TECHNICAL REPORT

Application of GIS Technologies for Hydrological Modeling Support

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Principal Investigator:

Leonel E. Lagos, Ph.D., PMP®

Florida International University Collaborators:

Angelique Lawrence, MS, GISP
Mehrnoosh Mahmoudi, PhD
Shimelis Setegn, PhD
Natalia Duque (DOE Fellow)
Awmna Rana (DOE Fellow)

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Executive Summary

The Applied Research Center (ARC) at Florida International University (FIU) is supporting the soil and groundwater remediation efforts of the Savannah River Site (SRS) through hydrological modeling of the fate and transport of contaminants. Research was initiated at SRS during FIU Performance Year 5 (2014 - 2015) of the DOE-FIU Cooperative Agreement with the task of developing a surface water model to simulate the fate and transport of mercury (Hg), tin (Sn) and sediments in the Tims Branch watershed. Hydrological simulations conducted for the purpose of calibrating the models, deriving model uncertainties, and for providing the analysis of remediation scenarios, results in gigabytes of simulation data. An advanced spatial data structure is therefore needed to address the management, processing, and analysis of the spatial and temporal data derived from multiple sources that is required for development of the numerical models.

This effort builds upon work previously carried out by ARC researchers who provided technical assistance and performed similar research to support remediation efforts at the Oak Ridge Reservation (ORR) in Tennessee. FIU developed an ArcGIS geodatabase to support the hydrological modeling work performed at ORR that was based on the ArcHydro and ArcGIS Base Map data models, with modifications made for project specific input parameters. The significance of this approach was to ensure its replicability for potential application at other DOE sites. The ORR geodatabase infrastructure was therefore used as the basis for development of the SRS geodatabase developed in 2015 that is currently being used to store and manage the GIS and timeseries data for hydrological model development at SRS.

This report provides an update of the work conducted during FIU Performance Year 6 (2015-2016) which includes: (1) a revision of the SRS geodatabase to incorporate additional data for an expanded hydrological model study domain; (2) the re-application of ArcGIS tools and process workflow models to pre- and post-process downloaded hydrological model configuration parameters and produce updated GIS data for incorporation into the revised numerical model; (3) creation of updated GIS maps for visualization and reporting purposes and for conducting simple geospatial analyses that may further support hydrological modeling results; and (4) the use of geoprocessing tools for preliminary creation of the Tims Branch stream network required for development of the MIKE 11 stream flow model.

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1. Introduction

1.1. Background

The Applied Research Center (ARC) is supporting the soil and groundwater remediation efforts of the Savannah River Site (SRS) through hydrological modeling of the fate and transport of contaminants. Research was initiated in 2014 (FIU Performance Year 5 of the DOE-FIU Cooperative Agreement) with the task of developing a surface water model to simulate the fate and transport of mercury (Hg), tin (Sn) and sediments in the Tims Branch watershed. This effort builds upon work previously carried out by ARC researchers who provided technical assistance and performed similar research to support remediation efforts at the Oak Ridge Reservation (ORR) in Tennessee. ARCdeveloped an ArcGIS geodatabase to support the hydrological modeling work performed at ORR that was based on the ArcHydro and ArcGIS Base Map data models, with modifications made for project specific input parameters. The significance of this approach was to ensure its replicability for potential application at other DOE sites. The ORR geodatabase infrastructure was therefore used as the basis for development of the SRS geodatabase developed in 2015 (towards the end of FIU Performance Year 5) for SRS.

The SRS geodatabase serves as a centralized data management system, facilitating storage, accessibility, concurrent editing and import/export of large amounts of spatial and temporal model configuration data that is specific to the hydrological models being developed. The use of ArcGIS ModelBuilder coupled with Python scripting extends the geodatabase capabilities for automating many of the repetitive geoprocessing tasks required for pre- and post-processing of hydrological modeling data and for documenting the geoprocessing workflows.

In 2015, ARC developed the existing geodatabase using primarily GIS data provided by the Savannah River Nuclear Solutions (SRNS) Geotechnical Engineering Department at SRS; however, much of this data was limited in extent to the Savannah River Site boundary. As such, preliminary model development in 2015 involved the use of a model domain that only covered the portion of the Tims Branch watershed that lies within the SRS boundary. As the aim of this task is to develop a hydrological model to study contaminant fate and transport along the full length and reaches of the Tims Branch stream, it was decided in 2016 to extend the model domain to cover the entire Tims Branch watershed. This therefore required additional geospatial and timeseries data to be downloaded from online databases of federal agencies such as the U.S. Geological Survey (USGS), the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) and the U.S. Environmental Protection Agency (EPA), to fill in data gaps needed for the revised Tims Branch watershed model domain. Work in 2016 has therefore focused upon modification of the SRS geodatabase to incorporate the downloaded data, and the use of ArcGIS tools to process the data using the expanded model domain for input into the hydrological model being developed for the Tims Branch watershed.

1.2. Objectives

The primary purpose of this report is to provide details of the work accomplished during FIU Performance Year 6 (2015-2016), which involved the utilization of GIS software and tools to store, manage and process data required for the development of a surface water contaminant fate and transport model of the Tims Branch watershed at Savannah River Site. Efforts were primarily focused on:

1. Downloading model-specific geospatial and timeseries configuration parameters such as precipitation, hydrology, geology, land use, vegetation cover and topography, to fill in data gaps for the revised Tims Branch watershed model domain.
2. Updating the original ArcGIS geodatabase developed for SRS in 2015 with the additional downloaded data.
3. Using ArcGIS tools to process the downloaded data to ensure that it is in the required model-specific format, that the appropriate coordinate system is assigned and that the data is clipped to the new model domain.
4. Reapplying previously developed process flow models using ArcGIS ModelBuilder to automate repetitive geoprocessing tasks and batch process data in order to save time, improve overall efficiency and document geoprocessing workflows.
5. Reproducing GIS maps of Tims Branch hydrology, geology, land use, vegetation cover, topography, etc. for the expanded model domain for visualization and reporting purposes.
6. Conducting geospatial analyses that can further support hydrological modeling results.
7. Using geoprocessing tools for preliminary creation of the Tims Branch stream network required for development of the MIKE 11 stream flow model.

1.3. Benefits

Advances in ArcGIS software through the development of geodatabase technology, coupled with the development of data models such as ArcHydro which possesses a spatial relational database management system (RDBMS) schema and relationship structure specific to hydrologic systems, provides modelers with tools and applications to assist in the processing, analysis and visualization of flow and contaminant transport data. In addition, the coupling of this type of geodatabase structure with a numerical model such as MIKE SHE/11 can serve as an efficient tool that significantly reduces the time needed for data preparation [12]. Gogu et al., 2001 [13] stress the benefits of putting large volumes of data into a structured, coherent and logical computer-supported system to ensure validity and availability for concurrent use by multiple users and to provide a foundation for building GIS-based water resources applications. In addition, many of the numerical models used today by hydrologists are highly dependent on the use of GIS data as input configuration parameters required for model development. GIS-based hydrologic models can provide a spatial element that other hydrologic models lack. Other benefits include the following:

- GIS enables hydrologists to pre-process and integrate data derived from multiple sources into a single manageable system.
- GIS-based approaches in hydrological modeling can provide the benefit of combining different layers of geographic data to create new integrated information which can be quite useful for creating dependent or independent hydrological variables.
- GIS can be used for visualization of model-derived research results via maps, graphs and reports.
- The geodatabase structure employed by ARC is replicable can be used as the basis for development of geodatabases to support similar modeling work performed at other DOE sites.
- ArcGIS tools such as ModelBuilder coupled with Python scripting enables the automation of repetitive geoprocessing tasks required for preparation of model-specific configuration parameters and facilitates more complex analyses of field test data. Model-specific data processing toolboxes can be created that are scalable and reusable for implementation at other DOE sites. Batch data processing also expedites hydrological model development.

2. Technical Approach

This task provides support to the hydrological modeling work being performed by ARC at SRS through: (1) the update and further development of an ArcGIS geodatabase to store and manage GIS and timeseries data; (2) the implementation of built-in ArcGIS tools to pre- and post-process model-specific data and automate repetitive geoprocessing tasks; (3) the production of maps for visualization and reporting purposes; and (4) the application of geoprocessing tools to conduct geospatial analyses that further support hydrological modeling results and to develop hydrologic features such as the Tims Branch stream network to simulate stream flow in the watershed.

