CRWR Online Report 01-7

GIS Algorithms for Large Watersheds with Non-contributing Areas

by

Melissa Jane Figurski, MSE

Graduate Research Assistant

and

David R. Maidment, PhD.

Principal Investigator

December 2001

CENTER FOR RESEARCH IN WATER RESOURCES

Bureau of Engineering Research • The University of Texas at Austin
J.J. Pickle Research Campus • Austin, TX 78712-4497

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by

Melissa Jane Figurski, B.S.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2001

GIS Algorithms for Large Watersheds with Non-contributing Areas

Approved by
Supervising Committee:

David Maidment

Randall Charbeneau

Joseph Malina

Acknowledgements

I would like to thank my advisor, Dr. David Maidment, for his guidance through this research. Additional thanks go to Dr. Francisco Olivera for sharing his wisdom of research endeavors as well as life endeavors.

I am grateful to the Texas Natural Resources Conservation Commission for funding this research; particularly to Michelle Town and the WAM staff for their support and patience through a lengthy process.

I appreciate all of my friends past and present at the Center for Research in Water Resources for the good conversations, good laughs and good friendships. You have helped create so many good memories of my time in Austin.

I also want to thank my parents, Kathy and Larry Roesner for their constant encouragement, guidance, and love. Likewise, I thank my brothers, David, Kevin and Nathan, for teaching me the ropes of life.

My most heartfelt thanks go to my husband, David. His support and love over these last two years cannot be valued enough.

December 7, 2001

Abstract

GIS Algorithms for Large Watersheds with Non-contributing Areas

Melissa Jane Figurski, M.S.E

The University of Texas at Austin, 2001

Supervisor: David R. Maidment

The Texas Natural Resources Conservation Commission is creating water availability models to plan and manage long-term use of the Texas water supply. The development of these models requires watershed attributes for control points in Texas river basins. Previous researchers developed a procedure in GIS to determine attributes on small basins in which all the drainage area contributes. This procedure proved inefficient for larger basins and basins with pits that do not allow runoff to flow to the drainage system. This thesis presents an algorithm to develop watershed parameters for large basins in which parameters are developed in subbasins and then mathematically updated to reflect contributions from upstream or downstream subbasins. Additionally, an algorithm is presented to remove non-contributing areas from a GIS analysis in which a pit depth is defined and removed from the flow direction grid created from the digital elevation model (DEM). The drainage area is delineated and compared to reported stream gage contributing areas from the U.S. Geological Survey, and, if necessary, the pit depth is redefined. A comparison of the drainage areas for DEM-delineated watersheds to reported U. S. Geological Survey values validates the algorithm for subdividing large basins, but in non-contributing regions, the comparison suggests that a finer resolution terrain representation is required.

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Chapter 1: Introduction

1.1 Background

Water is a limited resource. Civilization past and present has used water for transportation, recreation, food preparation, energy production, and irrigation. In regions without an abundant supply, water must be distributed by a system. In Texas, water is allocated through water right permits.

Water right permits in Texas are granted by the Texas Natural Resources Conservation Commission (TNRCC) for an allocated diversion of water from a river channel or reservoir. In 1996, a major drought in Texas led to drastically reduced water supplies and disagreements over water use, and attention was drawn to the lack of a comprehensive water plan necessary to protect existing water supplies and anticipate the increasing demands on this limited supply (TNRCC, 1998). The 1997 the Texas State Legislature enacted Senate Bill 1 in response to this concern. A section of this legislation mandated the creation of Water Availability Models (WAMs) by the TNRCC.

The purpose of the WAMs is to assist the TNRCC in water resources planning and management decisions. To resolve concerns over the reliability of individual water rights, output from the WAMs is incorporated into a letter to each existing permit holder outlining the reliability of water rights through a drought. These letters must be distributed within 90 days of a completed WAM, and by mandate in Senate Bill 1, WAMs and reports for all basins must be complete by December 31, 2001 (Texas State Legislature, 1997). When a new permit request is received, the TNRCC will use the WAMs to project whether sufficient water is available on a river segment to grant a new diversion permit while maintaining existing permits and minimum in-stream flows.

The TNRCC chose the Water Rights Analysis Package (WRAP) model written by Dr. Ralph Wurbs at Texas A&M University for use as the water availability model (TNRCC, 1998). Various consulting engineering firms were contracted to apply the WRAP model to 22 of the 23 basins in Texas. The Rio Grande basin was not included in the initial legislation and will be modeled separately. To correctly model the basins, watershed parameters are required at the location of each diversion, United States Geological Survey (USGS) stream gage, and various locations within each basin selected by the contractor. These set of points are referred to as control points. The requested watershed parameters differ among contractors, but a complete set consists of the drainage area to each control point, average SCS curve number and average annual precipitation over the drainage area, connectivity between control points, and a flow length from each control point to the outlet of the basin. The Center for Research in Water Resources (CRWR) at The University of Texas at Austin was selected for development of these parameters with a Geographic Information System (GIS). TNRCC is provided by CRWR with a database of watershed parameters, which TNRCC will update later as new water right permits are requested and granted.

1.2 Overview of WAM Project at CRWR

The WAM process at CRWR was undertaken in 1997 by Dr. David Maidment and Bradley Hudgens. Since then, principal researchers David Mason, Hema Gopalan, and the author of this thesis have assumed different roles in the process of parameter development. Hudgens developed the original methodology and scripts to prepare raw data for processing in ArcView 3.2. Mason revised some of the methods put forth by Hudgens when better data became available. The author implemented a process for working with large basins and non-contributing regions, and Gopalan will develop a procedure for parameter development entirely in the new ArcGIS platform.

Through this work, watershed parameters have been developed for every water right in the State of Texas with the exception of the Rio Grande River Basin. Additional points required by contractors for accurate modeling with the WRAP program such as stream gages, water quality segment endpoints, and return flows, bring the total number of points investigated in this process to 13,383. These parameters were completed on December 7, 2001.

The river basins of Texas overlaid by the points for which watershed parameters have been developed at CRWR is presented in Figure 1.1.

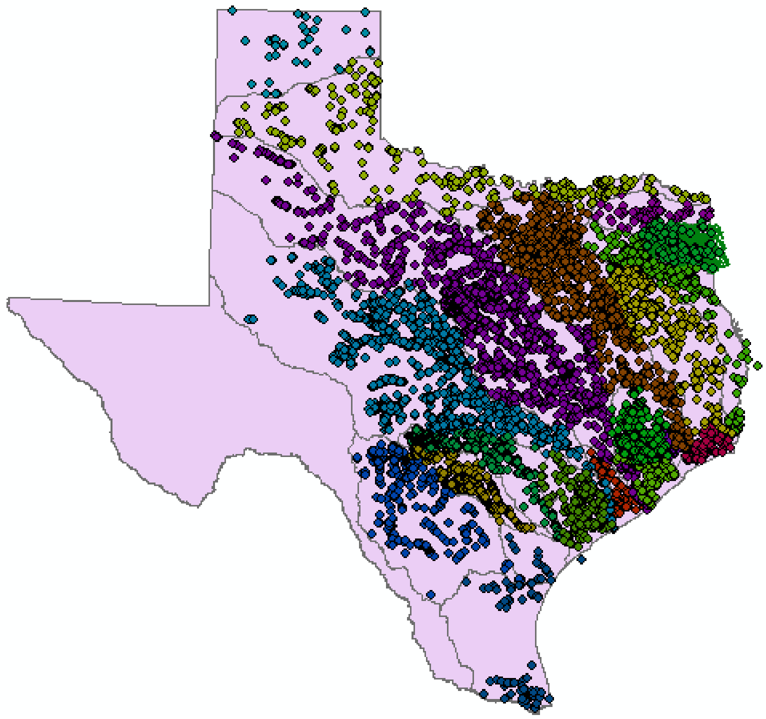


Figure 1.1: Summary of WAM Points

The first researcher on the project, Bradley Hudgens, developed a set of scripts to determine watershed parameters in the Environmental Systems Research Institute's (ESRI) ArcView 3.2 software environment (Hudgens, 1999). He and his successor, David Mason, completed six of the twenty-two WAM basins with these scripts including the Sulphur, Neches, San Jacinto, San Antonio, Guadalupe, and Nueces River basins (Hudgens, 1999; Mason 2000). The drainage areas of these basins ranged from the 3,600 mi^2 Sulphur basin to the 17,000 mi^2 Nueces basin with watershed parameters developed for 94 and 517 points, respectively (Hudgens, 1999; Mason, 2000). These two basins were processed with 90-meter Digital Elevation Model (DEM) data and the remaining four basins with 30-meter DEM data. The DEM is a digital representation of the terrain that provides the base grid for watershed delineation.

The next basin in line for parameter development was the Trinity River Basin to be processed by the author of this thesis. The drainage area of the Trinity basin is approximately 18,000 mi^2, and watershed parameters were required for 1,905 points. By the time parameter development began on the Trinity basin, 30-meter DEMs were available for all of Texas. The increased DEM resolution provides better delineation of watersheds, but the processing time and file size drastically increased from that of the 90-meter data.

Running the ArcView 3.2 script sequence developed by Hudgens on the Trinity basin required ten days to process. If the process needed to be run only once, this might not be an unreasonable amount of time. However, the TNRCC will use the model to consider the impact of new water right permits on water availability. To do this, the TNRCC will need to determine the watershed parameters of the new permit. If the addition of a stream is required, the whole basin must be reprocessed if the original procedure is used. The time required to reprocess the entire basin is not efficient for the TNRCC to maintain the database and update the models when a new permit is requested.

Another challenge to the method devised and revised by Hudgens and Mason are basins with non-contributing drainage area. The original six basins processed were within the central and eastern portions of Texas where all area in the basin drains to the basin outlet. Areas in West Texas, however, contain pits and depressions where runoff is trapped and prevented from contributing to the stream flow. This drainage area must be removed from analysis in order to define accurate watershed parameters. Some coastal drainage systems along the South-east coast of Texas contain non-contributing drainage areas as well, but this thesis concentrates on the non-contributing regions in West Texas.

1.3 OBJECTIVES

This research has two objectives:

1. To modify the previously developed methods to efficiently delineate watershed parameters in large basins.
2. To devise an automated method for identifying and removing non-contributing drainage areas from GIS analysis.

The first objective is accomplished by subdividing the basin and developing watershed parameters independently within each subbasin. The local parameters are then updated to include influence from upstream subbasins. The process of updating local parameters to include upstream drainage is referred to as 'cascading'. By subdividing the basin, the TNRCC will only need to update the affected subbasin when analyzing a new permit application.

The second objective is accomplished by building on work completed by Dr. Francisco Olivera (1995) while at The University of Texas at Austin. Olivera prepared a method for removing inland catchments (non-contributing areas) from GIS analysis. This method utilizes a user-defined threshold for depth and area of the inland catchment. This method is revised for application to the WAM basins such that only a depth will be used to define a non-contributing area. The success of the method is assessed by the ability to match reported drainage areas as defined by the USGS. Doing this comparison suggests that the USGS values are accepted as truth. For the purposes of this analysis, a working hypothesis is applied to this research that recognizes the USGS delineated drainage areas as such. The validity of the hypothesis is discussed at the end of this thesis.

1.4 STUDY AREA

1.4.1 Basin Subdivision

The process of subdividing a basin was developed with the Trinity River basin. The location of the Trinity River in Texas is illustrated in Figure 1.2.

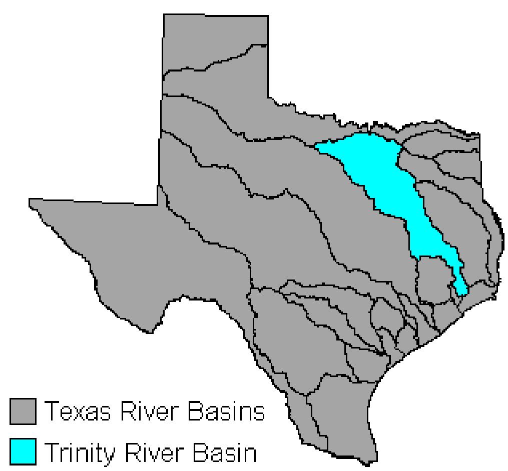


Figure 1.2: Location of Trinity River Basin in Texas

New GIS software, ArcGIS, was released during the investigation of this procedure. The capabilities of both ArcView and ArcGIS were considered when constructing the method for subdividing the basin and cascading the parameter attributes.

1.4.2 Non-contributing Area

Four basins in the state of Texas have non-contributing regions: the Red, Canadian, Colorado, and Brazos River basins.

The Brazos River basin was selected for development of the procedure to remove non-contributing area from the GIS analysis. The Brazos River basin is the largest basin in Texas and spans the state from northwest to southeast. The location of the Brazos River basin in Texas is presented in Figure 1.3.

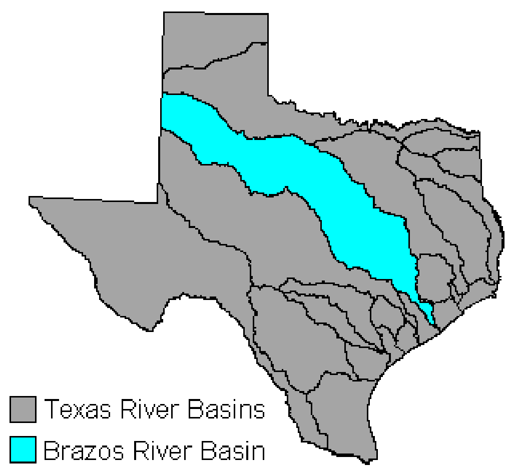


Figure 1.3: Brazos River Location in Texas

The most upstream portion of the Brazos lies in the flat, arid plains of West Texas that contain non-contributing areas. The drainage area of the Brazos is 45,573 mi^2 of which 9,566 mi^2 is non-contributing (USGS, 1977).

1.5 ORGANIZATION

This thesis is divided into eight chapters. Chapter Two provides a literature review of the research conducted at CRWR for the WAM process, USGS delineation of non-contributing areas in Texas, and the geologic formation of the Texas High Plains. Chapters Three and Four present the methodology for subdividing a basin and removing non-contributing area from watershed analysis, respectively. The procedures for these two methods are detailed in Chapters Five and Six. Chapter Seven presents the results of the subdivision and non-contributing procedures and a comparison between other basins to which the procedures were applied. Conclusions and recommendations for future study are discussed in Chapter Eight. The Appendix outlines an approach for updating the parameter data set of a subdivided basin. This thesis has been written with the assumption that the reader has a competent knowledge of ArcView and a working knowledge of ArcGIS.

Chapter 2: Literature Review

2.1 Introduction

The development of watershed parameters at CRWR has undergone multiple revisions as the WAM project proceeded because better data was made available, and basins were encountered that challenged the efficiency of existing procedures and their applicability to non-contributing regions. This chapter presents a review of the WAM work accomplished at CRWR and a discussion of non-contributing areas in Texas.

2.2 Summary of WAM Progress

The first researcher on the CRWR portion of the WAM project, Bradley Hudgens, provided the groundwork for developing WAM watershed parameters in GIS and produced parameters for two basins in Texas, the Sulphur and the Neches River basins (Hudgens, 1999). David Mason followed Hudgens in the continuation of parameter development while revising the method outlined by Hudgens with the availability of better data (Mason, 2000).

2.2.1 Development and Implementation of WAM Process by Hudgens

Hudgens' research was based on a set of existing GIS tools prepared at CRWR. This set of tools, CRWR PrePro, creates an input file from GIS data for use in the Hydrologic Engineering Center's watershed model, Hydrologic

Modeling System (Olivera, 1998). The tools are scripts incorporated into an ArcView 3.2 project written with the programming language, Avenue.

Hudgens revised the CRWR PrePro tools for direct application to WAM and developed new tools where necessary. The set of tools were then embedded into an ArcView 3.2 project named Wrap1117.apr. Through this process, he accomplished three objectives during his tenure at CRWR. These objectives were to create a geospatial database for a river basin, extract WRAP parameters for points in the basin, and delineate acceptable watersheds from digital data (Hudgens, 1999).

Hudgens (1999) provides a detailed discussion of the parameters required to develop input for the WRAP model at each control point. Hudgens describes the development of the datasets used for establishing parameters, which comprise the geospatial database for the river basin.

The set of tools in the Wrap1117 project prepare the data for extraction of watershed parameters and then perform the data extraction. To prepare the stream network, a tool in Wrap1117 draws the stream network path taken across the DEM. A tool is included to snap the control points to the DEM-derived network because accurate definition of watershed parameters requires that the control points be located exactly on top of a grid cell within this drainage path. The tools for raster data create the burn, fill, flow direction and flow accumulation grids from the DEM and the average SCS curve number and average annual precipitation grids from the SCS curve number and annual precipitation grids.

Prior to applying the tool set, some of the data must be modified, and Hudgens (1999) outlines the necessary data preparation prior to the application of the tools. During the creation and application of the Wrap1117 tools, Hudgens developed quality control procedures to ensure production of reliable parameters. These procedures consist of visual checks and manual delineation of watersheds if necessary.

The data for delineating watersheds changed towards the end of Hudgens' research. The original 90-meter DEMs were not reliable for the production of small watersheds (Hudgens, 1999). The National Elevation Dataset (NED) of 30-meter DEM data became available in 1999, and Hudgens compared the delineation of watersheds in the Sulphur basin with the two DEM resolutions. He found that the 30-meter DEMs provided more accurate delineation of watersheds and reduced the amount of time required for quality control measures, but the time to process the 30-meter data increased due to an increased file size (Hudgens, 1999).

Hudgens' contribution to the WAM project was a solid procedure and toolset for the determination of watershed parameters for inclusion in the WRAP model.

2.2.2 Modification and Implementation of WAM Process by Mason

David Mason was the second researcher on the WAM project at CRWR. Part of the legislation for WAM enacted by the Texas State Legislature was that six basins had to be modeled by the end of 1999. Mason completed the parameters for the last four of the first six basins: the Nueces, Guadalupe, San

Antonio, and San Jacinto River basins. His efforts included modification of the procedure outlined by Hudgens to incorporate better data sets as well as a detailed analysis of the accuracy of watershed delineation with regard to DEM resolution and terrain relief (Mason, 2000).

Mason (2000) presented a case study of the four basins he completed. Within each case study, he detailed the variations in procedures required for the incorporation of new data. One of these new data sets was the National Hydrography Dataset (NHD) of river reaches. Although incomplete for the basins studied by Mason, elements of the NHD were incorporated into the Environmental Protection Agency's (EPA) River Reach File Version 3 (Rf3) to reduce manual labor in preparation of the stream network for analysis.

In addition to augmenting the stream network with NHD data, Mason expanded the stream network used for DEM processing. He added streams to the network that surround and drain away from the basin. The inclusion of these streams provided a more accurate delineation of the basin boundary (Mason, 2000).

Mason (2000) recognized that the increased file size and processing time for the 30-meter DEMs could hamper delineation of larger basins in Texas. He proposed a method for dividing the basin into subbasins, but this method was not utilized for the four basins he studied.

For watershed delineations with 90-meter DEM resolution, Hudgens (1999) recommended a threshold value of 1,000 cells under which watersheds should be visually verified. Mason (2000) researched the applicability of this threshold to the 30-meter data, and found that it was still valid. The area covered by 1,000 grid cells in a 30-meter DEM environment is smaller than that of the 90-meter environment. Thus, the actual area of visually verified watersheds was smaller, but the cell threshold remained constant.

Through statistical analysis and visual inspection, Mason (2000) concluded that the 30-meter DEMs produced more accurate watershed delineations than the 90-meter DEMs. Mason also conducted a statistical analysis of the accuracy of watershed delineation with respect to slope over the watershed. There was no correlation evident for 90-meter DEM-derived watersheds; however, he found that 30-meter DEM-derived watersheds with a slope greater than 0.002 m/m correlated to USGS reported watershed areas within 1% (Mason, 2000). At a slope less than 0.002 m/m, the percent difference from USGS values rose. This analysis revealed the limitations of delineating watersheds with 30-meter DEM data in areas of low relief, but it also validated the use of drainage areas reported by the USGS as truth (Mason, 2000).

2.3 NON -CONTRIBUTING REGIONS

2.3.1 USGS

The USGS delineates contributing and non-contributing areas for stream gages. The following definition is employed by the USGS for contributing area:

> An area measured in a horizontal plane that is enclosed by a topographic divide so that direct surface runoff from precipitation normally drains by gravity into the river basin above the specified point (USGS, 1960).

Essentially, area that drains to a stream network is contributing area. In contrast, the USGS defines a non-contributing area as the following:

> An area that contributes no direct surface runoff to a stream at any time. (USGS, 1977)

Thus, a non-contributing region traps water and prevents it from draining to the stream network. With a sizeable or sustained storm event, it is possible that any depression could fill with water and become a contributing area. As previously mentioned, the WAM effort determines availability in drought conditions; so the effects of large storm events are not considered in this thesis.

Four WAM basins contain non-contributing regions; the Red, Canadian, Brazos, and Colorado River basins. For the Brazos River Basin, the USGS hand-delineated contributing and non-contributing areas for 491 locations using USGS paper topographic maps (USGS, 1977). These locations included existing and discontinued gage stations, major dams, and the mouths of tributaries (USGS, 1977). The drainage areas at these points are collected in a USGS report for the Brazos River basin listing for each point; the stream on which it is located, the latitude and longitude, and the non-contributing and contributing drainage areas (1977). A modified excerpt from the USGS Brazos River drainage report is shown in Table 2.1.

Name of Stream	Point of Determination	Drainage area above point (square miles) Noncontributing	Contributing
Salt Fork Brazos River	Below mouth of Wilfong Creek lat. 33°14'43", long. 100°04'35"	2,634	2,701
Salt Fork Brazos River	At confluence with Double Mountain Fork Brazos River lat. 33°16'08", long. 100°00'34"	2,634	2,717
Brazos River	Below confluence of Salt Fork Brazos River and Double Mountain Fork Brazos River lat. 33°16'08", long. 100°00'34"	9,566	4,839
Brazos River	Above mouth of North Croton Creek lat. 38°23'09", long. 100°00'25"	9,566	4,876

Table 2.1: Modified Excerpt from USGS Brazos River Drainage Report (1977)

The points listed in the drainage report, such as those in Table 2.1, are those at which the success of the method for removing non-contributing areas from GIS is evaluated. Reports were created by the USGS for all river basins in Texas with the exception of the Red and Arkansas River basins, which were delineated by the U.S. Army Corp of Engineers.

The USGS topographic maps are available in digital format. These Digital Raster Graphics (DRGs) are scanned versions of paper 7.5-minute maps available for the United States and U.S. territories and trusts (USGS-3, 2001). A portion of a DRG in the Brazos non-contributing region is shown in Figure 2.1 as an example of the data used to hand-delineate watersheds.

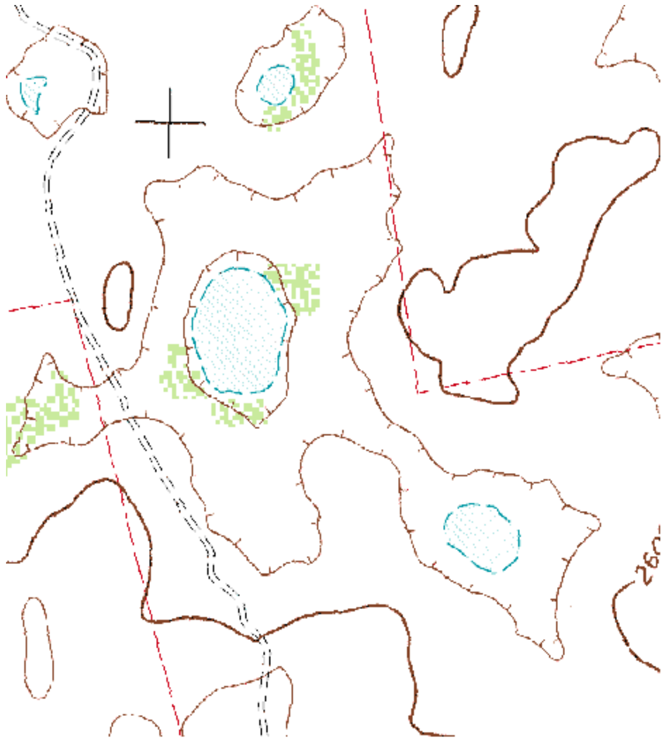


Figure 2.1 USGS Digital Raster Graphic Map

The brown lines in Figure 2.1 represent contours. Typically, a closed contour denotes a hill in which the elevation within the contour continues to rise. In Figure 2.1, dark brown lines signify hills. The light-brown lines with tick marks inside the circles symbolize pits where the elevation decreases within the closed contour.

2.3.2 High Plains Geologic History

The northwest region of Texas, the Panhandle, is referred to as the High Plains, and it is characterized as flat plains with numerous playas (Spearing, 1991). Playas are dry lake basins located in a desert (Houghton Mifflin, 2001). Playas collect surface runoff, preventing it from draining to the stream network.

By USGS definition, playas are non-contributing areas. The present-day topography of Texas is presented in Figure 2.2.

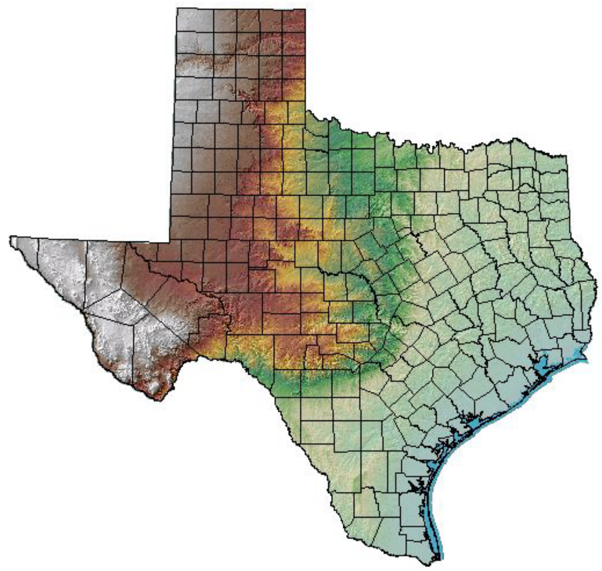


Figure 2.2: Present-day Topography of Texas (TNRIS, 2001)

An escarpment can be seen in Figure 2.2 running north-south through the panhandle of Texas. The area west of this escarpment represents the High Plains. It is helpful to look at the history of Texas geology to understand the formation of the High Plains region.

Until the beginning of the Ice Age 2 million years ago, Texas was intermittently covered by shallow marine seas. Sediment was deposited onto the Texas landscape by the marine seas and by the uprising of the Ouachita Mountain range 300 million years ago (Spearing, 1991) and the Rocky Mountain range 70 million years ago (National Park Service, 1998). The deposit resulted in a sediment wedge thought to be as thick as 50,000 feet. An uplift ten million years ago elevated the Texas Panhandle, and the Red, Brazos, and Colorado Rivers began to erode the edge of the plains ultimately creating the escarpment. The playas were formed by ponded water on the flat plains following storms (Spearing, 1991).

2.4 CONCLUSIONS

Hudgens and Mason developed and revised a procedure to create watershed parameters from GIS data and completed parameter sets for six river basins in Texas. The method works well for small datasets, but when using 30-meter DEM data, the grids for some of the remaining WAM basins are too large to efficiently apply the existing procedures necessitating a new approach for developing watershed parameters for these large basins.

In addition, the basins processed by Hudgens and Mason did not contain non-contributing drainage areas. Four of the remaining WAM basins have non-contributing regions resulting from the geologic history of Texas. The non-contributing areas have been quantified by the USGS, and watershed parameters for these basins cannot be developed without removing these regions from analysis requiring a change to the existing methods of developing watershed parameters in basins with non-contributing areas.

Chapter 3: Methodology: Basin Subdivison

3.1 Introduction

The concept of subdividing a basin is not new. Physically, a basin may have spatially varied characteristics that cannot be represented with one value across the basin. Some hydrologic models, like the Environmental Protection Agency (EPA) SWMM model, use sub-catchments to allow the application of appropriate characteristics to each sub-catchment for proper modeling of the basin.

A basin may need to be subdivided for computer processing because the processor cannot efficiently handle the size of the data. The difficulty inherent in subdividing a basin is defining the subbasins such that the pieces are easy to rejoin. This chapter presents a methodology for subdividing a basin. It also describes how watershed parameters can be developed locally within a subbasin and then updated to include upstream and downstream influences.

3.2 Subdividing the Basin

A fictional river basin with water right diversion locations shown in purple is presented in Figure 3.1. This example basin will be used throughout the chapter to illustrate the concepts of basin subdivision and restoration.

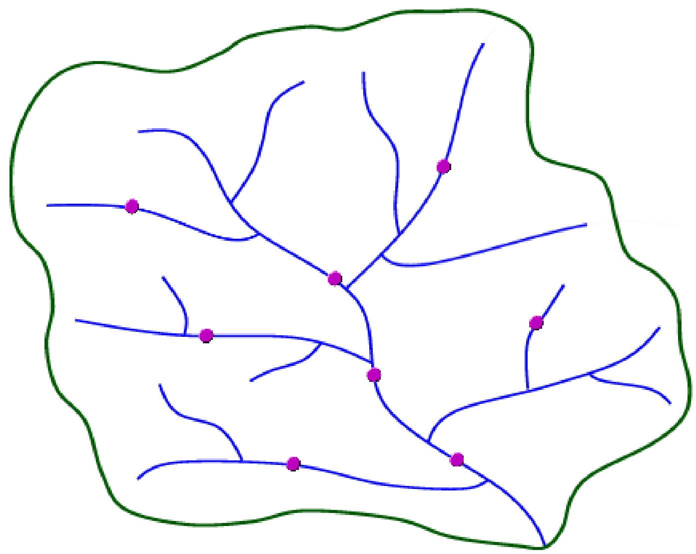


Figure 3.1: Example Basin

First, the basin must be separated into subbasins that can be investigated independently. Subbasin boundaries should be defined so that each subbasin creates a watershed that drains to a single outlet. By draining to a single outlet, the influences from each upstream subbasin can be transferred to the next subbasin at one location. The subbasin boundaries can be defined by agency boundaries such as USGS cataloging units, or arbitrarily by the investigator. Figure 3.2 shows an arbitrary subdivision of the example basin where each subbasin drains to a single outlet.

