GIS Tools for WEB DHM using ArcGIS

User's Manual

Version 2.0

June 2016

CHAPTER 1

General Background

A GIS based WEB DHM tools aim at simplifying the process of preparing the input datasets for the WEB DHM model. Originally, user need to run several codes written in Arc GIS workstation (*.aml), Fortran (*.f), C and C++ to prepare and process for the input data for the WEB DHM model which is sometime confusing and need manual editing of the code to get the required output. For the user without the knowledge of programming is difficult and need additional software and platform to run all these codes. To overcome all these problem, a GIS based WEB-DHM tool is developed. In this updated version (V2.0), it includes toolbox for Terrain Preprocessing, Basin Division, Soil data Processing, Land use data processing, LAI and FPAR data processing and Rainfall data processing. The newer version of the tool is more efficient at processing the data providing user friendly interface to interact with the tool. Now user can also participate in improving the tools and send their feedback and comments through the github platform.

Overview of Requirements

This is an additional tool which can be used in ArcGIS that provides the users with the set of tools and utilities for the preparation of the necessary data to run the WEB DHM model. This tool is designed for the users with the limited geographic information system (GIS) experience, extensive knowledge of ArcGIS is advantageous. Users, however must have experience in modeling with WEB-DHM and have a thorough understanding of data requirements to properly create and interpret the datasets created with this tool. This tool also requires an additional python modules to be installed for efficient processing of the data.

Software Requirements

A GIS based WEB DHM tool V2.1 is for the use with ArcGIS 10.1, 10.2, 10.3 and 10.4 (Separate versions are available for different version of Arc GIS). Spatial Analyst extension is required. Besides this following additional python package and software need to be installed in the computer.

1. Additional python modules (**numpy**, **scipy**,**netCDF4**, **lxml** and **pydap**)
2. MRT (Modis Re-projection Tool)

The detail process for downloading and installing these packages will be described in the later section.

User’s Manual Overview

This manual covers the detailed instruction for preparing and processing data for the WEB DHM model. It is organized as under the following topics:

Chapter 1-2 provides an introduction to the WEB DHM tool and instruction for getting started with the tool.

Chapter 3 provides a detail instruction for preparing Terrain preprocessing

Chapter 4 explains about the sub-basin division using the Otto-pfafstetter algorithm

Chapter 5 discusses in detail about the preparation of Soil and Land Use data

Chapter 6 provides a detail discussion for preprocessing of MODIS data for LAI (Leaf Area Index) and FPAR (Fraction of Photo-synthetically Active Radiation)

Chapter 7 explains the steps for the processing of rainfall data used for WEB DHM model

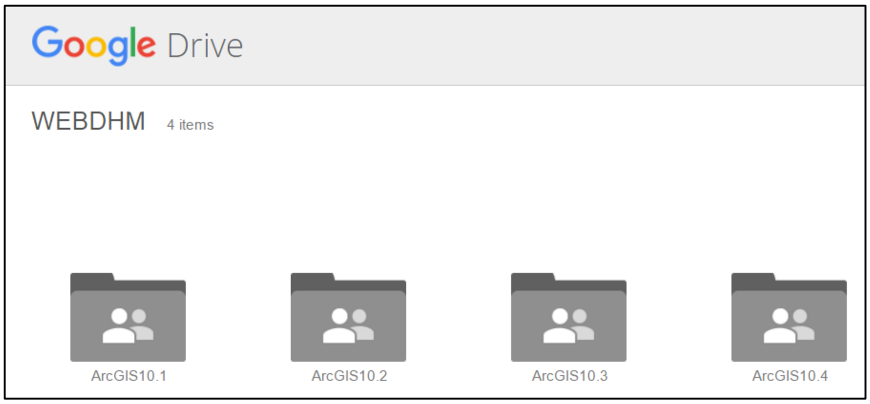
Chapter 7 provides a detail instruction on sharing their comments and feedback about the tool and participate in improving the tool.

CHAPTER 2

Installation and usage of the Tool

The newer version (2.0) of the WEB DHM Tool is available as an Arc Map addins toolbar as shown in below figure. WEB DHM tool can be accessed from this link below:

https://drive.google.com/open?id=0B36zBxbxhA63dnZIMEY0aHdvOUE. There are four different version of the tool available, user can download the appropriate version of the tool based on their Arc GIS version installed on their system.



After downloading the appropriate version of the tool user can follow these below steps to configure and install the tool:

1. Unzip the downloaded folder, User can see **WEBDHMV2** folder inside it
2. Copy **WEBDHMV2** into system **C:** . All the files inside the WEBDHMV2 are shown as in figure 1

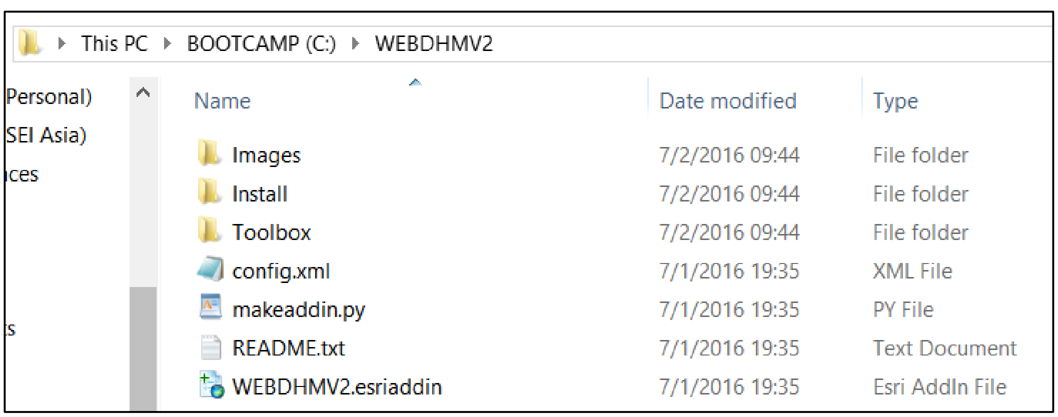
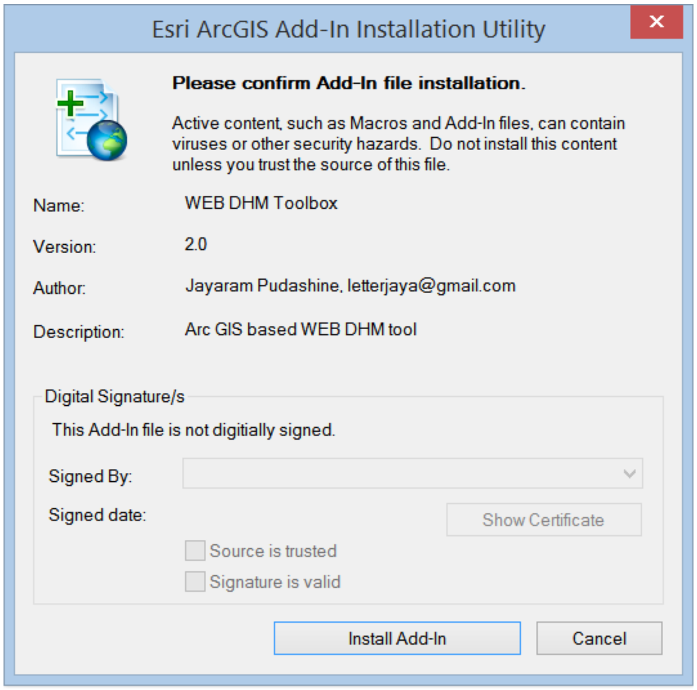


Figure 1 List of files and folder inside WEBDHM folder

3. Double click on **WEBDHMV2.esriadd** file, it will pop up the box



4. Click on **Install Add-In** button, it will display message as Installation Succeed. After this user can access the toolbar from the **Arc Map** as below :
   a. Start the Arc Map application
   b. Click on **Customize** menu and click on **Add In Manager.** User can see WEB DHM Toolbox on My Add-Ins category if the tool is properly installed into your system.

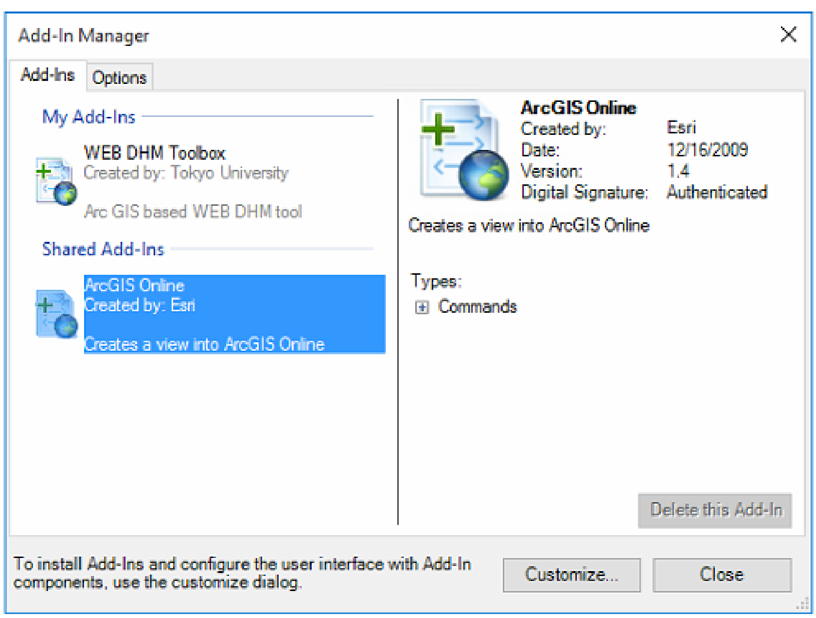
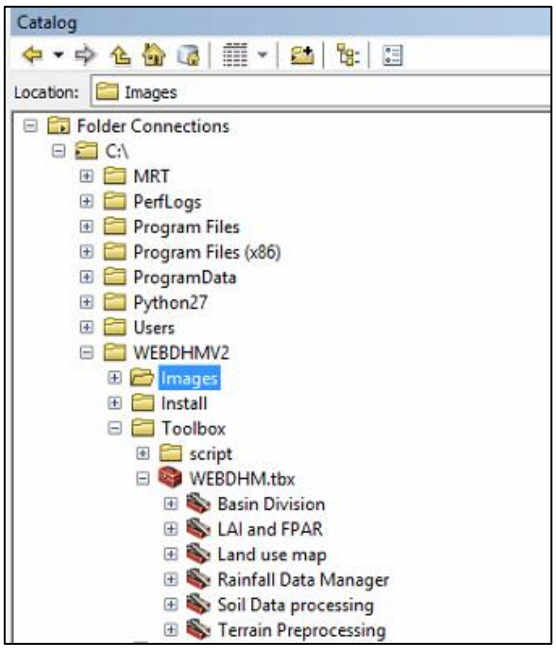


Figure 2 Add-In Manager dialog box

c. To open the WEB DHM Toolbar, click on **Customize menu** > and select **WEB DHM Toolbar** from the list, this will show the toolbar on the screen, now user can start using this tool for the processing of the data.

Figure 3 Web DHM Toolbar

5. User also can access the toolbox from the Arc Catalog window in the ArcMap. This tools is inside **WEBDHMV2** > **Toolbox** folder. This toolbox contains several tools for Terrain processing, Basin Division, Land use and Soil data processing, LAI and FPAR and Rainfall data processing.



Installing other software

This WEB DHM tool require some additional software and python packages to be installed in the system prior using the tool which are as below:

1. Installing addition python packages

There are basically two different ways to install additional python packages into the system, one using a standalone executable files (*.exe) and other using python packages. Not all the additional python packages are available in windows executable format (such as numpy, scipy and netCDF4) but other packages are **pydap**, **lxlm** are available only as python packages which need to be installed manually using pip (package management system). The installation of pip is described in the later section.

a) numpy package

This WEB DHM tool requires the numpy package (v 1.9.0 or higher). Usually with Arc GIS 10.1, numpy 1.8.0 is installed. Thus user need to update the numpy package. The latest version of numpy can be downloaded from the following URL:

http://sourceforge.net/projects/numpy/files/NumPy/

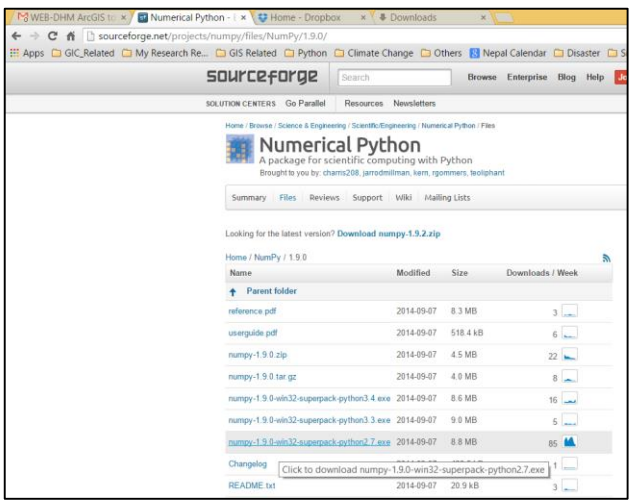


Figure 4 List of updated numpy package

User can select numpy 1.9.0 from the list and download the numpy version for windows with the name as numpy-1.9.0-win32-superpack-python2.7.exe. Once the file is downloaded, double click to install in the computer. User can follow the wizard to install it as shown in Figure 5.

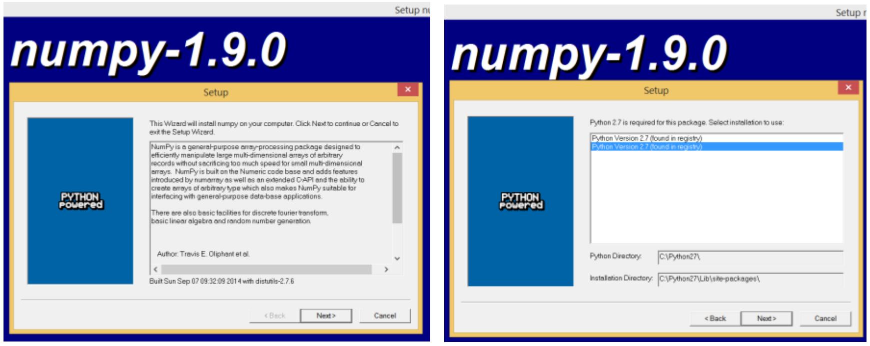


Figure 5 Wizard to install the latest numpy package

After installing the updated package of numpy, user can check the version of the numpy package in Arc Map window by following the steps:

- Open the Arc Map window (Start | All Programs | Arc GIS | Arc Map 10.1)
- Click on the Python button in the standard toolbar, it will pop up the python window as below and type the following code as shown in Figure 6 to check the version of numpy installed in your computer.

Figure 6 Python window showing the version of numpy

b) Scipy package

Similarly, the latest version of the scipy package can be downloaded from this link: https://sourceforge.net/projects/scipy/files/scipy/ . User can download the latest version of the scipy package and install on the computer following same as numpy package.