2.1. Download of Model-Specific Geospatial and Timeseries Configuration Parameters for Expanded Model Domain

The accuracy and predictive forecasting ability of hydrological models largely depend on the availability of daily/monthly/annual timeseries data as well as the overall period of time this data covers. The MIKE SHE/MIKE 11 model uses GIS data inputs for many of its configuration parameters which contain spatial features within the model domain, such as points representing monitoring stations, lines representing rivers/stream networks, or polygons which outline areas such as watershed and catchments (Figure 1). The significance of using GIS data is not just the spatial representation of hydrologic features, but their association with timeseries data attributes such as flow rates and directions, contaminant concentrations, water levels, precipitation, etc. Availability of data in this format shortens the time for data preparation and ultimately model development.

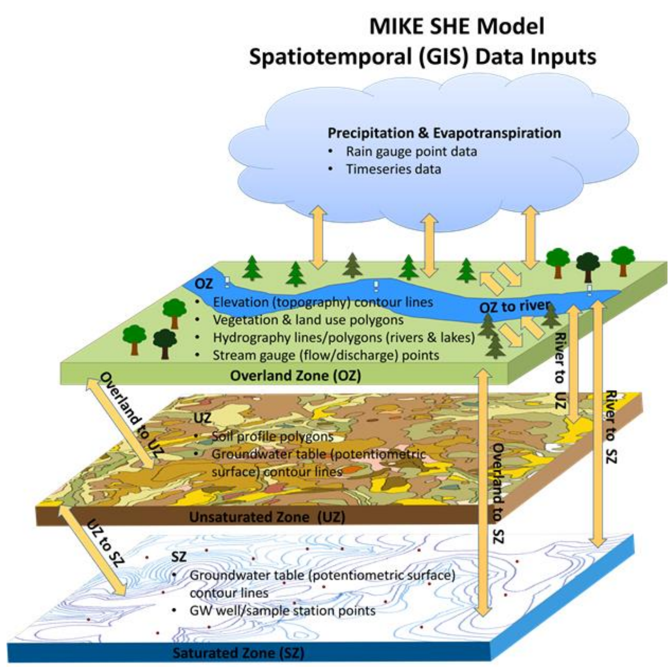

Figure 1. MIKE-SHE model spatiotemporal (GIS) data inputs.

An ArcGIS geodatabase was developed by FIU ARC researchers in 2015 to support development of a surface water model of Tims Branch, a small stream ecosystem in the northern portion of SRS that originates on the SRS, flows into Upper Three Runs Creek and eventually into the Savannah River. The geodatabase was comprised primarily of GIS data provided by the Savannah River Nuclear Solutions (SRNS) Geotechnical Engineering Department at SRS; however, much of this data was limited in extent to the Savannah River Site boundary. In 2016, a decision was made to extend the study area to the entire Tims Branch watershed, as opposed to only the portion of the watershed that lies within the SRS boundary. This therefore required additional geospatial and timeseries data (e.g., precipitation, stream flow, temperature, hydrology, geology, land use, vegetation cover and topography) to be downloaded to fill in data gaps for the revised Tims Branch watershed model domain.

Data was derived from online databases of federal agencies such as the U.S. Geological Survey (USGS), the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) State Soil Geographic (STATSGO) and Soil Survey Geographic (SSURGO) databases and the U.S. Geological Survey (USGS)/U.S. Department of the Interior (DOI) Multi-Resolution Land Characteristics Consortium (MRLC) national land cover database (NLCD). FIU ARC researchers also utilized several reports and journal publications provided by Savannah River National Laboratory (SRNL) and conducted an extensive literature review in order to characterize the study area and retrieve additional data required for model development and calibration.

2.2. Update of the SRS Geodatabase

The SRS geodatabase has a framework that was created based on the ArcHydro and ArcGIS Base Map data models with modifications made for MIKE SHE/MIKE 11 model-specific input parameters. The ArcHydro data model is designed to support water resources applications within the ArcGIS environment and possesses a spatial relational database management system (RDBMS) schema and relationship structure specific to hydrologic systems where spatial relationships between hydrological parameters and geographical features can be defined. The SRS geodatabase has a standardized data structure which helps in the organization of hydrologic features (e.g. channel cross sections, stream geometric networks and nodes, monitoring points, watersheds and subwatersheds, and other hydrographic and drainage files) and their relationships to each other, providing a common framework that can be utilized by various hydrologic models. Preliminary development of the SRS geodatabase involved the following steps:

1. Import of an XML file generated from a geodatabase created by FIU ARC for the Oak Ridge Reservation (ORR) to create a preconfigured database structure for the new SRS geodatabase.
2. Modification of the imported geodatabase configuration to support the hydrological model requirements specific to the SRS study domain.
3. Import of GIS and timeseries data derived from the SRNS Geotechnical Engineering Department.

4. Documentation of the geodatabase design using ArcGIS Diagrammer.

Work in 2016 has focused upon updating the geodatabase developed for SRS in 2015 to incorporate the recently downloaded data derived from the federal online databases described above for the expanded model domain of the Tims Branch watershed. As the data was collected from various sources, it was often necessary to conduct preprocessing in order to convert the files to compatible formats that could be uploaded into the ArcGIS geodatabase into the appropriate preconfigured feature datasets or raster catalogs. The MIKE SHE model uses GIS data inputs for many of its configuration parameters and as such, GIS data in shapefile (.shp) format can be directly input into the model. There are instances, however, where although MIKE SHE accepts the GIS shapefile, the attribute field with the relevant data required is not read by the model due to an incompatible field type. For example, a non-integer numeric field may be "single", however, the field type accepted by the model is"double". As a result, modification of the attribute table is necessary to create a new field with "double" as the field type into which the required numeric data can be copied. Data pre-processing also involved alteration of tabular data from pivot tables to simple spreadsheets, conversion of data units (e.g., feet to meters), modification of tabular field properties (e.g., short integer to scientific notation) and renaming of tabular field names as there is a 10-character limit in ArcGIS geodatabases. This process of data conversion and standardization also prepares the data for direct input into the MIKE SHE/MIKE 11 model.

Once the SRS geodatabase was updated with the new model configuration data, an updated geodatabase schema was created using ArcGIS Diagrammer for ArcGIS 10.2. ArcGIS Diagrammer is a downloadable diagramming utility used to create, edit or analyze geodatabase schema. It generates diagrams and reports in the form of editable graphics within an interface similar to Microsoft Visual Studio and serves as a visual editor which accepts XML workspace documents that are created from ESRI's ArcMap or ArcCatalog. Documenting the geodatabase design can assist in representation of the map layers, metadata and other elements specific to the data model used to create the geodatabase and is very useful for reporting purposes.

2.3. Geoprocessing of Updated Model Data using ArcGIS

With the expanded Tims Branch watershed study domain, hydrological model data had to be collected from multiple sources which often resulted in data with different spatial references, that were at different scales, and that were from different time periods. The application of ArcGIS tools enables pre-processing and integration of data from various sources into a single manageable system. As previously mentioned, the MIKE SHE model uses an extensive amount of GIS data inputs (Figure 1) for many of its configuration parameters. ESRI's ArcGIS 10.2 geoprocessing tools were used to process the downloaded data to ensure that it was in the required model-specific format, that the appropriate coordinate system was assigned and that the data was clipped to the new model domain.

2.3.1. Application of Process Flow Models using ArcGIS ModelBuilder

Development of process flow models using ArcGIS ModelBuilder which has built-in ArcGIS tools helps to automate repetitive geoprocessing tasks and batch process data in order to save time, improve overall efficiency and document geoprocessing workflows which visually represent the tools and scripts (if any) that have been incorporated in the data model. ArcGIS ModelBuilder is a scalable and reusable application that can iterate over the hydrological model configuration parameters, perform geoprocessing actions, calculate statistical parameters and generate maps and reports.