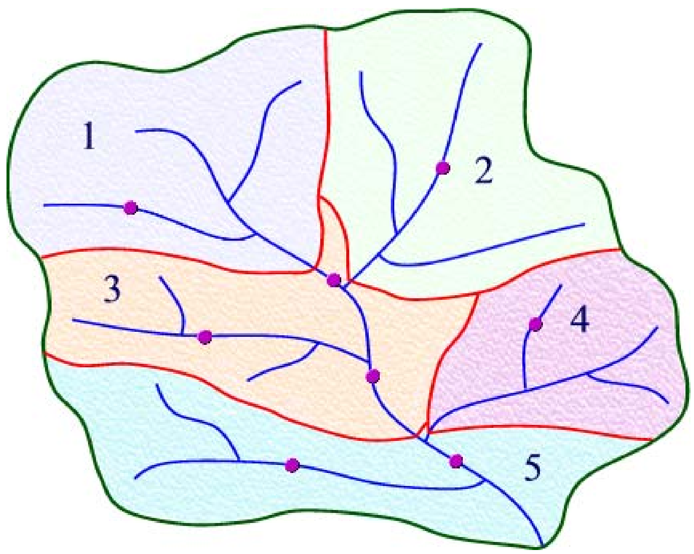


Figure 3.2: Example Subbasin Boundaries

Once the subbasins are defined and watersheds are developed for each, it is important to check that the total area of the individual subbasins equals the basin area. This will ensure that no drainage area is double counted or inadvertently left out of the analysis.

Watershed parameters for each water right diversion location can then be developed within each subbasin. Incremental watersheds for the water right diversion points within subbasin 3 are shown in Figure 3.3.

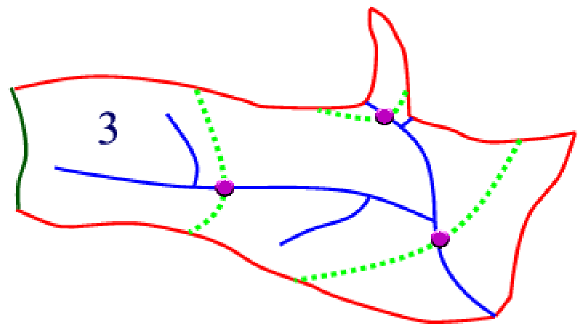


Figure 3.3: Incremental Watersheds for Subbasin 3

3.3 Restoring the Basin

The WAM process requires that the drainage area, average curve number, average precipitation, and flow length to the outlet be developed for each control point in the basin. The independent processing of each subbasin means that the resulting parameters do not include contributions from upstream or downstream areas that are required for WAM.

A schematic drainage network helps visualize how subbasins impact each other. This network is a straight-line diagram illustrating the drainage pattern of a basin. The drainage schematic for the example basin is shown in Figure 3.4.

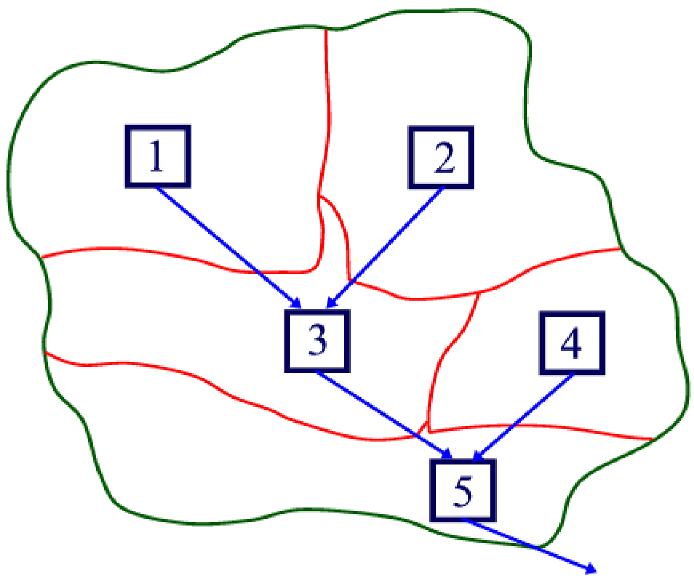


Figure 3.4: Basin Drainage Schematic

It is apparent from Figure 3.4 that both subbasins 1 and 2 influence subbasin 3. Additionally, it is evident that, for subbasin 3, the local flow length to the outlet of the basin must be updated with the flow length through subbasin 5.

An important part of updating the watershed parameters is to recognize which control points are influenced by other subbasins. The only points influenced by upstream subbasins are those on rivers draining those subbasins. Points on tributaries do not receive flow from upstream subbasins and therefore, are not affected by them. However, every control point in a subbasin must be updated with the flow length through downstream subbasins.

The concept that upstream portions of the basin affect only points on the main stem is illustrated in Figure 3.5. The streams and points highlighted in blue represent the stream segments and water right diversion points that are influenced by upstream subbasins.

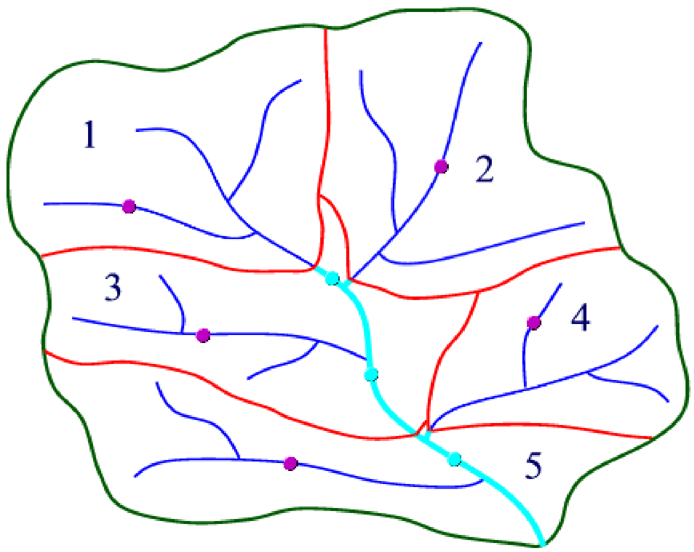


Figure 3.5: Influence of Upstream Subbasins in Example Basin

It is important to note where each subbasin connects to the main stem. The highlighted stream in Figure 3.5 shows that the most upstream highlighted point is only impacted by subbasin 1, the middle point is influenced by subbasins 1 and 2, and the most downstream point is affected by subbasins 1 through 4.

3.4 Cascading Parameters

Cascading, or updating, the watershed parameters for upstream influence of drainage area, average curve number and average precipitation will be demonstrated on a sample point. This point is the bright green point represented in Figure 3.6. This figure shows the drainage area of the sample point local to subbasin 3.

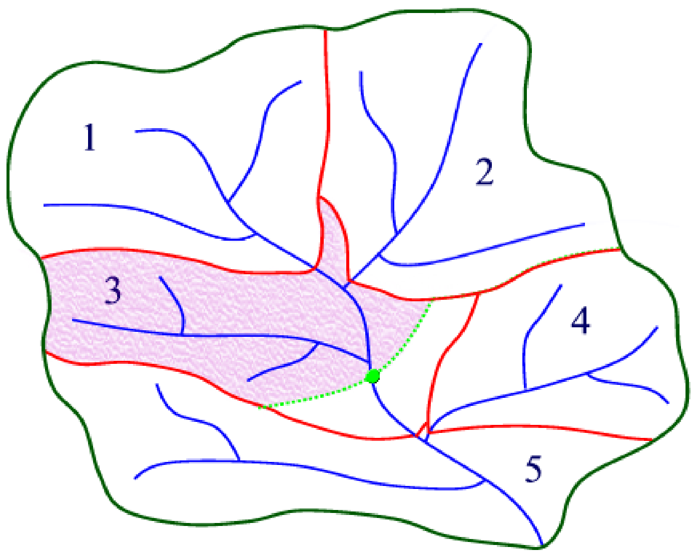


Figure 3.6: Local Drainage Area of Example Point

Formulas must be developed to update the attributes of the sample point. The first step is to determine the parameter values at the outlet of each subbasin. For WAM, these should be the subbasin drainage area, average curve number, and average precipitation. For flow length, the length from each inlet to a subbasin to the subbasin outlet should be recorded.

The drainage area can be cascaded by simple addition. The expanded drainage area of the sample point when the entire upstream area is considered is illustrated in Figure 3.7.

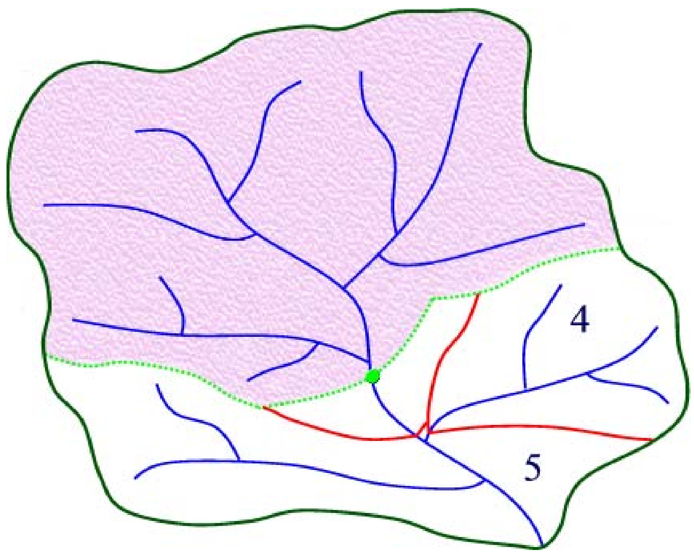


Figure 3.7: Entire Upstream Area of Example Point

The entire upstream area of subbasin 3 will equal the sum of the local watershed area of the sample point and the entire area of subbasins 1 and 2. Equation 3.1 shows the formula for updating area.

$$A_{TSP} = A_1 + A_2 + A_{SP} \qquad \text{(Eqn. 3.1)}$$

where,

A_{TSP} = Total area upstream of the sample point; [L^2]

A_i = Area of subbasin i, i = 1, 2; [L^2]

A_{SP} = Local area of sample point; [L^2]

The average curve number and average precipitation values must be cascaded with a weighted formula. The updated value should represent the average value of the curve number or precipitation over the entire upstream area.

This value is calculated by averaging the product of each area and its average curve number over the entire upstream drainage area. Equation 3.2 shows the formula for updating the average curve number of the sample point.

$$ACN_{TSP} = \frac{(ACN_1 * A_1) + (ACN_2 * A_2) + (ACN_{SP} + A_{SP})}{A_{TSP}} \qquad \text{(Eqn. 3.2)}$$

where,

ACN_{TSP} = Upstream average curve number for sample point

ACN_i = Average curve number of subbasin i

A_i = Area of subbasin i; $[L^2]$

A_{TSP} = Total area upstream of sample point; $[L^2]$

The updated average precipitation value is calculated with the same equation by replacing the average curve number values with average precipitation values.

A new point will be used to illustrate the need to cascade the flow length parameter for all points in a subbasin, not only points on the main stem. The path from the new sample point to the outlet of the basin is shown in Figure 3.8.

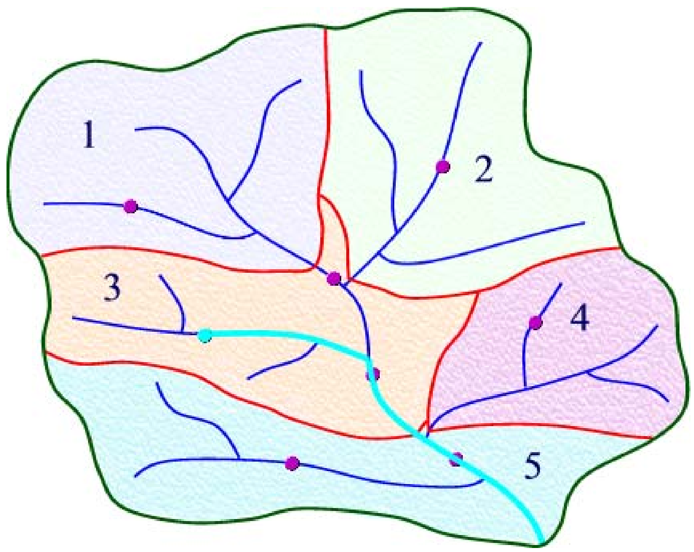


Figure 3.8: Path to Outlet for Sample Point

The flow length to the outlet of the sample point is simply the sum of the flow length through subbasin 3 and the flow length through subbasin 5 along the main stem as shown in equation 3.3.

$$F_{TSP} = F_{SP} + F_5 \qquad \text{(Eqn. 3.3)}$$

where,

F_{TSP} = Total flow length for sample point; [L]

F_{SP} = Flow length for sample point through subbasin 3; [L]

F_5 = Flow length along the main stem of subbasin 5; [L]

The process of cascading parameters must be done for all control points in the basin. Once the local parameter values are updated, the basin has been restored and all the parameter values reflect contributions from the entire basin.

Chapter 4: Methodology: Non-contributing Regions

4.1 Introduction

Depressions in landscapes occur naturally. Some of these depressions are pits that result in non-contributing areas, but others are simply depressions that will still allow runoff to flow to the stream network. For this analysis, a pit is defined using a threshold depth from the surrounding surface elevation at which flow would drain from the depression. If the depth of a depression is greater than or equal to the threshold depth, it is labeled as a pit and the area draining to it is removed from the analysis. Depressions of depth less than the threshold value are filled and considered part of the contributing drainage area. This chapter presents a methodology for determining the threshold depth and then removing non-contributing area from watershed analysis.

4.2 Defining the Non-conributing Region

Pits in watersheds provide another reason for subdividing the basin as described in the previous chapter. Separating this region from the remainder of the basin allows it to be analyzed independently with regard to the characteristics of non-contributing regions. Returning to the example basin from the Chapter Three, a revised basin with depressions represented as brown circles is shown in Figure 4.1.

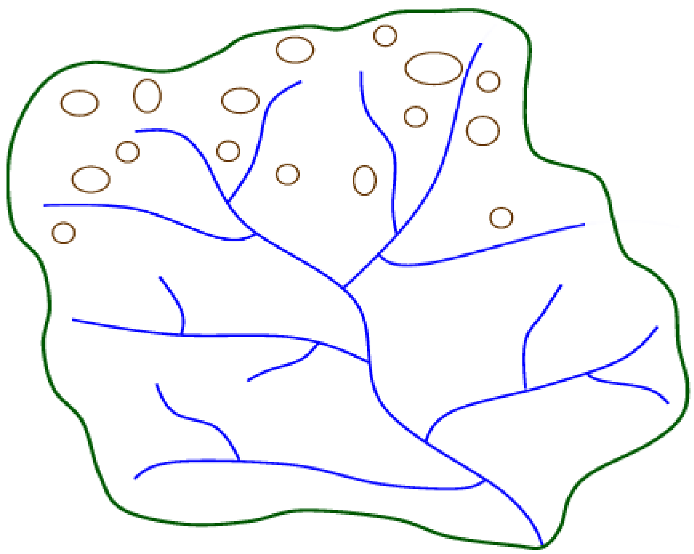


Figure 4.1: Example Basin with Depressions

The first step is to determine what portion of the basin contains non-contributing area. Using the USGS Drainage Reports discussed in Chapter Two, the points at which the USGS has delineated contributing and non-contributing drainage area can be located on the stream network. From the point locations and the reported drainage areas, the location on the stream network at which the non-contributing area stops increasing can be established. This is demonstrated with the help of the USGS drainage table presented in Chapter Two for the Brazos River basin; reintroduced as Table 4.1 for reference.

Name of Stream	Point of Determination	Drainage area above point (square miles)	
		Noncontributing	Contributing
Salt Fork Brazos River	Below mouth of Wilfong Creek lat. 33°14'43", long. 100°04'35"	2,634	2,701
Salt Fork Brazos River	At confluence with Double Mountain Fork Brazos River lat. 33°16'08", long. 100°00'34"	2,634	2,717
Brazos River	Below confluence of Salt Fork Brazos River and Double Mountain Fork Brazos River lat. 33°16'08", long. 100°00'34"	9,566	4,839
Brazos River	Above mouth of North Croton Creek lat. 38°23'09", long. 100°00'25"	9,566	4,876

Table 4.1: Modified Excerpt from USGS Drainage Report (1977)

The records in Table 4.1 are listed in order along the stream network starting from upstream. All gages downstream of the third record have a non-contributing drainage area of 9,566 mi^2, so the third record represents the point at which the non-contributing area stops increasing in the Brazos basin. The area of the basin below this location is 100 percent contributing. Once this gage is located, the subbasin(s) with non-contributing area should be separated from the rest of the basin.

For the example basin, suppose that the outlets of subbasins 1 and 2 represent the locations at which the non-contributing area stops increasing. The basin subbasins, depressions, and a line for which a cross-section will be developed are presented in Figure 4.2.

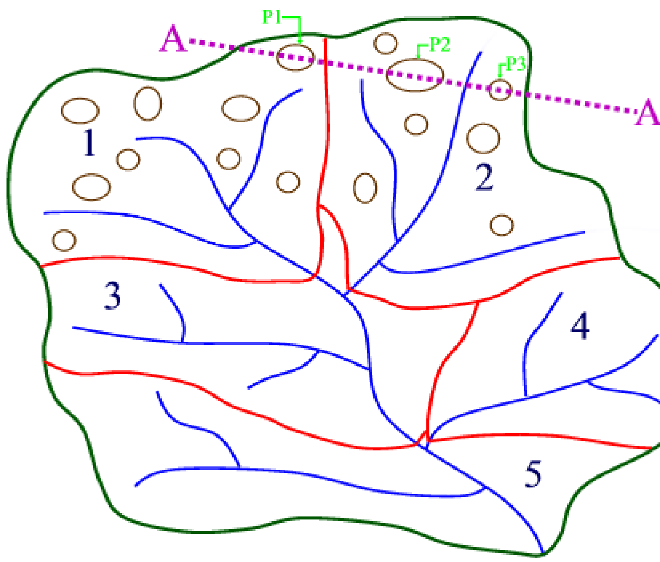


Figure 4.2: Example Subbasins and Cross-Section Line

Cross-section AA provides a representation for the pit analysis of the non-contributing region. Cross-section AA is shown in Figure 4.3.

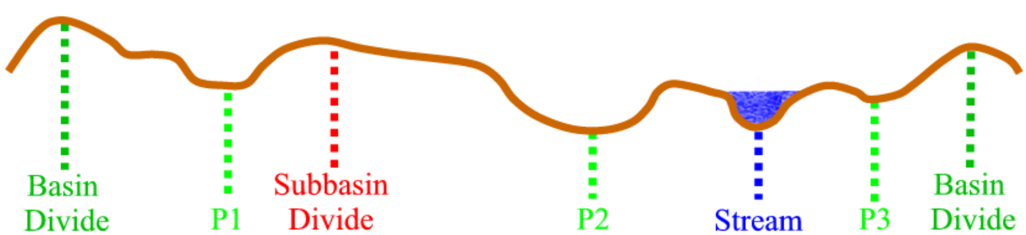


Figure 4.3: Cross-section AA (not to scale)

4.3 REMOVING PITS

The next step is to identify which depressions in the landscape are pits so they can be removed from analysis. The depths of the pits in cross-section AA are illustrated in Figure 4.4.

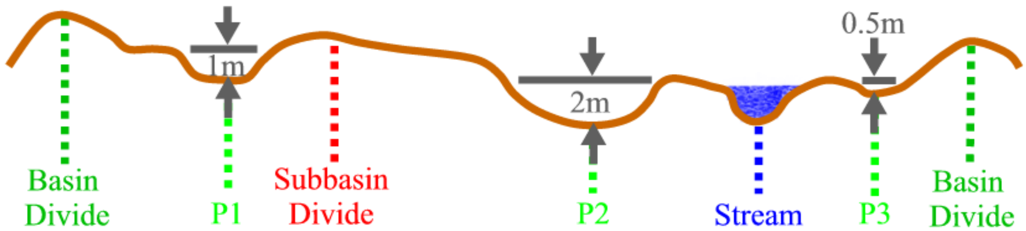


Figure 4.4: Pit Depths (not to scale)

The process of defining pits is iterative. First, a starting threshold for pit depth is selected. Then, a watershed is drawn for the area assuming that areas draining to pits do not contribute to the watershed. The area of the delineated watershed is compared to the USGS value of contributing area at the outlet of the subbasin. If the delineated contributing area is larger than the reported value from the USGS, more area should be removed from analysis. This means the threshold pit depth should be reduced. Conversely, if the contributing area is too small, the pit depth should be increased so that less area is removed from analysis.

The concepts of pit depth and contributing area are illustrated in Figures 4.5 and 4.6. The threshold pit depth was defined as 2 meters or greater in Figure 4.5, and in Figure 4.6, the threshold was defined as 0.5 meters or greater. The shaded areas represent the contributing portion of the watersheds.

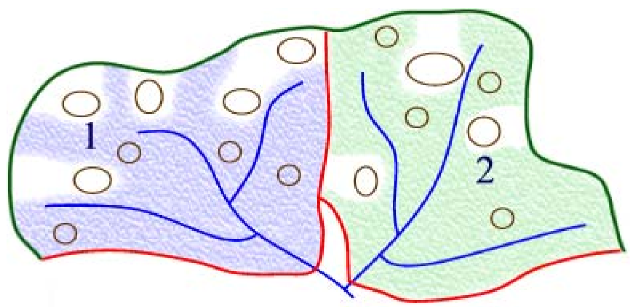


Figure 4.5: Contributing Drainage Area with 2-meter Pits

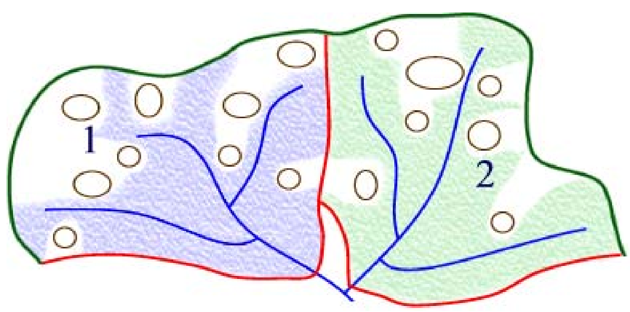


Figure 4.6: Contributing Drainage Area with 0.5-meter Pits

Once the appropriate threshold for pit depth is determined, the development of watershed parameters can proceed locally in the non-contributing subbasins. The parameters of these subbasins can then be cascaded as described in Chapter Three.

Chapter 5: Procedure: Basin Subdivision

5.1 INTRODUCTION

The Trinity River basin provided the first opportunity to develop a GIS process for subdividing large basins into manageable areas. The 30-meter DEM for the Trinity basin contains 237 million cells. The large file size of the grid requires long processing times. Subdividing the basin will create smaller grids, but it does not change the total processing time for the entire basin. In the future, however, the TNRCC will only need to reprocess the subbasin containing the water rights that need assessment. This chapter presents the procedure for subdividing the Trinity basin and presents two procedures for reconstructing the basin and cascading attributes. The first procedure for cascading attributes primarily uses network capabilities available in ESRI's ArcGIS software environment to select control points requiring cascaded attributes and to calculate new watershed parameters for these points, and the second method relies on the selection of points in ArcView 3.2 and the calculation of new watershed parameters in ArcGIS.

5.2 TRINITY RIVER BASIN

The Trinity River basin is composed of twelve hydrologic cataloging units (HUCs) as designated by the USGS. Each of these units is self-contained and drained by a single outlet. These agency-defined watersheds provided sensible delineation breaks for the subdivision process. The outline of the twelve HUCs of the Trinity River Basin is shown in Figure 5.1.

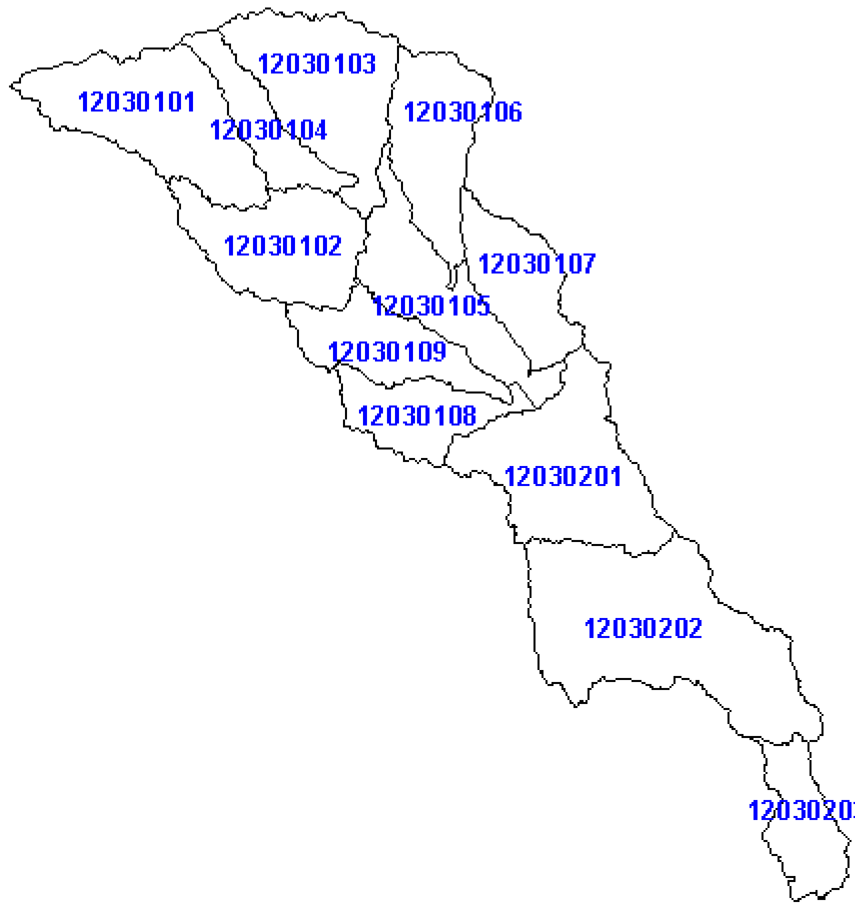


Figure 5.1: Hydrologic Cataloging Units of the Trinity Basin (USGS-1, 2001)

In addition to being predefined watersheds, the HUC boundaries were chosen as subbasin lines for the Trinity basin because many agencies disseminate data in packages that align with HUC boundaries.

Although the boundaries presented in Figure 5.1 represent watershed divides, the watersheds must be delineated with GIS. The boundaries in Figure

5.1 are a digital representation of hand-drawn watersheds from 1:250,000 scale maps, and the DEM-derived watershed boundaries may not match these exactly.

For the Trinity basin, the first five digits of the 8-digit HUC code are identical, so the HUCs will be referred to by the last three digits of the HUC code. The process for watershed delineation to define boundaries is the same for each HUC, so HUC 102 (12030102) is used to demonstrate the procedure.

5.3 PREPARING THE DATA

5.3.1 Basin Data

The 1° x 1° DEM grid tiles covering the Trinity basin were collected from the National Elevation Dataset (NED). The NED provides 30-meter resolution DEMs for the conterminous United States (USGS-3, 2001). The collection of tiles must be clipped to the extent of the Trinity basin to reduce the amount of data to process. The DEM was clipped to a buffered outline of the Trinity basin to ensure that all the appropriate area within the basin was captured.

The basin outline was buffered by 10 kilometers in ArcView 3.2. The width of the buffer required can vary. A 10-kilometer buffer of the basin outline was acceptable for watershed delineation along the basin boundary; however, subsequent investigations of watershed delineation for HUCs found that a 10-kilometer buffer is not wide enough to accurately delineate all boundaries. The author suggests a buffer of 25 kilometers for watershed delineation.

Through a series of commands in ArcInfo, the buffer shapefile, BUFFER, was converted to a grid, BUFF_GRID. BUFF_GRID was then divided by itself to create a mask grid, BUFF_MASK, where all cell values equal one. The DEM is multiplied by BUFF_MASK to clip the DEM to the buffered area. The commands in ArcInfo are as follows.

Arc: *shapearc* BUFFER BUFFER
Arc: *build* BUFFER *poly*
Arc: *grid*
Grid: *setcell* DEM
Grid: *setwindow* BUFFER DEM
Grid: BUFF_GRID = *polygrid*(BUFFER)
Grid: BUFF_MASK = BUFF_GRID / BUFF_GRID
Grid: CLIP_DEM = BUFF_MASK * DEM

The files required for obtaining the clipped DEM and the outcome of the commands listed above are shown in Figure 5.2.

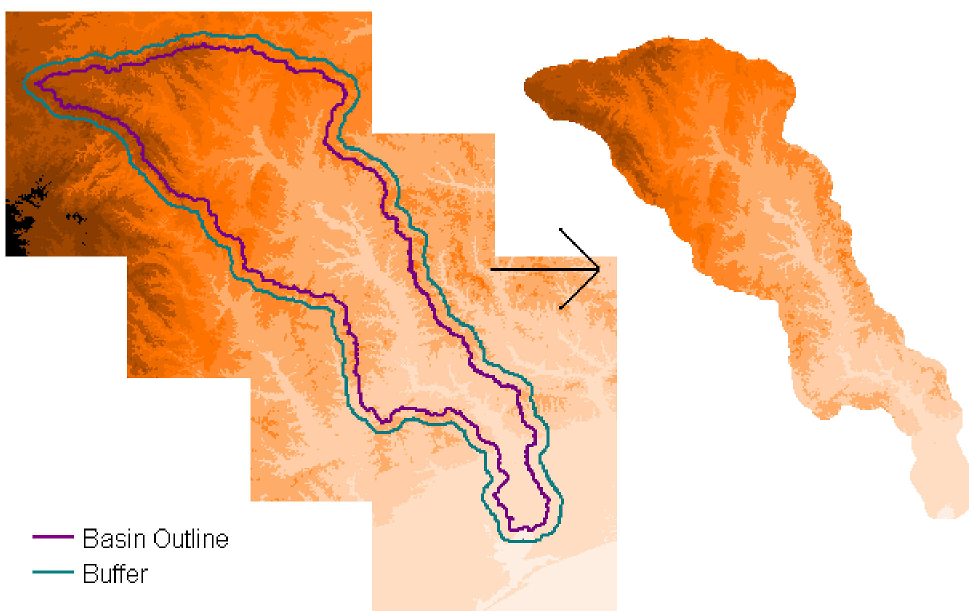


Figure 5.2: Clipping Buffered Basin from DEM

The first step in preparing the Trinity stream network for analysis was to remove loops and to remove or connect disconnected segments in the stream network. The details of stream network preparation for WAM can be found in Hudgens (1999). The streams surrounding the Trinity basin within the buffer zone were also obtained. These streams drain away from the Trinity watershed and help to define the watershed boundaries in the grid processing. Additionally, all streams must drain off the DEM for proper grid processing when a vector stream network is burned into a DEM grid. The streams in the Trinity basin and those surrounding it are illustrated in Figure 5.3.

