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GIS for Large-Scale Watershed Observational Data Model

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GIS for Large-Scale Watershed Observational Data Model

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Dedication

To the Almighty who keeps leading my way and to my wife Silvia and son Carlitos for their lovely support and inspiration.

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GIS for Large-Scale Watershed Observational Data Model

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Because integrated management of a river basin requires the development of models that are used for many purposes, e.g., to assess risks and possible mitigation of droughts and floods, manage water rights, assess water quality, and simply to understand the hydrology of the basin, the development of a relational database from which models can access the various data needed to describe the systems being modeled is fundamental. In order for this concept to be useful and widely applicable, however, it must have a standard design. The recently developed ArcHydro data model facilitates the organization of data according to the “basin” principle and allows access to hydrologic information by models. The development of a basin-scale relational database for the Rio Grande/Bravo basin implemented in a Geographic Information System is one of the contributions of this research. This geodatabase represents the first major attempt to establish a

more complete understanding of the basin as a whole, including spatial and temporal information obtained from the United States of America and Mexico.

Difficulties in processing raster datasets over large regions are studied in this research. One of the most important contributions is the application of a Raster-Network Regionalization technique, which utilizes raster-based analysis at the subregional scale in an efficient manner and combines the resulting subregional vector datasets into a regional database.

Another important contribution of this research is focused on implementing a robust structure for handling huge temporal data sets related to monitoring points such as hydrometric and climatic stations, reservoir inlets and outlets, water rights, etc. For the Rio Grande study area, the ArcHydro format is applied to the historical information collected in order to include and relate these time series to the monitoring points in the geodatabase. Its standard time series format is changed to include a relationship to the agency from which data is obtained.

Since ArcHydro was designed to store hydrologic GIS data in a manner conducive to data export for model use, a toolset is proposed to exchange temporal information between the Geodatabase and the Data Storage System (HEC-DSS).

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Chapter 1: Introduction

1.1 BACKGROUND

The problems related to water management around the world have become increasingly complex in recent years. A continually increasing population, serious problems related to lack of sanitation and clean water, as well as regular high investments in infrastructures which are not achieving their objectives, are likely to force the governments at various levels to search for alternative approaches, other than relying only on engineering solutions through supply management alone. The institutions concerned have yet to fully realize that successful water resources management requires a long term planning process from technical, economic, political, social, and environmental viewpoints. In addition, some decisions about water management are only partially supported, causing unforeseen alterations in the global ecosystem.

Integrated management of a river basin requires the development of data sources and simulation models leading to the concept of hydrologic information systems, which are used for many purposes, e.g. to assess risks and possible mitigation of droughts and floods, manage water rights, assess water quality, and simply to understand the hydrology of the basin. The development of a relational database including spatial and temporal information from which models can access the various data needed to describe the systems being modeled is fundamental. In other words, a database from which models read input data and to which they write output data. In order for this concept to work, however, it must have a standard design.

The use of Geographic Information System (GIS) is a valuable tool in support of hydrologic and hydraulic modeling such as the new HEC-GeoRAS and HEC-GeoHMS extensions that were developed through a development agreement between the Hydrologic Engineering Center (HEC) and the Environmental Systems Research Institute (ESRI). These extensions migrate the functionality of HEC-RAS and HEC-HMS from ArcView 3.x to the ArcGIS platform. In recent years, GIS technology has increasingly been employed for efficient management of large and complex databases. Several studies have been done to use GIS in hydrologic modeling of watersheds, incorporating, to a greater or lesser degree, the spatial variation of hydrologically significant watershed characteristics (Lacroix, et al, 2002). While the specific information requirements vary between models, most require information on watershed topographic properties such as the drainage area, average precipitation, and distance from monitoring points to the outlet of the watershed, among others; as well as topological information on the structure of a stream network and its contributing subcatchments. The application of any hydrologic model at the basin scale requires efficient management of large spatial and temporal datasets. This is done by integrating watershed simulation models and GIS, creating the ability to manage large volumes of data in a common spatial structure (Al-Sabhan et al, 2003).