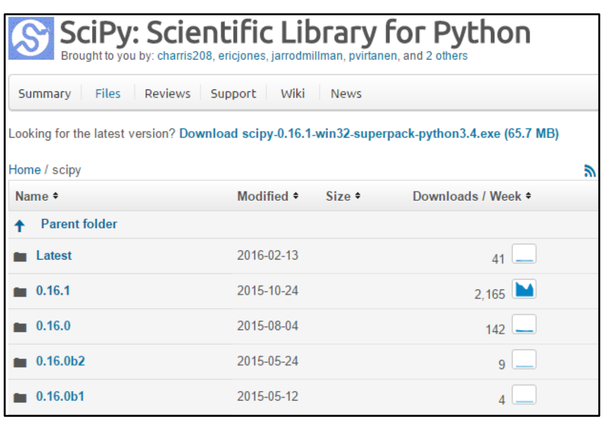


Figure 7 Different version of scipy packages available for download

2. Installing/updating additional python module using pip

Pip is a package management system used to install and manage software packages written in Python. Many packages can be found in the Python Package Index (PyPI)

Installing pip

1) Open this link : https://pip.pypa.io/en/stable/installing/

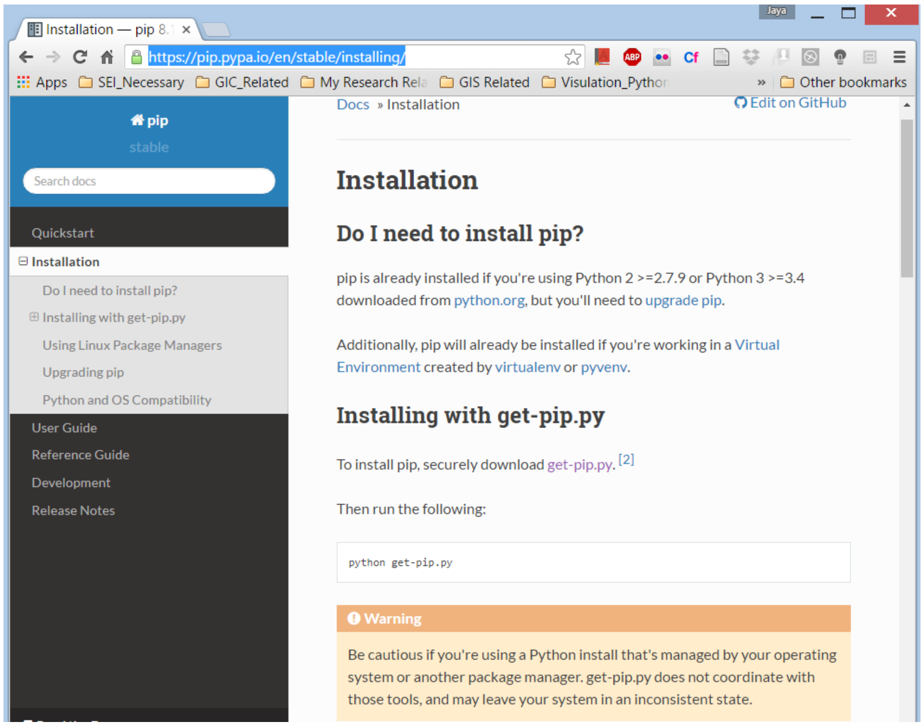


Figure 8 pip web page to download get-pip.py

2) Download **get-pip.py** file as shown on the screen and save it as .py file
3) Open the command prompt, change the directory to the same one where user have downloaded the file and type **python <u>get-pip.py.</u>** This will download and install pip package into your system and shows the progress as below :

```
C:\Users\Jaya\Desktop>python get-pip.py
```

```
Collecting pip
  Downloading pip-8.1.2-py2.py3-none-any.whl (1.2MB)
    100% |################################| 1.2MB 451kB/s
Collecting wheel
  Downloading wheel-0.29.0-py2.py3-none-any.whl (66kB)
    100% |################################| 71kB 1.2MB/s
Installing collected packages: pip, wheel
  Found existing installation: pip 7.0.1
    Uninstalling pip-7.0.1:
      Successfully uninstalled pip-7.0.1
Successfully installed pip-8.1.2 wheel-0.29.0
```

After completing installation, user need to add variable in System Environment path as below:

2. Open the **Control panel | System | Advance System settings**
3. Click on Environment variables button
4. In the system variable list is the dialog box as shown in Figure …, select the Path variable and click on edit
5. Add **C:\Python27\ArcGIS10.x\Scripts** at the end of the variable list separated by semicolon (;) (Note : x is the version of the Arc GIS as 10.1,10.2,10.3 or 10.4)
6. Click on Ok

Now user can use pip from the command prompt to install the required python modules.

Installation netCDF4 package

Open the command prompt and type **pip install netCDF4**. This will download the necessary package and install netCDF4 package inside the python folder as shown in below figure.

```
C:\Users\aitc_pe14>pip install netCDF4
Collecting netCDF4
  Downloading netCDF4-1.2.4-cp27-cp27m-win32.whl (1.9MB)
    100% |################################| 1.9MB 333kB/s
Requirement already satisfied (use --upgrade to upgrade): numpy>=1.7 in c:\python27\
arcgis10.4\lib\site-packages (from netCDF4)
Installing collected packages: netCDF4
Successfully installed netCDF4-1.2.4
```

Figure 9 Installation of netCDF4 package

Installation pydap package

Open the command prompt and type **pip install pydap**. This will download the necessary package and install pydap package inside the python folder as shown in below figure

```
C:\>pip install pydap
Collecting pydap
  Downloading Pydap-3.1.1.tar.gz (3.1MB)
    100% |################################| 3.1MB 217kB/s
Requirement already satisfied (use --upgrade to upgrade): numpy in c:\python27\arcgi
s10.4\lib\site-packages (from pydap)
Collecting httplib2>=0.4.0 (from pydap)
  Downloading httplib2-0.9.2.zip (210kB)
    100% |################################| 215kB 914kB/s
```

Figure 10 Installation of pydap package

Installing lxml package

Open the command prompt and type **pip install lxml**. This will download the necessary package and install lxml package inside the python folder as shown in below figure

```
C:\>pip install lxml
Collecting lxml
  Downloading lxml-3.6.0-cp27-none-win32.whl (3.0MB)
    100% |################################| 3.1MB 233kB/s
Installing collected packages: lxml
Successfully installed lxml-3.6.0

C:\>_
```

Figure 11 Installation of lxml package from pip

Updating numpy package from pip

User can update the numpy packages also using pip. This can be done by typing **pip install –upgrade numpy** in the command prompt. This will remove the old numpy files and install the latest version of in the system.

2. MRT (MODIS Re-projection Tool)

This tool can be downloaded from the following URL:

https://lpdaac.usgs.gov/tools/modis_reprojection_tool

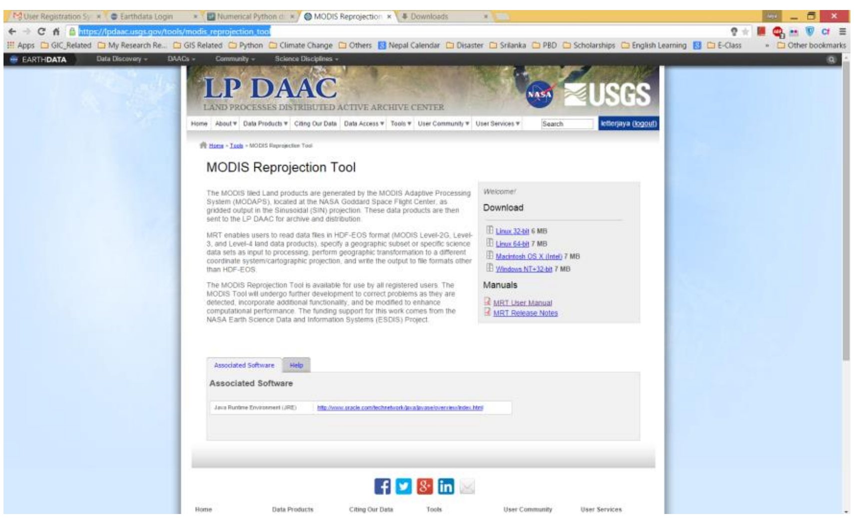


Figure 12 MRT download page

In the download page, user can select the link for Windows NT 32 bit. (Note: The link to download MRT will not activate if the user has not login into the account of USGS)

After MRT is downloaded, unzip the file and follow the steps:

- You will see the list of the files, among that double click on the MRT_install.bat which will display the option in command prompt as below figure 13.
- Press any key to continue the installation process

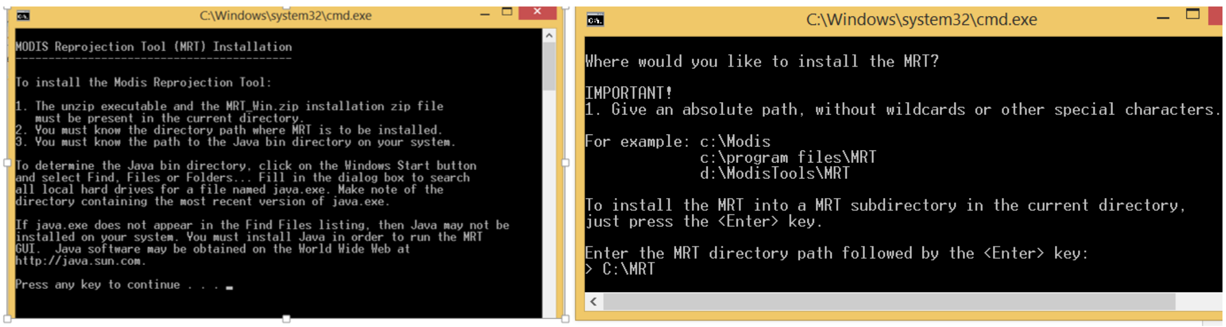


Figure 13 MRT installation wizard

- Type the location where you want to save the MRT for eg, you can type C:\MRT. It will install inside the C: drive in the MRT folder and press Enter
- Press 'y' to create the directory and press Enter
- Select option '1' for Windows XP or later and again press Enter
- Input the location for the Java. You need to check inside the program files folder whether Java is installed. If it is not installed, you can download it from the internet and install in the system. Once it is installed, you need to type the location of Java as : C:\Program Files (x86)\Java\jre1.8.0_45\bin and press Enter
- Press 'y' to confirm the location and press Enter to complete the MRT installation process

MRT tool should be accessed from python. For this user need to add the path of the MRT in the environment variable. This can be done as below:

1. Open the **Control panel | System | Advance System settings**
2. Click on Environment variables button
3. In the system variable list is the dialog box as shown in Figure 6, select the Path variable and click on edit
4. Add **C:\MRT\bin** at the end of the variable list separated by semicolon (;)
5. Click on Ok

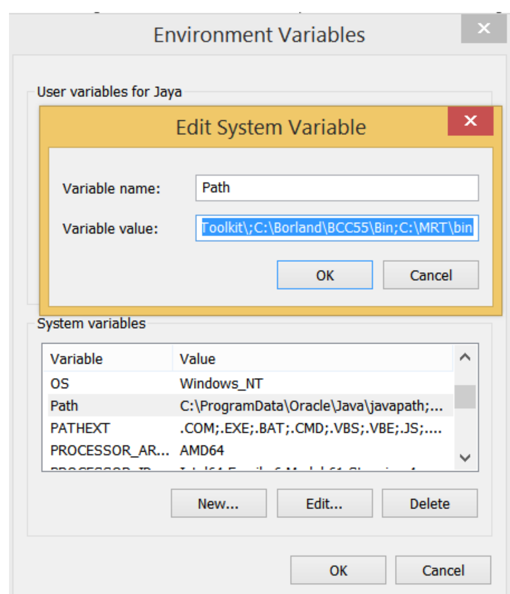


Figure 14 Dialog box for Environment variable

Once the installation is complete, follow the below steps to verify the installation.

7. Open the command prompt (Run | cmd)
8. Type resample / mrtmosaic

If the tool is properly installed and configured, it should show up with MRT tool option in the command prompt.

Initial setting up

Initial setting up can be performed as below.

1. Run Arc Map 10.x from Start > All Programs > Arc GIS > Arc Map 10.x

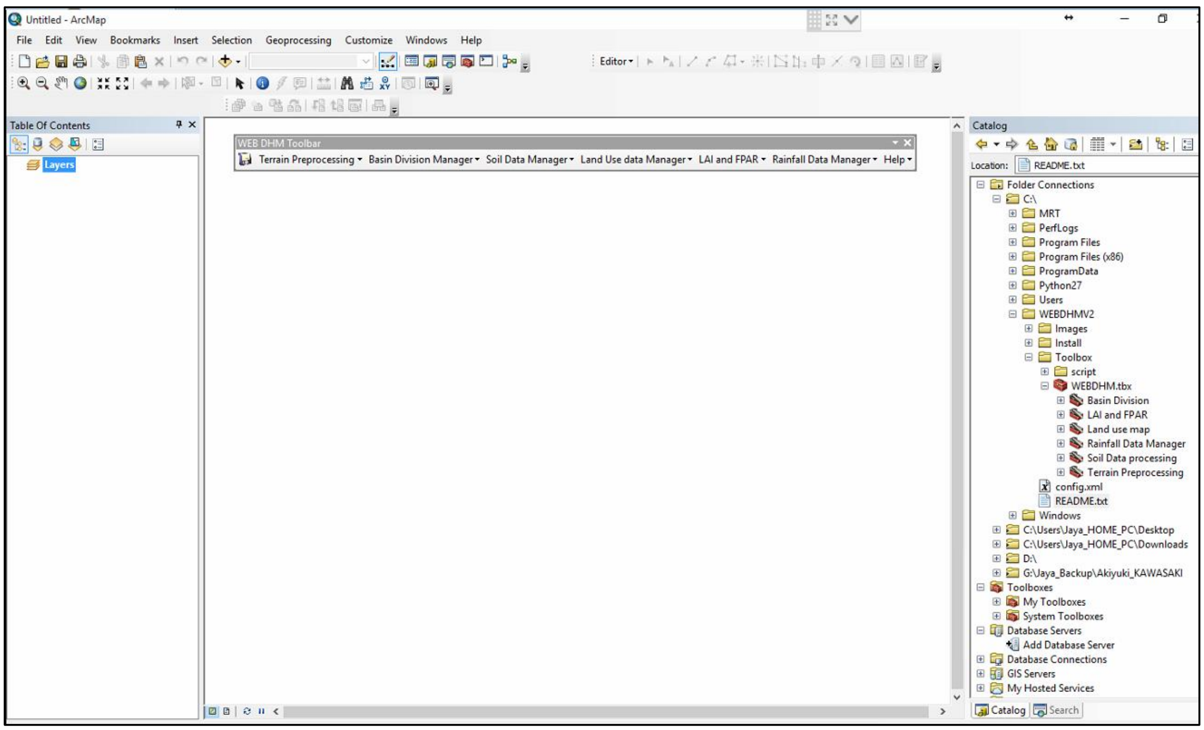


Figure 15 Arc Map window with the WEB DHM toolbar and toolbox in Arc Catalog

2. **Save** the new Arc Map document into the specific folder (It is always recommended to save in a new folder). This can be done by clicking on  on the toolbar. This step is very important as all the necessary files during the preprocessing will be stored inside the same folder where Arc map document is saved.
3. WEB-DHM toolbox can be accessed from the Catalog window. If catalog window is not displayed click on Windows menu and select Catalog. For the ease to access the toolbox, user can create the connection to the WEB DHM folder.