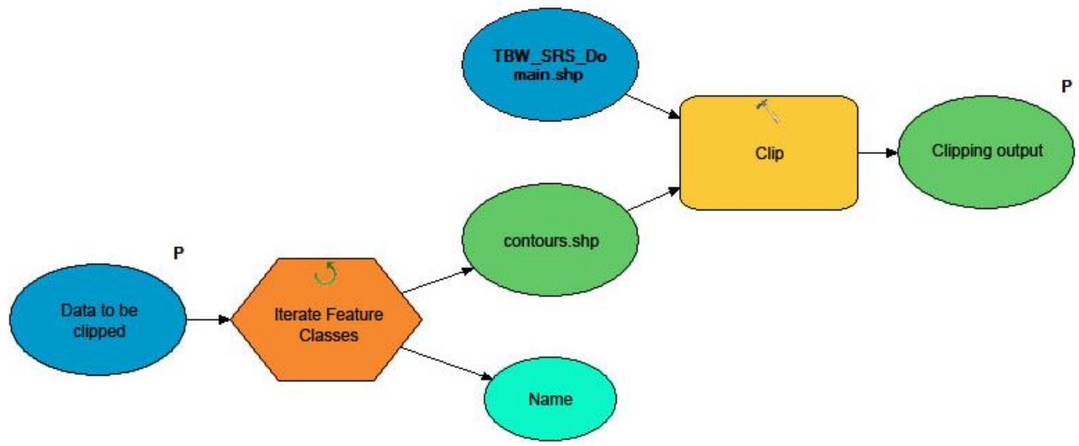

Figure 2. ArcGIS ModelBuilder workflow diagram for clipping GIS data to the study domain.

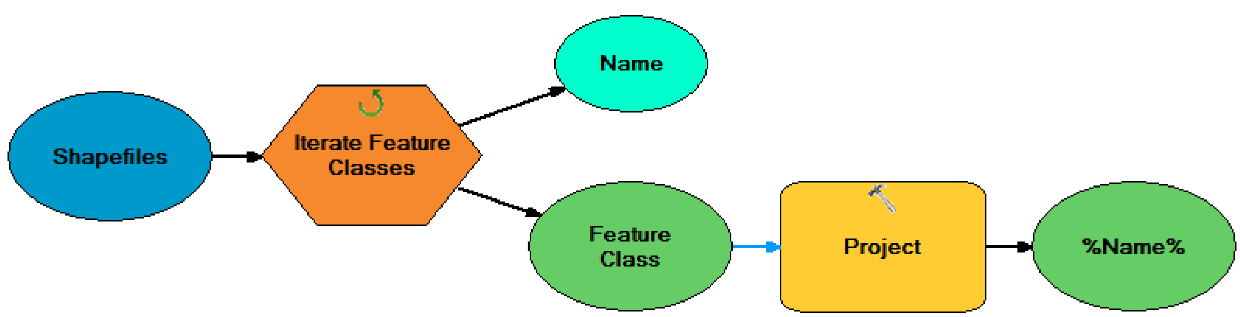

Figure 3. ArcGIS ModelBuilder workflow diagram for projecting GIS data to UTM coordinates.

Several ModelBuilder models (Figure 2 and Figure 3) were developed by FIU ARC researchers in 2015 during preliminary hydrological model development, in order to clip all of the GIS data to the study domain being used in the MIKE SHE model and project them into the appropriate coordinate system being used (*i.e., NAD 1983 UTM Zone 17N*); however, with the expansion of the study domain, it was necessary to reapply these models using the newly downloaded GIS data in order to clip them to the new Tims Branch watershed domain and project them into the UTM coordinate system. The process flow models developed were created so that they can also be implemented for other DOE sites by simply altering the study domain, the input files and the coordinate system.

2.3.2. Development of Model-Specific Input Files

New GIS shapefiles and maps were created for the expanded study domain which now incorporates the entire Tims Branch watershed as opposed to just the portion that lies within the SRS boundary. The following describes some of the significant model input parameters that were generated for the new revised study domain.

Model Domain

Preliminary model development in 2015 involved the use of a model domain that only covered the portion of the Tims Branch watershed that lies within the SRS boundary. In order to study contaminant fate and transport along the full length and reaches of the Tims Branch stream, the model domain was expanded to cover the entire Tims Branch watershed (Figure 4).

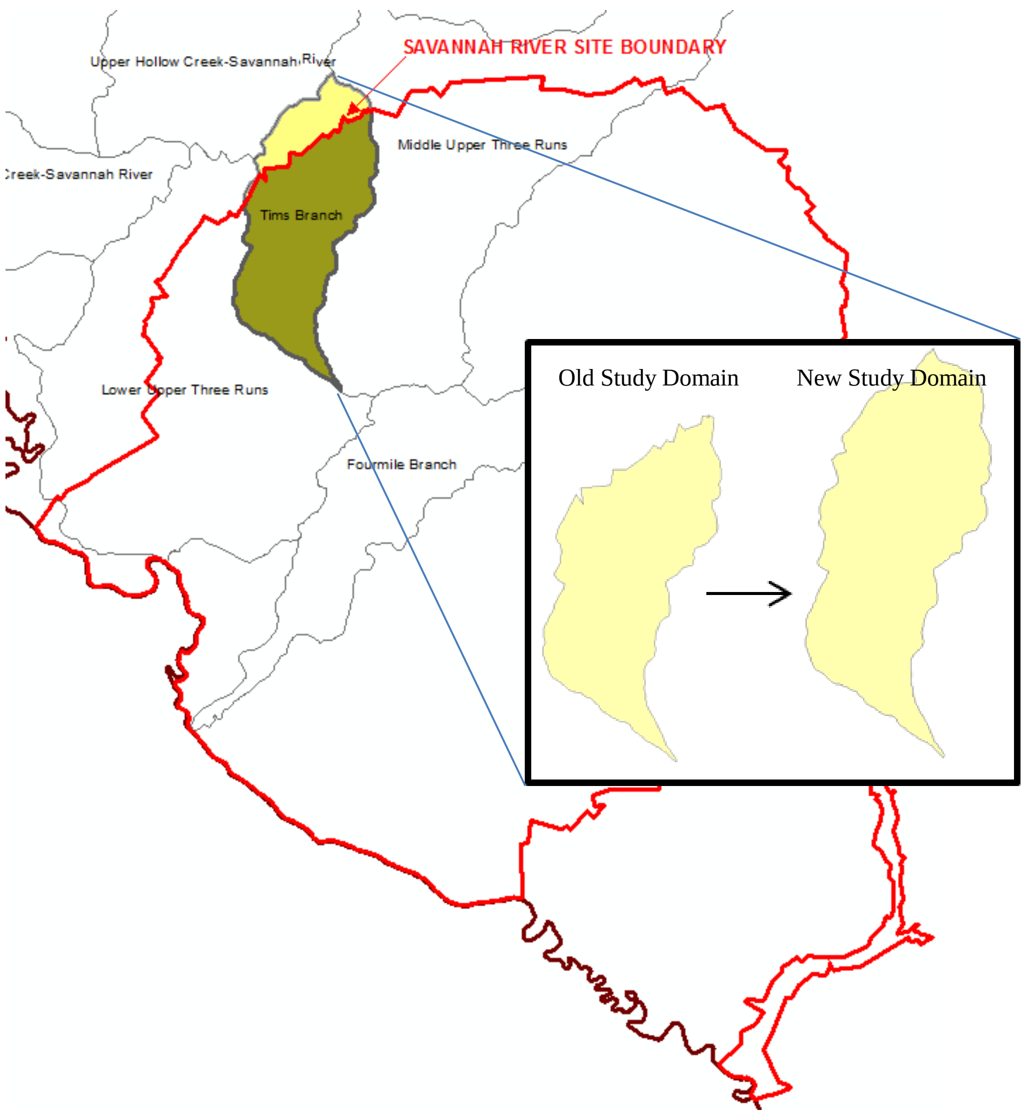

Figure 4. Expanded Tims Branch watershed study domain.

Timeseries

Precipitation is one of the critical variables in the integrated hydrological model, which determines the surface water flows in the watershed and the dynamics of the groundwater table. For use in MIKE SHE, the precipitation rate can be specified as a rate (e.g., mm/hr) or as an amount (e.g., mm). Rainfall timeseries data was provided by SRNL for approximately 50 years (01/01/1964 - 9/29/2014) in inches/day in an MS Excel spreadsheet. This data was copied into a MIKE SHE timeseries (.dfs0) file and input into the MIKE SHE model as precipitation during preliminary model development in 2015. The model automatically converts the units to mm/day in the graph generated and will only use the data within the specified simulation period. The aim in 2016 is to now refine the precipitation module of the MIKE SHE model which currently includes data for a single rain gauge station (700-A, located in the A/M Area) to include data from several other monitoring stations located within SRS (Figure 5) in order to generate spatially distributed rainfall and evapotranspiration timeseries grids.

