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SWMM Modeling Methods for Simulating Green Infrastructure at a Suburban Headwatershed: User's Guide

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SWMM Modeling Methods for Simulating Green Infrastructure at a Suburban Headwatershed: User's Guide

by

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Abstract

Urban stormwater runoff quantity and quality are strongly dependent upon catchment properties. Models are used to simulate the runoff characteristics, but the output from a stormwater management model is dependent on how the catchment area is subdivided and represented as spatial elements. For green infrastructure (GI) modeling, we suggest a discretization method that distinguishes directly connected impervious area from the total impervious area. We recommend identifying pervious buffers, which receive runoff from upgradient impervious areas, as a separate subset of the entire pervious area. This separation improves model representation of the runoff process. The rational and demonstration of the performance of this approach is presented and discussed in detail in Lee et. al. 2017.

Using these criteria for categorizing important land cover components governing runoff hydrology, an approach to spatial discretization for projects using the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) is demonstrated for the Shayler Crossing (SHC) headwatershed, a well-monitored, residential suburban area occupying 100 ha, east of Cincinnati, Ohio. The model relies on a highly resolved spatial database of urban land cover, stormwater drainage features, and topography. The approach accommodates the distribution of runoff contributions from different spatial components and flow pathways that would impact GI performance. In headwatersheds with relatively homogeneous landscape properties throughout the system like SHC, all subcatchments are discretized with the same land cover types, and instead of using a $j \times k$ array of calibration parameters, based on j subcatchments and k parameters per subcatchment, the values used for the parameter set for one subcatchment can be applied in all cases (i.e., just k parameters), reducing the number of modeled parameters to consider during calibration. Depending on the size of the watershed being modeled and the heterogeneity of the landscape, grouping subcatchments into categories, such as steep slope vs gentle slope, for example, may be necessary. This would result in an additional parameter set for consideration during calibration, but still limits the domain of parameter values compared to when each subcatchment is parameterized independently.

This report was written to outline the spatial database and SWMM model set-up steps required to simulate GI scenarios at a small watershed scale. We use the SHC headwatershed as the case study for describing the processes for model set-up and conducting simulations. While some modeling results are given, they are provided for context and guidance only, and were not meant for detailed discussion. The main purpose of the report is to provide SWMM model users interested in GI considerations at a watershed scale a framework for using common computer analytical software tools to configure a SWMM model for GI scenario analysis. The report is staged in a step by step, users guide, format for setting-up a SWMM model to simulate the effects of GI on small watershed rainfall-runoff hydrology.

This report was submitted in fulfillment of contract EP-C-14-012 by APTIM under the sponsorship of the United States Environmental Protection Agency. This report covers a period from June 1, 2017 to May 31, 2018.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) within the Office of Research and Development (ORD) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This report outlines in step by step format the application of a spatial discretization approach that can be used with the U.S. Environmental Protection Agency's (EPAs) Stormwater Management Model (SWMM) when the interest is modeling the effects of green infrastructure (GI) practices in urban areas. SWMM is a popular urban/suburban rainfall-runoff model used by water resource professionals and researchers. SWMM uses the term low impact development (LID) controls for GI that are designed to capture surface runoff and provide some combination of detention, infiltration, and evapotranspiration. The methods presented in this document were developed using the Shayler Crossing (SHC) headwatershed located in the East Fork of the Little Miami River Watershed (EFW) near Cincinnati, Ohio as a case study. The SHC is occupied by mainly residential with some agricultural land uses. The details of the data processing and modeling methodology are presented in this report to assist other users who may be considering similar effort using SWMM.

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Acronyms and Abbreviations

ARS	Agricultural Research Service
BioRet1	Bioretention 1
BPA	Buffering Pervious Area
CHI	Computational Hydraulics Institute
DA	Drainage Area
DCIA	Directly Connected Impervious Area
DEM	Digital Elevation Model
DisCoeff	Discharge Coefficient
DS	Depression Storage
EFW	East Fork Watershed
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
Esurf	Evaporation Surface
EvapFactor	Evaporation Factor
FBA	Filter Bed Area
FIPS	Federal Information Processing Standard
Ft2	Square foot
GEOM1,…4	Geometry 1,…4
GI	Green Infrastructure
GIS	Geographical Information System
ICIA	Indirectly Connected Impervious Area
IMD	Initial Moisture Deficit
In	Inches
In/hr	Inches per hour
Init_Depth	Initial Depth
InOffset	Inlet Offset
Inp	Input
Invert_Elv	Invert Elevation
IWS	Internal Water Storage
JPEG	Joint Photographic Experts Group
Ksat	Saturated Hydraulic Conductivity Coefficient
LID	Low Impact Development
LiDAR	Light Detection and Ranging
MOP	Manual of Practice
MR	Modeling Result
NAD	North American Datum
NCDC	National Climate Data Center
NEXRAD	Next-Generation Radar
N-Imperv	Manning n for impervious surface
N-Perv	Manning’s n for pervious surface
NRC	National Research Council
NRCS	National Resources Conservation Service
NRMRL	National Risk Management Research Laboratory
NSE	Nash-Sutcliffe Efficiency
ODNR	Ohio Department of Natural Resources

Ohio EPA	Ohio Environmental Protection Agency
ORD	Office of Research and Development
PA	Pervious Area
PctRouted	Percent Routed
PctZero	Percent Zero
PervBuffer	Pervious Buffer
Rim_Elv	Rim Elevation
Routeto	Route To
SCS	Soil Conservation Service
SHC	Shaylor Crossing
S-Imperv	Slope Impervious
SPA	Standalone Pervious Area
S-perv	Slope Pervious
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Data
SWAT	Soil Water Assessment Tool
SWMM	Stormwater Management Model
TPA	Total Pervious Area
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VegSwale	Vegetated Swale
WEF-ASCE	Water Environment Federation – American Society of Civil Engineers
WQv	Water Quality Volume
Xsection	Cross Section
YSI	Yellow Springs Instruments

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1. Introduction

Effective stormwater management requires a thorough understanding of the characteristics of rainfall-runoff generated during storm events. The U.S. Environmental Protection Agency's (EPAs) Storm Water Management Model (SWMM) is a popular urban/suburban rainfall-runoff model used by water resource professionals and researchers. SWMM can be used for single event or long-term (continuous) simulation of runoff quantity and quality. The runoff component operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. Since SWMM Version 5.0.019 the capability of explicitly evaluating the performance of several green infrastructure (GI) practices has been included. SWMM uses the term low impact development (LID) controls for GI that are designed to capture surface runoff and provide some combination of detention, infiltration, and evapotranspiration. The GI/LID controls modeled in SWMM include bioretention cells, rain gardens, green roofs, infiltration trenches, permeable pavements, rain barrels, rooftop disconnections, and vegetative swales.

Conventional stormwater modeling has focused on the design of urban drainage systems and flood control practices based on larger storms, such as 2 to 10-year return period storms for designing drainage systems and 25 to 100-year storms for designing flood control practices (NRC, 2009; WEF-ASCE, 2012). Conversely, nearly 95% of pollutant runoff from urban areas is produced from events smaller than a 2-year storm (Guo and Urbonas, 1996; Pitt, 1999; NRC, 2009). GI practices were developed to correct this water pollution problem (WEF-ASCE, 2012; USEPA, 2014). The specific design objectives for GI include minimizing the impervious areas directly connected to the storm sewer, increasing surface flow path lengths or time of concentration, and maximizing onsite depression storage at the lot-level (WEF-ASCE, 2012). This translates operationally to individual stormwater management practices that are relatively small but densely distributed in space (USEPA, 2009). To evaluate this management approach accurately detailed subcatchment delineation is required.

There is a great deal of interest in modeling GI effects at watershed scales to help inform regional stormwater management planning and design decisions. However, from a stormwater modeling perspective, the approach taken for model representations of GI requires different methodological considerations compared to the traditional large-size, low spatial density of the more centralized and regional control features. Impervious area should be further characterized as either directly connected impervious area (DCIA) or indirectly connected impervious area (ICIA). DCIA directly discharges runoff to the existing storm sewer system without any control, while ICIA discharges to adjacent pervious area. The pervious area that receives runoff from ICIA works like a buffer strip or swale, therefore acting like an existing GI practice albeit not intentionally designed as such, and is called buffering pervious area (BPA) in this study. The other pervious area is called standalone pervious area (SPA) that does not receive or control any impervious area runoff. This report describes an approach to SWMM GI modeling—how to delineate and characterize subcatchments for GI analysis, which is generally related to future improvement by varying the status of DCIA, ICIA, BPA, and SPA. This model setup not only allows for modeling the effects of various GI scenarios, but also facilitates the scaling of these scenarios from a small subcatchment, or lot-level to a watershed level.

SWMM is normally applied in spatial scales varying from an individual land parcel (or lot-level; within a few acres) to a catchment (or small) watershed scale (within a couple of hundred acres). SWMM uses a subcatchment based modeling approach to simulate runoff generated from rainfall, where the runoff is captured or diverted to different conveyances, storage, and/or treatment devices (Rossman, 2015). This report summarizes a SWMM modeling methodology for simulating GI at a headwatershed (in this particular case, a 250-acre watershed). In watershed terminology, a headwatershed characterizes the physical location of the system being modeled as the landscapes whose drainage initiates the formation of a natural stream channel, the 'head' or start of a natural drainage network, and typically includes all the lands draining to the point where a first order stream channel merges to form a second order channel.

The report contains a step-by-step, hands-on, guidance for the modeling methodology used to simulate GI at a headwatershed using a mix of commercially available computer tools. A formal analysis of the approaches presented herein in terms of model performance and the relevance of the simulation results to studying the effectiveness of urban GI has been undertaken. The results of this analysis have been included and discussed in a manuscript prepared for external publication. Upon the writing of this report that manuscript was undergoing both public and anonymous peer review by the Journal of Hydrology and Earth Systems Sciences, and can be downloaded at the following url: https://www.hydrol-earth-syst-sci-discuss.net/hess-2017-166/.

1.1 Study Area Overview

The methodology presented in this document was developed for the Shayler Crossing (SHC) headwatershed located in the East Fork of the Little Miami River Watershed (EFW) near Cincinnati, Ohio. The SHC catchment area is occupied by mainly residential and some agricultural land uses. Since 2006, EPA in partnership with the Clermont County Office of Environmental Quality and Soil and Water Conservation District has performed long-term extensive monitoring and modeling efforts in the EFW area for developing a systematic watershed management framework. The framework will allow for evaluating the feasibility and potential effectiveness of water quality management practices and programs at the interface of agricultural and suburban land uses (Ohio EPA, 2014). A more detailed site description and the sources of data used for developing this methodology are presented in the later sections of this report.

1.2 Report Objective

This report summarizes the modeling methods used for simulating GI at the headwatershed at SHC. The details of the data processing and modeling methodology are presented in this report to assist other users who may be considering this type of effort using SWMM. It should be noted that some of the data processing tasks overlap and the order and manner in which they are presented in this report is not meant to be prescriptive. The data processing and analytical tools used to perform this work include: ArcGIS[1], Microsoft Excel (MS-Excel)[2], PCSWMM[3] and SWMM. Other commercially available tools can be used to achieve similar results. The mention of trade names or specific commercial products in this report does not constitute as an endorsement or recommendation for use.

2. Data Preparation

The initial task for modeling stormwater rainfall-runoff over a study area is to prepare the required data. Available data needs to be collected from the appropriate sources for the study area and the targeted simulation period. This data characterizes the relevant spatial and/or temporal attributes of the study area. However, in most cases, the collected data would not be ready to use in SWMM modeling, it needs conditioning. Some of the required data may not be available, and, therefore, needs to be generated by estimations or other means. Thus, significant effort in data processing may have to be followed, in addition to just data gathering, and both can require considerable time. When using SWMM to model stormwater runoff over a study area, a modeler generally performs the following tasks:

1. Data collection: Collect site-specific data for model use from available sources.
2. Data processing: Review the collected data for gaps and prepare it for model use.
3. Spatial data analysis: Produce a digital version of a spatial network representation of the physical components of the study area including surface land use/land cover and subsurface storm sewer components. This is often produced with the guide of a drawn conceptual version of the network.
4. Model option selection: Specify a default set of modeling options to use for the study area.
5. Object editing: Edit the individual properties of the model objects (including LID options) that make up the system. In this study, we use the third-party tool MS-Excel.
6. Run Simulation(s): Run SWMM model simulation(s) and view/evaluate the results and refine/revise modeling approach, including sensitivity analysis, calibration, and validation as needed.

2.1 Data Collection

The following is a listing of site-specific data required to develop a SWMM model for GI considerations. If no relevant data is available, assumptions should be applied using available technical references. For example, the SWMM User's and Reference Manuals (Rossman, 2015; Rossman and Huber, 2016) provide valuable reference data for specific parameters and specific conditions being modeled.

- Spatial Data
  - Topography: digital elevation model (DEM) or topographic contours. Applied data should have sufficient resolution to identify individual subcatchments for every catch

[1] ArcGIS Desktop Version 10.2® is a registered trademark of ESRI, Redlands, CA, USA
[2] Microsoft Excel® is a registered trademark of Microsoft Corporation, Seattle, WA, USA
[3] PCSWMM 2016 is distributed by Computational Hydraulics Int. (CHI), Guelph, Ontario, Canada

basin. In this study, we used 2-ft contours and 2.5-ft DEM provided by Clermont County, OH.
  - Land use/cover: site-specific land cover data. This data set can be derived from aerial photographs with fine enough resolution to identify homogeneous land cover types (e.g., street, main building, miscellaneous building, driveway, sidewalk, parking, etc.).
  - Soils: soil type and soil type-specific parameters capillary suction head, saturated hydraulic conductivity, porosity, wilting point, field capacity. SSURGO provides more detailed data than STATSGO.
  - Storm drainage system design, built and natural: locations of inlet catch basins, manholes, sewer pipe characteristics, and channel characteristics
  - Retention/detention system: location, storage curve (depth-area), outlet structures (e.g., weir, orifice)
  - Other existing stormwater control systems (i.e., LID/GI): For example, grass swale, bioretention, permeable pavement, etc.
  - Aquifer: groundwater table elevation

- Monitoring Data
  - Precipitation data: Minimum hourly, preferably sub-hourly resolution
  - Evaporation data
  - System-level flow data: stream flow rate, channel, and/or culvert discharge rate
  - Water quality data if applicable: Concentrations of sediment, nutrients, metals, and other contaminants of interest for outlets and at other points in the drainage network

2.1.1 Spatial Data

For the case study presented in this report (SHC headwatershed), the geospatial data was provided by the Clermont County Office of Environmental Quality, OH and was in an ArcGIS compatible format. This is ideal but unfortunately not always common for County or municipal-level utilities (i.e., not every utility across the nation would have the same quality of available data). The datasets provided by the County included, surface topography (2.5-ft DEM and 2-ft contours), high-resolution aerial orthophotographs, soils data, existing stormwater management infrastructure (e.g., storm sewer inlets and manholes, storm sewer pipes, wet/dry detention ponds, and the natural channel network), and other urban infrastructure (e.g., streets, drinking water systems, wastewater systems). These data, presented as map products are shown in Figures 1 through 5. The SHC headwatershed boundary delineation represented in these figures was also provided from the County. Because of the ongoing urbanization around the study area, such as new constructions and the related adjustment of storm sewer systems, the exact watershed boundary is changing. The SHC watershed boundary delineation in this case study is based on the 2010 urban development condition.

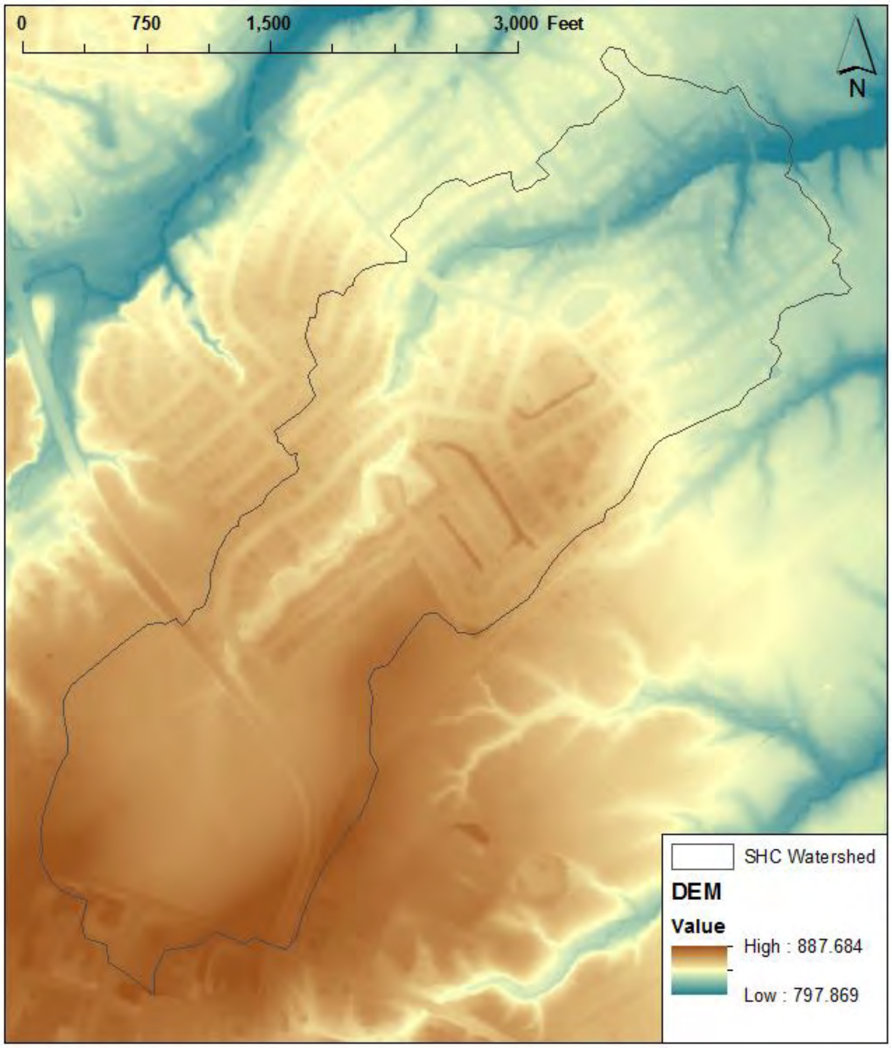


Figure 1. SHC Topography (DEM) from Clermont County. Legend is elevation in feet. The maximum elevation difference within SHC is about 62 feet.

Figure 2. SHC aerial orthophoto from Clermont County. This aerial orthophoto was used for identifying and digitizing detailed land cover types.

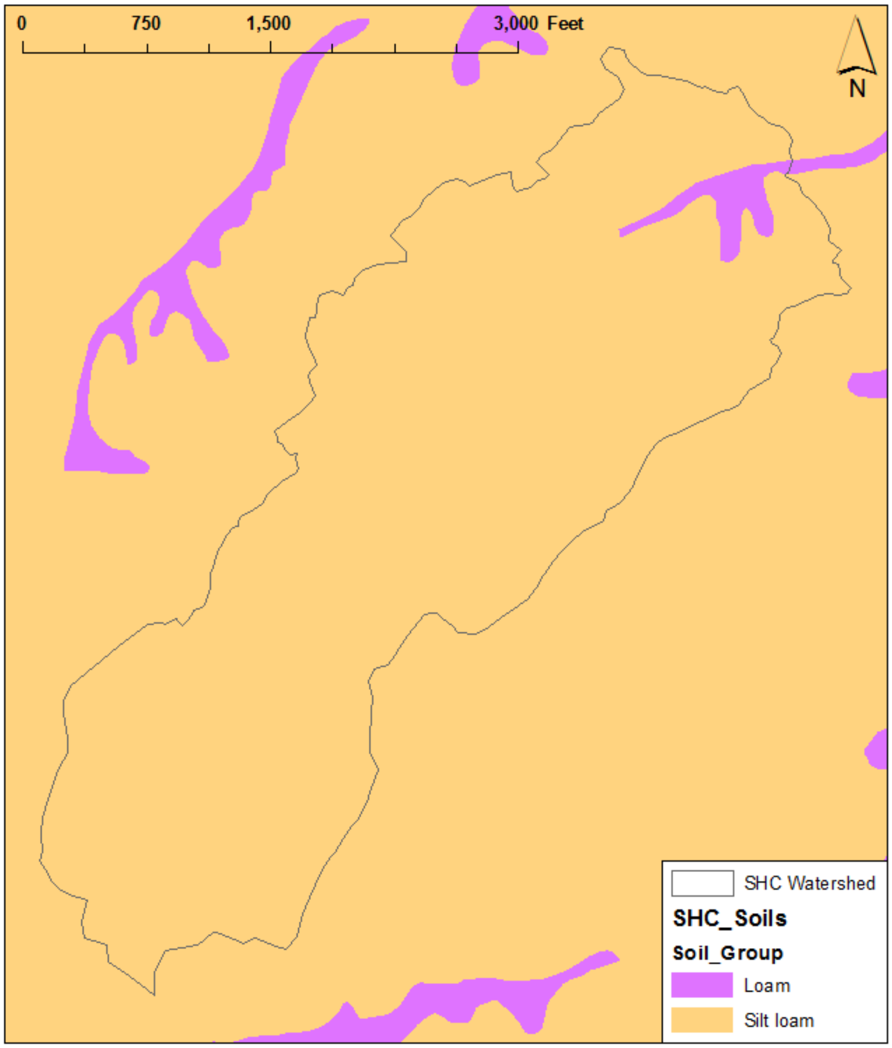


Figure 3. SHC Soils from Clermont County (based on SSURGO).

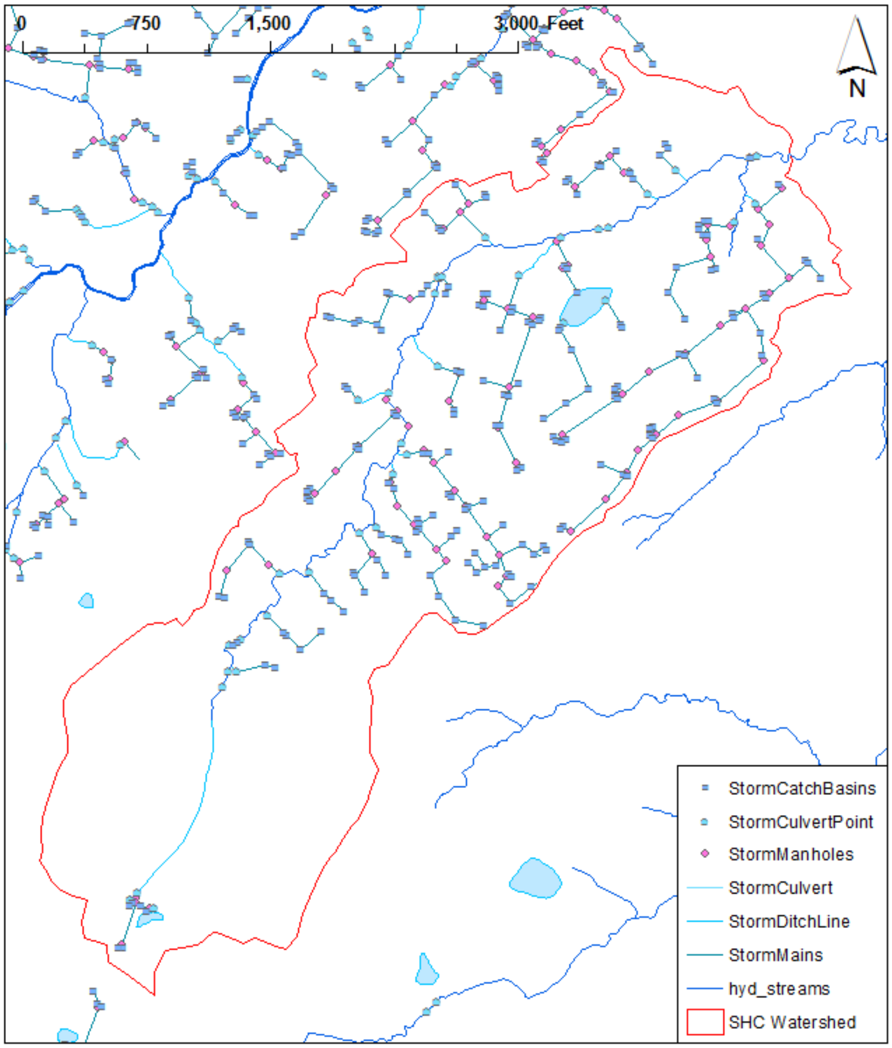


Figure 4. SHC streams, ponds, and existing stormwater management infrastructure from Clermont County.

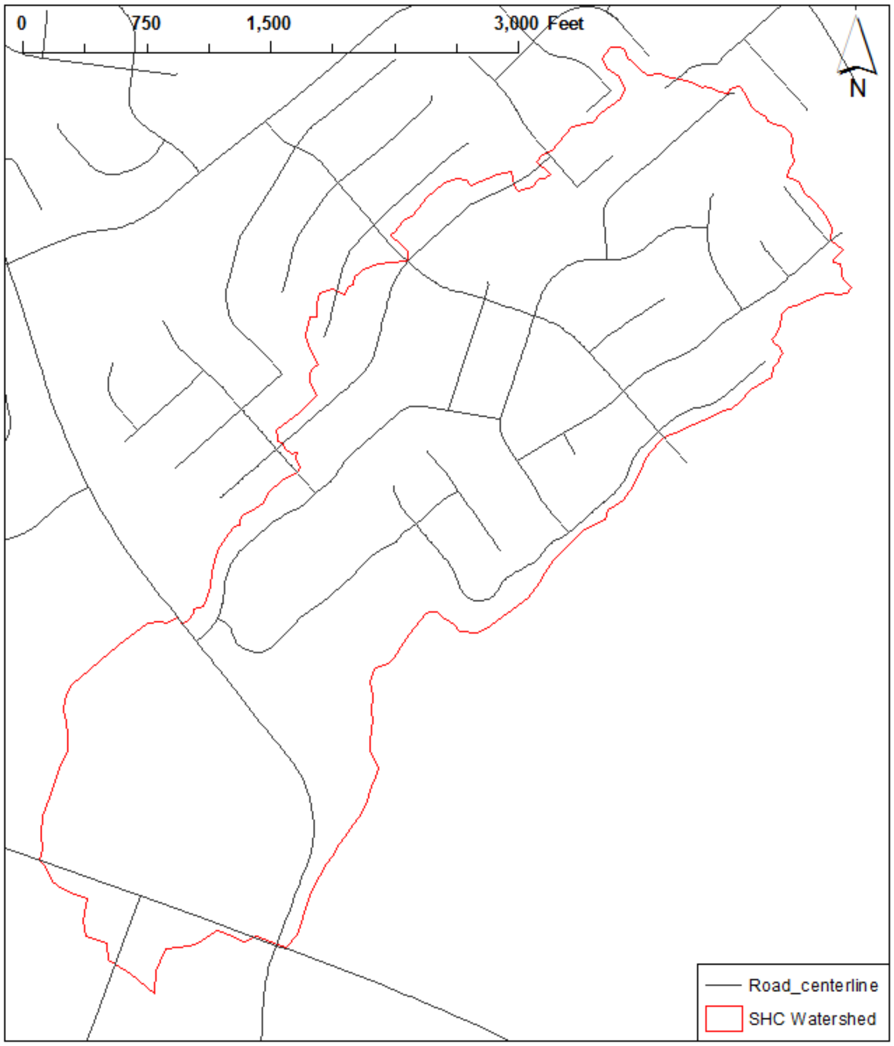


Figure 5. SHC road centerlines from Clermont County.

2.1.2 Monitoring Data

Site-specific climate and flow monitoring data available from the ongoing water quality monitoring and Soil and Water Assessment Tool (SWAT)[4] modeling effort for the East Fork Watershed (EFW) of the Little Miami River were used for this study. Specifically, the following data from the archive of EFW data managed by the U.S. EPA were used for this SWMM modeling study:

- Precipitation: 10-min, 0.1-mm tipping bucket rain gauge data
- Hourly precipitation data from the Lower EFW SWAT model prepared from NEXRAD data source (see Karcher et al., 2013)

[4] SWAT is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System.

- Flow data at the SHC headwatershed outlet estimated from a rating curve that measured flow rates and water levels. The outlet is located at the north-east corner of SHC where the main stream line meets the watershed boundary (see Figure 4). A continuous water level sensor (YSI LS-600 series) was used to record water level measurements on a 10 min interval nearly all year-round from the period April 2006 through Dec 2011. In some years the sensor was removed to avoid damage from freezing conditions in the winter months: January through mid-March.

If no monitoring data is available for a specific area of interest, a modeler can check other data sources in the public domain, such as precipitation records from the National Climactic Data Center (NCDC) and stream flow data from the U.S. Geological Survey (USGS). Both the precipitation and the stream flow data sets cover the entire country for multiple locations and over a number of decades. However, for the stream flow data, in particular, it is less common to find data existing for streams draining headwatersheds. Without stream flow data, it is impossible to calibrate the SWMM model, or gauge model performance relative to reality in any way. While expensive and time-consuming, it is worthwhile to obtain an accurate time series of flow measurements even if it is only for a period encompassing only a few storm events. We recommend using a minimum time series of continuous flow data that at least captures a small and intermediate to large size storm. For North American temperate latitudes, this could be obtained in the fall or spring seasons.

Evaporation data for the study area were obtained from publicly available sources:

- Evaporation Atlas for the Contiguous 48 States (http://www.nws.noaa.gov/oh/hdsc/Technical_reports/TR33.pdf)
- Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States (http://www.dynsystem.com/netstorm/docs/NWS34EvapTables.pdf)
- Monthly Average Evaporation Data from the National Stormwater Calculator (http://www.epa.gov/water-research/national-stormwater-calculator)

2.2 Spatial analysis to represent the study area prior to SWMM modeling

Detailed land use/land cover data were derived for the study area using the aerial orthophotographs. Using this land use/land cover data, site-specific imperviousness was estimated. The hydrologic connectivity of the impervious area to the existing storm drainage system was also estimated to further categorize the individual impervious surface features as directly connected impervious area (DCIA) or indirectly connected impervious area (ICIA).

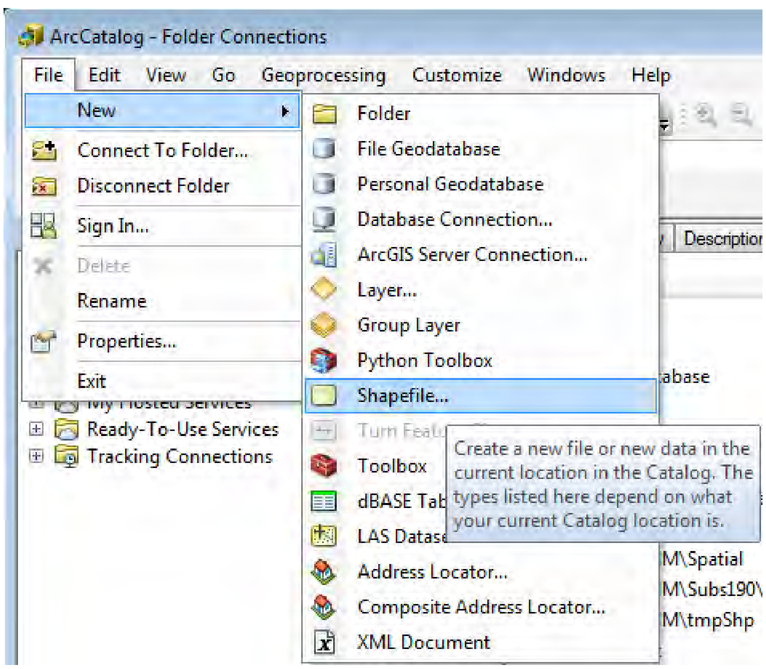
The soil layer from the County only provided soil types. Based on the soil types, the related parameters for SWMM modeling were initially selected using the reference data from the SWMM User's Manual (Rossman, 2015). Those parameters are capillary suction head, saturated hydraulic conductivity, soil porosity, wilting point of soil moisture content, and field capacity of soil moisture content. As shown in Figure 3, the soil type of the study watershed is virtually homogeneous loam. Unfortunately, no data was available for estimating any of the groundwater behaviors for the study area, such as groundwater elevations or aquifer boundaries.

2.2.1 Developing a Land Use/Land Cover Layer

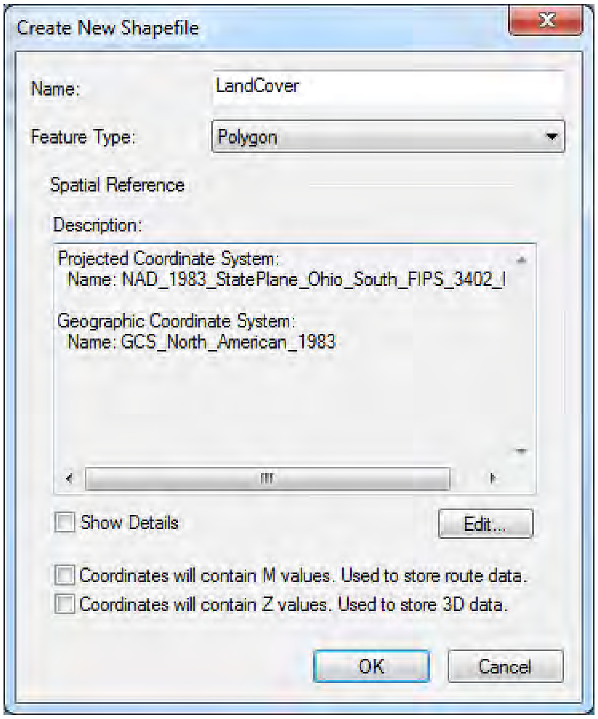
In order to represent the physical reality of the watershed in a model set-up every visually distinguishable type of land cover on the aerial orthophoto was identified and digitized. The spatial data was prepared using an interactive on-screen digitizing process in ArcGIS. In this process, the user creates a GIS data layer using the computer monitor and the mouse to delineate the boundaries for specific land cover types. This digitization of fine spatial resolution land cover types in the headwatershed can be time consuming, but in our opinion, is essential for GI modeling considerations.

The first step is to create a shapefile for the land cover layer using ArcCatalog:

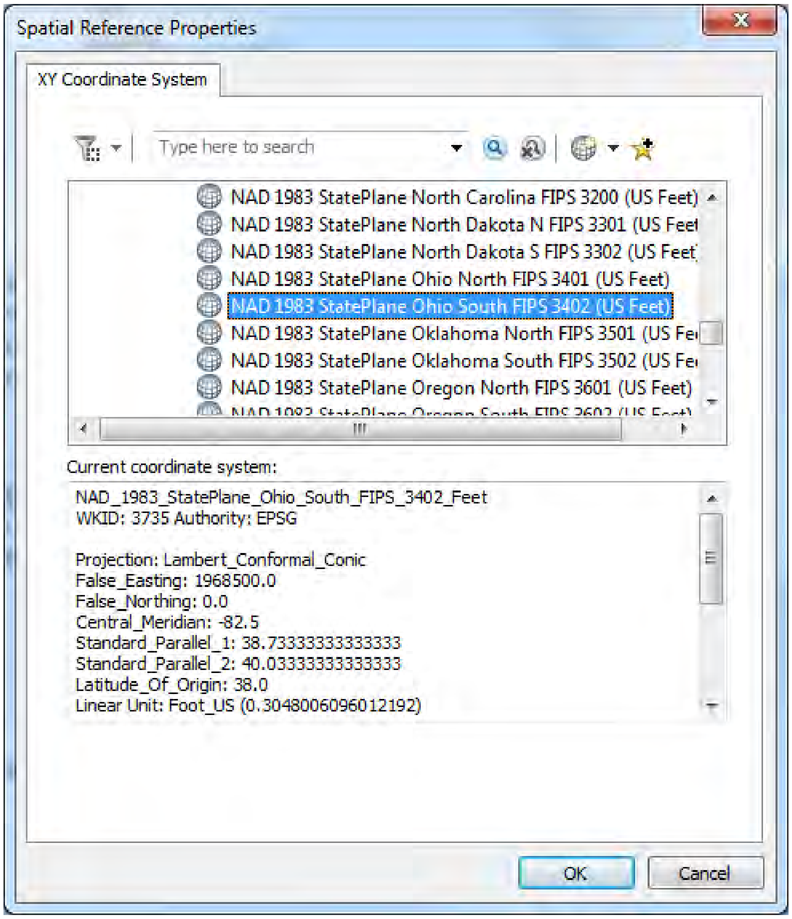
⇨ Run 'ArcCatalog'



⇨ Select 'File / New / Shapefile...' under the Main Menu



- ⇨ Specify the 'Name'
- ⇨ Select 'Polygon' for the 'Feature Type'
- ⇨ Click 'Edit…' to specify and match the 'Spatial Reference' of the coordinate system



⇨ Specify the reference: Projected Coordinate Systems / State Plane / NAD 1983 (US Feet) / NAD_1983_StatePlane_Ohio_South_FIPS_3402_Feet

⇨ Click 'OK'

Note: The Clermont County GIS database is based on the 'NAD_1983_StatePlane_Ohio_South_FIPS_3402_Feet' coordinate system. This will be different for each project, depending on the location and source of the aerial orthography data.

⇨ Click 'OK' to complete the 'Create New Shapefile'

⇨ Close ArcCatalog

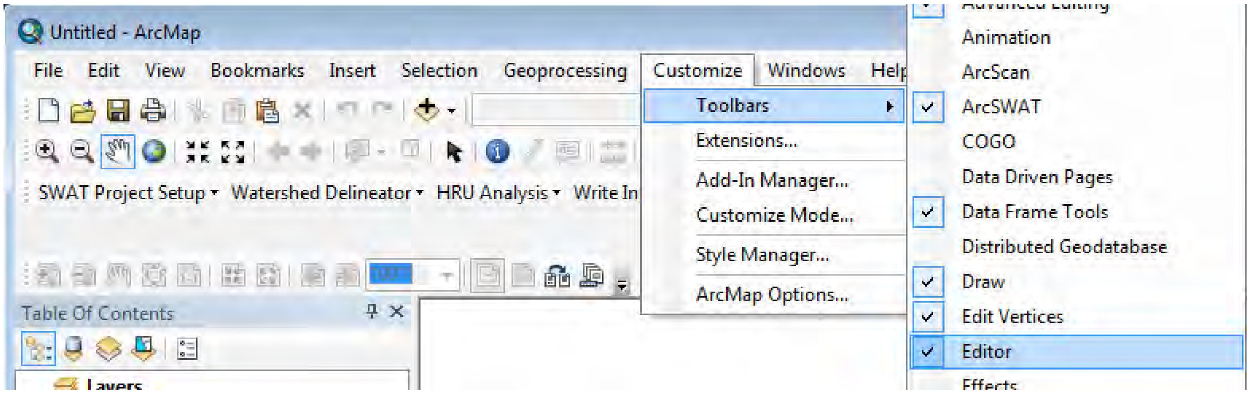
The next step is to digitize the individual land cover type in ArcMap:

⇨ Run 'ArcMap'

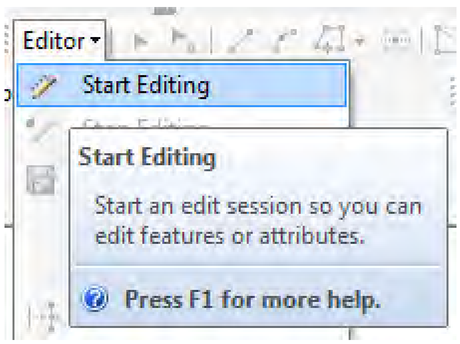
⇨ Add the aerial orthophotographs to the ArcMap

⇨ Add the polygon layer created from the previous step

If no 'Editor' tool is visible in ArcMap (i.e., it is not activated), process the following step. If the tool is visible (i.e., activated), skip this step and progress to the next step.



⇨ Select 'Customize / Toolbars / Editor' under the Main Menu



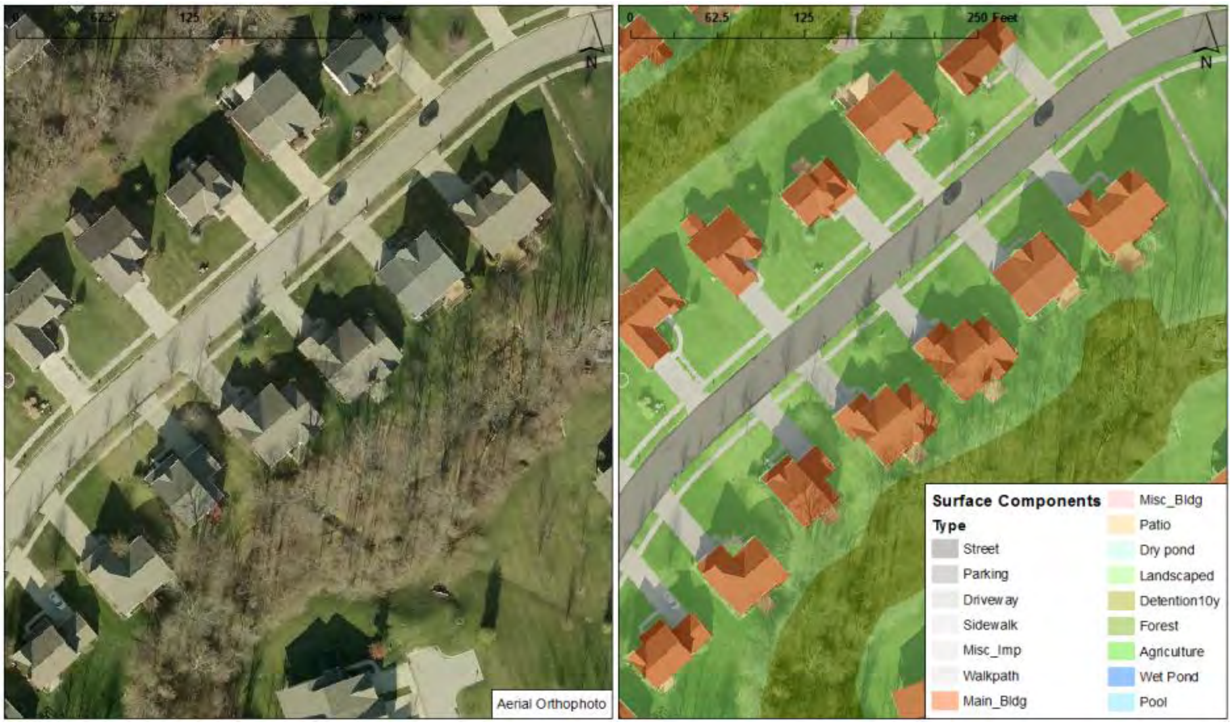
⇨ Click 'Editor / Start Editing'

⇨ Digitize all of the boundaries for a distinguishable land use/land cover feature to create a separate polygon for the feature

Figure 6. Example of the digitization of two "main buildings" polygons. The area contained within the red boundaries are classified as main buildings in the land cover layer.

⇨ Similarly, continue to digitize boundaries of all visually distinguishable land cover features (e.g., street, parking, sidewalk, etc.) and create separate polygons for the individual land use/land cover components

⇨ Complete the digitizing process



(a) Aerial orthophotograph (b) Digitized land cover

Figure 7. Creating a land use/land cover layer using aerial orthophotographs

Figure 7 shows an example of the on-screen digitized land use/ land cover layer for SHC using an aerial orthophotograph provided by the County as background. In this study, the on-screen digitization procedure was used to identify 16 homogeneous land cover types in the study area including: streets, parking areas, sidewalks, driveways, main buildings, miscellaneous buildings, paved walking paths, patios, other miscellaneous impervious areas, landscaped or lawn areas, agriculture, forest, dry ponds, stormwater detention areas, swimming pools, and wet ponds.

The individual land cover types include nine types of impervious areas, five types of pervious areas and two types of wet surfaces (ponds and swimming pools) as shown in Figure 8. The 16 land cover types were grouped as five impervious surface components, three pervious surface components, and two wet surface components to process the parameterization of the SWMM model (Table 1). All of the land cover types are managed under a spatial database in ArcGIS. Each digitized polygon (e.g., Figure 7) of a type of land cover becomes a “record” in the database, and may have its own attribute data (i.e., fields, or columns, in the database), representing its characteristics (e.g., area in square meters, land cover type name, etc.). Additional descriptions for adding a new field to a layer’s attribute data and estimating the areas of the individual polygons of a specific land cover type can be found in Section 2.4.1. In order to process GI-related analyses based on baseline and future implementation scenarios, the developed land use/land cover layer needs to be subcategorized using attributes that qualify each as ICIA or pervious area (PA), for example. Creating subset layers is explained in Section 2.2.2.

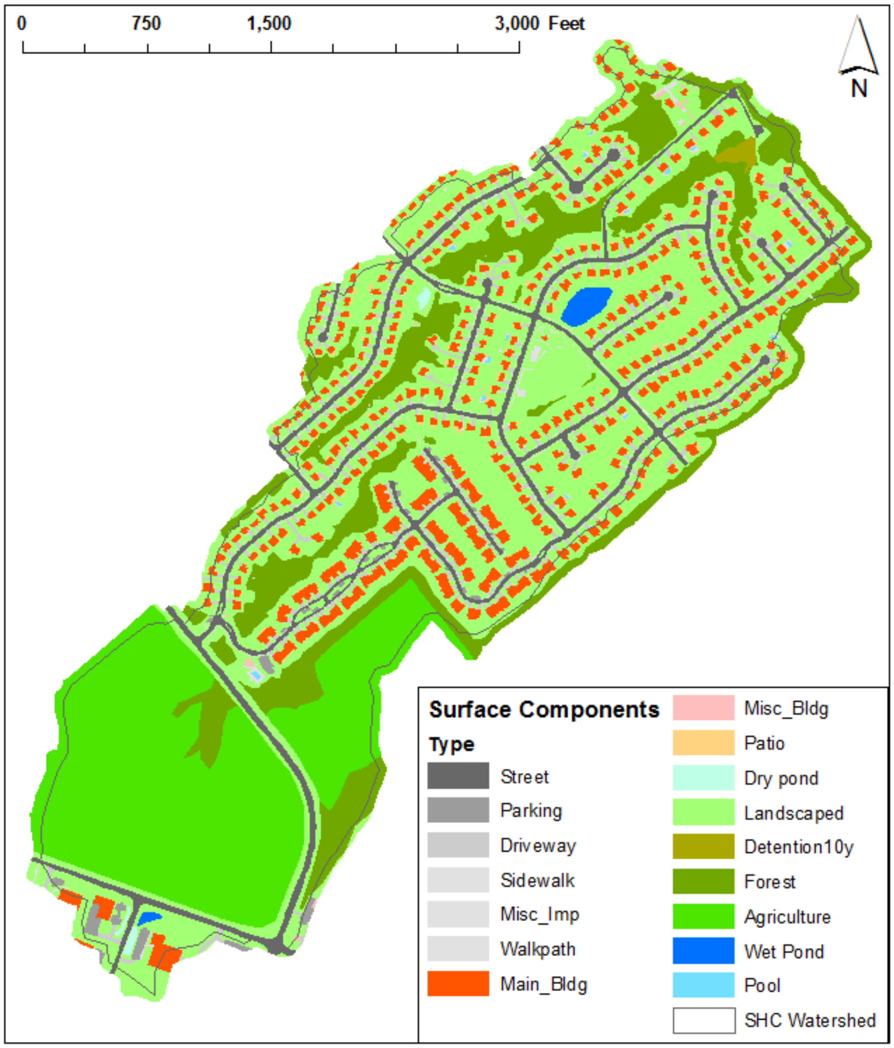


Figure 8. Map of land cover from the digitized spatial database for SHC.

Table 1. SHC land cover summary information.

<table>
<tr><th colspan="2">Surface Components</th><th>Area (ft^2)</th><th>Percentage</th></tr>
<tr><td rowspan="6">Impervious areas</td><td>Building</td><td>1,028,099</td><td>9.6%</td></tr>
<tr><td>Street</td><td>780,466</td><td>7.3%</td></tr>
<tr><td>Driveway</td><td>383,608</td><td>3.6%</td></tr>
<tr><td>Parking</td><td>59,382</td><td>0.6%</td></tr>
<tr><td>Sidewalk</td><td>125,734</td><td>1.2%</td></tr>
<tr><td>Miscellaneous</td><td>191,377</td><td>1.8%</td></tr>
<tr><td rowspan="3">Pervious areas</td><td>Lawn</td><td>4,312,276</td><td>40.3%</td></tr>
<tr><td>Agriculture</td><td>2,361,929</td><td>22.1%</td></tr>
<tr><td>Forest</td><td>1,383,788</td><td>12.9%</td></tr>
<tr><td rowspan="2">Other areas</td><td>Wet pond</td><td>53,972</td><td>0.5%</td></tr>
<tr><td>Swimming pool</td><td>10,752</td><td>0.1%</td></tr>
<tr><td colspan="2">Sum</td><td>10,691,383</td><td>100%</td></tr>
</table>

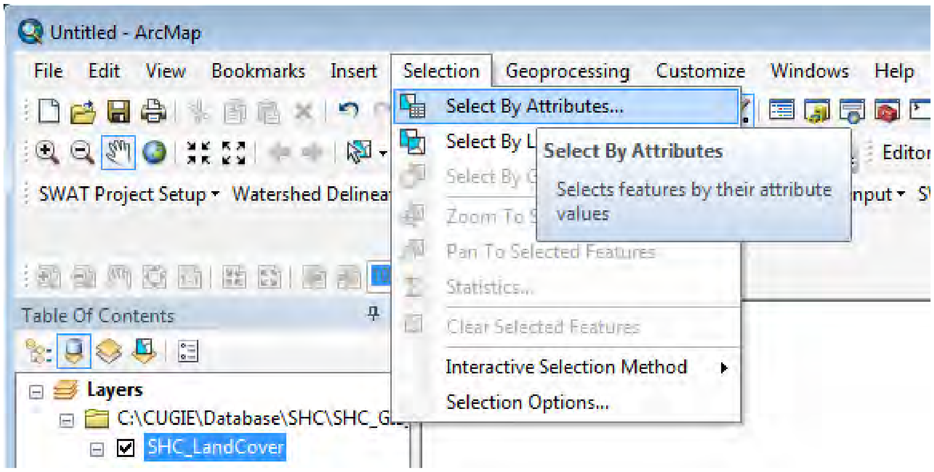
It is important to classify the nature of the hydrologic connectivity of impervious area land cover types relative to the existing storm drainage system. Directly connected impervious area (DCIA) is impervious area where stormwater runoff directly discharges to receiving waters via storm sewer pipes or channels without passing over or through any pervious area. Every main building in SHC is classified as DCIA because all of the rooftop downspouts are plumbed to directly discharge to the storm collection system, i.e., all downspouts are buried and connected to the storm sewer inlets through pipes or street gutters. Note, this distinction should be verified with a site visit, if possible.

All of the miscellaneous buildings (e.g. storage sheds) are not considered to be DCIA. Streets with curb-and-gutter drainage systems are identified as DCIA. Any directly connected up-gradient impervious area to these streets are initially considered as DCIA. These areas include directly connected driveways, parking areas, and sidewalks. However, if both sides of a sidewalk are surrounded by pervious area, the sidewalk is not identified as DCIA. Streets without curb-and-gutter drainage are not considered as DCIA. The miscellaneous impervious areas are not considered as DCIA. All of the remaining impervious area is classified as indirectly connected impervious area (ICIA), which basically delivers stormwater runoff to an adjacent pervious area. The end goal of this spatial analysis is to classify every piece of impervious area to be either DCIA or ICIA in the spatial database.

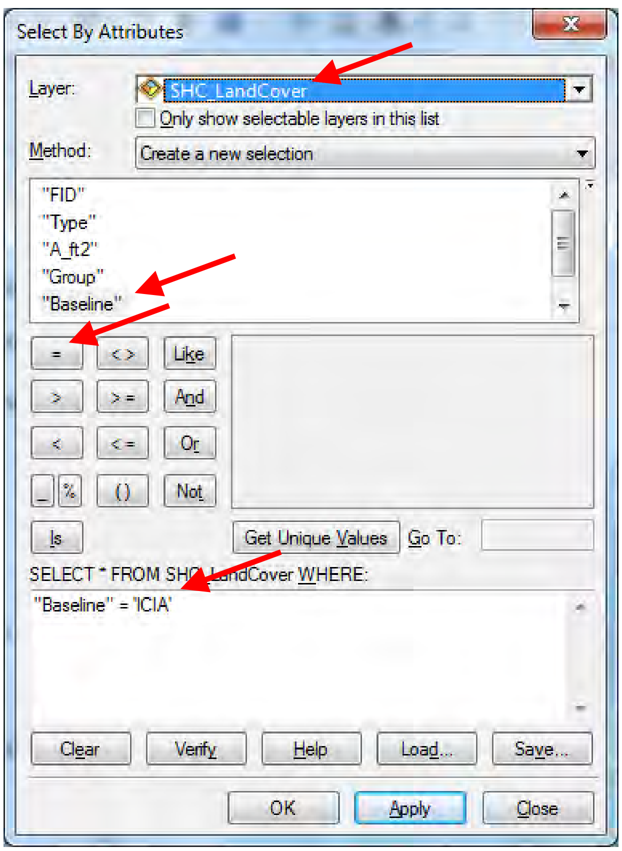
2.2.2 Creating GIS Layers for Designated Land Use/Land Cover Features

For GI-related modeling analyses separate data layers need to be created for ICIA and PA. A subset data layer can be created from an attribute of the original layer by conducting the following steps:

- ⇨ Run ArcMap
- ⇨ Add a GIS layer for creating subset layers



⇨ Select 'Selection / Select By Attributes...' under the Main Menu



⇨ Specify 'Layer'

⇨ Specify 'Method' for selecting data

⇨ Click 'OK'

Note: Text format data must be wrapped with single quotation marks ('text'). And in the spatial database developed as part of this project land cover was originally classified based on aerial orthophotographs. "Baseline" represents the existing land use/land cover status in 2010.

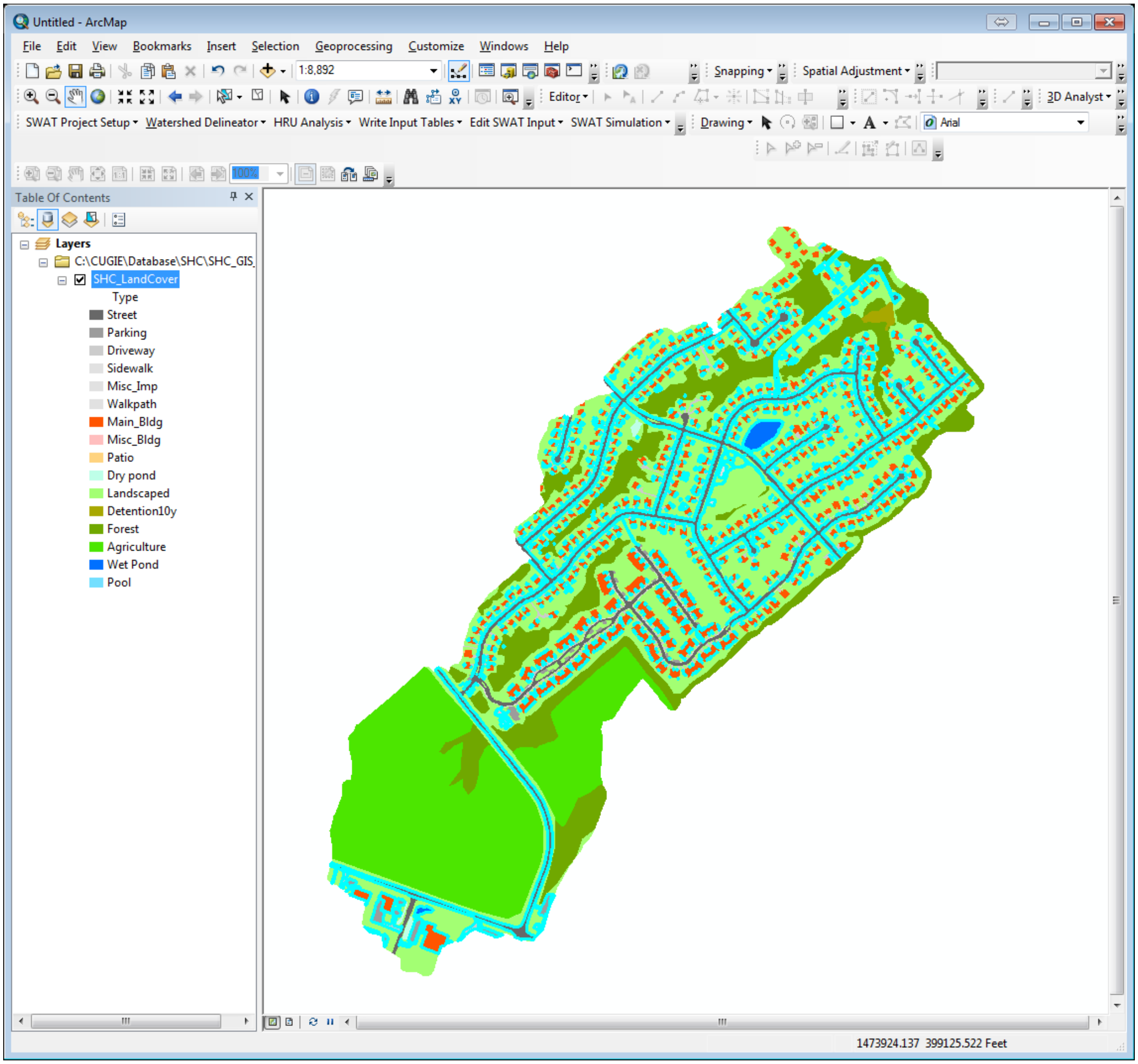
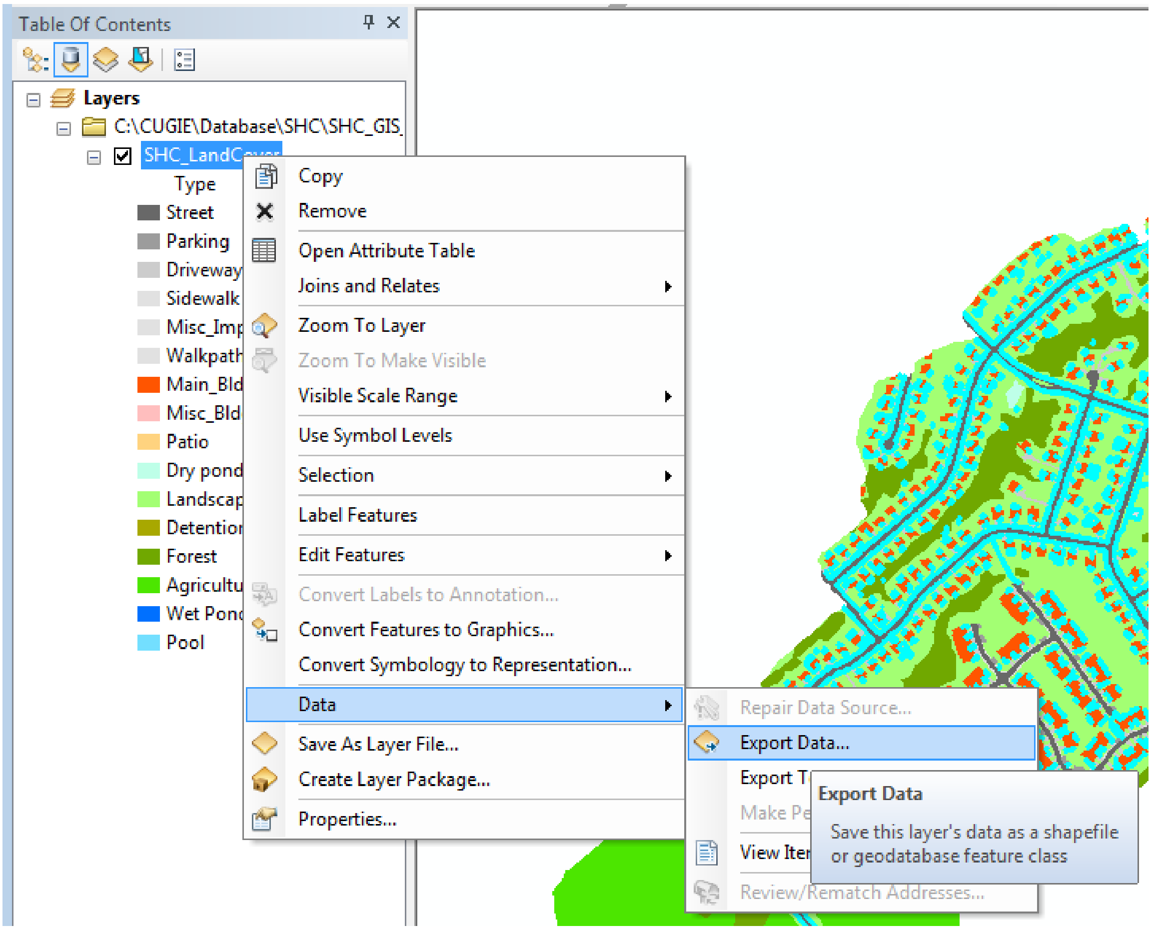
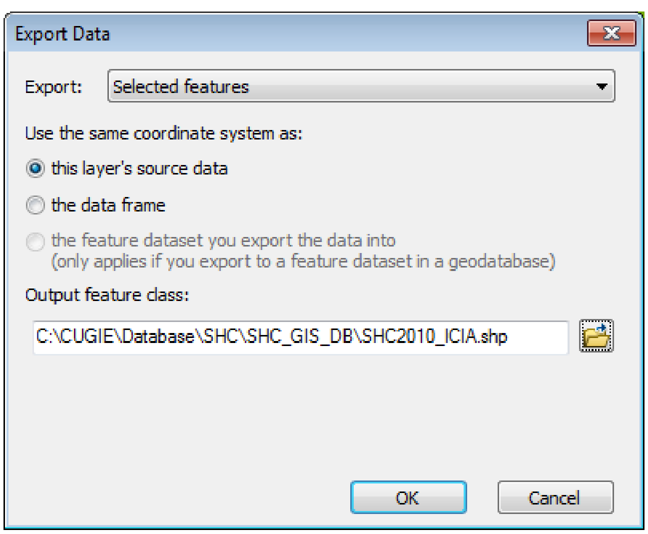


Figure 9. Example of selecting data from a GIS layer to create a subset layer of ICIA.

The selected feature data will be displayed with highlighted colors as shown in Figure 9 (in light blue). The next step is to export the selected data as a new shapefile.



⇨ Right-Click on the layer
⇨ Click 'Data / Export Data...'



⇨ Specify 'Export' as 'Selected features'
⇨ Specify 'Output feature class'
⇨ Click 'OK'

Use these steps to create the other required subset layers, which are: ICIA, PA, main building that is DCIA under the baseline condition. These layers will be used to identify buffering pervious area (BPA) for the baseline and additional BPA with GI implementation scenario. The following section (2.2.3) describes how to process the buffering analysis.

