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Atlas of Hydrologic Characteristics of the Wolf River Basin

by

Faraedoon Mohamad Amin Qaladize

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ABSTRACT

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An atlas of the hydrologic characteristics of the Wolf River basin in West Tennessee is derived by using a Geographic Information System (GIS) to simulate the watershed's hydrologic response. A 30-meter digital elevation model (DEM), extracted from the National Elevation Dataset (NED) and managed by United States Geologic Survey (USGS), is used to develop the database of watershed characteristics. Arc Hydro, created by Environmental Systems Research Institute (ESRI), and the Geospatial Hydrologic Modeling System (HEC-GeoHMS) program, created by the United States Army Corps of Engineers' Hydrologic Engineering Center (USACE-HEC), are used to delineate the watershed of the Wolf River basin and develop the hydrologic characteristics (physical parameters) of the main streams (creeks), such as length, slope, subbasin area, longest flow path, basin slope, centroid elevation, and centroidal flow path. These topographic characteristics were needed to analyze and evaluate every subbasin of the Wolf River floodplain from its outlet to its headwaters. The development of an atlas that contains such information would be an invaluable source of information to municipalities and consultants in the design of storm water networks, the design of box culverts, the design of sanitary sewer systems and interceptors, the complete analysis of flood plains, and the development of a flood hydrograph for each subdivision.

TABLE OF CONTENTS

Chapter Page

1 Introduction 1
  Brief Description of Study 1
  Objective 4
  Study Area 4
  Software Used 8
  Organization of the Thesis 9

2 Literature Review 11
  Hydrology Modeling and Subbasin Characteristics Derivation 11
  The Geographic Information System (GIS) 14
  Digital Elevation Models in Hydrology 17
  Vertical Accuracy of USGS NED (30-meters DEM) 19
  Threshold Area 20

3 Methodology 22
  Data 22
  Procedure 23
  Example: Extracting the Digital Elevation Model (DEM) of the Wolf River Basin 28
  Example: Extract Hydrologic Chracteristics of Mary's Creek Subbasin 43

4 Hydrologic Characteristics 82
  Stream and Basin Characteristics 83
  Stream Hydrologic Characteristics 83
  Subbasin Hydrologic Characteristics (Physical Parameters) 85
  Hydrologic Equation 87

5 Results and Conclusion 93
  Examples 108
  Conclusion 121
  Download the Software 123

References 117
Appendix A 132
Appendix B 210

LIST OF TABLES

Table 1: Population of Cities/Towns in the Wolf River Basin in 2000 6

Table 2: Creeks Identified in the Wolf River Basin Area 7

Table 3: Hydrologic Characteristics of Mary's Creek Streams and Subbasins 81

Table 4: Hydrologic Characteristic Parameters 82

Table 5: Percentage of the Wolf River Basin Area of Each County 98

Table 6: Ratios from NRCS Dimensionless Unit Hydrograph and Mass Curve 102

Table 7: Calculated Lag time and the Time Concentration for Each Subbasin of Mary's Creek 106

Table 8: Calculated Time Base of Unit Hydrograph and Peak Discharge in for Each Subbasin of Mary's Creek 107

Table 9: Calculated 30-min Duration Unit Hydrograph for Subbasin No.1 for Mary's Creek 108

Table 10: Calculated Lag Time for All Subbasins of the Wolf River Basin 112

Table 11: Calculated Peak Discharge for All Subbasin of Wolf River Basin 113

Table 12: Calculated the Base Time of Snyder Synthetic Unit Hydrograph for all Major Subbasins of the Wolf River Basin 114

LIST OF FIGURES

Figure 1: Cities and Towns within the Wolf River Basin 5

Figure 2: Example of National Elevation Datasets (NED) 29

Figure 3: Project NED Data to the State of Tennessee Coordinate System 30

Figure 4: Select the Tennessee Coordinate System 31

Figure 5: Export Raster Data (ned_16054708) 32

Figure 6: Raster Data (dem_16054708) 32

Figure 7: “Fill” Dialog Box 33

Figure 8: “Flow Direction” Dialog Box 34

Figure 9: Output Flow Direction Grid 34

Figure 10: Flow Accumulation Dialog Box 35

Figure 11: Flow Accumulation Grids 36

Figure 12: Create a Pour Point on the “Flow Accumulation Grids” 37

Figure 13: Watershed Dialog Box 38

Figure 14: Wolf River Watershed 38

Figure 15: Raster to Polygon Dialog Box 39

Figure 16: Wolf River Shape File 39

Figure 17: The Grid of Wolf River DEM 40

Figure 18: Raster Calculator Dialog Box 42

Figure 19: Wolf River Basin Data with X, Y, and Z in feet 43

Figure 20: Fill Sinks Dialog Box 46

Figure 21: Raster Fill 46

Figure 22: Flow Direction Dialog Box 47

Figure 23: Flow Direction Grids 47

Figure 24: Flow Accumulation Dialog Box 48

Figure 25: Flow Accumulation Grids 48

Figure 26: Stream Definition Dialog Box 50

Figure 27: Stream Threshold Dialog Box 50

Figure 28: Stream Network 51

Figure 29: Stream Segmentation Dialog Box 51

Figure 30: Stream Segmentation Map 52

Figure 31: Catchment Delineation Dialog Box 52

Figure 32: Catchment Grids 53

Figure 33: Catchment Polygon Processing Dialog Box 53

Figure 34: Catchment Polygons 54

Figure 35: Drainage Line Processing Dialog Box 54

Figure 36: Drainage Lines 55

Figure 37: Adjoin Catchment Processing Dialog Box 56

Figure 38: Catchments 56

Figure 39: Start New Project Dialog Box 58

Figure 40: Define New Project Dialog Box 58

Figure 41: Start New Project Window 59

Figure 42: Mary’s Creek Outlet Drainage Point 59

Figure 43: Project Points Dialog Box 60

Figure 44: Data Management Dialog Box 61

Figure 45: Mary’s Creek Basin (Threshold of 1.295 square kilometers) 61

Figure 46: The Project Layers of Mary’s Creek 62

Figure 47: Mary’s Creek Subbasins Outline 63

Figure 48: Merge Two Adjacent Subbasin 64

Figure 49: River Merge 65

Figure 50: River Length Dialog Box 66

Figure 51: Attribute Table for the Stream Lengths of the Mary’s Creek Subbasin 67

Figure 52: River Slope Computation Dialog Box 67

Figure 53: Attribute Table for the Stream Lengths and Slopes within the Mary’s Creek Subbasin 68

Figure 54: Longest Flow Path Dialog Box 68

Figure 55: Longest Flow Path Map 69

Figure 56: Flow Path Parameters Dialog Box 69

Figure 57: Attribute Table of Longest Flow Path 70

Figure 58: Slope Dialog Box 70

Figure 59: Basin Slope Dialog Box 71

Figure 60: Mary’s Creek Basin Slope 71

Figure 61: Attributes of Subbasin_M1 72

Figure 62: Mary’s Creek Subbasin 73

Figure 63: Mary’s Creek Subbasin, Labeled 73

Figure 64: Centroid Computation Method Dialog Box 74

Figure 65: Basin Centroid Computation Dialog Box 74

Figure 66: Centroids of the Subbasins 75

Figure 67: Centroid Elevation Computation Dialog Box 75

Figure 68: Attribute Table of Centroid65412 76

Figure 69: Centroidal Longest Flow Path Computation Dialog Box 77

Figure 70: Centroidal Longest Flow Path Map 77

Figure 71: Centroidal Longest Flow Path Attribute Table 78

Figure 72: Hydrologic Characteristics of Mary’s Creek Subbasin 79

Figure 73: Mary’s Creek Subbasins Map 80

Figure 74: Legend for a Key Map and all the Subbasins Map 100

Figure 75: Key Map 100

Figure 75.A: Key Map 101

Figure 75.B: Key Map 102

Figure 75.C: Key Map 103

Figure 75.D: Key Map 104

Figure 75.E: Key Map 105

Figure 75.F: Key Map 106

Figure 75.G: Key Map 107

Figure 76: Unite hydrograph of subbasin No.1 of Mary’s Creek 116

CHAPTER 1

INTRODUCTION

In brief, hydrology is a science that studies the waters of the surface of the earth and its associated problems. These problems include challenges such as defining drainage basins and flood plains. Water, from its source, is transported from a high point to a low point along swells, ditches and creeks, and canals and lakes to the sea. When rain hits the earth, the water begins flowing from the highest elevation of the drainage basin to the lowest point of interest. As these movements occur in all directions to the lowest point, these movements create basins, subbasins, and stream networks. Each basin can have many subbasins, depending on the drainage networks inside the basin. A subbasin is the key hydrologic unit that is used in most hydrologic rainfall-runoff volume calculations. Runoff volume is the amount of water flowing on the surface of a subbasin during a rain event to an outlet or a drainage structure, such as a culvert or bridge opening. This volume or volumetric flow rate is dependent on many factors such as the size of the subbasin and the travel time, which is the time it takes a drop of water to flow from the highest point to the lowest point (the outlet of the subbasin). Many equations have been developed to calculate the travel time (time of concentration). Most travel time equations depend on the distance the water travels (longest flow path) and the slope of the longest flow path or the slope of the subbasin. Some of the equations need a distance from the centroid of the subbasin to the outlet (centroidal longest flow path) and the surface soil characteristics. All of these parameters are topographic characteristics of the subbasin. A resource to provide this type of information is needed in order to facilitate the analysis of flood plains and the design of storm water systems to prevent flooding.

Previously, most of the topographic characteristics had to be calculated by a manual method, which takes an unreasonable amount of time. The data had to be extracted manually from United States Geologic Survey (USGS) quad maps, and the hydrologic characteristics calculated by hand. As a consequence, the engineer would prepare only those characteristics needed for his basin of interest. Thus, the data obtained in this manner was disparate and never completely organized in a useful manner. The advent of Geographic Information System (GIS) software and the availability of the National Elevation Dataset (NED) have enabled this process to be automated, and all of the subbasins within the watershed can be processed. The NED can be downloaded from http://seamless.usgs.gov/website/seamless/viewr.htm.

In the current study, a Digital Elevation Model (DEM) of the Wolf River watershed was developed by extracting digital elevation data from the NED and then importing the data into a GIS. This was done using ArcView software. Then, Arc Hydro and Geospatial Hydrologic Modeling Extension Software (HEC-GeoHMS) were used to prepare a hydrological model and determine the hydrologic characteristics of the subbasins.

In the two years prior to the study, Memphis, Tennessee had suffered from flooding that had not reached such levels since the historic floods of the Mississippi River in the 1920s and 1930s. But not only has the Mississippi River seen record flood stages, but local rivers (e.g., Wolf River) have also flooded several times, creating a dangerous situation in Shelby County. This recent flooding, particularly of the Wolf River, suggests the need for a comprehensive hydrologic atlas of all subbasins of the Wolf River basin so that it is possible to design drainage networks more capable of handling the flood-producing runoffs. Such an atlas would incorporate the hydrologic characteristics or physical parameters provided by a DEM for both streams and subbasins.

The current study focuses on the preparation of an atlas that contains subbasin maps and hydrologic characteristics for the subbasins of the Wolf River basin. The data required to compile an atlas of these hydrologic characteristics can be extracted automatically using several computer programs embedded in GIS software, including ArcView, Arc Hydro, and the Geospatial Hydrologic Modeling Extension Software (HEC-GeoHMS). These programs are a coordinated system of graphical user interfaces (GUI) with a hierarchal system of commands that lets users extract various hydrologic features to characterize the watershed basins at a speed and accuracy heretofore never imagined. These packages will be discussed in detail in a subsequent section. Municipalities in the Wolf River basin area can use the findings of this study to design and analyze hydrologic infrastructure. In addition, the methodology presented in the current study can be used by other municipalities to create a hydrologic atlas for basins within their region.

Objective

The objective of this study was to prepare a hydrologic atlas that covers the entire Wolf River basin and its subbasins and includes the hydrologic characteristics of the identified creeks, unnamed tributaries, and subbasins for each. The following hydrologic characteristics were calculated for each stream and subbasin: (1) subbasin drainage area; (2) subbasin slope; (3) basin centroid and centroidal elevation; (4) longest flow path; (5) slope of longest flow path; (6) centroidal longest flow path; and (7) river length and slope.

The hydrologic characteristics of all of the identified creeks, unnamed tributaries, and subbasins for each creek in the Wolf River basin do not currently exist. Consequently, the development of an atlas that contains such information would be an invaluable source of information to municipalities and consultants in the design of storm water networks, the design of box culverts, the design of sanitary sewer systems and interceptors, the complete analysis of flood plains, the design of detention basins, and the development of a flood hydrograph for each subdivision.

Study Area

The Wolf River is approximately 91.54 miles long and drains an area of 814.48 square miles in western Tennessee and northern Mississippi. The Wolf River also contributes to the flow of the Mississippi River. According to the Tennessee Department of Environment and Conservation (TDEC) (2010), approximately 68.5% of the entire Wolf River watershed lies in Fayette County and Shelby County, both in Tennessee. The Wolf River rises from north of

Ashland, Mississippi, in Holly Springs National Forest at Bakers Pond in Benton County. As displayed in Figure 1, the Wolf River flows northwest into Tennessee and drains a large area in Memphis, Tennessee (Shelby County) before entering the Mississippi River near the northern part of Mud Island in Memphis. The cities and towns in Tennessee and Mississippi lying within the Wolf River basin are shown in Figure 1 and listed in Table 1 in the upstream direction, from source to downstream, along with their population (U.S. Census Bureau, 2000).

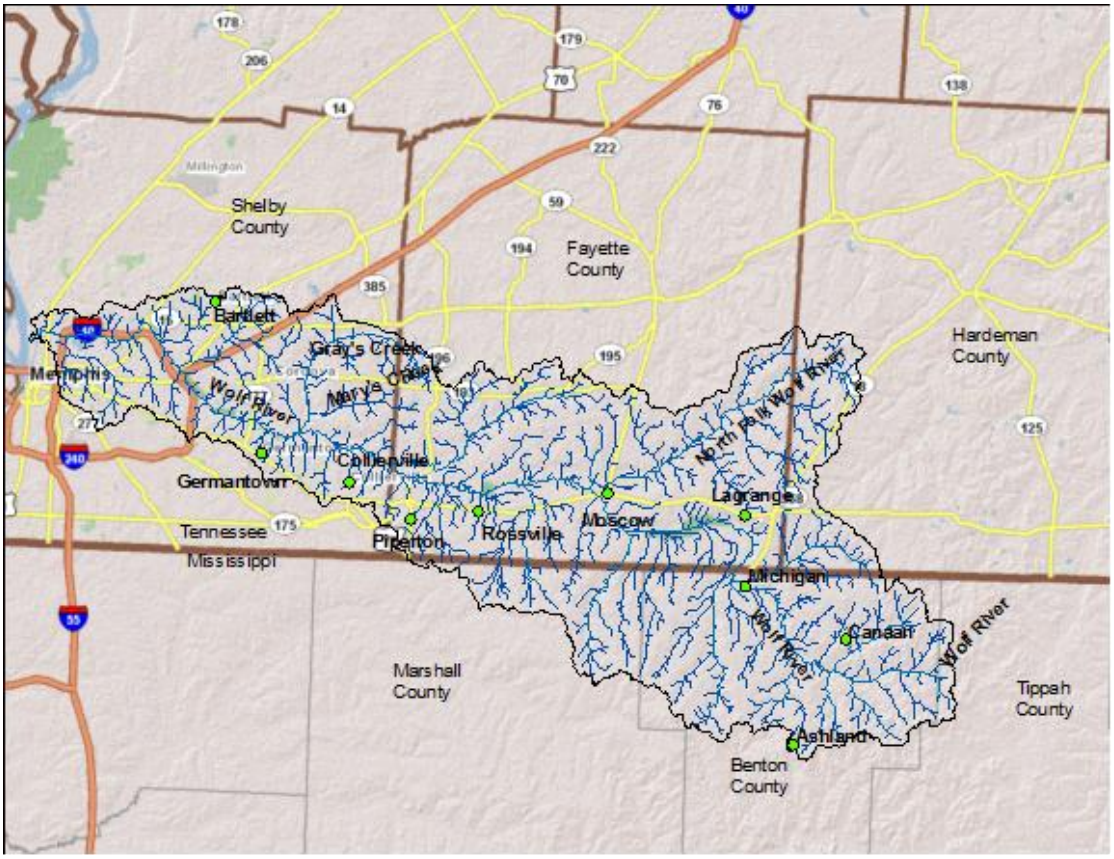


Figure 1. Cities and towns in the Wolf River basin area.

Table 1

Population of Cities/Towns in the Wolf River Basin in 2000

Name of City/Town	County	State	Population per 2000 Census (No. of People)
Ashland	Benton	Mississippi	577
Canaan	Benton	Mississippi	unincorporated
Michigan	Benton	Mississippi	unincorporated
LaGrange	Fayette	Tennessee	136
Moscow	Fayette	Tennessee	422
Rossville	Fayette	Tennessee	380
Piperton	Fayette	Tennessee	589
Collierville	Shelby	Tennessee	44,304
Germantown	Shelby	Tennessee	37,348
Bartlett	Shelby	Tennessee	40,543
Memphis	Shelby	Tennessee	670,100

The Wolf River Basin is divided between six counties, as shown in Figure 1. The largest portion of the Wolf River basin is in Fayette County, TN; most of this area is rural and undeveloped. The longest reach of the Wolf River is in Shelby County, within the city limits of Memphis, TN. Memphis is presently one of the largest municipalities in Tennessee. Almost the entire Wolf River drainage basin within the City of Memphis is on developed land. Approximately 15% of the Wolf River basin area is spread among Hardeman (TN), Marshall (MS), and Tippah (MS) counties. Almost all of the Wolf River basin area located in these three counties is made up of agricultural land or forest.

Many creeks contribute to the flow of the Wolf River (as shown in Appendices A and B). There are 48 identified creeks (see Table 2) (a map of these creeks is available at http://tnmap.tn.gov/wpc/) and approximately 167 unnamed tributaries flowing into the Wolf River in western Tennessee and northern Mississippi.

Table 2

Creeks Identified in the Wolf River Basin Area

Creeks South of Wolf River from Downstream to Upstream	
Cypress Creek (Shelby, TN)	Workhouse Bayou Creek
Harrison Creek	White Station Creek
Russell Creek	Morrison Creek
Grissum Creek	Sandy Branch of Grissum Creek
Teague Branch of Grissum Creek	Stout Creek of Grissum Creek
Golden Creek	Clear Creek
Early Grove Creek	Mount Tana Creek
Grays Creek (Benton, MS)	Chubby Creek
Tubby Creek	Cox Branch Creek of Tubby Creek
Indian Creek (Benton, MS)	Turkey Creek
Goose Creek	Wolf Creek
Sourwood Creek	
Creeks North of Wolf River from Downstream to Upstream	
Harrington Creek	Fletcher Creek
Gray’s Creek (Shelby, TN)	Field Creek
Mary’s Creek	Johnson Creek
Shaws Creek	Alexander Creek
Hurricane Creek	Stafford Creek
Indian Creek (Hardman, TN)	Sandy Branch of Indian Creek
Mody Branch of Indian Creek	Blind Tiger Creek
Cypress Branch (Benton, MS)	Grogg Creek
Miller Branch of Grogg Creek	Hood Branch of Grogg Creek
Wesley Branch of Grogg Creek	
North Fork of the Wolf River	
Hargis Branch	Watkins Creek
Shepard Creek	May Creek
McKinnie Creek	Beasley Creek

Software Used

ArcGIS, the Arc Hydro tool, and the HEC-GeoHMS software were used to delineate subbasins and determine the hydrologic characteristics within the Wolf River basin from the DEM. A Geographic Information System (GIS) is computer software used to manipulate, accumulate, analyze, and present data with respect to geographic location. The GIS software provides a method to delineate a drainage basin and a stream network by using DEMs of land surface terrain. ArcGIS, a computer program consisting of a set of GIS software products created by the Environmental Systems Research Institute (ESRI), has a data preprocessor to prepare input data for water resources and is a suitable tool for assembling water resources data. The GIS software components, ArcView, ArcEditor, and ArcInfo, allow one to edit, integrate, and analyze the geographic data. Several subcomponents of the ArcView software that are useful for delineating watersheds and determining the hydrologic characteristics of streams and subbasins are ArcMap, ArcCatalog, and ArcToolbox.

Arc Hydro is a geospatial data structure for water resources that operates within ArcGIS. Arc Hydro connects hydrologic information to the water resource data framework and assists in the building of data sets that can be integrated with the water resources data system. Arc Hydro data are complemented by a set of tools for building and running the data model and supporting water resources analysis. The ArcGIS and Arc Hydro tools are ultimately used to delineate watersheds from the DEMs.

The application software used to gather hydrologic characteristics for this study, the HEC-GeoHMS software package, was developed by the Hydraulic Engineering Center (HEC). It is used to predict stream flow in each subbasin. The software package consists of two components: (1) the HEC-GeoHMS preprocessing software, which is an extension for ArcView, and (2) the HEC-HMS (Hydrologic Modeling System) software, which is a stand-alone program that models runoff as a result of a design storm or precipitation event. The HEC-GeoHMS software processes the geometry of the basin to develop the majority of the input parameters for the HEC-HMS software. Since the analysis in this research project is based on a GIS, it was recommended to use GeoHMS, which is the most efficient method for assessing basins of this size (U.S. Army Corps of Engineers, 2009). All components of the atlas of the Wolf River basin, such as basin and subbasin maps and hydrologic characteristics of subbasins and streams, were developed using the abovementioned software.

Organization of Thesis

The remainder of the thesis is organized in the following manner. Chapter 2 reviews pertinent literature which explains the data and the software used to determine the hydrologic characteristics, the hydrologic modeling, and the derivation of the subbasin characteristics. Chapter 3 explains the basic steps taken to delineate the DEM of the Wolf River basin. A comprehensive example will explain how to delineate a watershed and obtain hydrologic characteristics. Chapter 4 will explain the hydrologic characteristic of a stream and subbasin. Chapter 5 will present the results and conclusions. The appendices comprise the hydrologic atlas in the form of tabulated hydrologic characteristics and maps for each subbasin in the Wolf River basin area.

CHAPTER 2

LITERATURE REVIEW

This chapter presents of a review of the literature pertaining to hydrologic modeling and the derivation of subbasin characteristics; the National Elevation Dataset (NED), which contains the Digital Elevation Model (DEM); the ArcGIS software and the Arc Hydro tool; and the Geospatial Hydrologic Modeling System (HEC-GeoHMS), which was used to compute the hydrologic parameters of the streams and subbasins.

Hydrology Modeling and Subbasin Characteristics Derivation

Beginning in the mid-1970s, the Hydrologic Engineering Center (HEC) started to develop software for hydrologic and flood damage calculations. The present developments build on those early experiences and contain the technology from several useful engineering products, including the HEC-GeoHMS) addition. With HEC-GeoHMS, users are able to extract hydrologic parameters of watersheds from DEMs. Merwade (2010) explained how an input file for hydrologic modeling with HEC-GeoHMS and ArcGIS were produced. He further stated the basic function of HEC-GeoHMS and showed how the HEC-GeoHMS project and hydrologic characteristics of streams and subbasins were prepared.

Dunn, C. N., Ackerman, C. T., Doan, J., and Evans, T. (2000) discuss their development of hydrologic models for the Sacramento and San Joaquin River basins. Their study was supported by the U.S. House of Representatives in 1998 to develop complete plans for flood control and hydrologic models of those river systems. The watershed of the two rivers studied was approximately 60,000 square miles. The DEM data they used were downloaded from the USGS website (www.usgs.gov). ArcView, along with the Spatial Analyst and GeoHMS tools, was used to determine the complete drainage basin, divide the basin into subbasins and subsequently define the stream networks. The HEC used GeoHMS to determine many of the physical parameters, such as length of longest flow path, length of flow path from subbasin centroid, elevation of subbasin centroid, subbasin area, slope of longest flow path, and subbasin slope. This hydrologic information was needed as input data to HEC-GeoHMS and to build the hydrologic models.

Fang, X., Thompson, D. B., Cleveland, T. G., Pradhan, P., and Malla, R. (2008) sought to estimate the time of concentration for 96 Texas watersheds using 5 empirical equations to extract watershed characteristics: the Williams, Kirpich, Johnstone-Cross, Haktanir-Sezen, and Simas-Hawkins methods. The watershed areas were approximately 0.88–440.3 km^2. Three different methods were used to extract watershed characteristics: an automated method using DEMs and GIS software, a manual method with watershed delineation, and a manual method without watershed delineation. The purpose of their study was to compare watershed parameters obtained by the three different methods. It was concluded that the manual and automated methods produced watershed characteristics that were qualitatively similar, but the differences between them were statistically significant. Manual and automatic procedures for calculating watershed characteristics may yield slightly different results when considering different minor sources of error and uncertainty. Furthermore, the Kirpich and Haktanir-Sezen methods were shown to dependable estimates of mean values of time of concentration.

Bozdag and Gocmez (2010) examined the Cihanbeyli subbasin of the Salt Basin in Turkey to determine water flow direction. In this study, a DEM was used to calculate the drainage networks parameters of which size, length, and slope of the subbasin were found to be the most useful topographic parameters for the hydrologic analysis. Also, Garbrecht and Martz (2000) analyzed the availability, quality, and resolution of a DEM and extracted topographic data from a DEM by GIS. Their research covered automated extraction of drainage networks and calculation of subbasins. The elevation data used in their study were derived from existing contour maps, digitized elevations, and aerial photographs. The USGS 7.5-minute DEM data used in their study have a grid spacing of 30 meters, which is the same as for the USGS 7.5-minute map series quadrangle. Garbrecht and Martz (2000) concluded that DEM quality and resolution were consistent with the scale of the application and of the processes that were modeled, the size of the basin, the type of watershed process (physical, empirical, etc.), and their assumptions. The USGS 30 x 30 meter DEM data has high accuracy standards rather than coarse resolution. It was shown that the DEM can be used in a GIS to calculate the channel network, channel length and slope, and subbasin physical properties. The automated calculation of such hydrologic characteristics from the DEM was demonstrated to be faster and more capable of reproducing measurements than traditional manual estimation.

Kost and Kelly (2001) used the NED to delineate watersheds and subwatersheds. Their research led some states and local agencies to recognize that the currently accessible hydrologic units were inadequate for many purposes. In turn, agencies such as the U.S. Geological Survey and the Natural Resource Conservation Service (NRCS) realized the need for more detailed watershed delineation data and information than currently existed. For this reason, the NED was prepared from distinct 7.5-minute DEMs by USGS. The NED contains the best available elevation data compiled into a seamless database for the entire US and can be used along with the ArcView tool. The projection of the NED was developed with a one arc-second cell size, which is about 30 meters.

The Geographic Information System

A drainage basin map and topographic characteristics can be automatically delineated using a GIS. Traditionally, hydrologic practitioners manually produced a number of maps, imageries, a stream network, and other data from field surveys to conduct catchment delineation. Hydrologic parameters are then derived manually from this data. These techniques are tedious, expensive, time-consuming, and subject to considerable operational variance. Furthermore, Elsheikh and Guercio (1997) stated that watershed delineation has largely been achieved by hand delineation. But lately, this has been accomplished by the GIS systems. According to Islam (n.d.), GIS tools are being extensively used for the delineation of watersheds and stream networks, and the use of DEMs allows for more accurate watershed delineation.

Maidment (2002) stated that GIS is a useful tool for water resource researchers and provides a reliable method to delineate the watershed and stream network of a drainage basin. The Arc Hydro tool is a geospatial dataset that is embedded in ArcGIS and has a set of tools that support hydrologic analysis. However, only a surface water system can be described by the Arc Hydro tool. This does not include constructed water pipe systems such as the water supply network, the sanitary sewer system, or the storm water network. The Arc Hydro framework can be applied to the existing digitized streams, watershed boundaries, and water bodies. Arc Hydro data can be assembled by using aerial photogrammetry to recognize vector features such as buildings, roads, and streams. The city of Austin, TX, digitized the drainage networks and all the area draining through the city based on interpretation of aerial photogrammetry (Maidment, 2002). This network is joined with a drainage area extracted from the NED to analyze water quality over the entire city.

Merkel, Kaushika, and Gorman (2008) suggest that GIS has increasingly been employed to assist hydrologists in delineating watersheds and extracting hydrologic characteristics of subbasins. Lacroix et al. (2002) found that the automatic derivation of watersheds is faster, less costly, and more reproducible than traditional manual techniques. Using GIS for hydrologic modeling has an advantage over manual methods and provides a higher degree of accuracy, flexibility, and the ability to carry out complex analyses.

Hahm, Park, and Yun (2010) found that a GIS can be used to extract various hydrologic features from the DEM. The important tasks for hydrologic analysis are the delineation of the watershed, the geometric characteristics of the watershed, and the stream networks. These are automated by using the functions of the ArcInfo software as a GIS package.

Bolstad (2002) indicated that a GIS provides users from a variety of backgrounds and professions both utility and convenience in the analysis of spatial information. This GIS spatial information is available in a variety of data models, and DEMs are one such spatial data model. A DEM gives a topographical representation of the earth’s surface. In addition, DEMs offer both a valuable and versatile tool for application in many disciplines that utilize GIS. These disciplines include flood modeling, resource management, shoreline delineation, hydrologic delineation, transportation and utility applications, seismic monitoring, and geologic applications.

Eash (1994) applied a GIS to quantify drainage basin characteristics for an Iowa flood-estimation study. This study was focused on a basin characteristics system. The conclusion of this study (Eash, 1994) was that improved accuracy in quantifying drainage basin characteristics using GIS is predictable with the availability of 1:24,000 scale digital cartographic data. Additionally, Vogt, Colombo, and Bertolo (2003) presented a new method to obtain river networks and subbasins over an unlimited area. The derivation of the landscape drainage density index, critical contributing area, and the basin extraction and channel network connection was described. Vogt et al. (2003) determined that it is possible to extract drainage networks and catchments with good accuracy from DEMs with a medium spatial resolution.

Digital Elevation Models in Hydrology

In recent years, Wu, Li, and Huang (2008) explained that DEMs have been widely applied to efficiently extract hydrologic characteristics used in hydrologic modeling such as the area, slope, centroid of a subbasin, longest flow path, slope of longest flow path, and centroidal longest flow path of a subbasin. Maidment (2002) stated that the value of the DEM in hydrologic applications is increasing. Dinesh (2008) concluded that with an accurate version of a plane, hydrologic characteristics can be extracted from that plane. Hydrologic parameters generated from DEM include drainage channel networks, stream characteristics, and watershed. These hydrologic features are readily created from DEM data through a diversity of software. Hoffman and Winde (2010) explained that the value of the DEM derivative features varies depending upon the intention and use of the data. Hydrologic data is often used to calculate runoff volume. Runoff modeling is helpful in calculating the course of water flow or flood of the landscape. Flooding, whether inland or along a coastline, in the case of a tsunami or severe storm, can be modeled with DEM data. The data from a DEM are a component in the set-up and building of nearly all types of physical parameters of surfaces. The service of DEMs in hydrologic modeling is increasing world-wide coverage with the accessibility of more accurate and higher resolution DEMs.

Garbrecht and Martz (2000) stated that DEMs provide excellent and useful information to determine the physical characteristics of drainage networks and the hydrologic characteristics of basins and subbasins. Whether a DEM provides a reasonable representation of surface elevation varies depending upon the user's purpose and needs. Both resolution and accuracy verify whether or not the dataset is adequate. Accuracy in relation to a DEM is evaluated based on how closely the modeled value approaches the actual surface value. Accuracy is measured along both horizontal and vertical axes. The effect of DEM data accuracy on the extraction of a basin's physical parameters (e.g., slope) has been studied by Zhou and Liu (2004). The slope error is connected to the DEM data accuracy. The uncertainty may occur during the creation of the DEM data, e.g., data capture, sampling, and interpolation. Zhou and Liu (2004) concluded that higher resolution DEM did not assure higher slope and aspect accuracy. Better results may only be possible with higher DEM data accuracy. In reality, where DEM data often contains errors, the accuracy of derived slope and aspect is increasing with lower DEM resolution.

Li and Wong (2009) studied the effect of a DEM's sources on hydrologic uses and selected three different DEMs with different resolution, such as the USGS NED with 10- and 30-meter resolution, a DEM of Shuttle Radar Topography Mission (SRTM) data, and Light Detection and Ranging (LIDAR) data. These DEMs were used to derive river network and flood simulations using the Arc Hydro tool with ArcGIS 9.2. In their study, the threshold value of approximately 0.36 km^2 was used to determine the river networks because this value was the most appropriate for the network extraction procedure built upon the resultant *t* statistic. It was concluded that the 10-meter NED has the best performance and the 30-meter NED outperformed most data sources at all cell sizes.

Vertical Accuracy of USGS NED (30-Meter DEM)

The NED, derived from various sources of DEMs, was created using several different methods. The NED 1-arc second is a 30-meter grid. Vertical NED accuracy is calculated as a root mean square error (RMSE) between elevations in the DEM and dependable true elevations from the available maps. It is determined by equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum (Z_i - Z_t)^2}{n}}$$

where Z_i is the interpolated DEM elevation of a test point, Z_t is the true elevation of a test point, and n is the number of test points (USGS, 2011). The NED vertical accuracy was tested several times (e.g., September 1999, October 2001, October 2002, June 2003), and the RMSE values were 3.74, 3.13, 2.7, and 2.44 meters, respectively. The absolute vertical accuracy, which is a measure of the combined regular and random errors of the DEM, changed every time because the NED was updated periodically by the USGS. Another measure used to estimate the error of the NED is called the relative vertical accuracy, which is a measure of the accuracy of slope. To calculate the relative vertical accuracy, assume the area is flat, and then determine the maximum measurement of error among the cells. The uncertainty of elevation is measured at 1.64 meters, and the estimated average is slope 2.73%. The 30-meter DEM, published in June 2003, was more accurate than previous versions because it was a more recent version. Erskine, R. H., Green, T. R., Ramirez, J. A., and Macdonald, L. H.

(2007) measured the uncertainty of the 30-meter DEMs of 2 agricultural farms in northeastern Colorado. The RMSE values were 0.58 meters and 1.49 meters. The NED error in elevation is related to the accuracy of the data sources and the method of data collection. The vertical accuracy has been improved because the NED is periodically upgraded.

Threshold Area

A major component that affects stream length and subbasin delineation is threshold area. A threshold drainage area is a parameter that a user specifies to place a delineation limitation on a stream network interpreted from a DEM. It is the smallest gathering area that drains into a given stream network. A small value of drainage threshold will produce a more complete stream network with extra tributaries (i.e., the smaller the delineation limitation on the drainage area, the more definition on the stream network and the more dense and refined are the streams). Stepinski and Collier (2004) reported that the total length of stream networks decreases with increasing drainage threshold. Hao, Li, and Wang, (2008) found that as the drainage threshold increases, the calculated outflow of the basins becomes slower, the peak discharge of the flood decreases, and the basin’s mean time of concentration becomes longer.

Qiu, Wu, and Yan (2010) explained that the Federal Emergency Management Agency’s (FEMA) Hazus flood modeling program can be sensitive to changing the drainage threshold. The optimal drainage threshold area was reported to be two square miles, while the maximum drainage size is a local county. Elsheikh and Guercio (1997) found that a threshold area of 0.036

km^2–0.054 km^2 (0.0139 mi^2- 0.0209 mi^2) for the 30-meter DEM was the most suitable threshold area for stream network extraction.

In this thesis, a threshold area of two square miles was used as the basis to generate the first set of basins in the Wolf River watershed. Subsequent thresholds of ½ mi^2 and ¼ mi^2 were used to further refine the stream network and provide more detail to the subbasins.

CHAPTER 3

METHODOLOGY

This chapter describes the methods employed in the current study. A logical sequence is followed, starting from downloading the National Elevation Dataset (NED) and moving to the extraction of hydrologic characteristics of streams and subbasins within the Wolf River basin area.

ArcGIS software, widely used in the US for comprehensive floodplain analysis, delineating watersheds, and preparing hydrologic models, was used in the current study. Arc Hydro tools and the HEC-GeoHMS software embedded in the ArcGIS software were used to obtain delineations. Various processes required to develop watersheds and extract hydrologic characteristics (physical parameters) such as terrain preprocessing, preparing a GeoHMS project, basin processing, and extracting physical parameters of streams and subbasins, are described in this chapter. Two examples are prepared to explain delineations step-by-step: the first example is to extract a 30-meter DEM of the Wolf River basin from the NED, and the second example is to determine the hydrologic characteristics of subbasins and streams within the Wolf River basin area from the DEM. The methods used in the current study are an alternative to the manual method for developing the watershed characteristics and for extracting physical parameters of streams and subbasins.

Data

In the US, the most extensively available DEMs are those published by the USGS as the NED and are formed using elevation data derived from existing contour maps, digitized elevations, and photogrammetric stereo-models that are dependent on aerial photographs and satellite remote-sensing images (Garbrecht & Martz, 2000). A typical USGS 7.5-minute map series quadrangle was used to delineate watershed and extract hydrologic characteristics. Sorensen and Seibert (2007) explained that the maximum-resolution DEM is not always the most valuable. The best resolution should correspond to the significant topographic features; using a resolution of better quality might actually deteriorate rather than improve associations with topographic indices.

