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WRAPHydro Data Model: Finding Input Parameters for the Water Rights Analysis Package

by

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Thesis

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WRAPHydro Data Model: Finding Input Parameters for the Water Rights Analysis Package

Approved by
Supervising Committee:

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David Maidment

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Daene McKinney

Dedication

This thesis is dedicated to my Amma and Appa

Acknowledgements

I would like to thank my advisor Dr. David Maidment for his guidance and support throughout this research. I am grateful to Texas commission on Environmental Quality for funding my project, especially Prescott Christian and Michelle Tischler for their help and patience in the past two years.

I would like to thank Melissa Figurski who taught me the basics of WAM, Tim Whiteaker for his amazing tools and all my friends at CRWR for the wonderful environment to work in.

I am most grateful to my parents, Mythili and Srinivasa Gopalan for their love, encouragement and constant guidance at every stage of my life. I wouldn’t be what I am today without your support. Special thanks to my brother, Sudarshan for all the fun and laughter we have had together.

My heartfelt thanks go to my husband, Vijay for his love and inspiration. The moral support you have given me in the past eight months cannot be valued enough. I also take this opportunity to thank everyone in my new family for their affection and for being such wonderful people.

Abstract

WRAPHydro Data Model: Finding Input Parameters for the Water Rights Analysis Package

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The University of Texas at Austin, 2003

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The Water Availability Model requires geospatial parameters to be used as inputs into the WRAP model. Previously these parameters were developed in ArcView 3.2 and processing suffered from performance and data management issues. This thesis presents a new hydro data model – WRAP Hydro developed specifically for the WRAP project. A new method of determining watershed parameters for the Guadalupe basin using the Arc Hydro and WRAP Hydro toolsets is discussed. The parameter processing is done in three stages, getting base data, preprocessing

and the actual processing. This provides a systematic and structured approach to determine watershed parameters. This work also validates the division of a basin into sub basins for a more efficient processing of parameters. It is found that both these methods give identical results. The values obtained by these two methods for upstream area for each control point were compared with the USGS area values and it was observed that they matched well. The process of finding parameters when new stream segments and control points are added without having to redo the whole process again is also discussed in the thesis. The WRAP Hydro toolset provides functions that help to add and remove control points from the network. It is also possible to incorporate a new stream edit without having to process the grids for the whole basin again.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 BACKGROUND

Water is a precious and finite resource, but water is already scarce in many countries, and competition for water from industrial and domestic users continues to grow. So where will we find the water to grow the crops that feed the world? No resource is more crucial than water, and no resource in Texas is surrounded by more controversy. For well over 200 years, Texans have fought over water rights and issues. There is an increasing need for water as the population and economy continues to grow rapidly. This increased need is creating a greater dependency on surface water because groundwater reserves are being mined. Water shortage problems arise primarily as a result of limited access to supplies and uneven distribution of water resources.

In response to the statewide drought of 1996, in 1997 the Texas legislature directed the Texas Commission on Environmental Quality (TCEQ), previously called the Texas Natural Resources Conservation Commission (TNRCC), to develop a new water availability model (WAM) which not only allows the TCEQ to more accurately determine whether sufficient water is available for issuing new water right permits, but also allow planners to determine the amount of water available for each water right and the percentage of time it is available.

The components that make up the WAM System include a database of water rights, water uses, and streamflows; geographic information system (GIS) tools for streamflow analysis and the water availability model. The availability model requires modifications as it is applied to each river basin to ensure it accurately represents each basin's hydrologic characteristics. The TCEQ chose the Water rights Analysis Package (WRAP) model developed by Ralph Wurbs at Texas A&M University as the New Water Availability Model (Wurbs 2001).

The WRAP is a hydrologic simulation model to evaluate, existing water right permits, permit approvals for new water rights, and overall water management in Texas under a priority based water allocation system. The principal results from a WAM analysis are the reliability of existing water rights and monthly estimates of unappropriated water that would be available for diversion or storage. These results are used to analyze the capability of a river basin to satisfy existing water use requirements and the amount of unappropriated streamflow remaining for potential additional water rights applicants.

The Center for Research in Water Resources (CRWR), at The University of Texas at Austin developed watershed parameters to be used as inputs to the WRAP model. These parameters include the area draining to each control point, the flow length from each control point to the outlet of the basin, the control point connectivity, the average precipitation and the average curve number over the drainage area. Control points here collectively refer to the location of each diversion point, United States Geological Survey (USGS) stream gage and various other basin nodes like reservoirs, return flows, streamflows, evaporation etc. as specified by the contractor. The WAM process as a whole is described diagrammatically below:

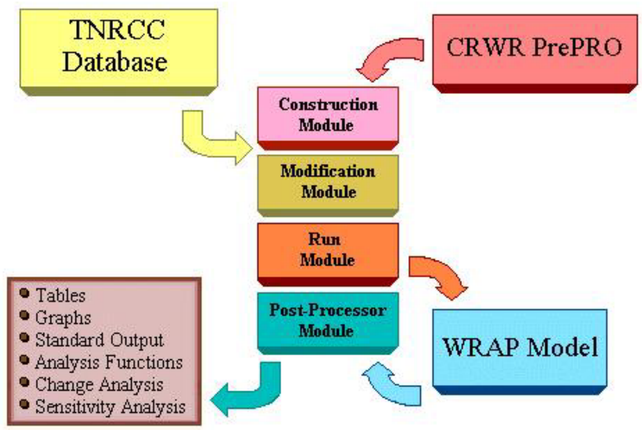


Figure1.1: Diagrammatic representation of the WAM process

Courtesy: TCEQ webpage (http://www.tceq.state.tx.us)

1.2 THE WAM PROCESS AT CRWR

The contract with CRWR for the WAM process began in 1997. Of the 23 basins in Texas, parameters for 22 basins with the exception of the Rio Grande were developed by December 2002. A set of scripts were developed in Avenue, ArcView 3.2, a premier Environmental Systems Research Institute (ESRI) software. Watershed parameters were first developed for two River basins in Texas, the Sulphur and the Neches (Hudgens 1999). The parameter development was done for four more basins: Nueces, Guadalupe, San Antonio and San Jacinto, by improving upon the previous method with the availability of better data (Mason 2000). An algorithm was developed for defining and removing non-contributing areas for four basins including the Red, Canadian, Colorado and Brazos River basins (Figurski 2001). The parameters for the Rio Grande basin are being developed for both the Mexican and American sides of the basin and will be completed by December 2003. The author of this thesis has developed a new method for determining watershed parameters using the WRAPHydro model in the ArcGIS platform.

1.3 OBJECTIVES

This research has five primary objectives:

- To build a hydro data model for the WRAP project from the basic Arc Hydro model. This model is called WRAP Hydro.
- To devise a new method of defining the basin boundary to act as an analysis mask for processing grids and watersheds.
- To develop a new vector based method for determining watershed parameters using the WRAP Hydro model.
- To verify the validity of dividing the basin into subregions for parameter development.
- To explore the possibility of efficiently adding stream lines and control points after completing the process of developing the parameters so as to facilitate editing and updating of database.

1.4 STUDY AREA

To illustrate the WRAP Hydro process for parameter development, the Guadalupe basin is chosen since the basin has a good size to be processed as a whole and to be divided into parts. The Guadalupe is the gem of Texas rivers, offering everything from tame flatwater to challenging rapids and water falls. The Guadalupe River rises on the Edwards Plateau at an elevation of 2,225 feet (680 meters). The River flows about 430 miles (690 Km) before draining into the San Antonio bay. Its total basin drainage area is about 6000 square miles (15530 Km^2). The United States is divided into Hydrologic units by the USGS. Each unit is indexed by an eight digit Hydrologic Unit Code (HUC). The Guadalupe basin has four HUCs, the Upper Guadalupe (12100201), the Middle Guadalupe (12100202), the San Marcos (12100203) and the Lower Guadalupe (12100204). Here the first two digits represent the region, second two the subregion, third two the basin and the last two represent the subbasin. The Figure below shows the four Hydrologic units for the Guadalupe with their codes:

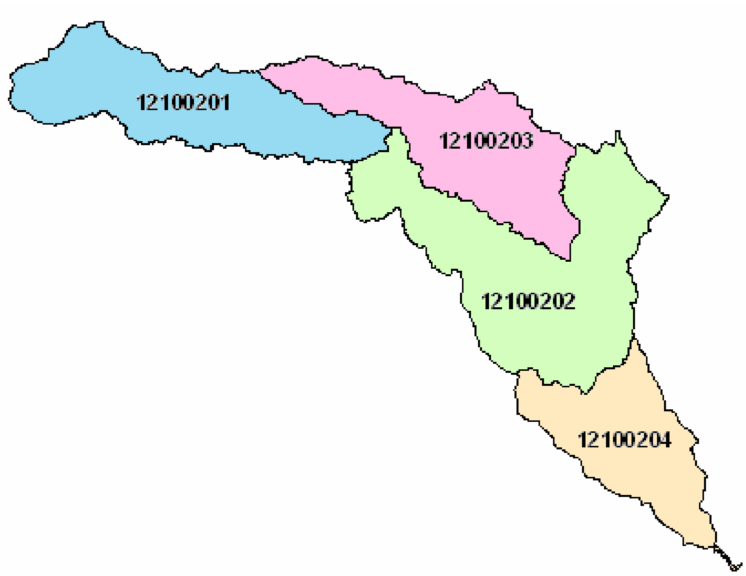


Figure 1.2 Guadalupe Hydrologic Unit Codes

The Upper Guadalupe starts out as a slow, meandering stream flowing into Canyon Lake. Below Canyon Lake, the Guadalupe flows down to the Gulf of Mexico.

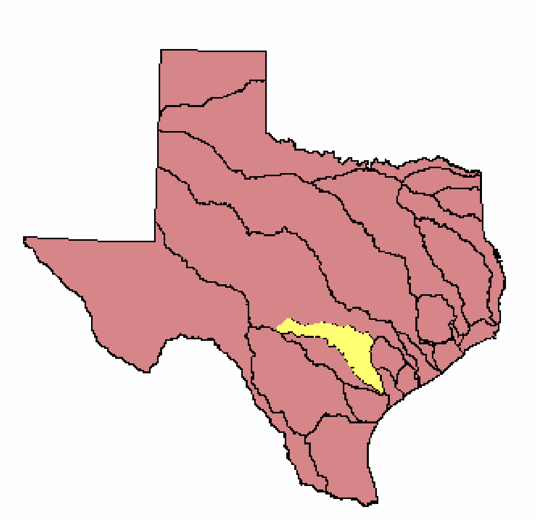


Figure 1.3: Location of Guadalupe basin in Texas

Chapter 2: Literature Review

Assessing water scarcity requires modeling both water availability and water use. Determination of natural water availability on a large spatial scale is an essential prerequisite to understand and to mitigate economic and social impacts of droughts of regional and state-wide extent. The main coupling aspect of water availability and water use/management is achieved by balancing the water resources available for water use. Different types of natural water resources and different sectors of water use have to be distinguished. This is important in the case where water demand exceeds available water resources and water management/use affects downstream water availability (Bronstert et al, 2000).

The use of geographic information system (GIS) and remote sensing to facilitate the estimation of hydrologic parameters for watersheds has gained increasing attention in recent years. This is mainly due to the fact that hydrologic models include both spatial and geomorphic variations. GIS technology provides suitable alternatives for efficient management of large and complex databases (Melesse et al, 2002).

Several studies have been done to incorporate GIS in hydrologic modeling of watersheds. These studies have different scopes and can be generally grouped into four categories. Computation of input parameters for existing hydrologic models is the most active area in GIS related hydrology (Djokic and Maidment, 1991; Olivera and Maidment, 1999). Hydrologic assessment refers to the mapping and display in GIS of hydrologic factors that pertain to some situation (Ragan and Kossicki, 1991). Measuring the spatial extent of hydrologic variables from paper maps may be tedious, labor-intensive and error prone. Watershed surface mapping refers to the uses of GIS in representation of watershed surface through the use of digital elevation model and gridded geographic data (Sasowsky and Gardner, 1991; Smith and Brilly, 1992). Identification of hydrologic response units is also another contribution of GIS to identify areas of watershed's having similar hydrologic response (Vieux et al, 1991).

Topography is a first-order control on the hydrological response of a catchment to rainfall. This reflects the role that topography plays in determining the spatial distribution of catchment-scale flow pathways resulting from the downward force of gravity. Topographic indices are strongly sensitive to grid size which in turn affects the model predictions (Brasington and Richards, 1997).

Improvements in hydrologic systems description through Digital Elevation Models, produced new approaches for the development of hydrological tools based on geomorphologic concepts. The space-filling representation of a network, directly derived from a DEM, leads to a unit response of the basin equivalent to the width function, defined as the increase of contributing area corresponding to an increase of distance from the outlet along the drainage paths (Ginnoni et al, 2000).

The application of any hydrologic model requires efficient management of large spatial data. This is done by integrating watershed simulation models and GIS which generates the capacity to manage large volumes of data in a common spatial structure (Al-Sabhan et al, 2003).

A set of tools were developed at the Centre for Research in Water resources for determining the watershed parameters. These tools were scripts written in Avenue and were embedded in an ArcView 3.2 project called WRAP1117.apr. These tools 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 curve number and average annual precipitation grids from the SCS curve number and annual precipitation grids. The toolset was first implemented on the Sulphur basin with two DEM resolutions, 90m and 30 m. It was found that 30 meter DEMs provided more accurate delineation of watersheds but the time to process the 30m data increased due to increased file size (Hudgens, 1999).

For a more precise delineation, the surrounding streams of a basin, apart from the stream network within the basin, have to be taken into consideration. 30 m DEM-derived watersheds with a slope greater than 0.002 correlated to the US Geological Survey (USGS) reported watershed areas within 1%. At a slope less than 0.002, the percent difference from USGS values rose (Mason, 2000).

For large watersheds, the data is too huge to be handled as one entity, this problem is dealt by subdividing the basins into parts. The hydrologic cataloging unit provides a good boundary in terms of size to divide large basins. The independent processing of each subbasin or cataloging unit means that the resulting parameters do not include contributions from upstream or downstream areas that are required for WAM. The values obtained from each subbasin can be cascaded downstream to get the final parameters for the control points for the entire basin (Figurski, 2001).

The problem of space has two aspects to it, scale and size (Schumm, 1991). Studies so far have shown that the better spatial resolution, the more accurate will be the results but the increase in file sizes will lead to increased time for processing data. This issue of scale has a compromise between accuracy and data management. The issue of size is dealt by working with more number of smaller units.

The ArcHydro framework provides a simple, compact data structure for storing the most important geospatial data describing a water resources system. This framework can support basic water resources studies and models, and can serve as a point of departure for the most extensive data models, that include time series and other ArcHydro components. The framework contains information organized in several levels (Maidment, 2002).

Chapter 3: Arc Hydro Framework

3.1 INTRODUCTION

Arc Hydro is a geospatial and temporal data model for water resources. It has an associated set of toolset developed jointly by ESRI and CRWR, that operates in the ArcGIS platform. The Arc Hydro toolset populates attributes of the features in the data framework, interconnects features in different data layers and supports hydrologic analysis (Maidment, 2002). The Arc Hydro framework consists of a geodatabase with feature dataset, feature classes, geometric network and relationship classes. A geodatabase is a relational database in the Microsoft access format (filename.mdb). A feature dataset is a folder within the geodatabase that has a defined projection and a specified coordinate system. Feature datasets contain feature classes that can either be point, line or polygon features. In the Arc Hydro jargon, a point feature class is called HydroEdge, a line feature class is called HydroJunction and a polygon feature class is called Watershed. Thus, in a basin the stream network is typically called HydroEdge, the control points have a one to many relationship with HydroJunctions since more than one control point can exist at the same location and the area delineated for each control point or stream reach is called Watershed. Figure 3.1 shows how the various feature classes are represented in a basin:

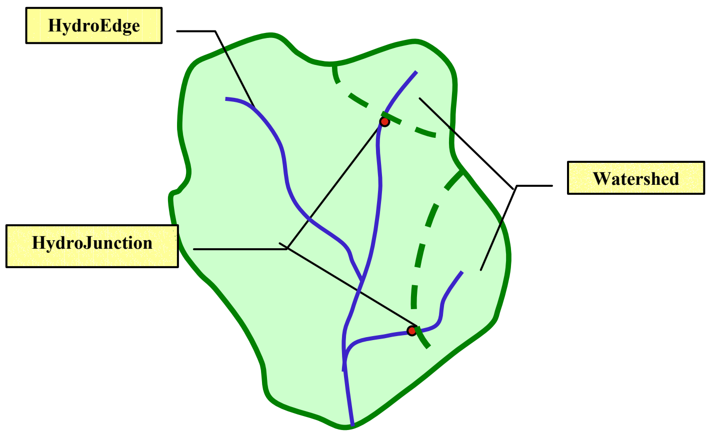


Figure 3.1: Representation of feature classes in the basin

A geometric network, called the HydroNetwork contains the topologic connectivity between the HydroEdges and the HydroJunctions. All Arc Hydro features have a unique identifier called the HydroID. Two tables, HydroIDTable and LayerKeyTable, help in assigning HydroIDs to features. This is described in more detail in the Arc HydroTools section of this chapter.

3.2 ARC HYDRO MODEL FOR WATER RESOURCES

The arc hydro model has the following components:

- Network
- Drainage
- Channel
- Hydrography
- Time Series

This work deals mainly with the first two components and they are described below.

3.2.1 Network

Water flows from the highest elevation of a basin down to the sink which is the outlet for a basin and thus at any point on the stream, there is one direction in which water flows. A HydroNetwork is a geometric network created with the HydroJunction and HydroEdge feature classes. The HydroEdge feature class is always built as a complex edge in a network. In a simple edge, the edges get split up at locations where a HydroJunction snaps on to them. In case of a complex edge each edge segment retains its original length even if a junction is snapped on to it. Generic junctions called the HydroNetwork_Junctions (created as a featureclass) are created at the ends of each HydroEdge. The HydroEdge feature has a field FlowDir, that contains values 0 through 3, which defines the flow direction for each attribute. Here 0 stands for uninitiated, 1 for with digitized, 2 for against digitized and 3 for indeterminate. Flow direction also helps in finding the connectivity between various features. For example it helps in determining the next downstream junction for each junction in the feature class. The Utility Network Analyst tool is used in conjunction with the flow direction assignment. The Figure 3.2 shows the components of this tool.

Figure 3.2: Utility Network Analyst toolbar

This tool helps in performing various functions like tracing upstream or downstream from a flag, finding connected or disconnected features, identifying loops in a network, drawing arrows to check the flow direction settings etc. Flags are placed at points where these functions have to be performed. This tool reduces to a great extent the effort of identifying such problems manually. The Figures 3.3, 3.4, 3.5 and 3.6 show the use of the Utility Network tool.

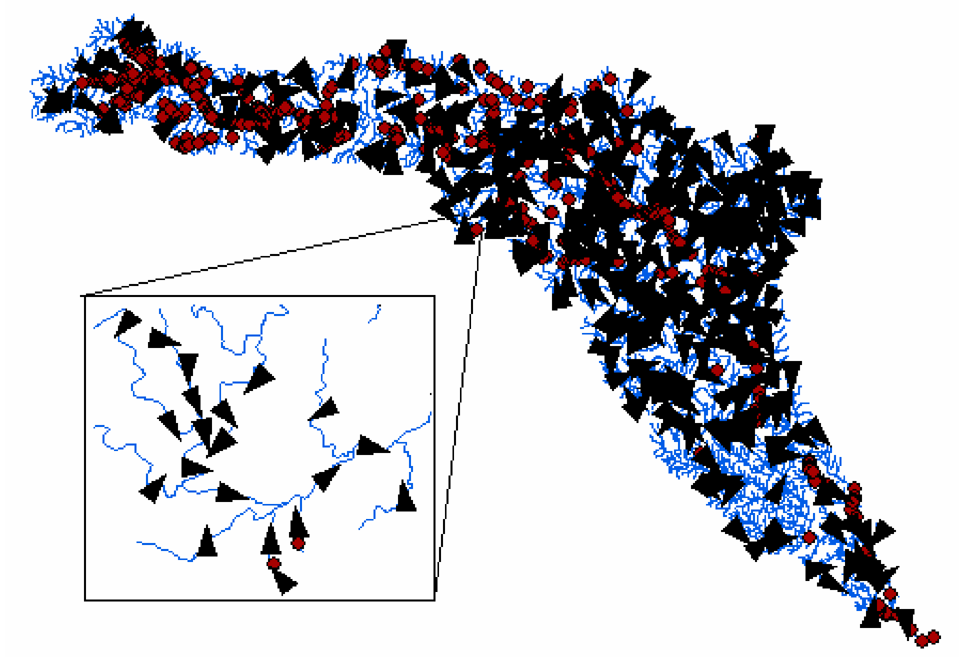


Figure 3.3: Setting Flow Direction for the Guadalupe basin

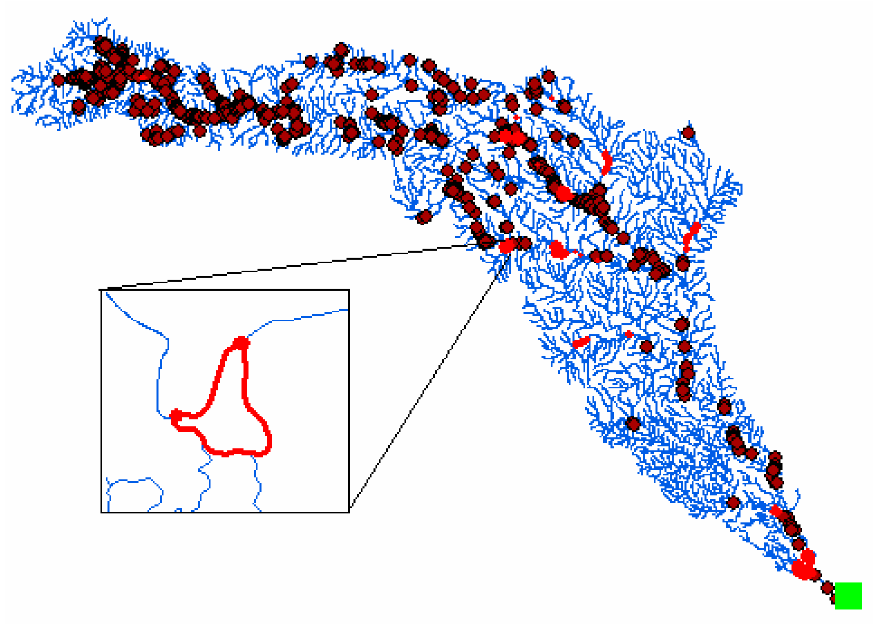


Figure 3.4: Finding loops in the network

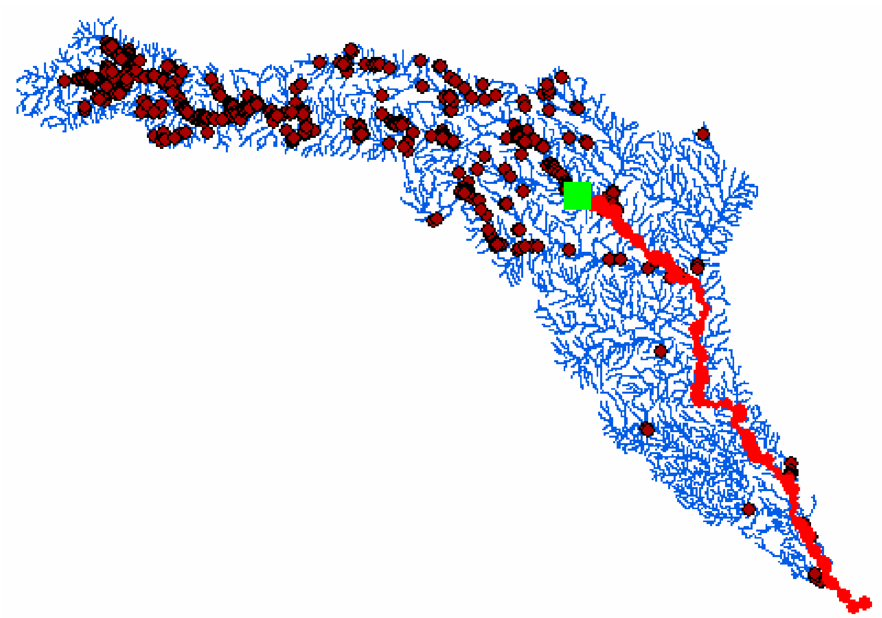


Figure 3.5: Tracing downstream in a network

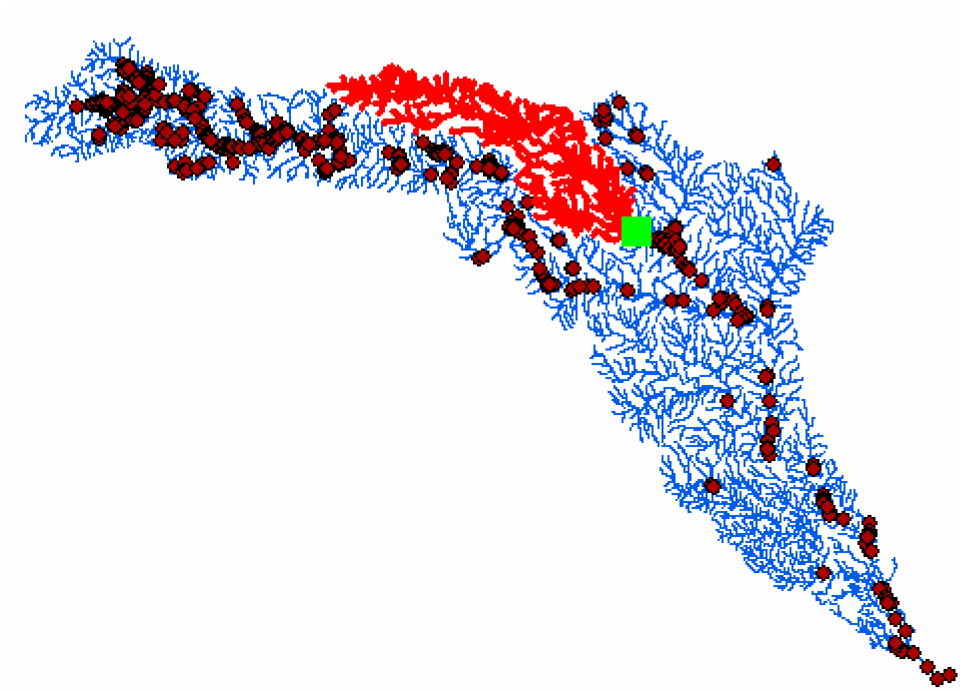


Figure 3.6: Tracing Upstream in a network

3.2.2 Drainage

Drainage areas are bounded by topographical divides in which all the water falling within that area drains to a line which in turn drains to a point at the outlet. Figure 3.7 shows the path in which water flows. The black arrows show the water draining from the area to lines and the blue arrows on the stream show the path from the streams to the point which is the outlet for the drainage area.