2.2.3 Creating the Buffering Pervious Area (BPA)

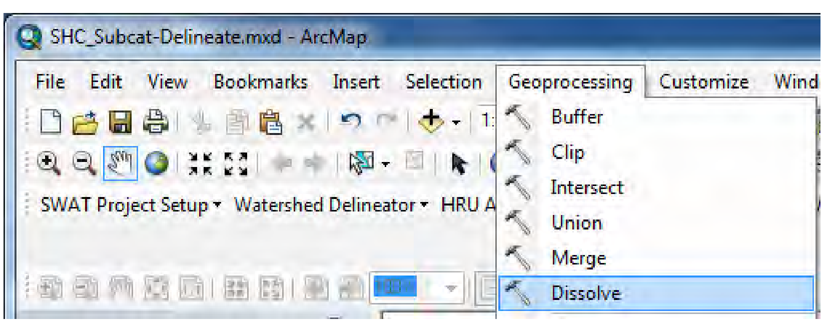
The runoff from ICIA discharges to pervious area. The portion of pervious area receiving runoff from ICIA works like an existing buffer strip or infiltrating swale (or existing GI, although maybe originally not intended for this purpose). This is referred to as buffering pervious area (BPA). BPA is not generally considered important in a typical urban stormwater modeling analysis. However, for GI design consideration, one might try to enlarge the size of the pervious buffer or apply additional engineered GI around the buffering area. Therefore, it is important to identify the BPA for modeling the existing baseline conditions and any future GI implementations in the watershed. The precise extent of existing BPA could only be defined from a detailed surface topographic study that would require an understanding of how storm intensity affects its width. This type of an analysis is not practical, or perhaps, not even possible. For instance, higher intensity storms would result in larger buffering areas than small ones, so that the actual size of the BPA for model parameterization would be an average across all storm types. Instead, several sets of potential BPA are derived using a spatial proximity analysis in ArcGIS and the set selected for the SWMM model is chosen during model calibration. In ArcGIS, the sets of potential BPA are derived by varying the distance around ICIA. Subsequently, the sizes of potential BPA are summarized for individual subcatchments in SWMM and modeled as a vegetated swale LID, as will be described further below.

The steps to process the proximity analysis in ArcGIS are presented below. An example of what the multiple sets of BPA around the existing ICIA looks like conceptually is shown in Figure 10.

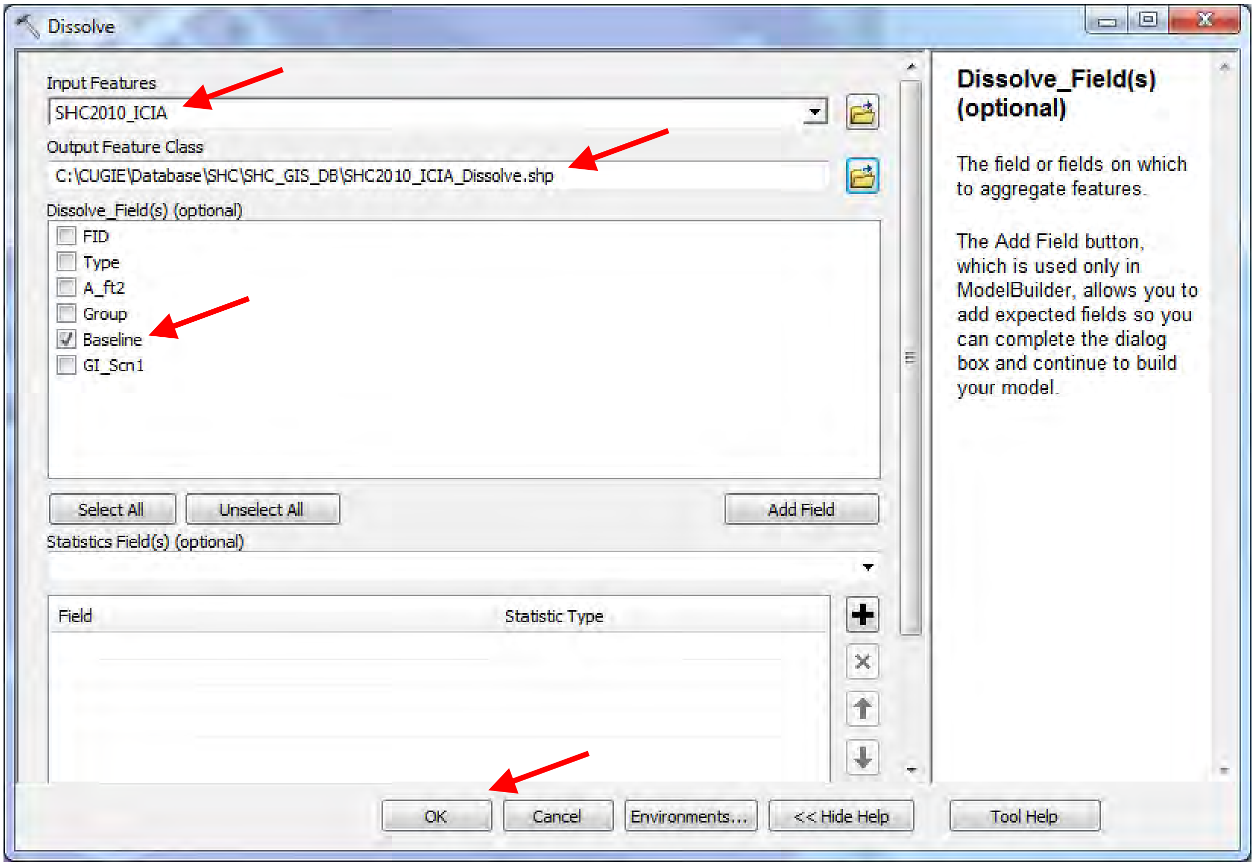
⇨ Run 'ArcMap'

⇨ Add the GIS layers: SHC2010_ICIA and SHC2010_PA in this example

The first step is to dissolve multiple records in each layer into a single record to process this analysis more efficiently.



⇨ Select 'Geoprocessing / Dissolve' under the Main Menu



⇨ Select 'Input Feature' to dissolve

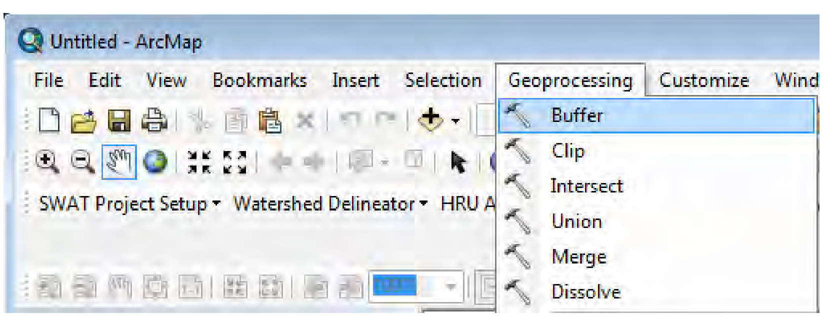
⇨ Specify 'Output feature class'

⇨ Specify 'Dissolve_Field(s)'

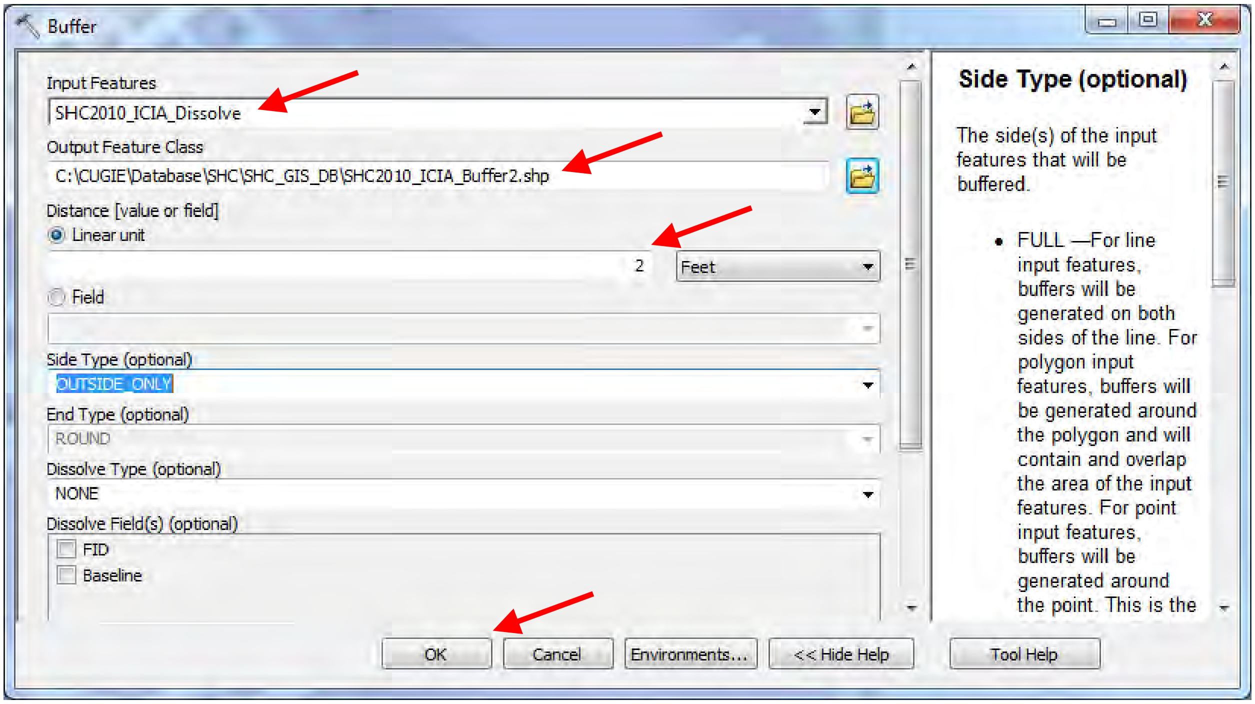
⇨ Click 'OK'

The above example shows how the ICIA layer is dissolved. The PA layer can be dissolved by the same steps.

⇨ Add the dissolved layers: SHC2010_ICIA_Dissolve and SHC2010_PA_Dissolve



⇨ Select 'Geoprocessing / Buffer' under the Main Menu



⇨ Specify ‘Input Features’ as the dissolved ICIA layer

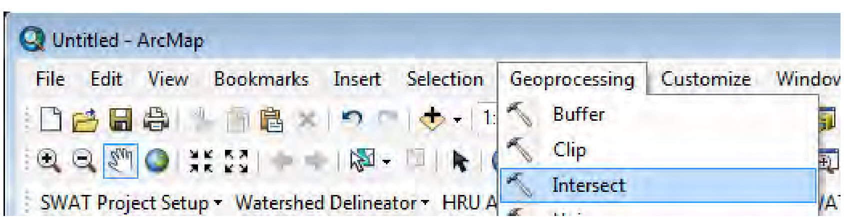
⇨ Specify ‘Output Feature Class’

⇨ Specify ‘Distance’ *(This establishes the width of the BPA for this set.)*

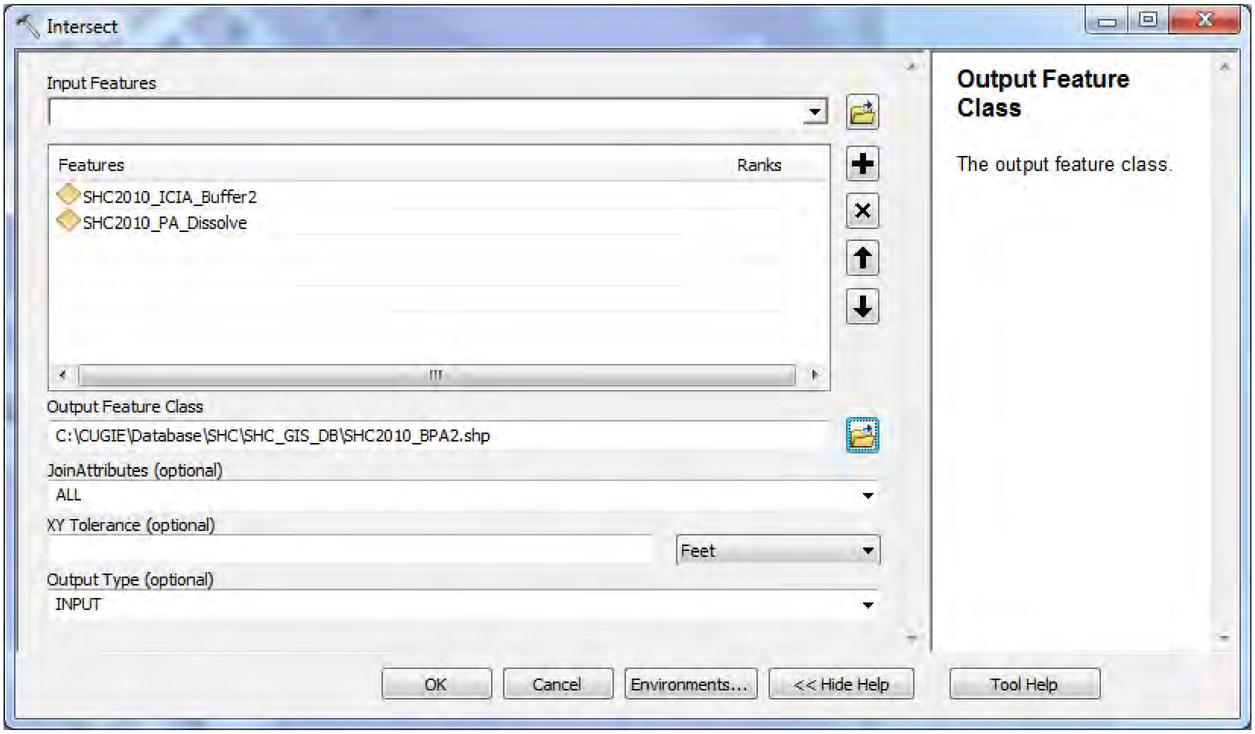
⇨ Specify ‘Side Type’ as ‘OUTSIDE_ONLY’

⇨ Click ‘OK’

The next step is to overlay the derived GIS layer for the same distance buffering areas with the pervious GIS layer:



⇨ Select ‘Geoprocessing / intersect’ under the Main Menu



- ⇨ Specify two 'Input Features': a layer for the derived BPA and the pervious layer
- ⇨ Specify 'Output Feature Class'
- ⇨ Click 'OK'

The resulting layer represents a set of BPA with a specified width around ICIA, effectively subtracting the BPA for the existing condition (i.e., baseline) from the total PA with the 'intersect' function in ArcGIS. The same procedure is done with a different buffering distance, to obtain another unique layer of BPA. Figure 10 shows three different sets of BPA each with different buffering width.

Figure 10. Example of multiple sets of BPA based on different buffering widths from the existing ICIA.

In SWMM, the sets of BPA were evaluated by comparing measured and modeled hydrographs during calibration (see Section 4). In this study, we checked hydrographs over the two-month period designated for modeling, focusing on small storms. After several trials, the BPA with a 2 ft width showed the best fit. The remaining PA that is not designated as BPA was identified as standalone pervious area (SPA). In the case of implementing a scenario-based GI analysis, another dataset of BPA with different proximity could be produced, but the total pervious area (TPA) should be maintained as the sum of BPA and SPA in all cases.

2.3 Deriving GIS Layers to set up a SWMM Model

A SWMM model for GI analysis simulates surface runoff, flow through stormwater drainage systems, and storage/treatment effects in stormwater control systems. Characteristic values derived from accurate spatial data must be provided during parameterization to model these processes. Spatial variability in these processes is accounted for by dividing the study area into a collection of smaller subcatchments. Each of the subcatchments contains its own fraction of pervious and impervious subareas. The model uses this information to route overland flow between subareas within a subcatchment, among subcatchments, or among entry points of a storm drainage system.

Several GIS layers representing the existing spatial variability need to be prepared to set up the subsequent SWMM model. Figure 11 shows typical modeling objects in a SWMM set up for GI modeling. Each object-type requires its own data layer to be part of the GIS for the watershed in question. The derivation of each of these layers is discussed subsequently.

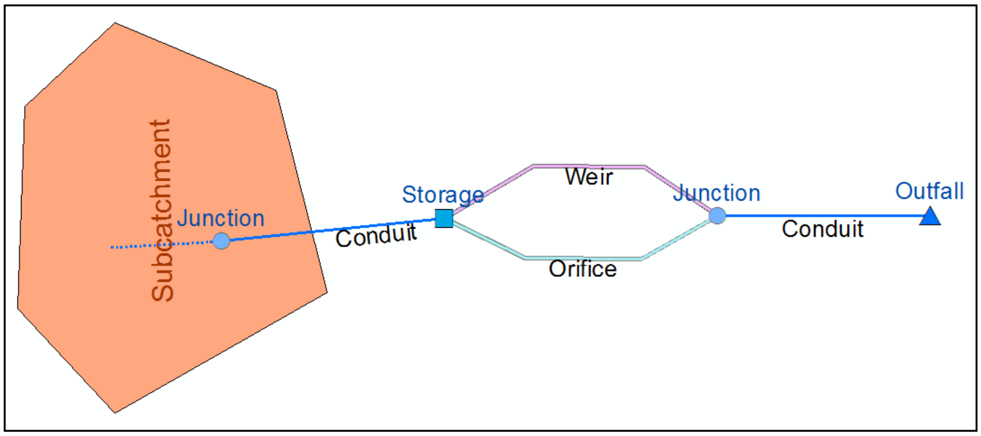


Figure 11. Example of modeling objects in SWMM.

2.3.1 GIS Layer for Subcatchments

First, it is important to define the exact boundary of the drainage area (in this case it is the boundary of the SHC headwatershed). The SHC boundary data was collected from the County. The drainage area then is further sub-divided into smaller subcatchments. The options available for watershed and subcatchment delineation are:

- Collect GIS-based stormwater catchment/subcatchments data from city/county
- Manual delineation using contours or DEM
- Applying GIS technology (e.g., ArcHydro)
- Combining GIS technology and manual delineation

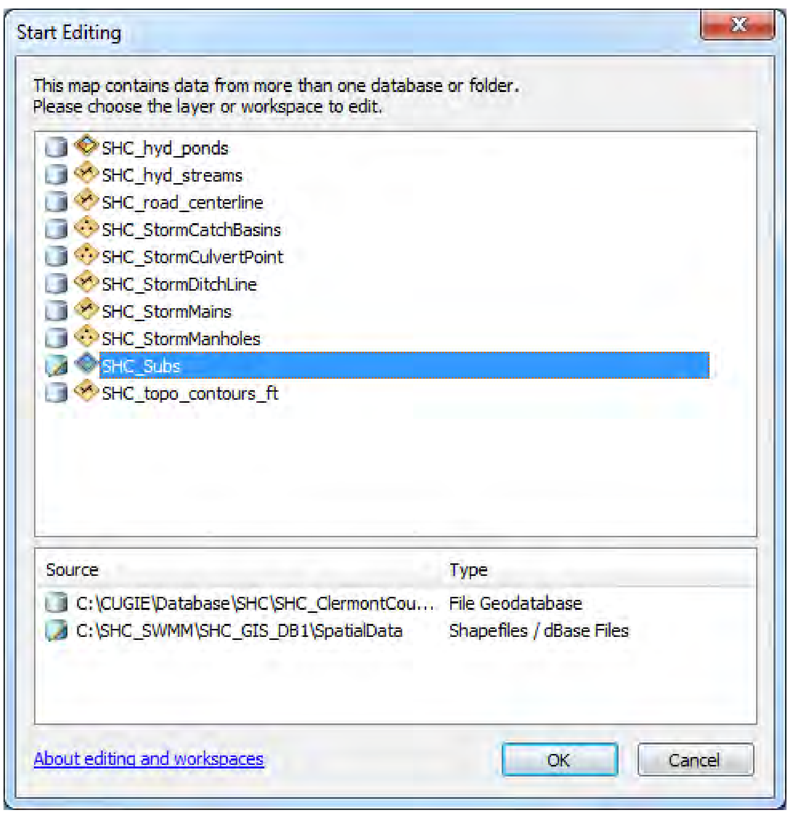
For this project, manual delineation was conducted from the single polygon watershed layer using ArcGIS software with the aid of both surface topography and an understanding of the subsurface drainage network (per Rossman and Huber, 2016). A subcatchment is identified as the area of land surface where precipitation collects and drains off into a storm catch basin. To derive the subcatchments layer, the study watershed was split multiple times using storm sewer infrastructure and the surface topographic data. The applied data sets are storm catch basin (point), storm culvert (point), storm manhole (point), stream (polyline), ditch (polyline), storm sewer main (polyline), road centerline (polyline), 2.5-ft DEM (raster), and 2-ft contours (polyline).

⇨ Run 'ArcMap'

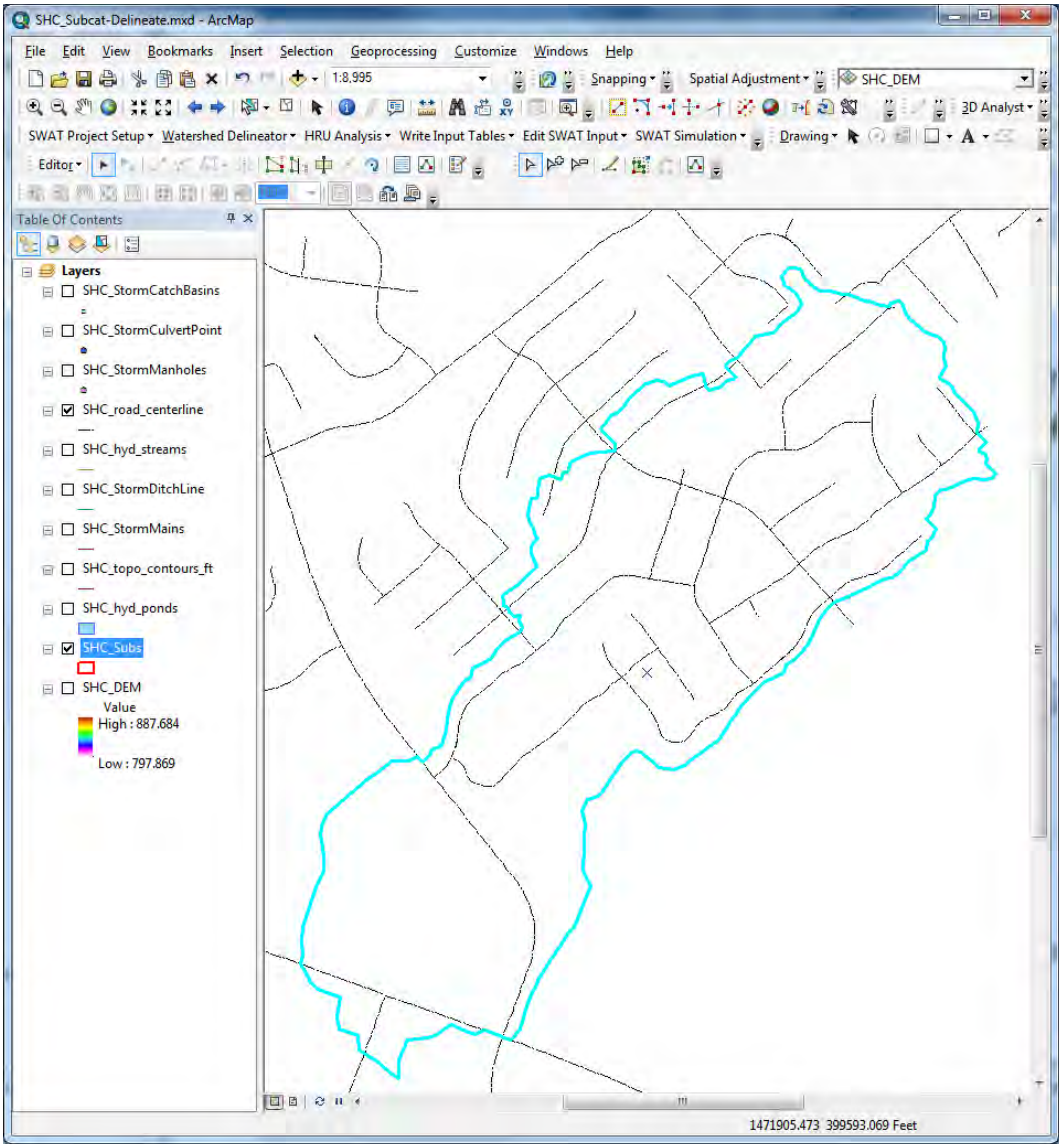
⇨ Add the GIS layers presented above

In ArcGIS, this task can be processed using the "Cut Polygons" tool on the Editor toolbar.

⇨ Click "Editor", and then click "Start Editing".



⇨ Select the target layer to split, and then click "OK".



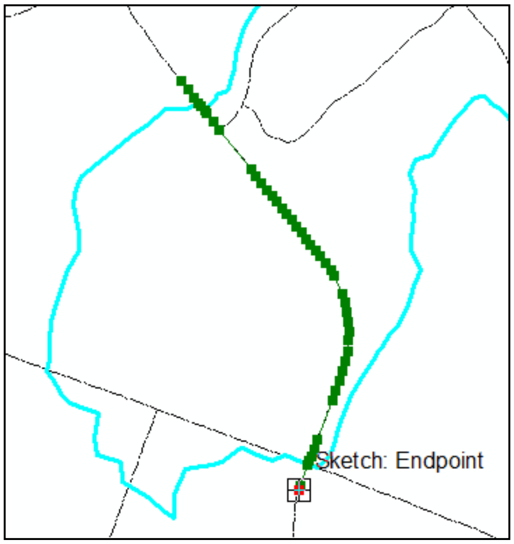
⇨ Select the polygon to split.

⇨ Display the street centerline.

⇨ Click the Cut Polygons tool  on the Editor toolbar.

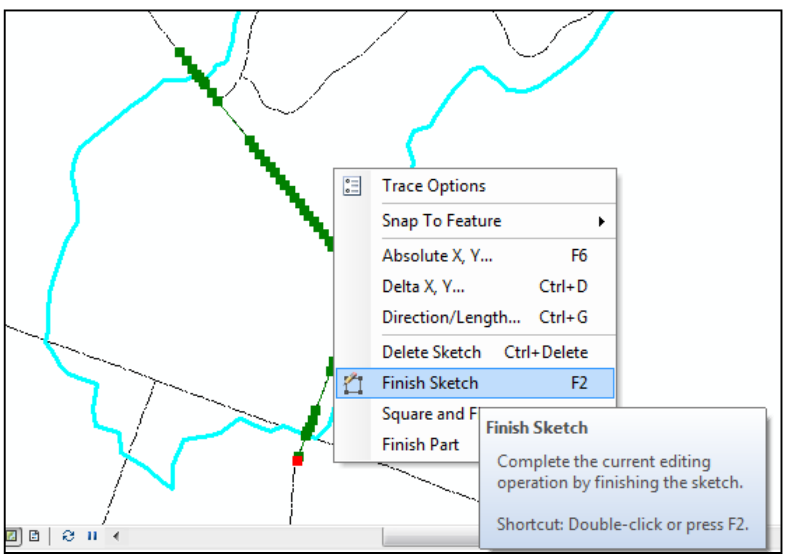
⇨ Click Trace  on the Editor toolbar palette.

The following example shows how to split the selected polygon using road centerline (shown as the black lines), which is often used to delineate subcatchment boundaries. Streets are paved to crown at the centerline. This can be used to subdivide drainage areas because it is higher than surrounding area, just like a natural topographic divide.

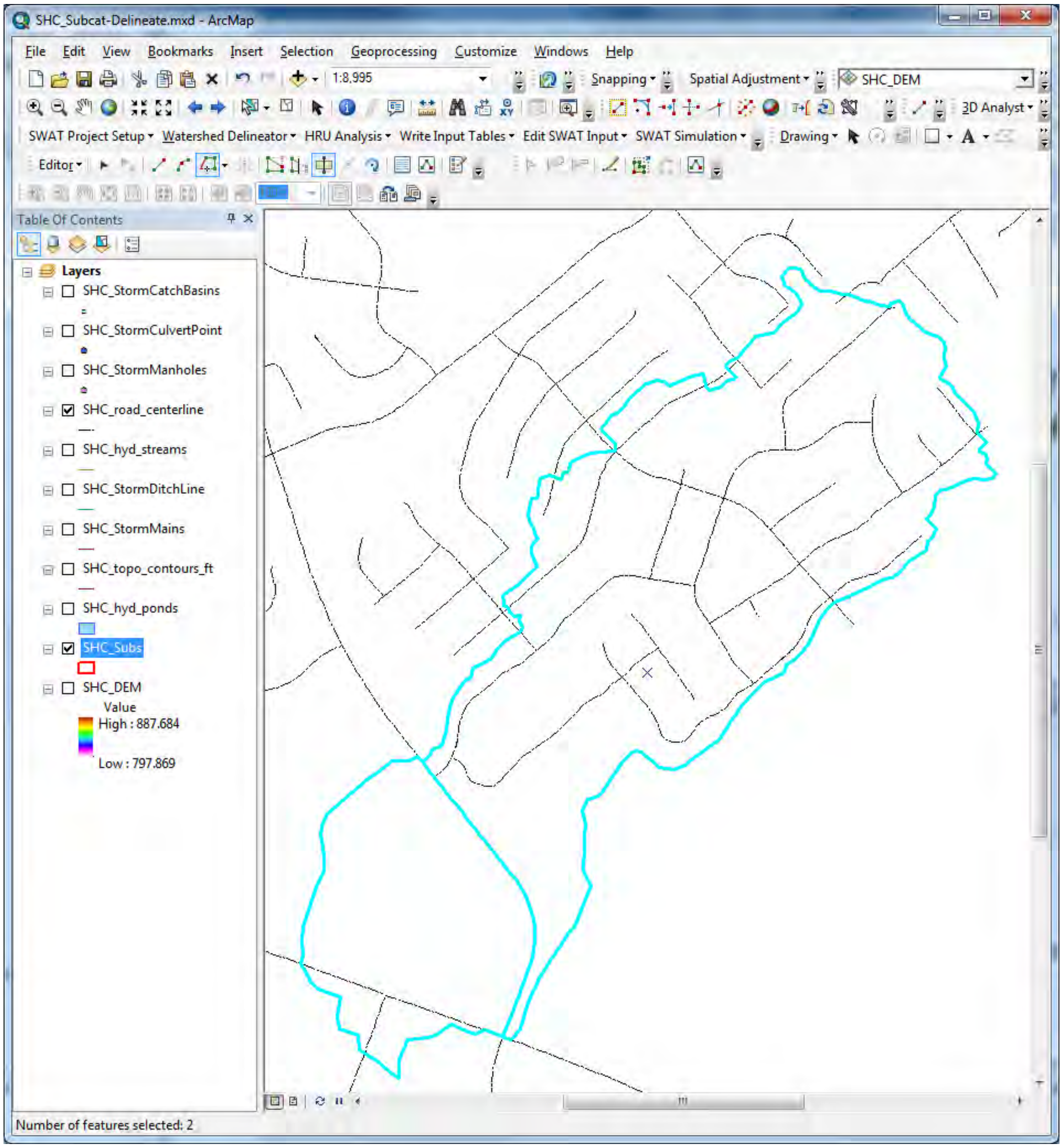


⇨ Click and trace along the existing line or polygon.

As we are tracing, we can change which features are being traced by pointing to them and clicking or dragging. The sketch must cross (or touch the edge) at least two times for the polygon to be split.

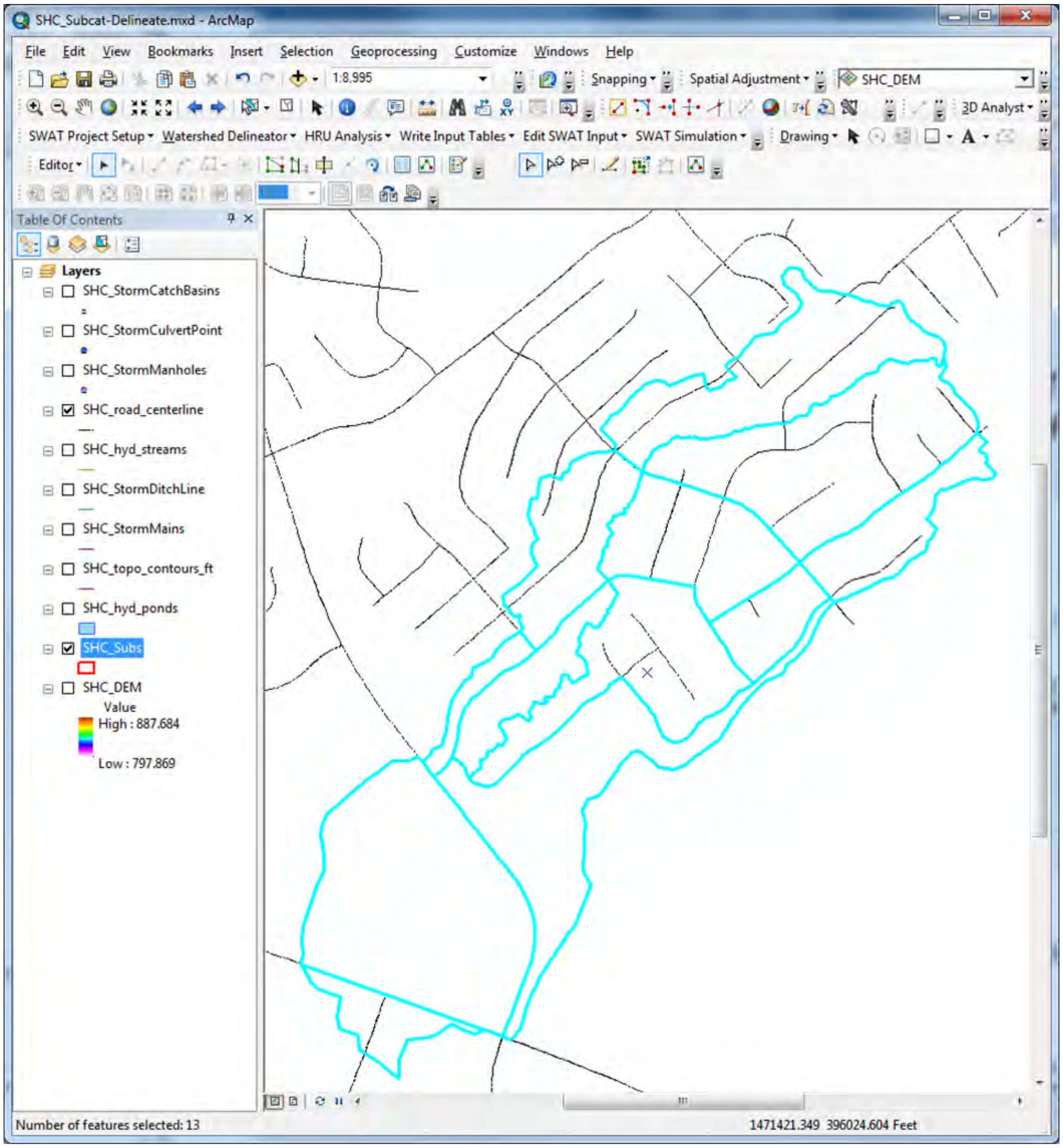


⇨ Right-click anywhere on the map and click “Finish Sketch”.



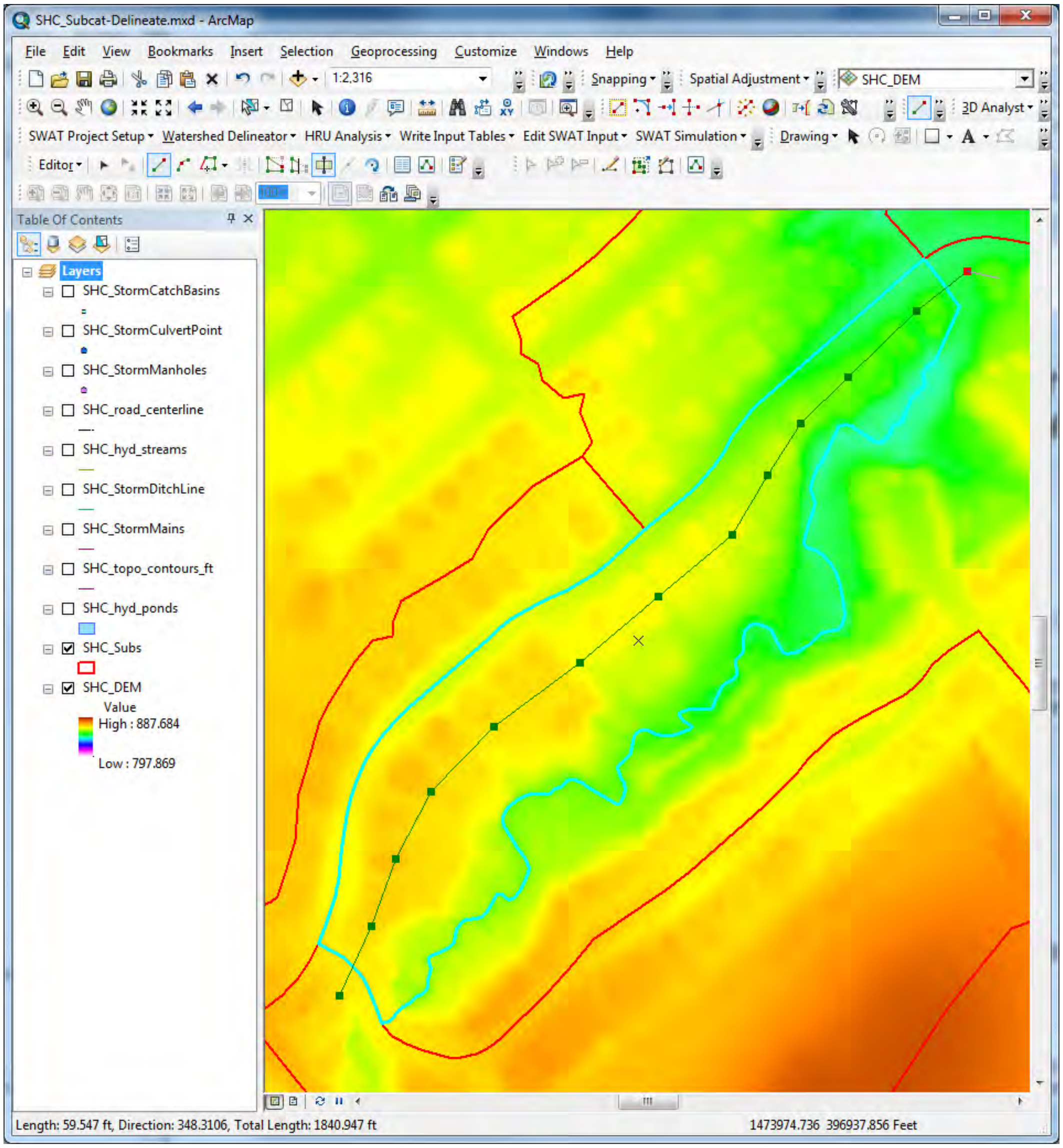
Now the polygon is subdivided into two pieces. The cut line shares edges with the two adjacent subdivided areas.

As shown above, street centerline can be used to subdivide a drainage area. Stream line can also subdivide a drainage area into two pieces: one on each side. Every cut line is based on a sketch we draw manually. The following example shows an interim result of the progress in subcatchment delineation.



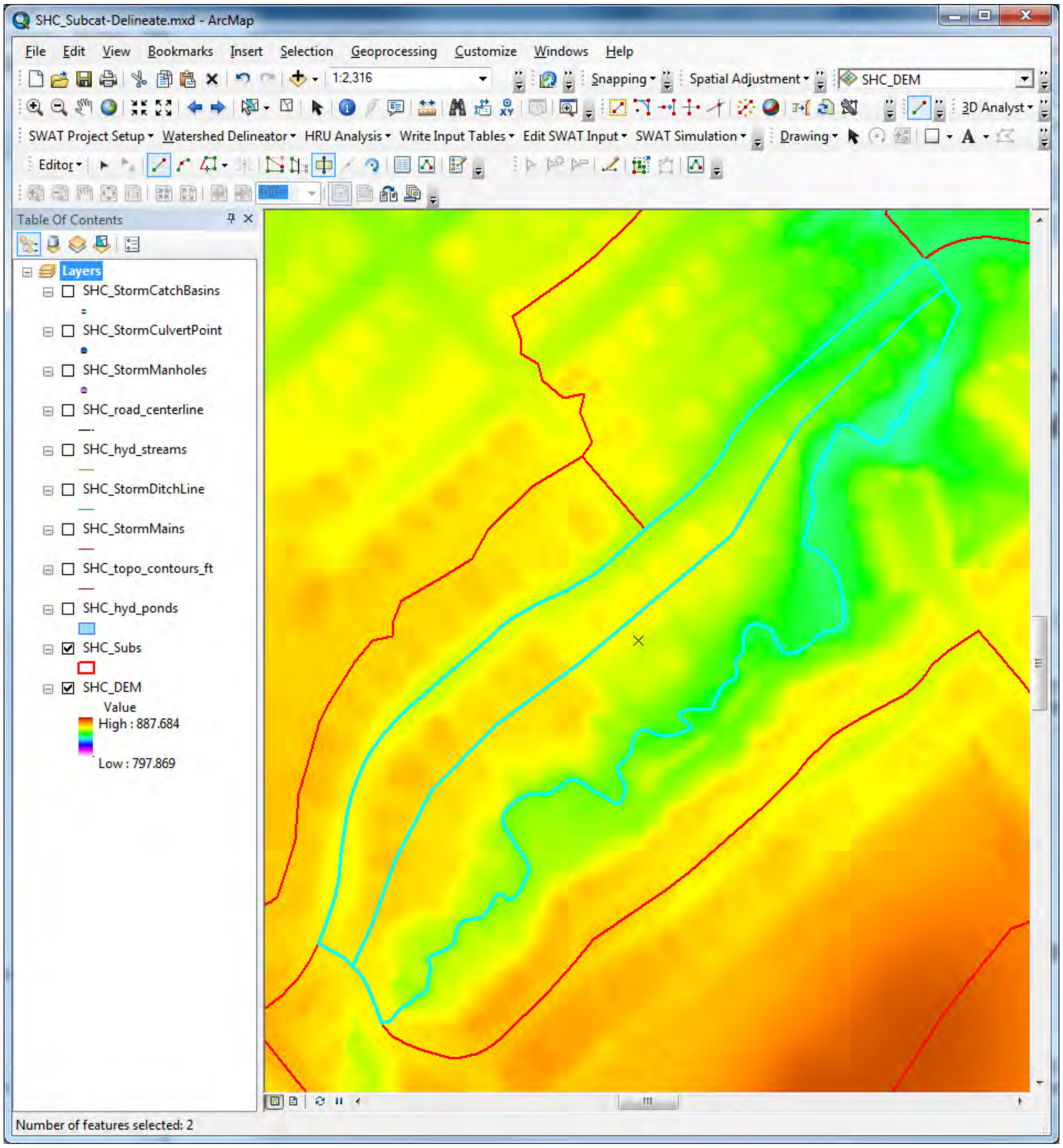
In addition to street centerline and stream line, a drainage area can be divided by topographic ridge or crest as shown in the following examples.

- ⇨ Display the topographic data: SHC_DEM
- ⇨ Select a polygon to split.
- ⇨ Click the Cut Polygons tool on the Editor toolbar.

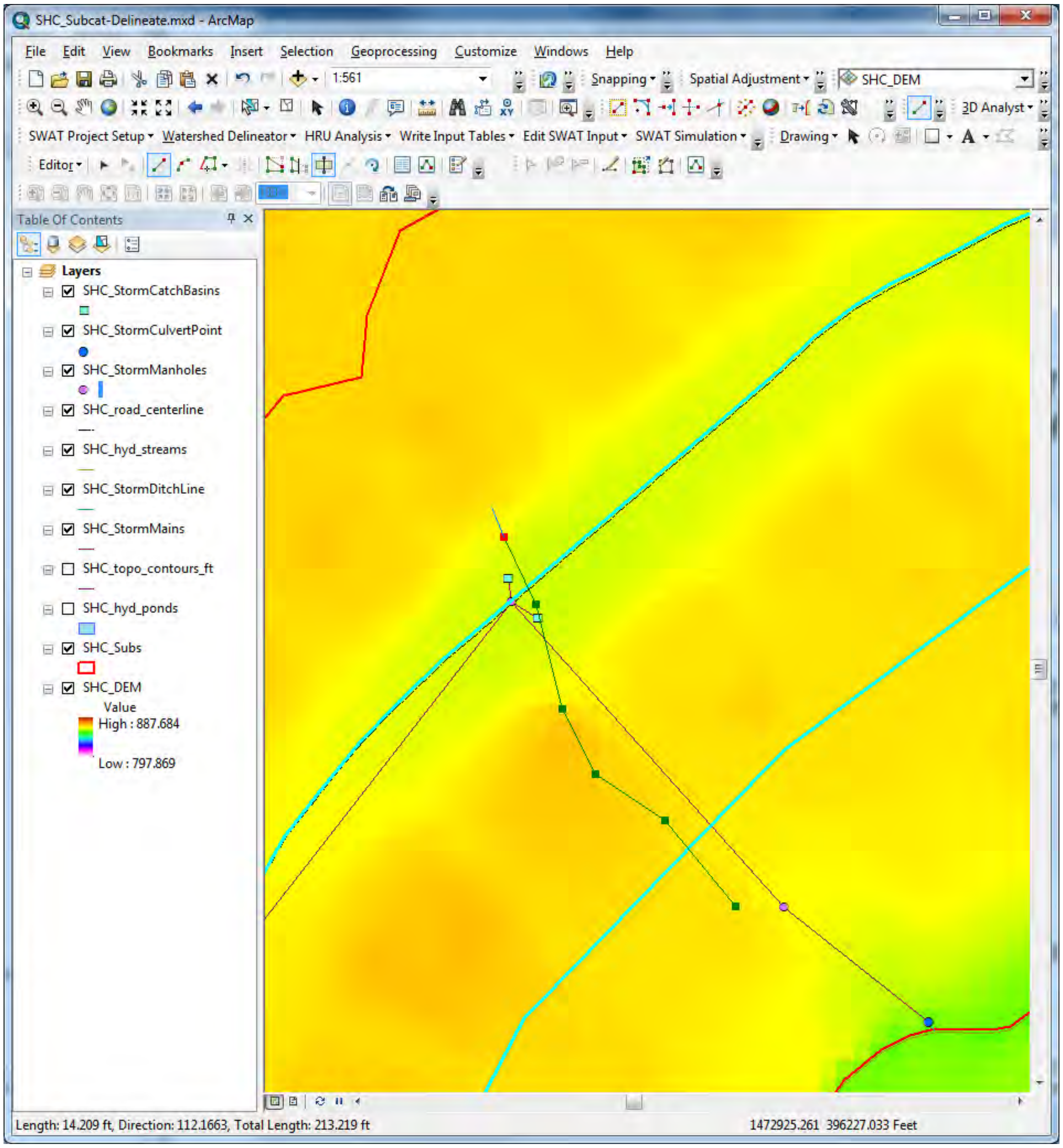


⇨ Create a sketch line along the ridge or crest. (*The sketch must cross (or touch the edge) at least two times for the polygon to be split.*)

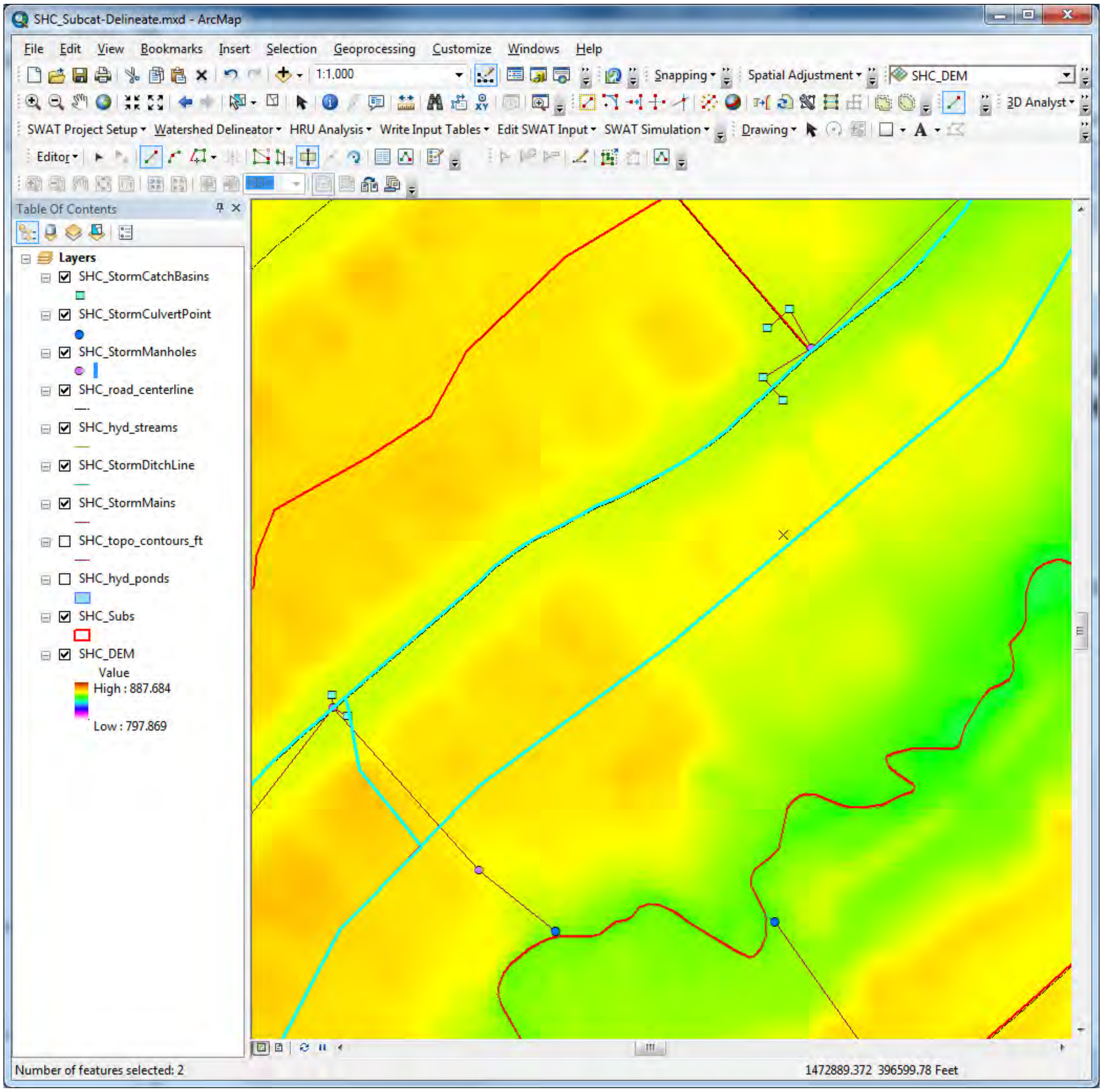
⇨ Right-click anywhere on the map and click "Finish Sketch".



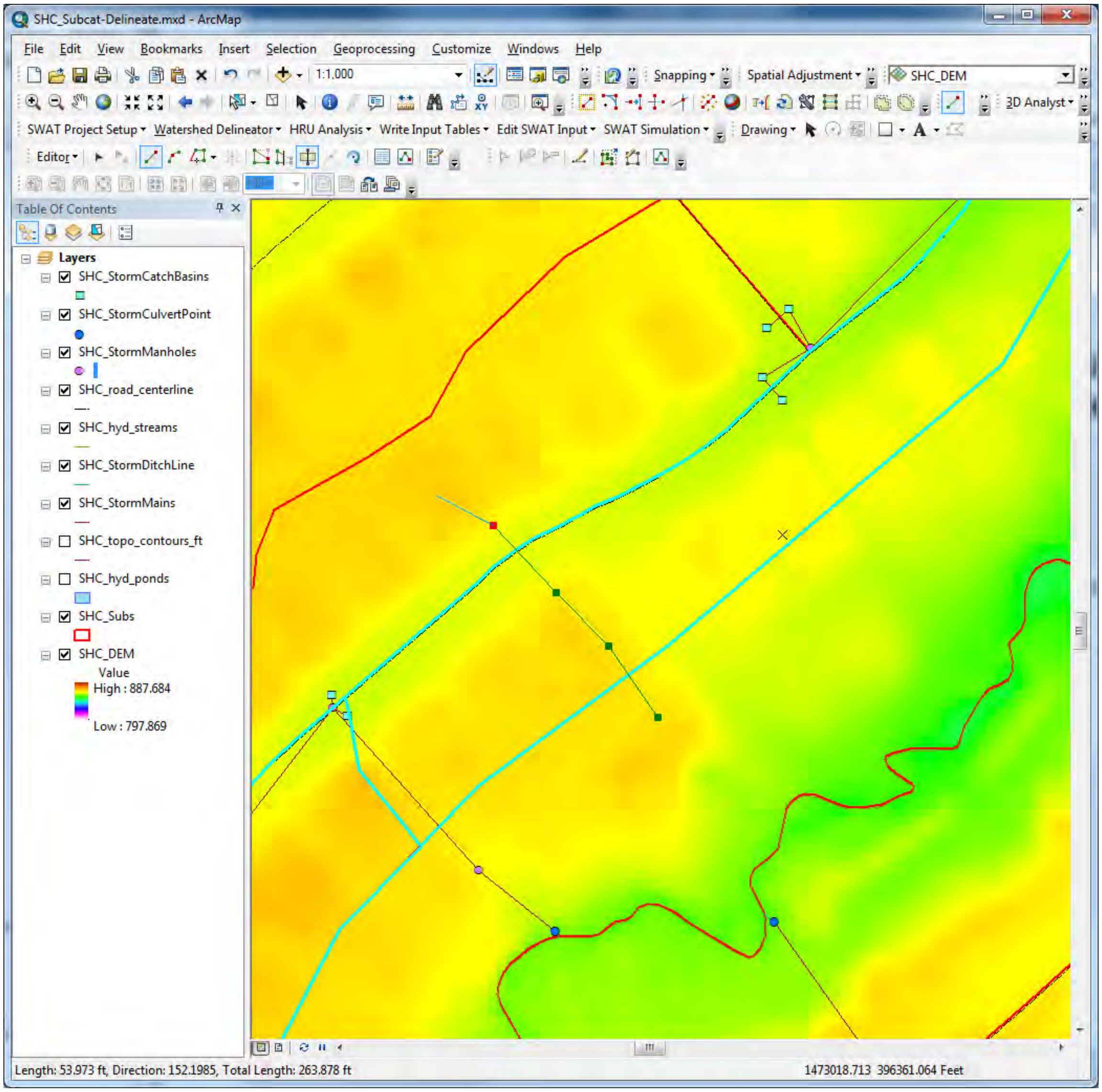
Now the polygon is subdivided into two pieces along to the topographic crest line. This approach can be used for identifying a subcatchment for a catch basin as shown below:



- ⇨ Display the storm sewer data: catch basin, culvert, manhole, stream, ditch, sewer main (pipe line)
- ⇨ Select a polygon to split.
- ⇨ Click the Cut Polygons tool on the Editor toolbar.
- ⇨ Create a sketch line along the topographic crest for a catch basin. (*The sketch must cross (or touch the edge) at least two times for the polygon to be split.*)
- ⇨ Right-click anywhere on the map and click “Finish Sketch”.



More examples of splitting a drainage to create individual subcatchments for catch basins are presented below:


SHC_Subcat-Delineate.mxd - ArcMap
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
1:1,000
Snapping
Spatial Adjustment
SHC_DEM
3D Analyst
SWAT Project Setup Watershed Delineator HRU Analysis Write Input Tables Edit SWAT Input SWAT Simulation Drawing
Editor
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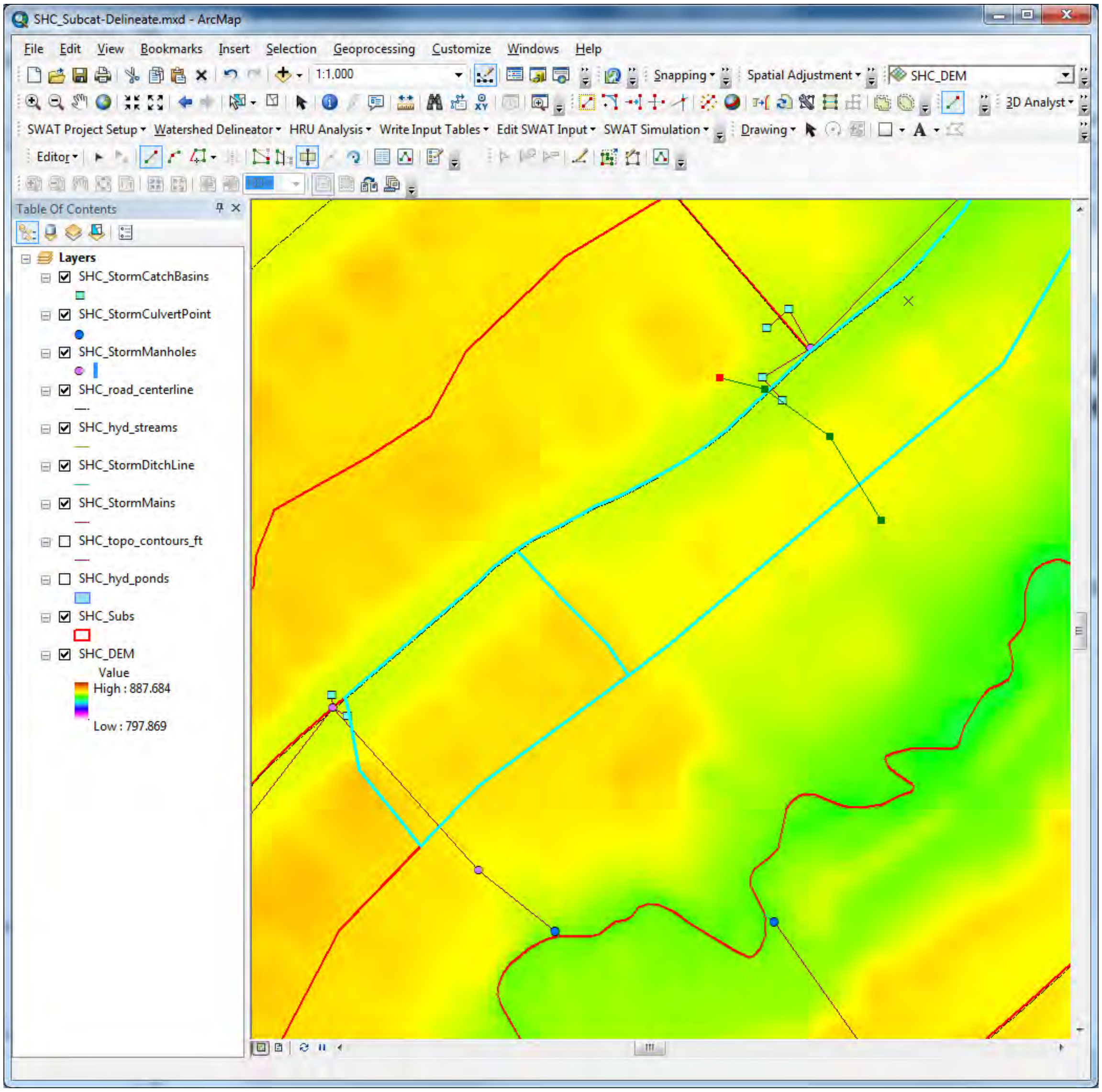
Layers
SHC_StormCatchBasins
SHC_StormCulvertPoint
SHC_StormManholes
SHC_road_centerline
SHC_hyd_streams
SHC_StormDitchLine
SHC_StormMains
SHC_topo_contours_ft
SHC_hyd_ponds
SHC_Subs
SHC_DEM
Value
High : 887.684
Low : 797.869
Length: 53.973 ft, Direction: 152.1985, Total Length: 263.878 ft
1473018.713 396361.064 Feet


SHC_Subcat-Delineate.mxd - ArcMap
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
1:1,000
Snapping
Spatial Adjustment
SHC_DEM
3D Analyst
SWAT Project Setup
Watershed Delineator
HRU Analysis
Write Input Tables
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Layers
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SHC_StormCulvertPoint
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SHC_road_centerline
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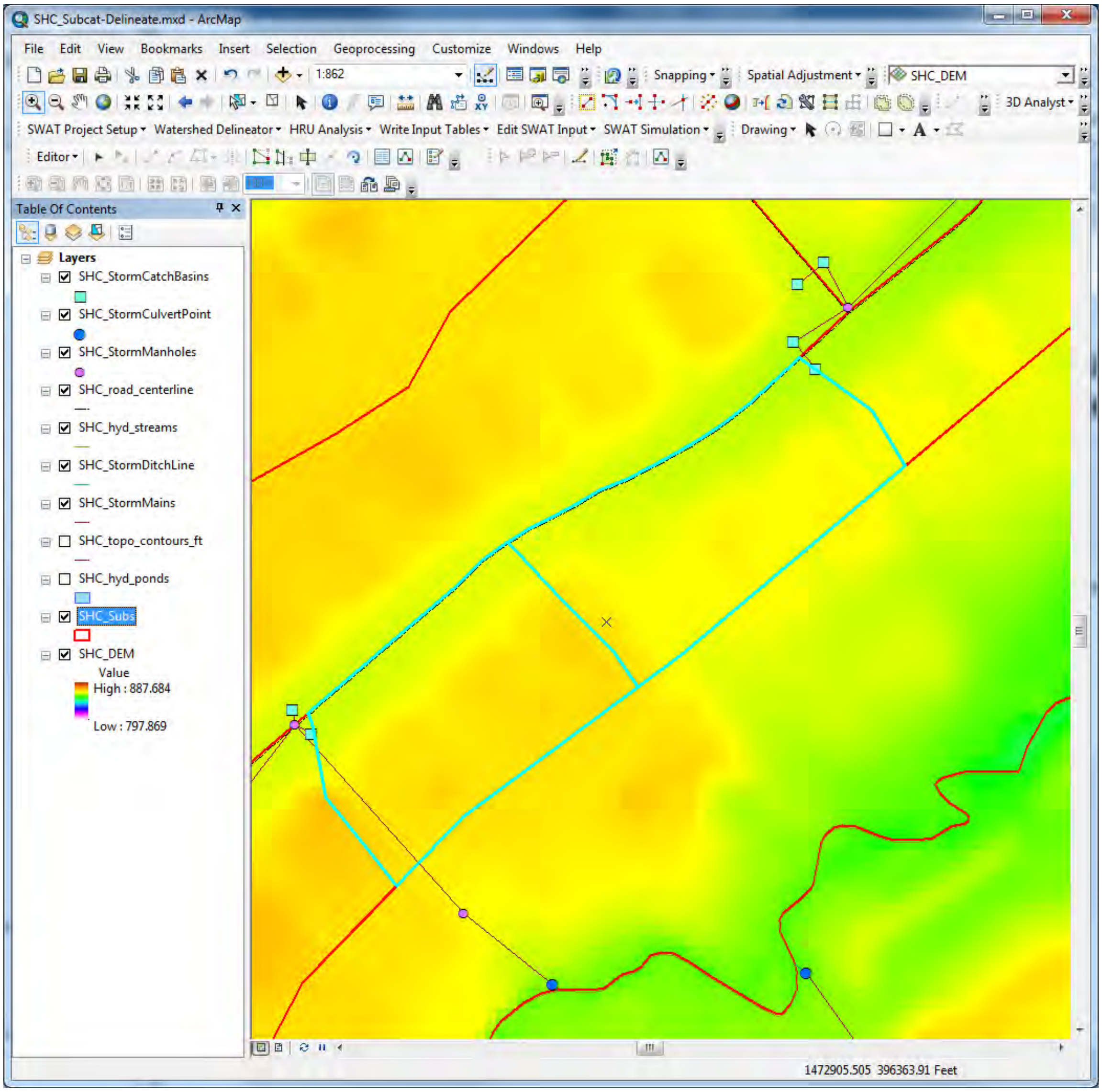
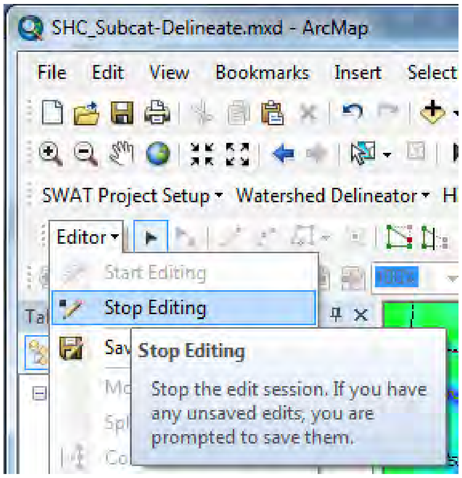
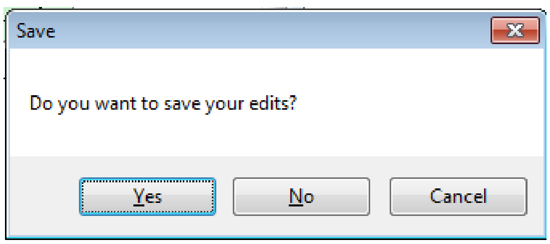
SHC_StormDitchLine
SHC_StormMains
SHC_topo_contours_ft
SHC_hyd_ponds
SHC_Subs
SHC_DEM
Value
High : 887.684
Low : 797.869



Continuing to perform this approach for all catch basins or storm sewer inlets eventually completes the subcatchment delineation step. If a subdivided area is much larger than other areas (e.g., the agricultural area), we can split the area along any internal topographic crest using the same approach.