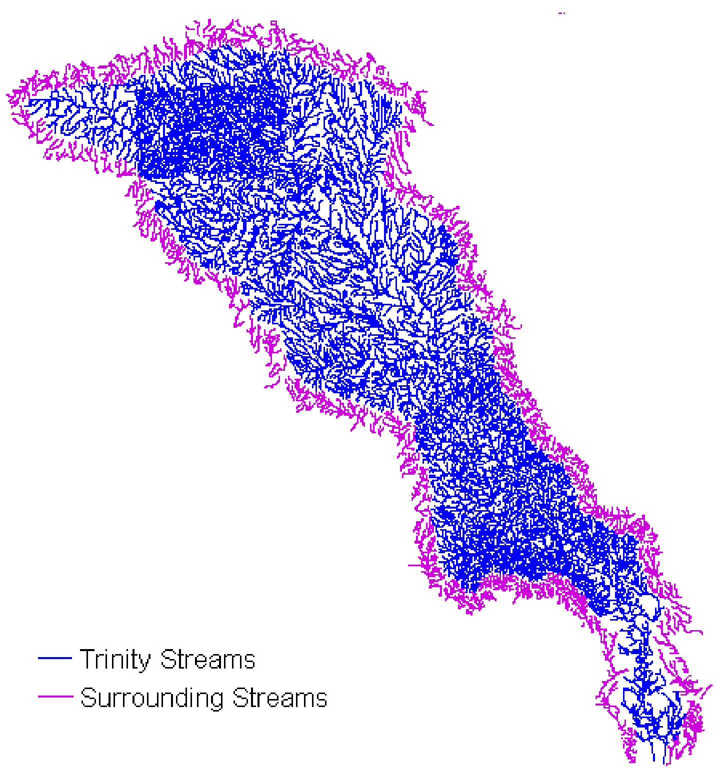


Figure 5.3: Trinity Streams and Surrounding Streams

The Trinity streams and surrounding streams were then merged into a single shapefile and burned into the DEM with Wrap1117. Burning the stream network raises the elevation of the DEM surrounding the streams to create a canyon to which all flow will drain. This process directs flow to the stream network and keeps it within the network until it reaches the outlet of the basin (Hudgens, 1999). Burning a stream into the DEM is illustrated in Figure 5.4.

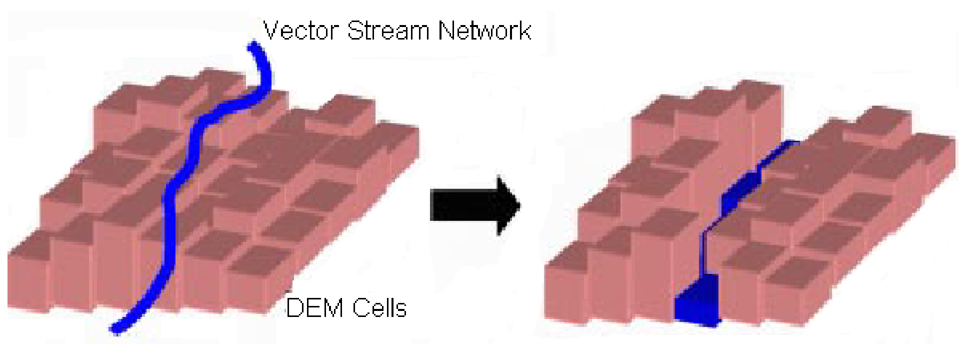


Figure 5.4: Burning Stream into the DEM (Hudgens, 1999)

5.3.2 HUC Data

To reduce the grid size for processing, the burned DEM must be cut to the buffer of HUC 102. To separate HUC 102 from the others, it was selected from the shapefile of HUCs and converted to a new shapefile. The HUC was then buffered by 25 kilometers and the burned DEM was clipped to the buffer as previously described. The process of clipping the burned DEM for HUC 102 is shown in Figure 5.5.

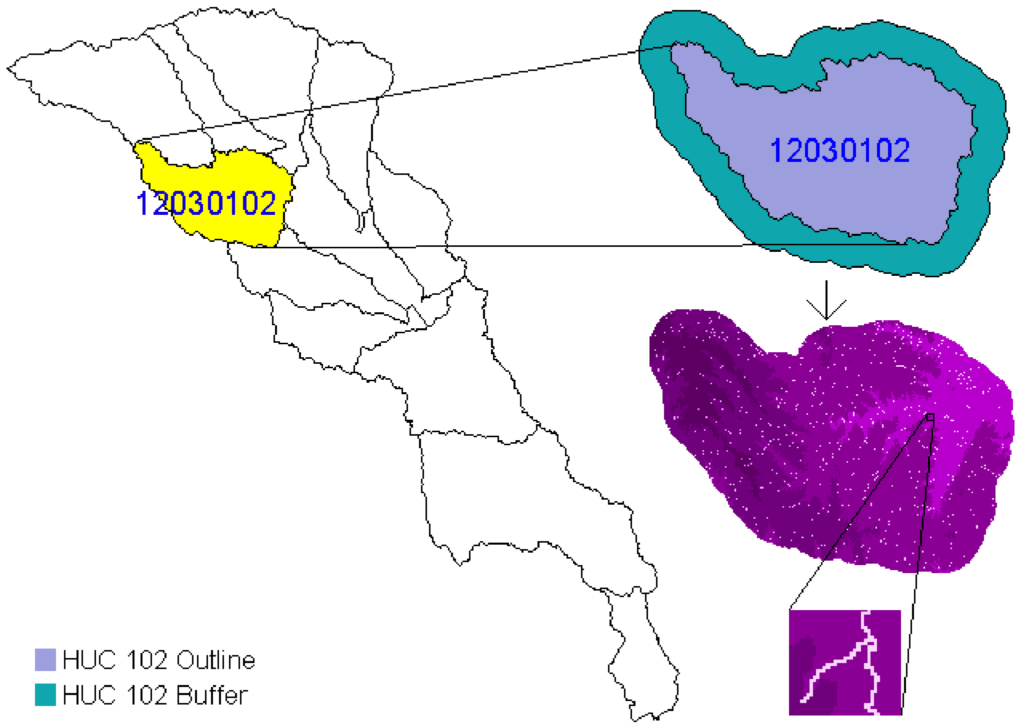


Figure 5.5: Extracting Burned DEM for HUC 102

5.4 Delineating HUC Watersheds

5.4.1 Processing Grids

Next, a fill grid was created from the burn grid of HUC 102 with a command in ArcInfo Workstation. Filling the grid raises the elevation of any grid cells that create a sink to the elevation of the surrounding cells. Filling sinks maintains the continuity of the DEM. The filling process is illustrated in Figure 5.6.

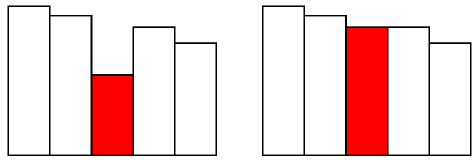


Figure 5.6: Filling Sinks

The command to create the fill grid in ArcInfo follows:

Grid: fill BURN_GRID FILL_GRID # # FDR_GRID

The grid FDR_GRID in the command line represents a second output grid created by the filling process called the flow direction grid. The flow direction grid is based on the Eight-direction Pour Point model in which each grid cell is assigned an integer value. The integer value represents the direction of flow to the next cell as defined in Figure 5.7.

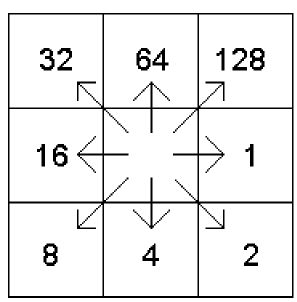


Figure 5.7: Eight-Direction Pour Point Model

An example of a flow direction grid and the arrows representing the integer values is shown in Figure 5.8.

4	2	2	1	128	64
1	1	2	1	1	1
2	1	2	4	4	2
2	1	2	1	4	4
4	4	2	1	2	4
8	4	2	1	1	2

↓	↘	↘	→	↗	↑
→	→	↘	→	→	→
↘	→	↘	↓	↓	↘
↘	→	↘	→	↓	↓
↓	↓	↘	→	↘	↓
↙	↓	↘	→	→	↘

Figure 5.8: Example Flow Direction Grid

5.4.2 Placing Outlet Cells

Watersheds can be delineated with ArcInfo Workstation from the flow direction grid and a grid of outlet cells. To delineate the HUC boundaries, a shapefile of points was first created in ArcView 3.2 to represent the outlets of the HUCs in which one outlet point was defined for each HUC watershed. The ID of each point was the 8-digit HUC code of the HUC drained by the outlet point.

The outlet must be placed within the burned stream to ensure that all flow in the HUC is captured. This can be done visually in ArcView 3.2, but care must be taken in placing the outlet cell. The potential for misplacing an outlet point is demonstrated with the example stream segment in Figures 5.9 – 5.11.

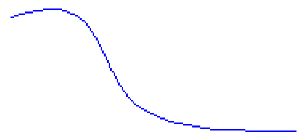


Figure 5.9: Example Stream Segment

The possible grid representation of the burned stream overlaying the vector stream is shown in Figure 5.10.

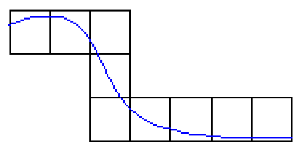


Figure 5.10: Grid Cell Overlay of Stream Segment

There are different possibilities for the flow direction grid created from this burn grid that depend on the elevation of the stream cells and surrounding cells. Two possible representations of the flow direction grid are shown in Figure 5.11.

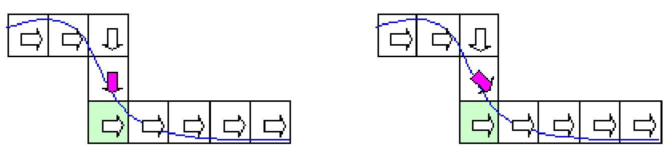


Figure 5.11: Possible Flow Direction for Example Stream Segment

The arrows in purple represent the differences in the flow direction grids. If an outlet point is placed in the green grid cell in the picture on the left in Figure 5.11, it will capture all of the flow from upstream. If the outlet cell is placed in the green grid cell in the picture on the right, the flow from upstream will not be captured and the watershed delineation will misrepresent the upstream contributions. The flow direction grid should be used to place outlet cells correctly.

When delineating a watershed for a subbasin, the outlet of the subbasin as well as any inlets to the subbasin should be represented in the outlet grid. This concept is illustrated with Figure 5.12.

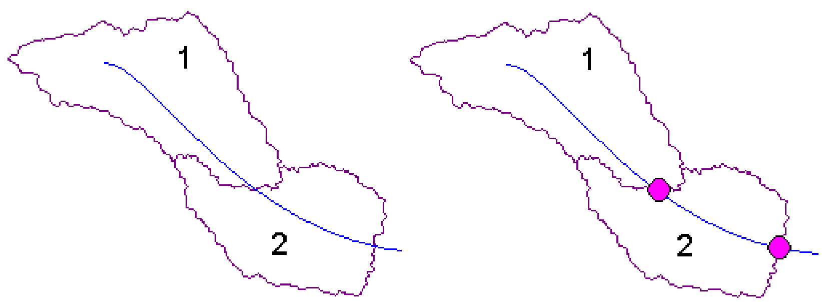


Figure 5.12: Outlet Cells

HUC 1 is the most upstream watershed of the basin and does not receive flow from another HUC. The only outlet point needed to delineate the watershed for this HUC is the one that drains it. However, HUC 2 receives flow from HUC 1, and the watersheds must be separated. Therefore, an outlet point must be placed at the location where HUC 1 drains into HUC 2 as well as at the outlet of HUC 2. The outlet point from HUC 1 represents an upper limit for the watershed of HUC 2.

5.4.3 Delineating the HUC Watershed

Returning to the Trinity basin, once the outlet points were created in ArcView 3.2, the shapefile was converted to a grid using the ID of the point for the grid cell ID. The following set of commands was then used in ArcInfo Workstation to delineate watersheds.

> *Grid:* *setcell* DEM
> *Grid:* *setwindow* BUFFER DEM
> *Grid:* WATERSHED = *watershed*(FDR_GRID, OUTLETS)

The grid of outlet cells represents the outlets for the HUCs across the entire Trinity basin. For analysis of HUC 102, the analysis extent was restricted to the buffer of HUC 102 in the ArcInfo command "setwindow". Setting the analysis extent is a very important step because it reduces the size of the grid to the area covered by the buffer of HUC 102. Remembering that the entire Trinity DEM is represented by over 237 million grid cells, reducing the analysis extent is really the step at which the basin is subdivided into more manageable regions.

The buffer includes portions of the surrounding HUCs, so portions of these HUCs are included in the delineation. The picture on the left of Figure 5.13 shows the analysis extent of the ArcInfo watershed delineation and the resulting grid.

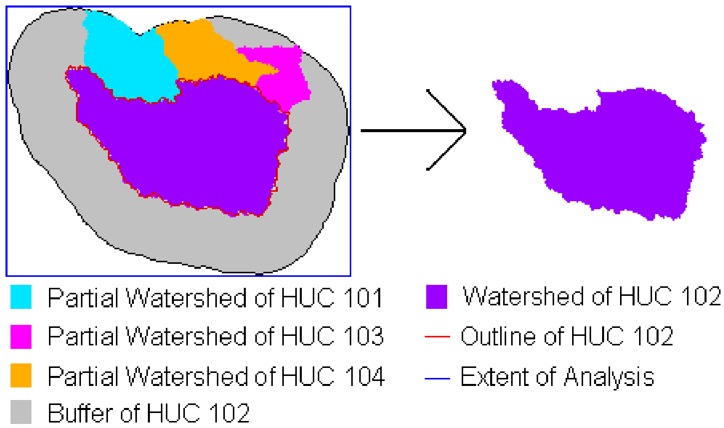


Figure 5.13: Delineation of Watersheds

The partial watersheds for HUCs 101, 103, and 104 are delineated because the outlets cell for these HUCs falls inside the 25-kilometer buffer for HUC 102. Each cell in the watershed grid is labeled with the ID of the outlet cell that it drains to. This ID tag was used to obtain the portion of the watershed delineation that represents only HUC 102. The following command found all the cells in the watershed grid with an ID equivalent to 12030102 (HUC 102) and replaced those values with "1".

Grid: WMASK_102 = *con*(WATERSHED = = 102, 1)

Values not equal to 12030102 were replaced with nodata cells leaving a mask grid of the watershed for HUC 102. The result is the picture on the right in Figure 5.13.

The process outlined in this section was repeated until watersheds were created for each HUC. The watersheds for each HUC in the Trinity River basin are shown in Figure 5.14.

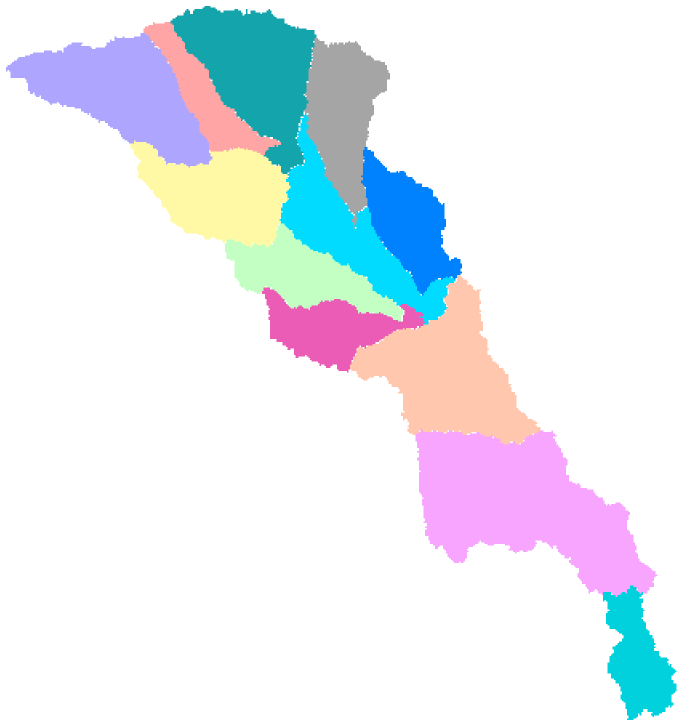


Figure 5.14: DEM Delineated Watersheds for Trinity HUCs

One last grid that was processed is the flow accumulation grid. Each cell in this grid contains a value of the number of cells that flows to it. The transition from a flow direction to a flow accumulation grid is shown in Figure 5.15.

↓	↘	↘	→	↗	↑
→	→	↘	→	→	→
↘	→	↘	↓	↓	↘
↘	→	↘	→	↓	↓
↓	↓	↘	→	↘	↓
↙	↓	↘	→	→	↘

0	0	0	0	1	0
1	2	4	1	2	3
0	0	1	5	0	0
0	1	2	8	10	0
0	1	0	3	15	1
1	2	0	1	2	20

Figure 5.15: Creating the Flow Accumulation Grid

To create this grid for each HUC, it is important to realize that the flow direction grid was created for the buffered area of the HUC. The flow accumulation grid, however, should only represent the watershed area. If outside area is included, it will falsely increase the drainage area of the HUC.

To rectify this situation, the flow direction grid was clipped to the watershed mask, and the flow accumulation grid was created from the clipped flow direction grid. This can be done in ArcInfo workstation with the following set of commands.

Arc: *grid*
Grid: *setcell* DEM
Grid: *setwindow* WMASK_102 DEM
Grid: CLIP_FDR_102 = WMASK_102 * FDR_102
Grid: FAC_102 = *flowaccumulation*(CLIP_FDR_102)

5.4.4 Problems Encountered in HUC Delineation

The watersheds in the Figure 5.14 are the final product of the watershed delineation. Not all of the watersheds delineated correctly on the first try. The two problems encountered when watersheds delineated incorrectly were misplacement of the outlet cell or a buffer that was too small. The watershed near the interface of HUC 202 and 203 did not delineate correctly and is shown in Figure 5.16.

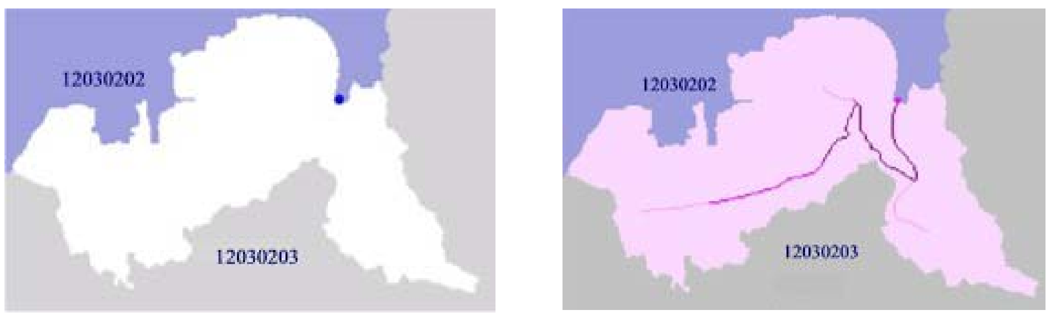


Figure 5.16: Incorrect Delineation of Watersheds

The white area in the picture on the left of Figure 5.16 was not delineated as belonging to either basin. The picture on the left includes the flow accumulation grid within the non-delineated section. The purple stream darkens as the flow accumulation increases. The flow should be draining towards HUC 203, but the flow accumulation grid shows it running the opposite direction. The problem was a result of the buffered area. A point within the interior of HUC 203 has an elevation lower than the outermost point on the northern edge of the buffer for HUC 203. This caused the flow accumulation grid to accumulate towards the lower elevation. Increasing the buffer size remedies this problem. Through investigations such as the delineation error between HUCs 202 and 203, it was determined that 25 kilometers is an appropriate buffer width for accurate watershed delineation because it typically ensures that there is an upstream elevation greater than all elevations in the downstream subbasin.

5.5 DEVELOPING WATERSHED PARAMETERS

Now that watersheds have been delineated for the HUCs, parameters for each HUC can be developed independently with Wrap1117. A detailed explanation of Wrap1117 processing can be found in Hudgens (1999). There are some things to keep in mind when processing individual subbasins of a basin.

Since the HUCs are processed independently and then pieced back together to correctly attribute all points, continuity must be maintained between the HUCs. This is done through the stream network and the control points.

When processing HUC 102, the streams in the interior of the watershed for HUC 102 were selected out of the Trinity streams shapefile and converted to a new shapefile. The streams at the outlet of the HUC and any inlets were selected just past the boundary of the HUC to maintain continuity with the next HUCs upstream and downstream.

The outlet points were included in the control point file to maintain continuity in the point file. When the control points within the HUC 102 watershed were selected out of the Trinity control point file, the outlet cell and all inlet cells were selected to provide a link between HUCs.

Through the grid processing, two flow direction grids were created for each subbasin. One is at the extent of the buffer and the other is clipped to the extent of the watershed. The buffered grid was used when creating the flow direction stream in Wrap1117, and the clipped grid was used when delineating the incremental watersheds to save processing time.

The curve number and precipitation grids used in Wrap1117 can be clipped to the HUC watershed masks as well. Knowing that the mask represents the entire drainage area of the HUC, the curve number and precipitation grids were multiplied by the watershed mask create a smaller area to work with.

5.6 Cascading Attributes

Once each HUC was processed locally with Wrap1117, the basin needed to be rejoined. For this process, it is important to know the drainage pattern of the basin. Figure 5.17 shows a schematic of the flow from HUC to HUC.

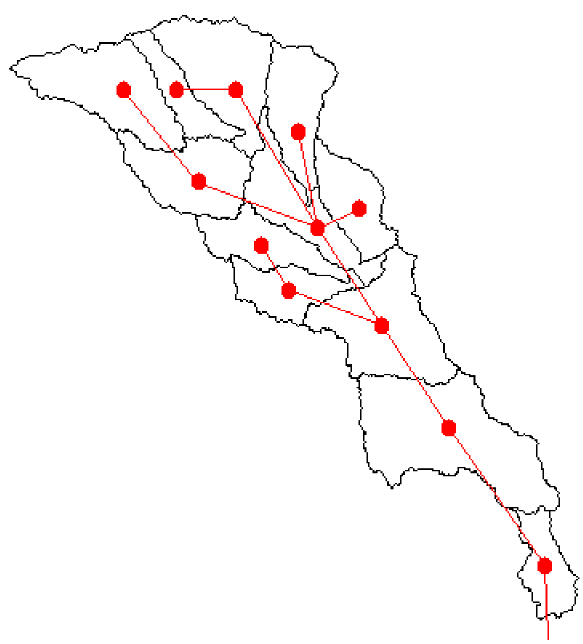


Figure 5.17: Schematic of HUC Drainage

Two methods of cascading attributes were investigated. The first primarily uses ArcGIS to cascade attributes while the second method primarily relies on ArcView 3.2. ArcGIS is relatively new software to GIS users and requires some discussion of its structure and capabilities.

5.6.1 ArcGIS 8.1

ArcGIS was introduced by ESRI as the next generation of their GIS software. ArcGIS is a suite of programs accessed through the interfaces such as ArcCatalog and ArcMap. These programs are used together for GIS analysis.

5.6.1.1 ArcCatalog

ArcCatalog is the data management interface for ArcGIS. All ArcGIS programs recognize the files used in ArcView 3.2 such as shapefiles, coverages and grids, but the primary data structure is contained within a geodatabase. The next level of organization in the geodatabase is the feature dataset. Feature datasets provide a means of organizing feature classes of the same reference frame (projection and areal extent). More than one feature dataset can be stored in a geodatabase, but all data within a single feature dataset must be in the same reference frame. Files stored in a feature dataset are called feature classes. Feature classes can be compared to shapefiles in ArcView 3.2 in that they represent points, lines, or polygons. Shapefiles or coverages can be imported as feature classes into a feature dataset, or new feature classes can be created in ArcCatalog. The data structure within ArcCatalog is shown in Figure 5.18.

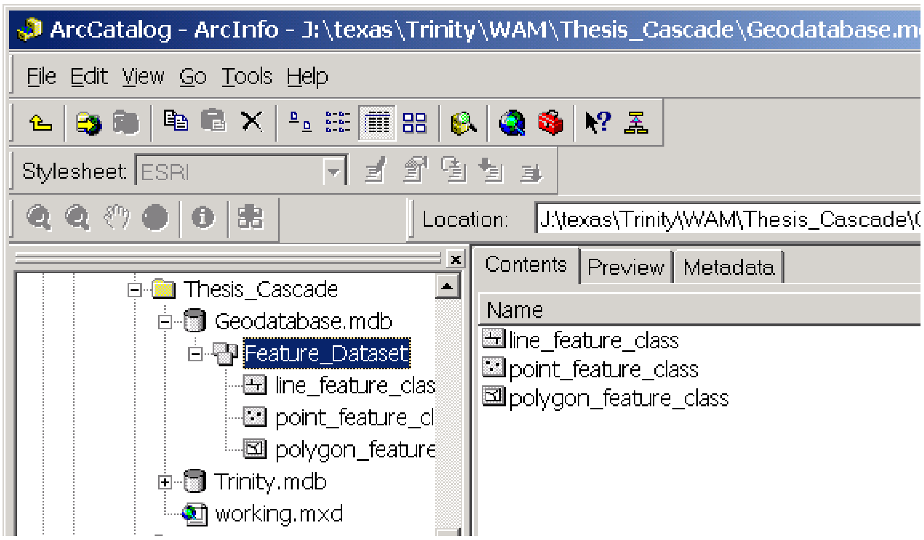


Figure 5.18: Data Structure in ArcCatalog

5.6.1.2 ArcMap

ArcMap provides an interface for viewing and analyzing GIS data. The basic functions are much the same as ArcView 3.2, and feature classes, shapefiles, coverages and grids can be viewed in this environment.

An important addition to ArcView 3.2 capabilities within ArcMap is network analysis. A geometric network in ArcGIS can be composed of multiple associated feature classes. Typically, one might think of a network as a collection of lines, such as a river or roadway diagram. In ArcGIS, the geometric network can contain the lines of the river and the points that lie on the river. Once the river and point files are created, they are converted into a geometric network within ArcCatalog. Flow direction can then be assigned to the network in ArcMap and trace functions can be carried out. These trace functions include tracing upstream or downstream from a flag, finding the path between flags, finding loops in the network, and finding segments disconnected from the main network. Once the network is properly formulated, these trace functions will also select points lying on the traced stream network.

5.6.2 Cascade Method 1

After creating the local parameter values for each control point in ArcView 3.2, the shapefiles of each set of local parameters were merged into a single shapefile called *cascade_parameters*. The DEM-derived stream networks within each HUC were also merged into a single shapefile called *dem_stream* to represent the analysis stream network. It should be pointed out that the DEM-derived stream network is created in Wrap1117, and represents the flow path of the streams across the DEM. This DEM-derived stream does vary slightly from the original vector stream, and this difference could affect the flow length parameter. However, the flow length parameter incorporated into the WRAP model is actually the flow length between control points to account for incremental channel losses. These incremental distances are not significantly affected by the differences between the original vector streams and the DEM-derived streams.

The attribute table of *cascade_parameters* was then edited to add five new fields labeled *Casc_FAC, Casc_Area, Casc_CN, Casc_Pr,* and *Casc_Fl.* These fields represent the cascaded flow accumulation, area in square miles, average curve number, average precipitation, and flow length respectively. These fields are used to update the parameters for the effects of outside HUCs.

The merged file of the parameter points and stream networks is shown in Figure 5.19.

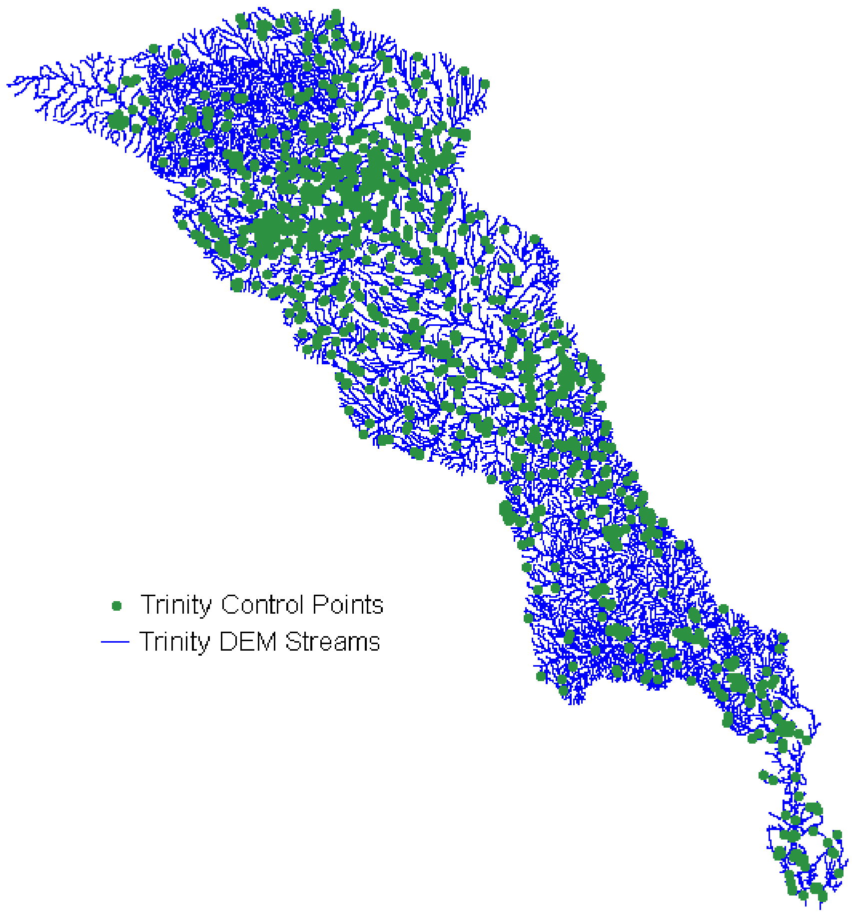


Figure 5.19: Merged Parameters and DEM Streams

The first step to importing the data into ArcGIS was to create a geodatabase in ArcCatalog. Then, the point and stream shapefiles were imported into a feature dataset within the geodatabase by right clicking on the geodatabase and selecting “Import” and then “Shapefile to Geodatabase…” from the resulting menus as illustrated in Figure 5.20.