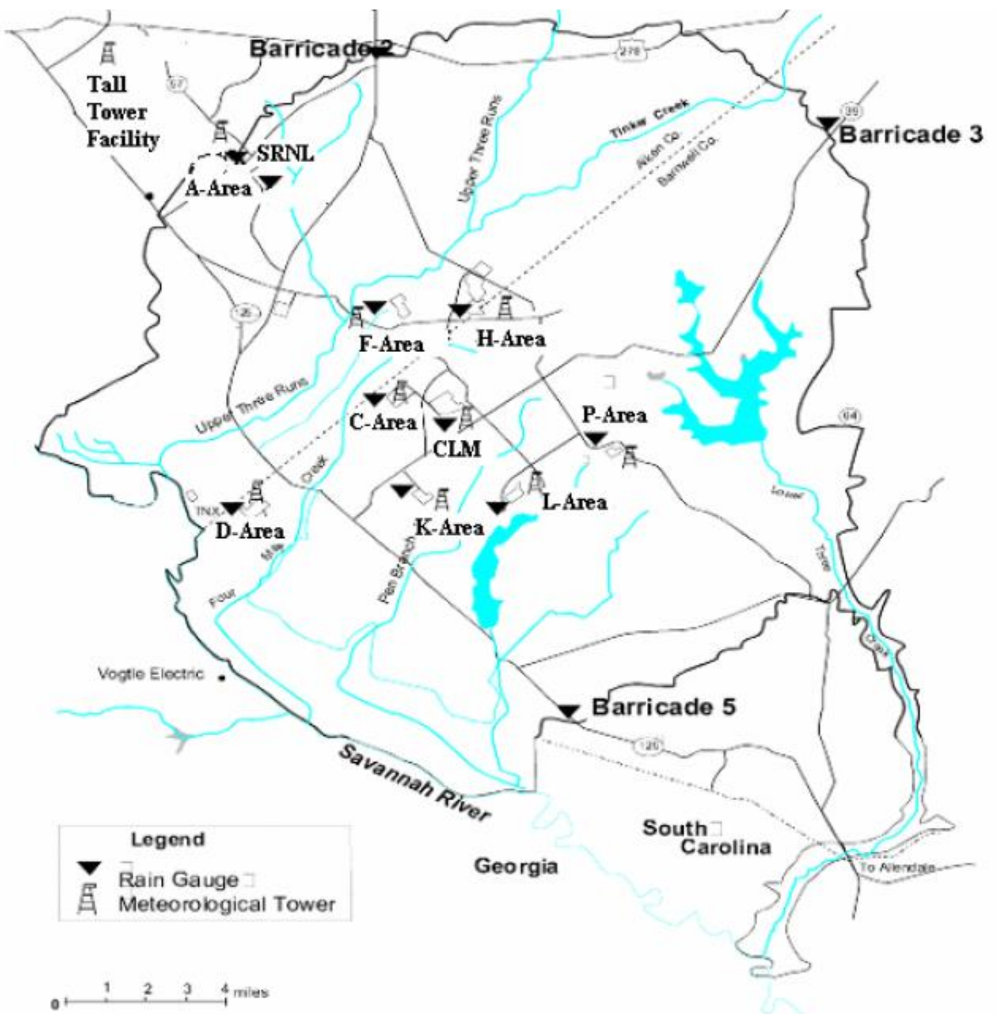

Figure 5. SRS meteorological monitoring network [17].

Topography

In MIKE SHE, topography defines the upper boundary of the model. The topography is used as the top elevation in both the Unsaturated Zone (UZ) and Saturated Zone (SZ) modules. It also defines the drainage surface of Overland flow (OL). The accuracy of the topography is therefore the most important parameter in the MIKE SHE model set up. The model input for topography was generated from a 10 foot (~3 m) resolution digital elevation model (DEM) of South Carolina that was provided by the SRNS Geotechnical Engineering Department, which they derived from the South Carolina Department of Natural Resources (SCDNR) GIS Data Clearinghouse. A polygon GIS shapefile representing the Tims Branch watershed boundary was used to clip the DEM to the model domain (Figure 6).

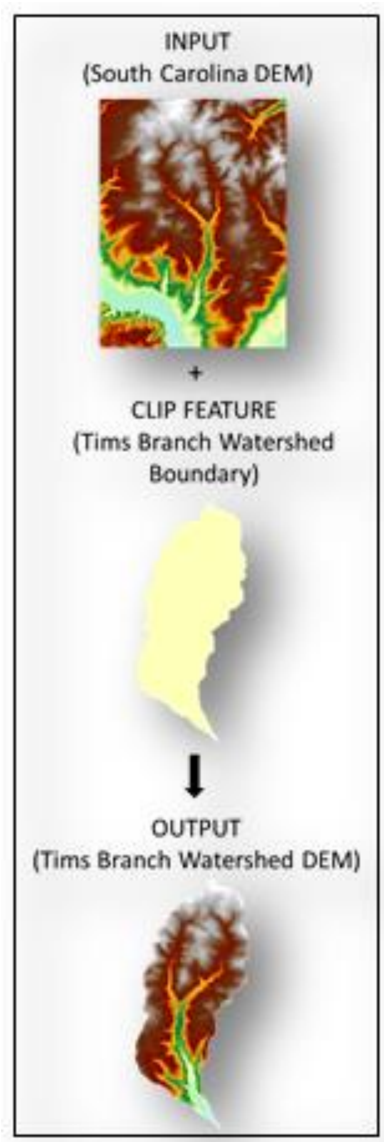

Figure 6. Digital Elevation Model (DEM) of the Tims Branch watershed.

The clipped DEM was then converted to a point shapefile which contained XY coordinate data with associated elevation values. The point shapefile was then imported into the MIKE SHE model which interpolates the point data via a triangular interpolation method into a gridded surface. The grid was then exported as a .dfs2 file, which is a native MIKE SHE grid file format. The .dfs2 file was then used to replace the point shapefile in the model.

Land Use

MIKE SHE uses land use/land cover data to calculate ponded water and the spatial and temporal distribution of evapotranspiration (ET). Land use/land cover GIS data for the state of South Carolina was downloaded from the U.S. Geological Survey (USGS)/U.S. Department of the Interior (DOI) Multi-Resolution Land Characteristics Consortium (MRLC) national land cover database (NLCD) for the years 1992, 2001, 2006 and 2011. ArcGIS tools were used to clip the downloaded GIS data to the revised Tims Branch watershed study domain and project the data into the appropriate coordinate system. The GIS shapefiles generated were then manipulated using ArcMap to create thematic maps which represent the land cover distribution in the Tims Branch watershed for that particular year. Figure 7 depicts maps of the 1992 land cover classification for the old and new study domains.

