L-THIA GIS Manual

(**L**ong-**T**erm **H**ydrologic **I**mpact **A**ssessment)

By Youn Shik Park, Kyoung Jae Lim, Larry Theller, Bernie A. Engel

Manual version: May 6th 2013

Department of Agricultural and Biological Engineering

Purdue University

2013

Contents

1. Introduction

Land use changes are influential to hydrology in an area, in other words they result in changes of runoff, streamflow, and groundwater recharge. Urbanization, leading to increased impervious surfaces, causes increased runoff and shorter time to peak typically. The increased runoff and shorter time to peak result in not only decreased ground water recharge but also increased NPS loads, furthermore, contribute to downstream flooding, and affect residential and municipal water supplies in turn. In other words, minimizing the disturbance of urbanization (e.g. low impact development, LID) is one way of ensuring stable water supply. A model allowing use it without profound knowledge has been necessary, which is capable to consider different level of impact of each landuse, for city managers, planners, and water resource professionals.

The Long-Term Hydrologic Impact Assessment (L-THIA) model has been used to estimate the long-term impacts of direct runoff and nonpoint source (NPS) pollution. L-THIA, requiring a modest effort to prepare input data, estimates runoff by SCS-CN method and a pollutant coefficient (Event Mean Concentration; EMC) based approach to estimate pollutant loads. The SCS-CN method is an empirical and watershed-scale approach to estimate event/daily direct runoff. L-THIA was originally implemented as a spreadsheet application and has been developed in ArcView 3.x and upgraded to ArcGIS 9.x. Lim et al. (1999) developed L-THIA/NPS WWW GIS system communicating with the ArcView GIS tool, which allows average annual NPS pollution for 15 pollutants using single rainfall events. The model was applied to the Wildcat Creek Watershed in north central Indiana by Pandey et al. (2000), showing the increased runoff and NPS loads by the significant landuse changes in the watershed. Tang et al. (2005) used L-THIA model to apply two watersheds that are Little Eagle Creek (LEC) in Indiana and Little Muskegon River (LMR) in Michigan. They showed that the runoff change by urbanization could be minimized by an appropriate planning. The LEC watershed had been significantly urbanized from 1991 to 1997, 49% of the watershed was urban in 1973, 63% in 1984, 68% in 1991, and 95% in 1997. The increased runoff between 1991 and 1997 was 1.4 million cubic meters (11% increased) by 34% of increased urban area, while the runoff was increased 3.5 million cubic meters (44% increased) between 1973 and 1984 by 14% of increased urban area in total watershed area. Bhaduri et al. (1997) applied the model to LEC watershed, 19% of landuse change from non-urban to urban caused 60% increase of phosphorus and nitrogen loads. Furthermore, 49% of urban area in the watershed resulted in 98% of total lead, 92% of total copper, and 93% of total zinc loads in 1973. Choi et al. (2009) used L-THIA model for two small watersheds in South Korea, which are Wol-oe and An-nae watersheds. Compared to the observed, the model performance showed 0.95 and 0.93 of Nash-Sutcliffe coefficient of efficiency (NSE) and R^2 in runoff simulation for Wol-oe watershed, 0.81 and 0.71 of NSE and R^2 in runoff simulation for An-nae. Also, the model showed 0.53 and 0.89 of R^2 for Wol-oe and An-nae in suspended solid estimations, 0.95 and 0.89 of R^2 for the watersheds in total phosphorous estimations.

A newer GIS-based L-THIA (L-THIA GIS ver. 2013) has been developed in the ArcGIS 10 platform to estimate long-term direct runoff and NPS loads, considering actual daily precipitation data. The easy-to-use philosophy is maintained with a user friendly interface, the model does not require profound knowledge and experience in ArcGIS.

2. Theory

2.1. Runoff Calculation

The SCS-CN method of the National Resources Conversion Service (formerly Soil Conservation Service) is simple and widely used method to calculate runoff, and is applied for hydrology and NPS simulation (Garen and Moore, 2005). The method requires rainfall amount and CN to calculate runoff, the CN is based on hydrological soil group (HSG), landuse, and hydrologic condition (i.e. Antecedent Moisture Condition; AMC) (Equation 1).

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad for \quad I_a < P$$

$$Q = 0 \quad for \quad I_a \geq P \qquad \text{Equation 1}$$

$$\mathrm{I_a} = 0.2\, S \qquad \text{Equation 2}$$

$$\mathrm{S} = \frac{1000}{\mathrm{CN}} - 10 \qquad \text{Equation 3}$$

Where, Q is runoff (in), P is rainfall (in), I_a is initial abstraction, and S is potential maximum retention after runoff begins.

Initial abstraction is all losses before runoff begins, in other words, it includes interception storage on plants, surface storage, evapotranspiration, and infiltration. Initial abstraction could be defined as a percentage of S, it was found to be approximated by the Equation 2 (USDA, 1986). S is related to landuse and HSG through CN ranging from 0 to 100. More and detailed information can be found at ‘https://engineering.purdue.edu/mapserve/LTHIA7/lthianew/documnt/tec_docs.htm‘.

L-THIA GIS model determines CN based on landuse and soil map in raster format, calculates daily runoff depth based on SCS-CN method, and calculates daily runoff volume (cubic meter) multiplying by area (cell size × cell size).

2.2. Antecedent Moisture Condition

Antecedent Moisture Condition (AMC) is related to soil moisture, the CN calculated by the Equation 1 is termed CN II on AMC II representing average soil moisture. AMC I represents dry soil moisture condition (i.e. the soil moisture content is very low or at wilting point), and AMC III represents wet soil moisture condition (i.e. the soils are saturated or the soil moisture content is at field capacity). The conditions are based on the 5-day antecedent rainfall (P_5, sum of antecedent 5 days precipitation) and growing/dormant season (Table 2.1).

Table 2.1. Classification of AMC

AMC	Description	5-day antecedent rainfall (P_5)	
		Growing Season	Dormant Season

AMC I	Soils are dry.	$P_5 < 35$ mm	$P_5 < 12$ mm
AMC II		35 mm $\leq P_5 \leq$ 53 mm	12 mm $\leq P_5 \leq$ 28 mm
AMC III	Soils are wet.	53 mm $< P_5$	28 mm $< P_5$

Once AMC is defined of the day, CN can be adjusted (i.e. CN I for AMC I and CN III for AMC III) by the equations below. AMC adjustment is optional in L-THIA GIS ver. 2013 model, if AMC is not applied, daily runoff is calculated with CN II.

$$\text{CN I} = \frac{\text{CN II}}{2.281 - 0.0128 \times \text{CN II}} \quad \cdots\cdots \text{Equation 4}$$

$$\text{CN III} = \frac{\text{CN II}}{0.427 + 0.0057 \times \text{CN II}} \quad \cdots\cdots \text{Equation 5}$$

2.3. Overview of L-THIA GIS ver. 2013

L-THIA GIS ver. 2013 estimates long-term runoff and NPS loads based on SCS-CN method and a pollutant coefficients (EMC) on a daily, monthly, and yearly. The model provides watershed delineation process as an option, creates CN map using landuse and soil map, and allows consideration of multiple precipitation data.