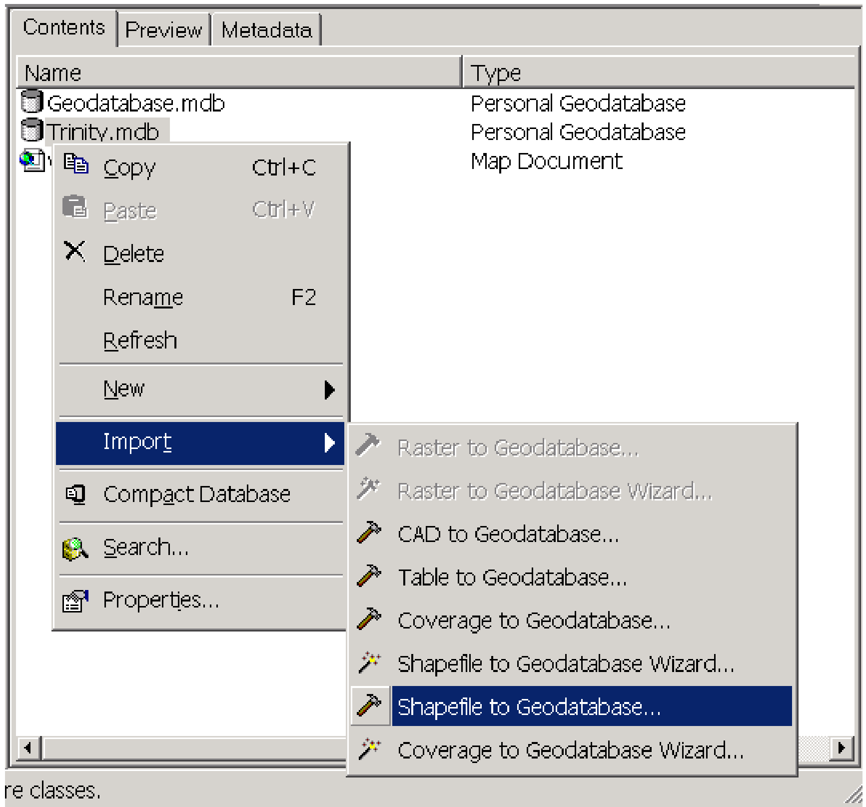


Figure 5.20: Importing Shapefiles to Geodatabase

The stream file was imported first because the spatial extent of this file is greater than the points, and the first file imported sets the extent of the feature dataset. The shapefiles imported as feature classes within the ArcGIS data structure are shown in Figure 5.21.

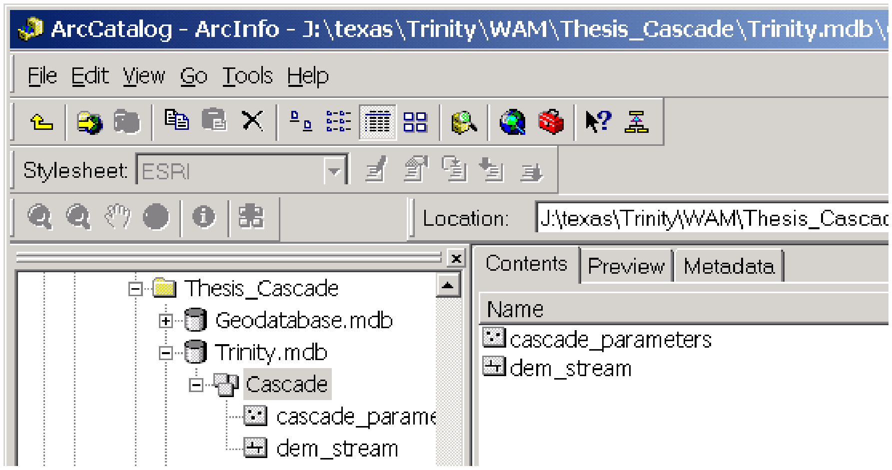


Figure 5.21: Imported Files

The data must further be built into a geometric network in order to use the tracing capabilities in ArcMap. The points and streams were chosen for inclusion in the network. For the tracing function to work correctly, the points need to be snapped to the network breaking the network lines, so simple lines were selected for the network creation. The point class was selected to represent sources and sinks in the network. The files added to the feature dataset after the geometric network creation are shown in Figure 5.22.

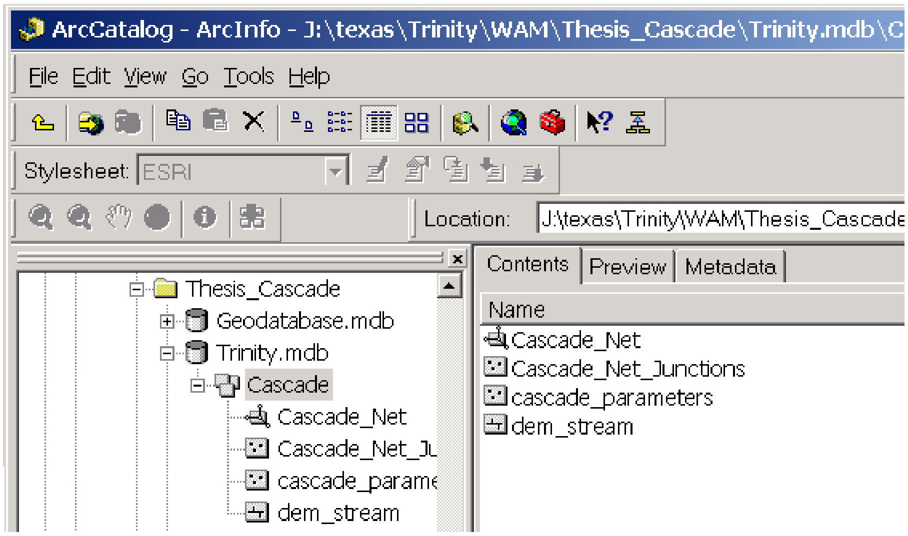


Figure 5.22: New Files Created by Geometric Network Wizard

The file *Cascade_Net* represents all the files within the geometric network such as the lines and points. The file *Cascade_Net_Junctions* represents a feature class of points located at the end of each network edge and at junctions in the network.

The data are now ready for processing in ArcMap. ArcCatalog has to be closed while working with the data in ArcMap because of conflicting editing locks placed on the data.

The data are added to a new ArcMap document by adding only *Cascade_Net*. This brings the stream edges, parameters, and network junctions into the document. For the network trace to select points lying on the network, the network edges must be broken at each parameter point. A stream segment that runs across three parameter points without breaking is shown in Figure 5.23.

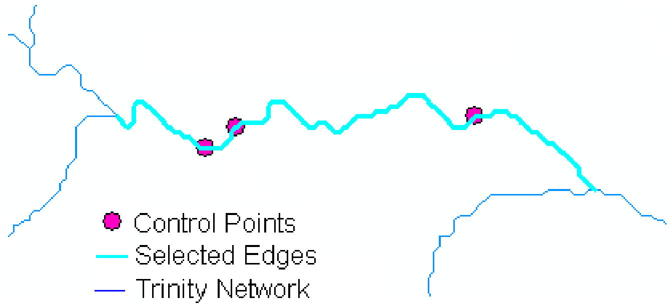


Figure 5.23: Stream Segment not Split at Points

In order for the points in *cascade_parameters* to break the edges, they were reloaded into the network with the Object Loader. This split the edges making the points selectable during traces. The revised stream network after reloading the points with stream segments that no longer spans over the control points is shown in Figure 5.24.

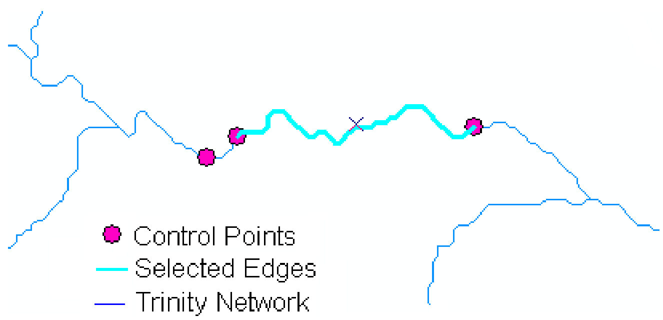


Figure 5.24: Split Stream Segment

Next, the flow direction was set on the stream network. By zooming into the bottom portion of the river basin, two basin outlets were found. A picture of the lower section of the basin is shown in Figure 5.25.

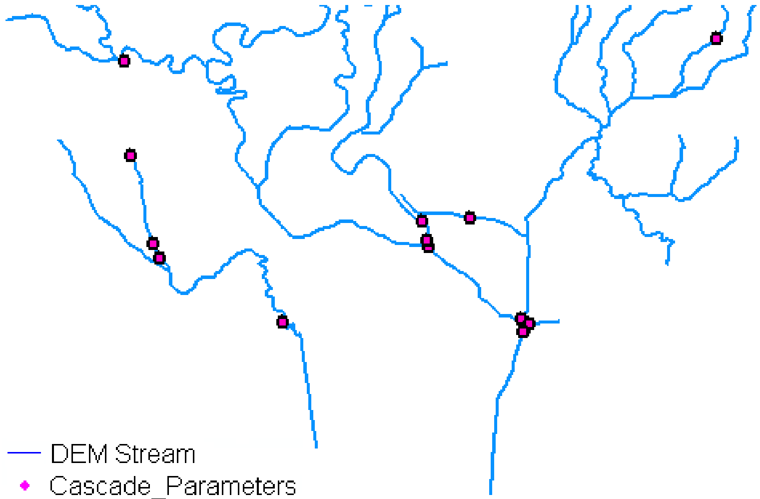


Figure 5.25: Lower Trinity

The outlet on the left in Figure 5.25 is for a self-contained subbasin that does not inherit anything from an upstream or downstream HUC, so it was not included in the cascading analysis. To set the flow direction on the stream network, the most downstream parameter on the network was selected and defined as a sink with the attribute window shown in Figure 5.26.

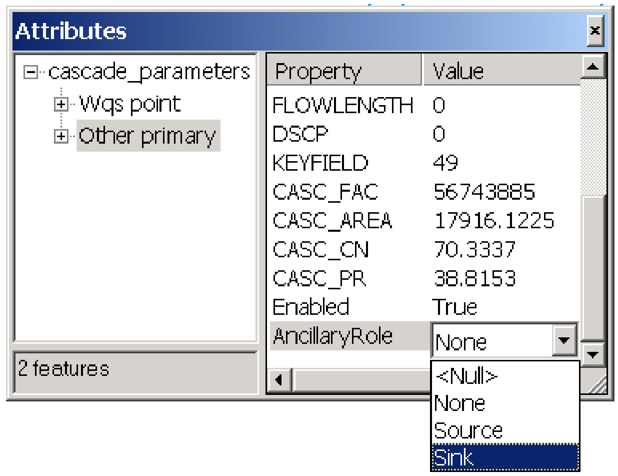


Figure 5.26: Ancillary Role

Once the sink was created, the flow direction was set. The flow direction arrows were the displayed on the network. The arrows representing flow direction in the lower part of the Trinity basin are shown in Figure 5.27.

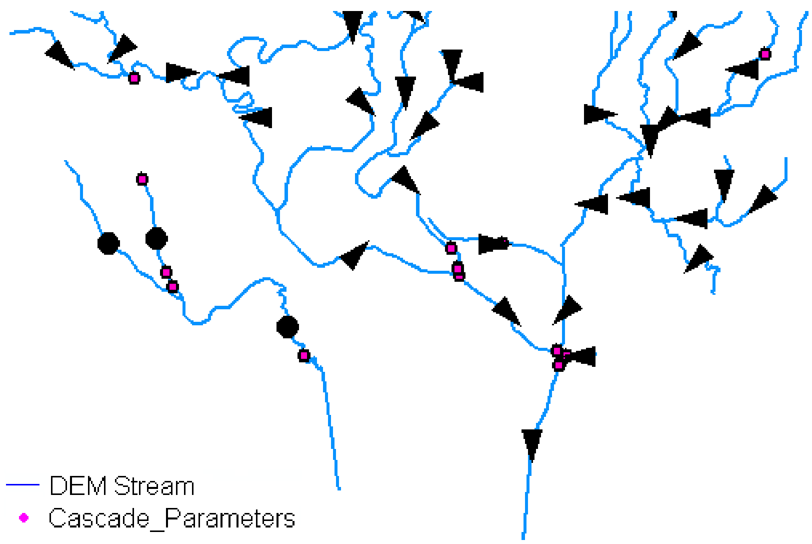


Figure 5.27: Flow Direction of lower Trinity

The black circles in Figure 5.27 represent arcs for which the flow is indeterminate. On the left subbasin, this is because there are multiple paths to a sink or a sink is not defined for this set of arcs. Viewing the entire Trinity stream network in Figure 5.28 displays other indeterminate flow sections in the network.

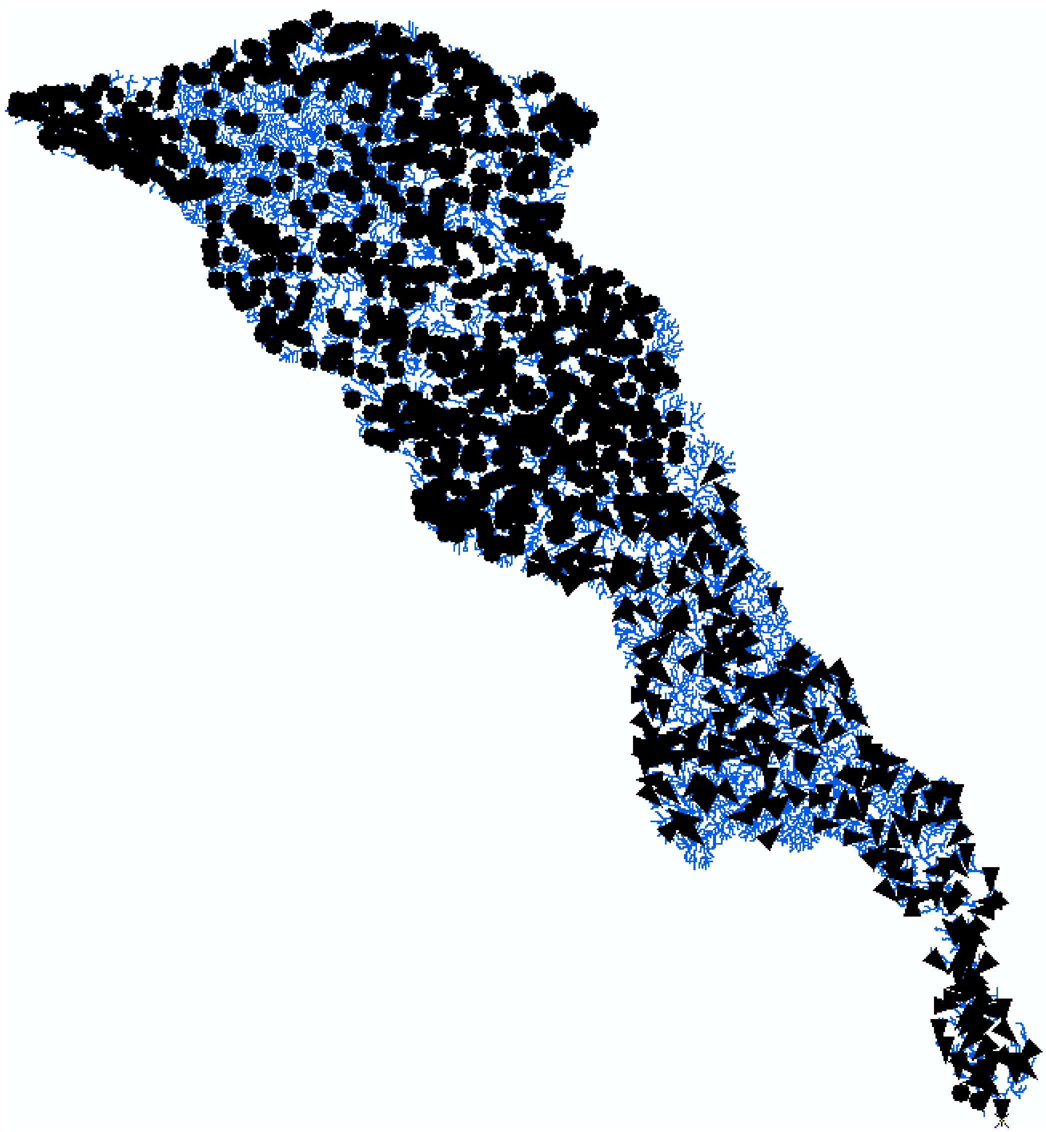


Figure 5.28: Flow direction arrows for entire Trinity

These indeterminate sections must be fixed before using the trace functions. The change from determinate arrows to indeterminate circles begins at the upstream side of HUC 201. The most downstream indeterminate point was found by zooming in on the stream network. A closer view of the stream network in this area is shown in Figure 5.29.

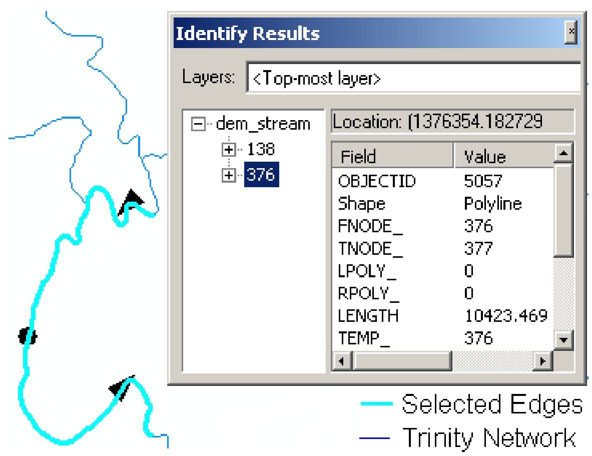


Figure 5.29: Most Downstream Indeterminate Arc

By identifying the streams highlighted in Figure 5.29, it was found that two streams overlap in this area, and the tributary entering the highlighted streams does not enter at the end of a stream segment. To rectify the problem, the highlighted stream must be split at the location of the junction with the tributary.

Once the stream is split, the flow direction must be set again to update the flow arrows. The new direction grid still has a problem that is illustrated in Figure 5.30.

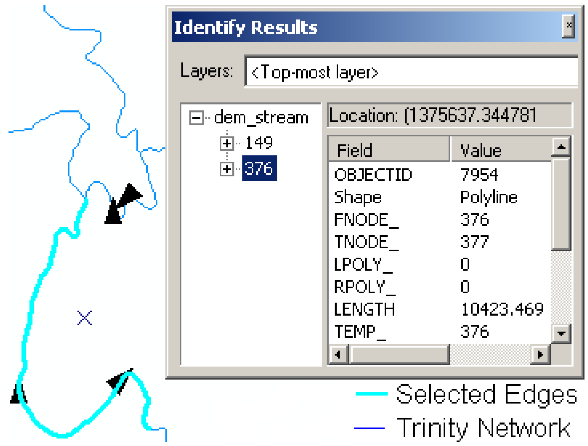


Figure 5.30: Reset flow direction

The flow direction on the newly split arc is flowing in the wrong direction. Remembering that two streams overlay in this section, the newly split stream segment that overlaps the existing stream was deleted. Once the duplicate stream was deleted, all flow direction arrows in this section were determinate and pointing in the right direction as shown in Figure 5.31.

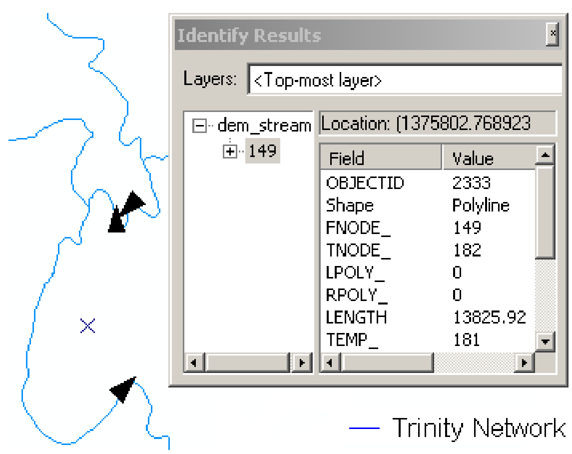


Figure 5.31: Fixed network

Fixing this one section of the stream network did not fix all of the indeterminate section. A problem similar to this was found at five other locations. It was noted that all of these problems occurred at HUC boundaries, but did not occur at all of the HUC boundaries, which suggests the problems arises from merging the streams.

The data are now prepared for cascading the parameters. First, a table of parameter values at the HUC outlets was created. This table was referred to throughout the cascading process. The watershed parameters at the outlet of each HUC are shown in Table 5.1. Flow lengths for control points in the Trinity River basin were not required, so that attribute is excluded from the parameter table.

Outlet ID	Flow Accumulation (# Cells)	Average Curve Number	Average Precipitation (in.)
101	6196783	74.65	32.09
102	4800659	79.67	34.02
103	5888612	73.83	36.72
104	2277684	70.09	35.12
105	4461377	74.09	37.5
106	4125613	75.91	39.65
107	3238903	70.67	40.03
108	2924210	69.53	36.72
109	3393215	73.95	36.28
201	6680044	61.00	40.81
202	10332689	64.64	43.94

Table 5.1: HUC Outlet Attributes

Then, a flag was placed just downstream of the outlet of HUC 101, and a downstream trace was run from the flag. The placement of the flag and the points and stream segments selected in the downstream trace are shown in Figures 5.32 and 5.33.

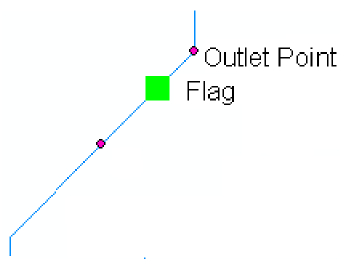


Figure 5.32: Placement of Flag at Outlet

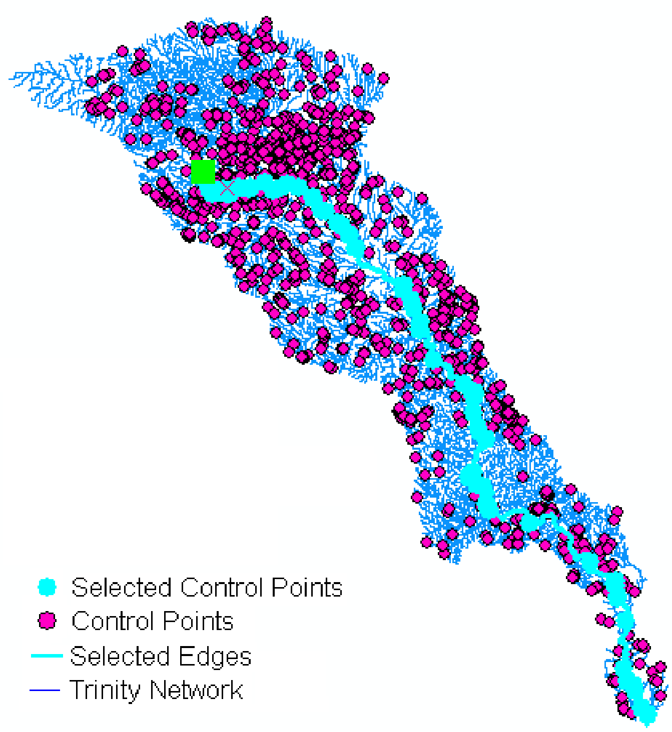


Figure 5.33: Downstream Trace from Outlet of HUC 101

If the points were not snapped to the network and the edges split, the downstream trace would not have selected the points lying on the network. One hindrance with this method is that the network will not recognize spatially coincident points. Only one of the coincident points is snapped to the network and selected in the downstream trace because a geometric network cannot have more than one junction at a given location.

The yellow point in Figure 5.34 is an example of spatially coincident points. The Identify tool finds two points at the location, but only one of them was selected in the attribute table. The other point must be manually selected from the attribute table. Therefore, all points along a downstream trace were checked for spatially coincident points that were not selected in the downstream trace.

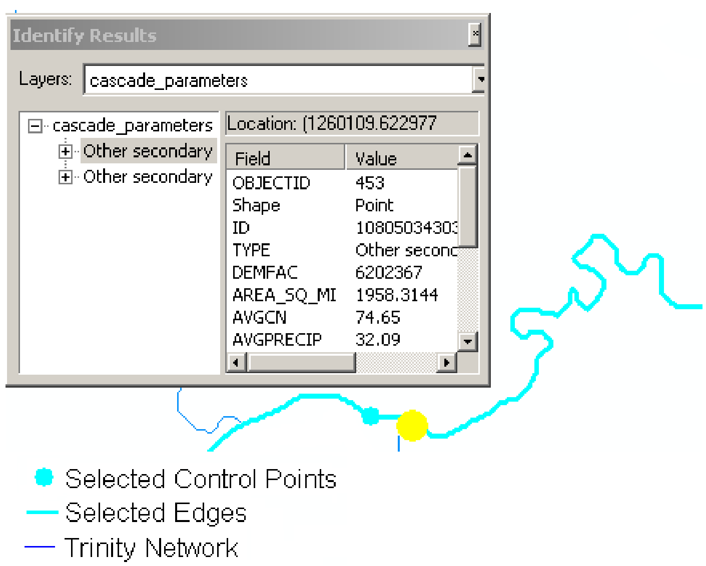
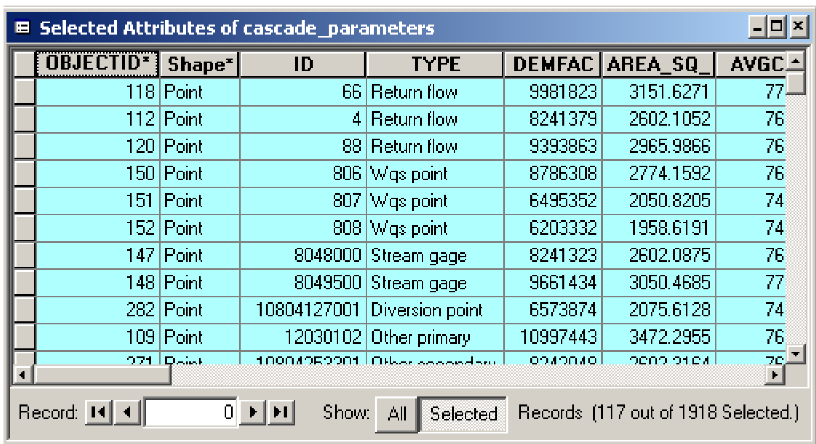


Figure 5.34: Spatially Coincident Points

Once the spatially coincident points have been selected along with the points along the downstream trace, the watershed parameters were updated by editing the attribute table. Notice at the bottom of the attribute table in Figure 5.35 that 117 of the 1,918 control points in the Trinity basin were selected as being impacted by HUC 101. It is only for the selected points that parameters are cascaded.


Selected Attributes of cascade_parameters

OBJECTID*	Shape*	ID	TYPE	DEMFAC	AREA_SQ_	AVGC
118	Point	66	Return flow	9981823	3151.6271	77
112	Point	4	Return flow	8241379	2602.1052	76
120	Point	88	Return flow	9393863	2965.9866	76
150	Point	806	Wqs point	8786308	2774.1592	76
151	Point	807	Wqs point	6495352	2050.8205	74
152	Point	808	Wqs point	6203332	1958.6191	74
147	Point	8048000	Stream gage	8241323	2602.0875	76
148	Point	8049500	Stream gage	9661434	3050.4685	77
282	Point	10804127001	Diversion point	6573874	2075.6128	74
109	Point	12030102	Other primary	10997443	3472.2955	76

Record: 0 Show: All Selected Records (117 out of 1918 Selected.)

Figure 5.35: Selection of Parameter Attribute Table

The formulas in Chapter Three were adjusted to reflect work in the GIS environment. The local watershed parameters are extracted from raster (grid) data and attached to the vector data (control points) located on the grid cells. The equations in Chapter Three must be modified to cascade the watershed parameters developed from raster data.

The flow accumulation parameter represents an area and was updated with a modification of Equation 3.1. In the raster environment, the flow accumulation attached to each grid cell is the number of cells flowing to that cell. Therefore, the flow accumulation value attached to a cell does not include the cell itself. In terms of cascading the attributes from HUC 101, the entire area of HUC 101 must be cascaded to the points influenced by the HUC, so the flow accumulation plus one (the cell representing the outlet) must be added to the flow accumulation value of each point selected in the downstream trace. The cascading formulas contain field names from the parameter attribute table. Utilizing field names means that the calculation is done for each selected control point using the value contained in the field name designated in the equation. Arguments in the following equations without subscripts represent field names. Arguments in the equations with subscripts are constants, and the subscript is used to convey the point that these equations can be modified for influences from different HUCs. The flow accumulation for HUC 101 is listed in Table 5.1 and is incorporated into the formula for cascading flow accumulation from HUC 101 as presented in Equation 5.1.

$$Casc\_FAC = DEMFAC + (FAC_{101} + 1) \qquad \text{(Eqn. 5.1)}$$

where

$Casc\_FAC$ = Cascaded Flow Accumulation at a Control Point; [# cells]

$DEMFAC$ = Local Flow Accumulation at a Control Point; [# cells]

FAC_{101} = 6196783 cells; Flow Accumulation of HUC 101

To further explain the use of field names, the formula presented in Equation 5.1 means that for every selected record in the attribute table, the value in column *Casc_FAC* equals the value in the flow accumulation field (*DEMFAC*) for that point plus the flow accumulation plus one of HUC 101. The calculation was performed by right-clicking on the *Casc_FAC* field in the attribute table and selecting "Calculate" from the drop-down menu. The formula was input into the Field Calculator shown in Figure 5.36.