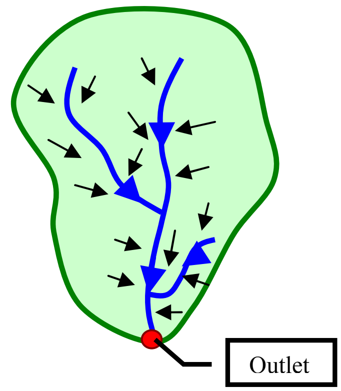


Figure 3.7: Drainage path in a basin

Drainage areas are delineated using Digital Elevation Models (DEM), which are rasters of a specific resolution. These rasters are made up of square grid cells and each cell has a value of the elevation at that point on the ground. The process of drainage delineation for DEMs is described in chapter 4. The DEM covering the Guadalupe basin has 6662 rows and 9507 columns. Thus there are a total of 63335634 cells that cover the basin.

In Arc Hydro, the delineated area is called the Watershed feature class and the model generates a relationship between the Watershed and the HydroJunction it is draining to. Each delineated watershed is connected to the HydroID field in the HydroJunction feature class by JunctionID which is an unique identifier for the HydroJunction.

3.3 ARC HYDRO TOOLSET

The Arc Hydro toolset has been developed jointly by ESRI and CRWR. It has five menus. This work does not use the Watershed Processing tools. All other tools used for this project are discussed below

Figure 3.8: ArcHydro Toolset

3.3.1 Terrain Preprocessing

It is used to preprocess the raw DEM for further analysis. For this project the first three utilities are used – DEM reconditioning, Fill sinks and Flow Direction. The DEM reconditioning, also referred to as 'burning the DEM with the stream' is done to raise the elevation of the cells that surround the stream. This is done to ensure that all the water that falls on the basin is captured by the stream and the stream follows the same path as in a topographic map. For this work, the number of buffer cells for burning the stream was specified as zero. Since the size of each cell is 30m, giving a buffer of even one cell would mean that the width of the stream becomes 90 m which is too high.

The Fill sinks tool fills all the sinks in the reconditioned DEM. A sink is defined as any cell that has a value less than all its surrounding eight cells. Its value is raised to the value of the lowest surrounding cell. The flow direction tool assigns a value of flow direction to each cell in the grid according to the eight direction pour point method. The directions and values are as shown in Figure 3.9

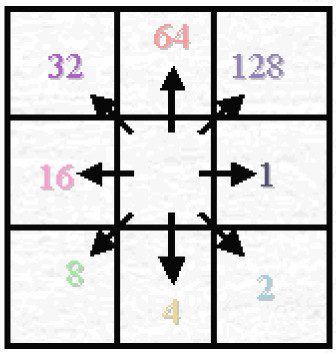


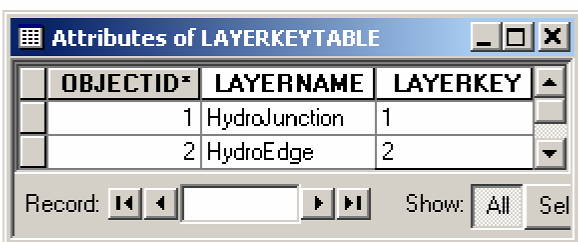
Figure 3.9 Eight pour point method for Flow Direction assignment

3.3.2 Network tools

The network tools help in assigning and storing the flow directions in a geometric network. The flow direction is usually set using the attributes of FlowDir field in the HydroEdge. Some of the edges might not have this attribute populated in which case it can be done using either the digitized or against digitized options to set the flow direction. The best way to identify the streams that do not have this attribute populated is by placing a flag at any point in the network and run a find disconnected. Any stream that does not have the flow direction attribute will be highlighted. Once all the flow directions are properly set, the store flow direction tool is used to store the attribute values so that if the network is to be built again, one need not go through the process of assigning directions to the streams with unpopulated attributes. The Node\Link Schema generation tool creates a line feature class that shows the connectivity between the junctions, it draws a line between a junction and its next downstream junction.

3.3.3 Attribute tools

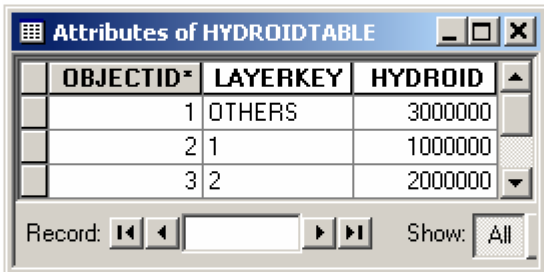
This tool is used to read and write attributes to tables. The assign HydroID tool assigns the HydroIDs to the specified layers. It is used in conjunction with the HydoID Tables Manager in the ApUtilities menu. When this tool is used to populate the HydroIDs for any layer the first time, it generates two tables – a HydroIDTable and a LayerKeyTable. The Layerkey table helps to specify a unique number or key for each layer. For example the HydroJunction can be given a Key value = 1 and the HydroEdge a Key value = 2 (See Figure 3.10).


Attributes of LAYERKEYTABLE

OBJECTID*	LAYERNAME	LAYERKEY
1	HydroJunction	1
2	HydroEdge	2

Figure 3.10: LayerKeyTable Attributes

The HydroID Table relates the assigning of HydroIDs to the Key of each layer. The table below shows that for the HydroJunction, which has a layer Key = 1, the HydroIDs will be assigned with an initial value of 1000000 and for the HydroEdge the HydoIDs will be assigned with initial value 2000000. For all other layers 3000000 will be the initial value of HydroID assignment.



Attributes of HYDROIDTABLE

OBJECTID*	LAYERKEY	HYDROID
1	OTHERS	3000000
2	1	1000000
3	2	2000000

Record: Show: All

Figure 3.11: HydroIDTable attributes

The find length downstream for junction tool finds the distance of each junction from the outlet of the basin by adding up the lengths of the edges that are downstream of them. The Find next downstream junction tool populates the NextDownID field in the HydroJunction with the HydroID of the junction that is the next downstream of it. This shows the connectivity of the junctions in the network.

3.3.4 ApUtilities

The initial HydroID values for each layer are set using the HydroID tables manager. Additionally if it is required to assign regional Ids to the layers, for example if a region is divided into two subregions and the HydroIDs for each subregion have to be assigned in accordance with the region number, the assign Regional ID can be used. The format of assigning the HydroIDs for the basin will be dealt with in more detail later.

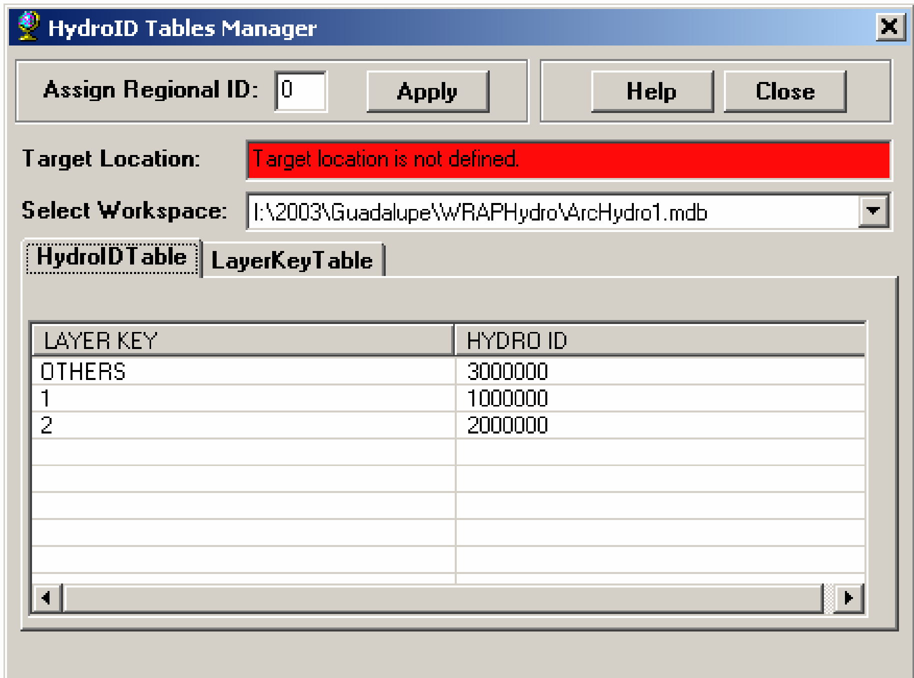


Figure 3.12: HydroID Tables Manager Setting

3.4 WRAPHydro Toolset

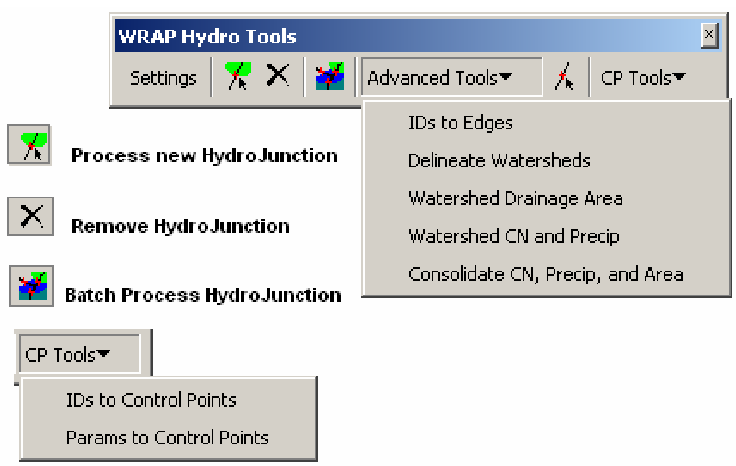


Figure 3.13: WRAPHydro Toolset

The WRAP Hydro toolset helps to find parameters like the total upstream drainage area, average upstream curve number and average upstream precipitation for each HydroJunction. The toolset also provides the provision to add a new HydroJunction to the network and also delete a junction. A batch processing of parameters can also be done for a new set of junctions.

The Ids to Edges tool populates the JunctionID attribute of each edge with the HydroID of the junction that is next downstream of it. Thus, all the edges between two junctions have the same JunctionID value (the HydroID of the downstream junction). The delineate watershed tool delineates watersheds to a source feature which could be a point, line or polygon feature using the Flow Direction grid.

The CP tools builds a relationship based on the spatial location between the WRAPJunction and ControlPoint feature classes and copies attributes from the WRAPJunction file to the Control Points file based on the relation.

The Process new HydroJunction button adds a new Junction to the network and updates the affected attributes on its upstream Junction. The Remove HydroJunction button removes an existing HydroJunction from the network and updates the required attributes. Batch process HydroJunction is used when more than one HydroJunction has to be added to the network. It populates attributes for the new Junctions, updates affected ones and delineates watersheds for the new junctions.

Chapter 4: The WRAP Hydro Data Model

4.1 WRAP HYDRO DATA MODEL

One of the main developments using the ArcHydro framework is to connect it to hydrologic models like WRAP, HMS and RAS. The WRAP Hydro data model has been derived from the Arc Hydro model and is tailored specifically for the WRAP project. The WRAPHydro data model is structured to suit the needs of the WRAP parameter processing. The feature classes and fields that are required for the WRAP process are retained, those that are not are removed and some others that do not exist in the ArcHydro Framework and are required by the WRAP process are added. For further details of model construction refer to ArcHydro – GIS for Water Resources (Maidment 2002).

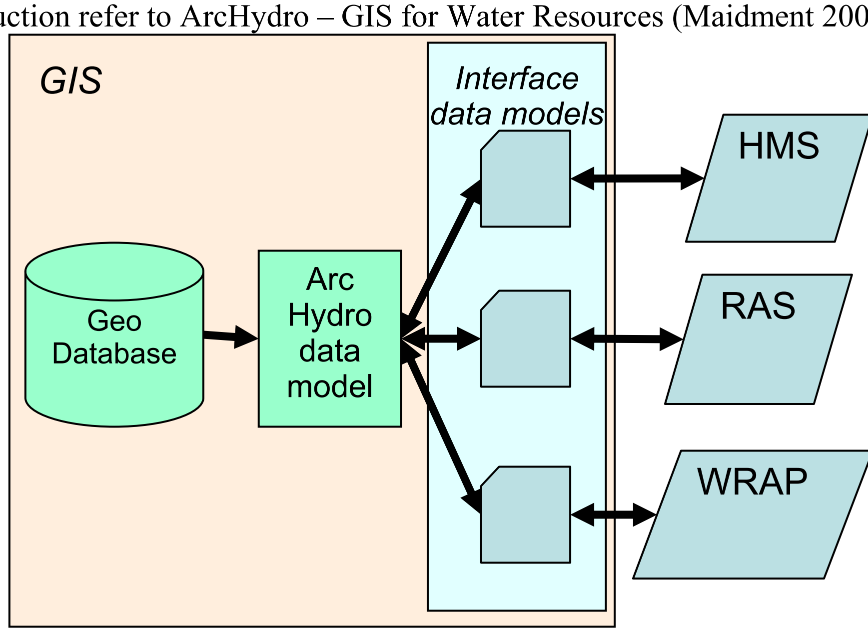


Figure 4.1: Interfacing Hydrologic models with ArcHydro framework

Courtesy: Tim Whiteaker

The structure of the model for Guadalupe is detailed in Figure 4.1 . The Guadalupe basin folder has a folder 'Grids' and a personal Geodatabase 'WRAPHydro.mdb'. The grids folder contains all the grids needed for processing at different levels, 'BaseGrids', 'PreProcessGrids' and 'WRAPHydroGrids', The geodatabase has four feature datasets 'ArcHydro', 'BaseData', 'PreProcess' and 'WRAPHydro'. Each of these datasets has feature classes that specify the mandatory fields that are contained within it. Thus, Figure 4.2 represents the model structure when the whole basin is processed in one piece. The basin is processed either as a single unit or in parts by dividing it into sub-basins. The regional WRAPHydro processing is discussed in Chapter 7.

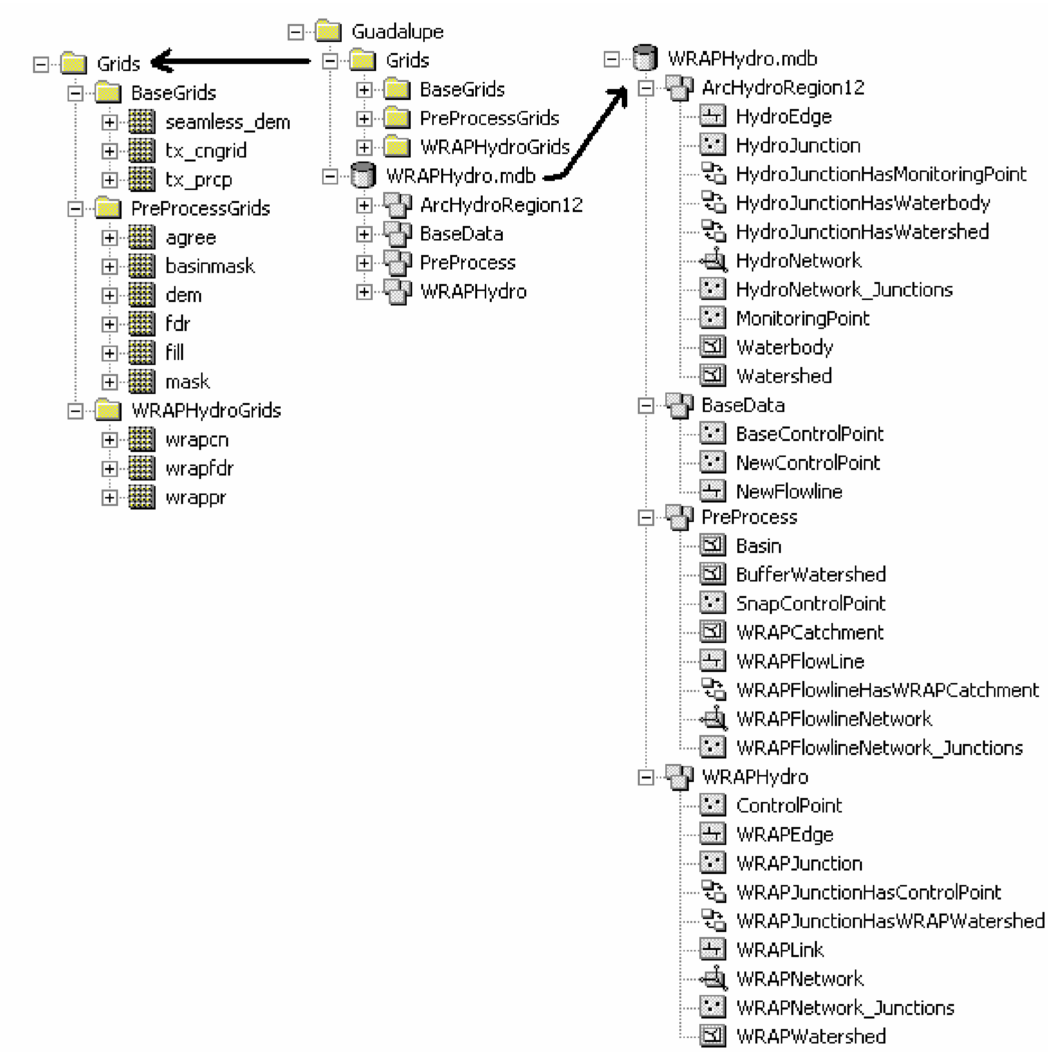


Figure 4.2 WRAPHydro Data model structure

4.2. GRIDS

The Grids folder contains all the grids that are required as a part of the process for developing watershed parameters.

4.2.1 BaseGrids

The base grids contains all the grids that are required before any processing can start. They are obtained from various sources and have different resolutions.

- *Seamless_dem* is obtained from the USGS site. It contains all the DEMs that cover the required basin area in a seamless format. These DEMs have a 30 m resolution
- *Tx_cngrid* is a Curve Number grid for Texas. The grid resolution is 250 m
- *Tx_prcp* is a annual precipitation grid for Texas. The grid resolution is 4294 m

4.2.2 PreProcessGrids

The Terrain Processing tools in the ArcHydro toolset are used to process the flow direction grid from the raw DEM. These grids are used in conjunction with the feature classes in the preprocess dataset to define the basin boundary

- *Mask* is a grid with all the cells having unit value whose extent is equal to the extent of the BufferWatershed (Refer section 4.3.2)
- *Dem* is the seamless_dem clipped to the mask grid
- *Agree* is obtained by burning the WRAPFlowLine (refer section 4.3.2) to the DEM grid

- *Fill* grid is the agree grid with all its sinks filled
- *Fdr* is the flow direction grid processed from the fill grid
- *Basinmask* is a grid with all its cells having unit value clipped to the basin feature class(refer section 4.3.2)

4.2.3 WRAPHydroGrids

These are grids that are obtained for use in the final processing of parameters.

- *wrapfdr* is the fdr grid clipped to basinmask
- *wrapcn* is the tx_cngrid grid clipped to basinmask
- *wrappr* is the tx_prcp grid clipped to basinmask

4.3 WRAPHYDRO GEODATABASE

The WRAPHydro contains all the feature classes that are used in conjunction with the grid processing to obtain watershed parameters.

4.3.1 ArcHydroRegion12

The ArcHydro data for region 12 is used as a base data for the WRAP model. It is assumed that the HydroEdge, which is the NHD stream network, has been edited, checked for nodes and has the flow direction set and the data is ready for use for further processing. It is also assumed that the Watershed feature class is the area defined by the set of HUC areas in region 12.

4.3.2 BaseData Feature Dataset

This feature dataset contains feature classes that are the raw data besides ArcHydro needed to begin the processing. Starting processing at this level creates a capability for base processing and then periodic updates.

- *BaseControlPoint* is a point feature class that contains the locations of all the control points in the basin. It is imported from control point shapefile provided by the TCEQ. The WRAPID is the unique identifier for these control points.
- *NewEdge* is a line feature class that contains the Edges that are added after the final parameter development is done.
- *NewJunction* is a point feature class that contains the junctions that are added after the final parameter development is done.

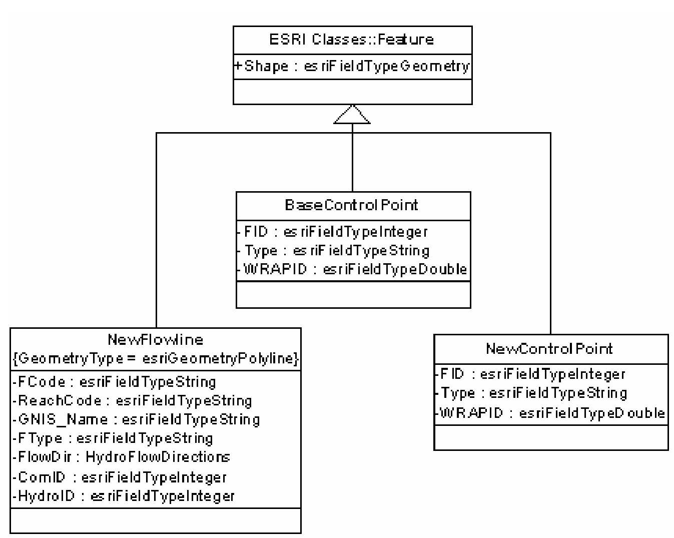


Figure 4.3: Unified Macro Language for the BaseData Feature Dataset

4.3.3 PreProcess Feature Dataset

After the base data is prepared, some preprocessing needs to be done before the data can be ready for processing parameters. This dataset has four feature classes:

- *BufferWatershed* is a polygon feature class obtained from the HUCs. It is the area as defined by the HUCs of the basin under study with a 10 Km buffer drawn around them.
- *WRAPFlowline* is a line feature that has all the HydroEdges that lie within the BufferWatershed.
- *WRAPCatchment* is a polygon feature class that has been obtained by delineating drainage areas for each stream segment in the WRAPFlowline with a unique identifier HydroID. These catchments are later used to define the basin boundary.
- *Basin* is also a polygon feature class that is derived by dissolving only those features from the WRAPCatchment that define the boundary of the basin under study.
- *SnapControlPoint* is a point feature class that is the BaseControlPoint with all the features snapped to the right location on the network. The WRAPCode is a unique identifier for this feature class.
- *WRAPFlowline Network* is a complex network built with WRAPFlowline. This is required to assign flow directions to the WRAPFlowlines and delineate catchments for them.

- *WRAPFlowlinehasWRAPCatchment* is a one to one relation between the WRAPFlowline and WRAPCatchment. The HydroID of the WRAPFlowline is related to the DrainID of the WRAPCatchment. this relationship is used to select the WRAPCatchments from the selected WRAPFlowlines.

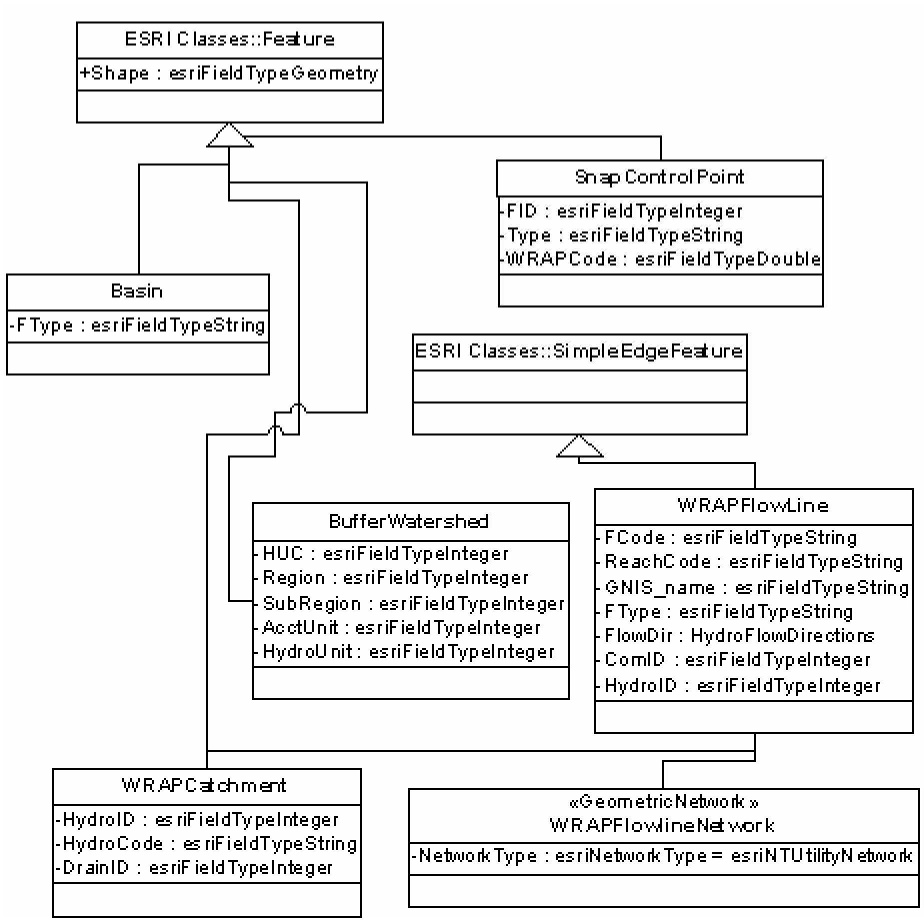


Figure 4.4: Unified Macro Language for the PreProcess Feature Dataset

4.3.4 WRAPHydro Feature Dataset

The WRAPHydro is the data set that contains all the data for which parameters need to be generated. It has four feature classes:

- *ControlPoint* is a point feature class that is essentially the BaseControlPoint, but has the attributes populated from WRAPJunction feature class. It might have more than one point at a single location.
- *WRAPJunction* is also a point feature class that is obtained from the SnapControlPoint feature class by removing all the coincident points. It has just one representative point at a location.
- *WRAPEdge* is a line feature class that contains only those Edges from the WRAPFlowline which lie within the Basin.
- *WRAPWatershed* is the watershed that has been delineated for each WRAPJunction in the network using WRAPEdge as the source layer for delineation.
- *WRAPNetwork* is a simple network built using the WRAPJunction and WRAPEdge.
- *WRAPLink* is a line feature class that shows the connectivity of the WRAPJunctions, i.e. which WRAPJunction is downstream of which one(s).
- *WRAPJunctionhasControlPoint* is a one to many relationship between WRAPJunction and ControlPoint feature classes since more than one control point can exist at the same location on the network. The HydroID of the WRAPJunction is related with the JunctionIDs of the corresponding

ControlPoints. This relationship is used for populating attributes to the ControlPoint feature class.

