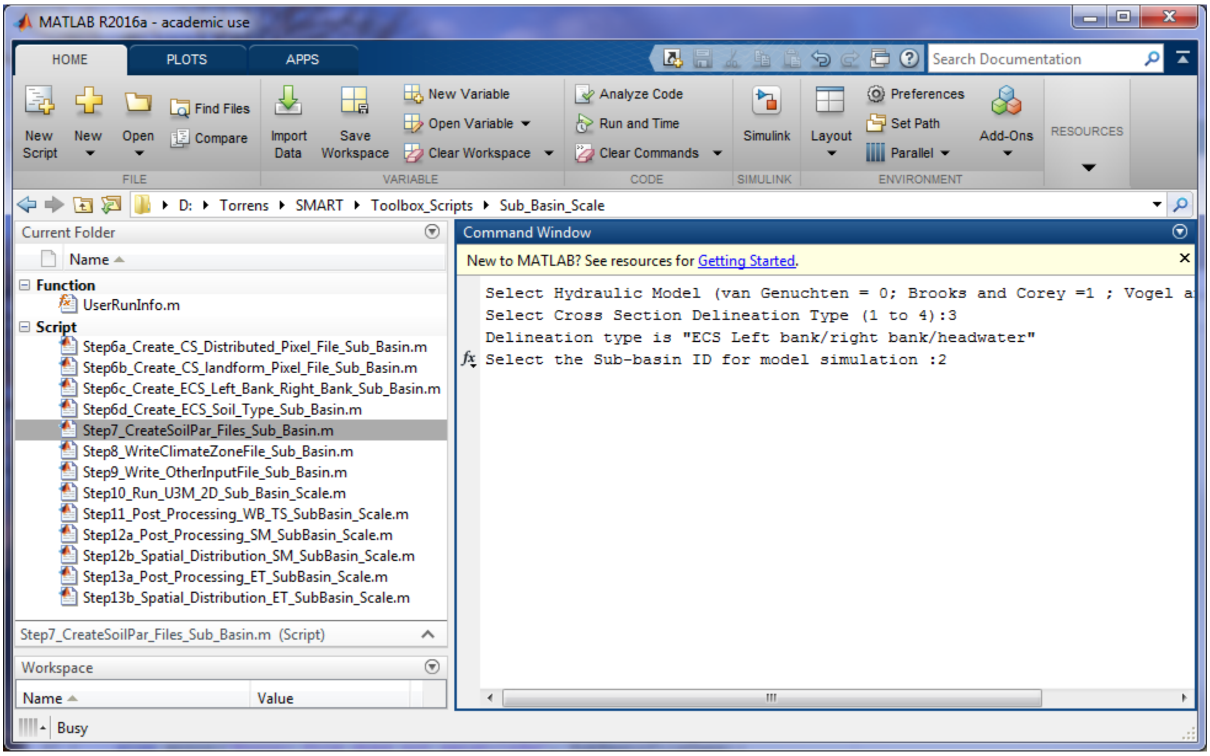


Figure 34. Step7_CreateSoilPar_Files_Sub_Basin.m dialog for creating soil parameter files for the 3 ECSs delineation option.

Upon successful execution of the script, three InputSHPTable_S_*_SB_2.txt and three InputSoilParS_*_SB_2.txt are generated for the sub-basin 2 (Figure 35).

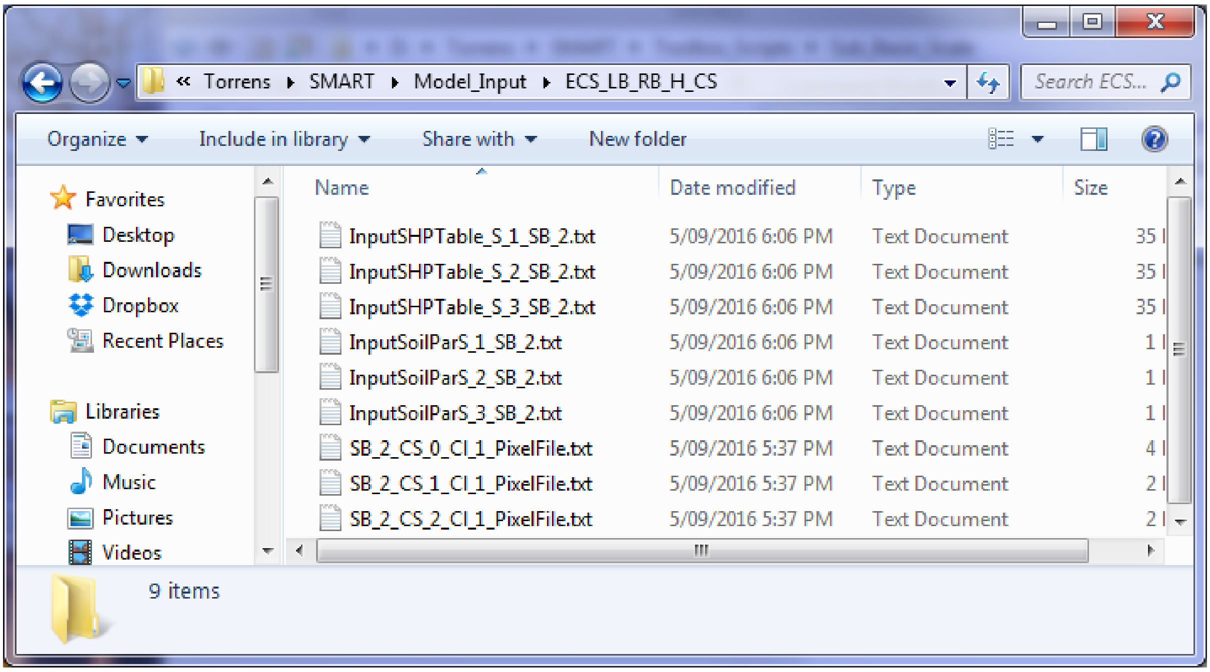


Figure 35. Soil hydraulic properties files for the 3 ECSs delineation. Three (InputSHPTable_S_*_SB_2.txt) and three (InputSoilParS_*_SB_2.txt) files are generated for the sub-basin 2. The number of soil parameter files should be equal to the number of pixel files in a sub-basin.

3.2.4. Generate Soil Parameter Files for the ECS Soil Type Cross Section Delineation

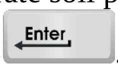
Open the **Step7_CreateSoilPar_Files_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to select a soil hydraulic model. Here, we are using the van Genuchten hydraulic model. Therefore, type 0 at the command prompt and click 

.

Select Hydraulic Model (van Genuchten = 0; Brooks and Corey =1; Vogel and Cislerova=2: 0

In the next step, the script asks to select the cross section delineation option. The value codes for cross section delineations are: 1 = Distributed Pixel based, 2 = Distributed landform based, 3 = 3 ECSs (headwater, left bank and right bank ECSs), and 4 = ECS Soil type. To generate soil parameter files for the ECS soil type option, type 4 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 4

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 36).

Select the Sub-basin ID for model simulation: 2

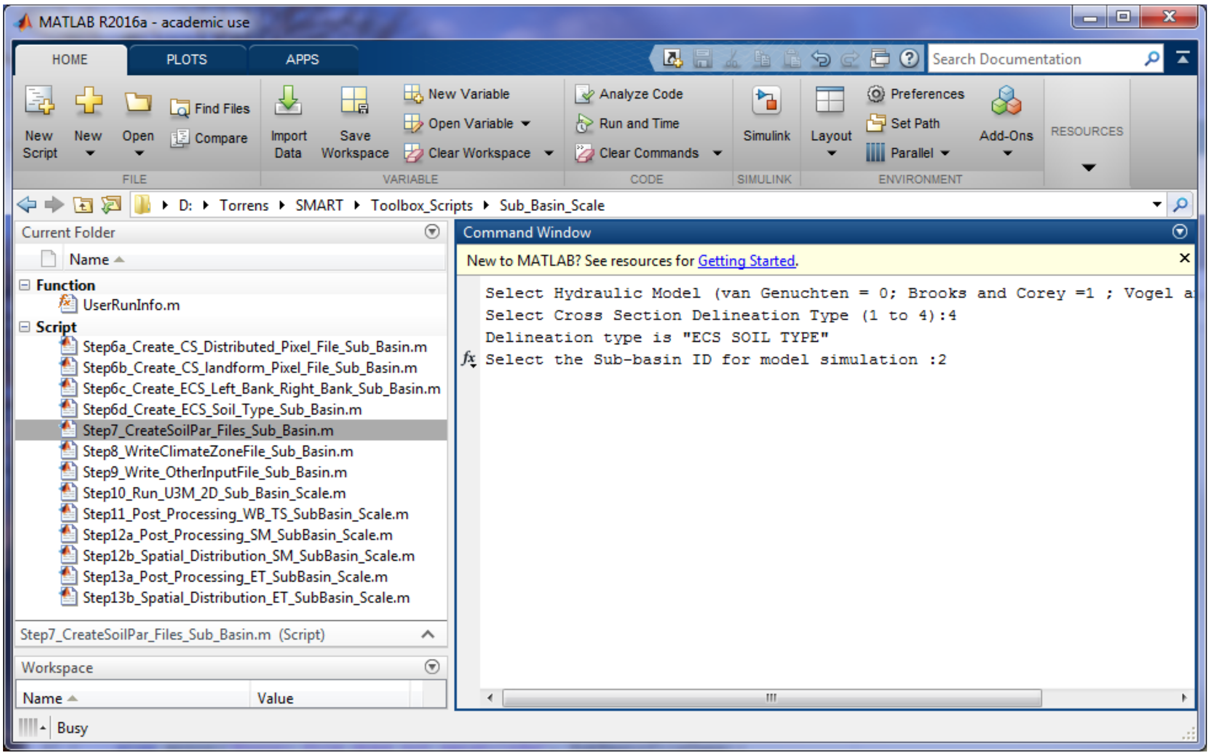


Figure 36. Step7_CreateSoilPar_Files_Sub_basin.m dialog for creating soil parameter files for the ECS soil type delineation.

Upon successful execution of the script, one InputSHPTable_S_1_SB_2.txt and one InputSoilParS_1_SB_2.txt are generated for the sub-basin 2 (Figure 37).

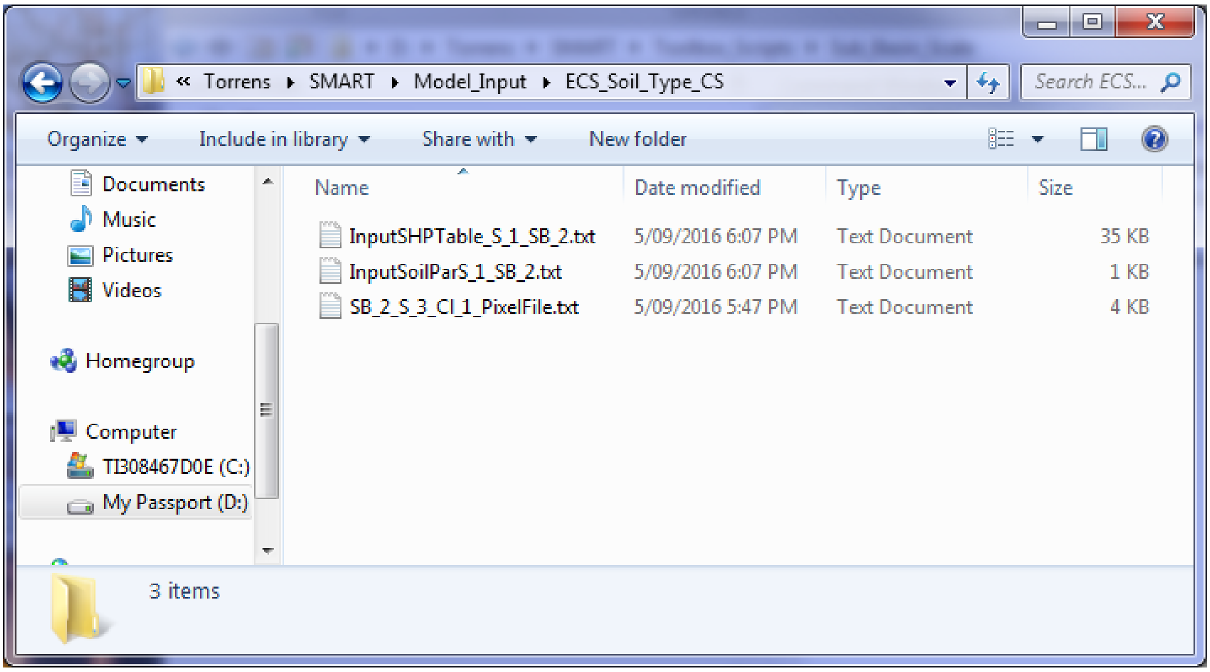


Figure 37. Soil hydraulic properties files for the ECS Soil Type delineation. One (InputSHPTable_S_1_SB_2.txt) and one (InputSoilParS_1_SB_2.txt) file are generated for the sub-basin 2.

3.3. Write Climate Zone Files

Open the **Step8_WriteClimateZoneFile_Sub_Basin.m** script to generate the climatezone.txt file for every climate zone in a select sub-basin. The ClimateZone.txt file includes information about the climate zone, daily precipitation, potential understory and overstory transpiration and potential soil evaporation.

Inputs:

- Monthly LAI climatology for tree, crop and pasture landcover classes (*.csv). The data file should be stored in the (…\SMART\Toolbox_Parameter_Files\) folder.

- Climate time series input file in the (…\SMART\Toolbox_Input) folder.

  ⚠ **Note:** If you are using pan evaporation data instead of PET, set the pan evaporation coefficient in **UserRunInfo.m** script to a value ranging between 0.8 to 0.9 (Vaze et al., 2004).

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); and 4 = ECS soil type). Depending on the cross section delineation option, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.

- Sub-basin identification number.

3.3.1. Generate Climate Zone Files for the Distributed Pixel based Cross Section Delineation

Open the **Step8_WriteClimateZoneFile_Sub_Basin.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to select the cross section delineation option. Type 1 for the distributed pixel based cross section delineation option and click .

Select Cross Section Delineation Type (1 to 4): 1

In the next step, the script asks to enter the name of the Monthly LAI climatology data file. In this tutorial, we are using the default parameter file provided in the toolbox. Type Monthly_LAI.csv and click .

Input Monthly LAI climatology file (.csv): Monthly_LAI.csv

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 38).
Select the Sub-basin ID for model simulation: 2

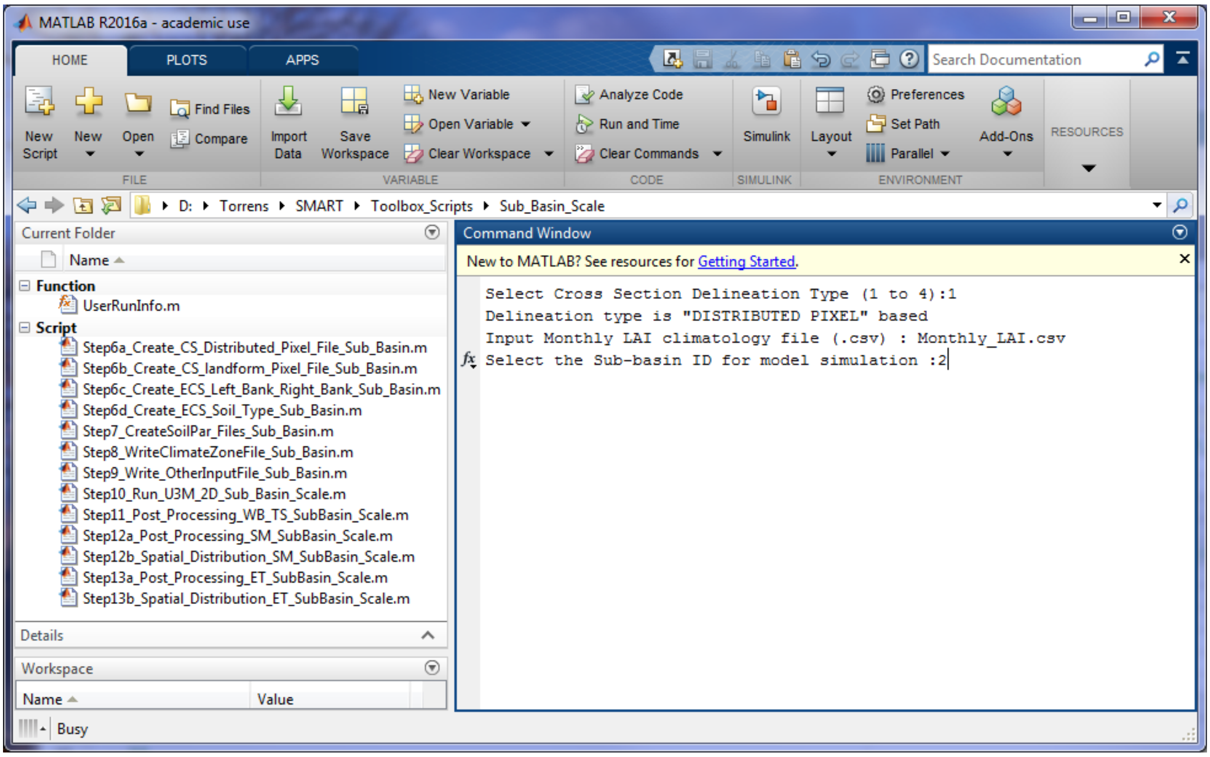


Figure 38. Step8_WriteClimateZoneFile_Sub_Basin.m dialog for creating climate zone files for the distributed pixel based delineation option.

In the next step, the script asks to enter the name of climate input time series file which is stored in the Toolbox_Input folder. Type Input_Climate.csv and click 

(Figure 39).

Input climate input file (.csv) for zone 1: Input_Climate.csv

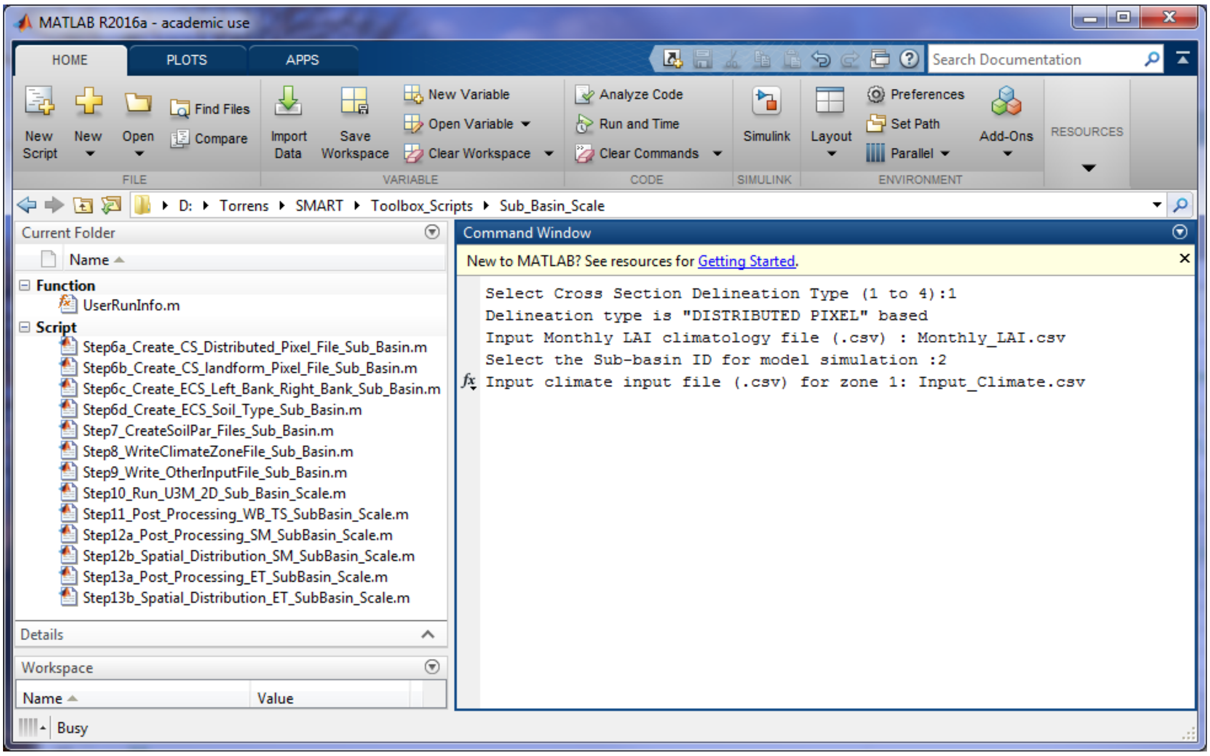


Figure 39. Step8_WriteClimateZoneFile_Sub_Basin.m dialog for creating climate zone files.

Outputs (...\SMART\Model_Input\Pixel_Distributed)**:**

- A climate zone file for every climate zone in the sub-basin. The file name is ClimateZone_Cl_(zone number)_(sub-basin unique number).txt and it is stored in the (...\Model_Input\ Pixel_Distributed) folder.

As there is only one climate zone in the catchment, one climate zone file is generated **(ClimateZone_Cl_1_2.txt). Copy** the ClimateZone_Cl_1_2.txt file from the (…\SMART\Model_Input\Pixel_Distributed) folder to the other three folders below:

…\SMART\Model_Input\Pixel_landform
…\SMART\Model_Input\ECS_LB_RB_H_CS
…\SMART\Model_Input\ECS_Soil_Type_CS

Now we have the climate time series files for all the cross section delineations.

3.4. Write Other Input Parameter File

The other input parameter file contains time step related parameters, root distribution and soil evaporation parameters. The **Step9_Write_OtherInputFile_Sub_Basin.m** script writes the other input parameter file for every cross section in a select sub-basin. The parameter files are stored in the (…\SMART\Model_Input) folder depending on the cross section delineation option.

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); and 4 = ECS soil type). Depending on the cross section delineation option and selected sub-basin, the script reads the cross section database file from the (…\SMART\Toolbox_Output) folder.

- Initial soil moisture condition

- Rainfall bands [mm/day] and time step bands [sec], otherwise default values are used.

- Root distribution file should be present in the parameter files folder (…\SMART\Toolbox_Parameter_Files\). A user defined root distribution parameter file should be stored in the (…\SMART\Toolbox_Parameter_Files\) folder and the file name must be written in the **UserRunInfo.m** script.

3.4.1. Write Other Input Parameter File for the Distributed Pixel based Cross Section Delineation

In this step, we generate the Input Parameter files for the distributed pixel based cross section delineation option.

Open the **Step9_Write_OtherInputFile_Sub_Basin.m** script and click on the button on the menu bar.

Upon clicking on the Run button, the script asks to enter the initial soil moisture content for the soil material 1 (top layer). We will use the value of 0.6 for all the soil materials. Type 0.6 and click .

Parameter for initial soil moisture content of material 1 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 2. We will use value of 0.6 again. Type 0.6 and click .

Parameter for initial soil moisture content of material 2 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 3. Type 0.6 and click .

Parameter for initial soil moisture content of material 3 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 4. Type 0.6 and click .

Parameter for initial soil moisture content of material 4 (0-1): 0.6

In the next step, the script asks to enter the Input Rainfall band. Just click 

so default values are chosen. Repeat this 5 times (Figure 40).

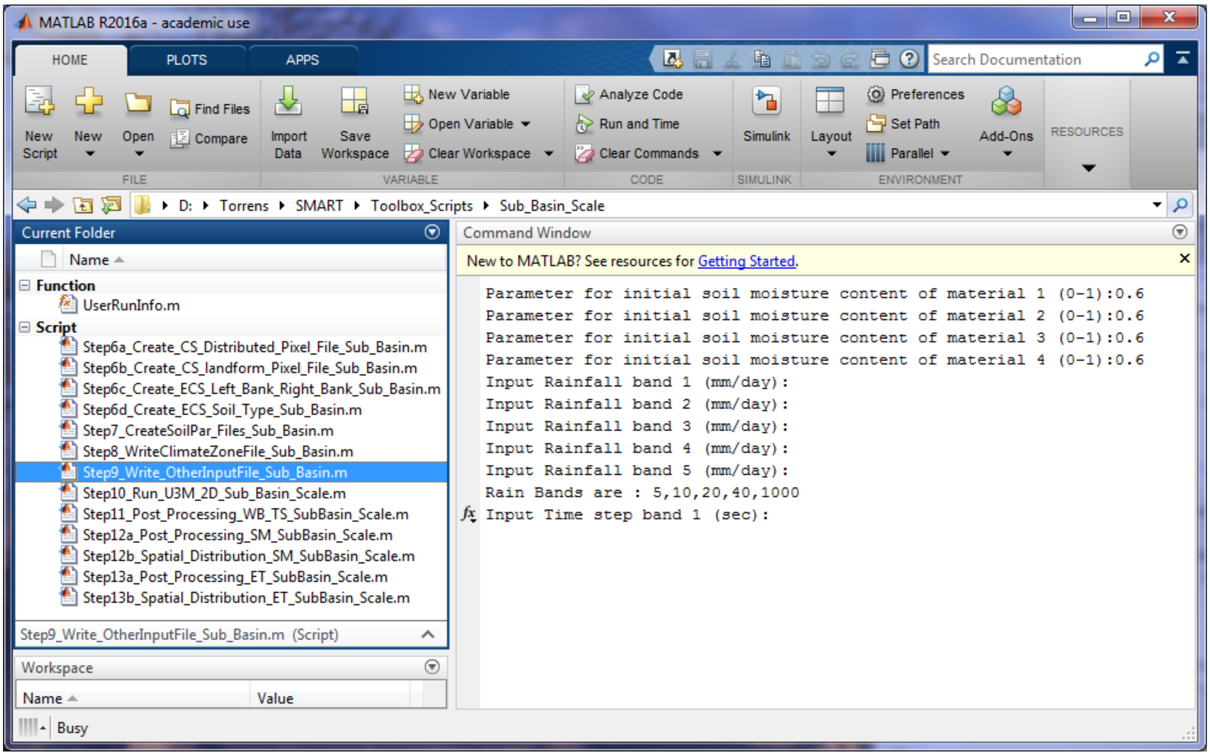


Figure 40. **Step9_Write_OtherInputFile_Sub_Basin.m** dialog

In the next step, the script asks to enter the Input Time Step band. Just click 

so default values are chosen. Repeat this 5 times (Figure 41).