Numerous products exist to obtain DEM raster product data; however, for purposes of the current study, the USGS NED 1-arc-second product (approximately a 30-meter grid) for the conterminous US was ultimately chosen. The NED contains high quality 30-meter DEM data and includes grid topographic information that represents the elevation of the midpoints of regularly spaced grid cells with 30-meter horizontal resolution. The NED uses a geographic coordinate system based on decimal degrees and projected to the North American Datum 1983 (NAD83). The NED is an elevation layer of the national map and presents basic elevation data for earth science studies in the US. All elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88), and are in meters. The NED is published by the USGS, is free to download, and is available online (http://seamless.usgs.gov/).

Procedure

The software used in the current study was ArcView GIS 9.3 with the Arc Hydro tool and the HEC-GeoHMS extension. ArcView is well-known and widely used GIS software. The Arc Hydro tool was used to delineate the watershed and hydrologic characteristics. The HEC-GeoHMS software package, developed by the US Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC), was used to predict stream flow in each subbasin. (Software available on the USACE website at http://www.hec.usace.army.mil/software/hec-geohms.) The HEC-GeoHMS is a framework designed to study large drainage basins, flood plains, and reservoir spillways. It prepares different models to solve the problems of urban or natural watershed runoff. The HEC-GeoHMS calculates the hydrologic properties of a watershed. This study is a GIS–detailed analysis, so the GeoHMS approach is an effective method to calculate the hydrologic characteristics of the Wolf River basin. The method used in this study is the same method used in user manual 4.2 of HEC-GeoHMS 9.3. To determine the hydrologic parameters of a subbasin the following processes were required: (1) terrain preprocessing, (2) preparation of a GeoHMS project, (3) basin processing, and (4) extraction of basin characteristics and parameters.

Terrain preprocessing. Terrain preprocessing uses a DEM to recognize the surface drainage and prepare the raster dataset for watershed delineation. The preprocessing function partitions the terrain into convenient units and is used to expedite watershed delineation operations. ArcGIS raster operations are involved in watershed delineation, based on the principle that water flows downhill. In a DEM grid structure, each cell has eight adjacent cells. Water in a single cell can flow to one or more of its eight adjacent cells according to the slopes of the drainage paths in each direction. This concept is called the 8-

direction pour point model and is used to calculate the flow path in each cell. The ArcGIS allows water from a given cell to flow into only one adjacent cell along the direction of steepest descent.

The terrain model is used as an input file and produces nine additional datasets. Six of these datasets are in a grid mode and are the fill sinks, flow direction, flow accumulation, stream definition, stream segments, and catchment grid. The other two datasets are created in vector layers that represent the watershed and streams, such as catchment polygon processing and drainage line processing. The last dataset, the aggregated watersheds, is adjoint catchments that are used primarily to improve the performance in watershed delineation. The following are the definitions of each of the datasets that are mentioned above and the necessary steps in the terrain preprocessing (For more information, visit http://www.ce.utexas.edu/prof/maidment/gishydro/ferdi/research/agree/agree.html).

1. Fill sinks: The fill sinks function is a process used to modify the elevation value of a cell that is surrounded by higher elevation cells.
2. Flow direction: Water flows from high points to low points. The DEM consists of, at most, eight cells adjacent to each other. The flow direction function computes the elevation values of the cells and indicates the direction of the steepest decent.

3. Flow accumulation: This function calculates the number of upstream slope cells. Flow accumulation is used to create a drainage network, based on the direction of flow of each cell.
4. Stream definition: This function calculates a stream grid and has a value of "1" for all the cells in the input flow accumulation that have a value greater than the specified threshold. All other cells in the stream grid have no data. There is no ultimate rule for calculating the stream definition threshold input. The stream threshold area that is suitable to generate realistic ground drainage networks is chosen. A stream threshold area value that is too large does not represent all possible streams. A stream threshold area that is too small illustrates several small tributaries that may be sustained by the topography but do not exist on the ground.
5. Stream segmentation: This tool generates a grid of stream segments that have a single identification. Each may be a start segment, or it may be defined as a piece between two segment junctions. All the cells in an exacting segment have a grid code that is specific to that segment.
6. Catchment Grid Delineation: This function produces a grid in which each cell takes a value (grid code) representing the catchment to which a cell belongs. The value relates to the value carried by the stream segment that drains that area, defined in the stream segment link grid.
7. Catchment polygon processing: This function transforms a catchment grid into a catchment polygon feature class.

8. Drainage line processing: This function transforms the input stream link grid into a drainage line feature class.
9. Adjoint catchment processing: This function creates the cumulative upstream catchments from the "Catchment" feature class. Then, each catchment that is not a head catchment has a polygon representing the whole upstream area seeping into its inlet point that is created and kept in a feature class that has an "Adjoint Catchment" tag. This process is used to speed up the point delineation procedure.

Prepare a GeoHMS project. HEC-GeoHMS software converts the drainage streams and basin boundaries into a hydrologic data structure that represents the watershed. In order to prepare the HEC-GeoHMS basin model, a GeoHMS Project must be prepared according to an outlet point and drainage area. It allows the use of different threshold areas to delineate the subbasins and stream networks.

Basin processing. Basin processing revises the subbasin delineations by merging multiple small subbasins into one large subbasin and merging multiple stream segments into one segment after merging multiple subbasins. This process is accomplished with tools in the basin processing menu.

Extract basin characteristics and parameters. The last process is extracting basin characteristics. The basin characteristics menu in the HEC-GeoHMS project view provides tools for extracting hydrologic characteristics of streams and subbasins, e.g., river length, river slope, basin slope, longest flow path, centroid of subbasin, centroidal elevation, and centroidal flow path. All of the aforementioned steps must be completed in sequential order to obtain the hydrologic characteristics of a subbasin and a stream.

Example: Extracting the Digital Elevation Model of the Wolf River Basin

The Arc Hydro tool in ArcGIS was used to extract the DEM of the Wolf River basin. The following sequenced steps were used to extract the DEM of the Wolf River basin from the NED data that was downloaded from http://seamless.usgs.gov. Since it is necessary to generate fill, flow direction, and flow accumulation and to create a pour point, the Spatial Analyst tool from the Arc toolbox was used to delineate the watershed.

The first step to extract a DEM of the Wolf River basin from the NED is to open a new empty ArcMap file. Next, load the NED data that were downloaded earlier to the ArcMap as illustrated in Figure 2. The file will be named and saved and projected to the state plane coordinate system (NAD_1983_State Plane_ Tennessee _FIPS_4100_Feet). Using the Spatial Analyst tool of the Arc toolbox menu in the Arc Hydro tool involves a series of steps. These steps pertain to (1) fill, (2) flow direction, and (3) flow accumulation. The next step is creating a “pour point,” which is a point feature placed at the intersection of the Wolf River and the Mississippi River. The following steps are required to produce the outline of a watershed: (1) Use the Watershed tool in the Hydrology menu of the Spatial Analyst tool to generate the watershed. (2) Convert the watershed into a shape file. (3) Extract the Wolf River DEM by using the Mask tool in the Extraction tool menu of the Arc toolbox. (4) Export the raster data of the Wolf River DEM to set up the grid; data for *X* and *Y* are in feet, and *Z* (elevation) units are in meters.

This DEM was used for the entire study with the exception of Mary's Creek basin. The Mary's Creek subbasins were created by the same DEM, but since this was the last example prepared, the DEM units, *X*, *Y*, and *Z* (elevation), were converted to feet.

The new raster data layer (DEM) was used as a base raster data to prepare the GeoHMS project, extract the hydrologic characteristics (physical parameters), and generate a subbasins map. The following steps were implemented to extract the Wolf River DEM. First, load the NED data to the ArcMap as illustrated in Figure 2 and project it onto the state plane coordinate system (NAD_1983 _ State Plane _ Tennessee _FIPS_4100_Feet) as shown in Figures 3 and 4.

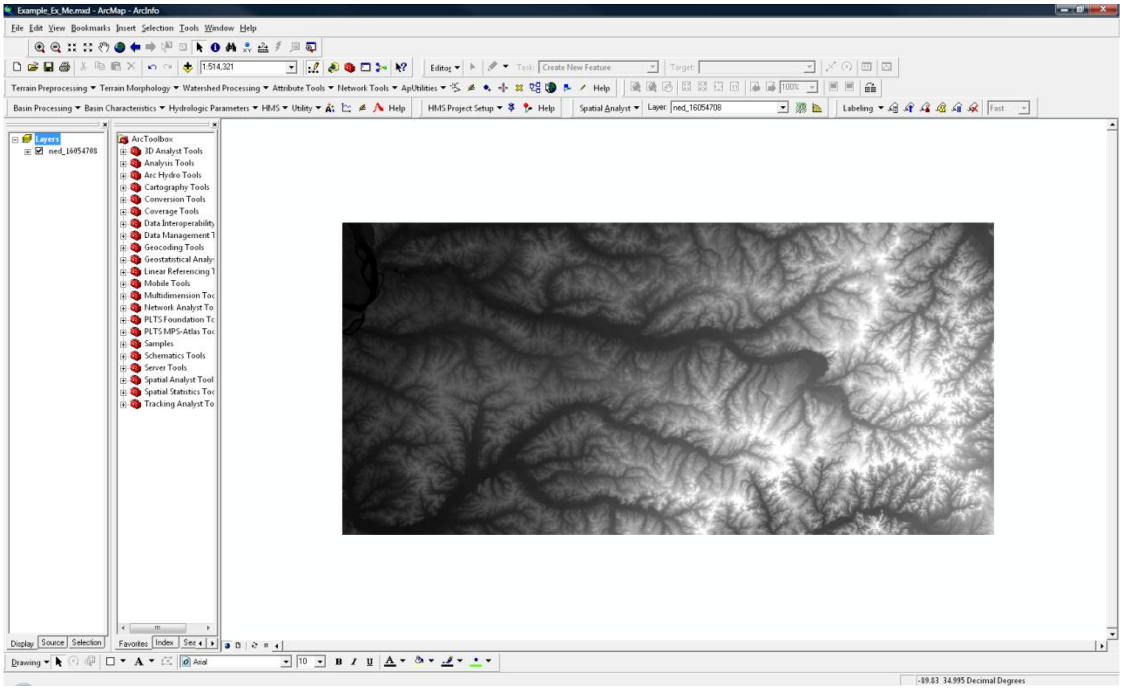
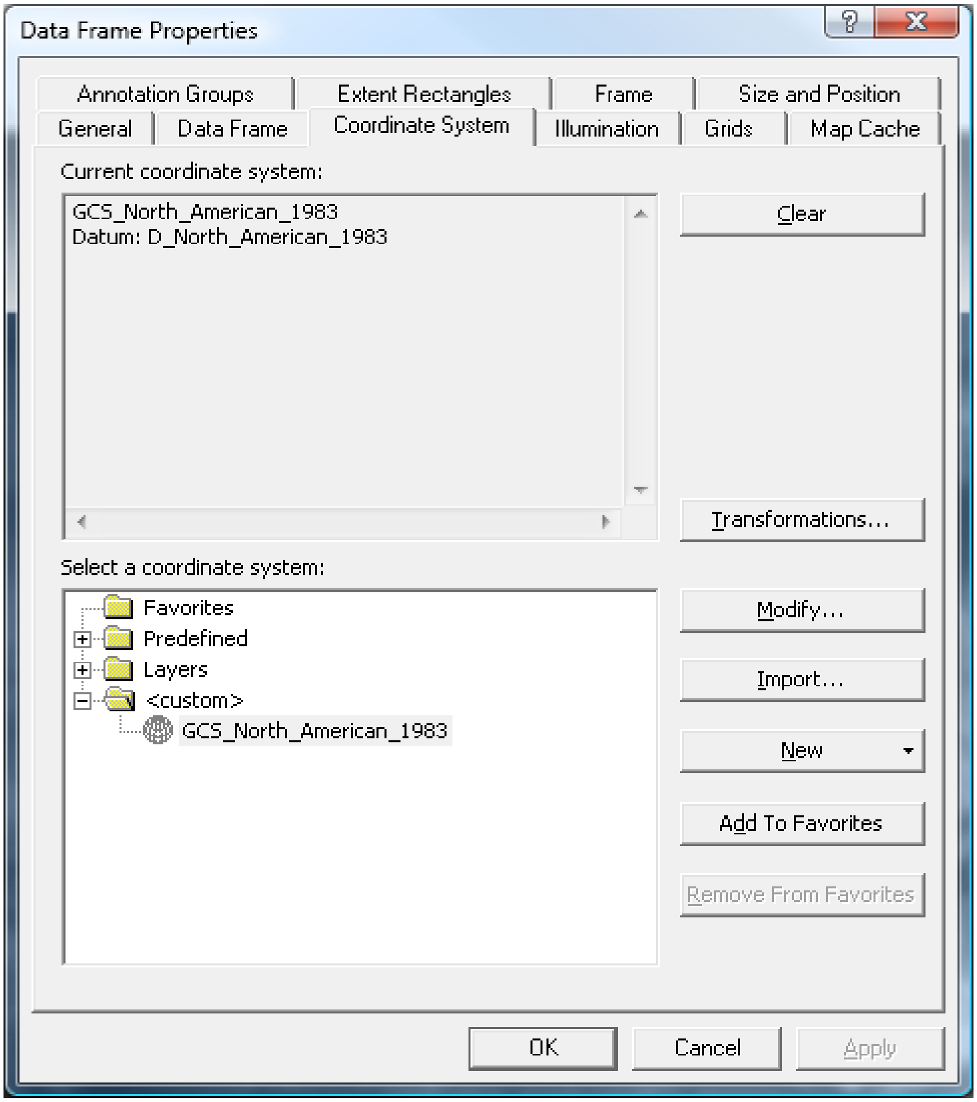


Figure 2. Example of National Elevation Datasets (NED).

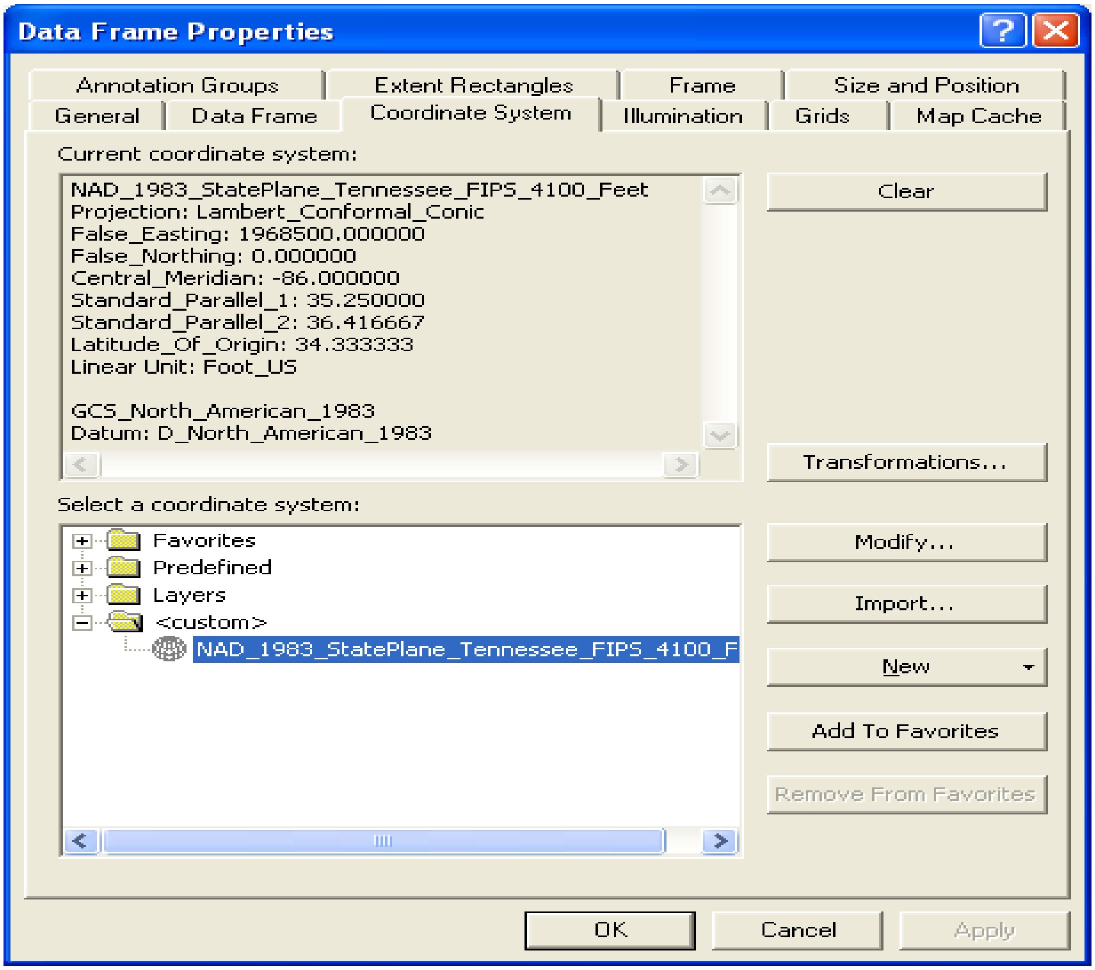


Current coordinate system:

GCS_North_American_1983
Datum: D_North_American_1983

Select a coordinate system: GCS_North_American_1983

Figure 3. Project NED data to the State of Tennessee Coordinate System.



Current coordinate system:

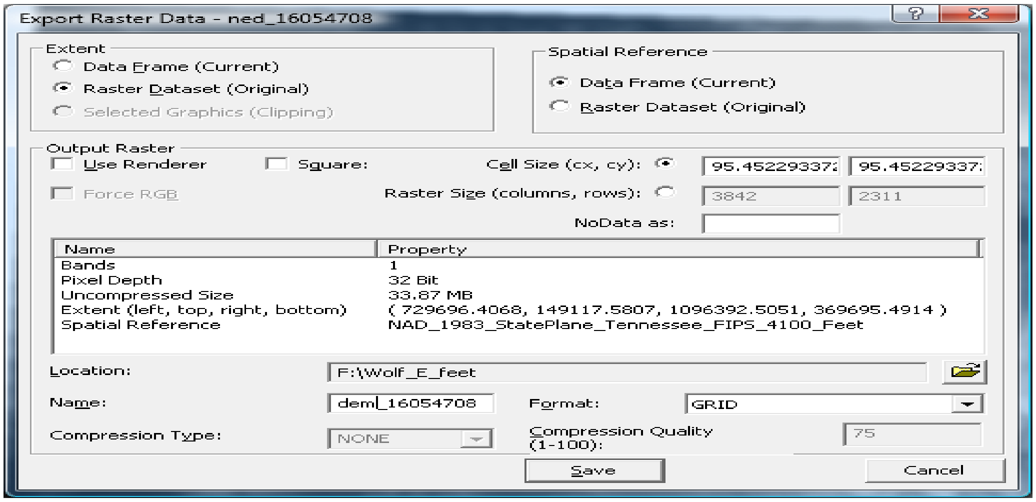
```
NAD_1983_StatePlane_Tennessee_FIPS_4100_Feet
Projection: Lambert_Conformal_Conic
False_Easting: 1968500.000000
False_Northing: 0.000000
Central_Meridian: -86.000000
Standard_Parallel_1: 35.250000
Standard_Parallel_2: 36.416667
Latitude_Of_Origin: 34.333333
Linear Unit: Foot_US

GCS_North_American_1983
Datum: D_North_American_1983
```

Select a coordinate system:

- Favorites
- Predefined
- Layers
- <custom>
  - NAD_1983_StatePlane_Tennessee_FIPS_4100_F

Figure 4. Select the Tennessee Coordinate System.

Grid definition. From the layer list, right-click the layer “Ned_16054708”, then click “data export”. The window editor appears, as shown in Figure 5. Select the data frame from the spatial reference box, the cell size from the output raster box, and the grid from the format menu. Give the name and location of ”dem_16054708” to the new file; click the “Save” button. In the DEM file, “dem_16054708”, *x* and *y* are in feet, but the elevation, *z*, is in meters and will appear as shown in Figure 6.



Export Raster Data - ned_16054708

Extent
○ Data Frame (Current)
● Raster Dataset (Original)
○ Selected Graphics (Clipping)

Spatial Reference
● Data Frame (Current)
○ Raster Dataset (Original)

Output Raster
☐ Use Renderer ☐ Square: Cell Size (cx, cy): ● 95.45229337 95.45229337
☐ Force RGB Raster Size (columns, rows): ○ 3842 2311
NoData as:

Name	Property
Bands	1
Pixel Depth	32 Bit
Uncompressed Size	33.87 MB
Extent (left, top, right, bottom)	(729696.4068, 149117.5807, 1096392.5051, 369695.4914)
Spatial Reference	NAD_1983_StatePlane_Tennessee_FIPS_4100_Feet

Location: F:\Wolf_E_feet
Name: dem_16054708
Format: GRID
Compression Type: NONE
Compression Quality (1-100): 75

Figure 5. Export raster data (ned_16054708).

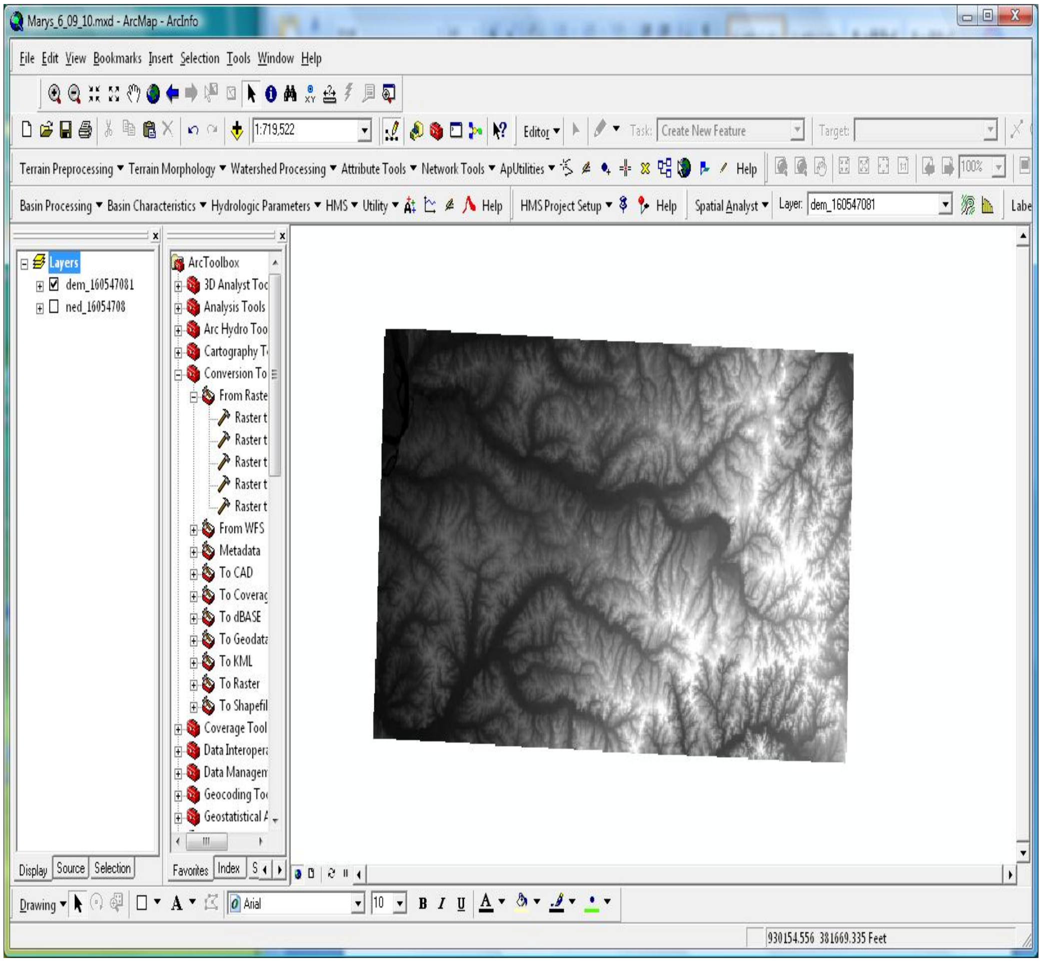
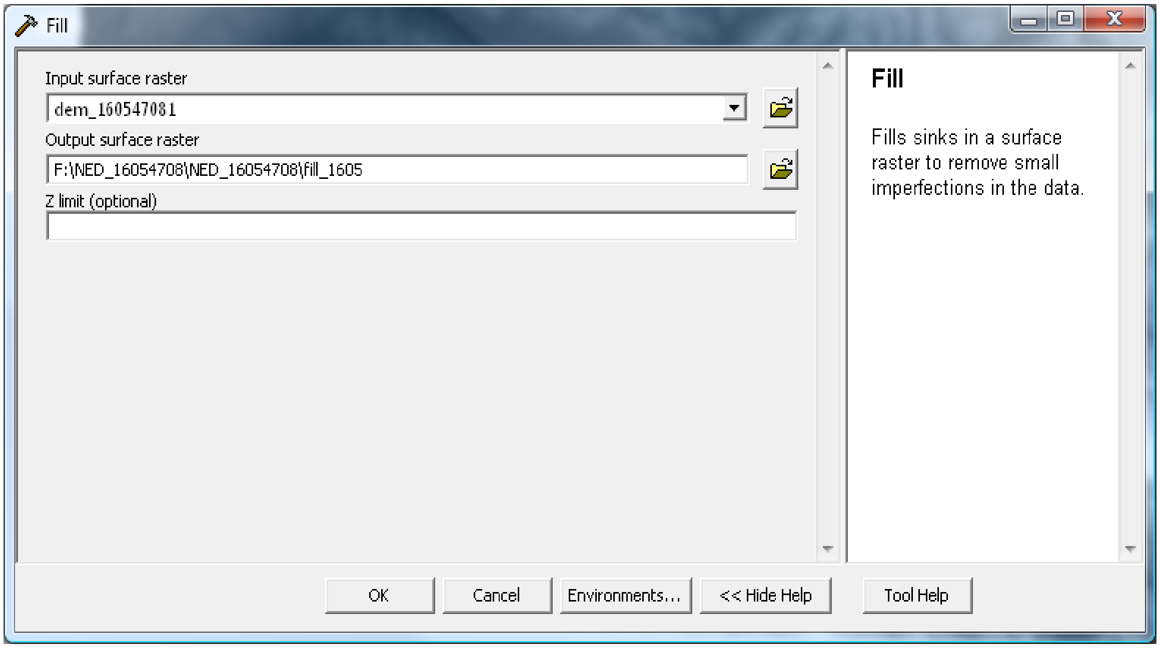


Figure 6. Raster data (dem_16054708).

Delineate the Wolf River watershed. To delineate the Wolf River watershed from the DEM data, it is necessary to generate the fill, flow direction, and flow accumulation and to create a pour point. Use the Spatial Analyst tool from Arc toolbox to delineate the watershed. The procedures that follow are used to extract the Wolf River watershed from the DEM:

1. Fill: Select “Fill” from the Hydrology menu of the Spatial Analyst tool in the Arc Hydro toolbox. When the dialog box (shown in Figure 7) appears, enter the name of the output layer and accept the result.



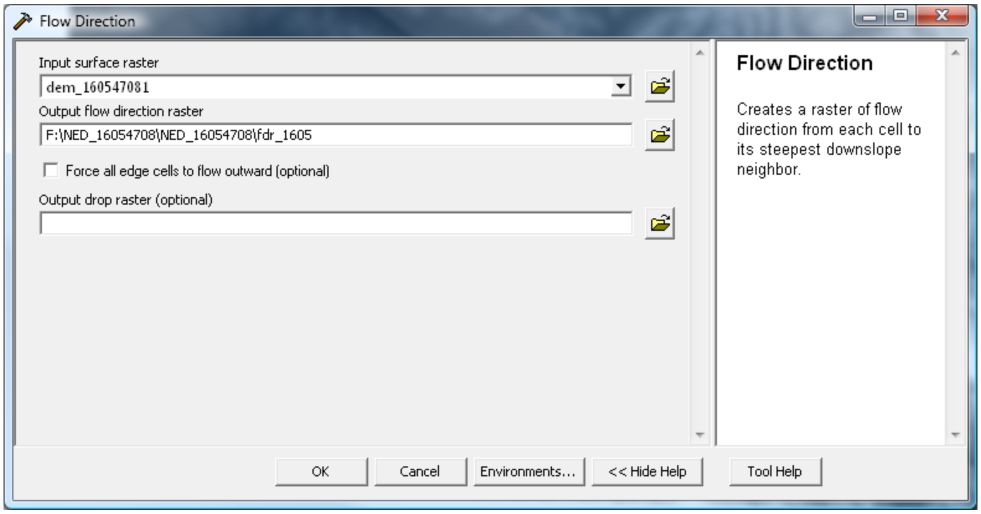
Input surface raster
dem_160547081
Output surface raster
F:\NED_16054708\NED_16054708\fill_1605
Z limit (optional)

Fill

Fills sinks in a surface raster to remove small imperfections in the data.

Figure 7. “Fill” dialog box.

2. Flow direction: Select “Flow Direction” from the Hydrology menu of the Spatial Analyst tool. Ascertain the Input flow direction raster and give the name to output flow direction raster “NED_16054708” (as shown in Figures 8 and 9).


Flow Direction

Input surface raster: dem_160547081

Output flow direction raster: F:\NED_16054708\NED_16054708\fdr_1605

☐ Force all edge cells to flow outward (optional)

Output drop raster (optional):

Flow Direction

Creates a raster of flow direction from each cell to its steepest downslope neighbor.

Figure 8. “Flow Direction” dialog box.

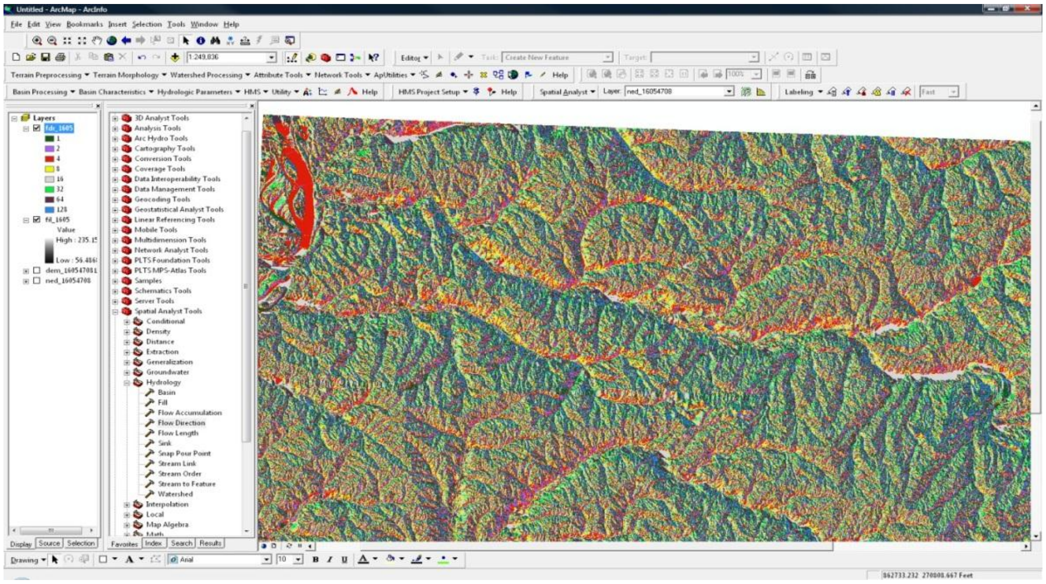
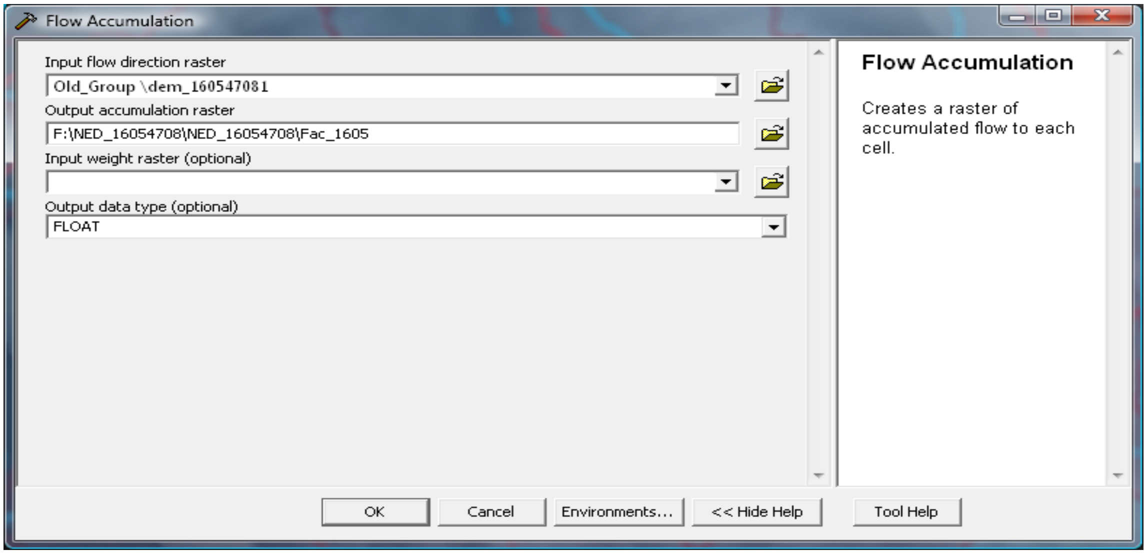


Figure 9. Output flow direction grids.

3. Flow accumulation: Select “Flow Accumulation” from the hydrology menu of the Spatial Analyst tool. The Flow Accumulation dialog box is shown in Figure 10. Accept the input raster data and name the output flow direction raster as “Fac_1605” (shown in Figure 10); select “OK”. The Flow Accumulation line of the river will be created as shown in Figure 11.



Input flow direction raster: Old_Group \dem_160547081
Output accumulation raster: F:\NED_16054708\NED_16054708\Fac_1605
Input weight raster (optional):
Output data type (optional): FLOAT

Flow Accumulation

Creates a raster of accumulated flow to each cell.

Figure 10. “Flow Accumulation” dialog box.

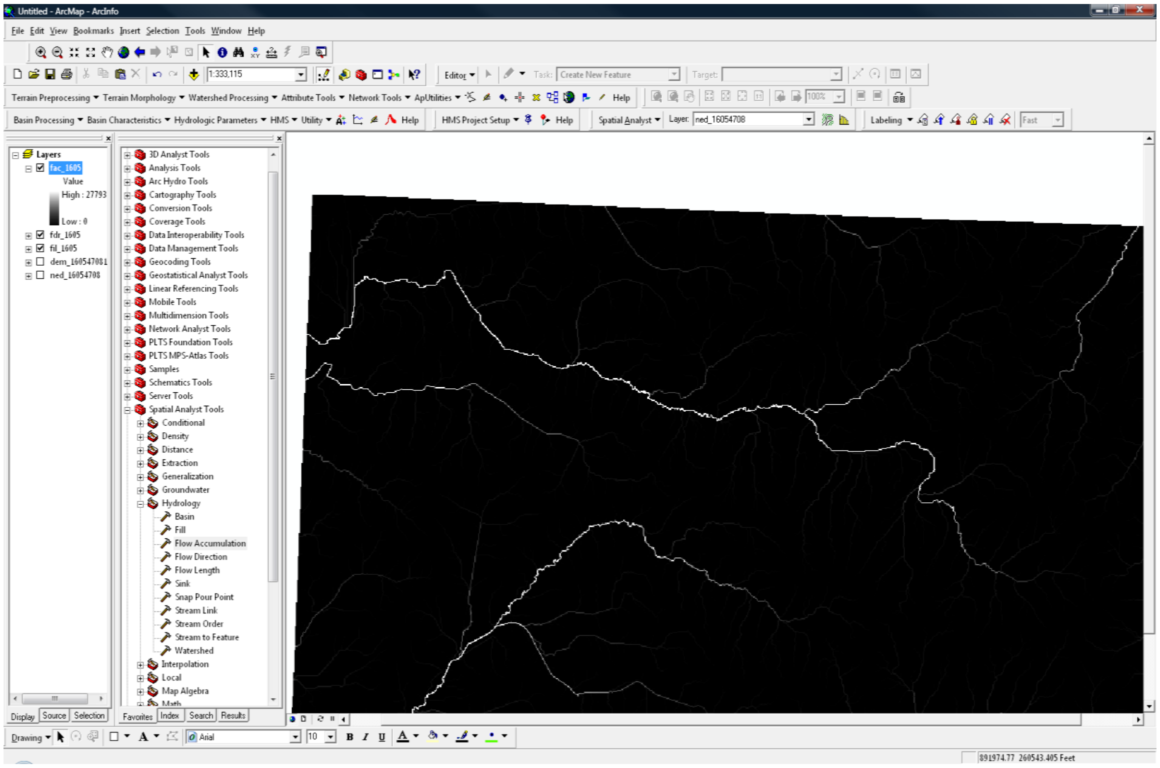


Figure 11. Flow accumulation grids.