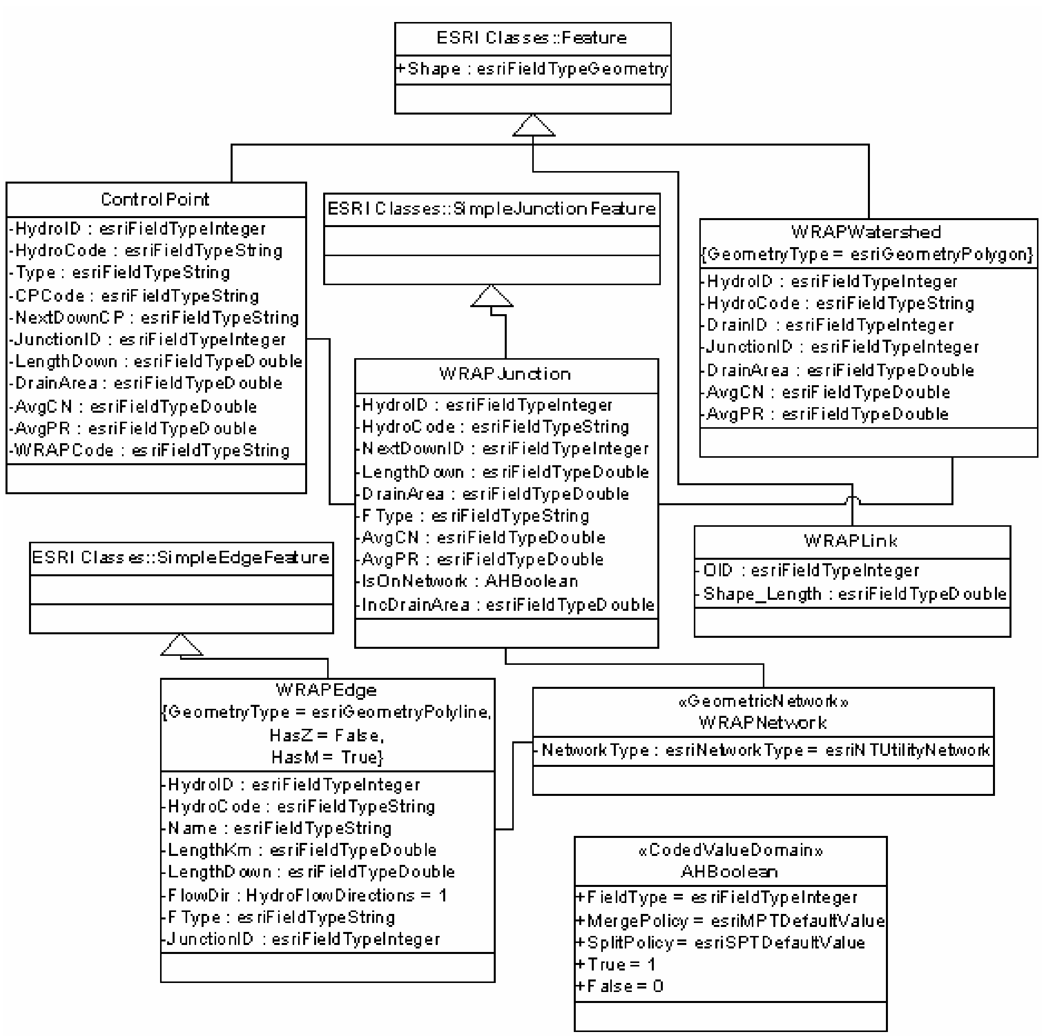


Figure 4.5: Unified Macro Language for the WRAPHydro Feature Dataset

Chapter 5: Methodology – Getting Base Data and Preprocessing

5.1 BASEDATA

The base data needed for this project are:

- HydroEdge for region12
- HUC Watersheds for region 12
- The shapefile having all the Water Right locations
- New control point and stream edits
- DEM covering the basin
- Curve Number Grid
- Annual precipitation grid

5.1.1. HydroEdge

The NHD network for Region 12 was obtained from Paul Wiese, USGS, Denver. This network called the NHD in Geo is created for the use of NHD in a geodatabase. It has a field FlowDir which contains attributes that defines the direction of flow for each segment of the network.

5.1.2 Watershed

In ArcHydro region12, a Watershed is the area that contains all the HUC features in Region 12.

5.1.3 Base Control Points

The Control points file is obtained from the TCEQ as a shapefile. It contains all the water right points in a basin which includes stream gage locations, diversion points, return flow points or any other location on the stream where calculations of flow are done. Each record describes what type of water right point it is and what its WRAPCode is. The WRAPCode is a unique identifier given by the contractors according to their numbering conventions. This shapefile is imported into the BaseData feature dataset and called BaseControlPoint

5.1.4 New control points and stream edits

These are data that either is obtained after the final parameter processing or the features that had been accidently left out. Sometimes small stream branches are neglected while digitization process in the NHD data. There might be new water right permits that are added at a later stage on these streams. If that is the case, to delineate an area for the new control point a stream has to be added at the required location along with the point. This can be done by manually digitizing onscreen by overlaying the NHD streams on the Digital Raster Graphics (DRGs) that are scanned topographic maps. In most cases however, these stream segments are provided by the TCEQ along with the new water right points.

5.1.5 Digital Elevation Model

The DEM can be downloaded in parts from the USGS site http://seamless.usgs.gov/. Once all the DEMs that cover the analysis area are obtained, they are merged. To prepare the DEM for further processing, the merged DEM is first resampled to a cell size of 30 m. The cell values are changed to centimeter units and then converted to integers. This helps in reducing their storage space to a great extent. This data has a Geographic projection with datum NAD83 and spheroid GRS80.

5.1.6 Curve Number grid

Tx_cngrid is a 250 m Curve Number grid which covers the whole Texas. This was obtained from the Blacklands Research Centre in Temple, Texas. This grid was prepared using the STATSGO soil coverage and the USGS Land Use Land Cover (LULC) coverage, by combining the soil and land values into curve numbers using the 1972 SCS Engineering Hydrology Handbook as a reference.

5.1.7 Annual Precipitation grid

Tx_prcp is a 250 m resolution annual precipitation grid for Texas. This was obtained from the Oregon State Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate grids. The grids can be obtained from the website: http://www.climatesource.com/support.html.

5.2. PROJECTION SYSTEM

The projection system chosen for this work is Texas State Mapping System (TSMS). It is a consistent map projection for Texas since it preserves the true earth surface area for polygons and this is important for this study when performing drainage area calculations. All the base data are projected to this projection system before any analysis is done. The parameters for this coordinate system are as follows:

Albers Equal Area

False Easting: 1000000

False Northing: 1000000

Central Meridian: -100

Standard Parallel 1: 27.416666666

Standard Parallel 2: 34.916666666

Latitude of Origin: 31.166666666

GCS North American 1983

Datum: D North American 1983

Prime Meridian: 0

5.3 PREPROCESSING

After the base data is obtained the initial analysis area is defined and some preprocessing needs to be done before the final parameter development can be done. The preprocessing basically deals with defining the basin boundary to set the analysis extent for any further processing. A 10 Km buffer is created around watershed and called BufferWatershed. All the HydroEdges that lie within this buffered area are selected and exported to a new feature class WRAPFlowline.

The larger the grids are, the longer it takes to process them. So, it is advisable to work only with the region within which the parameters have to be developed rather than the buffered region. The basin boundary is defined by the DEM. When watersheds are delineated for all the streams that lie within a basin using the flow direction grid, ideally it should delineate all the area that makes up the basin. But, it is seen in some very flat and marshy area like in the Lower Guadalupe where the DEM values over a large area is almost the same, path for the flow of water is not defined, which is reflected in the flow direction grid. Figure 5.1 shows a portion of the flow direction grid for lower Guadalupe.

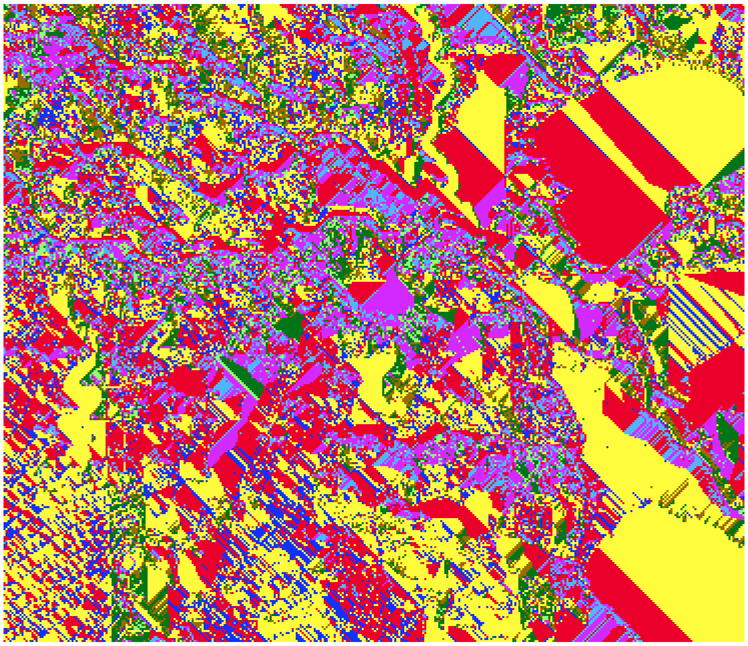


Figure 5.1 Portion of Flow Direction Grid at the Downstream end of Guadalupe

This kind of pattern in the flow direction tends to capture the neighboring area that does not lie within the study basin when delineating watersheds as seen in Figure 5.2. The grey area, which is a portion of the San Antonio River basin, has been captured by the stream circled red, though it is not within the Guadalupe basin area. Hence, it is necessary to come up with a method of defining the basin boundary before any further analysis can be done.

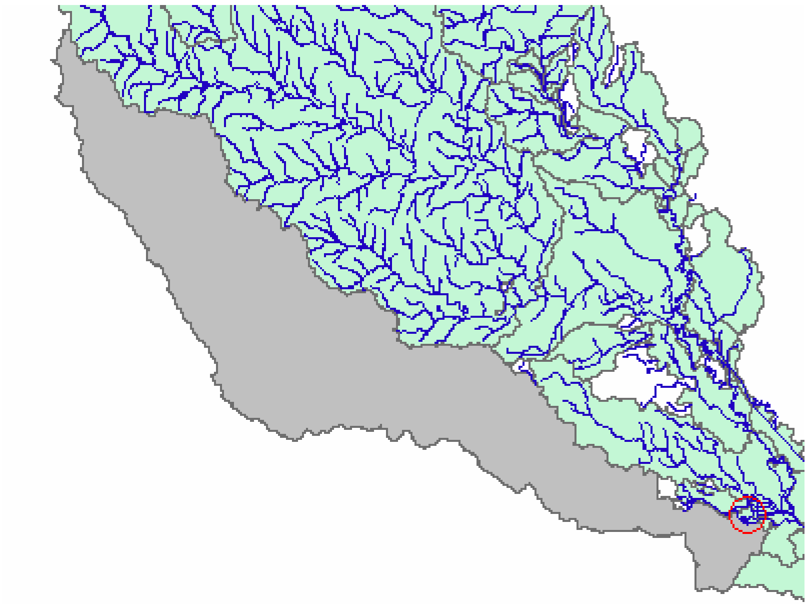


Figure 5.2: Catchment delineation problems

5.3.1 Grid processing

The terrain processing tools in the ArcHydro toolset are used to get the flow direction grid for the Guadalupe basin with a 10 Km buffer. The processes as described in *section 3.3.1* is followed.

5.3.2 Defining the basin boundary

Method I : Using HydroIDs of the WRAPFlowLine

This method deals with delineating watersheds for all the stream segments in the Guadalupe and selecting only those watersheds that are defined by the streams that lie within the Guadalupe. A network is built using only the WRAPFlowLine as a simple network and the flow directions are assigned using the FlowDir attribute. The HydroIDs are assigned using the attribute tools. The WRAP Hydro tool is used for delineation. The settings for delineating watersheds with source layer as Wrapflowline and the source attribute as HydroID is shown in Figure 5.3.

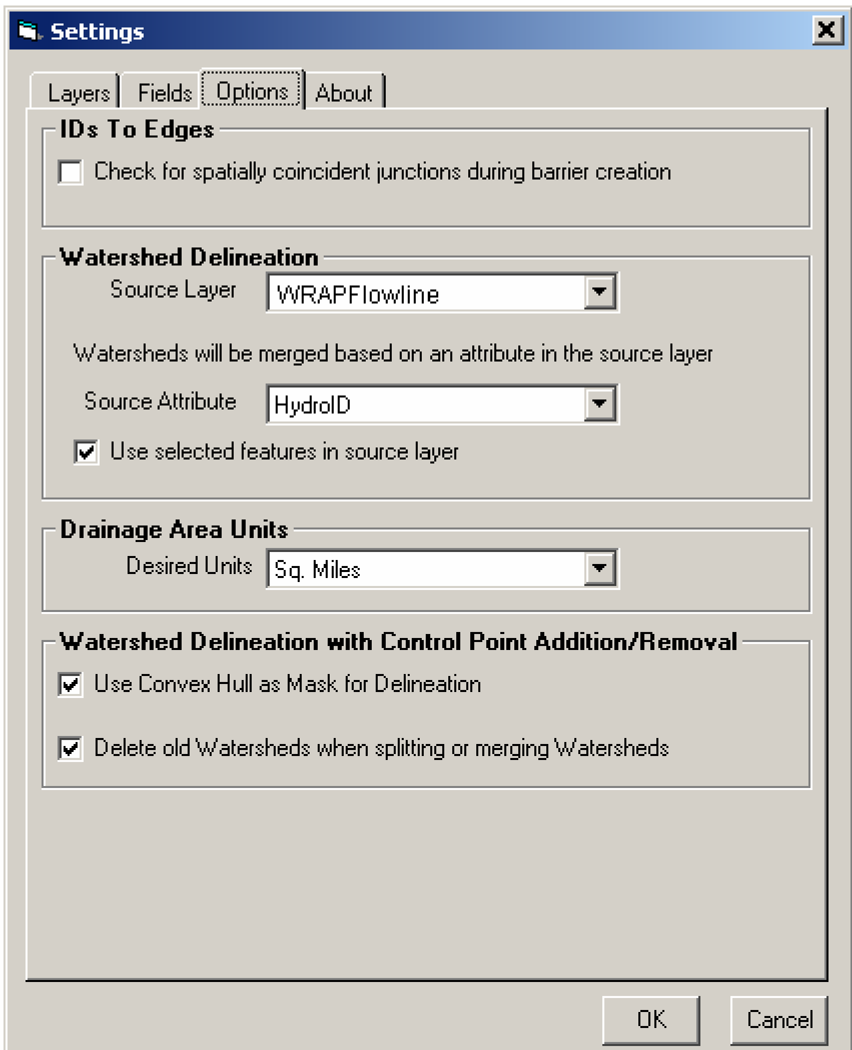


Figure 5.3 Settings window in WRAP Hydro toolset

The drainage areas are then delineated for each segment of the WRAPFlowLine using the advanced tools in the WRAP HYDRO toolset and are called WRAPCatchments. The delineated watershed has a field DrainID which is equal to the HydroID of the Stream to which it drains to. In Figure 5.4 the black texts are the DrainIDs of the Watershed and the Blue ones the HydroIds of the lines they are draining to.

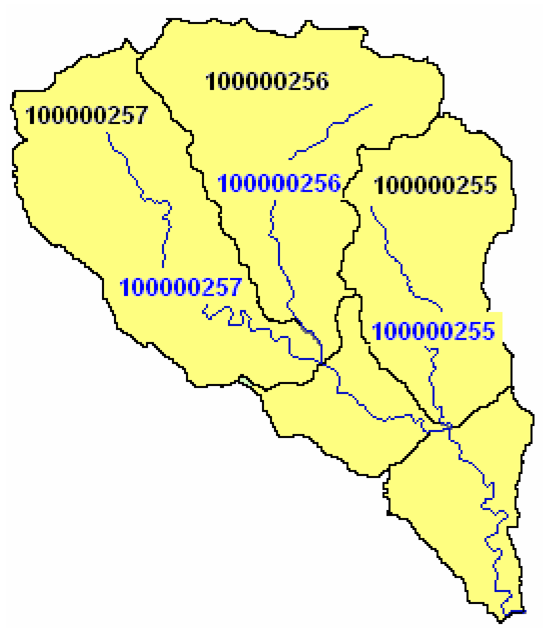


Figure 5.4: Populating DrainIDs of Watershed

Thus there exists a one to one relationship between WRAPFlowline and WRAPCatchment. Hence a relationship WRAPFlowlineHasWRAPCatchment is built. To select all the WRAPCatchments that make up the basin, first all the streams that lie in the basin should be selected. The Watershed class (HUCs without the buffer) is used as reference and all the features in WRAPFlowline that completely lie within this area are selected by location. As it can be seen from Figure 5.5, some stream segments that should be included in the basin are left out and vice versa. The green boxes show the segments that need to be selected and the red boxes show the ones that have to be unselected.

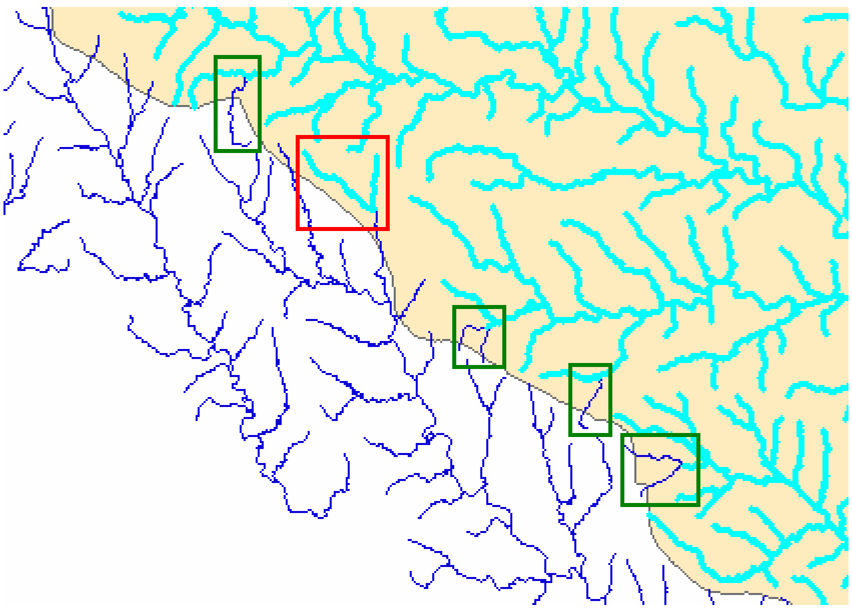


Figure 5.5: Selecting Streams for Processing

Once all the required streams are selected, the related WRAPCatchments can be selected since a relationship exists between them. This is done using the options/related tables tool in the attribute table of the Wrapflowline. The selected catchments are then dissolved using a common attribute (all the records must have the same value for that Field. If such a field does not exist, it is easiest to create one and calculate all its values = 1). Another method of selecting the required streams would be to place a flag at the most downstream location and do a trace upstream task. There is an option in the Utility Network Analyst tool (Analysis / Options) to select the features from the trace rather than just highlight them.

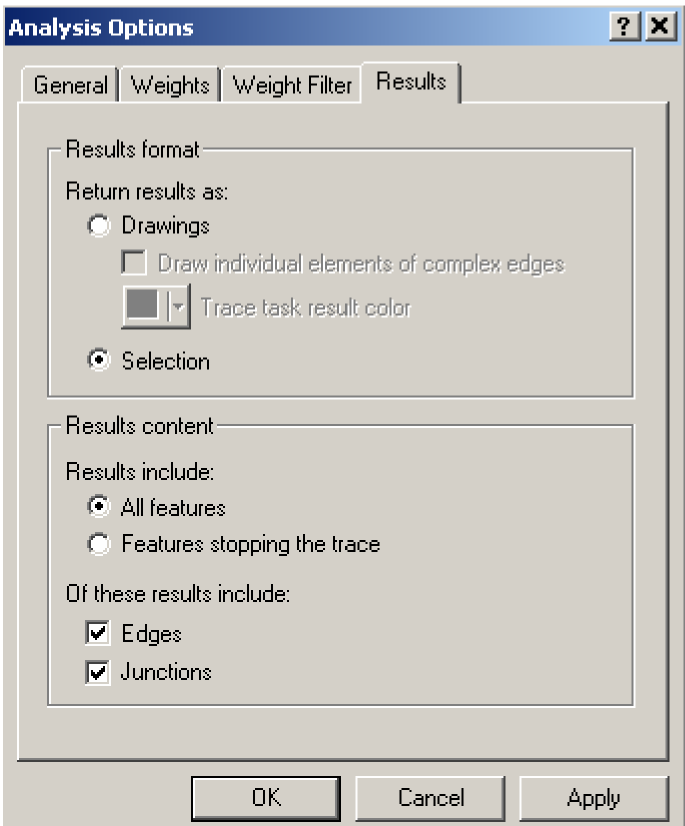


Figure 5.6: Selecting features with Trace Upstream task

However, this also traces the San Antonio River that merges with the Guadalupe just before the outlet of Guadalupe. To avoid the San Antonio being traced, a barrier should be placed just at the location where the San Antonio River merges with the Guadalupe.

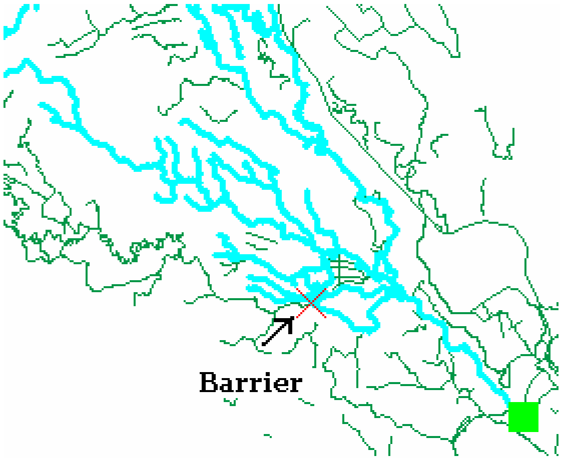


Figure 5.7: Placing a Barrier to restrict tracing

As it can be seen there are edges within the basin that have not been selected by the upstream trace. These are lone or dangling edges that are not connected to the rest of the network. Some issues regarding these dangling edges are discussed at the end of this section.

It is also necessary to consider the surrounding streams when delineating watersheds.

The Figure 5.8 shows the delineated area for the streams with and without considering the surrounding streams.

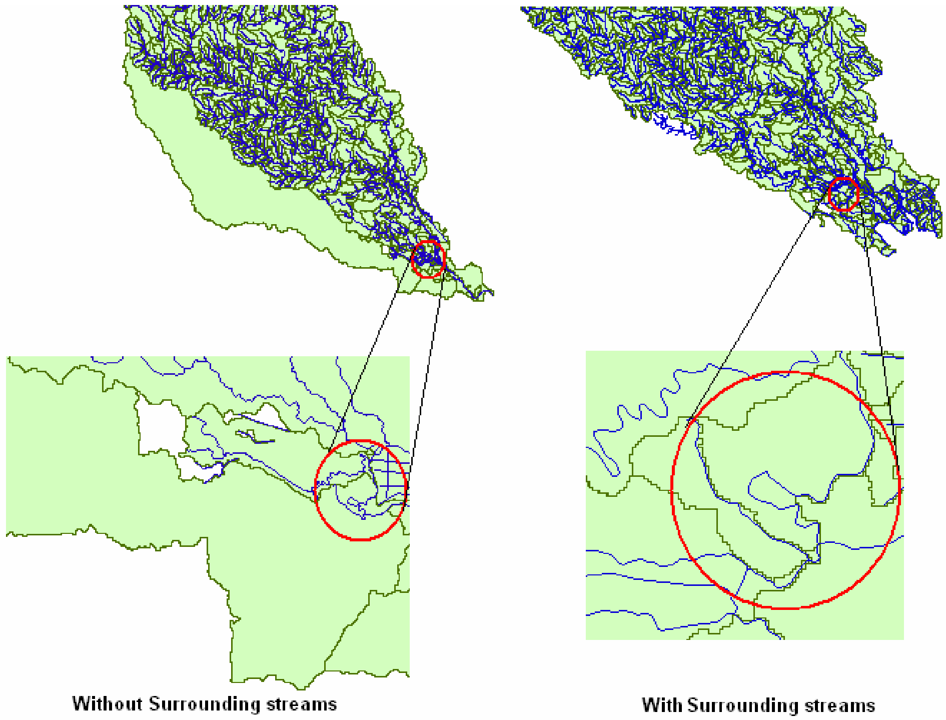


Figure 5.8: Delineation with and without considering Surrounding streams

When the surrounding streams are not used the stream circled red in Figure 5.8 (Without surrounding streams) captures areas that are supposed to flow into the San Antonio River. By considering the surrounding streams, Figure 5.8 (With surrounding streams), the same stream captures only that portion of the basin that lies within the Guadalupe basin.