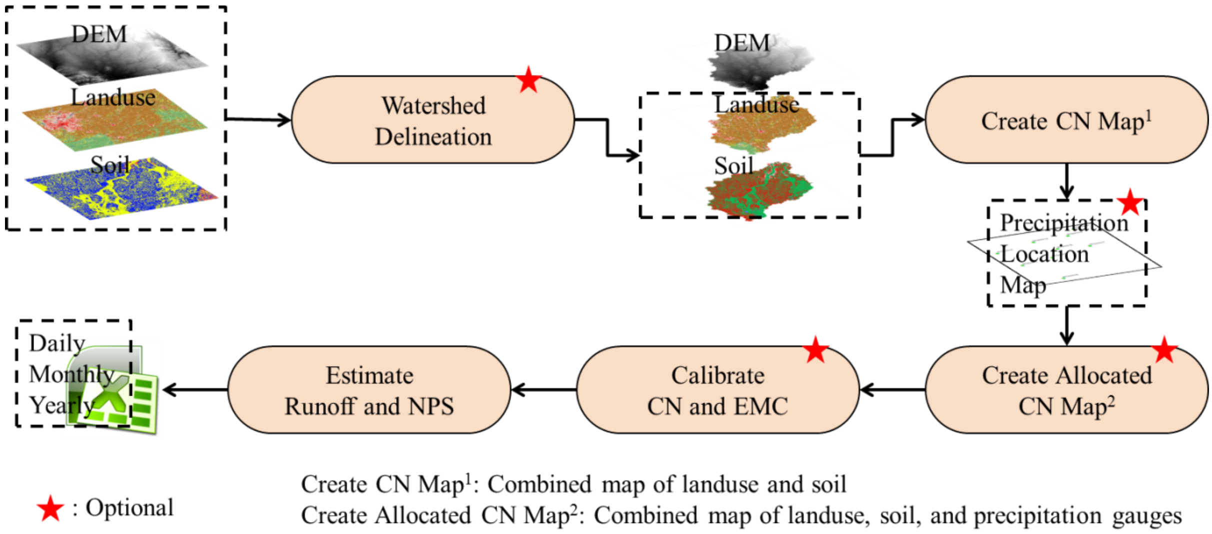


Figure 2.1. Overview of L-THIA GIS ver. 2013

3. User's Guide

3.1. Installation

L-THIA GIS ver. 2013 is an ArcGIS Desktop Add-in model programmed in VB.NET and ArcObjects. Installation kit includes four files that are '*LTHIA_GIS_2013.dll*', '*LTHIA_GIS_2013.esriAddIn*', '*LTHIA_GIS_2013.pdb*', and '*LTHIA_GIS_2013.xml*', all of the files should be in a folder together. Run '*LTHIA_GIS_2013.esriAddIn*' file to install the model.

Open '*Customize Mode*' in ArcMap menu (Figure 3.1.A), an icon named 'LTHIA GIS 2013' will be shown in *Commands* tab (Figure 3.1.B), drag the icon and put it in any extension toolbar (Figure 3.1.C).

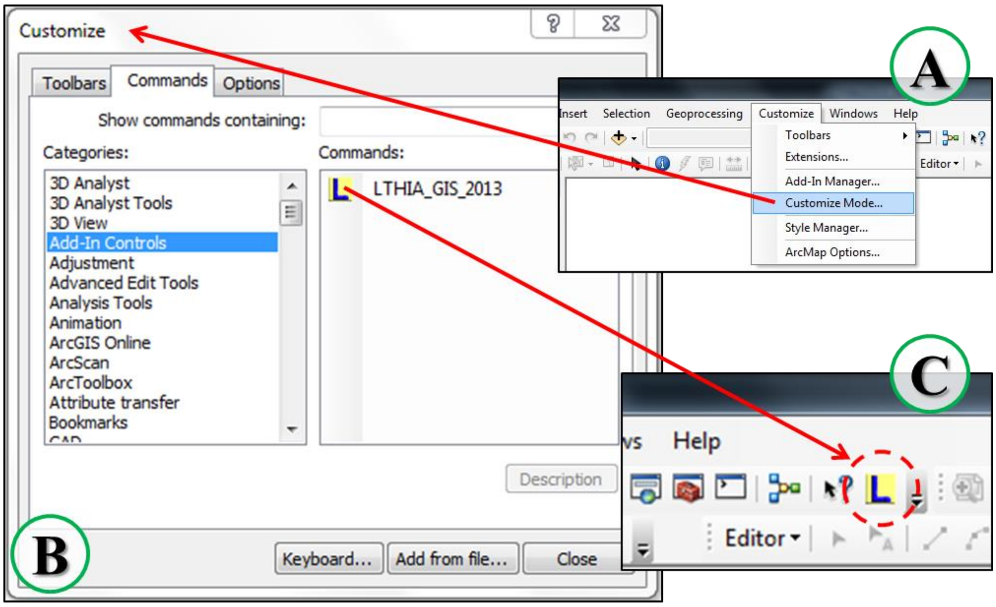
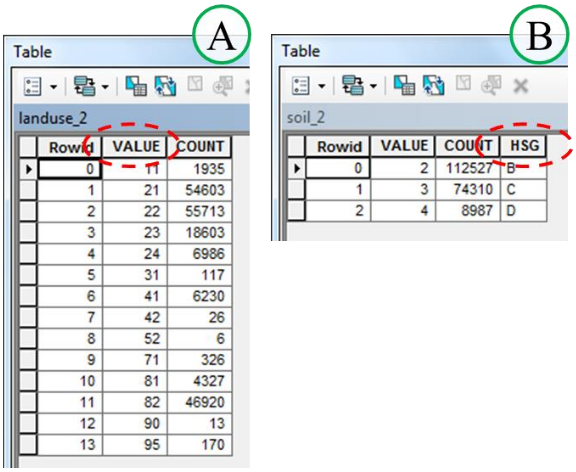


Figure 3.1. Installation of L-THIA GIS ver. 2013

If the interface of the model is shown up when the icon is clicked, the model is ready to use.

3.2. Data Preparation

The model requires raster format of inputs and assumes all of the spatial inputs (i.e. DEM, landuse, and soil map data) are in *meters*, thus, they need to be projected in meters. The raster format of inputs (DEM, landuse, and soil map) is suggested to be in '**TIFF**' format for **DEM** and '**GRID**' format for **landuse** and **soil map** in meters. Also all of inputs should have identical '*Spatial Reference*' in ArcGIS. The input DEM is required to delineate a watershed, however, if the watershed is already delineated or if it is a field-scale simulation, DEM is not required, while landuse and soil map are required for any simulation that are to define CN.