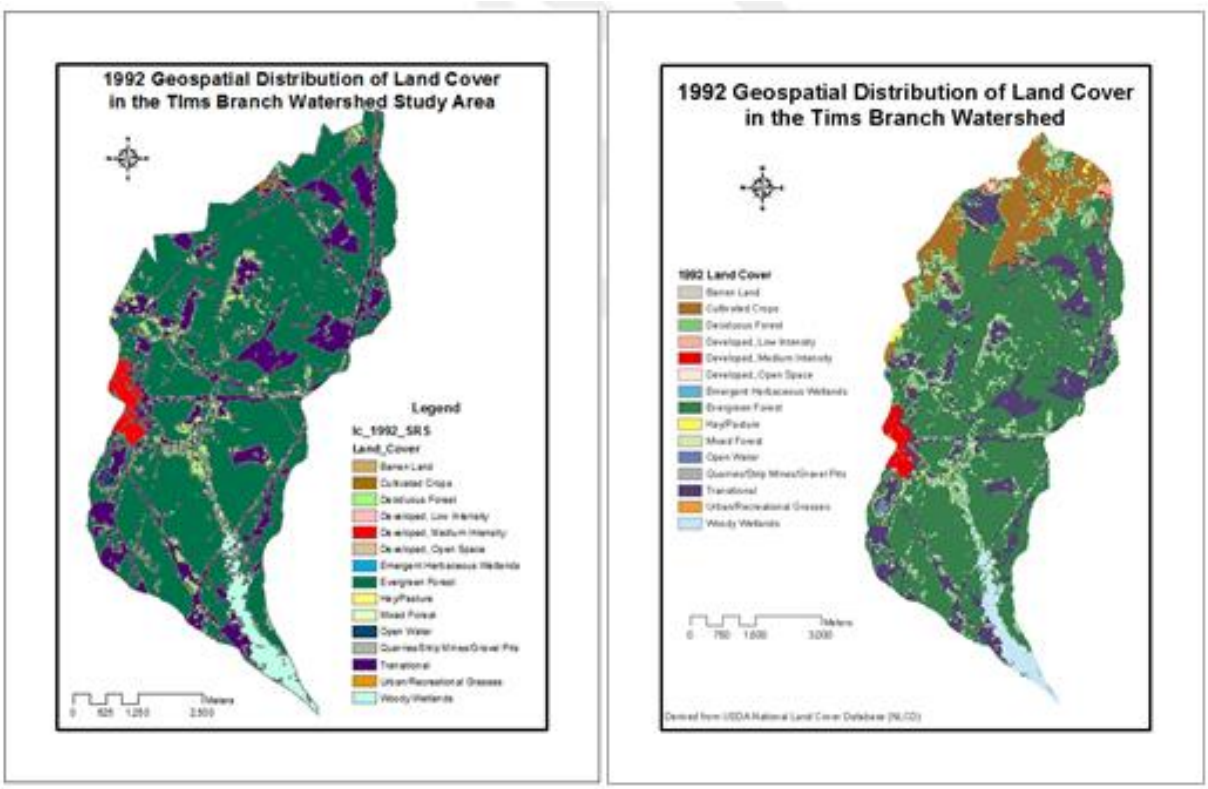

Figure 7. Map of the 1992 land cover classification in the Tims Branch watershed for the original study domain (left) and the new revised study domain (right).

Table 1 shows the 1992 land use/land cover data for the Tims Branch watershed with the associated leaf area indices (LAI) and root depths (RD) which MIKE SHE uses to calculate evapotranspiration. Currently, constant LAI and RD are assumed, however MIKE SHE has the capability to simulate spatiotemporal variations of evapotranspiration if the timeseries of LAI and RD are available.

Table 1. 1992 Land Use/Land Cover Data for Tims Branch Watershed

Land Use/Land Cover ID	LAI	RD (mm)
Barren Land	1.31	4000
Cultivated Crops	3.62	1500
Deciduous Forest	5.5	2000
Developed Low Intensity	2.5	2000
Developed Medium Intensity	2.0	2000
Developed Open Space	3.0	2000
Emergent Herbaceous Wetland	6.34	2000
Evergreen Forest	5.5	1800
Hay/pasture	1.71	1500
Mixed Forest	5.5	2400
Open Water	0.0	0.0
Quarries/Strip Mines/Gravel Pits	1.31	4000
Transitional	1.31	4000
Urban/Recreational Grasses	2.0	2000
Woody Wetland	6.34	2000

The revised land cover GIS data was also used as the basis for generating shapefiles which represent other configuration parameters required for development of the MIKE SHE model with the expanded study boundary, such as the Manning's roughness coefficient and the paved runoff coefficient.

Manning's Roughness Coefficient

Computation of flow in an open channel requires evaluation of the channel's resistance to flow, which is typically represented by a roughness parameter, such as Manning's n (Phillips et al, 2006 [15]). Table 2 shows the values of Manning's M ($1/n$) that were assigned to each land use classification in the land cover shapefile previously described. Manning's n values were obtained from standard civil engineering Manning's tables available online as well as *n* values derived from the technical report by Tachiev et al, 2014 [16].

Table 2. Land Use/Land Cover Classifications and Corresponding Manning's M (1/n) Number

Land Use/Land Cover ID	Manning's M (1/*n*) Number
Barren Land	11
Cultivated Crops	41
Deciduous Forest	10
Developed Low Intensity	40
Developed Medium Intensity	40
Developed Open Space	40
Emergent Herbaceous Wetland	22
Evergreen Forest	10
Hay/pasture	29
Mixed Forest	10
Open Water	50
Quarries/Strip Mines/Gravel Pits	11
Transitional	11
Urban/Recreational Grasses	40
Woody Wetland	22

The land cover shapefile attribute table was then modified to include a new field of Manning's M (i.e., 1/*n*) numbers. This added field was then used as the basis for generating a new polygon shapefile to represent the Manning's roughness coefficients within the SRS/Tims Branch study area (Figure 8). As the MIKE SHE model only accepts point/line shapefiles for spatially distributed Manning's M, ArcGIS tools were used to convert the polygon shapefile to a point shapefile which was then input into the model. The model then interpolated the values to generate a gridded surface which was saved as a MIKE (.dfs2) grid file. This grid file was then used to replace the shapefile in the model configuration.

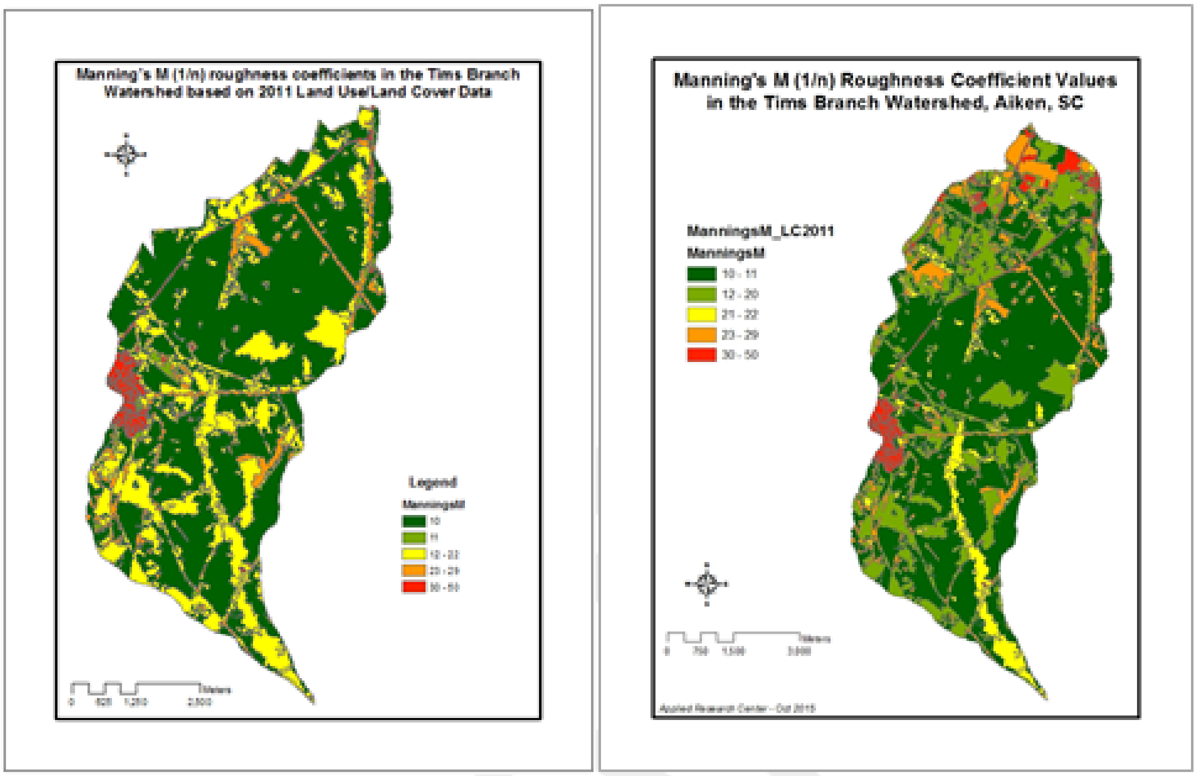

Figure 8. Map of the Manning's M (1/n) roughness coefficients in the Tims Branch watershed for the original study domain (left) and the new revised study domain (right).