Another problem that was encountered while delineation was that there were holes created in the delineated watersheds at locations where there were dangling edges.

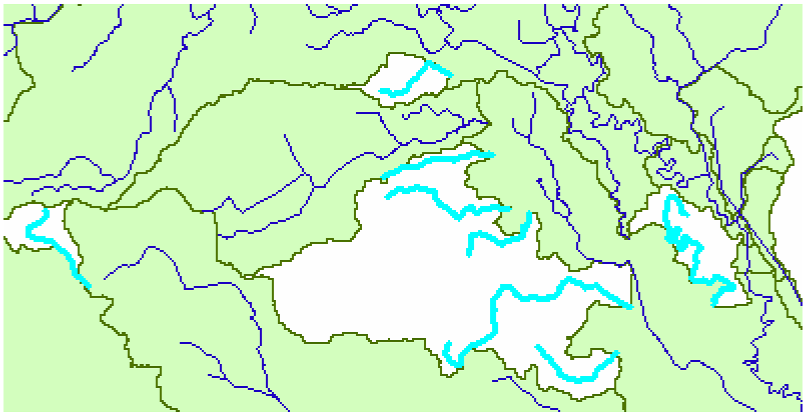


Figure 5.9: Holes Created by Dangling Edges

This was not suitable to define an analysis area since these holes would act as pockets of no data value when processing grids. The best way to deal with this problem is to delete these dangling edges before doing the delineation process. This works well when the dangling edges are in the middle of the basin. But for edges on the outer boundary (circled red), the area that should have been draining into them is left out, thus removing those areas from the analysis mask

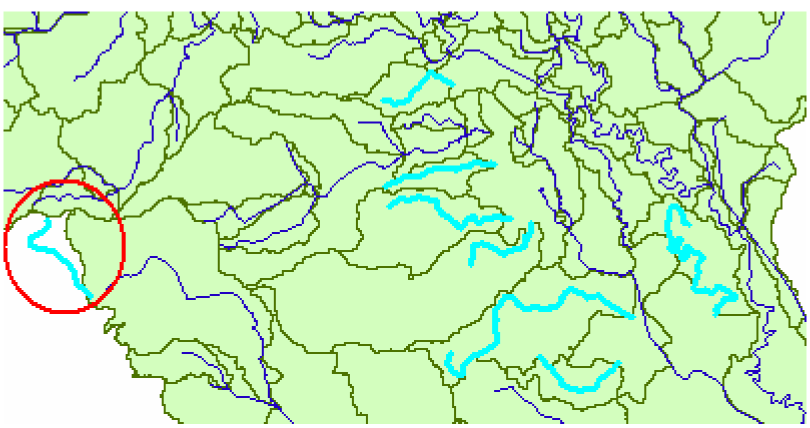


Figure 5.10: Dangling Edge on the boundary of the Basin

To include those areas, all the dangling edges that are on the outer boundary of the basin are selected and exported to a separate file. A network is created using this file and watersheds are delineated in the same way as above using the same flow direction grid. This should delineate a small catchment for each of the edges. These can then be merged with the Basin feature class to obtain the final analysis area.

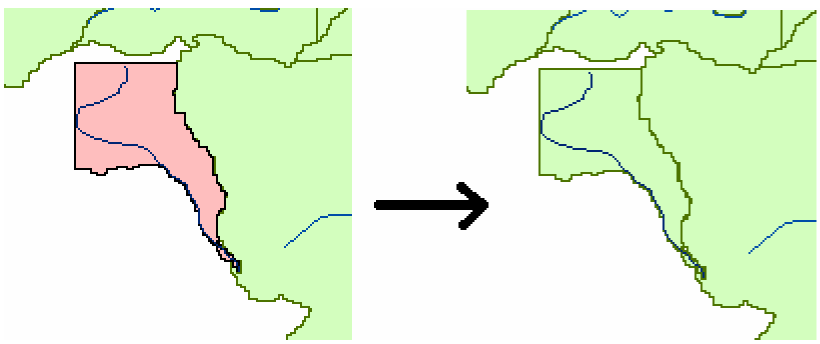


Figure 5.11: Merging Boundary area with the basin

Method II: Using EDNA catchments

Though this method was not used for creating the basin mask for this study, it is a recommended procedure for other basins. Elevation Derivatives for National Application (EDNA), USGS has derived catchments for Guadalupe. The process of catchment derivation is detailed in http://edna.usgs.gov. Figure 5.12 below shows a schematic diagram of the process.

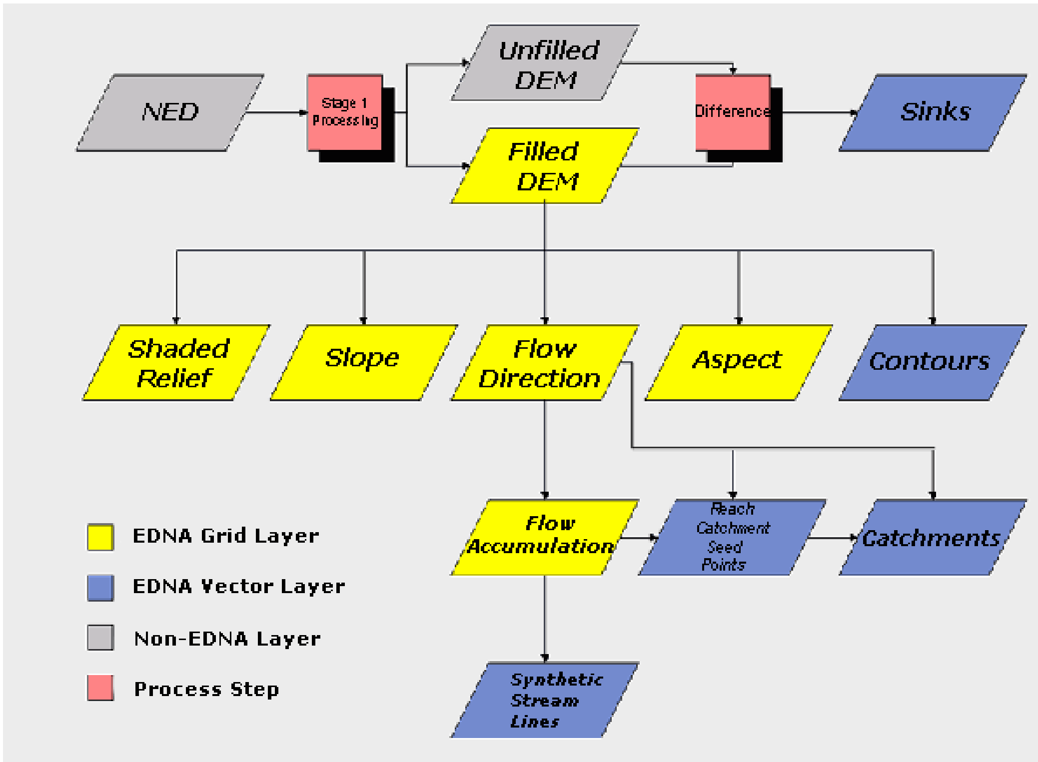


Figure 5.12: Schematic diagram of EDNA process

Courtesy http://edna.usgs.gov/Edna/datalayers/catch.asp

Comparing the EDNA catchments to the ones derived in *Method I* it is seen that the basin boundary matches perfectly except at the downstream end where it is seen that a part of the San Antonio basin joins in at the lower portion of the Guadalupe. This is due to the flat topography in this area of the basin. Also, there is a portion right at the outlet of Guadalupe for which catchments have not been derived by EDNA. EDNA catchments are still in the process of being developed for other basins in region 12. It is recommended to use these catchments to define the basin boundary where the topography is not too flat as in

Guadalupe and the whole area of the basin is included. Again a trace upstream from the most downstream point and the HUC boundaries could be used as references for the selection of catchments.

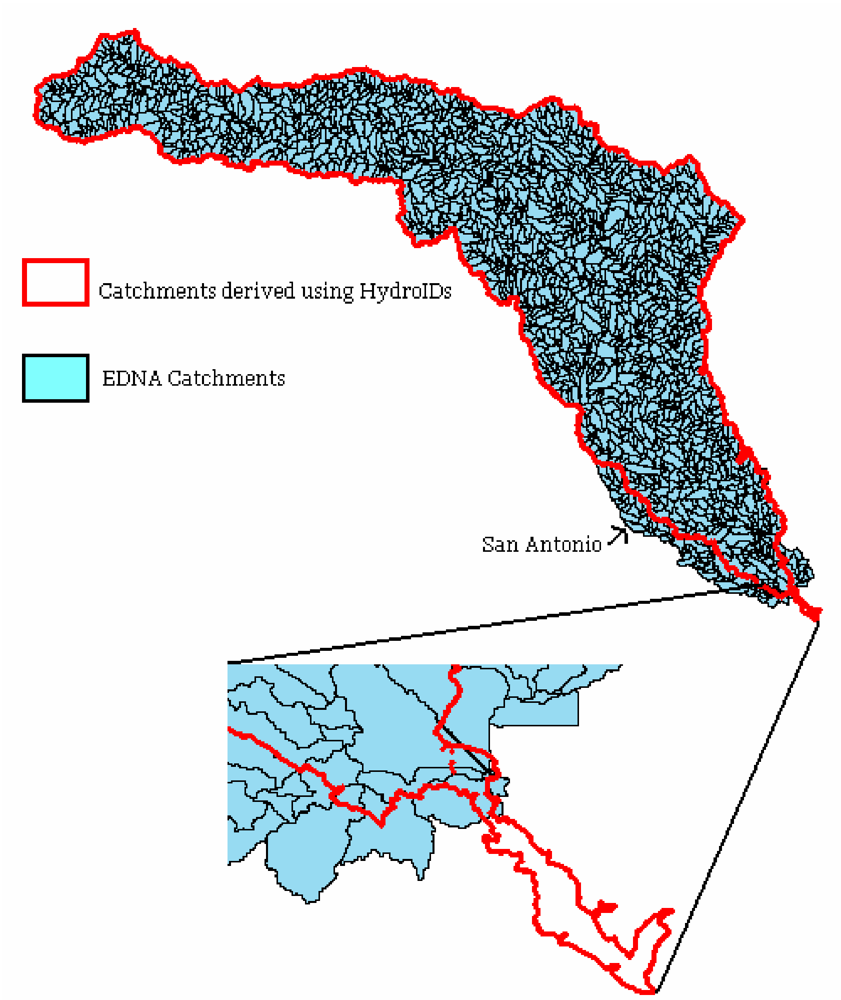


Figure 5.13: Comparison of Catchment Delineation

Another interesting fact that comes out of the EDNA catchments is that it has been developed from the DEM without burning the streams. Hence, if the results are the same without doing the burning process, which takes a considerable amount of time, it can as well be removed from the whole WAM parameter development process. It was necessary to do the burning earlier when the parameter development was done in ArcView3.2 since it made sure that the streams follow the same path as on the map. A DEM derived stream network was created from the original stream which made sure that all the streams passed through centers of cells so that when a control point was snapped to the network it was placed right at the centre of a cell. This ensured good delineation of watersheds for the points.

But now, since the delineation is done to the lines instead of points, the whole process of burning streams to the DEM could be avoided which saves a lot of time during processing.

To verify this hypothesis, the method was repeated without burning streams to the network. Figure 5.14 illustrates this. The blacke boundary is the delineated watershed obtained by burning streams to the DEM and the Red boundary is the watershed obtained by processing the flow direction without burning streams to the network. The Black and red labels are the area of the watersheds in square miles obtained with and without burning streams respectively. The Green circles highlight areas where the difference in delineation is seen. All these areas show that in the case where streams are not burned to the DEM, the cells that flow into the streams are not captured correctly since the area around the stream is not raised sufficiently.

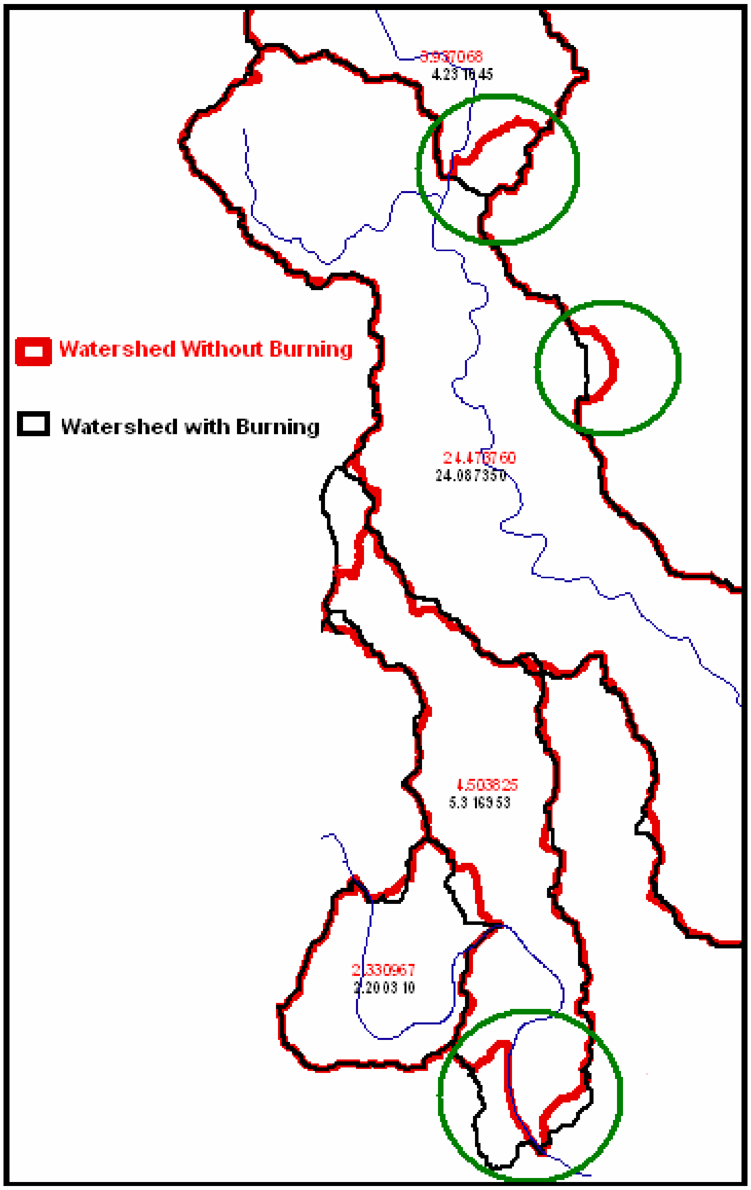


Figure: 5.14: Watersheds obtained with and without burning streams to the DEM

5.3.3. Clipping the Grids

Once the basin boundary is defined, the flow direction grid can be clipped to the required analysis area. A raster mask of the basin is created using the Spatial Analyst extension. A mask is a grid that covers the analysis region and all the cells in the mask have a unit value. For a step by step procedure to clip grids refer Appendix A.

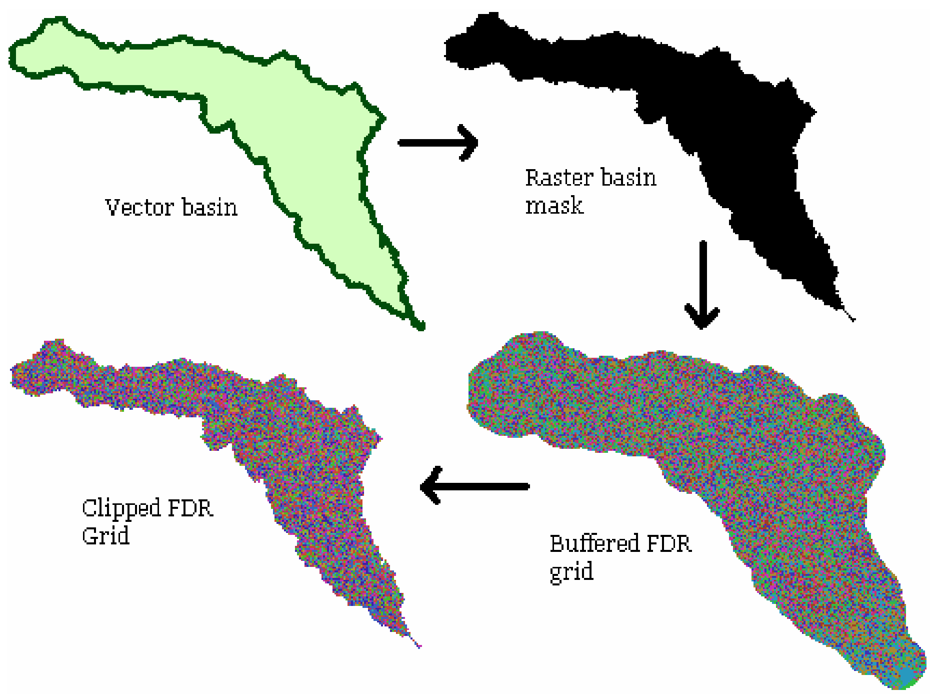


Figure 5.15: Clipping the Flow Direction grid

5.3.4 Snapping Control Points

Some Control Points may be at a considerable distance from their actual location. The BaseControlPoint feature class is exported to SnapControlPoint feature class in the PreProcess feature dataset. A new text field called WRAPCode is added to SnapControlPoint and the values of WRAPID is copied to it. The locations of the control points are corrected so that they lie within a distance of 25m from the stream segment to which they have to be snapped. The old network is deleted and a new network is built using WRAPFlowline and SnapControlPoint as a complex network. Further processing is described in Section 6.2.

Chapter 6 : Methodology – Finding Watershed Parameters

6.1. IMPORTING DATA

After the base data are prepared and the preprocessing is done for the data as discussed in Chapter 4, it is ready for parameter development. The main process of determining the watershed parameters is done in the WRAPHydro feature dataset. The names of the feature classes in this dataset are prefixed with a WRAP instead of Hydro in the ArcHydro dataset. This is done to show that all the WRAPHydro features support the WRAP model. The WRAPEdge feature class contains all the edges that lie within the basin mask. This is obtained by selecting and exporting all the WRAPFlowLine features that completely lie within the Basin. The BaseControlPoint features are exported to the ControlPoint feature class.

6.2 BUILDING THE NETWORK

As discussed in Section 5.3.4, a geometric network is built using SnapControlPoint and WRAPFlowline as a complex edge. A snapping tolerance of 25 m is given. There are two possibilities that a point is not connected to the network. One, if the point is more than 25 m away from the Edge, it would not have snapped to the network and the second if it has coincident points. For the first case the points can be identified by placing a flag at the outlet and tracing upstream. All the edges and junctions, including the coincident junctions will be traced. Those points that are not snapped to the network can be identified as seen in Figure 6.1.

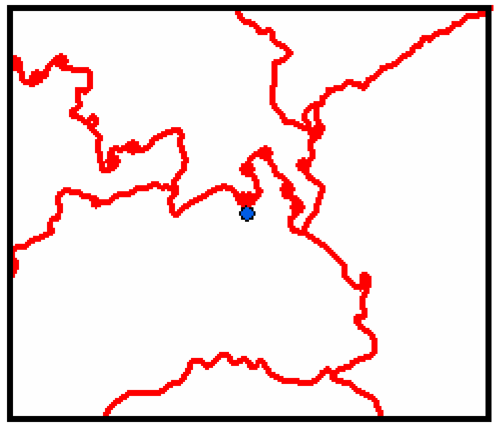


Figure 6.1: Junctions not on the Network

To identify coincident points, a flag is placed at the outlet and a trace upstream function is performed as in the first case but with the difference that the options of the trace is changed to selection. This means that all the features that are being traced will be selected rather than being highlighted. Only one point at a location will be actually connected to the network. Figure 6.2 shows the details of three control points that are coincident and Figure 6.3 shows the attribute table that shows the points in ascending order of their WRAPCodes, that are selected by the trace upstream task. As it can be seen only Control Point with WRAPCode 61802439001 is selected and not the other two. Hence all the control points that are not selected (as seen in the attribute table) are multiple points on a location.

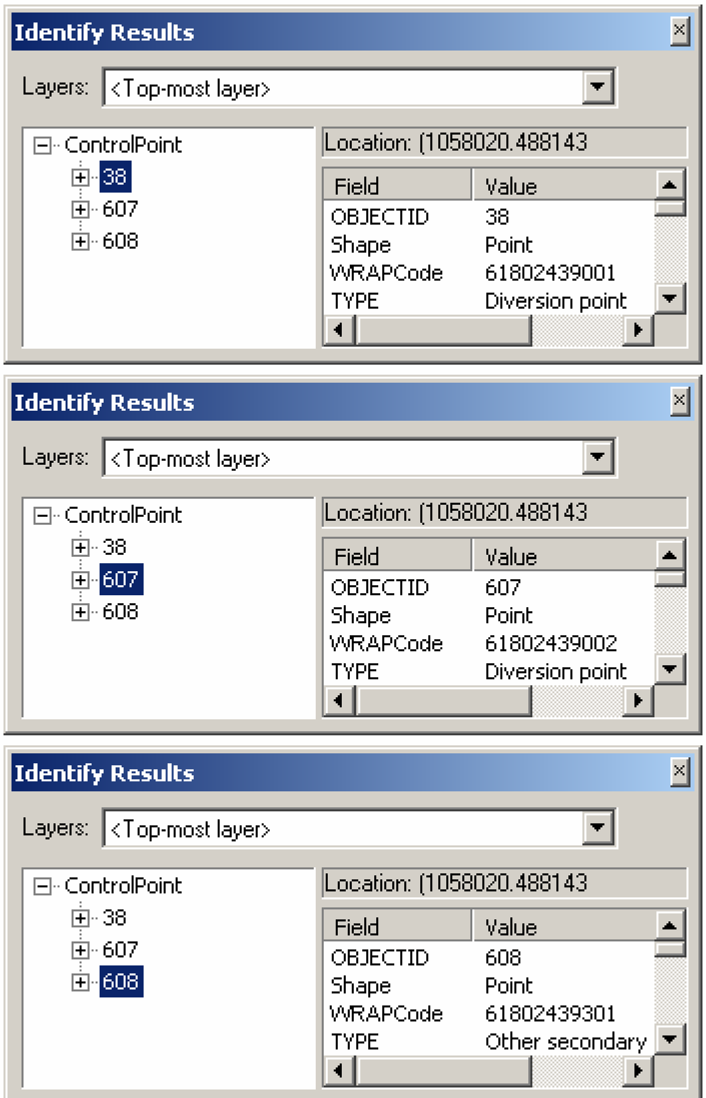


Figure 6.2: Identify window for three coincident control points

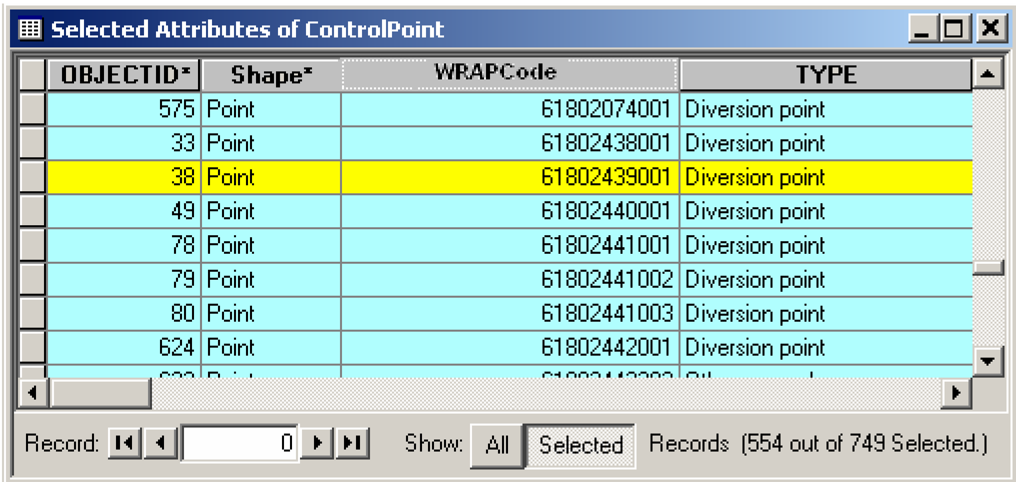


Figure 6.3: Attribute table of ControlPoint showing features selected by the trace upstream task

All the selected points are exported to another feature class WRAPJunction. The old network is deleted and a new network WRAPNetwork is created using the WRAPEdge and WRAPJunction. This network is built with WRAPEdge as a simple edge feature and with a 25 m snapping distance. Once the network is built the flow directions are assigned to the network using the FlowDir attributes in WRAPEdge.