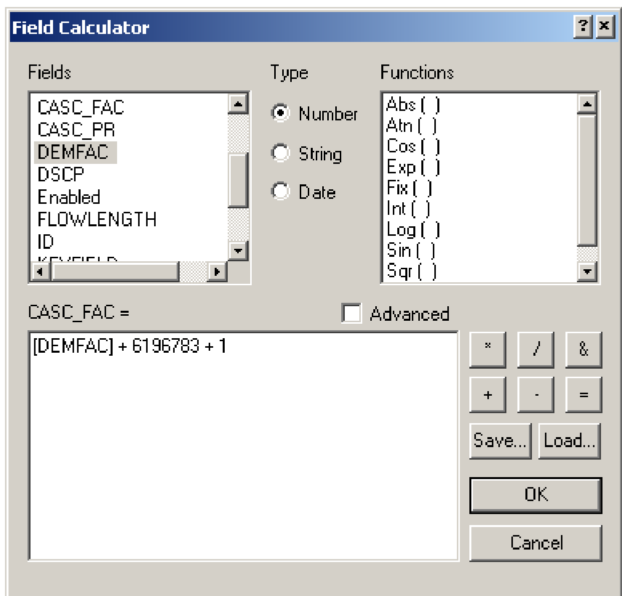


Figure 5.36: Field Calculator

The next field updated was *Casc_Area* representing the upstream area in square miles. This calculation simply required the application of conversion factors to the cascaded flow accumulation field. The size of each cell in the raster data was determined from the raster properties, and multiplying the flow accumulation value by the cell size squared provides an area in square meters.

The square meters were then converted to square miles with conversion factors as presented in Equation 5.2.

$$Casc\_Area = \frac{Casc\_FAC * cell\_size^2 * 10000}{25899881103} \qquad \text{(Eqn. 5.2)}$$

where,

Casc_Area = Cascaded Area at a Control Point; (mi^2)

Casc_FAC = Cascaded Flow Accumulation at a Control Point; [# cells]

Cell_size = Length of One Side of Grid Cell; (m)

The next field to cascade is the average curve number. The formula presented in the methodology chapter was again adjusted to reflect the raster environment by adding one cell to the flow accumulation values to represent the cell that the point is sitting on. Equation 5.3 presents the cascading equation for the average curve number from HUC 101.

$$Casc\_CN = \frac{(AVGCN * DEMFAC) + (AVGCN_{101} * (FAC_{101} + 1))}{(Casc\_FAC + 1)} \qquad \text{(Eqn. 5.3)}$$

where,

Casc_CN = Cascaded Average Curve Number at a Control Point

AVGCN = Local Average Curve Number at a Control Point

$AVGCN_{101}$ = 74.65; Average Curve Number of HUC 101

FAC_{101} = 6196783 cells; Flow Accumulation of HUC 101

The equation for cascading the average precipitation is the same as Equation 5.3, but the curve number values were replaced with precipitation values.

To complete the cascading of flow accumulation, area, average curve number and average precipitation, the local values must be made to equal the cascaded values. Some cascaded points will be affected by other HUCs and need to reflect the values already updated. This was done by right clicking on the field for each local value and calculating it to equal the cascaded value. For example, *DEMFAC* was calculated to equal *Casc_Fac* and so on.

This process of tracing downstream and calculating attributes was repeated from the outlet of each HUC to cascade the parameters of flow accumulation, area in square miles, average curve number and average annual precipitation.

The last parameter to cascade is the flow length. Although flow length was not requested for the Trinity basin, the flow length parameter is required for other basins and the cascading of this attribute is demonstrated with the Trinity basin.

As described in Chapter Three, flow length is not an attribute affected by upstream subbasins. The local value of flow length for each control point must be updated with the flow length through downstream subbasins to the outlet of the river basin. Therefore, the total flow length for each control point in HUC 101 will equal the local flow length at the point plus the flow length through each

HUC downstream of HUC 101. Figure 5.37 shows the flow path to the basin outlet from the outlet of HUC 101.

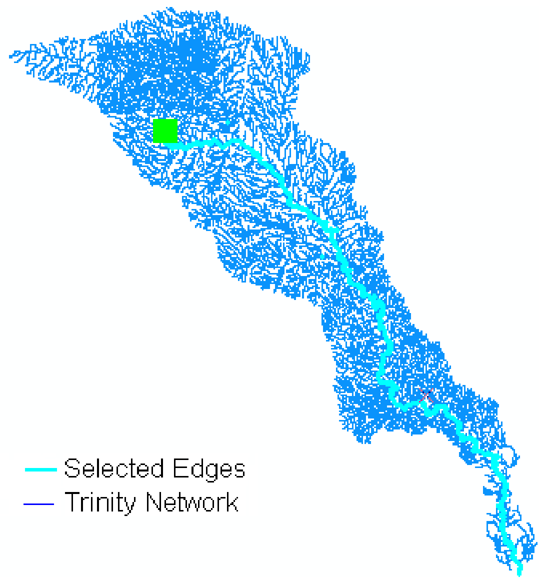


Figure 5.37: Flow Path from Outlet of HUC 101

In this first method of cascading the attributes of area, curve number and precipitation, the influence of one HUC is cascaded to the points affected by that HUC. To retain this system of cascading, the flow length is cascaded through one HUC at a time. For example, an upstream trace is run from the flag placed just downstream of the outlet of HUC 101 in Figure 5.32. As the outlet to HUC 101 also represents the inlet to HUC 102, the upstream trace selects all points for which the path to the outlet of the basin must travel through HUC 102. Figure 5.38 shows these selected points.

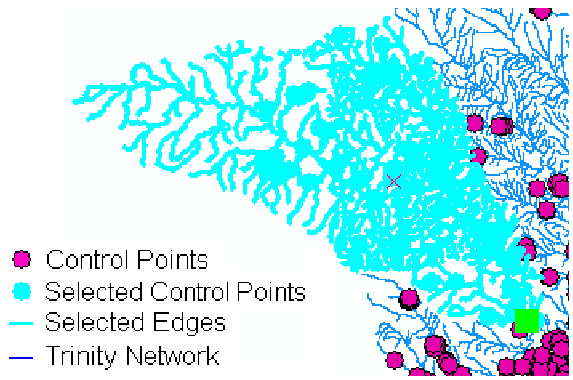


Figure 5.38: Upstream Trace from Inlet of HUC 102

Then, the field *Casc_Fl* for the selected points was calculated with Equation 5.4 to reflect the contribution to flow length through HUC 102. Remembering that flow length was not required for the Trinity River, a constant value is not available for the flow length through HUC 102.

$$Casc\_Fl = FLOWLENGTH + FL_{102} \qquad \text{(Eqn. 5.4)}$$

where,

Casc_Fl	= Cascaded Flow Length at a Control Point; (m)
FLOWLENGTH	= Local Flow Length at a Control Point; (m)
FL_{102}	= Constant; Flow Length through HUC 102; (m)

The local field for flow length, *FLOWLENGTH,* was then updated to equal *Casc_Fl*. This process of updating flow length was repeated from the inlet of each HUC creating a flow length for each point to the outlet of the basin.

There are two reasons a second method was investigated for cascading attributes. The time required to reload the points into the ArcGIS network to break edges was quite lengthy, and the manual selection of spatially coincident points defeats the purpose of the downstream trace.

5.6.3 Method 2 Cascade

The second method of cascading parameters makes use ArcView 3.2 to select the points for cascading and ArcGIS to calculate the cascaded values. This process requires more hand work, but is faster than the previous method and avoids the problems encountered with spatially coincident points and unbroken edges. This method updates all parameters locally rather than globally.

This process is illustrated with HUC 105. The first step is to select, in ArcView 3.2, the DEM-derived stream from each inlet to HUC 105 to the outlet of HUC 105. Although this sounds tedious, the HUCs are small and the process is quick. The selected stream is then converted into a new shapefile. Once the center streams are defined for all HUCs, they are merged into a single shapefile, *center_stream*, to represent the center stream of the Trinity River basin. The stream between each inlet and the outlet of HUC 105 is shown in Figure 5.39.

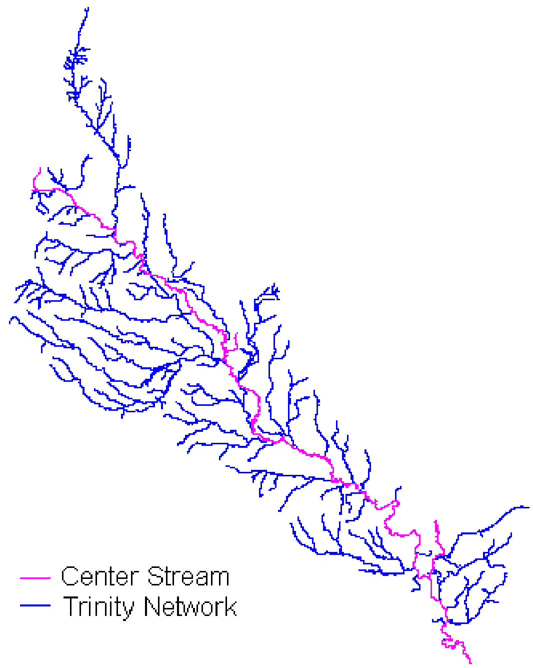


Figure 5.39: Center Stream of 105

Next, starting at one inlet to HUC 105 (such as 102), all the points that lie on the center stream are hand selected. It is important during this step to be aware of points near junctions that may be on a tributary and not on the main stem. The network schematic created in Wrap1117 is useful for this. The inlet point (the outlet to HUC 102) was not selected during this process, but the outlet of HUC 105 was selected. This new set of points was converted to a new shapefile named *center_par_102to105*. The results of the selection of points from the outlet of HUC 102 to the outlet of HUC 105 are shown in Figure 5.40. This process of point selection was repeated from each inlet to HUC 105.

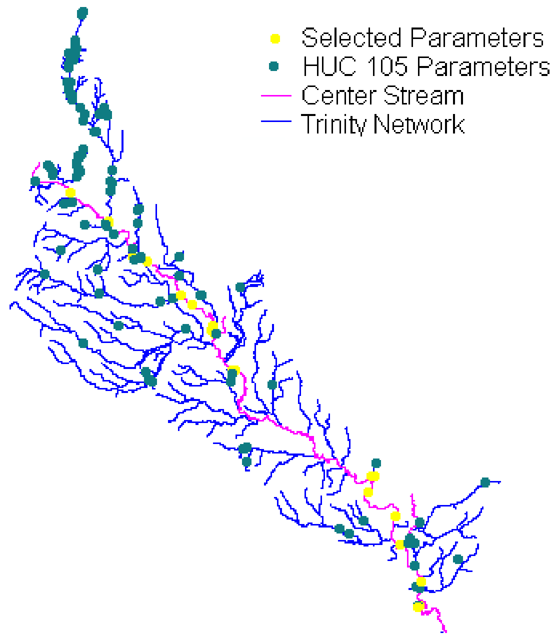


Figure 5.40: Selected Parameters

Next, the entire parameters shapefile for HUC 105 was converted to a new shapefile named *cascade_par105*. Then, the five cascading fields listed in the previous cascading method, *Casc_FAC, Casc_Area, Casc_CN, Casc_Pr, and Casc_Fl*, were added to the attribute table of the new shapefile.

The process of selecting center streams, points, and converting the parameters file to a new shapefile was repeated for each HUC in the Trinity with the exception of HUCs with no inlet.

The parameters were then updated in ArcMap. The updates could be done in ArcView 3.2, but ArcMap has the ability to store equations that will be used multiple times.

Again using HUC 105 as a demonstration, the shapefiles *cascade_par105, center_par_102to105, center_par_103to105, center_par106to105,* and *center_par107to105* were added to a new ArcMap document. Although unnecessary, adding the stream network was useful as a visual aid. Two more items on hand were the table of outlet attributes and a schematic drawing of the HUC drainage pattern as shown in Figure 5.41.

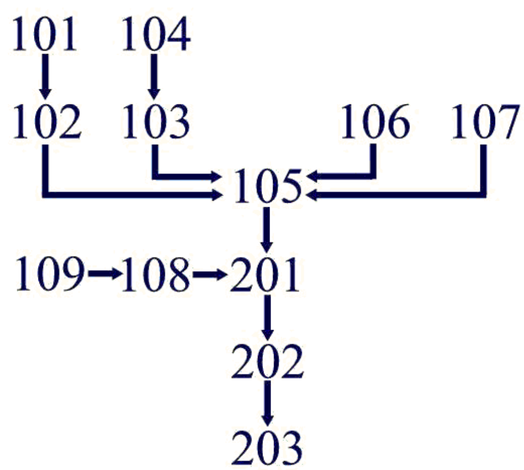


Figure 5.41: Drainage Schematic of HUCs

To cascade the parameters, a spatial selection was performed. Through the 'Select by Location' choice from the Selection menu, points were selected from *cascade_par105* that intersect with the points of *center_par_102to105* as shown in Figure 5.42.

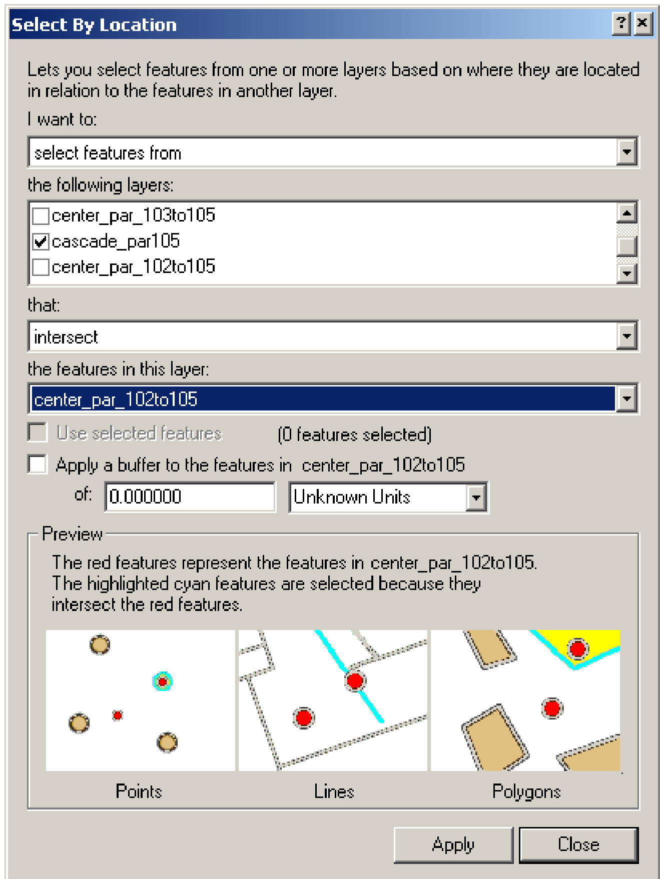


Figure 5.42: Select by Location Window

This process selected spatially coincident points as well. The number of points in the shapefile *center_par_102to105* was compared to the number of points selected in *cascade_par105* as a check.

The parameters were updated with attributes from each HUC upstream of the inlet HUC for each set of center points. For example, HUC 101 drains into HUC 102, so the center points in HUC 105 from HUC 102 will inherit from both upstream HUCs. This information was easily determined with the schematic in

Figure 5.41. Thus, the flow accumulation values for the points coinciding with *center_par_102to105* were updated with Equation 5.5.

$$Casc\_FAC = DEMFAC + \left(FAC_{101} + 1\right) + \left(FAC_{102} + 1\right) \qquad \text{(Eqn. 5.5)}$$

where,

Casc_FAC = Cascaded Flow Accumulation at a Control Point; [# cells]

DEMFAC = Local Flow Accumulation at a Control Point; [# cells]

FAC_{101} = 6196783 cells; Flow Accumulation of HUC 101

FAC_{102} = 4800059 cells; Flow Accumulation of HUC 102

The expression entered into the Field Calculator to update the flow accumulation of points inheriting from HUC 102 is presented in Figure 5.43.

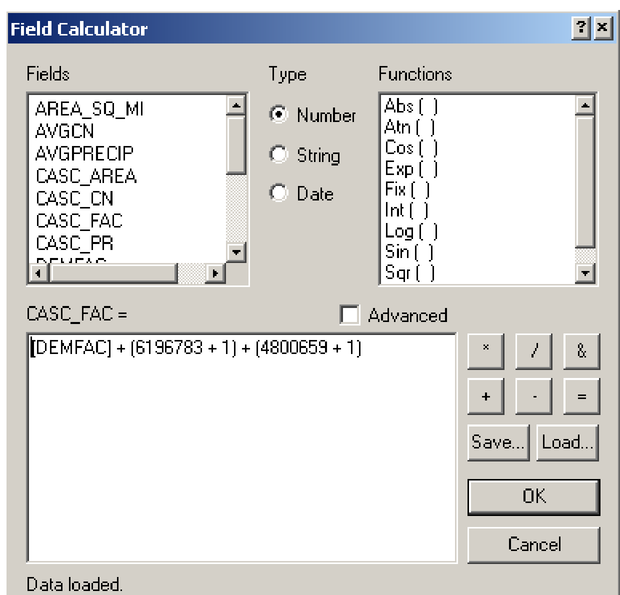


Figure 5.43: Field Calculator for HUC 102 to HUC 105 Cascade

The curve number expression for updating parameters inheriting from HUC 102 is expressed in Equation 5.6.

$$Casc\_CN = \frac{(CN*(F+1)) + (CN_{101}*(F_{101}+1)) + (CN_{102}*(F_{102}+1))}{Casc\_FAC+1} \quad \text{(Eqn. 5.6)}$$

where,

Casc_CN	= Cascaded Average Curve Number at a Control Point
CN	= Local Average Curve Number at a Control Point (the field AVGCN)
F	= Local Flow Accumulation at a Control Point (the field DEMFAC); [# cells]
CN_{101}	= 74.65; Average Curve Number of HUC 101
CN_{102}	= 79.67; Average Curve Number of HUC 102
F_{101}	= 6196783 cells; Flow Accumulation of HUC 101
F_{102}	= 4800659 cells; Flow Accumulation of HUC 102
Casc_FAC	= Cascaded Flow Accumulation at a Control Point; [# cells]

The average precipitation equation was the same as the curve number expression except values of precipitation were inserted where there is presently curve number data.

Once the parameters coinciding with *center_par_102to105* were cascaded, the cascaded values (fields beginning with ‘Casc’) were copied to the local fields for each attribute, and the process was repeated for the other center points in HUC 105.

The flow length must be updated for every point in the HUC. To do this, the selected points in *cascade_par105* were cleared. Then, the flow length value was cascaded for all points in the shapefile to represent the flow length to the outlet of the Trinity basin. From the schematic in Figure 5.41, it was seen that this would include the flow length through HUCs 201, 202, and 203. Therefore, the formula entered into the Field Calculator was the local flow length field (‘Flowlength’) plus the flow length through HUC 201, 202, and 203.

Expressions can be saved in the Field Calculator and reloaded. Using flow accumulation as an example, it was useful to save an expression that contained the flow accumulation values from each HUC. Then, this expression was loaded into the Field Calculator for each HUC and edited to reflect only the necessary HUC values. This saves the user from having to retype an equation multiple times risking transcription errors when many of the values are repeated.

Finally, the downstream control point for each outlet cell was manually updated with the next downstream point to maintain the continuity of the basin. Once the process outlined in this section was repeated on each HUC, the cascaded parameter shapefiles were merged into a single shapefile representing the final parameters for the Trinity River basin.

5.7 CONCLUSIONS

Subdividing the basin into smaller, more manageable subbasins is a sensible method of managing large basins. The second method of cascading parameters is recommended for analysis at this time because it is less time consuming than creating and editing the network in ArcGIS, snapping points to break edges, and finding spatially coincident points. The updates could be done in ArcView, but in ArcGIS the formulas can be saved in the calculations box and updated for application to each HUC making the process more efficient.

Chapter 6: Procedure: Non-Contributing Regions

6.1 INTRODUCTION

Using GIS to remove non-contributing areas from analysis provides a method of automating the process. This chapter presents a procedure for removing non-contributing areas from raster analysis in GIS. First, a discussion of raster processing is presented followed by the procedure for removing non-contributing areas in the Brazos basin. Two methods for removing pits are described.

6.2 METHODOLOGY OF DEM ANALYSIS

An example landscape represented by a burned DEM is shown in Figure 6.1.

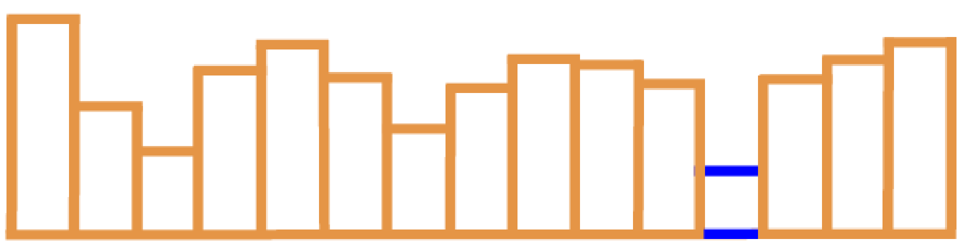


Figure 6.1: Example Burned DEM Landscape

The grid after filling and the direction of flow across those cells is represented in Figure 6.2. The green arrows represent contributing flow.

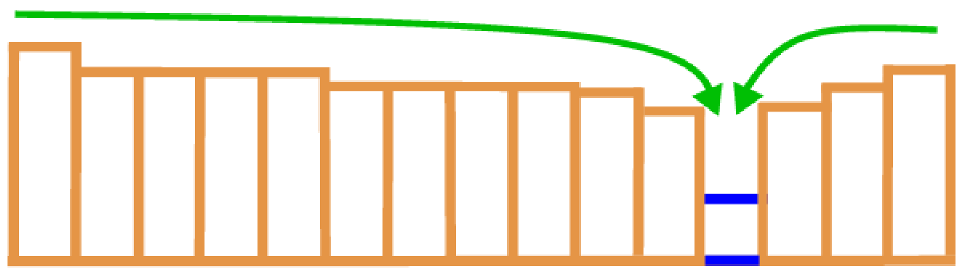


Figure 6.2: Filled DEM

Typically, a grid is processed to fill all pits so all of the flow across the landscape is directed to the stream. In non-contributing areas, some flow does not drain to the stream network, so some of the depressions should not be filled.

Figure 6.3 shows the fill depths of the deepest point in each depression. These depths are determined by subtracting the burn grid from the fill grid.

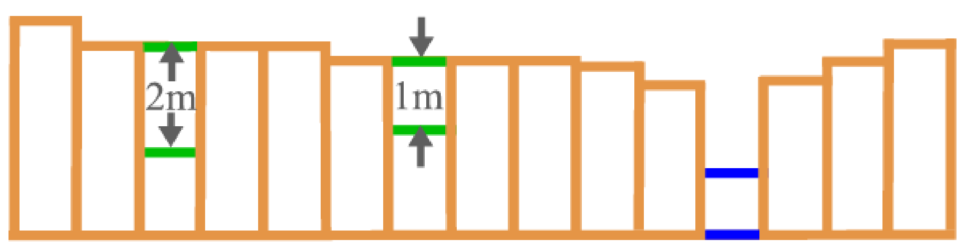


Figure 6.3: Fill Depths (not to scale)

The process of removing pits from DEM analysis is iterative, so a starting pit depth must be selected, analyzed and modified to correctly delineate the non-contributing region. For the example landscape, a pit depth of two meters is assumed as a starting threshold.

At this point, one of two methods is used to finish the delineation of the contributing area.

6.2.1 Method 1 Analysis of Non-contributing Area

The cells that represent pits of two meters or deeper are turned into *nodata* cells within the burn DEM, and the resulting grid is filled again. A *nodata* cell is viewed as a black hole by the GIS program, so the cells around it do not fill. Figure 6.4 shows the filled grid with the two-meter pit removed.

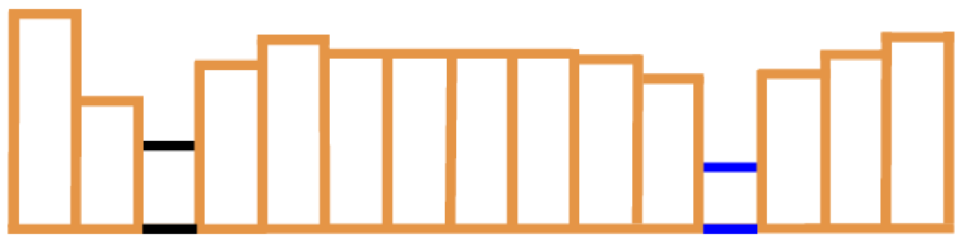


Figure 6.4: Filled Grid for 2-meter Pit Removal

The direction of flow across these cells is illustrated in Figure 6.5. The black arrows flow into the pit and will not contribute to the basin drainage area.

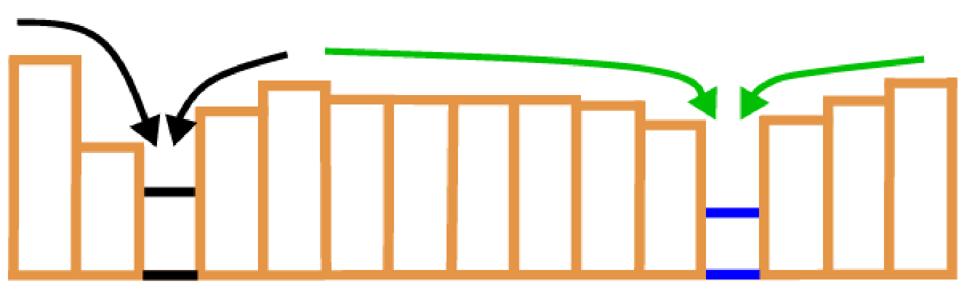


Figure 6.5: Direction of Flow for 2-meter Pit Removal

Once the flow direction is determined, the contributing watershed can be delineated and compared to reported USGS drainage areas. Supposing that the contributing area for the example landscape is too large, a smaller depth for pits should be chosen and analyzed. Turning cells with pit depths of one meter and greater into *nodata* cells will result in the fill grid and flow arrows presented in Figure 6.6.

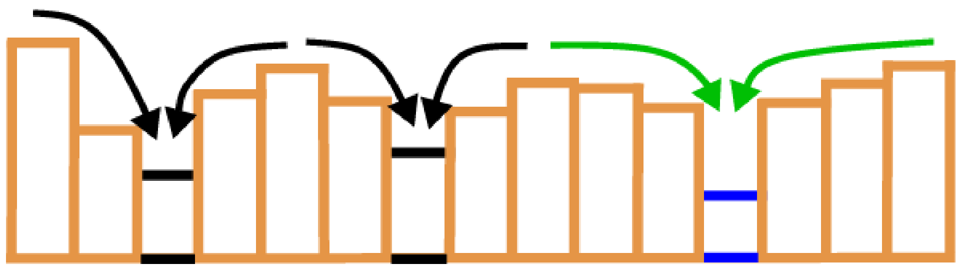


Figure 6.6: Direction of Flow for 1-meter Pit Removal

If the contributing drainage area with a 1-meter pit depth matches the USGS reported area, then the analysis is complete. Otherwise, the pit depth should be altered until the appropriate contributing drainage area results.

The most time-consuming process of this method is the recreation of the fill and flow direction grids every time the pit depth is revised. The second method presented requires that the fill and flow direction grids be created only once.

6.2.2 Method 2 Analysis of Non-contributing Areas

Stepping back to the point at which a pit was defined as 2 meters deep, the *nodata* cell is placed in the flow direction grid instead of the burn grid. Figure 6.7 shows the revised flow direction arrows when undertaking this method.

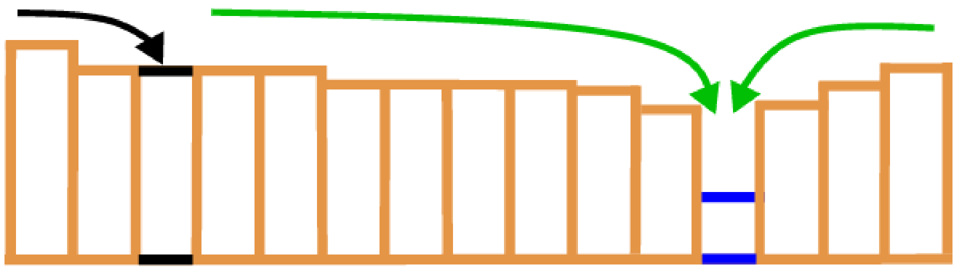


Figure 6.7: Method 2 Analysis of 2-meter Pits

Upon comparing Figures 6.5 and 6.7, it is clear that the second method of analysis slightly underestimates the non-contributing area. All area upstream of the pit is captured as non-contributing area, but the downstream side of the pit is not. The impact of this exclusion was investigated, and it was determined that there is no significant difference between the two methods at this spatial scale. There were also procedural difficulties encountered with the Method 1 that were absent when using the Method 2. The procedural differences are presented at the end of this chapter and the analysis of the two methods is outlined in Chapter Seven. Therefore, as the second method of pit removal avoids procedural obstacles and saves valuable time, it was chosen to develop the contributing watersheds within non-contributing regions.

6.3 BRAZOS RIVER BASIN

The Brazos River basin is used as an example basin for the non-contributing procedure. The basin was subdivided in the same manner as the Trinity along lines defined by the contractor for this basin. The separation lines are shown in Figure 6.8.