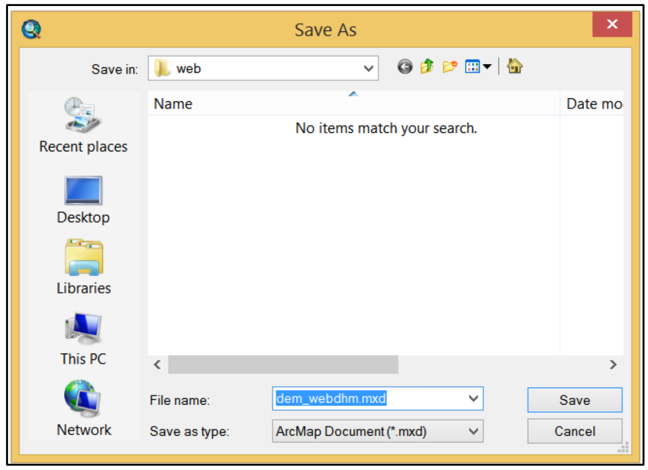


Figure 16 Dialog box for saving the map document

This integrated WEB DHM toolbar contains several tools for the preprocessing of WEB DHM model. All the tools available in the toolbox should be used in the sequential order as described in the manual.

CHAPTER 3

Terrain Preprocessing

Terrain Preprocessing includes the projection of DEM (Digital Elevation Model), DEM preprocessing as fill, flow accumulation and flow direction. Similarly, it includes the delineation of the watershed and the hill slope calculation.

Data Requirements

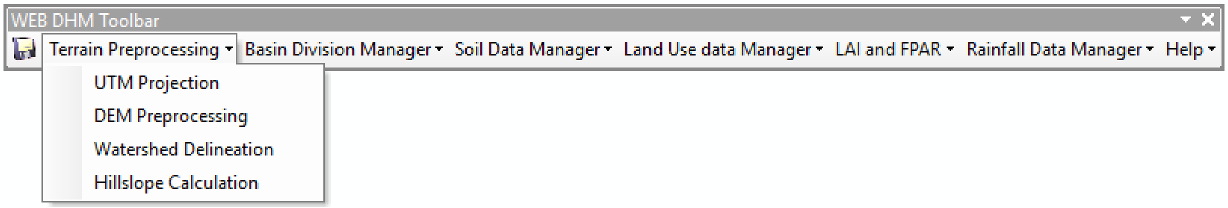
This tool requires a fine resolution DEM (Digital Elevation Model) which can be collected from various sources. Freely available DEM from SRTM (90m), SRTM (30m), and Hydroshed can be downloaded from the internet. The result from Distributed Hydrological Model as WEB DHM largely depends on the spatial resolution of the DEM. It also affect on the processing and simulation of the model. Thus it is always advisable to select the appropriate spatial resolution of the DEM.

UTM Projection

Basically, all the DEM's downloaded from the internet will be in WGS 1984. This need to be projected into appropriate UTM projection system before starting any other processing. This tool allow user to reproject into the appropriate projection system.

For the re-projection of the DEM to the UTM, follow the steps:

- In the WEB DHM Toolbar Click on Terrain Preprocessing, you will see several options as UTM Projection, DEM Preprocessing, Watershed Delineation and Hill Slope Calculation



- Click on **UTM Projection** which popup the dialog box as shown in below Figure 17.

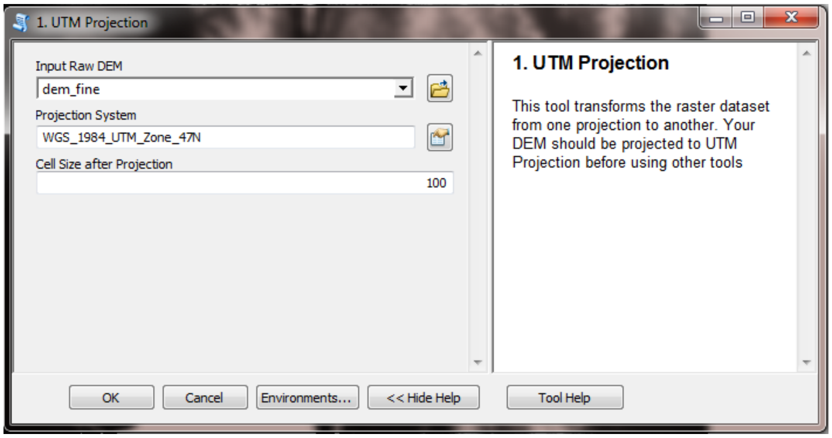


Figure 17 Dialog box for the re-projection of DEM

- Input the Raw DEM; select the required projection system and the zone.
- Input the Cell size of the projected DEM and click on ok
- After the processing is completed, DEM_Projected layer will be added in the Table of content.

DEM Preprocessing

DEM preprocessing involves various internal processes required for the model. It involves fill, flow accumulation, flow direction and stream generation.

Select **DEM Preprocessing** tool, this display the dialog box as shown in Figure 18.

Input the projected DEM which was obtained from the previous step.

Input the Cell size of the coarse watershed and provide the threshold for the stream definition (Lower the number smaller stream will be generated. This threshold is only used for delineating the catchment and may be different from other threshold value for the basin division)

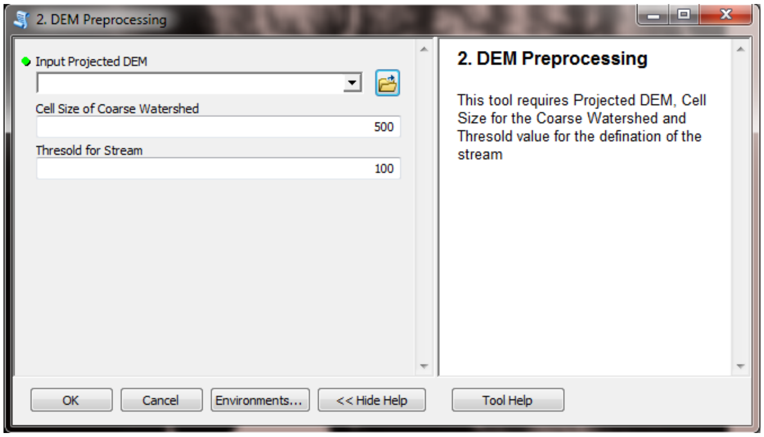


Figure 18 Dialog box for DEM Preprocessing

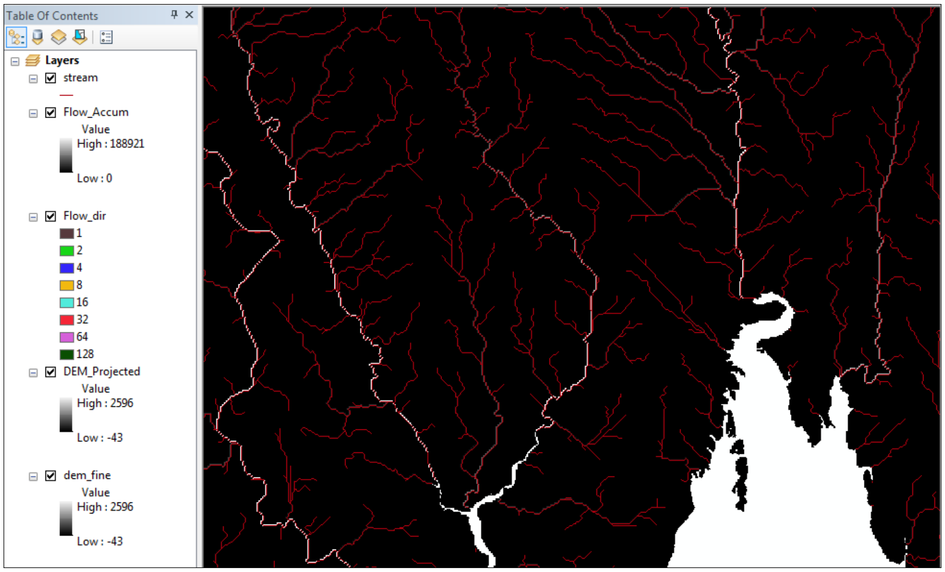


Figure 19 Flow_dir (flow direction), Flow_Accum(Flow accumulation) and streams added to the map

Watershed Delineation

Watershed delineation is a process of extracting the boundary of a watershed. This can be delineated from a DEM using the flow direction, flow accumulation and the outlet of the watershed. The outlet of the watershed can be created as below:

- In the Catalog window, right click on the working folder | Click on **New** | Click on **Shapefile**

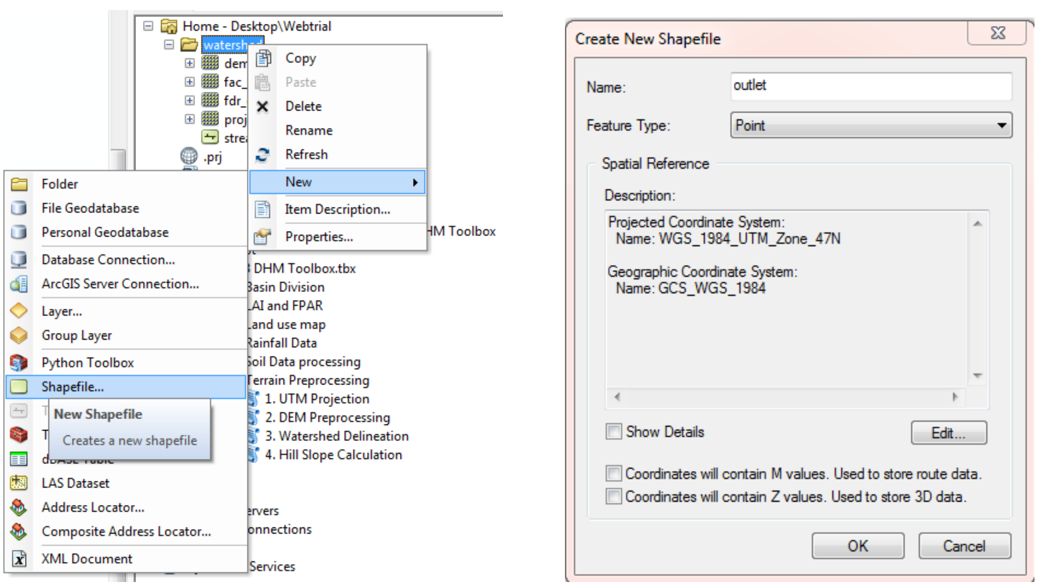


Figure 20 Creating outlet of the watershed

- In the dialog box, specify the name of the shape file. Select Point as a Feature Type and select the same UTM projection as the projected DEM and click on ok. This will add one point feature layer in the TOC. This layer will be empty in the beginning, user need to add the outlet point.
- To add the outlet point, right click on the layer which is added in the TOC, click on **Edit Feature | Start Editing**
- Zoom in to the outlet area in the window until you see the stream with the cells, click on the required location where the outlet of the watershed is located as shown in below Figure 21

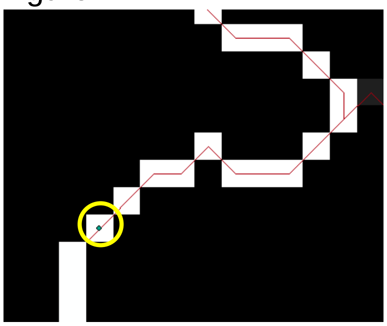


Figure 21 Outlet of the watershed

- Click on **Editors** in the Editor toolbar and select **Stop Editing**

After the outlet of the watershed is created, click on the **Terrain Preprocessing | Watershed Delineation** in WEB DHM Toolbar. The dialog box shown in Figure 22 will appear.

Select the Outlet of the watershed which was created in the previous step, input the flow direction and flow accumulation raster and click on ok

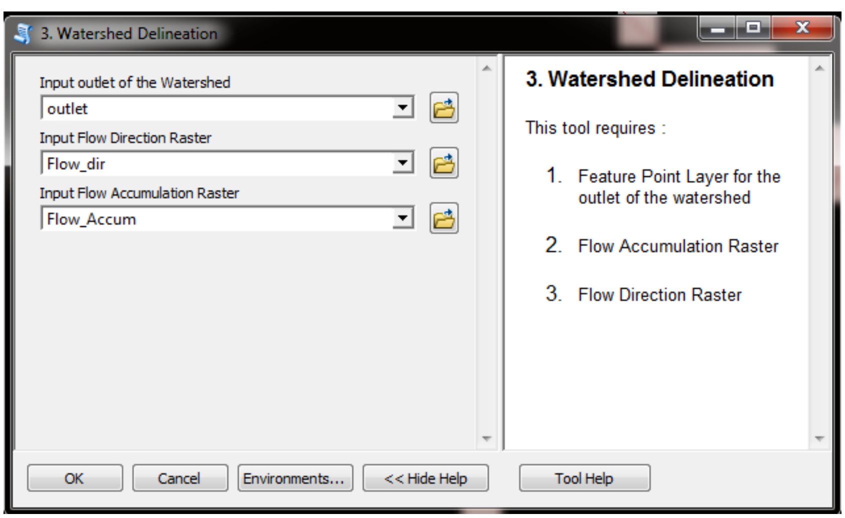


Figure 22 Watershed Delineation dialog box

This tool process the input to create the watershed raster as shown in figure below

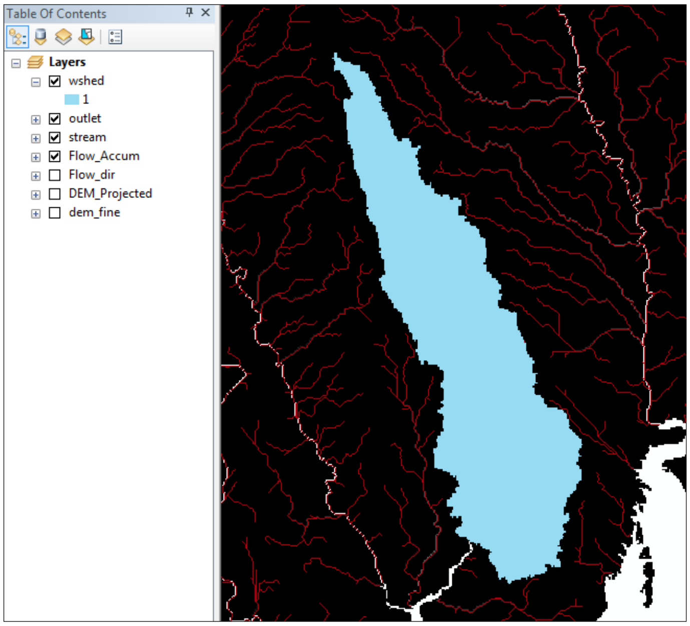


Figure 23 wshed (delineated watershed)

Hill Slope Calculation

Hill slope calculation includes all the processing and calculation needed for the WEB DHM model. Above three preprocessing steps are required to create the input for the Hill slope calculation. The steps for the hill slope calculation are listed below.