6.3 LOADING JUNCTIONS

The WRAPEdge is built as a simple feature so that the edges can be split at points where the WRAPJunctions are located. When the network is built and opened in ArcMap, it can be seen that some of the edges run past more than one junctions. So, when the watersheds are delineated to lines, it is going to delineate a single watershed for all the junctions that lie on the edge. To avoid this problem the edges need to be split at points where junctions are located. Figure 6.4 shows the difference in delineation when the edges are split and when they are not. This is done using the Load Objects. This process is detailed in Appendix B

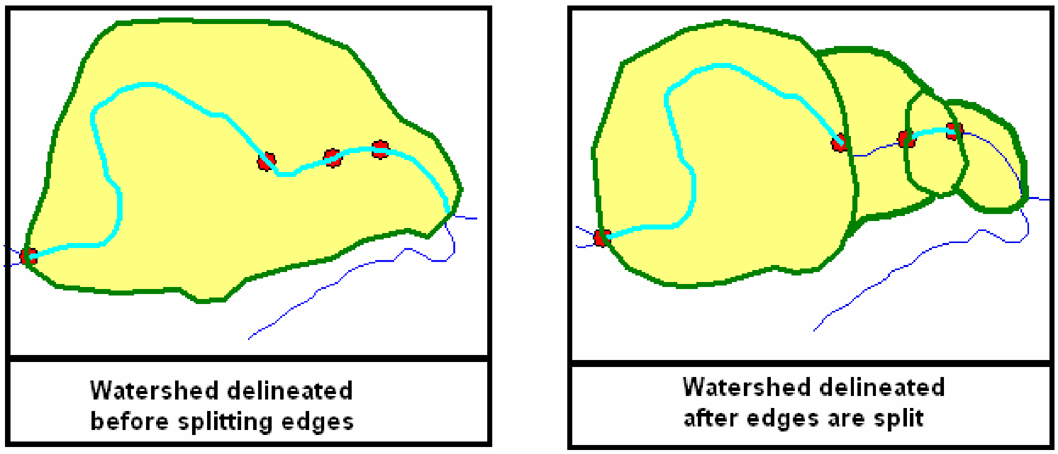


Figure 6.4: Watersheds delineated by splitting edges

6.4 HYDROID ASSIGNMENT

The first step in determining watershed parameters is to assign a unique identifier for each record in all the feature classes that are used. In WRAP Hydro, each HydroJunction is identified by its HydroID rather than the TCEQ supplied control point ID. A numbering convention is used to assign HydroIDs using the APUtilities tool as discussed in section 3.3.4. It is suggested to follow the same numbering convention for all the basins to standardadize this procedure. Depending on whether the basin is processed as a single unit or in parts, the HydroID assignment would differ accordingly. Chapter 7 discusses about assigning HydroIDs for the four sub basins for the Guadalupe. In this chapter the parameter development is done with Guadalupe as a single entity. To assign HydroIDs to the WRAPNetwork, the LayerKey for the WRAPJunction is set to 1 and the WRAPEdge to 2. The initial HydroID value for LayerKey 1 is set to 100000000 and LayerKey 2 to 200000000. Thus all the features in WRAPJunction will have a nine digit HydroID starting with a 1 and the WRAPJunction will have a HydroID of the same length but starting with a 2. The Guadalupe basin has 558 junctions and 3419 edges. So the HydroIDs of the WRAPJunction will vary from 100000000 to 100000558 and that for the WRAPEdge will vary from 200000000 to 200003419. The data is now ready for parameter development.

6.5 WRAP INPUT PARAMETERS

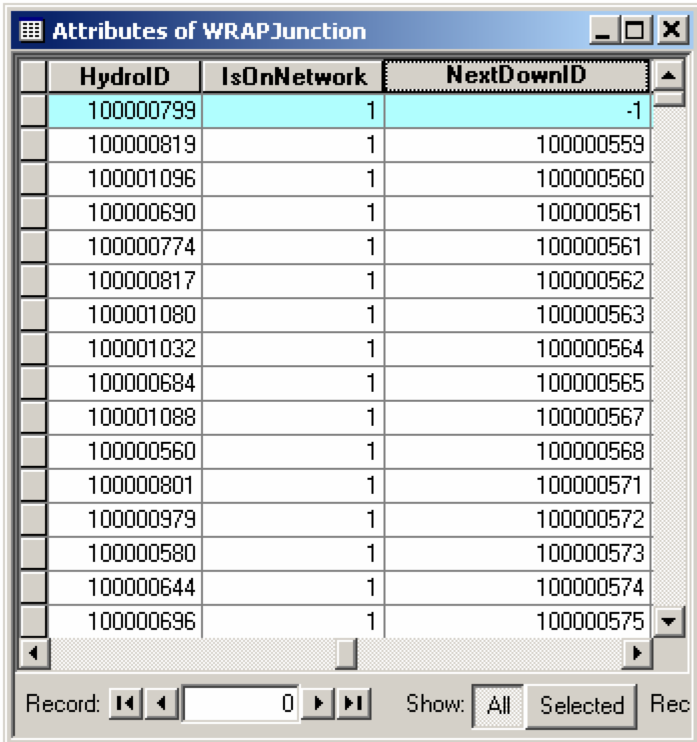
The WRAP model is a Fortran program that takes in input files that contain data regarding the river basin hydrology and produces output tables that show the amount of water released at each control point on a monthly basis and the time for which this amount of water is available. The parameters developed in the GIS environment for the WRAP input files are:

- Next downstream control point
- Distance of each control point to basin outlet
- Average upstream Area for each control point
- Average Curve Number for each control point
- Average annual Precipitation for each control point

6.5.1 Next Downstream Control Point

This parameter is populated in the NextDownID field in the HydroJunction feature class. It shows the connectivity of the control point, indicating which point is next downstream of another. For any Junction, The Find

Next Downstream Junction tool in the ArcHydro toolset assigns the HydroID of the next downstream junction to the NextDownID of that junction. Any junction that does not have a junction downstream of it will be assigned a value -1. Thus, the outlet of the basin will always have a NextDownID value = -1 (Figure 6.5). If any other junction other than the outlet has a -1 value, it means that the junction is not a part of the network. Thus, this tool also serves as a check to validate the location of all the control points on the network. Figure 6.6 shows the WRAPJunctions labeled with their HydroIDs and NextDownIDs. As seen from the Figure, the junctions 100000597, 100000598 and 100000602 have their NextDownID as 100000603 and 100000602 is downstream of 100000601.



Attributes of WRAPJunction

HydroID	IsOnNetwork	NextDownID
100000799	1	-1
100000819	1	100000559
100001096	1	100000560
100000690	1	100000561
100000774	1	100000561
100000817	1	100000562
100001080	1	100000563
100001032	1	100000564
100000684	1	100000565
100001088	1	100000567
100000560	1	100000568
100000801	1	100000571
100000979	1	100000572
100000580	1	100000573
100000644	1	100000574
100000696	1	100000575

Record: 0 Show: All Selected Rec

Figure 6.5: Attribute table showing NextDownID for WRAPJunction

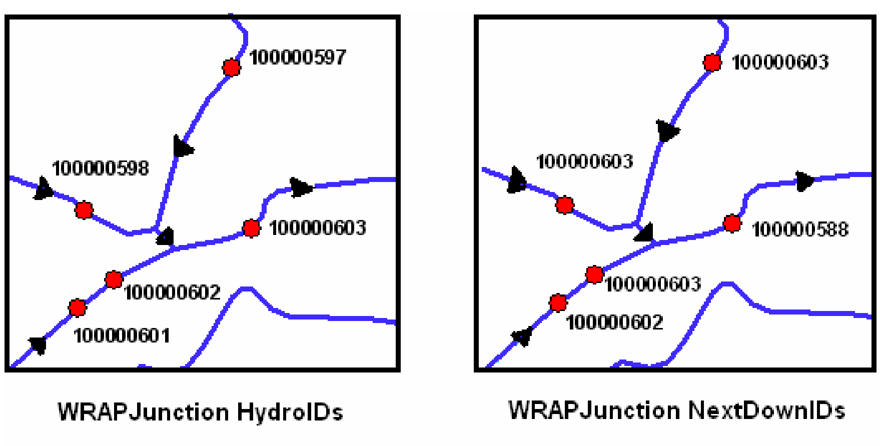


Figure 6.6 HydroIDs and NextDownIDs for WRAPJunction

Sometimes this tool doesn't work if there are loops in the network and if the flow direction assignment is wrong, the flow keeps returning to the same junction. Figure 6.7 illustrates this problem. The edge with flow direction highlighted in green causes the flow to go back into the loop and hence the junction 100000795 will always have itself for its next downstream ID. Since this flow direction assignment does not make sense, it is fixed by just changing the direction of flow of the highlighted stream segment.

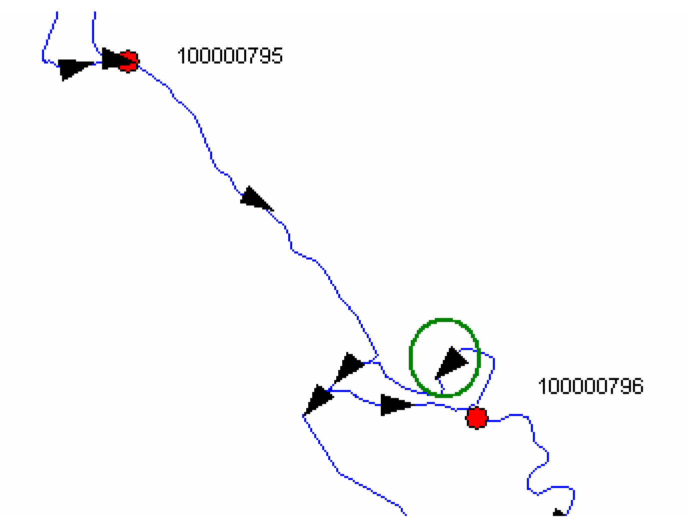


Figure 6.7: Loops in the Network

There might also be a very small edge that originates from a junction and ends on the same junction. ArcGIS 8.3 has tools to correct these connectivity problems. Appendix C shows ways to fix these connectivity problems Also, Sometimes there are edges created which have a Shape_Length = 0. These edges may create problems when running the Next Downstream tool. The best way to deal with this problem is to check if there are any such edges before running the tool and delete them. Since they have no length, deleting them will not create any problems in the network.

6.5.2 Length to outlet

This parameter is populated in the LengthDown field in the WRAPJunction feature class. The Calculate Length Downstream for Junctions tool in the ArcHydro toolset is used to find the distance of each WRAPJunction from the outlet. It calculates the length by adding up the lengths of all the WRAPEdges that are downstream of it. The Shape_Length field in WRAPEdge is used to specify the length of each edge in meters. The value obtained after running the tool is therefore in meters. The LengthDown values are converted to Kilometers by dividing itself by 1000. Similarly a new field is added to the WRAPEdge feature class called Length_KM and the Shape_Length values are converted to Kilometers and populated in the Length_KM field. This makes the value more readable considering that at the upstream value in meters is going to add up to huge numbers. To display the values of downstream length for WRAPJunctions and Shape_Length for WRAPEdge in a less congested format, the number of decimals is reduced to two. Figure 6.8 shows the value of Length Down for three WRAPJunctions. The blue labels are the shape_length values of each stream segment and the red labels are the length downstream calculated for the Junctions. The stream segments can be identified by the black line divisions as seen in the Figure. As it can be seen, each of the downstream WRAPEdge shape_length values adds up to the value of LengthDown for each of the junctions. The outlet has a LengthDown value = 0 since there are no edges beyond the outlet.

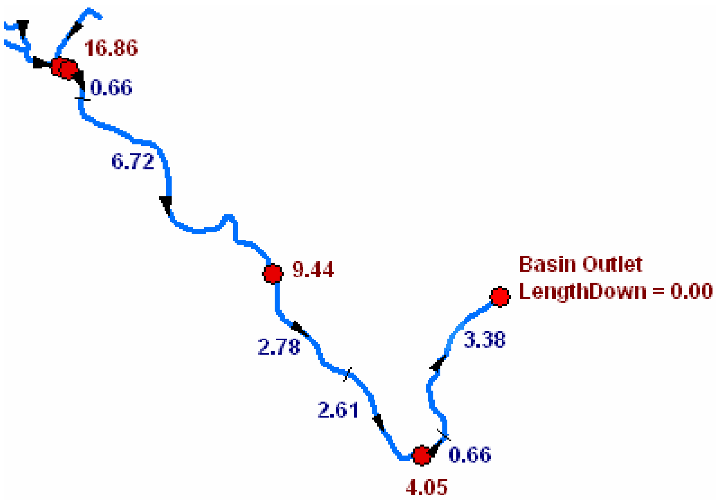


Figure 6.8 Length Downstream Assignment

Length down in Kilometers has to be multiplied by 0.6213 to get the length downstream in miles. As seen from Figure 6.9, the most upstream junction is at a distance of 437 miles from the outlet. The two intermediate junctions are 296 miles and 125 miles from the outlet. And the outlet junction shows a value zero miles.

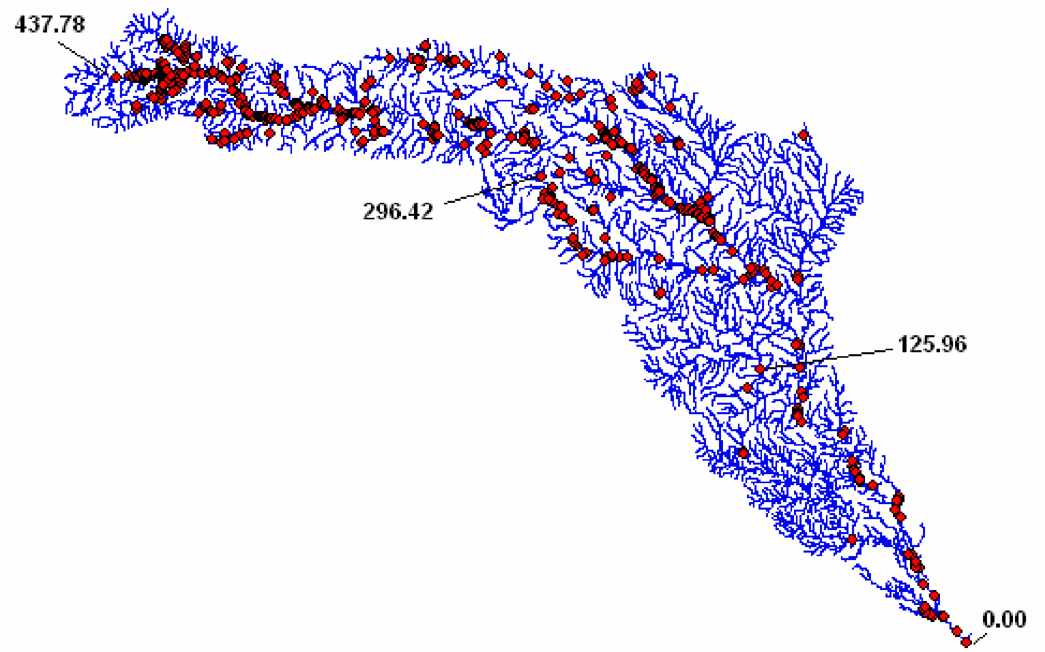


Figure 6.9: Length Downstream in miles

6.5.3 Upstream Area Delineation

To find the total area that drains into each control point, incremental watersheds are delineated for each junction and their value is accumulated downstream. The delineation process is done using the WRAP HYDRO toolset. The feature classes and grid names are specified in the layer tab in settings as shown in Figure 6.10, default fields are used in the fields tab and the WRAPedge is specified as the source layer for delineation with JunctionID as source attribute in the options tab.

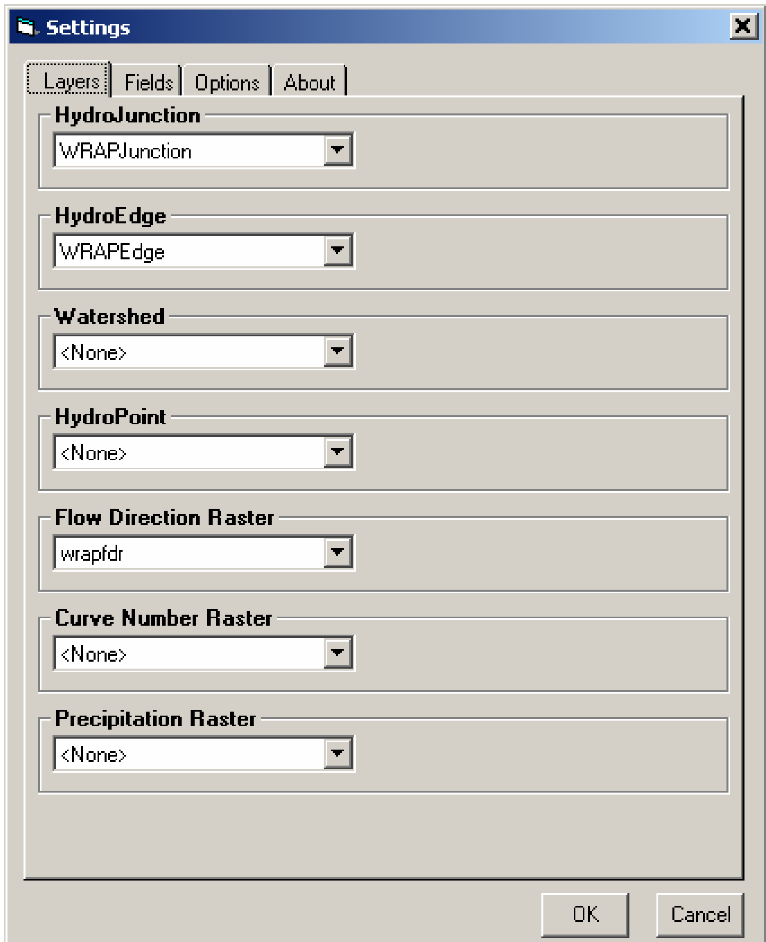


Figure 6.10: Settings tab for WRAPWatershed Delineation

The Ids to edges tool in the WRAPHydro toolset is used to populate the JunctionID field in WRAPEdge with the HydroID of the next downstream junction. Thus, all the Edges between two junctions will have the same JunctionID (which is the HydroID of the downstream junction). In Figure 6.11, the edges with JunctionIDs100000807 both have the same junction (HydroID 100000807) as the next downstream junction. Similarly the edge downstream of junction with HydroID 100000807 and upstream of junction with HydroID

100000892 is given a JunctionID value equal to its downstream junction i.e.100000892.

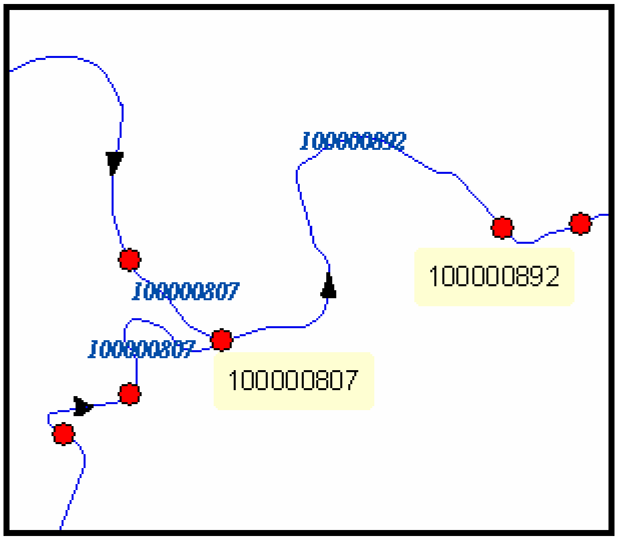


Figure 6.11: JunctionID assignment in WRAPEdge

Once all the JunctionIDs are populated, the Delineate Watersheds tool in the WRAPHydro toolset is used to delineate watersheds for each junction. The watersheds are delineated using the wrapfdr flow direction grid to the Edges and the feature class is called WRAPWatershed. For each value of JunctionID of the edges, a watershed is created. Thus, a watershed is created for each Junction, since all the edges between two junctions have the same JunctionIDs. The DrainID field in the WRAPWatershed is populated with the JunctionID value of the Edges it is draining to. Thus in Figure 6.12, the HydroIds of the WRAPJunction (red) are populated to the JunctionIDs of the WRAPEdge (Blue), which are in turn populated to the DrainIDs of the Watershed (Green).

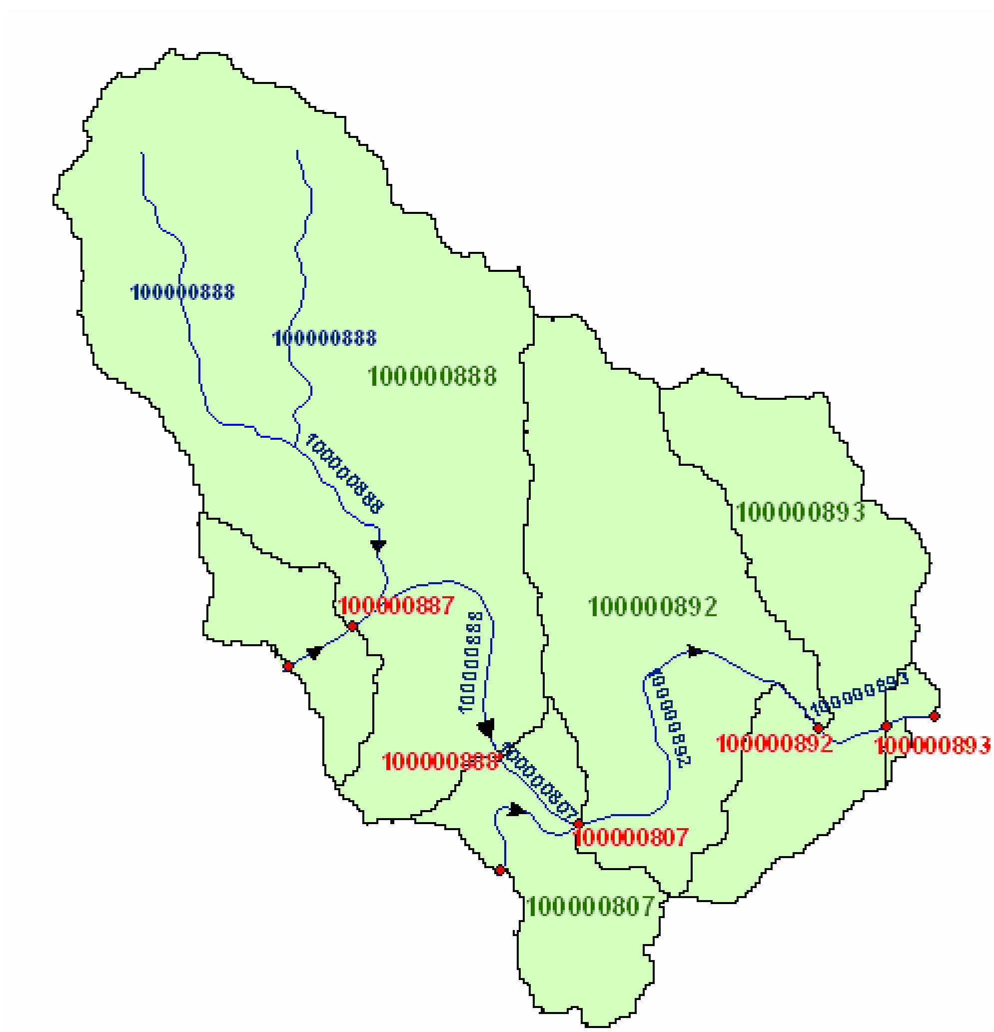


Figure 6.12: DrainID assignment in WRAPWatershed

6.5.4 WRAPJunction connectivity

The Node\Link Schema generation tool in the Arc Hydro toolset is used to generate a feature class that shows the connectivity between the WRAPJunctions. The NextDownID field has to be populated before running this tool. The tool takes the WRAPWatershed and WRAPJunctions as input and creates two feature classes, WRAPLink and WRAPNode. The WRAPLink is a line feature class that shows the connectivity of a WRAPJunction to the one downstream of it. The WRAPNode is the basically the WRAPJunctions which act as nodes for the lines connecting two Junctions

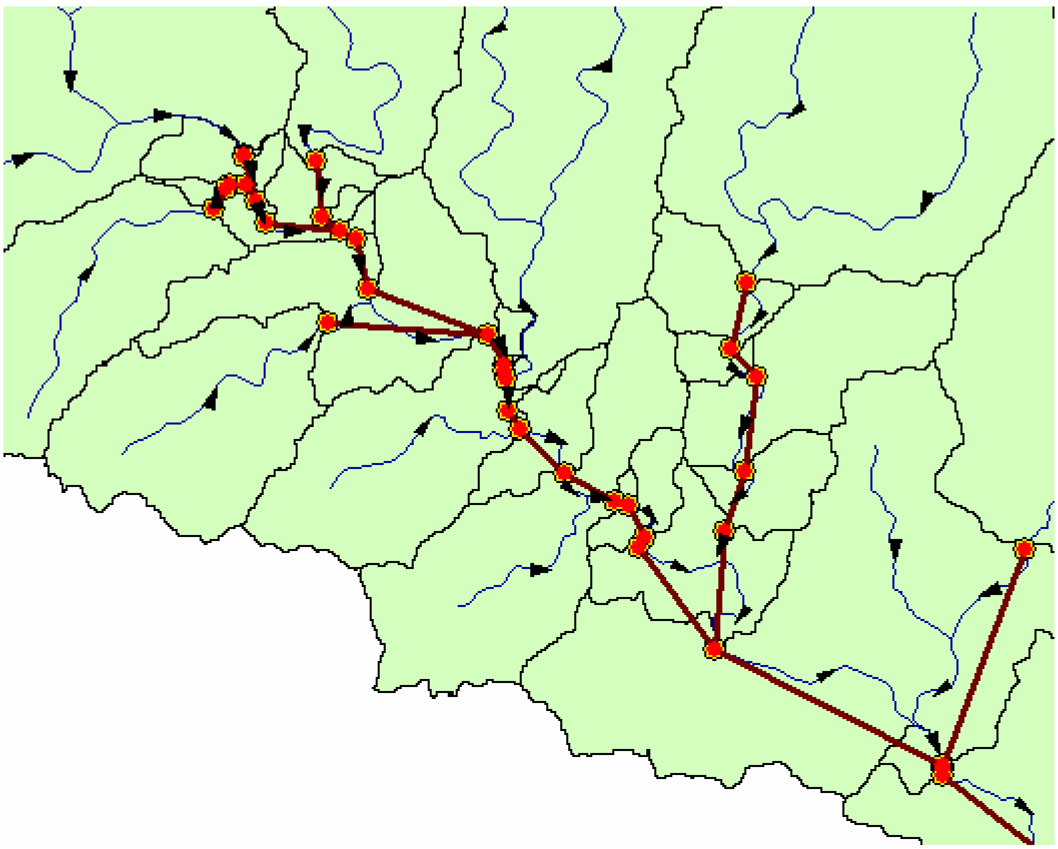


Figure 6.13: WRAPLink feature class showing connectivity between WRAPJunctions

6.5.5 Watershed Drain Area, Average Curve Number and Average precipitation

These values are populated in the DrainArea, AvgCN and AvgPR fields in the WRAPWatershed feature. The Average value of Curve Number and Annual

Precipitation for each Watershed is the mean of all the cell values within that area. Figure 6.14 shows the values populated for one of the delineated watershed. that the drain area of watershed has been populated with the shape area of the watershed with a conversion factor to convert the area in square meters to area in square miles (547.7 miles) and the average value of all the cells in the curve number and precipitation grids within the watershed have been populated to the AvgCN (64.91) and AvgPR (33.08 mm) fields in the WRAPWatershed.