4. Create a pour point: The pour point is created at the intersection of the flow accumulation line of the Wolf River and the Mississippi River (shown in Figure 12).

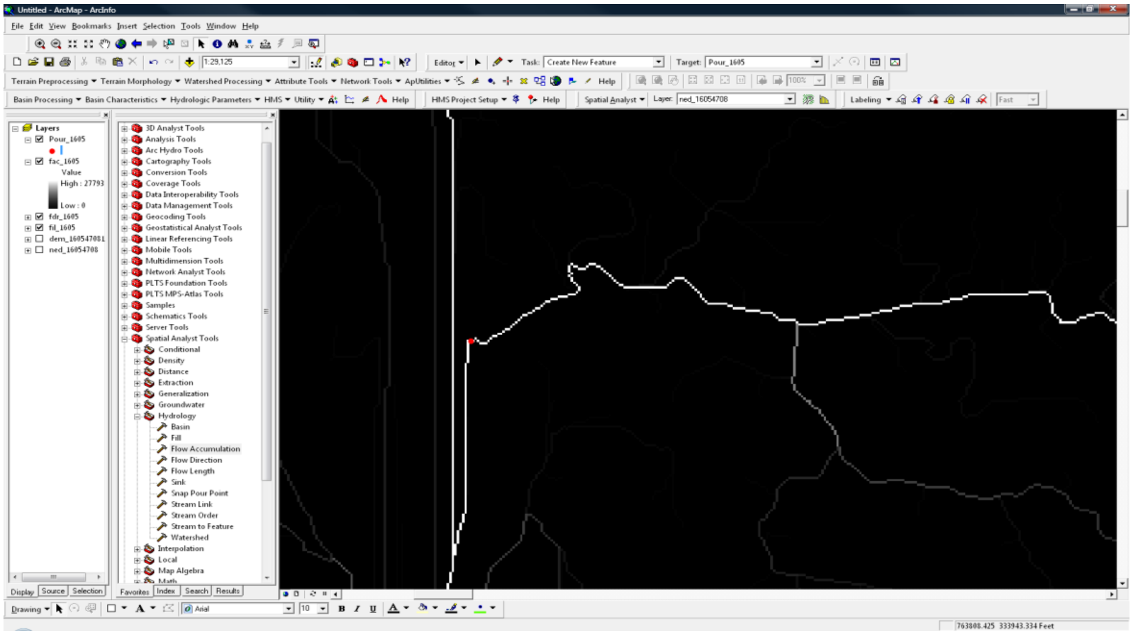
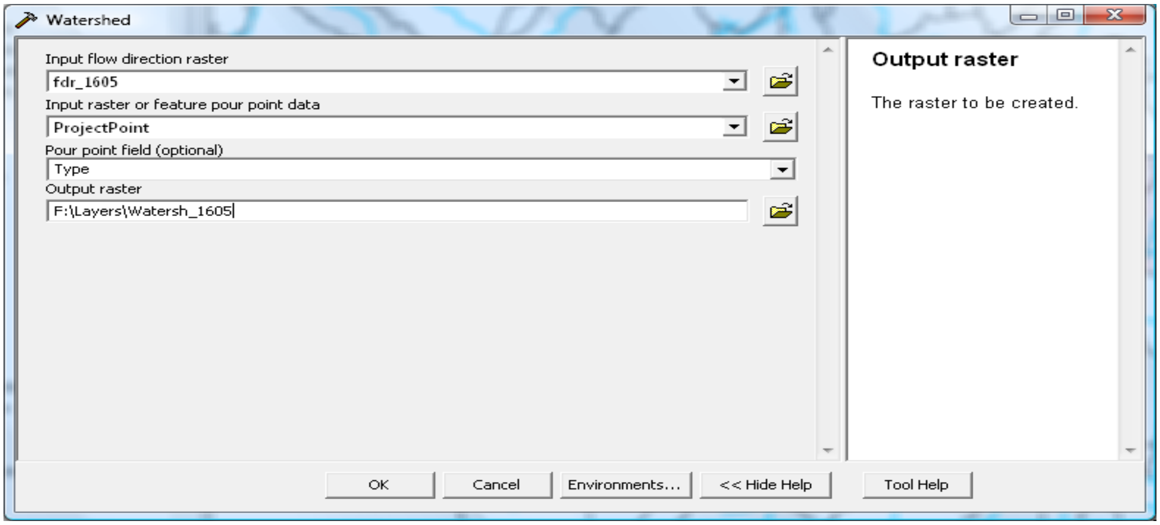


Figure 12. Create a pour point on the “Flow Accumulation” grids.

5. Define the watershed: Use the Watershed tool in the hydrology menu of the Spatial Analyst tool to define the watershed. The window appears (shown in Figure 13). Ascertain that “fdr_1605” is the input to the flow direction raster and “Pour_1605” is the input to the feature pour point data. Label the output raster “Watersh_1605”, and over-write the default names; press “OK”. The result of these operations is the Wolf River watershed raster map (illustrated in Figure 14).



Watershed

Input flow direction raster

fdr_1605

Input raster or feature pour point data

ProjectPoint

Pour point field (optional)

Type

Output raster

F:\Layers\Watersh_1605

Output raster

The raster to be created.

Figure 13. Watershed dialog box.

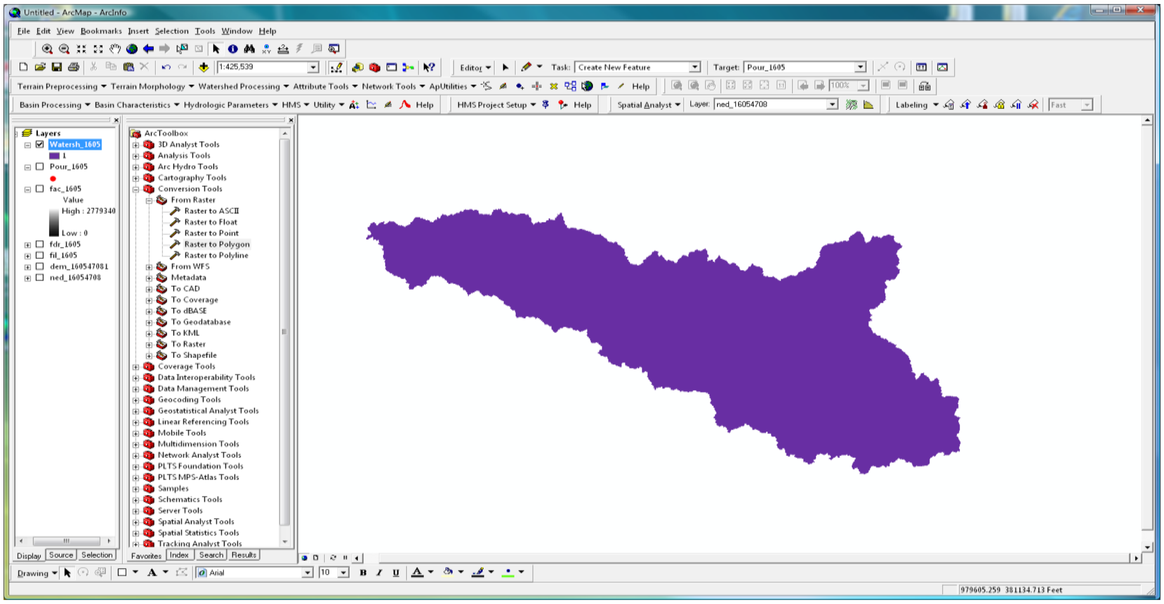
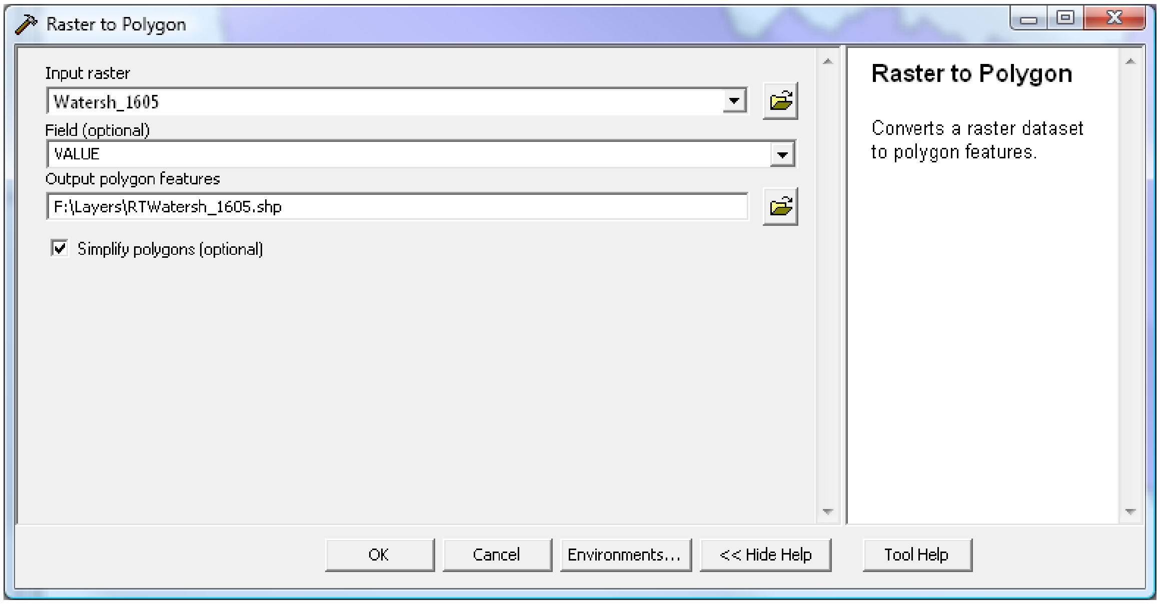


Figure 14. Wolf River watershed.

6. Watershed Shape File: Generate a watershed shape file by selecting “raster to polygon” from the Raster menu of conversion tools in the Arc toolbox. Figure 15 shows the “Raster to Polygon” dialog box. Ascertain that the input raster is “Watersh_1605” and give the new name

“Rtwatersh_1605” to the output polygon features; press “OK”. The Wolf River basin shape file will be generated as shown in Figure 16.



Raster to Polygon

Input raster: Watersh_1605

Field (optional): VALUE

Output polygon features: F:\Layers\RTWatersh_1605.shp

☑ Simplify polygons (optional)

Raster to Polygon

Converts a raster dataset to polygon features.

Figure 15. “Raster to Polygon” dialog box.

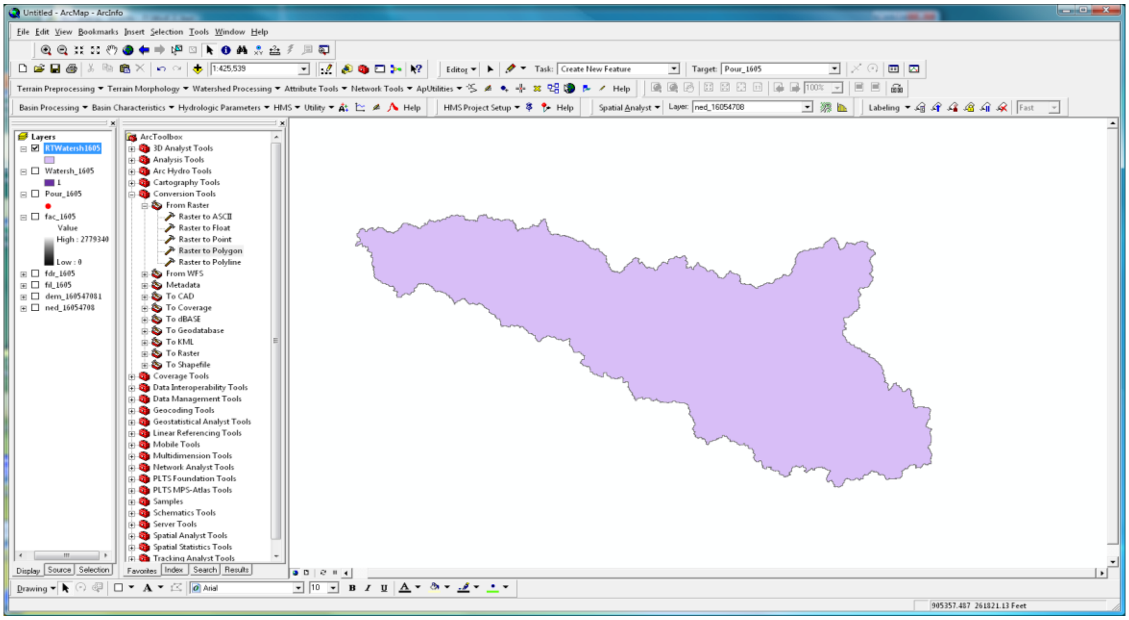


Figure 16. Wolf River shape file.

7. Wolf River DEM: Use the same steps listed above (as explained in Figure 5) to set up the grid for the raster to polygon “Rtwatersh_1605” file. In the DEM layer ”dem_1605”, *x* and *y* are in feet, but *z* (elevation) is in meters and will appear as shown in Figure 17.

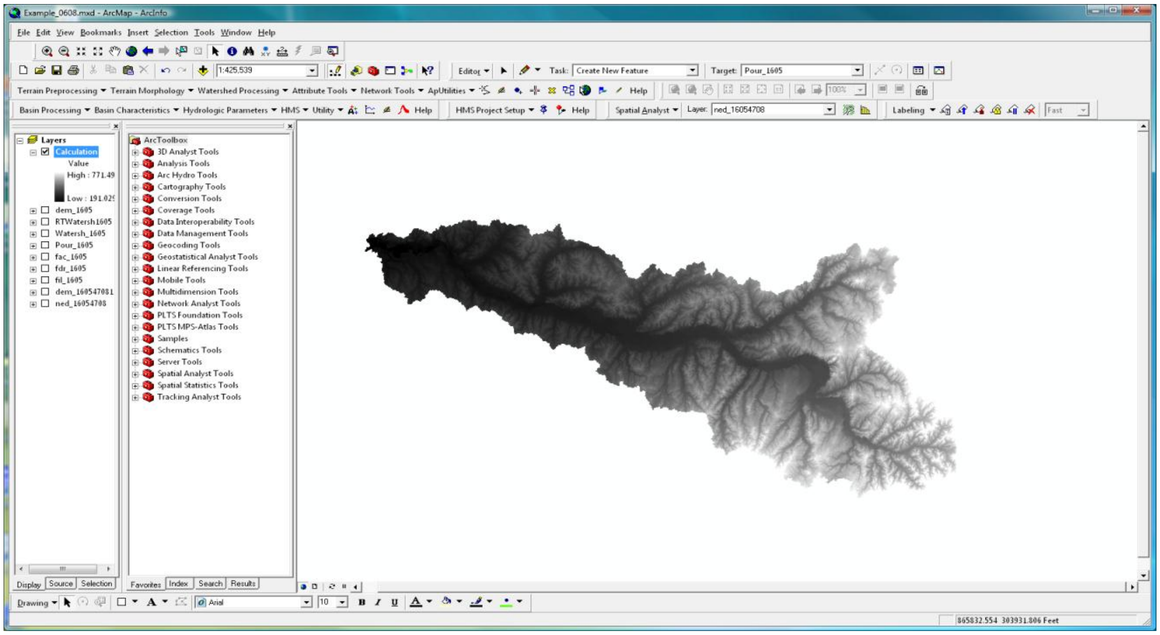


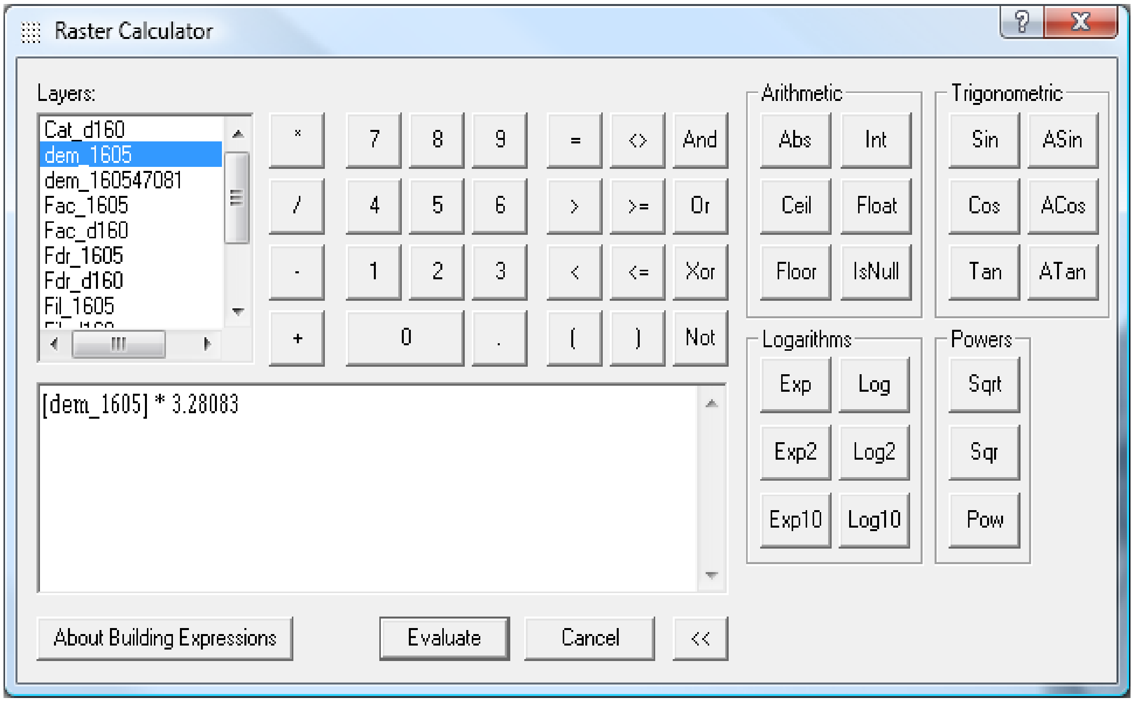
Figure 17. The grid of the Wolf River DEM.

Another important step in this study is to convert the elevation of the DEM data from meters to feet in ArcGIS. The *x* and *y* in the DEM data are in feet and elevation (*z*) is in meters. The elevation data must be converted from meters to feet through the following nine steps identified by the Community and Regional Planning Program (2001): (1) Activate the projected raster data layer; (2) Under the Analysis menu, open the Map Calculator; (3) Double-click on the name of the raster data in the left-hand column so that it appears in the text box below the menu; (4) Click on the multiplication symbol (the asterisk * key); (5) Type in

3.28083 (the conversion factor for meters to feet); (6) Click the Evaluate button. This will edit the new raster data so that every grid cell's original elevation value is multiplied by 3.28083, giving you a raster data file with *z* units in feet; (7) Now that *x*, *y*, and *z* units are all in feet, you can use all of the surface functions, such as derive slope, contour, and elevation, without any modifications; (8) Save the file, export the data, format a grid, and create a new DEM file that is projected to the Tennessee state plane coordinate system and *x*, *y*, and *z* have the same unit (feet); and (9) Use the new DEM in the ArcView program to make the grid layers, vector data, and prepare the GeoHMS project to calculate basin characteristics.

8. Convert z (elevation) from meters to feet: Use the raster calculator in the Spatial Analyst tool as shown in Figure 18 to convert the elevation from meters to feet. Double-click the DEM layer, ”dem_1605”, in the layer list. Select the multiplication symbol (the asterisk * key), and type in a conversion factor of 3.28083. Select the “Evaluate” button, and then the automatically calculated raster data will appear in the layer list. The calculated raster data has *z* (elevation) in feet. Replicate the same steps as explained in Figure 8 to set up a grid for the calculated raster data. The output raster data, ”dem_e_160feet” (illustrated in Figure 19), is the Wolf River basin raster data that was used to prepare the GeoHMS Project and determine the hydrologic characteristics within the subbasin. The raster data layer has *x*, *y*, and *z* units in feet.

In the Layer List menu, regroup the raster layers that were generated, with the exception of the raster grid layer “dem_e_160feet” called “Old Group”. Choose the “dem_e_160feet” layer as the active layer.



[dem_1605] * 3.28083

Figure 18. “Raster Calculator” dialog box.

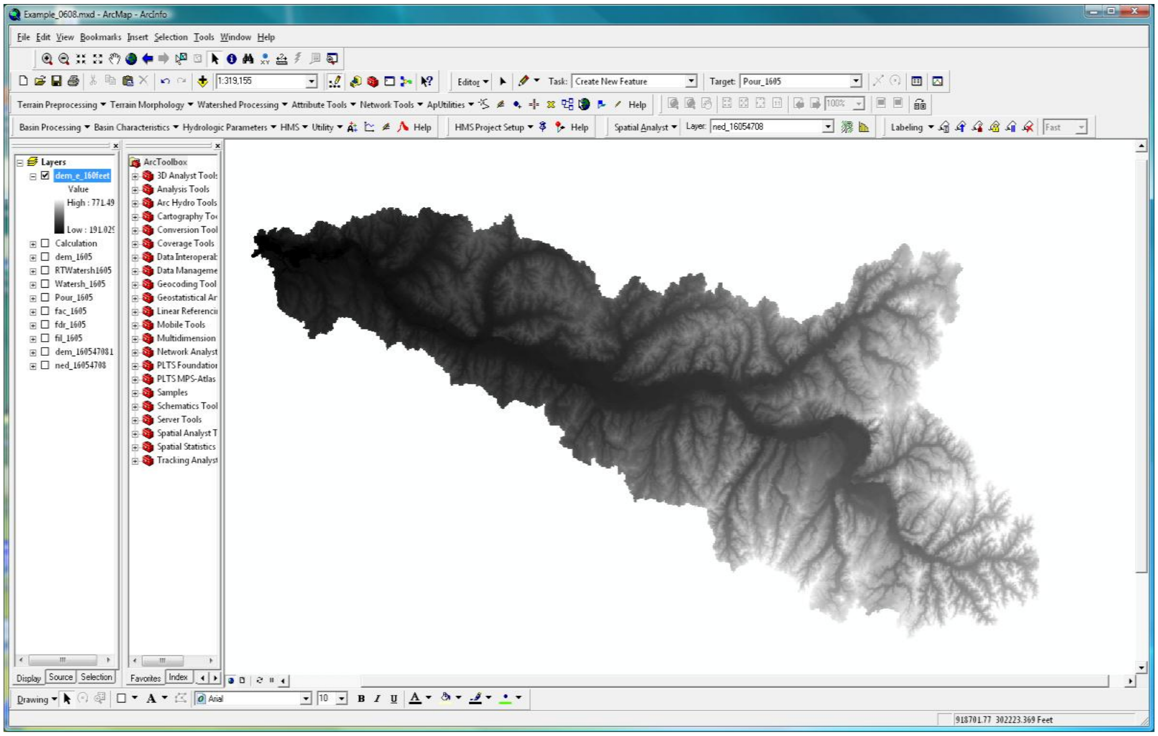


Figure 19. Wolf River Basin raster data with *x*, *y*, and *z* in feet.

Example: Extracting Hydrologic Characteristics of Mary’s Creek Subbasin

Mary’s Creek rises in western Fayette County, Tennessee, at Herb Parsons Lake, which is approximately 3,700 feet east of the Shelby County boundary. Mary’s Creek is approximately 8.51 miles long, drains an area in eastern Shelby County and western Fayette County, and contributes to the flow into Gray’s Creek at a point approximately 6,200 feet north of the intersection of the Wolf River and Gray’s Creek. The basin of Mary’s Creek is within the reserve area of the City of Memphis, and nearly all the basin is located in a rural area.

Delineate hydrologic characteristics of Mary’s Creek Basin. This example shows the major steps in watershed delineation by using the Arc Hydro tool and GeoHMS to extract the hydrologic characteristics of Mary’s Creek basin.

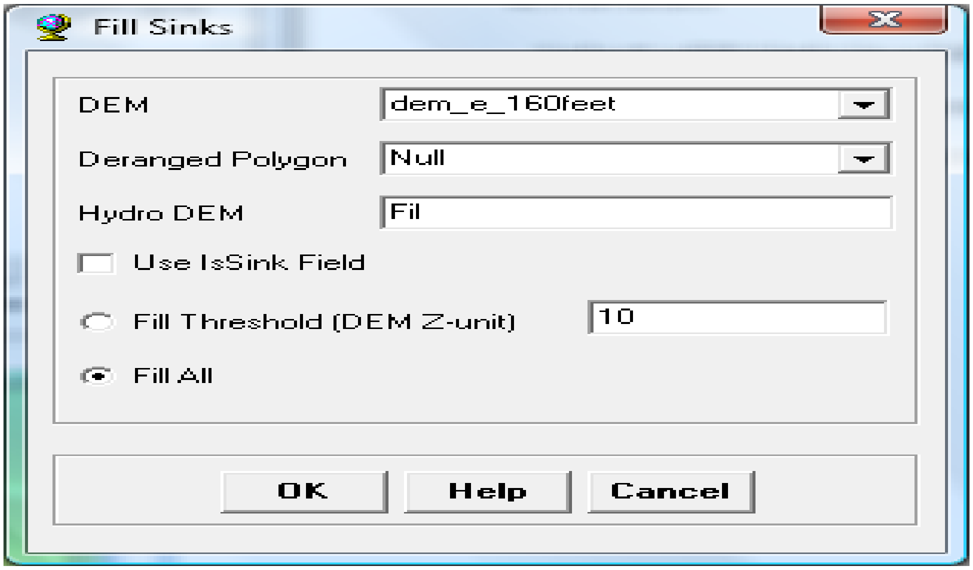
As stated above, the Mary’s Creek basin is approximately 16 square miles. The steps that follow are necessary to delineate the Mary’s Creek hydrologic characteristics (physical parameters).

Prior to the processing of Mary’s Creek basin, the extracted DEM data of the Wolf River basin is used to generate Mary’s Creek basin data. The next step is terrain preprocessing in the Arc Hydro tool; subsequent steps are preparing a GeoHMS project for Mary’s Creek basin and basin processing. The final step is calculating the hydrologic characteristics for each subbasin within the Mary’s Creek watershed.

1. Terrain preprocessing: Terrain preprocessing is a way to analyze the raster dataset for further processing. The DEM of the Wolf River basin that was extracted in the first example was used as input raster data for terrain preprocessing. Several preprocessing steps were conducted in the following order: fill sink, flow direction, flow accumulation, stream definition, stream segments, and catchment grid.

The raster data (DEM) were used to create the fill sink, flow direction, and flow accumulation layers. The next step is a stream definition; the stream definition function uses a flow accumulation grid as input and creates a stream for a user-defined threshold. Recalling from Chapter 2, the threshold governs the detail development of the stream network within a drainage basin. The size of the threshold may be increased to reduce the stream network and the number of catchment polygons; or if one wants a more densely refined network, the threshold may be decreased. A threshold area of 0.5 square miles (1.295 square kilometers) was used to extract the hydrologic characteristics of Mary's Creek basin. Next, the stream definition was used to generate the stream link grid and to determine the individual stream reaches in the hydrologic model. Both the stream link grid and flow direction were used to delineate a catchment grid (cat) of the Wolf River basin. The vector layers of the subbasin required the defining of a HEC-GeoHMS project; therefore, three vector layers were involved in delineating the subbasins. First, the catchment grid was used to create the catchment polygon processing (catchment). Second, drainage line processing was produced by using the stream link grid and the flow direction grid. Third, adjoint catchment was developed by using drainage line and catchment. Using this method generated the entire grid and vector layers of the Wolf River basin that contribute to the GeoHMS project. These data layers were a source file to all GeoHMS projects within the Wolf River basin.

A. Fill sinks: Select "Fill Sinks" in the DEM manipulation menu of the terrain preprocessing toolbar. Accept the result input for the DEM "dem_e_160feet", and the output is a Hydro DEM layer named by the default "Fil" as shown in Figure 20. Click "OK". The "Fil" layer is added to the layer lists and will create the map as illustrated in Figure 21.



DEM: dem_e_160feet

Deranged Polygon: Null

Hydro DEM: Fil

☐ Use IsSink Field

○ Fill Threshold (DEM Z-unit): 10

● Fill All

Figure 20. “Fill Sinks” dialog box.

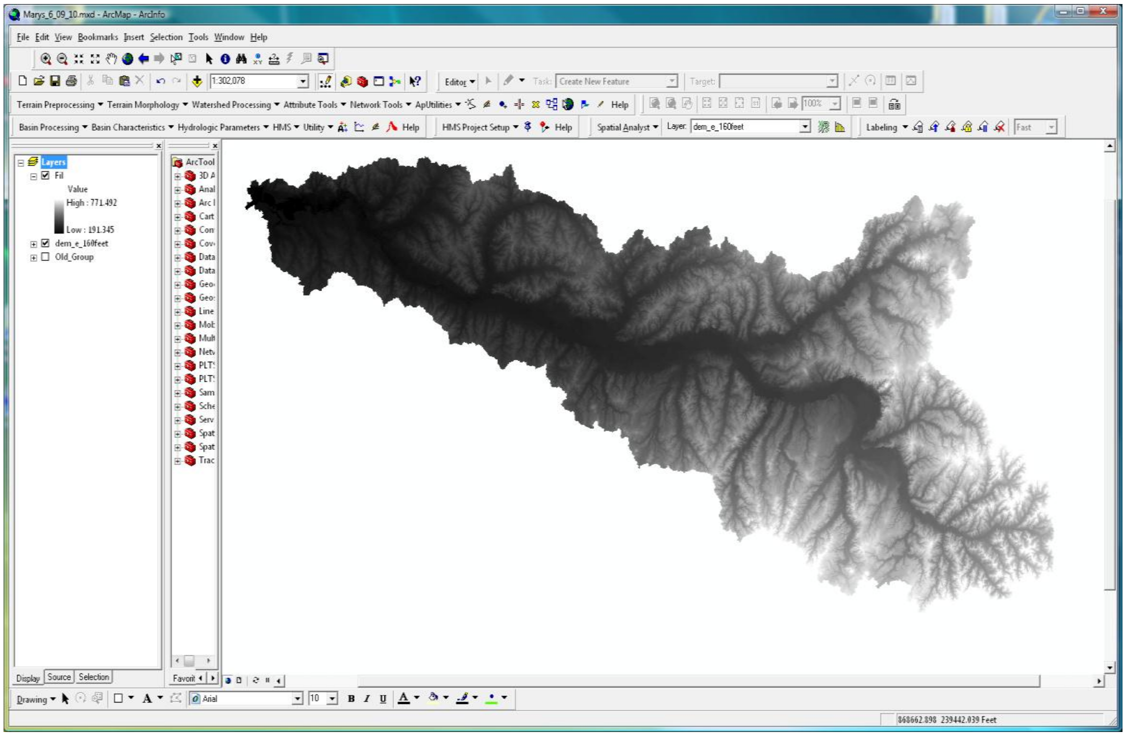
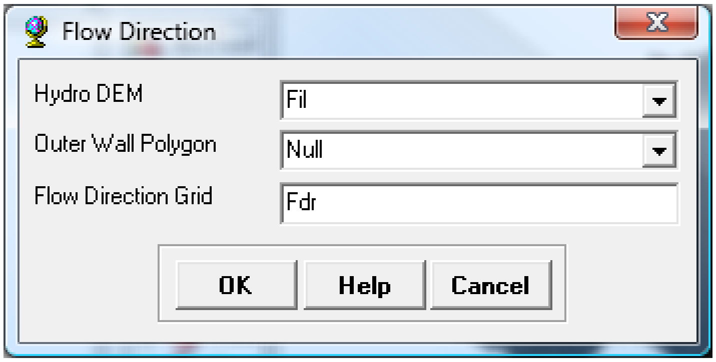


Figure 21. Raster fill.

B. Flow direction: Select flow direction from the terrain preprocessing toolbar. Accept ”Fil” input for the Hydro DEM, and the output is a flow direction grid layer named by the default “Fdr” (see Figure 22). Press “OK”, and the “Fdr” layer is added to the layer list as shown in Figure 23.



Hydro DEM: Fil

Outer Wall Polygon: Null

Flow Direction Grid: Fdr

Figure 22. “Flow Direction” dialog box.

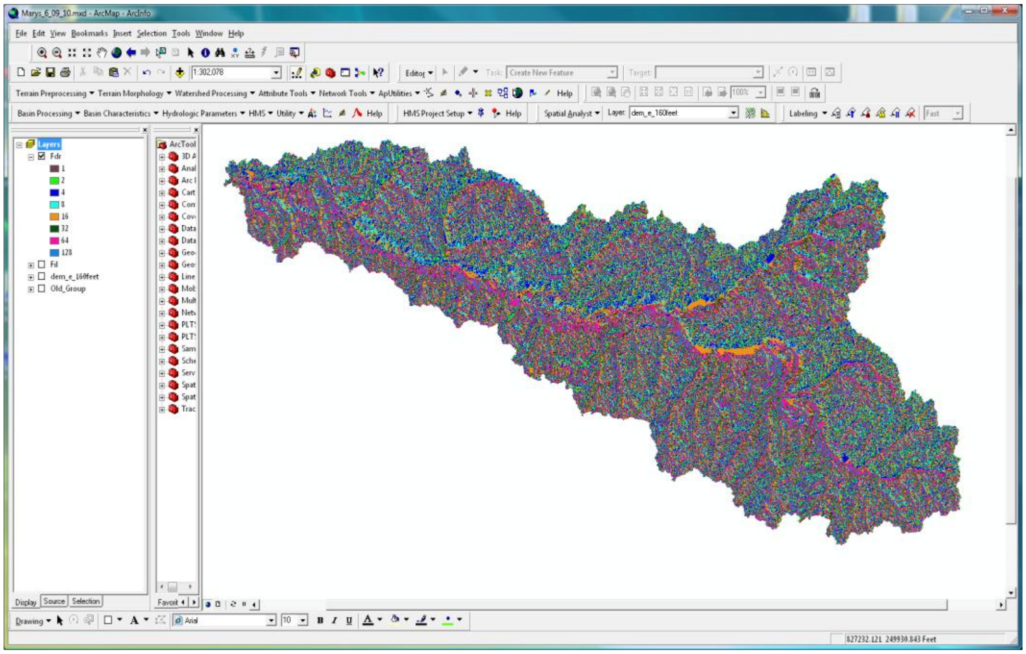
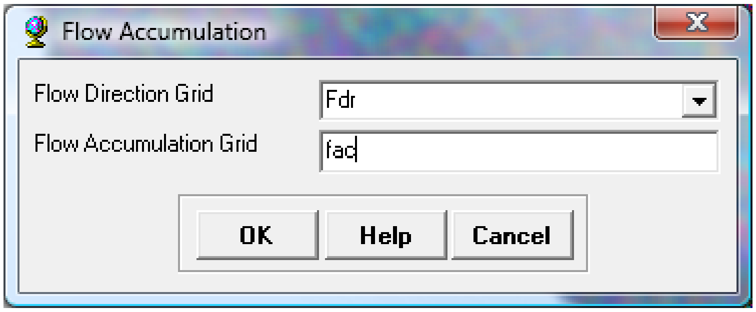


Figure 23. Flow direction grids.

C. Flow accumulation: Select flow accumulation in the terrain preprocessing toolbar. Accept input for the flow direction grid “Fdr”, and the output is a flow accumulation grid layer named by the default “fac” (see Figure 24). Press “OK”, and the “fac” layer is added to the layer list and will create the flow accumulation grid map (see Figure 25).



Flow Direction Grid: Fdr

Flow Accumulation Grid: fac

Figure 24. “Flow Accumulation” dialog box.

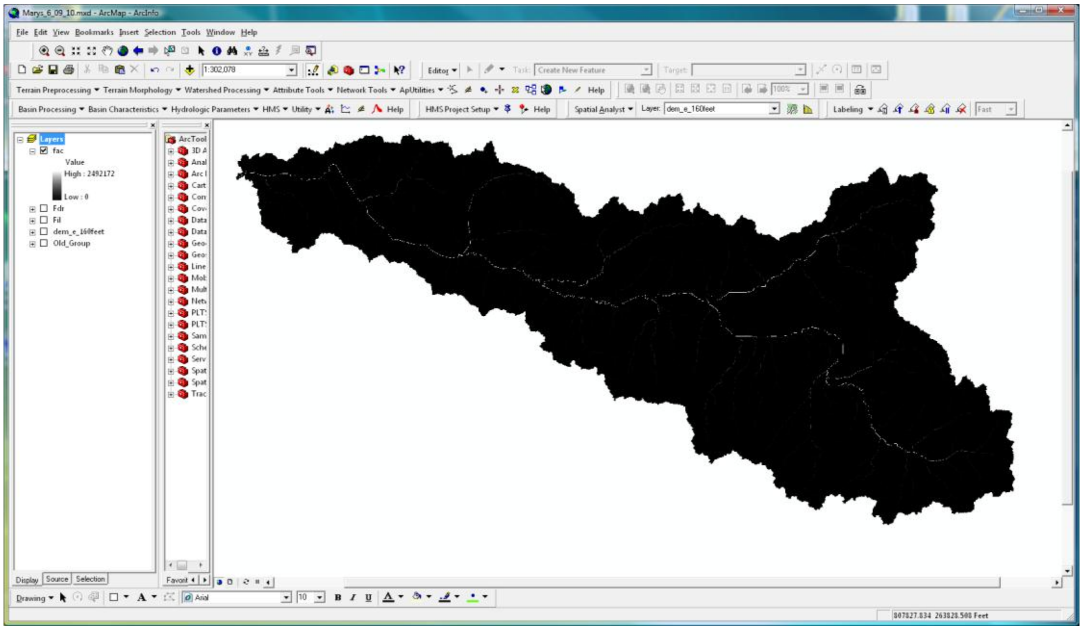
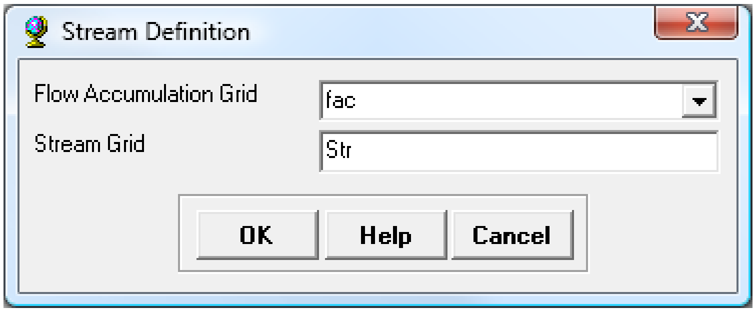


Figure 25. Flow accumulation grids.