- Open the Hill Slope Calculation tools under the Terrain Preprocessing Menu in the WEB DHM toolbar. The tool for hill slope calculation is shown in below Figure 24.
- Input the projected DEM, flow direction, flow accumulation and watershed(wshed) raster and click on ok

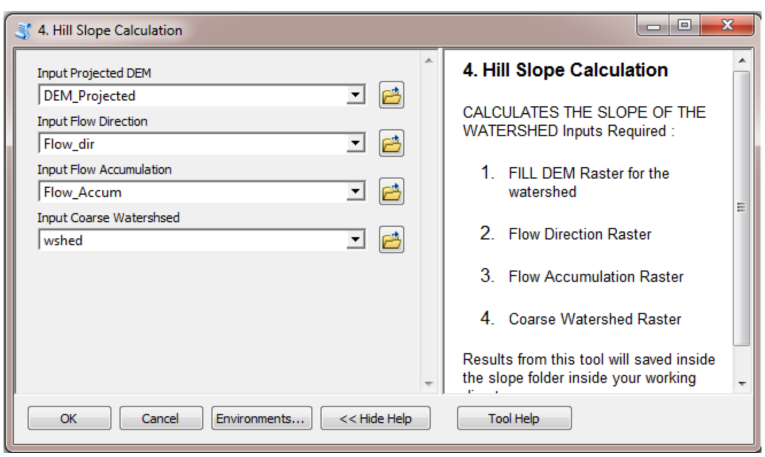


Figure 24 Hill slope calculation dialog box

This processing will take a few minutes. All the results from this processing will be saved in the ‘slope’ folder inside the working directory. Coarse bed slope will be added to the TOC and flow direction and accumulation layer will also be updated in the TOC for the watershed only.

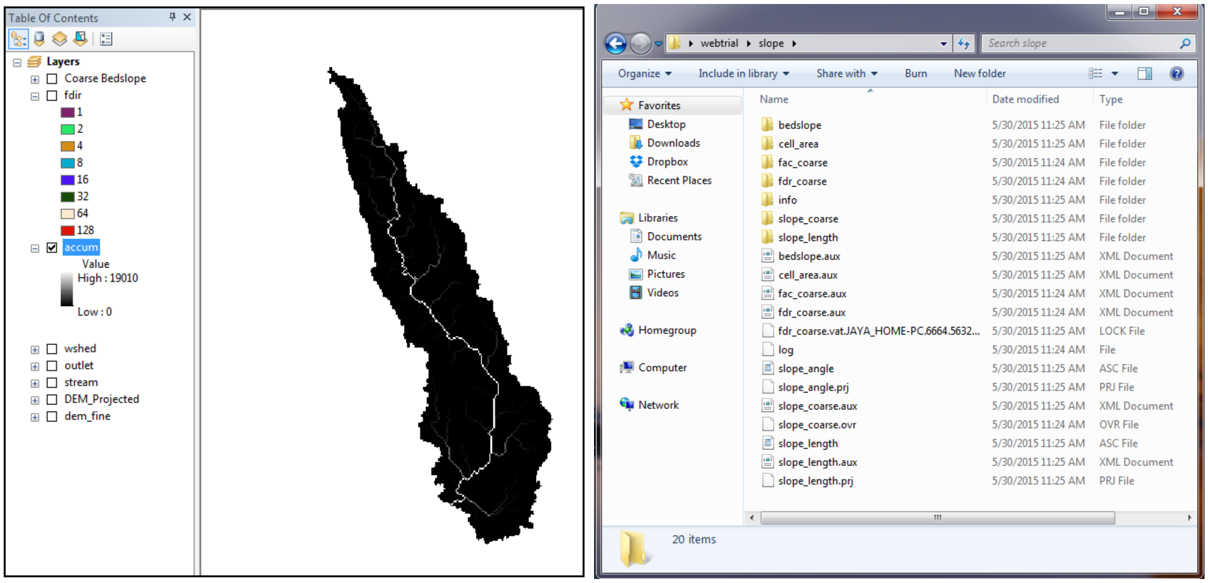


Figure 25 Hill slope calculation result

CHAPTER 4

Basin Division

Many hydrological models, especially physically based models need to subdivide the large catchment into the sub-basins to achieve more accurate representation of spatial variation. This tool for the basin division is based on the Otto-Pfafstetter algorithm.

The Pfafstetter coding system developed by Otto Pfafstetter in 1989 is a methodology for assigning watershed IDs based on the topology of the land surface. The system is hierarchal and the watersheds are delineated from junctions on a river network. Level 1 watershed corresponds to continental watersheds. Higher level (Levels 2, 3, 4 etc) represents even-finer tessellations of the land surface into smaller watersheds, which are sub watersheds of lower level watersheds. Each watershed is assigned a specific Pfafstetter code based on its location with the overall drainage system and on the total drainage area upstream of the watershed's outlet.

According the Pfafstetter system, watersheds are divided into 3 types; basins, inter-basins and internal basins. A Pfafstetter basin is an area that does not receive drainage from any other area; a basin contains headwater of the river reach for which the watershed is defined. Conversely, a Pfafstetter inter-basin is a drainage area that does not contribute flow to another watershed or to a water body (such as ocean or lake). The algorithm for the Pfafstetter basin codification is described below:

1. Four tributaries with the highest flow accumulations (largest drainage areas) along the main river are identified
2. These are assigned even digits from downstream to upstream
3. Odd digits to the inter basins are assigned along the main stem.

This can be seen in below Figure 26

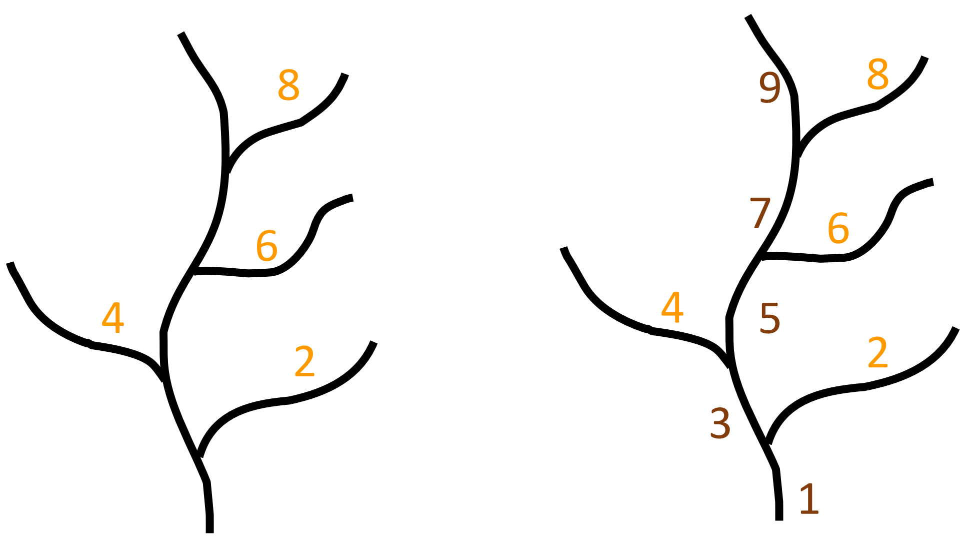


Figure 26 Otto-Pfafstetter basin codification algorithm

In the beginning, first level of basin codification is done and once it is completed second, third and higher basin codification can be done based on the same algorithm. While coding for the higher order, lower order basin is considered as the main basin and sub division are based on the Otto-Pfafstetter basin codification algorithm. Figure 27 shows the basin codification for the first level and second level codification for basin 2.

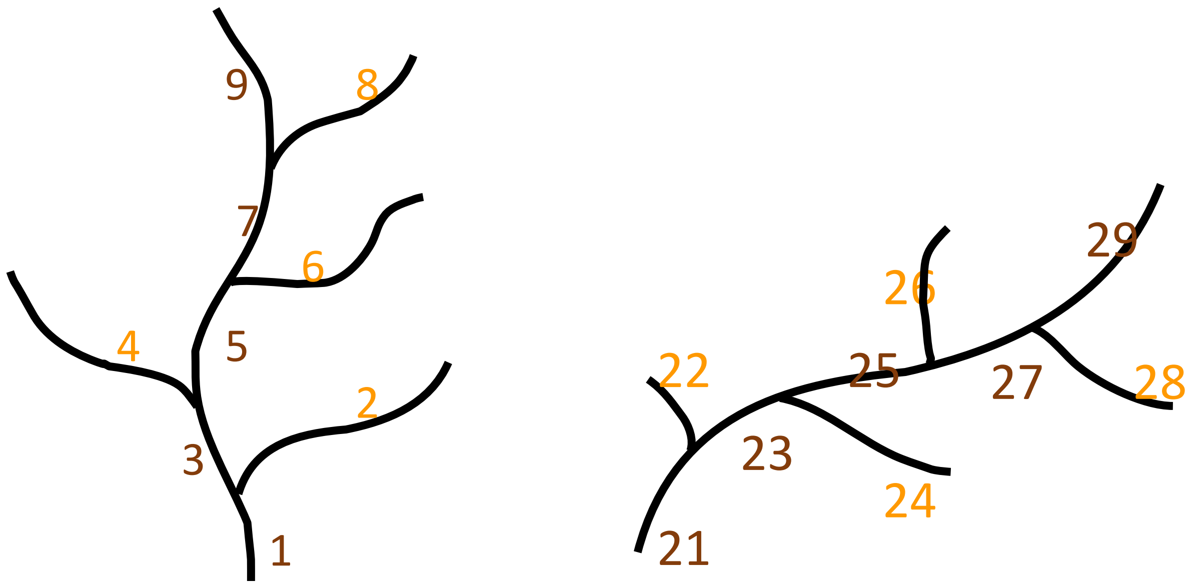
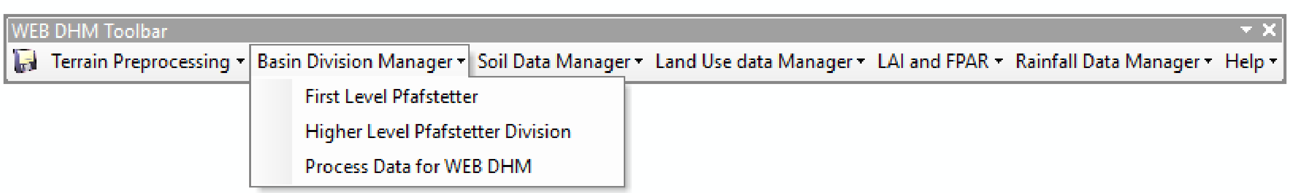


Figure 27 Higher level Basin codification

Basin division Manager incorporates the basin division based on Otto-Pfafstetter algorithm. It has the capability to subdivide the basin up to 4th level. This tool will be developed later for the higher division. This basin division includes three options; First level Pfafstetter Division, Higher level Pfafstetter division and Process data for WEB DHM Input which is shown as below



Data Requirements

This tool requires flow direction, flow accumulation and bed slope raster (these are the output from the Terrain Processing tool). This tool also requires kfs.dat and subcatchment.dat which includes various parameter for sub basins. The detail about these two file will be described in later topics.

First Level Pfafstetter Division

This tool performs the Pfafstetter basin codification for the first level. This tool can be accessed under the **Basin Division Manager | First Level Pfafstetter Division**.

The follow dialog box will appear (Figure 28). User need to input the flow accumulation and flow direction raster. User need to input the threshold for the stream definition (Lower the threshold value smaller stream can be generated and the sub basin division can go up to higher levels)

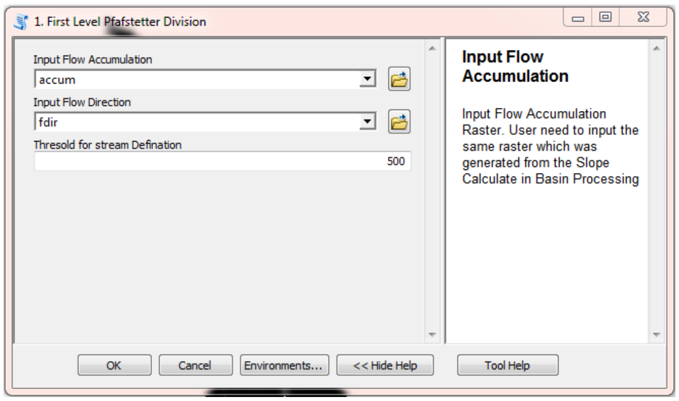


Figure 28 Dialog box for the first level Pfafstetter division

Results from this tool will be saved in the ‘pfafstetter’ folder in the same working directory. After all the processing is finished, basin sub division result will be added to the TOC as in Figure.

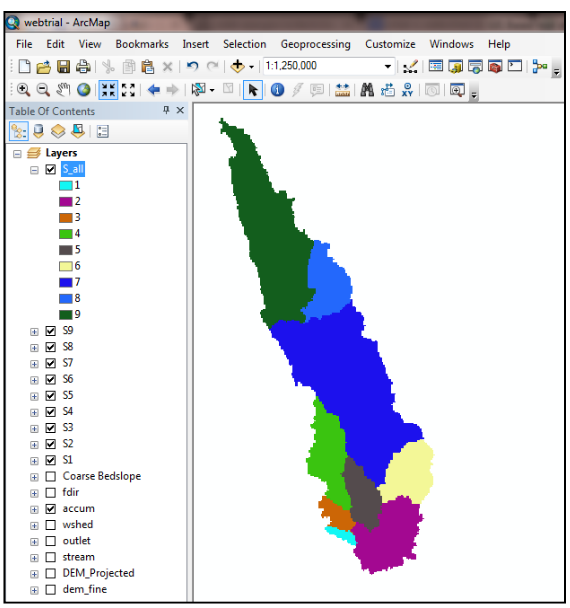


Figure 29 All 9 sub basins (S1, S2…S9) are added in the TOC, S_all is the raster for all sub basins

Higher Level Pfafstetter Division

Once the First level Pfafstetter basin codification is completed, higher level codification can be done using this tool which can go up to 4th level of Pfafstetter codification. User can perform the higher level codification in a sequential order. For example, first user need to perform the 2nd level codification then only allowed to perform 3rd and so forth. This tool can be access under **Basin Division Manager** | First Level Pfafstetter Division

Following dialog box as shown in Figure 30 will be displayed.

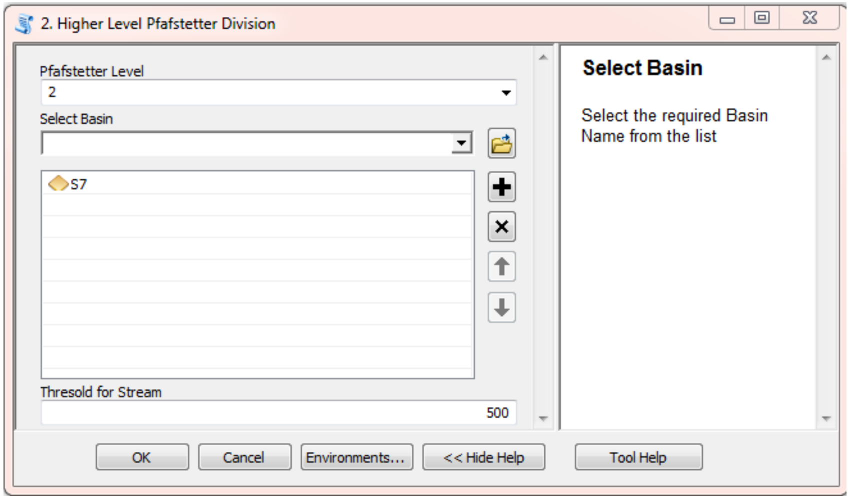


Figure 30 Dialog box for higher level Pfafstetter division

Follow the steps to perform the higher level Pfafstetter codification:

- Select the Pfafstetter Level (2,3, and 4)
- Select the sub basins as S1, S2, S3…S9 for the 2nd Level. If 2nd Level Pfafstetter coding has already been done and you are performing for the 3rd level coding in that case select the sub basin as S21, S23, S24…S29. You can select more than one sub basin at a time.
- At the end input the threshold for the stream definition and click on ok

Results from this tool will be saved inside the 'pfafstetter' folder with the name of the basin which you have selected for e.g. If you have selected S2 and S9, then 'basin 2' and 'basin9' will be added inside that folder. After all the processing is finished, basin sub division result will be added to TOC. The result for Basin No 2 for 2nd level Pfafstetter coding is shown in Figure 31.