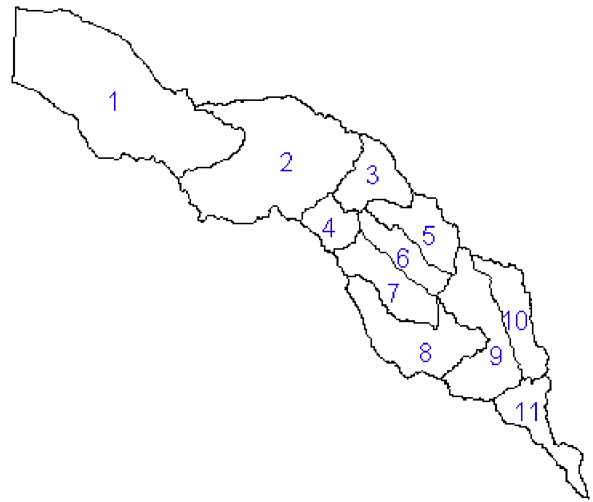


Figure 6.8: Brazos Areas

Area 1 abruptly ends on the West side in Figure 6.8 because the contractor lines ended at the western border of Texas. However, the whole basin, extending slightly into New Mexico, was used for analysis.

Area 1 in Figure 6.8 represents the area draining to the confluence of the Salt Fork Brazos River and the Double Mountain Fork Brazos River. There is not a USGS gage associated with this points, so it has no identifying number from the USGS, but this location represents the start of the main stem of the Brazos River and the point at which non-contributing area in the basin stops increasing (USGS, 1977). Therefore, below this point, all area in the basin is contributing.

Each of the eleven areas of the Brazos was divided into individual watersheds using the procedure outlined in Chapter Five. The only subbasin that will be analyzed with respect to non-contributing area is Area 1.

The USGS Drainage Report (1977) for the Brazos basin provides 32 locations within the non-contributing area for which the contributing and non-contributing drainage areas were determined. The latitude and longitude of these points is also provided in the report, and a shapefile of the points was created by the contractor for use in the Brazos basin. Figure 6.9 shows these points and their location within Area 1.

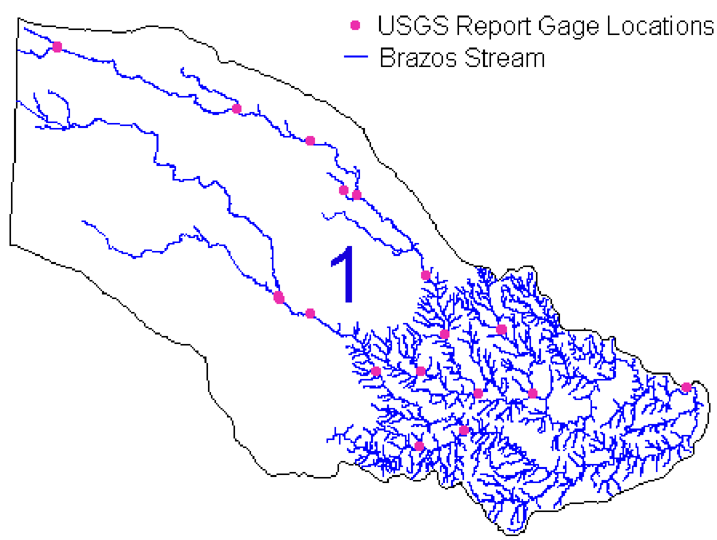


Figure 6.9: USGS Points for Drainage Delineation

6.4 REMOVING PITS FROM ANALYSIS

The entire Brazos stream network was burned into the DEM with Wrap1117. The burn grid, BURN, was then clipped to the watershed mask of area 1 (WMASK1) and filled in ArcInfo Workstation. A grid representing depression depths (DEPTH) was created by subtracting the burn grid (BURN1) from the fill grid (FILL1). The depth grid can be queried to locate all cells of a specific depth or greater. The units of the burn, fill, and depth grids are in centimeters. The commands to create these grids and query the depth grid for depressions greater than or equal to one meter are given below:

Arc: grid
Grid: setcell DEM
Grid: setwindow WMASK1 DEM
Grid: BURN1 = WMASK1 * BURN
Grid: fill BURN1 FILL1# # FDR1
Grid: DEPTH = FILL1 - BURN1
Grid: ALL_PITS_100 = *con*(DEPTH >= 100, DEPTH)

The location of all pits greater than or equal to one meter in area 1 of the Brazos River are shown in Figure 6.10.

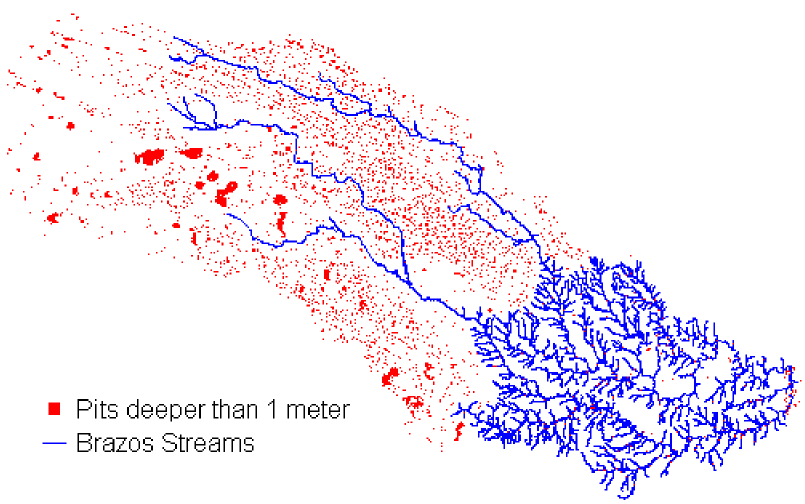


Figure 6.10: 1-meter Pits in the Brazos River Basin (Area 1)

All of these pits cannot be removed from the analysis because some of them fall within the stream network. A stream segment in which pits appear is shown in Figure 6.11.

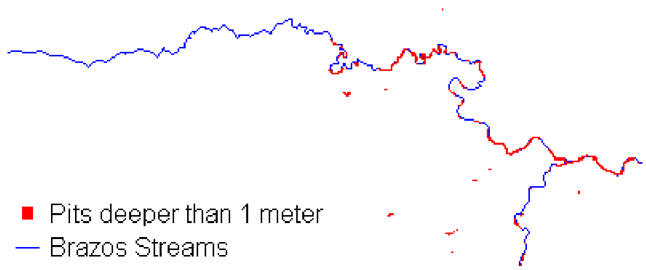


Figure 6.11: Pits in Stream

Before analyzing the grids further, the pits that fall inside the stream network must be removed. The stream network within area 1 must first be converted to a grid with ArcView 3.2. A field called *Value* was added to the stream attribute table and populated with a value of 1 for each arc. After setting the analysis extent and cell size to the watershed mask, the stream was converted to a grid. Figure 6.12 show a portion of the grid stream overlaid with the vector stream.

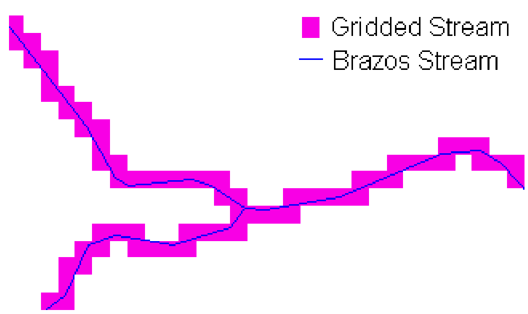


Figure 6.12: Grid Stream and Vector Stream

The stream is now represented as a grid (STREAM_MASK) with a value of one in each grid cell. The intent of the next steps is to create a grid in which all pits within the stream have been removed (EDIT_PITS_100). First, the pits in the stream were identified and then removed from the grid ALL_PITS_100 with the following commands.

Grid: STREAM_PITS = STREAM_MASK * ALL_PITS_100
Grid: STREAM_PITS_0 = *con*(*isnull*(STREAM_PIT), 0, STREAM_PITS)
Grid: NO_STREAM_PITS = ALL_PITS_100 - STREAM_PITS_0
Grid: EDIT_PITS_100 = *con*(NO_STREAM_PITS > 0, NO_STREAM_PITS)

A mask of the pits was then created to replace these cells in the flow direction grid with *nodata* cells. The following set of ArcInfo commands replaces cells in the flow direction grid that coincide with pits in EDIT_PITS_100 with *nodata* cells.

Grid: PIT_MASK_100 = EDIT_PITS_100 / EDIT_PITS_100
Grid: FDR_PIT_MSK = PIT_MASK_100 * FDR1
Grid: FDR_PIT_Z = *con*(*isnull* (FDR_PIT_MSK), 0, FDR_PIT_MSK)
Grid: FDR_W_PITS_Z = FDR1 – FDR_PIT_Z
Grid: FDR_W_PITS = *setnull*(FDR_W_PITS_Z == 0, FDR_W_PITS_Z)

Then, the watershed function is run using the grid FDR_W_PITS to delineate the watershed in Figure 6.13 for a pit depth of 1 meter.

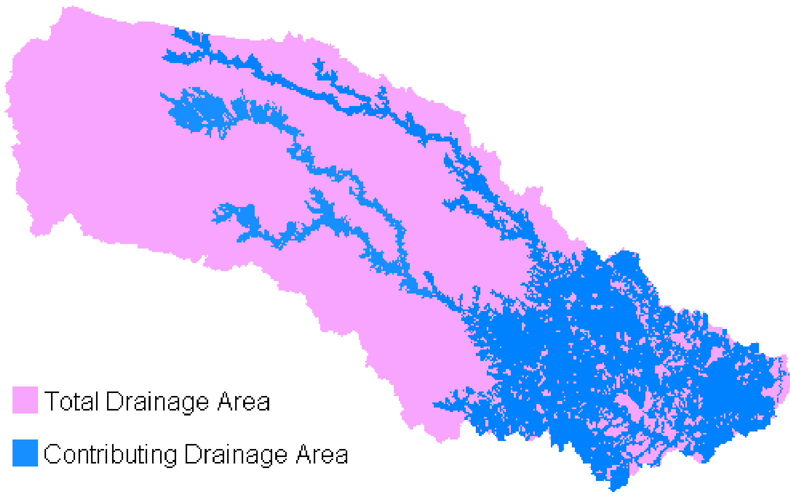


Figure 6.13: Contributing Drainage Area for 1-meter Pit Depth

A flow accumulation grid is created for this watershed, and the resulting drainage areas for stream gages within area 1 are compared to the USGS reported drainage areas at select locations. This comparison is presented in Table 6.1.

CRWR Gage Number	USGS Incremental Area (mi^2)	CRWR Delineation 1-m pits # cells	CRWR Delineation 1-m pits Incr. Area (mi^2)
6	236	2113131.00	667.03
11	805	2078557.00	656.12
26	526	1678750.00	529.91
28	608	1712858.00	540.68
32	599	1696520.00	535.52
33	2065	4858963.00	1533.78

Good Match
Area Over
Area Under

Table 6.1: Comparison of Drainage Areas

The table shows that the CRWR delineated area for gage 26 matches the USGS drainage area within 1% whereas the other gages do not. Some contain too much contributing area and some do not have enough. This variation in areas reveals errors in the 30-meter data or in the original USGS delineated areas. If the data were accurate, then one pit depth should suffice for the entire watershed. The non-contributing area was further subdivided to create a threshold pit depth appropriate to different areas because one pit depth could not be defined across the entire region.

As previously mentioned, there were 32 gaged locations within the non-contributing area. The calibration of all of these gages would defeat the purpose of creating an automated process, so the six gages used for comparison in Table 6.1 were chosen for calibration. Figure 6.14 illustrates the location of these gages.

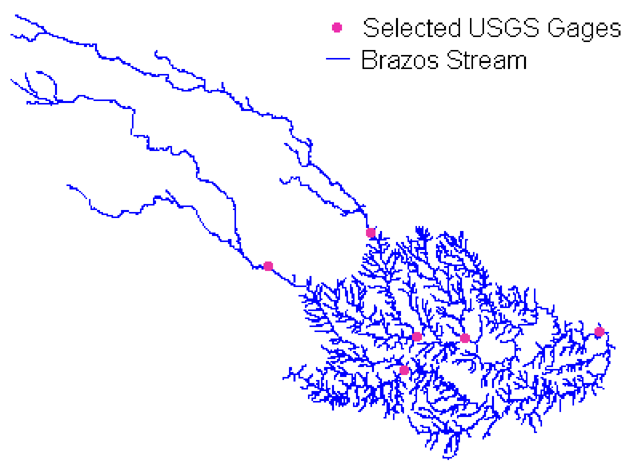


Figure 6.14: Gages Selected for Calibration

The watersheds for each of these gages were created with the same procedure as subdividing the basin. The watersheds for each of the gages (including non-contributing areas) are represented in Figure 6.15.

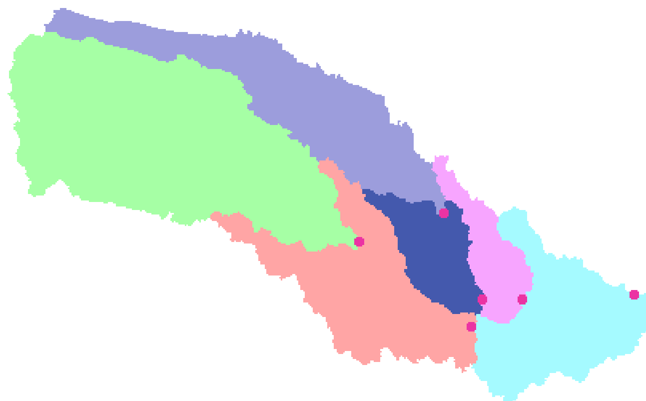


Figure 6.15: Gage Watersheds

The gage areas were calibrated to the incremental area between gages because of the need for different pit depths in each subbasin, and the appropriate pit depth was defined for each gage subbasin through the process previously outlined. Figure 6.16 shows the completed watersheds for the calibrated gages in the non-contributing region of the Brazos basin and the depth of pit defined in each subbasin.

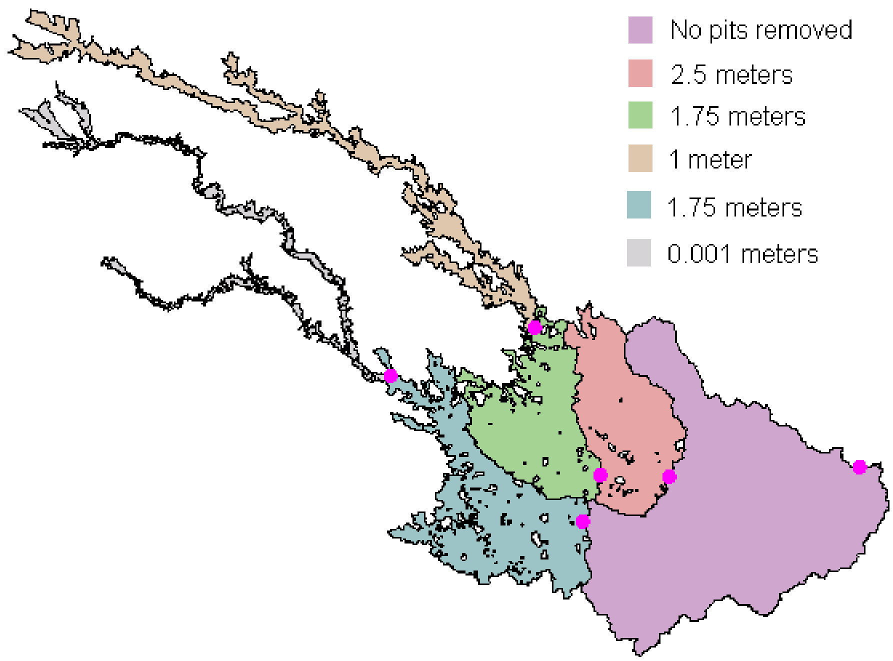


Figure 6.16: Final Watersheds for Calibrated Gages in Non-contributing Region

The final pit depths determined for each calibrated drainage area and the comparison with the USGS reported values are shown in Table 6.2.

CRWR Gage Number	USGS Incremental Area (mi^2)	CRWR Area (mi^2)	% Difference	Pit Depth (m)
6	236	245.46	-4.01	0.00001
11	805	806.94	-0.24	1.75
26	526	529.91	-0.74	1.00
28	608	602.66	0.88	1.75
32	599	603.12	-0.69	2.50
33	2065	2085.2	-0.98	no pits
TOTAL	4839	4873.29	-0.71	

Table 6.2: Comparison of Drainage Areas and Pit Depths

The criterion for calibrating the gage areas is to match the USGS area within 1%. It is obvious from Table 6.2 that gage 6 does not meet that criterion. Defining a smaller pit depth than 0.00001 meters was not possible with the DEM data used. However, the drainage area over the entire non-contributing region is still within 1% of the USGS value.

Once the appropriate pit depths were determined for each gage watershed, a watershed mask of each gage area from Figure 6.15 was created. Then, the appropriate pits were obtained for each gage area. For example, Table 6.2 shows that the pit depth for gage 11 is 1.75 meters. The watershed mask of gage 11 was multiplied by the grid EDIT_PITS_175 to obtain the pits that fall only within the watershed for gage 11. This was repeated for each gage and the pits were then merged into one grid with the following ArcInfo commands:

Grid: PITS_11 = WMASK11 * EDIT_PITS_175
Grid: EDIT_PITS = *merge*(PITS_11,…)

Once the contributing watersheds were defined, the boundaries of the non-contributing area were known. To reduce processing time, the flow direction, curve number and precipitation grids were clipped to these boundaries. This was done by creating a mask of the contributing watershed and multiplying it by the aforementioned grids. Figure 6.17 shows the unclipped and clipped flow direction grids.

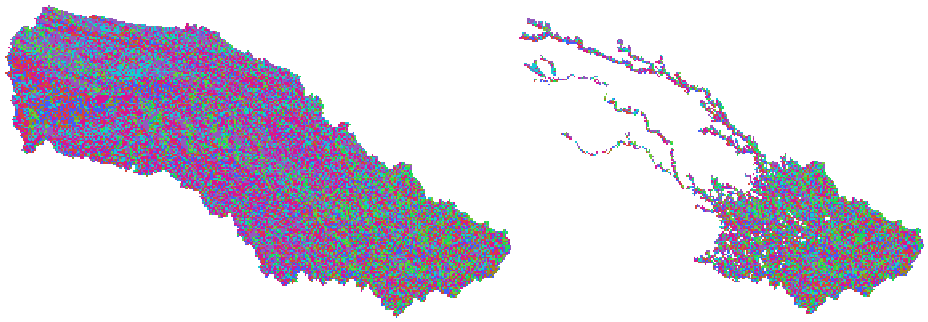


Figure 6.17: Unclipped and Clipped Flow Direction Grids

It should be apparent from Figure 6.17 that the amount of data to process in the clipped grid is greatly reduced; however, clipping the grid simply converts the non-contributing cells to *nodata* cells, so the number of grid cells remains constant. The overall processing time is reduced with the introduction of *nodata* cells, but the decline in processing time for the *nodata* cells is not proportional to the reduction of the number of grid cells with values.

Once the flow accumulation, average curve number, average precipitation, and flow length grids were created from the clipped grid, control points in the Brazos basin were ready to be processed in Wrap1117 and the parameters cascaded as described in Chapter Five.

6.5 PROCEDURAL DIFFERENCES BETWEEN PIT REMOVAL METHODS

As mentioned earlier in this chapter, the second method of removing pits from GIS analysis was chosen partly because of procedural difficulties encountered with the first method. These problems stemmed from pits beside the stream network.

The first pit depth defined and analyzed with Method 1 was set at two meters over the entire subbasin. The watersheds delineated when using Method 1 where pits were removed from the burn grid is shown in Figure 6.18.

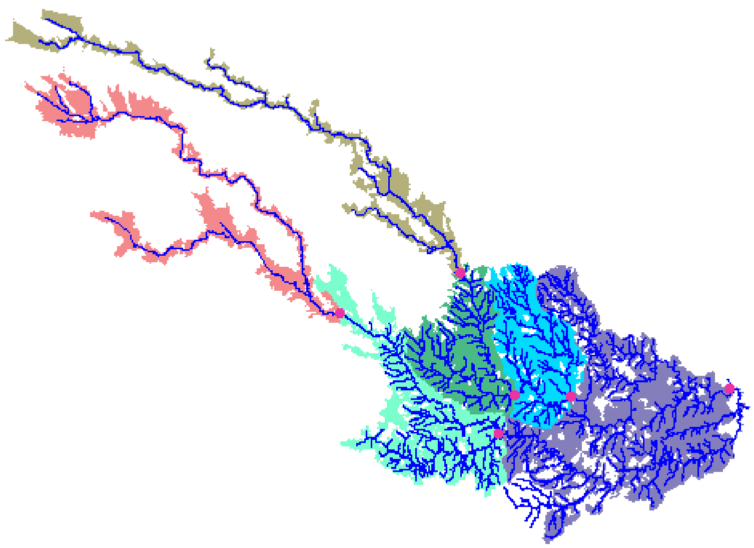


Figure 6.18: Watersheds for 2-meter Pit Removal (Method 1)

Note that in Figure 6.18, the watershed did not extend over the stream network in the lower portion of the subbasin. A close-up of this area is presented in Figure 6.19.

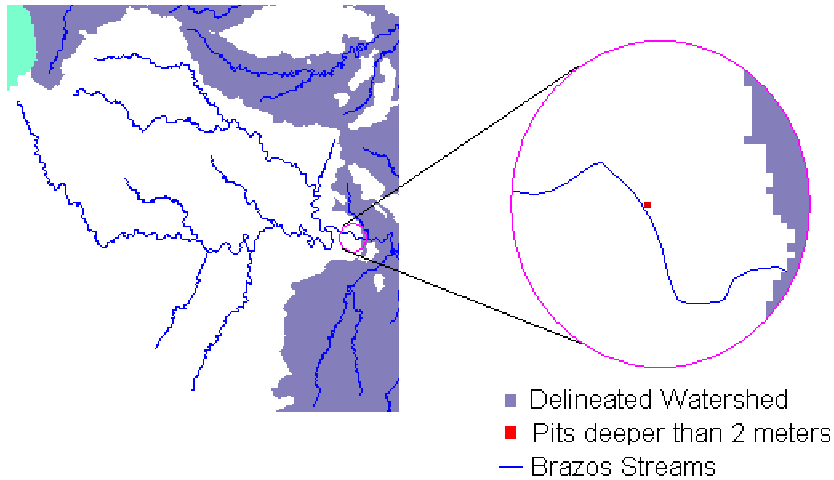


Figure 6.19: Close-up of Delineation Error

The reason for the delineation error is a pit beside the stream network. The location of the pit relative to the grid stream network is shown in Figure 6.20.

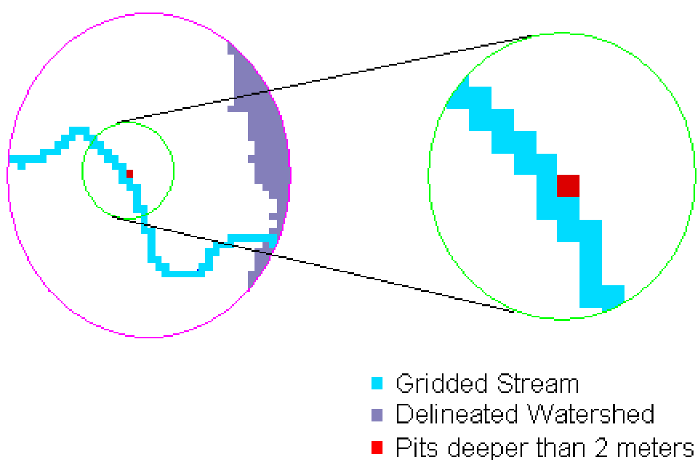


Figure 6.20: Pit by Grid Stream

In Method 1, this pit is removed from the burn grid that is then filled. Next, the flow direction grid is created from the fill grid with the pit represented as a *nodata* cell. The result is that the flow enters the stream network and is then directed into the *nodata* cell beside the network. To illustrate, the flow direction arrows that will result within the stream from the two methods are shown in Figure 6.21. Recall that Method 2 uses the fill and flow direction grids created before replacing pits with a *nodata* cell.

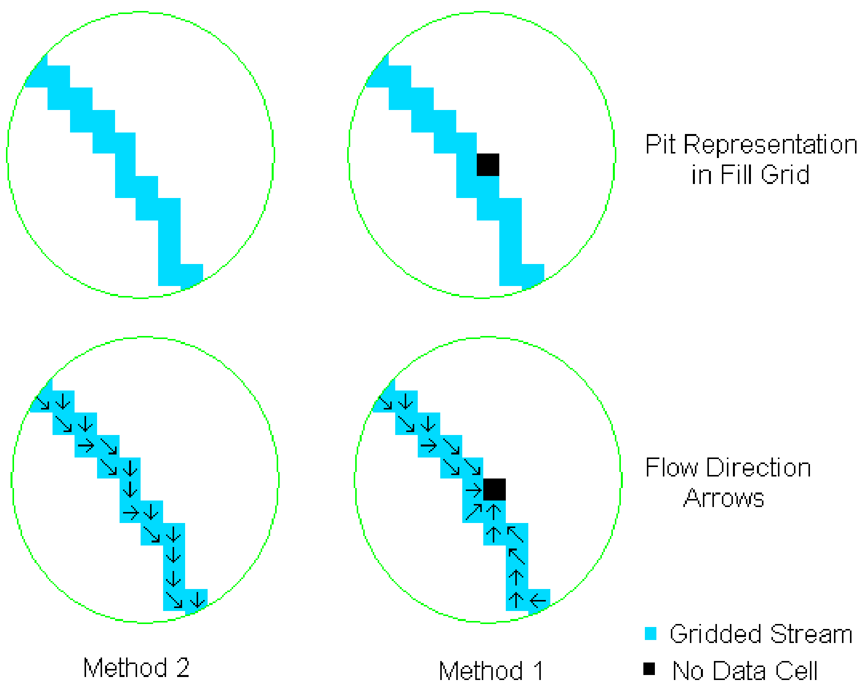


Figure 6.21: Flow Direction for Two Methods

It should be apparent from Figure 6.21 that when the watershed is delineated for Method 1, all area that flows to the stream in this section will then flow into the *nodata* cell beside the stream and not be included in the watershed. In Method 2, the next step is to place a *nodata* cell in the flow direction grid. Thus, when a watershed is delineated for Method 2, the flow direction in the stream has already been defined to continue flowing downstream and the watershed delineates correctly.

The pits beside the stream network must be located and that cell must be added to the stream network to fix the problem in Method 1. Thus, when pits are removed from the stream network, the pit beside the stream will be removed as well. This was done by placing a point in the pit, turning the point into a grid of value 1, and merging it with the stream network. This process is illustrated in Figure 6.22.

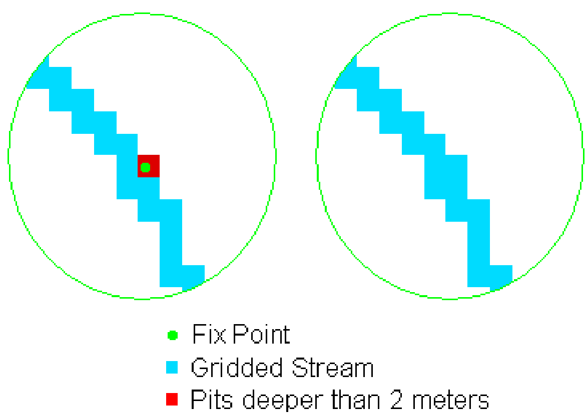


Figure 6.22: Adjusting the Grid Stream

Pits beside the stream can only be located by visual inspection or by finding errors in the delineated watersheds. Therefore, Method 1 is not efficient for pit removal.

Chapter 7: Results

7.1 INTRODUCTION

The effectiveness of techniques for watershed delineation can be assessed by comparing DEM delineated areas with USGS reported drainage areas at stream gages. This chapter presents a comparison of the Trinity and Brazos River basin drainage areas with the reported USGS areas as well as a comparison of results from other basins using the procedures outlined in Chapters Five and Six.

7.2 CASCADING WATERSHED ATTRIBUTES DOWN A DRAINAGE NETWORK

7.2.1 Trinity River Basin

Watershed parameters were developed for twenty-four stream gages in the Trinity River basin. Of these, six gages were on the main stem of the Trinity meaning that their total drainage area is a product of the cascading process.

A comparison between the drainage areas reported by the USGS and those delineated by CRWR within the Trinity River Basin is provided in Table 7.1. The data italicized and highlighted in red represents gages on the main stem of the Trinity

Gage Number	USGS Area mi^2	CRWR Area mi^2	% Difference	Gage Number	USGS Area mi^2	CRWR Area mi^2	% Difference
8042800	683.00	668.95	-2.06	8057200	66.40	66.72	0.48
8044000	333.00	333.31	0.09	8061750	1118.00	1116.36	-0.15
8044500	1725.00	1710.97	-0.81	8062000	1256.00	1253.52	-0.20
8047000	431.00	431.49	0.11	*8062500*	*8147.00*	*8124.20*	*-0.28*
8047500	518.00	517.99	0.00	*8062700*	*8538.00*	*8525.67*	*-0.14*
8048000	2615.00	2602.09	-0.49	8063100	333.00	333.38	0.11
8049500	3065.00	3050.47	-0.47	8063800	178.00	174.53	-1.95
8050100	298.00	298.06	0.02	8064700	142.00	141.04	-0.68
8051500	295.00	294.62	-0.13	*8065000*	*12833.00*	*12864.76*	*0.25*
8053000	1673.00	1673.95	0.06	*8065350*	*13911.00*	*13888.42*	*-0.16*
8053500	400.00	399.60	-0.10	8065800	321.00	330.63	3.00
8057000	*6106.00*	*6091.55*	*-0.24*	*8066500*	*17186.00*	*17155.74*	*-0.18*

Table 7.1: Trinity Stream Gage Comparison

The average percent difference for the stream gage drainage areas in Table 7.1 is –0.16%, and the average absolute percent difference is 0.51%. Mason (2000) used a threshold of ±3% as an acceptable difference between USGS and CRWR stream gage area comparisons. Retaining this threshold, the delineated watershed for each stream gage in the Trinity basin is acceptable. A graphical comparison of the USGS and CRWR delineated drainage areas is provided in Figure 7.1.