⇨ When completed, click ‘Editor’ and select ‘Stop Editing’.



⇨ Click ‘Yes’ to save the result.

Because GI is designed to capture and control stormwater runoff before it discharges to the storm sewer system, the subcatchment in a SWMM project that is intent on conducting GI scenario analysis should be delineated as the area that drains runoff to an actual storm sewer inlet. In addition, the following two rules were applied for subcatchment delineation: 1) If two adjacent storm inlets were located side–by–side at one street location, and one of the two drainage areas was smaller than 0.5 acre, the two drainage areas are combined into one subcatchment, and 2) to help maintain hydrologic continuity the subcatchment boundaries were generally selected with an intent to keep all subcatchments a similar size. This second criterion breaks up large areas of homogeneous land cover that can result in mixed land use watersheds. The final result of subcatchment delineation in this study is presented in Figure 12. Any and all surfaces contained within the headwatershed boundaries must be assigned to a specific subcatchment.

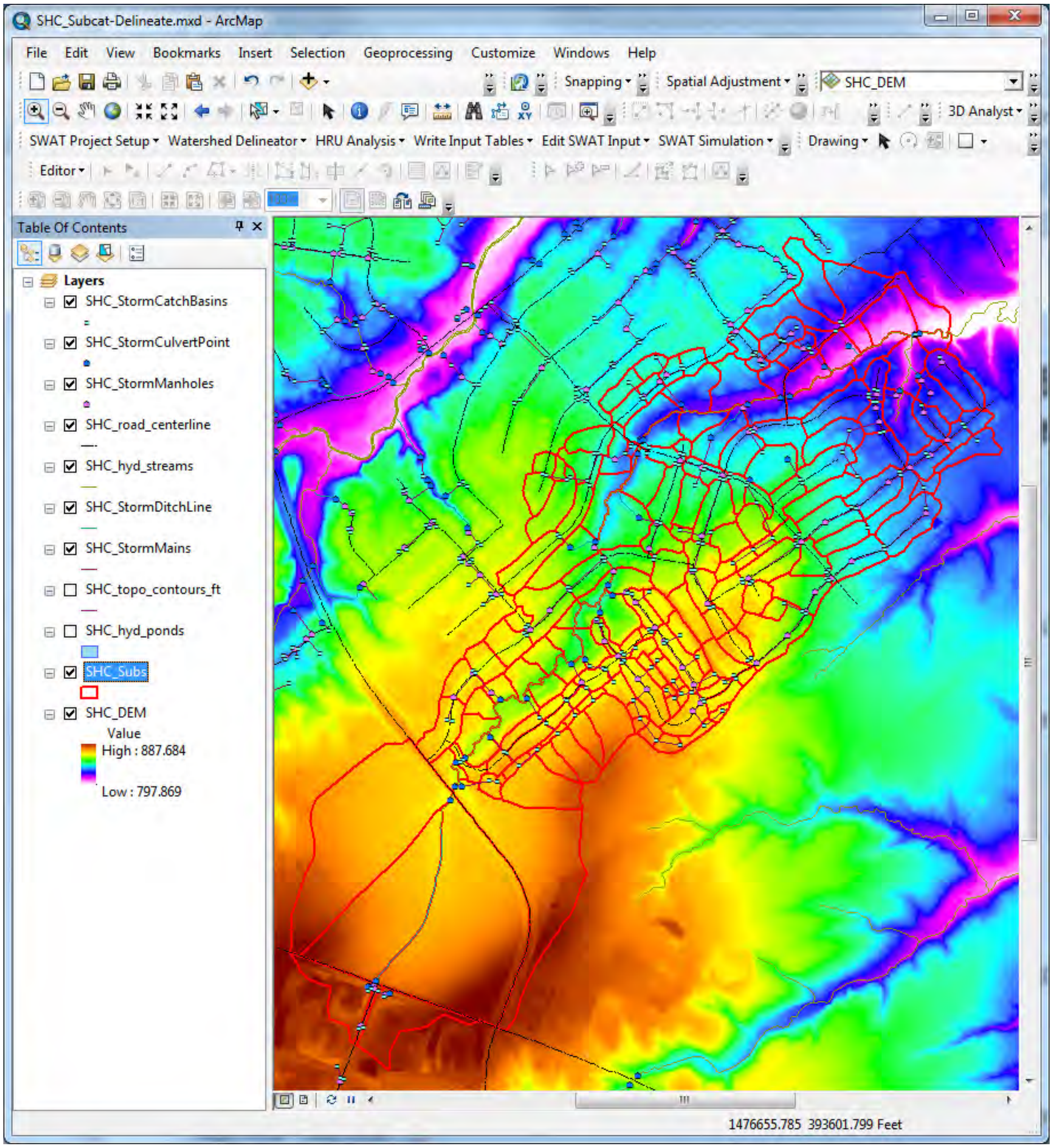


Figure 12. Completed subcatchment delineation. Catch basins are the inlets to the storm sewer systems. The area within each subcatchment boundary drains to one catch basin.

2.3.2 GIS Layers for Storm Sewer Systems – Junctions, Conduits, and Outfalls

Storm sewer systems consist of catch basins (or inlets), manholes, culverts, sewer pipes, built channels, and natural streams. In a SWMM model set up, these features are modeled as "Junctions", "Conduits" (i.e., pipes, built channels, or natural streams), and "Outfalls" (i.e., culvert outlet, or watershed outlet). A junction is an individual node with a unique spatial reference within the storm collection system, such as a catch basin or manhole, and typically represents the entry point for surface runoff or an intersection point in the network of sewer pipes. Each junction must have an invert elevation. A conduit defines a concentrated flow path from an upstream junction to a downstream junction. If we use the EPA SWMM, we don't need to create these data sets separately. In this study, we used PCSWMM to create a SWMM input file using GIS data. All parts of the flow path within a conduit should be connected as a polyline. However, in some cases, a conduit is split into more than one. The GIS data should be checked before importing the shapefile to PCSWWMM to make sure that each conduit has a defined length, shape and size. An outfall is the final discharge point of the modeled area. The outfall must have an invert elevation. In this study, individual layers for "Junctions", "Conduits", and "Outfalls" were derived using the County GIS data, presented in Figure 4. The derived GIS layers for storm sewer systems are shown in Figure 13 (see "inp_Junctions", "inp_Conduits", and "inp_Outfalls").

2.3.3 GIS Layers for Storm Control Systems – Storages, Orifices, and Weirs

An existing urban watershed has stormwater control features mandated by local urban drainage ordinances or state/federal MS4 permit requirements, such as wet/dry detention areas (i.e., ponds) or impoundments. Each control feature has a storage volume and outflow control structure (i.e., a regulating orifice and/or weir). The storage volume for each feature varies as a function of water level (or stage). The discharge rate for the outflow structure is also a function of water level. In SHC, there are 5 stormwater control features: 2 dry ponds, 2 wet ponds, and a 10-year detention basin. All of the control features are modeled as "Storages" in SWMM. A storage is expressed as a point with a stage (or water level) – storage curve. Either a weir, orifice or both are modeled as a polyline with required design specifications (see Figure 11 for a conceptual representation of these objects.) Each outflow structure (weir or orifice) is identified with an inlet node (storage), an outlet node (junction), type or shape, height, length, discharge coefficient, etc. The derived GIS layers for storm control systems are shown in Figure 13 (see "inp_Storages", "inp_Orifices", and "inp_Weirs").

The attribute data for a GIS layer are saved as a table. All of the GIS layers for SHC are presented in Figure 13. This map can be imported as a backdrop image into the SWMM model. The method of creating a geo-referenced backdrop image is described in the following section.

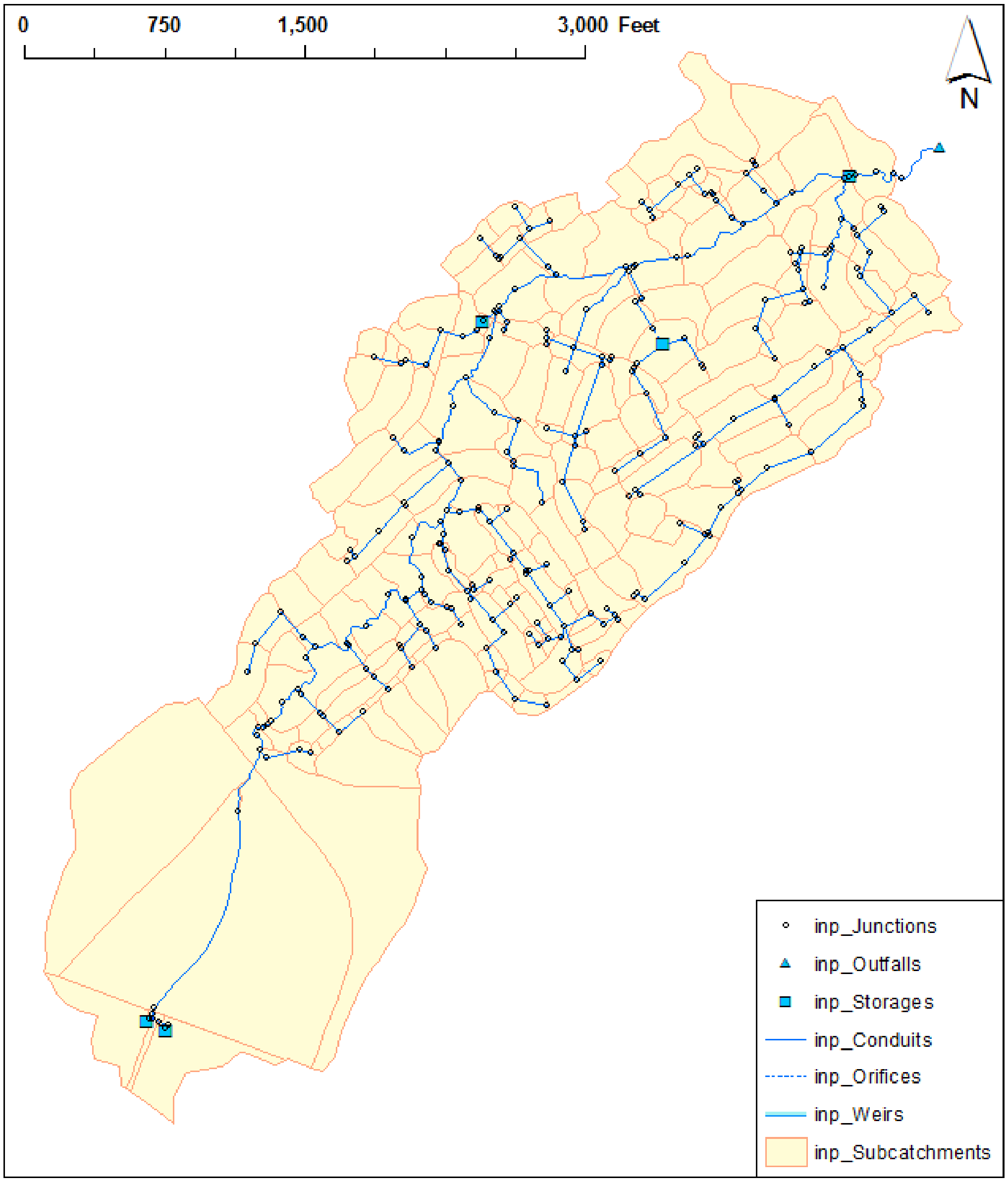


Figure 13. Delineated SWMM Objects for SHC: Junctions, Outfalls, Storages, Conduits, Orifices, Weirs, and Subcatchments. Each object represents a separate data layer in the spatial database, and, therefore, a separate file (polygon, polyline, or point) in the folder containing the GIS data for the modeling effort.

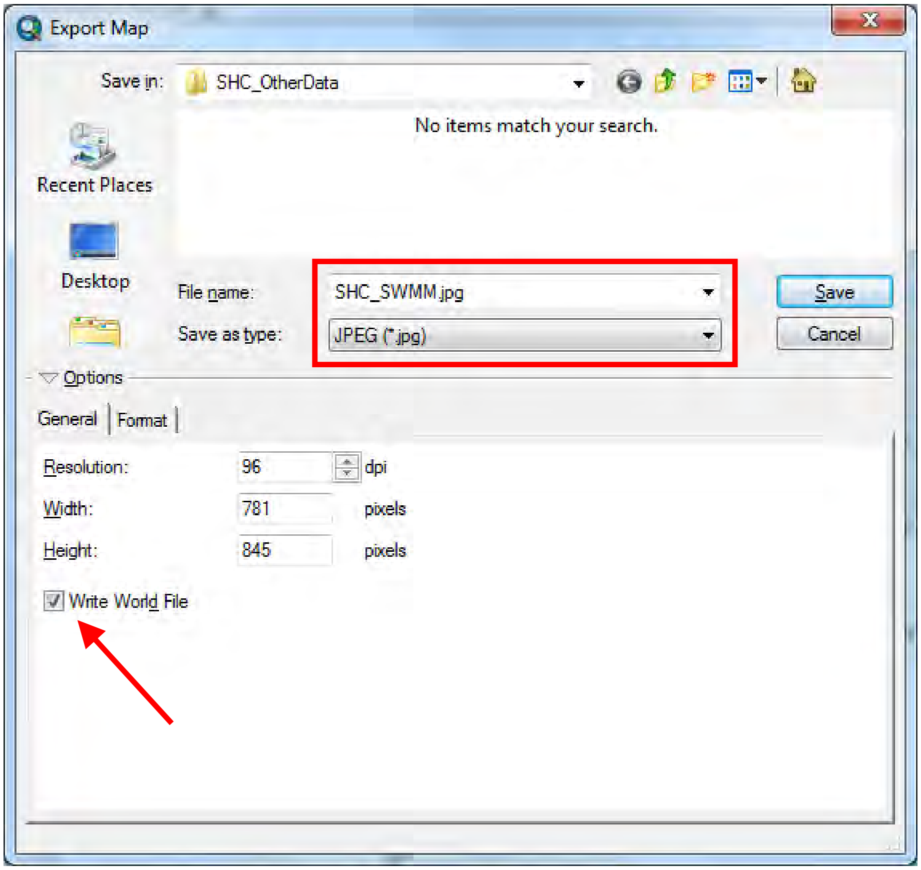
2.3.4 Create Backdrop Image

A geo-referenced backdrop image can be created using ArcGIS as follows:

⇨ Run 'ArcMap'

⇨ Display relevant spatial data layers

⇨ Click 'File / Export Map…' under the Main Menu



⇨ Specify 'File Name' and the 'type' of the file

⇨ Mark 'Write World File' to create a world file

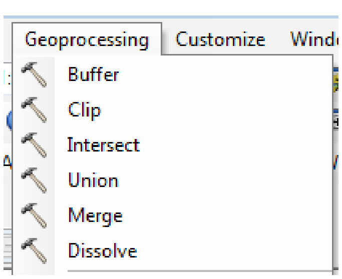
⇨ Click 'Save'

Note: A world file is a six-line plain text file used by GIS systems to geo-reference raster-based map images.

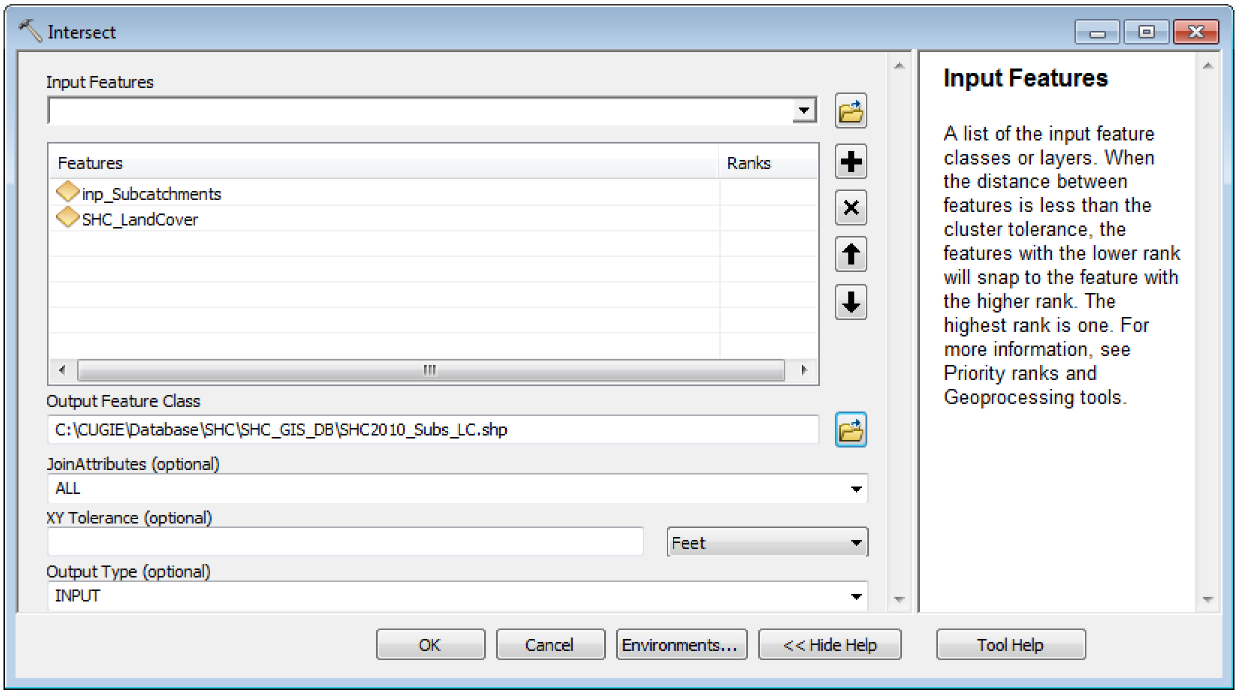
2.4 Deriving Modeling Parameters for Individual Subcatchments

2.4.1 Overlay the Land Cover Data and the Subcatchments Data Layers

In order to specify surface characteristics for individual subcatchments in SWMM, the digitized land cover data is overlaid with the delineated subcatchments. This spatial overlay can be processed as follows:



⇨ Select 'Geoprocessing / Intersect' under the Main Menu

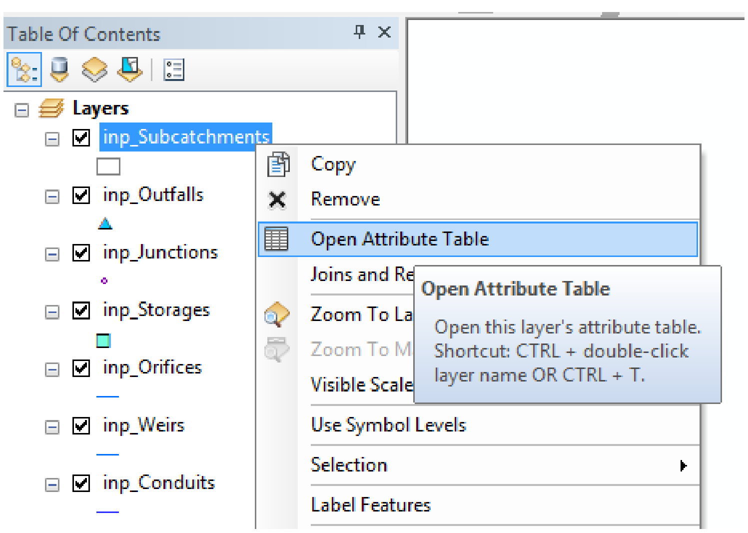


⇨ Select 'Input Features'

⇨ Specify 'Output Feature Class'

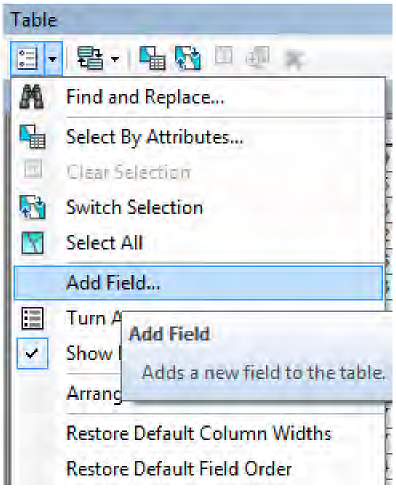
⇨ Click 'OK'

The overlaid layer of land use/land cover and subcatchments is presented in Figure 14. After overlaying, the size of every spatial feature can be estimated as follows:

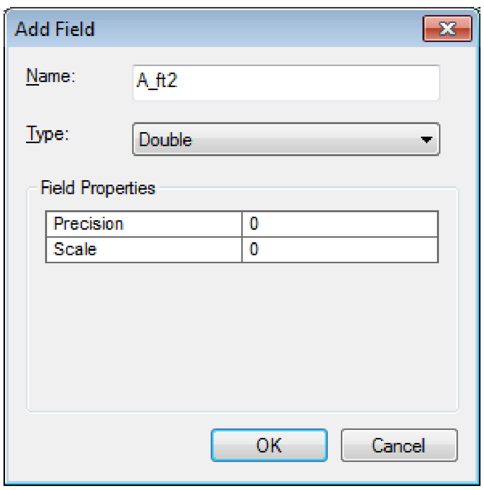


⇨ Right-Click on a GIS layer that needs to be adjusted

⇨ Click 'Open Attribute Table'



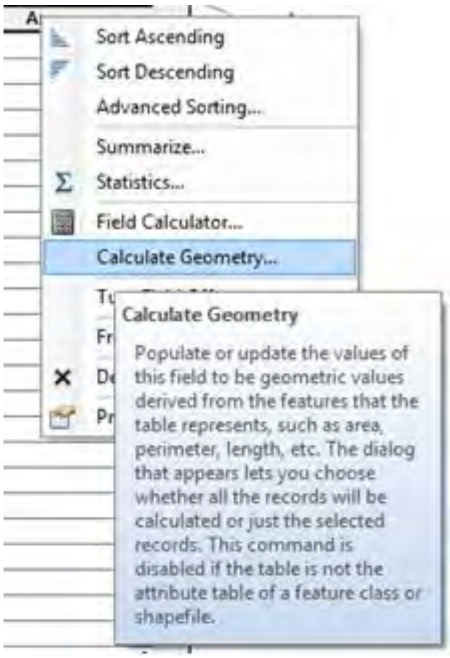
⇨ Click  icon, then select 'Add Field...'



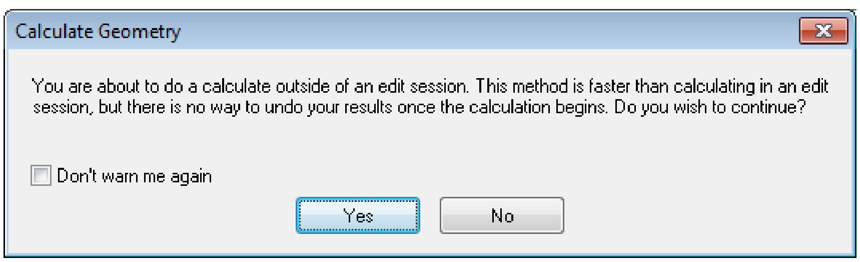
⇨ Specify 'Name', in this example 'A_ft2' was written *(this is for the area of each polygon – square feet).*

⇨ Specify 'Type', select 'Double' *(this stands for double-precision floating point value).*

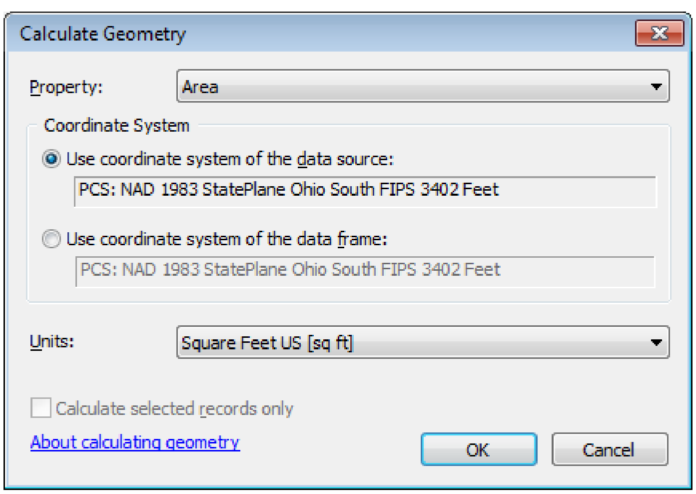
⇨ Click 'OK'



- ⇨ Right-Click on the field (A_ft2) that needs to be updated
- ⇨ Select 'Calculate Geometry…'

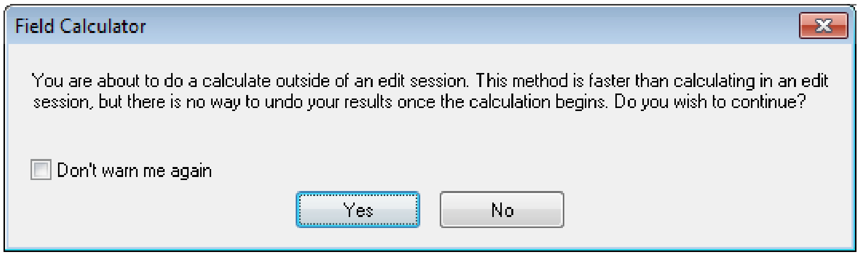


- ⇨ Click 'Yes'



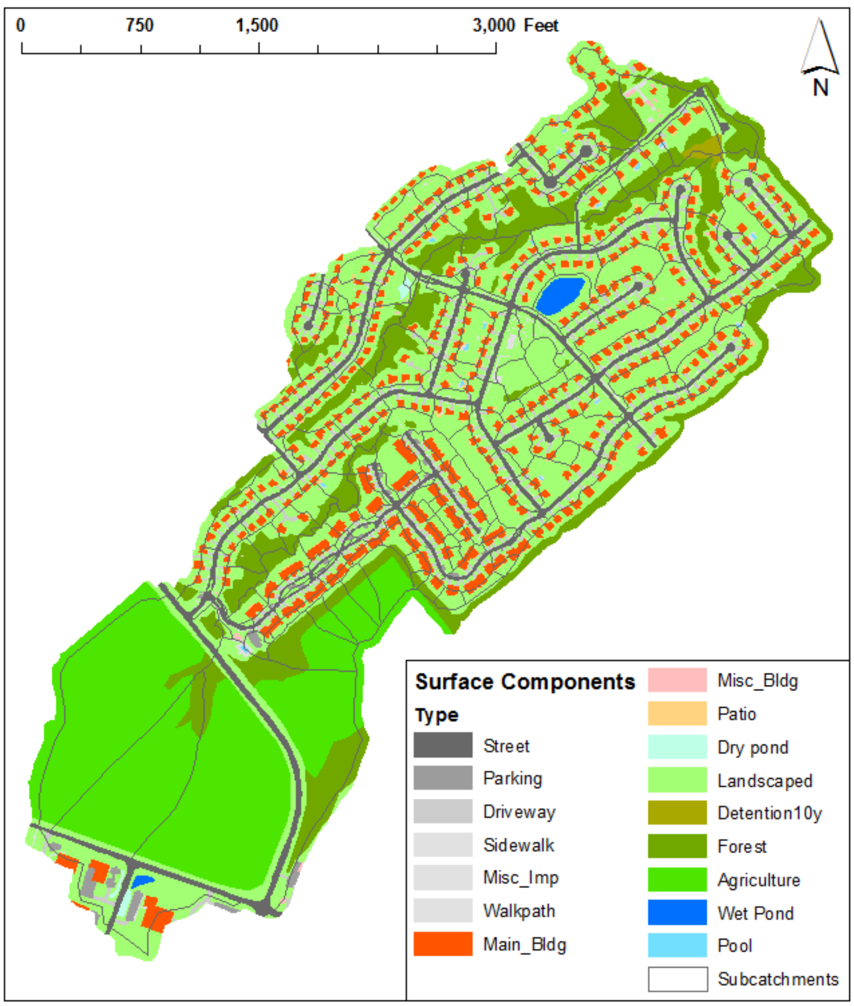
- ⇨ Specify 'Property' as 'Area'
- ⇨ Specify 'Units'

⇨ Click 'OK'



⇨ Click 'Yes'

Now, the 'A_ft2' field is updated with the sizes of all polygons. The overlaid layer and an example of some of the data contained in the attribute table are presented in Figure 14. This data table is used for estimating SWMM modeling parameters for every subcatchment, the details for doing such are presented in the following section.



SubID	A_ft2	Type
Sub000	2052.448641	Street
Sub000	13728.291452	Street
Sub001	15535.855514	Main_Bldg
Sub001	7623.508875	Dry pond
Sub001	7013.703608	Wet Pond
Sub001	10980.450279	Street
Sub001	2483.056548	Driveway
Sub001	68.411035	Walkpath
Sub001	2057.472433	Walkpath
Sub001	71611.6215	Landscaped
Sub001	4830.240504	Landscaped
Sub001	1284.885068	Landscaped
Sub001	29666.950115	Landscaped
Sub001	11089.608891	Parking
Sub001	1063.569174	Driveway
Sub002	12551.352031	Main_Bldg
Sub002	2814.668719	Main_Bldg
Sub002	3506.024927	Dry pond
Sub002	8897.899588	Street
Sub002	6101.446548	Driveway
Sub002	1928.755674	Driveway
Sub002	83.343795	Walkpath
Sub002	90.478678	Walkpath
Sub002	2.23437	Walkpath
Sub002	401.272695	Walkpath
Sub002	735.304777	Landscaped
Sub002	841.031132	Landscaped
Sub002	0.448981	Landscaped
Sub002	1554.463695	Landscaped
Sub002	0.065962	Landscaped
Sub002	6257.694095	Landscaped
Sub002	6341.766918	Parking
Sub002	12768.025778	Parking
Sub002	2908.000507	Parking
Sub002	61093.744437	Landscaped
Sub003	6863.535559	Street
Sub003	33977.284735	Forest

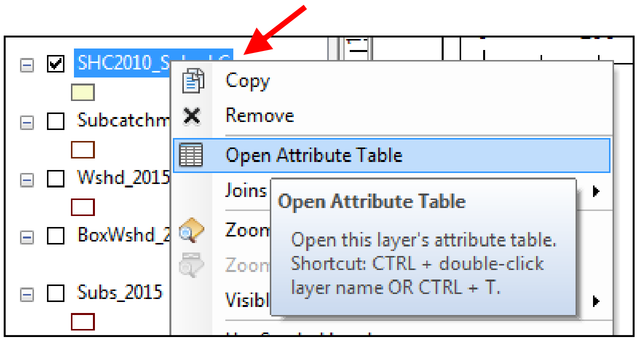
Figure 14. A map and related data table derived from overlaying land cover and subcatchments data layers.

2.4.2 Arrange Spatial Attribute Data using MS-Excel

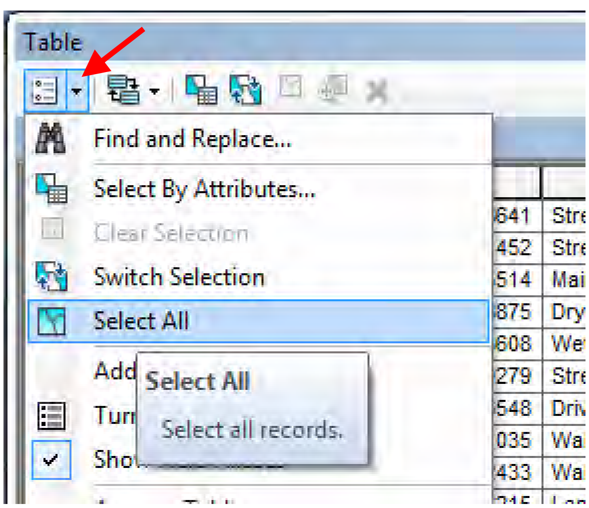
Using MS-Excel we can arrange spatial databases from the developed GIS layers, described in the previous sections. Each layer contains attribute data (e.g., subcatchment ID, land cover type, area). The following example shows how we can arrange land cover data for subcatchments.

⇨ Run ArcMap

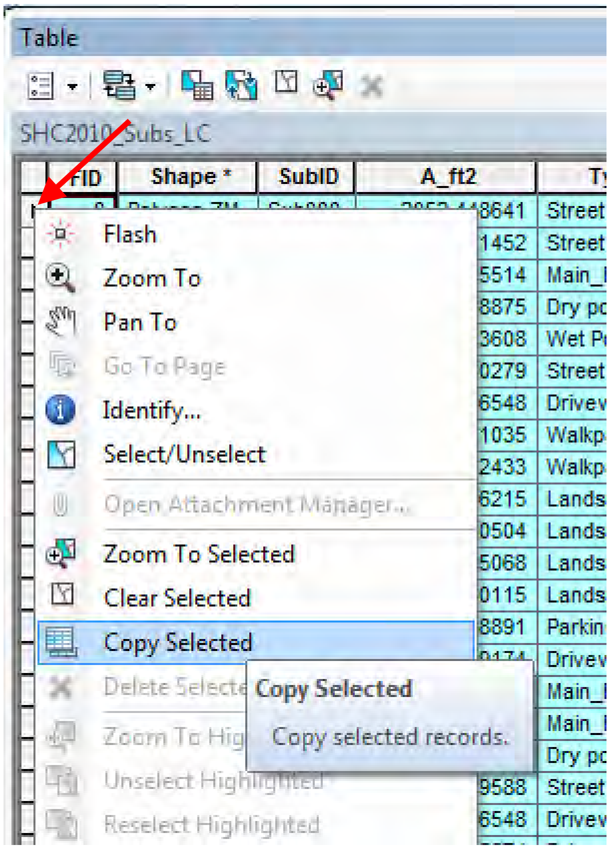
⇨ Add/Display a GIS layer that contains required attribute data *('SHC2010_Sub_LC' contains land cover data for individual subcatchments in the study watershed.)*



⇨ Right-click the layer and select 'Open Attribute Table' to open the attribute table.

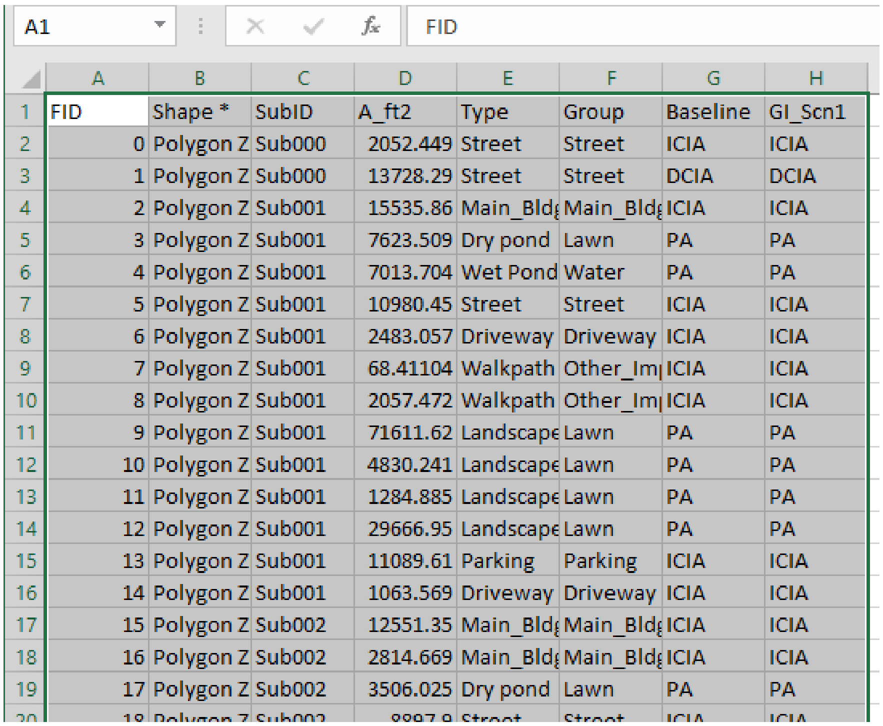


⇨ Click the Table Options arrow , and click 'Select All'.



⇨ Right-click the left-most column of the attribute table, and select Copy Selected.

⇨ Run MS-Excel

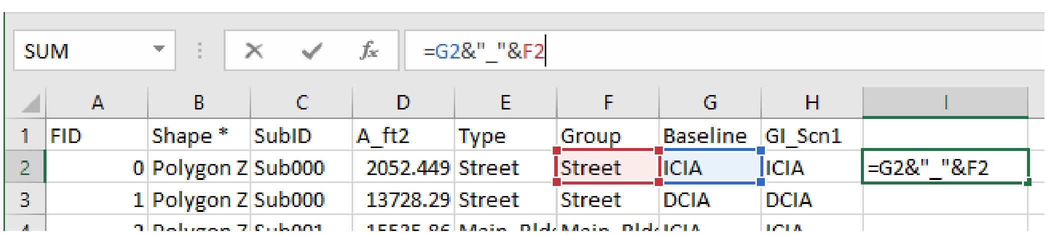


A1 | FID

	A	B	C	D	E	F	G	H
1	FID	Shape *	SubID	A_ft2	Type	Group	Baseline	GI_Scn1
2	0	Polygon Z	Sub000	2052.449	Street	Street	ICIA	ICIA
3	1	Polygon Z	Sub000	13728.29	Street	Street	DCIA	DCIA
4	2	Polygon Z	Sub001	15535.86	Main_Bld	Main_Bld	ICIA	ICIA
5	3	Polygon Z	Sub001	7623.509	Dry pond	Lawn	PA	PA
6	4	Polygon Z	Sub001	7013.704	Wet Pond	Water	PA	PA
7	5	Polygon Z	Sub001	10980.45	Street	Street	ICIA	ICIA
8	6	Polygon Z	Sub001	2483.057	Driveway	Driveway	ICIA	ICIA
9	7	Polygon Z	Sub001	68.41104	Walkpath	Other_Im	ICIA	ICIA
10	8	Polygon Z	Sub001	2057.472	Walkpath	Other_Im	ICIA	ICIA
11	9	Polygon Z	Sub001	71611.62	Landscape	Lawn	PA	PA
12	10	Polygon Z	Sub001	4830.241	Landscape	Lawn	PA	PA
13	11	Polygon Z	Sub001	1284.885	Landscape	Lawn	PA	PA
14	12	Polygon Z	Sub001	29666.95	Landscape	Lawn	PA	PA
15	13	Polygon Z	Sub001	11089.61	Parking	Parking	ICIA	ICIA
16	14	Polygon Z	Sub001	1063.569	Driveway	Driveway	ICIA	ICIA
17	15	Polygon Z	Sub002	12551.35	Main_Bld	Main_Bld	ICIA	ICIA
18	16	Polygon Z	Sub002	2814.669	Main_Bld	Main_Bld	ICIA	ICIA
19	17	Polygon Z	Sub002	3506.025	Dry pond	Lawn	PA	PA

⇨ Right-click cell A1 of the Excel file, and select Paste.

Following these steps, we can copy and paste all records in the attribute table into the Excel file. In Excel, we can adjust the attribute data to process SWMM parameterization, described in the following sections. For instance, we can arrange a new key field to create 'Pivot Table' using the '&' text operator in Excel:



SUM | =G2&"_"&F2

	A	B	C	D	E	F	G	H	I
1	FID	Shape *	SubID	A_ft2	Type	Group	Baseline	GI_Scn1	
2	0	Polygon Z	Sub000	2052.449	Street	Street	ICIA	ICIA	=G2&"_"&F2
3	1	Polygon Z	Sub000	13728.29	Street	Street	DCIA	DCIA	

⇨ Type 'G2&"_"&F2 in Cell 'I2' and click 'Enter'

⇨ Cell 'I2' becomes "ICIA_Street"

⇨ Using Copy and Paste, this process can be applied to the entire column 'I'.

⇨ Create another Excel file to save the required data for processing model parameterization

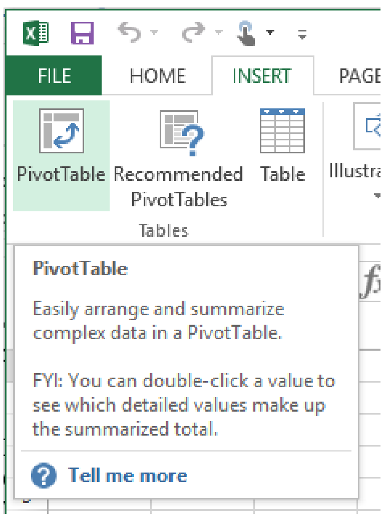
The main data table (Columns 'A' through 'D') in 'LandCover' tab, shown in Figure 15, was initially created from this approach, and saved as "SHC_SWMM_DataProcessing.xlsx". The 'PervBuffer' tab in the Excel file was created using attribute data from the BPA layers (Section 2.2.3 and Figure 10). Parameters for groundwater modeling is saved under 'GW' tab in the same Excel file. Surface elevation ('Esurf' in Column 'S') was prepared using the inp_Subcatchments layer (Section 2.3.1 and Figure 13) and DEM. More details on arranging groundwater parameters will be presented in Section 3.5.1.

2.4.3 Develop a Component-based Spatial Database using "PivotTable" in MS-Excel

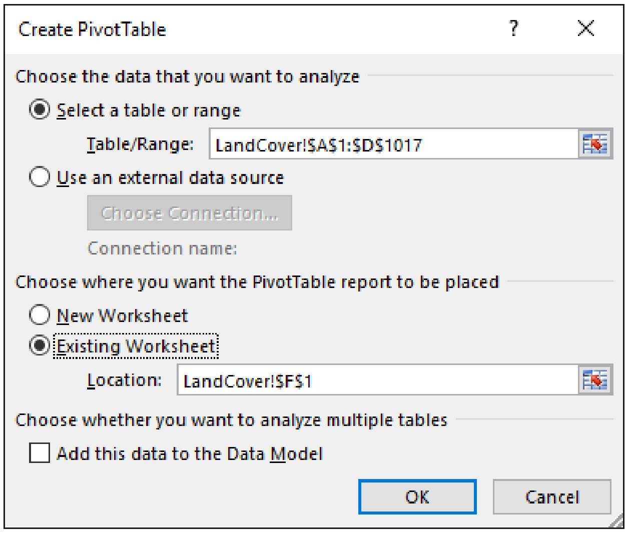
In order to retain the ability to bulk edit the properties (e.g., width and initial saturation) of the different subcatchments in the watershed, the use of a spreadsheet tool such as MS-Excel is highly recommended. This section along with some of the following sections demonstrates the use of a spreadsheet tool to process data in bulk.

The attribute data for the overlaid land cover and subcatchments layers contains a "SubID" field as the name of each subcatchment, "Component" based on land use/land cover status, and "A_ft2" as area in square feet. Using 'Insert / PivotTable' option in MS-Excel, the attribute data can be summarized for individual subcatchments as follows:

- ⇨ Run MS-Excel
- ⇨ Open "SHC_SWMM_DataProcessing.xlsx"
- ⇨ Open or create a "LandCover" worksheet



- ⇨ Select 'PivotTable' under 'INSERT'

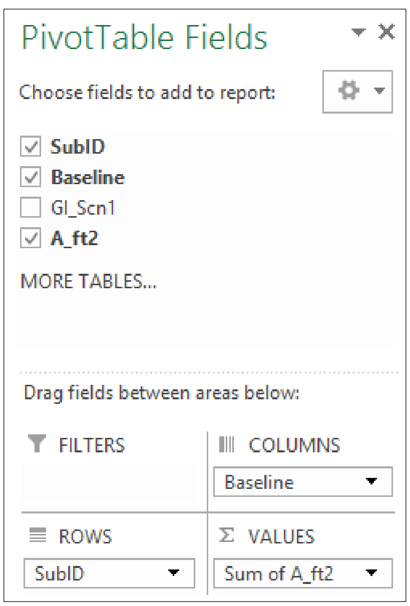


⇨ Specify 'Table/Range'

⇨ Specify 'Location' of the PivotTable report to be placed

⇨ Click 'OK'

Specify 'PivotTable Fields' as follows:



⇨ ROWS: "SubID"

⇨ COLUMNS: "Baseline" *(Baseline represents the existing condition.)*

⇨ ∑ VALUES: "Sum of A_ft2"

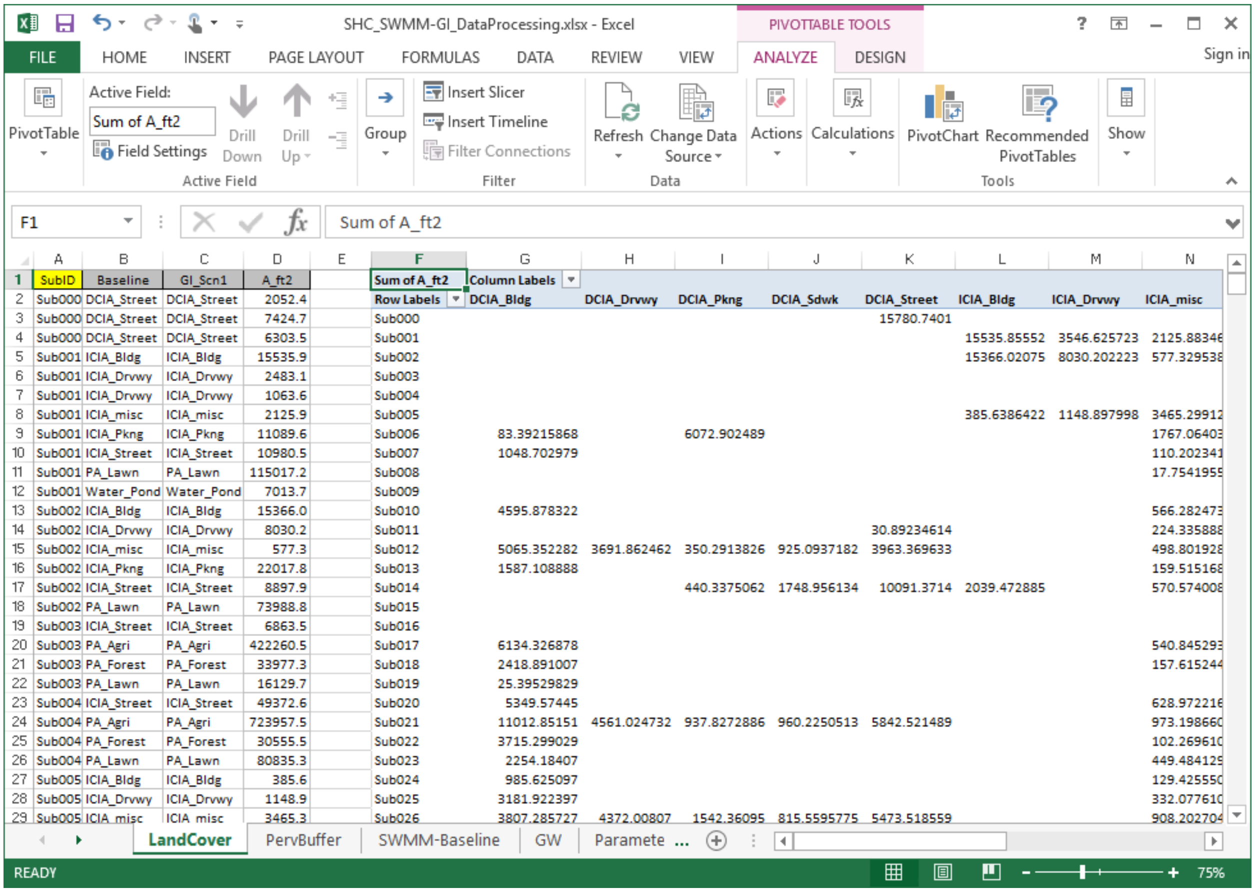


Figure 15. Example of PivotTable created in MS-Excel that summarizes the area of each subcatchment based on its component land cover classes. PivotTable fields are shaded in light blue.

2.4.4 Specify Modeling Parameters for Individual Surface Components

The derived PivotTable shown in Figure 15 provides detailed land cover status for all of the individual subcatchments. If designated modeling parameters were allocated to the individual land use/land cover features, the overall SWMM modeling parameters for subcatchments can be estimated using area-weighting approaches. This is presented in the following section. Examples of specified parameters are shown in Tables 2 through 4. Values for 'Length' and 'Slope' were initially estimated using ArcGIS at multiple locations in the study watershed. Values for Manning's roughness coefficient, n; surface depression storage, DS; and saturated hydraulic conductivity, Ksat, were chosen from the SWMM User's Manual (Rossman, 2015).

Table 2. Parameters for DCIA.

Parameter	Building	Driveway	Parking	Sidewalk	Street
Length (ft)	25	12	10	3	10
Slope	15	1.5	1.5	1.5	2.5
n	0.01	0.01	0.01	0.01	0.01
DS (in)	0.05	0.05	0.05	0.05	0.05

Table 3. Parameters for ICIA.

Parameter	Building	Driveway	Parking	Sidewalk	Street	Misc.
Length (ft)	15	12	10	3	10	8
Slope	15	1.5	1.5	1.5	2.5	1.5
n	0.01	0.01	0.01	0.01	0.01	0.01
DS (in)	0.05	0.05	0.05	0.05	0.05	0.05

Table 4. Parameters for pervious areas.

Parameter	Agriculture	Forest	Lawn
Length (ft)	100	80	80
Slope	2	2	2
n	0.3	0.6	0.3
DS (in)	0.2	0.3	0.2
Ksat (in/hr)	0.04	0.06	0.035

2.4.5 Arrange a Worksheet in MS-Excel to Estimate Modeling Parameters for Individual Subcatchments

In a SWMM model set up each subcatchment must be modeled with spatial specifications and modeling parameters. Using the derived PivotTable from the land cover and subcatchments layers, the specifications and parameters were estimated in MS-Excel as shown in Figure 16.

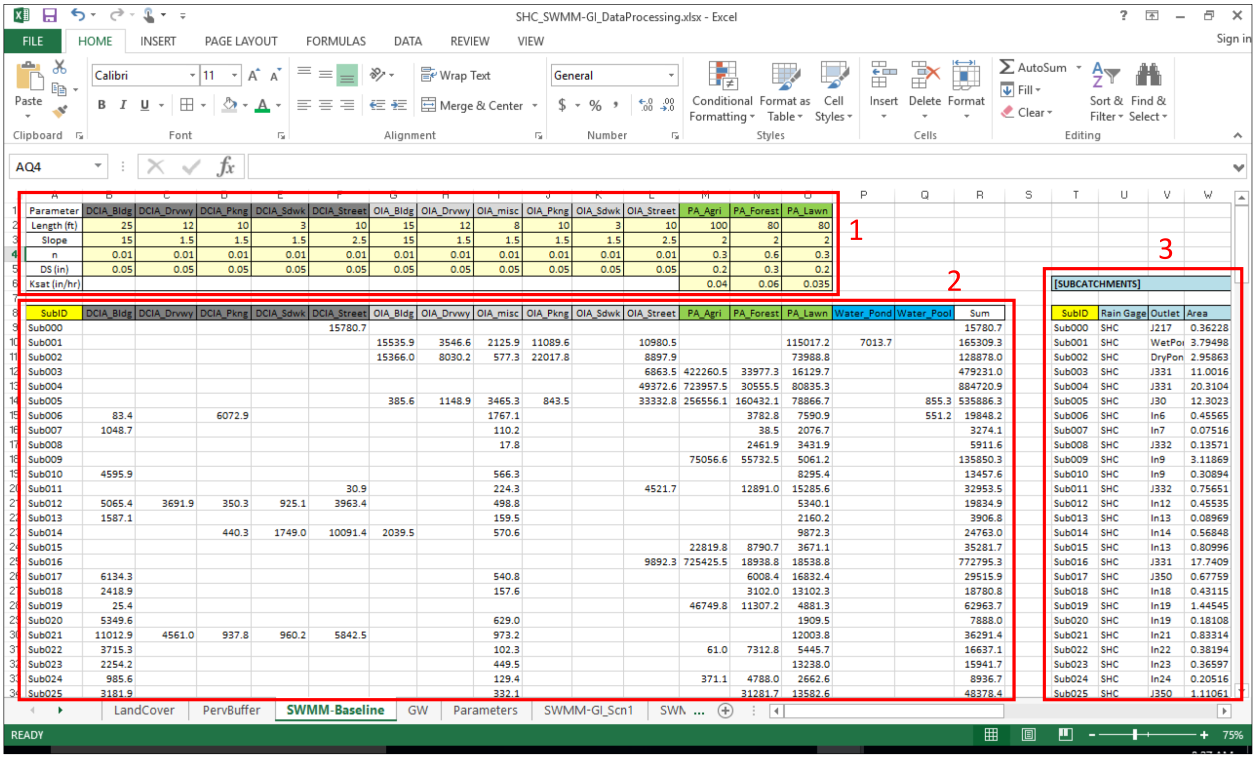


Figure 16. Subcatchment parameterization using MS-Excel. Box 1: Parameters for individual land cover components (if any value is changed, all of the related calculations are automatically updated). Box 2: Spatial data from the Pivot Table. Box 3: Estimated SWMM inputs based on the 'Parameters' and the 'Spatial data'.

Each subcatchment is modeled with the following specifications and parameters. All of the calculations are processed in MS-Excel. The SWMM User's Manual (Rossman, 2015) should be referred to for the precise definition and additional information on the individual parameters listed below.

- Rain Gage = rain gauge(s) assigned for individual subcatchments as appropriate or based on data availability
- Outlet = runoff outlet (It can be a junction, a subcatchment, or a storage feature. All outlets from the individual subcatchments are defined in the developed subcatchment GIS layer, "inp_Subcatchments".)
- Area = subcatchment area in acres (If needed, an appropriate unit conversion should be applied. In this study, area of square-feet from GIS was converted to acres: [acre] = [ft^2] / 43,560.)
- %Imperv = (sum of the impervious areas within the subcatchment) / (total area of the subcatchment)
- Width = (total area of the subcatchment) / (representing overland flow length of the subcatchment)
- (representing overland flow length of the subcatchment) = ∑{(overland flow length per component) (area of the component)} / (total area of the subcatchment)

- %Slope = ∑{(slope per component) (area of the component)} / (total area of the subcatchment)
- N-Imperv = ∑{(n per impervious component within the subcatchment) (area of the impervious component)} / (total impervious area of the subcatchment) : "N-Imperv" stands for the Manning's n value assigned to impervious surfaces in the subcatchment.
- N-Perv = ∑{(n per pervious component within the subcatchment) (area of the pervious component)} / (total pervious area of the subcatchment) : "N-Perv" stands for the Manning's n value assigned to pervious surfaces in the subcatchment.
- S-Imperv = ∑{(DS per impervious component within the subcatchment) (area of the impervious component)} / (total impervious area of the subcatchment) : "S-Imperv" stands for the depression storage value assigned to impervious surfaces in the subcatchment.
- S-Perv = ∑{(DS per pervious component within the subcatchment) (area of the pervious component)} / (total pervious area of the subcatchment) : "S-Perv" stands for the depression storage value assigned to pervious surfaces in the subcatchment.
- PctZero = 100 * (sum of the impervious area with zero DS within the subcatchment) / (total impervious area of the subcatchment)
- RouteTo = "IMPERVIOUSA" if any street exists as DCIA within the subcatchment. Otherwise (i.e., no street as DCIA in the subcatchment) = "OUTLET"
- PctRouted = "100" (In this study, ICIA runoff discharges to BPA not the entire pervious area. To model BPA, we are using an LID option and parameters.)
- Suction = same values for the all subcatchments
- Ksat, saturated hydraulic conductivity of the soil = ∑{(Ksat per pervious component within the subcatchment) (area of the pervious component)} / (total pervious area of the subcatchment)
- IMD, initial soil moisture deficit = applied as the same default value (0.22) for all the subcatchments (While IMD was modeled using the same default values, the modeling results may not be affected by the initial values in model setup because the model was running a few months of warming-up period.)

Two surface components for wet areas (i.e., pond and pool) are treated as impervious areas with zero-DS in this modeling approach. However, the area for water is not included in the area-weighted calculation for subcatchment parameter estimation. The developed Excel file will be used for setting up SHC SWMM model (see Section 3.3.1).

2.4.6 Attribute Data and Additional GIS Layers for SWMM Modeling

Each of the developed GIS data layers should have specific attribute data for setting up a SWMM model. The required attribute data for the individual layers are listed below. Again, the SWMM User's Manual (Rossman, 2015) should be referred to for definitions and additional information.

Subcatchments (inp_Subcatchments.*)

- SubID: Name of the subcatchment
- A_ft2: Area in ft^2
- A_acres: Area in acres
- Outlet: Outlet of the subcatchment

- GWshed: Name of the groundwater-shed (optional)

Junctions (inp_Junctions.*)
- Name: Name of the junction
- Invert_Elv: Invert elevation of the junction in feet
- Rim_Elv: Rim elevation of the junction (optional)
- Depth: Depth of the junction
- Type: Type of the junction (optional)

Outfalls (inp_Outfalls.*)
- Name: Name of the outfall
- InvertElv: Invert elevation of the outfall
- Type: Type of the outfall

Storages (inp_Storages.*)
- Name: Name of the storage unit
- Invert_Elv: Invert elevation of the storage unit
- Rim_Elv: Rim elevation of the storage unit
- Depth: Depth of the storage unit
- Init_Depth: Initial depth of the storage unit
- EvapFactor: Evaporation factor for the storage unit
- Storage: Configuration data type for the storage unit (stage-area)
- CurveName: Curve name of the storage unit shape configuration data

Conduits (inp_Conduits.*)
- Name: Name of the conduit
- Inlet: Inlet node (junction) of the conduit
- Outlet: Outlet node (junction) of the conduit
- Length: Length of the conduit in feet
- Roughness: Manning's roughness coefficient, n, of the conduit
- XSection: Cross section type of the conduit (e.g., circular, rectangular, trapezoidal, etc.)
- GEOM1: Geometry variable 1 of the conduit
- GEOM2: Geometry variable 2 of the conduit
- GEOM3: Geometry variable 3 of the conduit
- GEOM4: Geometry variable 4 of the conduit
- Pipe_Size: Pipe size of the sewer, same as Geom1 (optional)
- Category: Category of the conduit (optional)

Orifices (inp_Orifices.*)
- Name: Name of the orifice
- Inlet: Inlet of the orifice
- Outlet: Outlet of the orifice
- Type: Type of the orifice
- XSection: Cross section of the orifice

- Height: Height of the orifice
- Width: Width of the orifice
- InOffset: Inlet offset of the orifice
- DisCoeff: Discharge coefficient of the orifice

Weirs (inp_Weirs.*)
- Name: Name of the weir
- Inlet: Inlet of the weir
- Outlet: Outlet of the weir
- Type: Type of the weir
- Height: Height of the weir
- Length: Crest length of the weir
- InOffset: Inlet offset of the weir
- DisCoeff: Discharge coefficient of the weir

3. Model Set Up

There are several steps that need to be performed to successfully complete the set up and run of a SWMM model. For setting up a SWMM model, we have used EPA SWMM with Excel Editor, described in detail below. But, because the EPA SWMM cannot directly import GIS data to specify or define spatial information into a SWMM input file, we used PCSWMM – a commercial adaptation of EPA SWMM. Since PCSWMM can initially set up a SWMM model using GIS data (e.g., shapefiles), a modeler doesn't have to perform screen digitizing to identify SWMM modeling objects (e.g., subcatchments, junctions, conduits, etc.) using backdrop maps or images. This takes full advantage of the highly resolved spatial database developed in previous sections, and significantly reduces the time required to set-up a SWMM model for a small watershed. Doing this step also makes the conceptual representation of the watershed in SWMM software more realistic. The internal SWMM algorithm does not require geospatial reference of modeling objects for accurate simulation, but maintaining the representation of geographical realities in the model set-up makes the iterative process of modeling (i.e., model simulation, study of model output, parameter adjustment, and re-run) more efficient. Again, at the time of writing this document the EPA version of SWMM that is free for download at the EPA's website (https://www.epa.gov/water-research/storm-water-management-model-swmm#downloads) does not yet have a GIS file interface capability.

After importing the spatial data into PCSWMM (described subsequently), an input file is created. This input file can be read directly by EPA SWMM software, and, most importantly, can be adjusted using the "Excel Editor" function. This function allows for bulk editing of the input file, which takes advantage of our approach to subcatchment parameterization. The overall utility of this approach will hopefully become apparent as we proceed to describe the necessary steps below.

3.1 Initiate a SWMM Model Set Up using EPA SWMM

Download, install, and run the EPA SWMM program to create a blank or new project. Click [File/Save] under the main menu bar, then save your SWMM model (e.g., "SHC_SWMM.inp") to initiate the model set up process.