D. Stream definition: Select stream definition in the terrain preprocessing toolbar. Accept input for the flow accumulation grid “fac”, and the output is a stream grid layer named by the default “Str” (see Figure 26). Select “OK”, and the “Stream Threshold” dialog box will appear (see Figure 27).

Threshold area. The purpose of this section is to specify the sizes of the respective threshold areas used in developing the stream definition for various sizes of basins. Three thresholds, all with varying sizes, were used depending on the size of the watershed of the identified creeks and tributaries. The hydrologic unit code (HUC-12) of the Wolf River was generated by using the stream threshold area of 5.18 square kilometers (2 square miles). Stream networks, such as those of Gray’s Creek and Mary’s Creek, were extracted from the DEM using a threshold area of 1.295 square kilometers (0.5 square mile), and for the stream network for the rest of the identified creeks and the unnamed lateral tributaries, a threshold area of 0.6475 square kilometers (0.25 square mile) was used.

As previously stated, a threshold of 0.6475 square kilometers was used to generate the small lateral streams. Next, the stream definition was used to generate the stream link grid and to determine the individual stream reaches in the model.

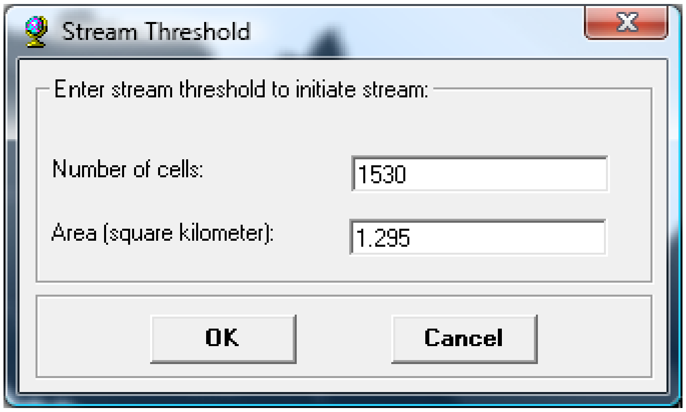


Flow Accumulation Grid: fac

Stream Grid: Str

Figure 26. “Stream Definition” dialog box.

The stream threshold default number for both cells and area will appear in the dialog box. Overwrite the default number and use the area 1.295 square kilometers (0.5 square miles) (see Figure 27). The smaller threshold areas generate a denser stream network and a greater number of catchments. Select “OK”, and stream networks appear as shown in Figure 28.



Enter stream threshold to initiate stream:

Number of cells: 1530

Area (square kilometer): 1.295

Figure 27. “Stream Threshold” dialog box.

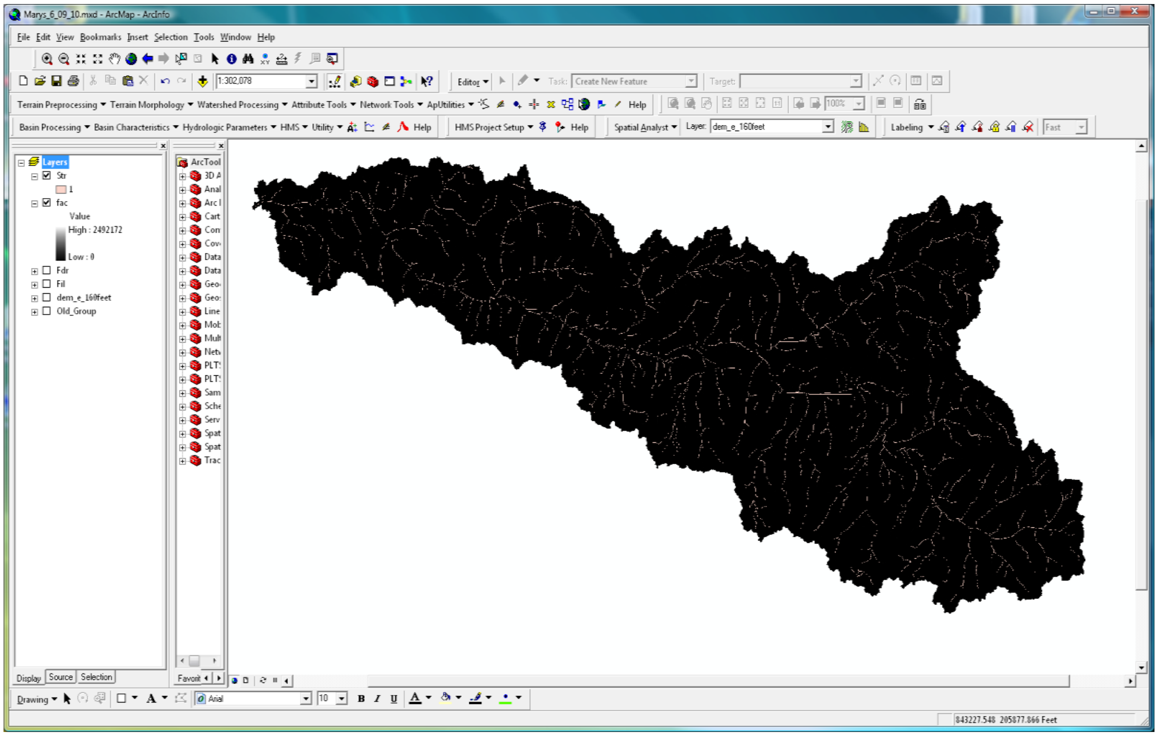
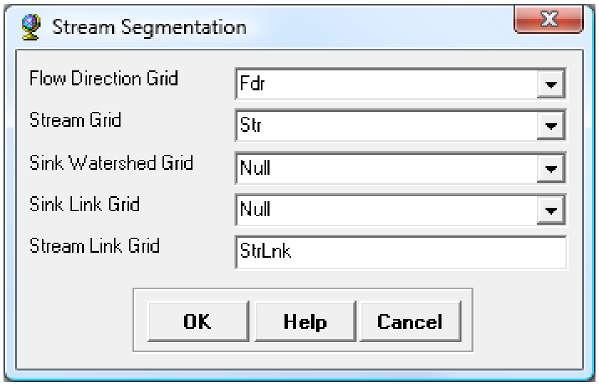


Figure 28. Stream network.

E. Stream segmentation: Select stream segmentation in the terrain preprocessing toolbar. Accept input for the flow direction grid “Fdr”, and the output is a stream segmentation grid layer named by the default “StrLnk” (see Figure 29). Press “OK”, and the “StrLnk” layer is added to the layer list (stream segmentation map displayed in Figure 20).



Stream Segmentation

Flow Direction Grid: Fdr
Stream Grid: Str
Sink Watershed Grid: Null
Sink Link Grid: Null
Stream Link Grid: StrLnk

Figure 29. “Stream Segmentation” dialog box.

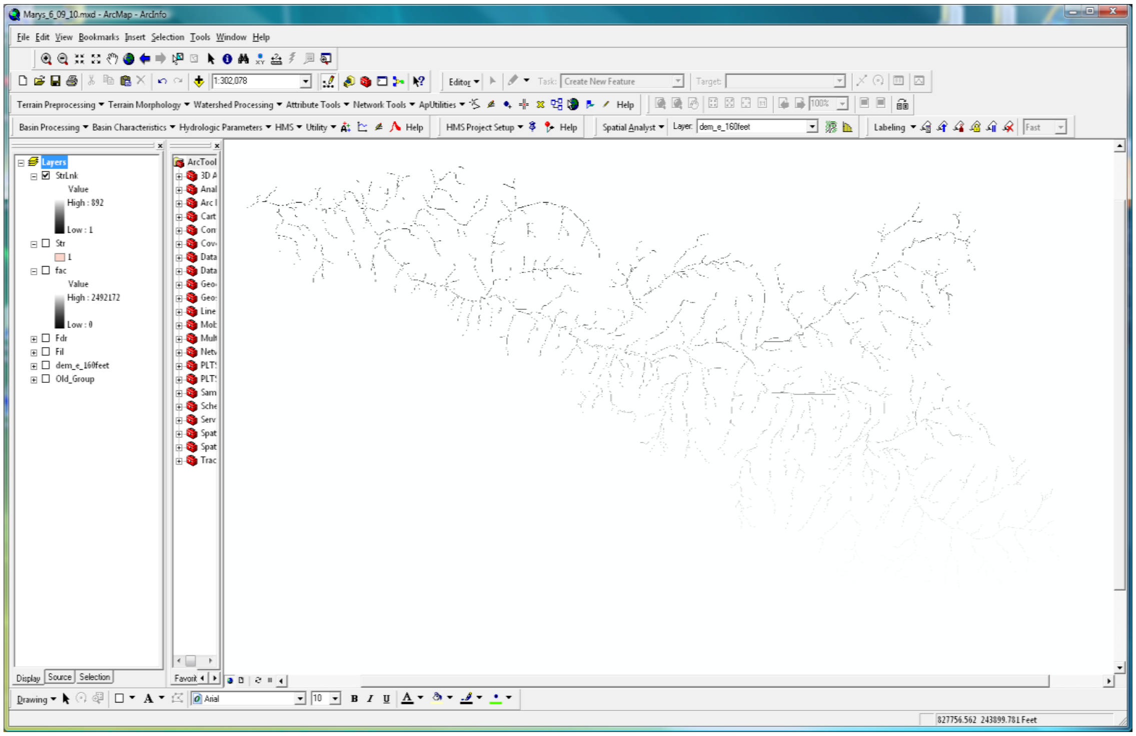
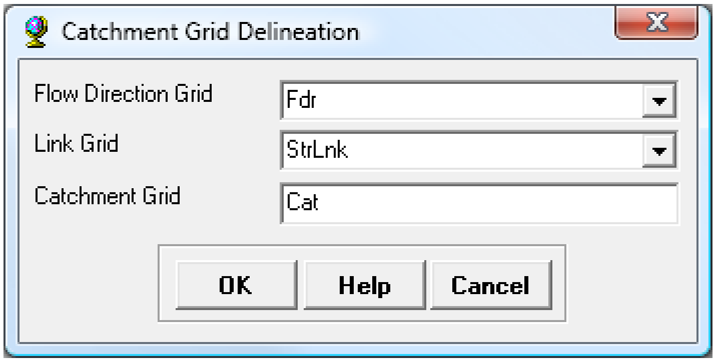


Figure 30. Stream segmentation map.

F. Catchment grid delineation: Select catchment grid delineation in the Terrain Preprocessing toolbar. Accept input for the flow direction grid “Fdr” and Link Grid “StrLnk”. The output is a catchment grid layer named by the default “Cat” (see Figure 31). Press “OK”, and the “Cat” layer is added to the layer list; the catchment grid map is displayed in Figure 32).



Flow Direction Grid: Fdr

Link Grid: StrLnk

Catchment Grid: Cat

Figure 31. “Catchment Delineation” dialog box.

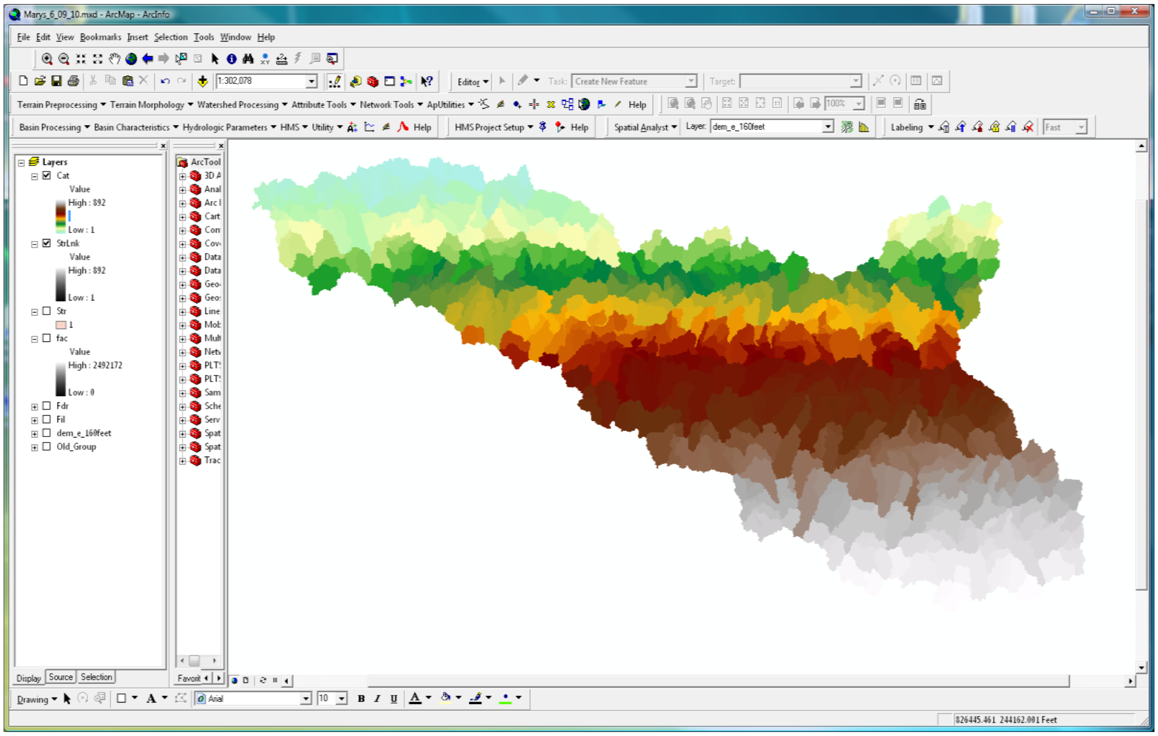
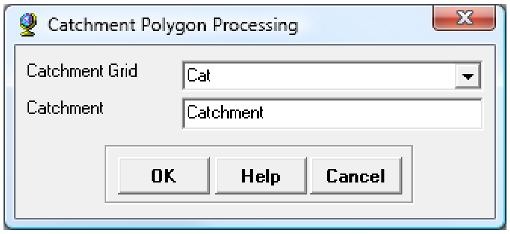


Figure 32. Catchment grids.

G. Catchment polygon processing: Select Catchment Polygon Processing in the Terrain Preprocessing toolbar. Accept input for the catchment grid “Cat”. The output is a catchment layer named by the default “Catchment” (see Figure 33). Press “OK”, and the Catchment layer is added to the layer list; the catchment polygon map appears as shown in Figure 34.



Catchment Grid: Cat

Catchment: Catchment

Figure 33. “Catchment Polygon Processing” dialog box.

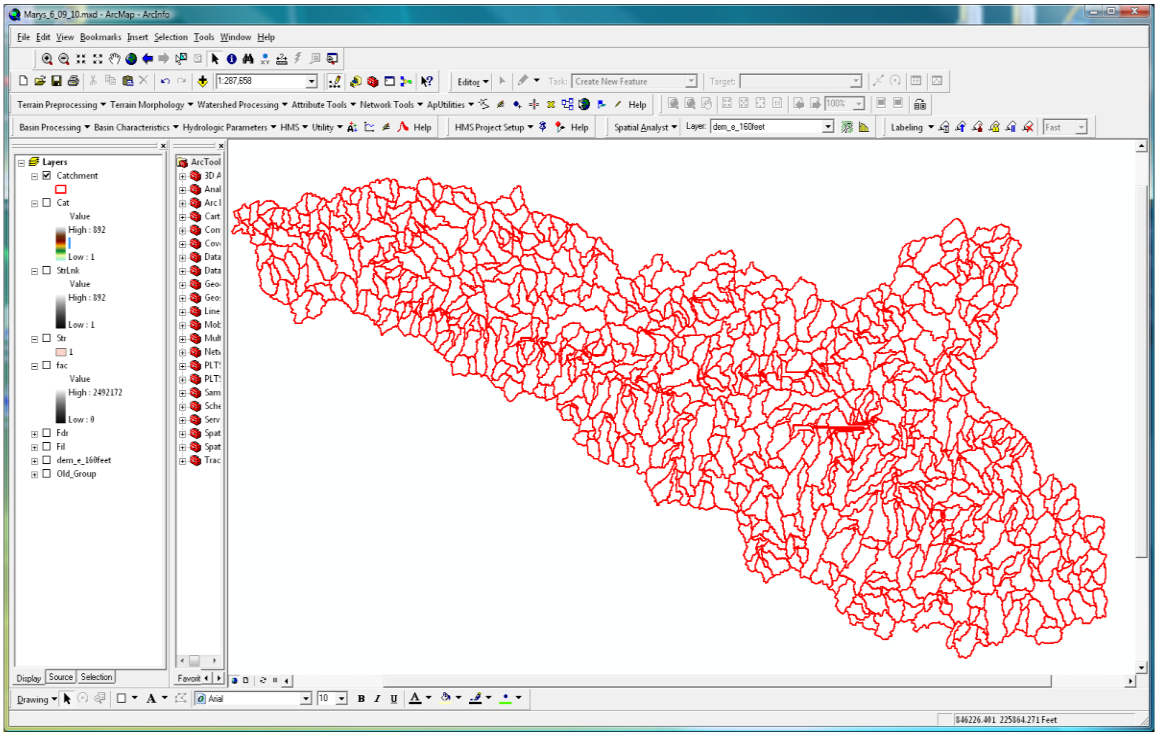
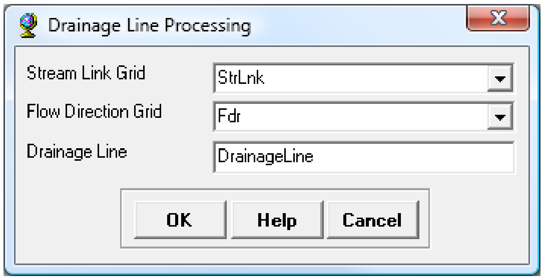


Figure 34. Catchment polygons.

H. Drainage line processing: Select drainage line processing in the Terrain Preprocessing toolbar. Accept input for the flow direction grid “Fdr”, and link grid “StrLnk”. The output is a drainage line layer named by the default “DrainageLine” (see Figure 35). Press “OK”, and the “DrainageLine” layer is added to the layer list. The drainage line map is displayed in Figure 36.



Stream Link Grid StrLnk

Flow Direction Grid Fdr

Drainage Line DrainageLine

Figure 35. “Drainage Line Processing” dialog box.

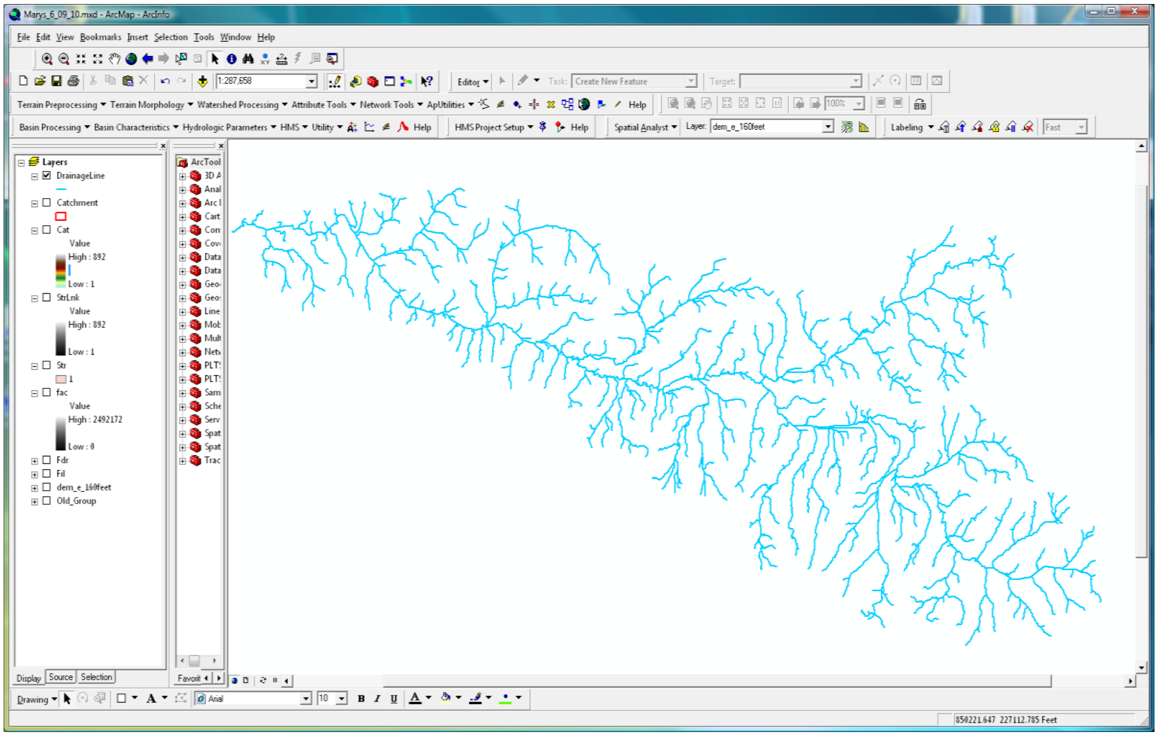
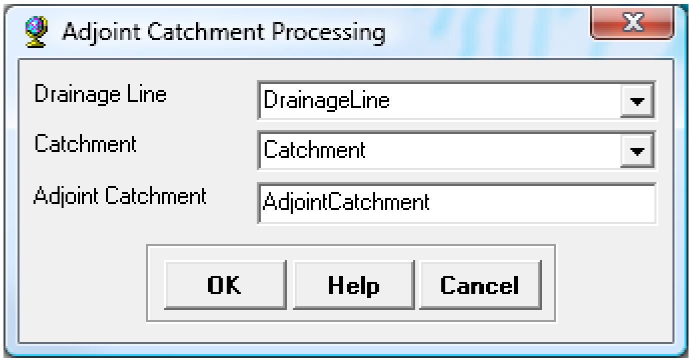


Figure 36. Drainage lines.

I. Adjoint Catchment Processing: Select adjoint catchment processing in the Terrain Preprocessing toolbar. Accept input for both drainage line (DrainageLine) and catchment (Catchment). The output is an adjoint catchment layer named by the default “AdjointCatchment” (see Figure 37). Select “OK”. The layer “AdjointCatchment” is then added to the layer list, and the Catchment map is displayed as shown in Figure 38.



Drainage Line: DrainageLine

Catchment: Catchment

Adjoint Catchment: AdjointCatchment

Figure 37. “Adjoint Catchment Processing” dialog box.

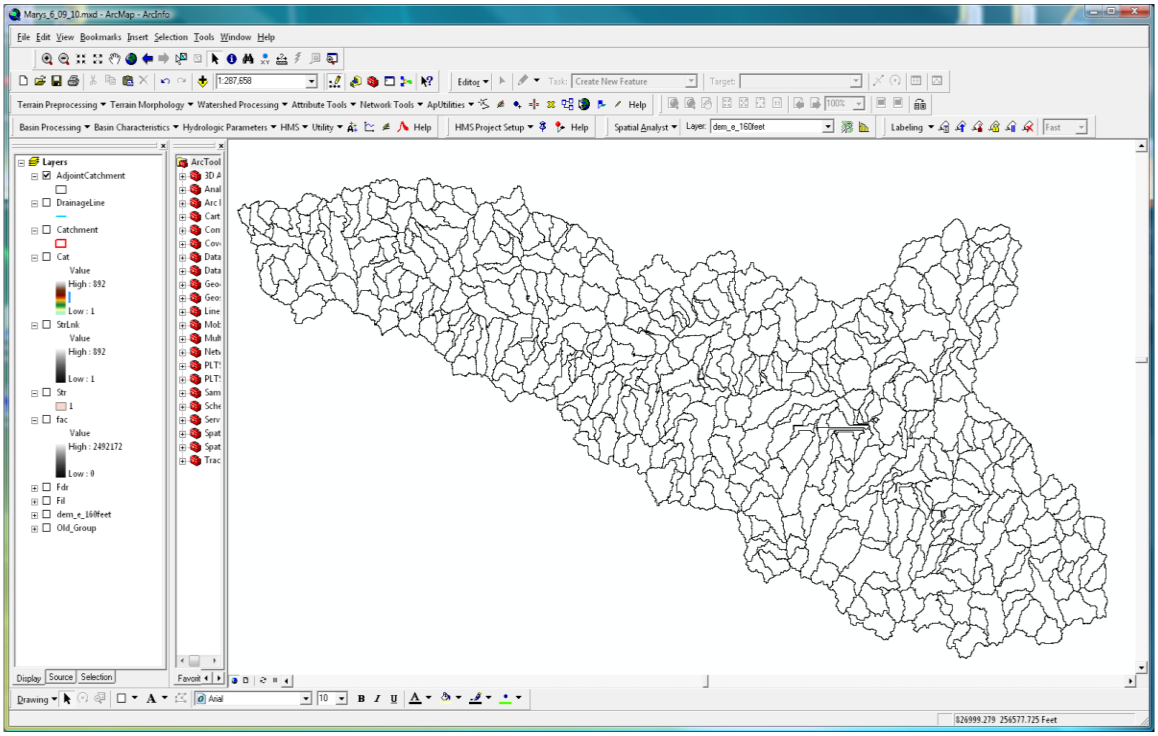


Figure 38. Catchments.

2. Generate a GeoHMS project: The previous steps created all the grids and vector layers that were necessary to run GeoHMS projects and delineate the Mary's Creek subbasin. The next step was to create a Mary's Creek subbasin project.

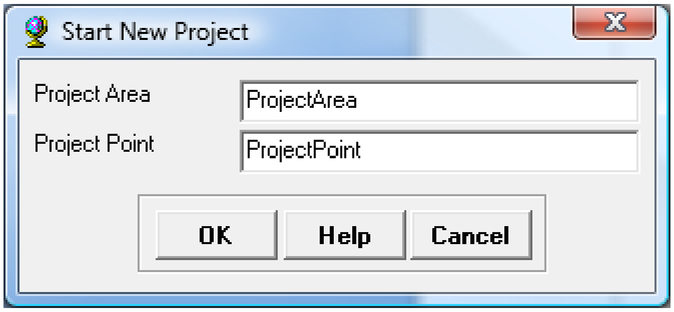
Prepare a GeoHMS project. The source file that was created in the previous step can be used to prepare a GeoHMS project of any of the basins within the Wolf River basin. The derivation procedure involves specifying control points at the basin outlet, which defines the stream of the basin. Many GeoHMS projects can be developed in one file.

The projects are defined by two feature classes: project point and project area. To define a project from the HMS Project tool, select "Start a New Project" and then confirm project point and project area. Next, select "Define a New Project" and zoom in to the intersection of the creek with the main channel of the Wolf River to describe the watershed outlet of the stream. Add a project point on the downstream outlet area of the creek. Next, select "Generate Project." The new file will be established, including the new grid layer, subbasin, river, and project point.

Start new project. Select "Start New Project" from the HMS Project Setup menu of the HEC-GeoHMS toolbar. A dialog box (as shown in Figure 39) will be displayed. Accept the defaults by pressing "OK", and the new dialog box appears (see Figure 40). Type the project name "Marys_Creek1" and the description "GeoHMS of Marys_Creek1" as indicated. Choose the location for the target project file, then click "OK". A new message window will open (see Figure 41).

Read the instructions and follow the steps that appear in the message window.

To define a Mary's Creek subbasin project, zoom in to the outlet area of Mary's Creek, upstream of Gray's Creek (see Figure 42).

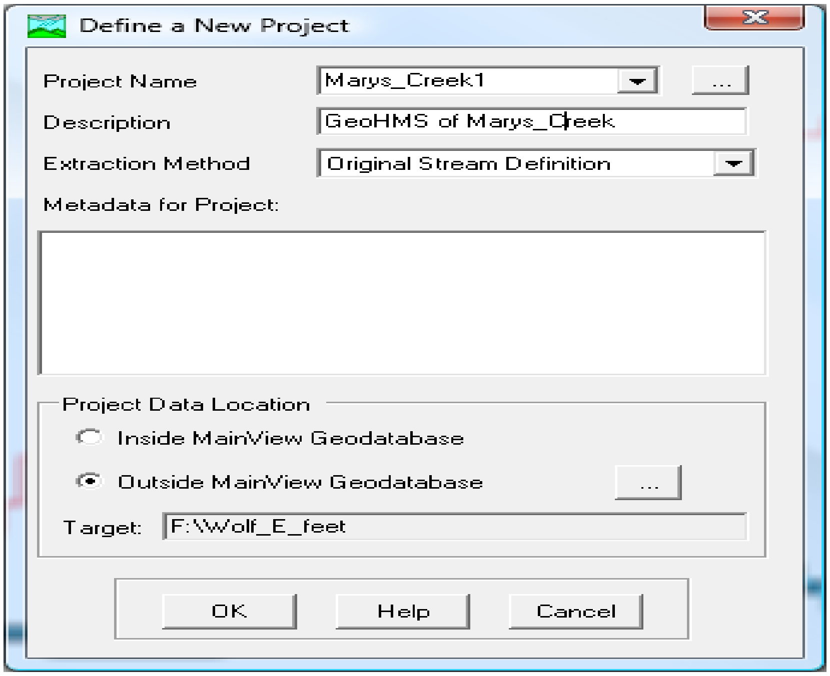


Start New Project

Project Area: ProjectArea

Project Point: ProjectPoint

Figure 39. “Start New Project” dialog box.



Define a New Project

Project Name: Marys_Creek1

Description: GeoHMS of Marys_Creek

Extraction Method: Original Stream Definition

Metadata for Project:

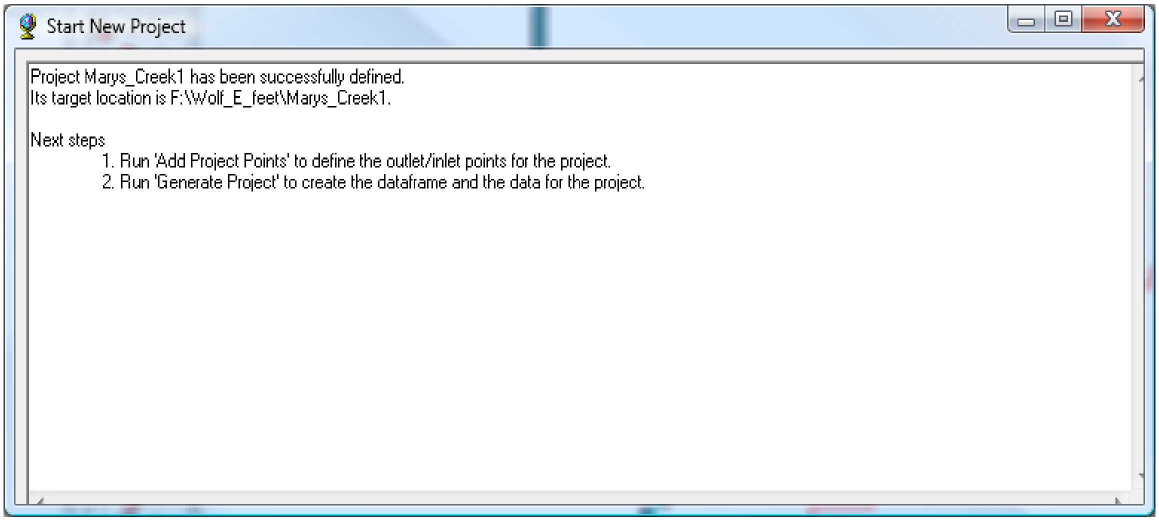
Project Data Location

○ Inside MainView Geodatabase

● Outside MainView Geodatabase

Target: F:\Wolf_E_feet

Figure 40. “Define a New Project” dialog box.



Project Marys_Creek1 has been successfully defined.
Its target location is F:\Wolf_E_feet\Marys_Creek1.

Next steps
1. Run 'Add Project Points' to define the outlet/inlet points for the project.
2. Run 'Generate Project' to create the dataframe and the data for the project.

Figure 41. “Start New Project” window.

Select “Add Project Point” in the HEC-GeoHMS toolbar, and click on a point at the mouth of Mary’s Creek (see Figure 42). Accept the defaults (as shown in Figure 43) that specify the outlet points of Mary’s Creek.

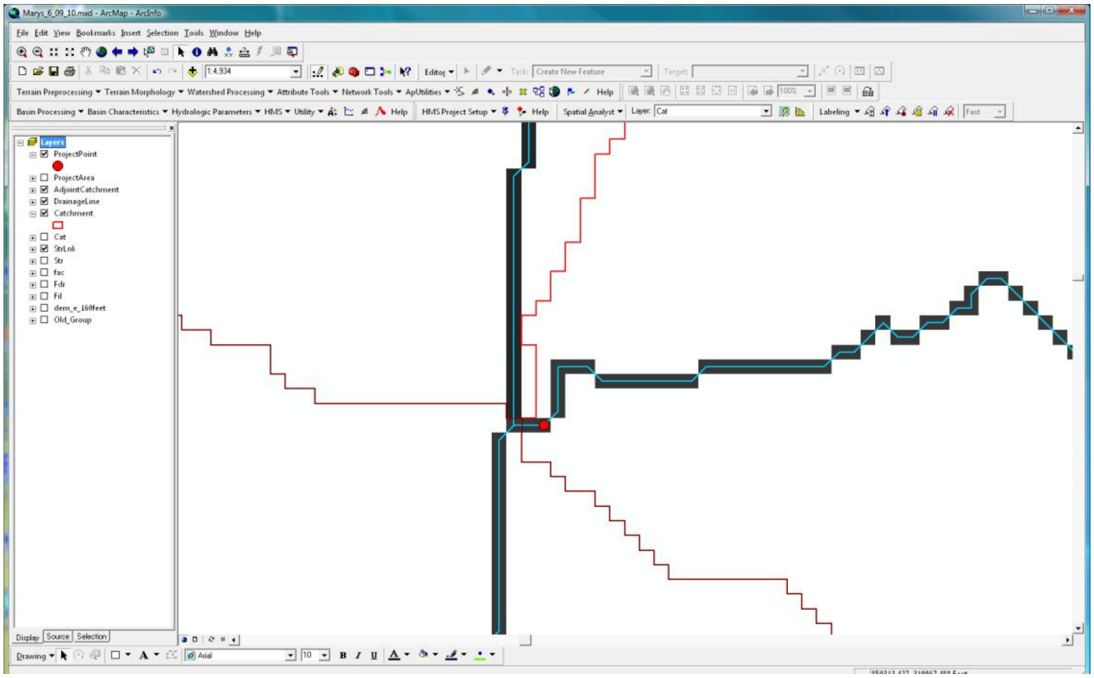
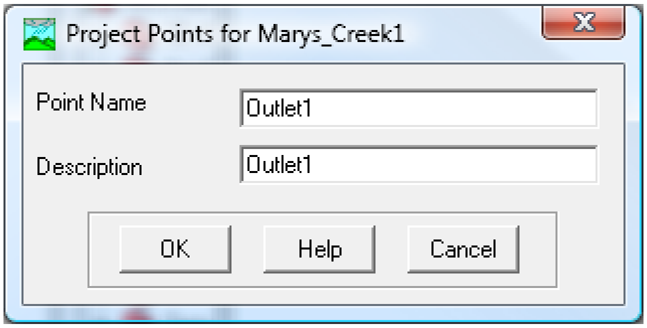


Figure 42. Mary’s Creek outlet drainage point.