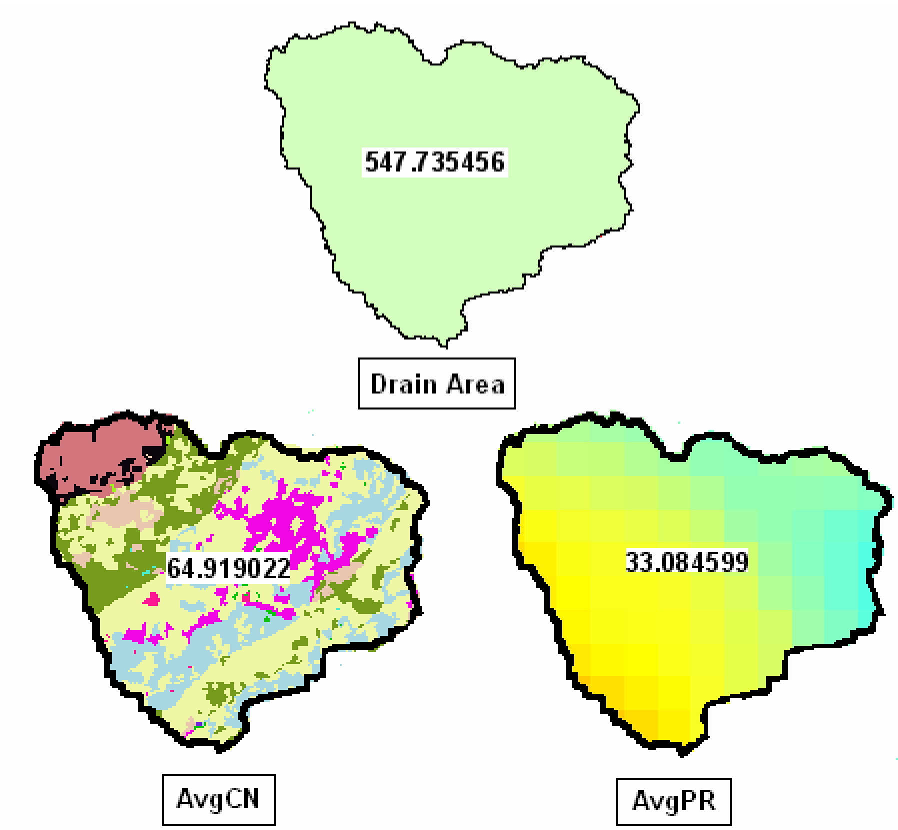


Figure 6.14 DrainArea, AvgCN and AvgPR populated in WRAPWatershed

6.5.6 Consolidating Attributes

Once the incremental values for the drain area, curve number and annual precipitation have been determined for each feature in WRAPWatershed, these values are consolidated to add in the effects of all the area that is upstream of each junction. This is done using the 'Accumulate CN, Precip and Area' tool in the WRAPHydro toolset. The drain area values are added downstream and are stored in the Drain_Area field in the WRAPJunction. The curve number and precipitation values are populated in the AvgCN and AvgPR fields in the WRAPJunction by taking a weighted average of the respective values over each watershed.

This process is illustrated in Figures 6.15 and 6.16. Figure 6.15 shows three WRAPJunctions with HydroIDs 100000897, 100000898 and 100000994. For convenience they will be referred to as Junctions 897, 898 and 994 respectively. Similarly the WRAPWatersheds with respective DrainIDs will be referred to as watersheds 897,898 and 994. As it can be seen, junctions 994 and 897 are both upstream of junction 898. Thus, the effects of watersheds 994 and 897 will be seen in watershed 898. Figure 6.16 shows the attribute table for WRAPWatershed and WRAPJunction for the three junctions. The DrainArea value of junctions 994 and 897 will remain the same as that of their respective watersheds since the only area that drains into them is from their own watershed. But the DrainArea of junction 898 will be the accumulated area of all the three watersheds, i.e. 2.47 + 3.49 + 17.34 = 23.03. The average weighted curve number for the junction 898 is calculated by dividing the sum of the product of all the incremental curve number values with the respective incremental area by the total upstream area for that junction.

$$AvgCN_{898} = \frac{(71.64 \times 2.47) + (69.02 \times 17.34) + (65.01 \times 3.49)}{23.3} = 68.70$$

Similarly the average weighted precipitation for junction is calculated by:

$$AvgPR_{898} = \frac{(32.20 \times 2.47) + (32.53 \times 17.34) + (32.66 \times 3.49)}{23.3} = 32.51$$

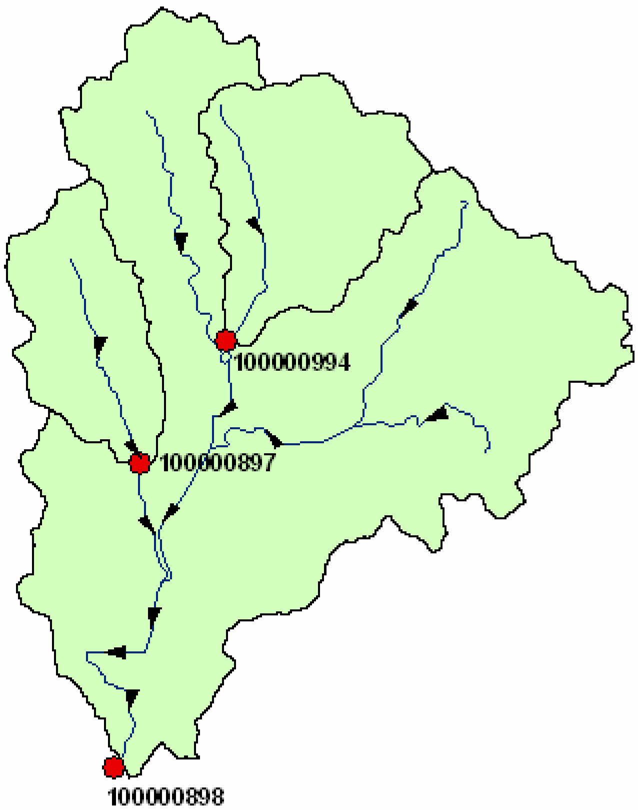
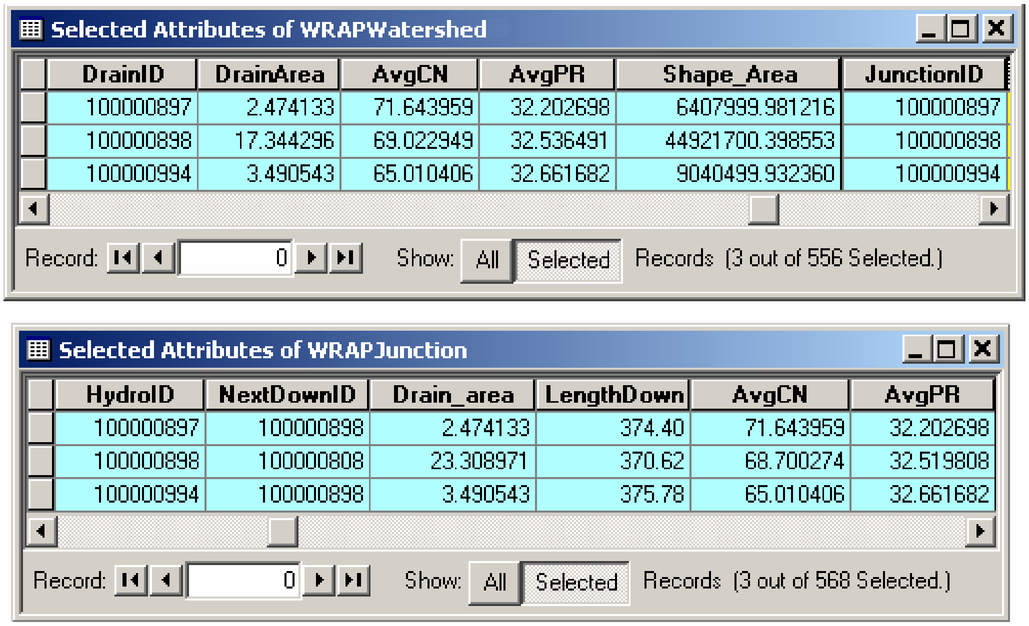


Figure 6.15: Illustration showing three WRAPJunctions whose values are accumulated downstream



Selected Attributes of WRAPWatershed

DrainID	DrainArea	AvgCN	AvgPR	Shape_Area	JunctionID
100000897	2.474133	71.643959	32.202698	6407999.981216	100000897
100000898	17.344296	69.022949	32.536491	44921700.398553	100000898
100000994	3.490543	65.010406	32.661682	9040499.932360	100000994

Record: 0 Show: All Selected Records (3 out of 556 Selected.)

Selected Attributes of WRAPJunction

HydroID	NextDownID	Drain_area	LengthDown	AvgCN	AvgPR
100000897	100000898	2.474133	374.40	71.643959	32.202698
100000898	100000808	23.308971	370.62	68.700274	32.519808
100000994	100000898	3.490543	375.78	65.010406	32.661682

Record: 0 Show: All Selected Records (3 out of 568 Selected.)

Figure 6.16: Attribute tables showing incremental values in WRAPWatershed and Accumulated values in WRAPJunction

6.6 COPYING ATTRIBUTES FROM WRAPJUNCTIONS TO CONTROLPOINT

The last step in parameter development is to copy the attributes from WRAPJunction to all the points including the coincident ones in the Control Points feature class. The 'CP tools' in the WRAPHydro toolset is used. The Settings form is used to specify layers, fields, and processing options to be used by various functions in the WRAPHydro toolset. The 'Ids to Control Point tool' populates the HydroID of the WRAPJunction to the JunctionID of the ControlPoint point based on spatial location. Thus JunctionIDs are calculated only for coincident features. Since in the ControlPoint feature class, the features have not been snapped to the network to retain their location as given by the TCEQ, the

SnapControlPoint feature class in the Preprocess feature dataset is used for intermediate calculations. The SnapControlPoint is specified as the ControlPoint file in the settings and a JunctionID field is added to it. This is shown in Figure Figure 6.17. The HydroIDs of the WRAPJunction are populated to the JunctionID field of all SnapControlPoint features using the “Ids to control points’ tool.

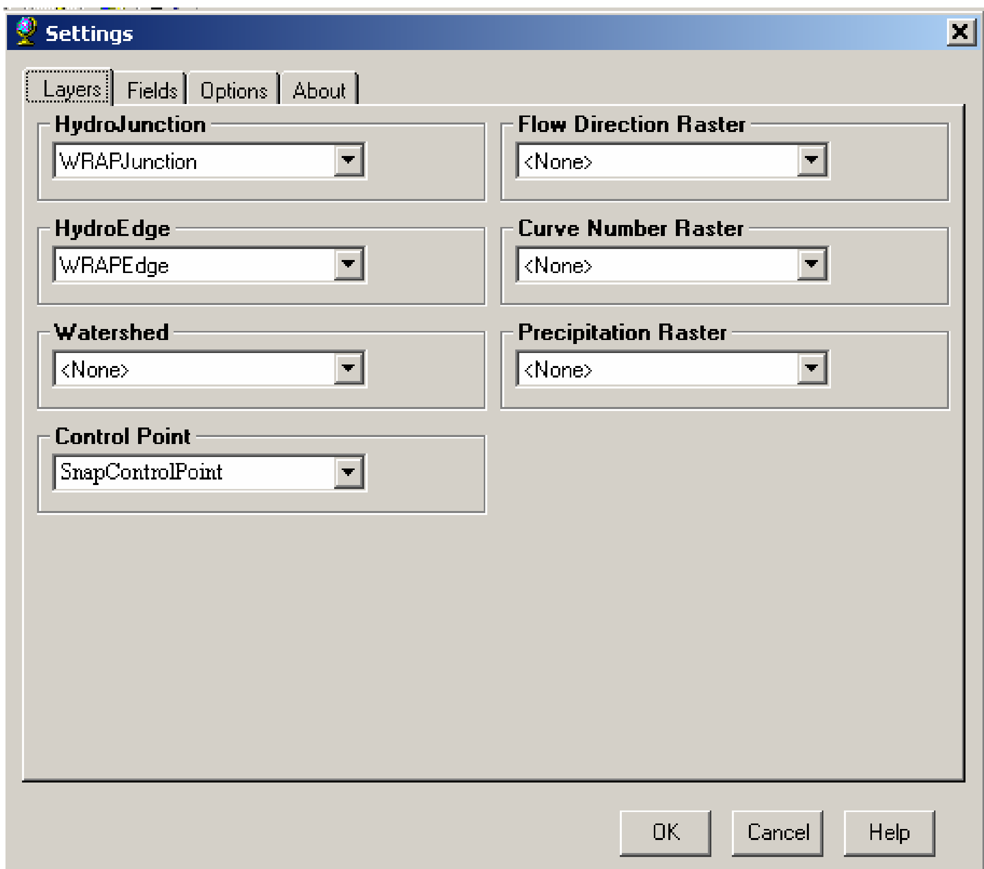


Figure 6.17: Layer settings for populating JunctionIDs to SnapControlPoint feature class

The SnapControlPoint attribute table is joined with ControlPoint attribute table with WRAPCode as the common field. The values of JunctionIds of

SnapControlPoint feature class are copied to JunctionIds of ControlPoint feature class

Thus there now exists a one to many relationship between WRAPJunction and Control Point. The 'Params to Control Points tool' is used to copy the attributes to Control Point. For each match of HydroID in WRAPJunction with JunctionID in Control Point, the respective attributes for LengthDown, Drain_Area, AvgCN and AvgPR values are copied as it is. The settings for Control Points are shown in Figure 6.18.

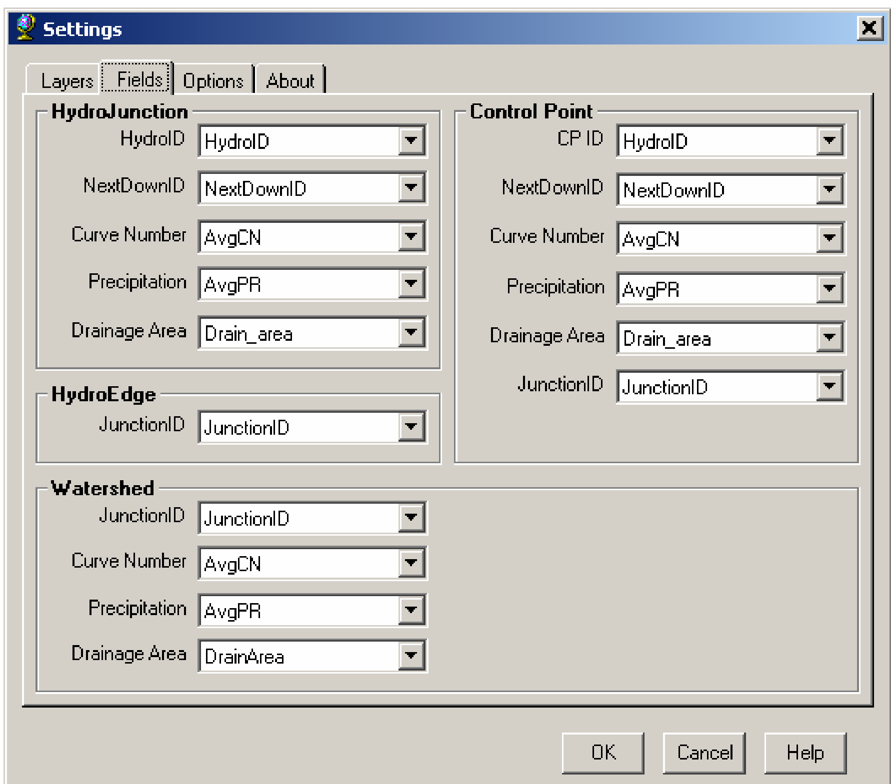


Figure 6.18: Layer Settings for populating parameters to ControlPoint feature class

The connectivity of Control Points should specify which WRAPCode is next downstream instead of NextDownID, which is the HydroID of the next downstream junction. So, the NextDownCP is populated using the HydroID – JunctionID relation between the two feature classes.

Chapter 7: Regionalization

7.1 Subdividing the Basins

When working with huge basins like the Red, Canadian, Colorado, Brazos, Trinity and Rio Grande, the computer processor might not be able to handle the large datasets, especially the raster processing part. This is dealt with by dividing the basin into sub regions and processing grids individually for each region. The results from each sub basin are merged on the vector side for determining parameters. Though the Guadalupe is not a very large basin and could be worked on without subdivision, this exercise is performed to verify the validity of dividing a basin for processing without compromising on the accuracy of the parameter values determined. This is also helpful when new edits have to be incorporated after all the parameter processing is done.

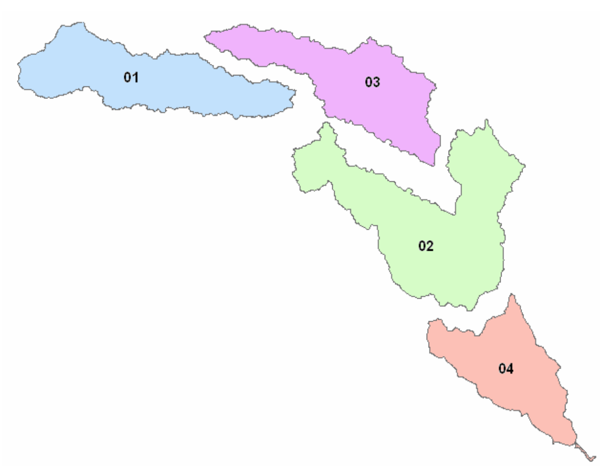


Figure 7.1 Dividing Guadalupe to process in parts

7.2 REGIONAL WRAPHYDRO STRUCTURE

Figure 7.2 shows the WRAP Hydro model structure for regional analysis. When dealing with sub basins, four in case of Guadalupe, the main Guadalupe folder has four folders one each for a region. Each region has a 'grids' folder and a 'WRAPHydro' geodatabase suffixed by the region number.

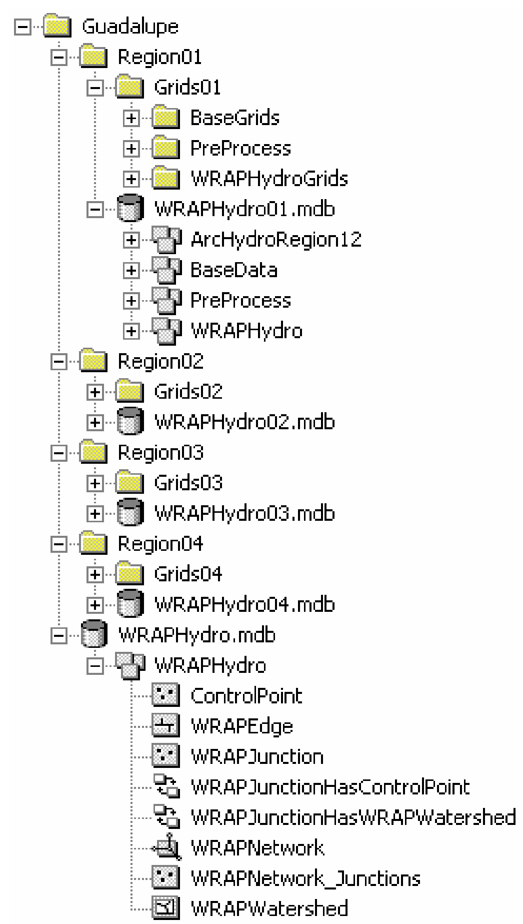


Figure 7.2 WRAPHydro Data Model Regional Structure

Individually they have the same structure as the WRAPHydro model in Section 4.1. The Guadalupe folder has a Geodatabase WRAPHydro.mdb that has one Feature dataset WRAPHydro. This geodatabase contains the merged product from each regional processing.

7.3 METHODOLOGY

The methodology of dealing with sub basins is similar to the method described in Chapters 5 and 6. Instead of creating a buffer around the whole basin for initial grid processing, a 10 Km buffer is created for each of the four sub basins and the streams within these buffers are selected. The DEM for each area with the buffer is processed to get the flow direction grid. Catchments are delineated for each stream segment, the required catchments are selected and a mask is created for each sub basin to define its boundary. The grids are clipped to this mask. A network is built using the WRAPEdges and WRAPJunctions and an outlet point is placed in each of the four areas. Watersheds are delineated for each JunctionID value of WRAPEdge. The four WRAPEdges, WRAPJunctions and WRAPWatersheds are then merged and the parameters are processed. Since most of the procedure is the same as discussed in previous chapters, only the methods specific to regionalization are discussed below.

7.3.1 Selecting streams and placing outlet points

One of the most important steps in basin subdivision is to identify the stream network that could make up a sub basin. All the streams within a sub basin should drain to a single outlet so that the outlet can be representative of all that is upstream of it and its effect can be carried downstream from a single point. This outlet acts as a sink for the basin where water falling at every part of the basin flows down to. Figure 7.3 shows the selected streams for the Upper Guadalupe (HUC01). The streams are selected in the same way as discussed in section 5.3.2. It is important to cut off streams in such a way that no stream segment is selected in any two sub basins. This is done to avoid any overlapping problems encountered when merging files at the parameter development stage. Since the WRAPHydro tools delineate watersheds to edges, an outlet junction is added at the most downstream end of the sub basin to ensure that all the necessary area are captured. An outlet need not be added to the most downstream sub basin since it does not drain into any other sub basin. Adding an outlet does not affect the parameter values for any of the junctions. Though there will be an extra area delineated for each basin by the outlet junction, it will not affect the total area upstream for the next downstream junction.

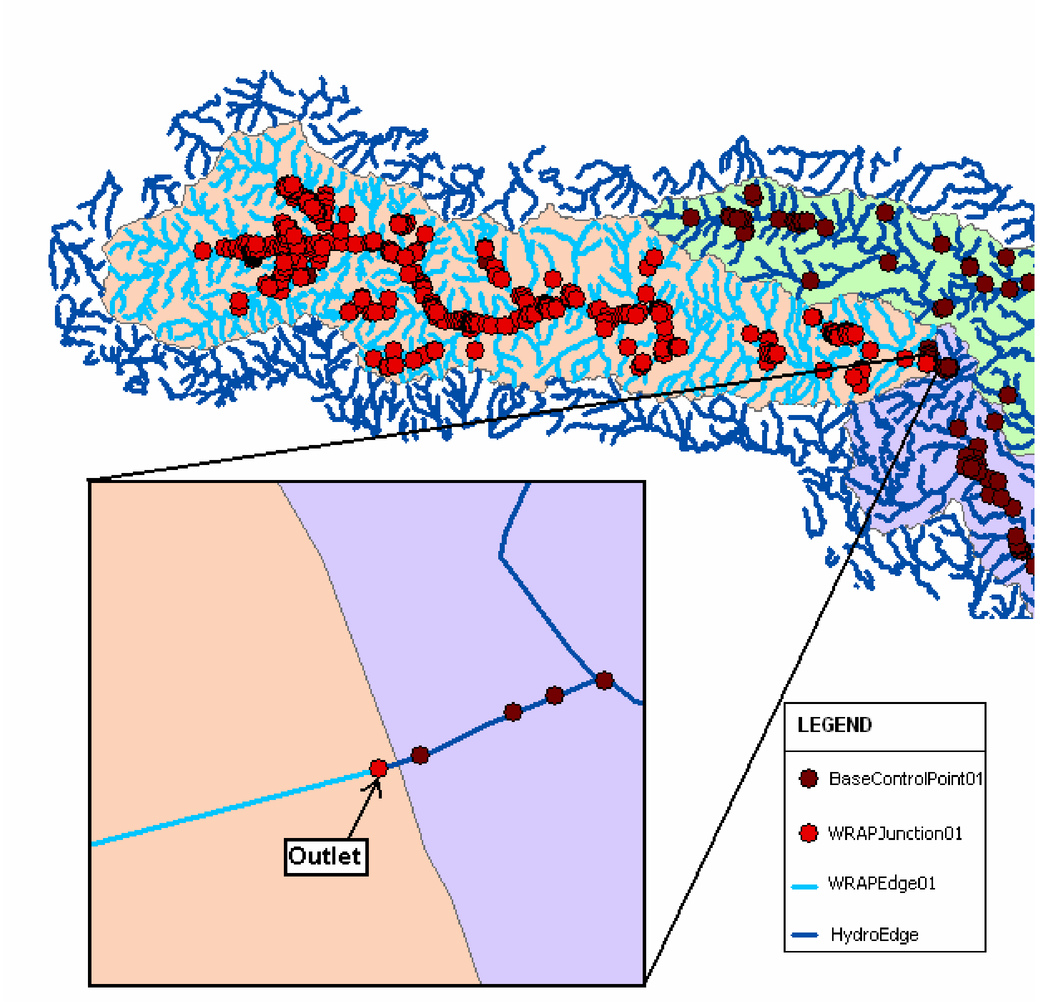


Figure 7.3 Placing Outlets

7.3.2 Assigning Regional HydroIDs

When assigning HydroIDs to the sub basin WRAPJunctions and WRAPEdges, it is essential to specify the region to which they belong to make it easier to identify them when the four areas are merged. Figure 7.4 shows the HydroID assignment for sub region 4 of Guadalupe. For any sub basin, the

HydroIDs are a nine digit integer. The first two digits specify the sub area number, 04 in this case. Two digits are allocated for the region number since there could be more than ten sub basins for some of the basins. It is assumed here that that no basin is so big that it can be divided into more than 99 parts.