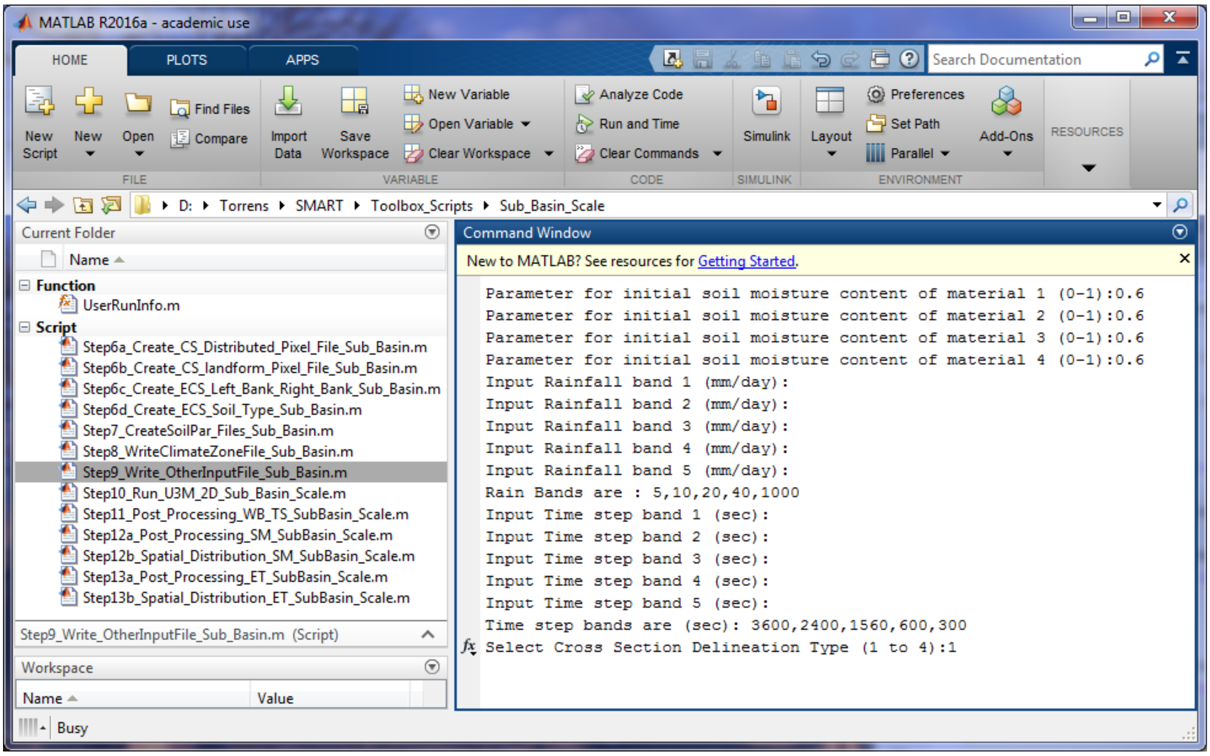


Figure 41. **Step9_Write_OtherInputFile_Sub_Basin.m** dialog

In the next step, the script asks to enter the cross section delineation option. Type 1 for the distributed pixel based cross section delineation and click 

.

Select Cross Section Delineation Type (1 to 4): 1

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click 

and the script asks you to enter the sub-basin identification number. Type 2 and click 

(Figure 42).

Select the Sub-basin ID for model simulation: 2

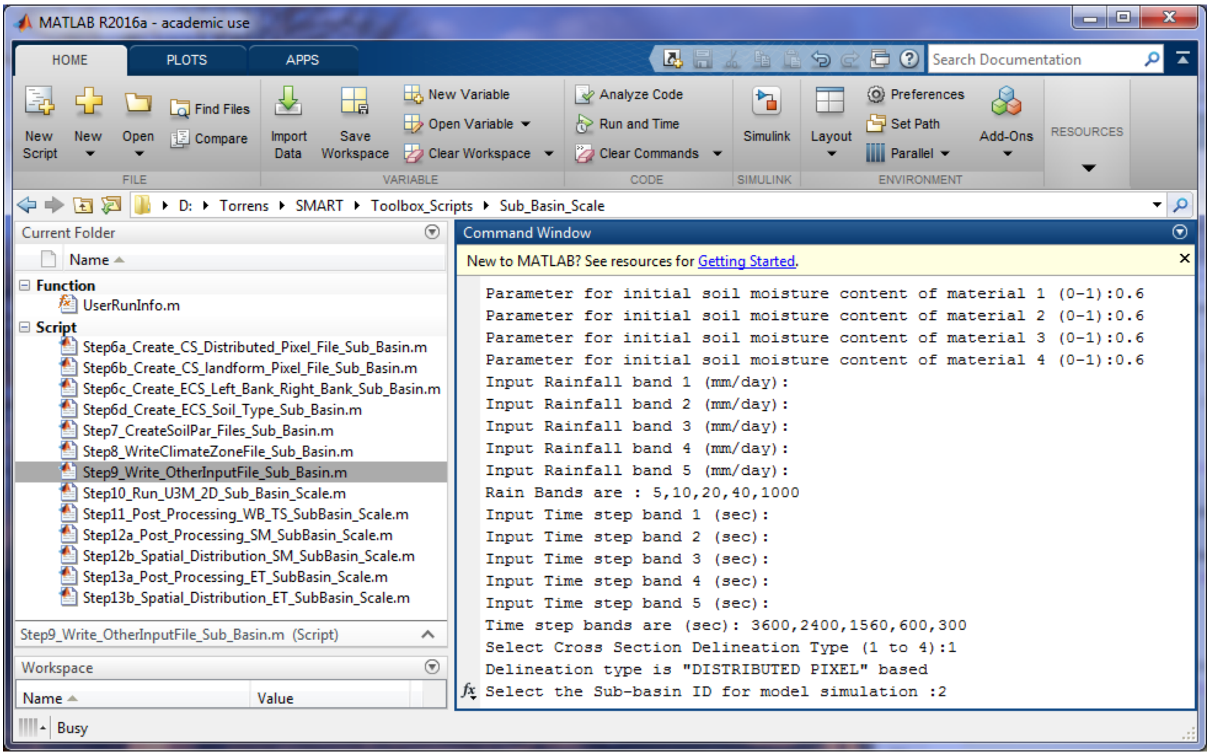


Figure 42. Step9_Write_OtherInputFile_Sub_Basin.m dialog for the distributed pixel cross section delineation.

Outputs:

- A cross section other Input file (InputOtherData_S_(cross section id)_SB_(sub-basin id).txt) for every cross section in the select sub-basin in (...\SMART\Model_Input\Pixel_distributed) folder.

Upon successful execution of the script, nine InputOtherData_S*_SB_2.txt files are generated.

3.4.2. Write Other Input Parameter File file for the Distributed Landform Cross Section Delineation

In this step, we generate the Other Input Parameter files for the distributed landform based delineation option.

Open the **Step9_Write_OtherInputFile_Sub_Basin.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the initial soil moisture content for the soil material 1 (top layer). We will use the value of 0.6 for all the soil materials. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 1 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 2. We will use value of 0.6 again. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 2 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 3. Type 0.6 and click Enter.

Parameter for initial soil moisture content of material 3 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 4. Type 0.6 and click Enter.

Parameter for initial soil moisture content of material 4 (0-1): 0.6

In the next step, the script asks to enter the Input Rainfall band. Just click Enter so default values are chosen. Repeat this 5 times (Figure 43).

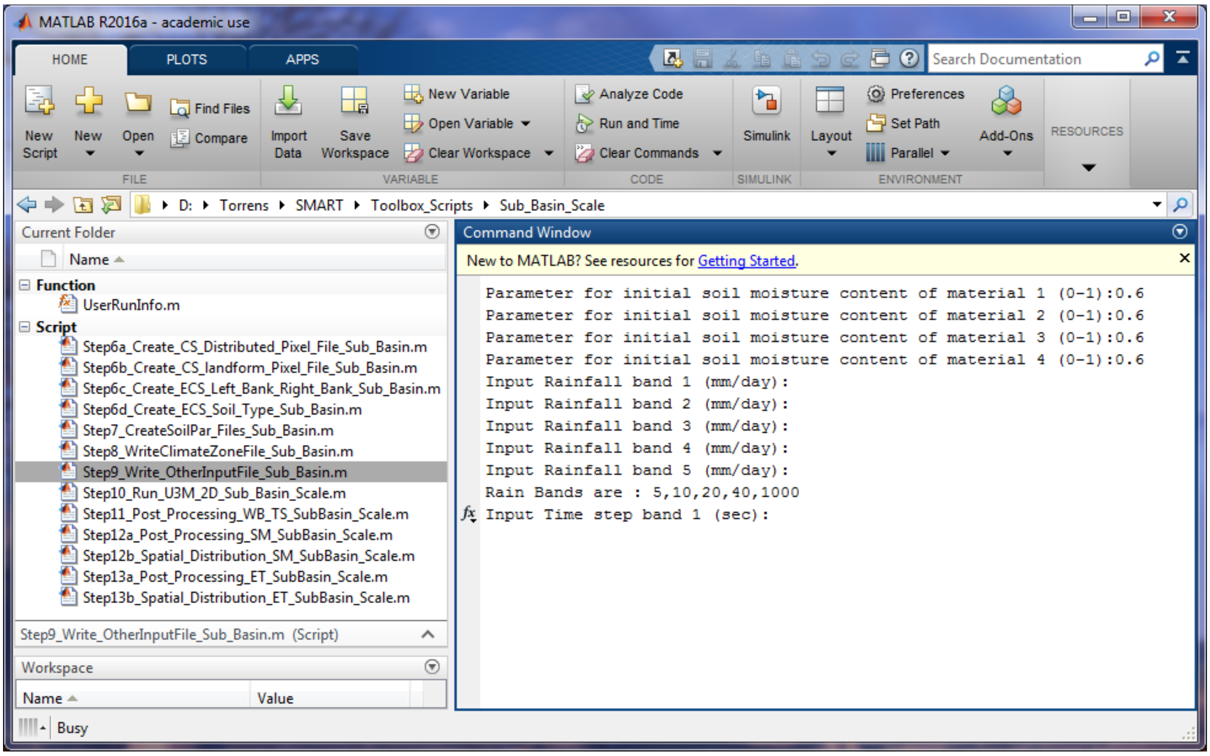


Figure 43. **Step9_Write_OtherInputFile_Sub_Basin.**m dialog

In the next step, the script asks to enter the Input Time Step band. Just click Enter so default values are chosen. Repeat this 5 times (Figure 44).

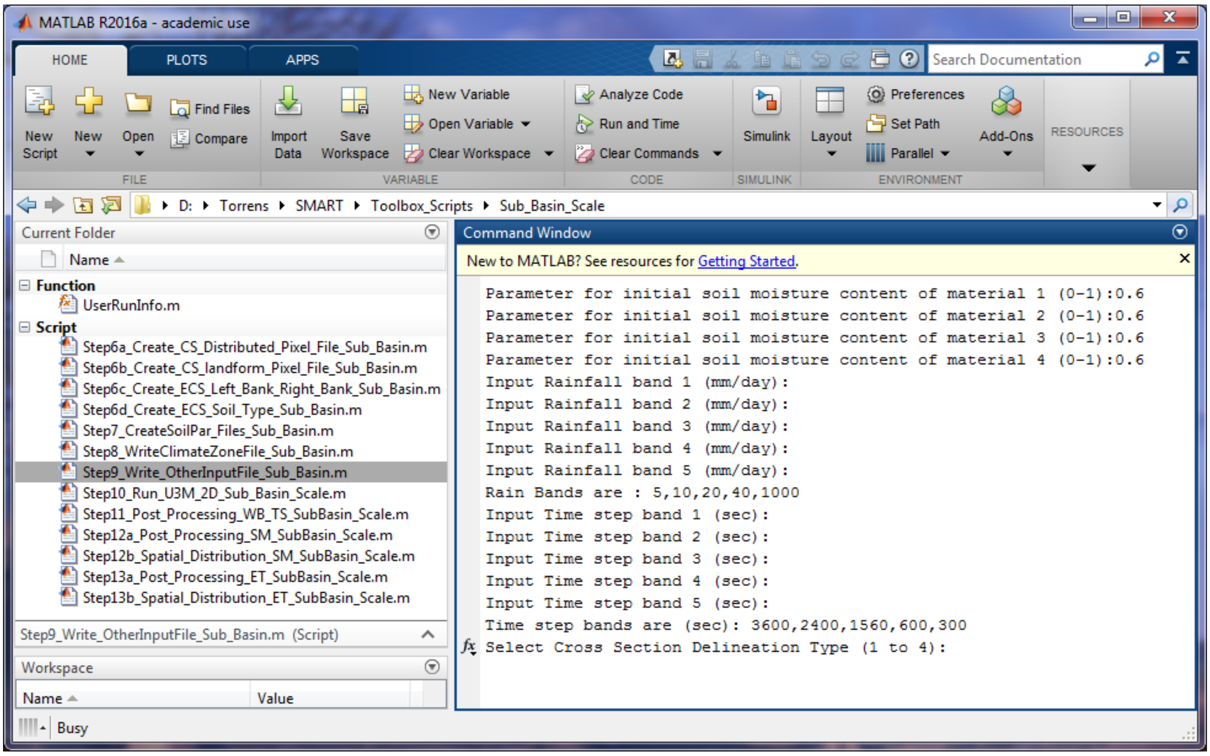


Figure 44. **Step9_Write_OtherInputFile_Sub_Basin**.m dialog

In the next step, the script asks to enter the cross section delineation option. Type 2 for the distributed landform based delineation option and click 

(Figure 45).

Select Cross Section Delineation Type (1 to 4): 2

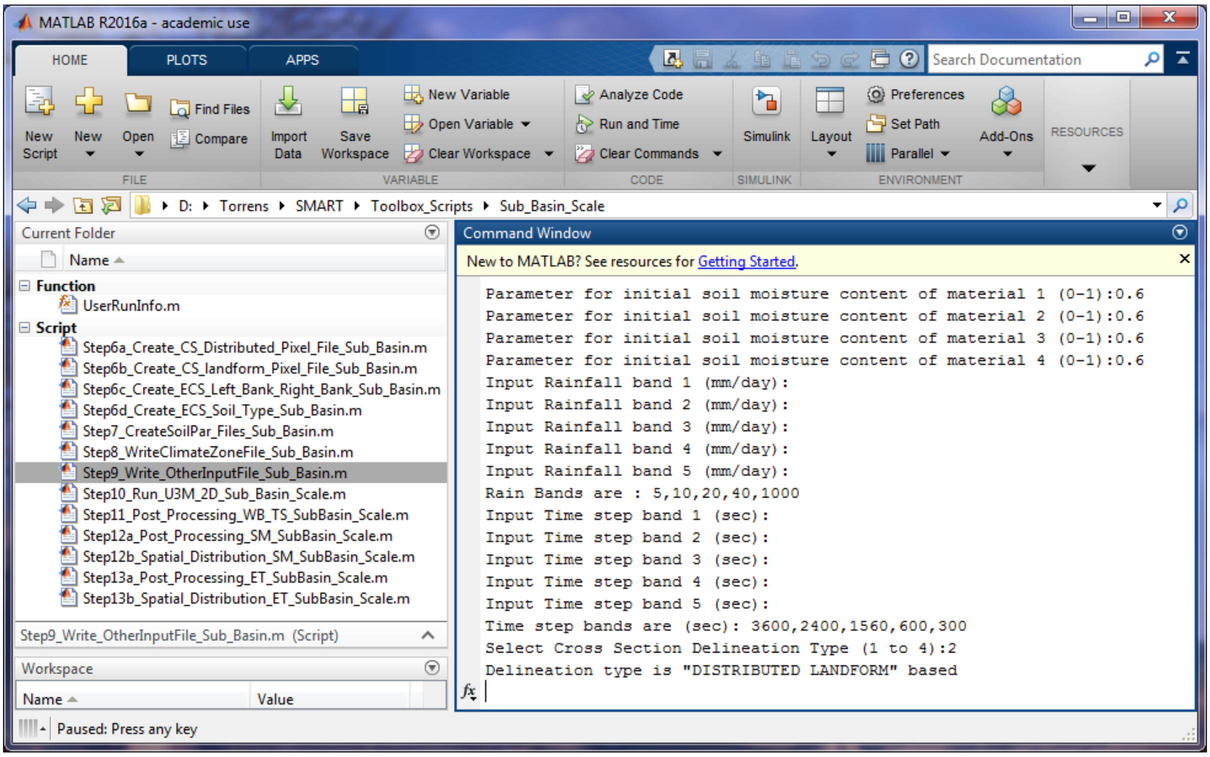


Figure 45. **Step9_Write_OtherInputFile_Sub_Basin**.m dialog
for the distributed landform cross section delineation.

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 46).

Select the Sub-basin ID for model simulation: 2

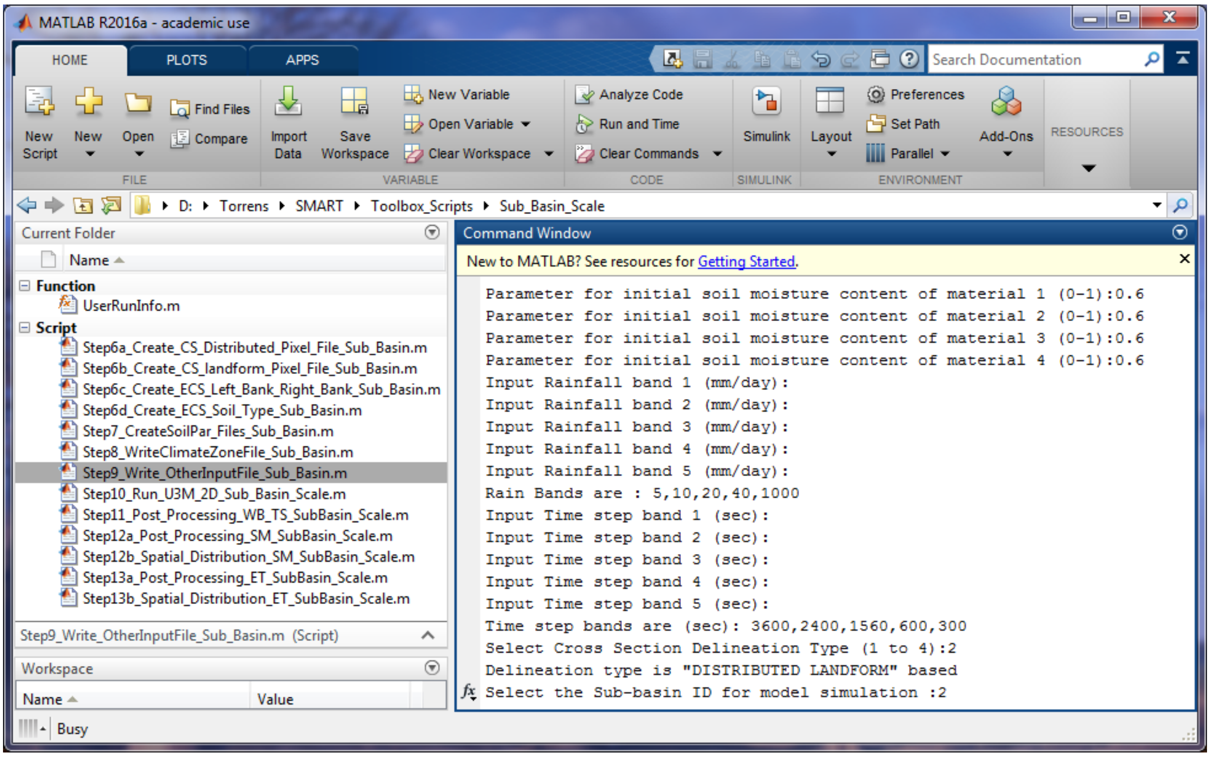


Figure 46. Step9_Write_OtherInputFile_Sub_Basin.m dialog for the distributed landform cross section delineation.

Outputs:

- A cross section other Input file (InputOtherData_S_(cross section id)_SB_(sub-basin unique number).txt) for every cross section in the select sub-basin in the (...\SMART\Model_Input\Pixel_Landform) folder.

Upon successful execution of the script, nine InputOtherData_S*_SB2.txt files are generated.

3.4.3. Write Other Input Parameter File file for the 3 ECSs Delineation

In this step, we generate the Other Input Parameter files for the 3 ECSs delineation option.

Open the **Step9_Write_OtherInputFile_Sub_Basin.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the initial soil moisture content for the soil material 1 (top layer). We will use the value of 0.6 for all the soil materials. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 1 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 2. We will use value of 0.6 again. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 2 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 3. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 3 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 4. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 4 (0-1): 0.6

In the next step, the script asks to enter the Input Rainfall band. Just click 

so default values are chosen. Repeat this 5 times (Figure 47).

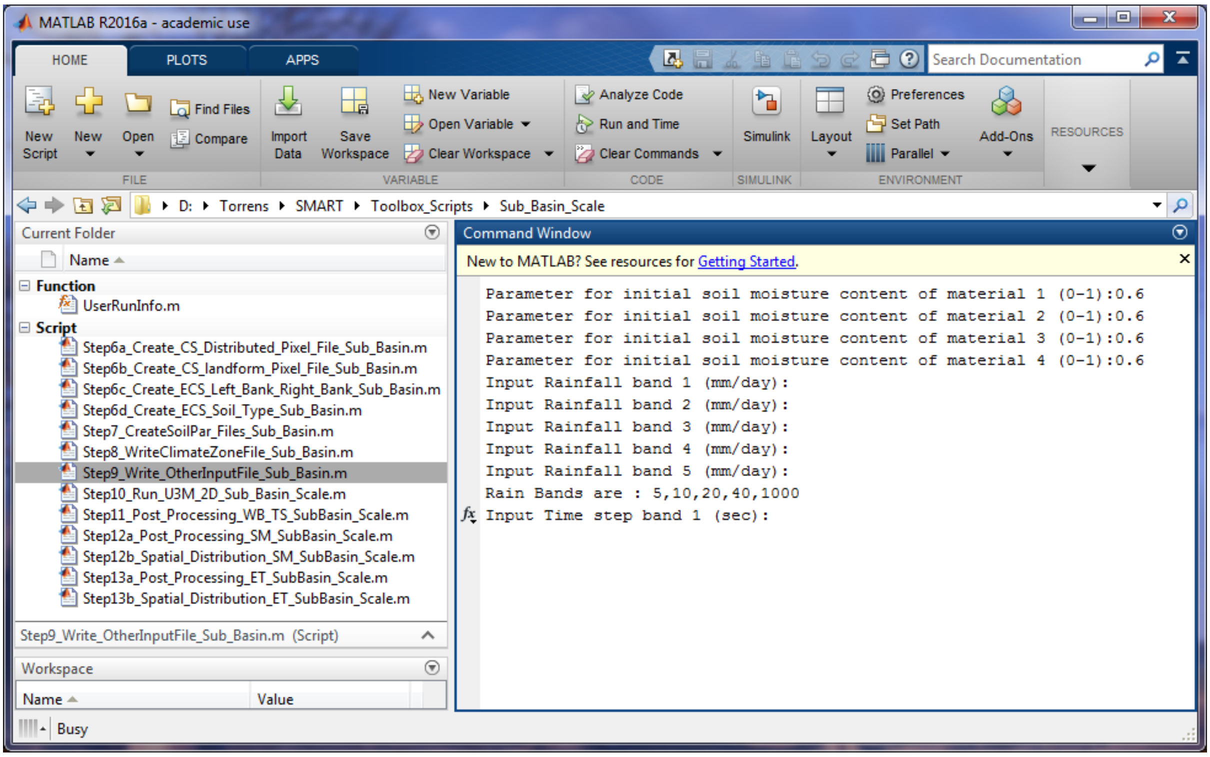


Figure 47. **Step9_Write_OtherInputFile_Sub_Basin.m** dialog

In the next step, the script asks to enter the Input Time Step band. Just click  so default values are chosen. Repeat this 5 times (Figure 48).