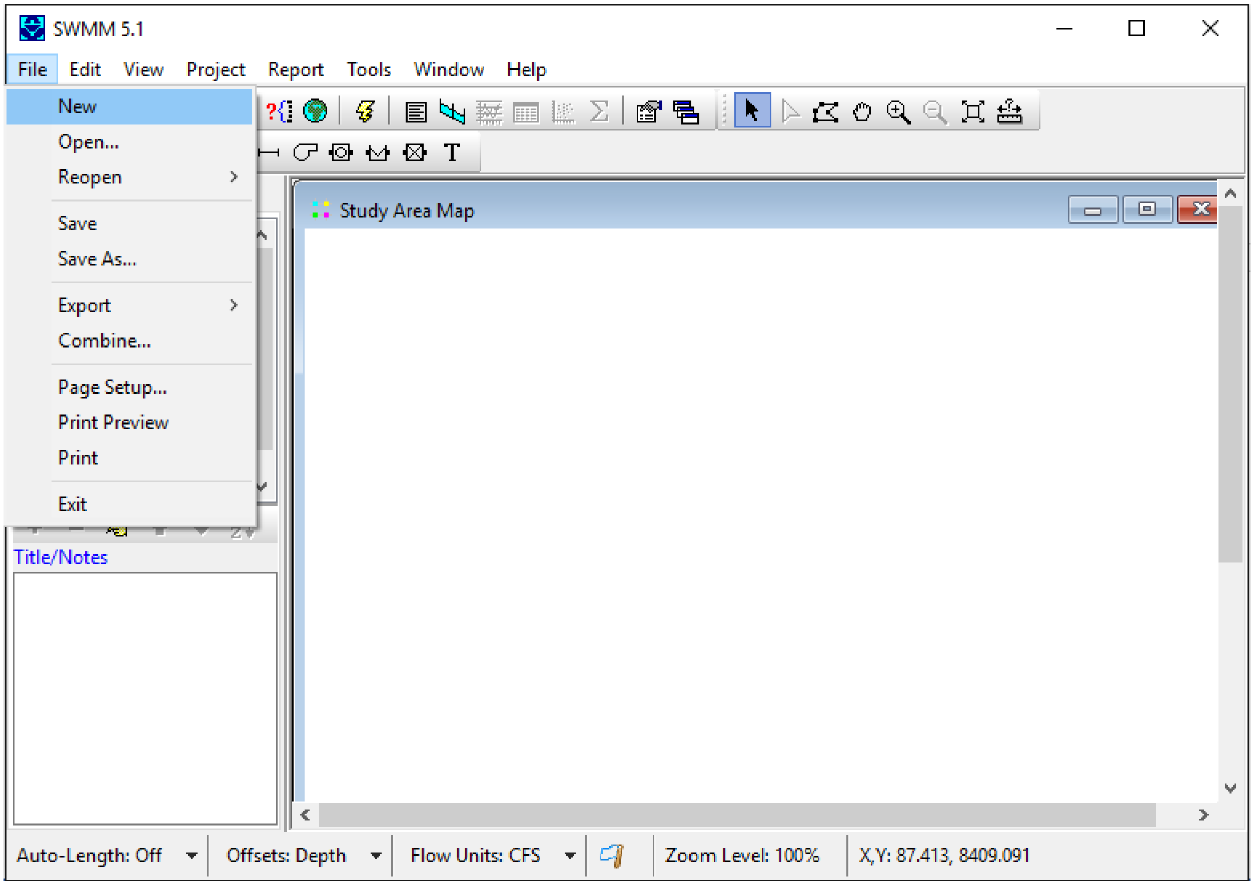


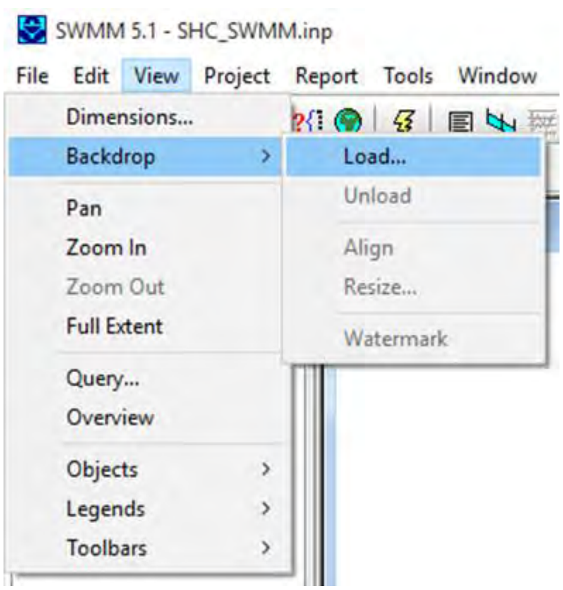
Figure 17. Opening page of the EPA SWMM 5.1 software program.

3.1.1 Set Backdrop Image for Spatial Reference

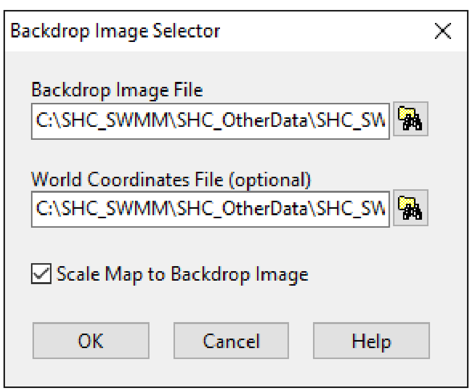
This procedure allows for a backdrop image to be added, positioned, and viewed behind the SWMM network map to allow for spatial reference. For using automatic distance and area calculation features in SWMM, it is essential to set the map dimensions immediately after creating a new project. The backdrop image must be a Windows metafile, bitmap, or JPEG image created outside of SWMM. Once imported, its features cannot be edited, although its scale and viewing area will change as the map window is zoomed and panned. For this reason, windows metafiles work better than bitmaps or JPEGs because they will not lose resolution when re-scaled. Most GIS programs have the ability to save the map layers as metafiles (Rossman, 2015).

A world coordinate file named *.*w (e.g., "SHC_SWMM.jgw) contains geo-referencing information for the backdrop image and can be created from the software that produced the image file or by using a text editor. See SWMM user manual for creating the file manually. If no world coordinate file is specified, then the backdrop will be scaled to fit into the center of the map display window.

⇨ Run EPA SWMM



⇨ Click [View/Backdrop/Load] to import a backdrop image (e.g., "SHC_SWMM.jpg).



⇨ Locate the 'Backdrop Image File' (e.g., SHC_SWMM.jpg)

⇨ Locate the 'World Coordinates File' (e.g., SHC_SWMM.jgw)

⇨ Mark the 'Scale Map to Backdrop Image'

⇨ Click [OK]

3.1.2 Set Rainfall Data for the Study Area

To perform rainfall runoff calculations, each study area must include a rain gage. For SHC SWMM modeling, user defined precipitation data was arranged using the monitoring data and NEXRAD data as presented in Section 2.1.2. The site-specific 10-min, 0.1-mm tipping bucket data was primarily used. The NEXRAD data used in the Lower EFW SWAT modeling effort was used to compensate for some missing periods in the monitoring data. The user defined rainfall data file is named ‘SHC_amd_10min_intensity.dat’. This file consists of the following 7 columns of data: ‘Station ID (SHC_amend)’, ‘Year’, ‘Month’, ‘Day’, ‘Hour’, ‘Minute’, and ‘Precipitation (as intensity, in/hr)’ with ‘tab’ delimiters.

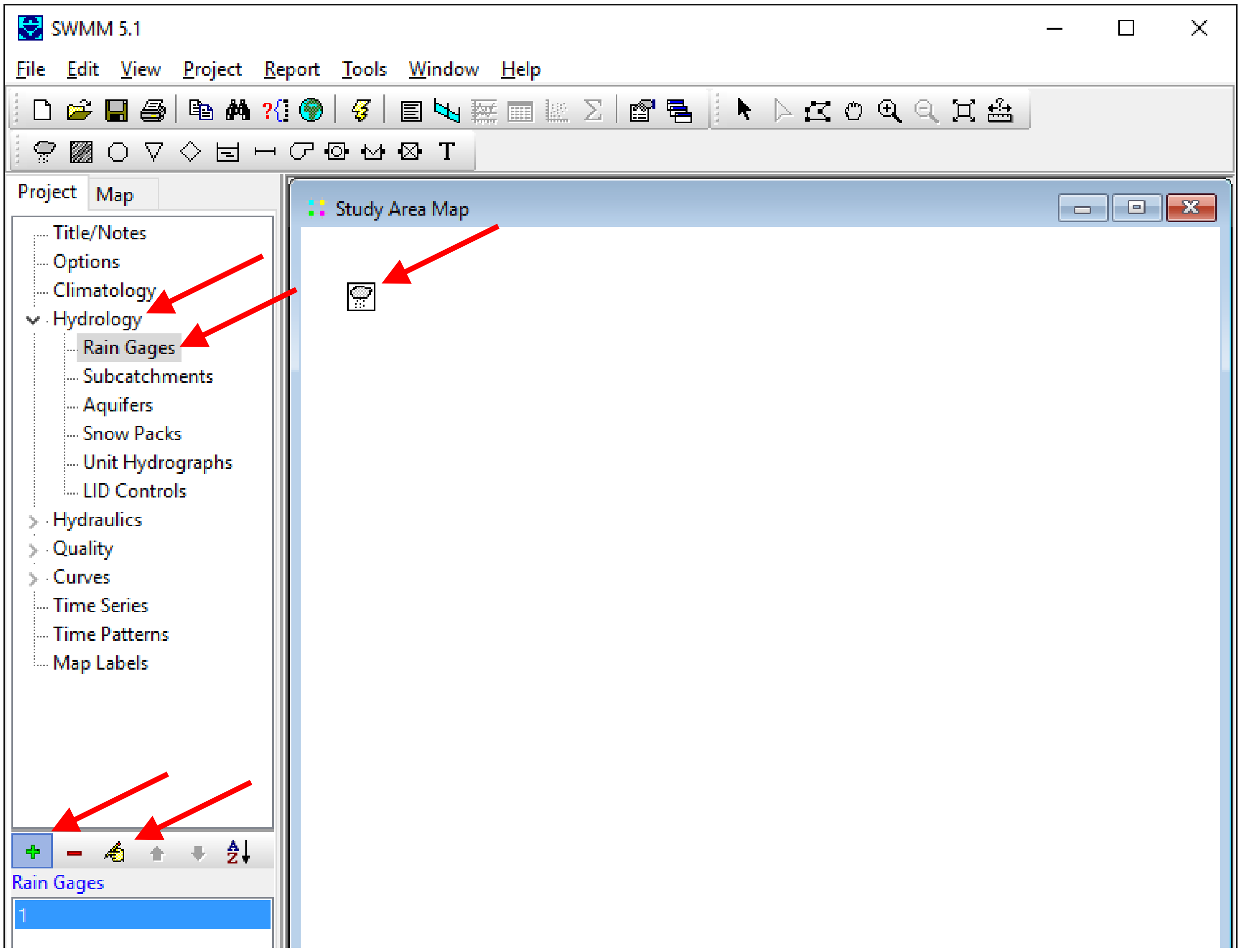
SHC_amd_10min_intensity.dat - Notepad

File Edit Format View Help

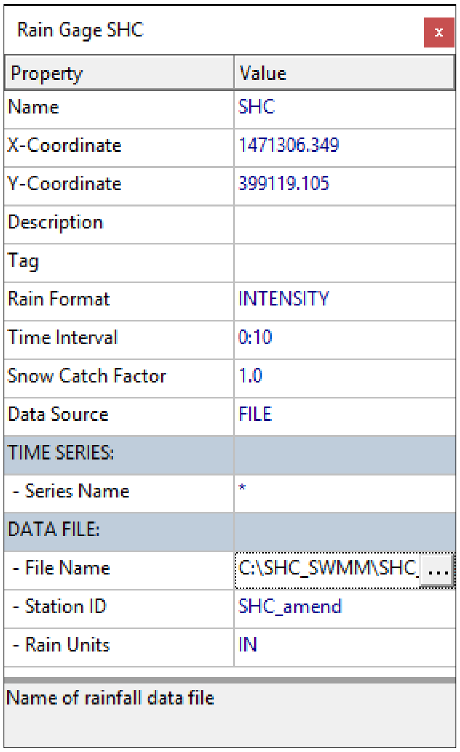
```
;Rainfall data collected at the SHC Station w/ 10-min intervals
;Some missing data were amended using the hourly SWAT-PCP data at SHC
;Station        Year    Month   Day     Hour    Minute  Rainfall (in/hr)
SHC_amend       2009    1       10      5       50      0.06
SHC_amend       2009    1       10      7       0       0.06
SHC_amend       2009    1       10      8       10      0.06
SHC_amend       2009    1       10      8       40      0.06
SHC_amend       2009    1       10      9       0       0.06
SHC_amend       2009    1       10      9       10      0.06
SHC_amend       2009    1       10      9       20      0.06
SHC_amend       2009    1       10      9       40      0.12
SHC_amend       2009    1       10      9       50      0.12
SHC_amend       2009    1       10      10      0       0.12
SHC_amend       2009    1       10      10      10      0.12
SHC_amend       2009    1       10      10      20      0.24
SHC_amend       2009    1       10      10      30      0.24
SHC_amend       2009    1       10      10      40      0.42
SHC_amend       2009    1       10      10      50      0.78
SHC_amend       2009    1       10      11      0       0.36
SHC_amend       2009    1       10      11      10      0.06
SHC_amend       2009    1       10      12      20      0.06
```

To assign this user defined data to the model setup, follow the detailed steps outlined on page 23 of the SWMM User’s Manual. To add a rain gage:

- ⇨ Select the ‘Hydrology’ under the ‘Project’
- ⇨ Select ‘Rain Gages’ under ‘Hydrology’
- ⇨ Click [Add Object] button
- ⇨ Click any location of the ‘Study Area Map’ to place a rain gage
- ⇨ Specify rainfall data by clicking [Edit Object] button in the Project Browser (on the Left bottom of the screen shown above) and edit the object properties as defined below and the image immediately following the text:



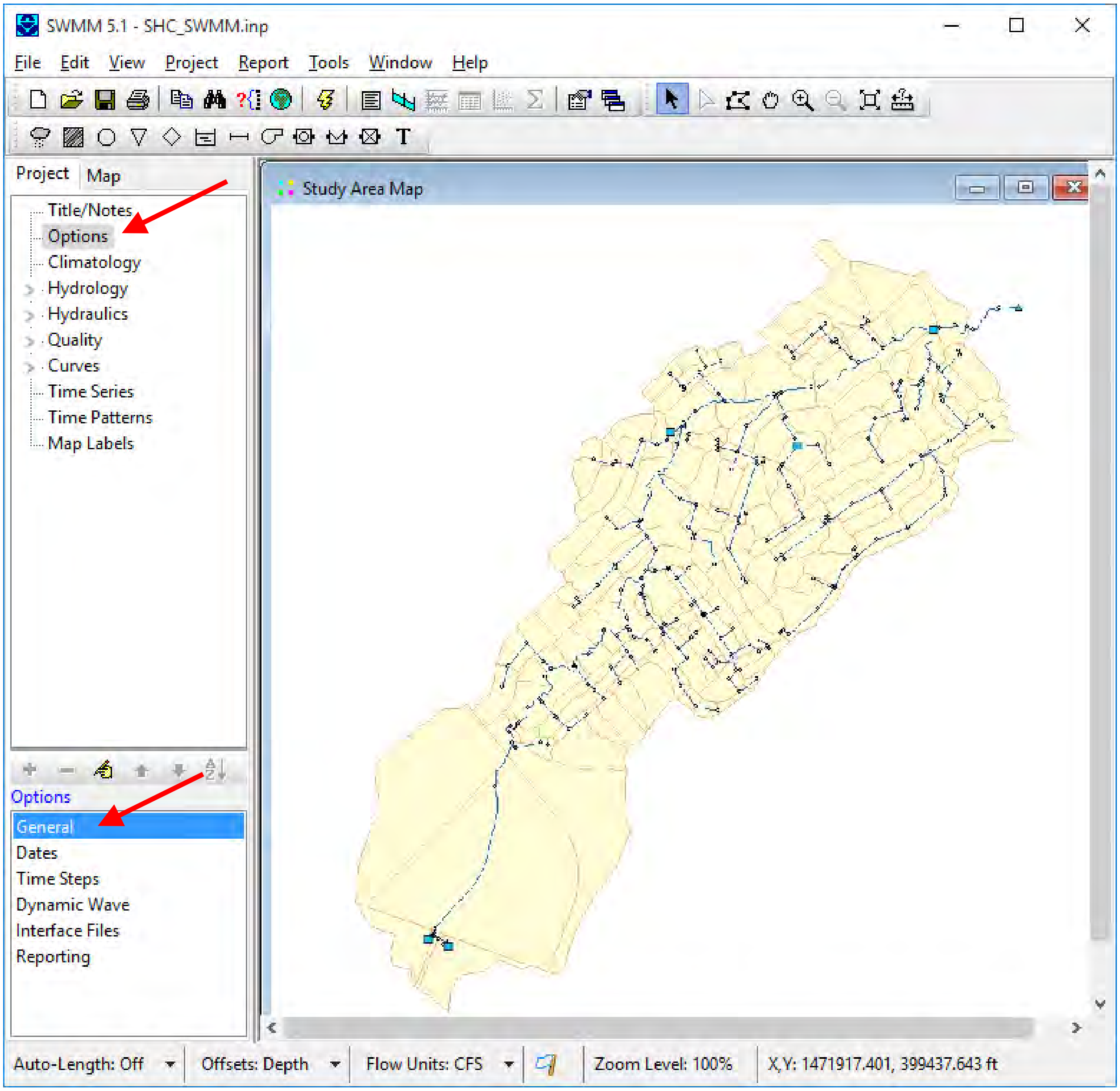
- Name: 'SHC' (Default value is "Gage 1")
- Rain Format: 'INTENSITY' (this is the Default Value)
- Time Interval: '0:10' (Default value is 1:00 i.e., 1-hour)
- Data Source: 'FILE' (Default value is "TIMESERIES")
- File Name: "SHC_amd_10min_intensity.dat"
- Station ID: "SHC_amend" (Should match the name contained in the .dat file selected above)
- Rain Units: 'IN'



⇨ Close the box after defining the aforementioned object properties.

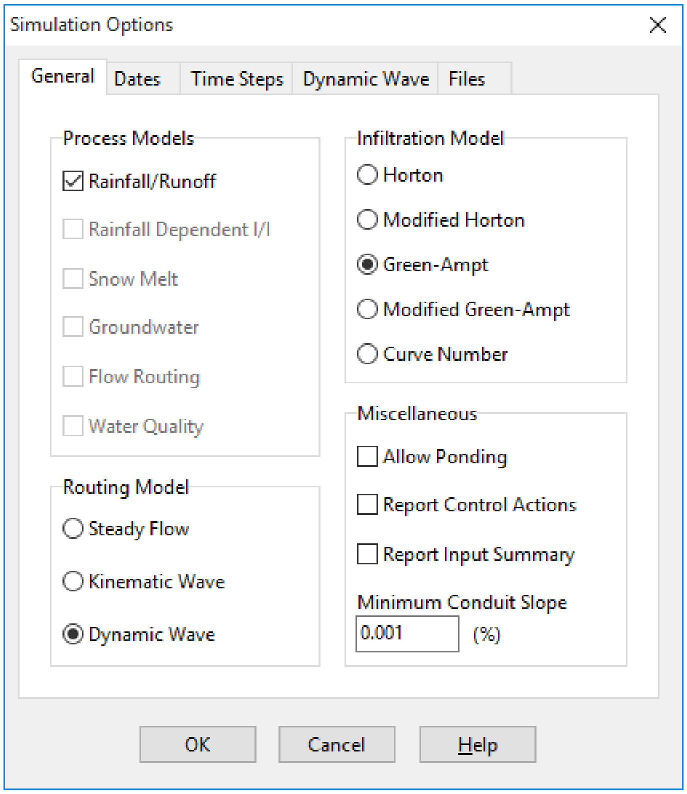
3.1.3 Set Model Options

SWMM has a number of options that control how the simulation of a stormwater drainage system is performed. These options are selected from the Options category from the Project Browser (as shown):



⇨ Select the 'Options' under the 'Project'

⇨ Double click 'General' under the 'Options'

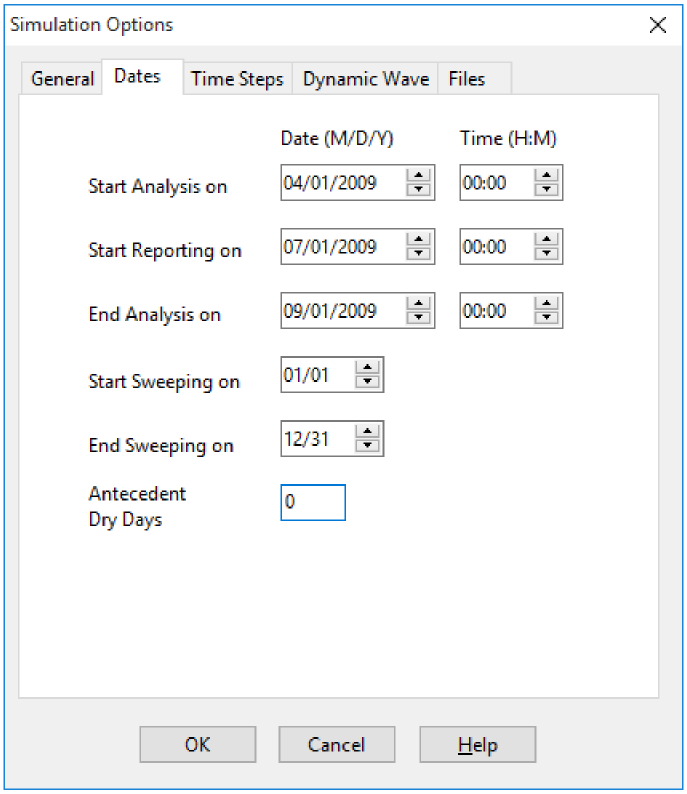


⇨ Specify the "General" options as shown above.

A value of 0.001% is recommended for minimum conduit slope. If the default value (blank or zero) is chosen then no minimum is imposed, but SWMM uses a lower limit on the elevation drop of 0.001 ft (0.00035 m) when computing a conduit slope.

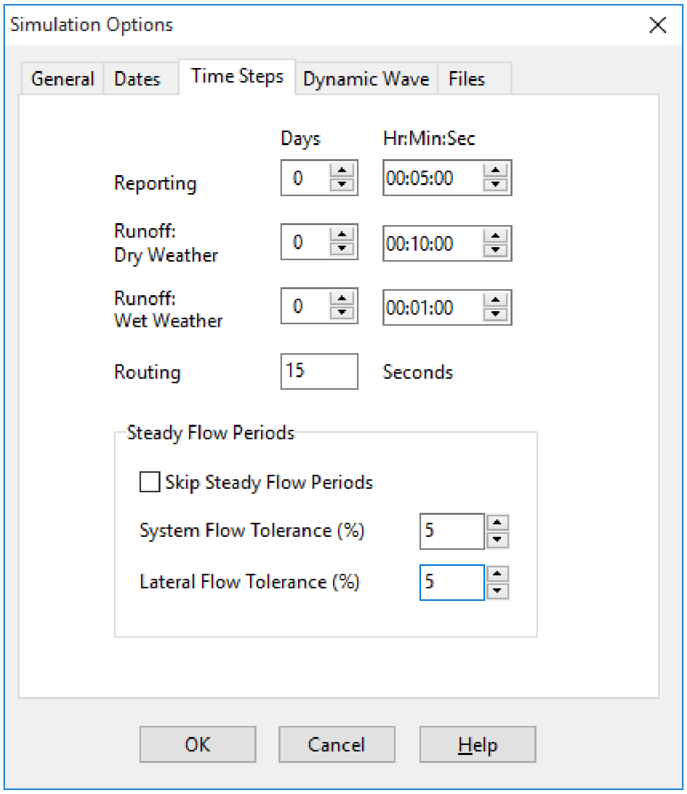
The SWMM default option for a routing model is the Kinematic Wave method, which is an efficient but simplified approach that cannot deal with such phenomena as backwater effects, pressurized flow, flow reversal, and non-dendritic layouts. The Dynamic Wave routing procedure was chosen in case these conditions need to be represented. Note, the Dynamic Wave procedure requires more computation time, due to the need for smaller time steps to maintain numerical stability.

SWMM offers three options for modeling infiltration: Horton's Equation, Green-Ampt Method and Curve Number Method. Infiltration accounts for the process of rainfall penetrating the ground surface of pervious areas to move into the unsaturated soil zone of subcatchment areas. The default method used by SWMM is the Horton's Equation, which is based on empirical observations showing that infiltration decreases exponentially from an initial maximum rate to some minimum rate over the course of a long rainfall event. In this project, the Green-Ampt Method was chosen. This method assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. The input parameters required are the initial moisture deficit of the soil, the soil's hydraulic conductivity, and the suction head at the wetting front. The recovery rate of the moisture deficit during dry periods is empirically related to the hydraulic conductivity. The Curve Number Method is adopted from the NRCS (formally, SCS) Curve Number method for estimating runoff which is designed for a single storm event, it can be scaled to find average annual runoff values.



⇨ Double click 'Dates' under the 'Options' tab to set the date to match the simulation period and the available rainfall data.

Under the date options, it is typical to define a model "warm up" period before data is reported. In this case, a 3-month period between April 1, 2009 and July 1, 2009 was used. The sweeping (associated with street sweeping operations) and antecedent dry days are not used in this model setup.



⇨ Double click 'Time Steps' tab to set the options presented above

The reporting time interval (default value is 15 minutes) is used for reporting results. The Runoff – Wet Weather time step (default value is 5 minutes) is used to compute runoff from subcatchments during periods of rainfall, or when ponded water still remains on the surface, or when LID controls are still infiltrating or evaporating runoff. The Runoff – Dry weather time step (default value is 1 hour) used for runoff computations (consisting essentially of pollutant buildup) during periods when there is no rainfall, no ponded water, and LID controls are dry. This time step must be greater or equal to the Wet Weather time step. The routing time step length (default value is 30 seconds) is used for routing flows and water quality constituents through the conveyance system. Note that Dynamic Wave routing requires a smaller time step compared to the other methods of flow routing.

⇨ Use the default values for 'Dynamic Wave' and 'Files' tabs.

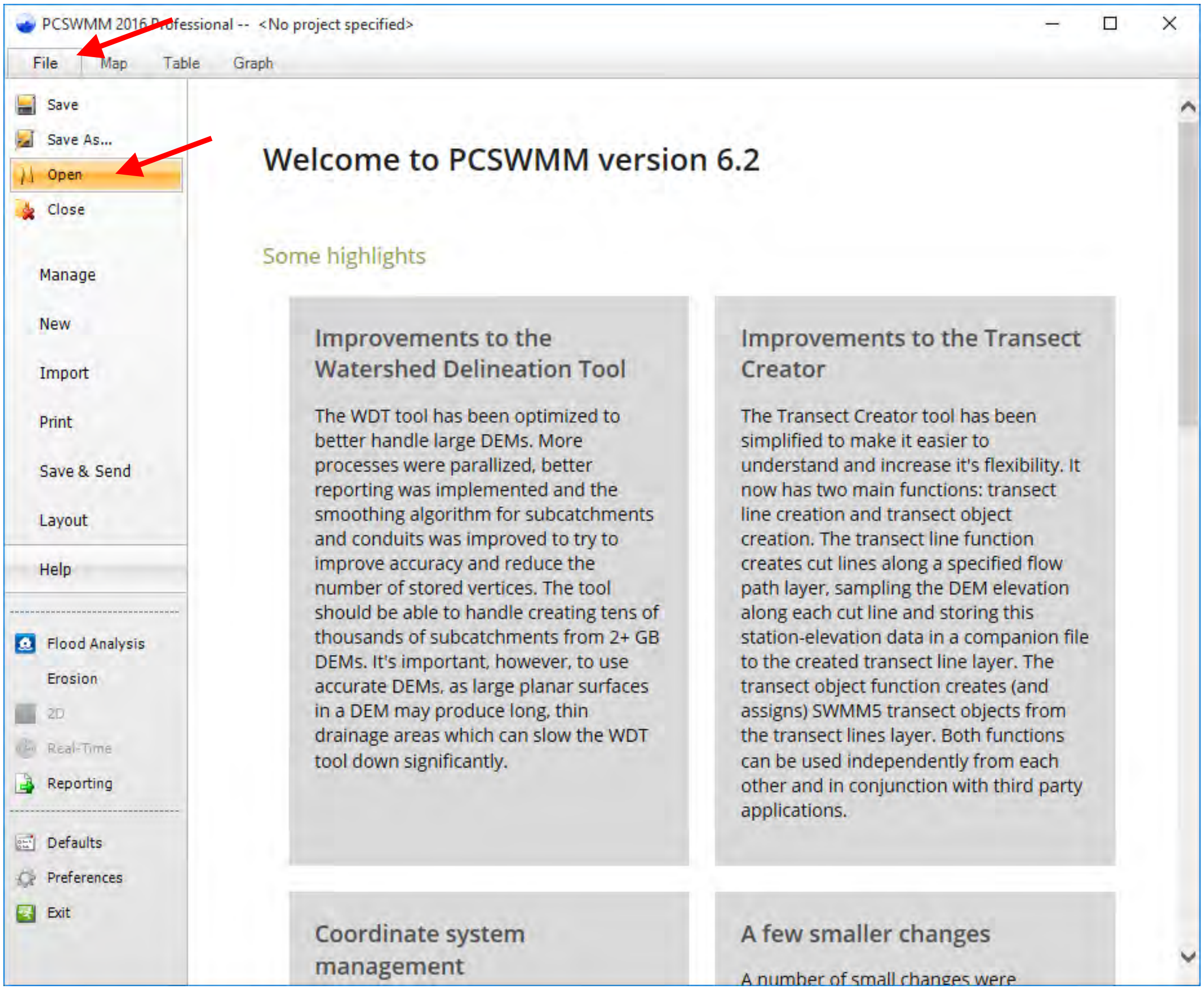
⇨ Click [OK] button to finish specifying the 'Simulation Options'

⇨ Save the current project and close EPA SWMM.

While the remainder model set up can be performed using the SWMM model's built-in menus/icons/ tools as described in the SWMM User's Manual (Rossman, 2015). In this project, we used the PCSWMM model to import GIS data to the SWMM model, which is described in the next section.

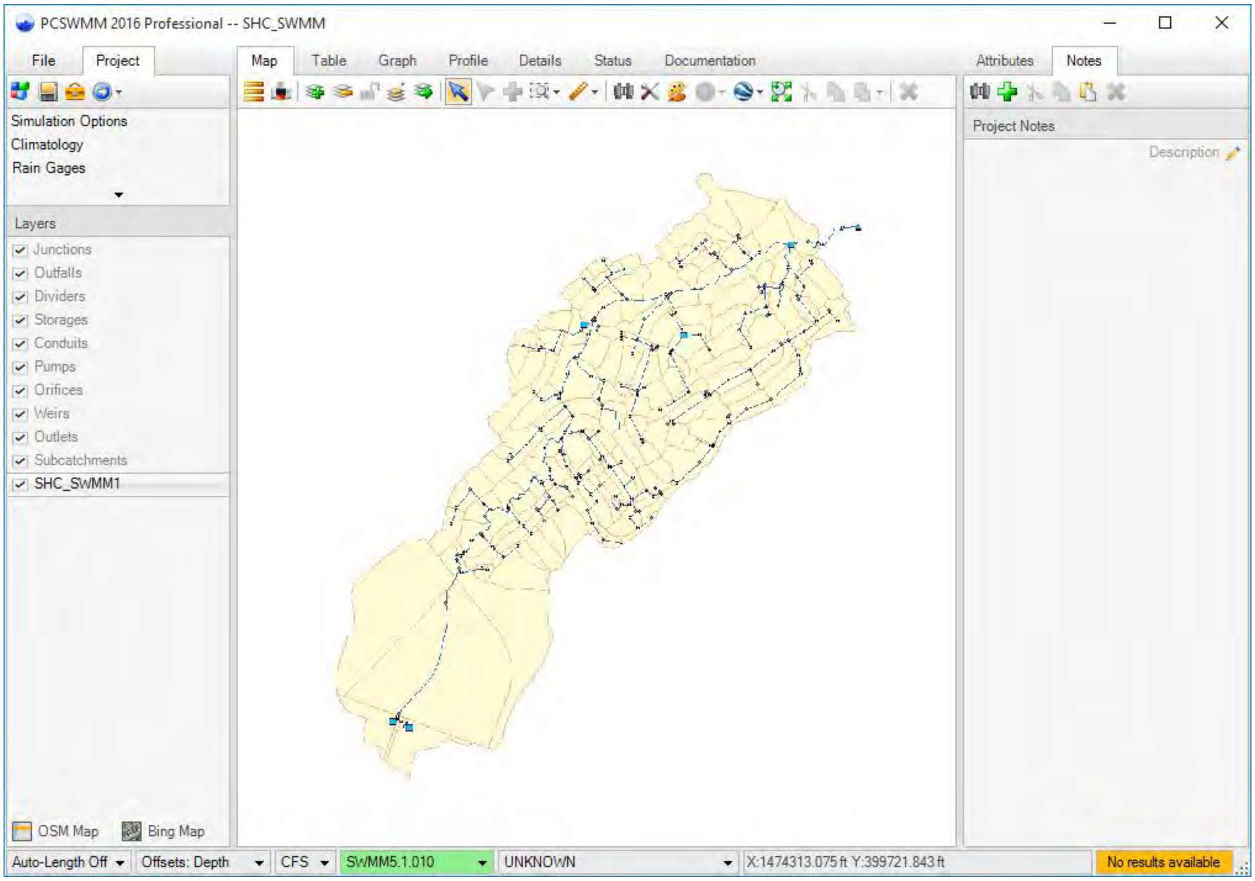
3.2 Import Processed GIS Data to the SWMM Model using PCSWMM

PCSWMM needs to be downloaded, installed, licenses activated, and then run. When the program is run the following window opens.



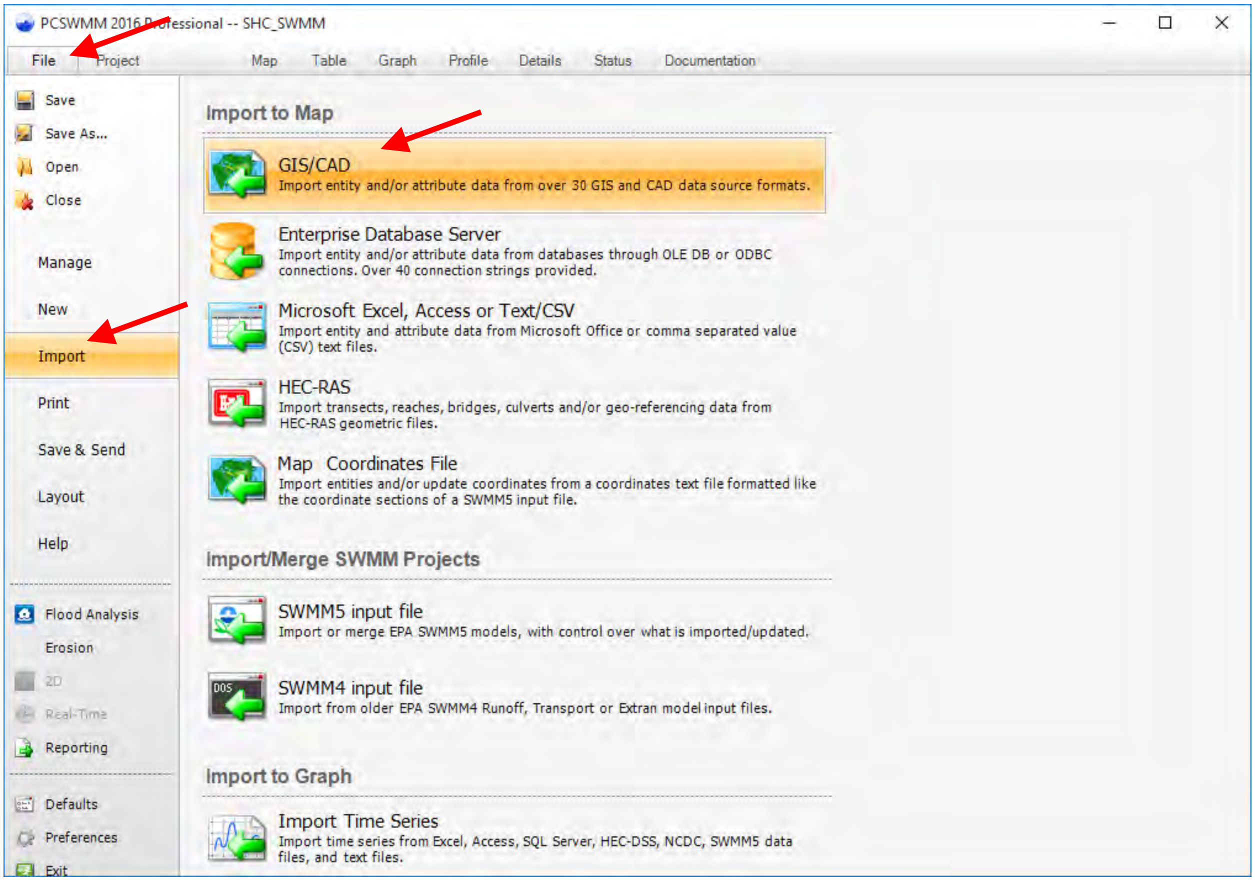
⇨ Click [File/Open] to open the SWMM file ("SHC_SWMM.inp") previously saved at the end of Section 3.1.

This will import the file and load the backdrop image. Setting up the source layers for the PCSWMM project requires specifying the file location and attributes of the data that were generated as part of following the procedures outlined in section 2.4.5.

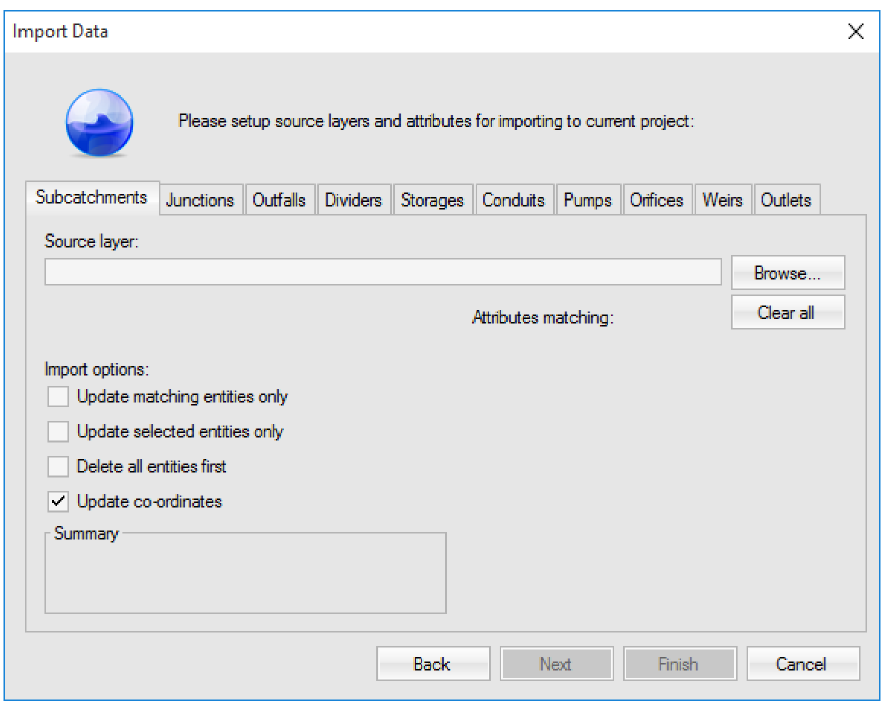


3.2.1 Importing Subcatchment GIS Layer

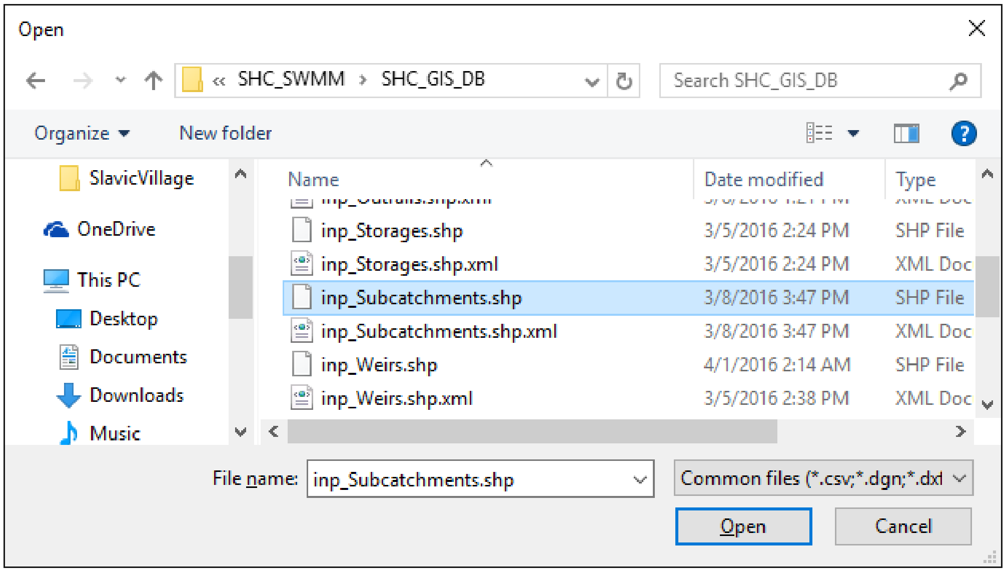
The following steps import the Subcatchment GIS shapefile into a SWMM input file format using PCSWMM.



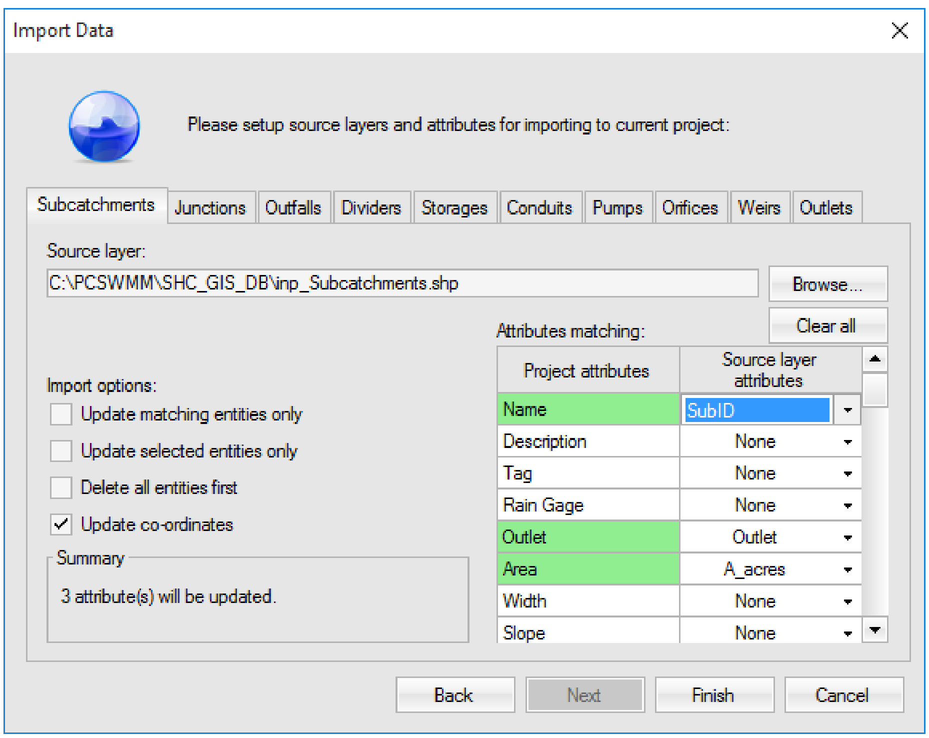
⇨ Click [File/Import], then select the ‘GIS/CAD’ option in the main window



⇨ Select the [Subcatchments] tab, then click [Browse…] button to import GIS data for 'Subcatchments'



⇨ Locate the relevant shapefile (inp_Subcatchments.shp), then click [Open] button.



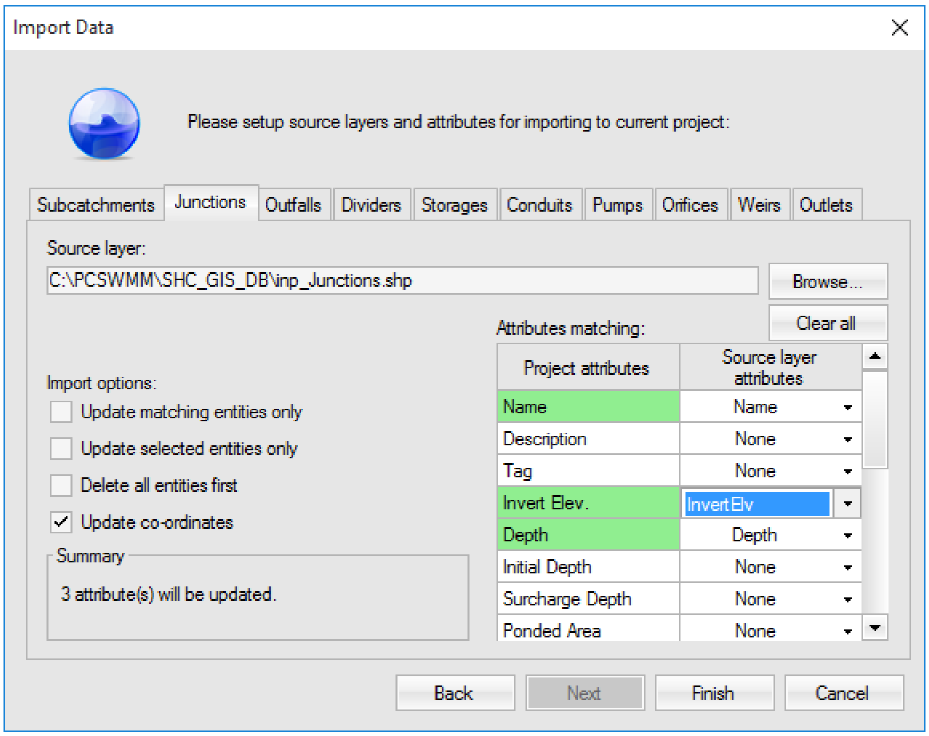
⇨ Specify relevant attributes for 'Name', 'Outlet', and 'Area'

PCSWMM will try to automatically match the required project attributes with source layer attributes (shown in green). One should confirm all of the individual matches. For this layer, match the following three key attributes: Name – 'SubID', Outlet – 'Outlet', and Area –

'A_acres'. Depending upon how the shapefile was created, there may be other GIS attributes that need not be imported. The other required subcatchment object attributes will be imported later from the MS-Excel tables that were prepared during the data preparation step shown previously in Section 2.4.

3.2.2 Importing Junctions GIS Layer

The following steps need to be performed to import the Junctions GIS shapefile into a SWMM input file format using PCSWMM.



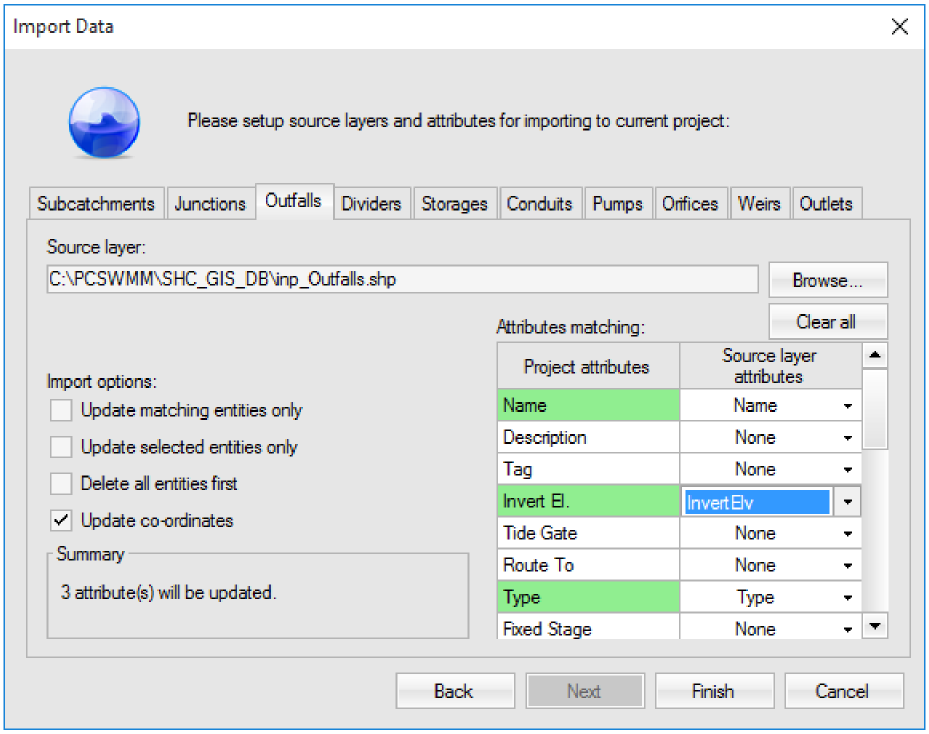
⇨ Import GIS data for 'Junctions'

⇨ Open the relevant shapefile (inp_Junctions.shp) for the [Junctions]

⇨ Specify 'Attributes' matching: Name – 'Name', Invert Elev. – 'InvertElv', and Depth – 'Depth'

3.2.3 Importing Outfalls GIS Layer

The following steps need to be performed to import the Outfalls GIS shapefile into a SWMM input file format using PCSWMM.



⇨ Import GIS data for 'Outfalls'

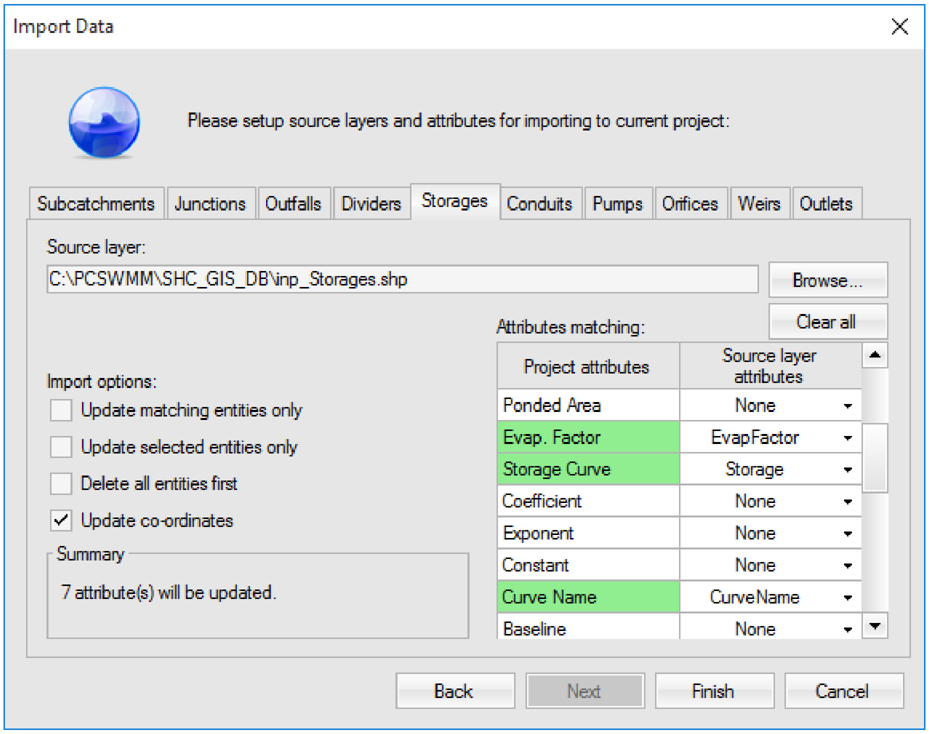
⇨ Open the relevant shapefile (inp_Outfalls.shp) for the [Outfalls]

⇨ Specify 'Attributes' matching: Name – 'Name', Invert El. – 'InvertElv', Type – 'Type'

⇨ (Skip the next tab. Dividers are not used in SHC)

3.2.4 Importing Storage GIS Layer

The following steps need to be performed to import the Storage GIS shapefile into a SWMM input file format using PCSWMM.



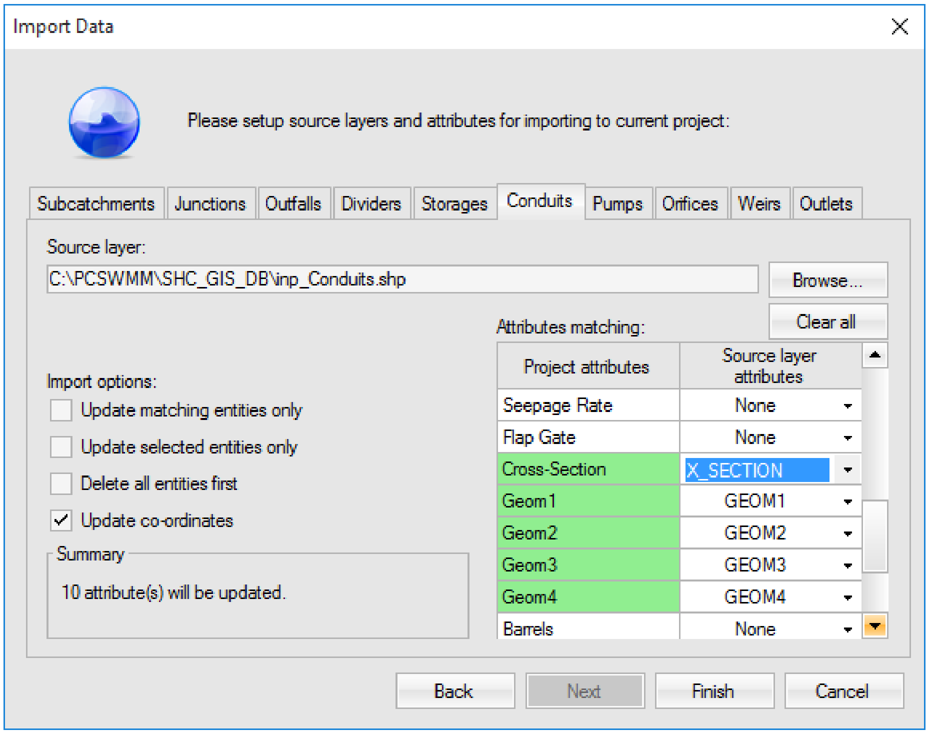
⇨ Import GIS data for ‘Storages’

⇨ Open the relevant shapefile (inp_Storages.shp) for the [Storages]

⇨ Specify ‘Attributes’ matching: Name – ‘Name’, Invert El. – ‘InvertElv’, Depth – ‘Depth’, Initial Depth – ‘Init_Depth’, Evap. Factor – ‘EvapFactor’, Storage Curve – ‘Storage’, and Curve Name – ‘CurveName’

3.2.5 Importing Conduits GIS Layer

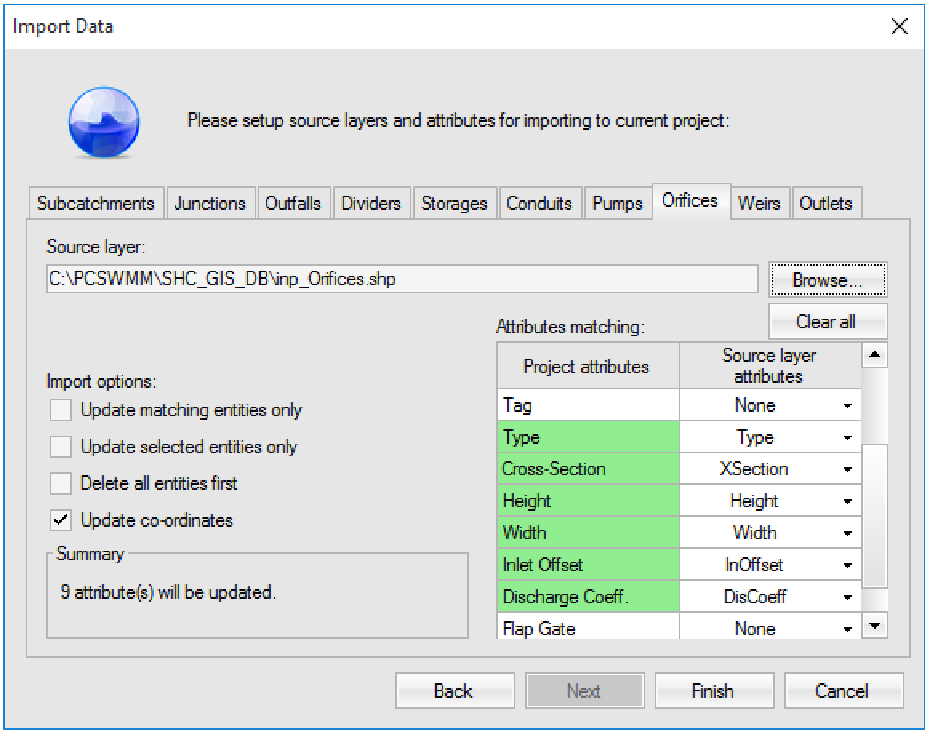
The following steps need to be performed to import the Conduits GIS shapefile into a SWMM input file format using PCSWMM.



- ⇨ Import GIS data for ‘Conduits’
- ⇨ Open the relevant shapefile (inp_Conduits.shp) for the [Conduits]
- ⇨ Specify ‘Attributes’ matching: Name – ‘Name’, Inlet Node – ‘InletNode’, Outlet Node – ‘OutletNode’, Length – ‘Length’, Roughness – ‘Roughness’, Cross-Section – ‘X_Section’, Geom1 – ‘GEOM1’, Geom2 – ‘GEOM2’, Geom3 – ‘GEOM3’, and Geom4 – ‘GEOM4’
- ⇨ (Skip Pumps tab)

3.2.6 Importing Orifices GIS Layer

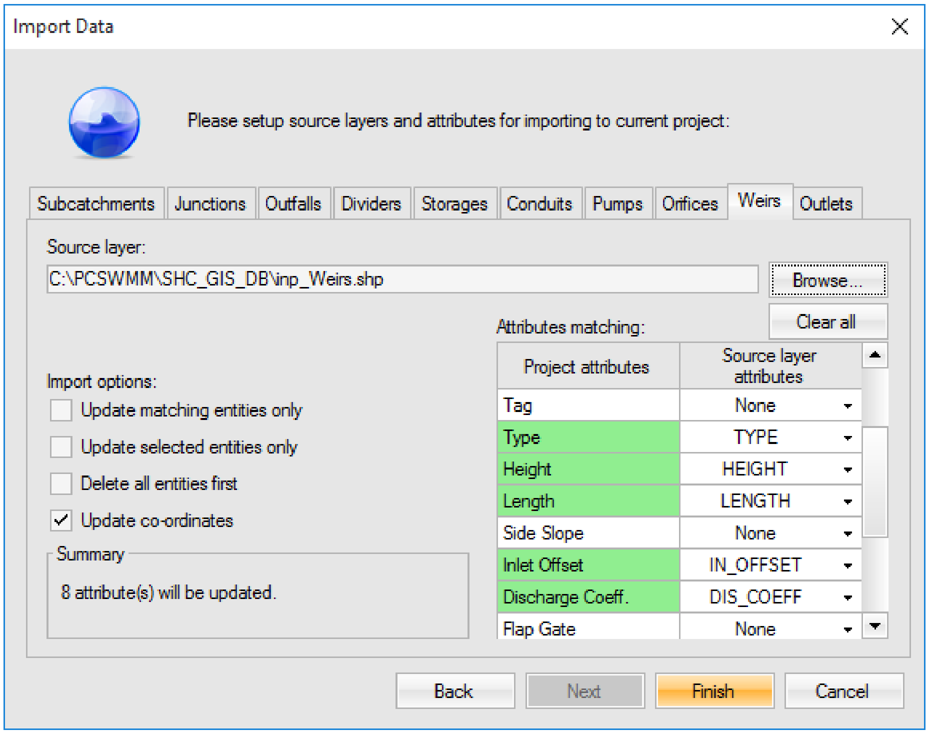
The following steps need to be performed to import the Orifices GIS shapefile into a SWMM input file format using PCSWMM.



- ⇨ Import GIS data for ‘Orifices’
- ⇨ Open the relevant shapefile (inp_Orifice.shp) for the [Orifices]
- ⇨ Specify ‘Attributes’ matching: Name – ‘Name’, Inlet Node – ‘Inlet’, Outlet Node – ‘Outlet’, Type – ‘Type’, Cross Section – ‘XSection’, Height – ‘Height’, Width – ‘Width’, Inlet Offset – ‘InOffset’, and Discharge Coefficient – ‘DisCoeff’

3.2.7 Importing Weirs GIS Layer

The following steps need to be performed to import the Weirs GIS layer in shapefile into a SWMM input file format using PCSWMM.



⇨ Import GIS data for 'Weirs'

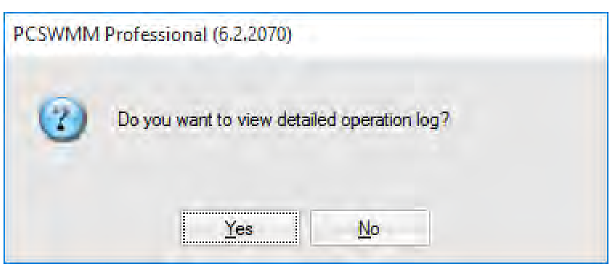
⇨ Open the relevant shapefile (inp_Weirs.shp) for the [Weirs]

⇨ Specify 'Attributes' matching: Name – 'Name', Inlet Node – 'Inlet', Outlet Node – 'Outlet', Type – 'Type', Height – 'Height', Length – 'Length', Inlet Offset – 'In_Offset', and Discharge Coefficient – 'Dis_Coeff'

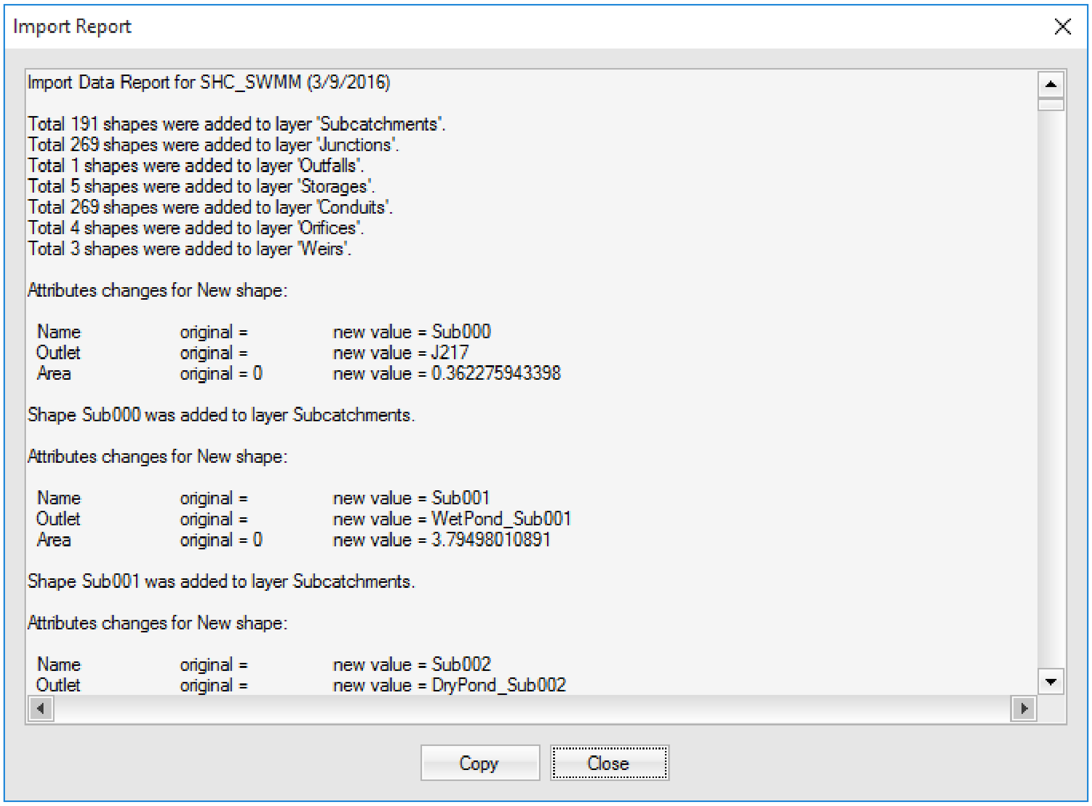
3.2.8 Completing GIS Layer Imports

The following steps complete the import of the various GIS layers into a SWMM input file format using PCSWMM.