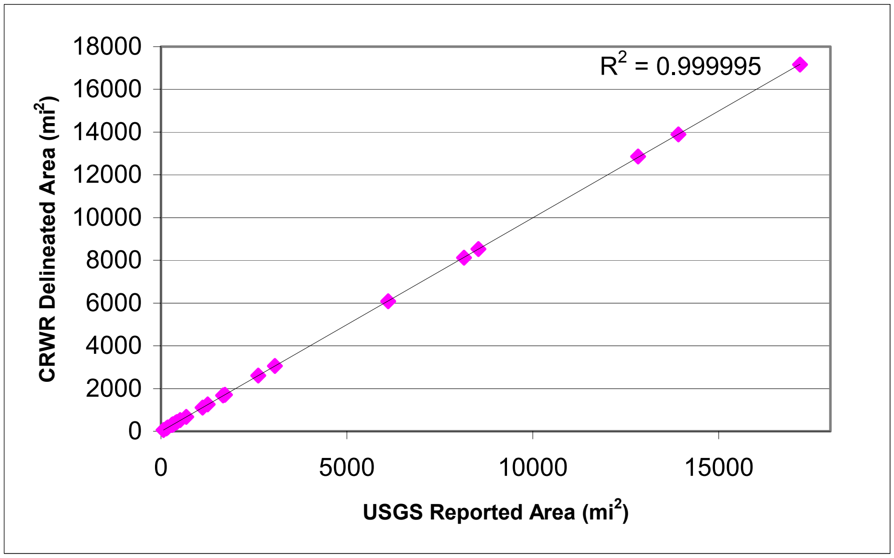


Figure 7.1: Comparison of USGS and CRWR Drainage Areas – Trinity Basin

7.2.2 Brazos River Basin

In contrast to the Trinity River basin, which has no significant non-contributing drainage areas, the upstream end of the Brazos basin has a substantial amount of non-contributing area. The gages within the non-contributing area were removed from the following comparison for the discussion of the subdivision of the Brazos basin. The non-contributing region is the most upstream subbasin, and the gages within it do not participate in the cascading process. The area at the outlet to the non-contributing region was calibrated to within 1% of the USGS area as mentioned in Chapter Six.

The USGS and CRWR drainage areas for the stream gages downstream of the non-contributing region are compared in Table 7.2. Again, the data highlighted in red represents gages for which the total drainage area was cascaded.

Gage Number	USGS Area mi^2	CRWR Area mi^2	% Difference	Gage Number	USGS Area mi^2	CRWR Area mi^2	% Difference
08093500	308.00	307.07	0.30	08095400	78.20	77.37	1.07
08110430	97.20	97.00	0.21	08104100	1321.00	1321.36	-0.03
08115000	42.80	45.54	-6.39	08103800	818.00	816.64	0.17
08095600	1656.00	1659.98	-0.24	08104000	1240.00	1240.17	-0.01
08093100	*17678.00*	*17746.45*	*-0.39*	*08102500*	*3542.00*	*3579.27*	*-1.05*
08109000	*29949.00*	*30015.99*	*-0.22*	08099100	479.00	475.87	0.65
08090800	*15671.00*	*15732.75*	*-0.39*	*08100500*	*2342.00*	*2378.96*	*-1.58*
08091000	*16252.00*	*16320.03*	*-0.42*	*08100000*	*1891.00*	*1927.96*	*-1.95*
08098290	*20870.00*	*20899.613*	*-0.14*	*08099500*	*1261.00*	*1282.62*	*-1.71*
08111500	*34314.00*	*34374.36*	*-0.18*	*08106500*	*7065.00*	*7100.25*	*-0.50*
08089000	*14245.00*	*14308.96*	*-0.45*	*08104500*	*5228.00*	*5265.81*	*-0.72*
08114000	*35441.00*	*35454.11*	*-0.04*	08095300	182.00	181.27	0.40
08116650	*35773.00*	*35775.34*	*-0.01*	08111700	376.00	376.767	-0.20
08088000	13107.00	13170.80	-0.49	08082700	104.00	105.85	-1.78
08082500	5972.00	5996.18	-0.40	08083245	205.00	208.09	-1.51
08096500	*20007.00*	*20065.10*	*-0.29*	08109700	236.00	235.16	0.36
08086290	280.00	284.88	-1.74	08111000	1454.00	1426.93	1.86
08084800	478.00	475.99	0.42	08110500	968.00	935.67	3.34
08088450	97.00	97.43	-0.44	08110325	240.00	239.70	0.13
08087300	5697.00	5738.17	-0.72	08095000	968.00	977.02	-0.93
08085500	3988.00	4031.11	-1.08	08094800	359.00	359.78	-0.22
08083240	1416.00	1456.31	-2.85	08095200	1146.00	1158.50	-1.09
08084000	2199.00	2236.10	-1.69	08082180	251.00	250.25	0.30
08083100	228.00	266.00	-16.66	08104700	248.00	248.38	-0.15
08101000	455.00	454.60	0.09	08092000	282.00	282.24	-0.08
08110100	195.00	194.83	0.09	08091500	410.00	410.59	-0.15
08109800	244.00	239.37	1.90	08090500	573.00	574.25	-0.22
08105000	405.00	404.07	0.23	08099300	264.00	267.46	-1.31
08105700	738.00	737.44	0.08	08104900	133.00	132.16	0.63
08088400	221.00	223.79	-1.26	*08088600*	*14030.00*	*14093.30*	*-0.45*
08086212	613.00	612.11	0.15	08110000	1009.00	1010.73	-0.17
08086500	1089.00	1092.28	-0.30				

Table 7.2: Brazos Stream Gage Comparison

The average percent error of the data in Table 7.2 is –0.64% and the average absolute error is 1.03%. Three gages in Table 7.2 contain an error greater than ±3%. For gage 08115000, the drainage area is small which magnifies any error. As the error in square miles is small, the delineation of this gage is assumed to be correct. The delineated boundaries of gages 08083100 and 08110500 have been visually checked against the DRGs and appear to be delineated correctly. The reason for the discrepancy with the USGS reported drainage area will require further investigation. It is possible that the original USGS areas were not delineated correctly.

Comparison to drainage areas of USGS stream gages also provides a check on the numbers used for cascading. During the first run of the Brazos River, drainage areas of stream gages on the main stem were found to exceed the USGS drainage area by 17,000 square miles. The reason for this is that a million cells had accidentally been added to the outlet of one of the areas through a transcription error. The error was corrected in the cascading formulas saved in ArcGIS, and the watershed parameters of affected control points were easily corrected.

7.2.3 Conclusions of Cascading

Comparisons of stream gage drainage areas in the contributing subbasins of the Trinity and Brazos River basins indicate that cascading process is a success. The drainage areas compared are within reasonable differences from the USGS reported areas for both basins. The percent absolute difference of drainage areas across both basins is 0.89%. Additionally, the comparison of drainage areas along the main stem inherently verifies the delineation of the subbasin boundaries. Differences in the delineation of watersheds for the stream gages would alert the user to any inconsistencies created by poor delineation of the watershed for any subbasin.

7.3 Non-Contributing Area Analysis

7.3.1 Brazos River Basin

In Chapter Six, the CRWR delineation for calibrated gages within the non-contributing area was shown to match the USGS areas within 1% with the exception of gage 6. A portion of this table is repeated in Table 7.3 for reference.

CRWR Gage Number	USGS Incremental Area (mi^2)	CRWR Area (mi^2)	% Difference
6	236.00	245.46	-4.01
11	805.00	806.94	-0.24
26	526.00	529.91	-0.74
28	608.00	602.66	0.88
32	599.00	603.12	-0.69
33	2065.00	2085.2	-0.98
TOTAL	4839.00	4873.29	-0.71

Table 7.3: Comparison of Calibrated Gages

With the exception of gage 6 as discussed in Chapter Six, the gage areas in Table 7.3 match well to the USGS areas because they are calibrated specifically for that comparison. The more revealing comparison is to look at the resulting drainage areas of gages in the non-contributing area that were not used in the calibration process as presented in Table 7.4 and Figure 7.2.

CRWR Number	USGS Area (mi^2)	CRWR Area (mi^2)	% Difference	CRWR Number	USGS Area (mi^2)	CRWR Area (mi^2)	% Difference
2	97.40	163.91	-68.28	17	206.00	67.92	67.03
3	97.10	69.73	28.19	18	309.00	183.33	40.67
4	194.00	233.64	-20.43	19	25.10	42.49	-69.28
5	200.00	234.84	-17.42	20	334.00	225.83	32.39
7	372.00	393.68	-5.83	21	382.00	295.28	22.70
8	23.00	15.24	33.74	22	416.00	348.88	16.14
9	296.00	408.92	-38.15	23	8.37	15.73	-87.91
10	244.00	265.29	-8.72	24	12.60	25.61	-103.23
12	105.00	79.21	24.56	25	429.00	374.49	12.71
13	86.60	119.17	-37.61	27	689.00	688.46	0.08
14	192.00	198.38	-3.32	29	95.30	113.56	-19.16
15	173.00	33.57	80.60	30	51.00	52.94	-3.80
16	33.20	34.35	-3.46	31	146.00	166.50	-14.04

Table 7.4: Comparison of Non-calibrated Gages – Brazos Basin

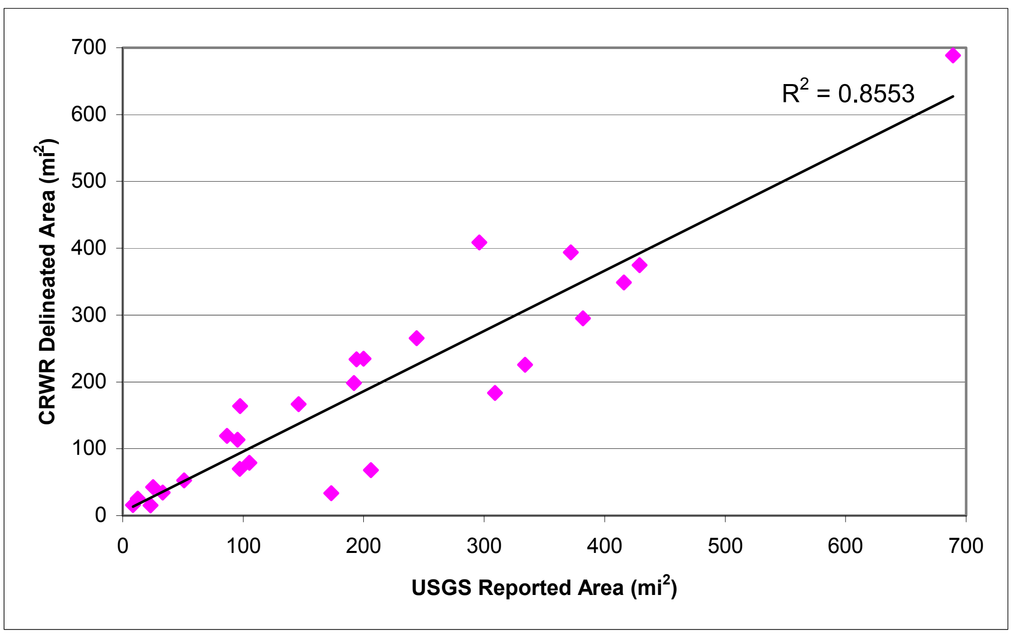


Figure 7.2: Comparison of USGS and CRWR Drainage Areas – Brazos Basin Non-contributing Region

The data in Table 7.4 and Figure 7.2 indicate that the DEM-delineated drainage areas for non-calibrated gages are not good. The average percent difference is –5.46% and the average absolute difference is 33.06%. It was pointed out in Chapter Six that, physically, one pit depth should be appropriate for the entire basin, but that the 30-meter data are not refined enough. This suggests that partitioning the basin into six calibrated subbasins will not completely rectify the situation either.

7.3.2 Colorado River Basin

The non-contributing region of the Colorado basin was partitioned into nine subbasins for which the gage areas were calibrated. Table 7.5 compares the delineated drainage areas and shows the pit depth defined for each subbasin.

USGS Gage	USGS Incremental Area (mi^2)	CRWR Area (mi^2)	% Difference	Pit Depth (m)
08120700	1531.00	1520.99	0.65	0.85
08123700	1527.00	1516.89	0.66	0.32
08123900	1679.00	1683.23	-0.25	2.50
08126500	1423.00	1422.04	0.07	no pits
08128500	1685.00	1682.53	0.15	0.75
08132500	1003.00	999.98	0.30	0.14
08133500	568.00	568.63	-0.11	0.75
08135000	882.00	881.93	0.01	3.00
08136700	2504.00	2272.17	9.26	no pits

Table 7.5: Comparison of Drainage Areas and Pit Depths – Colorado Basin

The criterion for calibrating the gage areas is to match the USGS drainage area within 1%. Like a gage in the Brazos basin, the last gage in Table 7.5 does not match the criterion. This gage represented the most downstream subbasin of the non-contributing area. Investigation of the watershed for gage 08136700 indicates that the watershed probably delineated incorrectly along the border with the next subbasin downstream. The absolute difference over the entire non-contributing region is 1.98%. Correcting the delineation error for gage 08136700 would have been time consuming, and the contractor for the Colorado basin accepted the 2% drainage error. Again, the revealing comparison is of the non-calibrated gages shown in Table 7.6.

USGS Gage	USGS Area (mi^2)	CRWR Area (mi^2)	% Difference
08119500	1027.00	1074.16	-4.59
08120500	188.00	193.04	-2.68
08121000	1585.00	1575.05	0.63
08123600	186.00	175.97	5.39
08123800	1988.00	1973.76	0.72
08123850	4650.00	4559.46	1.95
08124000	5047.00	5046.31	0.01
08126380	6098.00	6089.96	0.13

USGS Gage	USGS Area (mi^2)	CRWR Area (mi^2)	% Difference
08127000	386.50	463.87	-20.02
08128000	354.40	258.12	27.17
08128400	1116.00	1613.30	-44.56
08129300	405.30	339.56	16.22
08130500	217.57	163.83	24.70
08134000	1190.90	1202.12	-0.94
08136000	4411.00	4139.14	6.16

Table 7.6: Comparison of Non-calibrated Gages – Colorado Basin

As expected, the non-calibrated gage areas do not match up well to the USGS areas. The average error for the data in Table 7.6 is 0.69%, and the average absolute error is 10.39%. Another possible explanation of the poor correlation in non-calibrated gages is the definition of a pit. The *fill* command in ArcInfo Workstation was created to fill in accidental sinks or mistakes in the DEM to maintain a continuous landscape. It is possible that some one or two-cell sinks were removed from analysis as pits when they could be mistakes in the DEM that should be filled and not treated as pits.

7.3.3 Canadian River Basin

Two methods were presented in Chapter Six for removing pits from raster data. Briefly stated, Method 1 replaces pits with *nodata* cells in the burned grid and then develops the flow direction grid, and Method 2 replaces pits with *nodata* cells in the flow direction grid created from the unaltered burn grid. It was stated that the error in the second method presented is statistically equivalent to the first and that it is less time-intensive. Although the second method seems less accurate physically, it was chosen for use because of the reduced time requirement, reduced procedural difficulties, and the lack of statistical merit for using the alternate method.

The conclusion that no significant difference existed between the two methods was based on an investigation of the non-contributing area in the Canadian River Basin. Two stream gages were calibrated to within 1% of the USGS drainage area for both methods. The percent difference of the calibrated gages from the USGS drainage areas for both methods is shown in Table 7.7. A positive percent difference reflects an overestimation of the DEM-delineated drainage area.

USGS Gage Number	Method 1 % Difference from USGS Drainage Area	Method 2 % Difference From USGS Drainage Area
7227500	0.72	0.50
7228000	0.79	0.37

Table 7.7: Comparison of Calibrated Gages for Pit Removal Methods

Like the Brazos and Colorado River basin, the non-calibrated gages in the Canadian do not match well to the USGS reported drainage areas. The absolute difference between the two methods with non-calibrated gages is presented in Table 7.8. Again, a positive percent difference reflects an overestimation of the DEM-delineated drainage area.

USGS Gage Number	Method 1 Absolute % Difference from USGS Drainage Area	Method 2 Absolute % Difference from USGS Drainage Area
07206000	10.43	8.75
07216500	0.56	0.83
07203000	11.07	8.44
07207000	8.98	10.64
07208500	13.52	15.09
07211500	11.21	12.69
07221500	13.33	13.11
Average	9.87	9.94

Table 7.8: Comparison of Pit Removal Methods – Absolute Percent Difference

By comparing the average absolute difference, it was concluded that there is no significant difference between the two methods. The actual difference between the two methods is shown in Table 7.9, and a graphical representation is presented in Figure 7.3.

USGS Gage Number	Method 1 Absolute % Difference from USGS Drainage Area	Method 2 Absolute % Difference from USGS Drainage Area
07206000	10.43	8.75
07216500	-0.56	-0.83
07203000	11.07	8.44
07207000	-8.98	-10.64
07208500	-13.52	-15.09
07211500	-11.21	-12.69
07221500	-13.33	-13.11
Average	-3.73	-5.02

Table 7.9: Comparison of Pit Removal Methods – Percent Difference

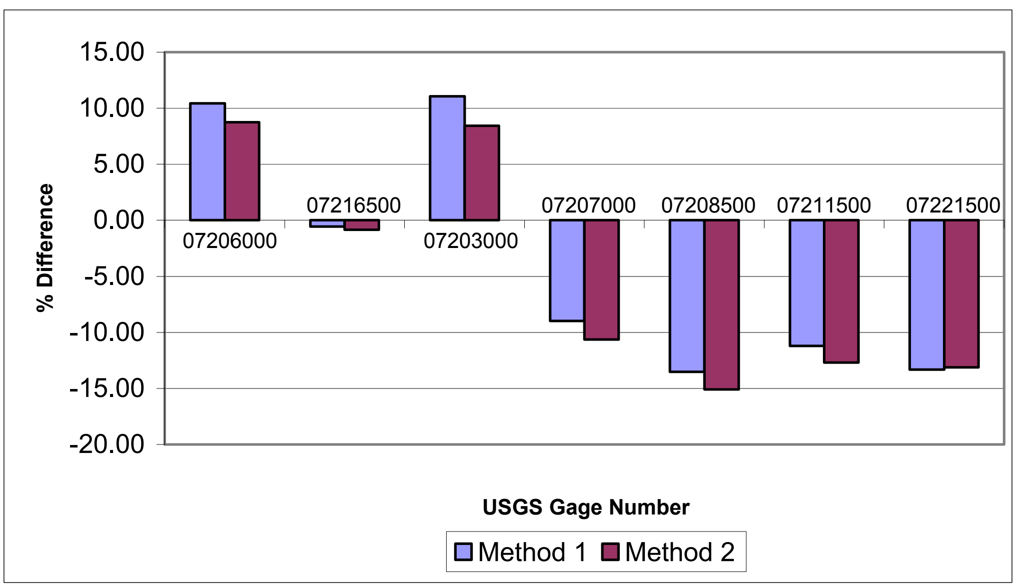


Figure 7.3: Graphical Comparison of Pit Removal Methods

The graphical comparison presented in Figure 7.3 shows that the methods were consistent in overestimating or underestimating the drainage area at each gage. The graph shows that Method 1 delineated drainage areas greater than Method 2 for overestimations and delineated drainage areas less than Method 2 for underestimations with the exception of gage 07221500. A conclusion cannot be drawn from this comparison, though, because the drainage areas of the calibrated gages for the two methods were not exactly the same.

7.3.4 Conclusions of Non-contributing Area Analysis

Data for the Red River basin showed similar results with respect to non-calibrated gages. Although the drainage area for calibrated gages in the Brazos, Colorado, Canadian and Red River basins matches well with the USGS reported drainage areas, the comparison of non-calibrated gages in this chapter indicate that the pits removed in the GIS analysis are not necessarily pits in the physical landscape. Otherwise, there would be better agreement in the non-calibrated regions.

7.4 USGS DRAINAGE AREA ANALYSIS

A hypothesis accepting USGS drainage areas as truth was presented at the beginning of this thesis. Section 7.2 presents a comparison of delineated drainage areas to the USGS areas in the contributing basins and subbasins of the Trinity and Brazos River Basins. Out of 87 drainage areas delineated at USGS gage locations, only three drainage areas (3.4%) exceeded the threshold difference of ±3% from the reported USGS drainage areas. This correlation is excellent and supports the proposed hypothesis.

Chapter 8: Conclusions

8.1 Cascading Watershed Attributes Down a Drainage Network

The first objective in this thesis was to modify the methods previously developed at CRWR to efficiently determine watershed parameters in large basins. This objective is successfully accomplished by subdividing the large basin into subbasins, developing local parameters for the control points in each subbasin with Wrap1117, and then cascading parameter values down the drainage network. Cascading refers to the process of updating local parameters in subbasins to reflect contributions from upstream or downstream subbasins.

The requirement of making an efficient process is met by the ability to work within one subbasin independent from the rest of the basin. A control point or stream can be added to the data, and only the subbasin containing the changes needs to be reprocessed.

A buffer for delineating watersheds must be wide enough to capture an elevation upstream of the subbasin to be delineated that is higher than every point in the subbasin of interest. This will ensure that all flow drains downstream within the buffered area. Watersheds for all subbasins in this research were accurately delineated with a buffer width of 25 kilometers.

The drawback to the cascading process defined in Chapter Five is that it requires a large amount of handwork. The process is relatively simple, but there is room for error in the selection of points along the main stem and transcription of outlet attributes in the cascading equations. The process needs to be automated, but the standard tool sets available in ArcView 3.2 and ArcGIS do not allow for the automation. The geometric network capabilities of ArcGIS presented in the first cascading method in Section 5.6.2 are promising, but the time required to snap points to the network and the inability to select spatially coincident points limit the efficiency of the ArcGIS approach at this time.

The basin subdivision and cascading process was developed for the Water Availability Modeling project, but the concept of basin subdivision and cascading attributes can be applied to any GIS investigation of a large study area. The expressions for cascading attributes in this thesis are a straight addition for the parameters of drainage area and flow length, and an area weighted average for curve number and precipitation. Other GIS investigations may require different watershed attributes, but the procedure for subdividing the basin and delineating watersheds for each subbasin and the methodology for cascading attributes will not change.

8.2 Non-contributing Analysis

The second topic addressed in this thesis is analysis of drainage areas in terrain with non-contributing regions. A method was developed to automatically define and remove pits from GIS analysis. This method identifies depressions within the region containing non-contributing drainage areas by subtracting the burn grid from the fill grid. An initial pit depth is then defined, pits equal to or deeper than the set threshold are replaced with *nodata* cells in the flow direction grid, and a contributing drainage area is delineated. The contributing drainage area is then compared to the reported USGS drainage areas and the pit depth is redefined if necessary. Using this method, the drainage areas for calibrated stream gages in the Brazos and Colorado River basins match the USGS drainage areas with an average absolute difference of 1.27% over the 15 gaged locations, but the results for non-calibrated gages within those two basins is 24.76% over 41 gaged locations.

The 30-meter DEM resolution is too coarse to properly represent the landscape in regions with non-contributing pits. The misrepresentation of the landscape by the 30-meter DEM is indicated by the inability to define a consistent pit depth criterion over the entire non-contributing subbasin.

The lack of agreement between USGS reported stream gage areas and delineated areas for non-calibrated gages further supports the conclusion that the 30-meter DEM resolution is too coarse. The poor results of non-calibrated gages suggest that although the overall drainage area to calibrated gages is correct, the areas defined as pits within those gage subbasins are not correct.

As with basin subdivision, the methodology of determining non-contributing areas can be applied to investigations outside of the WAM project. Although the methodology is sound, the procedure should be revised with better terrain data such as from LIDAR measurements or a new definition of a pit for application to a non-contributing analysis in GIS.

8.3 USGS GAGE HYPOTHESIS

The hypothesis used throughout this research is that the USGS drainage areas for stream gages area accepted as truth. This hypothesis is validated by the 96.6% agreement of the USGS drainage areas and GIS-delineated drainage areas for basins and subbasins in which all area contributes to runoff. The lack of agreement in non-contributing regions suggests a deficiency in the data used for delineation, rather than the USGS drainage values.

8.4 Recommendations for Future Work

8.4.1 Developing Parameters in Large Basins

A procedure for cascading watershed parameters in large basins with less handwork needs to be developed. Two approaches could be used.

The first approach is to continue developing local parameters in ArcView 3.2 with the existing Wrap1117 project and scripts, and then improve the process of cascading parameters in ArcGIS presented in section 5.6.2. As mentioned, the geometric network capabilities in ArcGIS are promising, but the standard tools are inefficient. New tools should be developed to recognize points requiring cascading and then cascade the parameters with attributes from upstream or downstream subbasins.

The alternative is to recreate the entire parameter development process in ArcGIS; creating a sister project to Wrap1117 in ArcGIS. This alternative is recommended by the author because ArcGIS is the next generation of GIS software from ESRI and contains more options for data development and data storage than ArcView 3.2.

The raw stream network and control point data requires editing before watershed parameters can be developed. The standard tools for editing in ArcGIS are more robust than the tools in ArcView 3.2, and a new method of data preparation should be created for ArcGIS. Developing parameters entirely in

ArcGIS may allow the large basins to be kept intact, and should better automate the process.

8.4.2 Removing Non-contributing Drainage Areas from Analysis

The process outlined in Chapter Six for removing non-contributing areas from GIS analysis should be redone and reevaluated when a higher-resolution DEM becomes available for the study region. A variation of the procedure presented in Chapter Six can be explored if the match of non-calibrated drainage areas is still poor with the new data.

The method originally outlined by Olivera (1995) uses a threshold for area as well as depth to define a pit. This method might avoid the selection of one or two-cell sinks in the DEM that are actually mistakes and not pits. The time involved in this type of analysis, though, was not feasible within the time constraints of the WAM project.

Appendix A: Updating Cascaded Parameters

A.1 INTRODUCTION

The purpose of this appendix is to provide the TNRCC with a method for adding control points and updating parameters in a basin that requires cascading of parameter attributes. The processes of updating parameters will be demonstrated with points in HUC 105 of the Trinity River basin as shown in Figure A.1.

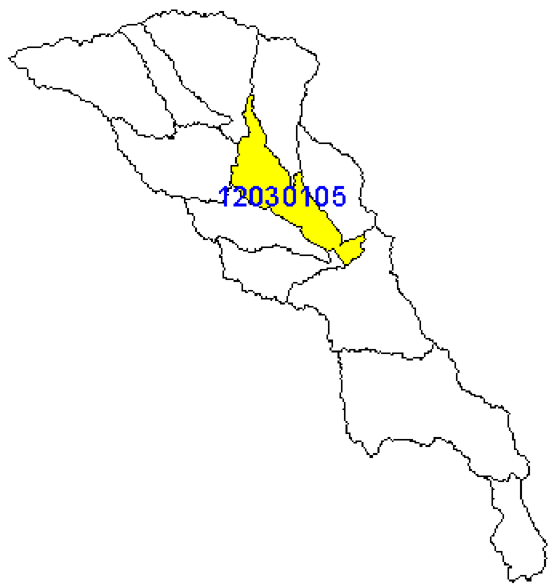


Figure A.1: Location of HUC 105 in Trinity River Basin

The following files should be available from the CRWR final deliverables to update parameters within HUC 105:

Tricptalb – Control Points for Trinity River Basin
Tristralb – Stream Network for Trinity River Basin
Center_Stream – Center Stream of the Trinity River Basin
Surrounding – Streams Surrounding the Trinity River Basin
Tridemalb – DEM Grid for Trinity River Basin
Tricpt105alb – Control Points for HUC 105
Triscp105alb – Snapped Control Points for HUC 105
Tricpp105alb – Local Parameters for HUC 105
Trinet105alb – Schematic Network for HUC 105
Tridst105alb – DEM Derived Stream for HUC 105
Cascade_par105 – Cascaded Parameters for HUC 105
Trifac105 – Flow Accumulation Grid
Triacn105 – Average Curve Number Grid
Triapr105 – Average Precipitation Grid
Triflo105 – Flow Length Grid (not created for Trinity basin, but is included in other basins)
Mask105 – Grid of Buffer for HUC 105 (all values equal one)
Wmask105 – Grid of Watershed for HUC 105 (all values equal one)
Tricng105 – Unprocessed Curve Number Grid for HUC 105
Tripcp105 – Unprocessed Precipitation Grid for HUC 105

A.2 ADDING A CONTROL POINT

All of the files listed above should be added to a Wrap1117 project in two separate views. The first five files, those representing the entire basin, should be in one view and the rest of the files in the second. For this appendix, the control point to be added will be a diversion point with an ID of 1000.

If the new point falls on an existing stream, the grids do not have to be reprocessed. Regardless of the location of the new control point, though, the following steps will be done first.

Also, add the new control point to the shapefile *tricptalb* with the 'Add Control Point' tool. To keep the basin files current, a new control point should always be added to the control point file for the entire basin.

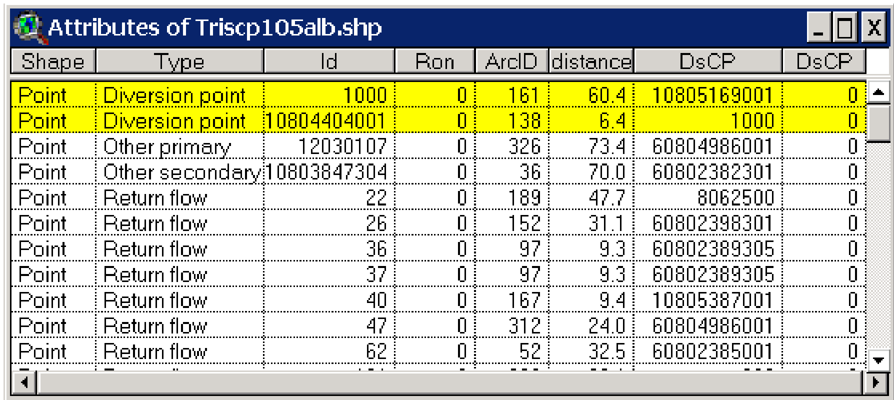
Add the new control point to the control point file for HUC 105, *tricpt105alb*. Then, select the stream segment from *tridst105alb* on which the point will be located, and add a new snapped control point to the snapped control point file for HUC 105, *triscp105alb*, with the 'Add Snapped Control Point' tool in Wrap1117. The attribute table for the snapped control points is shown in Figure A.2.