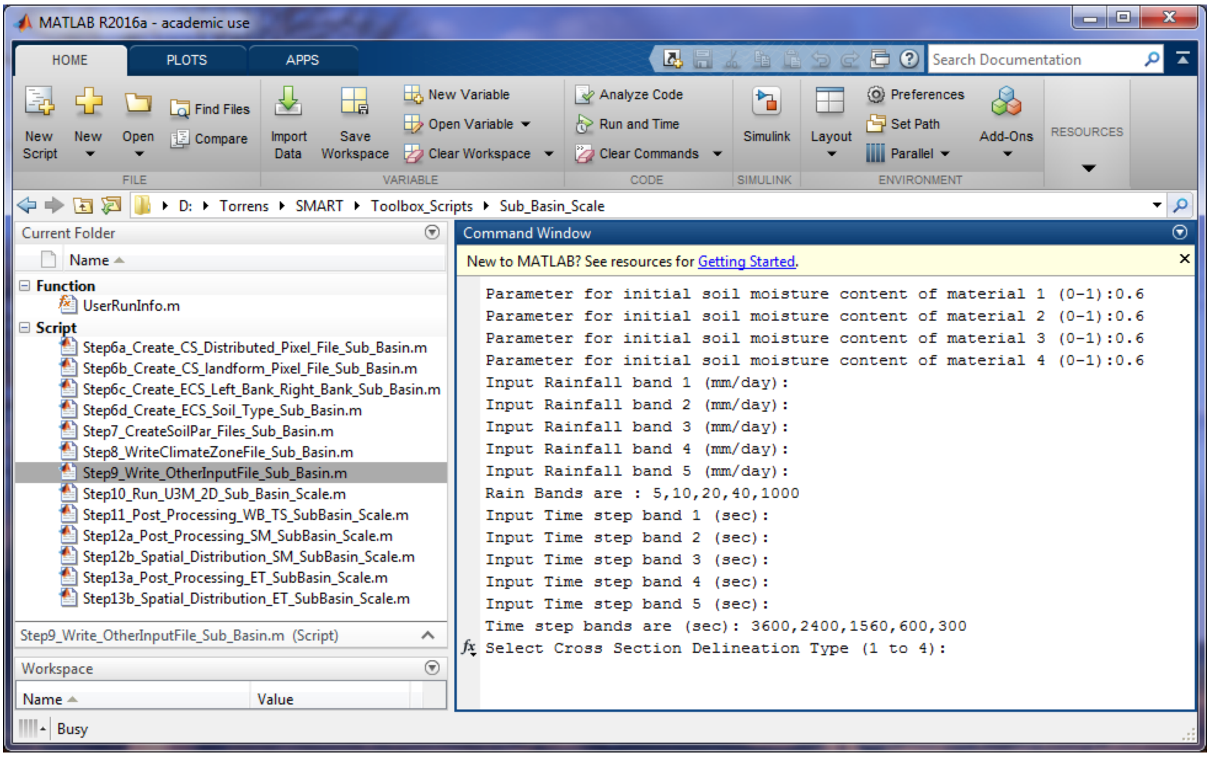


Figure 48. **Step9_Write_OtherInputFile_Sub_Basin.m** dialog

In the next step, the script asks to enter the cross section delineation option. Type 3 for the 3 ECSs delineation option and click .

Select Cross Section Delineation Type (1 to 4): 3

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 49).

Select the Sub-basin ID for model simulation: 2

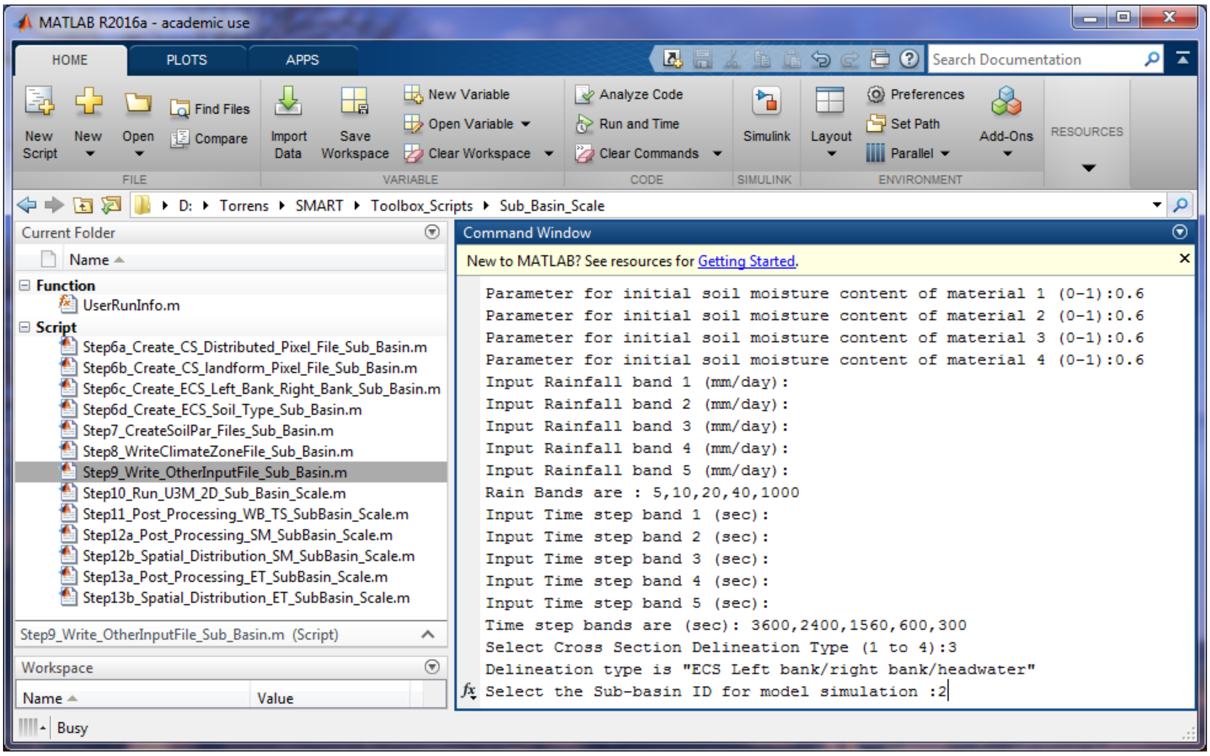


Figure 49. Step9_Write_OtherInputFile_Sub_Basin.m dialog for the 3 ECS delineation option.

Outputs:

- A cross section other Input file (InputOtherData_S_(cross section id)_SB_(sub-basin unique number).txt) for every cross section in the select sub-basin in (...\Model_Input\ECS_LB_RB_H_CS) folder

Upon successful execution of the script, 3 InputOtherData_S*_SB2.txt files are generated**.**

3.4.4. Write Other Input Parameter File for the ECS Soil Type Delineation

In this step, we generate the Other Input Parameter files for the ECS soil type delineation option.

Open the **Step9_Write_OtherInputFile_Sub_Basin.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the initial soil moisture content for the soil material 1 (top layer). We will use the value of 0.6 for all the soil materials. Type 0.6 and click .

Parameter for initial soil moisture content of material 1 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 2. We will use value of 0.6 again. Type 0.6 and click .

Parameter for initial soil moisture content of material 2 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 3. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 3 (0-1): 0.6

In the next step, the script asks to enter the initial soil moisture content for the soil material 4. Type 0.6 and click 

.

Parameter for initial soil moisture content of material 4 (0-1): 0.6

In the next step, the script asks to enter the Input Rainfall band. Just click 

so default values are chosen. Repeat this 5 times (Figure 50).

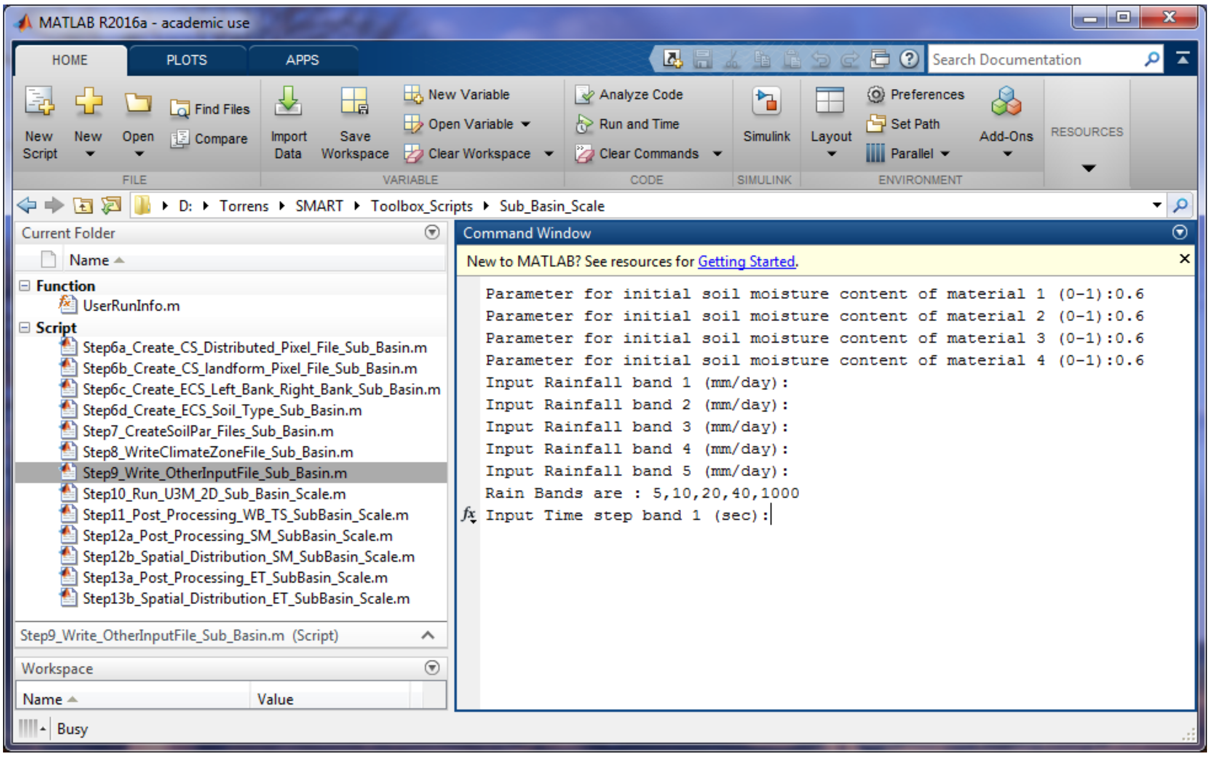


Figure 50. Step9_Write_OtherInputFile_Sub_Basin.m dialog.

In the next step, the script asks to enter the Input Time Step band. Just click 

so default values are chosen. Repeat this 5 times (Figure 51).

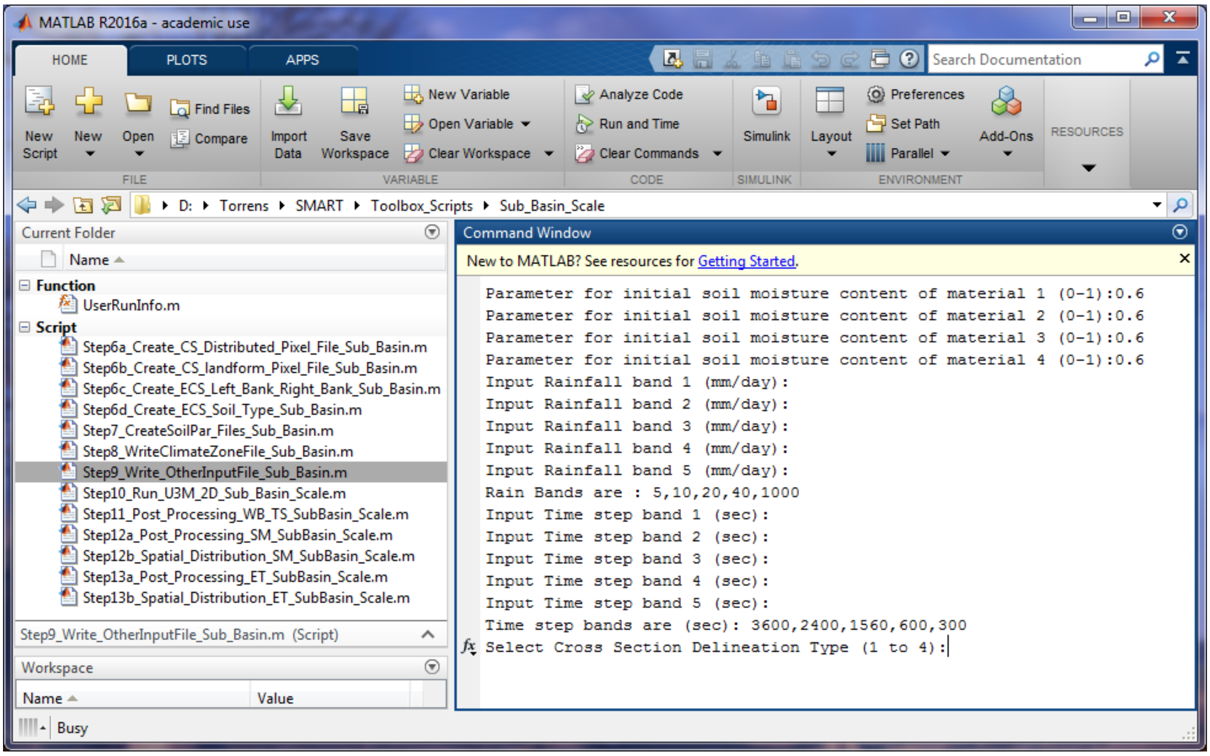


Figure 51. Step9_Write_OtherInputFile_Sub_Basin.m dialog.

In the next step, the script asks to enter the cross section delineation option. Type 4 for the ECS soil type delineation option and click Enter.

Select Cross Section Delineation Type (1 to 4): 4

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click Enter and the script asks you to enter the sub-basin identification number. Type 2 and click Enter (Figure 52).

Select the Sub-basin ID for model simulation: 2

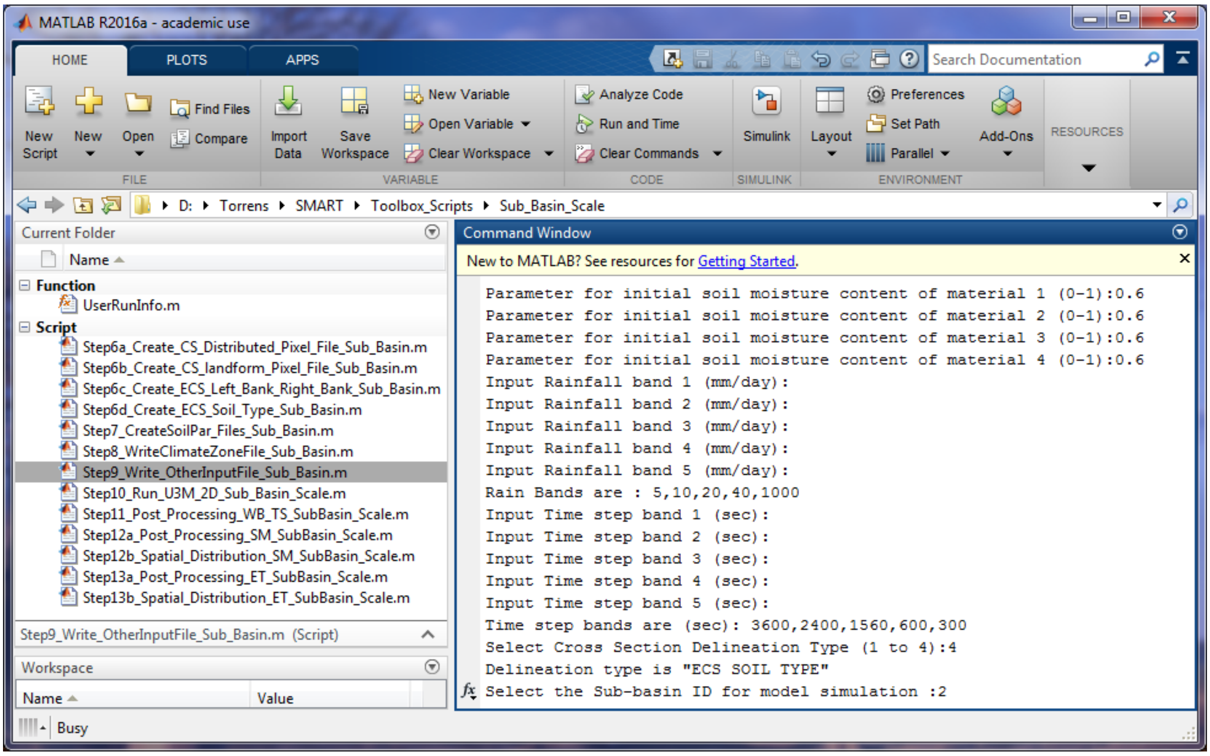


Figure 52. Step9_Write_OtherInputFile_Sub_Basin.m dialog for the ECS Soil Type delineation.

Outputs:

- A cross section other Input file (InputOtherData_S_(cross section id)_SB_(sub-basin unique number).txt) for every cross section in the selected sub-basin in the (...\SMART\Model_Input\ECS_Soil_Type_CS) folder.

Upon successful execution of the script, one InputOtherData_S*_SB2.txt file is generated.

4. Perform Model Simulations

In this tutorial, we perform model simulations for the selected sub-basin in the Waterfall Gully catchment in South Australia. The objective is to compare the results of four cross section delineation approaches in terms of water balance calculations at the sub-basin scale.

The **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script controls model simulations across all the cross sections delineated for a sub-basin. The user must enter the cross section delineation option, number of processors and the sub-basin identification number upon running the script.

Inputs:

- Cross section delineation option (1 = distributed pixel based; 2 = distributed landform based; 3 = 3 ECSs (headwater, left bank and right bank ECSs); and 4 = ECS soil type). The script reads the cross section database file from the (…\SMART\Toolbox_Output) folder depending on the cross section delineation option.

- Number of processors for parallel processing

- Sub-Basin identification number

4.1. Step10_Run_U3M_2D_Sub_Basin_Scale.m for the Distributed Pixel based Cross Section Delineation

Now that all the model input files are generated, we start model simulations. Open the **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. First, we are going to perform model simulations for the distributed pixel based cross section delineation. Type 1 at the command prompt and click  (Figure 53).

Select Cross Section Delineation Type (1 to 4): 1

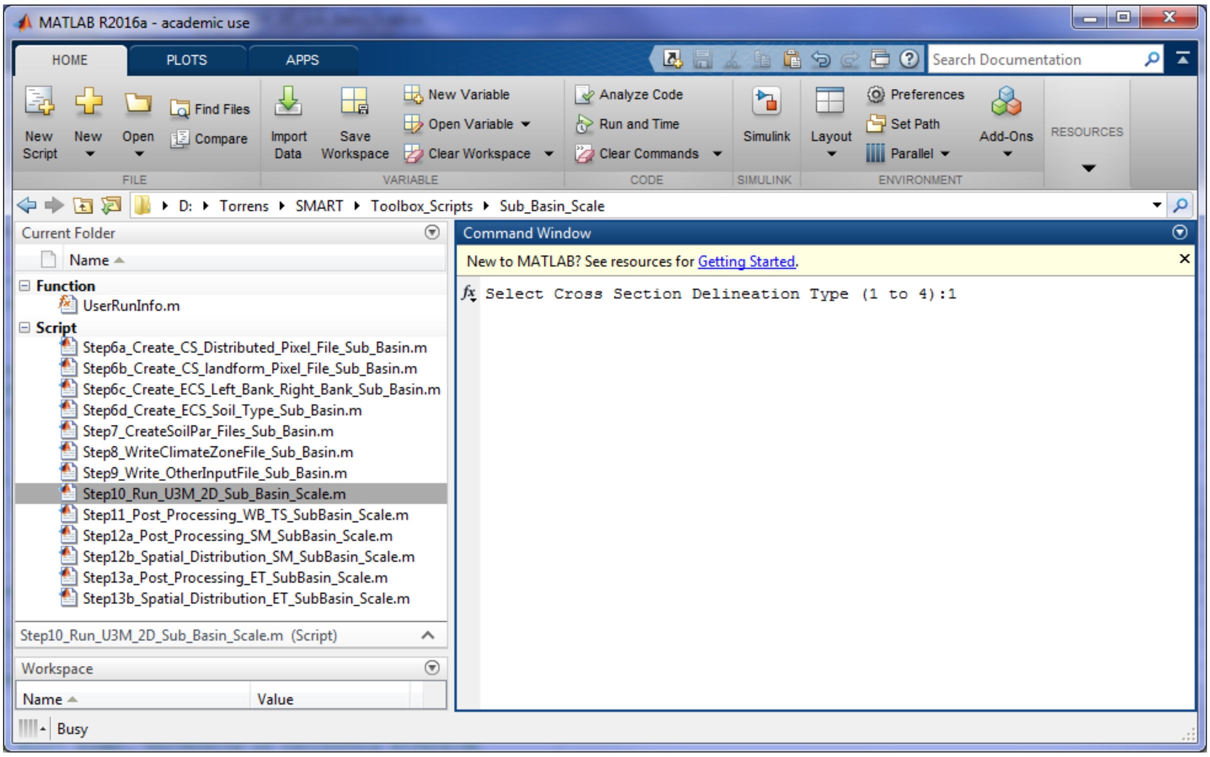


Figure 53. Step10_Run_U3M_2D_Sub_Basin_Scale.m dialog

In the next step, the script asks to enter the number of processors. This depends on the number of cores in your computer. Here we are using two processors. Type 2 and click .

Enter number of processors: 2

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number (Figure 54).

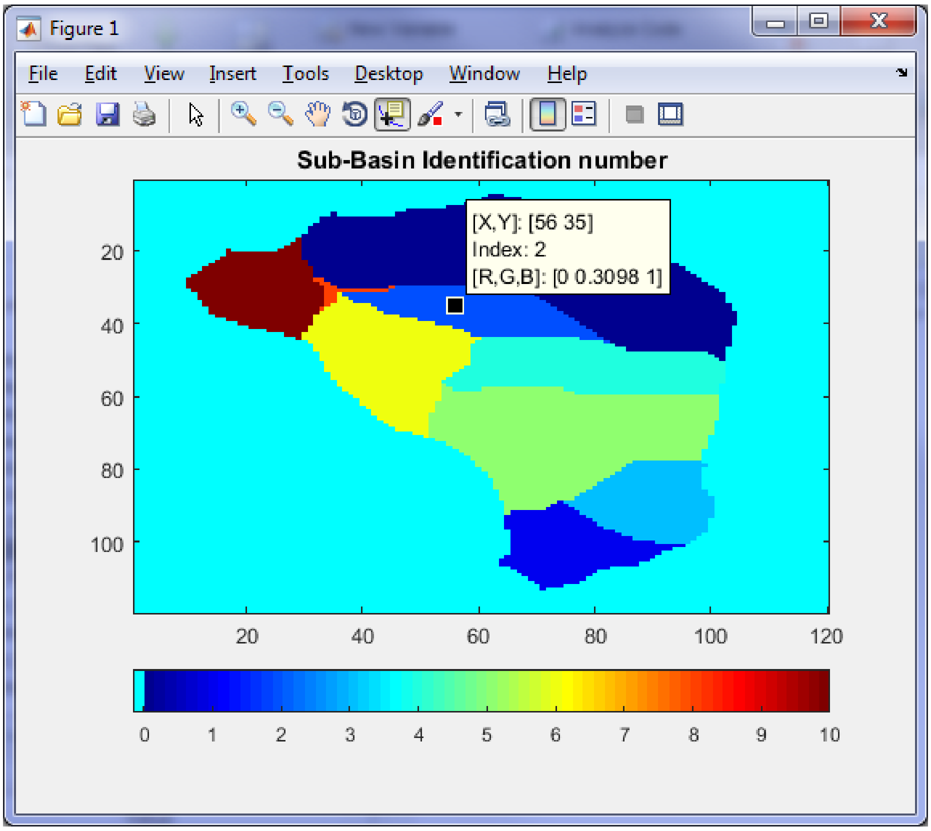


Figure 54. Sub-basin identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click Enter and the script asks you to enter the sub-basin identification number. Type 2 and click Enter (Figure 55).

Select the Sub-basin ID for model simulation: 2

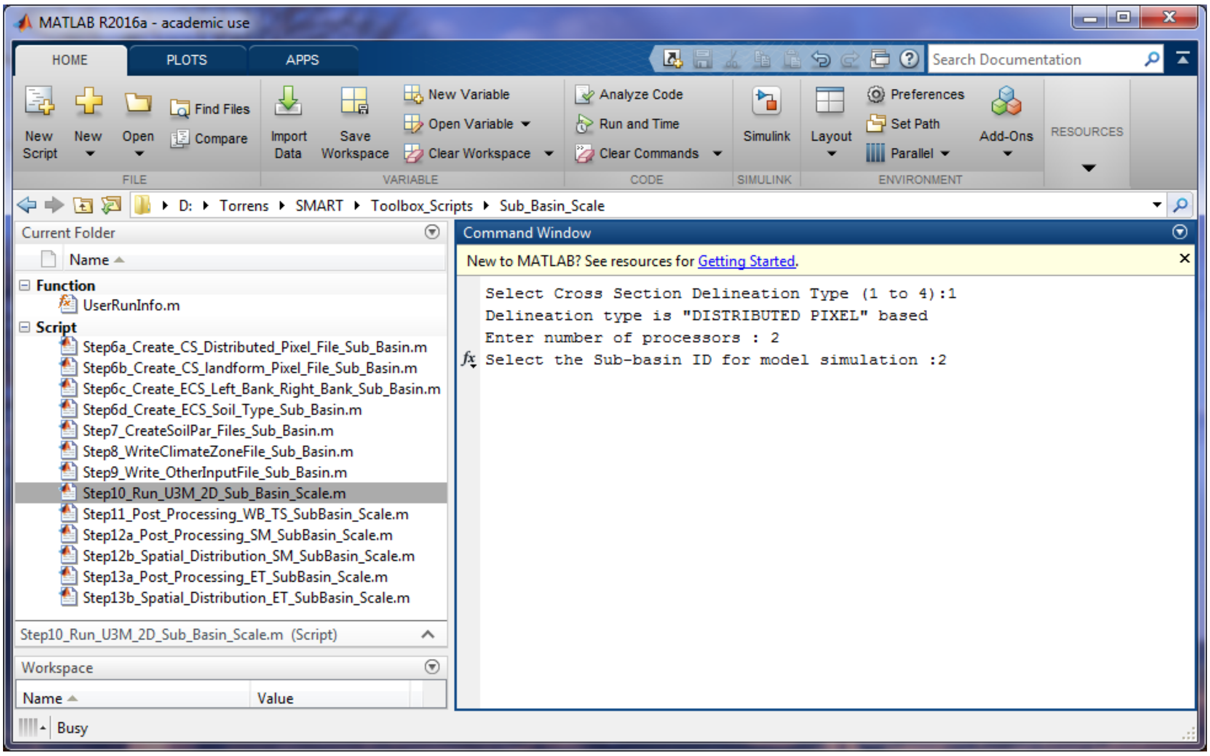


Figure 55. Step10_Run_U3M_2D_Sub_Basin_Scale.m dialog

If everything is set-up properly and there is no error in model input files, U3M-2D will start the simulations. You will see simulation days and pixel numbers in the MATLAB command window as the simulation progress (Figure 56).