⇨ Click 'Finish' to complete importing the GIS data

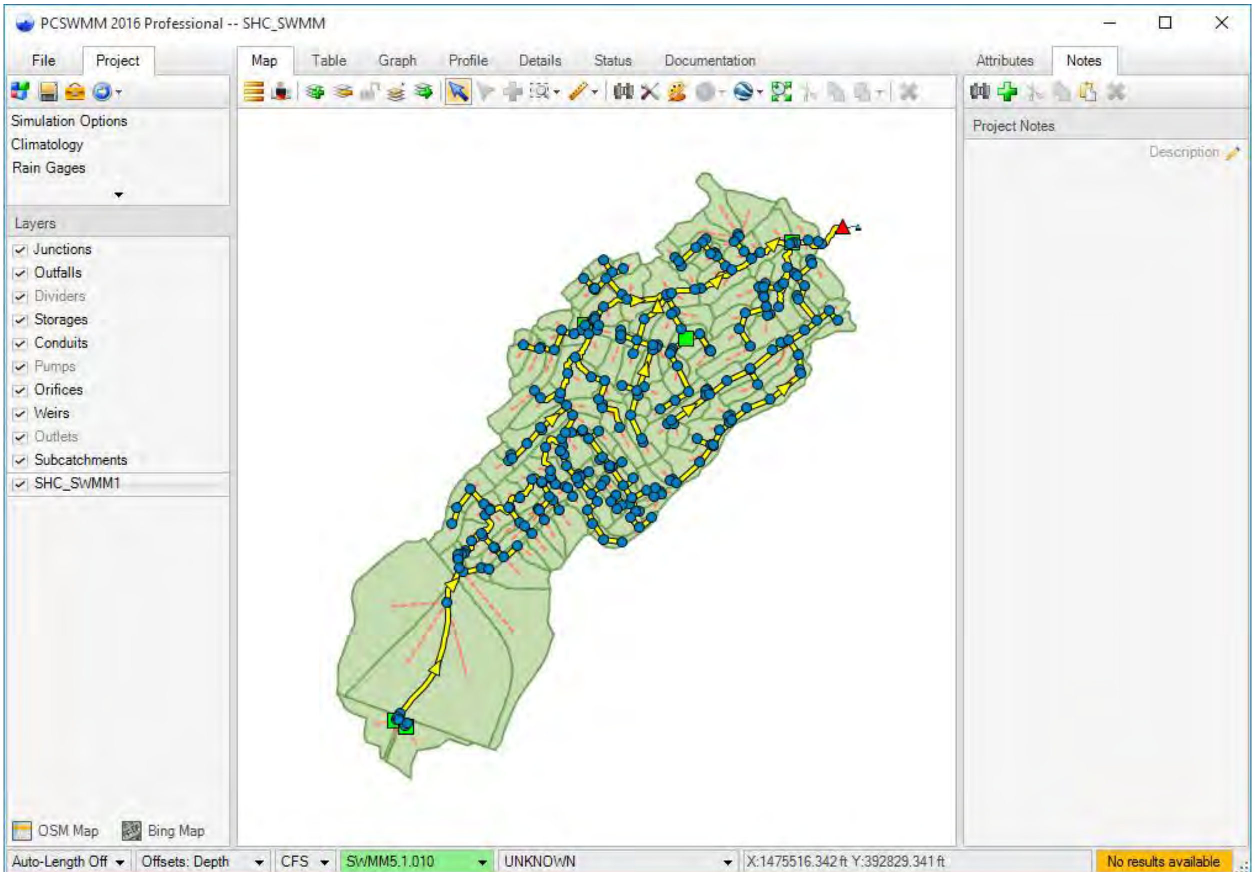


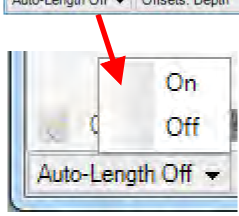
⇨ Click 'Yes' button if you want to check the data import status



⇨ Click 'Close'

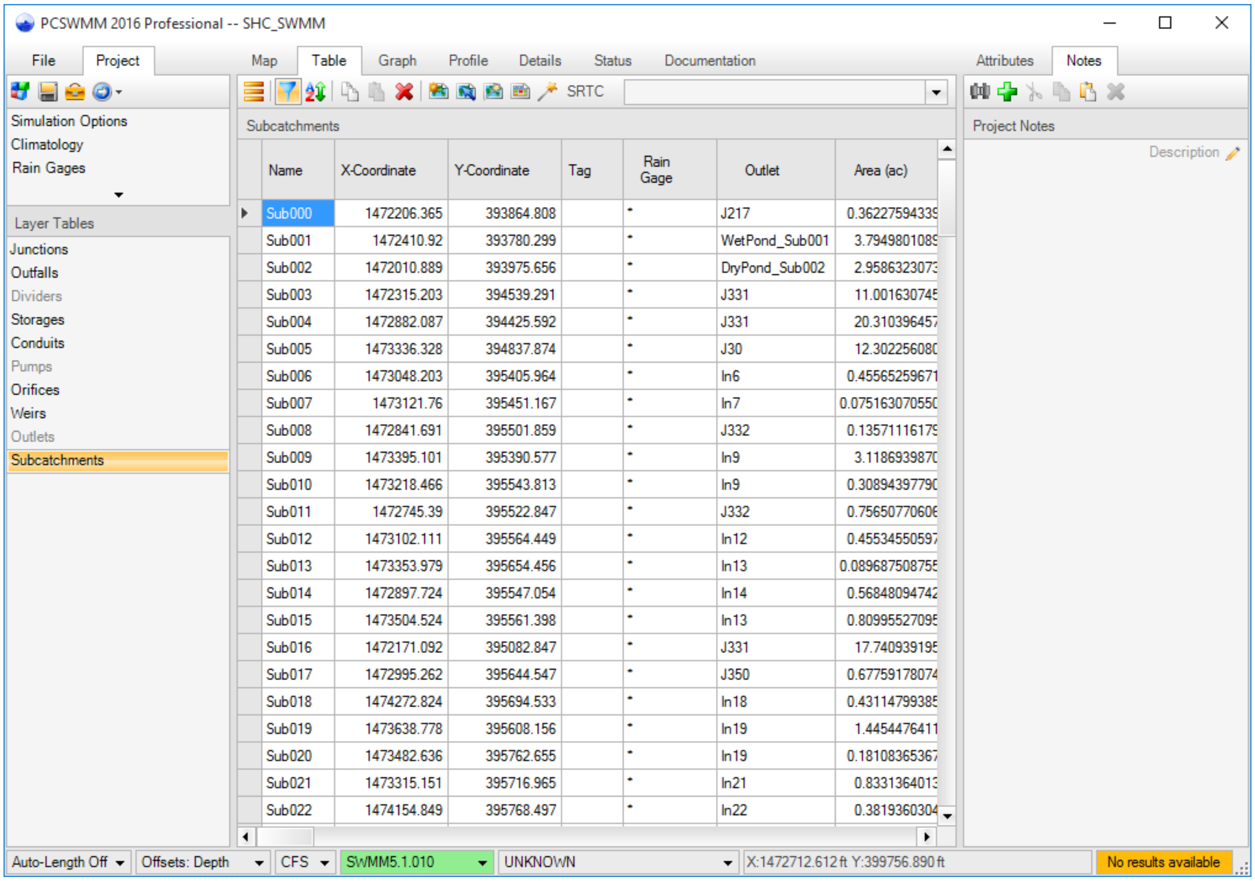
PCSWMM imported GIS data as shown below.





⇨ Specify 'Auto-Length' as 'Off'

In this project auto update of lengths was set to 'Off' because all of the estimates will be supplied from another data file (see Section 3.3). Attribute data can be updated using PCSWMM as briefly described below.

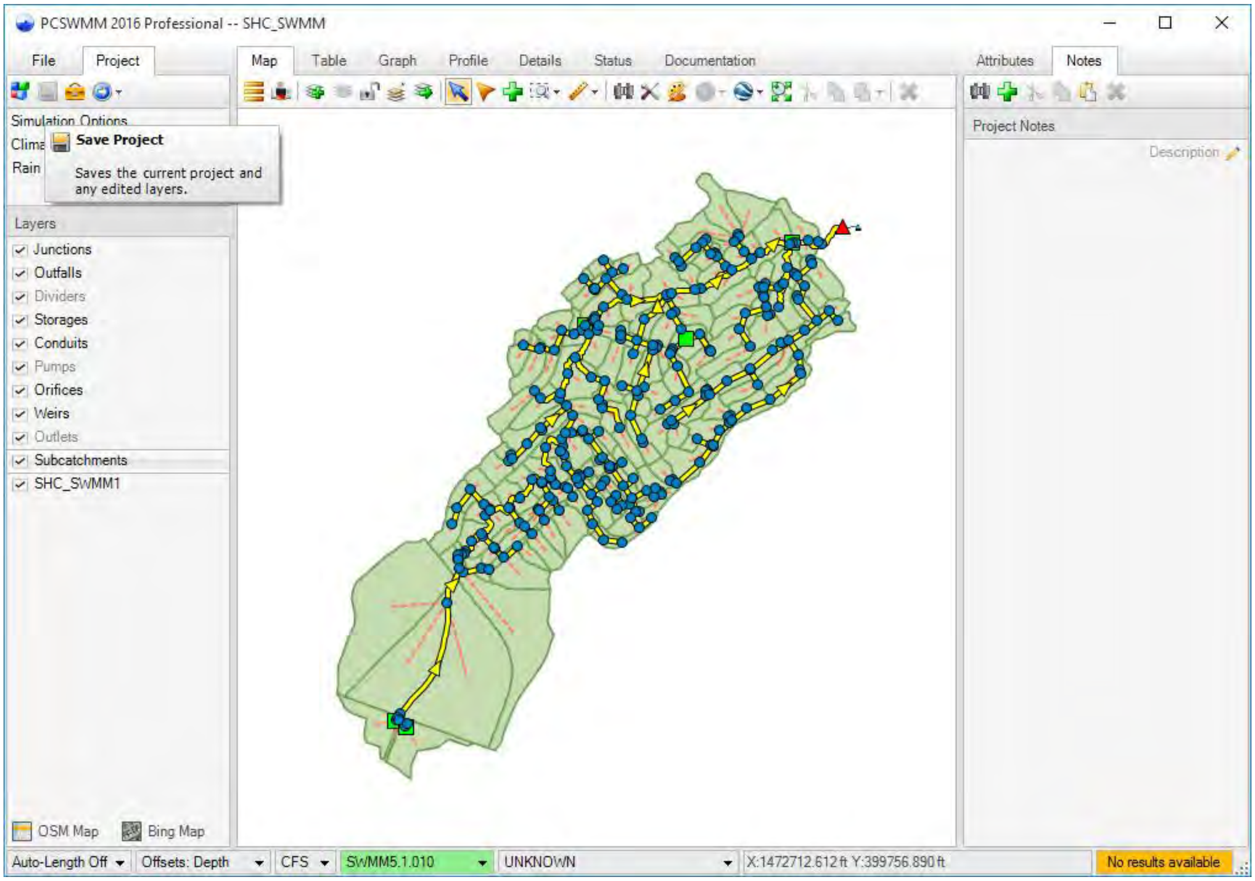


⇨ Update attributes under the [Table] tab

⇨ Select "Subcatchments" under the [Table] tab: You can copy/paste column by column from the Excel file ("SHC_SWMM_DataProcessing.xlsx") to this table

Note: Copy/pasting can be done only one column at a time in PCSWMM.

You can check/edit the other tables for "Junctions", "Outfalls", "Storages", "Conduits", "Orifices", and "Weirs"



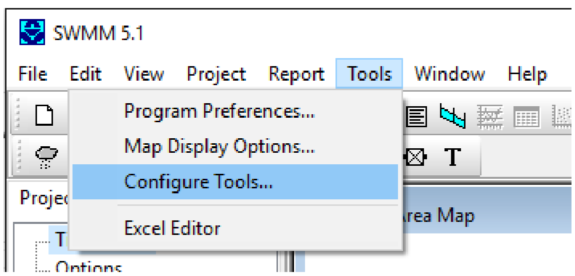
⇨ Save the SWMM Project, then close PCSWMM

3.3 Import Modeling Parameters to the SWMM Model using EPA SWMM and the Excel Editor

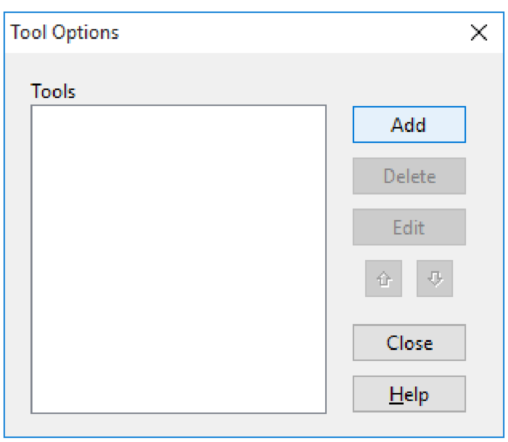
In order to use Excel to import modeling parameters, Excel needs to be configured as a tool that can be launched within the SWMM interface. Also, Excel can use various formats to organize data in rows and columns (e.g., comma separated variable, tab delimited, etc.). The tab delimited format is compatible with the SWMM input file (*.inp) storage format. Therefore, this configuration will be used so that data processed in MS-Excel can be imported directly into SWMM input files. To facilitate the direct import, first the Excel tool needs to be configured in SWMM for use and then specific "blank" input object data structure needs to be created initially in SWMM (for each type of structure that is represented in this modeling effort) to allow for such direct data import.

3.3.1 Configure the Excel Editor as Tool in SWMM

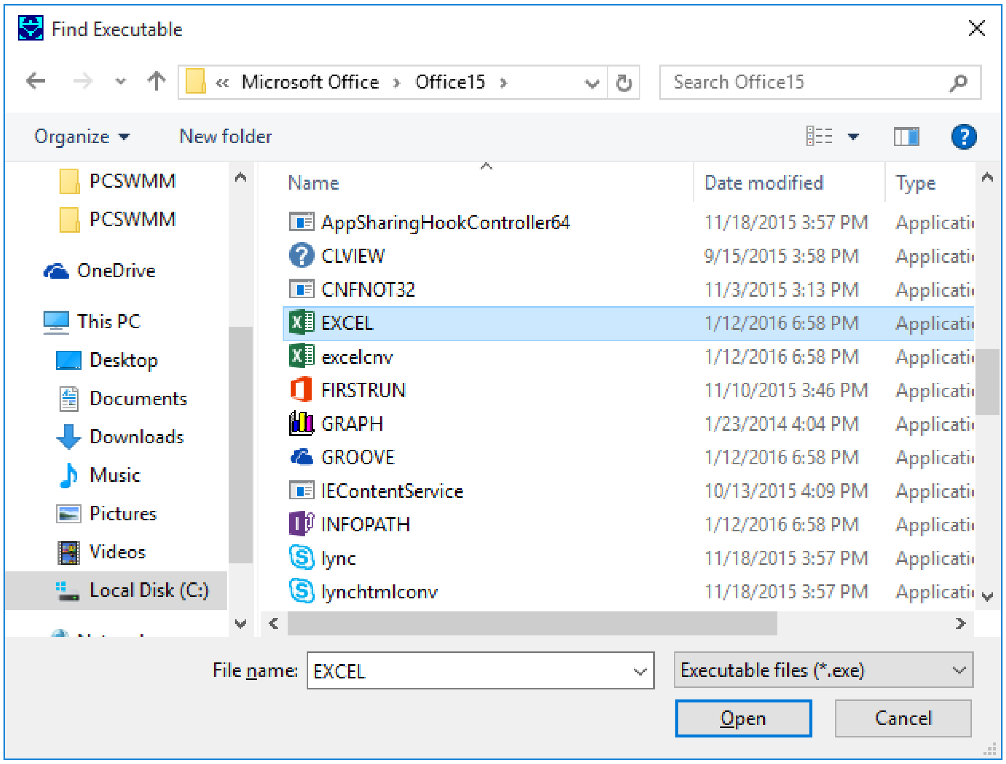
The following steps need to be performed to configure MS-Excel as an editing tool in SWMM.



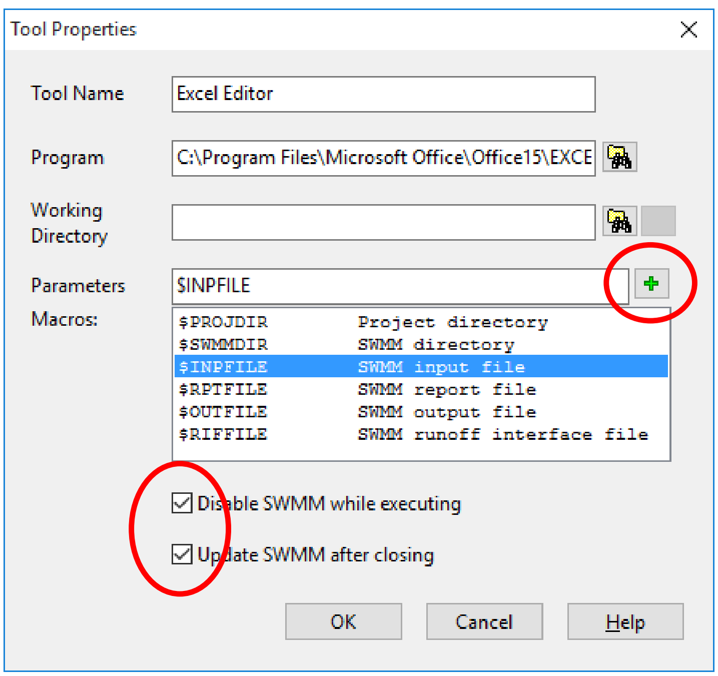
⇨ Select 'Tools / Configure Tools' under the Main Menu of the EPA SWMM



⇨ Click 'Add' button



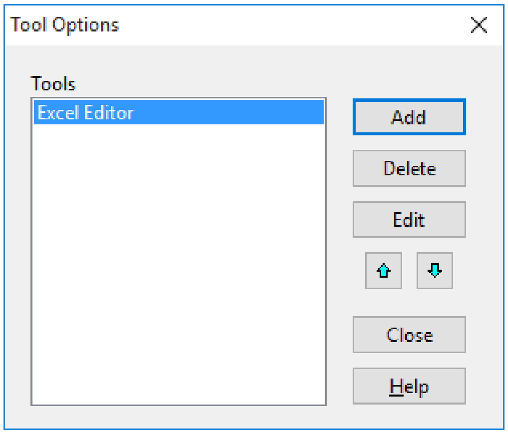
⇨ Locate the 'EXCEL.EXE' file, then click [Open] button



⇨ Add '$INPFILE' for 'Parameters' using button

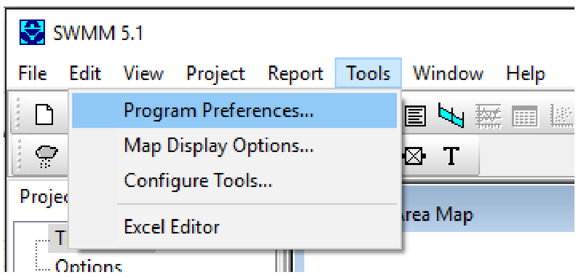
⇨ Mark 'Disable SWMM while executing' and 'Update SWMM after closing'

⇨ Click 'OK' button

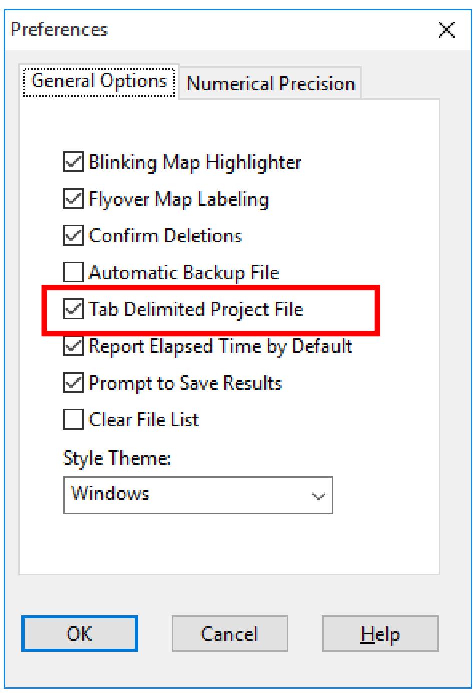


⇨ Click 'Close' button

In order to use the Excel Editor, add another program preference as follows:



⇨ Select 'Tools / Program Preferences' under the Main Menu



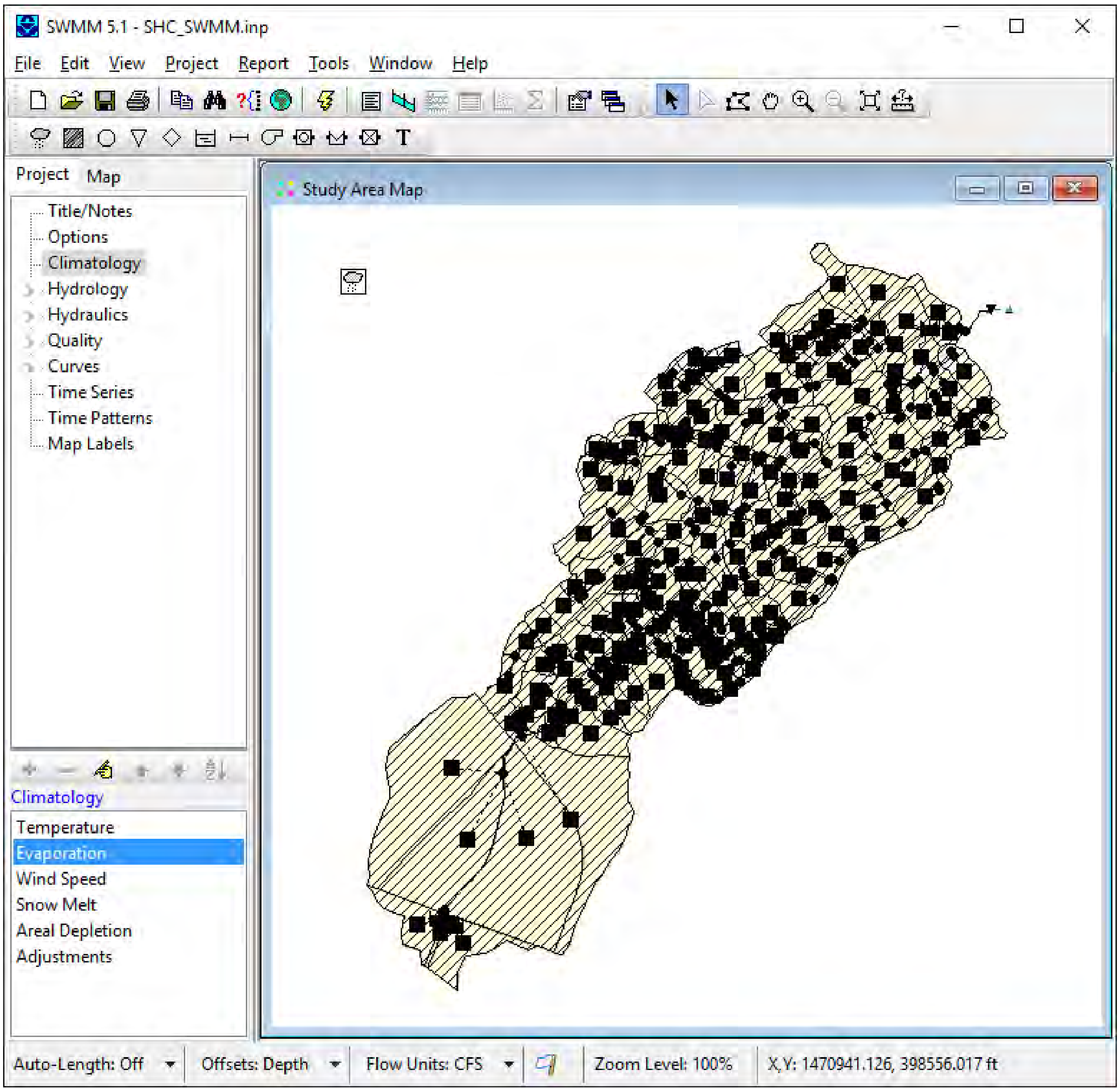
⇨ Mark 'Tab Delimited Project File', then click 'OK' button

The tab delimited specification structures the SWMM input file (*.inp) in a manner such that any compatible data processed in MS-Excel can be imported directly using the Excel Tool option within the SWMM program interface.

3.3.2 Data Entry/Editing Using the Excel Editor

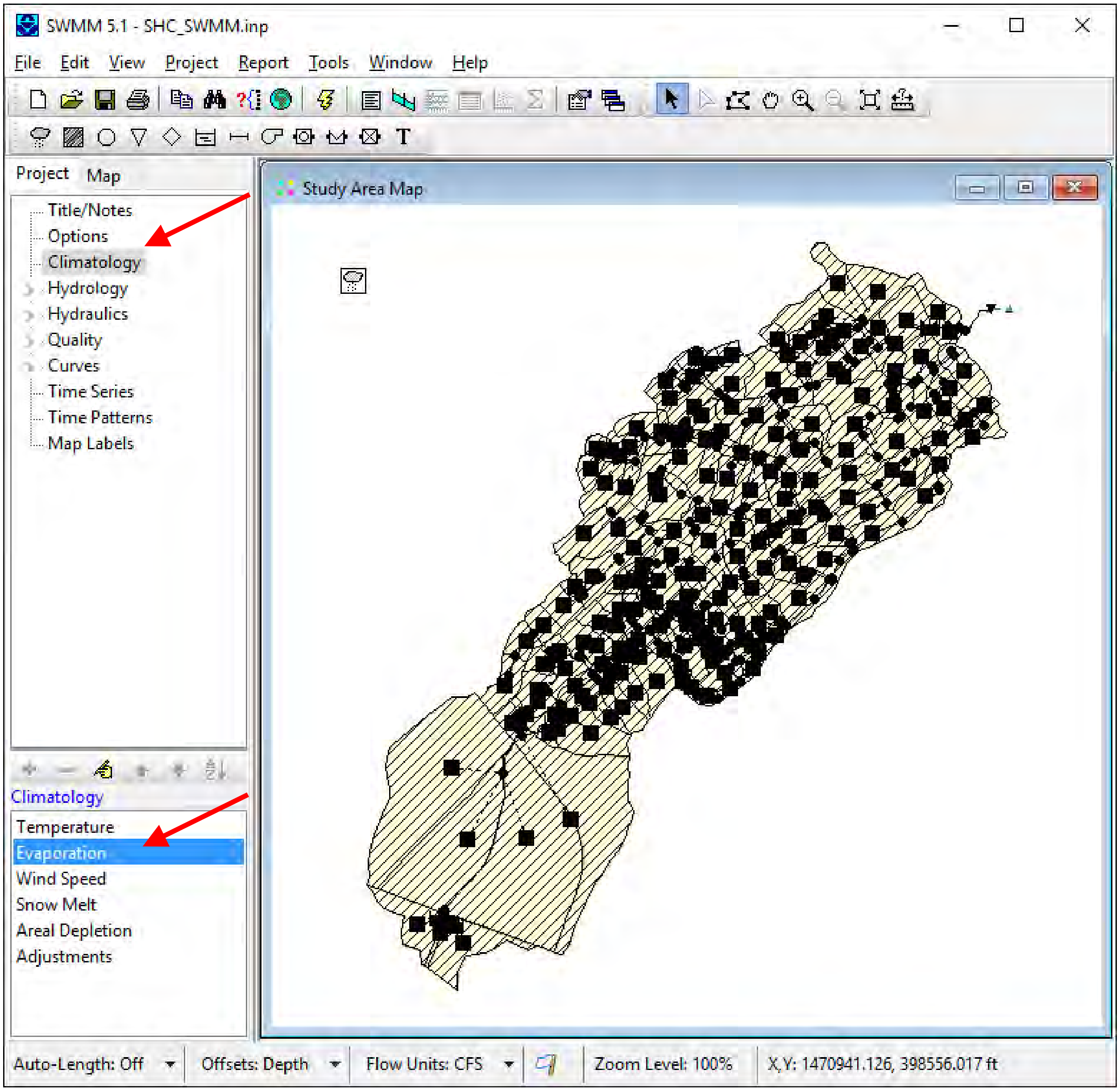
In order to complete developing the SWMM model, the next step is to open the existing SWMM input file derived from the previous section, Section 3.2.

⇨ Run the EPA SWMM



⇨ Open the input file ("SHC_SWMM.inp") previously updated by PCSWMM.

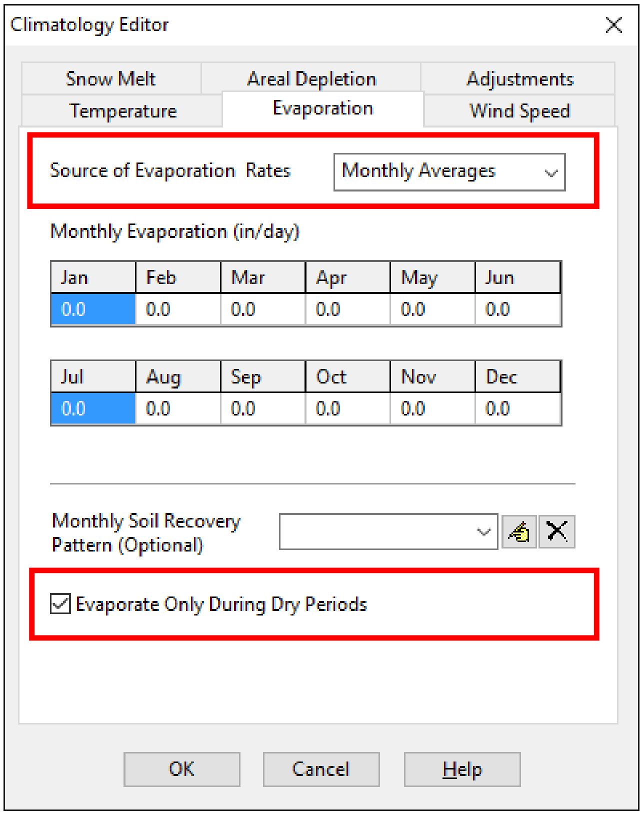
The next step is to create the “blank” or template input data structure of evaporation to allow for data import from MS-Excel.



⇨ Click ‘Climatology’ under the ‘Project’ tab

⇨ Double click the ‘Evaporation’ under the ‘Climatology’

Specify ‘Evaporation’ tab under ‘Climatology Editor’ as follows:



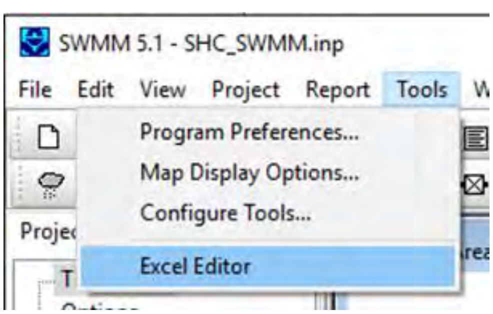
⇨ Source of Evaporation Rates: "Monthly Averages"

⇨ Mark "Evaporation Only During Dry Periods"

⇨ Click [OK] button

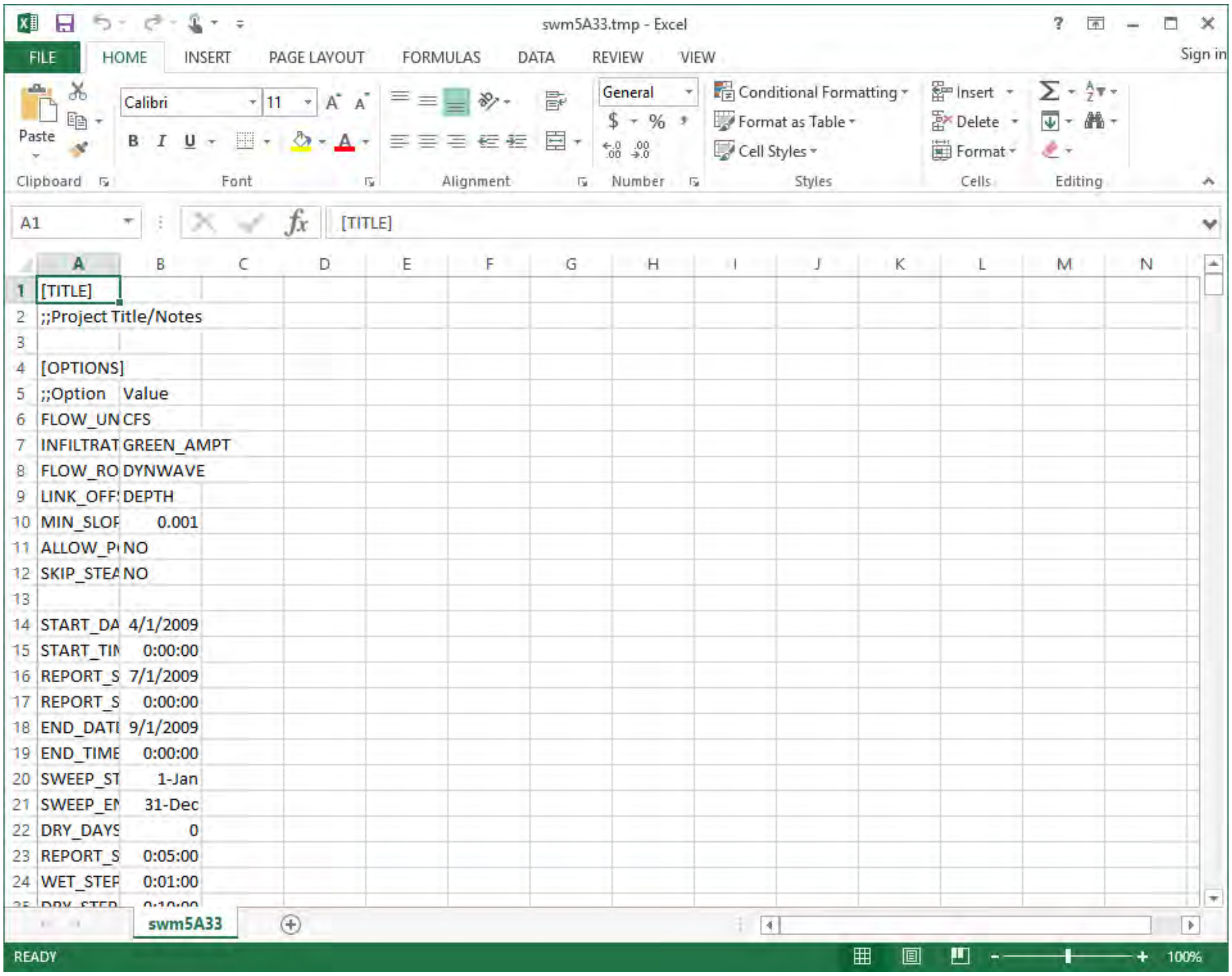
Note: No data is entered here. This step is just to setup a template to allow for data import from MS-Excel.

To enter data from MS-Excel, call the previously configured 'Excel Editor' using the tool option from the Main Menu of the EPA SWMM.



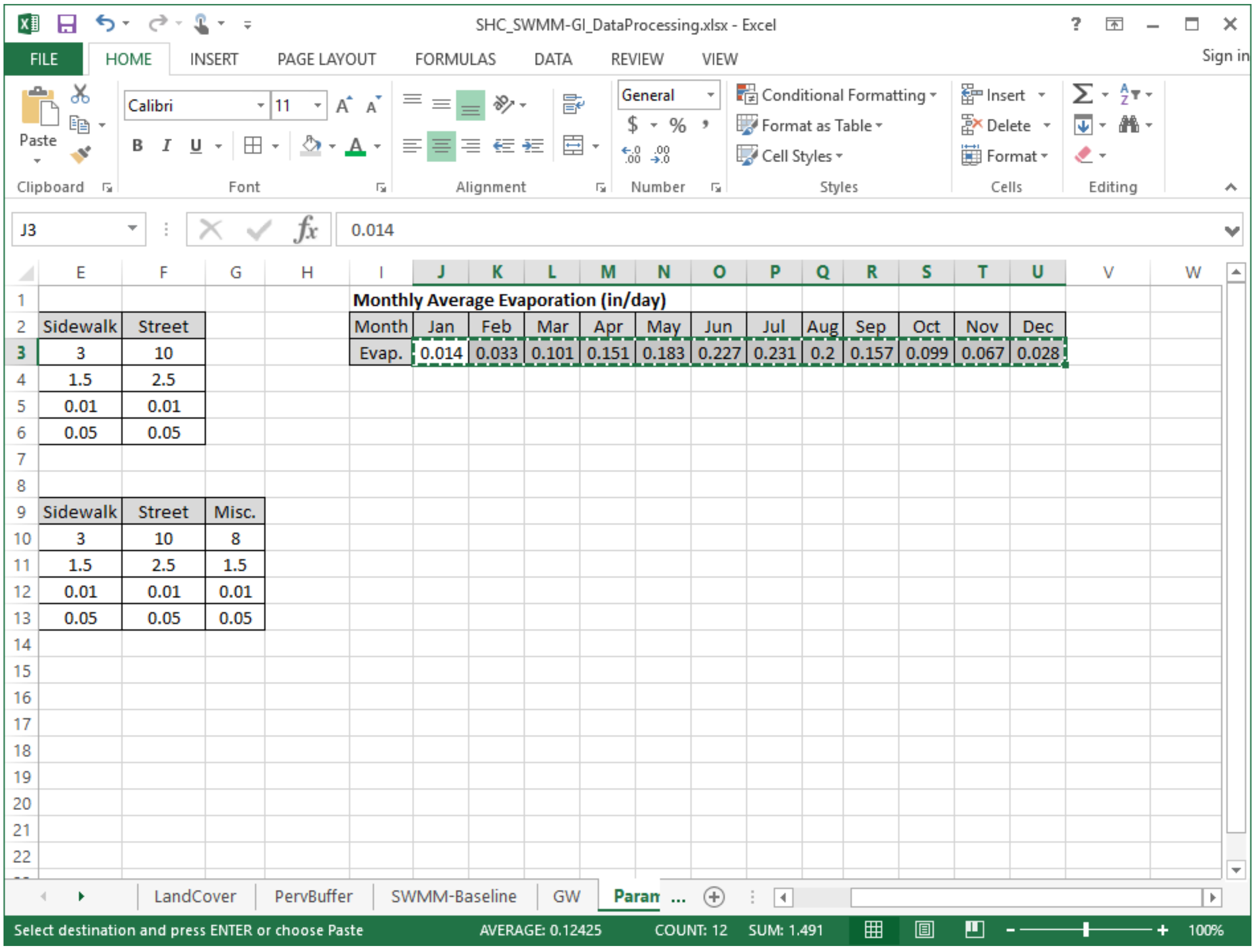
⇨ Click [Tools/Excel Editor] under the main menu

Note: Generally speaking, any open MS-Excel files prior to this operation must be closed before calling the 'Excel Editor'. Otherwise, the edited file may not be saved correctly, which may depend on the computer and/or the version of MS-Excel that the computer is running.

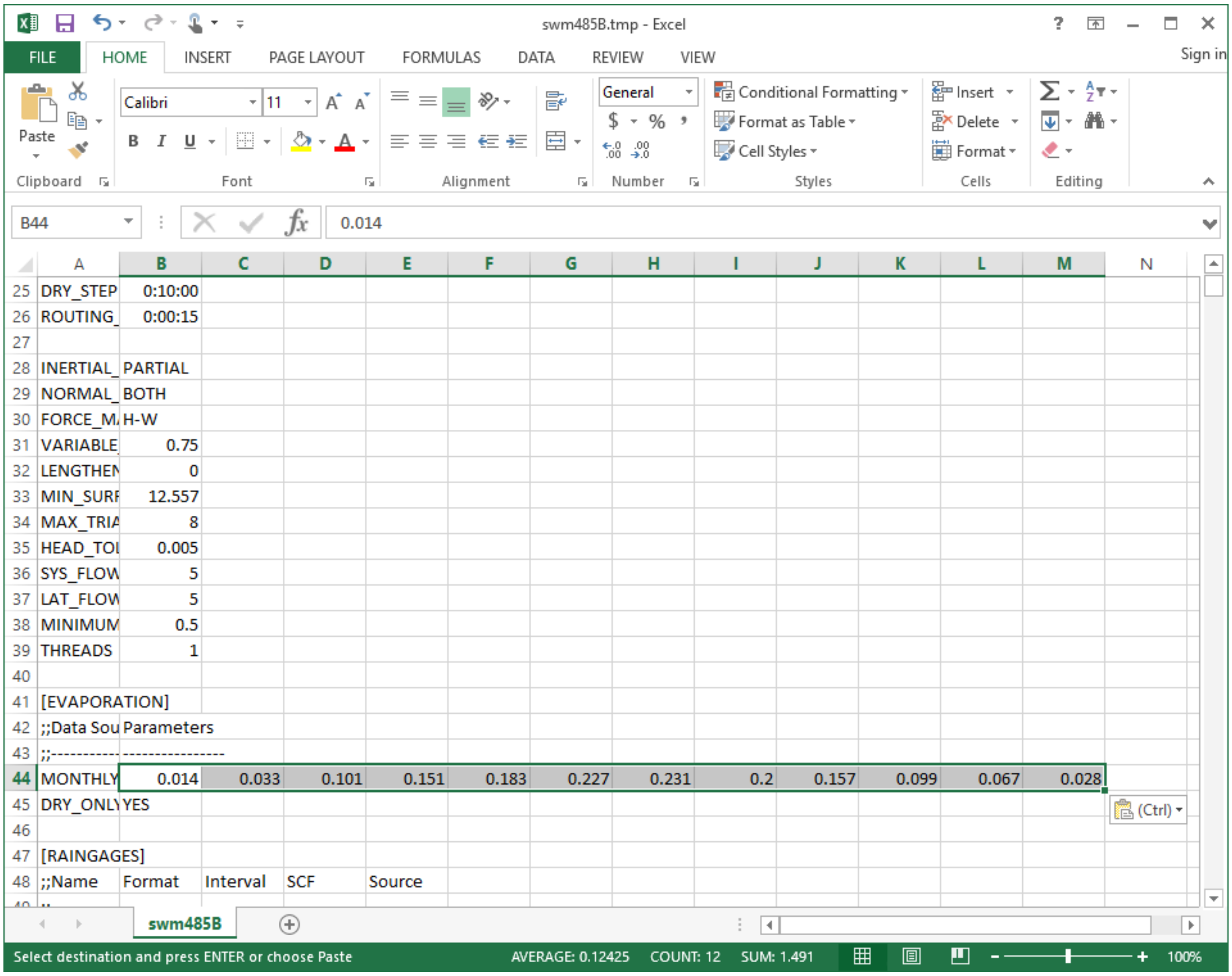


The next steps are to edit the SWMM input file using the Excel Editor. In order to import relevant modeling parameters, open "SHC_SWMM_DataProcessing.xlsx" which is the file that was created previously with the required values (see Section 2.4).

First, copy the values from the parameters tab in the workbook to update the 'Monthly Average Evaporation'. (see Section 2.1.2)



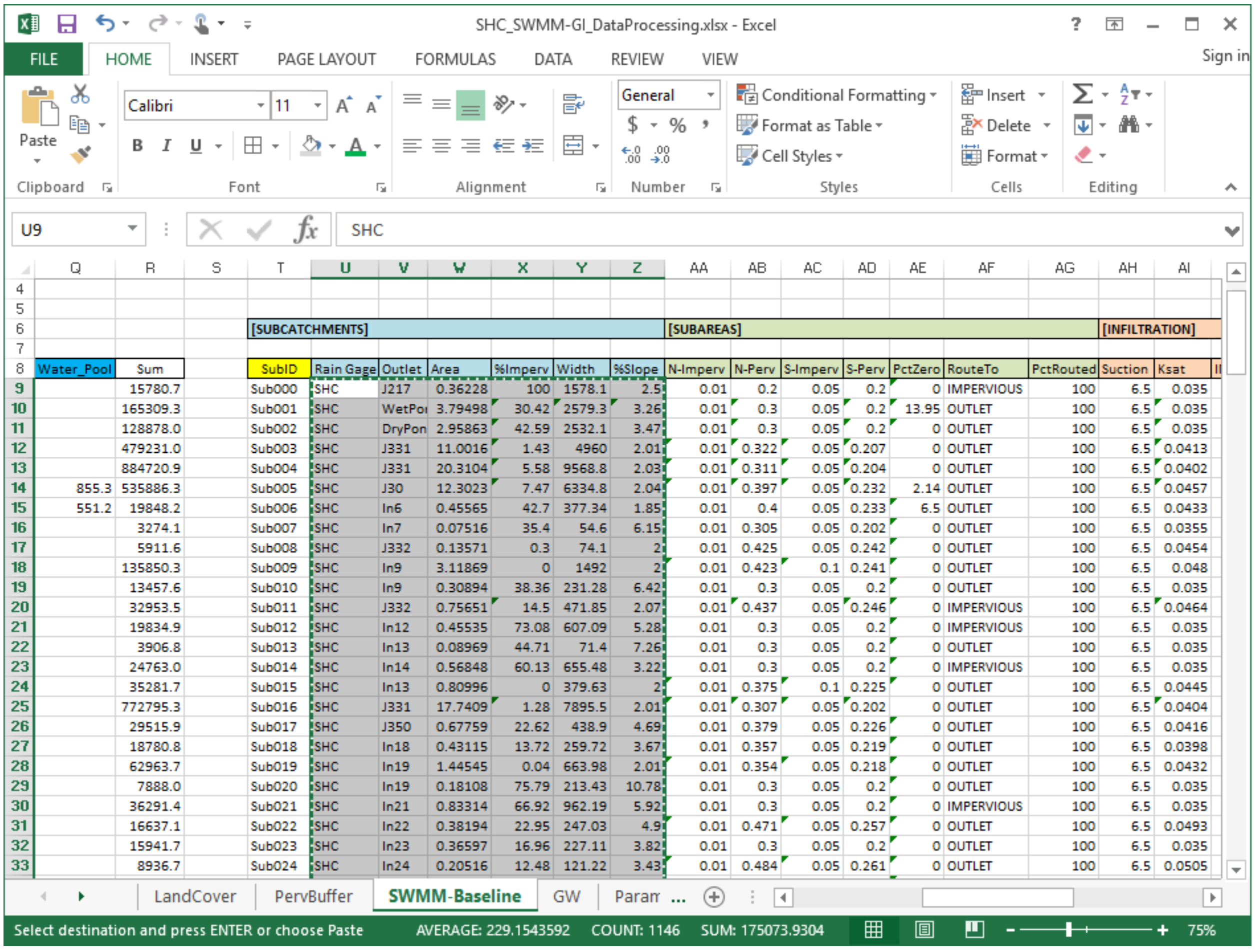
⇨ Copy the "Monthly Average Evaporation (in/day)" from tab [Parameters] in "SHC_SWMM_DataProcessing.xlsx"



⇨ Paste the data to the SWMM input file: Right click on cell "B44", select "Value" for the Paste option

Note: Skip header and 'SubID' column in the spreadsheet because those are already included when the blank/template input was created in SWMM.

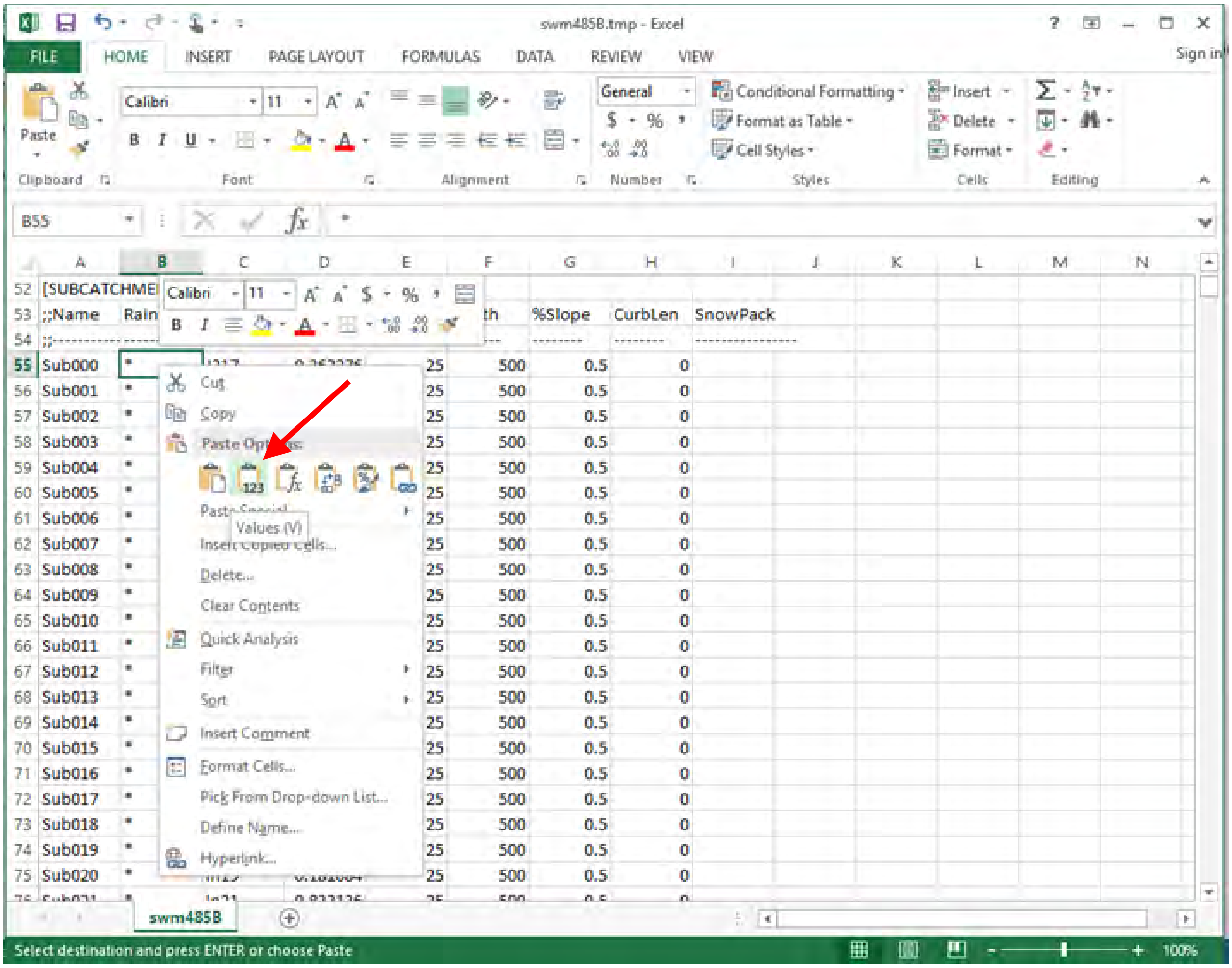
Next, update the parameters of 'Rain Gage', 'Outlet', 'Area', '%Imperv', 'Width', and '%Slope' for the [Subcatchments] from the 'SWMM-Baseline' tab in the Excel file.



	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
6				[SUBCATCHMENTS]							[SUBAREAS]							[INFILTRATION]	
8	Water_Pool	Sum		SubID	Rain Gage	Outlet	Area	%Imperv	Width	%Slope	N-Imperv	N-Perv	S-Imperv	S-Perv	PctZero	RouteTo	PctRouted	Suction	Ksat
9		15780.7		Sub000	SHC	J217	0.36228	100	1578.1	2.5	0.01	0.2	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035
10		165309.3		Sub001	SHC	WetPo	3.79498	30.42	2579.3	3.26	0.01	0.3	0.05	0.2	13.95	OUTLET	100	6.5	0.035
11		128878.0		Sub002	SHC	DryPon	2.95863	42.59	2532.1	3.47	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035
12		479231.0		Sub003	SHC	J331	11.0016	1.43	4960	2.01	0.01	0.322	0.05	0.207	0	OUTLET	100	6.5	0.0413
13		884720.9		Sub004	SHC	J331	20.3104	5.58	9568.8	2.03	0.01	0.311	0.05	0.204	0	OUTLET	100	6.5	0.0402
14	855.3	535886.3		Sub005	SHC	J30	12.3023	7.47	6334.8	2.04	0.01	0.397	0.05	0.232	2.14	OUTLET	100	6.5	0.0457
15	551.2	19848.2		Sub006	SHC	In6	0.45565	42.7	377.34	1.85	0.01	0.4	0.05	0.233	6.5	OUTLET	100	6.5	0.0433
16		3274.1		Sub007	SHC	In7	0.07516	35.4	54.6	6.15	0.01	0.305	0.05	0.202	0	OUTLET	100	6.5	0.0355
17		5911.6		Sub008	SHC	J332	0.13571	0.3	74.1	2	0.01	0.425	0.05	0.242	0	OUTLET	100	6.5	0.0454
18		135850.3		Sub009	SHC	In9	3.11869	0	1492	2	0.01	0.423	0.1	0.241	0	OUTLET	100	6.5	0.048
19		13457.6		Sub010	SHC	In9	0.30894	38.36	231.28	6.42	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035
20		32953.5		Sub011	SHC	J332	0.75651	14.5	471.85	2.07	0.01	0.437	0.05	0.246	0	IMPERVIOUS	100	6.5	0.0464
21		19834.9		Sub012	SHC	In12	0.45535	73.08	607.09	5.28	0.01	0.3	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035
22		3906.8		Sub013	SHC	In13	0.08969	44.71	71.4	7.26	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035
23		24763.0		Sub014	SHC	In14	0.56848	60.13	655.48	3.22	0.01	0.3	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035
24		35281.7		Sub015	SHC	In13	0.80996	0	379.63	2	0.01	0.375	0.1	0.225	0	OUTLET	100	6.5	0.0445
25		772795.3		Sub016	SHC	J331	17.7409	1.28	7895.5	2.01	0.01	0.307	0.05	0.202	0	OUTLET	100	6.5	0.0404
26		29515.9		Sub017	SHC	J350	0.67759	22.62	438.9	4.69	0.01	0.379	0.05	0.226	0	OUTLET	100	6.5	0.0416
27		18780.8		Sub018	SHC	In18	0.43115	13.72	259.72	3.67	0.01	0.357	0.05	0.219	0	OUTLET	100	6.5	0.0398
28		62963.7		Sub019	SHC	In19	1.44545	0.04	663.98	2.01	0.01	0.354	0.05	0.218	0	OUTLET	100	6.5	0.0432
29		7888.0		Sub020	SHC	In19	0.18108	75.79	213.43	10.78	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035
30		36291.4		Sub021	SHC	In21	0.83314	66.92	962.19	5.92	0.01	0.3	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035
31		16637.1		Sub022	SHC	In22	0.38194	22.95	247.03	4.9	0.01	0.471	0.05	0.257	0	OUTLET	100	6.5	0.0493
32		15941.7		Sub023	SHC	In23	0.36597	16.96	227.11	3.82	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035
33		8936.7		Sub024	SHC	In24	0.20516	12.48	121.22	3.43	0.01	0.484	0.05	0.261	0	OUTLET	100	6.5	0.0505

- ⇨ Open the "SHC_SWMM_DataProcessing.xlsx"
- ⇨ Select cells [U9:Z199] from [SWMM_Baseline] tab, then Copy

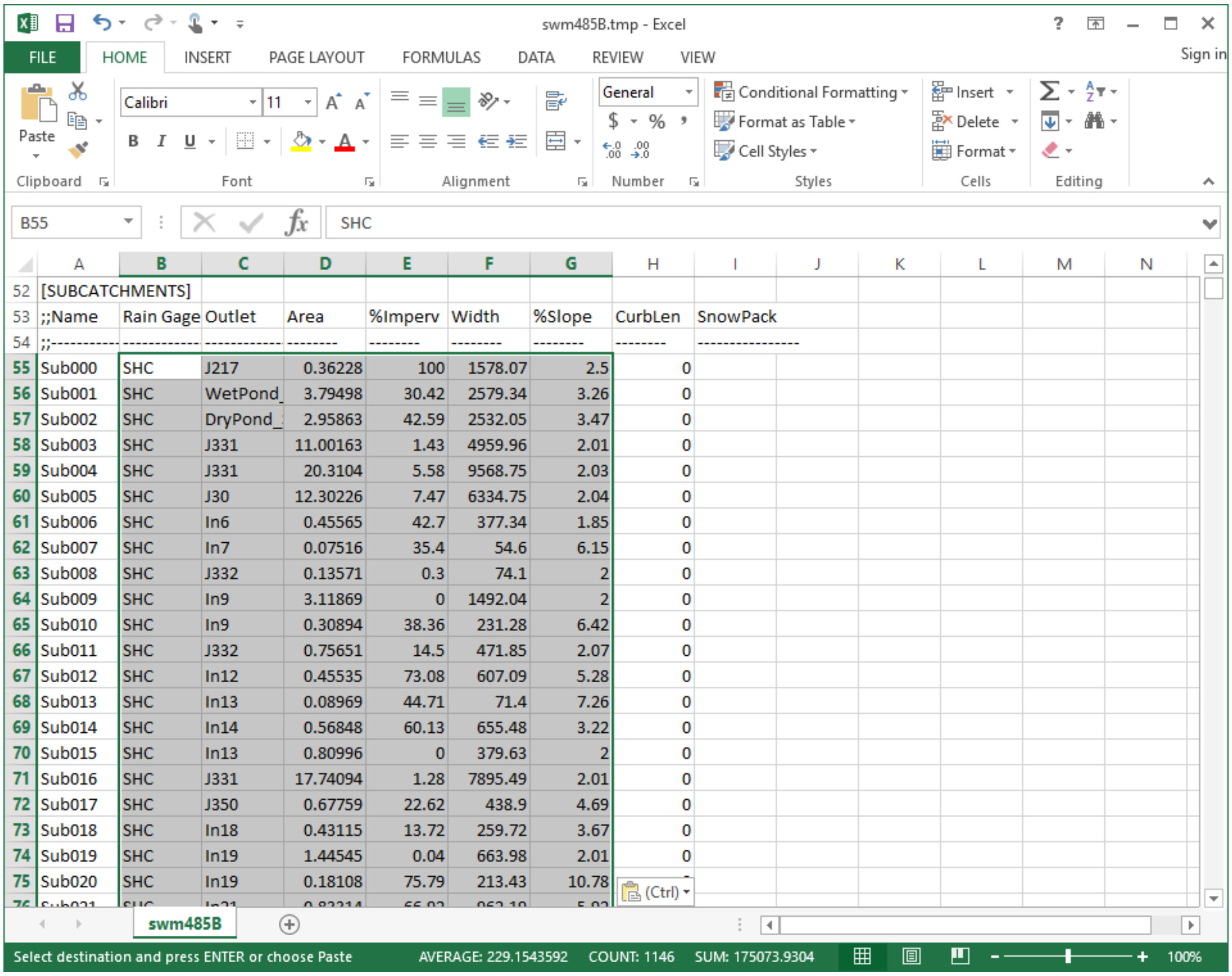
Note: The total rows of information copied will vary across modeling projects based on the number of subcatchments defined and how the individual spreadsheet is laid out.



⇨ Open the SWMM input file using the Excel Editor

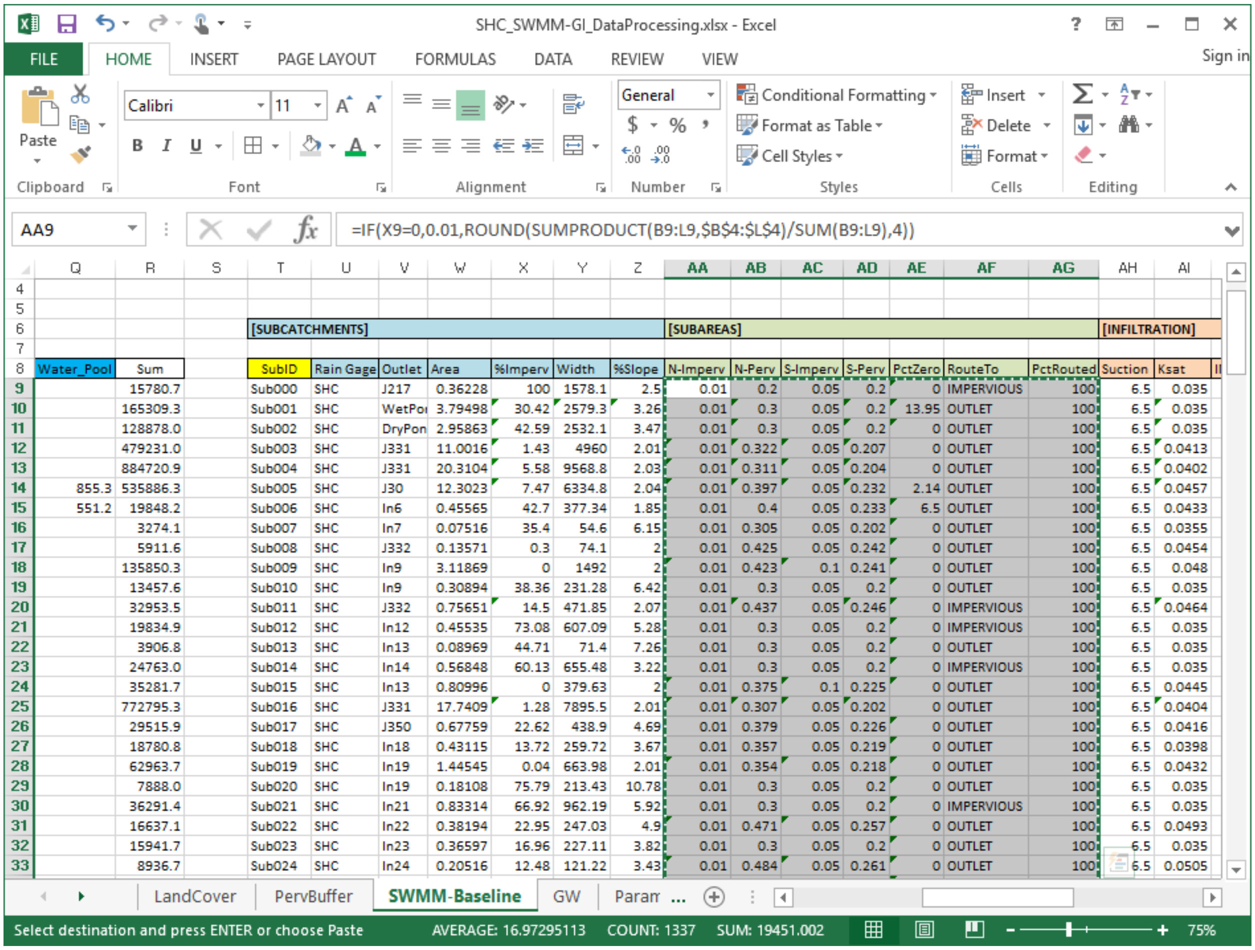
⇨ Right Click at the cell “B55”, then click the “Value” icon for the ‘Paste Options”

Note: You must use the “Paste Special” with “Value” option to prevent copy/pasting formulae.