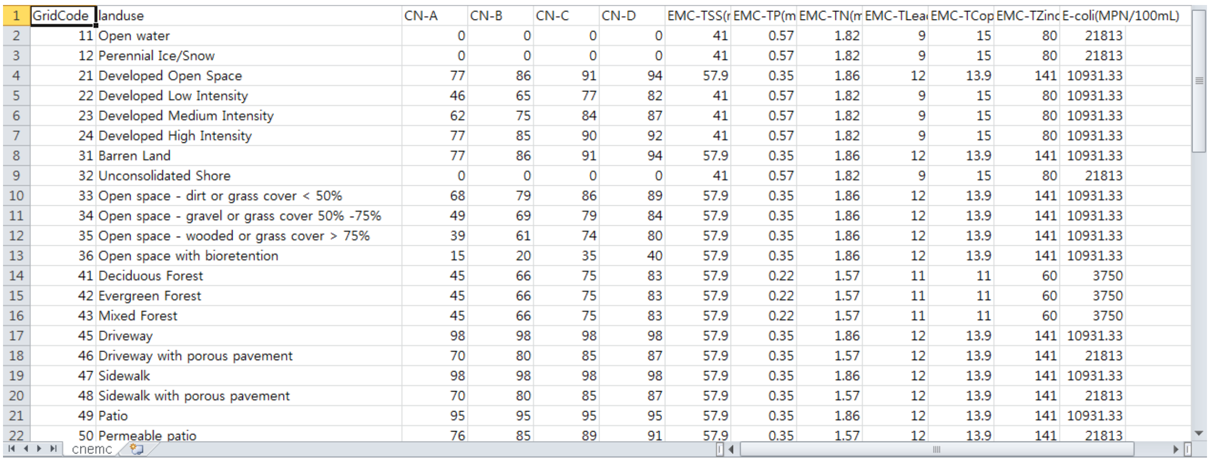
Rowid	VALUE	COUNT
0	11	1935
1	21	54603
2	22	55713
3	23	18603
4	24	6986
5	31	117
6	41	6230
7	42	26
8	52	6
9	71	326
10	81	4327
11	82	46920
12	90	13
13	95	170

Rowid	VALUE	COUNT	HSG
0	2	112527	B
1	3	74310	C
2	4	8987	D

CN is defined by landuse and soil map, the landuse should have 'VALUE' field, and soil map should have 'HSG' field (Figure 3.2). In the landuse data, the 'VALUE' field is landuse codes indicating landuse types, for instance, '11' is 'Open Water', and '82' is 'Cultivated Crops' as defaults (Figure 3.2.A).

Figure 3.2. Required Format for Landuse and Soil map

The model uses only four types of HSG that are 'A', 'B', 'C', and 'D' within soil map. The field name should be 'HSG' and should have one of the four types, any other text is not allowed (Figure 3.2.B). The model prints out a DB file showing default CN and EMC (Figure 3.3) when the folder for simulation is defined ('Step 2' in the model), any value in the file is allowed to change before the following step ('Step 3' in the model that is to create CN map). This is because the model defines CN and EMC based on the landuse code, HSG, and 'cnemc.csv' file. Thus, all of landuse codes should be defined in the 'cncmc.csv' file, in other words, all of values in the 'VALUE' field of landuse data should exist in 'GridCode' of 'cnemc.csv' file.

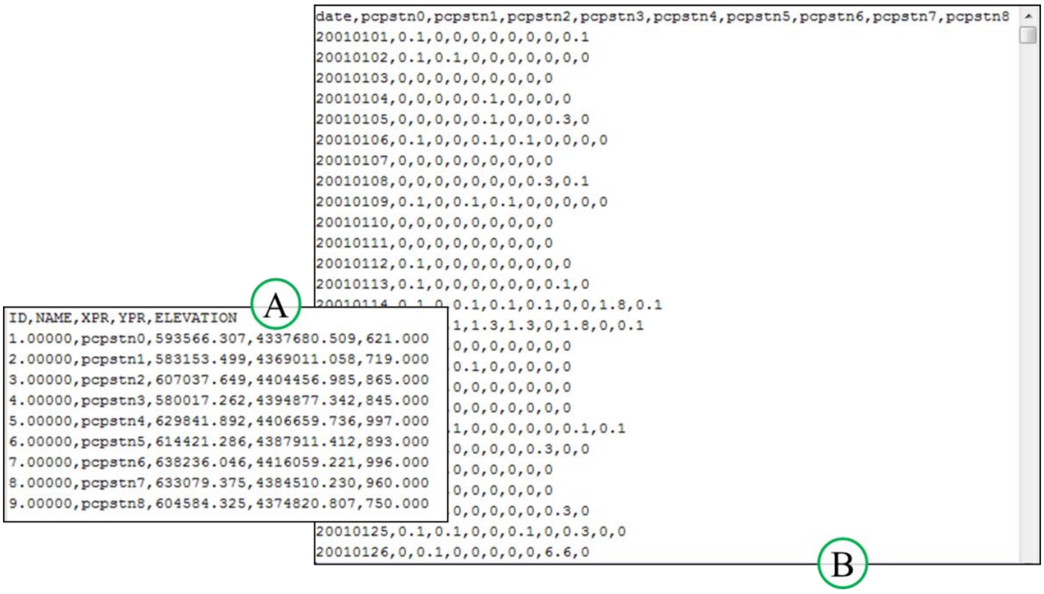


1	GridCode	landuse	CN-A	CN-B	CN-C	CN-D	EMC-TSS(r	EMC-TP(m	EMC-TN(m	EMC-TLea	EMC-TCop	EMC-TZinc	E-coli(MPN/100mL)
2	11	Open water	0	0	0	0	41	0.57	1.82	9	15	80	21813
3	12	Perennial Ice/Snow	0	0	0	0	41	0.57	1.82	9	15	80	21813
4	21	Developed Open Space	77	86	91	94	57.9	0.35	1.86	12	13.9	141	10931.33
5	22	Developed Low Intensity	46	65	77	82	41	0.57	1.82	9	15	80	10931.33
6	23	Developed Medium Intensity	62	75	84	87	41	0.57	1.82	9	15	80	10931.33
7	24	Developed High Intensity	77	85	90	92	41	0.57	1.82	9	15	80	10931.33
8	31	Barren Land	77	86	91	94	57.9	0.35	1.86	12	13.9	141	10931.33
9	32	Unconsolidated Shore	0	0	0	0	41	0.57	1.82	9	15	80	21813
10	33	Open space - dirt or grass cover < 50%	68	79	86	89	57.9	0.35	1.86	12	13.9	141	10931.33
11	34	Open space - gravel or grass cover 50% -75%	49	69	79	84	57.9	0.35	1.86	12	13.9	141	10931.33
12	35	Open space - wooded or grass cover > 75%	39	61	74	80	57.9	0.35	1.86	12	13.9	141	10931.33
13	36	Open space with bioretention	15	20	35	40	57.9	0.35	1.86	12	13.9	141	10931.33
14	41	Deciduous Forest	45	66	75	83	57.9	0.22	1.57	11	11	60	3750
15	42	Evergreen Forest	45	66	75	83	57.9	0.22	1.57	11	11	60	3750
16	43	Mixed Forest	45	66	75	83	57.9	0.22	1.57	11	11	60	3750
17	45	Driveway	98	98	98	98	57.9	0.35	1.86	12	13.9	141	10931.33
18	46	Driveway with porous pavement	70	80	85	87	57.9	0.35	1.57	12	13.9	141	21813
19	47	Sidewalk	98	98	98	98	57.9	0.35	1.86	12	13.9	141	10931.33
20	48	Sidewalk with porous pavement	70	80	85	87	57.9	0.35	1.57	12	13.9	141	21813
21	49	Patio	95	95	95	95	57.9	0.35	1.86	12	13.9	141	10931.33
22	50	Permeable patio	76	85	89	91	57.9	0.35	1.57	12	13.9	141	21813