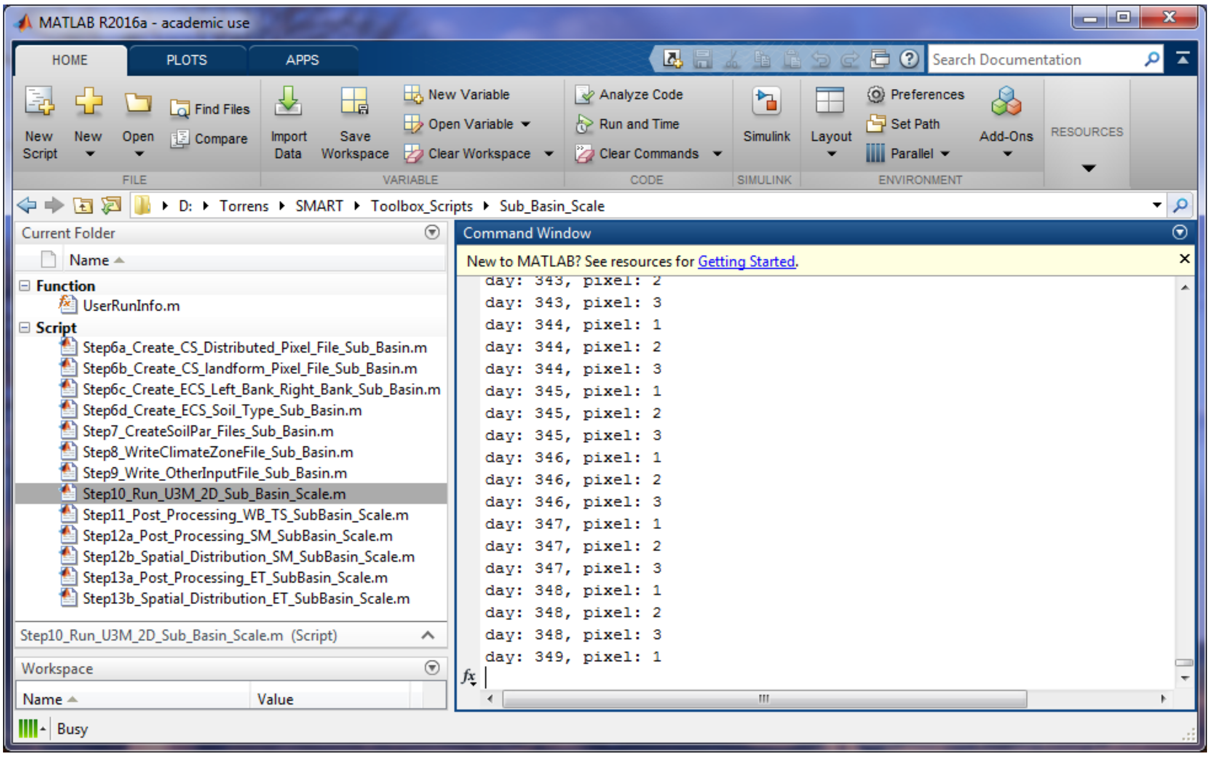


Figure 56. MATLAB command window is showing U3M-2D simulation progress.

Open the (…\SMART\Model_Output\Pixel_Distributed) folder in windows explorer to see simulation results as the model runs (Figure 57).

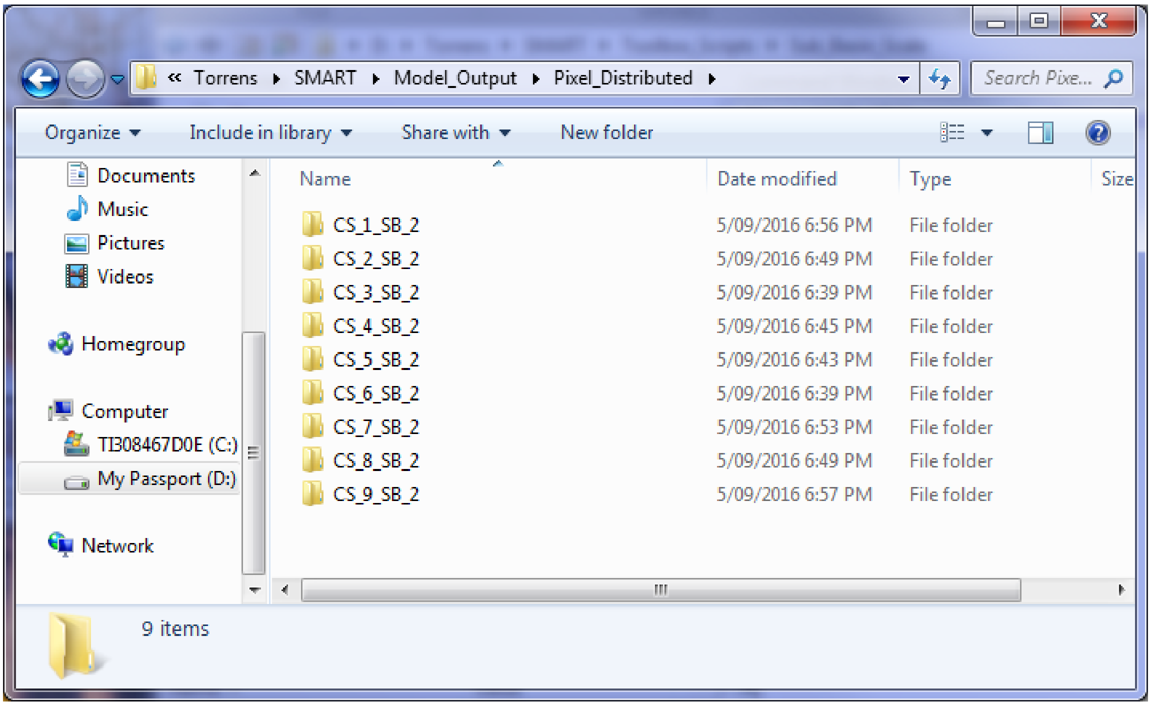


Figure 57. Cross section simulation folders are stored in the …\SMART\ \Model_Output\Pixel_Distributed folder. Becuase there are nine cross sections in the sub-basin 2, nine folders are generated once the simulations are finished.

Outputs:

- For every cross section, a folder is generated in the (...\SMART\Model_Output\Pixel_Distributed) folder. The folder name is CS_(cross section number)_SB(sub-basin unique number).

- Within each simulation folder, four sets of output files are generated. The number of output files for each cross section depends on the number of pixels in the cross section. The following files are generated by the U3M-2D:

  OutputExcessSoilMoisture_(Pixel_number).txt
  OutputFlux_(Pixel_number).txt
  OutputHorizontalDistribution_(Pixel_number).txt
  OutputSoilMoisture_(Pixel_number).txt

4.2. Step10_Run_U3M_2D_Sub_Basin_Scale.m for the Distributed Landform Cross Section Delineation

Once the simulations are finished for the first cross section delineation approach, we will perform simulations for the distributed landform based cross section delineation.

Open the **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. In this step, we are going to perform model simulations for the distributed landform cross section delineation. Type 2 at the command prompt and click Enter (Figure 58).

Select Cross Section Delineation Type (1 to 4): 2

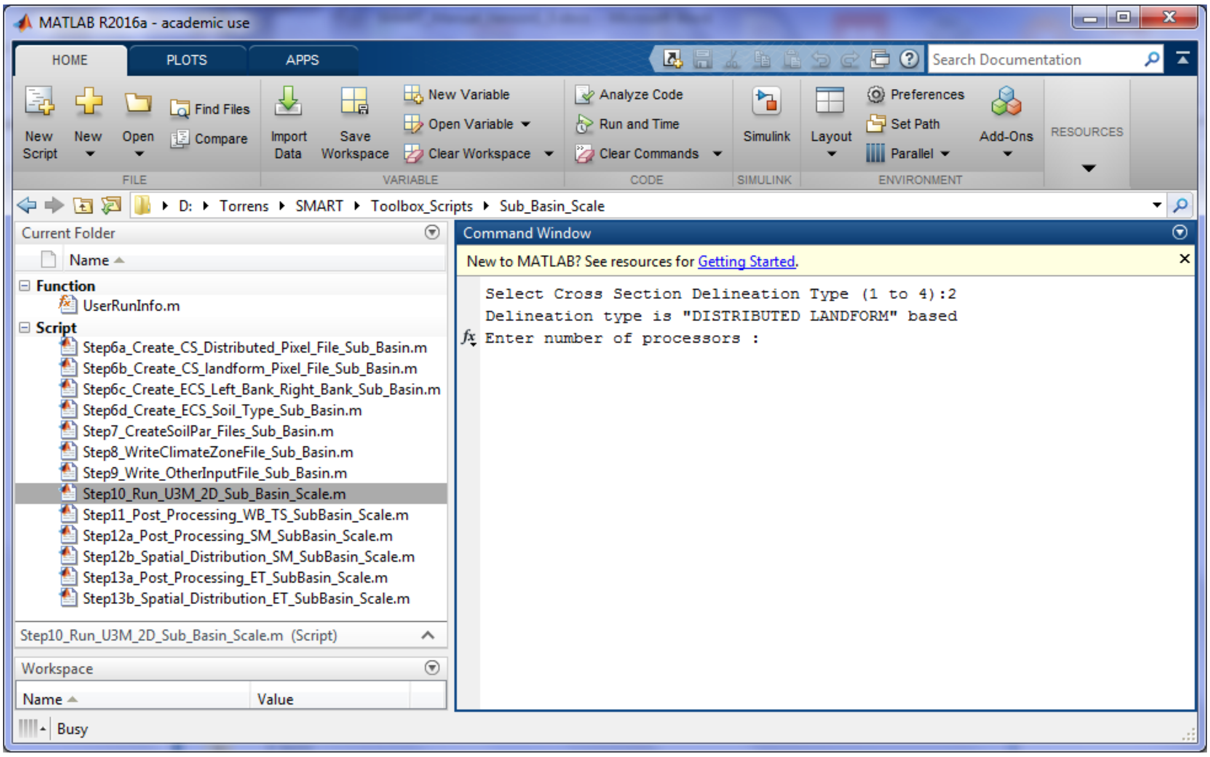


Figure 58. Step10_Run_U3M_2D_Sub_Basin_Scale.m dialog for the distributed landform based cross section delineation option.

In the next step, the script asks to enter the number of processors. This depends on the number of cores in your computer. Here we are using two processors. Type 2 and click Enter.

Enter number of processors: 2

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click Enter and the script asks you to enter the sub-basin identification number. Type 2 and click Enter.

Select the Sub-basin ID for model simulation: 2

If everything is set-up properly and there is no error in your input files, U3M-2D will start the simulations. You will see simulation days and pixel numbers in the MATLAB command window as the simulation progress. Open the **(**…\SMART\Model_Output\Pixel_Landform) folder in windows explorer to see simulated folders as the model runs (Figure 59).

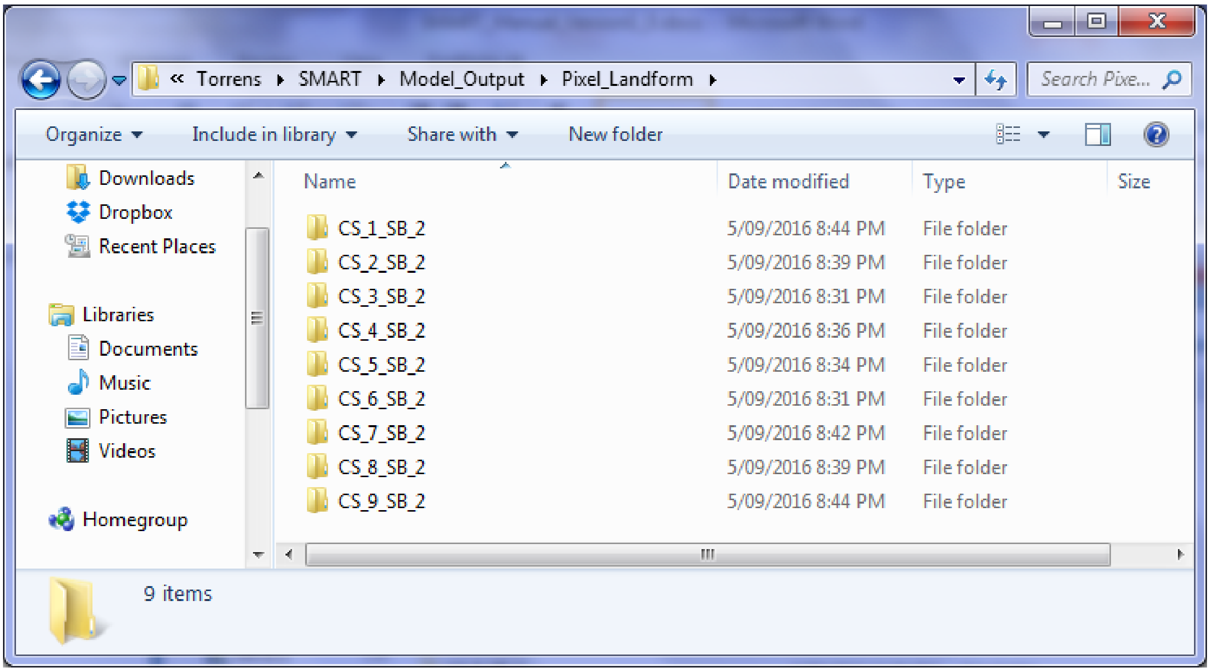


Figure 59. Cross section simulation folders are stored in the …\SMART\ \Model_Output\Pixel_Landform folder. Because there are nine cross sections in the sub-basin 2, nine folders are generated once the simulations are finished.

Outputs:

- For every cross section, a folder is generated in the (...\SMART\Model_Output\Pixel_Landform) folder. The folder name is CS_(cross section number)_SB(sub-basin unique number).

- Within each simulation folder, four sets of output files are generated. The number of output files for each cross section depends on the number of pixels in the cross section. The following files are generated by the U3M-2D:

  OutputExcessSoilMoisture_(Pixel_number).txt
  OutputFlux_(Pixel_number).txt
  OutputHorizontalDistribution_(Pixel_number).txt
  OutputSoilMoisture_(Pixel_number).txt

4.3. Step10_Run_U3M_2D_Sub_Basin_Scale.m for the 3 ECSs Delineation

Once the simulations are finished for the second cross section delineation approach, we perform simulations for the 3 ECSs delineation option.

Open the **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. In this step, we are performing model simulations for the 3 ECSs delineation option. Type 3 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 3

In the next step, the script asks to enter the number of processors. This depends on the number of cores in your computer. Here we are going to use two processors. Type 2 and click .

Enter number of processors: 2

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 60).

Select the Sub-basin ID for model simulation: 2

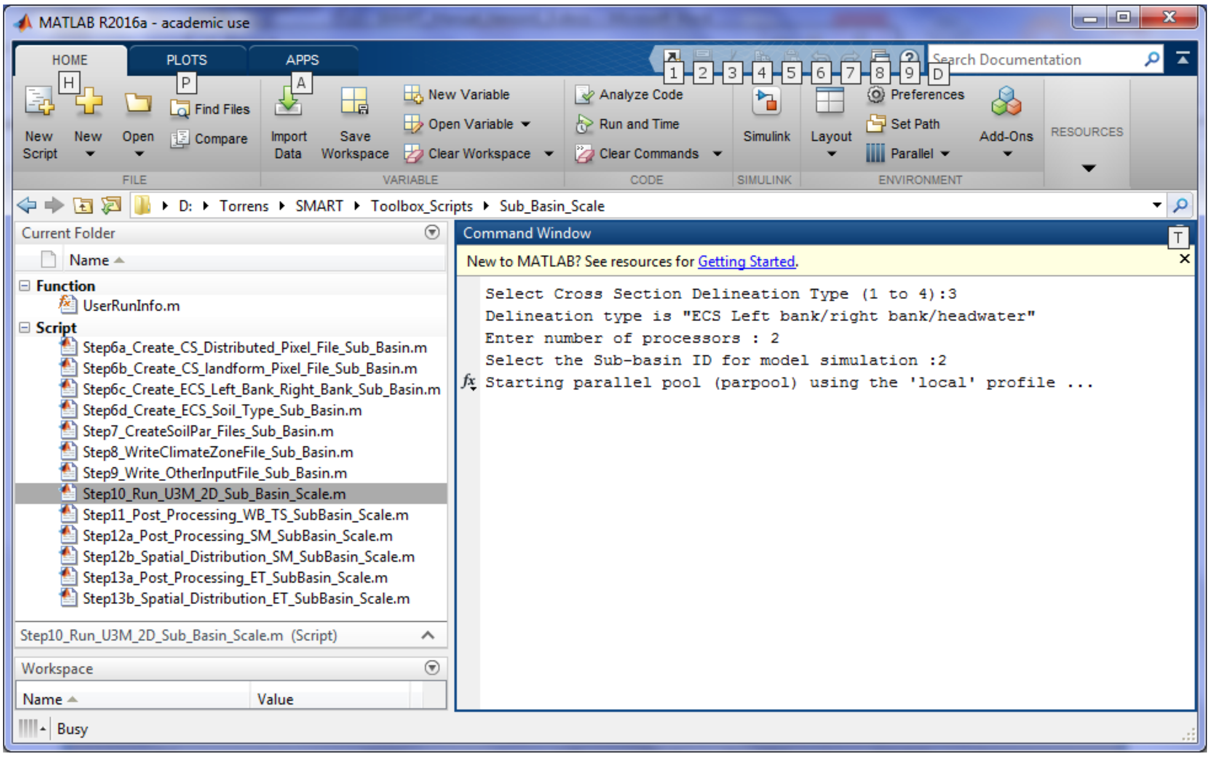


Figure 60. Step10_Run_U3M_2D_Sub_Basin_Scale.m dialog for simulating the left bank, right bank and headwater ECSs.

If everything is set-up properly and there is no error in your input files, U3M-2D will start the simulations. You will see simulation days and pixel numbers in the MATLAB command window. Open the **(**…\SMART\Model_Output\ECS_LB_RB_H_CS) folder in windows explorer to see simulated folders as the model runs (Figure 61).

Outputs:

- For every cross section, a folder is generated in the (...\SMART\Model_Output\ECS_LB_RB_H_CS) folder. The folder name is CS_(cross section number)_SB(sub-basin unique number).

- Within each simulation folder, four sets of output files are generated. The number of output files for each cross section depends on the number of pixels in a given cross section. The following files are generated by the U3M-2D:

  OutputExcessSoilMoisture_(Pixel_number).txt
  OutputFlux_(Pixel_number).txt
  OutputHorizontalDistribution_(Pixel_number).txt
  OutputSoilMoisture_(Pixel_number).txt

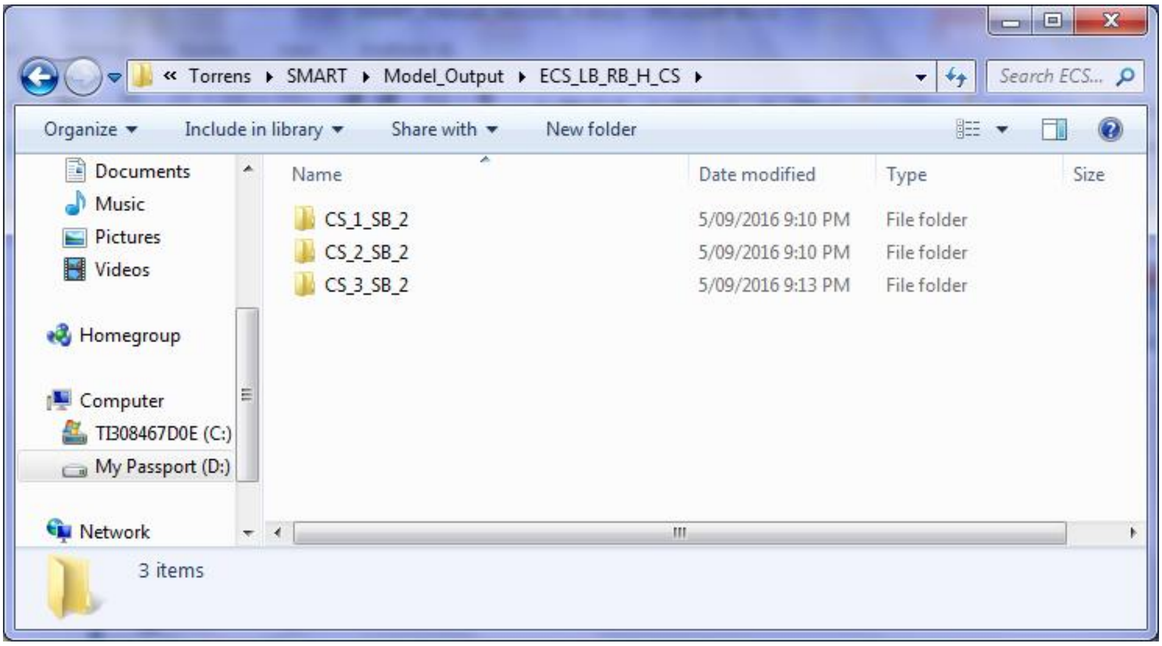


Figure 61. Cross section simulation folders are stored in the …\SMART\Model_Output\ECS_LB_RB_H_CS folder for the 3 ECSs delineation option.

4.4. Step10_Run_U3M_2D_Sub_Basin_Scale.m for the ECS Soil Type Delineation

Once the simulation is finished for the third cross section delineation approach, we will perform simulations for the ECS Soil Type delineation.

Open the **Step10_Run_U3M_2D_Sub_Basin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. In this step, we are performing model simulations for the ECS soil type delineation option. Type 4 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 4

In the next step, the script asks to enter the number of processors. This depends on the number of cores in your computer. Here we are using two processors. Type 2 and click .

Enter number of processors: 2

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to perform model simulations. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to simulate fluxes for the sub-basin 2, click  and the script asks you to enter the sub-basin identification number. Type 2 and click  (Figure 62).
Select the Sub-basin ID for model simulation: 2

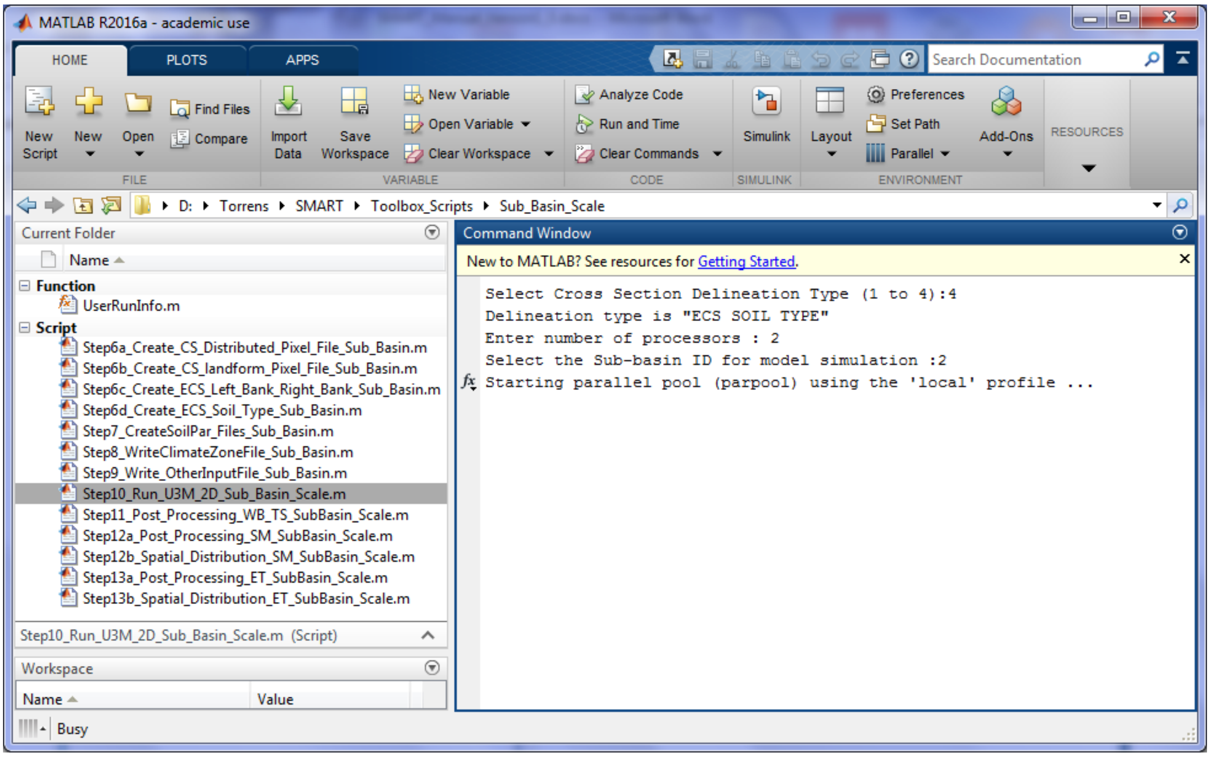


Figure 62. Step10_Run_U3M_2D_Sub_Basin_Scale.m dialog for simulating ECS Soil type delineation.