Paved Runoff Coefficient

Paved runoff coefficient values were derived from the Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment State Water Resources Control Board 5.1.3 FS-(RC) 2011 [19], which specifies the runoff coefficient (C) as a dimensionless coefficient relating the amount of runoff to the amount of precipitation, with larger values for areas with low infiltration and high runoff (pavement, steep gradient), and lower values for permeable, well vegetated areas (forest, flat land). This data is required by the MIKE SHE model and can be a significant parameter indicating flooding areas during storm events as water moves fast overland on its way to a river channel or a valley floor. Paved runoff coefficient values were assigned to the land use classifications outlined in Table 1 above. A value of 0.7 was given to the urban/developed land and a value of zero assigned to all other land use types. In the same manner as described above for development of the Manning's coefficient GIS shapefile, the land cover shapefile attribute table was modified to include a new field of runoff coefficients. This added field was then used as the basis for generating a new polygon shapefile (Figure 9) to represent the paved runoff coefficients within the SRS/Tims Branch study area. As the MIKE SHE model only accepts point/line shapefiles for spatially distributed paved runoff coefficients, ArcGIS tools were used to convert the polygon shapefile to a point shapefile which was then input into the model.

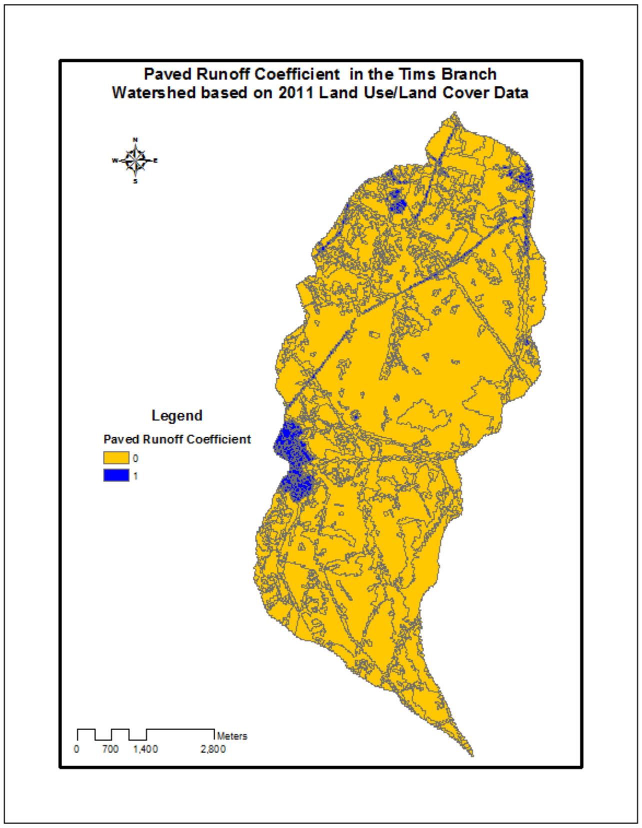

Figure 9. Map of paved runoff coefficient values in the Tims Branch watershed based on 2011 land use/land cover data.

Soils

Soil profile GIS data was acquired from the U.S. Department of Agriculture (USDA) Web Soil Survey website (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx). Soil textures within the Tims Branch watershed were identified by investigating soil map units on the basis of geologic formation, geomorphology, and soil parent material at SRS. Soil map units were delineated within the Tims Branch watershed boundary according to the SRS soil coding and classifications described by Aadland et al., 1995 [1]. Figure 10 shows GIS maps of the soil classification for the old and revised Tims Branch study domains. The soil data was reclassified into 6 classes which include 4 dominant soil types (sand, sandy loam, loam, and loamy sand) as well as urban areas and open water (Figure 11).

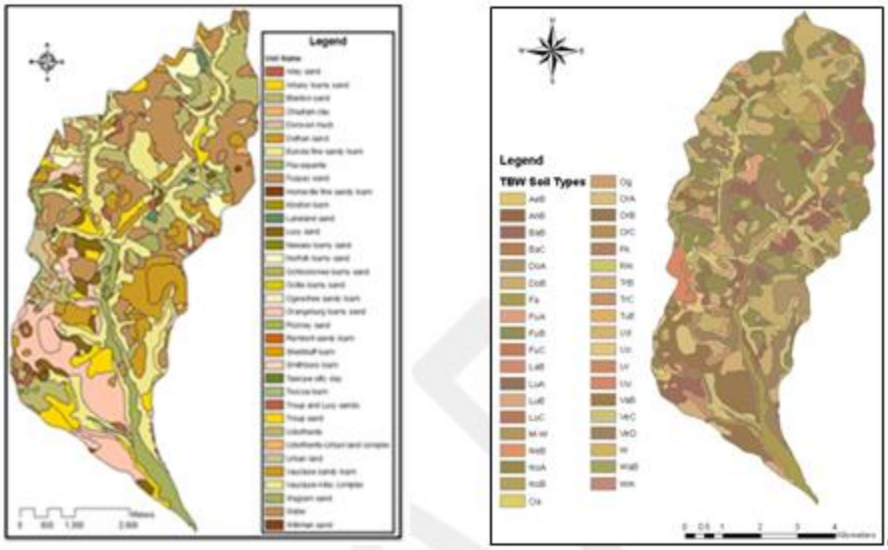

Figure 10. Soil classification maps of the Tims Branch watershed for the original study domain (left) and the new revised study domain (right).

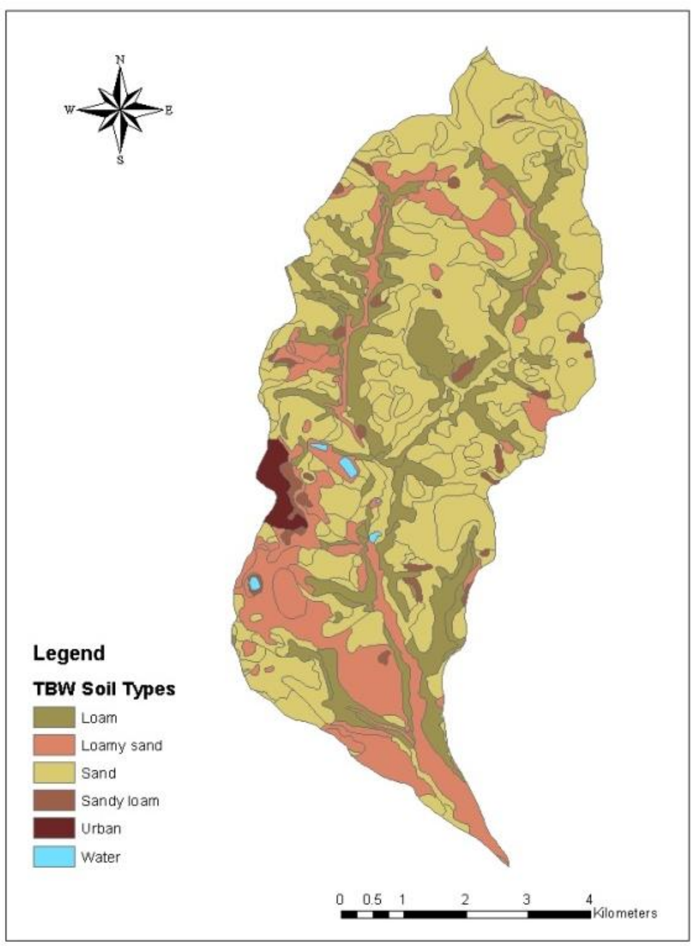

Figure 11. Map of the re-classified soil data in the Tims Branch watershed.

Initial Water Depth

A GIS-based methodology was employed to generate a shapefile representing the initial water depth in Tims Branch. This task involved GIS raster calculations, conversions, and modifications. The initial depth of water was calculated assuming an initial depth of 10 cm in an observation location (based on observation during the last site visit by FIU) and topography.

A DEM of the Tims Branch watershed was converted from feet to meters by multiplying the raster file by 0.3048 and then clipping the file to the Tims Branch watershed domain. A point near outfall A-11 was used as a reference point for the initial water depth (Location: 432,839.875; 3,688,280.806 meters; Elevation: 71.63 meters). A value of 10 cm was then added to the ground surface elevation at the selected reference point. This new elevation is the water elevation (H). A uniform potentiometric line was assumed along the domain (Figure 12).