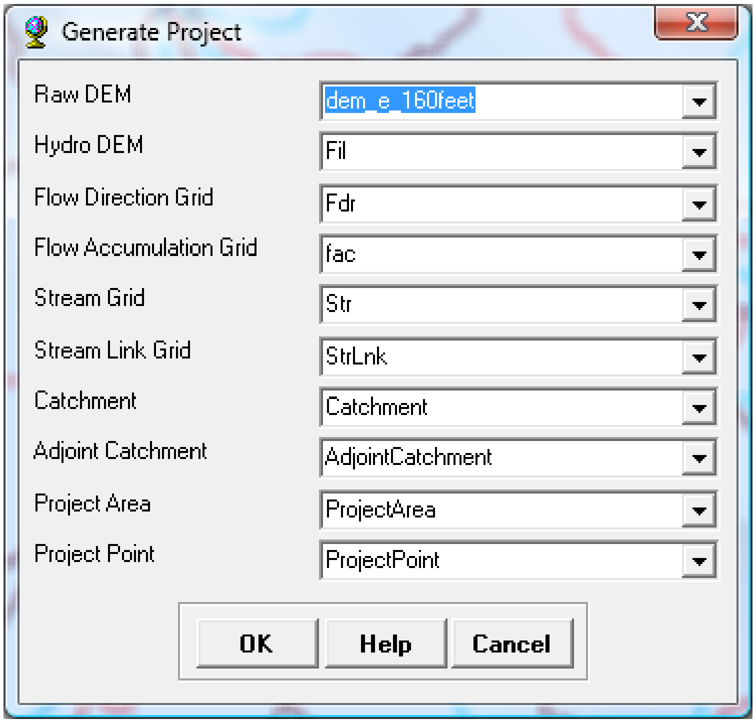

Project Points for Marys_Creek1

Point Name: Outlet1

Description: Outlet1

Figure 43. Project points dialog box.

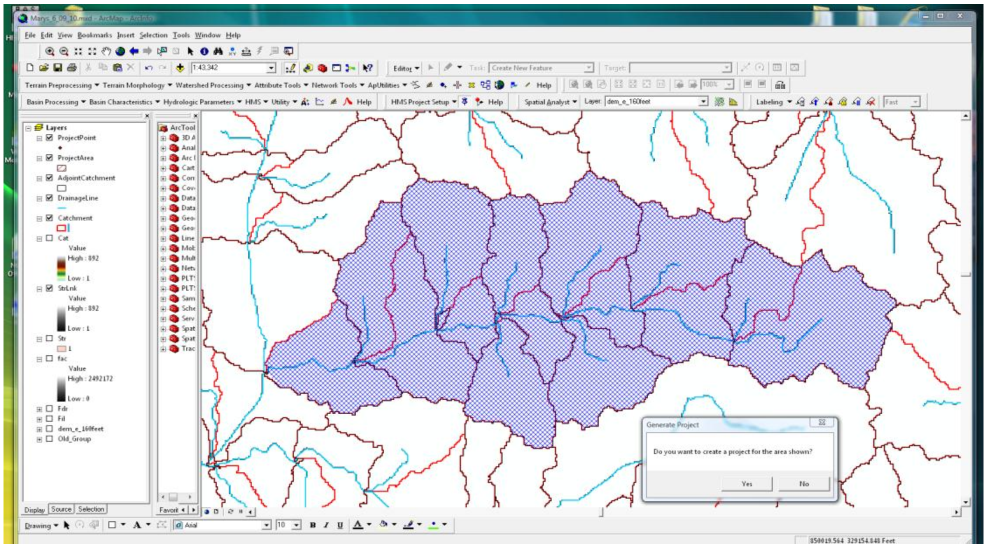
Select “Generate Project” from the GeoHMS project setup menu. The data management dialog box will open. Select the dataset that is associated with the project layer (as shown in Figure 44). Press the “OK” button; the map of the Mary’s Creek basin will be shaded (as shown in Figure 45). Accept the results by clicking “OK”. A new data management window will open. Enter the new name for every layer, or confirm the default names for the new Mary’s Creek subbasin layers as displayed in Figure 46, then click OK. Mary’s Creek subbasin outline will create as shown in Figure 47.



Generate Project

Raw DEM	dem_e_160feet
Hydro DEM	Fil
Flow Direction Grid	Fdr
Flow Accumulation Grid	fac
Stream Grid	Str
Stream Link Grid	StrLnk
Catchment	Catchment
Adjoint Catchment	AdjointCatchment
Project Area	ProjectArea
Project Point	ProjectPoint

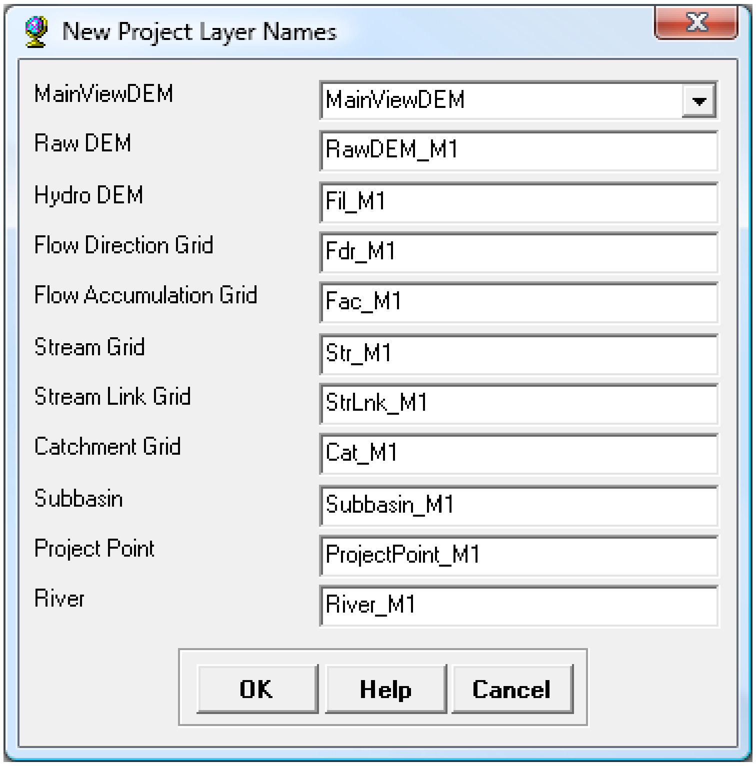
Figure 44. Data management dialog box.



Generate Project

Do you want to create a project for the area shown?

Figure 45. Mary’s Creek basin (threshold of 1.295 square kilometers).



MainViewDEM: MainViewDEM
Raw DEM: RawDEM_M1
Hydro DEM: Fil_M1
Flow Direction Grid: Fdr_M1
Flow Accumulation Grid: Fac_M1
Stream Grid: Str_M1
Stream Link Grid: StrLnk_M1
Catchment Grid: Cat_M1
Subbasin: Subbasin_M1
Project Point: ProjectPoint_M1
River: River_M1

Figure 46. The project layers of Mary’s Creek

After the basin for Mary’s Creek is generated, basin processing is necessary to revise the subbasin delineation in some of the subbasins. In some instances during basin processing, small basin polygons are generated due to the technique for developing basin divides. In areas where the relief or change in elevation is small with respect to the overall elevation change of the grid, smaller basins may be generated. In the basin processing of Mary’s Creek basin, two small subbasins are generated that need to be revised (as shown in Figure 48).

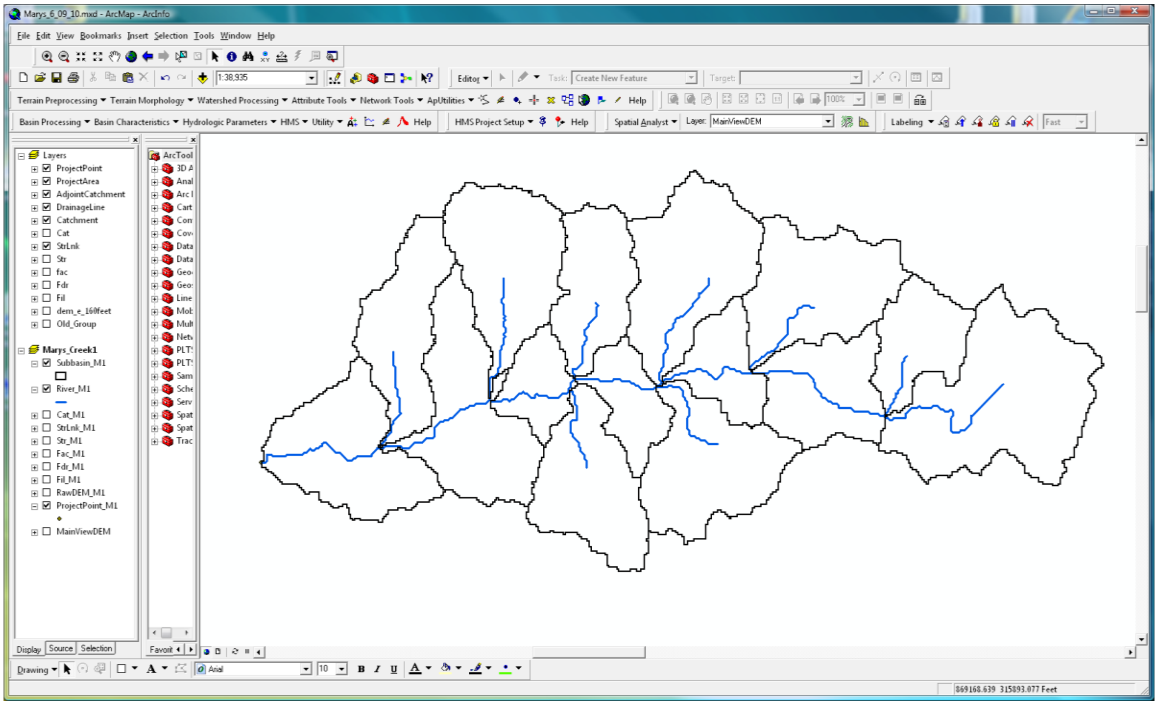
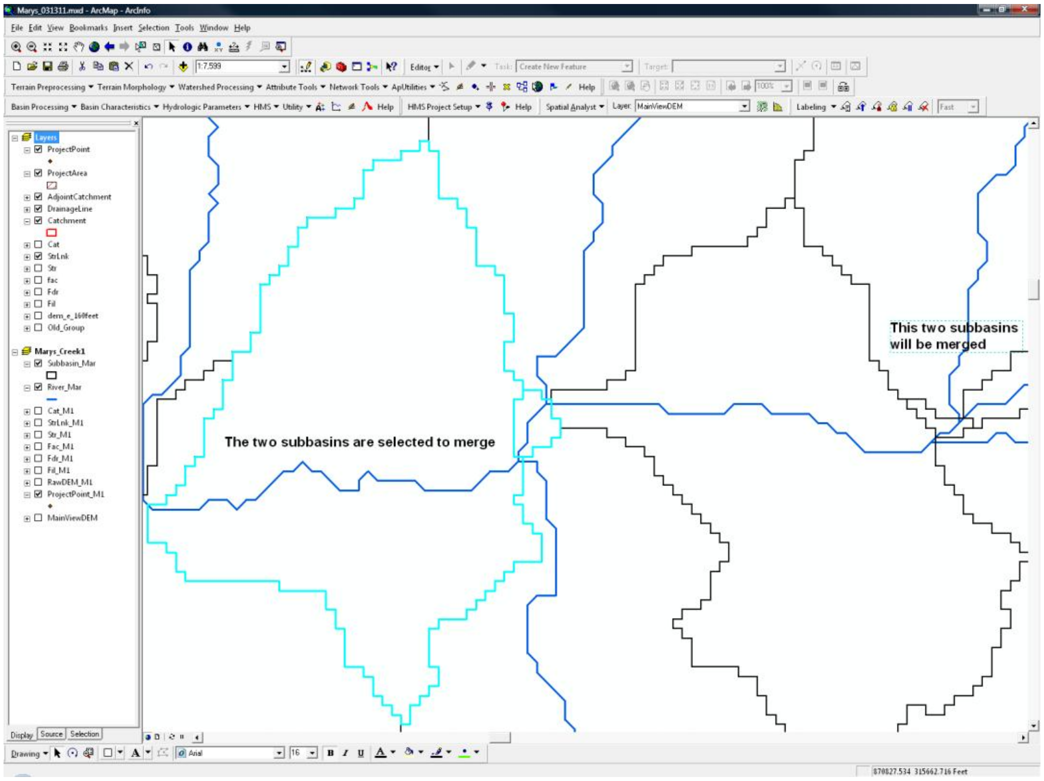


Figure 47. Mary's Creek subbasins outline.

3. Basin processing: Basin processing occurs after the GeoHMS project is completed. The basin processing menu from the GeoHMS project toolbar is used to revise the subbasin delineations and merge multiple subbasins into one large subbasin, if necessary. Also, in merged subbasins, those respective stream segments are merged into one stream. The steps to merge multiple subbasins and multiple streams in one subbasin are as follows:

    - To merge basins, determine the affected basins by visual inspection of the subbasin outline (Figure 47); then select "Basin Merge" from the basin processing menu of the HEC-GeoHMS toolbar. Select the two adjoining basins as shown in Figure 48;

the two subbasins will be highlighted. Click “Basin Merge”, and accept the merge result by pressing “Yes”.

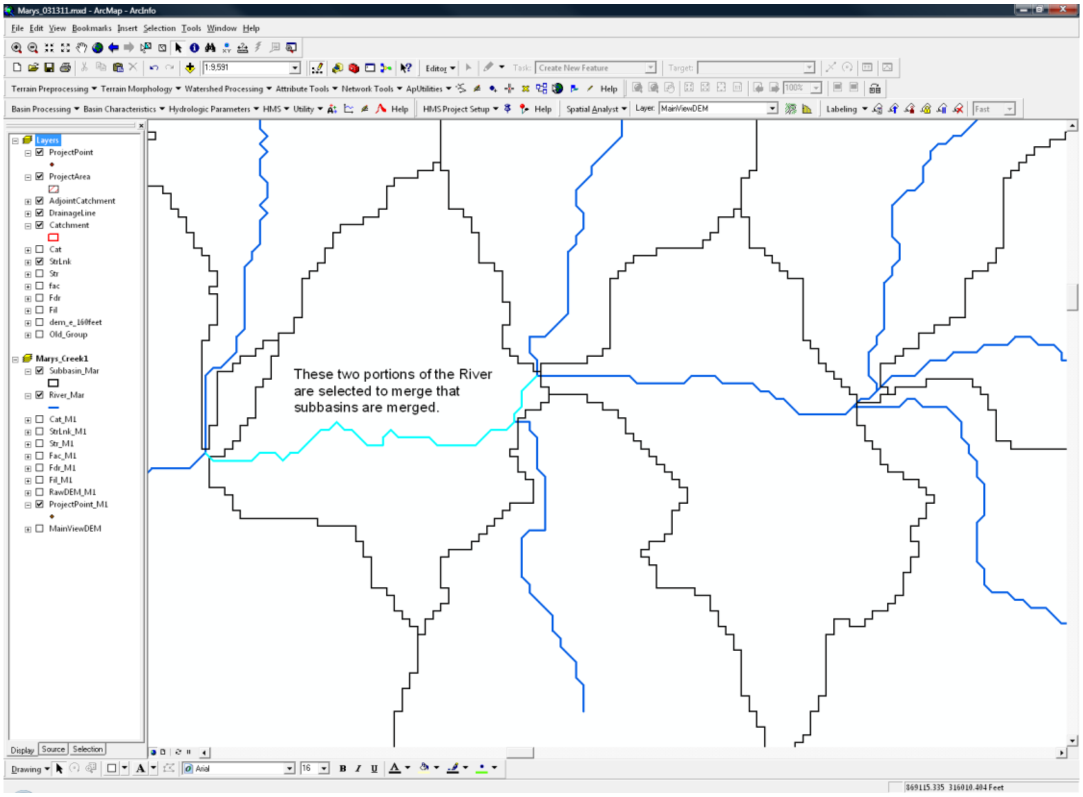


The two subbasins are selected to merge

This two subbasins will be merged

Figure 48. Merge two adjacent subbasins.

- River merge: Subsequently, use “River Merge” from the basin processing menu of the HEC-GeoHMS toolbar to merge two stream lengths. Select the two streams in the same subbasins previously merged (as shown in Figure 49); the two streams will be highlighted. Click “River Merge”, and accept the merge result by pressing “Yes”. The two stream segments will become one. Continue repeating the process until all basins and stream sections that have been tagged for merging have been completed.



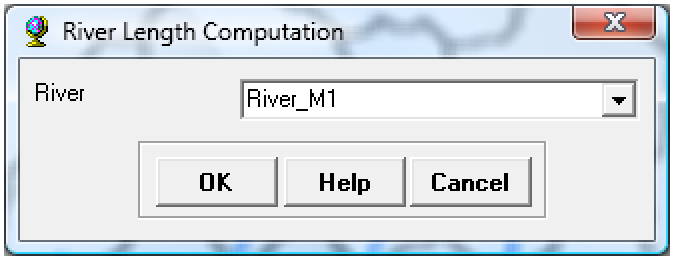
These two portions of the River are selected to merge that subbasins are merged.

Figure 49. River merge.

4. Extracting basin characteristics and parameters: Next, go to the basin characteristics menu in the HEC-GeoHMS project. View provides tools for extracting hydrologic characteristics of streams and subbasins, such as river length, river slope, basin slope, longest flow path, centroid of subbasin, centroidal elevation, and centroidal flow path.

All of the data generated by the program are stored in attribute tables, with elevation in meters and slope in meters per feet for the current study. The elevation and slope are converted from meters to feet by multiplying by 3.2808. In the current study, the watershed tool in the Arc Hydro menu was used to calculate the longest flow path because the longest flow path tool in the basin characteristics menu did not execute the command and created an error message.

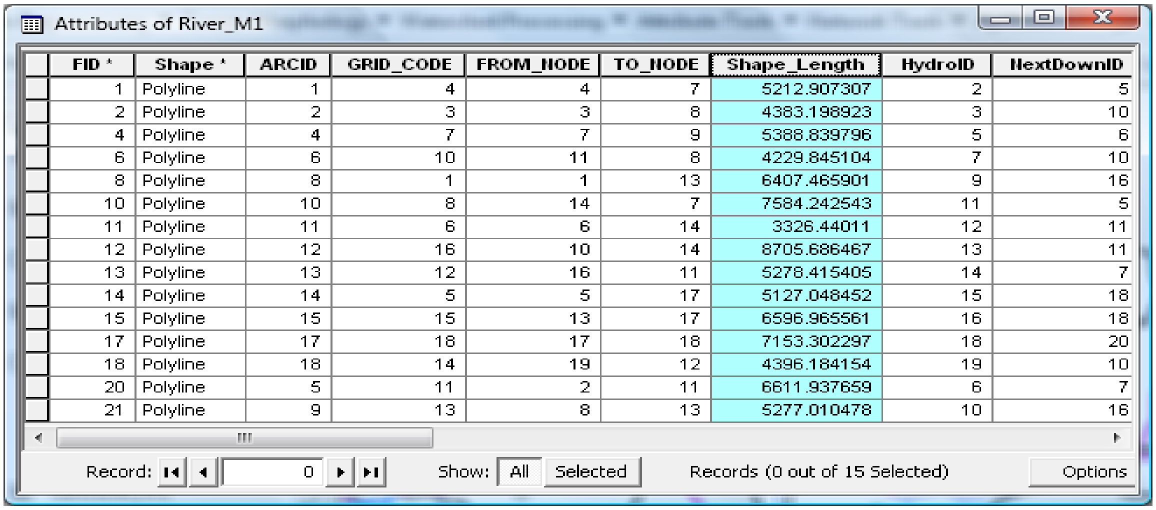
River length. Select river length from the basin characteristics menu of HEC-GeoHMS toolbars. The “River Length Computation” dialog box will open (see Figure 50); press “OK” to compute the river length.



River: River_M1

Figure 50. “River Length Computation” dialog box.

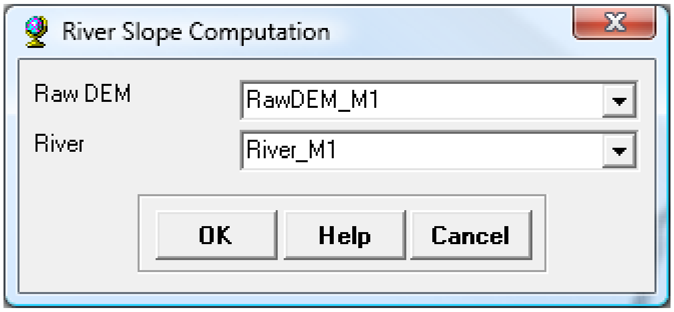
Right-click the river layer in the ”Marys_creek1” layer lists. The menu will open. Click Open Attribute Table. The attribute table of Mary’s Creek subbasin river lengths will display as shown in Figure 51.



FID *	Shape *	ARCID	GRID_CODE	FROM_NODE	TO_NODE	Shape_Length	HydroID	NextDownID
1	Polyline	1	4	4	7	5212.907307	2	5
2	Polyline	2	3	3	8	4383.198923	3	10
4	Polyline	4	7	7	9	5388.839796	5	6
6	Polyline	6	10	11	8	4229.845104	7	10
8	Polyline	8	1	1	13	6407.465901	9	16
10	Polyline	10	8	14	7	7584.242543	11	5
11	Polyline	11	6	6	14	3326.44011	12	11
12	Polyline	12	16	10	14	8705.686467	13	11
13	Polyline	13	12	16	11	5278.415405	14	7
14	Polyline	14	5	5	17	5127.048452	15	18
15	Polyline	15	15	13	17	6596.965561	16	18
17	Polyline	17	18	17	18	7153.302297	18	20
18	Polyline	18	14	19	12	4396.184154	19	10
20	Polyline	5	11	2	11	6611.937659	6	7
21	Polyline	9	13	8	13	5277.010478	10	16

Figure 51. Attribute table for the stream lengths of the Mary’s Creek subbasin.

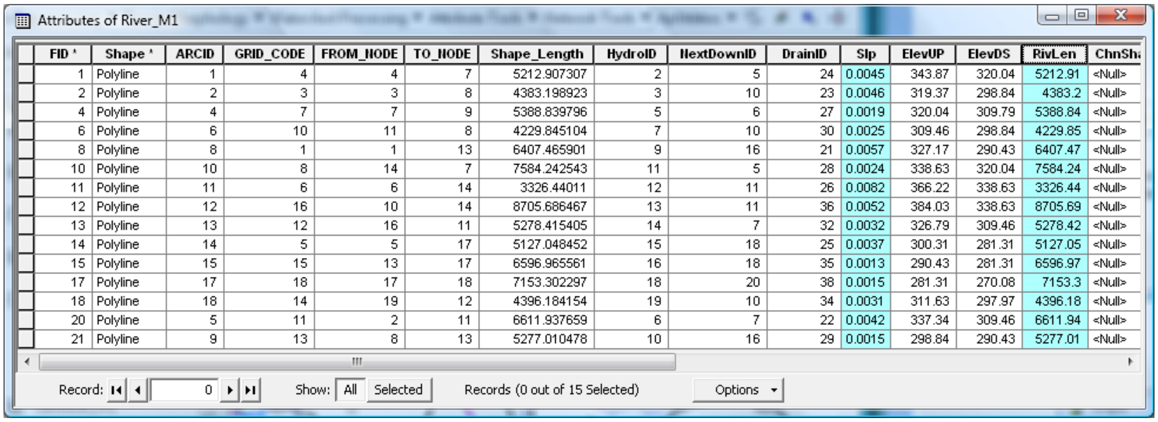
River slope. Select “River Slope” from the basin characteristics menu of the HEC-GeoHMS toolbar. The “River Slope Computation” dialog box will open (see Figure 52). Select the “OK” button to compute the river slope.



Raw DEM: RawDEM_M1
River: River_M1

Figure 52. “River Slope Computation” dialog box.

Right-click the river layer in the “Marys_creek1” layer lists. The menu will open. Click the Open Attribute Table. The attribute table of Mary’s Creek subbasin river lengths and slopes will display as shown in Figure 53.



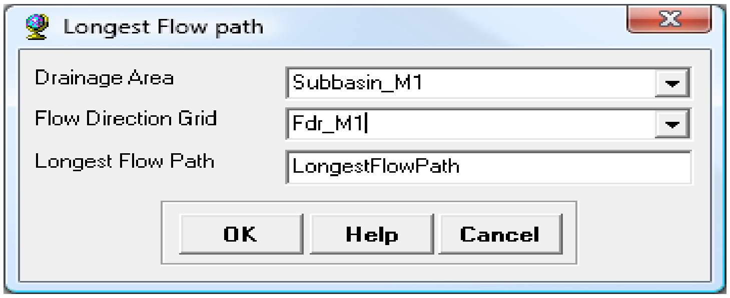
Attributes of River_M1

FID *	Shape *	ARCID	GRID_CODE	FROM_NODE	TO_NODE	Shape_Length	HydroID	NextDownID	DrainID	Slp	ElevUP	ElevDS	RivLen	ChnSh
1	Polyline	1	4	4	7	5212.907307	2	5	24	0.0045	343.87	320.04	5212.91	<Null>
2	Polyline	2	3	3	8	4383.198923	3	10	23	0.0046	319.37	298.84	4383.2	<Null>
4	Polyline	4	7	7	9	5388.839796	5	6	27	0.0019	320.04	309.79	5388.84	<Null>
6	Polyline	6	10	11	8	4229.845104	7	10	30	0.0025	309.46	298.84	4229.85	<Null>
8	Polyline	8	1	1	13	6407.465901	9	16	21	0.0057	327.17	290.43	6407.47	<Null>
10	Polyline	10	8	14	7	7584.242543	11	5	28	0.0024	338.63	320.04	7584.24	<Null>
11	Polyline	11	6	6	14	3326.44011	12	11	26	0.0082	366.22	338.63	3326.44	<Null>
12	Polyline	12	16	10	14	8705.686467	13	11	36	0.0052	384.03	338.63	8705.69	<Null>
13	Polyline	13	12	16	11	5278.415405	14	7	32	0.0032	326.79	309.46	5278.42	<Null>
14	Polyline	14	5	5	17	5127.048452	15	18	25	0.0037	300.31	281.31	5127.05	<Null>
15	Polyline	15	15	13	17	6596.965561	16	18	35	0.0013	290.43	281.31	6596.97	<Null>
17	Polyline	17	18	17	18	7153.302297	18	20	38	0.0015	281.31	270.08	7153.3	<Null>
18	Polyline	18	14	19	12	4396.184154	19	10	34	0.0031	311.63	297.97	4396.18	<Null>
20	Polyline	5	11	2	11	6611.937659	6	7	22	0.0042	337.34	309.46	6611.94	<Null>
21	Polyline	9	13	8	13	5277.010478	10	16	29	0.0015	298.84	290.43	5277.01	<Null>

Record: 0 Show: All Selected Records (0 out of 15 Selected) Options

Figure 53. Attribute table for the stream lengths and slopes within the Mary's Creek subbasin.

Longest flow path. The longest flow path is the greatest distance from the subbasin outlet along the stream length to a point on the subbasin divide. Select "Longest Flow Path" from the watershed processing menu of the Arc Hydro toolbar. The "Longest Flow Path" dialog box will open (see Figure 54). Verify the drainage area "Subbasin_M1" and flow direction grid "Fdr_M1". Accept the default name for the longest flow path. Press the "OK" button to compute the longest flow path. A new data layer will be added to the layer list of Marys_Creek1 project named "Longest Flow Path". The longest flow path map will display as seen in Figure 55.



Longest Flow path

Drainage Area: Subbasin_M1

Flow Direction Grid: Fdr_M1

Longest Flow Path: LongestFlowPath

Figure 54. "Longest Flow path" dialog box.

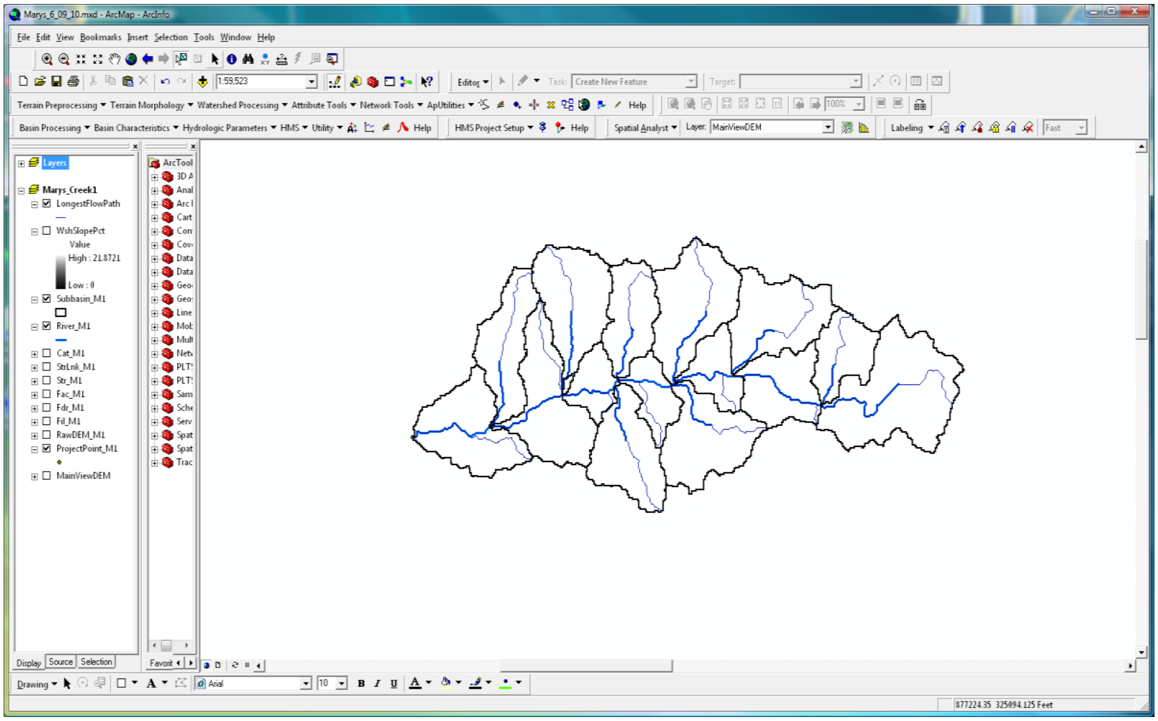
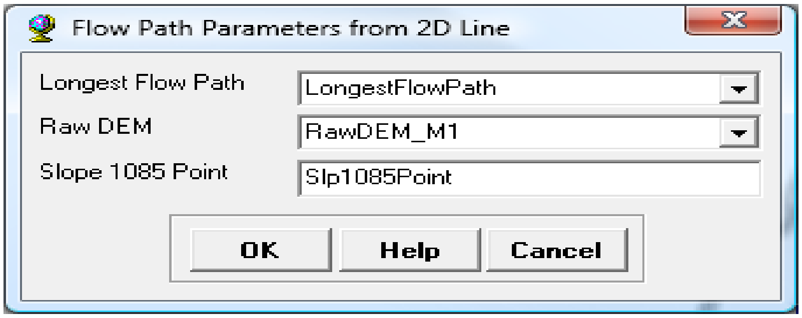


Figure 55. Longest flow path map.

Select “Flow Path Parameters from 2D Line” from the longest flow path parameters of the watershed menu of the Arc Hydro toolbar. A dialog box will open. Confirm the input layers. Accept the default name for the slope (see Figure 56).



Flow Path Parameters from 2D Line

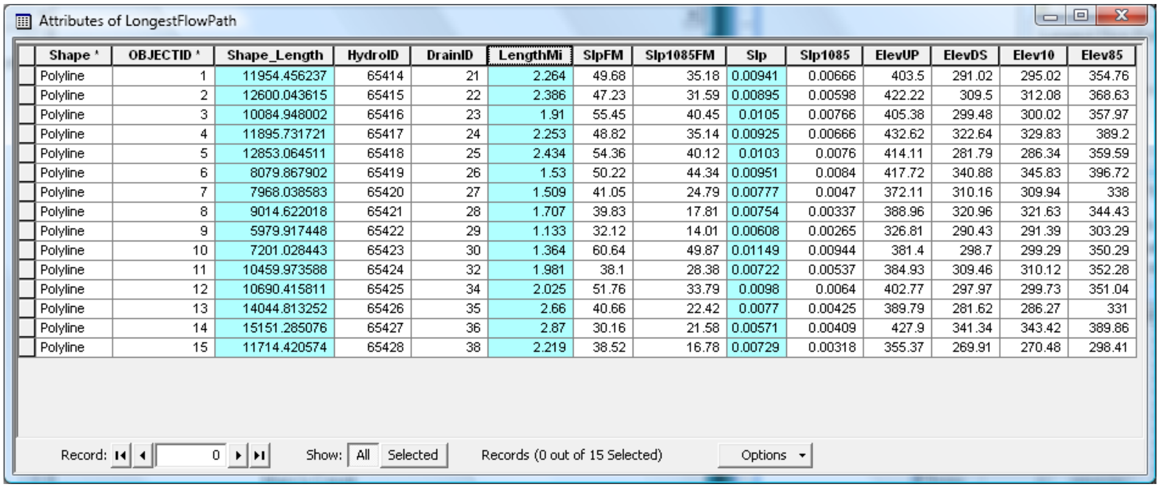
Longest Flow Path: LongestFlowPath

Raw DEM: RawDEM_M1

Slope 1085 Point: Slp1085Point

Figure 56. “Flow Path Parameters from 2D Line” dialog box.

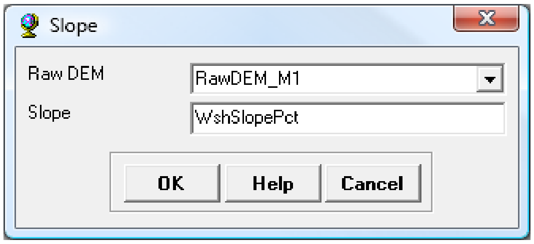
Right-click the longest flow path from the “Marys_creek1” layer lists. The menu will open. Click Open Attribute Table. The attribute table of Mary’s Creek subbasin’s longest flow path length and slope will display (see Figure 57).



Shape *	OBJECTID *	Shape_Length	HydroID	DrainID	LengthMi	SlpFM	Slp1085FM	Slp	Slp1085	ElevUP	ElevDS	Elev10	Elev85
Polyline	1	11954.456237	65414	21	2.264	49.68	35.18	0.00941	0.00666	403.5	291.02	295.02	354.76
Polyline	2	12600.043615	65415	22	2.386	47.23	31.59	0.00895	0.00598	422.22	309.5	312.08	368.63
Polyline	3	10084.948002	65416	23	1.91	55.45	40.45	0.0105	0.00766	405.38	299.48	300.02	357.97
Polyline	4	11895.731721	65417	24	2.253	48.82	35.14	0.00925	0.00666	432.62	322.64	329.83	389.2
Polyline	5	12853.064511	65418	25	2.434	54.36	40.12	0.0103	0.0076	414.11	281.79	286.34	359.59
Polyline	6	8079.867902	65419	26	1.53	50.22	44.34	0.00951	0.0084	417.72	340.88	345.83	396.72
Polyline	7	7968.038583	65420	27	1.509	41.05	24.79	0.00777	0.0047	372.11	310.16	309.94	338
Polyline	8	9014.622018	65421	28	1.707	39.83	17.81	0.00754	0.00337	388.96	320.96	321.63	344.43
Polyline	9	5979.917448	65422	29	1.133	32.12	14.01	0.00608	0.00265	326.81	290.43	291.39	303.29
Polyline	10	7201.028443	65423	30	1.364	60.64	49.87	0.01149	0.00944	381.4	298.7	299.29	350.29
Polyline	11	10459.973588	65424	32	1.981	38.1	28.38	0.00722	0.00537	384.93	309.46	310.12	352.28
Polyline	12	10690.415811	65425	34	2.025	51.76	33.79	0.0098	0.0064	402.77	297.97	299.73	351.04
Polyline	13	14044.813252	65426	35	2.66	40.66	22.42	0.0077	0.00425	389.79	281.62	286.27	331
Polyline	14	15151.285076	65427	36	2.87	30.16	21.58	0.00571	0.00409	427.9	341.34	343.42	389.86
Polyline	15	11714.420574	65428	38	2.219	38.52	16.78	0.00729	0.00318	355.37	269.91	270.48	298.41

Figure 57. Attribute table of longest flow path.

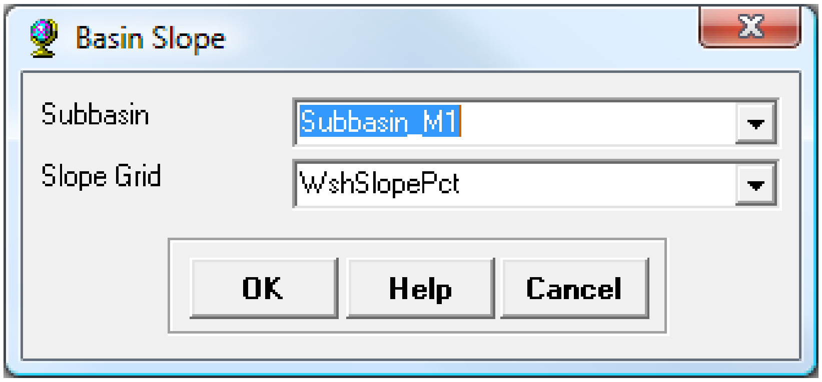
Basin slope. To generate a watershed slope for Mary’s Creek, select “Slope” from the terrain preprocessing menu of the Arc Hydro toolbar. A dialog box will open (see Figure 58). Verify the raw DEM as “RawDem_M1”. Accept the default slope layer name of ”WshSlopePct”, and the “WshSlopePct” will be added to the layer list.