1.2 PROBLEM STATEMENT AND MOTIVATION

GIS has become the primary mechanism for data management, analysis, and mapping of water resources data. It is clear that great benefits come from using a GIS to integrate the spatial and temporal data components of a hydrologic model into a relational database, from which models read input data and to which they write output results. In order for this concept to work, however, the database must have a standard design. This research focuses on means for achieving that integration using the latest GIS software.

1.2.1 First Motivation: Development of a basin-scale database

Due to its size, complexity and importance, the Rio Grande/Bravo basin is the case study area considered in this research. Although separate research efforts have been carried out in the United States and Mexico, there is no integral database that includes information from both sides of the Rio Grande/Bravo basin yet. As in many watersheds, knowledge and information available about the basin are fragmented, disjointed, incomplete, and sometimes inaccurate. The development of a methodology to create a basin-scale GIS database and its application in the Rio Grande/Bravo basin is one of the main motivations of this research.

The Rio Grande/Bravo is a transboundary water source shared by the United States and Mexico. At this time, Mexico has limited capacity to develop efficient management plans for the water in the basin, given the existing infrastructure and methods of application and distribution of water. A continually increasing population, serious problems related to lack of sanitation and clean

water, as well as regular large investments in infrastructures which are not achieving their objectives, are forcing governments at various levels to search for alternative approaches, other than relying only on traditional supply-side water management alone. The institutions concerned are slowly coming to realize that successful water resources management requires a long term planning process from technical, economic, political, social, and environmental viewpoints.

In addition, some water management decisions are supported only partially, causing alterations in the basin ecosystem. For this reason it is necessary to improve the administration and management of water in this watershed. This requires assessment of water availability and how to manage it appropriately for agriculture, industry and other services, also taking into account ecosystem preservation.

Recent drought conditions in the Rio Grande/Bravo have increased tensions over water sharing in this basin. Several areas of conflict and possible negotiated remedies have been identified, but there is a lack of data available to use in analysis of alternative solutions to these problems.

Minute 308 of the International Boundary Waters Commission (IBWC), June 28, 2002, states that it is very important to support projects that increase data exchange related to the management of hydrological information systems. These systems should include information from both sides of the basin in a timely manner to enable the IBWC to adopt principles and understandings under which both Governments provide the highest priority to fulfilling their respective

obligations under the 1944 Water Treaty. For this reason, the development of a watershed-scale database for the Rio Grande/Bravo basin is fundamental.

In part of this research project, the Center for Research in Water Resources (CRWR) of the University of Texas at Austin, the Texas Commission on Environmental Quality (TCEQ), the Mexican Institute of Water Technology (IMTA), and the National Water Commission (CNA) of Mexico have cooperated to develop the relational database containing geographic, hydrologic, hydraulic and related data for the basin. This geospatial database has been implemented using the recently developed ArcHydro data model, which facilitates access to hydrologic information by models (Maidment, 2002), and is being applied to the entire Rio Grande/Bravo basin.

1.2.2 Second Motivation: Development of a Raster-Network Regionalization Technique

The large amount of spatially detailed information included in a raster and handled within a GIS offers opportunities for hydrologic modeling. Raster tools provide a convenient method for delineating watersheds from Digital Elevation Models (DEM), as well as calculating parameter values for watersheds based on raster datasets describing the spatial distribution of each parameter. Distributed parameters can be summarized and accumulated using a variety of raster tools available in GIS software. These tools work well when the number of grid cells in the analysis is not too large (less than 50 million cells). However, some agencies that manage large river basins are faced with the challenge of incorporating finer resolution digital elevation models (DEMs) into watershed analysis routines.

While an agency may desire to use 10-meter DEMs to delineate watersheds, this would require processing raster datasets nine times larger than datasets based on 30-meter DEMs (Whiteaker, 2004). Difficulties in processing these datasets arise as the size of the rasters increases or with very high-resolution data. These problems include:

- a. Processing large rasters requires a very long time and the computation can become unstable. When processing raster datasets for large watersheds such as the Rio Grande/Bravo basin (around 480 000 square kilometers) the dataset is too large to be handled as one entity, and the computer processor might not be able to execute the raster processing part. Figurski (2001) reported processing times on the order of 10 days for calculating watershed parameters using a 30-meter raster resolution and over 100 million cells. This problem is dealt with by subdividing the basin into hydrological distinct subregions, in which separate raster analyses are performed.
- b. The problem of space. This problem has two aspects to it, scale and size (Schumm, 1998). Studies have shown that a finer spatial resolution leads to more accurate results but this leads to increase processing time and hard disk requirements. As a result data management and processing may become impossible. This issue of scale leads to a compromise between accuracy and data management. Floating point grids generally require more space than integer grids for DEMs and hydrologic parameter values. Grids with a spatially

variegated distribution of values; for example, minimal contiguous areas of equal cell values, require more disk space than uniform grids. The grid format uses a run length encoding scheme, whose effectiveness is reduced when there is much variation in adjacent cell values; e.g. a raster with 100,000 x 100,000 cells of the same integer value (1) is around 110 MB; while another one having 100,000 x 100,000 cells of alternating integer cell values of 0 and 1 is about 1.4GB. Now, a grid with 23,000 x 23,000 cells of random floating point numbers from 0 to 1 is about 2.12 GB. This issue of memory management and storage space for grids can be dealt with in several ways: Decomposing large grids into a number of smaller units; reducing the resolution of the grid; or converting the grid data to a less memory intensive format

- c. A raster exceeds the maximum allowable grid size. The maximum size any single file that 32 bit software application can address is 2.147 GB, and this is independent of the capabilities of the operating system (if using a 64 bit OS, for example). The actual number is $2^{31} - 1$ bytes (2147483647). No single GIS file can exceed this size; however the total size of a collection and related files can exceed this amount. This issue is resolved in ArcGIS 9.x, and there is no limit on the size of an ESRI grid that can be used within the ArcGIS Desktop. This has been accomplished by tiling the ESRI grids internally, so that each component remains below the 2.1GB limit. ArcInfo Workstation and

ArcView 3.x do not support this new grid format (ESRI, 2005). The Center for Research in Water Resources (CRWR) encountered this problem when attempting to create the Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM) for the Rio Grande/Bravo basin. The development of a Raster-Network Regionalization technique for large river basins utilizing raster-based analysis at the sub regional scale in an efficient manner is one of the motivations of this research.

1.2.3 Third Motivation: Enhancement of the time series component of the ArcHydro data model

The representation of hydrologic phenomena in GIS requires the integration of geospatial data with time series. Rainfall, stream flow, nutrient loading, and stream stage are examples of hydrologic parameters that exhibit high spatial and temporal variability and, therefore, must be described with both spatial and temporal data. While the representation and visualization of geospatial hydrologic data in GIS is established practice, extending GIS to the temporal domain is a relatively new concept that introduces additional complexities (Goodall et al, 2004). The ArcHydro Time Series format can be applied to time series to include and relate them to spatial points in a geodatabase. This method results in a large base of data containing all types of time series data for various features and times. However, to accommodate large data sets and many variables such as water quality data, climatic data, and more, the data model must be extended to accommodate separate time series tables for different variables.

For the study area considered in this research, the Rio Grande, temporal information was collected from the most important American and Mexican agencies. Unfortunately these data were generated in different formats by each agency, so another motivation in the research is the enhancement of the time series component of the Arc Hydro Data Model to more efficiently store and manage large numbers of time series records using a common data schema.

1.2.4 Fourth Motivation: Sharing ArcHydro time series data with a data storage system

Even though data management and geospatial analysis solutions have been developed during the last decade, the challenge of integrating the data with models still remains. Hydrologic simulation models have existed for decades. The routines to perform hydrologic computations are well understood, and the models themselves have been validated through many years of use. However, most models are designed to operate solely as autonomous units with a specific focus, such as river channel hydraulics (Whiteaker, 2004). The concept of geospatial integration can be applied to both the integration of spatial data, and the connection of spatial and temporal data with simulation models.