If everything is set-up properly and there is no error in your input files, U3M-2D will start the simulations. You will see simulation days and pixel numbers in the MATLAB command window. Open the (…\SMART\Model_Output\ECS_Soil_Type_CS) folder in windows explorer to see simulated folders as the model runs (Figure 63). Because there is only one ECS for this sub-basin, one cross section simulation folder is generated.

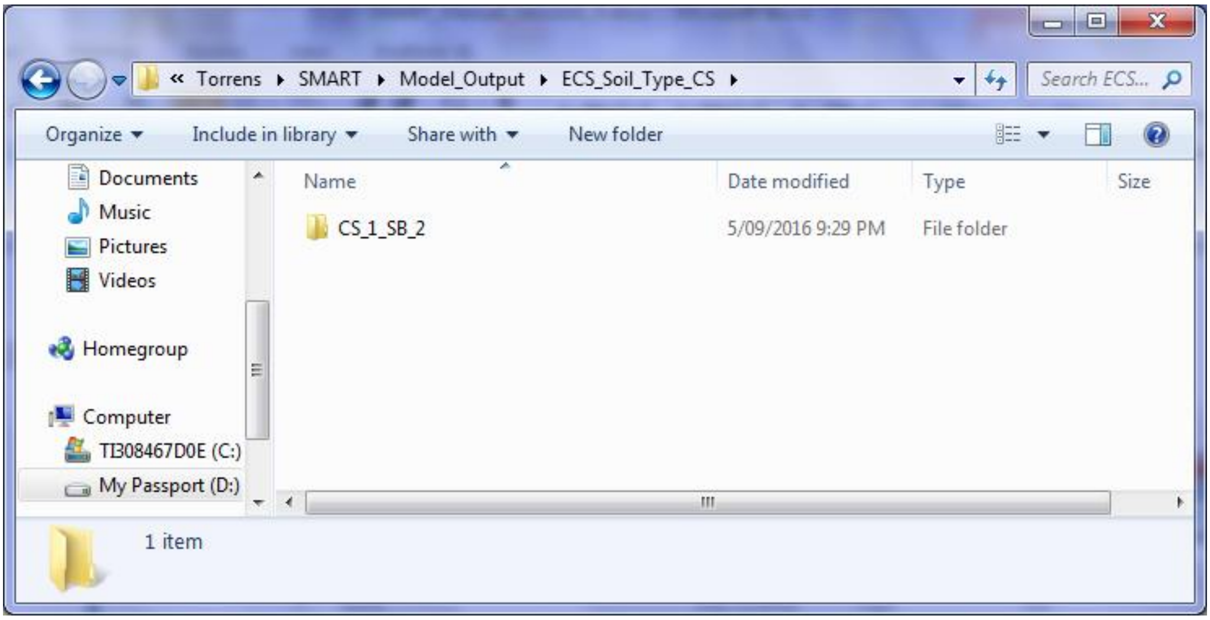


Figure 63. Cross section simulation folders are stored in the (…\SMART \Model_Output\ECS_Soil_Type_CS) folder for the ECS Soil Type delineation option.

Outputs:

- For every cross section, a folder is generated in the (...\SMART\Model_Output\ECS_Soil_Type_CS) folder. The folder name is CS_(cross section number)_SB(sub-basin unique number).

- Within each simulation folder, four sets of output files are generated. The number of output files for each cross section depends on the number of pixels in a given cross section. The following files are generated by the U3M-2D:

  OutputExcessSoilMoisture_(Pixel_number).txt
  OutputFlux_(Pixel_number).txt
  OutputHorizontalDistribution_(Pixel_number).txt
  OutputSoilMoisture_(Pixel_number).txt

Open the **(**…\SMART\Model_Output\ECS_Soil_Type_CS\CS_1_SB_2) folder in windows explorer to view U3M-2D output files. As you see in this folder, there are 18 files for every output type because U3M-2D stores outputs for every pixel in a separate file. You can also see model input files: ClimateZone.txt, InputOtherData.txt, InputSHPTable.txt, InputSoilPar.txt, and PixelFile.txt and the U3M-2D executable in the simulation directory (Figure 64).

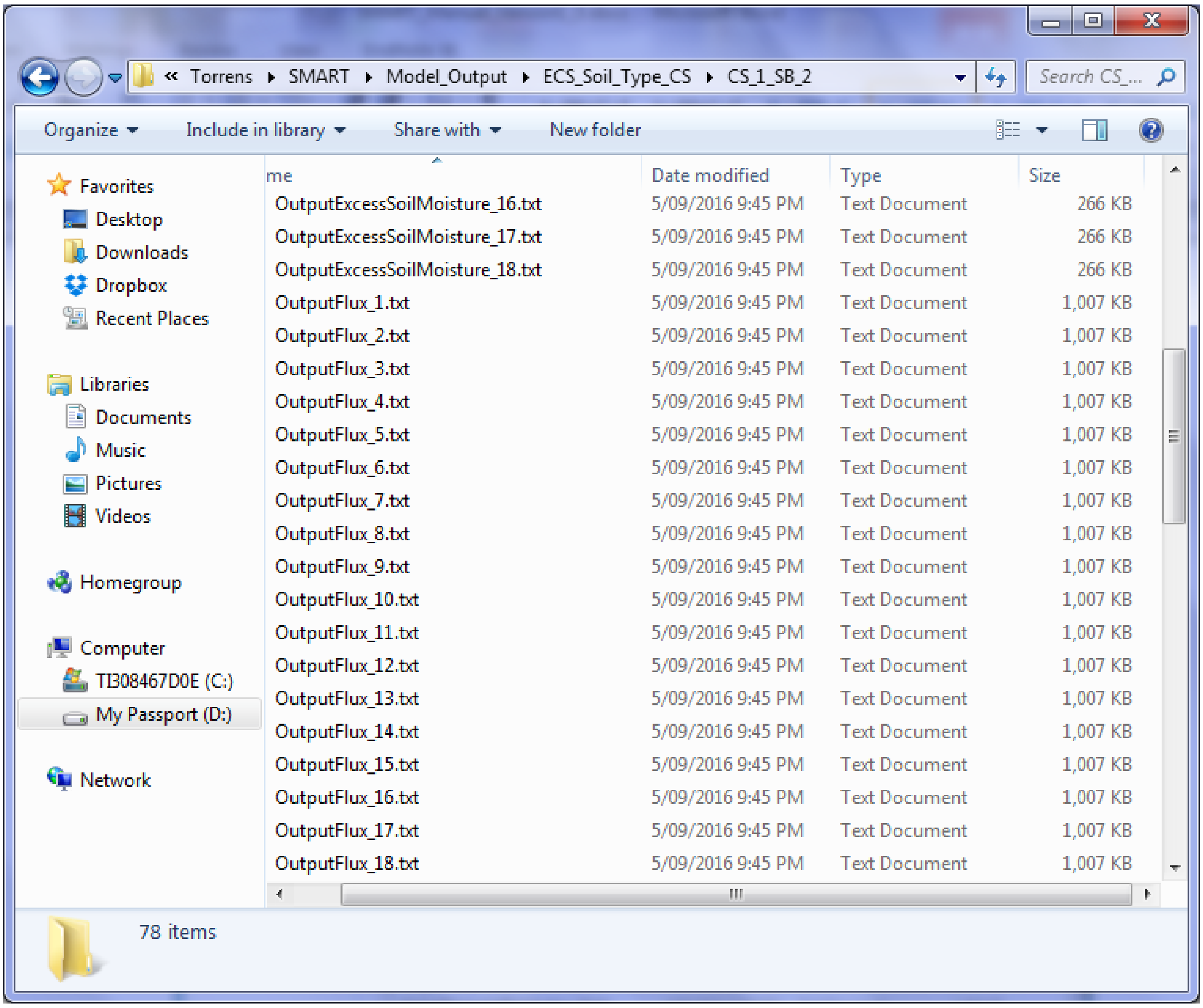


Figure 64. U3M-2D output files for a single cross section. This cross section has 18 pixles so 18 files are generated for each output type**.**

Open the OutputHorizontalDistribution_4.txt file in a text editor like NotePad to view its content (Figure 65).

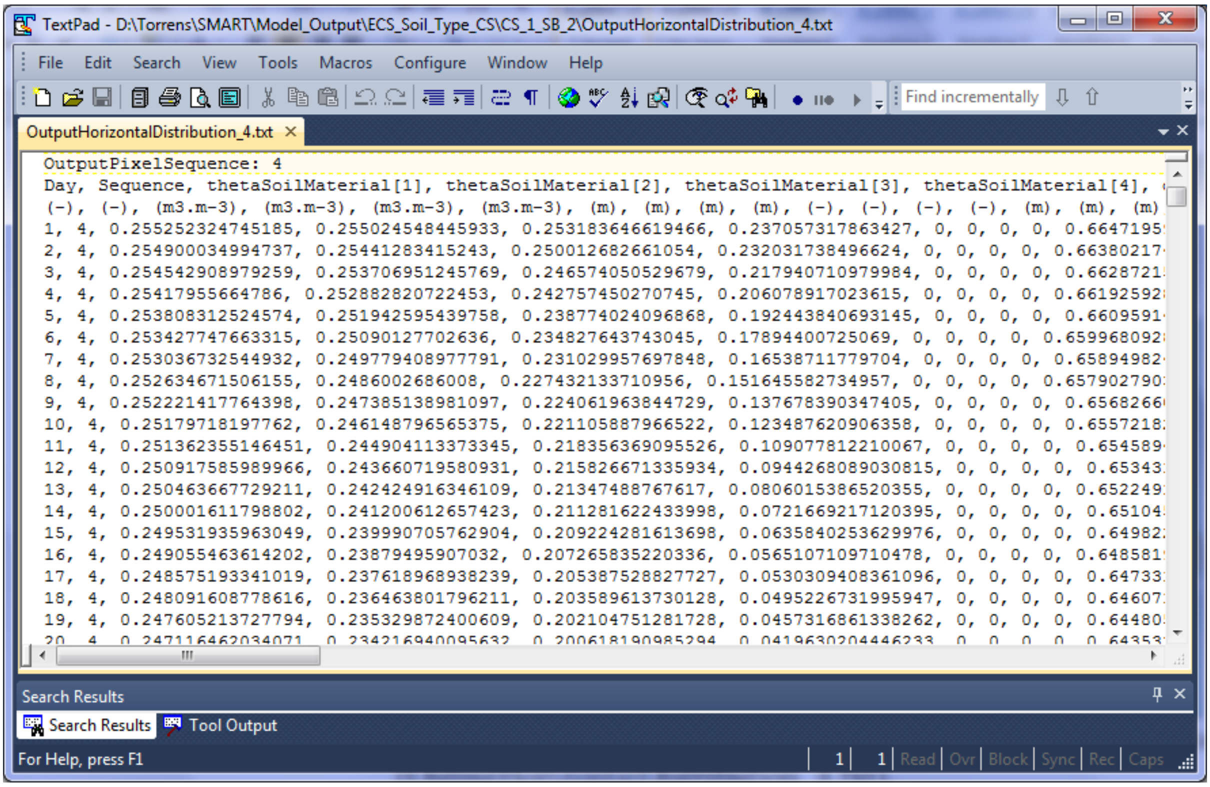


Figure 65. U3M-2D horizontal distribution output file for pixel 4 of a given cross section (OutputHorizontalDistribution_4.txt).

As can be seen in Figure 64, lots of outputs are generated during model simulations and we need to use post processing tools of SMART to analyze the results.

5. Post Processing of Simulation Results

In this tutorial, we are generating two types of model outputs for the simulated sub-basin.

5.1. Generating Time Series Output Files

To generate time series output files, the **Step11_Post_Processing_WB_TS_SubBasin_Scale.m** script is used to process simulated cross section data for the selected sub-basin.

5.1.1. Generating Time Series Output Files of Distributed Pixel based Cross Section Delineation Simulations

Open the **Step11_Post_Processing_WB_TS_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. First, we process simulation results of the distributed pixel based cross section delineation. Type 1 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 1

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click 

and the script asks to enter the sub-basin identification number. Type 2 at the command prompt and click 

.

Select the Sub-basin ID to process results: 2

Upon successful execution of the script, four MATLAB files are generated for the sub-basin 2 in the (…\SMART\Model_Output\Pixel_Distributed) folder (Figure 66).

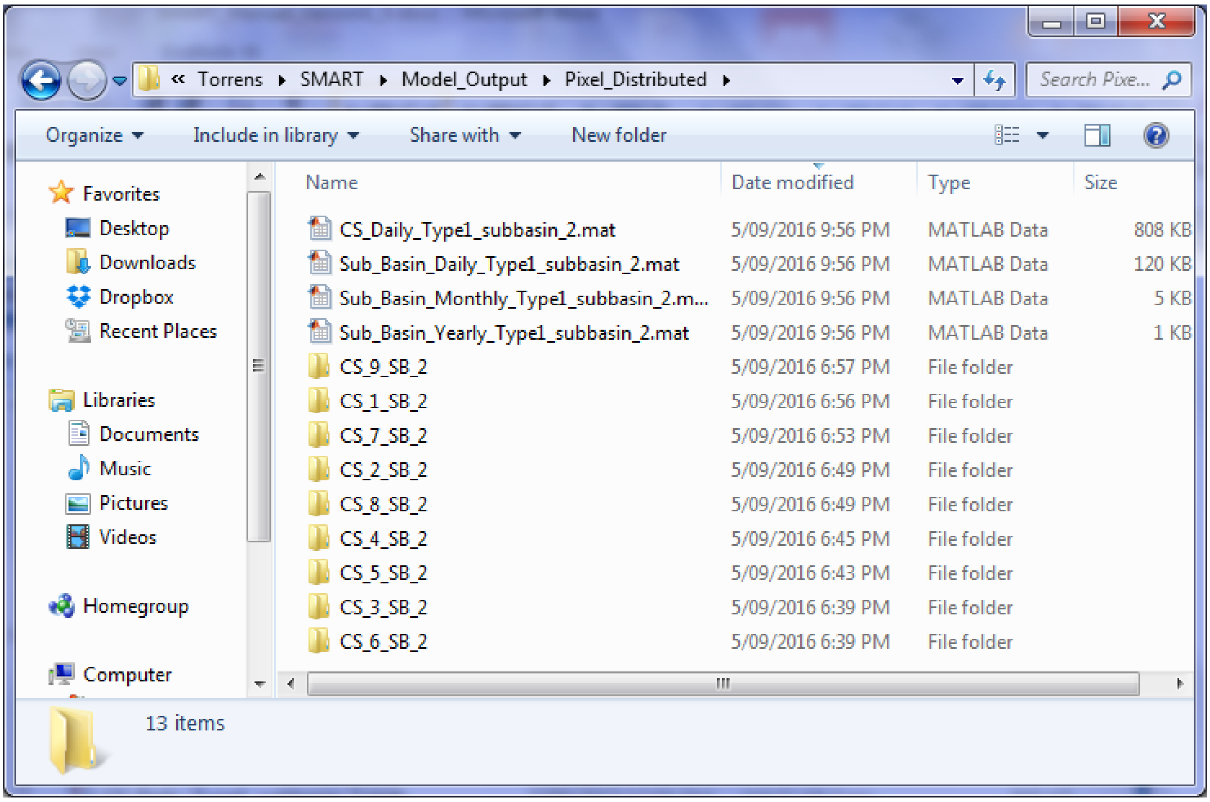


Figure 66. Processed output files at the scale of cross sections and sub-basins for the distributed pixel based delineation.

To view the content of these files, navigate to the folder in MATLAB Table of Contents and double click on the name of a file to open it in MATLAB. Alternatively, you can use the MATLAB command "load" to load the MATLAB file into your workspace.

As can be seen in Figure 67, the CS_Daily_Type1_subbasin_2.mat file in MATLAB is opened. This file contains six variables that are stored in the Output_CS_d structure. These variables are:

P_CS: daily precipitation [m^3]
Qh_CS: daily horizontal flow [m^3]
Qb_CS: daily deep drainage [m^3]
Trans_o_CS: daily overstory transpiration [m^3]
Trans_u_CS: daily understory transpiration [m^3]
Evap_CS: daily soil evaporation [m^3]

The volumetric fluxes are calculated by multiplying a given cross section flux by its contributing area.

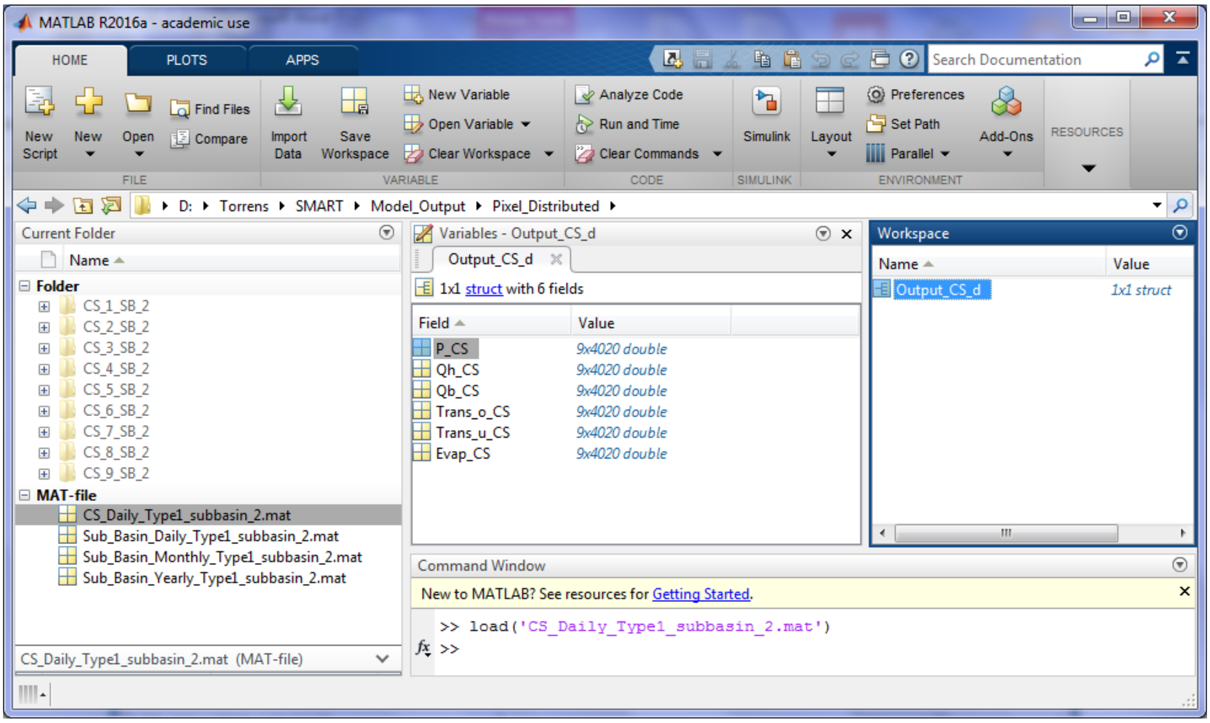
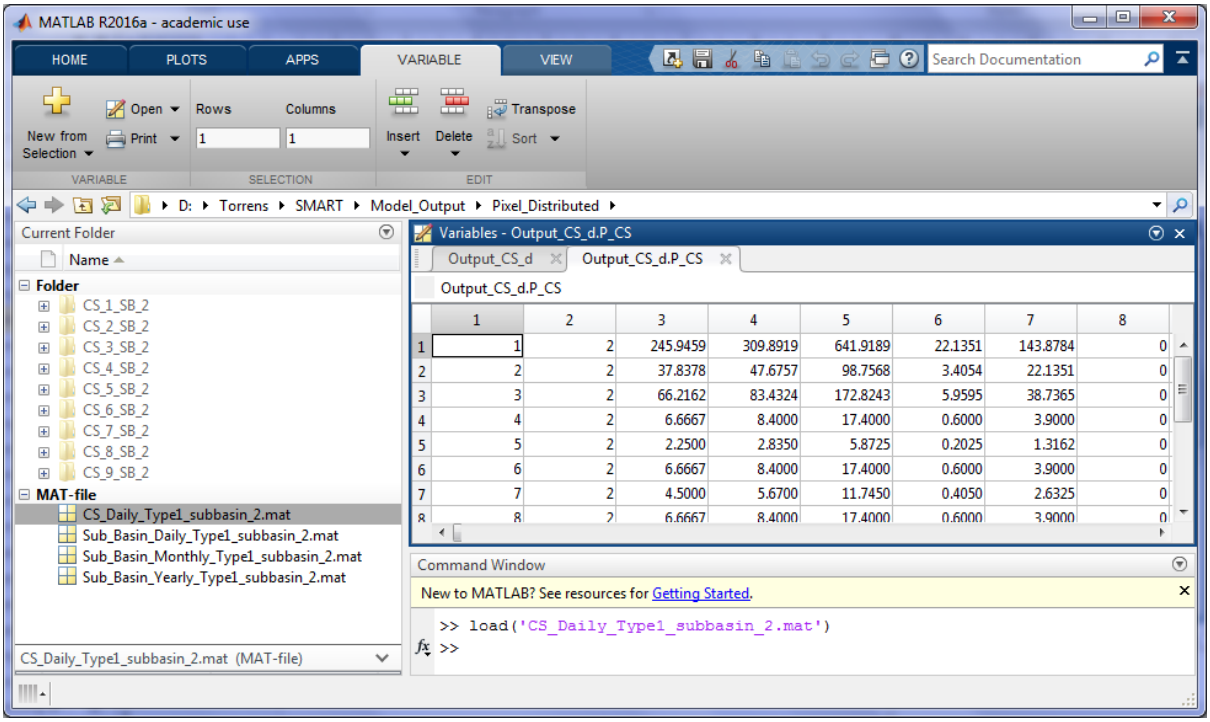


Figure 67. Cross section fluxes are stored as matrices inside the CS_Daily_Type1_subbasin_2.mat file

In the next step, double click on the matrix name to view its content. Double click on the P_CS as in the Figure 68. Every row in this matrix corresponds to time series of daily precipitation for a given cross section. The first two columns are cross section id and sub-basin id respectively. Columns 3 to 4020 correspond to the daily time series of rainfall for every cross section in a sub-basin.



	1	2	3	4	5	6	7	8
1	1	2	245.9459	309.8919	641.9189	22.1351	143.8784	0
2	2	2	37.8378	47.6757	98.7568	3.4054	22.1351	0
3	3	2	66.2162	83.4324	172.8243	5.9595	38.7365	0
4	4	2	6.6667	8.4000	17.4000	0.6000	3.9000	0
5	5	2	2.2500	2.8350	5.8725	0.2025	1.3162	0
6	6	2	6.6667	8.4000	17.4000	0.6000	3.9000	0
7	7	2	4.5000	5.6700	11.7450	0.4050	2.6325	0
8	8	2	6.6667	8.4000	17.4000	0.6000	3.9000	0

Figure 68. Daily precipitation values for every cross section in the sub-basin 2.

Sub-basin level fluxes are stored in the Sub_Basin_*_Type1_subbasin_2.mat files at three different time steps: daily, monthly and annual. Double click on the Sub_Basin_Daily_Type1_subbasin_2.mat file to view its contents. As you can see in Figure 69, 7 variables are stored in Output_sub_d structure. These variables are:

P_sub: sub-basin daily precipitation [mm/day]
Qh_sub: sub-basin daily horizontal flow [mm/day]
Qb_sub: sub-basin daily deep drainage [mm/day]
Qtot_sub: sub-basin daily total runoff [mm/day]
Trans_o_sub: sub-basin daily overstory transpiration [mm/day]
Trans_u_sub: sub-basin daily understory transpiration [mm/day]
Evap_sub: sub-basin daily soil evaporation [mm/day]

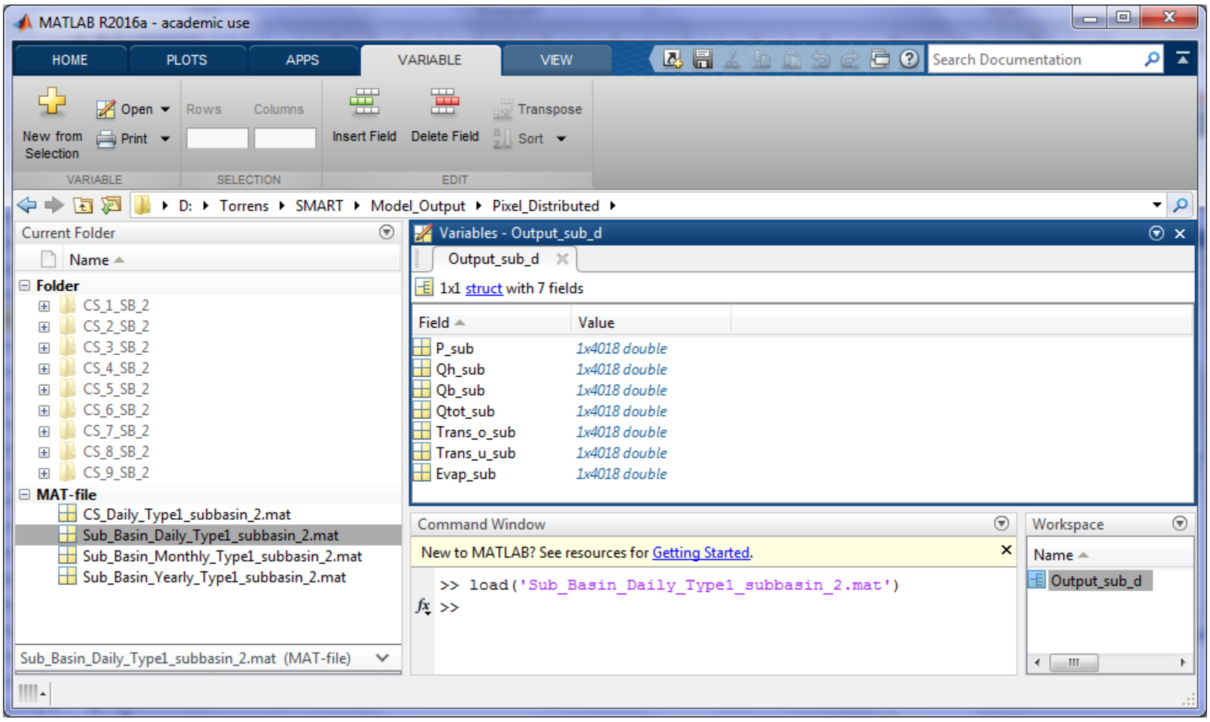


Figure 69. Sub-basin fluxes are stored as matrices inside the Sub_Basin_Daily_Type1.mat file

Double click on Qtot_sub to view its content. The first column has the sub-basin identification number and the rest are daily runoff values in [mm/day] for each sub-basin (Figure 70). Because we only simulated one sub-basin, one record exist in this file.