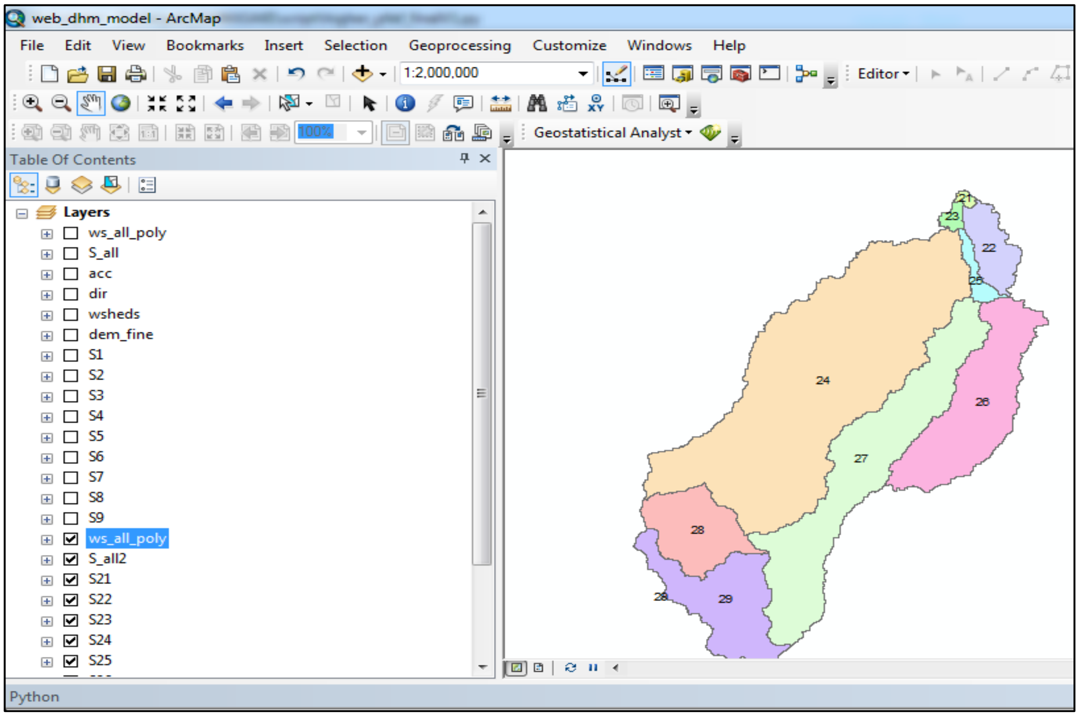


Figure 31 2nd level Pfafstetter division for Basin No 2

Similarly, 3rd level Pfafstetter for sub basin no 24 result is shown below (Figure 33)

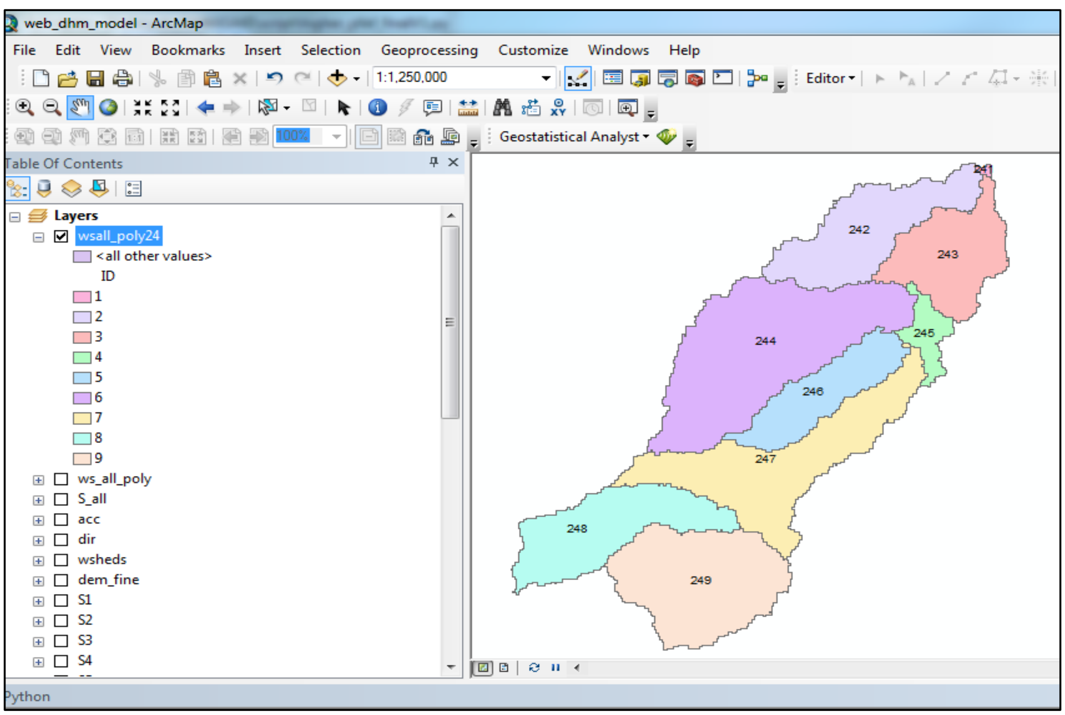


Figure 33 3rd level Pfafstetter division for Basin No 24

The below figure 34 shows the overall result for the basin codification.

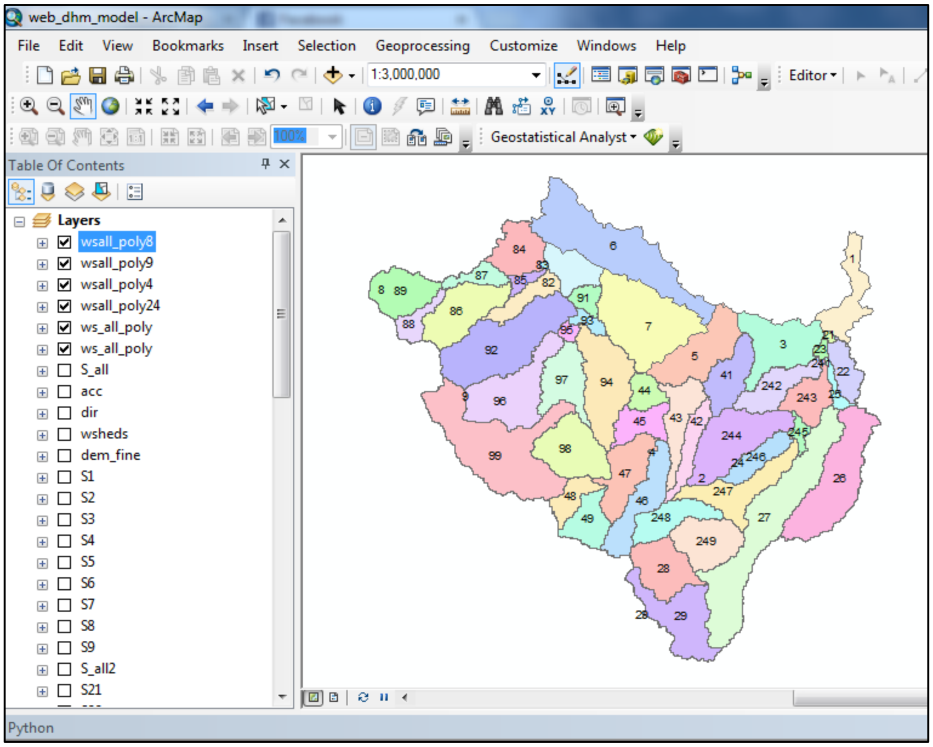


Figure 34 Overall Result from Pfafstetter Division

Process data for WEB DHM Input

This tool processes the data from the Pfafstetter basin division to create the basin input data for the WEB DHM model. This tool requires bedslope raster, kfs.dat and subcatchment.dat. Bedslope raster is already obtained from Terrain Processing tool. But kfs.dat and subcatchment.dat files need to prepared and manually edited by user based on the Pfafstetter codification.

Kfs.dat

The template for the kfs.dat file is provided with the tool. User can open the file in notepad and edit as per the requirement. In the Basin below the 'Level_1', user has to type either '0' or '1'. If the particular sub basin has higher level of Pfafstetter codification, then user need to type 1 otherwise type 0. In the Figure 25 below, all values are set to be '0' in Basin. This means that basin codification has been done only for the 1st level.

kfs.dat

```
'Maximum_level:' 3
'Location'   1  2  3  4  5  6  7  8  9
'Level_1'
'Basin:'     0, 0, 0, 0, 0, 0, 0, 0, 0
'Level_2'
'Basin1:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin2:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin3:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin4:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin5:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin6:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin7:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin8:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin9:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'END'
```

Figure 35 kfs.dat for 1st Level Pfafstetter codification

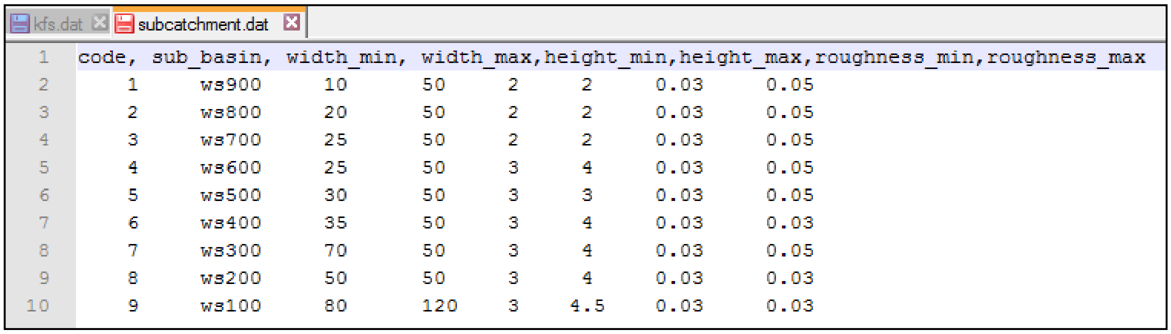
Similarly, if the sub basin 2 has codification up to 2nd level, then type ‘1’ in the Basin below Level_1. Again if the basin 2 has the codification up to 3rd level then type ‘1’ in the particular basin in the Level_2.

```
'Maximum_level:' 3
'Location'   1  2  3  4  5  6  7  8  9
'Level_1'
'Basin:'     0, 1, 0, 0, 0, 0, 0, 0, 0
'Level_2'
'Basin1:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin2:'    0, 1, 0, 0, 0, 0, 0, 0, 0
'Basin3:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin4:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin5:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin6:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin7:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin8:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'Basin9:'    0, 0, 0, 0, 0, 0, 0, 0, 0
'END'
```

Figure 36 kfs.dat for higher level codification

subcatchment.dat

The template for the subcatchment.dat is also provided with this tool. This file contains the information about the minimum and maximum width, height and roughness coefficient of all the sub basins. Sub-catchment number should be arranged in the descending order as shown in Figure 37 below. These parameters can also be used for the model calibration purpose.



code,	sub_basin,	width_min,	width_max,	height_min,	height_max,	roughness_min,	roughness_max
1	ws900	10	50	2	2	0.03	0.05
2	ws800	20	50	2	2	0.03	0.05
3	ws700	25	50	2	2	0.03	0.05
4	ws600	25	50	3	4	0.03	0.05
5	ws500	30	50	3	3	0.03	0.05
6	ws400	35	50	3	4	0.03	0.03
7	ws300	70	50	3	4	0.03	0.05
8	ws200	50	50	3	4	0.03	0.03
9	ws100	80	120	3	4.5	0.03	0.03

Figure 37 Template for the subcatchment.dat

The tool can be accessed from **Basin Division Manager |** Process Data for WEB DHM Input (Figure 38). After preparing kfs.dat and subcatchment.dat files, follow the below steps to process the data for the model input.

- Select the Bed slope raster
- Select the kfs.dat and subcatchment.dat files
- Input the value of 'dx'. This value is usually 1.5 to 2 times of the coarse resolution of the watershed. If the resolution of the coarse size of watershed is 500m, this value can be 750-1000

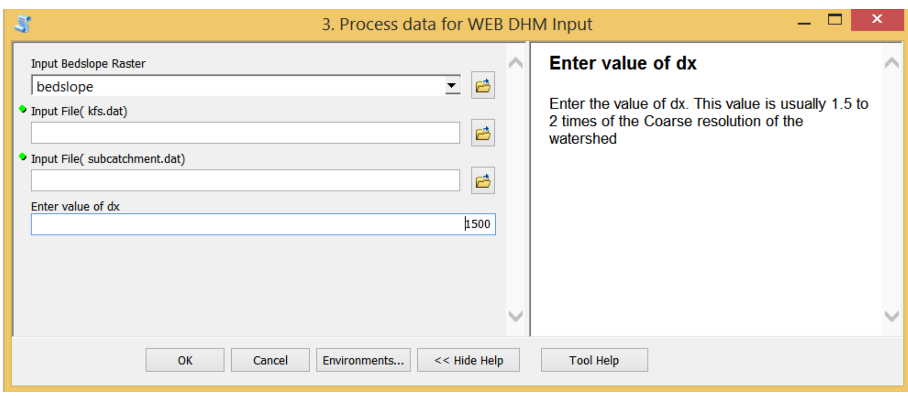


Figure 38 Dialog box for process data for WEB DHM Input tool

Results from this tool will be saved in the model folder inside the pfafstetter which contains all necessary basin information for the WEB DHM model.

CHAPTER 5

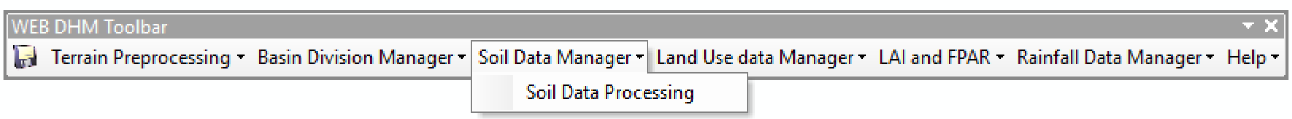
Soil Data Processing

The Soil data is processed from the FAO global soil map. The soil properties from this soil map data are spatially distributed at approximately 9 km resolution grid size. This input data for WEB DHM models is static. The processed parameters are listed in table below

Table 1: Soil Parameters

Parameter	**Assumption**
Hydraulic conductivity for surface soil (ks1)	
Hydraulic conductivity for unsaturated zone(ks2)	Ks1 x 0.1
Hydraulic conductivity for groundwater zone (ksg)	1
Residual soil moisture (Thetar)	
Saturated soil moisture content (Thetas)	
Alpha (Van Genutchen parameters)	
N (Van Genutchen parameters)	

Soil Data processing tool in the WEB DHM tools can be accessed under Soil Data Manager



Data Requirements

This tool requires 6 files which can be obtained from the FAO web sites. These files are as follow

1. soil_unit
2. thetas
3. thetar
4. alpha
5. ks
6. watern

All these files should be downloaded and saved inside some folder with the same name as shown in the above list.