Raw DEM: RawDEM_M1
Slope: WshSlopePct

Figure 58. “Slope” dialog box.

Next, select “Basin Slope” from the basin characteristics menu of the HEC-GeoHMS toolbar. The basin slope computation dialog box will open (see Figure 59). Select the “OK” button to compute the slope of each subbasin (see Figure 60).


Basin Slope

Subbasin: Subbasin_M1

Slope Grid: WshSlopePct

Figure 59. “Basin Slope” dialog box.

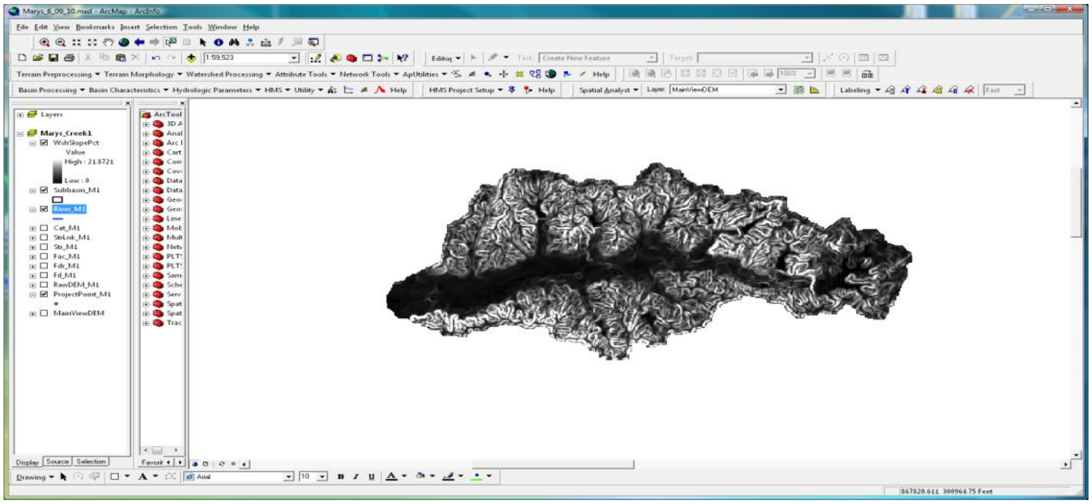
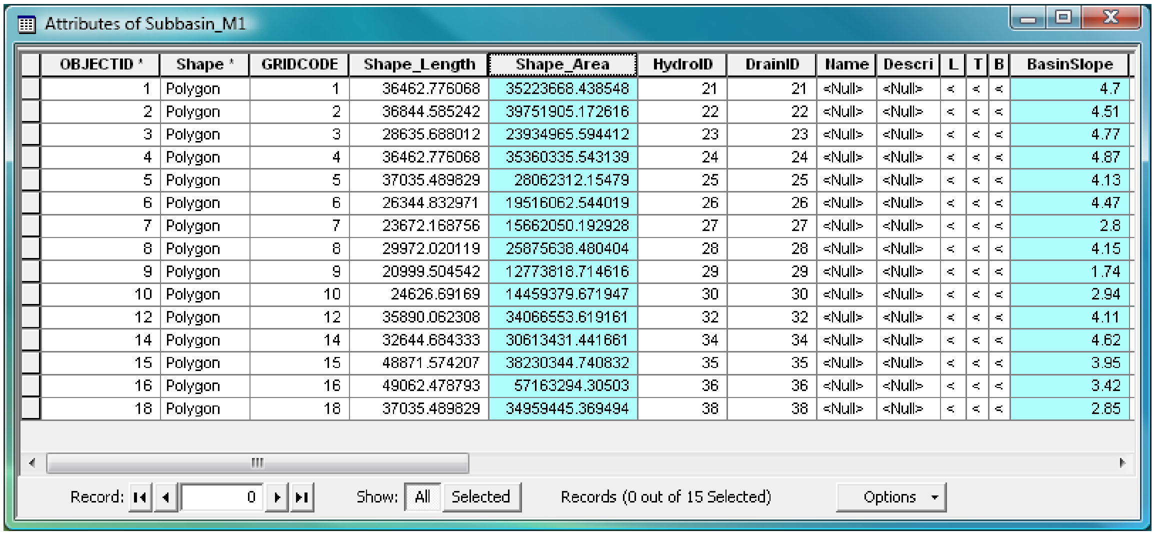


Figure 60. Mary’s Creek basin slope.

Right-click the subbasin_M1 in the “Marys_Creek1” layer lists. The menu will open. Click Open Attribute Table. The attribute table basin slope of Mary’s Creek subbasins will display as shown in Figure 61.



OBJECTID *	Shape *	GRIDCODE	Shape_Length	Shape_Area	HydroID	DrainID	Name	Descri	L	T	B	BasinSlope
1	Polygon	1	36462.776068	35223668.438548	21	21	<Null>	<Null>	<	<	<	4.7
2	Polygon	2	36844.585242	39751905.172616	22	22	<Null>	<Null>	<	<	<	4.51
3	Polygon	3	28635.688012	23934965.594412	23	23	<Null>	<Null>	<	<	<	4.77
4	Polygon	4	36462.776068	35360335.543139	24	24	<Null>	<Null>	<	<	<	4.87
5	Polygon	5	37035.489829	28062312.15479	25	25	<Null>	<Null>	<	<	<	4.13
6	Polygon	6	26344.832971	19516062.544019	26	26	<Null>	<Null>	<	<	<	4.47
7	Polygon	7	23672.168756	15662050.192928	27	27	<Null>	<Null>	<	<	<	2.8
8	Polygon	8	29972.020119	25875638.480404	28	28	<Null>	<Null>	<	<	<	4.15
9	Polygon	9	20999.504542	12773818.714616	29	29	<Null>	<Null>	<	<	<	1.74
10	Polygon	10	24626.69169	14459379.671947	30	30	<Null>	<Null>	<	<	<	2.94
12	Polygon	12	35890.062308	34066553.619161	32	32	<Null>	<Null>	<	<	<	4.11
14	Polygon	14	32644.684333	30613431.441661	34	34	<Null>	<Null>	<	<	<	4.62
15	Polygon	15	48871.574207	38230344.740832	35	35	<Null>	<Null>	<	<	<	3.95
16	Polygon	16	49062.478793	57163294.30503	36	36	<Null>	<Null>	<	<	<	3.42
18	Polygon	18	37035.489829	34959445.369494	38	38	<Null>	<Null>	<	<	<	2.85

Figure 61. Attributes of Subbasin_M1.

The Mary’s Creek subbasin was delineated as observed in Figure 62. All of the subbasins that were generated were labeled according to the DrainID in the attribute table from smallest DrainID to largest DrainID, as illustrated in Figure 63.

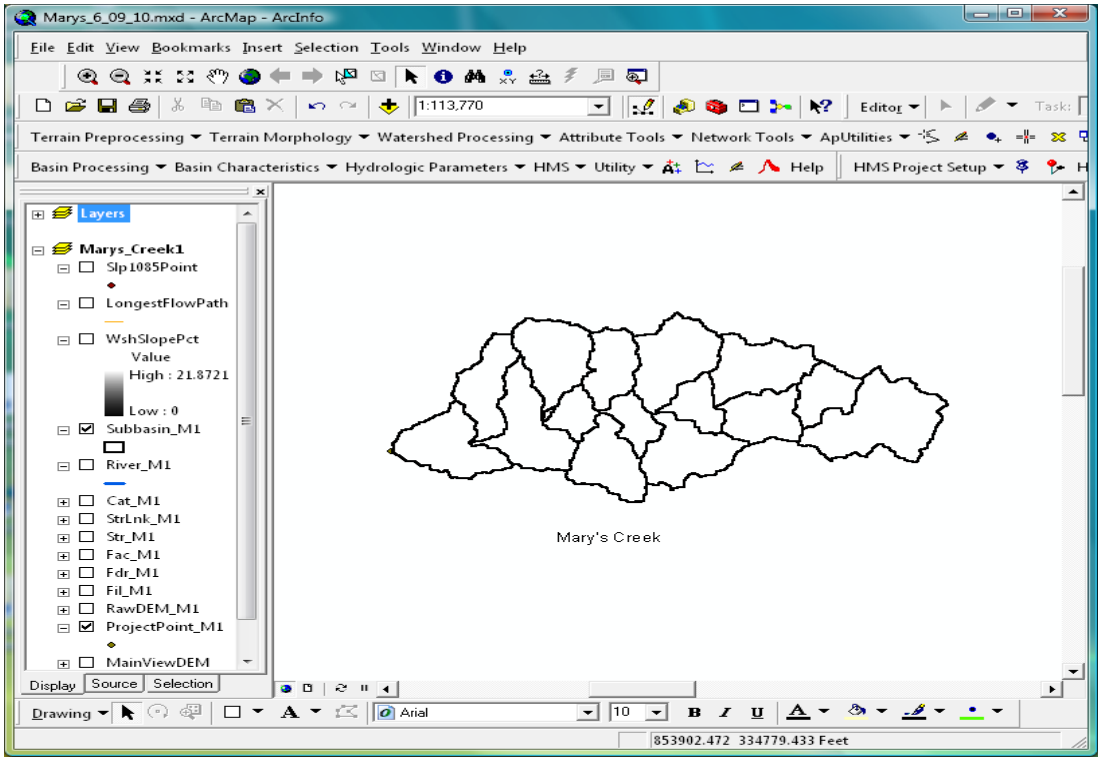


Figure 62. Mary’s Creek subbasin.

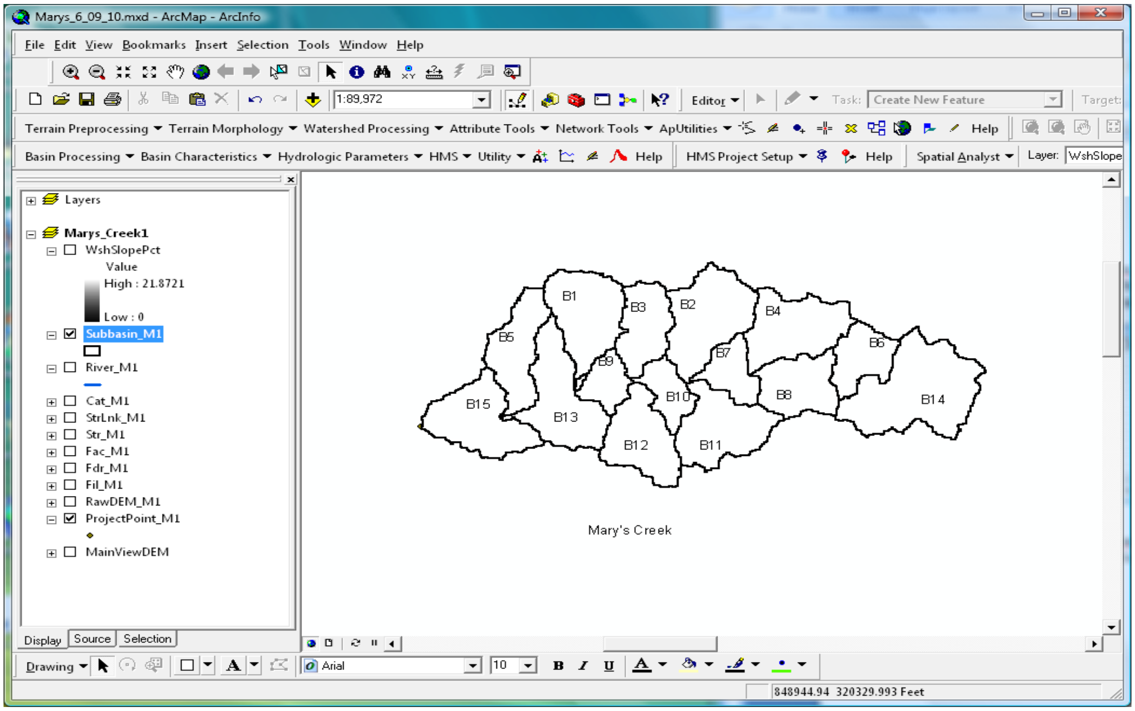


Figure 63. Mary’s Creek subbasin, labeled.

Select Basin Centroid from the basin characteristics menu of the HEC-GeoHMS toolbar. The basin “Centroid Computation Method” dialog box will open (see Figure 64). Select the “Center of Gravity Method”, and press the “OK” button to compute. A new dialog box will appear (see Figure 65). Accept the default name for the centroid layer. The centroid data layer will be added to the layer list, and the centroid of each subbasin will display in the map as shown in Figure 66.

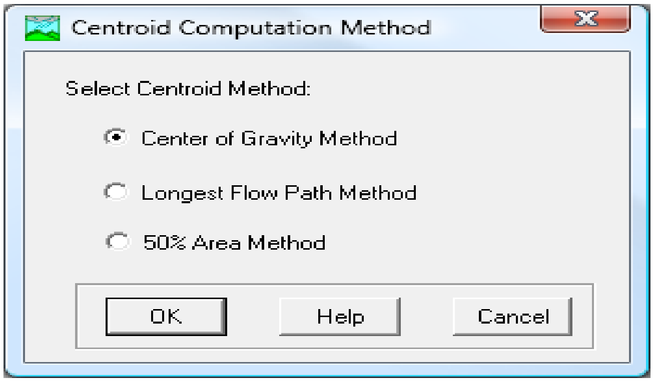
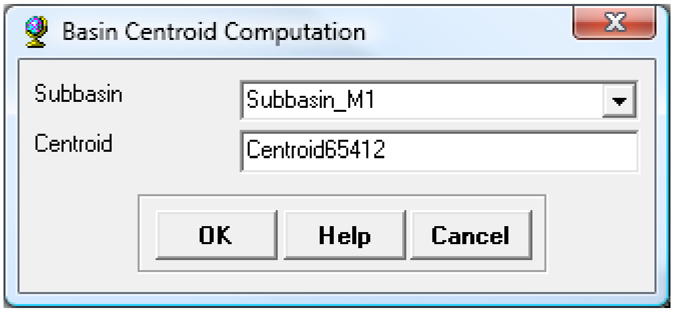


Figure 64. “Centroid Computation Method” dialog box.



Subbasin: Subbasin_M1

Centroid: Centroid65412

Figure 65. “Basin Centroid Computation” dialog box.

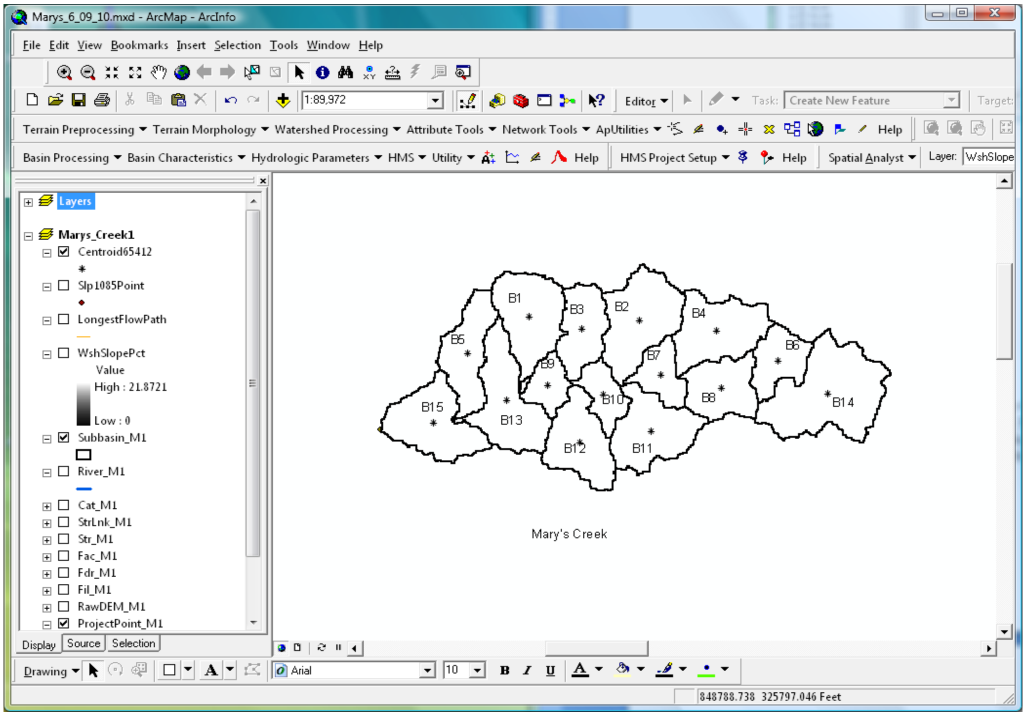
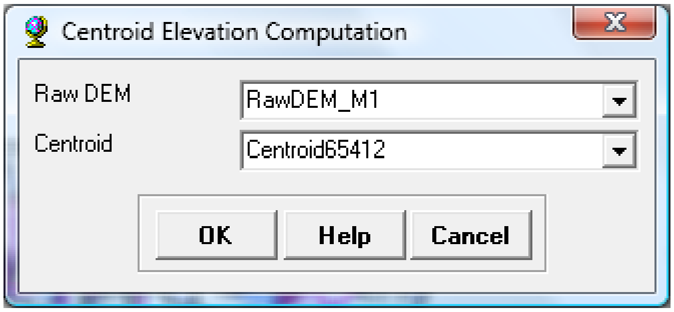


Figure 66. Centroids of the subbasins.

Centroid elevation. Select the Centroid Elevation from the basin characteristics menu of the HEC-GeoHMS toolbar. The “Centroid Elevation Computation” dialog box will open (see Figure 67). Select the “OK” button to compute.

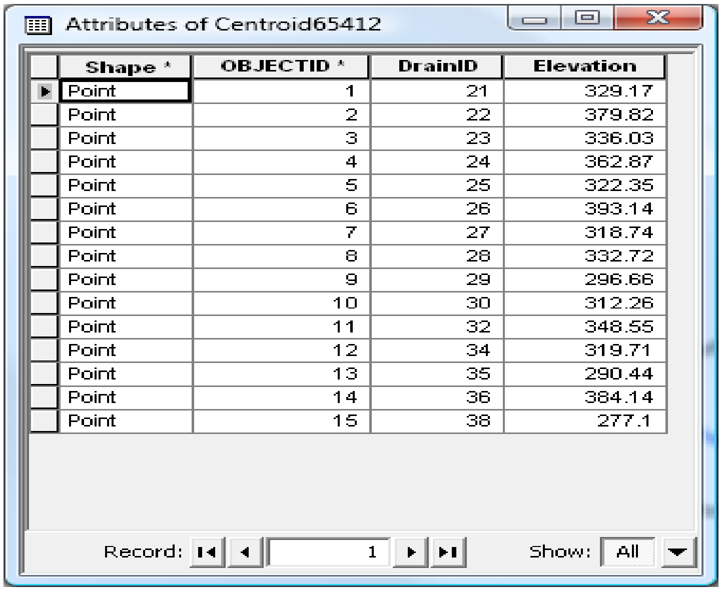

Centroid Elevation Computation

Raw DEM: RawDEM_M1

Centroid: Centroid65412

Figure 67. “Centroid Elevation Computation” dialog box.

Right-click the “Centroid65412” layer in the “Marys_Creek1” layer lists. A menu will open. Click Open Attribute Table. The attribute table of Mary’s Creek subbasin centroids will display as shown in Figure 68.



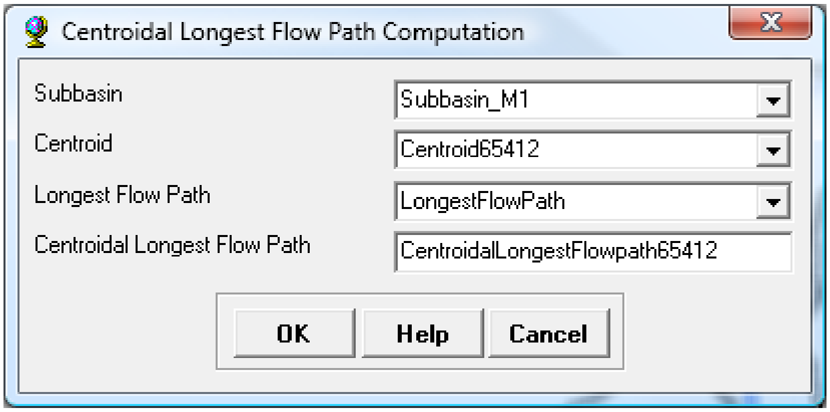
Shape *	OBJECTID *	DrainID	Elevation
Point	1	21	329.17
Point	2	22	379.82
Point	3	23	336.03
Point	4	24	362.87
Point	5	25	322.35
Point	6	26	393.14
Point	7	27	318.74
Point	8	28	332.72
Point	9	29	296.66
Point	10	30	312.26
Point	11	32	348.55
Point	12	34	319.71
Point	13	35	290.44
Point	14	36	384.14
Point	15	38	277.1

Record: 1

Show: All

Figure 68. Attribute Table of Centroid65412.

Centroidal flow path. Select Centroid Flow Path from the basin characteristics menu of the HEC-GeoHMS toolbar. The “Centroidal Longest Flow Path Computation” dialog box will open (see Figure 69). Verify the subbasin “Subbasin_M1” centroid “Centroid65412”, and longest flow path “LongestFlowPath”, and accept the default name for the centroidal longest flow path. Select the “OK” button to compute. The new layer data will be added to the layer list. The centroidal longest flow path of each subbasin will display in the map as shown in Figure 70.



Centroidal Longest Flow Path Computation

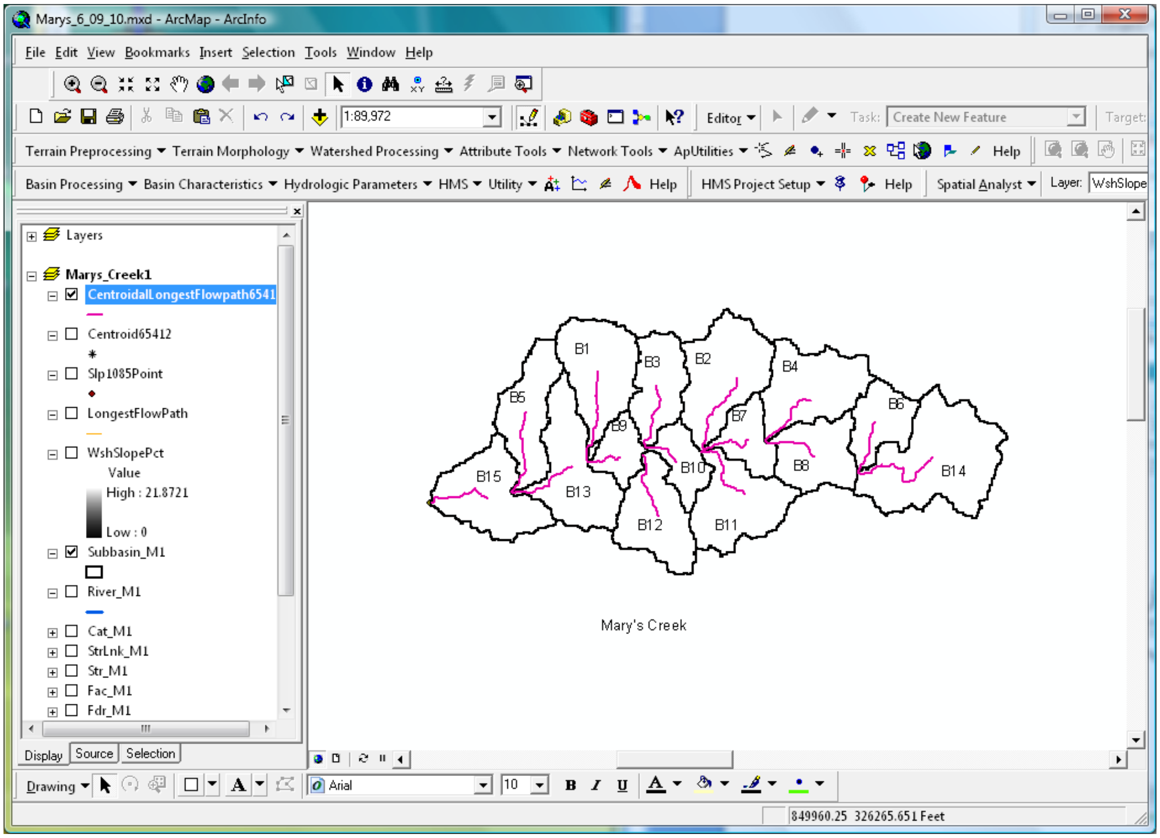
Subbasin: Subbasin_M1

Centroid: Centroid65412

Longest Flow Path: LongestFlowPath

Centroidal Longest Flow Path: CentroidalLongestFlowpath65412

Figure 69. “Centroidal Longest Flow Path Computation” dialog box.

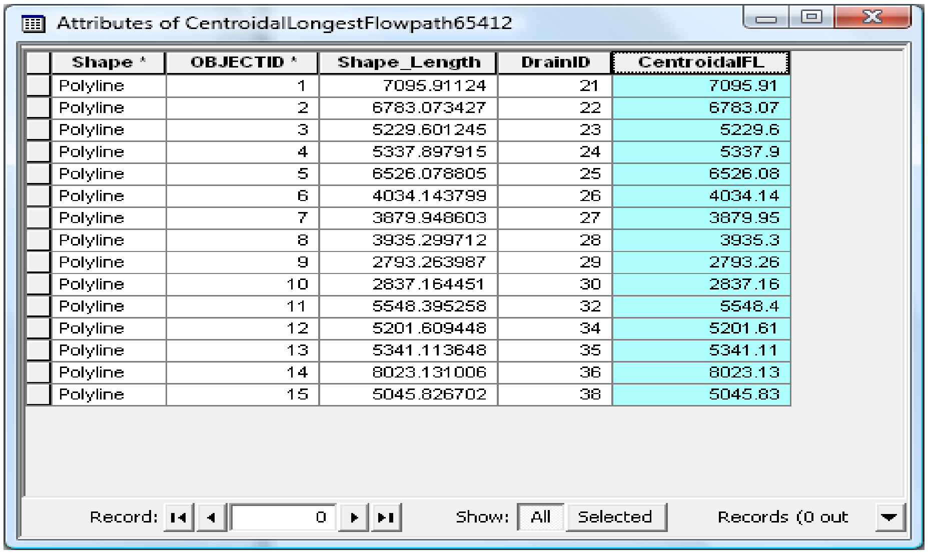


Marys_6_09_10.mxd - ArcMap - ArcInfo

Figure 70. Centroidal longest flow path map.

Right-click the “CentroidLongestFlowpath65412” layer in the”Marys_Creek1” layer lists; the menu will open. Click Open Attribute Table. The attribute table

“CentroidLongestFlowpath65412” of Mary’s Creek subbasins will display as shown in Figure 71.



Shape *	OBJECTID *	Shape_Length	DrainID	CentroidalFL
Polyline	1	7095.91124	21	7095.91
Polyline	2	6783.073427	22	6783.07
Polyline	3	5229.601245	23	5229.6
Polyline	4	5337.897915	24	5337.9
Polyline	5	6526.078805	25	6526.08
Polyline	6	4034.143799	26	4034.14
Polyline	7	3879.948603	27	3879.95
Polyline	8	3935.299712	28	3935.3
Polyline	9	2793.263987	29	2793.26
Polyline	10	2837.164451	30	2837.16
Polyline	11	5548.395258	32	5548.4
Polyline	12	5201.609448	34	5201.61
Polyline	13	5341.113648	35	5341.11
Polyline	14	8023.131006	36	8023.13
Polyline	15	5045.826702	38	5045.83

Figure 71. Centroidal longest flow path attribute table.

The hydrologic characteristics of Mary’s Creek subbasin are shown in the maps in Figures 72 and 73 and in Table 3.

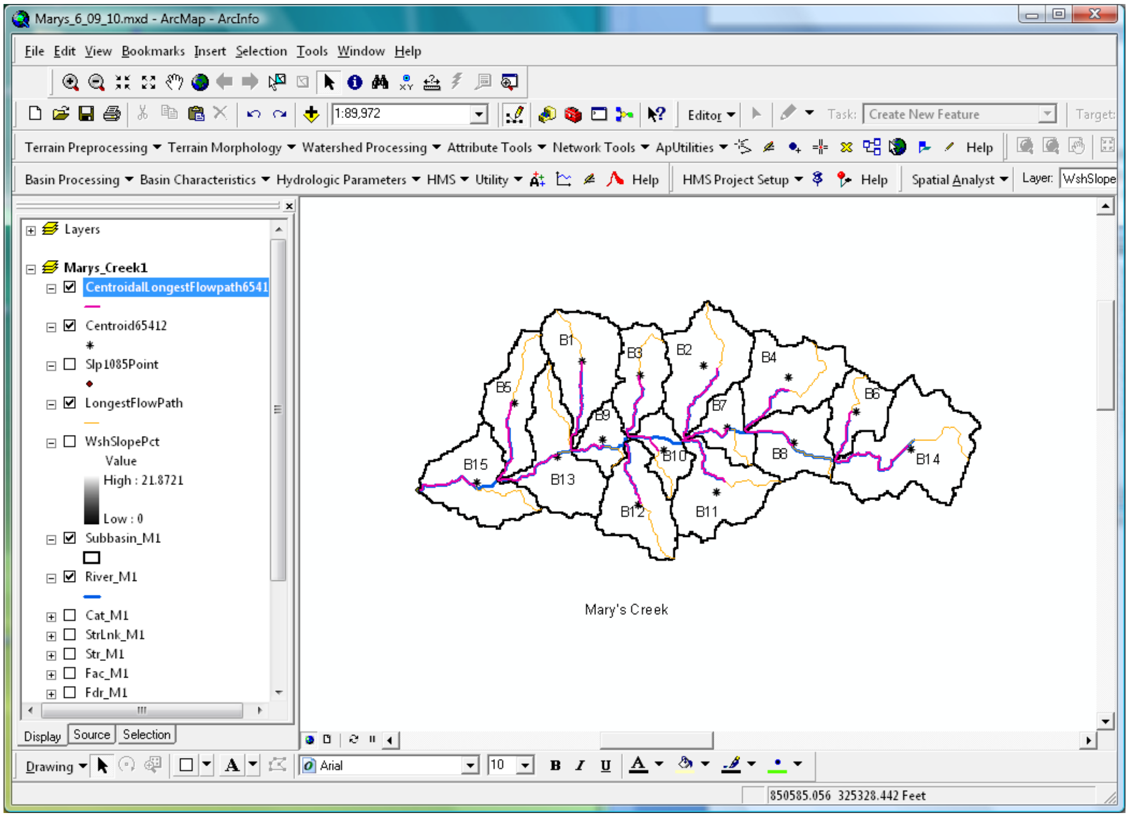


Figure 72. Hydrologic characteristics of Mary’s Creek subbasin.

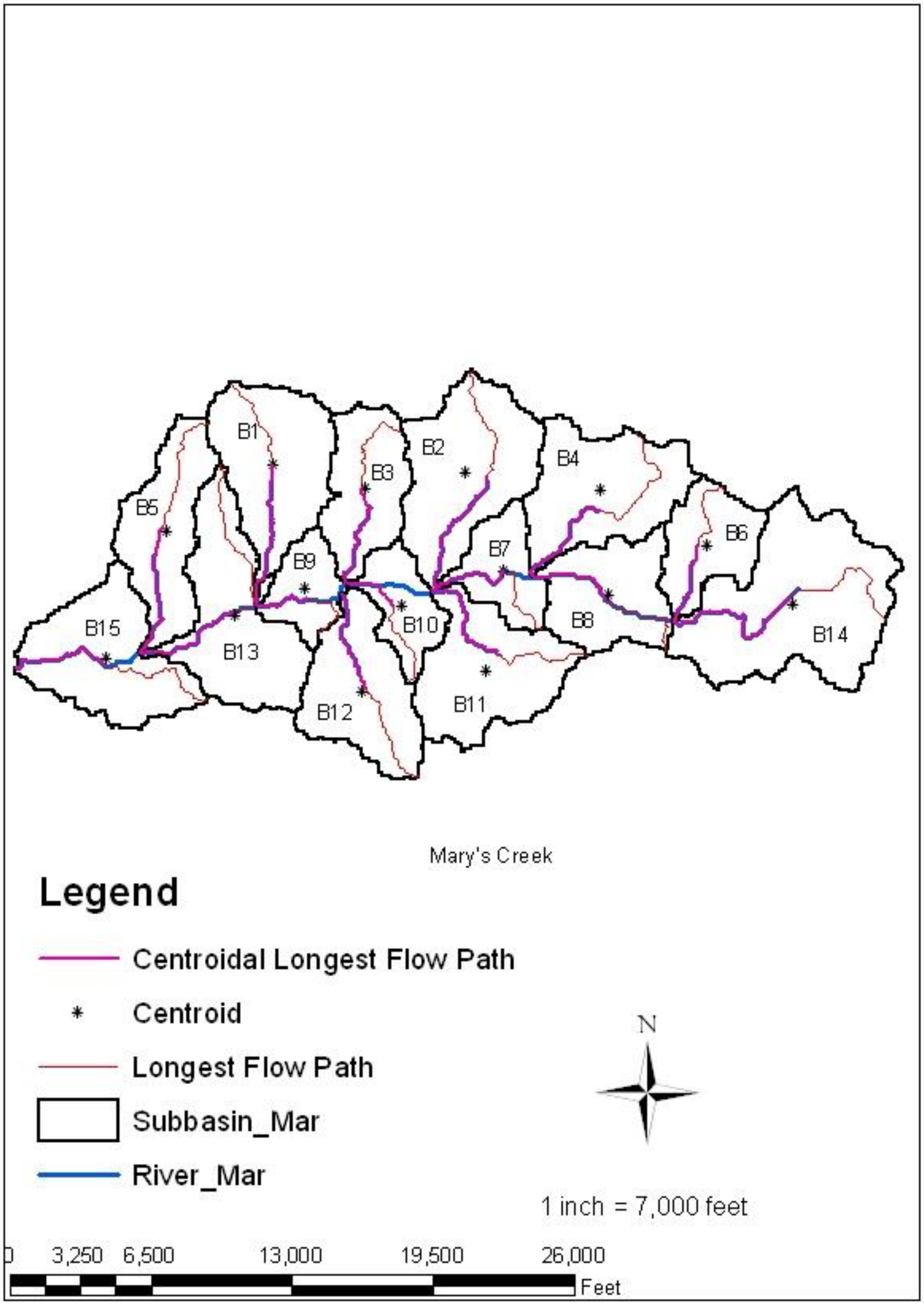


Figure 73. Mary's Creek subbasins map.

Table 3

Hydrologic Characteristics of Mary's Creek Streams and Subbasins

Subbasin No.	Subbasin Area (square feet)	Subbasin Slope (%)	Centroid Elevation (feet)	Longest Flow Path (feet)	Longest Flow Path Slope (feet/feet)	Centroidal Longest Flow Path (feet)	Stream Length (feet)	Stream Slope (feet/feet)
1	35,223,668	4.70	329.17	11,954	0.00941	7,096	6,407	0.00573
2	39,751,905	4.51	379.82	12,600	0.00895	6,783	6,612	0.00422
3	23,934,966	4.77	336.03	10,085	0.01050	5,230	4,383	0.00468
4	35,360,336	4.87	362.87	11,896	0.00925	5,338	5,213	0.00457
5	28,062,312	4.13	322.35	12,853	0.01030	6,526	5,127	0.00371
6	19,516,063	4.47	393.14	8,080	0.00951	4,034	3,326	0.00829
7	15,662,050	2.80	318.74	7,968	0.00777	3,880	5,389	0.00190
8	25,875,638	4.15	332.72	9,015	0.00754	3,935	7,584	0.00245
9	12,773,819	1.74	296.66	5,980	0.00608	2,793	5,277	0.00159
10	14,459,380	2.94	312.26	7,201	0.01149	2,837	4,230	0.00251
11	34,066,554	4.11	348.55	10,460	0.00722	5,548	5,278	0.00328
12	30,613,431	4.62	319.71	10,690	0.00980	5,202	4,396	0.00311
13	38,230,345	3.95	290.44	14,045	0.00770	5,341	6,597	0.00138
14	57,163,294	3.42	384.14	15,151	0.00571	8,023	8,706	0.00522
15	34,959,445	2.85	277.10	11,714	0.00729	5,046	7,153	0.00157

The procedure outlined in this chapter must be repeated for every other subbasin in the Wolf River basin to define their hydrologic characteristics. In all, there were 48 identified creeks and 168 unnamed tributary creeks within the Wolf River basin. These procedures were individually applied to calculate subbasin and hydrologic characteristics each of them and the results can be found in Appendices A and B, respectively.

CHAPTER 4

HYDROLOGIC CHARACTERISTICS

This chapter discusses the calculation of the hydrologic characteristics of streams and subbasins of the Wolf River. The hydrologic characteristics of a stream include stream length, upstream and downstream elevations, and stream slope. Similarly, hydrologic characteristics for a subbasin, such as area, longest flow path, centroidal flow path flow lengths, and slopes, were extracted from terrain data and stored in attribute tables. These hydrologic characteristics can be exported and used externally to estimate hydrologic parameters. The list of the hydrologic characteristics and their corresponding data layers and attribute table headings, extracted from attribute tables of streams and subbasins, appear in Table 4.