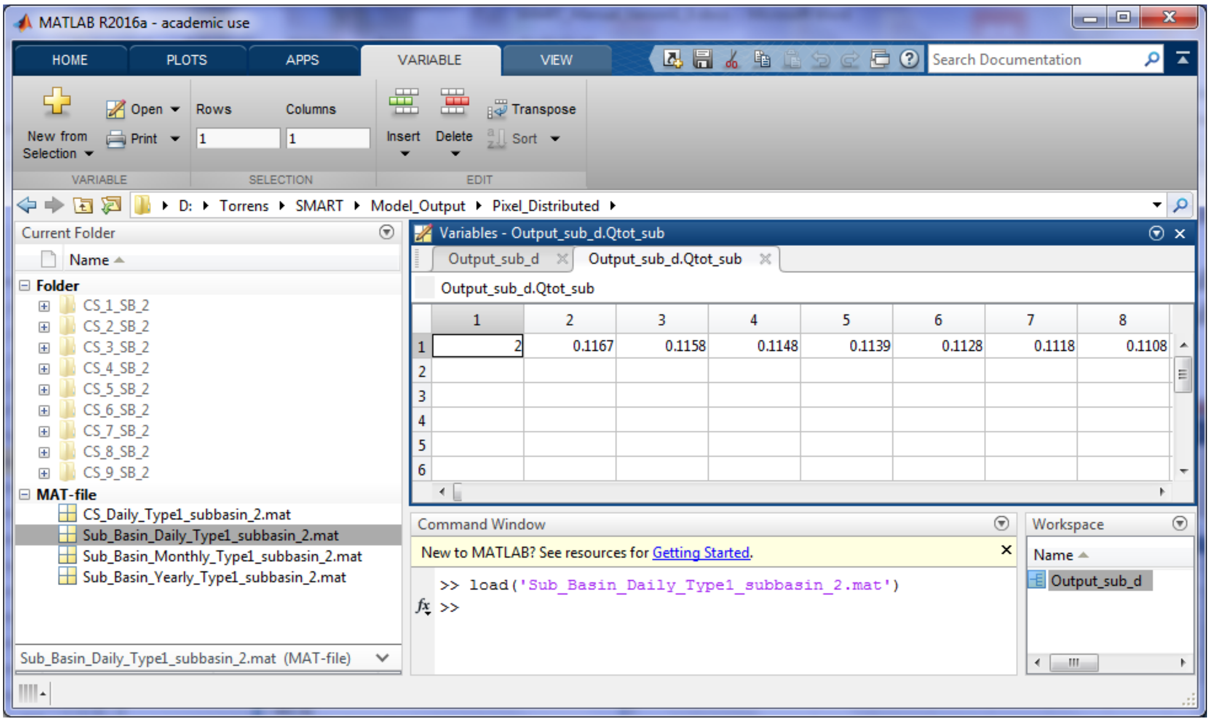


Figure 70. Total daily runoff from sub-basin 2.

5.1.2. Generating Time Series Output Files of the Distributed Landform Cross Section Delineation Simulations

Open the **Step11_Post_Processing_WB_TS_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed landform based cross section delineation. To do this, type 2 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 2

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click  and the script asks to enter the sub-basin identification number. Type 2 at the command prompt and click .

Select the Sub-basin ID to process results: 2

Upon successful execution of the script, four MATLAB files are generated in the (…\SMART\Model_Output\Pixel_Landform) folder (Figure 71).

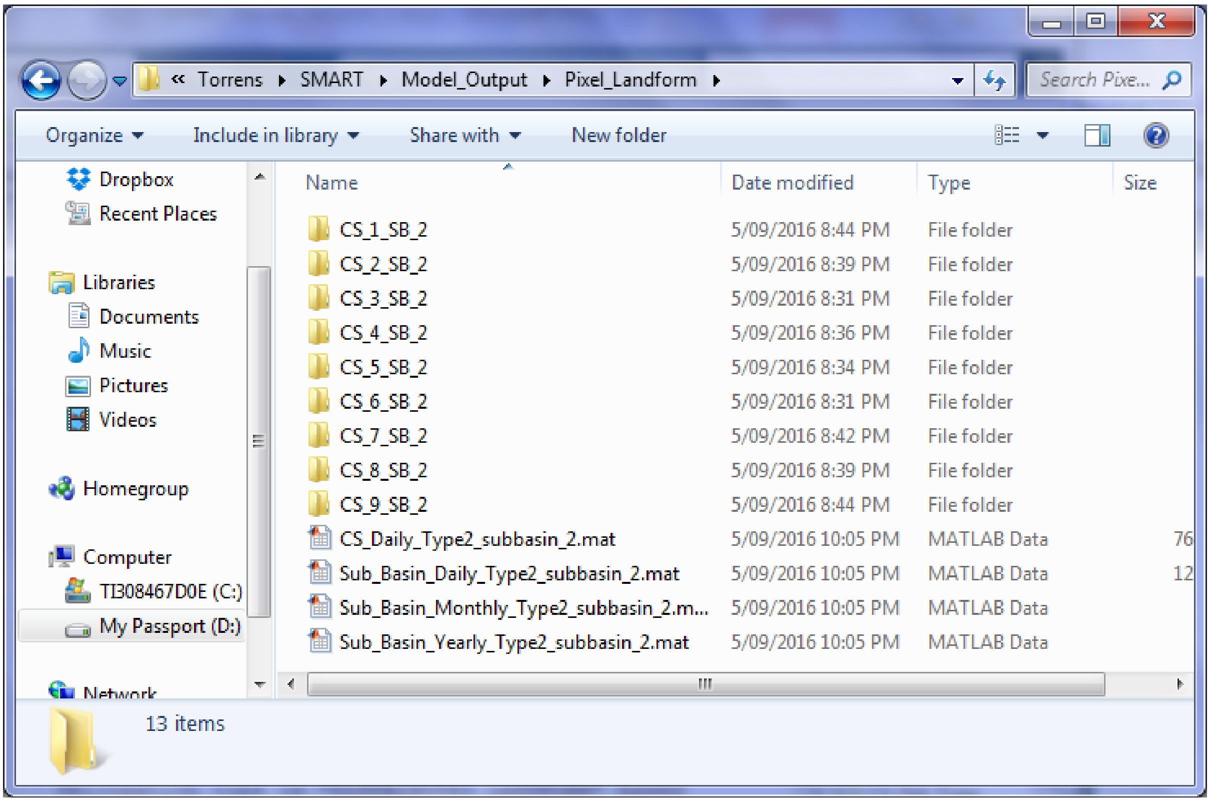


Figure 71. Processed output files at the scale of cross sections and sub-basins for the distributed landform based cross section delineation.

To view the content of these files, navigate to the folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Follow the steps in section 5.1.1 to view the variables.

5.1.3. Generating Time Series Output Files of the Headwater/Left bank/Right bank ECSs Delineation Simulations

Open the **Step11_Post_Processing_WB_TS_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the Left bank/right bank/headwater ECS delineation. To do this, type 3 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 3

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click  and the script asks to enter the sub-basin identification number. Type 2 and click 

Select the Sub-basin ID to process results: 2

Upon successful execution of the script, four MATLAB files are generated in the (…\SMART_Toolbox\Model_Output\ECS_LB_RB_H_CS) folder (Figure 72).

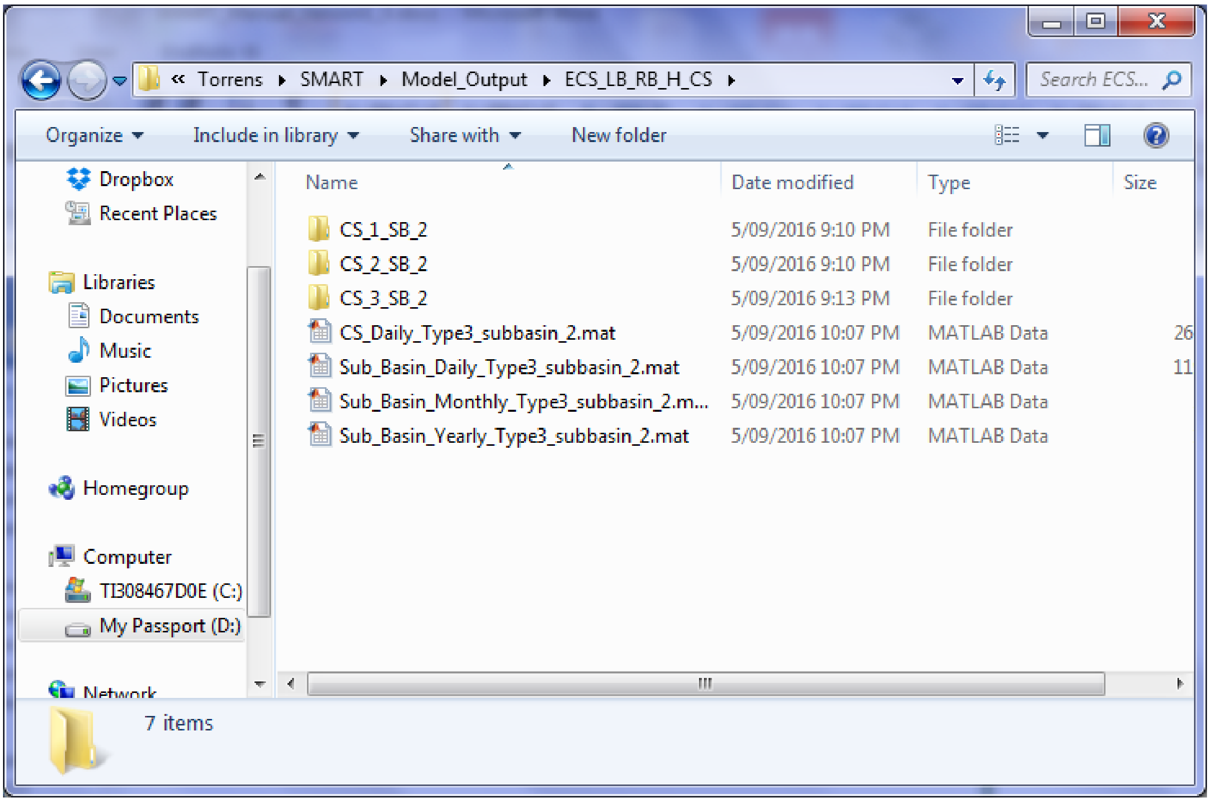


Figure 72. Processed output files at the scale of cross sections and sub-basins for the left bank/right bank/headwater ECSs delineation.

To view the content of these files, navigate to the folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Follow the steps in section 5.1.1 to view the variables.

5.1.4. Generating Time Series Output Files for the ECS Soil Type Delineation Simulations

Open the **Step11_Post_Processing_WB_TS_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the ECS soil type delineation. Type 4 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 4

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click 

and the script asks to enter the sub-basin identification number. Type 2 at the command prompt and click 

.

Select the Sub-basin ID to process results: 2

Upon successful execution of the script, four MATLAB files are generated in the (…\SMART\Model_Output\ECS_Soil_Type_CS) folder (Figure 73).

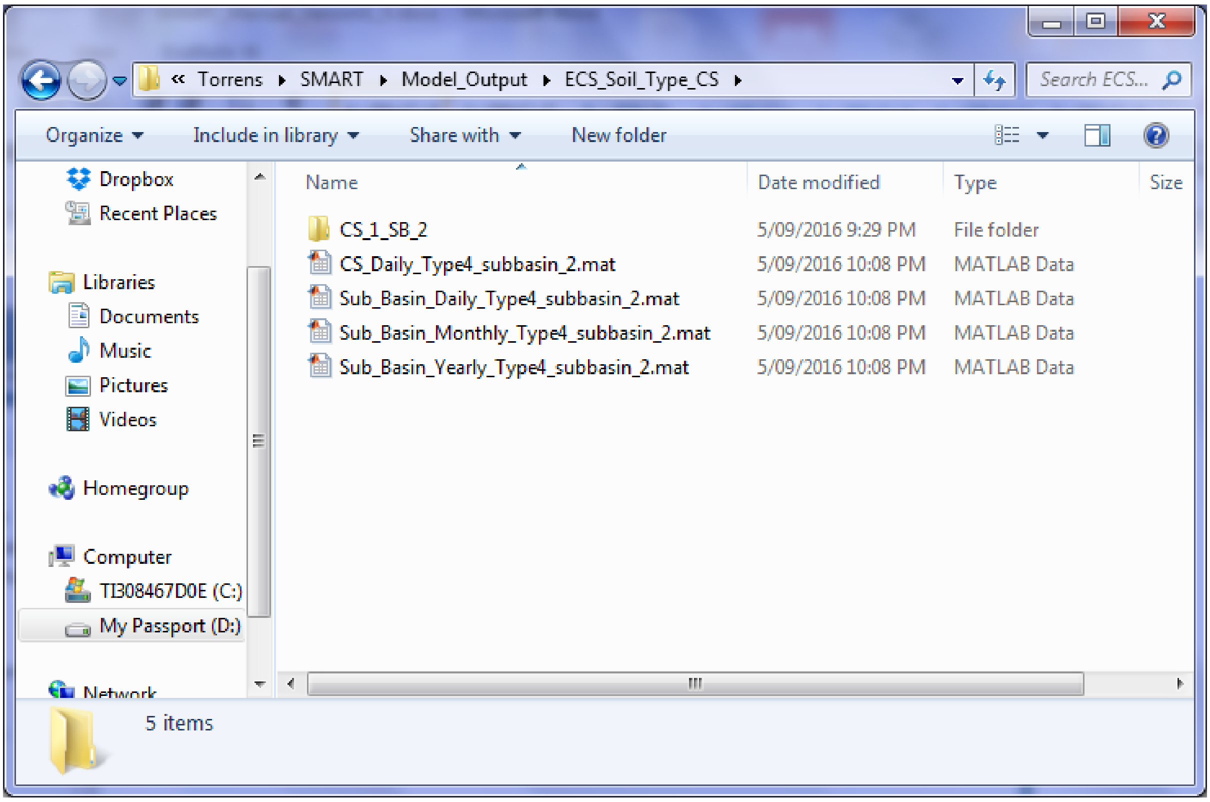


Figure 73. Processed output files at the scale of cross sections and sub-basins for the ECS soil type delineation.

To view the content of these files, navigate to the folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Follow the steps in section 5.1.1 to view the variables.

5.2. Generating Spatially Distributed Soil Moisture Outputs

To generate spatially distributed soil moisture outputs, two steps should be taken in SMART: 1) Processing of U3M-2D output files at the smallest conceptual modelling element scale (pixel or landform), and 2) mapping of soil moisture to a pixel level.

5.2.1. Processing at the Smallest Conceptual Modelling Element Scale-Distributed Pixel based Cross Section Simulations

The first step is to process simulated soil moisture data at the smallest conceptual modelling element scale for each cross section delineation approach. **Step12a_Post_Processing_SM_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step12a_Post_Processing_SM_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed pixel based cross section delineation. To do this, type 1 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 1

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click 

and the script asks to enter the sub-basin identification number. Type 2 and click 

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\Pixel_Distributed) folder, the following MATLAB .mat files are generated:

Pixel_Soil_Moisture_Daily_Type1_ subbasin_2.mat
Pixel_Soil_Moisture_Monthly_Type1_subbasin_2.mat

To view the content of these files, navigate to the Pixel_Distributed folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. In Figure 74, the **Pixel_Soil_Moisture_Daily_Type1_subbasin_2.mat** is opened.

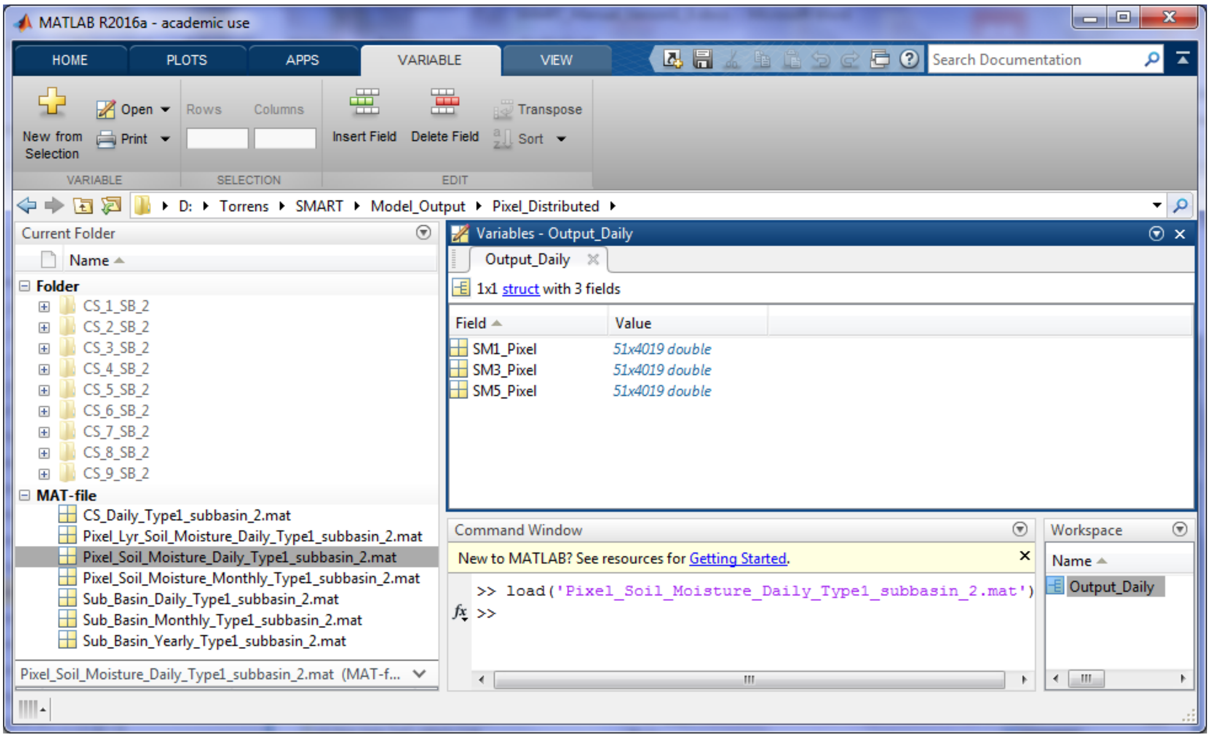


Figure 74. Contents of the Pixel_Soil_Moisture_Daily_Type1_subbasin_2.mat file

In the Output_Daily structure, there are three matrices:
SM1_Pixel: Top layer soil moisture [m^3/m^3]
SM3_Pixel: Average soil moisture for 0-0.3 m depth [m^3/m^3]
SM5_Pixel: Average soil moisture for 0-0.5 m depth [m^3/m^3]

Double click on the SM1_Pixel to view its contents. As can be seen in Figure 75, the first column has the cross section identification number and the second column has the sub-basin identification number. The rest of the columns are daily soil volumetric water content.

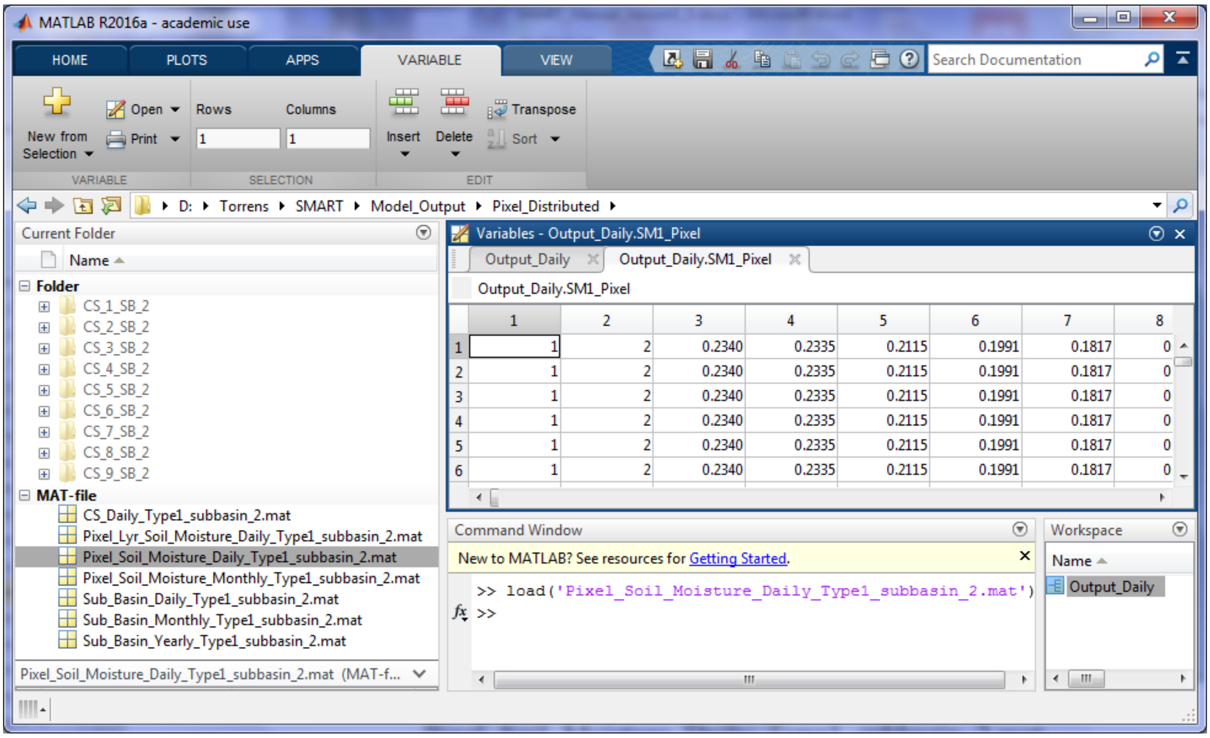


Figure 75. Simulated top layer soil moisture from the Pixel_Soil_Moisture_Daily_Type1_subbasin_2.mat file

5.2.2. Processing at the Smallest Conceptual Modelling Element Scale-Distributed Landform Cross Section Simulations

The first step is to process simulated soil moisture data at the smallest conceptual modelling element scale. **Step12a_Post_Processing_SM_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step12a_Post_Processing_SM_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed landform delineation option. To do this, type 2 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 2

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations result. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click 

and the script asks to enter the sub-basin identification number. Type 2 and click 

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\Pixel_Landform) folder, the following MATLAB .mat files are generated:

> **Pixel_Soil_Moisture_Daily_Type2_subbasin_2.mat**
> **Pixel_Soil_Moisture_Monthly_Type2_subbasin_2.mat**
> **LF_Soil_Moisture_Daily_Type2_subbasin_2.mat**
> **LF_Soil_Moisture_Monthly_Type2_subbasin_2.mat**
> **LF_Soil_Moisture_Annual_Type2_subbasin_2.mat**

To view the content of these files, navigate to the Pixel_Landform folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Double click on **LF_Soil_Moisture_Daily_Type2_subbasin_2.mat** to view its contents (Figure 76).