Figure 3.3. Default CN and EMC File (cnemc.csv)

L-THIA GIS ver. 2013 uses daily precipitation data, therefore, daily precipitation data needs to be prepared with correct format. There are three cases in use of precipitation data. The first case is to use more than 1 precipitation data, for example, it is the case more than 1 of precipitation gauge station exists in the study area. The second case is to use only one precipitation data, and the last case is to use the precipitation data downloaded from Web-based L-THIA (https://engineering.purdue.edu/~lthia/).

The first case requires two kinds of inputs that are location file (Figure 3.4.A) and precipitation data file (Figure 3.4.B). The model plots the locations of precipitation gauge stations, the study area is divided into several areas based on the locations, and then different precipitation data are applied in runoff calculation. Location file needs to be text file (*.txt), to have 5 columns (ID, NAME, coordinate of X-axis, coordinate of Y-axis, Elevation), and to be delimited with comma. In the header of the file, the name of X-axis coordinate should be 'XPR', and the name of Y-axis coordinate should be 'YPR'. Precipitation data file needs to be text or CSV (comma separated values), and the number of precipitation data columns should be same to the number of rows of the location file, of course. The first column is date, three types of date are allowed that are 'yyyymmdd', 'mm/dd/yyyy', and 'yyyy-mm-dd'. The columns from the second to the last are precipitation data, the order of precipitation data columns needs to be matched to the order of rows of location of the location file, for instance, the first precipitation data column is for the first row in the location file.



A

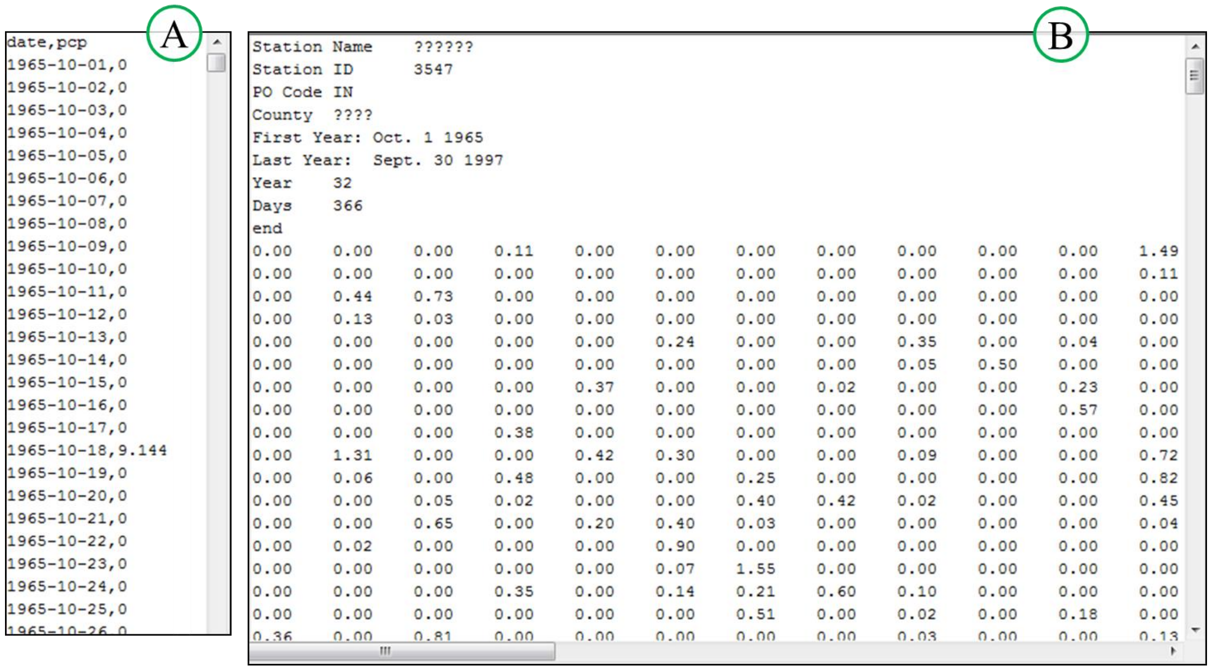
```
ID,NAME,XPR,YPR,ELEVATION
1.00000,pcpstn0,593566.307,4337680.509,621.000
2.00000,pcpstn1,583153.499,4369011.058,719.000
3.00000,pcpstn2,607037.649,4404456.985,865.000
4.00000,pcpstn3,580017.262,4394877.342,845.000
5.00000,pcpstn4,629841.892,4406659.736,997.000
6.00000,pcpstn5,614421.286,4387911.412,893.000
7.00000,pcpstn6,638236.046,4416059.221,996.000
8.00000,pcpstn7,633079.375,4384510.230,960.000
9.00000,pcpstn8,604584.325,4374820.807,750.000
```

B

```
date,pcpstn0,pcpstn1,pcpstn2,pcpstn3,pcpstn4,pcpstn5,pcpstn6,pcpstn7,pcpstn8
20010101,0.1,0,0,0,0,0,0,0,0.1
20010102,0.1,0.1,0,0,0,0,0,0,0
20010103,0,0,0,0,0,0,0,0,0
20010104,0,0,0,0,0.1,0,0,0,0
20010105,0,0,0,0,0.1,0,0,0.3,0
20010106,0.1,0,0,0.1,0.1,0,0,0,0
20010107,0,0,0,0,0,0,0,0,0
20010108,0,0,0,0,0,0,0,0.3,0.1
20010109,0.1,0,0.1,0.1,0,0,0,0,0
20010110,0,0,0,0,0,0,0,0,0
20010111,0,0,0,0,0,0,0,0,0
20010112,0.1,0,0,0,0,0,0,0,0
20010113,0.1,0,0,0,0,0,0,0.1,0
0.1,0.1,0.1,0,0,1.8,0.1
1,1.3,1.3,0,1.8,0,0.1
0,0,0,0,0,0,0
0.1,0,0,0,0,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0
1,0,0,0,0,0,0.1,0.1
0,0,0,0,0.3,0,0
0,0,0,0,0,0
0,0,0,0,0,0
0,0,0,0,0,0.3,0
20010125,0.1,0.1,0,0,0.1,0,0.3,0,0
20010126,0,0.1,0,0,0,0,0,6.6,0
```