In some cases, such as with the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC) HMS and RAS models, components of Interface Data Models (IDM) may overlap (i.e., the DSS time series component in the HEC models.) An Interface Data Model defines a structure for data storage, much like Arc Hydro. An Interface Data Model does not contain the simulation model itself, but rather the information that the simulation model requires prior to

execution, as well as outputs from the simulation model after execution. Thus, an Interface Data Model facilitates two-way communication between a database and a simulation model. For this reason, another motivation of this research is the development of a toolset to transfer time series data between a geodatabase and IDM, such as the HEC-DSS, in both directions. This toolset would be implemented in the ArcGIS platform.

1.2.5 Fifth motivation: Implementing a water quality data model

Since there is not any binational database that includes water quality parameters for both sides of the Rio Grande/Bravo basin and this type of database is desired, a standard structure to manage this water quality information in a relational database is fundamental. The development of a Water Quality Data Model (WQDM) based on a framework developed in Visio 2000 and exported as a schema in a Microsoft Access mdb file is another important motivation of this research. This standard framework is implemented following criteria and parameters from the International Boundary Water Commission (IBWC), Texas Commission on Environmental Quality (TCEQ), United States Geological Survey (USGS), Environmental Protection Agency (EPA), Mexican National Water Commission (CNA), and the Mexican Natural Resources and Environmental Secretary (SEMARNAT). The WQDM framework is based on the ArcHydro data model structure developed at the Center for Research in Water Resources of the University of Texas at Austin (CRWR-UT).

1.3 OBJECTIVES

The first step to improve the water management in the Rio Grande/Bravo basin is to create a geospatial database using the ArcHydro data model for the entire basin, as well as the development of a framework to manage the water quality information for this basin. This geodatabase represents the first major attempt to establish a more complete understanding of the basin as a whole, using both Mexican and U.S. data. The geodatabase is named “ArcHydro Rio Grande/Rio Bravo,” and it is possible to obtain information from the database about climatology, water availability, water uses, hydraulic infrastructure, and drainage in the basin. This binational database will permit water resources models to calculate the state of water availability under different climatic and development scenarios and management plans in the future, as well as support hydrologic analysis and modeling in this basin.

One of the most important steps in developing a geodatabase for a region is to process the digital elevation model in raster format. For the Rio Grande/Bravo basin this raster dataset is too large for normal computation procedures. This research addresses the difficulties in processing large raster datasets. One of the most important objectives of this research is the application of a GIS Raster-Network Regionalization technique, which utilizes raster-based analysis at the subregional scale and vector network-based attribute accumulation at the regional scale in order to process large regions in an efficient manner. GIS tools already exist for subdividing watersheds into hydrologic subregions. The challenge consists in applying these techniques over very large (>500,000 km²)

regions, and integrating the results of subregional analyses to produce valid results for regional analysis.

Another objective of this research is to improve the time series component of the Arc Hydro Data Model to more effectively store and manage large numbers (several million) of records using the same schema. With this improvement, users can select a specific monitoring point within the geodatabase, and based on several relationships previously established for it, they can identify the sources from which the temporal data were derived, as well as the type of variable. This new time series format is more robust and can handle millions of records distributed in dozens of variable types. The time series framework is applied to the Rio Grande/Bravo basin geodatabase to improve the management of temporal information gathered from U.S. and Mexican agencies.

A final objective of this research is to develop a methodology for transferring temporal data between the ArcHydro data model and the HEC Data Storage System (HEC-DSS). A GIS toolset is developed and implemented in the ArcGIS platform to achieve this task. Also, the communication between the geodatabase and the HEC-DSS is in two directions. This toolset enhances the ability of modelers to access the rich datasets that are now being developed in GIS relational database format.

Thus, this research will provide answers to the following four questions:

1. How can a relational database be implemented for large river basins integrating temporal and geographic information?

2. How can the results from raster-based analysis at the subregional scale be integrated into large regional datasets in a vector format?
3. How can the time series component of the ArcHydro data model store and manage more effectively large numbers of records for large river basins?
4. How can the ArcHydro data model share time series data with a data storage system, such as the HEC-DSS, for use in water resource models?
5. How can a relational data model be designed for including water quality parameters for large river basins integrating historical and geographic information?