Follow the below steps to process the soil data.

- Soil Data Processing | Soil Data Processing for WEB DHM
- Select the folder where you have save all six files
- Select the coarse watershed raster and click on ok

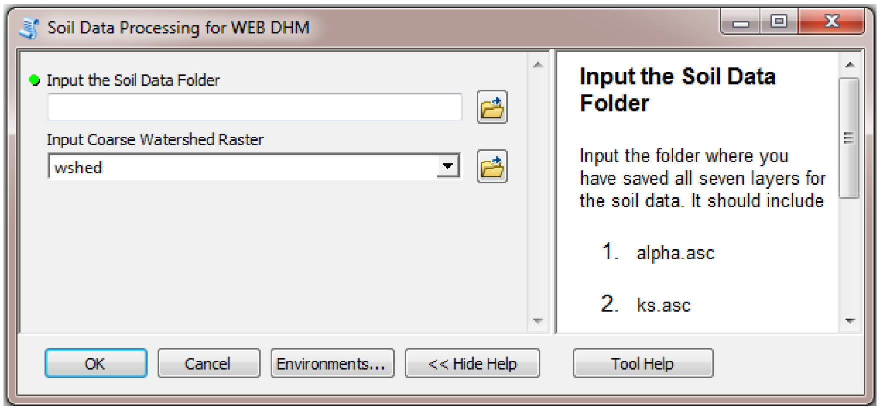
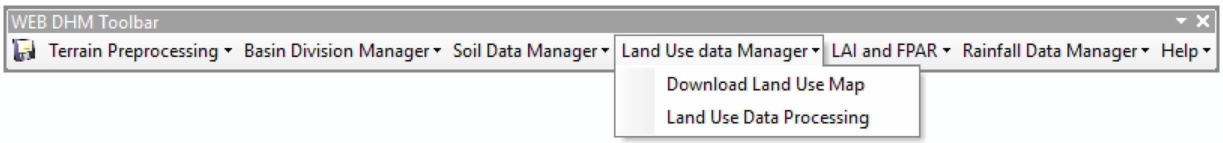


Figure 39 Dialog box for the Soil data processing

This tool will process and result will be stored in the 'soil' folder inside the working directory. Three files naming soil_depth.asc, soil_code.asc and soil_water_para.dat will be obtained after the processing which is required for the WEB DHM model.

Land Use Data Processing

The USGS Land Cover map which has global land cover characteristic database was developed on a continent basis. All continents in the global database share the same map projection (Lambert Azimuthal Equal area) and have a 1-km nominal spatial resolution and are based on 1-km AVHRR data spanning April 1992 through March 1993. Each continental database has unique elements that are based on the salient geographic aspects of the specific continent. In addition, a core set of derived thematic maps produced through the aggregation of seasonal land cover regions are included in each continental database. The WEB DHM utilizes the Simple Biosphere 2 Model. Land use data processing tool includes Downloading and processing as shown below.



Land use Data Download

Global land use data can be downloaded from http://edc2.usgs.gov/glcc/glcc.php. To ease this process for the user can use this tool for downloading the land use data. User can select the region of their interest and click on OK. It will redirect to the browser automatically then user can download the required dataset.

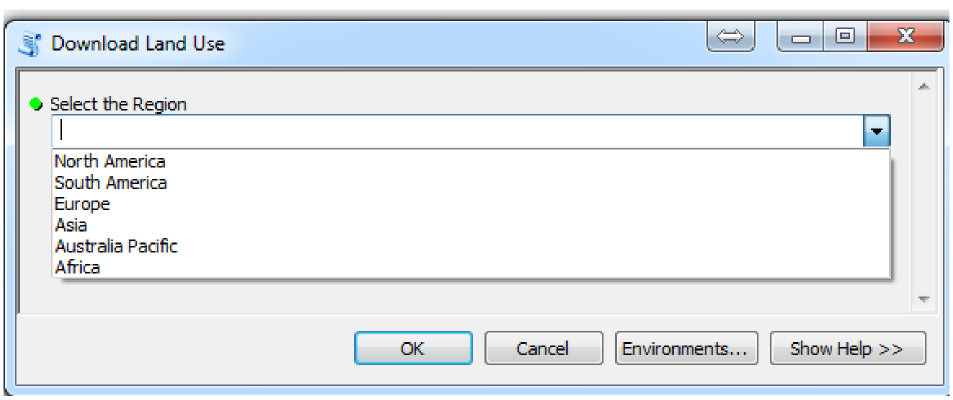


Figure 40 Global Land use data download tool

Download Land use data from Earth Explorer

SiB2 Land use data can also be downloaded from http://earthexplorer.usgs.gov/

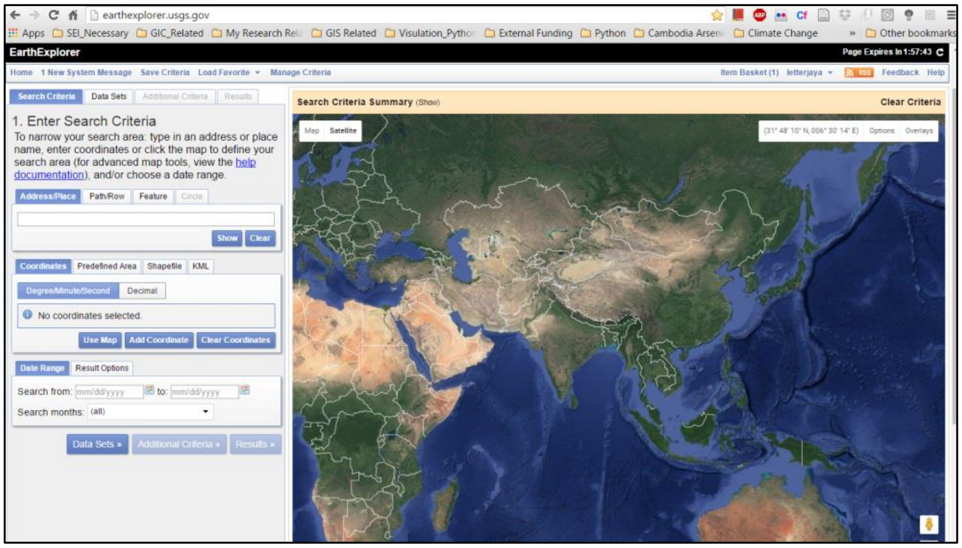
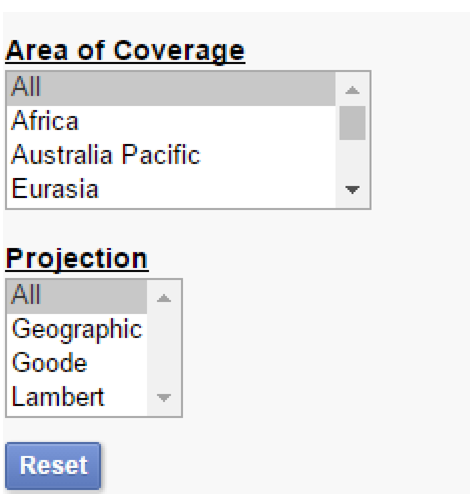


Figure 41 Earth explorer web page

User need to register first to download the data from earth explorer. To download SiB2 Land use data, user can follow the below steps:

- On the earth explorer window, click on **Data Sets**
- Under the data category, expand **Land Cover** | activate **GLCC** as shown on figure
- Click on **Additional Criteria**
- Select the Area of Coverage | Projection
- Click on **Results** | Click on **download** | Select **Download as TIF**



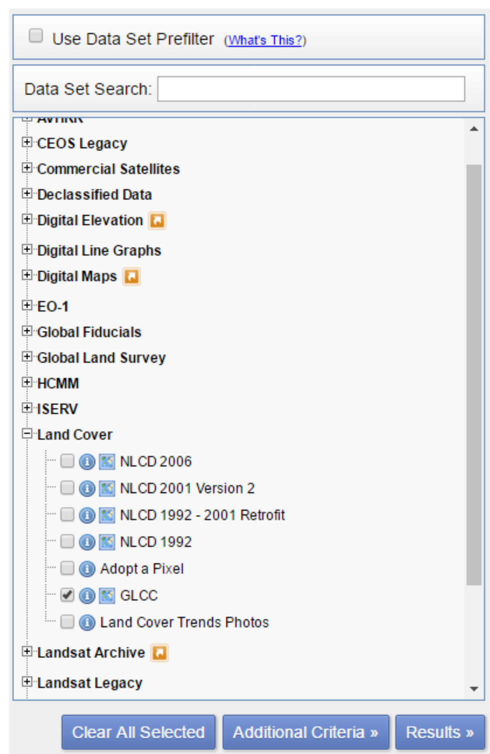


Figure 43 Data sets and additional criteria on earth explorer

- Downloaded file will be saved in zip format, unzip the downloaded file. It contains several **.tif* and legend files. User need to aware that only the selected *.tif* and legend file which are useful for WEB DHM.

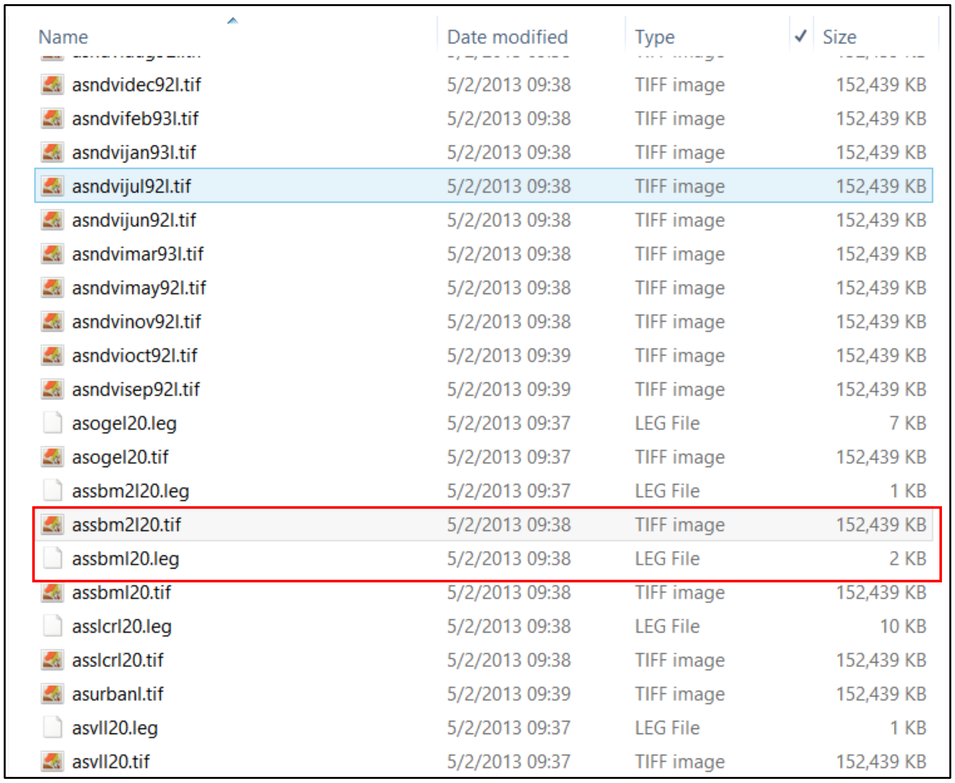


Figure 44 List of files downloaded from earth explorer

Only the files which are highlighted with red box above in figure 44 will be used for processing. These data are on *Lambert Azimuthal Equal Area* which need to be projected into the UTM projection system and clip based on the watershed area. This will be performed by Land use Data Processing Tool.

To use the land use data processing tool, first user need to select the region according to their area of interest and select the folder where they have downloaded files and then click on OK.

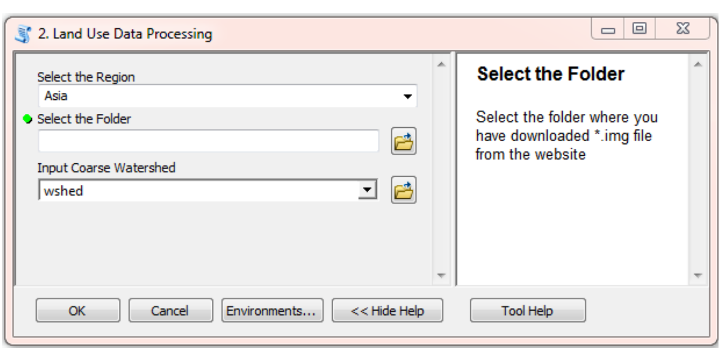


Figure 45 Land Use Data processing Tool

The final result both land use data in ASCII format and LEG(legend) file will be stored in the 'land use' folder. Land Use raster layer will also be added in the TOC as in Figure 46.

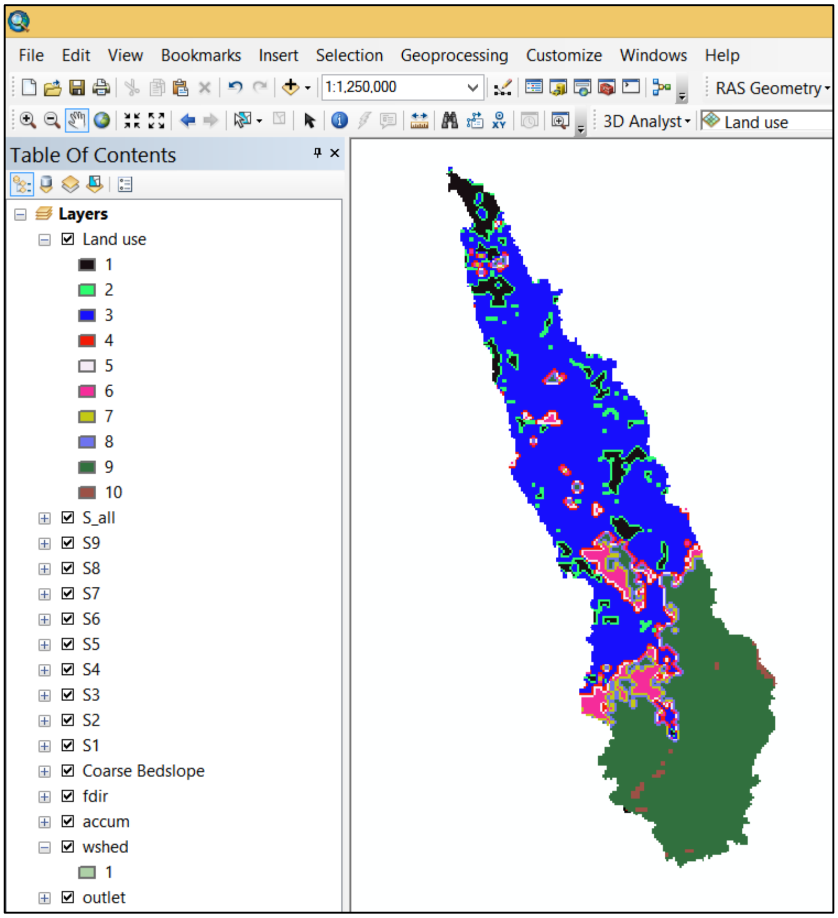


Figure 46 Land use data layer added in the TOC

CHAPTER 6

LAI and FPAR Processing

The Leaf Area index (LAI) defines an important structural property of a plant canopy as the one-sided leaf area per unit ground area. LAI is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. LAI is a dimensionless value typically ranging from 0 for bare ground to 6 for dense forest. The fraction of incident radiation absorbed by greed canopy (FPAR) measures the proportion of available radiation in the photo synthetically active wave lengths that a canopy absorbs. LAI and FPAR and biophysical variables which describe the canopy structure and are related to functional process rates of energy and mass exchange. These parameters can be derived from satellite data MODIS.