- Water elevation along the domain: 71.73 meters (above mean sea level)

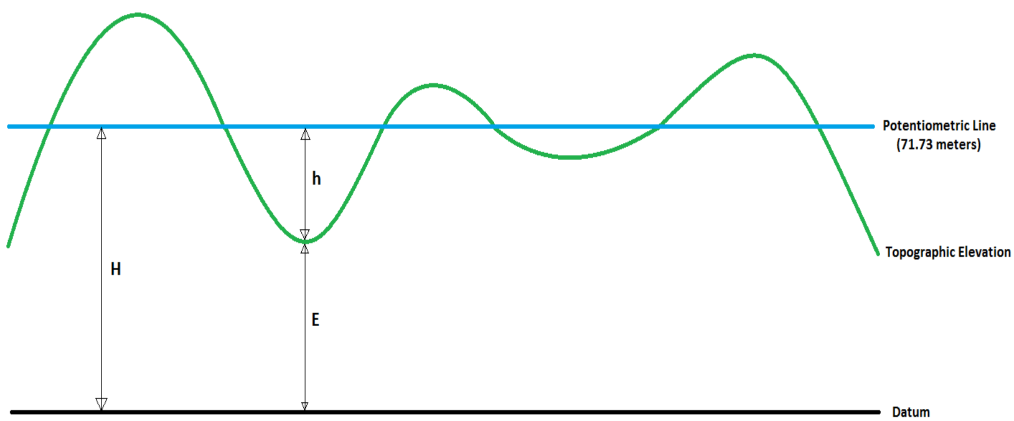

Figure 12. Topographic elevation.

Using the ArcGIS raster calculator, the following operation was then performed on the entire raster file:

$$h = H - E$$

Where: h = initial water depth, H = water elevation (from datum), and E = ground surface elevation.

The resulting water depth file contained negative numbers. These values refer to the locations with higher elevation which mainly stay dry. Therefore, water depth at these locations is zero. Using the ArcGIS raster calculator, a value of zero (0) was assigned to all water elevation with negative values in the resulting raster.

Expression: Con("water_depth" < 0, 0 , "water_depth")

Finally, using the "Raster to Point" tool in ArcToolbox, the resulting water depth raster file (Figure 13) was converted into a GIS point shapefile which is interpolated when added to MIKE SHE to create a grid (.dfs2) file to be used in the model.

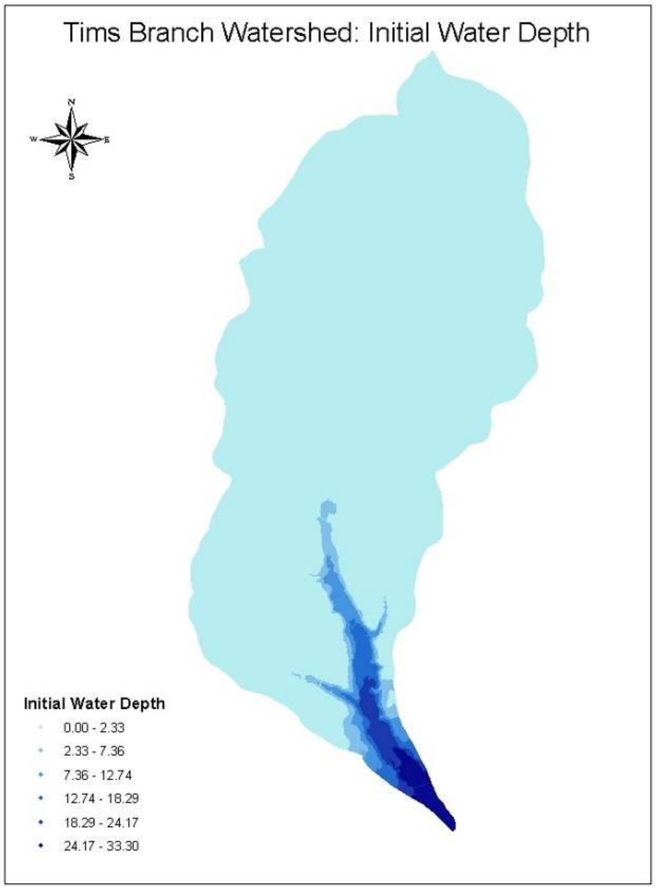

Figure 13. Initial water depth raster created using ArcGIS raster calculator.

2.4. Preliminary Development of the MIKE 11 Stream Network

Development of the MIKE 11 stream flow model is targeted for FIU Performance Year 7 (2016-2017); however, ARC researchers have begun preliminary preparation by delineating the Tims Branch stream network and cross sections, and defining the river chainages and linkages using ArcGIS (Figure 14). Two approaches are being taken in developing the MIKE 11 model. The first is to delineate the Tims Branch stream network at the watershed scale and the second is to delineate a smaller scale, higher resolution network which represents the A014 Outfall tributary which flows from the SRS A/M Area into the main Tims Branch river channel. The smaller scale model will focus on the flow and contaminant transport in the A014 Outfall tributary that has several man-made structures implemented (weir, rip rap and culvert) to determine if these have any impact on the hydrology. More than 80% of the cross sections for the Tims Branch study area have been prepared. The DOE Fellows supporting the project are being trained to delineate the stream network, cross sections and river chainages using both ArcGIS and MIKE 11.

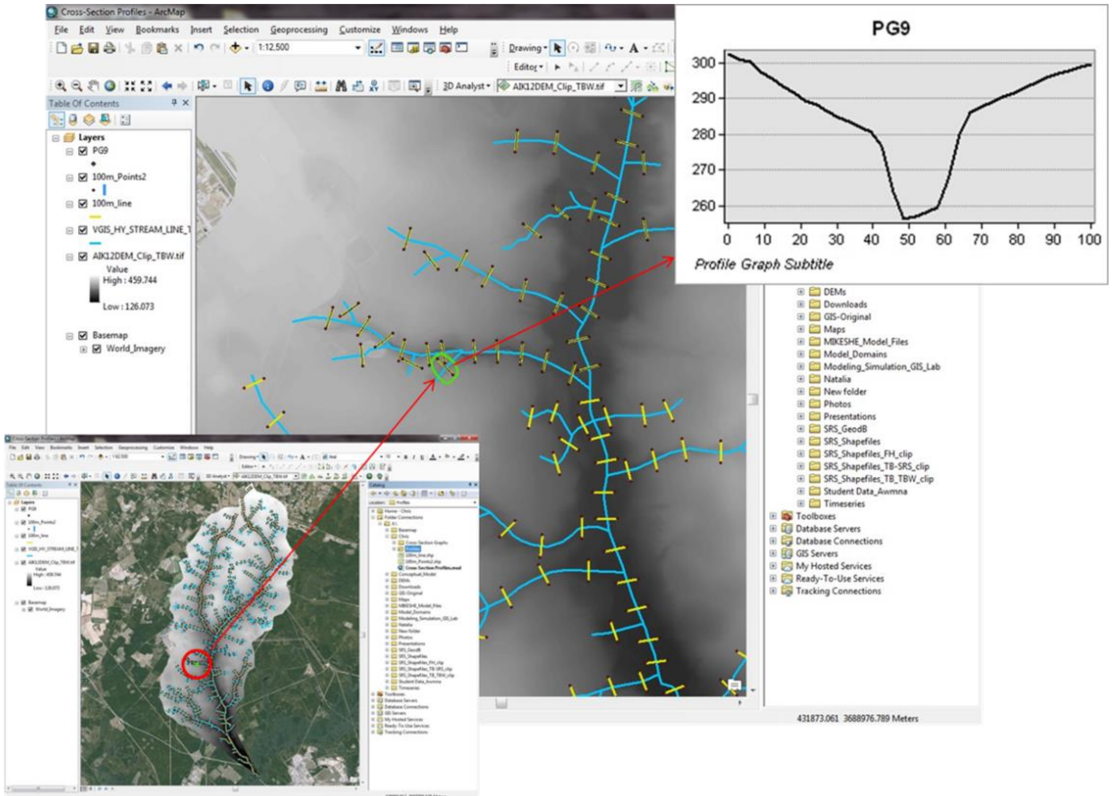

Figure 14. An ArcMap view of the Tims Branch delineated cross sections (left and center); the cross section profile of the cross section #PG9 (right).

2.5. Geospatial Analysis of Land Cover Change in the Tims Branch Watershed

FIU ARC researchers and students began a preliminary geospatial analysis of land cover and land use change due to urbanization in the Tims Branch watershed using ArcGIS geoprocessing and statistical analysis tools, as this can have an impact on the watershed hydrology. The methodology [18] followed in this study required the use of "projected urban growth" data; however, since this data was unavailable for South Carolina, the 1992 National Land Cover Dataset (NLCD) was used as the "historical" data and the 2011 NLCD dataset as the "projected urban growth" for the purpose of this study. The geospatial analysis conducted involved:

- Downloading land cover datasets for different years from the NLCD online database.
- Clipping the data to the Tims Branch watershed study domain.
- Converting the downloaded grid files from the NLCD database to GIS shapefiles.
- Extracting regions within Tims Branch watershed where land cover change occurred.
- Projecting the data to the appropriate coordinate system.
- Calculating the area of land cover change from 1992 to 2011 due to urbanization.