Chapter 2: Literature Review

2.1 BUILDING A GEOREFERENCED RELATIONAL DATA MODEL

A continually increasing population, serious problems related to lack of sanitation and clean water, as well as large infrastructure investments which may not be achieving their objectives, are causing riparian governments at various levels to search for alternative water management approaches in the world. In addition, recent, long-term drought conditions have increased tensions over transboundary water sharing around the world. The institutions concerned have realized that successful water resources management requires a long term planning process from technical, economic, political, social, and environmental viewpoints. Several areas of conflict and possible negotiated remedies have been identified, but a lack of data for analyzing alternative scenarios has hampered the solutions to these problems.

Today, there is a huge amount of data gathered about the Earth, not only from new spatial information systems, but also from new and more sophisticated data collection technologies. During the last decade, data from one-meter resolution satellites or less have become available. Current information systems are becoming increasingly distributed and heterogeneous. Digital libraries are a very important part of this actual trend towards knowledge-based distributed environments.

Clearly a high proportion of the data needed for environmental management and hydrological analysis are geographic (Goodchild, 2003). Maps and atlases include huge quantities of geographic information, and geographic

data can also be found scattered through books, journal articles, and many other media. Today, increasing quantities of geographic data take the form of electronic transactions, such as the location telemetered from a gage or water quality station to a researcher doing hydrological analysis. A huge amount of geographic information are now gathered daily by imaging satellites and distributed by Internet, and increasing amount are collected by networks of ground-based sensors and through field observation. One of the most important questions is how to integrate this geographic data of different kinds at different levels of detail within a standard framework. It is widely recognized that the need to integrate information is so pressing that researchers often accept loss of detail to achieve it. A solution for this problem leads by finding a GIS architecture that can enable geographic information integration in a seamless and flexible way. To this end, it is necessary to develop a conceptual model for geographic data and its computer representation (Fonseca et al, 2002).

Environmental management has been a main motivator of developments in GIS, and a major area of application, throughout its history. The first GIS, the Canada Geographic Information System, was developed in the middle of 1960s in order to manage the vast amount of mapped information collected by the Canada Land Inventory and from it to provide data to the Government of Canada. Geographic data and GIS are of such importance to the environmental disciplines that today people tend to think of them as indispensable parts of the research, teaching, and policy arenas. A lot of applications of GIS use in this context are available in textbooks, journal, conference proceedings, and on the Internet.

In principle, a GIS can be designed to perform any conceivable operation on any kind of geographic information. Like many other computer process, its success depends on a fundamental economy of scale: Once the foundation has been built for managing geographic data, it is possible to expand the list of supported operations very quickly, at minimal cost.

Because integrated management of a river basin requires the development of models that are used for many purposes, the development of a georeferenced relational database (geodatabase) based of GIS from which models can access data needed to describe the systems being studied is primordial. The recently developed ArcHydro data model facilitates the organization of data according to the “basin” principle and allows access to hydrologic information by models in GIS (Maidment, 2002). This robust structure allows for handling huge temporal data sets related to monitoring points such as hydrometric and climatic stations, reservoir inlets and outlets, water rights, etc., integrating spatial and temporal information within a common framework. Also, ArcHydro enhances the sharing of data among different organizations. Efforts have already been carried out to incorporate Arc Hydro into national applications such as the National Hydrography Dataset (Hickman, 2002)

2.2 WATERSHED PARAMETERIZATION IN GIS

Traditionally, watershed topographic properties such as the extent, drainage area, surface gradient, and channel length have been derived manually from maps, aerial photographs and field surveys. These techniques are tedious, costly, time consuming and subject to considerable operator variance. In recent

years, the GIS technology has increasingly been employed to assist hydrologist and decision makers with the task of model parameterization (Spence et al, 1995)