The Moderate resolution Imaging Spectro-radiometer (MODIS) is a key instrument aboard Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning while aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands or groups of wavelengths. These data will improve our understanding of global dynamics and processes occurring on t1/he land, in the oceans and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection on our environment.

Version 005

+ Overview

− Layers

Science Data Sets for MODIS/Terra Leaf Area Index/FPAR 8-Day L3 Global 1km SIN Grid V005 (MOD15A2):

Science Data Sets (HDF Layers) (6)	UNITS	BIT TYPE	FILL	VALID RANGE	MULTIPLY BY SCALE FACTOR
Fpar_1km	Percent	8-bit unsigned integer	249–255	0–100	0.01
Lai_1km	m2plant/m2ground	8-bit unsigned integer	249–255	0–100	0.1
FparLai_QC	Class flag	8-bit unsigned integer	255	0–254	na
FparExtra_QC	Class flag	8-bit unsigned integer	255	0–254	na
FparStdDev_1km	Percent	8-bit unsigned integer	248–255	0–100	0.01
LaiStdDev_1km	m2plant/m2ground	8-bit unsigned integer	248–255	0–100	0.1

The QA information below is excerpted from an HDF-EOS file of the MODIS LAI/FPAR product MOD15A2.

Figure 47 Product table of MOD15A2

LAI and FPAR data processing tool can be assessed under LAI and FPAR data Manager as shown below

Download LAI and FPAR data

In the current version of the tool, user can use the tool itself to download the LAI and FPAR data. But there is still a leverage for user to download it manually and store it in a folder and use the processing tool to prepare the data for WEB DHM Model. Basically, user can download the data from either of these links:

- https://reverb.echo.nasa.gov/ ,
- http://e4ftl01.cr.usgs.gov/MOTA/MCD15A2.005/

The temporal coverage of LAI and FPAR data is from **March 5 2000** till date. Follow the below steps to download the LAI/FPAR data

- **LAI and FPAR** | **Download LAI FPAR data**

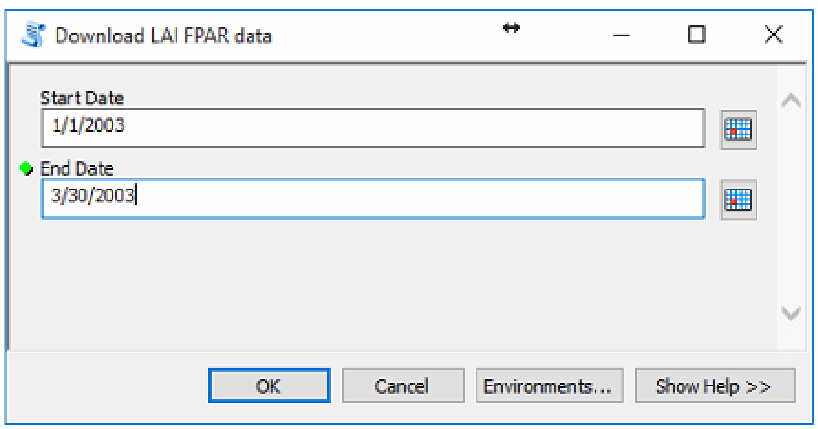


Figure 48 Dialog box for Downloading LAI FPAR data

- Input Start and End Date

Based on the date provided by the user, this tool will automatically identify the appropriate rows and paths to be downloaded and store it in a folder **modis_download** inside your current working directory as shown below.

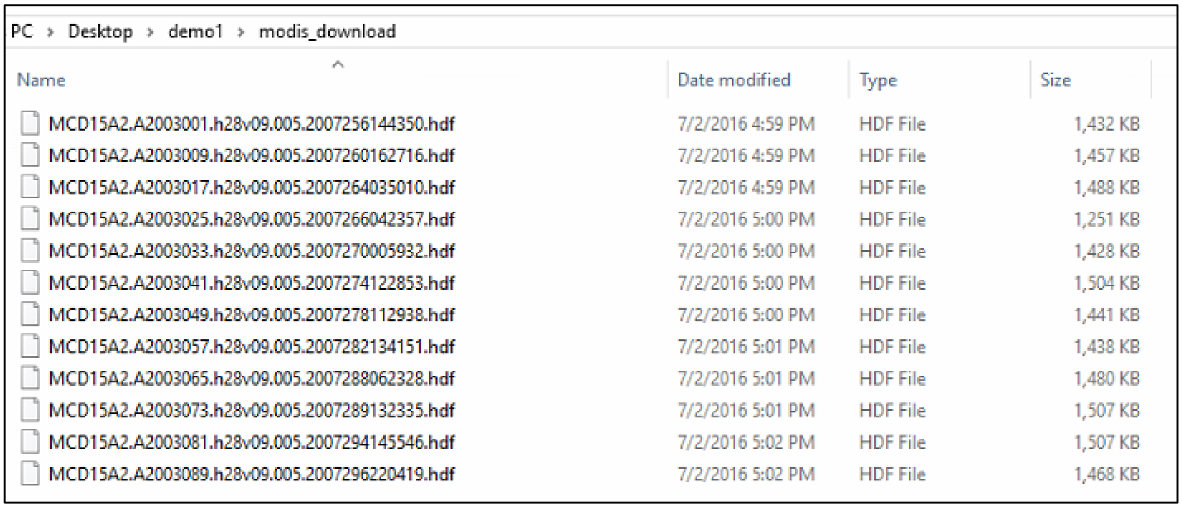


Figure 49 List of downloaded MODIS files

This tool basically re-projects and mosaic MODIS sinusoidal projection system to UTM projection system (same as for the watershed). It will also perform further processing on preparation of binary file for the WEB DHM model.

This tool can be accessed from **LAI and FPAR** | **LAI and FPAR Data Process** for WEB DHM which pop up the dialog box as shown in Figure 50.

In LAI and FPAR data processing tool, user needs to input the folder where they have stored all the downloaded files from MODIS website for LAI and FPAR data. User need to input the coarse watershed raster as well. If the MODIS data need mosaicking, then user need to activate the option 'Need to Mosaic Tiles'.

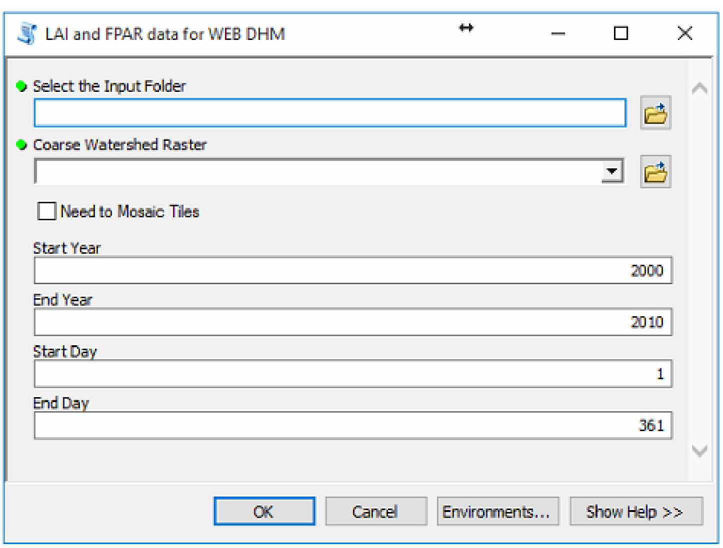


Figure 50 Dialog box LAI and FPAR data processing

The result from this tool will be saved in 'LAI_FPAR' folder.

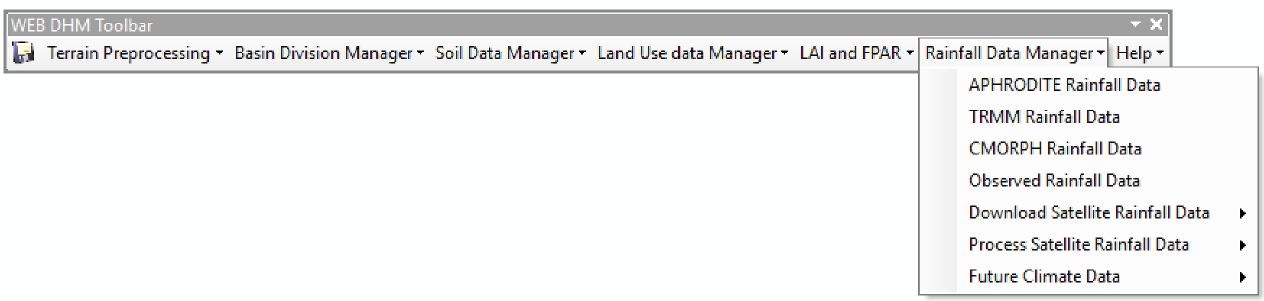
CHAPTER 7

Rainfall Data Preparation and Processing

Rainfall is one of the main driving forcing for any hydrological model. This includes all form of water deposited on the earth's surface and derived from atmospheric water vapor. Basically rainfall source can be of two types one is observed gauge data and another is satellite derived or re-analysis data. There are several global datasets for precipitation that is freely available online in the form of gridded raster dataset or asci files. This chapter describes in detail about the use and application of freely available datasets and formatting them at the basin scale to make them readable by WEB-DHM. Rainfall Data Manager provides all the necessary tools for rainfall data processing for the WEB-DHM as shown in below figure.

List of some of the common rainfall datasets

- APHRODITE
- TRMM
- CMORPH
- GPM
- IMERGE
- NOAA rainfall
- GsMaP
- Observed gauge data



Aphrodite Rainfall Data

Asian Precipitation-highly resolved observational data integration towards the evaluation of water resources management (APHRODITE) dataset contains a dense network of daily rain gauge data for Asia Including the Himalayas, South and South East Asia and Mountains areas in the Middle East. The number of valid stations was between 5000 and 12,000 representing 2.3 to 4.5 times the data available through the Global Telecommunication System network, which were used for most daily grid precipitation products. This dataset is a long-term, continental scale 52 year gridded (0.25°x0.25° or 0.50° x 0.50°) daily precipitation dataset with the temporal coverage from 1951 till 2007.

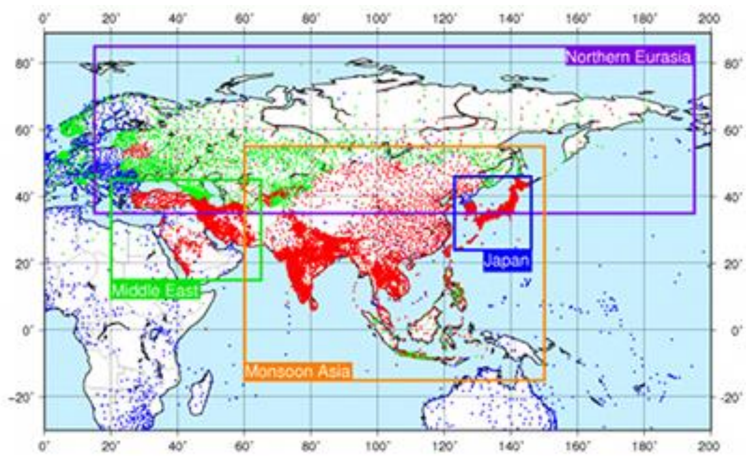


Figure 51 Domain of the APHRODITE Rainfall data

This data tool can be accessed from **Rainfall Data Manager | APHRODITE Rainfall Data**.

Start Date: 01 Jan 1951

End Date: 31 Dec 2007

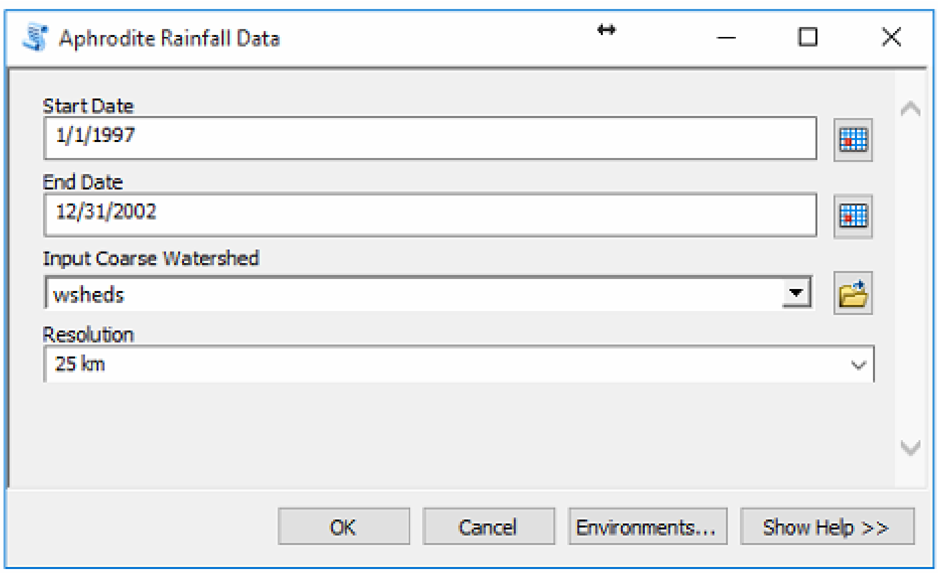


Figure 52 Dialog box for the Aphrodite Rainfall data download and processing

User need to input Start Date and End Date with the coarse watershed which provides the boundary to download the data. This tool requires internet connection as it need the connection to download the data. User do not require to download the whole dataset, this tool will slice automatically based on the watershed boundary. This tool will downscale the original data to watershed grid size (eg 500m x 500m) using nearest neighborhood method.

TRMM Rainfall Data

The Tropical Rainfall Measurement Mission (TRMM) is a join mission between NASA and JAXA designed to monitor and study tropical rainfall. The accurate measurement of the spatial and temporal variation of tropical rainfall around the globe remains one of the critical unsolved problems of meteorology. This mission was launched in 1997. In coordination with other satellites in NASA's Earth Observing System, TRMM provides important precipitation information using several space borne instruments till date. The spatial resolution of TRMM rainfall data is 25 km and temporal resolution is 3 hour. The data is available from **01 Jan 1998** to **29 Feb 2016**. TRMM data processing tool can be assessed from **Rainfall Data Manager | TRMM Rainfall Data**.