The first step of the geospatial analysis was to spatially join two land cover GIS shapefiles for different years using tools within ArcToolbox. In this case, the NLCD datasets for 1992 and 2011 were used to find the areas where similar land cover types of the two layers intersect. The result of spatially joining the 1992 and 2011 datasets was a feature class consisting of all the urbanized areas in 2011.

The next step involved dissolving the data based on fields in the attribute table. These fields can be joined as they have the same land use value. This minimizes features with the same attributes and simplifies the data, making it easier to work with. For example, the land use value "Developed Low" is present in both the 1992 and 2011 datasets, indicating that the "Developed Low" attribute remained the same. The focus was on total areas of non-urban land cover that changed due to urbanization by 2011. The dissolve process resulted in the creation of a new GIS shapefile consisting of multi-part polygons of each land use type. The ArcToolbox "dissolve" tool was utilized to minimize the LUCODE and LANDUSE records in the attribute table. All other values were left at their default settings. When the new feature class was viewed in ArcMap, it depicted a significant reduction in the number of features, and the features that remained consisted of multi-part polygons for all the features with the same LUCODE value.

After creating the new aggregated land use shapefile, the spatial reference of the data frame was changed from a geographic coordinate system (Albers Conical Equal Area) to the appropriate projected coordinate system for Aiken, SC (NAD 83 UTM Zone 17N). The area of each land use type that was urbanized from 1992 to 2011 was then calculated based on the feature geometry. A new field, "Area", was added to the attribute table of the aggregated land use shapefile. The field calculator within ArcMap was then used to calculate the area of each of the features in the feature class, populating the values in the "Area" field. The purpose of calculating the area is to generate a new land cover shapefile which depicts only the extracted features that changed from non-urban to urban land use from 1992 to 2011 (Figure 15).

It should be noted that during the geospatial analysis, a discrepancy was noted when attempting to conduct the spatial join. The attribute table of the 1992 shapefile had one classification that was not present in the 2011 shapefile. For the purpose of this preliminary exercise, and in order to compare the 1992 and 2011 shapefiles, the classification type "Urban/ Recreational Grasses" in the 1992 shapefile was changed to "Developed Medium Intensity". It is noted on the NLCD website that "the NLCD 1992 is not recommended for direct comparisons with any subsequent NLCD data products (i.e. NLCD 2001, NLCD 2006, NLCD 2011). The typical result of direct comparison will result in a change map showing differences between legends and mapping methods rather than real changes on the ground." This study will therefore be repeated to compare data from the 2001, 2006 and 2011 NLCD datasets and the results reported in the final end of year report due in October 2016.

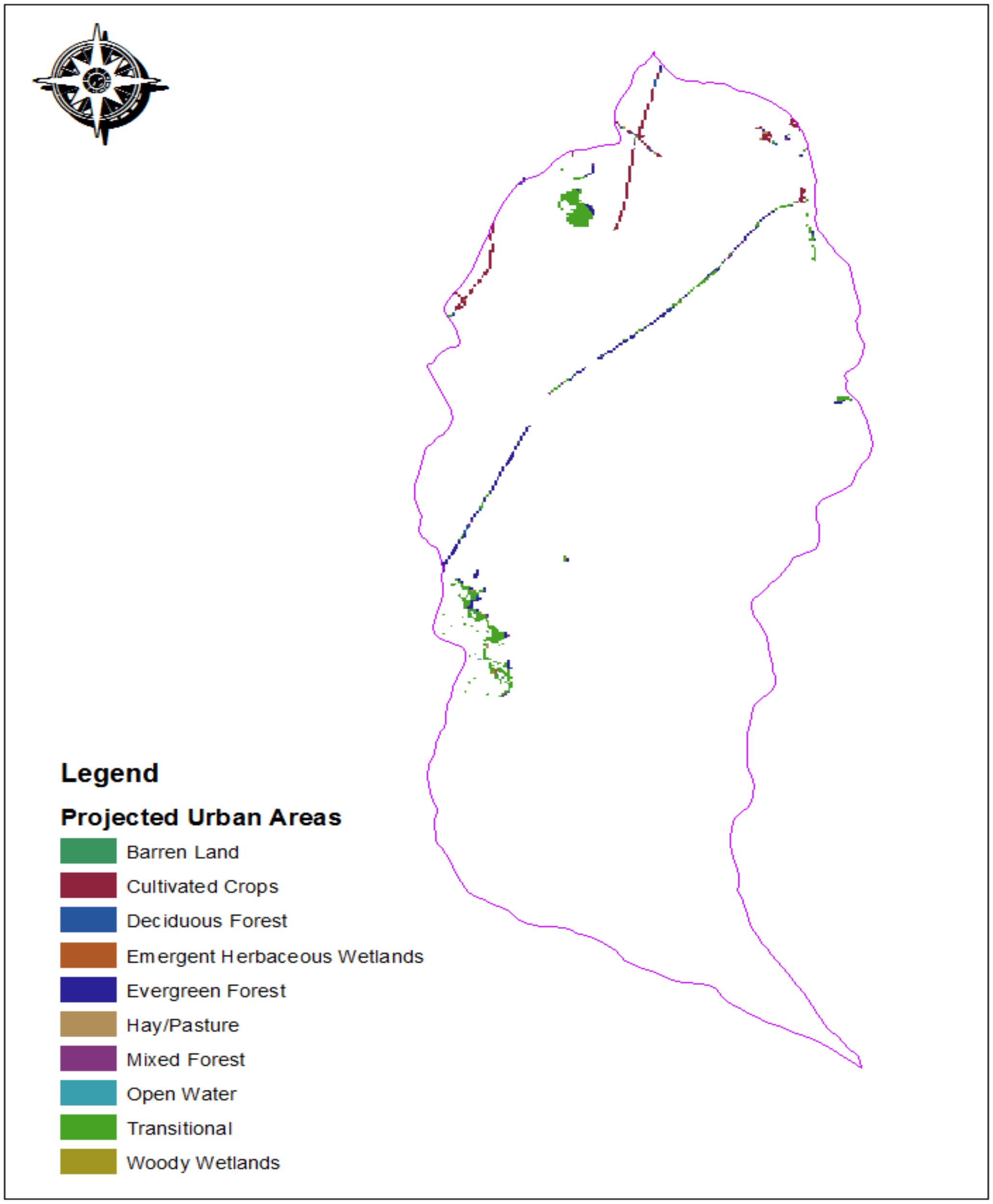

Figure 15. Map of the land cover in the Tims Branch watershed depicting only the extracted features that changed from non-urban to urban land use from 1992 to 2011.

3. Future Work

Application of GIS technology is a key component in hydrological modeling that helps to prepare data, display results and conduct further spatial analyses. The use of GIS technology has supported the preliminary development of the MIKE SHE and MIKE 11 models. During the rest of FIU Performance Year 6 (2015 - 2016), ARC will continue the development of the MIKE SHE model to complete the saturated zone module. GIS tools will be applied to assist in preparation of configuration parameters such as the groundwater table GIS shapefile to support this effort.

In FIU Performance Year 7 (2016 - 2017), ARC will continue to support hydrological model development with pre- and post-processing of data. GIS tools will support the development of the MIKE SHE/MIKE 11 model for delineation of the stream network and generation of cross-sections and chainages of the major and minor tributaries of Tims Branch. Advanced geospatial analyses will also be conducted for the Tims Branch watershed. This will include the examination of timeseries land use and land cover maps of the Tims Branch watershed to evaluate if there is any impact of land use/land cover change on the watershed hydrology. In addition, topographical changes as a result of the implementation of man-made structures along the A-014 outfall tributary will be examined to determine any hydrological impacts on the Tims Branch watershed.

FIU graduate and undergraduate students will be mentored and trained on how to update and query the existing geodatabase within the ArcGIS environment, perform geoprocessing tasks, conduct geospatial analyses and generate maps and graphs for reporting purposes.

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