Table 4

Hydrologic Characteristic Parameters

Data Layer	Hydrologic Characteristics	Attribute Table Heading
Stream layer	Length	RivLen
	Upstream elevation	ElevUP
	Downstream elevation	ElevDS
	Slope	Slp
Subbasin layer	Area	Area
	Slope	Slp
Centroid layer	Centroid elevation	Elevation
Longest flow path layer	Longest flow length	LongestFL
	Upstream elevation	ElevUS
	Downstream elevation	ElevDS
	Slope between endpoints	Slp
Centroidal flow path	Centroidal length	CentroidalFL

Stream and Basin Characteristics

The topographic characteristics of a basin and a stream determine the hydrology of a basin or subbasin. These parameters have an effect on the catchment stream flow pattern through their effect on the time of concentration. Hydrologic studies of basins normally require the stream characteristics length and slope. Subbasin parameters are area, slope, centroid elevation, longest flow path, and centroidal flow path. After delineating the basin and subbasin, it is then possible to collect subbasin and stream data.

The hydrologic parameters extracted by the GeoHMS include the river length, river slope, area of the subbasins, subbasin centroid, elevation, longest flow path of the subbasin, and centroidal flow path of the subbasin. Each of these parameters is saved to an attribute table. The physical parameters are calculated and copied to Excel spreadsheets (as shown in Appendices A and B). At the first stage of analysis, they were used to determine lag time or time of concentration.

Stream Hydrologic Characteristics

The *river length* of a subbasin is the length of the main stream (channel) inside the subbasin, and it is measured from the outlet of the subbasin along an upstream channel to the last grid of the stream segment as defined by the threshold limit. The stream flow of the subbasin depends on the outflow of the upstream channel. In all of the hydrologic equations, time of concentration is dependent on physical parameters such as the longest flow path and basin slope. A *river slope* is the slope of a stream bed in the subbasin. The *stream slope* is the rate of change of elevation from upstream to downstream. The topographic parameters of a basin and subbasin affect basin and subbasin hydrology through their influence on time of concentration. Usually, time of concentration will decrease and runoff volume will increase with increasing channel slope.

Since streams are open channels, the stream length and slope parameters are used to determine the velocity of flow and travel time by using open-channel hydrologic equations. Both the channel length and bottom slope are used with other channel parameters, such as geometry and roughness, to estimate the flood runoff. These parameters are fundamental elements for flood plain analysis by any of the following methods: Muskingum-Cunge, kinematic wave model, and modified Puls (Wurbs & James, 2007).

The river length and slope tools in the basin characteristics menu of the GeoHMS toolbar are used to calculate river length and slope. The data generated by the program are upstream and downstream elevations and length of the stream. The calculated slope is in units of meters per feet because the vertical unit of the Digital Elevation Model (DEM) is not converted into feet and does not convert when imported. The program will assume that the vertical units are the same as the horizontal units. Converted stream slope is multiplied by 3.28083 to convert to feet per feet, as shown in the tables in Appendices A and B.

Channel length and slope can be extracted from the DEM data, but average width and depth are not as easily extracted. Ames, D. P., Rafn, E. B., Kirk, R. V., and Crosby, B. (2009) explained that the U.S. Environmental

Protection Agency (EPA) Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) watershed analysis system currently includes functions for estimating an average bankfull width and depth. The equations used in the BASINS software to estimate stream width and depth, respectively, are $W = 1.29A^{0.6}$ and $D = 0.13A^{0.4}$. where W = bankfull channel width (m); D = bankfull channel depth (m); and A = drainage area (km^2). Average depth and bankfull width can be calculated for a rectangular channel but cannot account for basin parameters. The benefit of both of the above equations is that they serve as reliable average width and depth predictors when applied nationally.

Subbasin Hydrologic Characteristics (Physical Parameters)

The physical parameters of subbasins are drainage area, slope, centroid, longest flow path, and centroidal flow path. A *drainage area* is one of the most important hydrologic characteristics that reflect the amount of water that can be collected from rainfall. Runoff volume increases in proportion to the size of the subbasin. The subbasin size is the boundary of the subbasin. The subbasin area is required as input data to a hydrologic model of a computer program (HEC-GeoHMS) or any equation to determine runoff volume. In addition, Solyom and Tucker (2007) found that the storm runoff volume that accumulates in a catchment area is linearly comparative to the catchment's volume and independent of its shape for a spatially homogeneous rainfall and infiltration. If the rainfall period is long as compared to the maximum travel time in the catchment, the resulting discharge will be steady, and peak flows will be linearly related to the catchment area. These circumstances are abnormal in large catchments. Total runoff is fairly insensitive to the shape of the catchment, as long as the storm falls next to the center of the catchment.

The Arc Hydro tool in the Geographic Information System (GIS) is used to calculate an accurate area of the basin by using DEMs. The subbasin area and slope are calculated by using the basin slope tool in the basin characteristics menu on the GeoHMS toolbar. The data generated by the program are stored in the attribute table. *Subbasin slope* is the average value of a grid slope for each subbasin and is one of the key hydrologic factors of the subbasin. It is used for the computation of the lag time parameter. In general, the average subbasin slope is greater than the channel slope because the side slopes of the subbasin are always steeper than the channel. Since the slope is steeper, volumes of rain collect faster at the outlet and create the flood.

The *subbasin centroid* is defined as a point at the center of the subbasin. The centroid of the subbasin is necessary to develop the Hydrologic Modeling System (HMS) model because the centroidal longest flow path depends on the subbasin centroid as discussed above. There are several options for the calculation of the subbasin centroid. The method used in the current study is the “center of gravity.” Other methods can be used if the subbasin’s center of gravity lies outside the subbasin. The subbasin centroid elevation is stored in the basin centroid shape file.

The *longest flow path* is one of the fundamental subbasin parameters. The length of the longest flow path is the distance that water travels from the boundary of the basin to the outlet and is required for the time of concentration calculations. The longest flow path may not follow the river path through the subbasin. The length, the top and bottom elevation, and the slope of longest flow path are generated by the program and are stored in the attribute table. Many equations have been developed to calculate the travel time of a drop of rain from the highest point to the outlet of a subbasin. In all of the equations, the time of concentration increases in proportion to the length of the longest flow path if the subbasin is flat.

The *centroidal flow path* is the length of flow of a drop of rain from the centroid of a subbasin to the outlet of the subbasin, and it uses the same path as the longest flow path. The centroidal flow path used to compute the time of concentration is generated by the GeoHMS program and is stored in the attribute table.

Hydrologic Equation

The hydrologic characteristic parameters are important parameters used to calculate the time of concentration or lag time of the subbasin. The *lag time* is the time between the center of mass of the rainfall and the peak of the runoff hydrograph. The *time of concentration* is the travel time of rainfall from the most remote point of a subbasin to the subbasin outlet. The lag time can be calculated by using several different methods based on the size and slope of the watershed being selected. These are described next. Municipalities located in the Wolf River basin area can choose the appropriate equation to perform hydrologic studies.

The Kirpich equation. Fang et al. (2008) points out that Kirpich (1940) developed an empirical equation to estimate time of concentration (t_C) in hours for small watersheds in Tennessee.

$$t_C = 5.735 L^{0.77} S^{0.38},$$

where t_C = time of concentration in minutes; L = length of the main stream in miles; and S = slope in ft/ft. The watershed sizes ranged from 0.004 to 0.45 km^2 and slopes ranged from 3% to 12%. Typically, the Kirpich equation is applied to small watersheds with drainage areas of less than 200 acres. It is used primarily in municipal areas for both overland flow and channel flow. Time of concentration should be multiplied by 0.4 when the overland flow path is concrete and 0.2 when the overland flow path is asphalt (Ponce, 1989). The Kirpich and Haktanir-Sezen equations described next provide dependable estimates of mean values of time of concentration (Fang et al., 2008).

The Haktanir-Sezen equation. Fang et al. (2008) explained how Haktanir and Sezen (1990) studied 10 watersheds in Anatolia, Turkey, and developed 3-parameter beta and 2-parameter gamma distributions to develop synthetic unit hydrographs. Haktanir and Sezen developed an empirical equation to calculate lag time based on channel length only:

$$t_L = 40.06 L^{0.841},$$

where, t_L = lag time in minutes and L = length of the main stream in miles.

National Resources and Conservation Service equation. The U.S. Department of Agriculture Soil Conservation Service (SCS)(1972), now the National Resources Conservation Service (NRCS), developed an equation for ungauged watersheds with an area of less than about 8 km^2 (2,000 acres) and CN (SCS curve number) values between 50 and 95 (Wurbs & James, 2002). The SCS curve number reflects the soil and vegetative characteristics of the watershed. The NRCS lag time formula is:

$$t_L = L^{0.8} \frac{(1000 - 9CN)^{0.7}}{1900CN^{0.7}\sqrt{Y}},$$

where t_L = lag time in hours, L = longest flow path, feet, Y = average watershed slope, percent (%), and CN = SCS curve number.

Indent time of concentration (t_C) is computed from the lag time based on the National Resources and Conservation Service (NRCS) (1972, 1986) relationship:

$$t_L = 0.6t_C$$

Rational formula. The rational formula is the most commonly used method for determining peak discharges for designing drainage facilities for small watersheds ranging from 10 acres to 4.6 square miles (Wurbs & James, 2002.) The rational formula is:

$$Q_p = CiA$$

where Q_p= peak discharge, cfs; i= rainfall intensity, in/hr; A = drainage area, acres, and C = coefficient of imperviousness, (i.e, the ratio of runoff to precipitation). The equation has the conversion factor of 1.0083 from (in.acre/hr) to cfs is often omitted because it is close to one.

Snyder lag time equation and Snyder's synthetic unit hydrograph. Snyder (1938) developed a synthetic unit hydrograph. Snyder used the following relationship to compute the lag time (as cited in Mays, 2001):

$$t_p = C_t (L \cdot L_C)^{0.3}$$

where t_P = Snyder's lag time in hours; C_t = lag coefficient, dependent upon basin properties and ranges were from 1.8−2.2 with a mean of 2 (Wurbs & James, 2002); L = main channel length from basin outlet point to upstream watershed boundary, miles; and L_C = main channel length from outlet to a point opposite the center of gravity of the basin, miles. Indent the lag time is similar in nature to the SCS method; however, unlike the SCS method, the duration t_r is computed from the empirical equation:

$$t_r = \frac{t_p}{5.5}$$

where t_r = duration of standard unit hydrograph. The duration computed by the equation above may not be the desired duration; therefore, Snyder (1938) provided the following relationship for calculating adjusted lag time:

$$t_{PR} = t_p + 0.25(t_R - t_r)$$

where t_{PR} = adjusted lag time; t_r = previously calculated duration, and t_R = desired duration (which is chosen by the user). The adjusted lag time can now be substituted for lag time in the remaining equations.

Indent the peak discharge of the unit hydrograph is given by:

$$Q_{PR}=\frac{640AC_p}{t_{PR}}$$

where A = watershed area, square miles; Q_{PR} = peak discharge, cfs; and C_P = peak flow coefficient, which is dependent upon the topographic basin characteristics and ranges from 0.56 to 0.69 (Wurbs & James, 2002).

The Snyder synthetic unit hydrograph represents 1 in of direct runoff volume. The base time of the unit hydrograph is determined by these equations:

$$T_b=2581\frac{A}{Q_{PR}}-1.5W_{50}-W_{75}$$

$$W_{50}=770\left(\frac{Q_{PR}}{A}\right)^{-1.08}$$

$$W_{75}=440\left(\frac{Q_{PR}}{A}\right)^{-1.08}$$

where T_b = base time, hr; A = watershed area, mi^2; Q_{PR} = peak discharge, cfs; W_{50} = width of unit hydrograph at 50% of the peak; and W_{70} = width of unit hydrograph at 75% of the peak.

As in the SCS method, the time to peak is equal to the lag time plus half the duration (Wurbs & James, 2002):

$$t_{PK}=t_{PR}+\frac{t_R}{2}$$

where t_{PK} = time to peak, t_R = duration of the standard unit hydrograph, and t_{PR} = adjusted lag time.

Time to peak and peak discharge. Time to peak (t_{PK}) is the time from beginning of rainfall to the time of peak discharge (Mays, 2001):

$$t_{PK} = \frac{t_R}{2} + t_p$$

The SCS recommends that t_R be 0.133 of the time of concentration of the watershed, t_C:

$$t_R = \Delta D = 0.133 t_C$$

$$t_{PK} = 0.67 t_C$$

where ΔD = duration of rainfall, hours; t_P = lag time in hours; and t_C = time of concentration of watershed, hours.

The peak of the triangular SCS unit hydrograph is calculated by this equation (Wurbs & James, 2002):

$$Q_P = \frac{484A}{t_{PK}}$$

where A = watershed area, mi^2 and t_{PK} = time to peak, hr.

There is no one universally accepted equation to calculate time of concentration and lag time; therefore, each of the equations above can be used to estimate the time of concentration and lag time based on the size of the subbasin. The decision to use this time of concentration or that lag time formula is the prerogative of the user. Sometimes, the user may select two methods and then choose the method that gives the most conservative discharges.

CHAPTER 5

RESULTS AND CONCLUSION

The hydrologic characteristics of the entire Wolf River basin obtained using ArcGIS and GeoHMS software programs (as shown in the tables in Appendices A and B) are dependent on the Digital Elevation Model (DEM) elevation and threshold area. The DEM data with a 30-meter grid size (downloaded from seamless.usgs.gov) were used to delineate watersheds of the Wolf River. After the calculations for this study were finished in May 2011, the U.S. Geological Survey (USGS) posted 10-meter grid size DEMs online. Future studies may evaluate the new DEMs to determine if significant improvements are possible.

Hydrologic characteristic parameters and maps of each subbasin that were determined by the HEC-GeoHMS program were exported from attribute tables and ArcMap to Excel and PDF files, respectively. Forty-eight Excel files (in table format) and figures for each identified creek were prepared with the basin name and hydrologic characteristic parameters of each subbasin with their units (see Appendix A). Other tables and figures for the unnamed tributaries of the Wolf River basin start on U1 and extend to U169 (see Appendix B). Identified creeks and unnamed small tributaries of the Wolf River drainage basin were extracted from the DEM elevation data by using a threshold area of 0.6475 square kilometers (160 acres). An increase of stream length was obtained by using small threshold areas. The Wolf River basin area includes 48 named creeks and branches, as listed in the Table 2; however, the ArcGIS created 167 unnamed tributaries during drainage line processing of the Wolf River basin. The same raster data were used to determine the subbasins of named creeks and unnamed tributaries within the Wolf River basin.

First, the Hydrologic Unit Code (HUC) of the Wolf River basin, HUC-12, was created by the ArcGIS program; it consisted of 20 subbasins within the overall watershed of 814.48 square miles. The Wolf River channel length was calculated to be 91.54 miles, starting from the beginning of the channel in the Wolf Creek subbasin (see Figure A-23 in Appendix A and Subbasin B1) and extending to the intersection of the Wolf River and the Mississippi River. Olivera, F., Furnans, J., Maidment, D., Djokic, D., and Ye, Z. (2002) state that a threshold cell may be any value, but for values less than 1000 cells, the resulting catchment area delineations become more doubtful in flat regions. Inside cities, defining stream networks is difficult because the water flows along curbs and ditches that drain into underground storm sewer pipes before being released into watercourses. The DEM data does not contain elevations of underground infrastructure, such as pipes or box culverts. The subbasins are produced by Arc Hydro inside the cities and towns and may not accurately represent the shape of the subbasin because most of the streams were covered.

Some subbasins were compared with the 1985 subbasin drainage map (see Figure B-47 in Appendix B) of the City of Memphis, such as Cypress Creek. The Cypress Creek basin (see Figure A-2 in Appendix A) drains to the downstream section of the Wolf River. The basin is fully developed and covers a large part of downtown Memphis. The Cypress Creek basin, as defined by the

City of Memphis, included Subbasins U1 and U3 of this study, which were subdivided into 16 subbasins manually by the City of Memphis, The ArcGIS developed many subbasins because a small threshold area was used. After merging many small subbasins, 19 subbasins remained after using the GIS procedure. Observation of both basins showed that the two basins are similar.

The subbasins of unnamed tributaries (as illustrated in the key map in Figures 74 75, and 75 A-G) that were determined by the ArcGIS were compared with the City of Memphis drainage map. It was observed that most of the unnamed tributaries were not shown in the drainage map because the threshold area, 0.6475 square kilometers, was small and the small streams delineated by the model were part of the Wolf River channel. The threshold area should be increased so that it does not create as many small streams. Using the small threshold area means increased length of streams and generates many small subbasins.

Some of the channel lengths of the unnamed tributaries, such as Subbasins U2, U5, U8, U18, U22, U89, U100, U101, U120, U128, U136, U143, U144, U156, and U1, were less than 1,000 feet (as shown in Table B-1 in Appendix B). Therefore, these subbasins were practically part of the Wolf River basin and within the flood plain. The channel slope of some of the unnamed tributaries had a negative value (see Table B-1), such as U18, U19-B1, U22, U29, U49-B1, U55, U66-B2, and U76-B3. The ArcGIS was used to calculate channel slopes; the slope was equal to the difference of the channel bed elevation divided by the length of the channel. The negative slope meant that the downstream channel elevation was greater than the upstream channel elevation. This happened because most of these subbasins were located in the Wolf River channel and the channel bed path was irregular. The unnamed tributaries that are part of the Wolf River channel are U2, U5, U7, U20, U33, U41, U43, U48, U49, U50, U54, U53, U55, U89, U91, U94, U96, U101, U10, U103, U137, U142, U143, and U152 (as well as some of the small subbasins of named creeks located in the intersection of creeks and the Wolf River). The subbasins of these named creeks were part of the Wolf River or the flood plain. These unnamed tributaries were compared with the Shelby County drainage basin map and were shown to be located within the Wolf River basin area (see Figure B-47 in Appendix B, the City of Memphis drainage map). The channel slopes of U110, U128, and U144 were calculated as “0” because the channel beds were flat.

Some of the subbasin creeks consist of many named branches, such as Grissum, Tubby, Gray’s, Indian, and Grogg Creeks. These subbasins are generated individually as shown in Appendix A (Figures A-7, 14, 21, 34, and 37, respectively). In the basin processing procedure of the above creeks, many small subbasins were merged into one subbasin. When the subbasins of the branches are extracted, the small subbasins are not merged and the same subbasins are created. The small branches are the Sandy and Teague branches of Grissum Creek, Cox Branch of Tubby Creek, Field Creek of Gray’s Creek, Sandy Branch and Moody Creek of Indian Creek, and Mill Branch, Hood Branch, and Wesley Branch of Grogg Creek.

Six counties in the State of Tennessee and Mississippi are covered by the Wolf River basin. The hydrologic characteristics of the Wolf River basin (HUC-12) (see Table A-1 in Appendix A) were calculated in the current study to determine the area of the Wolf River basin covered in each county. The counties in Tennessee and Mississippi covered by the Wolf River basin and the percent of the basin area within each county are listed in Table 5-1.

Table 5

Percentage of the Wolf River Basin Area in Each County

County	State	Area (Square Feet)	Area (%)
Fayette	Tennessee	8,461,700,515	37.27
Shelby	Tennessee	5,801,234,784	25.55
Hardeman	Tennessee	1,560,639,523	6.87
Benton	Mississippi	5,214,106,395	22.96
Marshall	Mississippi	1,522,332,663	6.70
Tippah	Mississippi	146,442,000	0.64

The data necessary to study any creeks or laterals of named and unnamed tributaries of the Wolf River basin were determined and are shown in the tables in Appendices A and B. Also, all of the subbasins of the entire Wolf River basin were delineated, and their maps are attached in the appendices.

All of the stream networks inside cities and towns were not visible since most storm water flows along streets and empties into the storm water sewer system before discharging into the natural stream. Since these drainage systems are not digitized inside the western Tennessee cities, the Arc Hydro tool used DEM data to delineate the watershed and subwatersheds inside urban areas.

Another concern is the flow paths that intersect with major highways. Significant effort is necessary to determine what happens under the highway.

The hydrologic characteristics of the subbasins can be used to determine peak flows, times to peak, and runoff volumes of the subbasins. When studying the hydrologic characteristics of any subbasin of the Wolf River, the local municipality and its guidelines have to be taken into account. For example, both the City of Memphis and Shelby County have a drainage manual. The City of Memphis drainage manual has rules and methods established that are best-suited to the Memphis region. Three methods were described in the City of Memphis drainage manual to analyze the hydrologic performance of the drainage basin: the rational method, NRCS TR-55 graphical method of 1986, and NRCS TR-55 tabular method of 1986. The method that yielded the higher result was the method that governed and was used in the current study (City of Memphis, 2006).

The City of Memphis and Shelby County have typically used a topographic map to delineate watersheds or survey data. Topographic maps are insufficient to define the drainage patterns in flat and urban areas where man-made drainage features must be considered. The watershed delineation must account for the actual drainage patterns of the area, longest flow path, length and slope of stream, and subbasin slope. The subbasin parameters determined by using the topographic map are insufficient if this is the only data that will be use to evaluate the hydrologic condition of the subbasin.

Hydrologic studies are required to evaluate the impact of land development on the existing storm water system. The results of the current study can be used to compare current conditions and post-construction conditions of any proposed project in the Wolf River basin area. The steps needed to perform a hydrologic study of a subbasin are:

1. Determine the drainage area boundaries for the entire project watershed.
2. Determine the longest flow path and the slope, including existing and proposed drains.
3. Determine the pre- and post-construction basin slope.
4. Divide the drainage basin into subbasins as derived in the delineation processes.

The following two examples explain how to use the hydrologic characteristics to determine the time of concentration and prepare the unit hydrograph.

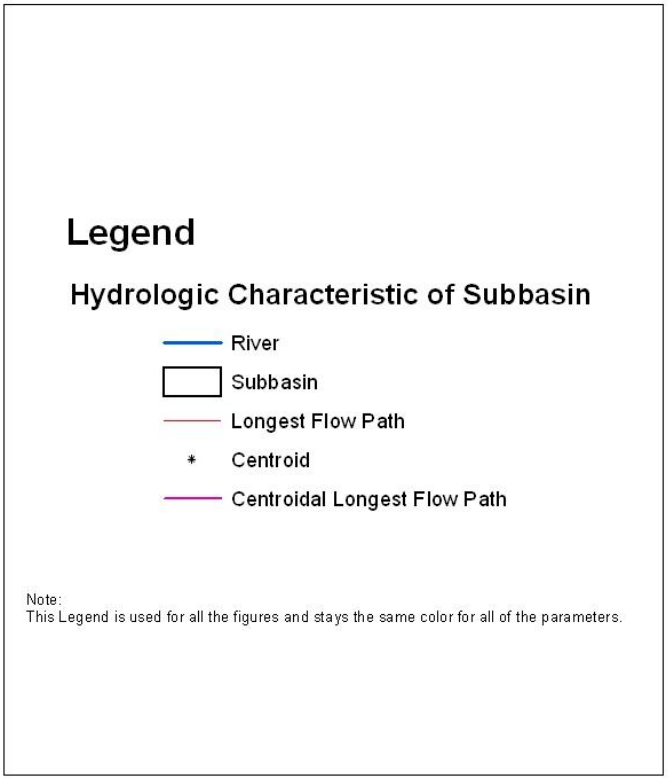


Figure 74. Legend for a key maps and all the subbasins map.

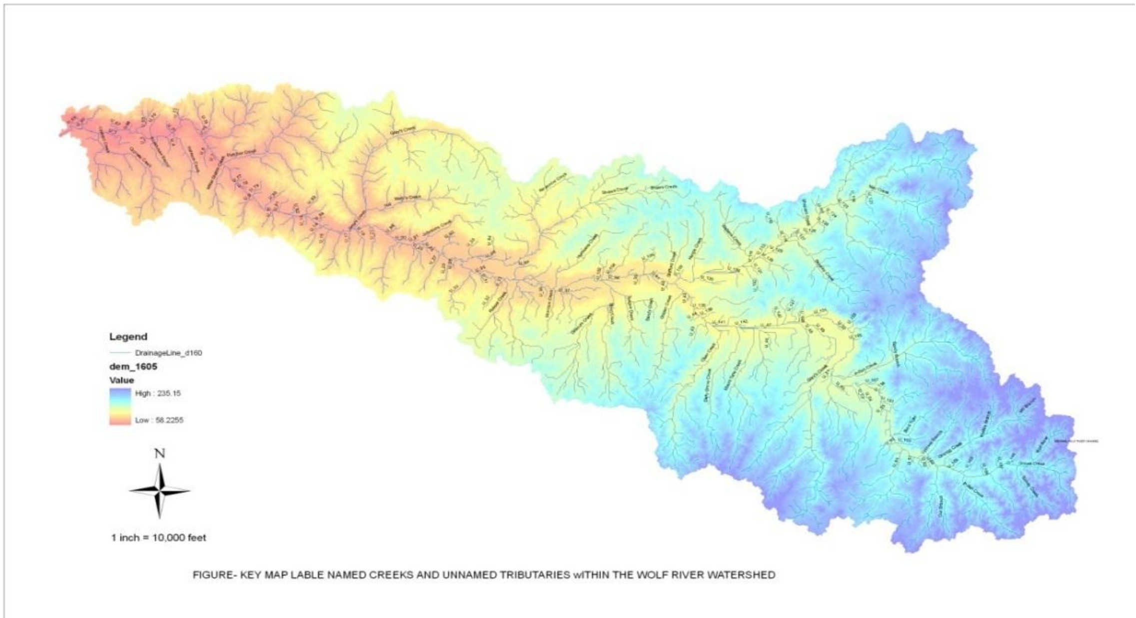


*Figure 7*5. Key map.

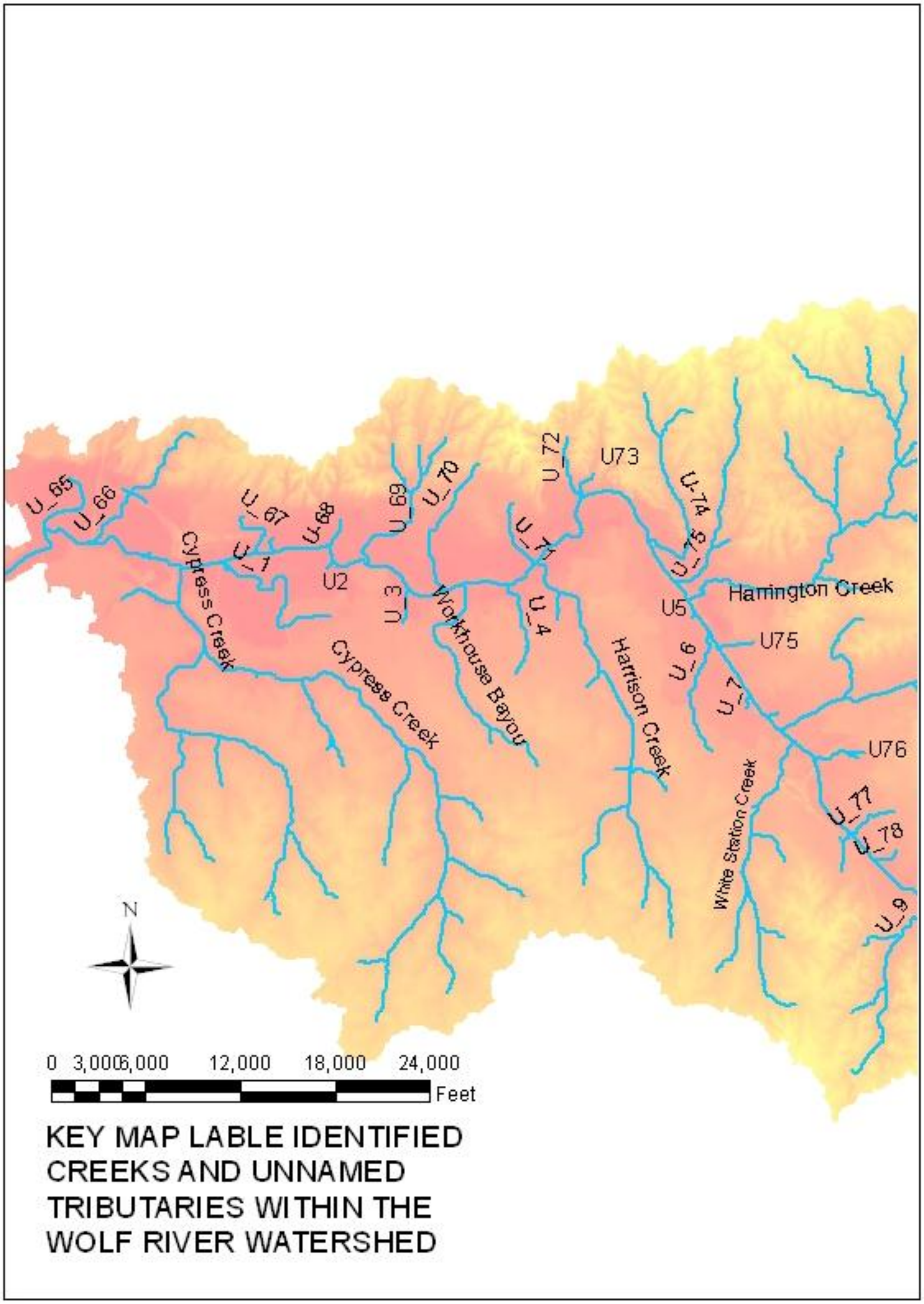


Figure 75 A. Key Map.

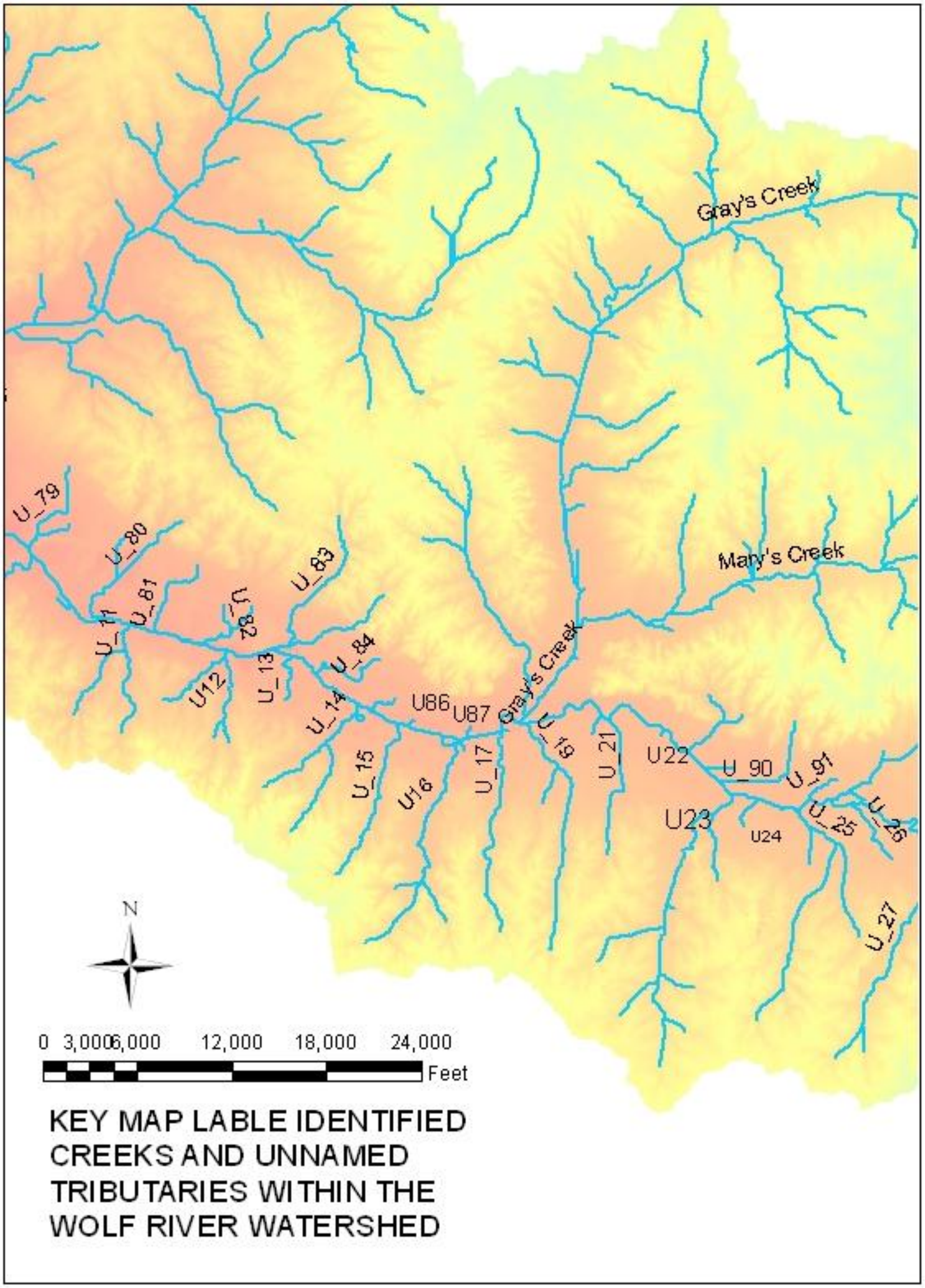


Figure 75 B. Key Map.

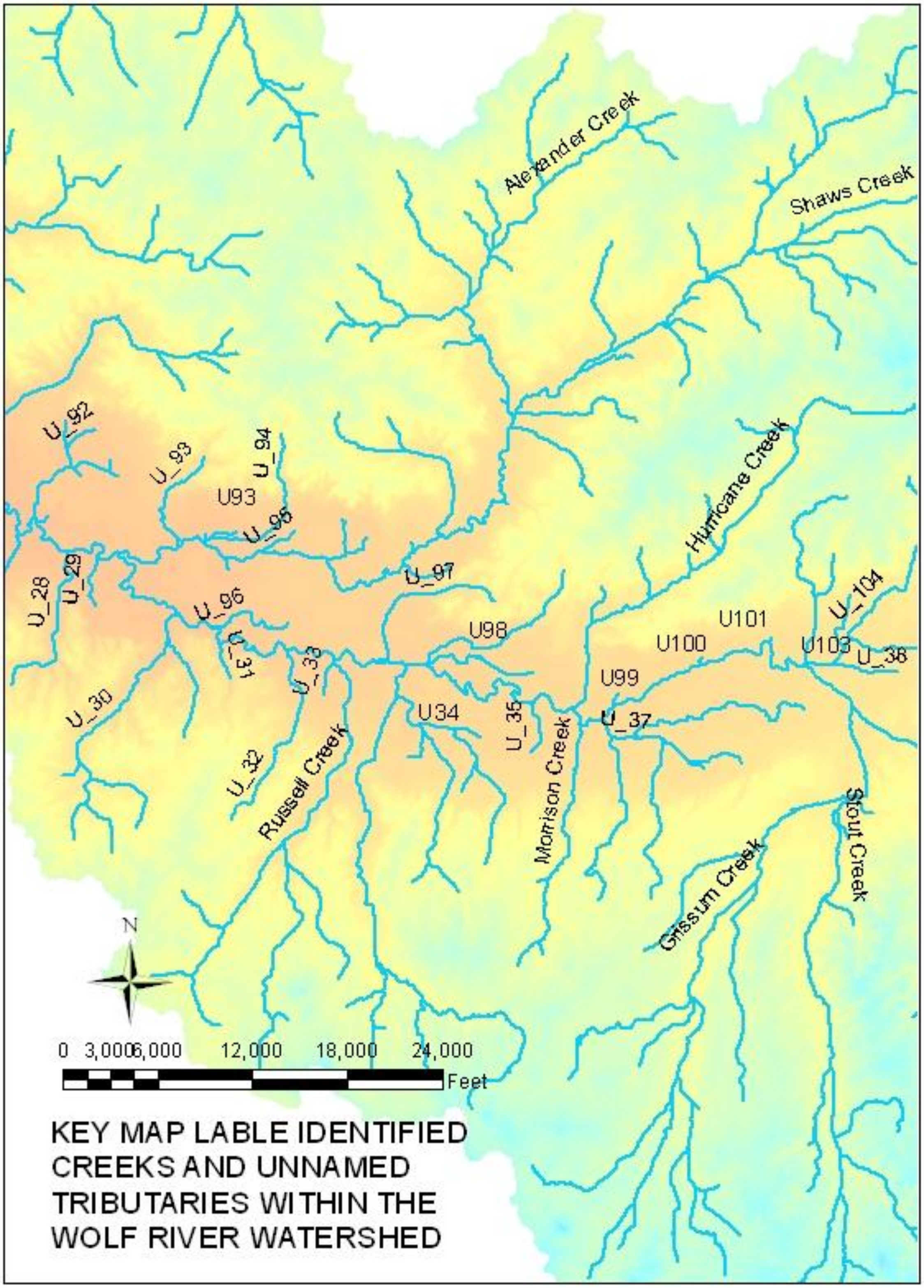


Figure 75 C. Key Map.