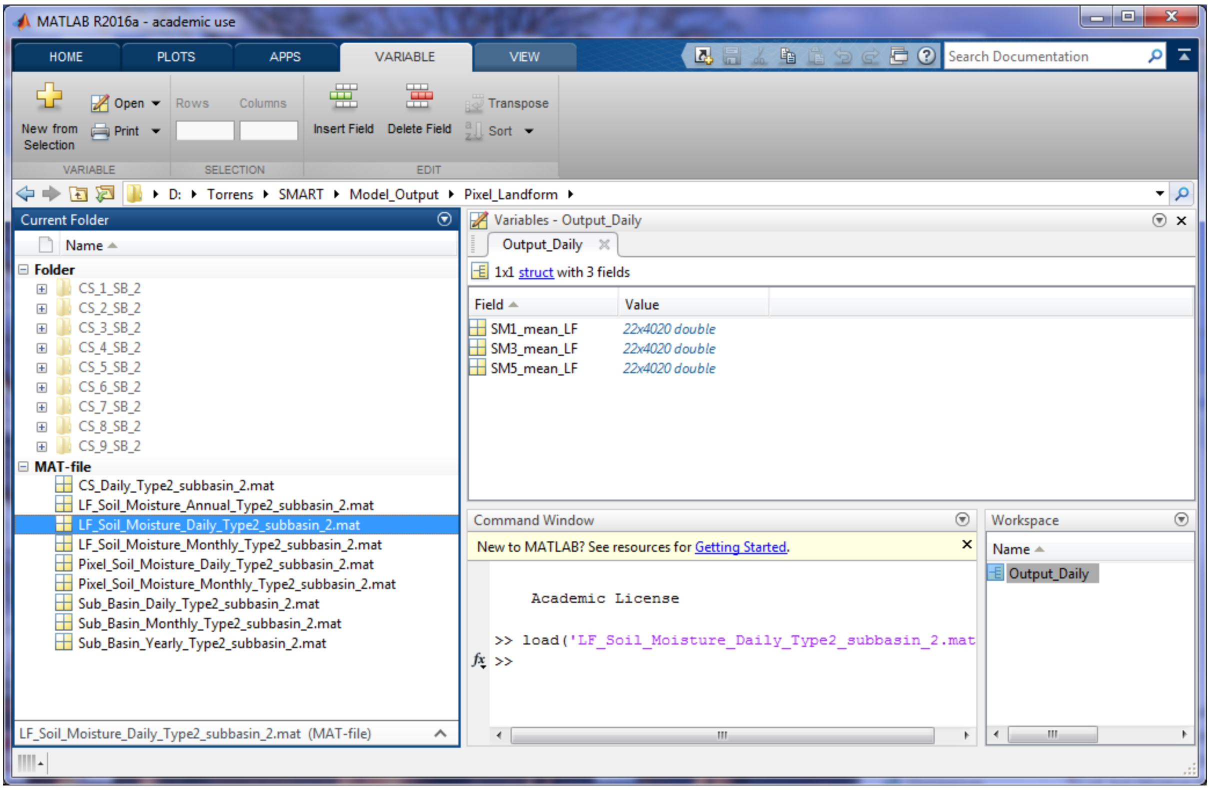
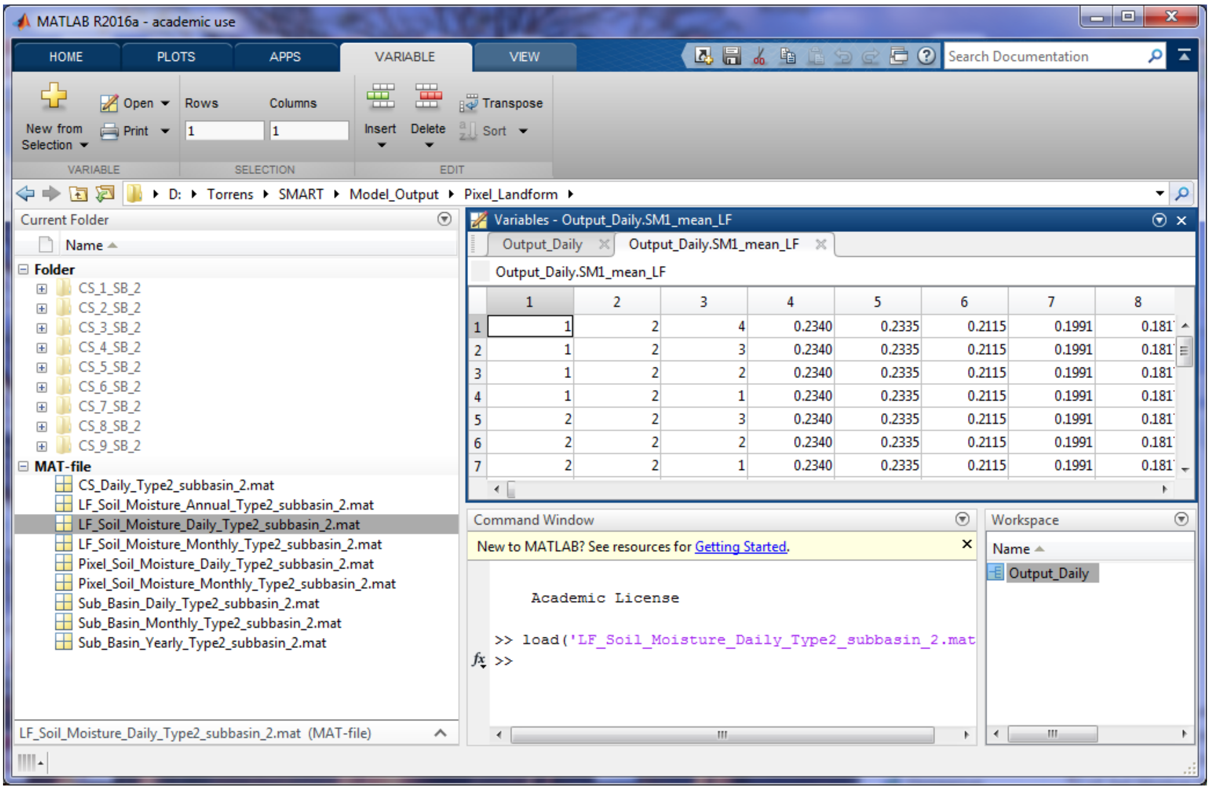


Figure 76. Contents of the LF_Soil_Moisture_Daily_Type2_subbasin_2.mat file. This file has daily mean soil moisture values per landform

In the Output_Daily structure, there are three matrices:
SM1_mean_LF: Top layer soil moisture for every landform in a cross section [m^3/m^3]

SM3_mean_LF: Average soil moisture at 0-0.3 m depth for every landform in a cross section [m^3/m^3]
SM5_mean_LF: Average soil moisture at 0-0.5 m depth for every landform in a cross section [m^3/m^3]

Double click on SM1_mean_LF to view its content. As can be seen in Figure 77, the first column is the cross section identification number, second column is the sub-basin identification number, third column is the landform number and the rest of columns contain daily soil volumetric water content of every landform.



	1	2	3	4	5	6	7	8
1	1	2	4	0.2340	0.2335	0.2115	0.1991	0.181
2	1	2	3	0.2340	0.2335	0.2115	0.1991	0.181
3	1	2	2	0.2340	0.2335	0.2115	0.1991	0.181
4	1	2	1	0.2340	0.2335	0.2115	0.1991	0.181
5	2	2	3	0.2340	0.2335	0.2115	0.1991	0.181
6	2	2	2	0.2340	0.2335	0.2115	0.1991	0.181
7	2	2	1	0.2340	0.2335	0.2115	0.1991	0.181

Figure 77. Simulated top layer soil moisture in the LF_Soil_Moisture_Daily_Type2_subbasin_2.mat file.

5.2.3. Processing at the Smallest Conceptual Modelling Element Scale- 3 ECSs Delineation Simulations

The first step is to process simulated soil moisture data at the smallest conceptual modelling element scale. **Step12a_Post_Processing_SM_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step12a_Post_Processing_SM_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the 3 ECSs delineation. Type 3 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 3

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click  and the script asks to enter the sub-basin identification number. Type 2 and click .

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\ECS_LB_RB_H_CS) folder, the following MATLAB .mat files are generated:

LF_Soil_Moisture_Daily_Type3_subbasin_2.mat
LF_Soil_Moisture_Monthly_Type3_subbasin_2.mat
LF_Soil_Moisture_Annual_Type3_subbasin_2.mat

To view the content of these files, navigate to the folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB (Figure 78).

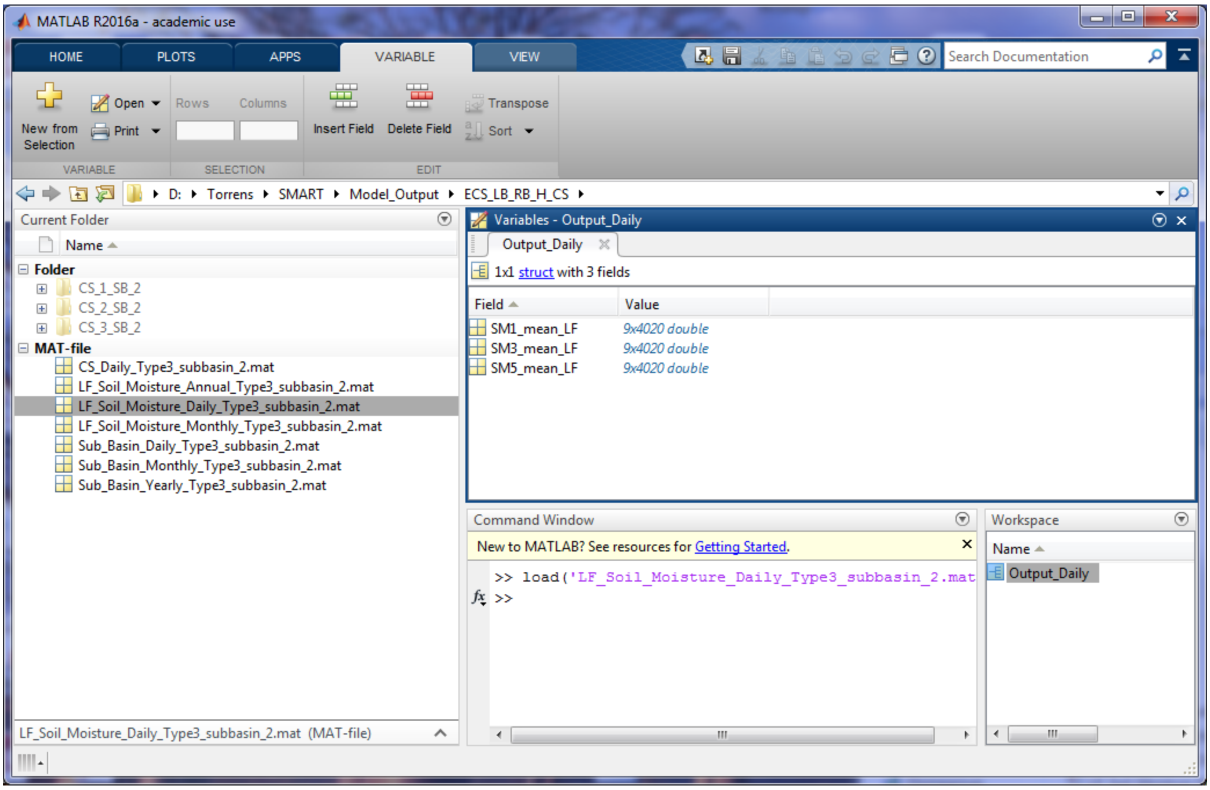


Figure 78. Contents of the LF_Soil_Moisture_Daily_Type3_subbasin_2.mat file.

5.2.4. Processing at the Smallest Conceptual Modelling Element Scale - ECS Soil Type delineation Simulations

The first step is to process simulated soil moisture data at the smallest conceptual modelling element scale. **Step12a_Post_Processing_SM_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step12a_Post_Processing_SM_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the ECS soil type delineation option. To do this, type 4 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 4

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click 

and the script asks you to enter the identification number of the sub-basin that you are interested. Because, I selected sub-basin 2, I type 2 and click 

.

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\ECS_Soil_Type_CS) folder, the following MATLAB .mat files are generated:

LF_Soil_Moisture_Daily_Type4_subbasin_2.mat
LF_Soil_Moisture_Monthly_Type4_subbasin_2.mat
LF_Soil_Moisture_Annual_Type4_subbasin_2.mat

To view the content of these files, navigate to the ECS_Soil_Type_CS folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Double click on **LF_Soil_Moisture_Daily_Type4_subbasin_2.mat** to view its contents (Figure 79).

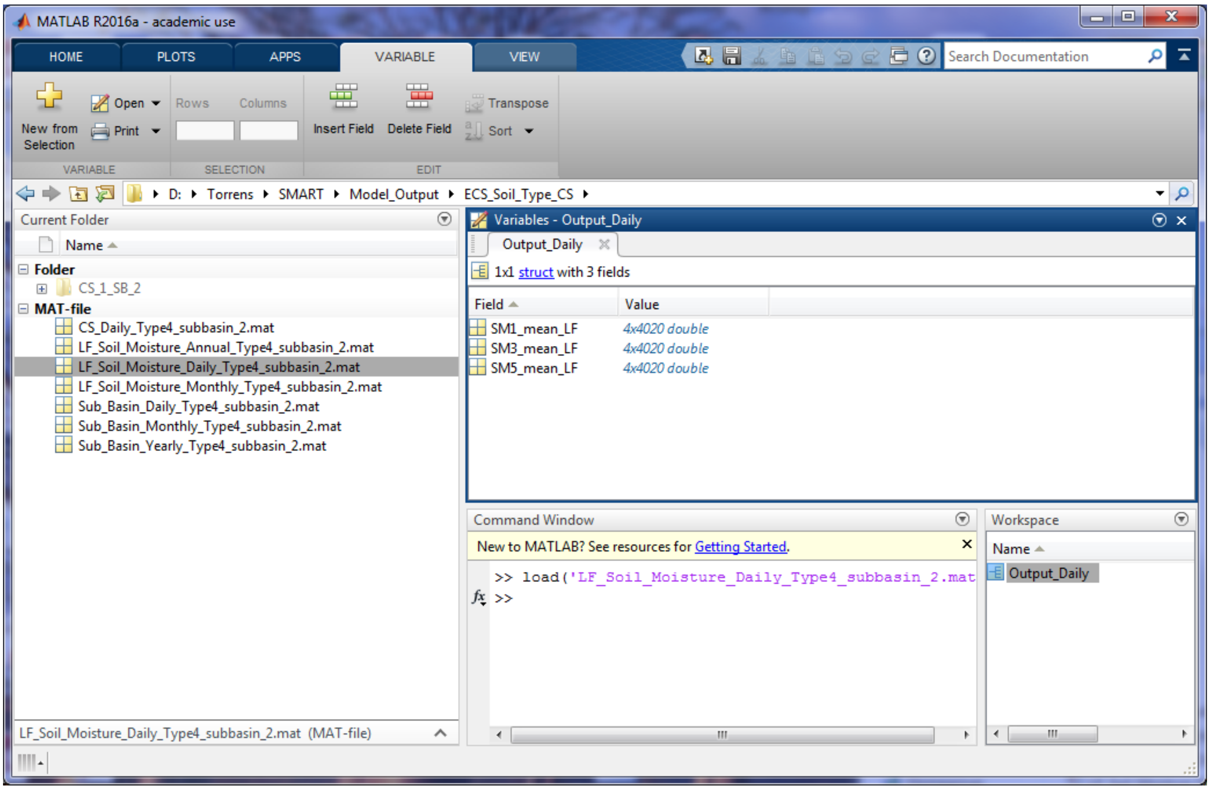


Figure 79. Contents of the LF_Soil_Moisture_Daily_Type4_subbasin_2.mat file.

5.2.5. Mapping of Soil Moisture for the Pixel based Cross Section Delineation Simulations

In this tutorial, we will explore soil moisture distribution approaches of SMART using data from the distributed pixel based delineation simulation. We are going to use the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script to do this task.

Open the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script and click on the 

button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed pixel based cross section delineation. To do this, type 1 at the command prompt and click 

.

Select Cross Section Delineation Type (1 to 4): 1

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click 

and the script asks you to enter the identification number of the sub-basin that you are interested. Type 2 and click 

Select the Sub-basin ID to process results: 2

In the next step, the script asks to enter the start date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/06/1985 and click 

.

Write the start date to process results (dd/mm/yyyy): 01/06/1985

In the next step, the script asks to enter the end date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/01/1986 and click 

(Figure 80).

Write the end date to process results (dd/mm/yyyy): 01/01/1986

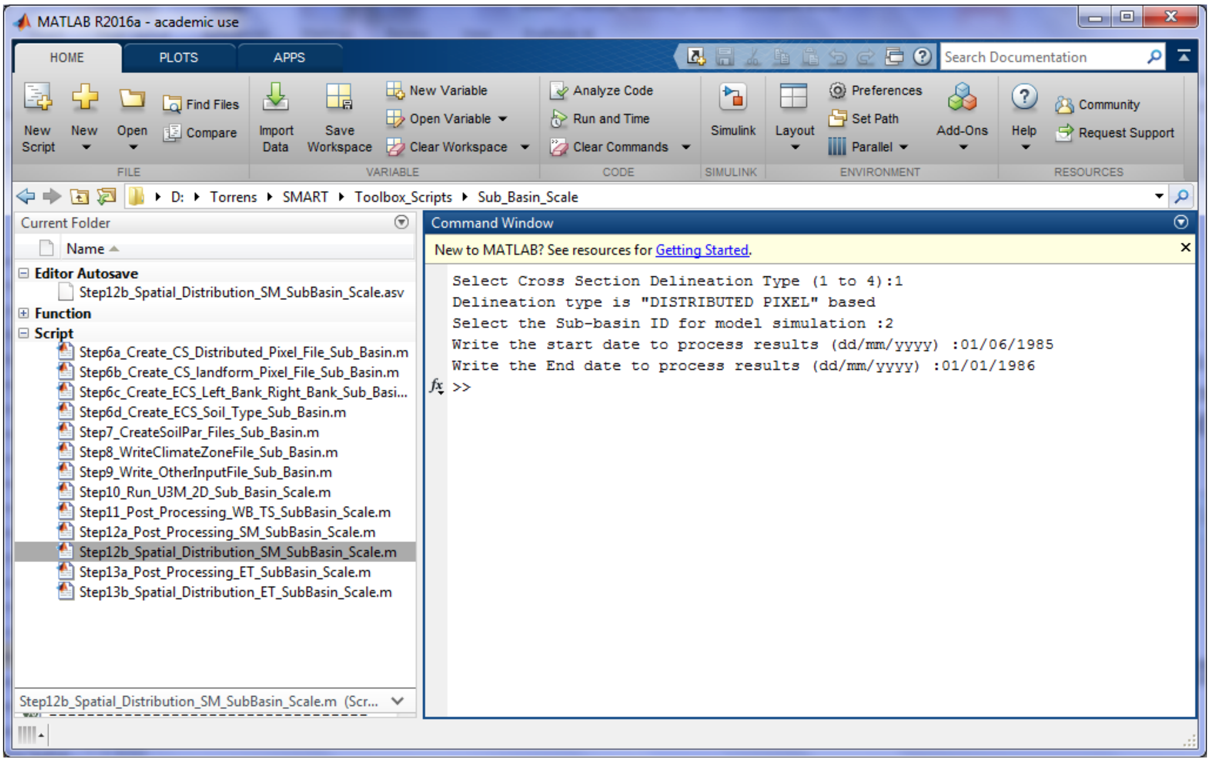


Figure 80. Generating soil moisture maps for the selected simulation period.

Upon successful execution of the script, two MATLAB files are generated in the (…\SMART\Model_Output\Pixel_Distributed) folder. These files are multi-dimensional arrays that store spatial distribution of soil moisture for every time step. These files are:

- **Map_Pixel_Soil_Moisture_Daily_Type1_subbasin_2.mat:** soil moisture for every pixel of a cross section in the sub-basin 2 for the selected time steps.
- **Map_subbasin_Soil_Moisture_Daily_Type1_subbasin_2.mat:** sub-basin average soil moisture is assigned to all pixels in the sub-basin 2 for the selected time steps.

⚠ **Note**: This script generates large files.

These files can be used in MakeMovies_Double_Frame.m function to generate movie files.

5.2.6. Mapping of Soil Moisture for the Distributed Landform Cross Section Delineation Simulations

In this tutorial, we will explore soil moisture distribution approaches of SMART using data from the distributed landform based delineation simulation. We are going to use the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script to do this task.

Open the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script and click on the button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed landform based cross section delineation. To do this, type 2 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 2

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click and the script asks you to enter the identification number of the sub-basin that you are interested. Type 2 and click

Select the Sub-basin ID to process results: 2

In the next step, the script asks to enter the start date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/06/1985 and click .

Write the start date to process results (dd/mm/yyyy): 01/06/1985

In the next step, the script asks to enter the end date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/01/1986 and click .

Write the end date to process results (dd/mm/yyyy): 01/01/1986

Upon successful execution of the script, three MATLAB files are generated in the (…\SMART\Model_Output\Pixel_Landform) folder. These files are multi-dimensional arrays that store spatial distribution of soil moisture for every time step. These files are:

- **Map_Pixel_Soil_Moisture_Daily_Type2_subbasin_2.mat:** soil moisture for every pixel of a cross section in the sub-basin 2 for the selected time steps.

- **Map_subbasin_Soil_Moisture_Daily_Type2_subbasin_2.mat:** sub-basin average soil moisture is assigned to all pixels in the sub-basin 2 for the selected time steps.

- **Map_LF_Soil_Moisture_Daily_Type2_subbasin_2.mat:** landform average soil moisture for the selected time steps is distributed to all pixels of a given landform.

⚠ **Note**: This script generates large files.

5.2.7. Mapping of Soil Moisture for the 3 ECSs Delineation Simulations

In this tutorial, we will explore soil moisture distribution approaches of SMART using data from the 3 ECSs delineation simulation. We are going to use the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script to do this task.

Open the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script and click on the Run button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the 3 ECSs delineation. To do this, type 3 at the command prompt and click Enter.

Select Cross Section Delineation Type (1 to 4): 3

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click Enter and the script asks you to enter the identification number of the sub-basin that you are interested. Type 2 and click Enter

Select the Sub-basin ID to process results: 2

In the next step, the script asks to enter the start date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/06/1985 and click Enter.

Write the start date to process results (dd/mm/yyyy): 01/06/1985

In the next step, the script asks to enter the end date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/01/1986 and click Enter.

Write the end date to process results (dd/mm/yyyy): 01/01/1986

Upon successful execution of the script, two MATLAB files are generated in the (…\SMART\Model_Output\ECS_LB_RB_H_CS) folder. These files are multi-dimensional arrays that store spatial distribution of soil moisture for every time step. These files are:

- **Map_subbasin_Soil_Moisture_Daily_Type3_subbasin_2.mat:** sub-basin average soil moisture is assigned to all pixels in the sub-basin 2 for the selected time steps.

- **Map_Hillslopes_Soil_Moisture_Daily_Type3_subbasin_2.mat:** landform average soil moisture for the selected time steps is distributed to all pixels of a given landform per hillslope.

⚠ **Note**: This script generates large files.

5.2.8. Mapping of Soil Moisture for the ECS Soil Type Delineation Simulations

In this tutorial, we will explore soil moisture distribution approaches of SMART using data from the ECS Soil Type delineation simulation. We are going to use the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script to do this task.

Open the **Step12b_Spatial_Distribution_SM_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the ECS Soil Type delineation. To do this, type 4 at the command prompt and click .

Select Cross Section Delineation Type (1 to): 4

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click  and the script asks you to enter the identification number of the sub-basin that you are interested. Type 2 and click 

Select the Sub-basin ID to process results: 2

In the next step, the script asks to enter the start date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/06/1985 and click .

Write the start date to process results (dd/mm/yyyy): 01/06/1985

In the next step, the script asks to enter the end date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/01/1986 and click Enter.

Write the end date to process results (dd/mm/yyyy): 01/01/1986

Upon successful execution of the script, two MATLAB files are generated in the (…\SMART\Model_Output\ECS_Soil_Type_CS) folder. These files are multi-dimensional arrays that store spatial distribution of soil moisture for every time step. These files are:

- **Map_subbasin_Soil_Moisture_Daily_Type4_subbasin_2.mat:** sub-basin average soil moisture is assigned to all pixels in the sub-basin 2 for the selected time steps.

- **Map_LF_Soil_Moisture_Daily_Type4_subbasin_2.mat:** landform average soil moisture for the selected time steps is distributed to all pixels of that landform per soil type.

⚠ **Note**: This script generates large files.

5.3. Generating Spatially Distributed Evapotranspiration Outputs

To generate spatially distributed evapotranspiration (ET) outputs, two steps should be taken in SMART: 1) Processing of simulations at the smallest conceptual modelling element scale, and 2) mapping of ET to a pixel level.

5.3.1. Processing at the Smallest Conceptual Modelling Element Scale-Distributed Pixel based Cross Section Delineation Simulations

The first step is to process simulated ET data at the smallest conceptual modelling element scale. **Step13a_Post_Processing_ET_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step13a_Post_Processing_ET_SubBasin_Scale.m** script and click on the Run button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed pixel based cross section delineation. To do this, type 1 at the command prompt and click Enter.

Select Cross Section Delineation Type (1 to 4): 1

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click Enter and the script asks to enter the sub-basin identification number. Type 2 and click Enter

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\Pixel_Distributed) folder, the following MATLAB .mat files are generated:

Pixel_ET_Daily_Type1_ subbasin_2.mat
Pixel_ET_Monthly_Type1_subbasin_2.mat
Pixel_ET_Yearly_Type1_subbasin_2.mat

To view the content of these files, navigate to the Pixel_Distributed folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. In Figure 108, the **Pixel_ET_Daily_Type1_subbasin_2.mat** is opened.