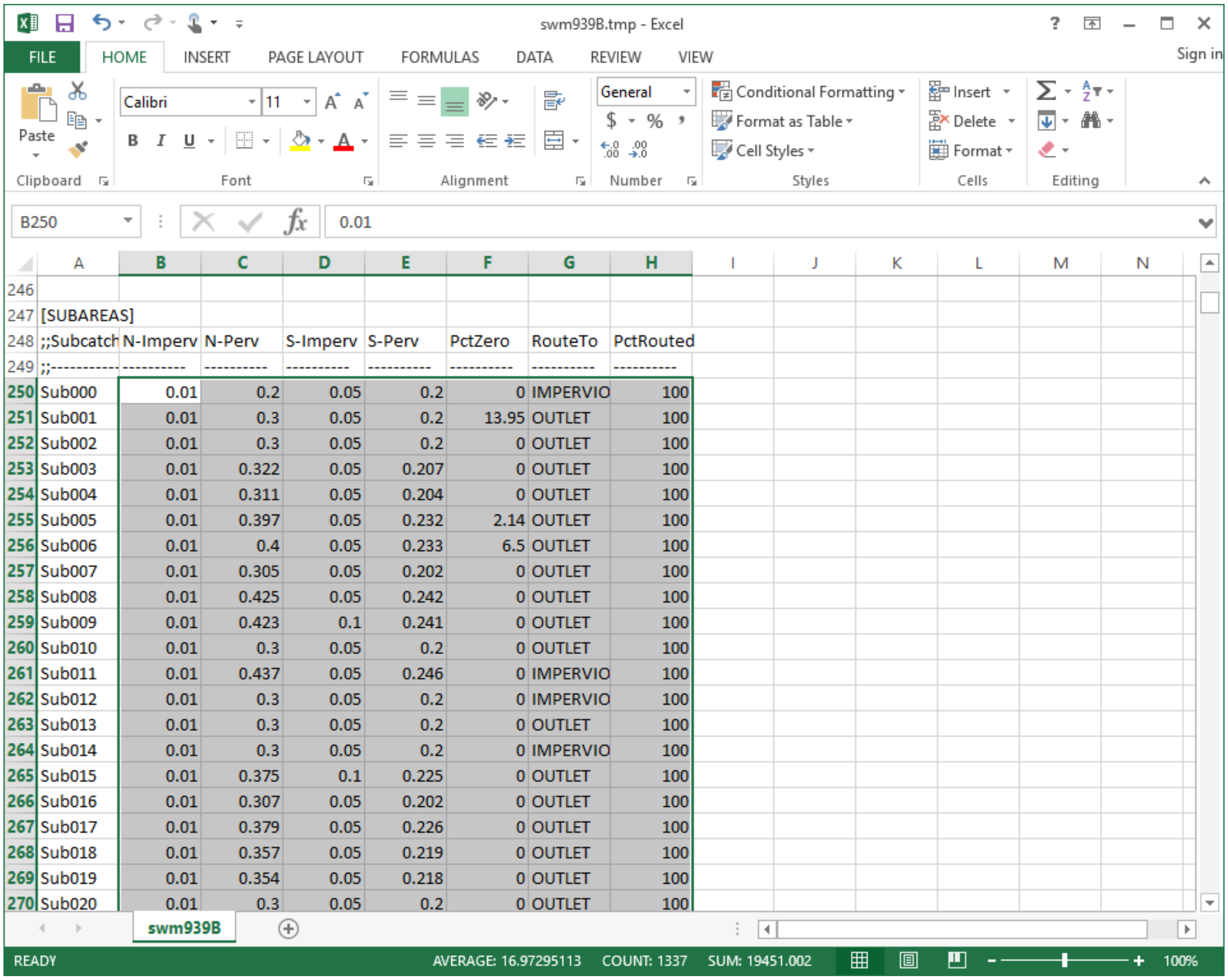
	A	B	C	D	E	F	G	H	I
52	[SUBCATCHMENTS]								
53	;;Name	Rain Gage	Outlet	Area	%Imperv	Width	%Slope	CurbLen	SnowPack
54	;;----------	------------	------------	--------	--------	--------	--------	--------	----------------
55	Sub000	SHC	J217	0.36228	100	1578.07	2.5	0	
56	Sub001	SHC	WetPond_	3.79498	30.42	2579.34	3.26	0	
57	Sub002	SHC	DryPond_	2.95863	42.59	2532.05	3.47	0	
58	Sub003	SHC	J331	11.00163	1.43	4959.96	2.01	0	
59	Sub004	SHC	J331	20.3104	5.58	9568.75	2.03	0	
60	Sub005	SHC	J30	12.30226	7.47	6334.75	2.04	0	
61	Sub006	SHC	In6	0.45565	42.7	377.34	1.85	0	
62	Sub007	SHC	In7	0.07516	35.4	54.6	6.15	0	
63	Sub008	SHC	J332	0.13571	0.3	74.1	2	0	
64	Sub009	SHC	In9	3.11869	0	1492.04	2	0	
65	Sub010	SHC	In9	0.30894	38.36	231.28	6.42	0	
66	Sub011	SHC	J332	0.75651	14.5	471.85	2.07	0	
67	Sub012	SHC	In12	0.45535	73.08	607.09	5.28	0	
68	Sub013	SHC	In13	0.08969	44.71	71.4	7.26	0	
69	Sub014	SHC	In14	0.56848	60.13	655.48	3.22	0	
70	Sub015	SHC	In13	0.80996	0	379.63	2	0	
71	Sub016	SHC	J331	17.74094	1.28	7895.49	2.01	0	
72	Sub017	SHC	J350	0.67759	22.62	438.9	4.69	0	
73	Sub018	SHC	In18	0.43115	13.72	259.72	3.67	0	
74	Sub019	SHC	In19	1.44545	0.04	663.98	2.01	0	
75	Sub020	SHC	In19	0.18108	75.79	213.43	10.78	(Ctrl)	

Next, Copy/Paste parameters for the [SUBAREAS]: ‘N-Imperv’, ‘N-Perv’, ‘S-Imperv’, ‘S-Perv’, ‘PctZero’, ‘RouteTo’, and ‘PctRouted’.



- ⇨ Open the “SHC_SWMM_DataProcessing.xlsx”
- ⇨ Select cells [AA9:AG199] from [SWMM_Baseline] tab, then Copy.

Note: The total rows of information copied will vary in modeling projects based on the number of subcatchments defined and how the individual spreadsheet is laid out.

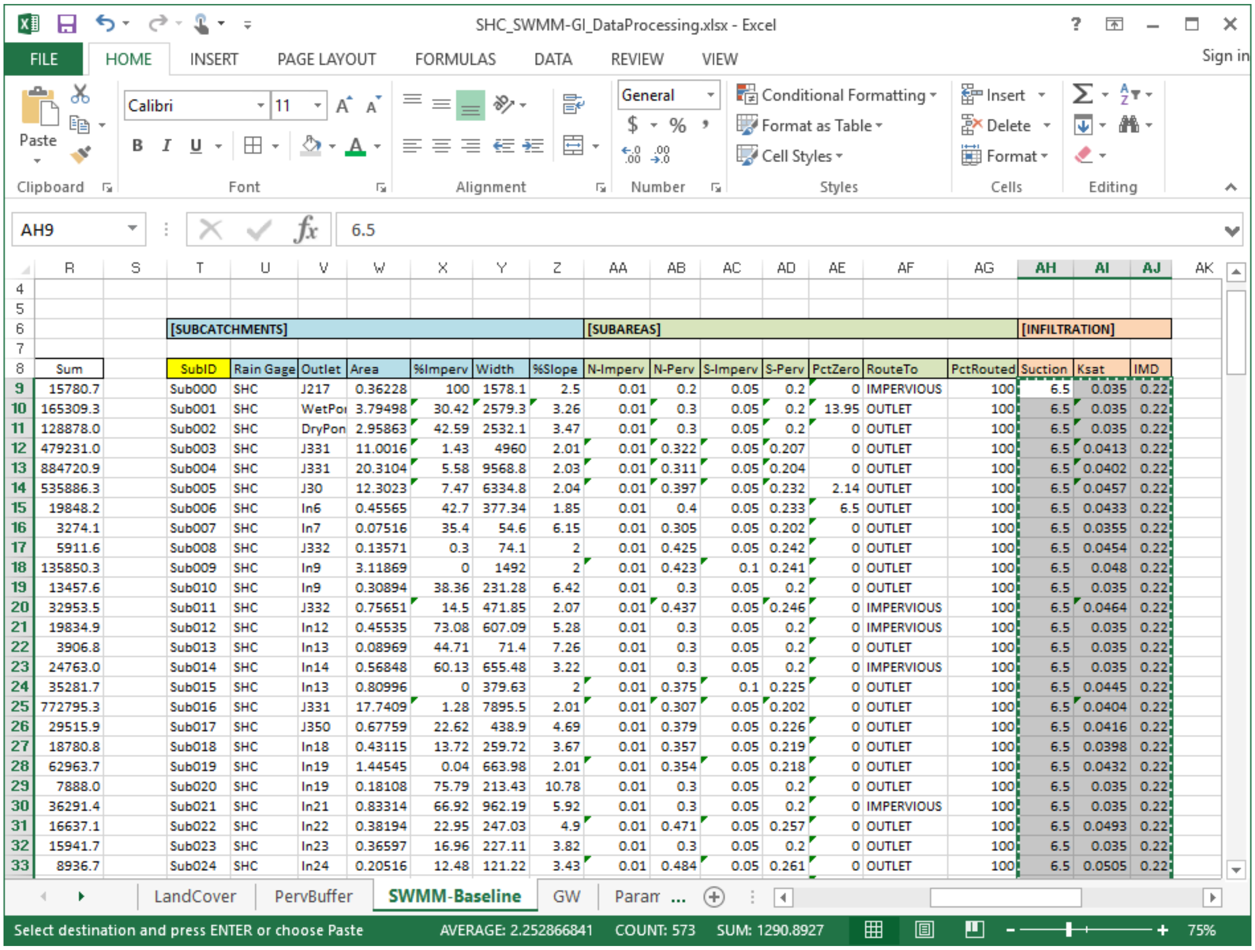


	A	B	C	D	E	F	G	H
246								
247	[SUBAREAS]							
248	;;Subcatch	N-Imperv	N-Perv	S-Imperv	S-Perv	PctZero	RouteTo	PctRouted
249	;;----------	----------	----------	----------	----------	----------	----------	----------
250	Sub000	0.01	0.2	0.05	0.2	0	IMPERVIO	100
251	Sub001	0.01	0.3	0.05	0.2	13.95	OUTLET	100
252	Sub002	0.01	0.3	0.05	0.2	0	OUTLET	100
253	Sub003	0.01	0.322	0.05	0.207	0	OUTLET	100
254	Sub004	0.01	0.311	0.05	0.204	0	OUTLET	100
255	Sub005	0.01	0.397	0.05	0.232	2.14	OUTLET	100
256	Sub006	0.01	0.4	0.05	0.233	6.5	OUTLET	100
257	Sub007	0.01	0.305	0.05	0.202	0	OUTLET	100
258	Sub008	0.01	0.425	0.05	0.242	0	OUTLET	100
259	Sub009	0.01	0.423	0.1	0.241	0	OUTLET	100
260	Sub010	0.01	0.3	0.05	0.2	0	OUTLET	100
261	Sub011	0.01	0.437	0.05	0.246	0	IMPERVIO	100
262	Sub012	0.01	0.3	0.05	0.2	0	IMPERVIO	100
263	Sub013	0.01	0.3	0.05	0.2	0	OUTLET	100
264	Sub014	0.01	0.3	0.05	0.2	0	IMPERVIO	100
265	Sub015	0.01	0.375	0.1	0.225	0	OUTLET	100
266	Sub016	0.01	0.307	0.05	0.202	0	OUTLET	100
267	Sub017	0.01	0.379	0.05	0.226	0	OUTLET	100
268	Sub018	0.01	0.357	0.05	0.219	0	OUTLET	100
269	Sub019	0.01	0.354	0.05	0.218	0	OUTLET	100
270	Sub020	0.01	0.3	0.05	0.2	0	OUTLET	100

⇨ Open the SWMM input file using the Excel Editor

⇨ Right Click at the cell "B250", then click the 'Value' icon for the 'Paste Options'

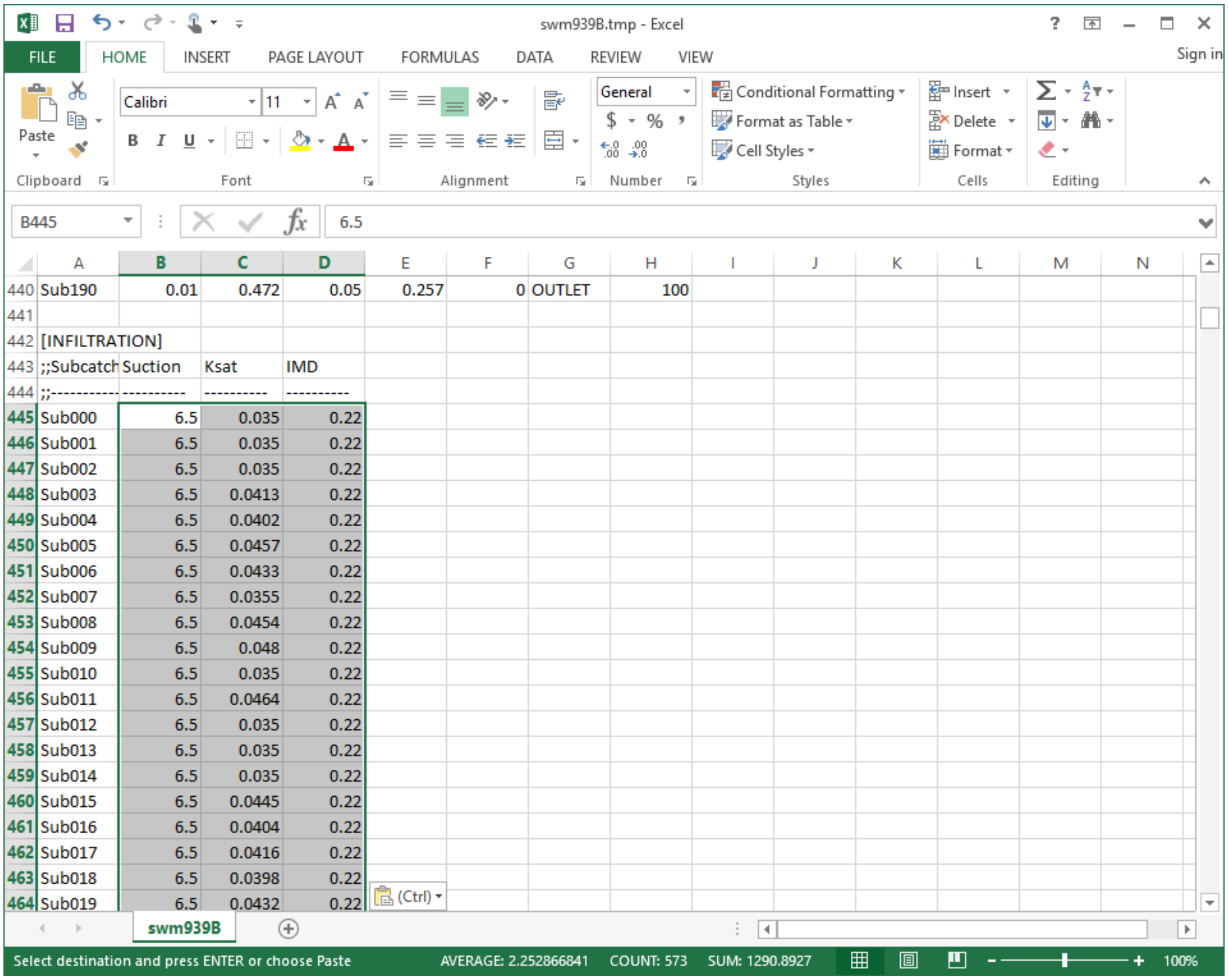
Next, Copy/Paste parameters for the [INFILTRATION]: 'Suction', 'Ksat', and 'IMD'



Sum	SubID	Rain Gage	Outlet	Area	%Imperv	Width	%Slope	N-Imperv	N-Perv	S-Imperv	S-Perv	PctZero	RouteTo	PctRouted	Suction	Ksat	IMD
	[SUBCATCHMENTS]							[SUBAREAS]							[INFILTRATION]		
15780.7	Sub000	SHC	J217	0.36228	100	1578.1	2.5	0.01	0.2	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035	0.22
165309.3	Sub001	SHC	WetPo	3.79498	30.42	2579.3	3.26	0.01	0.3	0.05	0.2	13.95	OUTLET	100	6.5	0.035	0.22
128878.0	Sub002	SHC	DryPon	2.95863	42.59	2532.1	3.47	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035	0.22
479231.0	Sub003	SHC	J331	11.0016	1.43	4960	2.01	0.01	0.322	0.05	0.207	0	OUTLET	100	6.5	0.0413	0.22
884720.9	Sub004	SHC	J331	20.3104	5.58	9568.8	2.03	0.01	0.311	0.05	0.204	0	OUTLET	100	6.5	0.0402	0.22
535886.3	Sub005	SHC	J30	12.3023	7.47	6334.8	2.04	0.01	0.397	0.05	0.232	2.14	OUTLET	100	6.5	0.0457	0.22
19848.2	Sub006	SHC	In6	0.45565	42.7	377.34	1.85	0.01	0.4	0.05	0.233	6.5	OUTLET	100	6.5	0.0433	0.22
3274.1	Sub007	SHC	In7	0.07516	35.4	54.6	6.15	0.01	0.305	0.05	0.202	0	OUTLET	100	6.5	0.0355	0.22
5911.6	Sub008	SHC	J332	0.13571	0.3	74.1	2	0.01	0.425	0.05	0.242	0	OUTLET	100	6.5	0.0454	0.22
135850.3	Sub009	SHC	In9	3.11869	0	1492	2	0.01	0.423	0.1	0.241	0	OUTLET	100	6.5	0.048	0.22
13457.6	Sub010	SHC	In9	0.30894	38.36	231.28	6.42	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035	0.22
32953.5	Sub011	SHC	J332	0.75651	14.5	471.85	2.07	0.01	0.437	0.05	0.246	0	IMPERVIOUS	100	6.5	0.0464	0.22
19834.9	Sub012	SHC	In12	0.45535	73.08	607.09	5.28	0.01	0.3	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035	0.22
3906.8	Sub013	SHC	In13	0.08969	44.71	71.4	7.26	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035	0.22
24763.0	Sub014	SHC	In14	0.56848	60.13	655.48	3.22	0.01	0.3	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035	0.22
35281.7	Sub015	SHC	In13	0.80996	0	379.63	2	0.01	0.375	0.1	0.225	0	OUTLET	100	6.5	0.0445	0.22
772795.3	Sub016	SHC	J331	17.7409	1.28	7895.5	2.01	0.01	0.307	0.05	0.202	0	OUTLET	100	6.5	0.0404	0.22
29515.9	Sub017	SHC	J350	0.67759	22.62	438.9	4.69	0.01	0.379	0.05	0.226	0	OUTLET	100	6.5	0.0416	0.22
18780.8	Sub018	SHC	In18	0.43115	13.72	259.72	3.67	0.01	0.357	0.05	0.219	0	OUTLET	100	6.5	0.0398	0.22
62963.7	Sub019	SHC	In19	1.44545	0.04	663.98	2.01	0.01	0.354	0.05	0.218	0	OUTLET	100	6.5	0.0432	0.22
7888.0	Sub020	SHC	In19	0.18108	75.79	213.43	10.78	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035	0.22
36291.4	Sub021	SHC	In21	0.83314	66.92	962.19	5.92	0.01	0.3	0.05	0.2	0	IMPERVIOUS	100	6.5	0.035	0.22
16637.1	Sub022	SHC	In22	0.38194	22.95	247.03	4.9	0.01	0.471	0.05	0.257	0	OUTLET	100	6.5	0.0493	0.22
15941.7	Sub023	SHC	In23	0.36597	16.96	227.11	3.82	0.01	0.3	0.05	0.2	0	OUTLET	100	6.5	0.035	0.22
8936.7	Sub024	SHC	In24	0.20516	12.48	121.22	3.43	0.01	0.484	0.05	0.261	0	OUTLET	100	6.5	0.0505	0.22

- ⇨ Open the "SHC_SWMM_DataProcessing.xlsx"
- ⇨ Select cells [AH9:AJ199] from [SWMM_Baseline] tab, then Copy. *(Section 2.4.4)*

Note: The total rows of information copied will vary across modeling projects based on the number of subcatchments defined and how the individual spreadsheet is laid out.

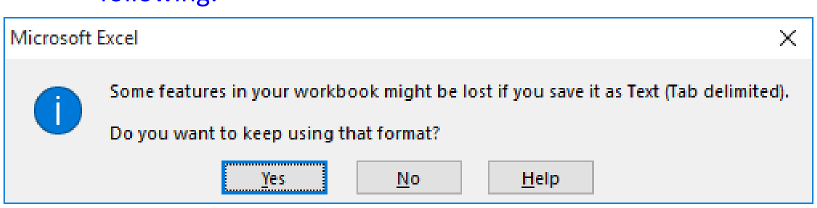


⇨ Open the SWMM input file using the Excel Editor

⇨ Right Click at the cell "B445", then click the "Value" icon for the 'Paste Options"

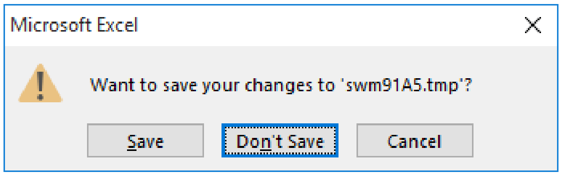
Next, save the SWMM input file from the Excel Editor as follows:

⇨ Click 'File / Save' under the Main Menu (or click button to save), then you will get the following:



⇨ Click 'Yes' button.

⇨ Close the Excel Editor by clicking the relevant button or menu, then you will get the following:



⇨ Click ‘Don’t Save’ button

Note: This is a temporary Excel file created while processing the data that shouldn’t be saved.

⇨ Close the “SHC_SWMM_DataProcessing.xlsx”

Confirm to ensure that the updates performed were saved in the SWMM input file. For example, select the subcatchments option in SWMM and check to see if the ‘Area’ and ‘%Imp’ values were updated to the spreadsheet computed values.

3.4 Set up LID Controls to model the Baseline Buffering Pervious Area

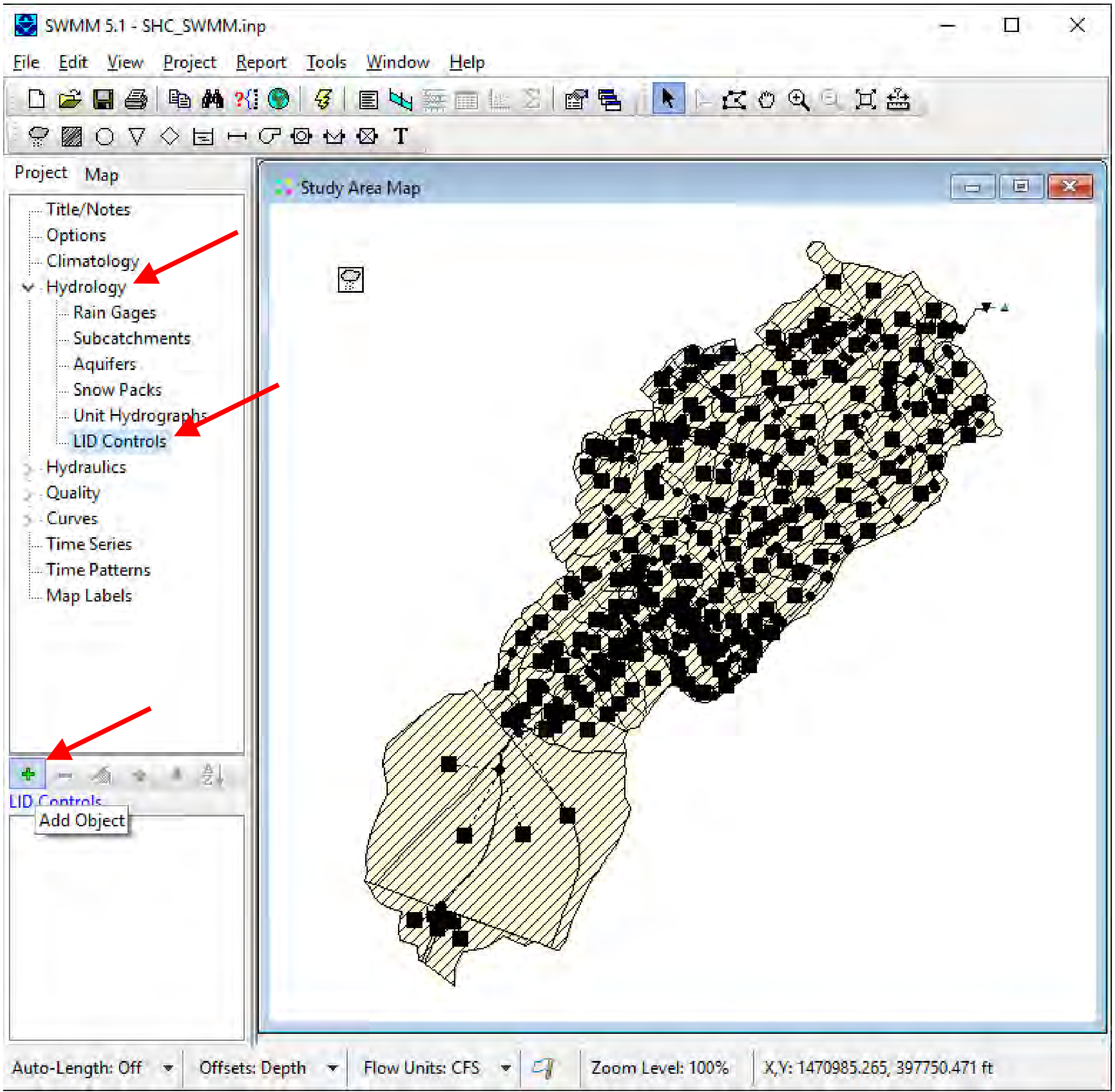
The next steps set up LID controls to model the baseline buffering pervious area using the EPA SWMM and the Excel Editor.

⇨ Run EPA SWMM

⇨ Open the “SHC_SWMM.inp”

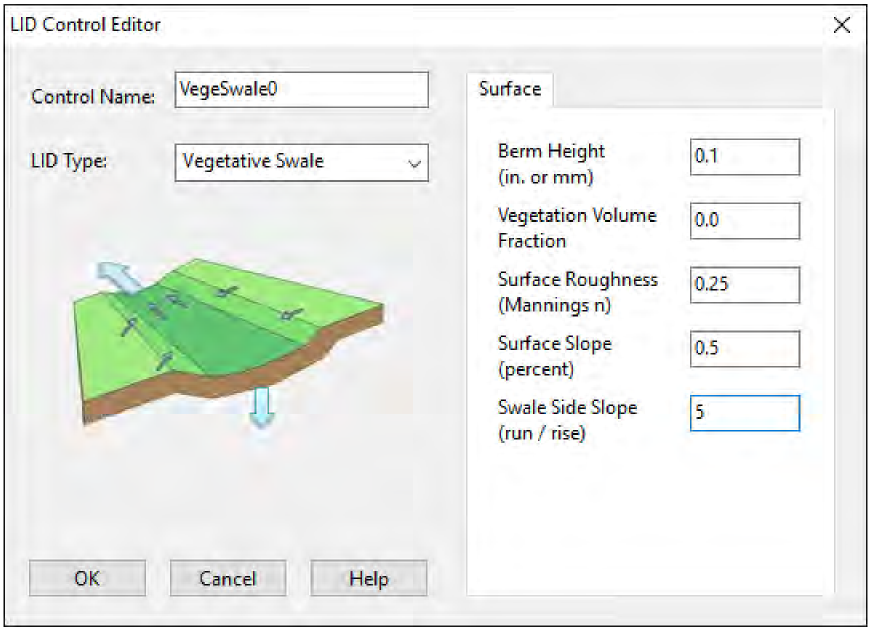
3.4.1 Add a LID Control using EPA SWMM

The following steps need to be performed to add an LID control template in SWMM.



⇨ Click “Hydrology” under the “Project” tab, then click “LID Controls”

⇨ Click [Add Object] button



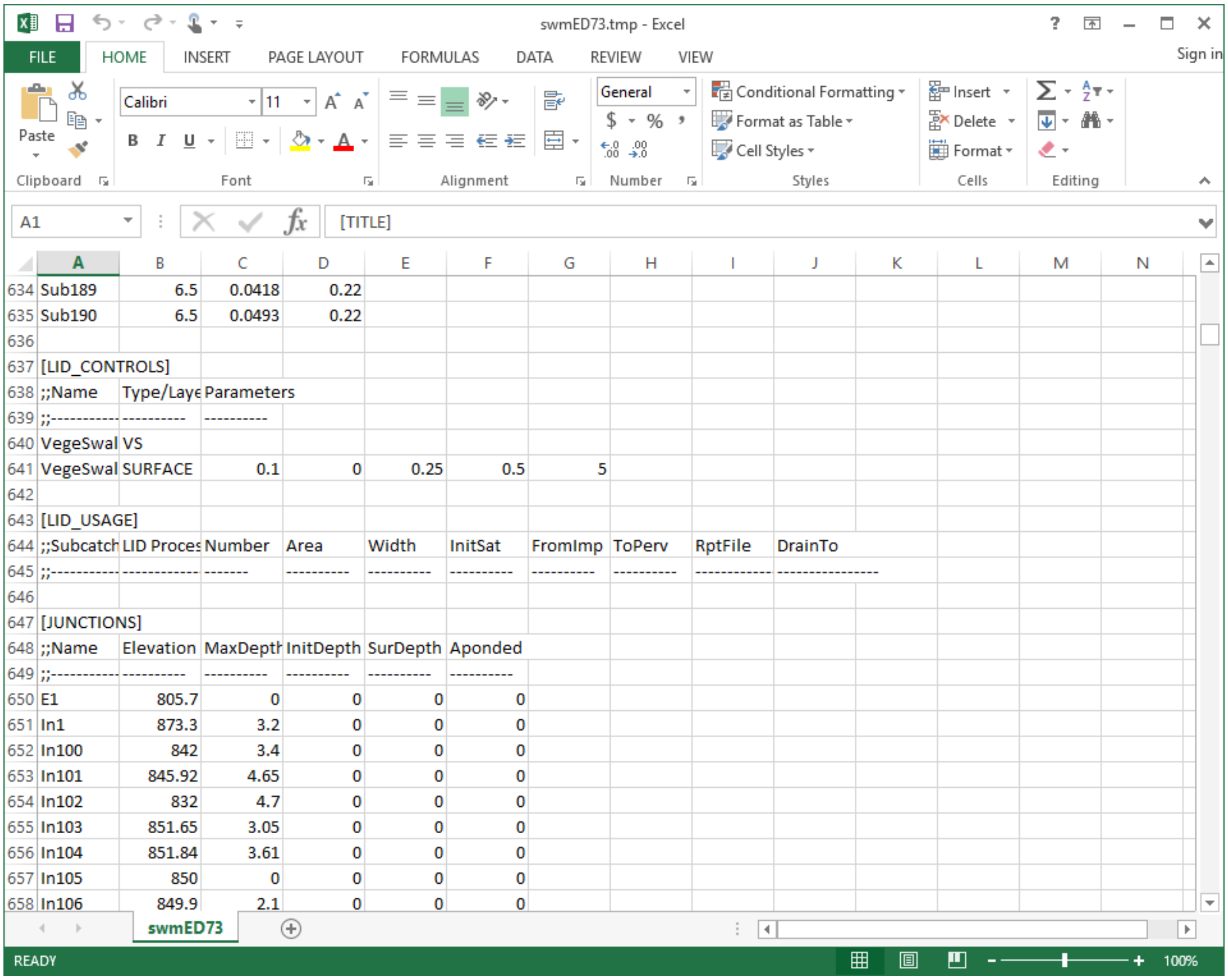
- ⇨ Control Name: 'VegeSwale0'
- ⇨ LID Type: 'Vegetative Swale'
- ⇨ Specify parameters for the 'Surface' as shown above (Berm Height 0.1, surface roughness from 0.1 to 0.25, surface slope 1.0 to 0.5)
- ⇨ Click [OK] button

3.4.2 Set up all of the Existing Baseline Buffering Pervious Area using the Excel Editor

The following steps need to be performed to add data to the LID control template using the Excel Editor in SWMM.

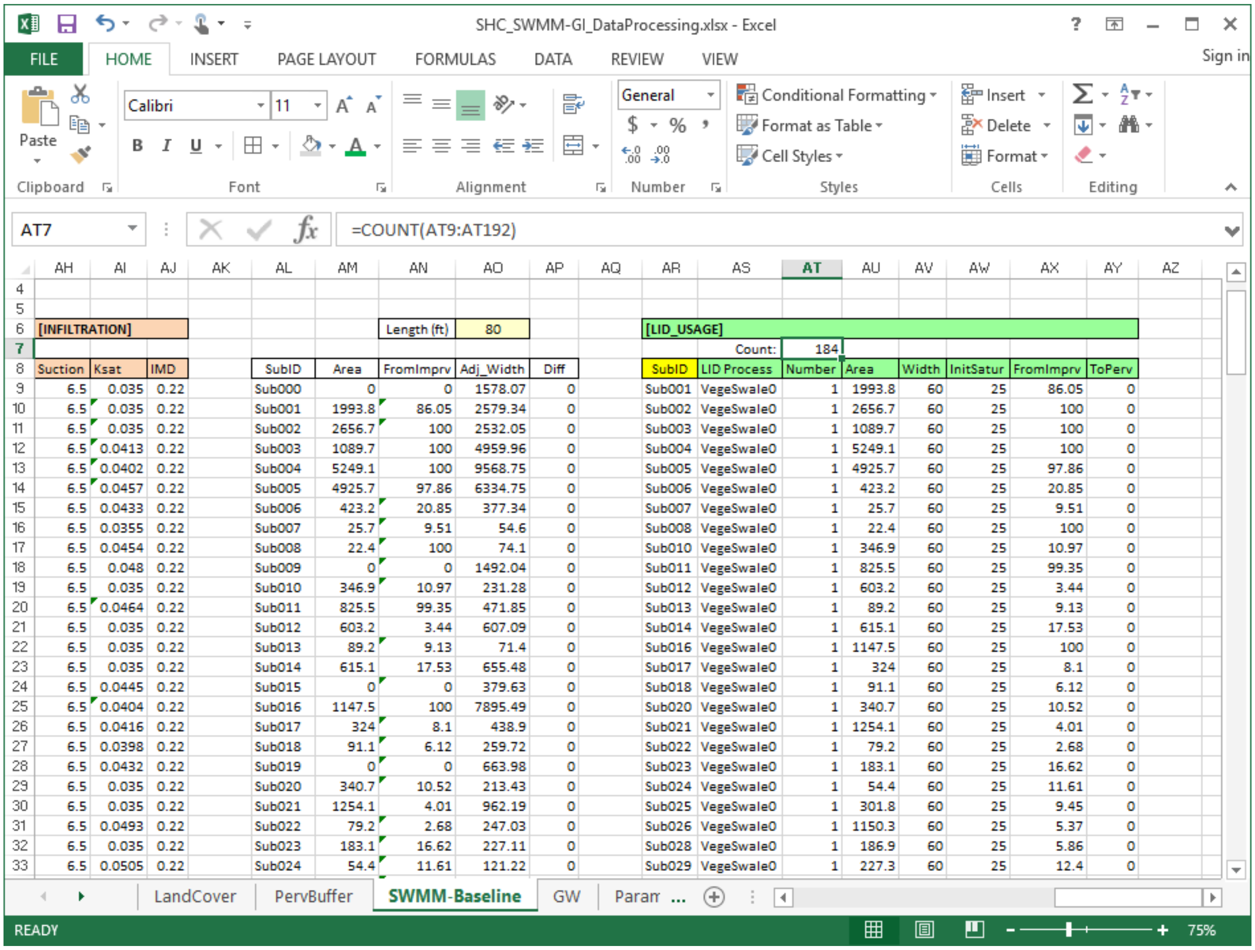
- ⇨ Click ' Tools / Excel Editor' under the Main Menu

Note: All of MS-Excel files must be closed before calling the 'Excel Editor'. Otherwise, the edited file may not be saved. This may vary from computer to computer and/or depend on the version of MS-Excel running.



⇨ Scroll down to locate [LID_USAGE] as shown above

⇨ Open “SHC_SWMM_DataProcessing.xlsx”



SHC_SWMM-GI_DataProcessing.xlsx - Excel

AT7 =COUNT(AT9:AT192)

	AH	AI	AJ
6	[INFILTRATION]		
8	Suction	Ksat	IMD
9	6.5	0.035	0.22
10	6.5	0.035	0.22
11	6.5	0.035	0.22
12	6.5	0.0413	0.22
13	6.5	0.0402	0.22
14	6.5	0.0457	0.22
15	6.5	0.0433	0.22
16	6.5	0.0355	0.22
17	6.5	0.0454	0.22
18	6.5	0.048	0.22
19	6.5	0.035	0.22
20	6.5	0.0464	0.22
21	6.5	0.035	0.22
22	6.5	0.035	0.22
23	6.5	0.035	0.22
24	6.5	0.0445	0.22
25	6.5	0.0404	0.22
26	6.5	0.0416	0.22
27	6.5	0.0398	0.22
28	6.5	0.0432	0.22
29	6.5	0.035	0.22
30	6.5	0.035	0.22
31	6.5	0.0493	0.22
32	6.5	0.035	0.22
33	6.5	0.0505	0.22

	AL	AM	AN	AO	AP
6			Length (ft)	80	
8	SubID	Area	FromImprv	Adj_Width	Diff
9	Sub000	0	0	1578.07	0
10	Sub001	1993.8	86.05	2579.34	0
11	Sub002	2656.7	100	2532.05	0
12	Sub003	1089.7	100	4959.96	0
13	Sub004	5249.1	100	9568.75	0
14	Sub005	4925.7	97.86	6334.75	0
15	Sub006	423.2	20.85	377.34	0
16	Sub007	25.7	9.51	54.6	0
17	Sub008	22.4	100	74.1	0
18	Sub009	0	0	1492.04	0
19	Sub010	346.9	10.97	231.28	0
20	Sub011	825.5	99.35	471.85	0
21	Sub012	603.2	3.44	607.09	0
22	Sub013	89.2	9.13	71.4	0
23	Sub014	615.1	17.53	655.48	0
24	Sub015	0	0	379.63	0
25	Sub016	1147.5	100	7895.49	0
26	Sub017	324	8.1	438.9	0
27	Sub018	91.1	6.12	259.72	0
28	Sub019	0	0	663.98	0
29	Sub020	340.7	10.52	213.43	0
30	Sub021	1254.1	4.01	962.19	0
31	Sub022	79.2	2.68	247.03	0
32	Sub023	183.1	16.62	227.11	0
33	Sub024	54.4	11.61	121.22	0

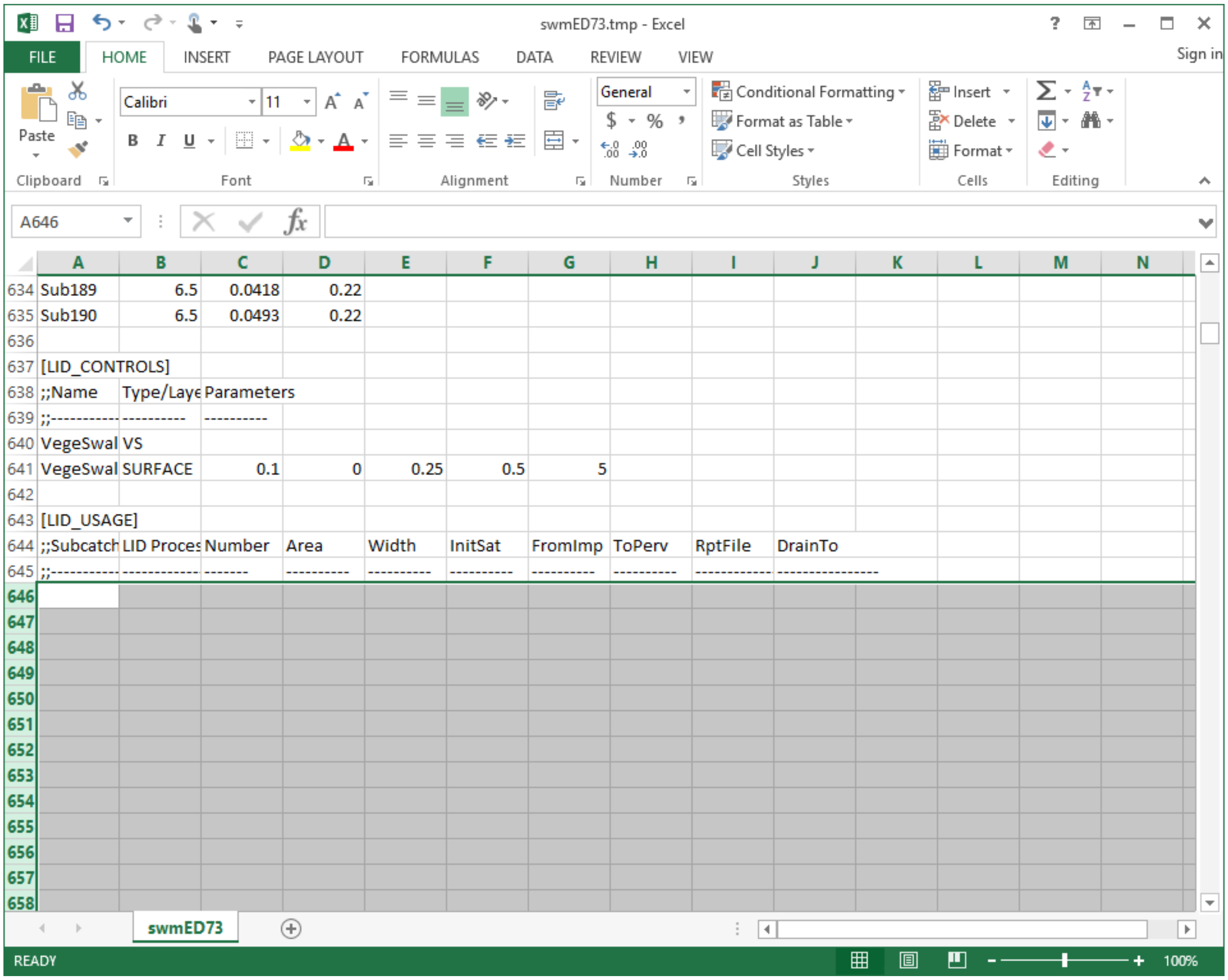
	AR	AS	AT	AU	AV	AW	AX	AY
6	[LID_USAGE]							
7		Count:	184					
8	SubID	LID Process	Number	Area	Width	InitSatur	FromImprv	ToPerv
9	Sub001	VegeSwale0	1	1993.8	60	25	86.05	0
10	Sub002	VegeSwale0	1	2656.7	60	25	100	0
11	Sub003	VegeSwale0	1	1089.7	60	25	100	0
12	Sub004	VegeSwale0	1	5249.1	60	25	100	0
13	Sub005	VegeSwale0	1	4925.7	60	25	97.86	0
14	Sub006	VegeSwale0	1	423.2	60	25	20.85	0
15	Sub007	VegeSwale0	1	25.7	60	25	9.51	0
16	Sub008	VegeSwale0	1	22.4	60	25	100	0
17	Sub010	VegeSwale0	1	346.9	60	25	10.97	0
18	Sub011	VegeSwale0	1	825.5	60	25	99.35	0
19	Sub012	VegeSwale0	1	603.2	60	25	3.44	0
20	Sub013	VegeSwale0	1	89.2	60	25	9.13	0
21	Sub014	VegeSwale0	1	615.1	60	25	17.53	0
22	Sub016	VegeSwale0	1	1147.5	60	25	100	0
23	Sub017	VegeSwale0	1	324	60	25	8.1	0
24	Sub018	VegeSwale0	1	91.1	60	25	6.12	0
25	Sub020	VegeSwale0	1	340.7	60	25	10.52	0
26	Sub021	VegeSwale0	1	1254.1	60	25	4.01	0
27	Sub022	VegeSwale0	1	79.2	60	25	2.68	0
28	Sub023	VegeSwale0	1	183.1	60	25	16.62	0
29	Sub024	VegeSwale0	1	54.4	60	25	11.61	0
30	Sub025	VegeSwale0	1	301.8	60	25	9.45	0
31	Sub026	VegeSwale0	1	1150.3	60	25	5.37	0
32	Sub028	VegeSwale0	1	186.9	60	25	5.86	0
33	Sub029	VegeSwale0	1	227.3	60	25	12.4	0

LandCover | PervBuffer | SWMM-Baseline | GW | Param ...

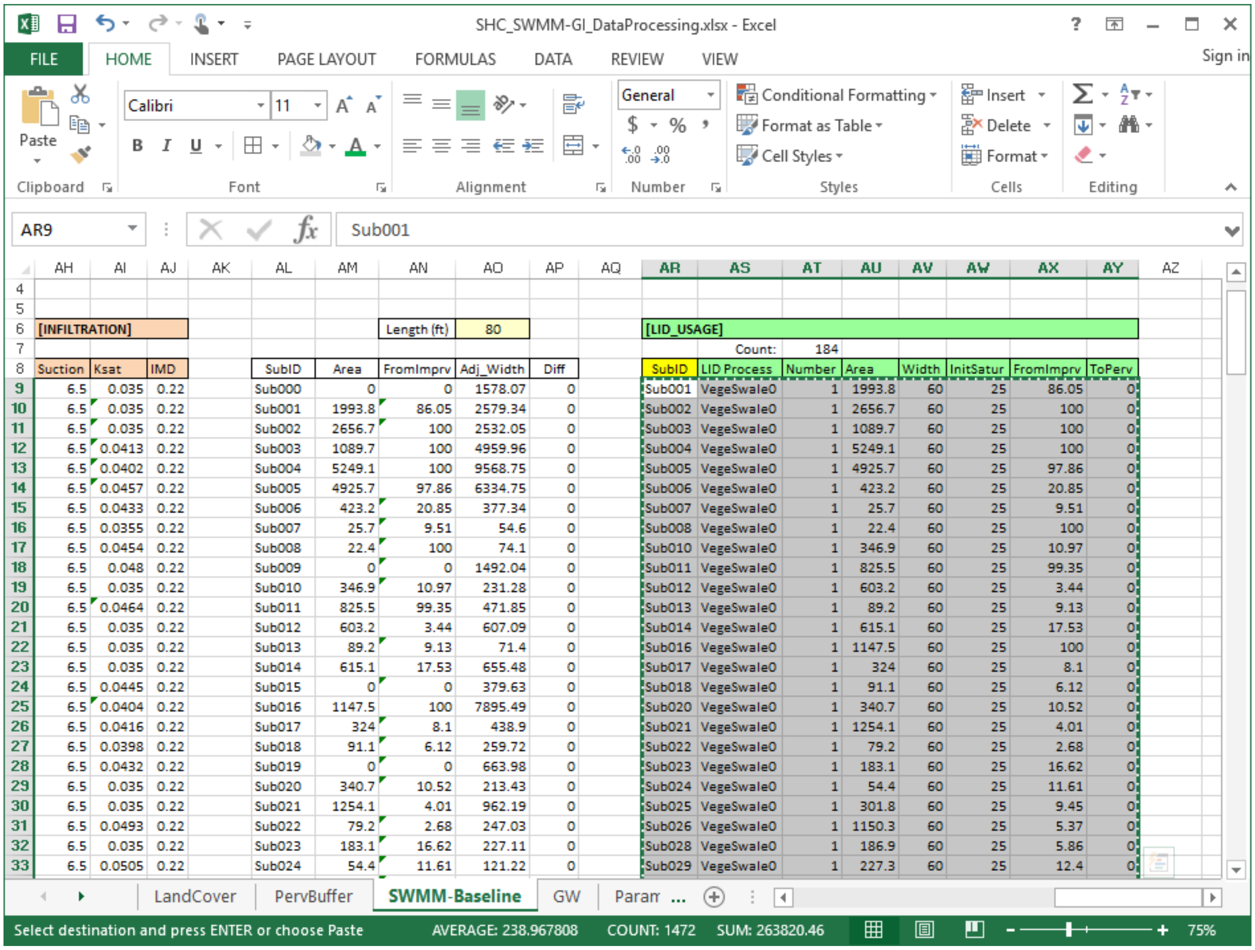
⇨ Count the number of subcatchments that have existing BPA *(‘LID_USAGE’ was arranged using the ‘PervBuffer’ tab.)*

Note: 184 subcatchments have BPA in the SHC watershed.

⇨ Go back to the SWMM input file using the Excel Editor



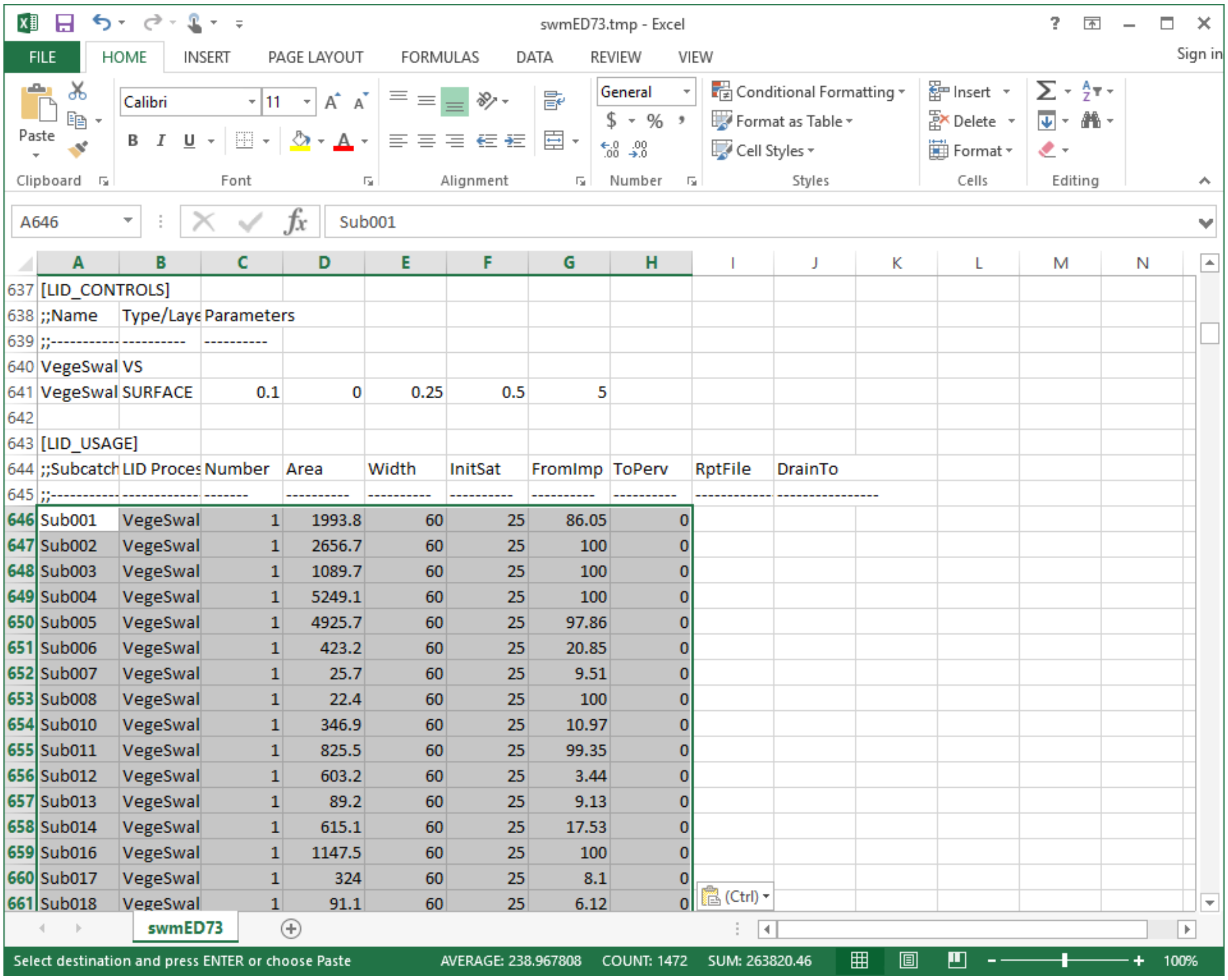
⇨ Underneath the [LID_USAGE], insert the same number of rows as the 'Count' from the previous screenshot (184), as shown above



⇨ Return to the “SHC_SWMM_DataProcessing.xlsx”

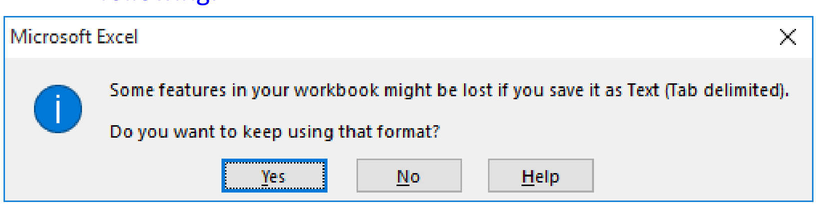
⇨ Select cells [AR9:AY192] from [SWMM-Baseline] tab. Copy and, then, Paste to the Excel Editor file

Note: You must use the “Paste Special” with “Value” option to prevent copy/pasting of any formulas referencing cells that don’t contain the correct information in this file.



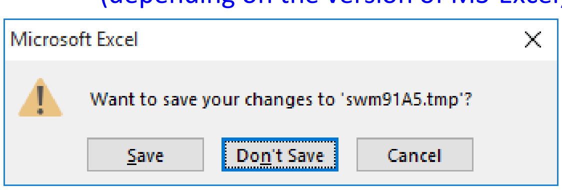
Next, save the SWMM input file from the Excel Editor as follows:

⇨ Click 'File / Save' under the Main Menu (or click  button to save), then you will get the following:



⇨ Click 'Yes' button to save the update.

⇨ Close the Excel Editor by clicking the relevant button or menu, then you may get the following (depending on the version of MS-Excel):



⇨ Click 'Don't Save' button

(Note: If you click 'Save', the file format will be changed as an MS-Excel file.)

⇨ Close the "SHC_SWMM_DataProcessing.xlsx"

⇨ Save the SWMM input file and switch to the EPA SWMM program

3.5 Set up Aquifers and Groundwater Modeling Specifications

Aquifers are only required in models that need to explicitly account for the exchange of groundwater with the drainage system or to establish baseflow and recession curves in natural channels (Rossman, 2015). Aquifers model the vertical movement of water infiltration from the subcatchments that lie above them. Depending on the hydraulic gradient, they also permit the infiltration of groundwater into the drainage system, or exfiltration of surface water from the drainage system. The same aquifer object can be shared by several subcatchments. In this study, 5 groundwater basins were established, largely arbitrarily, based on the exiting storm drainage networks as shown in Figure 18. There was no groundwater data to use as means of better qualifying the delineation of groundwater basins.

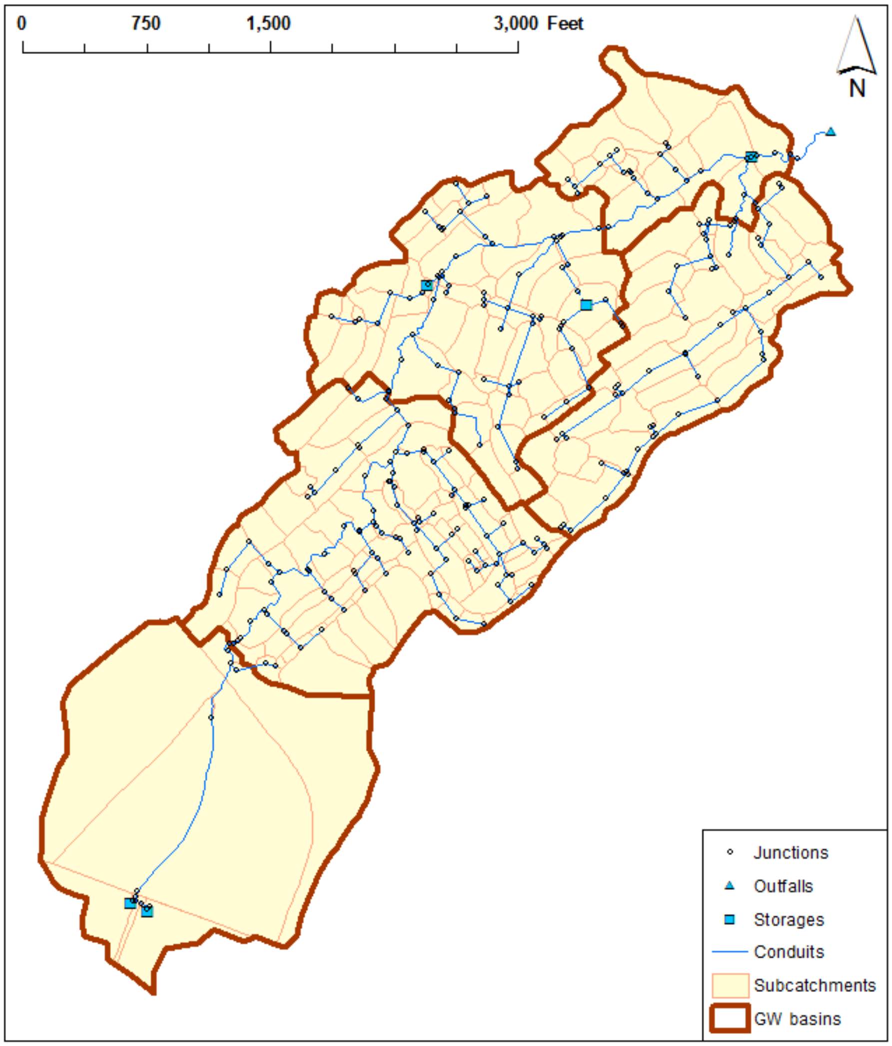


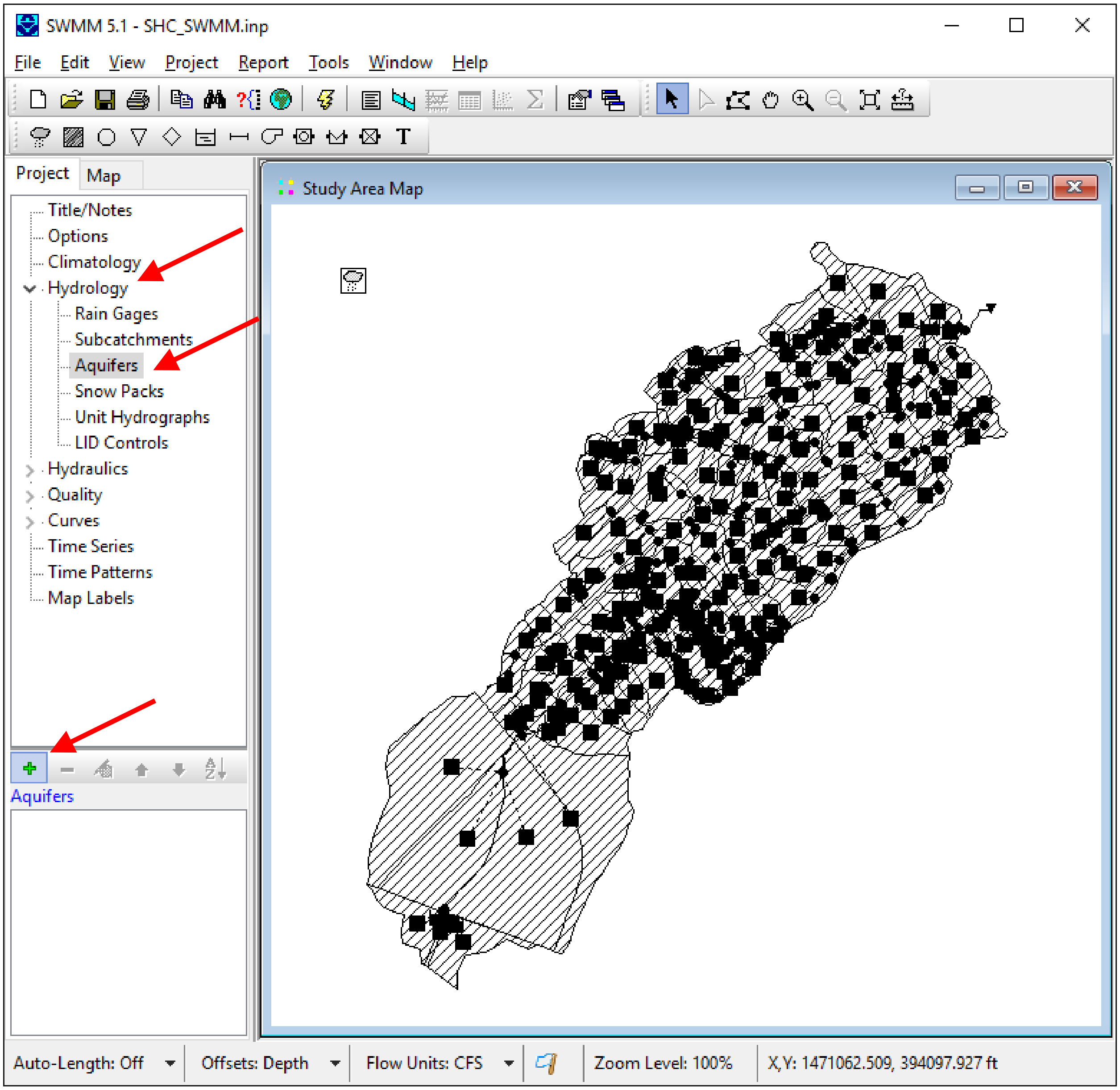
Figure 18. SHC groundwater basins based on the existing storm drainage networks (assumed for modeling baseflow).

The following steps demonstrate the set-up of aquifers and groundwater modeling specifications using EPA SWMM and the Excel Editor. The groundwater flow component connects the saturated zone of the aquifers to the subcatchments and to drainage system nodes as defined in a subcatchment's groundwater flow properties. These predefined properties also contain parameters that govern the rate of groundwater flow between the aquifer's saturated zone and the drainage system node. Parameters for groundwater modeling were arranged using the site-specific soil data (Section 2.1.1). As shown in Figure 3, the study watershed has very homogeneous soil: silt loam or loam. Based on the soil texture, parameters for aquifer (e.g., Ksat, wilting point, field capacity) was initially selected from the SWMM User's manual (Rossman, 2015).

⇨ Run the EPA SWMM, and open the "SHC_SWMM.inp" if it is closed

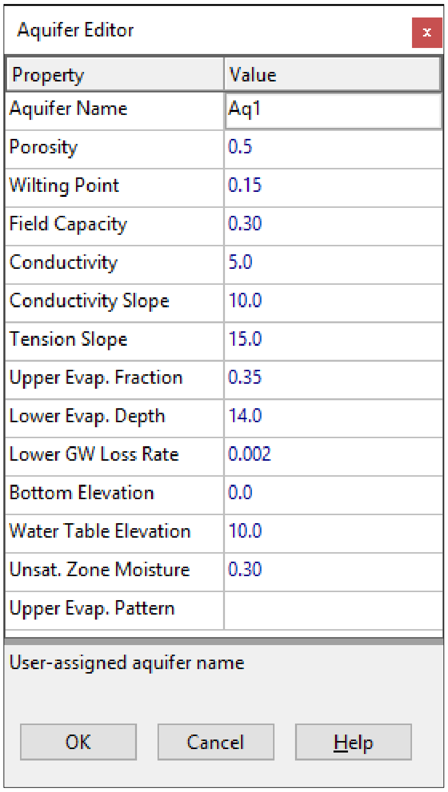
3.5.1 *Add an ‘Aquifer’ using EPA SWMM*

The following steps need to be performed to add an Aquifer template in SWMM.