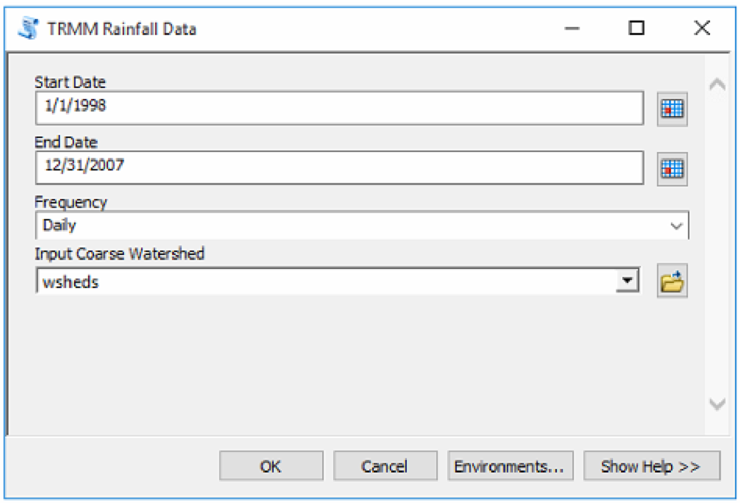


Figure 53 Dialog box for processing TRMM rainfall data

User need to input the start and end data, frequency of the data (as daily or 3 hourly) and coarse watershed raster. The processed data will be saved in the **TRMM** folder

Observed Rainfall Data

WEB DHM rainfall data manager also has the capability to interpolate observed gauge rainfall data. This tools support both hourly and daily rainfall data. To process the data using this tool, user need to prepare the data in a csv file format as shown in below examples:

Template for the CSV file

Station	St 1	St2	St 3	St 4	St 5	St 6	St 7	St 8
Longitude								
Latitude								
1/1/2000 01:00								
1/1/2000 02:00								
1/1/2000 03:00								

A	B	C	D	E	F	G	H	I	J	
station	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Sta
Longitude	101.95	103.5	103.8	103.95	103.9639	104.27	103.8169	104.2	103.95	10
Latitude	23.65	22.85	22.6	22.5	22.50389	22.2	22.35278	22.08306	22.5	22
6/1/2005 23:00	-9999	-9999	-9999	0	2	-9999	-9999	-9999	-9999	
6/2/2005 0:00	-9999	-9999	-9999	0	2	-9999	-9999	-9999	-9999	
6/2/2005 1:00	-9999	-9999	-9999	0	2	-9999	-9999	-9999	-9999	
6/2/2005 2:00	-9999	-9999	6	10	7	7	7	8	7	
6/2/2005 3:00	-9999	-9999	6	10	7	7	7	8	7	
6/2/2005 4:00	-9999	-9999	6	10	7	7	7	8	7	
6/2/2005 5:00	-9999	-9999	6	10	7	7	7	8	7	
6/2/2005 6:00	-9999	-9999	6	10	7	7	7	8	7	
6/2/2005 7:00	-9999	-9999	6	10	7	7	7	8	7	
6/2/2005 8:00	-9999	-9999	1	1	1	3	1	6	2	
6/2/2005 9:00	-9999	-9999	1	1	1	3	1	6	2	
6/2/2005 10:00	-9999	-9999	1	1	1	3	1	6	2	
6/2/2005 11:00	-9999	-9999	1	1	1	3	1	6	2	
6/2/2005 12:00	-9999	-9999	1	1	1	3	1	6	2	
6/2/2005 13:00	-9999	-9999	1	1	1	3	1	6	2	
6/2/2005 14:00	-9999	-9999	-9999	0	-9999	-9999	0	-9999	-9999	
6/2/2005 15:00	-9999	-9999	-9999	0	-9999	-9999	0	-9999	-9999	
6/2/2005 16:00	-9999	-9999	-9999	0	-9999	-9999	0	-9999	-9999	
6/2/2005 17:00	-9999	-9999	-9999	0	-9999	-9999	0	-9999	-9999	

Figure 54 Sample observed data prepared in CSV format

This tool used IDW (Inverse Distance Weighing) method to prepare the gridded data based on the basin configuration. To use this tool, follow these steps:

- **Rainfall Data Manager | Observed Rainfall Data**
- Select the CSV file which has been prepared as explain above
- Specify the start date and end date
- Select the Frequency | **Daily** or **Hourly**
- Input the watershed which defines the boundary for the interpolation.

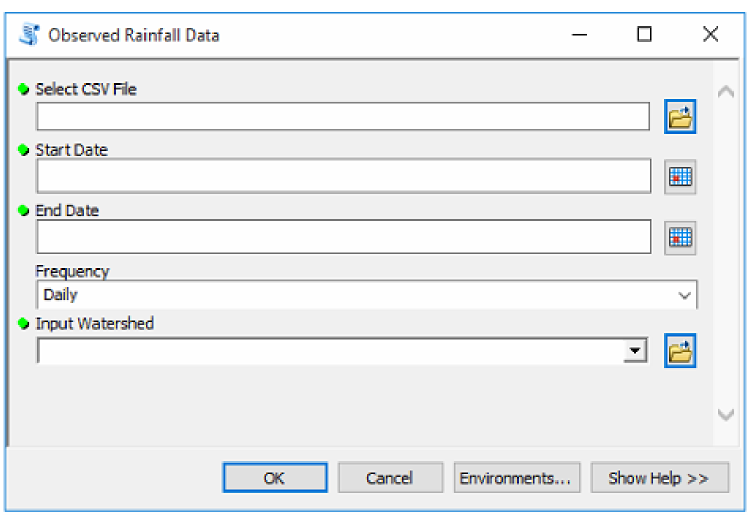


Figure 55 Dialog box for observed rainfall data processing tool

CMORPH Rainfall Data

CMORPH (CPC MORPHing technique) produces global precipitation analyses at very high spatial and temporal resolution. This technique uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data. At present it incorporate precipitation estimates derived from the passive microwaves aboard the DMSP 13, 14 & 15 (SSM/I), the NOAA-15, 16, 17 & 18 (AMSU-B), and AMSR-E and TMI aboard NASA's Aqua and TRMM spacecraft, respectively. These estimates are generated by algorithms of Ferraro (1997) for SSM/I, Ferraro et al. (2000) for AMSU-B and Kummerow et al. (2001) for TMI. Note that this technique is not a precipitation estimation algorithm but a means by which estimates from existing microwave rainfall algorithms can be combined. Therefore, this method is extremely flexible such that any precipitation estimates from any microwave satellite source can be incorporated. With regard to spatial resolution, although the precipitation estimates are available on a grid with a spacing of 8 km (at the equator), the resolution of the individual satellite-derived estimates is coarser than that - more on the order of 12 x 15 km or so. The finer "resolution" is obtained via interpolation.

In effect, IR data are used as a means to transport the microwave-derived precipitation features during periods when microwave data are not available at a location. Propagation vector matrices are produced by computing spatial lag correlations on successive images of geostationary satellite IR which are then used to propagate the microwave derived precipitation estimates. This process governs the movement of the precipitation features only. At a given location, the shape and intensity of the precipitation features in the intervening half hour periods between microwave scans are determined by performing a time-weighting interpolation between microwave-derived features that have been propagated forward in time from the previous microwave observation and those that have been propagated backward in time from the following microwave scan. We refer to this latter step as "morphing" of the features.

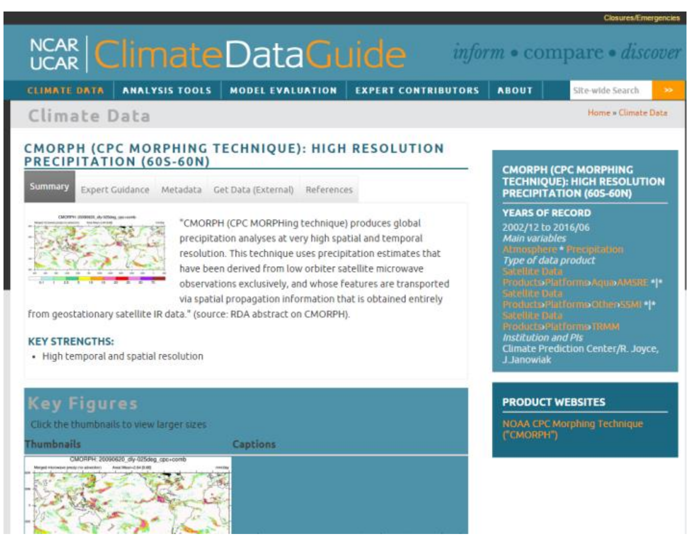


Figure 56 CMORPH information

Temporal resolution: 23 Feb 2005 till date

Spatial resolution: 25 km

To use this tool, follow these steps:

- **Rainfall Data Manager | CMORPH Rainfall Data**
- Specify the start date and end date
- Select the Frequency | **Daily** or 3 **Hourly**
- Input the watershed which defines the boundary for the interpolation.

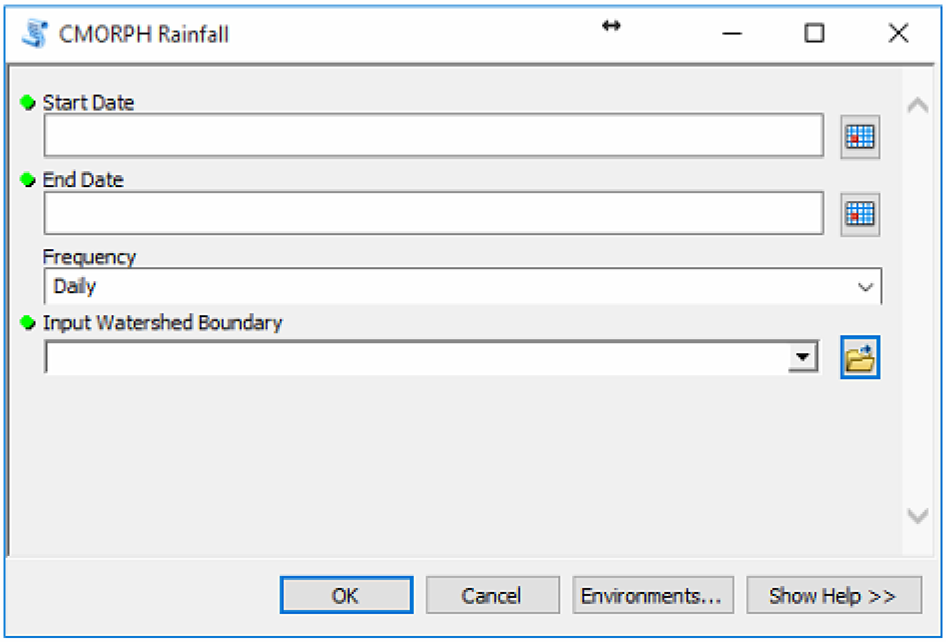


Figure 57 Dialog box for CMORPH rainfall data processing

NASA Earth Exchange (NEX) Downscaled Climate Projection

The NASA Earth Exchange (NEX) Downscaled Climate Projections dataset is comprised of downscaled climate scenarios that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs) developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The dataset includes downscaled projections from 33 models, as well as ensemble statistics calculated for each RCP from all model runs available. The purpose of these datasets is to provide a set of high resolution, bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions.

Each of the climate projections includes monthly averaged maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2005 (Retrospective Run) and from 2006 to 2099 (Prospective Run).

This tool download the selected GCM for the watershed boundary

To use this tool, follow these steps:

- **Rainfall Data Manager | Future Climate Data | Download NASA Downscaled GCM**
- Select the Model (21 models are available) and select Scenario (Historical, RCP45 and RCP8.5)
- Specify the start date and end date which is based on the scenario. (Historical : 1950-2005, RCP4.5/RCP8.5 : 2006-2090)
- Input the watershed which defines the boundary for the interpolation.

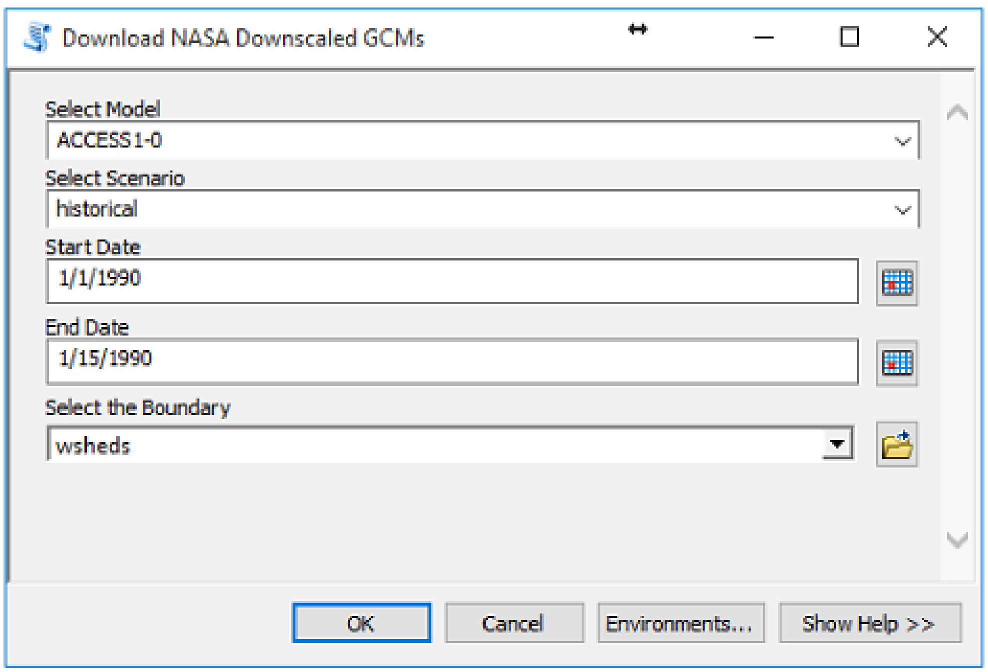
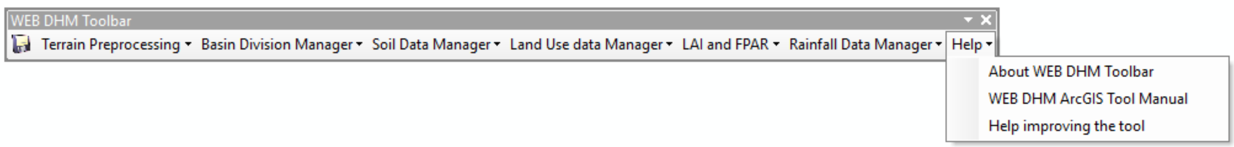


Figure 58 Dialog box for processing GCM data

CHAPTER 8

User Feedback and improvement of the tool

This WEB DHM tool for ArcGIS is at an initial stage of development, so there may be bugs and glitches. All users are requested to provide their feedback, comments or problems using this tool on letterjaya@gmail.com. To make this process much easier, we have shared all our source code in github account. Some of the users having experience and interest in computer programming can also contribute towards the further development of this tool. But at the same time, user can use the github platform to report the problems so that the developer team can respond in a timely manner.



User can provide their feedback or contribute on the development of the tool as below:

- Click on **Help | Help improving the tool**