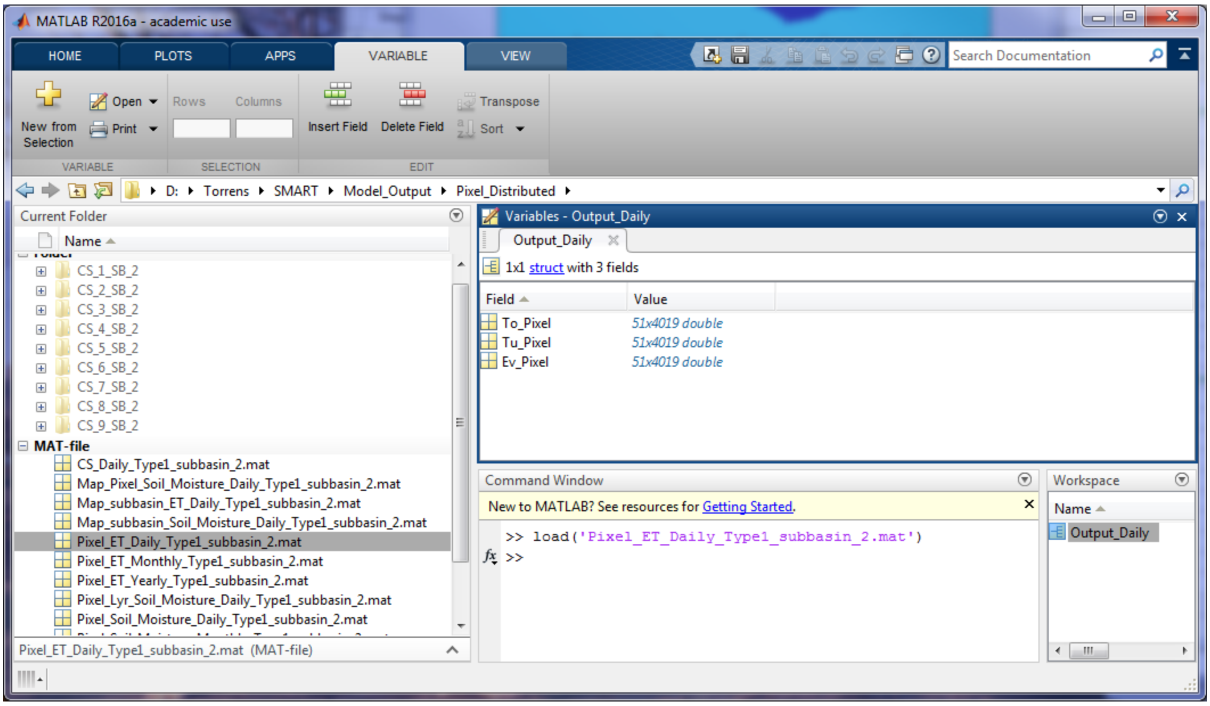
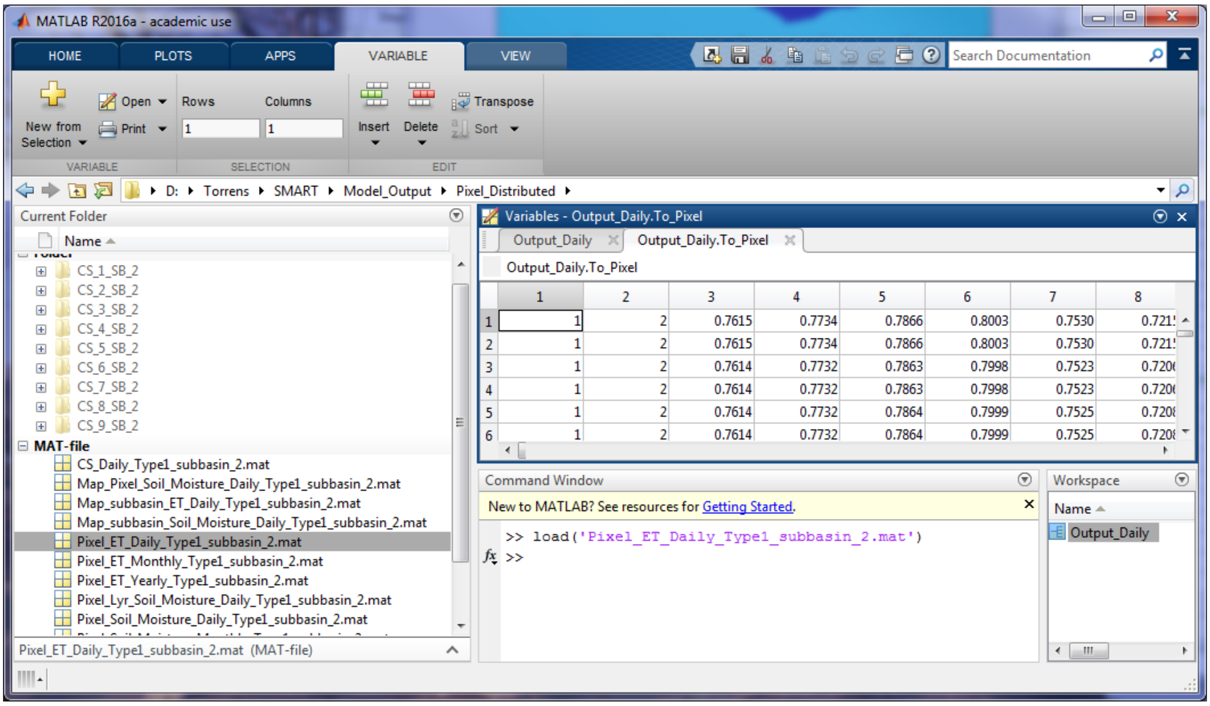


Figure 81. Content of the Pixel_ET_Daily_Type1_subbasin_2.mat

In the Output_Daily structure, there are three matrices:
To_Pixel: Daily overstory transpiration [mm/day]
Tu_Pixel: Daily undersotry transpiration [mm/day]
Ev_Pixel: Daily soil evaporation [mm/day]

Double click on To_Pixel to view its contents. As can be seen in Figure 82, the first column has the cross section identification number and the second column is the sub-basin identification number. The rest of columns are daily overstory transpiration values.



	1	2	3	4	5	6	7	8
1	1	2	0.7615	0.7734	0.7866	0.8003	0.7530	0.721
2	1	2	0.7615	0.7734	0.7866	0.8003	0.7530	0.721
3	1	2	0.7614	0.7732	0.7863	0.7998	0.7523	0.720
4	1	2	0.7614	0.7732	0.7863	0.7998	0.7523	0.720
5	1	2	0.7614	0.7732	0.7864	0.7999	0.7525	0.720
6	1	2	0.7614	0.7732	0.7864	0.7999	0.7525	0.720

Figure 82. Simulated overstory transpiration from the Pixel_ET_Type1.mat

5.3.2. Processing at the Smallest Conceptual Modelling Element Scale-Distributed Landform Cross Section Delineation Simulations

The first step is to process simulated ET data at the smallest conceptual modelling element scale. **Step13a_Post_Processing_ET_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step13a_Post_Processing_ET_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed landform cross section delineation. To do this, type 2 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 2

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations result. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click  and the script asks to enter the sub-basin identification number. Type 2 and click 

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\Pixel_Landform) folder, the following MATLAB .mat files are generated:

Pixel_ET_Daily_Type2_subbasin_2.mat

Pixel_ET_Monthly_Type2_subbasin_2.mat
Pixel_ET_Yearly_Type2_subbasin_2.mat
LF_ET_Daily_Type2_subbasin_2.mat
LF_ET_Monthly_Type2_subbasin_2.mat
LF_ET_Yearly_Type2_subbasin_2.mat

To view the content of these files, navigate to the Pixel_Landform folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Double click on **LF_ET_Daily_Type2_subbasin_2.mat** to view its contents (Figure 83).

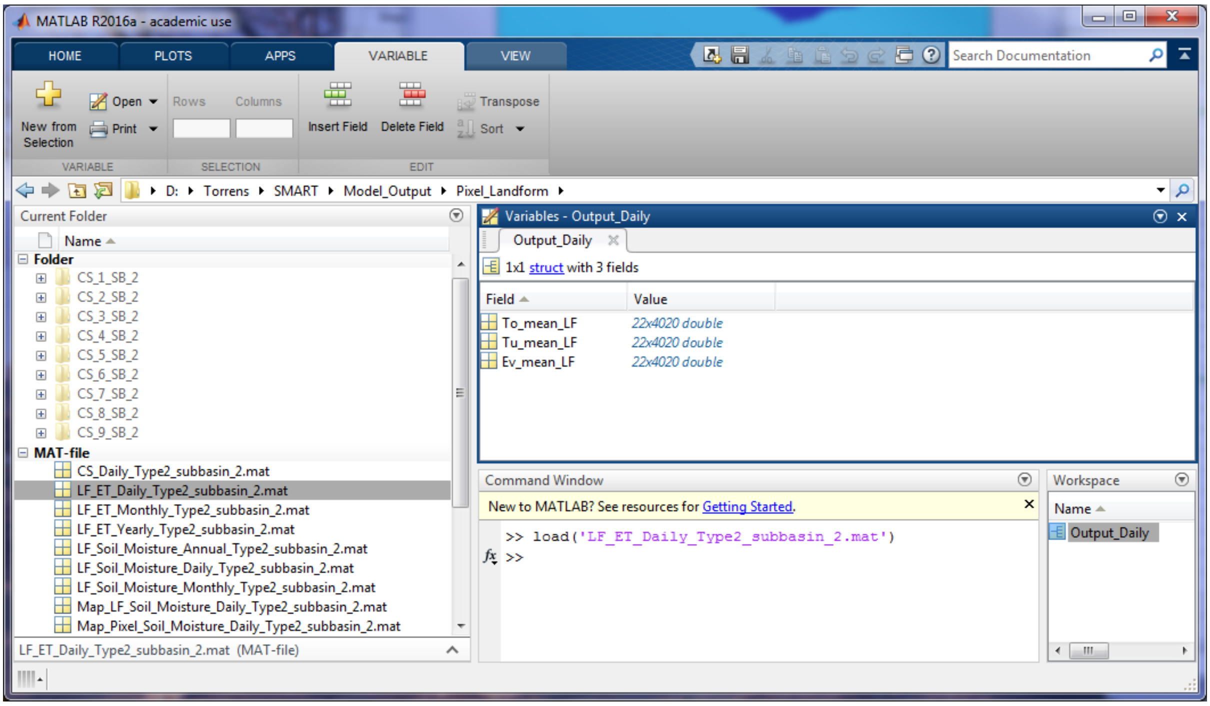
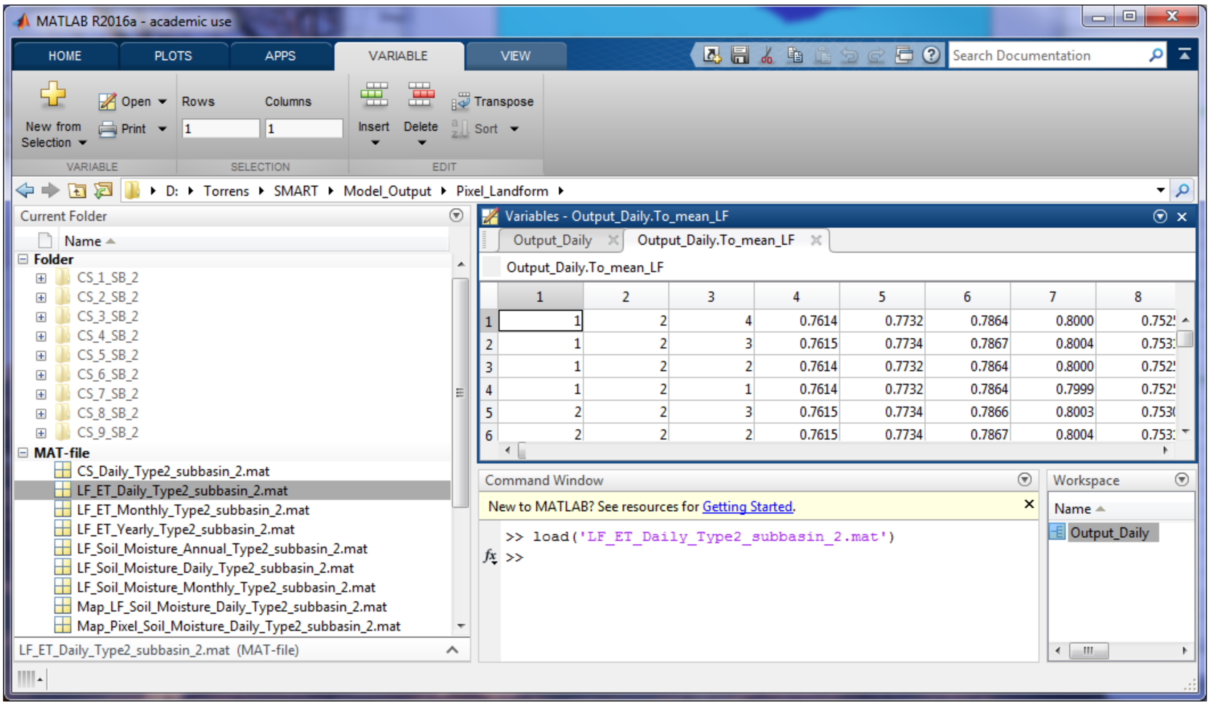


Figure 83. Content of the LF_ET_Daily_Type2_subbasin_2.mat. This file has ET values per landform.

In the Output_Daily structure, there are three matrices:
To_mean_LF: Overstory transpiration for every landform [mm/day]
Tu_mean_LF: Understory transpiration for every landform [mm/day]
Ev_mean_LF: Soil evaporation for every landform [mm/day]

Double click on To_mean_LF to view its content. As can be seen in Figure 84, the first column is the cross section identification number, the second column is the sub-basin identification number, the third column is the landform number and the rest are daily overstory transpiration for every landform.



	1	2	3	4	5	6	7	8
1	1	2	4	0.7614	0.7732	0.7864	0.8000	0.752
2	1	2	3	0.7615	0.7734	0.7867	0.8004	0.753
3	1	2	2	0.7614	0.7732	0.7864	0.8000	0.752
4	1	2	1	0.7614	0.7732	0.7864	0.7999	0.752
5	2	2	3	0.7615	0.7734	0.7866	0.8003	0.753
6	2	2	2	0.7615	0.7734	0.7867	0.8004	0.753

Figure 84. Simulated overstory tranpiration in the LF_ET_Daily_Type2_subbasin_2.mat.

5.3.3. Processing at the Smallest Conceptual Modelling Element Scale- 3 ECSs Delineation Simulations

The first step is to process simulated ET data at the smallest conceptual modelling element scale. **Step13a_Post_Processing_ET_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step13a_Post_Processing_ET_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the 3 ECSs delineation option. Type 3 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 3

In the next step, the script generates a Figure so you can select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

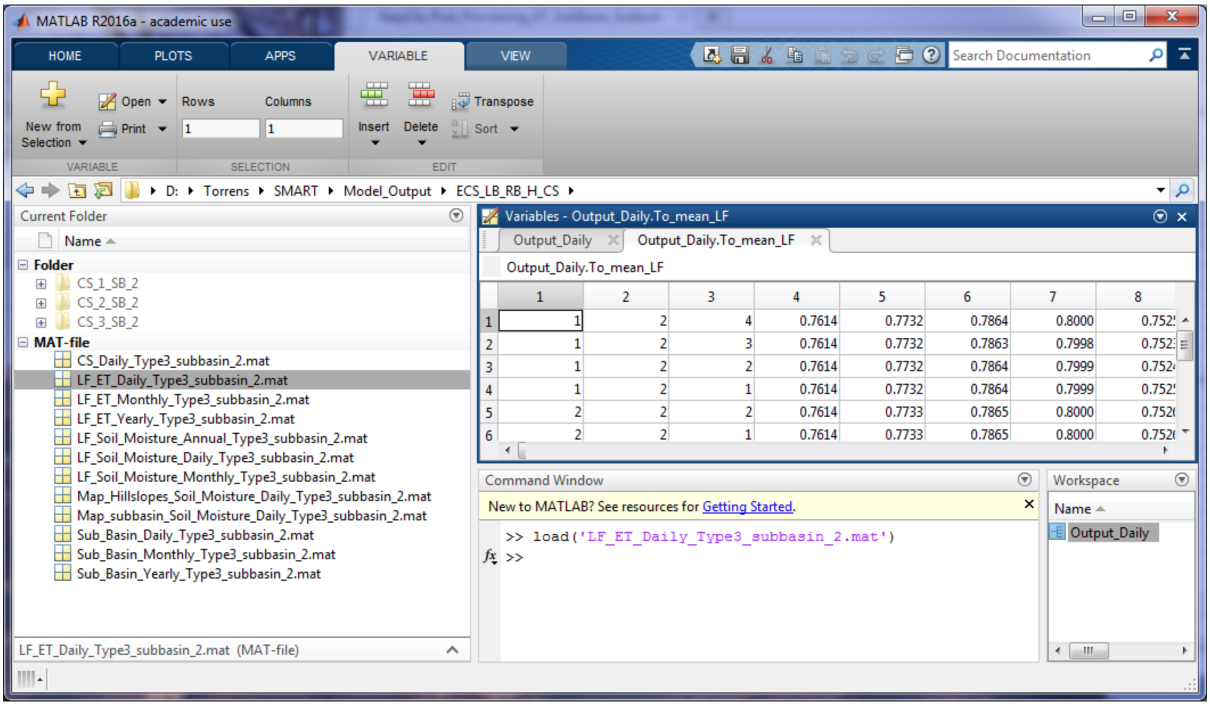
Since we are interested to process fluxes for the sub-basin 2, click  and the script asks to enter the sub-basin identification number. Type 2 and click .

Select the Sub-basin ID to process results: 2

In the (...\SMART\Model_Output\ECS_LB_RB_H_CS) folder, the following MATLAB .mat files are generated:

LF_ET_Daily_Type3_subbasin_2.mat
LF_ET_Monthly_Type3_subbasin_2.mat
LF_ET_Yearly_Type3_subbasin_2.mat

To view the content of these files, navigate to the folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB (Figure 85).



	1	2	3	4	5	6	7	8
1	1	2	4	0.7614	0.7732	0.7864	0.8000	0.752
2	1	2	3	0.7614	0.7732	0.7863	0.7998	0.752
3	1	2	2	0.7614	0.7732	0.7864	0.7999	0.752
4	1	2	1	0.7614	0.7732	0.7864	0.7999	0.752
5	2	2	2	0.7614	0.7733	0.7865	0.8000	0.752
6	2	2	1	0.7614	0.7733	0.7865	0.8000	0.752

Figure 85. Content of LF_ET_Daily_Type3_subbasin_2.mat file.

5.3.4. Processing at the Smallest Conceptual Modelling Element Scale - ECS Soil Type Simulations

The first step is to process simulated ET data at the smallest conceptual modelling element scale. To do this **Step13a_Post_Processing_ET_SubBasin_Scale.m** script is used to process simulation results from a single sub-basin.

Open the **Step13a_Post_Processing_ET_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the ECS soil type delineation option. To do this, type 4 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 4

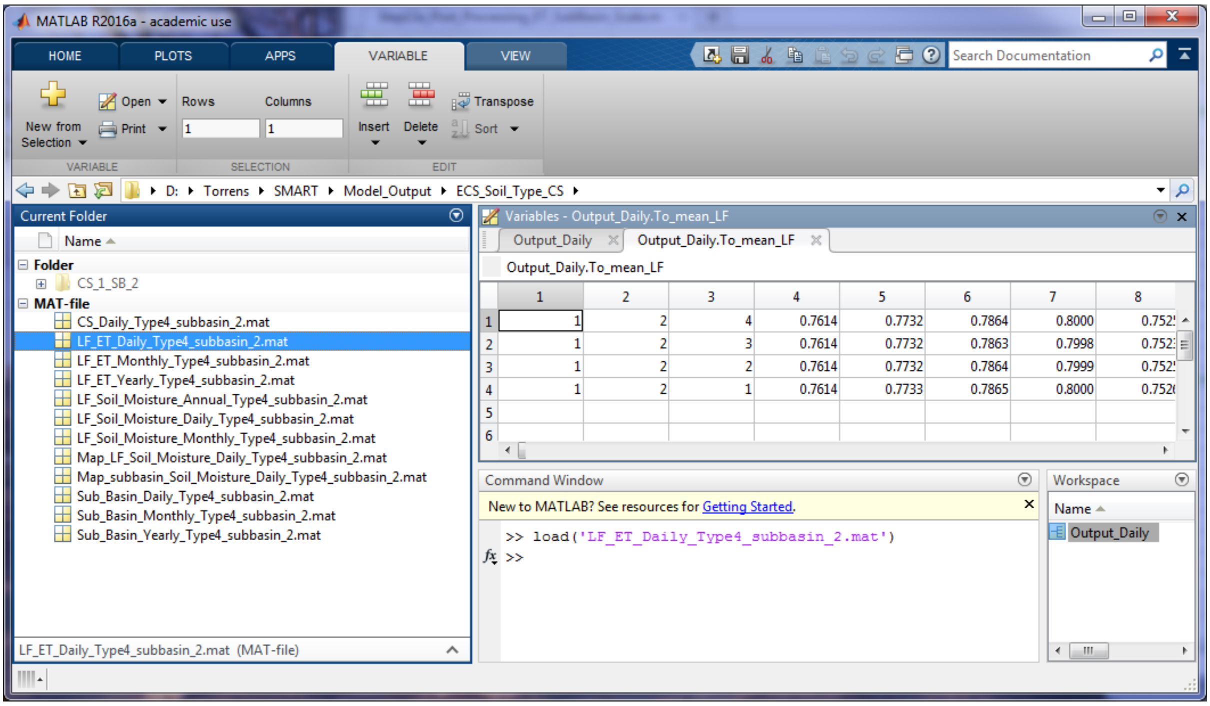
In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the  tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for sub-basin 2, click  and the script asks you to enter the identification number of the sub-basin that you are interested. Because, I selected sub-basin 2, I type 2 and click .

Select the Sub-basin ID to process results: 2
In the (...\SMART\Model_Output\ECS_Soil_Type_CS) folder, the following MATLAB .mat files are generated:

> **LF_ET_Daily_Type4_subbasin_2.mat**
> **LF_ET_Monthly_Type4_subbasin_2.mat**
> **LF_ET_Yearly_Type4_subbasin_2.mat**

To view the content of these files, navigate to the ECS_Soil_Type_CS folder in MATLAB Table of contents and double click on the name of the file to open it in MATLAB. Double click on **LF_ET_Daily_Type4_subbasin_2.mat** to view its contents (Figure 86).



	1	2	3	4	5	6	7	8
1	1	2	4	0.7614	0.7732	0.7864	0.8000	0.752
2	1	2	3	0.7614	0.7732	0.7863	0.7998	0.752
3	1	2	2	0.7614	0.7732	0.7864	0.7999	0.752
4	1	2	1	0.7614	0.7733	0.7865	0.8000	0.752

Figure 86. Content of LF_ET_Daily_Type4_subbasin_2.mat file.

5.3.5. Mapping of Evapotranspiration at a Pixel Level

In this tutorial, we will explore two ET distribution approaches of SMART using data from the distributed pixel based delineation simulation. We are going to use the **Step13b_Spatial_Distribution_ET_SubBasin_Scale.m** script to do this task.

Open the **Step13b_Spatial_Distribution_ET_SubBasin_Scale.m** script and click on the  button on the menu bar.

Upon clicking on the Run button, the script asks to enter the cross section delineation type. We are going to process simulation results of the distributed pixel based cross section delineation. To do this, type 1 at the command prompt and click .

Select Cross Section Delineation Type (1 to 4): 1

In the next step, a Figure is generated in the script to select the sub-basin that you are interested to process its simulations results. Click on the tool of the Figure and select a sub-basin to view its identification number.

Since we are interested to process fluxes for the sub-basin 2, click and the script asks you to enter the identification number of the sub-basin that you are interested. Type 2 and click

Select the Sub-basin ID to process results: 2

In the next step, the script asks to enter the start date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/06/1985 and click .

Write the start date to process results (dd/mm/yyyy) : 01/06/1985

In the next step, the script asks to enter the end date for processing of simulation results. Since model simulations are performed from 1/1/1985 until 31/12/1995, you can enter any dates within this range. Type 01/01/1986 and click .

Write the end date to process results (dd/mm/yyyy) : 01/01/1986

Upon successful execution of the script, two MATLAB files are generated in the (…\SMART\Model_Output\Pixel_Distributed) folder. These files are multi-dimensional arrays that store spatial distribution of ET for every time step. These files are:

- **Map_Pixel_ET_Daily_Type1_subbasin_2.mat:** daily ET for every pixel in a cross section in the sub-basin 2 for the selected time steps.

- **Map_subbasin_ET_Daily_Type1_subbasin_2.mat:** sub-basin average ET is assigned to all pixels in the sub-basin 2 for the selected time steps.

⚠ **Note**: This script generates large files.

References

Beven K. 1997. TOPMODEL: A critique. Hydrological Processes, 11: 1069-1085. DOI: 10.1002/(SICI)1099-1085(199707)11:9<1069::AID-HYP545>3.0.CO;2-O.

Bogaart PW, Troch PA. 2006. Curvature distribution within hillslopes and catchments and its effect on the hydrological response. Hydrology and Earth System Sciences, 10: 925-936.

Fan Y, Bras RL. 1998. Analytical solutions to hillslope subsurface storm flow and saturation overland flow. Water Resources Research, 34: 921-927. DOI: 10.1029/97WR03516.

Khan U, Tuteja NK, Ajami H, Sharma A. 2014. An equivalent cross-sectional basis for semidistributed hydrological modeling. Water Resources Research: n/a-n/a. DOI: 10.1002/2013WR014741.

Khan U, Tuteja NK, Sharma A. 2013. Delineating hydrologic response units in large upland catchments and its evaluation using soil moisture simulations. Environmental Modelling & Software, 46: 142-154. DOI: http://dx.doi.org/10.1016/j.envsoft.2013.03.005.

Noel P, Rousseau AN, Paniconi C, Nadeau DF. 2014. Algorithm for Delineating and Extracting Hillslopes and Hillslope Width Functions from Gridded Elevation Data. J. Hydrol. Eng., 19: 366-374. DOI: doi:10.1061/(ASCE)HE.1943-5584.0000783.

Schaap MG, Leij FJ, van Genuchten MT. 2001. rosetta: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. Journal of Hydrology 251(3–4) 163-176.

Summerell GK, Vaze J, Tuteja NK, Grayson RB, Beale G, Dowling TI. 2005. Delineating the major landforms of catchments using an objective hydrological terrain analysis method. Water Resources Research, 41: n/a-n/a. DOI: 10.1029/2005WR004013.

Tarboton DG.2013.TauDEM 5.1 Guide to using the TauDEM command line functions

Tuteja N K, Vaze J, Murphy B, Beale GTB. 2004. CLASS: Catchment scale multiple-landuse atmosphere soil water and solute transport model, Tech. Rep. 04/12, Coop. Res. Cent. for Catchment Hydrol., Canberra. [Available at http://www.toolkit.net.au/Tools/CLASSU3M-1D/publications].

Vaze, J, Tuteja, NK, Teng J.2004. CLASS Unsaturated Moisture Movement Model U3M-1D—User’s Manual, NSW Dep. of Infrastruct., Plann. and Nat. Resour., Sydney, Australia.