Figure 3.4. Location and Precipitation Files

Location file is not required for the second and third cases. For the second case, only precipitation data needs to be prepared, the required format is two columns of date and precipitation data delimited with comma (Figure 3.5.A). The 3 types of date format stated above are allowed. There is no need to change format for the precipitation data file downloaded from the Web-based L-THIA (Figure 3.5.B).



```
date,pcp
1965-10-01,0
1965-10-02,0
1965-10-03,0
1965-10-04,0
1965-10-05,0
1965-10-06,0
1965-10-07,0
1965-10-08,0
1965-10-09,0
1965-10-10,0
1965-10-11,0
1965-10-12,0
1965-10-13,0
1965-10-14,0
1965-10-15,0
1965-10-16,0
1965-10-17,0
1965-10-18,9.144
1965-10-19,0
1965-10-20,0
1965-10-21,0
1965-10-22,0
1965-10-23,0
1965-10-24,0
1965-10-25,0
```

```
Station Name    ??????
Station ID      3547
PO Code  IN
County  ????
First Year: Oct. 1 1965
Last Year:  Sept. 30 1997
Year    32
Days    366
end
0.00  0.00  0.00  0.11  0.00  0.00  0.00  0.00  0.00  0.00  0.00  1.49
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.11
0.00  0.44  0.73  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.13  0.03  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.24  0.00  0.00  0.35  0.00  0.04  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.05  0.50  0.00  0.00
0.00  0.00  0.00  0.00  0.37  0.00  0.00  0.02  0.00  0.00  0.23  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.57  0.00
0.00  0.00  0.00  0.38  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  1.31  0.00  0.00  0.42  0.30  0.00  0.00  0.09  0.00  0.00  0.72
0.00  0.06  0.00  0.48  0.00  0.00  0.25  0.00  0.00  0.00  0.00  0.82
0.00  0.00  0.05  0.02  0.00  0.00  0.40  0.42  0.02  0.00  0.00  0.45
0.00  0.00  0.65  0.00  0.20  0.40  0.03  0.00  0.00  0.00  0.00  0.04
0.00  0.02  0.00  0.00  0.00  0.90  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.07  1.55  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.35  0.00  0.14  0.21  0.60  0.10  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.51  0.00  0.02  0.00  0.18  0.00
```

Figure 3.5. Single Precipitation Data File Format

3.3. Simulation

The model works with ArcMap tools, ‘3D Analyst’ and ‘Spatial Analyst’ should be checked in ‘Extensions’ menu before the model execution. Any tool in ArcGIS 10 is executed in background mode, in other words, ArcMap 10 allows extra action while a tool is under execution. However, **it is not allowed to execute any ArcGIS Desktop Add-in model in background mode.** Some steps of the model execute ArcMap tools, **it may cause an error if any action is requested while the step is under execution**. For example, do not try to move the model interface or ArcMap window until a pop-up window shows up informing the execution of ArcMap tools in the step is finished.

Workspace Setting: Two empty folders need to be prepared before a simulation, which are for ‘Workspace’ in ArcGIS and for simulation folder to write temporary text files for the simulation and to print out result files. Open ‘Environment Settings’ window in ArcMap (‘Geoprocessing’ >> ‘Environments…’), change the folder for ‘Current Workspace’ and ‘Scratch Workspace’ in ‘Workspace’ drop-down menu to the folder prepared for ‘Workspace’, and set the extent in ‘Processing Extent’ same to the input data (e.g. ‘same as layer DEM’). Do not set a Geodatabase for workspace. Open the input data (DEM, landuse, and soil map), and then click L-THIA GIS ver. 2013 icon.

Step 1. Watershed Delineation (Optional) (Figure 3.6.a): The model has 6 steps including optional steps, the running time depends on the scale of data. The first step named ‘Step 1. Watershed Delineation’ is optional, is to delineate watershed using DEM. Checking ‘Landuse and Soil maps are already prepared.' shown between the frames of step 1 and 2, the step can be skipped, if the dataset is already delineated or it is to simulate a field. In the 'Step 1a Watershed Delineation', select DEM layer and click 'Select' button. The model executes 'Fill', 'Flow Direction', 'Flow Accumulation' ArcGIS tools in turn. A pop-up window will be shown up after the process is finished. Outlet (point feature file) is required for the 'Step 1b Watershed Delineation', it can be prepared manually based on 'FAC' (Flow Accumulation Map) created by the Step 1a. Select soil map layer, landuse layer, and outlet data, and then click 'Delineate' button. Two ArcGIS tools that are 'Watershed' and 'Extract by Mask' will be executed.

Step 2. Simulation Folder Setting (Figure 3.6.b): The step is to define a window folder for temporary text files and result files. Click 'Select Folder', and then find the folder. Once the folder is defined, the 'cnemc.csv' file can be found in the folder. If CN or EMC need to be changed, change the value in the file before the Step 3.

Step 3. Create CN Map (Figure 3.6.c): The step is to create CN map and to print out hydrologic response unit (HRU) file. Define landuse and soil map layers in the drop-down menus. If the Step 1 was not skipped, select the layers created in Step 1 that are 'wsd_luse' and 'wsd_soil' layers. Click 'Create CN Map' button. After a pop-up window saying 'CN map has been created.' shows up, click 'Write HRU File' button. The step may take about 10 minutes. The step executes 'Combine' and 'Raster to Polygon' ArcGIS tools.

Step 4. Precipitation Data Folder (Figure 3.6.d): The step is asking the folder precipitation data stored. The model will copy precipitation data file and location file from the folder selected in this step to the simulation folder selected in Step 2.

Step 5. Multiple Precipitation Data (Optional) (Figure 3.6.e): The step is optional. If more than 1 location exists in the study area, the step can be performed. In the drop-down menu, select the location file, and then click 'Plot Location' button. Confirm that the points of location are plotted correctly, and then click 'Create Allocated CN Map' button. The 'Allocated CN Map' is different CN map created by Step 3, the Allocated CN Map has the information of precipitation gauge location. After a pop-up window shows up, click 'Write Allocated HRU File' button. The step executes 'Make XY Event Layer', 'Euclidean Allocation', and 'Combine' ArcGIS tools.