⇨ Click “Hydrology” under the “Project” tab, then click “Aquifers”

⇨ Click  ‘Add Object’ button



⇨ Specify 'Aquifer Name' as 'Aq1'

⇨ Leave all of the parameters as default values

⇨ Click 'OK' button to close the 'Aquifer Editor'

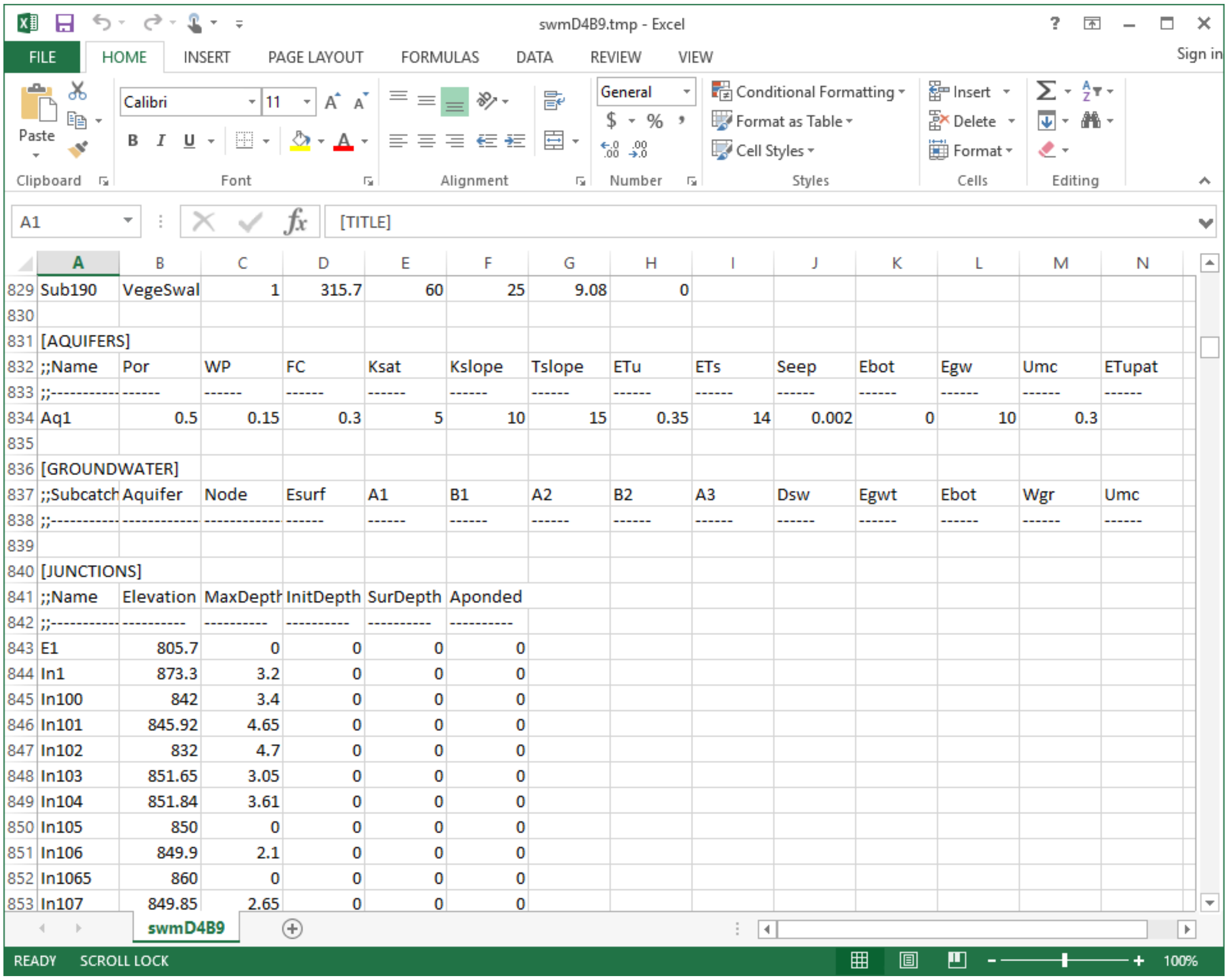
Note: This one Aquifer creates a template for adding additional aquifers and editing data in Excel.

3.5.2 Set up all of the Aquifers using the Excel Editor

The following steps need to be performed to add data to the Aquifer template using the Excel Editor in SWMM.

⇨ Click 'Tools / Excel Editor' under the Main Menu

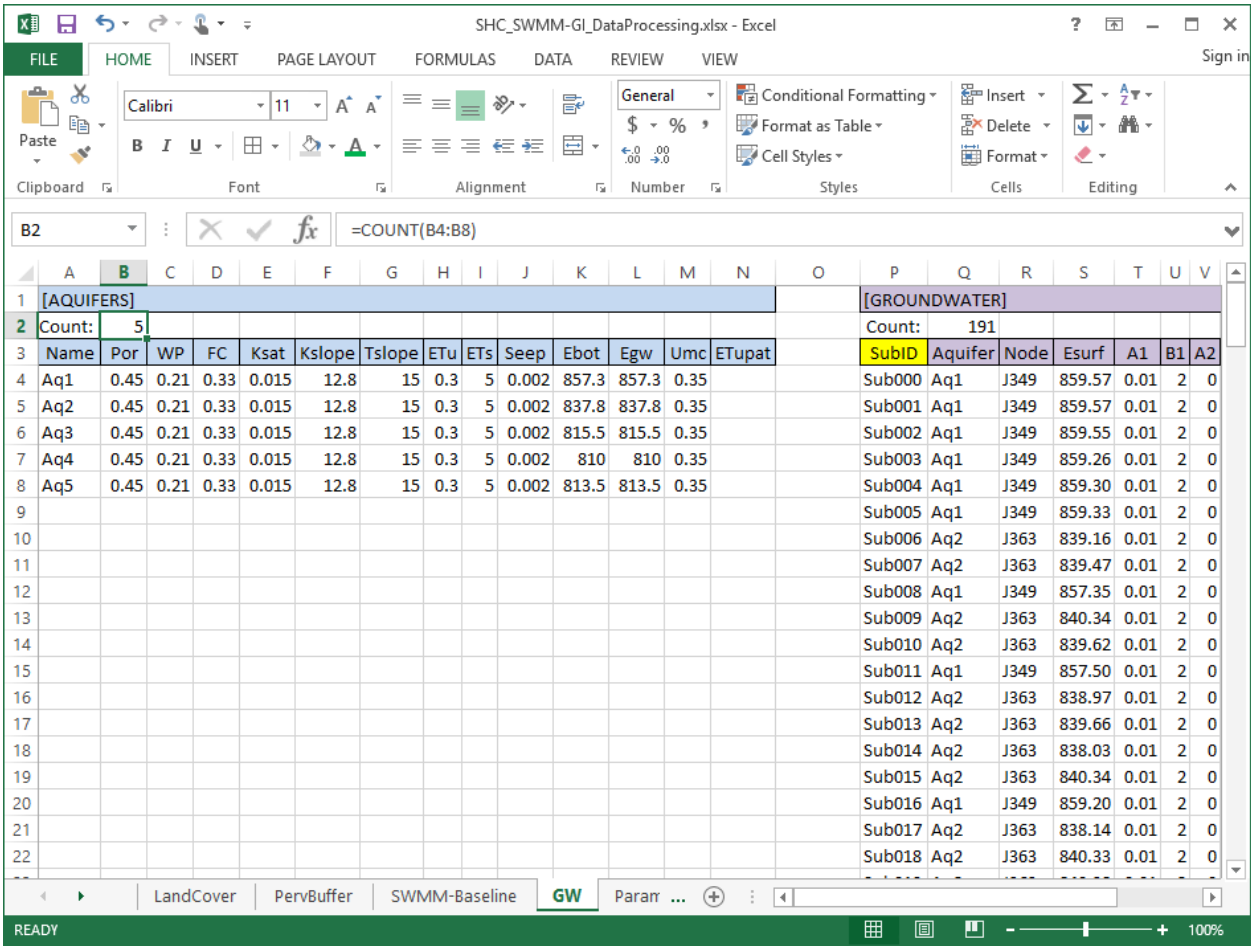
Note: All of MS-Excel files must be closed before calling the 'Excel Editor'. Otherwise, the edited file may not be saved, which depends on the computer and/or the version of the MS-Excel running.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
829	Sub190	VegeSwal	1	315.7	60	25	9.08	0						
830														
831	[AQUIFERS]													
832	;;Name	Por	WP	FC	Ksat	Kslope	Tslope	ETu	ETs	Seep	Ebot	Egw	Umc	ETupat
833	;;----------	------	------	------	------	------	------	------	------	------	------	------	------	------
834	Aq1	0.5	0.15	0.3	5	10	15	0.35	14	0.002	0	10	0.3	
835														
836	[GROUNDWATER]													
837	;;Subcatch	Aquifer	Node	Esurf	A1	B1	A2	B2	A3	Dsw	Egwt	Ebot	Wgr	Umc
838	;;----------	------------	------------	------	------	------	------	------	------	------	------	------	------	------
839														
840	[JUNCTIONS]													
841	;;Name	Elevation	MaxDepth	InitDepth	SurDepth	Aponded								
842	;;----------	----------	----------	----------	----------	----------								
843	E1	805.7	0	0	0	0								
844	In1	873.3	3.2	0	0	0								
845	In100	842	3.4	0	0	0								
846	In101	845.92	4.65	0	0	0								
847	In102	832	4.7	0	0	0								
848	In103	851.65	3.05	0	0	0								
849	In104	851.84	3.61	0	0	0								
850	In105	850	0	0	0	0								
851	In106	849.9	2.1	0	0	0								
852	In1065	860	0	0	0	0								
853	In107	849.85	2.65	0	0	0								

⇨ Scroll down to locate [AQUIFERS] as shown above

⇨ Open “SHC_SWMM_DataProcessing.xlsx”

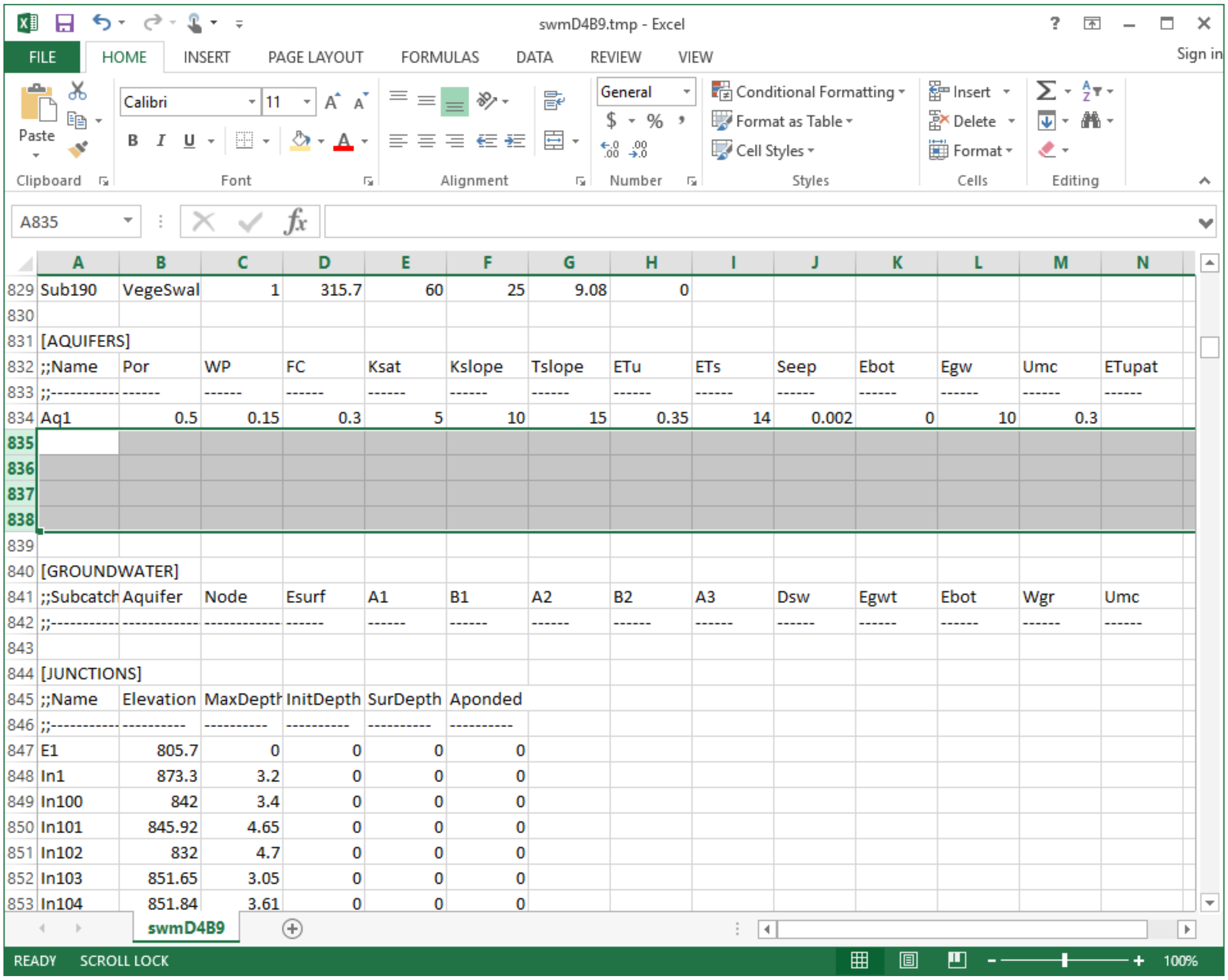


⇨ Open the [GW] tab

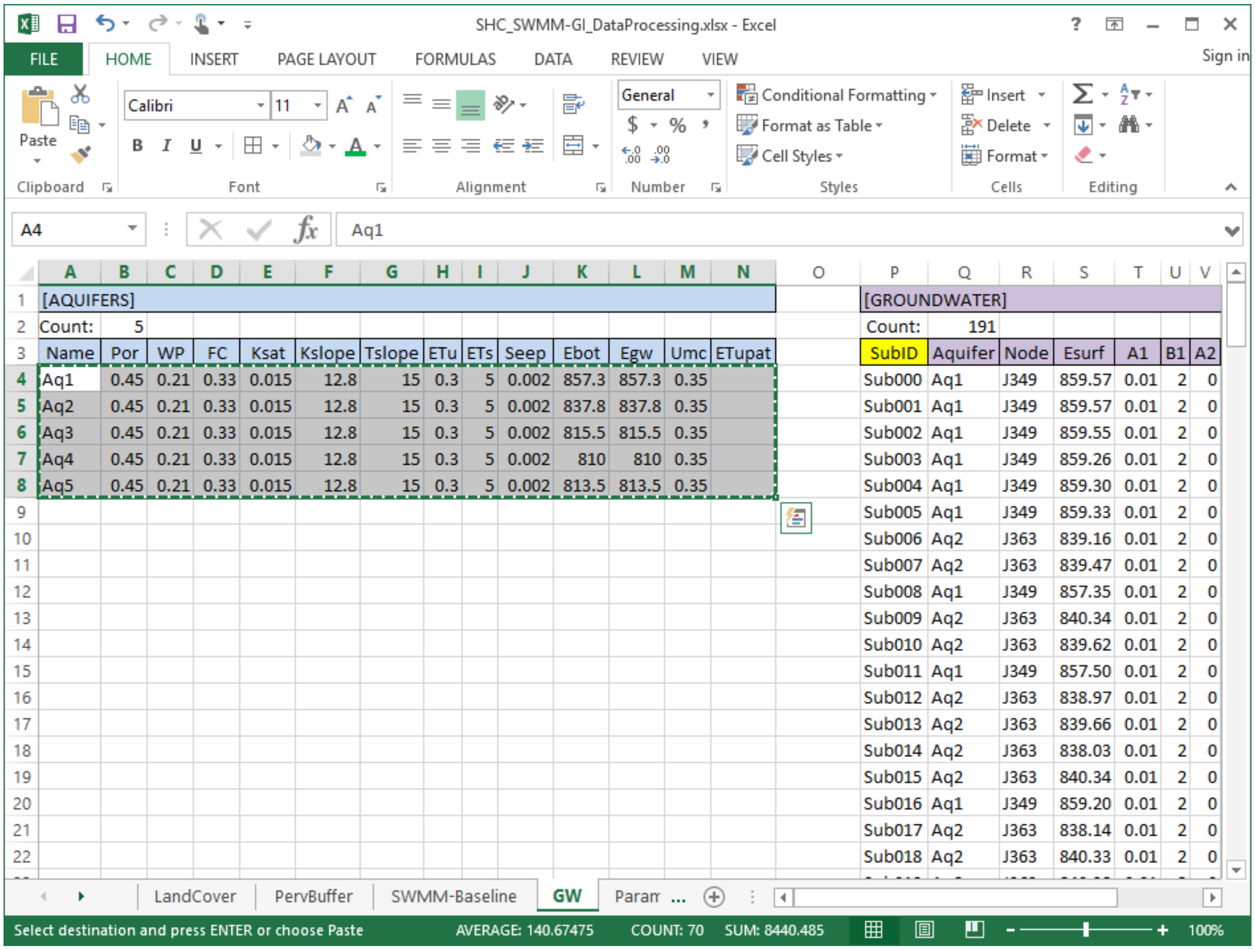
⇨ Count the number of aquifers that will be included in the model

Note: The study area was modeled with 5 aquifers in this case study as presented earlier.

⇨ Open the SWMM input file using the Excel Editor

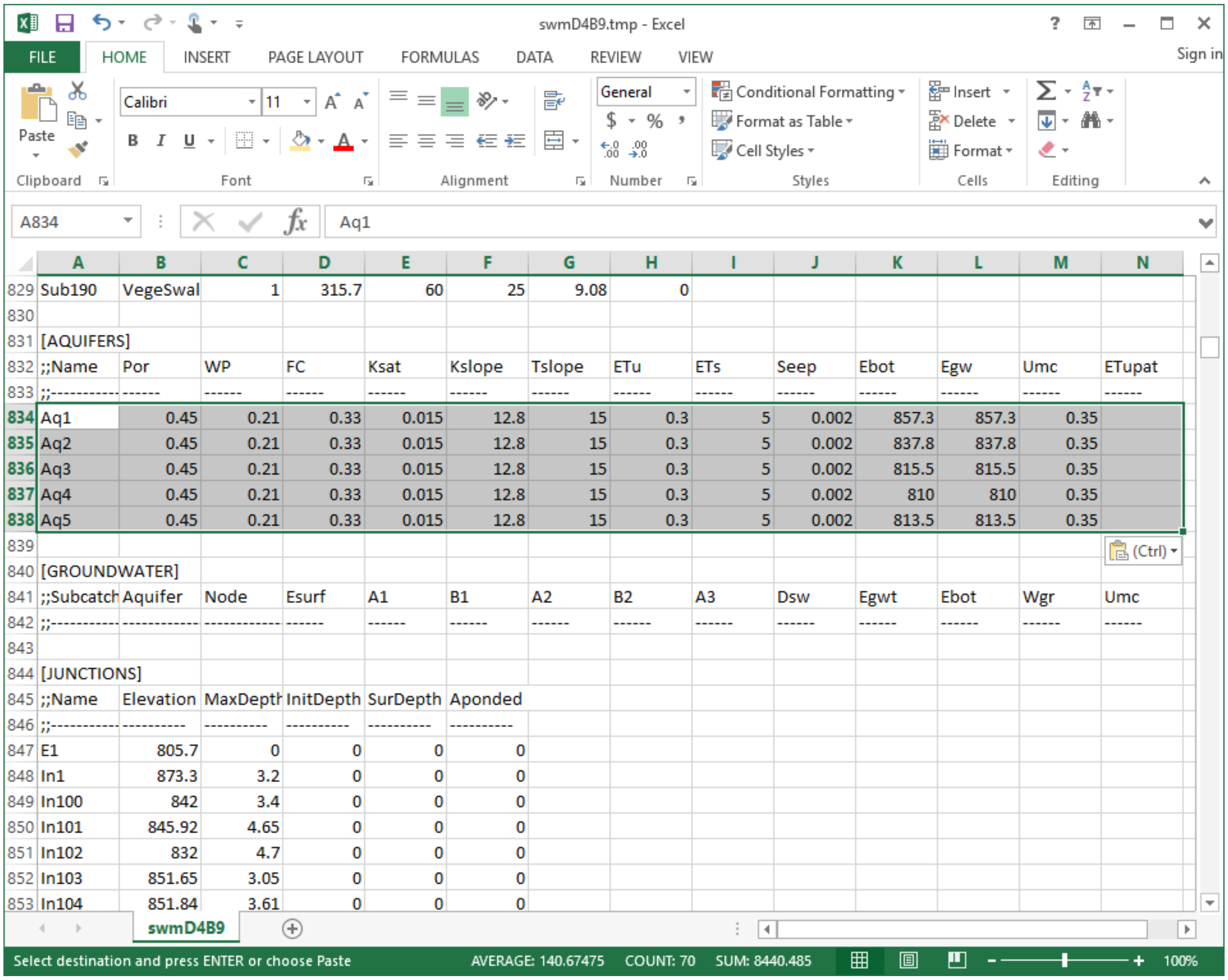


⇨ Underneath the [AQUIFERS], insert the ‘Count’ (from the previous step) minus 1 rows, as shown above



⇨ Go back to the “SHC_SWMM_DataProcessing.xlsx”

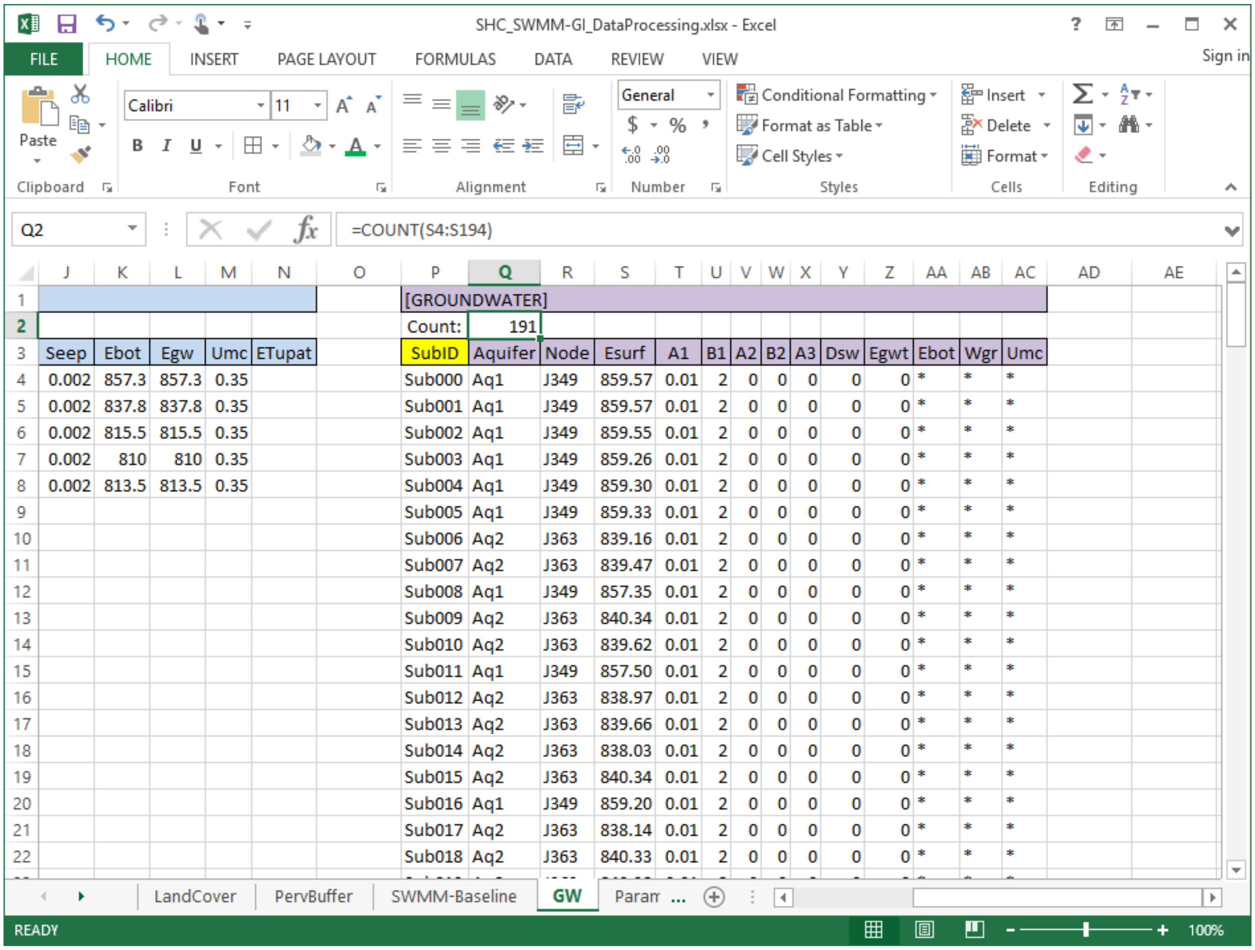
⇨ Select cells [A4:N8] from [GW] tab. Copy and then “Paste Value” into the blank cells previously created in Excel Editor File as shown below.



Note: The parameters for the 'Aq1' are also replaced by this step.

3.5.3 Set up Groundwater Parameters for all Subcatchments using the Excel Editor

The following steps need to be performed to add groundwater parameters to the template using the Excel Editor in SWMM.



Seep	Ebot	Egw	Umc	ETupat
0.002	857.3	857.3	0.35	
0.002	837.8	837.8	0.35	
0.002	815.5	815.5	0.35	
0.002	810	810	0.35	
0.002	813.5	813.5	0.35	

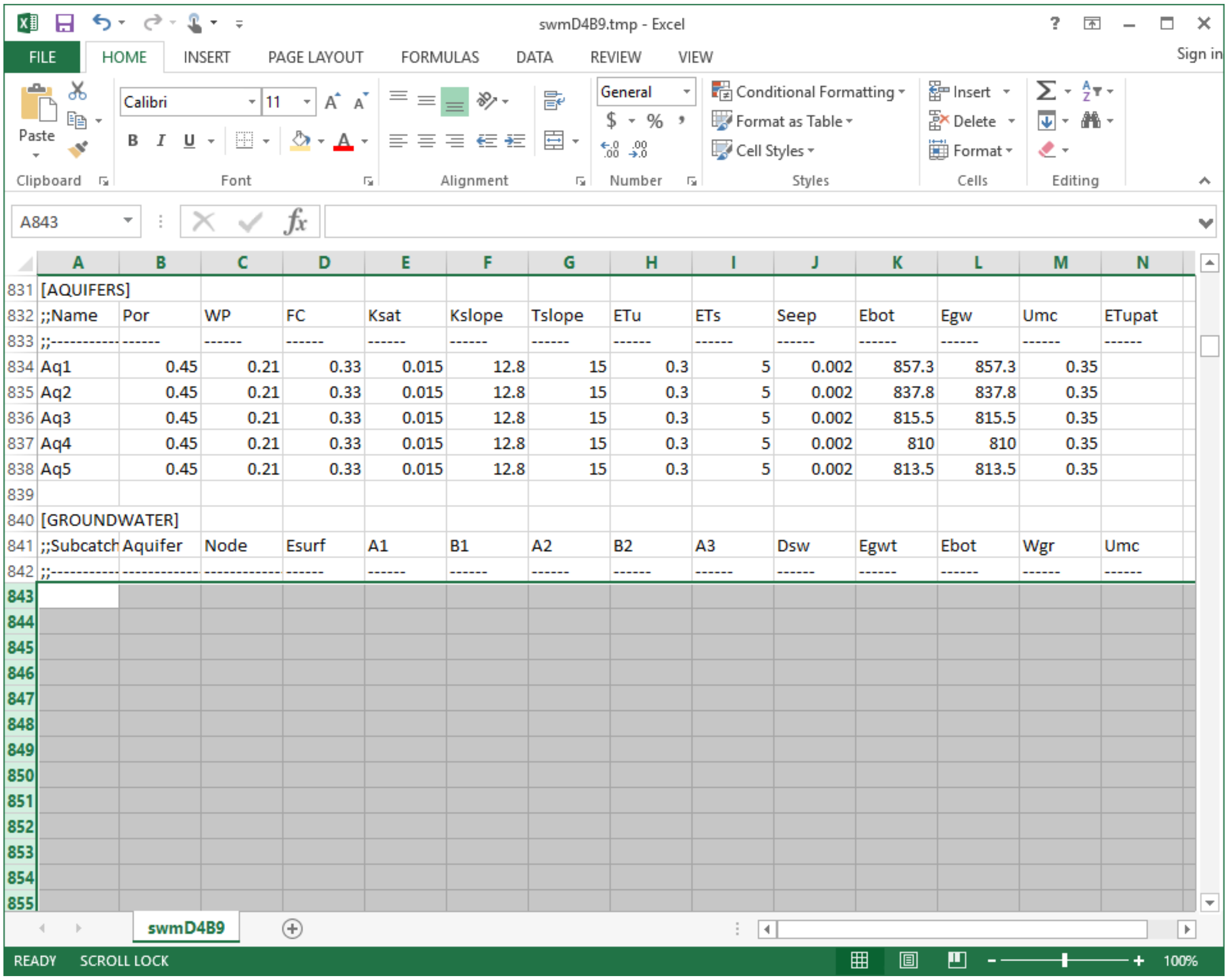
[GROUNDWATER]
Count: 191

SubID	Aquifer	Node	Esurf	A1	B1	A2	B2	A3	Dsw	Egwt	Ebot	Wgr	Umc
Sub000	Aq1	J349	859.57	0.01	2	0	0	0	0	0	*	*	*
Sub001	Aq1	J349	859.57	0.01	2	0	0	0	0	0	*	*	*
Sub002	Aq1	J349	859.55	0.01	2	0	0	0	0	0	*	*	*
Sub003	Aq1	J349	859.26	0.01	2	0	0	0	0	0	*	*	*
Sub004	Aq1	J349	859.30	0.01	2	0	0	0	0	0	*	*	*
Sub005	Aq1	J349	859.33	0.01	2	0	0	0	0	0	*	*	*
Sub006	Aq2	J363	839.16	0.01	2	0	0	0	0	0	*	*	*
Sub007	Aq2	J363	839.47	0.01	2	0	0	0	0	0	*	*	*
Sub008	Aq1	J349	857.35	0.01	2	0	0	0	0	0	*	*	*
Sub009	Aq2	J363	840.34	0.01	2	0	0	0	0	0	*	*	*
Sub010	Aq2	J363	839.62	0.01	2	0	0	0	0	0	*	*	*
Sub011	Aq1	J349	857.50	0.01	2	0	0	0	0	0	*	*	*
Sub012	Aq2	J363	838.97	0.01	2	0	0	0	0	0	*	*	*
Sub013	Aq2	J363	839.66	0.01	2	0	0	0	0	0	*	*	*
Sub014	Aq2	J363	838.03	0.01	2	0	0	0	0	0	*	*	*
Sub015	Aq2	J363	840.34	0.01	2	0	0	0	0	0	*	*	*
Sub016	Aq1	J349	859.20	0.01	2	0	0	0	0	0	*	*	*
Sub017	Aq2	J363	838.14	0.01	2	0	0	0	0	0	*	*	*
Sub018	Aq2	J363	840.33	0.01	2	0	0	0	0	0	*	*	*

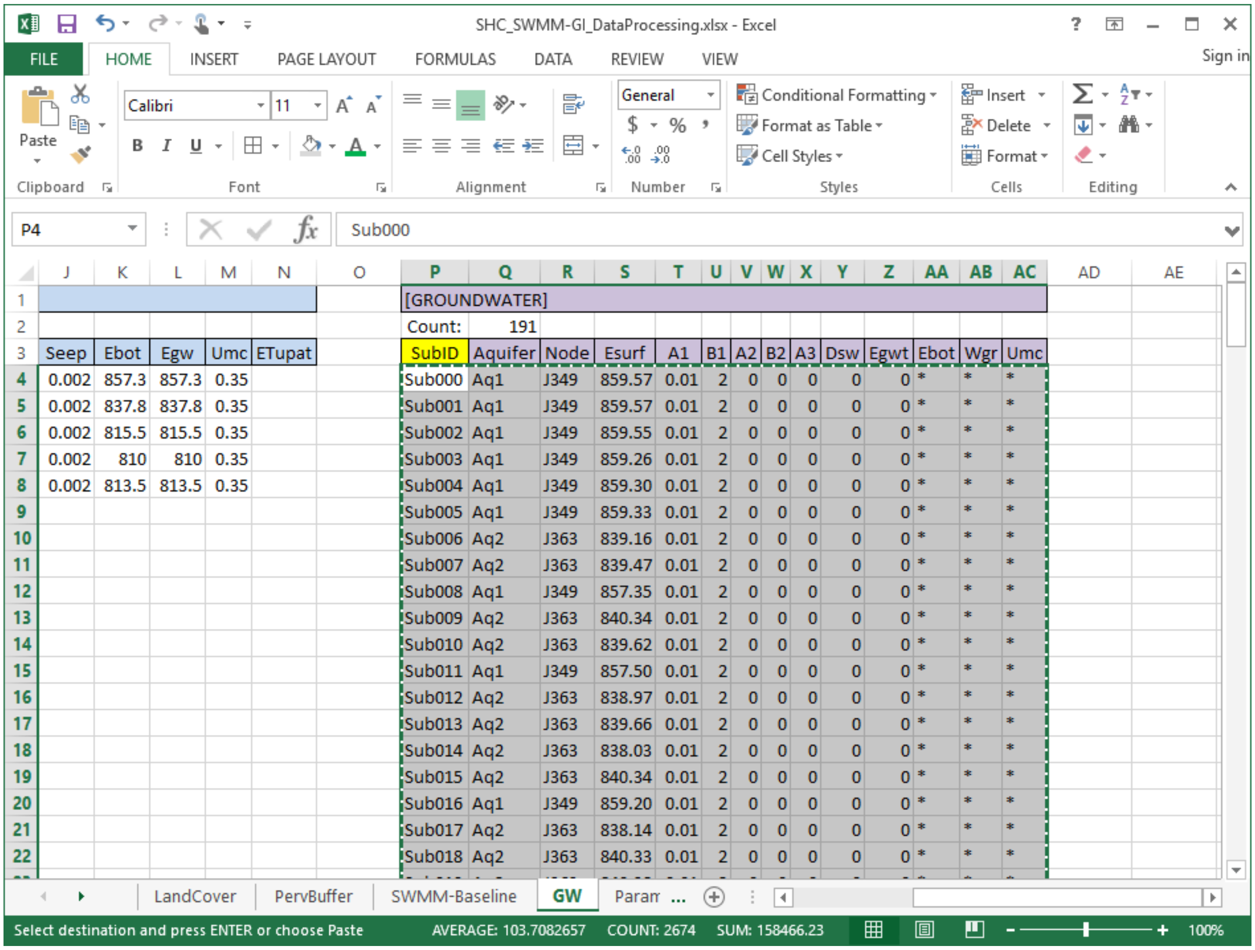
⇨ Open the [GW] tab in the “SHC_SWMM_DataProcessing.xlsx”

⇨ Check the number of subcatchments in the SWMM model

⇨ Open the SWMM input file using the Excel Editor



⇨ Underneath the [GROUNDWATER], insert the same number of rows as the ‘Count’ from the previous step, as shown above



⇨ Open the "SHC_SWMM_DataProcessing.xlsx"

⇨ Select cells [P4:AC194] from [GW] tab. Copy and then Paste Value into the SWMM input file using the Excel Editor

⇨ Save the input file following the same steps described previously

3.6 Specify 'Transects' and 'Curves' using the EPA SWMM

Open channels are represented with a rectangular, trapezoidal, or user-defined irregular cross-sectional shape. For defining an irregular shape in the model, the "Transect" object is used to define the variation in depth with distance across the cross-section.

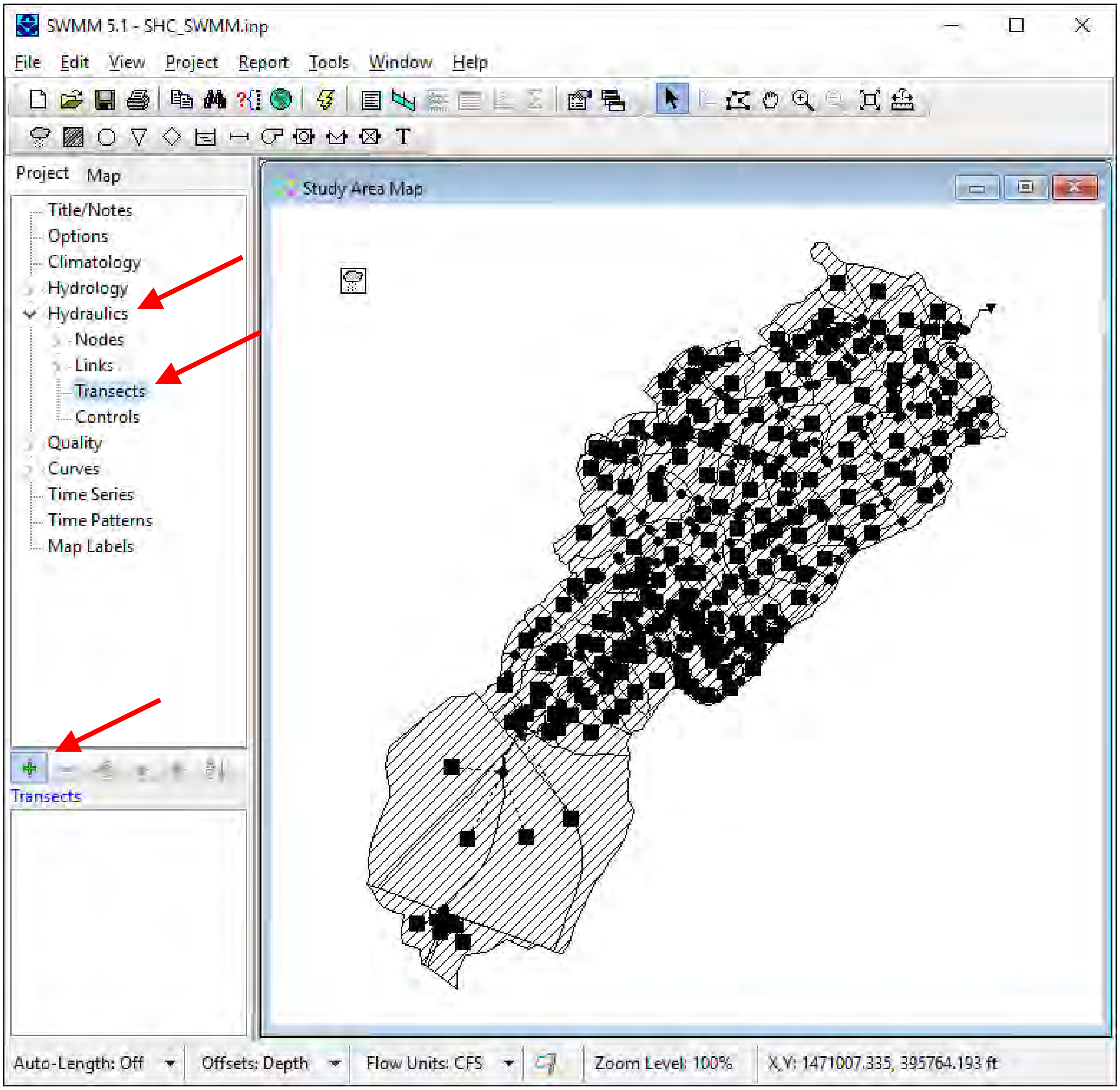
A storage "curve" is a methodology for representing the geometric shape of a storage unit. A functional form can be used for well-defined shapes and a tabular form can be used to represent irregularly shaped storage areas. In this study, the tabular form of the storage "curve" (i.e., a table of area versus depth) was used for model computations.

The next steps specify 'Transects' and 'Curves' using the EPA SWMM.

⇨ Run EPA SWMM, and open the "SHC_SWMM.inp" if it is closed

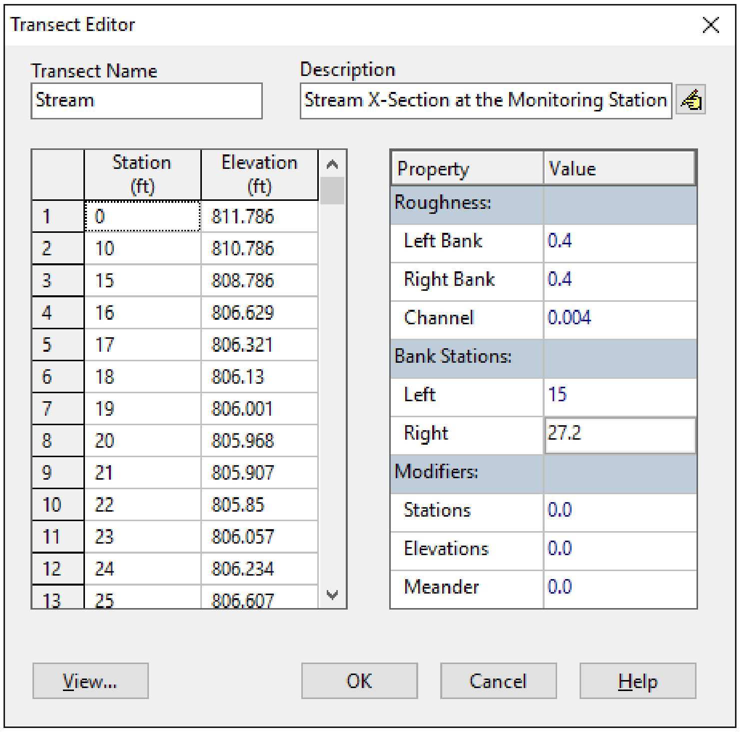
3.6.1 Add Cross Section Data for the Natural Stream using *the "Transect Editor" in* EPA SWMM

The following steps create a template for adding a natural stream in SWMM.



⇨ Click "Hydraulics" under the "Project" tab, then click "Transects"

⇨ Click 'Add Object' button

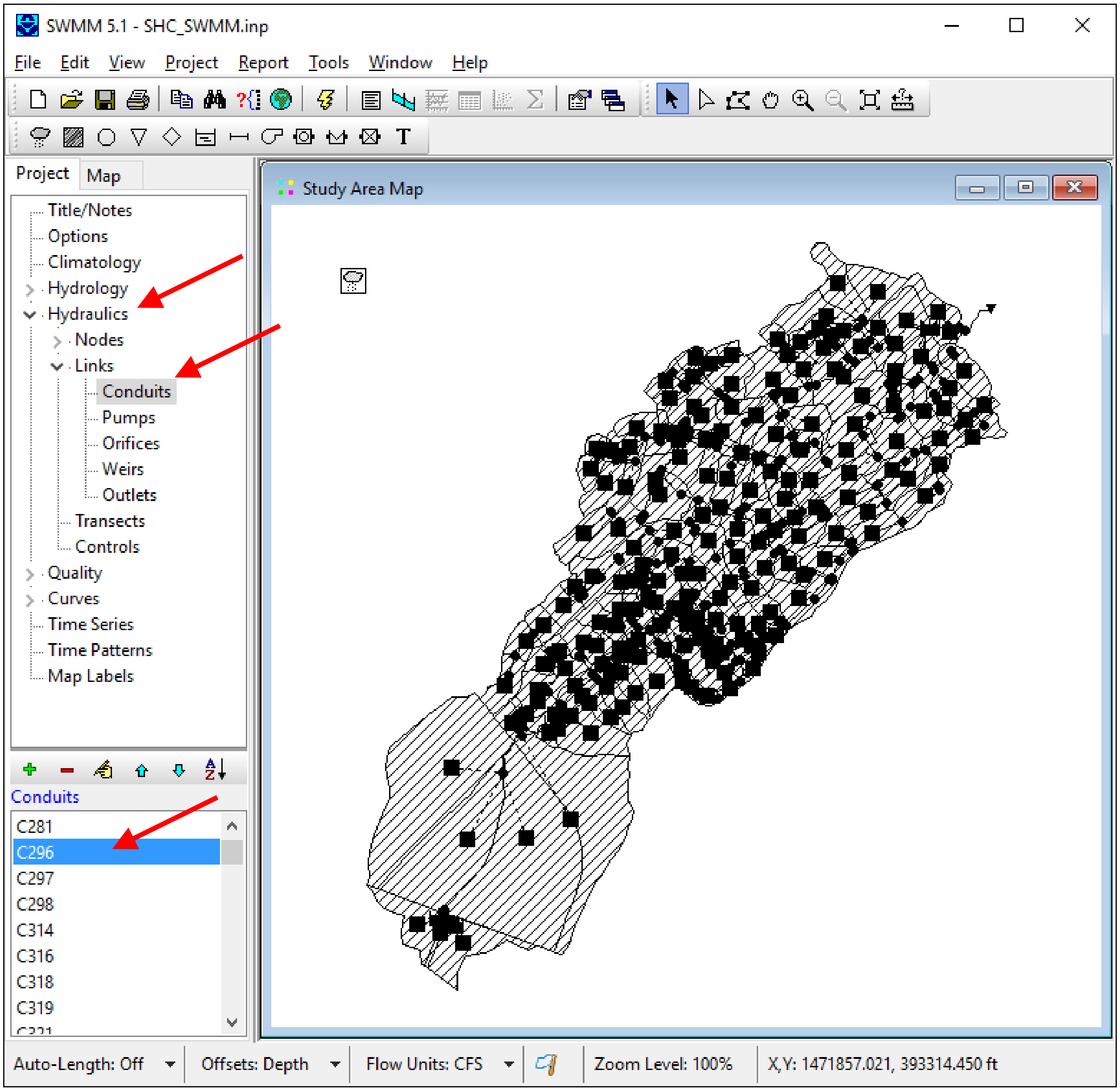


⇨ Specify 'Transect Name' as 'Stream', and add 'Description' (optional)

⇨ Specify all of the parameters as shown above using the "Stream_X-Section.txt", then click [OK] button *(This observed cross-sectional data was collected from the EFW monitoring and modeling project. Vertical profiles were measured at the natural stream where the flow monitoring is conducted.)*

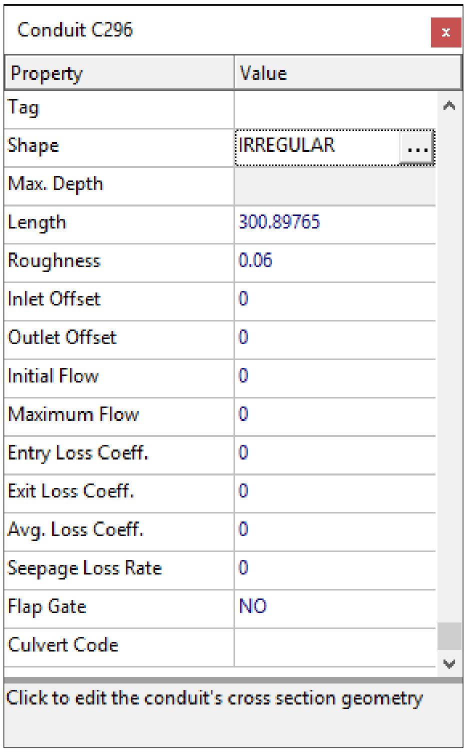
⇨ Specify the 'Transect Name' for the natural 'Irregular' streams

Note: Stream channels near the flow monitoring stations are modeled as 'Irregular' to compare the modeling results with the observed data more directly. All the other natural stream channels were modeled with 'Trapezoidal' cross sections in the SHC watershed.

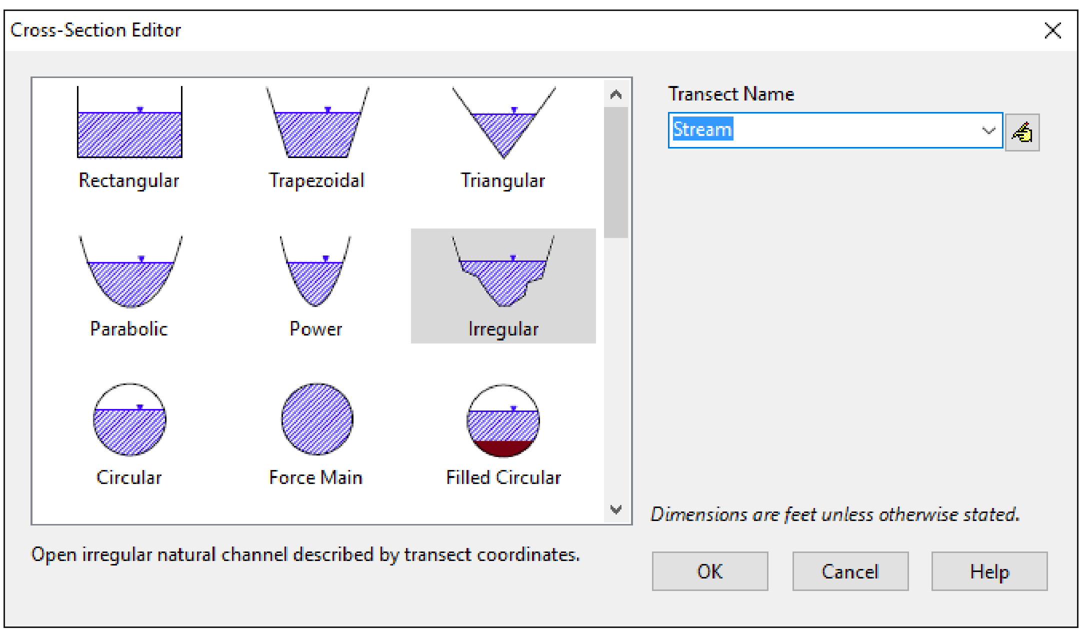


⇨ Click "Hydraulics" under the "Project" tab, then click "Conduits"

⇨ Scroll down the list of 'Conduits', then double click 'C296' under the 'Conduits'

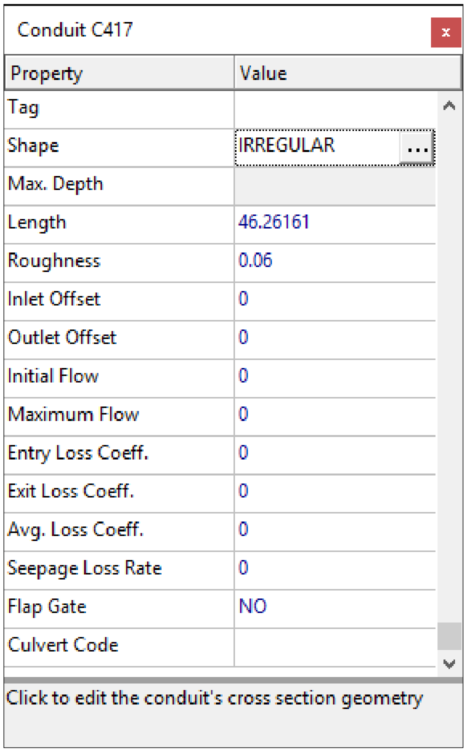


⇨ Click ... button to specify the 'Shape'

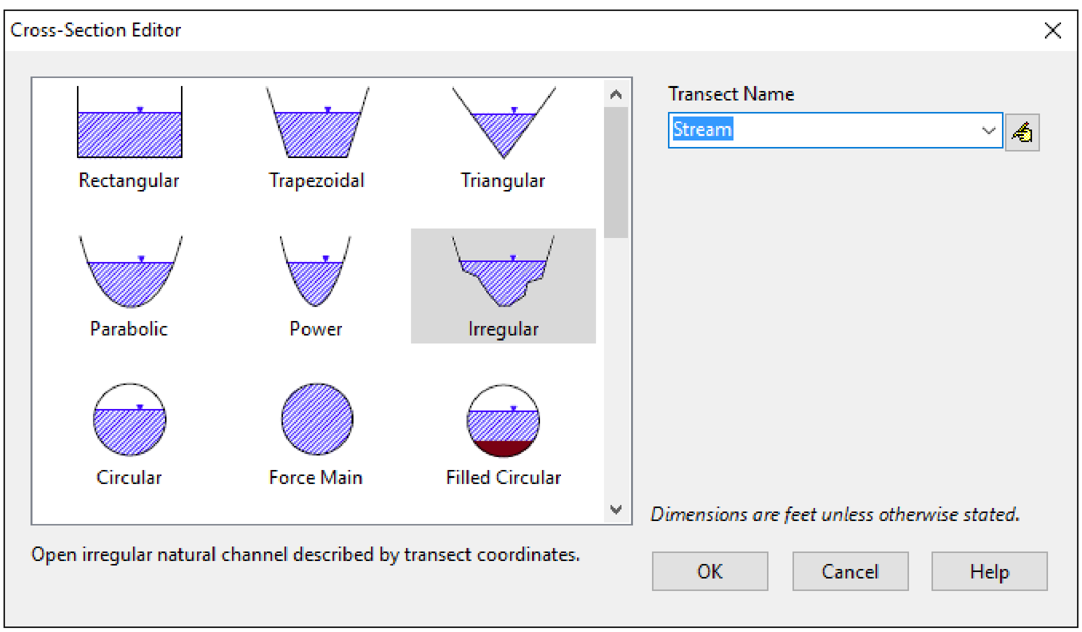


⇨ Select 'Transect Name' as 'Stream' from dropdown box, then click 'OK' button

⇨ Scroll down the list of 'Conduits', then double click 'C417' under the 'Conduits'



⇨ Click ... button to specify the 'Shape'



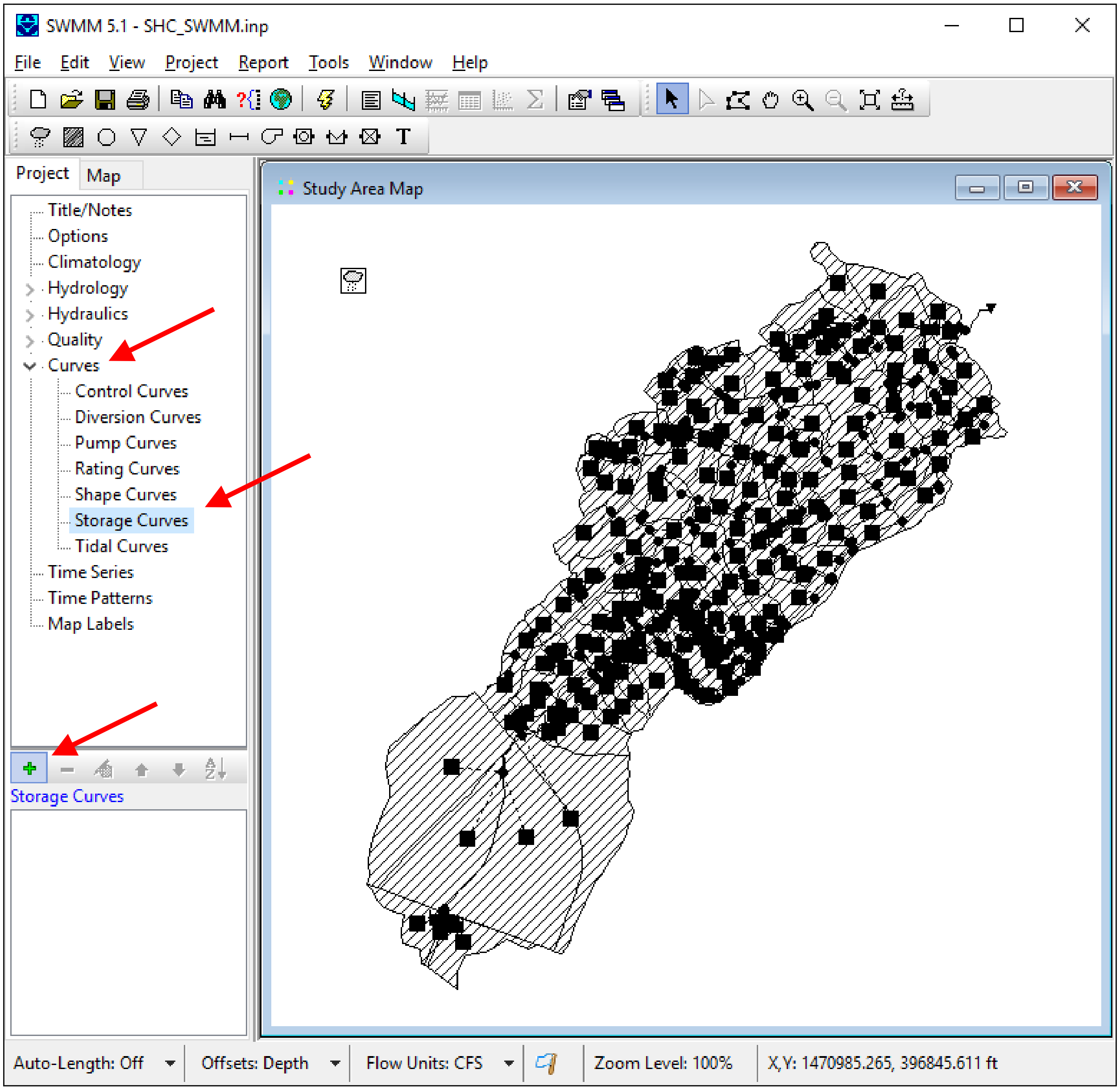
⇨ Specify 'Transect Name' (initially shows up as 0) as 'Stream' from dropdown, then click [OK] button

⇨ Click × button to close the 'Conduit C417'

⇨ Save the SWMM input file

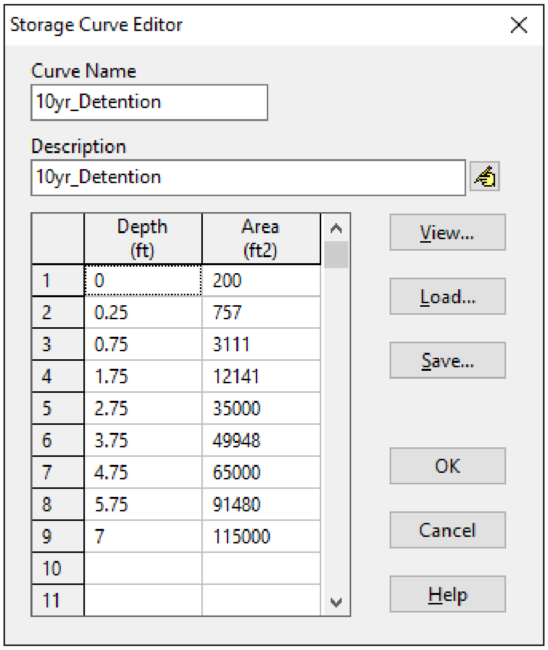
3.6.2 Specify the Storage Curves

Storage curves for individual storage units were developed using the most up-to-date GIS data from the County. The next steps are to specify the 'Storage Curves' for the storage units in the SWMM model using the "Storage_Curves.txt". The data for storage curves was collected from a previous SWMM modeling analysis conducted in 2006 (Bennett 2006). The older data was verified by the County GIS data and with real site visits. The text file for the storage curves contains stationary data that represent the physical condition of storage units, while the Excel SHC_SWMM_DataProcessing.xlsx file is used for adjustable parameters and variables.