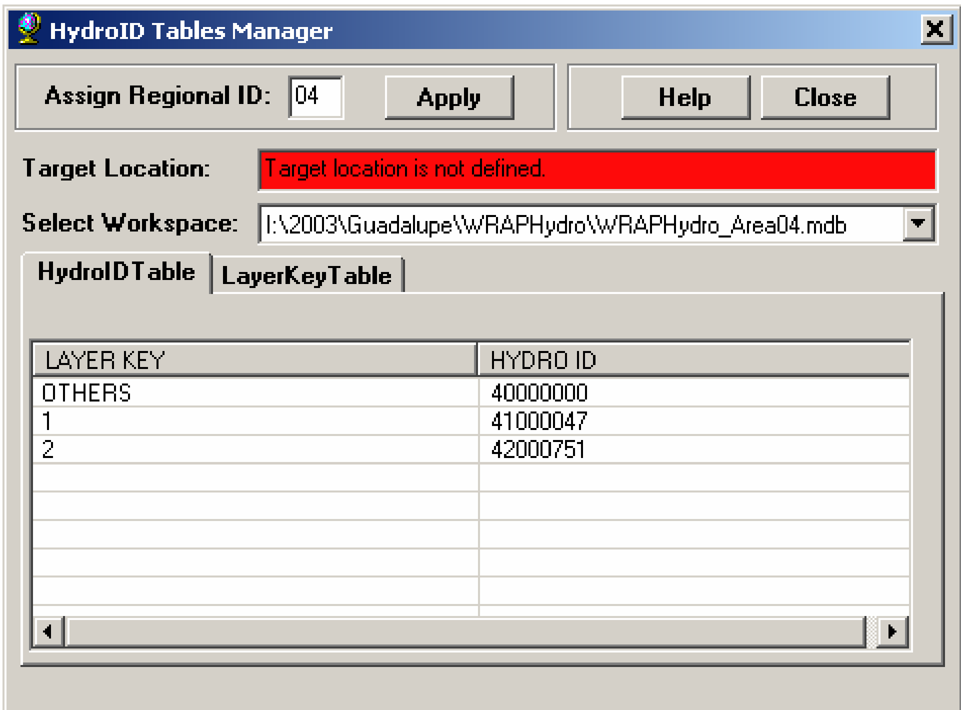


Figure 7.4: Regional HydroID assignment

Since the Guadalupe has just four sub basins, the HydroIDs are eight digit integers, the first digit specifying the Region number, the second digit either a ‘1’ or a ‘2’, for WRAPJunction or WRAPEdge respectively. The rest of the digits are unique for each feature in both the classes starting with a ‘1’ to as many number of features in the class.

7.3.3 Merging Areas

The WRAPWatersheds for the four subbasins are delineated and the DrainID of the Watershed is populated with the JunctionID of the WRAPEdge it flows to, which in turn is populated by the HydroID of the Next Downstream WRAPjunction. The respective flow direction, Curve number and Precipitation grids are clipped to their sub basin mask. The Junctions, Edges and Watersheds of all the four parts are merged together using the Geoprocessing wizard, exported into the main WRAPHydro geodatabase, and called WRAPJunction, WRAPEdge and WRAPWatershed respectively. Another method of merging the four parts is by exporting one of the areas, say 01, to the WRAPHydro Geodatabase and import the other three areas giving a snapping tolerance using the 'Load Objects' tool. Refer appendix B for more details on how to use this tool.

Figure 7.5 shows the watersheds delineated for the four areas and the associated junctions for each watershed. The area where sub region 03 drains down to sub region 02, has been expanded in view. The flow direction arrows show that the water from the outlet of sub basin 03 flows down to WRAPJunction in sub basin 02 with HydroID 21000071. So, after merging the four Junction layers, the HydroID of the next downstream junction is entered in the NextDownID field of the outlet junction. A network is built with WRAPEdge and WRAPJunction and an upstream trace is run by placing a flag at the most downstream end to ensure all the edges and junctions are connected to the network. The procedure to determine parameter values is the same as discussed in section 6.4.

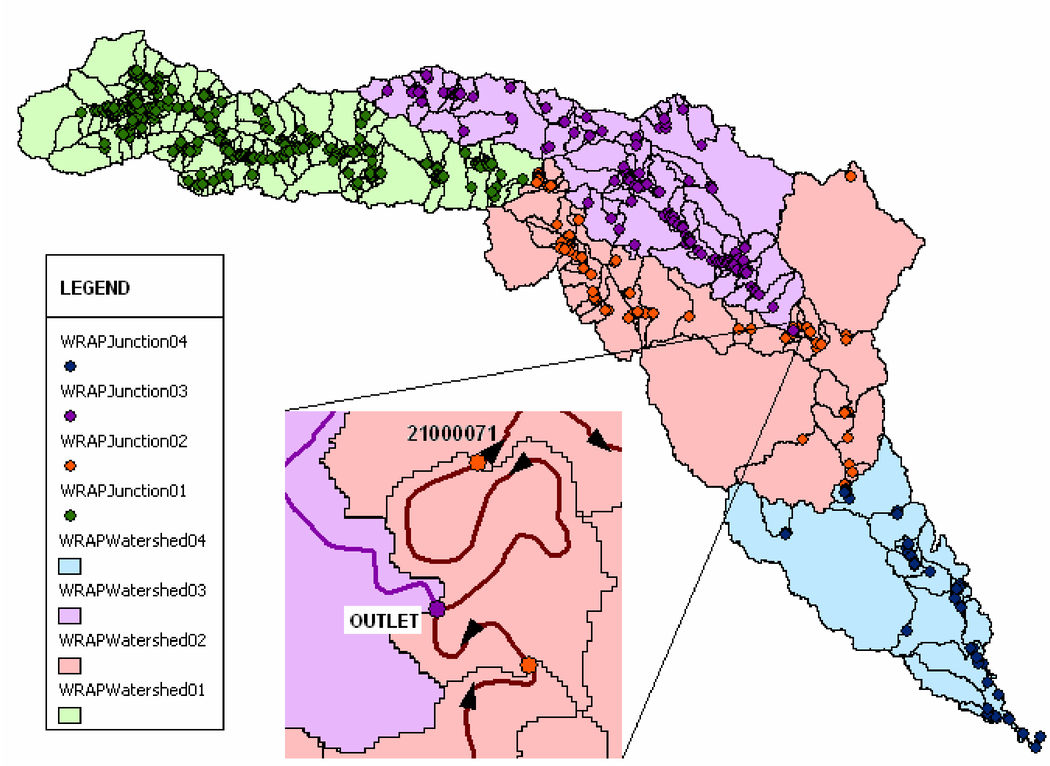


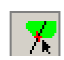
Figure 7.5 Merged Sub Region Geodatabases into a Regional Geodatabase

Chapter 8: Adding New Streams and Junctions

8.1 ADDING NEW DATA

After the parameters are determined for a basin either as one unit or by splitting into parts, there are chances that some Edges or Junctions or both may be left out of processing. Usually new junctions are added when a new water right permit is granted, a new stream gage location is added to the existing ones, or for any other reason. There also might be points that would have been overlooked. Some stream segments may be omitted while digitizing. It wouldn't matter to omit these streams since the DEM would take care of the watershed delineation, but if there are control points on these stream segments, the watersheds need to be delineated for each of these points. This is when it becomes necessary to add a stream segment to the network.

8.2 ADDING NEW JUNCTIONS

The buttons 'Process New HydroJunction'  and 'Batch Process HydroJunctions'  in the WRAPHydro toolset are used to incorporate new junction edits into the network. These tools are used when the new junctions have to be added on an already existing stream network. If there is only one new junction, the Process New HydroJunction is used. A watershed is delineated for that junction and the other parameters, NextDownID, Drain_area, average curve number and precipitation values are populated automatically in the respective fields. When several new junctions are added, rather than processing each one individually a batch processing is done on them. This creates a new watersheds file and updates all the other parameters as well. However, both these tools do not compute the length downstream and the LengthDown field has to be populated using the 'Find Length Downsream for Junction' tool in ArcHydro toolset. Figure 8.1 shows the watershed delineated when a new junction is added to the network. The new junctions are automatically assigned HydroIDs in the same sequence as other junctions in the layer. For example if the original WRAPjunction had HydroIDs ranging from 41000001 to 41000056 and if five more new junctions are added, the new HydroIDs will range from 41000057 to 41000061.

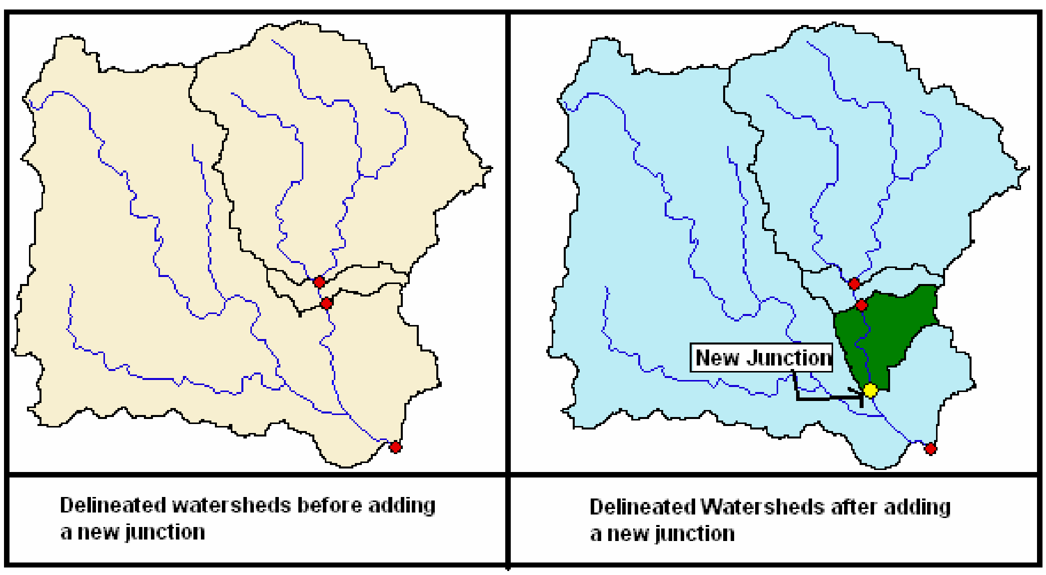
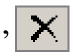


Figure 8.1 Adding new junctions

8.3 REMOVING A JUNCTION

Sometimes, some existing water right permits are cancelled and no calculation needs to be done on that location. Also, a junction may be wrongly placed on the network or may have shifted in location due to a given snapping environment or any other reason. In these cases a junction has to be removed from the network using the 'Remove HydroJunction tool'  in the WRAPHydro toolset. As and when a junction is removed from the network, the NextDownID of the upstream junction, the JunctionID of the upstream edge and the DrainID of the Watershed it delineated are automatically updated. Figure 8.2 (A) shows four junctions with HydroIDs 1 through 4 and the DrainIDs of the respective watersheds. If junction 2 is removed, the NextDownID of junction 1 changes from 2 to 3 [Figure 8.2 (B)] and the DrainID of watershed 2 changes to 3 [Figure 8.2 (C)]. The watersheds are dissolved based on DrainID. The rest of the parameters are determined the usual way.

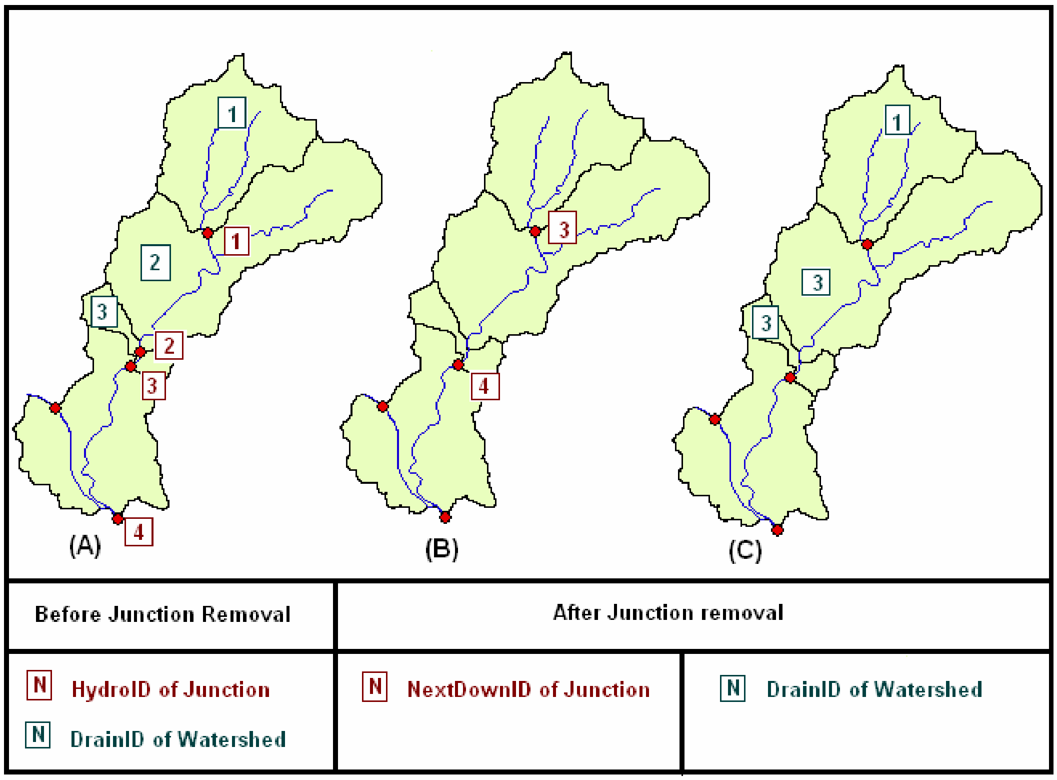


Figure 8.2: Removing a junction

8.4 ADDING A STREAM SEGMENT

As discussed earlier, it becomes necessary to add stream segments when new control points are located on them. Every time a new stream edit is added, the DEM has to be processed again. This is very time consuming especially if the basin is not processed in parts since the whole procedure of processing the DEM, delineating catchments and populating parameters has to be repeated. A new method is discussed below to deal with this problem.

For any new stream edit and control point added to the network, the first step is to identify the delineated watershed(s) that the edits lie within. Figure 8.3

shows an example of a new stream edit with a new control point located on it. The selected watershed that contains the new stream and control point is exported to a new feature class and converted to a raster mask. The new edits are imported into the WRAPJunction and WRAPEdge feature classes. This assigns the new features their HydroIDs in sequence with the existing HydroID values. All the WRAPEdges and WRAPJunctions that lie within the new exported watershed are selected (which includes the edits), and exported to new feature classes. The DEM is clipped to the mask and is processed to get the flow direction grid for that small watershed. If the new stream segment(s) pass through more than one existing watershed, all the watersheds it passes through have to be selected. This case is illustrated in Figure 8.4. Thus, in case I, the new stream segment is within one watershed and hence just that watershed is selected. But in Case II, the new stream segment passes through three watersheds and hence all three watersheds are selected.

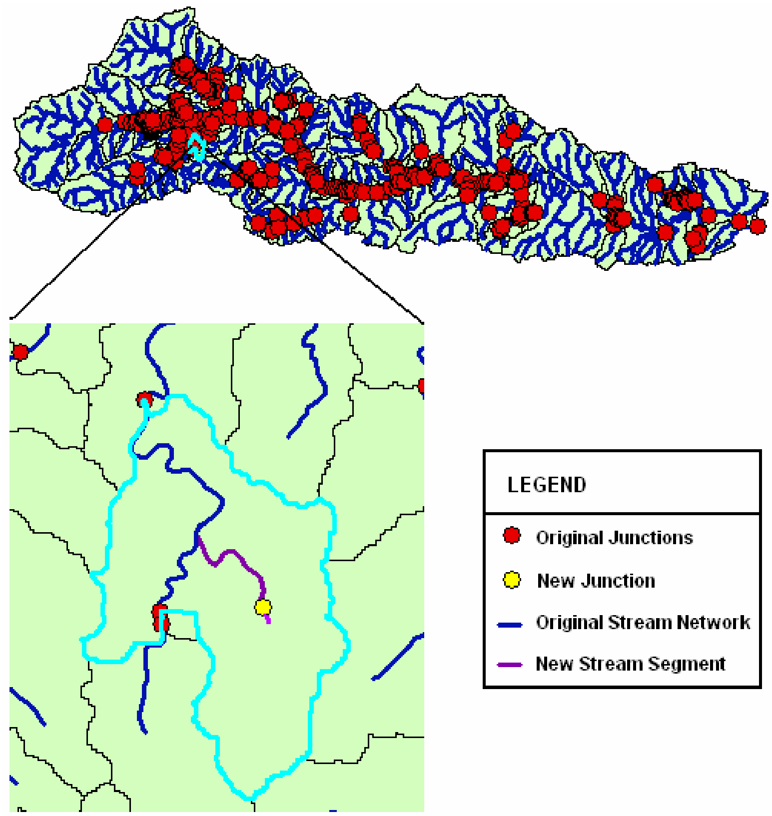


Figure 8.3 Selecting Watersheds (Case I)

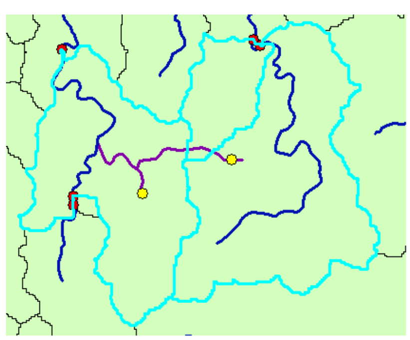


Figure 8.4: Selecting Watersheds (Case II)

After the grids are processed for the small region, the new edges are populated with the JunctionIDs and watersheds are delineated. As seen from Figure 8.5, the new junction has a watershed delineated within the existing watershed.

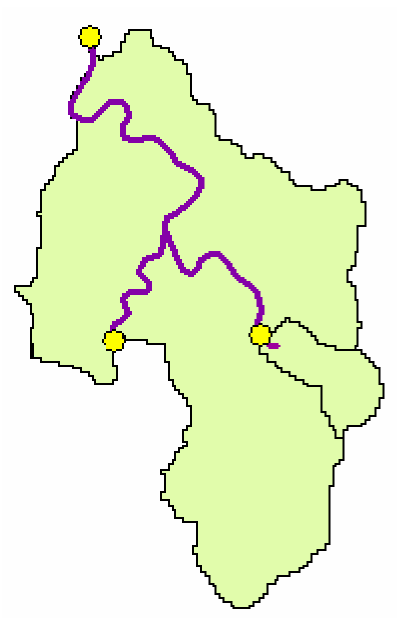


Figure 8.5 Delineating Watershed for new Junction

The union function in the ArcGIS Geoprocessing wizard is used to merge the new delineated watershed with the original WRAPWatershed. The union function cookie cuts the original watershed by creating a new boundary in the WRAPWatershed that coincides with the boundary of the new delineated watershed, also making sure that the same area is not overlapped. It is necessary to dissolve the resulting watershed as the union function leads to a number of small areas where ever there are intersections. As in case of the intersection between the two watersheds shown in Figure 8.6, each small area will be considered as a separate watershed. Dissolving based on DrainID will take care of this problem.

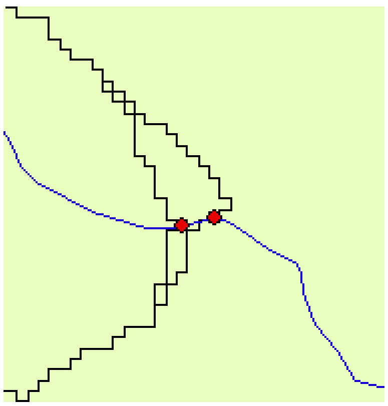


Figure 8.6 Intersections between watersheds

It is better to work on the edits at the sub regional level if the basin is worked on in parts. This is because, by working on the regional level, the HydroIDs for the edits are assigned according to the region numbers accordingly. If these edits are incorporated at the last stage after merging the features, the HydroIds will be assigned in a random fashion and it would be difficult to identify the region to which the edits belong based on their HydroIDs.

Chapter 9: Results

9.1 STREAM GAGE AREA COMPARISON

The results obtained for total upstream area for stream gages from three different methods are compared to the USGS reported value for these stream gages. As it can be seen from the Figure 9.1, the stream gages (Highlighted) are evenly distributed across the basin. Hence they are used as representative points for comparison. The three methods are: WRAPHydro method for parameter development for the whole basin, WRAPHydro-Regional method of working with a basin in parts and the WRAP1117 method of determining parameters in ArcView. For convenience they are referred to as methods (1), (2) and (3) respectively.

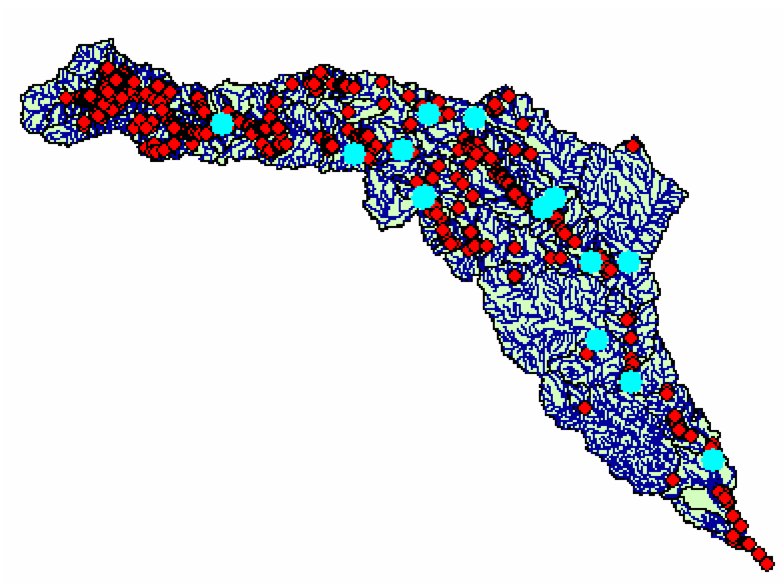


Figure 9.1 Location of Stream Gages on Guadalupe

Table 9.1 and Table 9.2 below show the values calculated for stream gages by the three methods and the percent difference in these values with respect to the USGS area. Drain_area is obtained from WRAP1117, Drain_area_region from WRAPHydro and Area_1117 from method 3. The areas are in square miles. The USGS areas were not available for three of the stream gages: 6, 12 and 38. The values for stream gages 1 through 15 in each case match very closely to the USGS area. The Area obtained by Method 3 most closely matches the USGS area. This is because, there were a few dangling edges on the boundary of the basin which were deleted since they created holes in watershed processing. Figure 9.2 shows a comparison of EDNA catchments and the catchments delineated when dangling edges were removed from analysis at the boundary. The areas on the boundary delineated by these dangling edges were not accounted for in methods 1 and 2. Also, it can be seen that for stream gage 38 which is located at the downstream end of the basin, the values for areas found by methods 1 and 2 are far different from that found in method 3. The area of Guadalupe basin is around 6000 square miles (as in the literature). The big difference of more than 5000 square miles in method 3 is because a part of the San Antonio basin has been captured during delineation. This accounts for the fact that Guadalupe is very flat at its downstream end (refer section 5.3 for more details). Figure 9.3 shows the USGS stream gage area values plotted against the Area obtained by the WRAPHydro method. It is seen that the plot shows a R^2 value of 1 which means both the values match perfectly.

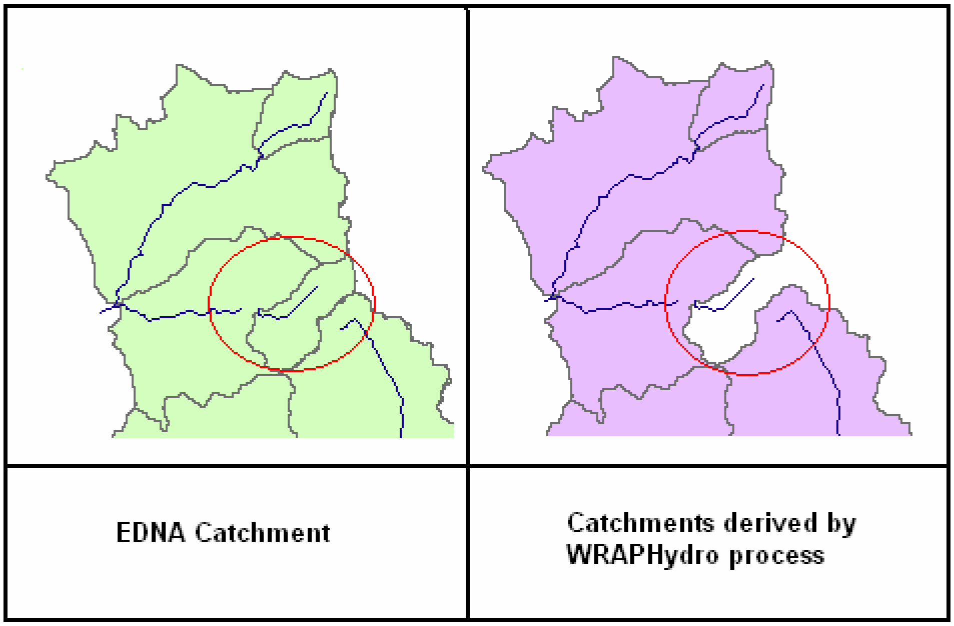


Figure 9.2: Illustration showing Catchments left out by removing dangling edges from the boundary

ID	Area_USGS	Drain_area	Drain_area_region	Area_1117
1	839.000	836.476	836.512	837.780
2	1315.000	1313.231	1312.753	1314.700
3	1436.000	1426.489	1426.924	1432.250
4	1518.000	1516.817	1517.433	1519.030
5	130.000	129.420	129.068	129.540
6		2101.816	2100.773	2103.070
8	355.000	355.264	354.803	355.310
9	412.000	412.336	412.049	412.430
10	838.000	838.745	838.430	838.810
11	309.000	310.077	309.793	310.630
12		459.925	459.715	459.790
13	549.000	548.820	547.735	549.050
14	4934.000	4932.783	4931.082	4935.000
15	5198.000	5188.828	5187.091	5195.880
38		5941.848	5943.252	10122.300

Table 9.1 Stream Gage area comparison

ID	%Diff	%Diff_Region	%Diff_1117
1	0.2966	0.2966	0.1454
2	0.1709	0.1709	0.0228
3	0.6320	0.6320	0.2611
4	0.0373	0.0373	-0.0679
5	0.7171	0.7171	0.3538
6			
8	0.0556	0.0556	-0.0873
9	-0.0118	-0.0118	-0.1044
10	-0.0513	-0.0513	-0.0967
11	-0.2566	-0.2566	-0.5275
12			
13	0.2303	0.2303	-0.0091
14	0.0591	0.0591	-0.0203
15	0.2099	0.2099	0.0408

Table 9.2: Percent Difference between the calculated areas and USGS areas

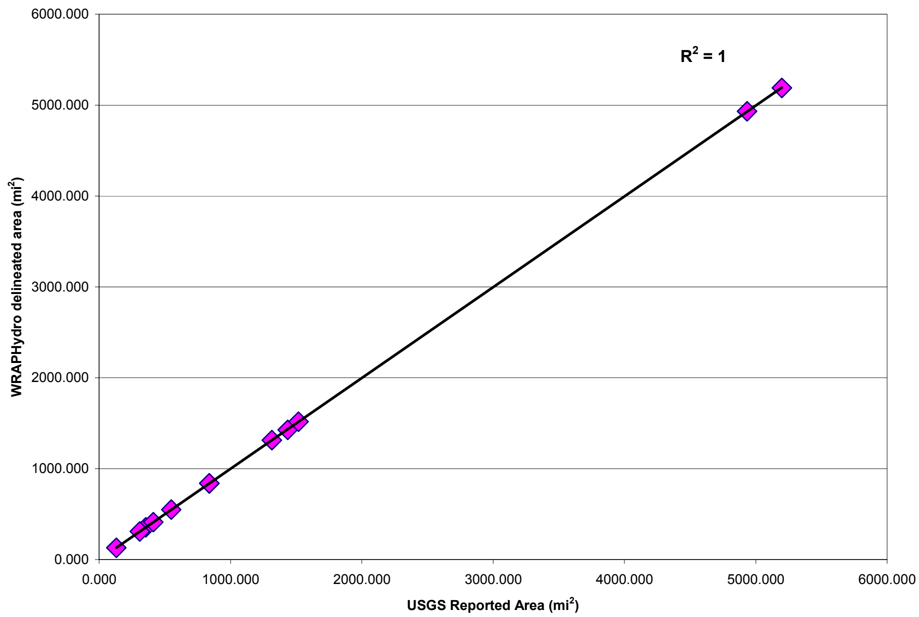


Figure 9.3: Comparison of USGS area and WRAPHydro delineated area in mi^2

9.2 LENGTH DOWNSTREAM COMPARISON

The length downstream values in miles are compared in Table 9.3 for the three methods. Results from WRAP1117 and 2 are the same, but differ considerably from the results from method 3. This difference is attributed to the fact that in WRAP1117, DEM derived stream networks were used for determining parameters. Figure 9.3 shows a close up of the DEM stream used in WRAP1117 and the NHD stream used in the current method. Two cases are illustrated as Case I and Case II. In both cases a segment of The NHD is taken (Orange lines) and their lengths are compared with that of DEM derived stream (Blue lines) The length of NHD in Case I is 624 meters and DEM stream is 883 meters.