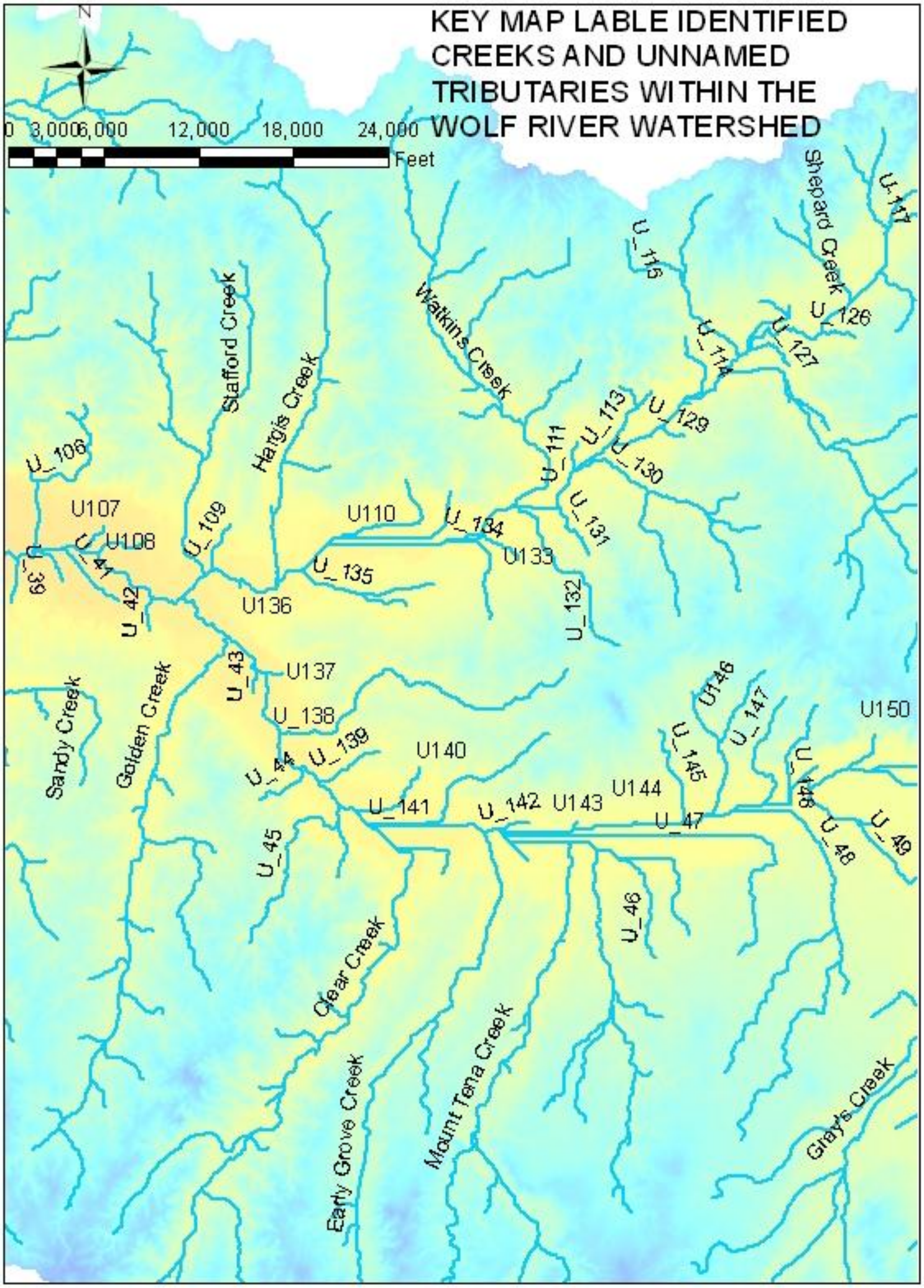


Figure 75 D. Key Map.

Figure 75 E. Key Map.

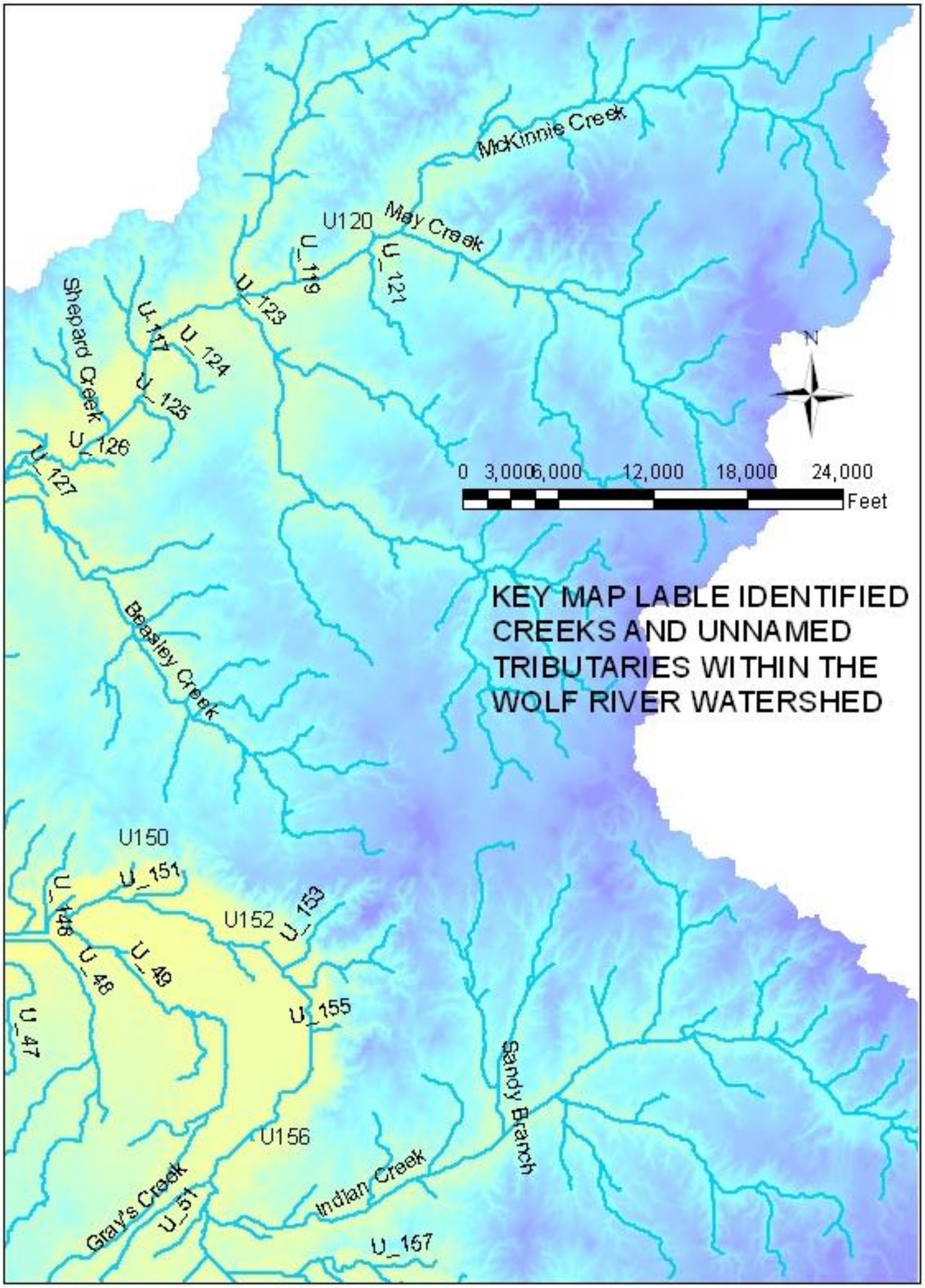


Figure 75 E. Key Map.

Figure 75 F. Key Map.

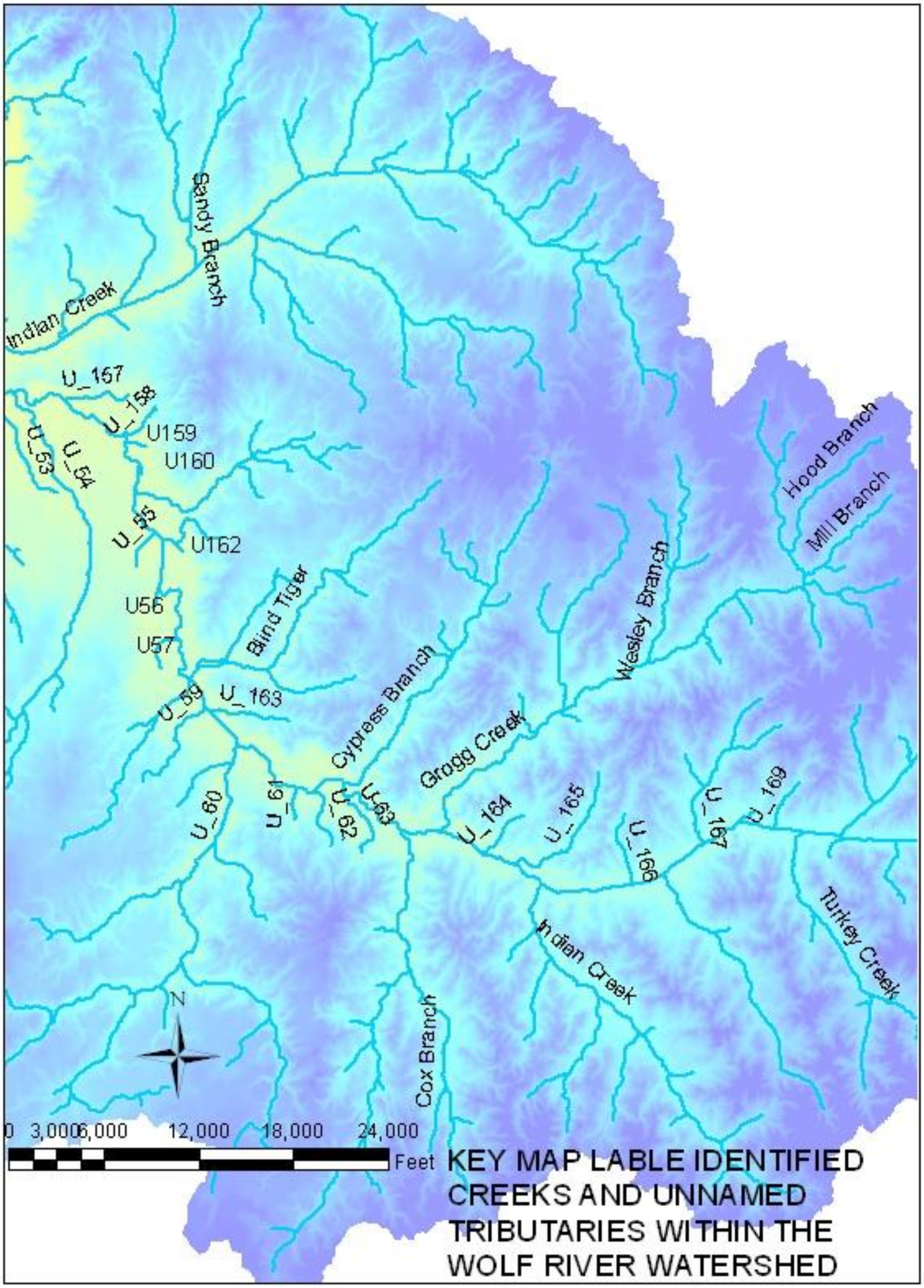


Figure 75 F. Key Map.

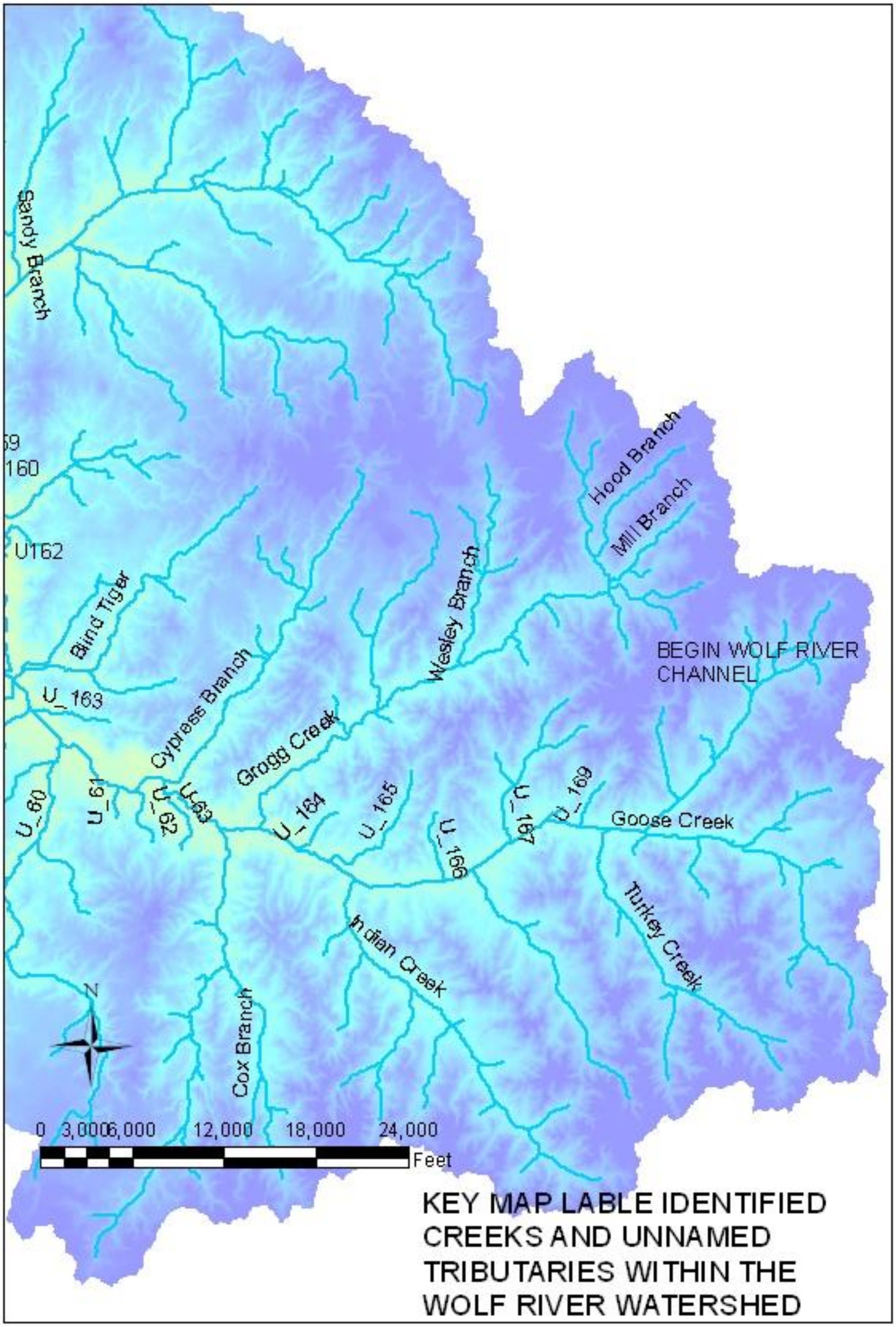


Figure 75 G. Key Map.

Examples

Hydrologic characteristics of the Mary’s Creek basin are used to determine the time of concentration and the NRCS dimensionless unit hydrograph in Example 1. The hydrologic characteristics of the Wolf River basin (HUC-12) are used to develop the standard unit hydrograph. The Snyder’s synthetic unit hydrograph equations are used in Example 2 to prepare the unit hydrograph.

Example 1. Determine the time of concentration and the NRCS dimensionless unit hydrograph for the Mary’s Creek basin by using the hydrologic characteristics of the basin (see Table A-29 in Appendix A). Use Snyder’s equation to determine lag time; if the C_t range is from 1.8−2.2, use an average value of 2, and if the C_p range is from 0.56−0.69, use an average value of 0.625.

In 1972, the U.S Department of Agriculture Soil Conservation Service published dimensionless values of time and discharge rate as shown in Table 6 that can be used to calculate the NRCS dimensionless unit hydrograph (Mays, 2001).

Table 6

Ratios from NRCS Dimensionless Unit Hydrograph and Mass Curve

Time Ratios t/t_{pk}	Discharge Ratios q/q_p	Mass Curve Ratios Q_a/Q	Time Ratios t/t_{pk}	Discharge Ratios q/q_p	Mass Curve Ratios Q_a/Q
0	0.000	0.000	1.7	0.460	0.790
0.1	0.030	0.001	1.8	0.390	0.822
0.2	0.100	0.006	1.9	0.330	0.849
0.3	0.190	0.012	2	0.280	0.871
0.4	0.310	0.035	2.2	0.207	0.908
0.5	0.470	0.065	2.4	0.147	0.934
0.6	0.660	0.107	2.6	0.107	0.953
0.7	0.820	0.163	2.8	0.077	0.967
0.8	0.930	0.228	3	0.055	0.977
0.9	0.990	0.300	3.2	0.040	0.984
1	1.000	0.375	3.4	0.029	0.989
1.1	0.990	0.450	3.6	0.021	0.993
1.2	0.930	0.522	3.8	0.015	0.995
1.3	0.860	0.589	4	0.011	0.997
1.4	0.780	0.650	4.5	0.005	0.999
1.5	0.680	0.700	5	0.000	1.000
1.6	0.560	0.751			

Calculation:

The following is the calculation of lag time, time of concentration, time to peak, and peak discharge for subbasin No.1 of Mary’s Creek. (See Appendix A, Table A-29, for the unique hydrologic characteristics of subbasin No. 1).

$$L=\frac{L(ft)}{5280(ft/mi)}=\frac{11954}{5280}=2.264mi$$

$$L_C=\frac{L_C(ft)}{5280(ft/mi)}=\frac{7096}{5280}=1.344mi$$

$$A=\frac{A(ft^2)}{(5280)(ft/mi)x(5280)(ft/mi)}=\frac{35223668}{(5280)(5280)}=1.263mi^2$$

Use the average values of C_t and C_P (C_t=2 and C_P= 0.625) to calculate the lag time by Snyder's equation:

$$t_p=C_t(L \cdot L_C)^{0.3}$$

where L = main channel length from basin outlet point to upstream watershed boundary, miles; and L_C = main channel length from outlet to a point opposite the center of gravity of the basin, miles.

$$t_p=C_t(L \cdot L_C)^{0.3} = (2) \text{ x } (2.264 \text{ x } 1.344)^{0.3} = 2.79 \text{ hr}$$

In the equation below, Q_p = peak discharge, A = area in mi^2, t_{PK} = time to peak, t_r = duration of the rainfall excess in hours, t_b = time base, t_R = the duration of rainfall, and ΔD = the duration:

$$t_r=\frac{t_p}{5.5} = 2.79/5.5 = 0.51 \text{ hr},$$

therefore set t_R = 0.5 hr = 30 minutes,

$$t_{PR}=t_p+0.25(t_R-t_r)=t_p-0.25(t_r-t_R)= 2.79 - (0.25) \text{ x } (0.51\text{-}0.50) = 2.788 \text{ hr}$$

$$Q_{PR}=\frac{640AC_p}{t_{PR}} =\frac{640(1.263)(0.625)}{2.788}=181cfs$$

By the above method, calculate the lag time and peak discharge for each subbasin:

$$t_P = 0.6\ t_C$$

$$t_C = \frac{t_P}{0.6} = \frac{2.79}{0.6} = 4.65 \text{ hr}$$

$t_{PK} = 0.67t_C = (0.67)(4.65) = 3.12$ hr = 186.9 min

$t_R = \Delta D = 0.133\ t_C$

$\Delta D = (0.133)(4.65)\ (60) = 37.14$ minutes (use 30 minutes).

Use the above method to calculate the time of concentration and peak discharge for each subbasin. The results are shown in Tables 7 and 8.

To calculate the NRCS dimensionless unit hydrograph of subbasin No. 1 of the Mary's Creeks basin, $t_C = 4.65$ hour, $t_{PK} = 186.9$ minutes (use 187 minutes); and $t_R = \Delta D = 37.14$ minutes (use 30 minutes). Use the above data and Table 6 to determine the dimensionless unit hydrograph for subbasin No. 1 of Mary's Creek. The results are shown in Table 9.

Sample of calculation of unit hydrograph of Subbasin No.1 of Mary's Creek: $t/t_{PK} = 30$ min/185 min = 0.16. From Table 6, if $t/t_{PK} = 0.1$ $q/q_p = 0.03$, if $t/t_{PK} = 0.20$, $q/q_p = 0.10$; then by interpolation for $t/t_{PK} = 0.16$, $q/q_p = 0.073$, and $q = (0.073) \times (181) = 13.2$ cfs. The unit hydrograph of subbasin No.1 of Mary's Creek is shown in Figure 76. The rest of them are calculated by the same way.

To check that the unit hydrograph volume is equal to 1 inch, use this equation (from Drainage Manual Volume 2; City of Memphis, 2006):

$$V = \frac{12\Delta \sum q_i}{A(43560)}$$

where V = volume under the hydrograph, (in inches), Δt = time increment of the runoff hydrograph ordinates (in seconds), Σq_i = sum of the runoff hydrograph ordinates (in cfs); for each time increment i, A = basin drainage area (in acres).

The area of subbasin No. 1 is = 1.263 mi^2 = 35223668 ft^2 = 808.624 acres. From Table 9, Σq_i = 1507 cfs and Δt = 30 minutes. Substituting into the equation above,

$$V=\frac{(12)(60)(30)(1507)}{(35223668)}=0.92 \text{ (Close to 1 in unit hydrograph).}$$

This difference results from the use of 30 minutes for the duration of the unit hydrograph instead of the 37 minutes called for by the t_R equation. Normal durations for unit hydrographs are simple multiples of 60 minutes. In summary, a 30-minute duration unit hydrograph of the subbasin No. 1 has a peak of 181 cfs at the time to peak of 3.12 hours.

Table 7

Calculated Lag Time and Time of Concentration for each Subbasin of Mary's Creek

Subbasin No.	Longest Flow Path	Centroidal Longest Flow Path (feet)	Lag Time	Area
No.	L	L_C	t_P	A
#	mi	mi	hr	mi^2
1	2.264	1.344	2.79	1.263
2	2.386	1.285	2.80	1.426
3	1.910	0.990	2.42	0.859
4	2.253	1.011	2.56	1.268
5	2.434	1.236	2.78	1.007
6	1.530	0.764	2.10	0.700
7	1.509	0.735	2.06	0.562
8	1.707	0.745	2.15	0.928
9	1.133	0.529	1.72	0.458
10	1.364	0.537	1.82	0.519
11	1.981	1.051	2.49	1.222
12	2.025	0.985	2.46	1.098
13	2.660	1.012	2.69	1.371
14	2.870	1.520	3.11	2.050
15	2.219	0.956	2.51	1.254

Table 8

Calculated Time Base of Unit Hydrograph and Peak Discharge for each Subbasin of Mary's Creek

Sub. No.	Duration of Stander Unit Hydrograph (t_r)	Desired Duration (t_R)	Adjusted Lag Time (t_{PR})	Time of Con. (t_C)	Rainfall Duration (ΔD)	Use (ΔD)	Peak Discharge (Q_{PR})
No.	hr	hr	hr	hr	min	min	cfs/in
1	0.51	0.5	2.79	4.65	37.12	30	181
2	0.51	0.5	2.80	4.66	37.20	30	204
3	0.44	0.5	2.44	4.06	32.41	30	141
4	0.47	0.5	2.57	4.28	34.17	30	198
5	0.51	0.5	2.78	4.64	37.00	30	145
6	0.38	0.5	2.13	3.54	28.27	30	132
7	0.38	0.5	2.09	3.49	27.85	30	107
8	0.39	0.5	2.18	3.63	28.96	30	171
9	0.31	0.5	1.76	2.94	23.44	25	104
10	0.33	0.5	1.86	3.11	24.79	25	111
11	0.45	0.5	2.50	4.17	33.30	30	195
12	0.45	0.5	2.47	4.12	32.90	30	178
13	0.49	0.5	2.69	4.49	35.83	30	204
14	0.57	0.5	3.09	5.16	41.16	30	265
15	0.46	0.5	2.52	4.19	33.47	30	199

Table 9

Calculated 30-Minute Duration Unit Hydrograph for Subbasin No. 1 for Mary's Creek

Time (min)	Time Ratio (t/t_{pk})	Discharge Ratio (q/q_p)	Discharge (q) cfs
0	0.00	0.000	0.0
30	0.16	0.073	13.2
60	0.32	0.214	38.8
90	0.48	0.438	79.3
120	0.64	0.724	131.1
150	0.80	0.930	168.4
180	0.96	0.996	180.4
210	1.12	0.978	177.1
240	1.28	0.874	158.3
270	1.44	0.740	134.0
300	1.60	0.560	101.4
330	1.76	0.418	75.7
360	1.93	0.315	57.0
390	2.09	0.247	44.7
420	2.25	0.192	34.8
450	2.41	0.145	26.3
480	2.57	0.113	20.5
510	2.73	0.088	15.9
540	2.89	0.067	12.1
570	3.05	0.052	9.4
600	3.21	0.040	7.2
630	3.37	0.031	5.6
660	3.53	0.022	4.0
690	3.69	0.018	3.3
720	3.85	0.0045	0.8
750	4.01	0.011	2.0
780	4.17	0.009	1.6
810	4.33	0.007	1.3
840	4.49	0.005	0.9
870	4.65	0.004	0.7
900	4.81	0.003	0.5
930	4.97	0.001	0.2

Σq_i = 1506.7 cfs

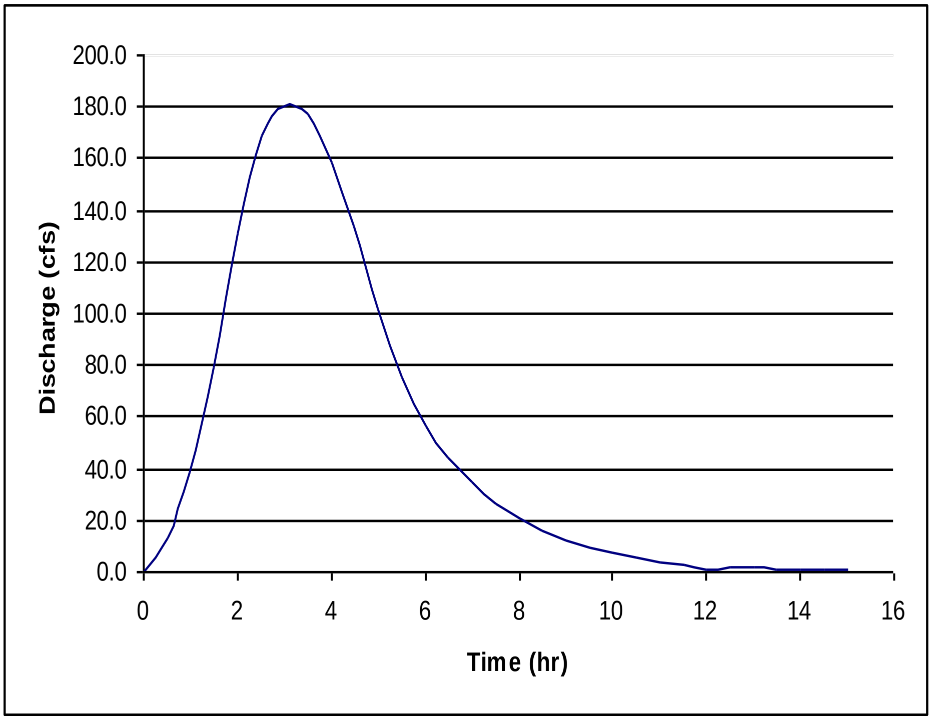


Figure 76. Unite hydrograph of subbasin No.1 of Mary's Creek

Example 2. Determine the standard unit hydrograph parameters for the Wolf River basin by using the hydrologic characteristics of the basin in Table A-1 of Appendix A. Use Snyder's method to determine the 1-hour unit hydrograph parameter for $C_t = 2$ and $C_p = 0.625$.

Use the Snyder equation to calculate the lag time:

$$t_p = C_t (L \cdot L_C)^{0.3}$$

where L = main channel length from basin outlet point to upstream watershed boundary, miles; and L_C = main channel length from outlet to a point opposite the center of gravity of the basin, miles.

Calculation:

For subbasin No.1 of the Wolf River basin (as shown in Table A-1 of Appendix A): L = 66,512 ft, L_C = 31,346 ft, and A = 892,636,638 ft^2. Convert the length of L and L_C from feet to miles and the area A to square miles:

$$L=\frac{L(ft)}{5280(ft/mi)}=\frac{66512}{5280}=12.597mi$$

$$L_C=\frac{L_C(ft)}{5280(ft/mi)}=\frac{31346}{5280}=5.937mi$$

$$A=\frac{A(ft^2)}{(5280)(ft/mi)x(5280)(ft/mi)}=\frac{892,636,638}{(5280)(5280)}=32.019mi^2$$

Use C_t =2, C_p = 0.625:

$$t_p= (2)\ (12.597x\ 5.937)^{0.3} = 7.298\ hours$$

$$t_r=\frac{t_p}{5.5}=\frac{7.298}{5.5}=1.33\ hr\text{, therefore use } t_R = 60 \text{ minutes (1 hour)}$$

$$t_{PR}=t_p-0.25(t_r-t_R) =7.298 - (0.25) x (1.33-1) = 7.22 \text{ hours}$$

$$Q_{PR}=\frac{640AC_p}{t_{PR}}=\frac{640(32.019)(0.625)}{7.22}=1775\ cfs$$

Using the above method, calculate the lag time and peak discharge for each subbasin. The results are shown in Tables 10 and 11. The base time of the unit hydrograph is determined by this equation:

$$T_b=2581\frac{A}{Q_{PR}}-1.5W_{50}-W_{75}$$

where $W_{50}=770\left(\frac{Q_{PR}}{A}\right)^{-1.08}$

$$W_{75}=440\left(\frac{Q_{PR}}{A}\right)^{-1.08}$$

where T_b = base time, hr; A = watershed area, mi^2; Q_{PR} = peak discharge, cfs; W_{50} = width of unit hydrograph at 50% of the peak; and W_{75} = width of unit hydrograph at 75% of the peak.

As in the SCS method, the time to peak is equal to the lag time plus half the duration (Wurbs & James, 2002):

$$t_{PK}=t_{PR}+\frac{t_R}{2}$$

where t_{PK} = time to peak, t_R = duration of the standard unit hydrograph, and t_{PR} = adjusted lag time.

The base time of Snyder's synthetic unit hydrograph is calculated as follows:

$$W_{50}=770\left(\frac{1775}{32.019}\right)^{-1.08}=10.07\text{hr};$$

$$W_{75}=440\left(\frac{1775}{32.019}\right)^{-1.08}=5.76\text{hr};$$

$$T_b=(2581)(\frac{1775}{32.019})-1.5(10.07)-(5.76)=25.69 \text{ hr},$$

By the above method, calculate Snyder's synthetic unit hydrograph for each subbasin. The results are shown in Table 12.

In summary, the unit hydrograph of the subbasin 1 of the Wolf River basin has a peak of 1775 cfs at the time to peak of 7.72 hours with a time base of 25.69 hours. This is a 1-hour duration unit hydrograph.

Table 10

Calculated Lag Time for All Subbasin of Wolf River Basin

Subbasin No.	Longest Flow Path	Centroidal Longest Flow Path (feet)	Lag Time	Area of Subbasin
No.	L	L_C	t_P	A
#	mi	mi	hr	mi^2
1	12.597	5.937	7.298	32.019
2	18.831	7.615	8.871	62.263
3	8.314	3.303	5.403	21.620
4	12.505	2.423	5.565	65.261
5	16.884	7.836	8.660	57.147
6	20.374	11.191	10.196	50.033
7	16.949	6.845	8.325	61.466
8	5.349	3.311	4.737	6.075
9	15.175	7.189	8.173	47.275
10	20.254	9.355	9.645	67.973
11	11.261	5.850	7.025	37.134
12	18.225	8.770	9.165	45.028
13	14.010	12.666	9.457	59.949
14	13.704	6.621	7.733	36.098
15	11.922	5.426	6.987	26.547
16	11.760	3.704	6.205	49.224
17	14.140	6.470	7.752	35.610
18	9.129	4.349	6.035	16.498
19	7.356	3.070	5.095	20.905
20	8.650	3.499	5.563	16.361

Table 11

Calculated Peak Discharge for All Subbasin of Wolf River Basin

Subbasin No.	t_r	t_R	t_{PR}	Peak Discharge (Q_{PR})
No.	hr	hr	hr	cfs/in
1	1.33	1	7.22	1775
2	1.61	1	8.72	2857
3	0.98	1	5.41	1599
4	1.01	1	5.56	4693
5	1.57	1	8.52	2684
6	1.85	1	9.98	2005
7	1.51	1	8.20	3000
8	0.86	1	4.77	509
9	1.49	1	8.05	2349
10	1.75	1	9.46	2875
11	1.28	1	6.96	2135
12	1.67	1	9.00	2002
13	1.72	1	9.28	2585
14	1.41	1	7.63	1892
15	1.27	1	6.92	1535
16	1.13	1	6.17	3189
17	1.41	1	7.65	1862
18	1.10	1	6.01	1098
19	0.93	1	5.11	1635
20	1.01	1	5.56	1177

Table 12

Calculated Base Time of Snyder's Synthetic Unit Hydrograph for all Major Subbasins of the Wolf River Basin

Subbasin No.	Width of Unit Hydrograph at 50% Q_{PR}	Width of Unit Hydrograph at 75% Q_{PR}	Base Time	Time to Peak
No.	W_{50}	W_{75}	T_b	t_{PK}
#	hr	hr	hr	hr
1	10.07	5.76	25.69	7.72
2	12.36	7.06	30.66	9.22
3	7.38	4.22	19.61	5.91
4	7.61	4.35	20.14	6.06
5	12.05	6.88	29.99	9.02
6	14.30	8.17	34.78	10.48
7	11.56	6.61	28.94	8.70
8	6.45	3.68	17.44	5.27
9	11.34	6.48	28.46	8.55
10	13.49	7.71	33.07	9.96
11	9.68	5.53	24.82	7.46
12	12.79	7.31	31.58	9.50
13	13.22	7.55	32.49	9.78
14	10.70	6.12	27.07	8.13
15	9.63	5.50	24.70	7.42
16	8.51	4.86	22.20	6.67
17	10.73	6.13	27.13	8.15
18	8.27	4.73	21.65	6.51
19	6.95	3.97	18.61	5.61
20	7.60	4.34	20.13	6.06

Conclusion

The current study presents a method to quickly delineate the Wolf River basin area in western Tennessee and northern Mississippi and to extract the hydrologic characteristics of the subbasins using topographic data from a DEM. The time required using available GIS tools to extract necessary topographic data for modeling flows is significantly reduced as compared to the extraction of similar values using hand methods. But not only is the time reduced, more detail can be made available to produce the necessary flood hydrographs. GeoHMS software significantly reduces the effort and time required to develop the hydrologic characteristics of the subbasins that are necessary to calculate peak flows, times to peak, and run-off volumes. If a threshold area of one-half of a square mile (1.295 square kilometers) is used, an excellent definition of stream networks, length, and subbasins for the small tributaries can be obtained. If the chosen threshold area is made smaller, then this operation increases the length of streams but increases the number of small basins, most of which lie within the Wolf River flood plain.

GeoHMS is a powerful tool that can greatly improve hydrologic analyses of basins and assist in the design of the storm water management system. The subbasin characteristics determined in this study are valuable data that can be used to study existing storm water systems for any storm event and to design a storm water drainage system for a new development within the Wolf River basin.

GeoHMS may also aid in the design of sanitary sewers because of its ability to quickly generate basin and subbasin areas and slopes. Population and population density are primary criteria used to design sanitary sewers. By applying the projected population density to the basin or subbasin areas and by using the main channel slope, an engineer can more quickly determine the design peak discharge and an appropriate sanitary sewer pipe size. The hydrologic parameters of the subbasins required estimating peak discharges for designated storm events, and flood hydrographs resulting from storms may be used to evaluate the existing drainage system and the impact of proposed developments.

The results of the current study provide the necessary topographic information needed to analyze and evaluate every subbasin of the Wolf River floodplain from its outlet to its headwaters. The availability of this data will enable engineering staff of the municipalities within the Wolf River basin to create an awareness of potential dangers of flooding and assists the respective staffs as they design storm water networks inside the boundary of municipalities. As presented and represented in the current study, there is a strong need to develop the subbasins in the Wolf River basin area by calculating the hydrologic characteristics of the subbasins.

Download the Software

To process the delineation, download the following software, which were the latest versions at the time of study and are available either from the website of the Environmental Systems Research Institute (ESRI), Hydrologic Engineering Center (HEC), or Center for Research in Water Resources:

- ApFramework (required for all applications);
- XML Data Exchange (required for HEC-GeoRAS and HEC-GeoHMS);
- Arc Hydro tools (required for HEC-GeoHMS and DSSToGDB);
- DSSToGDB (integrated into Arc Hydro for 9.2 versions after February 13, 2008); and
- HEC-GeoHMS.

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