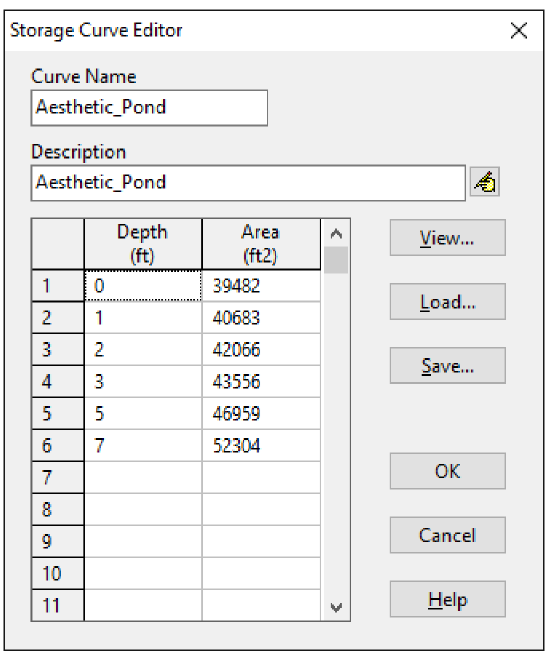
⇨ Click "Curves" under the "Project" tab, then click "Storage Curves"

⇨ Click [Add Object] button

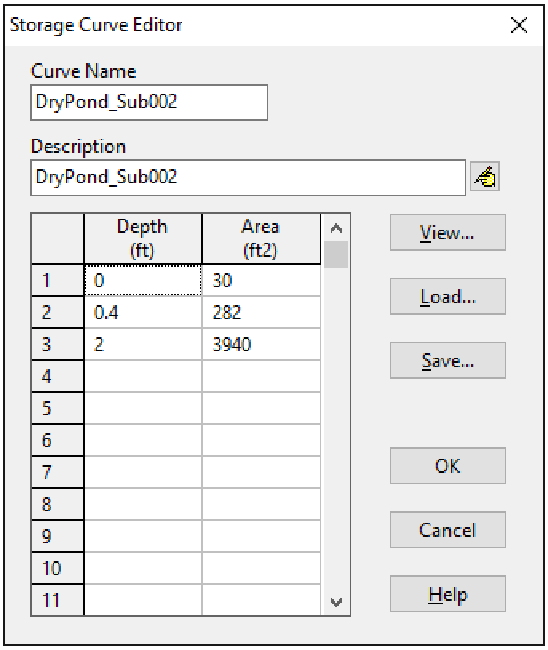


⇨ Specify '10yr_Detention' as shown above using 'Storage_Curves.txt', then click 'OK' button

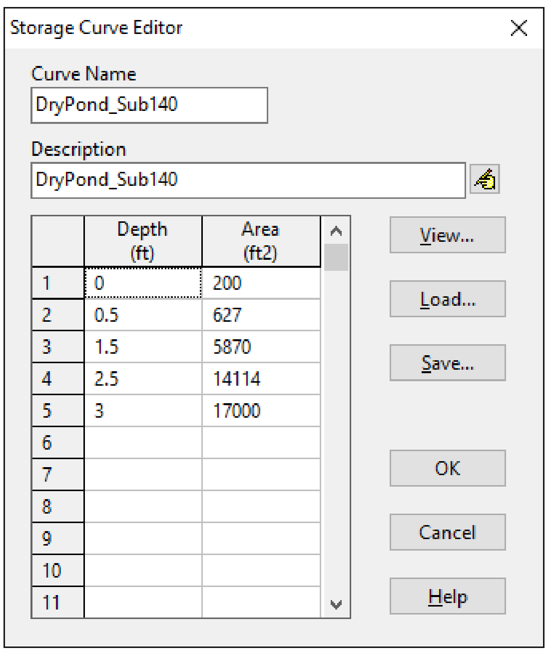
⇨ Repeat the same steps to complete specifying 'Storage Curves': Click 'Add Object' button and specify the following individual storage curves using the "Storage_Curves.txt"



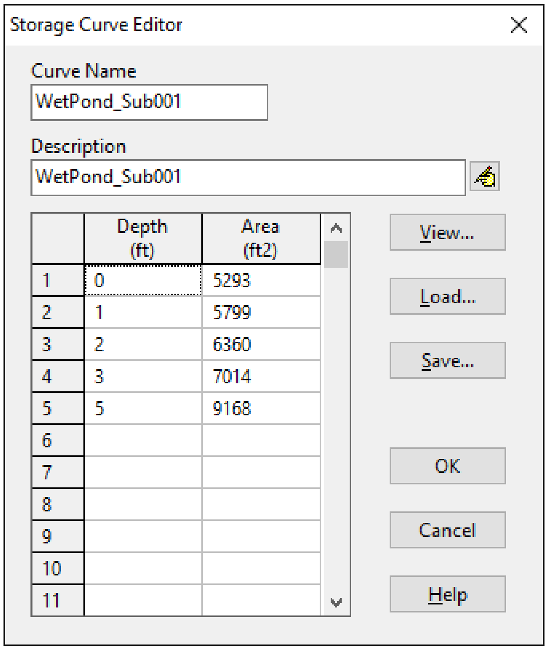
⇨ Specify the 'Aesthetic_Pond'



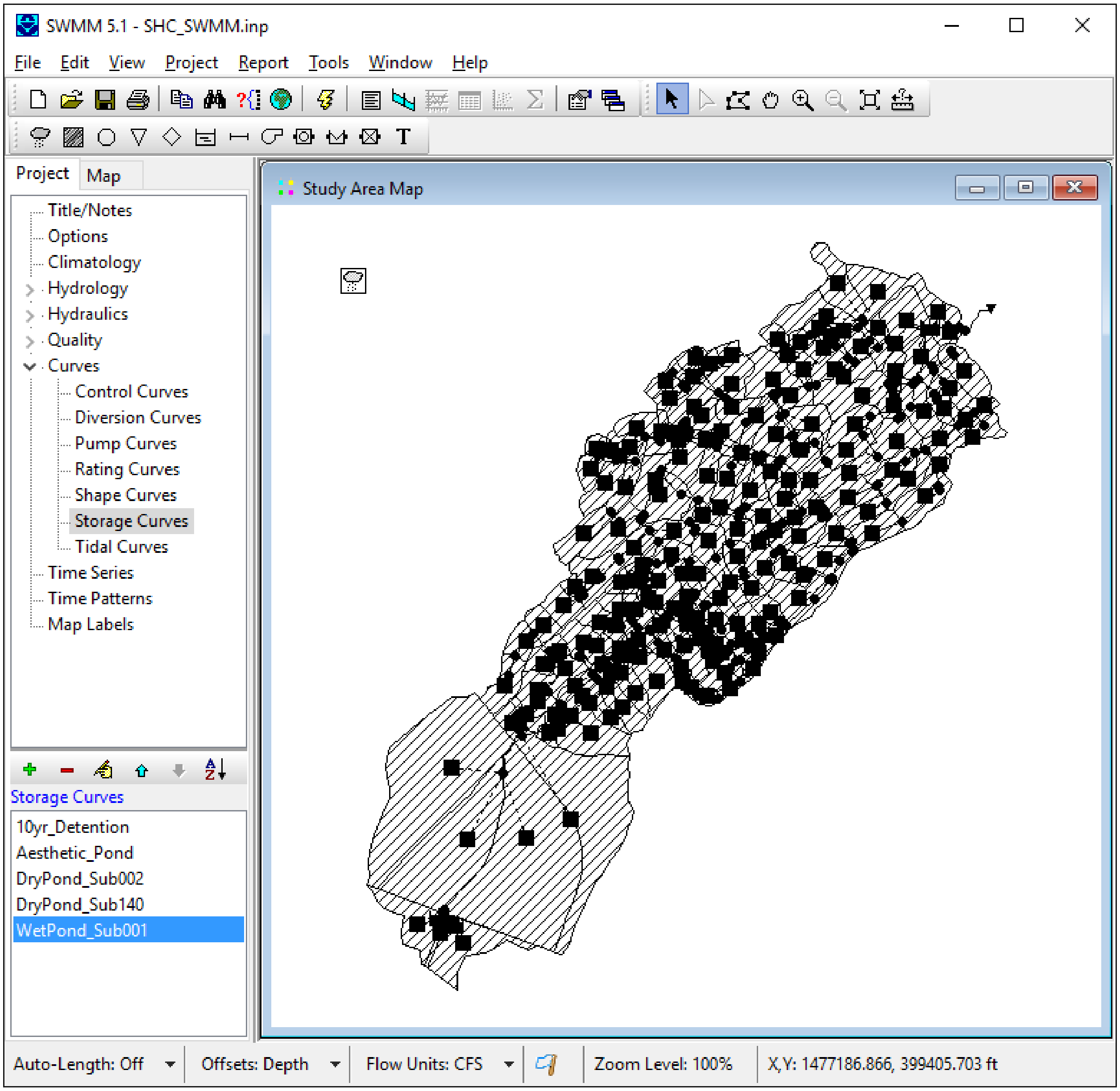
⇨ Specify the 'DryPond_Sub002'



⇨ Specify the 'DryPond_Sub140'



⇨ Specify the 'WetPond_Sub001'

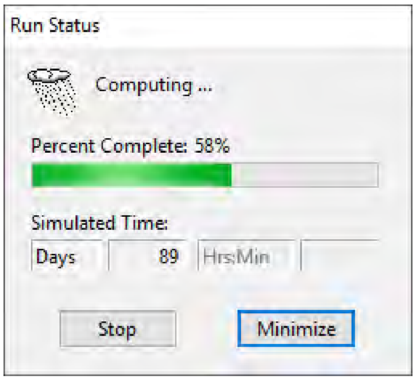


⇨ Save the SWMM input file

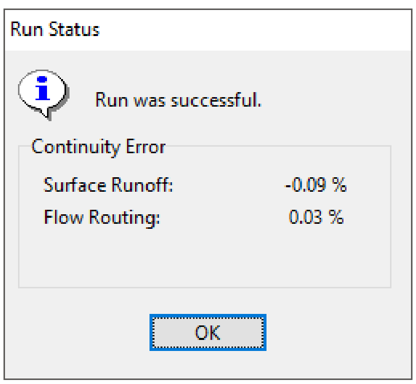
3.7 Run the developed SWMM model using EPA SWMM

The next step is to run the developed SWMM model.

⇨ Click button to run the SWMM model

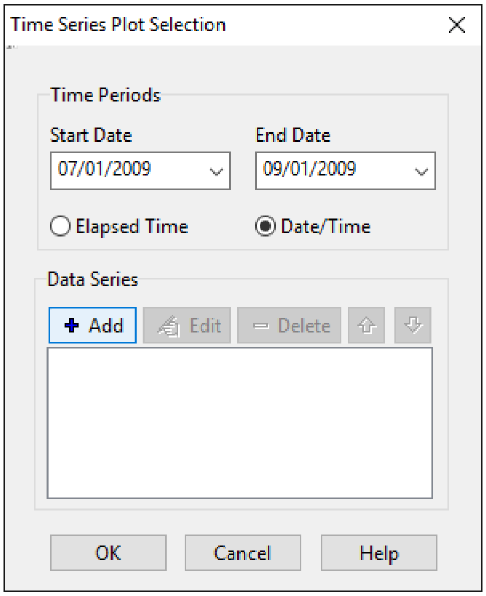


When the model run is completed, the 'Run Status' pops up.

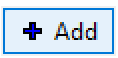


Now, a modeler can check the modeling results as graphs or tables. The next steps create a plot of simulated flow for the conduit in the SWMM model that represents the natural stream at the pour point of the SHC headwatershed.

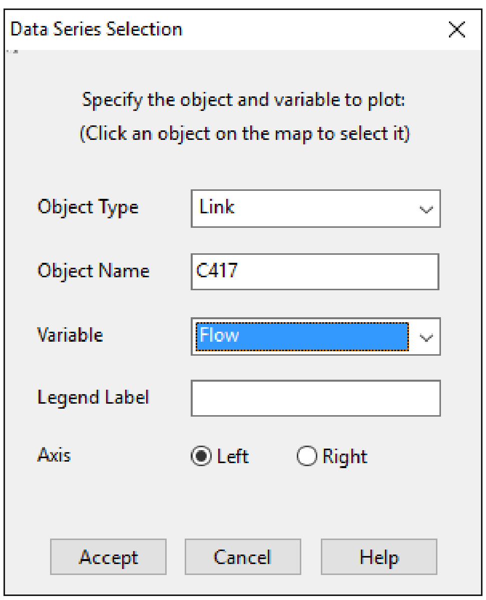
⇨ Click 'Create a Time Series Plot' button



⇨ Select ‘Date/Time’

⇨ Click 

button

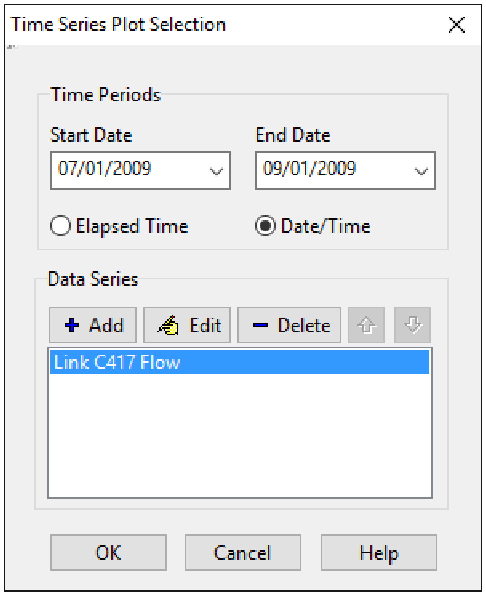


⇨ Specify ‘Object Type’ as ‘Link’

⇨ Specify ‘Object Name’ as ‘C417’

⇨ Specify ‘Variable’ as ‘Flow’

⇨ Click ‘Accept’



⇨ Click 'OK' to check out the modeling results using the 'Time Series Plot'

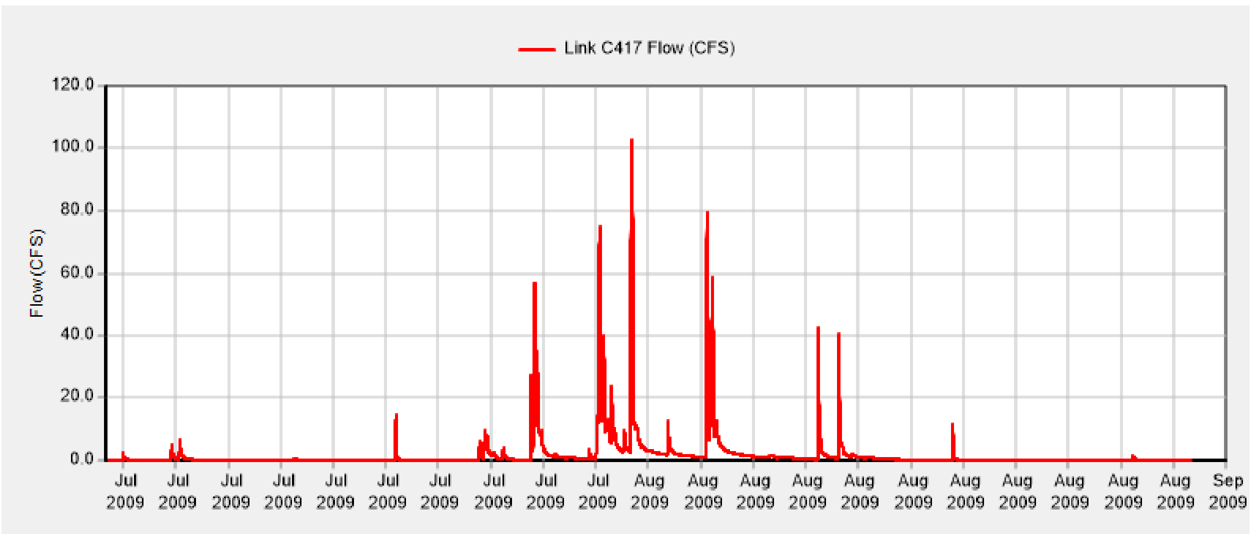


Figure 19. Example of the SWMM modeling results: hydrograph.

Note: Refer to the SWMM User's Manual for much more detail on how to present and study the results of a model run.

⇨ Save your file/run results

4. Model Calibration

Model calibration in this context is the process of adjusting the model's parameters within certain applicable value ranges in order to obtain a result that best represents the hydrologic processes of interest, and for which there is measured or observed data. In this case, and, as is typical, the model was calibrated using flow observations made through measurements and periods of continuous stream water depth monitoring. If calibration proceeds using EPA SWMM it has to be done manually. The PCSWMM software offers options for automatic calibration, which may be considered as a significant advantage. Modelers may be interested in exploring this utility, but we do not discuss it further here. Our focus has been initial model set-up, and it is our experience with the case-study watershed that model calibration requirements and effort were significantly reduced by starting with the fine resolution of spatial reality afforded by the development of the spatial database.

For the SHC calibration, stream flows were measured at the outlet from a rating curve using water depth recorded at 10 min intervals. A tipping bucket rain gauge measured rainfall depths at 10 min intervals, with a minimum detectable rainfall depth of 0.01 inch. The SWMM model for SHC was run for a six-month period (01 April 2009 to 31 August 2009) where the first four months of this period were used to stabilize the continuous simulation, in particular for the groundwater simulation. This is defined as the model 'warm–up' period, which is the time period required to achieve a stable condition wherein the groundwater level ceases to increase or decrease by a specified initial parameter threshold value. After the warm–up period, the last two months, from July to August 2009, were used for model calibration.

Model calibration was done manually by adjusting the initial values for the 10 land cover types, and using the different sets of BPA. Changes were integrated one at a time into every subcatchment using the area–weighting approach in the Excel spreadsheet. The calibrated modeling parameters for individual land cover types are given in Table 5 alongside their initial values. An Excel worksheet was created with embedded look–up and averaging functions so that changes made to the original values in Table 5 or switches between BPA sets configured using the different buffer distances could be easily propagated to changes in the related parameter values used in the SWMM model. With this approach, the calibration effort is evenly applied to the urban land cover types, which in turn are propagated to the parameterization of all subcatchments, instead of calibrating parameters individually for each subcatchment.

This methodology assumes that urban land cover components are generalizable, and independent of scale even though the subcatchments themselves are not generalizable or easily scalable. Also notable about this approach, the parameter calibration domain remains the same even if the total number of subcatchments is increased and/or the size of watershed area is increased. Note, while this approach was rational for the case study watershed, in other systems landscape form and process may not have an appropriate level of homogeneity to make it so. For example, in areas where topographic relief is highly variable across space a higher order subcatchment categorization would be necessary (i.e., separating subcatchments with steep hillslopes from those with more moderate topographic relief). This can be accounted for in the spatial database with attribute data and then propagated through the Excel file set-up and the

SWMM model parameterization, but it does increase the domain of parameters that may have to be considered during model calibration.

Table 5. Initial and calibrated modeling parameters for the Shayler Crossing watershed.

Land Cover	Length (ft)		Slope (%)		n		DS (in)		Ksat (in/hr)	
	Initial	Calibrated	Initial	Calibrated	Initial	Calibrated	Initial	Calibrated	Initial	Calibrated
Main Building	30	25	10	15	0.014	0.01	0.08	0.05	n/a	n/a
Misc. Building	15	15	10	15	0.014	0.01	0.08	0.05	n/a	n/a
Street	10	10	2	2.5	0.011	0.01	0.10	0.05	n/a	n/a
Driveway	15	12	2	1.5	0.012	0.01	0.10	0.05	n/a	n/a
Parking	10	10	1	1.5	0.012	0.01	0.12	0.05	n/a	n/a
Sidewalk	3	3	1	1.5	0.012	0.01	0.12	0.05	n/a	n/a
Other Impervious	10	8	1	1.5	0.012	0.01	0.12	0.05	n/a	n/a
Lawn	80	80	2	2	0.2	0.3	0.20	0.20	0.063	0.035
Forest	80	80	3	2	0.6	0.6	0.40	0.30	0.063	0.060
Agriculture	100	100	2	2	0.3	0.3	0.30	0.20	0.063	0.040

Sensitivity analysis was conducted for the modeling parameters width, slope, n and DS for IA and PA respectively, Ksat, and the size of BPA. Each parameter was decreased and increased 5, 10, and 20 %, respectively, one at a time, and in separate model runs. The sensitivity of each parameter was estimated as:

$$\text{Sensitivity}=(\Delta MR/MR)/(\Delta p/p)$$

Where, MR = modeling result from SWMM run; ΔMR = change in SWMM modeling result based on change in parameter value; p = parameter value; and Δp = change in parameter value.

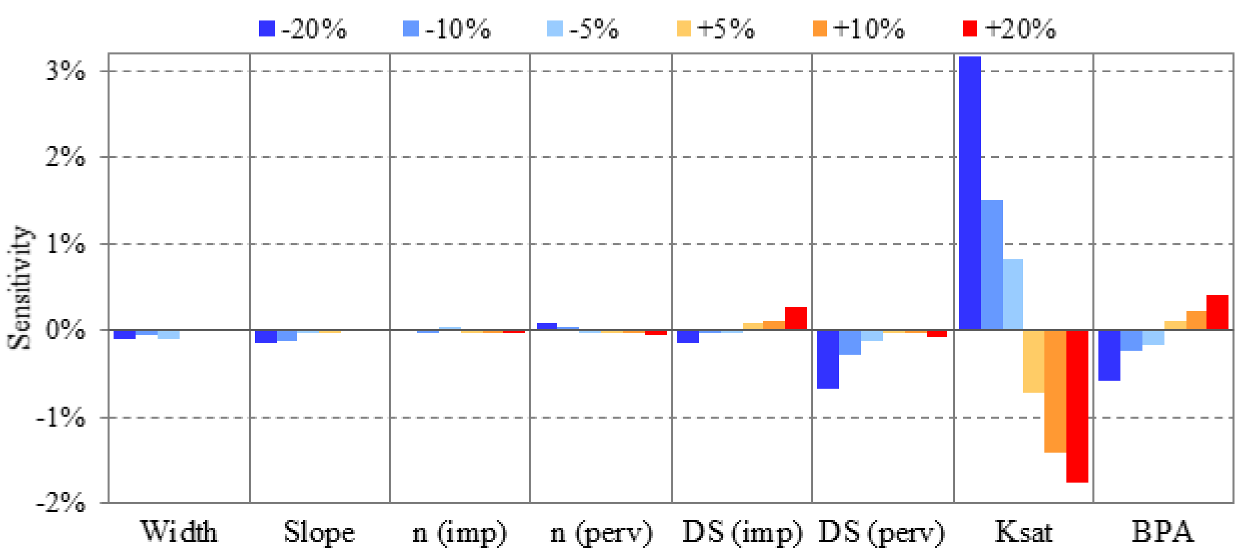


Figure 20. Sensitivity analysis of the SWMM parameters at SHC.

Model calibration was conducted by adjusting the land cover–based modeling parameters and BPA to the entire study watershed (see Section 2.4.5). As shown in Table 5, parameters for the impervious land cover types changed little and were made equivalent for n and *DS*. As expected, parameters for the pervious land cover types needed more adjustment than those for the impervious. The initial value of K_{sat} was defined using the site–specific soil types (mainly silty loam clay), but the values for the individual pervious land cover types were varied by the model calibration effort. Whereas K_{sat} for forest area was adjusted only slightly (i.e., 0.063 in/hr initially to 0.060 in/hr for the final calibration), the values for lawn (or landscaped area) and agriculture required a higher degree of adjustment (from 0.063 in/hr initial to 0.040 in/hr for agriculture, and from 0.063 in/hr initial to 0.035 in/hr for lawns). The relatively large changes for Ksat are indicative of a higher degree of soil compaction for urban and agricultural soils compared to the expected native soil condition.

The measured rainfall intensities and stream flow rates, along with the calibrated model results are presented in Fig. 21. The modeled hydrographs agreed with the measured data at the watershed scale very well with a Nash-Sutcliffe Efficiency coefficient = 0.852 and R^2 = 0.871.

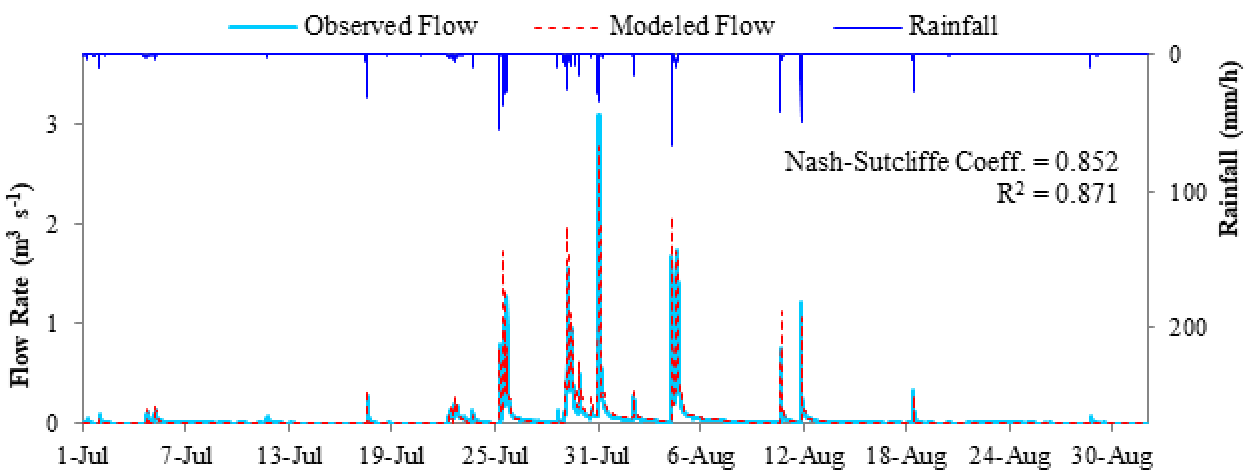


Figure 21. SWMM modeling results from July 1 to August 31, 2009.

5. Scenario-based GI Modeling Analysis

Using the GIS data and the baseline SWMM model that represent the existing conditions, possible GI implementation scenarios can be derived. In this case study, two scenarios were arranged to present the required steps for scenario-based GI modeling analysis. The overall objectives for the consideration of the GI scenarios were to try to minimize DCIA and maximize onsite stormwater controls.

5.1 GI-Scenario 1 – Disconnecting Downspouts from the Main Buildings

The first scenario is to disconnect rooftop downspouts from all of the main buildings within the study watershed. This means the runoff from the main buildings discharges to adjacent pervious areas instead of discharging directly to the storm sewer systems. The pervious areas that receive the runoff from the main buildings will work like BPA in this scenario. BPA was calibrated to be areas with 2-ft buffering distance in the baseline model. Based on this result, the BPA for the disconnected main buildings was estimated by applying 2-ft buffering distance. The required steps to process this GI scenario analysis are presented below:

⇨ Create a GIS layer for the main buildings using ArcGIS, following the relevant steps presented in Section 2.2.2 *(Create a subset layer for the disconnected main buildings only to perform another buffering analysis.)*

⇨ Conduct a proximity analysis to derive the additional BPA layer for the disconnected main buildings following the steps in Section 2.2.3

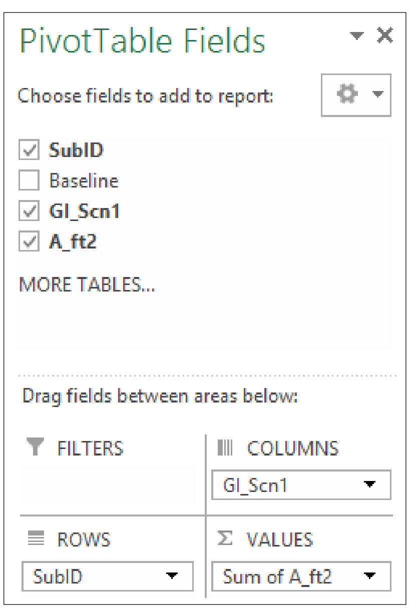
⇨ Estimate the sizes of additional BPA for the individual subcatchments, following the steps in Section 2.4.1

Now, the next steps are to estimate the sizes of the changed subareas (DCIA, ICIA, BPA, and SPA) per subcatchment that resulted from implementing the GI scenario. If any portion of disconnected main buildings exist within a subcatchment, the subareas within the subcatchment should be re-estimated as follows:

- DCIA = (DCIA of the baseline condition) – (area of the disconnected main buildings)
- ICIA = (ICIA of the baseline condition) + (area of the disconnected main buildings)
- BPA = (BPA of the baseline condition) + (BPA for the disconnected main buildings)
- SPA = (SPA of the baseline condition) – (BPA for the disconnected main buildings)

These calculations can be automatically processed in the [SWMM-GI_Scn1] tab of the "SHC_SWMM-GI_DataProcessing.xlsx" as follows:

⇨ Update the 'PivotTable Fields' in [LandCover] tab as follows (refer to Section 2.4.2)

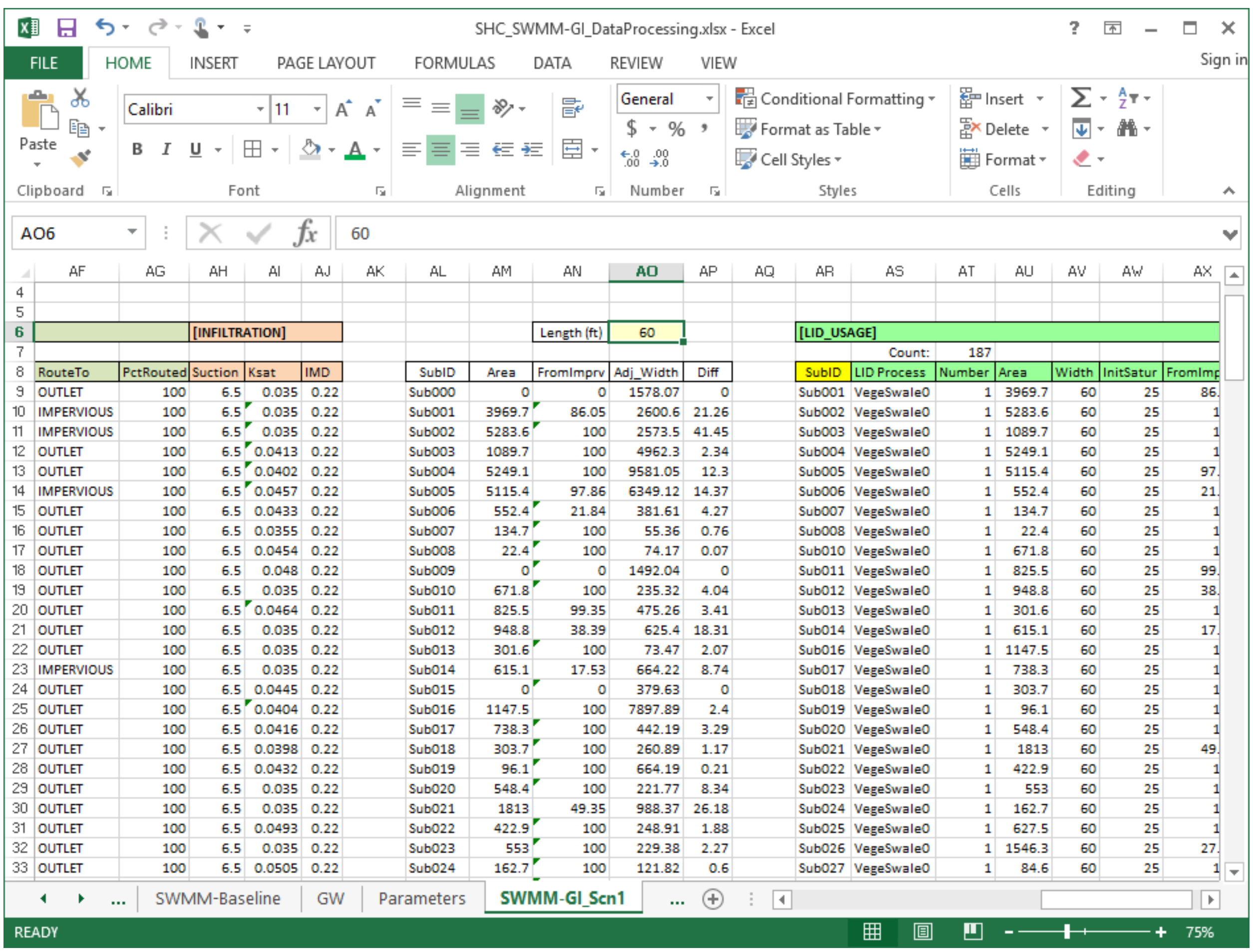


- ⇨ ROWS: “SubID”
- ⇨ COLUMNS: “GI_Scn1”
- ⇨ ∑ VALUES: “Sum of A_ft2”

- ⇨ Copy/Paste the ‘PivotTable’ from [LandCover] tab to [SWMM-GI_Scn1] tab
- ⇨ Proceed taking similar steps as described in Sections 3.3.2 to update [SUBCATCHMENTS], [SUBAREAS], and [INFILTRATION] of the SWMM input file for including the GI scenario
- ⇨ Proceed taking similar steps as described in Sections 3.4.2 to update [LID_USAGE] of the SWMM input file for including the GI scenario

Note: The above steps should be processed using [SWMM-GI_Scn1] tab that represents the GI scenario, instead of [SWMM-Baseline] tab that represent the existing condition in the “SHC_SWMM-GI_DataProcessing.xlsx” file.

By implementing this GI scenario, the sheet flow length over BPA might be varied. This can be modeled by adjusting the ‘Length’ in Cell [AO6] in the [SWMM-GI_Scn1] tab as shown below. If the value for ‘Length’ is changed, all of the related parameters can be automatically updated in the MS-Excel file.



	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX
4																			
5																			
6			[INFILTRATION]						Length (ft)	60			[LID_USAGE]						
7														Count:	187				
8	RouteTo	PctRouted	Suction	Ksat	IMD		SubID	Area	FromImprv	Adj_Width	Diff		SubID	LID Process	Number	Area	Width	InitSatur	FromImp
9	OUTLET	100	6.5	0.035	0.22		Sub000	0	0	1578.07	0		Sub001	VegeSwale0	1	3969.7	60	25	86.
10	IMPERVIOUS	100	6.5	0.035	0.22		Sub001	3969.7	86.05	2600.6	21.26		Sub002	VegeSwale0	1	5283.6	60	25	1
11	IMPERVIOUS	100	6.5	0.035	0.22		Sub002	5283.6	100	2573.5	41.45		Sub003	VegeSwale0	1	1089.7	60	25	1
12	OUTLET	100	6.5	0.0413	0.22		Sub003	1089.7	100	4962.3	2.34		Sub004	VegeSwale0	1	5249.1	60	25	1
13	OUTLET	100	6.5	0.0402	0.22		Sub004	5249.1	100	9581.05	12.3		Sub005	VegeSwale0	1	5115.4	60	25	97.
14	IMPERVIOUS	100	6.5	0.0457	0.22		Sub005	5115.4	97.86	6349.12	14.37		Sub006	VegeSwale0	1	552.4	60	25	21.
15	OUTLET	100	6.5	0.0433	0.22		Sub006	552.4	21.84	381.61	4.27		Sub007	VegeSwale0	1	134.7	60	25	1
16	OUTLET	100	6.5	0.0355	0.22		Sub007	134.7	100	55.36	0.76		Sub008	VegeSwale0	1	22.4	60	25	1
17	OUTLET	100	6.5	0.0454	0.22		Sub008	22.4	100	74.17	0.07		Sub010	VegeSwale0	1	671.8	60	25	1
18	OUTLET	100	6.5	0.048	0.22		Sub009	0	0	1492.04	0		Sub011	VegeSwale0	1	825.5	60	25	99.
19	OUTLET	100	6.5	0.035	0.22		Sub010	671.8	100	235.32	4.04		Sub012	VegeSwale0	1	948.8	60	25	38.
20	OUTLET	100	6.5	0.0464	0.22		Sub011	825.5	99.35	475.26	3.41		Sub013	VegeSwale0	1	301.6	60	25	1
21	OUTLET	100	6.5	0.035	0.22		Sub012	948.8	38.39	625.4	18.31		Sub014	VegeSwale0	1	615.1	60	25	17.
22	OUTLET	100	6.5	0.035	0.22		Sub013	301.6	100	73.47	2.07		Sub016	VegeSwale0	1	1147.5	60	25	1
23	IMPERVIOUS	100	6.5	0.035	0.22		Sub014	615.1	17.53	664.22	8.74		Sub017	VegeSwale0	1	738.3	60	25	1
24	OUTLET	100	6.5	0.0445	0.22		Sub015	0	0	379.63	0		Sub018	VegeSwale0	1	303.7	60	25	1
25	OUTLET	100	6.5	0.0404	0.22		Sub016	1147.5	100	7897.89	2.4		Sub019	VegeSwale0	1	96.1	60	25	1
26	OUTLET	100	6.5	0.0416	0.22		Sub017	738.3	100	442.19	3.29		Sub020	VegeSwale0	1	548.4	60	25	1
27	OUTLET	100	6.5	0.0398	0.22		Sub018	303.7	100	260.89	1.17		Sub021	VegeSwale0	1	1813	60	25	49.
28	OUTLET	100	6.5	0.0432	0.22		Sub019	96.1	100	664.19	0.21		Sub022	VegeSwale0	1	422.9	60	25	1
29	OUTLET	100	6.5	0.035	0.22		Sub020	548.4	100	221.77	8.34		Sub023	VegeSwale0	1	553	60	25	1
30	OUTLET	100	6.5	0.035	0.22		Sub021	1813	49.35	988.37	26.18		Sub024	VegeSwale0	1	162.7	60	25	1
31	OUTLET	100	6.5	0.0493	0.22		Sub022	422.9	100	248.91	1.88		Sub025	VegeSwale0	1	627.5	60	25	1
32	OUTLET	100	6.5	0.035	0.22		Sub023	553	100	229.38	2.27		Sub026	VegeSwale0	1	1546.3	60	25	27.
33	OUTLET	100	6.5	0.0505	0.22		Sub024	162.7	100	121.82	0.6		Sub027	VegeSwale0	1	84.6	60	25	1

- ⇨ Adjust the 'Length' of sheet flow to change flow travel time. *('Length' means the flow length where the flow is maintained as sheet flow. It doesn't mean the physical length of the actual area.)*
- ⇨ Save the updated SWMM input file with another name (e.g., "SHC_GI-scn1.inp")

When the SWMM input file is completely updated, the model can be run to evaluate the GI scenario. The modeling results can be compared to the results from the baseline model.

5.2 GI-Scenario 2 – Implementing Bioretention Areas for Individual Subcatchments

The second scenario considered is to implement bioretention areas for individual subcatchments. This scenario is arranged to represent more of an engineering approach to GI applications. In order to size individual bioretention areas, guidelines from the Ohio Storm Water Management manual (Mathews, 2014) were applied. The manual proposed simple, quantitative design criteria for a bioretention system as follows:

- Drainage area (DA): less than 2 acres
- Drawdown time: 12 to 48 hrs (24 hrs for ponding water)
- Ponding volume = water quality volume (WQv)
- Ponding depth: less than or equal to 12-in.
- Fall from Inflow to underdrain outlet: exceeding 3.5-ft
- Groundwater separation: min. 2-ft recommended and 1-ft required from the bottom
- Setback from building foundations: 25-ft (10-ft with underdrains)
- Surface filter bed area: 5-10% of the contributing impervious area
  - Width ≥ 10-ft., Length ≥ 2 x Width
  - If imperviousness > 25%, FBA ≥ 5% of impervious area
  - If imperviousness < 25%, FBA ≥ WQv/(ponding depth in ft)
  - WQv = C · P/12 · A
    where, FBA = filter bed area in ft^2, WQv = water quality volume in ft^3, i = imperviousness, $C = 0.858\, i^3 - 0.78\, i^2 + 0.774\, i + 0.04$ (Ohio EPA NPDES permit), P = 0.75-in. precipitation, A = drainage area in ft^2
- Gravel layer and underdrain
  - Gravel layer: # 57 washed stone (porosity = 0.35), 10 to 12-in. thick (min. 3-in.)
  - Underdrain: min. 4-in. diameter perforate pipe with min. 3-in. of gravel above and below
  - Observation/cleanout pipe: 4-in. non-perforated

The Ohio Storm Water Management Manual also presented a design approach for a site of limited infiltration capacity and/or enhanced nitrogen treatment as follows:

- Hydraulic conductivity (K): $0.05 \le K \le 0.5$ in/hr
- An internal water storage (IWS) layer below the upturned outlet of the underdrain pipe.
- This standing water zone holds water and extends opportunity (both in time and quantity) for exfiltration.
- This layer also acts as an anoxic zone that encourages denitrification, and thus is an aid in preventing eutrophication of receiving waters.

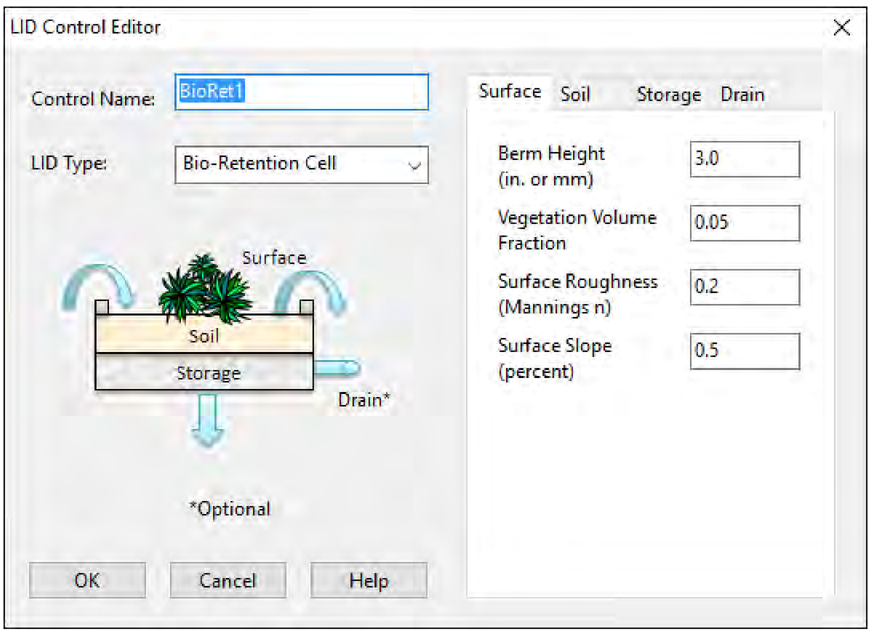
- This design is expected to provide better than 40% and perhaps as high as 80% mass removal of nitrogen from surface runoff.

Additional adjustments can be applied to derive a more plausible GI implementation scenario. A modeler can apply his/her own scenario. The following steps should be processed first in order to include bioretention to the SWMM input file:

⇨ Run EPA SWMM

⇨ Open the "SHC_SWMM.inp"

Proceed by conducting similar steps to those presented in Section 3.4.1 in order to add another LID Control for bioretention as follows:



⇨ Specify 'Control Name'

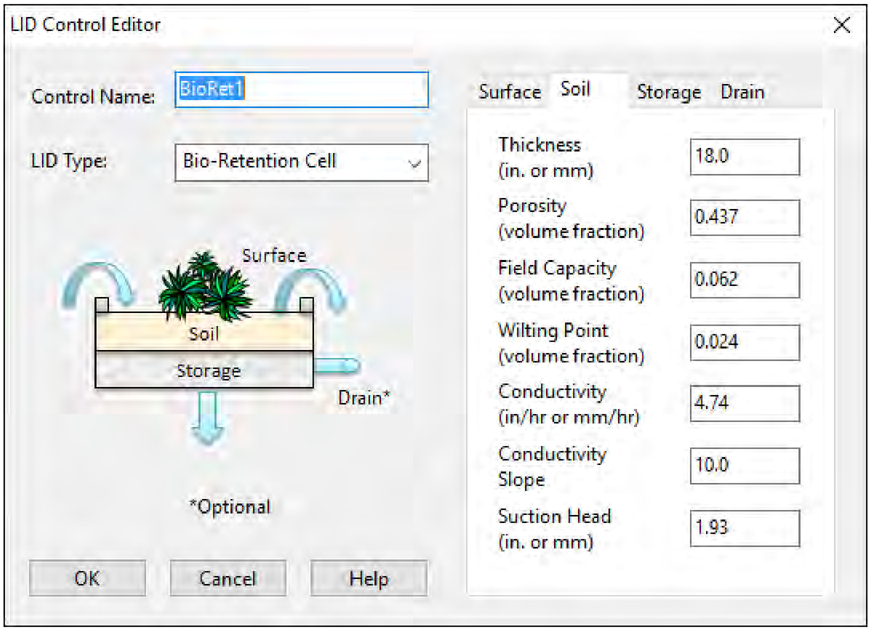
Specify 'Surface' properties as:

⇨ Berm Height (Ponding Depth) = 3.0 inches

⇨ Vegetation Volume Fraction = 0.05

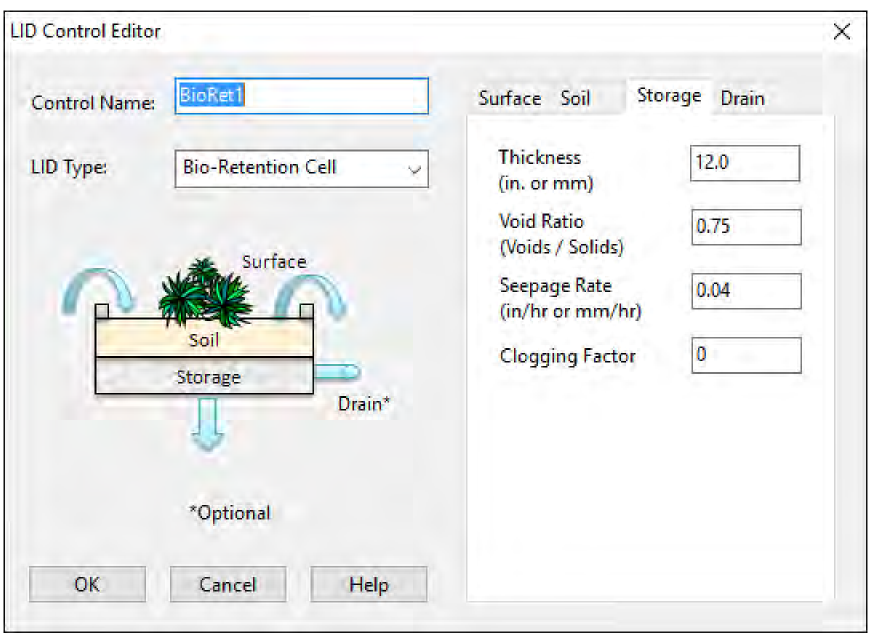
⇨ Surface Roughness (Manning's n) = 0.2

⇨ Surface Slope (percent) = 0.5



Specify ‘Soil (media)’ properties based on sandy soil:

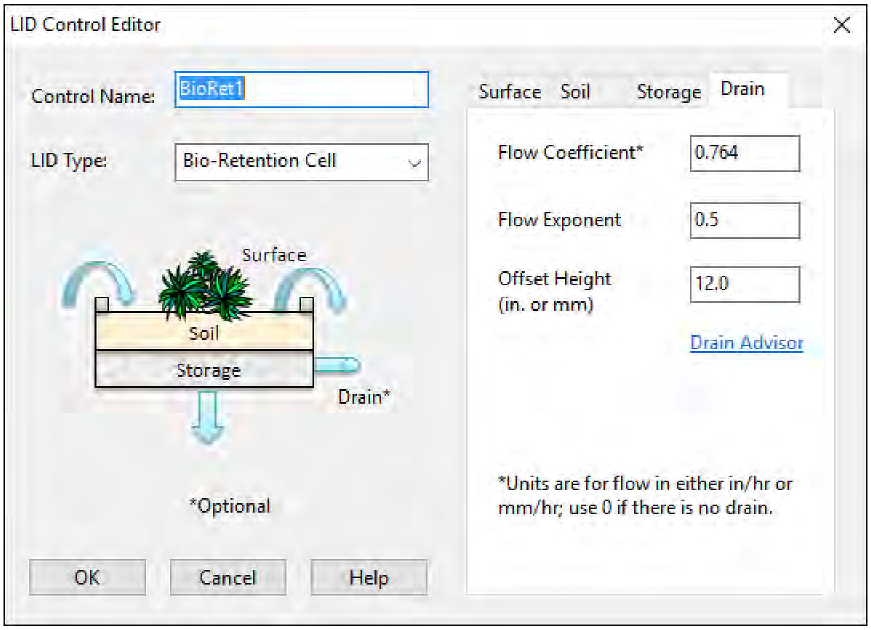
- ⇨ Thickness = 18.0 inches
- ⇨ Porosity (volume fraction) = 0.437
- ⇨ Field Capacity (volume fraction) = 0.062
- ⇨ Wilting Point (volume fraction) = 0.024
- ⇨ Conductivity = 4.74 in/hr
- ⇨ Conductivity Slope = 10.0
- ⇨ Suction Head = 1.93 inches



Specify ‘Storage (gravel layer)’ properties as:

- ⇨ Thickness = 12.0 inches

- ⇨ Void Ratio (Voids / Solids) = 0.75
- ⇨ Seepage Rate = 0.04 in/hr
- ⇨ Clogging Factor = 0



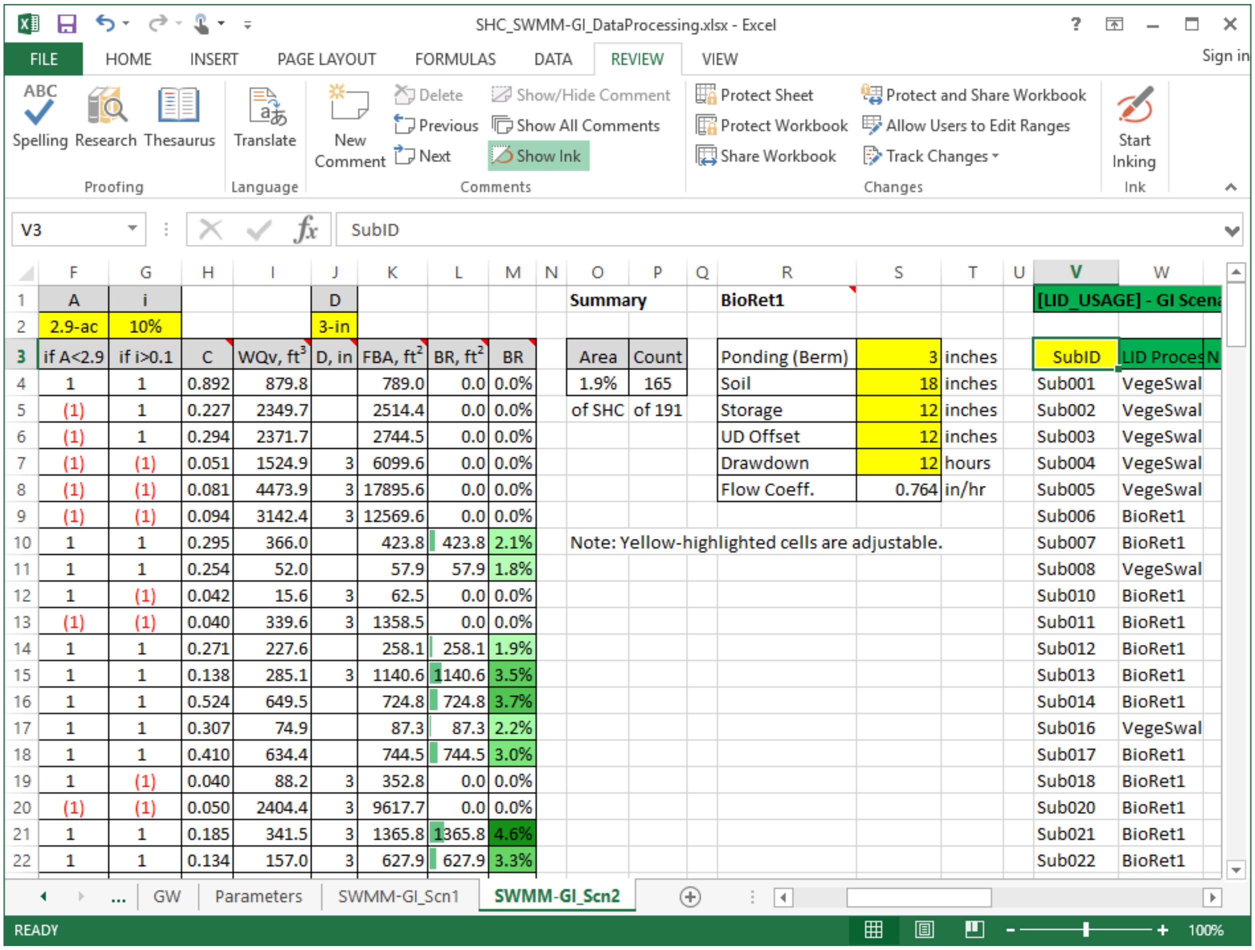
Specify 'Drain (underdrain)' properties as:

- ⇨ Flow Coefficient = 0.764 in/hr
- ⇨ Flow Exponent = 0.5
- ⇨ Offset Height = 12.0 inches
- ⇨ Click 'OK' to complete adding the bioretention LID control

The 'Flow Coefficient' can be estimated using the Drain Advisor: "If the goal is to drain a fully saturated unit in a specific amount of time then set the drain exponent to 0.5 (to represent orifice flow) and the drain coefficient to $2D^{1/2}/T$ where D is the distance from the drain to the surface plus any berm height (in inches or mm) and T is the time in hours to drain. For example, to drain a depth of 36 inches in 12 hours requires a drain coefficient of 1. If this drain consisted of the slotted pipes described in the previous bullet, whose coefficient was 2, then a flow regulator, such as a cap orifice, would have to be placed on the drain outlet to achieve the reduced flow rate."

$D = 3.0 + 18.0 = 21.0$ inches
$T = 12$ hours
Flow Coefficient $= 2 * 21^{0.5} / 12 = 0.764$ in/hr

When the above steps are completed, it is time to update the SWMM input file to include bioretention areas for individual subcatchments. As mentioned above, bioretention design criteria were applied from the Ohio Storm Water Management manual with additional adjustments. In this study, it was assumed that a bioretention system can receive runoff from all of the impervious area within the subcatchment. If the runoff is beyond the capacity of the bioretention, that portion will be overflowed or bypassed. If no bioretention system exists, the subcatchment was modeled the same as the baseline condition. All of these processes were arranged within the [SWMM-GI_Scn2] tab of the “SHC_SWMM-GI_DataProcessing.xlsx” as shown below. The yellow-highlighted cells are adjustable. If any of these cells are updated, the entire [SWMM-GI_Scn2] tab can be automatically updated.



	F	G	H	I	J	K	L	M
1	A	i			D			
2	2.9-ac	10%			3-in			
3	if A<2.9	if i>0.1	C	WQv, ft³	D, in	FBA, ft²	BR, ft²	BR
4	1	1	0.892	879.8		789.0	0.0	0.0%
5	(1)	1	0.227	2349.7		2514.4	0.0	0.0%
6	(1)	1	0.294	2371.7		2744.5	0.0	0.0%
7	(1)	(1)	0.051	1524.9	3	6099.6	0.0	0.0%
8	(1)	(1)	0.081	4473.9	3	17895.6	0.0	0.0%
9	(1)	(1)	0.094	3142.4	3	12569.6	0.0	0.0%
10	1	1	0.295	366.0		423.8	423.8	2.1%
11	1	1	0.254	52.0		57.9	57.9	1.8%
12	1	(1)	0.042	15.6	3	62.5	0.0	0.0%
13	(1)	(1)	0.040	339.6	3	1358.5	0.0	0.0%
14	1	1	0.271	227.6		258.1	258.1	1.9%
15	1	1	0.138	285.1	3	1140.6	1140.6	3.5%
16	1	1	0.524	649.5		724.8	724.8	3.7%
17	1	1	0.307	74.9		87.3	87.3	2.2%
18	1	1	0.410	634.4		744.5	744.5	3.0%
19	1	(1)	0.040	88.2	3	352.8	0.0	0.0%
20	(1)	(1)	0.050	2404.4	3	9617.7	0.0	0.0%
21	1	1	0.185	341.5	3	1365.8	1365.8	4.6%
22	1	1	0.134	157.0	3	627.9	627.9	3.3%

	O	P	R	S	T
1	Summary		BioRet1		
3	Area	Count	Ponding (Berm)	3	inches
4	1.9%	165	Soil	18	inches
5	of SHC	of 191	Storage	12	inches
6			UD Offset	12	inches
7			Drawdown	12	hours
8			Flow Coeff.	0.764	in/hr
10	Note: Yellow-highlighted cells are adjustable.				

	V	W
1	[LID_USAGE] - GI Scena	
3	SubID	LID ProcesN
4	Sub001	VegeSwal
5	Sub002	VegeSwal
6	Sub003	VegeSwal
7	Sub004	VegeSwal
8	Sub005	VegeSwal
9	Sub006	BioRet1
10	Sub007	BioRet1
11	Sub008	VegeSwal
12	Sub010	BioRet1
13	Sub011	BioRet1
14	Sub012	BioRet1
15	Sub013	BioRet1
16	Sub014	BioRet1
17	Sub016	VegeSwal
18	Sub017	BioRet1
19	Sub018	BioRet1
20	Sub020	BioRet1
21	Sub021	BioRet1
22	Sub022	BioRet1

⇨ Adjust any of the yellow-highlighted cells to prepare more specific GI implementation criteria.

⇨ Copy/Paste [LID_USAGE] from “SHC_SWMM-GI_DataProcessing.xlsx” to the SWMM input file using the Excel Editor (refer to Section 3.4.1)

Note: There is no need to add or delete any rows in the Excel Editor for modeling this GI scenario because it was assumed that each subcatchment may have up to only one LID control, either bioretention (BioRet1) or vegetative swale (VegeSwale0).

⇨ Save the updated SWMM input file with another name (e.g., “SHC_GI-scn2.inp”)

When the SWMM input file is completely updated, the model can be run to evaluate the GI scenario. The modeling results can be compared to the results from the baseline model.

5.3 Comparison of the Modeling Results with GI Scenarios

The SWMM modeling results with two GI implementation scenarios were compared to the baseline modeling results. Three hydrographs from the three SWMM input files are presented in Figure 22.

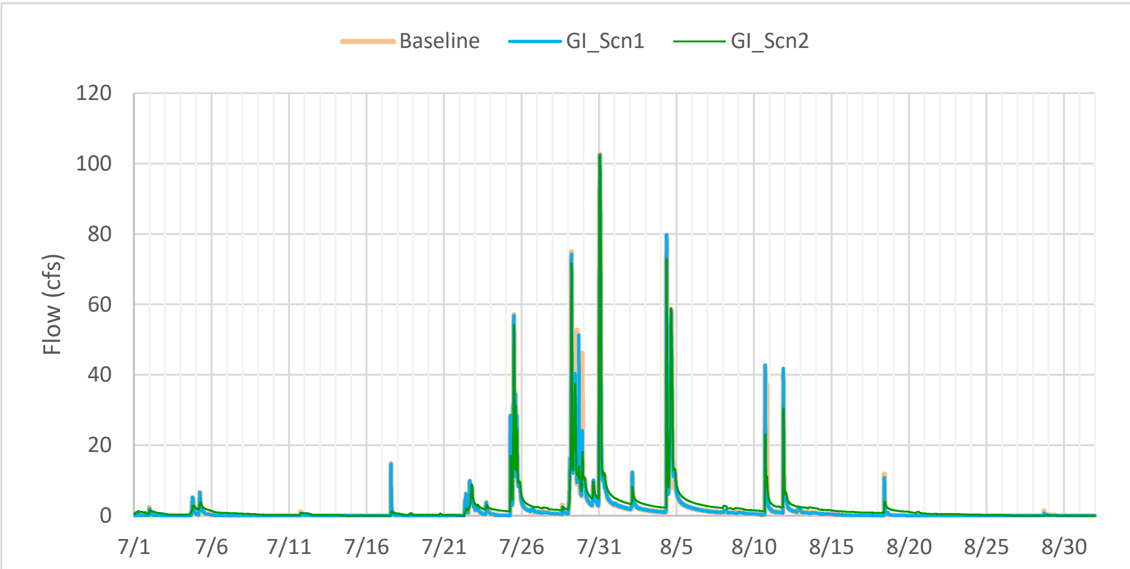


Figure 22. Comparison of the SWMM modeling results.

As shown in Figure 22, the differences with and without GI scenarios may not be significant, particularly in large storm situations. However, the differences can be quite significant under a small storm event as shown in Figure 23.

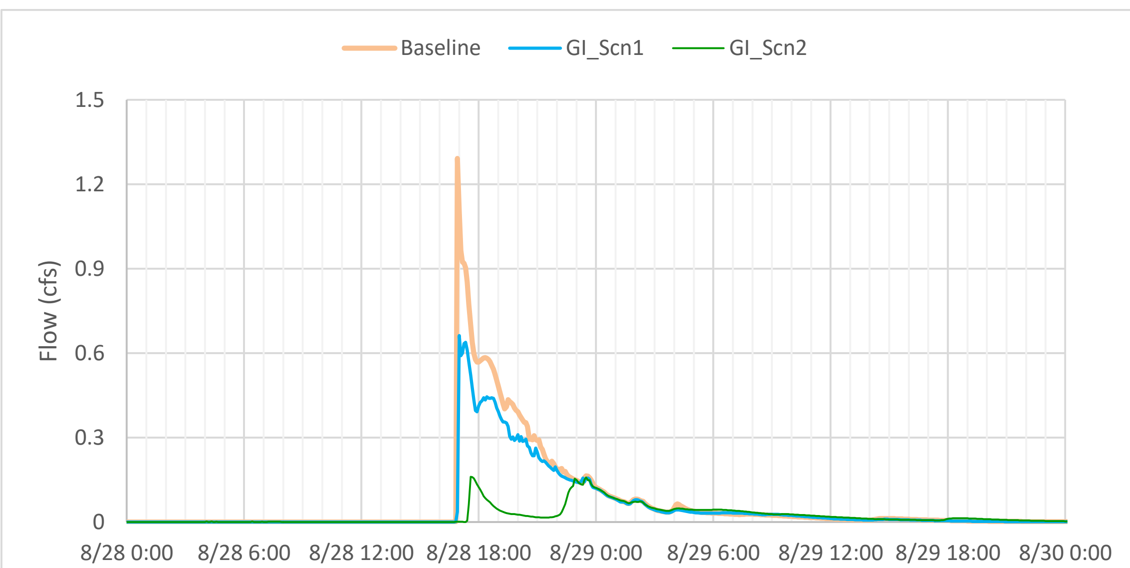


Figure 23. SWMM modeling results from a small storm event.

If a number of consecutive storms last a long period, the runoff hydrographs show very interesting behaviors as shown in Figure 24. Because there were a number of storms at the end of June, the soils and the implemented GI were fully saturated. Particularly in the second GI scenario, all of the available storages in bioretention would be fully charged with stormwater and continuously release baseflow at a much slower rate.

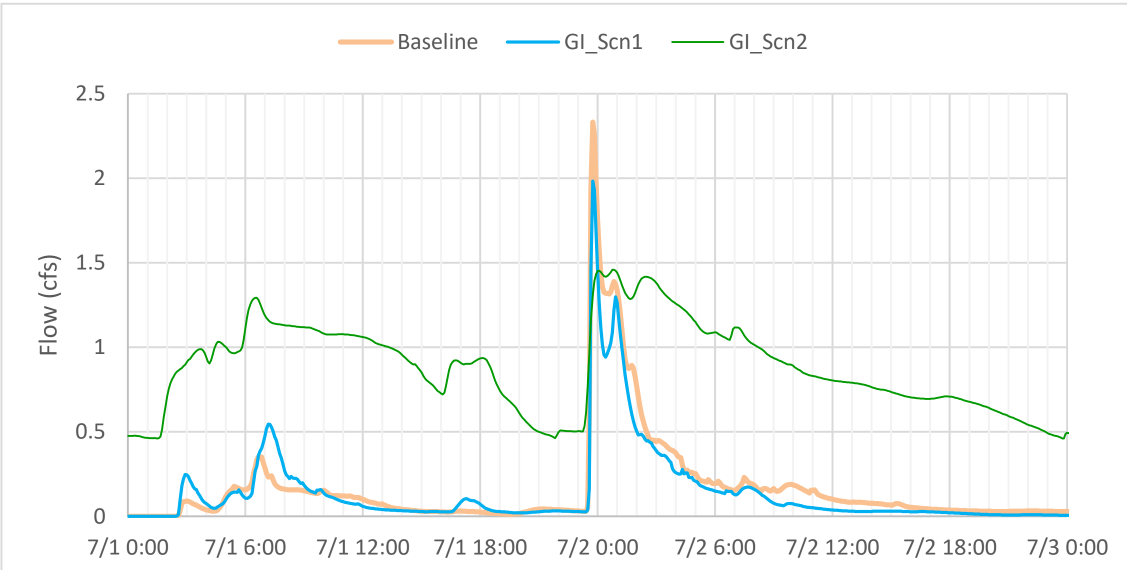


Figure 24. SWMM modeling results from a number of consecutive storm events.

6. Conclusion

This report shows how high resolution spatial data is derived and can be applied to spatially discretize a watershed for storm water management considerations involving GI. We have shown in a companion contribution (Lee et al., 2017) that this methodology increases model accuracy, and, in our case study system, reduced calibration effort. During the process of developing the spatial representation for SWMM, it is important to distinguish DCIA from ICIA, and BPA from SPA, and explicitly model these subareas. The geodata processing steps required to do this were outlined above. Also demonstrated was how to use this highly resolved spatial database of urban watershed drainage properties to most efficiently set-up a SWMM modeling effort and parameterize the model. This approach is particularly useful when modeling the impact of small storms, and, therefore, is specifically tailored to GI design, which emphasizes the mitigation of small storm hydrologic impacts of urban development. For our case study watershed that was relatively homogeneous with respect to land form and process, instead of using $j \times k$ calibration parameters, which are based on j subcatchments and k parameters per subcatchment, only k parameters needed to be calibrated and applied to all subcatchments. In systems like this the land cover based spatial discretization approach can be considered scale–independent. Even if the watershed of interest requires a higher order subcatchment characterization to account for landscape heterogeneities the approach affords the opportunity to evaluate urban stormwater management strategies for small storms with improved accuracy and expanded applicability to GI planning, design, and implementation.

We have demonstrated the suitability of the spatial discretization approach with eight synthetic storms of various sizes in Lee et. al. 2017. In the SHC watershed, the modeled hydrographs matched observed data over a two-month continuous simulation (Nash–Sutcliffe coefficient = 0.852; R^2 = 0.871). Finally, we show how a GI scenario that modeled downspout disconnection from all the main buildings that are DCIA can be easily implemented in the SWMM model, as well as one that considers bioretention; two commonly considered implementations of GI. Adopting the described approach and data processing steps for SWMM model set-up and parameterization forces placing considerable effort on the digital characterization of the land cover of the watershed and capturing its hydrologic connectivity and interactions with a highly resolved representation of the stormwater drainage network. The advantage of this should be improved simulation accuracy, particularly with respect to GI scenario analysis, while minimizing the considerations and effort required for model calibration.

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