Attributes of Triscp105alb.shp

Shape	Type	Id	Rcn	ArcID	distance	DsCP
Point	Diversion point	1000	0	161	30.5	0
Point	Diversion point	10804404001	0	138	6.4	10805169001
Point	Diversion point	10805198301	0	235	64.6	8062500
Point	Diversion point	60804967001	0	300	41.7	60804968001
Point	Diversion point	10804483005	0	23	77.1	10803847002
Point	Diversion point	10805198002	0	236	94.7	8062500
Point	Diversion point	60802374001	0	64	19.1	60802457004
Point	Diversion point	60802461001	0	70	38.0	10805448301
Point	Diversion point	10803847001	0	32	73.8	10803847303
Point	Diversion point	10804483004	0	28	97.1	10803847002
Point	Diversion point	10804483003	0	24	96.5	10803847002

Figure A.2: Attribute Table for Snapped Control Points in HUC 105

The two points highlighted in Figure A.2 are the new control point (1000) and the control point just upstream of it. The downstream control point of point 10804404001 should be point 1000, but notice that the downstream control point field (DsCP) in Figure A.2 is not automatically updated by adding a snapped control point. To update this field, rerun the 'Make a Network Wire Diagram' script under the Wrap Parameters menu. Recreating the network schematic will repopulate the field for downstream control point with the correct IDs. The updated attribute table is shown in Figure A.3.



Attributes of Triscp105alb.shp

Shape	Type	Id	Ron	ArcID	distance	DsCP	DsCP
Point	Diversion point	1000	0	161	60.4	10805169001	0
Point	Diversion point	10804404001	0	138	6.4	1000	0
Point	Other primary	12030107	0	326	73.4	60804986001	0
Point	Other secondary	10803847304	0	36	70.0	60802382301	0
Point	Return flow	22	0	189	47.7	8062500	0
Point	Return flow	26	0	152	31.1	60802398301	0
Point	Return flow	36	0	97	9.3	60802389305	0
Point	Return flow	37	0	97	9.3	60802389305	0
Point	Return flow	40	0	167	9.4	10805387001	0
Point	Return flow	47	0	312	24.0	60804986001	0
Point	Return flow	62	0	52	32.5	60802385001	0

Figure A.3: Updated Attribute Table for Snapped Control Points in HUC 105

Note than an extra ‘DsCP’ field was added to the attribute table in this process. Delete the extra field. Running this script adds a new coverage, *network*, to the view. This coverage should be converted to a shapefile named *trinet105alb_2* because it is the second version of the network schematic.

The file *tricpp105alb* already contains the local parameters for all points in HUC 105 except the new point. However, as noted previously, the value for the downstream control point is not correct for the point just upstream of the new control point. The easiest way to keep a current file of local parameters is to rerun the script ‘Report the Control Point Parameters’ from the Wrap Parameters menu. This script does not take long to process. After running this script, a new coverage, *Parameters*, is added to the view. This coverage should be converted to a shapefile and named *tricpp105alb_2*.

Now, all points, including the new point, are attributed with the local watershed parameters. To avoid re-cascading all of the points in HUC 105, the new point will be merged with the existing cascaded parameters. To do this, select the new point in the shapefile *tricpp105_alb2*. Then, open the Geoprocessing Wizard from the View menu. In the first window, choose 'Merge themes together' and press 'Next'. Figure A.4 shows the second window of the Geoprocessing Wizard.

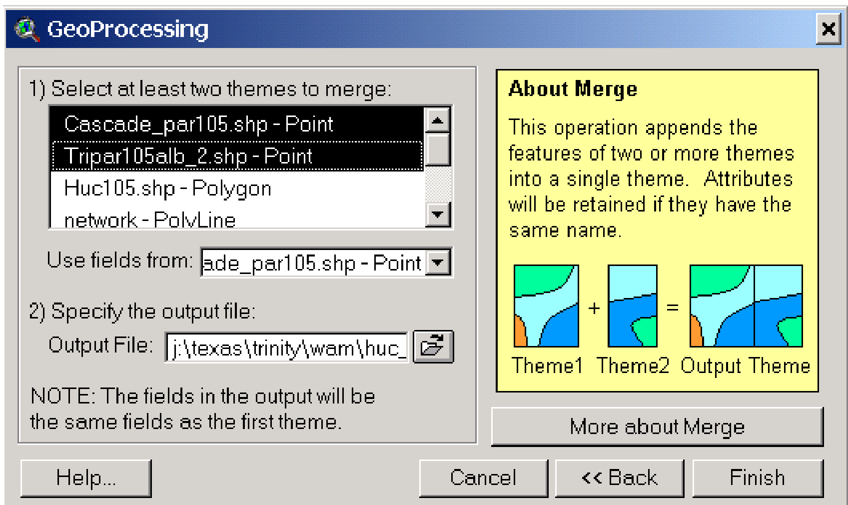


Figure A.4: Second Window of Geoprocessing Wizard

The window in Figure A.4 asks which themes should be merged. Select *cascade_par105* and *tricpp105alb_2*, and use fields from *cascade_par105* for merging. Save the output file as *cascade_par105_2*. The output file will include the cascaded parameters from *cascade_par105* and the new point parameters selected from *tricpp105alb_2*. Check the attribute table of the output file to ensure that the correct number of points is included.

In the new shapefile, *cascade_par105_2*, all points except the new point have accurate cascaded parameters, but again, the downstream control point is wrong for the point directly upstream of the new point. To correct this field, open the attribute table for *tricpp105alb_2* and select 'Start Editing' from the Table menu. Select 'Add Field…' from the Edit menu and call the field 'DsCP1'. Select 'Calculate' from the Field menu, and populate this field with the values from the field 'DsCP'. The calculator is shown in Figure A.5.

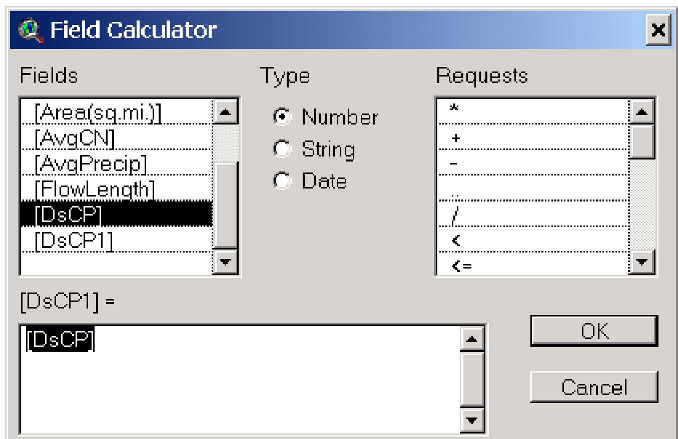


Figure A.5: Field Calculator

Once the field is populated, select 'Stop Editing' from the Table menu. With the attribute table still open, make the ID field active by clicking on the name of the field. Then, open the attribute table for *cascade_par105_2*. Make the ID field active in this table as well. Then select 'Join' from the Table menu. This will add the attributes from the table *tripar105alb_2* to the attribute table for *cascade_par105_2.*

Once the tables are joined, start editing the attribute table for *cascade_par105_2* again. Make the first 'DsCP' field active and select 'Calculate' from the Table menu. Populate the field with the values from 'DsCP1'. Now, the downstream control point values are correct. Stop editing the table and then select 'Remove All Joins' from the Table menu. This will remove the fields joined to the attribute table.

Next, determine whether or not the new control point falls on the center stream of the Trinity River, *center_stream*. If it does not, the point is located on a tributary and will not inherit attributes from upstream HUCs. If it does fall on the center stream, attributes from all upstream HUCs will be cascaded to the new point.

A2.1 Parameters on a Tributary

If the new control point does not fall on the center stream, the only attribute that will have to be updated is the flow length. Figure A.6 shows the location of the tributary and new control point in HUC 105 that will be used as an example for this section.

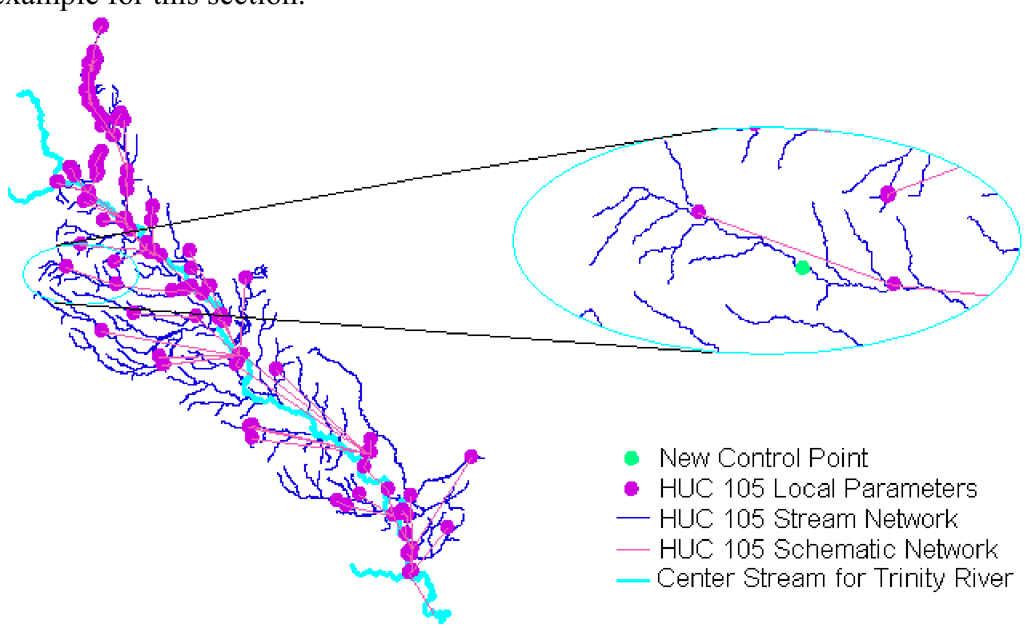


Figure A.6: Tributary Example

Next, the path from the point to the outlet of the basin must be determined. For reference, the schematic drainage diagram for the Trinity River is repeated in Figure A.7.

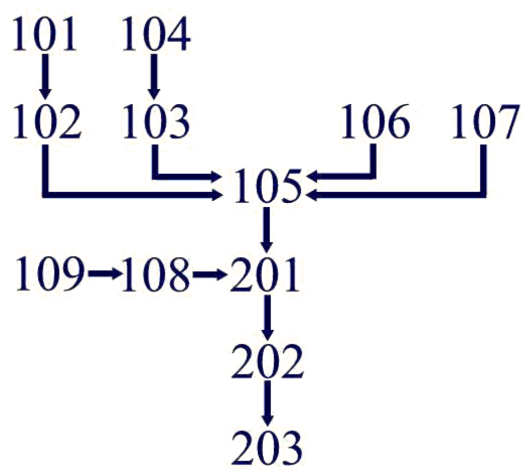


Figure A.7: Schematic Drainage Diagram

From the drainage diagram, it is apparent that the flow length through HUCs 201, 202 and 203 needs to be added to the local flow length of point 1000 to obtain the flow length to the outlet of the Trinity basin.

To update the flow length parameter, open the attribute table for *cascade_par105_2* and select (highlight) the record for the new parameter. Then, make the 'Casc_Fl' field active in the attribute table. This field represents the cascaded flow length. Select 'Calculate' from the Field menu, and calculate a new flow length equal to the field 'Flowlength' plus the flow lengths through HUCs 201, 202, and 203. Now, the flow length is updated in the Casc_Fl field.

With the new point record still highlighted, make the 'Flowlength' field active and calculate this field to equal 'Casc_Fl'. The local flow length value in 'Flowlength' now represents the flow length to the outlet of the basin. With this done, all parameters in *cacade_par105_2* represent the cascaded parameters for HUC 105 and can be used as input to the WRAP model.

A.2.2 Parameters on the Center Stream

The process outlined above is followed for a point that falls on the center stream as well because the flow length needs to be updated for any point regardless of where it falls on the network. The process will be expanded to account for upstream influences for points on the center stream. Figure A.8 shows a new control point that is located on the center stream.

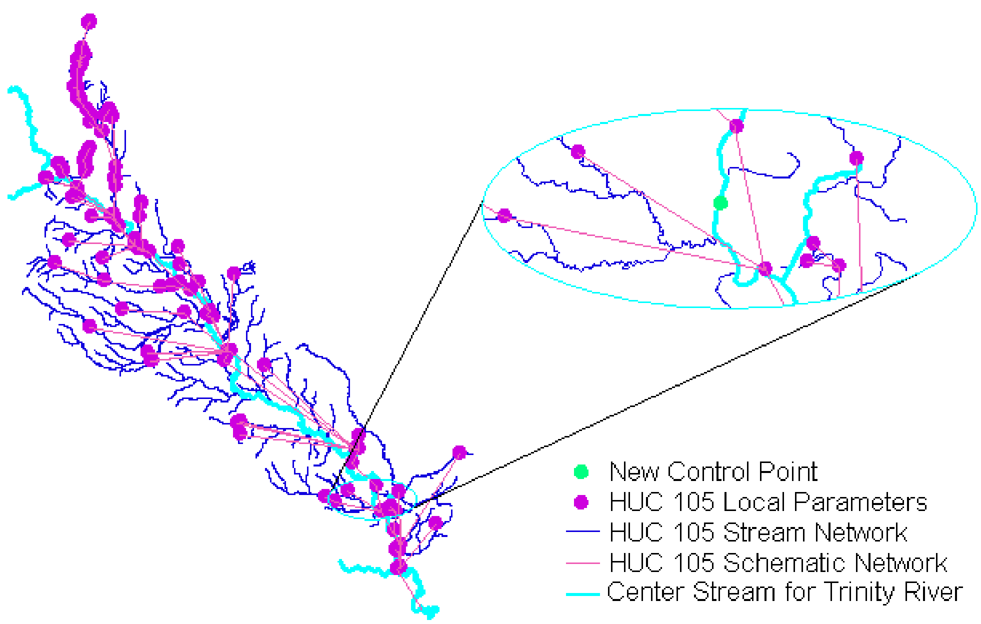


Figure A.8: Center Stream Example

From the process outlined through section A.2.1, the file *cascade_par105_2* contains the correct cascaded parameters for all points except the new point located on the center stream. The new point has the correct values for the downstream control point and the flow length, but the area, curve number and precipitation are still local values and need to be cascaded.

Looking at the schematic in Figure A.7, it seems as though the point should be cascaded with values from HUCs 101, 102, 103, 104, 106, and 107. However, taking a closer look at the area around the new point will show that HUC 107 enters downstream of the new point as shown in Figure A.9.

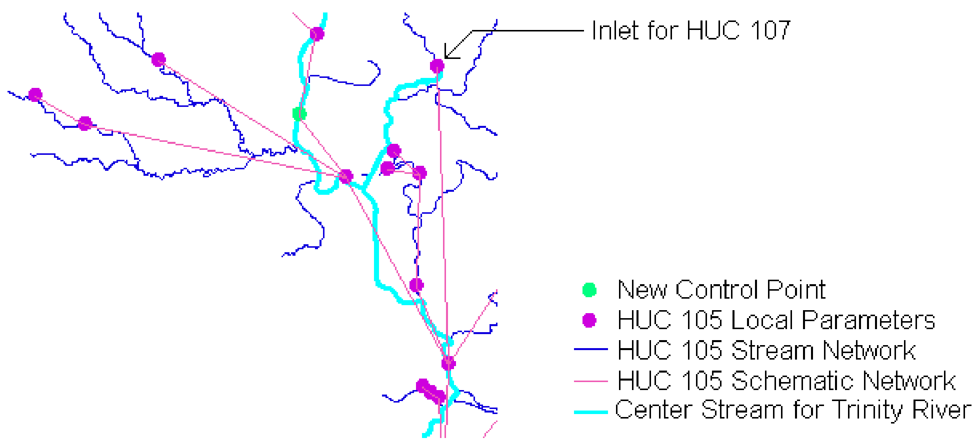


Figure A.9: Entry Point for HUC 107

Therefore, only the parameters from HUCs 101, 102, 103, 104, and 106 will be cascaded to the new control point. In addition to the schematic diagram, the table of outlet parameters should be nearby. The outlet attributes are repeated in Table A.1 for convenience.

Outlet ID	Flow Accumulation (# Cells)	Average Curve Number	Average Precipitation (in.)
101	6196783	74.65	32.09
102	4800659	79.67	34.02
103	5888612	73.83	36.72
104	2277684	70.09	35.12
105	4461377	74.09	37.5
106	4125613	75.91	39.65
107	3238903	70.67	40.03
108	2924210	69.53	36.72
109	3393215	73.95	36.28
201	6680044	61.00	40.81
202	10332689	64.64	43.94

Table A.1: HUC Outlet Attributes

If it is not still selected, select the record for the new point in the attribute table for *cascade_par105_2*. To update the flow accumulation, make the Casc_FAC field active and use the Field Calculator to sum the local flow accumulation with the flow accumulation from the upstream HUCs. Remembering that the value for flow accumulation does not include the actual cell at which the value is determined, one cell is added to the flow accumulation from each HUC. The formula in the calculator should look like Figure A.10.

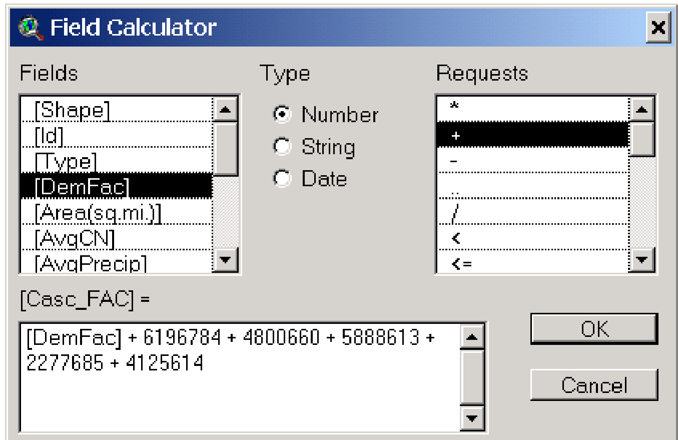


Figure A.10: Updating the Flow Accumulation

To update the field for area, make the 'Casc_Area' field active and update the field with Equation A.1 in the Field Calculator.

$$Casc\_Area = \frac{Casc\_FAC * cell\_size^2 * 10000}{25899881103} \qquad \text{(Eqn. A.1)}$$

The cell size can be determined by making the flow accumulation grid active in the View and selecting 'Properties' from the Theme menu.

The next field to cascade is the average curve number. Again, make the 'Casc_CN' field active while the record for the new point is highlighted, and open the Field Calculator. To update the average curve number, the flow accumulation plus one of each upstream HUC is first multiplied by its average curve number. The local flow accumulation of the point is also multiplied by its local average curve number. These products are then summed and divided by the total upstream flow accumulation, Casc_FAC plus one. The equation for updating the example point in the Field Calculator is shown in Figure A.11.

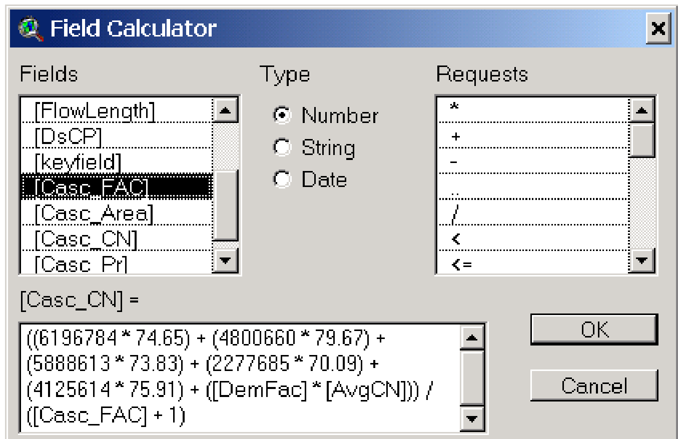


Figure A.11: Updating the Average Curve Number

The value for the cascaded precipitation, Casc_Pr, is updated with the same equation as the average curve number except that precipitation values are substituted for curve number values.

The last step is to update the local parameter fields with the cascaded values. To do this, make the field DemFac active. Once again, be sure the only record highlighted is the new point, and use the Field Calculator to make the field DemFac equal to Casc_FAC. Do the same for the fields Area, AvgCN, and AvgPrecip.

All parameter values in the shapefile *cascade_par105_2* are now cascaded for every point in HUC 105.

A.3 ADDING A POINT AND A STREAM

If adding a new control points requires the addition of a stream to the network, the grids will have to be reprocessed for the affected HUC. Add the new stream segment to the stream network for the entire basin, *tristralb*, to keep that file current. Then, use the Geoprocessing Wizard to merge this stream network with the shapefile *surrounding* to create the stream network that will be burned into the DEM, *trimstalb*.

Next, set the analysis properties under the Analysis menu. Both the analysis extent and cell size should be set to the Trinity DEM. Using the script 'Burn the Stream Network' from the WRAP Parameters menu, burn *trimstalb* into Tridemalb. This process does not take long and preserves a current copy of the burned grid. Save the temporary burn grid with 'Save Data Set…' from the Theme menu. The grid should be named *Triburalb2*. When naming grids, keep in mind that the number of characters cannot exceed 13.

The next grid processing steps take longer and should only be done for the affected HUC. Supposing a stream edit was made in HUC 105, the burn grid must be clipped to the buffer of HUC 105. To clip the grid, add the burn grid to the view that contains the files for HUC 105. All files should be deleted from this view with the exception of the grids *Mask105, Wmask105, CN105,* and *Pr105*. Set the analysis extent and the cell size to *Mask105*, the grid of the buffer for HUC 105. Then, select 'Map Calculator…' from the Analysis menu. In the Map Calculator, multiply the mask grid and the burn grid. The expression in the Map Calculator will look like Figure A.12.

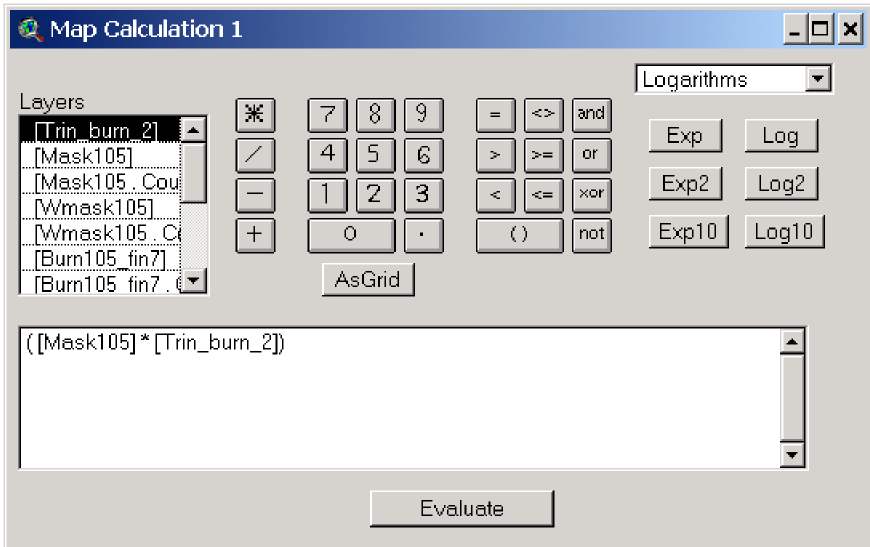


Figure A.12: Clipping Burn Grid to HUC 105 Buffer

The result will be *Map Calculation 1* which should be saved as *Tribur105_2*. The fill grid should then be created from this burn grid and the flow direction grid from the fill grid. These can be created with the scripts in Wrap1117 or in ArcInfo Workstation. The commands in ArcInfo are detailed in Appendix B.

The next grid created is the flow accumulation grid, but it cannot be created from the buffered flow direction grid. Using that grid will include cells upstream of the HUC 105 watershed in the flow accumulation and falsely increase the drainage area for points within the HUC. To correct this, multiply the new flow direction grid, *Trifdr105_2,* by *Wmask105* in the Map Calculator. Save the resulting grid as *Clipfdr105_2.*

Next, develop the flow accumulation grid from *Clipfdr105_2.* The resulting grid should be called *Clipfac105_2*. The average curve number and average precipitation grids should be created from the *Tricng105* and *Tripcp105* grids with the clipped flow direction and flow accumulation grids.

Now all of the grids have been updated and the watershed parameters can be re-developed. Add the stream network for the Trinity basin, *tristralb*, to the view. Turn on the grid *Wmask105* and select all streams that fall inside the watershed mask. Also select streams entering and exiting the watershed, and convert the selected streams to a new shapefile, *tristr105alb_2*. Figure A.13 shows the selection of streams in HUC 105 and a close-up of selecting streams entering the HUC.

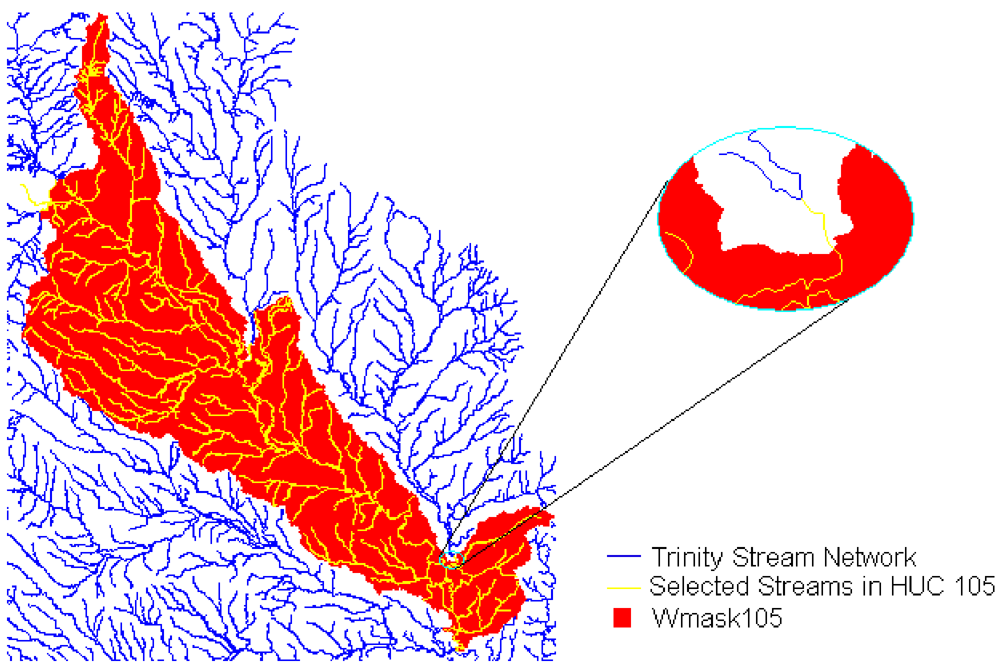


Figure A.13: Selected Streams in HUC 105

Next, add the updated control point file for the entire basin, *tricptalb*, to the view. The control points inside HUC 105 should be selected from the shapefile, including the outlet and inlet points to the HUC. This selection of points should be converted to a new shapefile, *tricpt105alb_2*. The addition of a stream may change the parameters for points near the stream edit and downstream of it. For this reason, all Wrap1117 processes should be rerun on the control points in HUC 105. The Wrap1117 process is detailed by Hudgens (1999).

To accurately cascade the parameters, some guidelines should be followed when running the Wrap1117 process on local watersheds. The unclipped flow direction grid should be used to create the DEM derived stream network and the clipped flow direction grid should be used to delineate watersheds for the control points. After running the Wrap1117 processes, the new parameters file, *tricpp105alb_2*, will only include local parameters and must be cascaded to reflect upstream and downstream influences. The cascading of the parameters file is detailed in Chapter Five, section 5.6.3.

Appendix B: AML for Grid Processing

B.1 Introduction

Grid processing for WAM can be done in ArcView with Wrap1117 or in ArcInfo Workstation. In ArcInfo, many functions can be run in succession with an Arc Macro Language (AML) file. Once run, ArcInfo will read each line of the AML and execute the processes.

The text of an AML file should be written in Notepad. When saving the file, it is important to select "All Files" from the "Save As Type" box and to add the extension ".aml" to the file name. Otherwise, ArcInfo will not recognize the file as an AML. To run an AML, the user must open ArcInfo workstation, navigate to the directory containing the AML, and then type "&run *filename*".

The following text is an AML for WAM grid processing. This file will create a fill, flow direction, clipped flow direction, flow accumulation, average curve number, average precipitation, and flow length grid. Italicized characters are ArcInfo commands and should not be changed. Non-italicized characters are filenames that should be changed to reflect the user's environment and files. It is important to know that grid names cannot exceed 13 characters and that there must be a space between mathematical operators and filenames.

```
w z:\your_directory
grid
setcell mask101
setwindow mask101 mask101
fill burn101 fill101 # # fdr101
clip_fdr101 = wmask101 * fdr101
clip_fac101 = flowaccumulation(clip_fdr101)
acn101 = (flowaccumulation(clip_fdr101, cn101) + cn101) / (clip_fac101 + 1)
apr101 = (flowaccumulation(clip_fdr101, pr101) + pr101) / (clip_fac101 + 1)
flow101 = flowlength(clip_fdr101, #, downstream)
q
&return
```

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Vita

Melissa Jane Figurski was born on April 18, 1977 in Walnut Creek, California, the daughter of Kathleen Ann Roesner and Larry August Roesner. After graduating from Lake Brantley High School in Altamonte Springs, Florida, she entered the College of Engineering at The University of Florida in 1995. In 1999, she graduated with her Bachelors of Science degree in Civil Engineering with honors. She then entered The Graduate School at The University of Texas at Austin in 2000.

Permanent address: 1831 Wells Branch Parkway, 736
Austin, Texas 78728

This thesis was typed by the author.