Step 6. Precipitation Setting (Figure 3.6.f): The step is related to precipitation data. Define the unit of the precipitation data (i.e. inch or mm). If AMC needs to be considered, the option needs to be checked and growing season needs to be defined. Select the precipitation file in the drop-down menu, click 'Setup L-THIA Run' button.

There two buttons in the bottom of the interface, that are 'Adjust CN and EMC' and 'Run L-THIA' buttons (Figure 3.6.g). The button 'Run L-THIA' is to estimate daily/monthly/yearly runoff and NPS loads, 3 results files for daily/monthly/yearly simulations will be written in the simulation folder. The button 'Adjust CN and EMC' is to change CN/EMC values after all of GIS processes are finished through Step 1 to Step 6. The module changes CN/EMC values in HRU file written in Step 3 and updates the ‘cnemc.csv’ as well, the updated ‘cnemc.csv’ could be used for other simulations. In a nutshell, the module provides easy and quick manual calibration process.

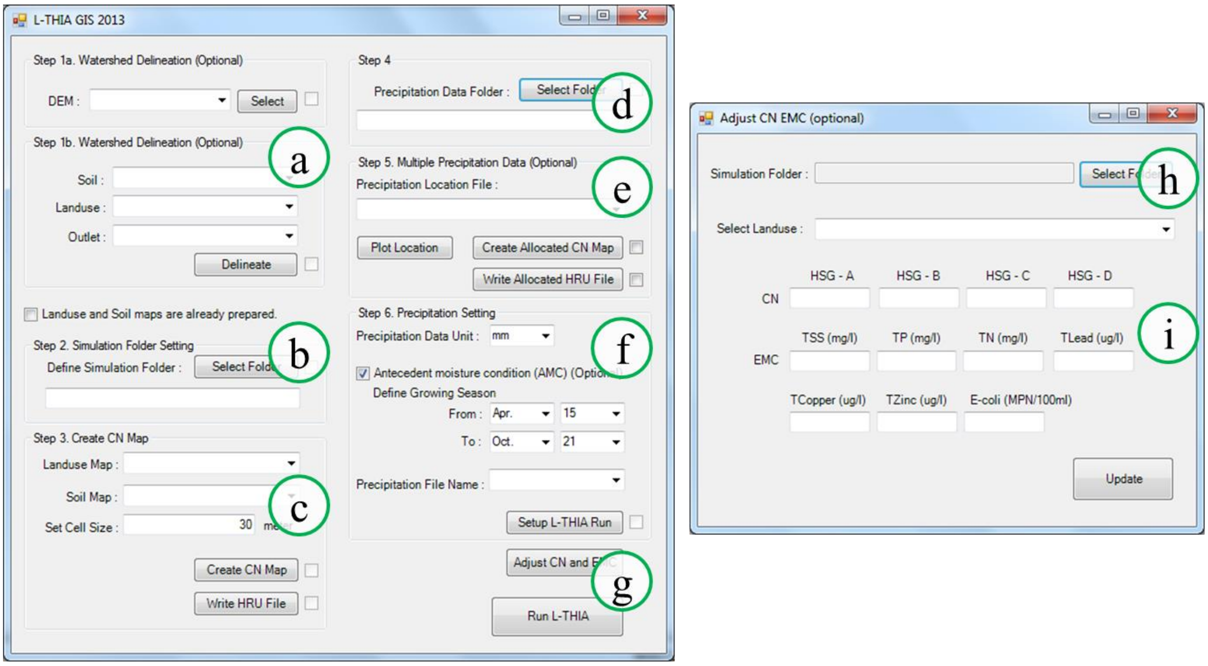


Figure 3.6. Interfaces of L-THIA GIS ver. 2013

4. L-THIA GIS ver. 2013 Applications

Workspace Setting: Prepare two empty folders. Open layers (DEM, landuse, and soil map), and then set ‘Workspace’ and ‘Processing Extent’ in ArcGIS. This is common process for both applications, expect ‘Same as layer dem_2.tif’ needs to be selected in the Processing Extent for Application 2.