This shows that creating the DEM stream network increased the length of the original stream by 259 meters. But in Case II, the NHD segment has a length of 2742 meters and DEM stream has a length of 1674 meters. Hence, here the DEM stream has reduced in length considerably. This shows that a DEM derived stream network could either increase or decrease the length of the original stream network. For the Length Downstream values obtained for the stream gages, it can be seen that though the most downstream gage 14, has a greater LengthDown value obtained from methods 1 and 2 than from method 3, the most upstream gage 1, has a much lower value obtained from WRAP1117 and 2 than from method 3. The fifth column shows the percent difference in WRAP1117 and method 3 (methods 1 and 2 have the same result). Thus on an average, the NHD network is 0.52 % longer than DEM derived stream network as calculated by the values for the stream gages in Guadalupe basin.

WRAPCode	LengthDown	LengthDown _Region	LengthDown11 17	Percent Difference
1	387.28	387.28	402.01	-3.80
2	324.21	324.21	330.75	-2.02
3	299.39	299.39	302.41	-1.01
4	277.77	277.77	278.36	-0.21
5	277.7	277.7	278.06	-0.13
6	178.52	178.52	176.84	0.94
7	279.54	279.54	277.26	0.82
8	262.63	262.63	257.96	1.78
9	212.11	212.11	208.07	1.90
10	210.19	210.19	206.29	1.86
11	155.94	155.94	153.74	1.41
12	125.97	125.97	125.21	0.60
13	101.91	101.91	100.48	1.40
14	52.03	52.03	50.08	3.75
			Average =	0.52

Table 9.3: Length Downstream Comparison

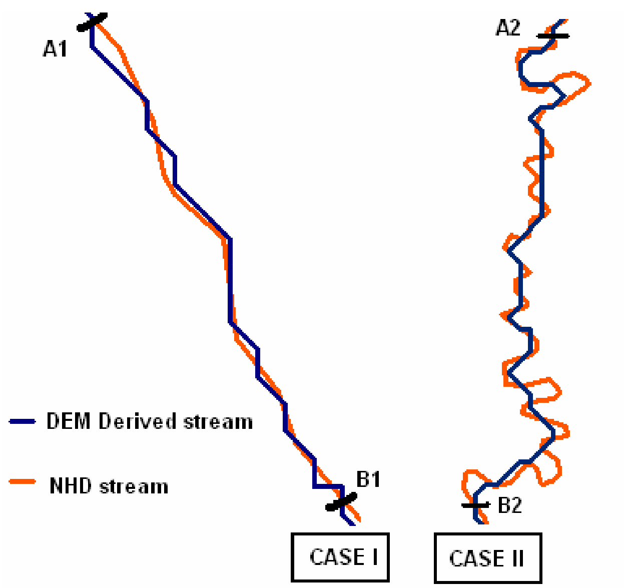


Figure 9.4: Comparison of NHD and DEM derived stream

9.3 AVERAGE CURVE NUMBER AND AVERAGE PRECIPITATION COMPARISON

The average curve number and precipitation values for methods 1 and 2 are compared in Table 9.4. These values were not calculated by method 3 for the Guadalupe basin. The results show an exact match in values for both these parameters.

ID	AvgCN	AvgCN_Region	AvgPR	AvgPR_Region
1	59.99	59.98	29.06	29.06
2	61.81	61.82	30.42	30.42
3	62.92	62.91	30.70	30.70
4	63.06	63.06	30.92	30.92
5	62.05	62.06	34.08	34.08
6	64.75	64.75	31.80	31.80
8	70.42	70.41	33.63	33.63
9	69.26	69.26	33.71	33.71
10	68.78	68.78	34.07	34.07
11	68.69	68.69	34.13	34.13
12	62.90	62.90	36.08	36.08
13	64.92	64.94	33.08	33.09
14	66.40	66.40	33.27	33.27
15	66.60	66.60	33.39	33.39

Table 9.4: Comparison of Average Curve Number and Average Precipitation Values

Chapter 10: Conclusions

10.1 INTRODUCTION

This main objective of this thesis is to develop a new methodology called WRAPHydro for determining watershed parameters for use as input into the Water Rights Analysis Package (WRAP) model in the ArcGIS environment and to compare the results obtained with those determined earlier by an alternate procedure developed in the ArcView 3.2 environment called WRAP1117. The WRAP model calculates the water availability for surface water rights on a priority based allocation system. For convenience, the WRAP1117 process in ArcView 3.2 is referred to as WRAP1117 and the new method of parameter processing in the ArcGIS environment is referred to as WRAPHydro.

The main difference in processing watershed parameters in both these methods is that in WRAP1117, the watershed parameters are determined from the raster data directly whereas WRAPHydro uses a combination of raster and vector data to find these parameters. The watershed parameters, namely, upstream area above each control point, average upstream curve number and average upstream annual precipitation are determined locally for each control point and these values are accumulated downstream to add the effects of all the area that is upstream of each control point. When processing these parameters by WRAP1117, raster data are used both for determining the local values as well as upstream accumulated values of the watershed parameters. However, in WRAPHydro, the local areas are derived from rasters and all the other values are determined in a vector environment. Thus, WRAP1117 requires a significant amount of raster processing that consumes a lot of computer memory and processing time. The WRAP1117 method is complex especially when working on a basin in parts. The cascading of parameters for adding the effects of upstream basins, requires a lot of handwork which leads to the possibility of errors Moreover, whenever a new edit is incorporated into the basin, there is a lot of reprocessing required to be done.

From the results obtained from the three methods, it is clear that the WRAPHydro method is as accurate as the WRAP1117 method for finding upstream area and more reliable for distance to outlet calculations. Also, a comparison of WRAP1117 and WRAPHydro methods shows that the accuracy of parameter determination is not compromised by dividing the basins into sub basins for parameter processing. Additionally, in WRAPHydro when new junctions are added at a subbasin level, the HydroIDs are accordingly assigned which makes it easy to identify which region the new edits belong to after merging the results. The Curve Number and Average Precipitation values are correctly accumulated downstream.

The five objectives of this thesis are addressed in the following sections of this chapter.

10.2 WRAPHYDRO DATA MODEL

Though the WRAP1117 files had naming conventions, it was up to the persons working on them to structure them in their own way which differed from person to person. To avoid this inconsistency, the first step in this research was to build a new data model called WRAPHydro adapting the existing ArcHydro framework for use with WRAP model. The WRAPHydro schema contains all the feature classes, networks, relationships and fields within each feature class that are required in this project. It provides a very organized and structured platform to work on. By dividing the work into three stages: base data acquisition, preprocessing and actual parameter development on both raster and vector data, the data processing becomes more systematic and easy to manage. Thus, building the WRAPHydro model for this project defines a step wise procedure to work on the parameter development. It gives the Water Availability Model project the basic structure to build upon and be worked upon in a systematic manner. Building from existing data in ArcHydro for water resource region 12 (covers almost all of Texas) within this model allows the user to derive data from the basic ArcHydro framework for the WRAPHydro framework.

10.3 DEFINING BASIN BOUNDARY

Another objective of this research was to define the area to act as the analysis extent for grid processing, i.e. to define a basin mask. This needs to be done since the HUC boundaries do not correctly define the basin boundary. It is necessary to consider the surrounding streams in the analysis to avoid the problems of capturing extra area during delineation in flat basins like the Guadalupe. If the network contains dangling edges, holes are created in the watersheds and if they are deleted, areas delineated by the dangling edges on the basin boundaries are left out. Though a method is described to delineate catchments for those areas separately and merging them with the basin area, it might lead to merging problems and also increases the complexity in dealing with a number of small areas.

This research shows that burning the streams with the DEM to delineate catchments is necessary. The comparison of the watersheds delineated by burning the streams with the DEM and those obtained by avoiding the step of burning the streams shows that in the latter case, in some areas, the cells that flow into the streams are not captured correctly since the area around the stream is not raised sufficiently. Thus, this concludes that it is desirable to burn the streams with the DEM before the flow direction grid can be processed.

10.4 FINDING PARAMETERS IN WRAPHYDRO

The ArcHydro and WRAPHydro toolsets are used to find watershed parameters. Migrating from a raster environment in ArcView 3.2 to a more vector environment in ArcGIS considerably reduces the complexity and the time taken for obtaining watershed parameters. The ability to create a network and assign flow direction saves a lot of time and labor. The process of creating a DEM derived network in WRAP1117 is avoided and the National Hydrography Dataset network is not altered in anyway. This not only reduces the time for processing, but also increases the accuracy. The DEM derived stream can either be longer or shorter than the length of the actual stream network. Delineating watersheds to lines and accumulating the value downstream in a vector environment also saves a lot of time during processing since processing a flow accumulation raster in WRAP1117 is avoided. Thus, the WRAPHydro method of determining watershed parameters is faster and more accurate and overall more efficient as compared to the WRAP1117 processing.

10.5 Basin Sub Division

When dividing the basins into parts and working with each part individually, the accuracy of the watershed parameter values is not compromised in WRAPHydro. Assigning unique identifiers, HydroIDs, for each feature helps in better identification of the features belonging to each subregion after they are merged to get the regional form for parameter development. It is also essential to place an outlet at the most downstream location of each subbasin to ensure that all the necessary areas are captured. Besides this, it should be made sure that no stream segment is repeated in two sub regions. This will cause duplication of watershed delineation and will cause problems while merging.

10.6 Incorporating New Edits

The WRAPHydro tools add and remove junctions and simultaneously update the parameters in the affected features automatically. This not only speeds up the process of incorporating edits but also reduces manual errors that could occur in updating parameter values. Also, when working in regions, if the edits are worked upon on a subregional level, the HydroIDs are assigned so that the new features are identifiable even in the merged product. The new method of adding new stream edits to the network confirms the possibility of adding new streams without burning the DEM for the whole region under consideration.

10.7 Future Work and Recommendations

As future work, the author recommends exploiting some functionalities provided in newer versions of ArcGIS. The Geoprocessing environment in

ArcGIS 8.3 and 9.0 includes a component called the Model Builder that allows users to chain processes together and run them all at once from a custom tool, instead of one by one. Though this component supports only those functions that are inbuilt and are found in ArcToolbox, some customization could be done to get the tools processed according to the user's requirement. For example, for Grid processing, the DEM is first burned with the stream, then it is filled and then the flow direction grid is processed. The ArcGIS has inbuilt tools that fill the sinks and process the Flow direction grid, but it does not have a burning tool, which is a process specific to WRAP. By customizing the tools for the WRAP project, it might be possible to build a model that has all the functionalities to do the stepwise processing of parameters in an automated manner.

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Appendix A: Creating a mask and clipping grids

A.1 Converting Features to Raster

Any feature, a shapefile, coverage or a feature class, can be converted into a raster file using the Spatial analyst extention → Convert → Features to raster.

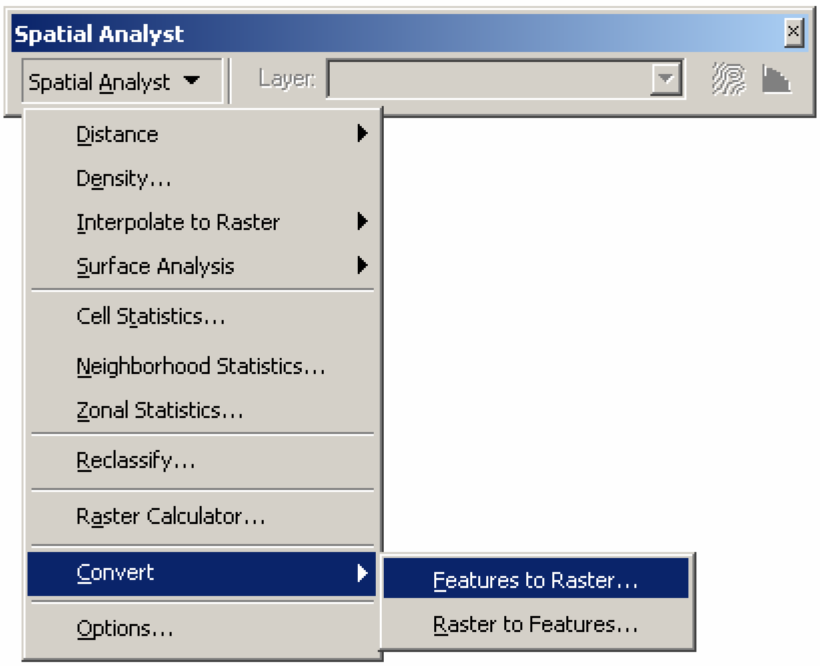

Figure A.1: Convert Raster to Feature Tool

The options in Spatial analyst should be used to set the working directory, the extent of analysis and the cell size. The analysis extent should be selected such that it covers all the required area. A smaller extent will result in incomplete rasters and a larger extent will take longer processing time than required. The cell size for this project is considered to be 30 m.

The feature basin, which is the Guadalupe basin polygon is entered as input. The Field could be any field as long as it does not have a zero value record, and an output raster is specified. This is going to create a raster with its cells having the value of the field 'ID'.

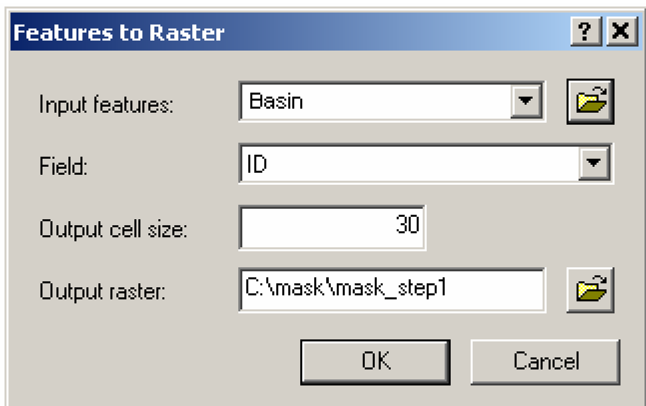

Figure A.2: Feature to Raster Conversion process

A.2 CREATING A MASK

A mask is a grid with all its cell values equal to one. The raster calculator is used to divide each cell in the output grid (mask_step1 in this case) with itself to get a new grid which has unit value in all its cells.

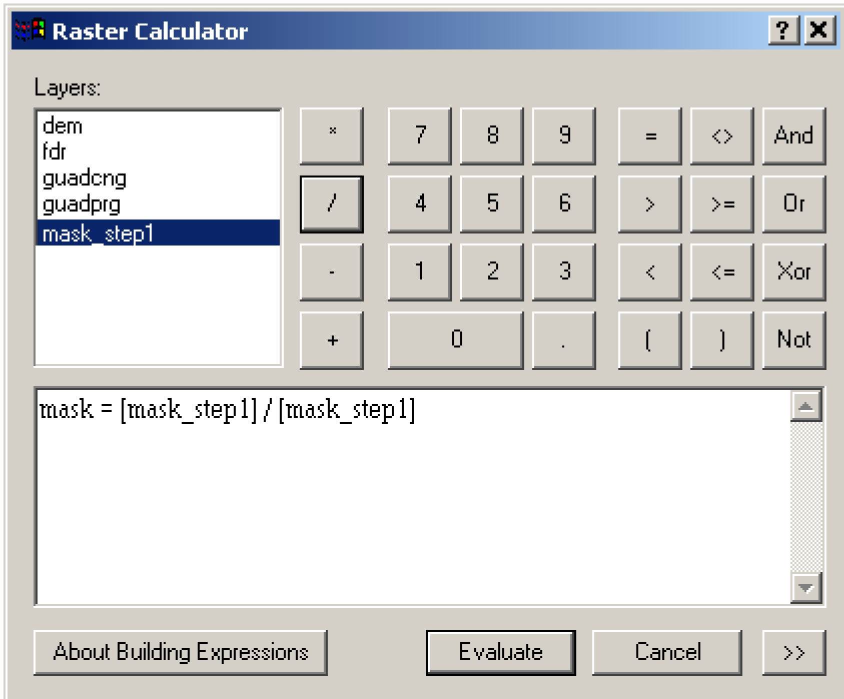

Figure A.3: Raster Calculator for creating mask

A.3 CLIPPING GRIDS

Whenever a grid needs to be clipped to another extent, it is easiest to create a mask of the extent needed and multiply the grid with the mask. Each value in the grid will be multiplied with the respective cell value in the mask which is always one and thus create a clipped grid from the original one. The raster calculator is used to create the clipped grid.

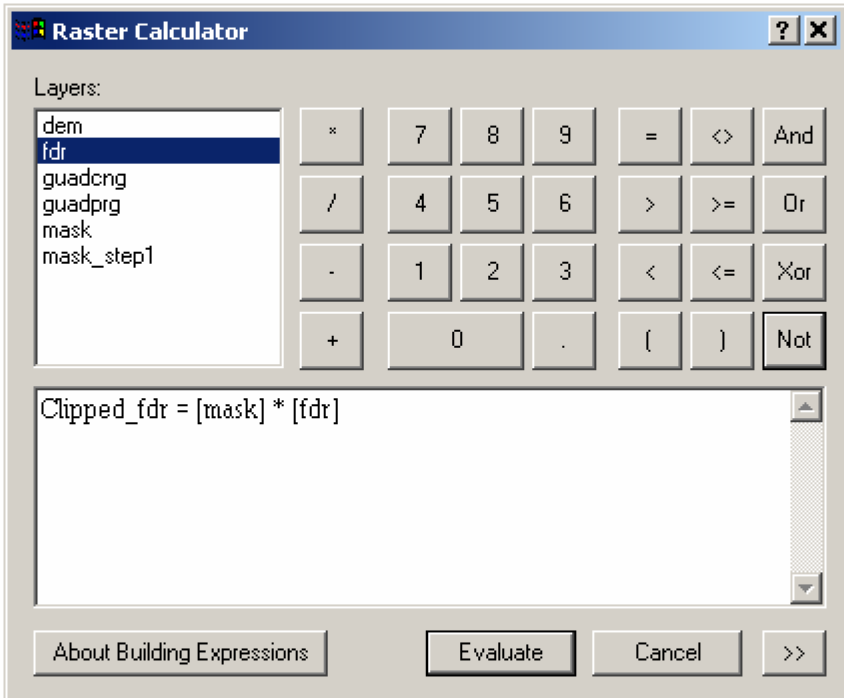

Figure A.4: Raster Calculator for clipping grids

Appendix B: Load objects

B.1 Loading the Command

The Load Objects command loads data from one or more existing shapefile, coverage, feature class or table to an existing simple feature class as long as they have the same schema. It appends the new records to the existing table of the feature class to which they are loaded. To load the command first go to tools→ customize → commands tab → data converters. Click and drag the Load Objects command to the toolbar area. Figure B.1 shows the customize tool. One has to be in the editing mode to use this command.

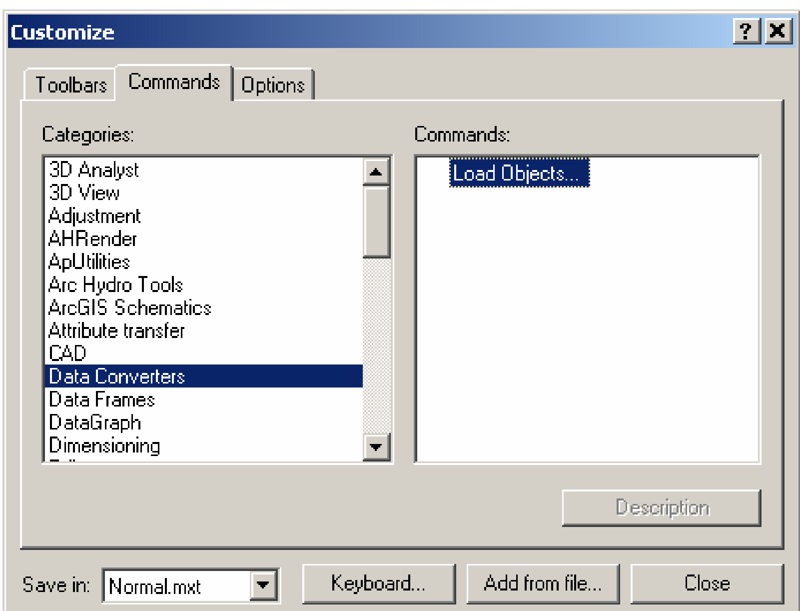

Figure B.1: Load Objects Command

B.2 LOADING JUNCTIONS

The problem in this project deals with loading the WRAPJunctions so that the WRAPEdges which are built as simple edges are split at points where these junctions are placed. A network has to be built before the Junctions can be loaded. First a copy of the WRAPJunction feature class is made and is called WRAPJunction_copy. All the features from WRAPJunction are deleted and the target object class is set to WRAPJunction in the editor toolbar. By clicking the Load Objects command, the window as shown in Figure B.2 is displayed. The input or source feature class object is selected as WRAPJunction_copy and added to the list of source data. The target and source fields will be an exact match since the source is a copy of the target feature. The option to load all of the data is selected and finally the option to move the source features to the current snapping environment is chosen.

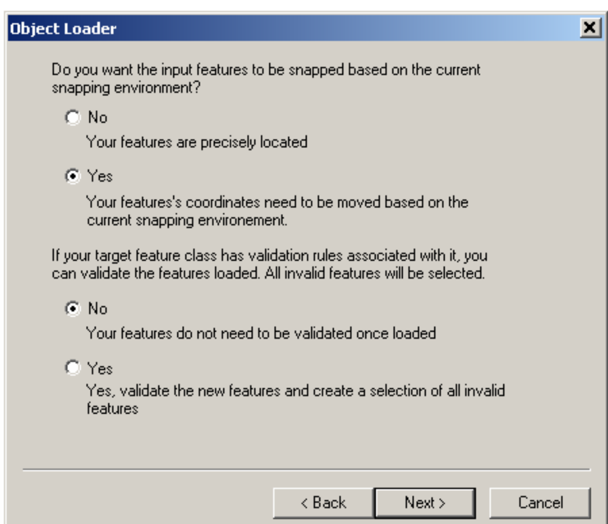

Figure B.2: Object Loader Process

After all the data is loaded, it is seen that the edges are snapped at the required locations. Since the Junctions are snapped and they split edges, the flow direction would get uninitialized for those edges. So, it is important to set the flow direction again before any further processing is done.

Appendix C: Connection Problems in networks

C.1 TYPES OF CONNECTION PROBLEMS

Three types of connection problems were found while finding the NextDownID for WRAPJunctions.

- An edge connected to the same junction more than once, which results in the NextDownstream identifying the same junction as its own Next Down over and over again.
- Flow directions in the network that result in loops in the network.
- Zero length edges on the network that causes the tool to hang.

These problems and their solutions are discussed in Section 6.4.1. ArcGIS 8.3 provides tools to find connectivity problems and solve them (Figure C.1). These tools are part of the advanced editing tools in the editor toolbar. The Verify connectivity identifies all the edges that have connectivity problems like the first one discussed above and the repair connectivity corrects the problem automatically.

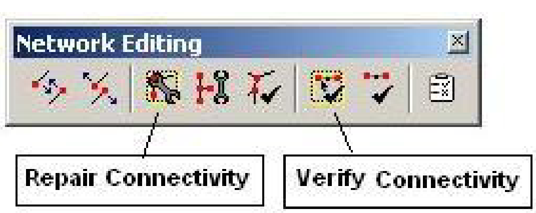

Figure C.1: Network Editing Toolbar

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