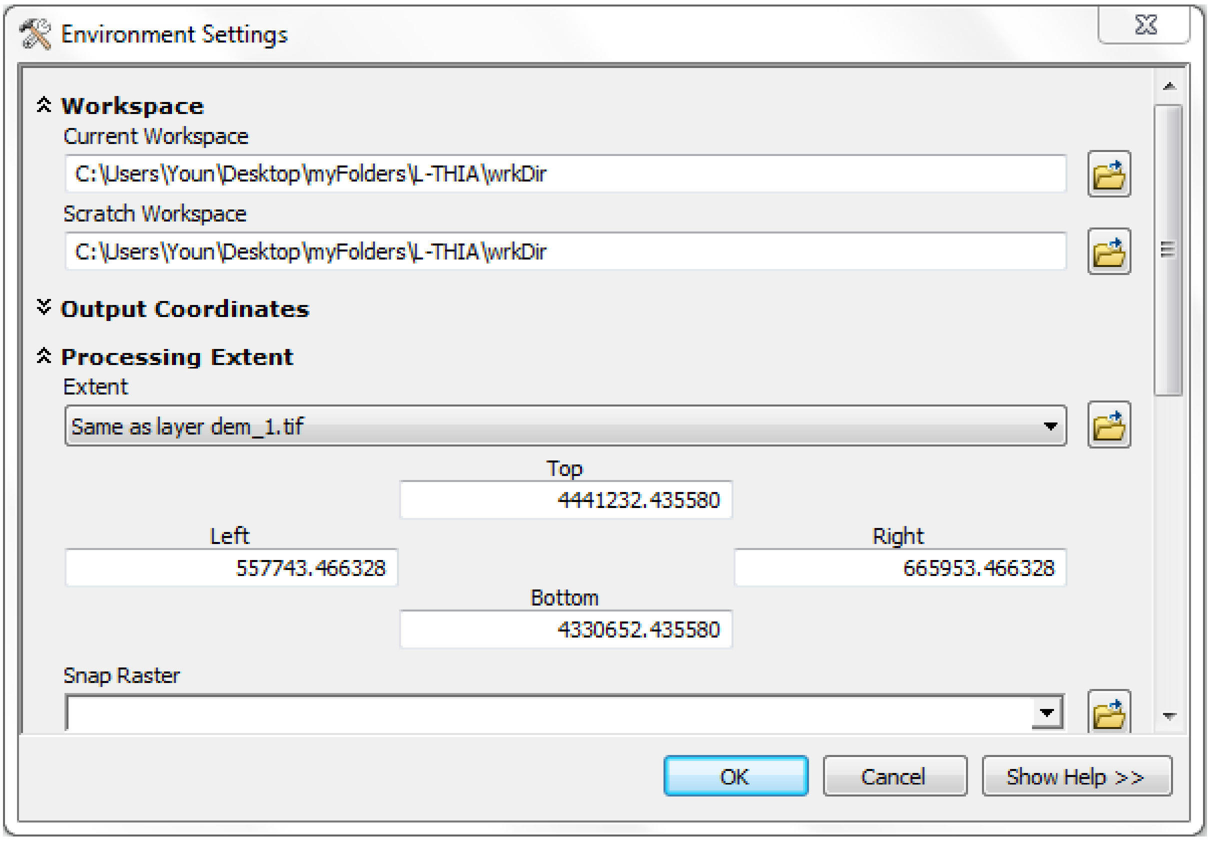
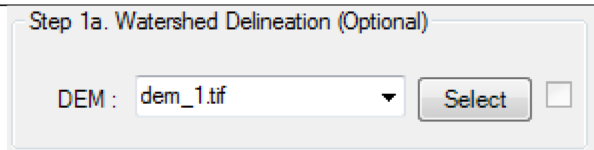
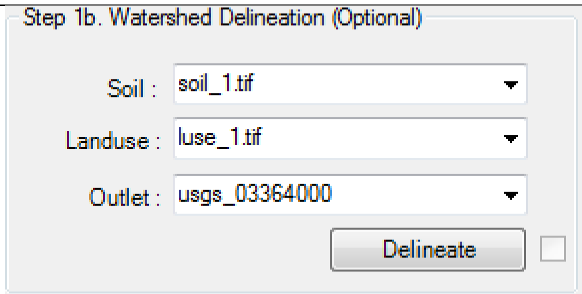
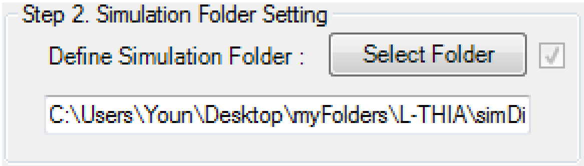
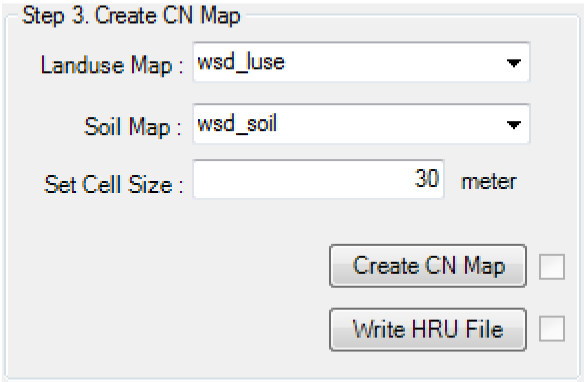
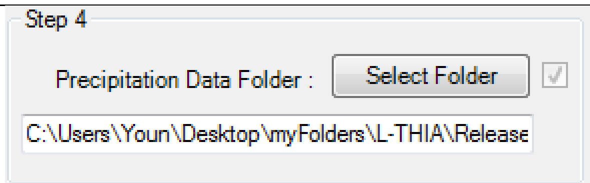
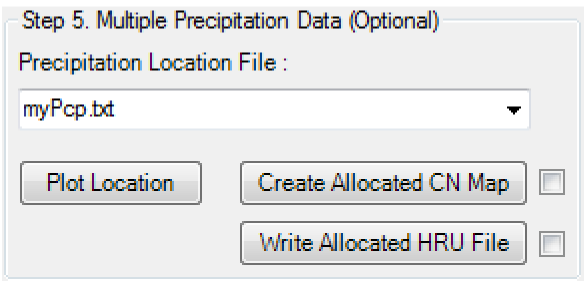


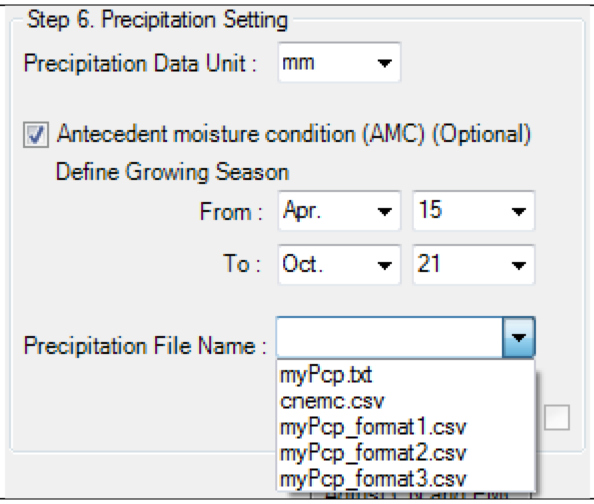
Figure 4.1. Workspace and Process Extent Setting

4.1. Application 1

This application is related to the simulation with multiple precipitation data. The dataset can be found in ‘dataset_1’ folder. Every button in each step has checkbox next the button, if it is checked, it indicates that the step is finished well and that it is ready to move to next step.

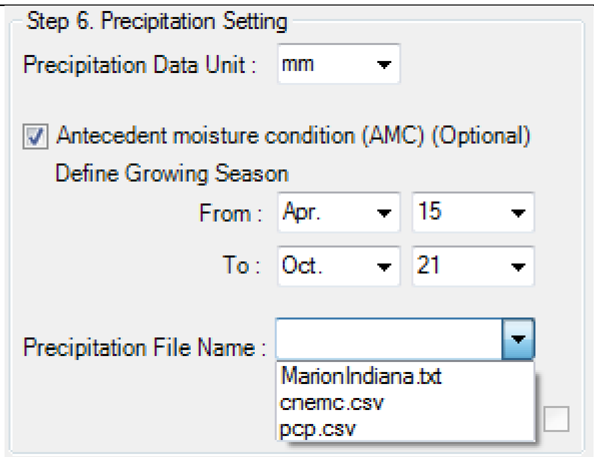
Step 1a: Select ‘dem_1.tif’ layer, and then click ‘Select’ button. ‘FillDEM’, ‘FDR’, and ‘FAC’ layers will be created.	

<table>
<tr>
<td>Step 1b: Select layers, ‘soil_1.tif’ for Soil, ‘luse_1.tif’ for Landuse, and ‘usgs_0336400’ for Outlet. Click ‘Delineate’ button. The step is to prepare watershed-delineated landuse and soil map layers, ‘wsd_luse’ and ‘wsd_soil’ will be created.</td>
<td>
</td>
</tr>
<tr>
<td>Step 2: Click ‘Select Folder’ button, and find the folder prepared for temporary text files and output files. Once it is defined, the ‘cnemc.csv’ file can be found in the folder. If CN/EMC needs to be changed, update the file in this step.</td>
<td>
</td>
</tr>
<tr>
<td>Step 3: The step is to create CN map based on landuse and soil map. Select ‘wsd_luae’ and ‘wsd_soil’ for Lauduse Map and Soil Map respectably. Landuse and soil map layers may have different cell size, thus, define cell size to create CN map. Click ‘Create CN Map’ button, then ‘CNmap’ layer will be created. This will take about 10 minutes. After ‘CNmap’ layer is created, click ‘Write HRU File’.</td>
<td>
</td>
</tr>
<tr>
<td>Step 4: This step is asking the folder precipitation data file is stored. Precipitation dataset can be found at ‘pcp’ folder for this application.</td>
<td>
</td>
</tr>
<tr>
<td>Step 5: The watershed for the Application 1 has 7 gauge stations inside the watershed and 2 gauge stations nearby the watershed. Select the location files named ‘myPcp.txt’, and then click ‘Plot Location’. The layer ‘PcpLoc’ shows the locations. Confirm if the points indicating the locations are plotted correctly or not. If yes, click ‘Create Allocated CN Map’ button. If not, check the format or coordinate system of the location file. After a new CN layer named ‘mCNmap’ will be created, click ‘Write Allocated HRU File’ button. The HRU file written in the Step 3</td>
<td>
</td>
</tr>
</table>

<table>
<tr><td>will be updated to include precipitation gauge location information.</td><td></td></tr>
<tr><td>Step 6: The step is to define the unit (mm or inch) of precipitation data and to set AMC. The unit of precipitation data for the Application 1 is ‘mm’, select ‘mm’. AMC is optional, if AMC needs to be applied, check the checkbox, and define growing season. There will be 3 precipitation data that are same data in different format. Select one of them, and then click ‘Setup L-THIA Run’ button.</td><td>
</td></tr>
<tr><td>Simulation: Click ‘Run L-THIA’ button. Result files can be found at the simulation folder designated in Step 2.</td><td></td></tr>
</table>

4.2. Application 2

This application is related to the simulation with single precipitation data and downloaded precipitation data. The dataset can be found in ‘dataset_2’ folder. The processes from Step 1 to Step 4 are same to the processes of Application 1. The Step 5 is not required in the Application 2 that is for single precipitation data.

<table>
<tr><td>Step 6: Step 6: The step is to define the unit (mm or inch) of precipitation data and to set AMC. The unit of precipitation data for the Application 2 is ‘inch’ for the downloaded data (MarionIndiana.txt) and ‘mm’ for the ‘pcp.csv’, select ‘inch’ or ‘mm’. AMC is optional, if AMC needs to be applied, check the checkbox, and define growing season. There will be 2 precipitation data that are same data in different format. The file ‘pcp.csv’ is prepared in the format ‘date’ and ‘precipitation’, the file ‘MarionIndiana.txt’ is downloaded from Web-based L-THIA. Select one of them, and then click ‘Setup L-THIA Run’ button.</td><td>
</td></tr>
<tr><td>Simulation: Click ‘Run L-THIA’ button. Result files can be found at the simulation</td><td></td></tr>
</table>

folder designated in Step 2.	

5. Error Handling

If an error is detected, this section would be helpful. L-THIA GIS ver. 2013 works with ArcGIS tools and ArcObject programmed in VB.NET, thus, the error may result in use of ArcGIS tools or ArcObject with inputs. The raster format of inputs (DEM, landuse, and soil map) is suggested to be in ‘**TIFF**’ format for **DEM** and ‘**GRID**’ format for **landuse** and **soil map** in meters, a window folder should be selected for ‘Workspace’ not any Geodatabase. Note that any interference is not allowed during the step is under ArcGIS tool execution, the step employing ArcGIS tool (Step 1, 3, 5) will show a pop-up window when the process is finished, thus, do not try to do anything with ArcMap window and the model interface until the pop-up window shows up.

Table 5.1. Error Handling

<table>
<tr><th>Step</th><th>ArcGIS Tools Employed</th><th>Description</th></tr>
<tr><td>Step 1</td><td>Fill, Flow Direction,
Flow Accumulation,
Extract Mask,
Watershed</td><td>Test the input with these tools manually, it may be caused by use of ArcGIS tool with the input. Or, landuse layer should have ‘VALUE’ field, soil map layer should have ‘HSG’ field.</td></tr>
<tr><td>Step 2</td><td>N/A</td><td></td></tr>
<tr><td>Step 3</td><td>Combine,
Raster to Polygon</td><td>Cell size should be in meter, only numbers are allowed.</td></tr>
<tr><td>Step 4</td><td>N/A</td><td></td></tr>
<tr><td>Step 5</td><td>Make XY Event Layer
Euclidean Allocation</td><td>If locations are not correctly plotted, check the coordinate system of location file.</td></tr>
<tr><td>Step 6</td><td>N/A</td><td>Make sure if correct precipitation data was selected, because the drop-down menu includes all of text files in the folder.</td></tr>
<tr><td>Setup L-THIA Run</td><td>N/A</td><td>Check if the precipitation data has a text (e.g. string, character, or letter) or blanks. Excluding the header of file, if any value is not available to convert into a number, it will make an error.</td></tr>
<tr><td>Adjust CN and EMC</td><td>N/A</td><td rowspan="2">Make sure that any text file hasn’t been deleted manually, that the simulation folder was selected correctly, and that there was not any manual updates of text file in simulation folder.</td></tr>
<tr><td>Run L-THIA</td><td>N/A</td></tr>
</table>

6. Reference

Budhendra, B. Harbor, J., Engel, B., Lim, K. J. and D. Jones. 1999. Assessing the Long-Term Hydrologic Impact of Land Use Change using a GIS-NPS Model and the World Wide Web. Environmental Problem Solving with GIS: A National Conference, Cincinnati, Ohio. Proceedings Volume (USEPA).

Choi, J. W., Lee, H., Shin, D. S., S. U. Cheon. 2009. Evaluation of Estimated Storm runoff and Non-point Pollutant Discharge from Upper Watershed of Daecheong Reservoir during Rainy Season using L-THIA ArcView GIS Model. Journal of Korean Society on Water Quality 25(6), 984-993

Garen D. C. and D. S. Moore. 2005. Curve Number Hydrology in Water Quality Modeling: Uses, Abuses, and Future Directions. Journal of the American Water Resources Association. 377-388.

Lim, K. J., Engel, B. A., Kim, Y., Bhaduri, B. and J. Harbor. 1999. Development of the Long Term Hydrologic Impact Assessment (L THIA) WWW Systems. Soil Conversion Organization Meeting held May 24-29, 1999. 1018-1023.

Pandey, S. Gunn, R., Lim, K. J., Engel, B. and J. Horbor. 2000. Developing a Web-enabled Tool to Assess Long-term Hydrologic Impacts of Land-use Change: Information Technology Issues and a Case Study. URISA Journal. 12(4), 5-17.

Tang, Z. Engel, B. A., Lim, K. J., Pijanowski, B. C. and J. Harbor. 2005. Minimizing the Impact of Urbanization on Long Term Runoff. Journal of the American Water Resources Association. 1347-1359.

USDA. 1986. Urban Hydrology for Small Watersheds. Natural Resources Conservation Service. United States Department of Agriculture