Over the past 15 years, research has demonstrated the viability of techniques for automatically deriving a wide variety of topographic and topologic watershed information directly from Digital Elevation Models (DEM) (Jenson et al, 1988). This raster format provides a powerful means from which topographic parameters can be quickly and efficiently extracted that are transformed into meaningful input for hydrologic applications over a wide range of scales (Lacroix et al, 2002). DEM coupled with automated methods are available for delineating a basin, channel network and calculating a variety of hydrologic parameters such as drainage area, channel length, travel time, etc. (Tribe, 1992). The automatic derivation of watershed data is faster, less costly and more reproducible than traditional, manual techniques and provides data in digital form that can be readily imported and analyzed by GIS. Several tools based on ArcView 3.2 software have been developed at the US Geological Survey's EROS Data Center to extract topographic information, to delineate sub basins and to generate drainage lines from DEMs. These tools were developed with general-purpose raster and vector spatial analysis and relational data base management packages. The first phase of analysis considers a reconditioning phase that generates three main results: the original DEM with depressions filled (filling the sinks), a raster including the flow direction for each cell of the DEM, and a flow accumulation raster in which each cell receives a value equal to the total number of cells draining to it. Garbrecht and Martz (1993) developed the model DEDNM for

automating extraction of channel network and subwatershed characteristics from DEM. This model can process DEM data of limited vertical resolution representing low relief terrain. The case study area was a low relief watershed of 84 km² in southwestern Oklahoma. The standard for validation is the network and subwatershed parameters defined by the blue line method on USGS 7.5-minute topographic maps. Evaluation of the calculated and validation networks by visual comparisons shows a high degree of correlation.

Liu et al (2004) describe the development of a comprehensive subwatershed parameterization method for medium and large-scale basin modeling based upon the fully distributed WetSpa model. This model combines elevation; soil and land use data within ArcGIS framework, and predicts the flood hydrograph and water balance over a river basin. The method was applied to the Alzette River basin, an 1176 –km² medium size watershed in the Grand-Duchy of Luxembourg.

The parameterization of a large-scale hydrological model for a forested region in Australia is described by Watson et al (1996). Using the Geographic Resources Analysis Support System (GRASS), a range of topographic, vegetative, and climatic parameters were mapped over the region. A regional DEM was validated and shown to give an excessively smooth representation of the terrain which influences moisture distribution predictions. Precipitation was mapped using both elevation lapse rates and a more data-intensive 3D spline interpolation, the latter proving more appropriate.

2.3 HYDROLOGIC ANALYSIS IN LARGE WATERSHEDS: A RASTER-NETWORK REGIONALIZATION TECHNIQUE

Watershed modeling of relatively small catchments with high-resolution DEM has been the dominant practice in the past. In recent years more attention has been given to modeling regional scale drainage basins to study various aspects of global water and energy exchanges (Kite, 1995). Armstrong and Martz (2003) encountered the direct segmentation and parameterization of such large basins ($> 10^5 \text{ Km}^2$) from high-resolution DEM is limited, as it would result in unmanageable volumes of data and severe computational demands. They examined the effects of increasing grid-cell size on the delineation of drainage boundaries and drainage networks, and derived topographic variables for several regional and continental-scale drainage basins. Two continental-scales DEM with a horizontal resolution of 1 km are initially extracted from the HYDRO1k DEM of North America. These initial DEMs are then averaged to generate several coarser resolution DEMs to assess the impact of increasing grid size on basin boundaries, drainage networks and several topographic variables commonly used in hydrologic modeling and water resources management. The digital terrain analysis model TOPAZ (Garbrecht and Martz, 2000) is used to segment and parameterize the initial and aggregated DEMs of the Mackenzie and Missouri River basins that are located in northwestern of Canada and the USA, respectively. As is often the case, the best available elevation data were already in raster format and independent stream and river data consistent with the topographic data were not considered for this study.

For large watersheds, the raster data is too huge to be analyzed as one entity. This problem is solved by subdividing the river basin into sub basins. The Hydrological Cataloging Units (HUC) from the United States Geological Survey (USGS) 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 hydrological modeling. The values from each subbasin can be cascaded downstream to get the final parameters for the control points for the entire basin (Figurski, 2001)

Streit and Kleeberg (1996) identified the spatial scaling as the main problem of transferring hydrological information between spatial objects, and used regionalization to deal with this issue. The regionalization of hydrological information requires the acquisition, management, analysis and cartographic presentation of large hydrological data sets. Therefore, the application of the GIS technology is an essential prerequisite. However, Streit and Kleeberg also recognized that regionalization may introduce errors into the data.

Funke and Schumann (1999) described a regionalization method for parameterization of mesoscale hydrological models. The aim of the method is a controlled parameterization of a conceptual model from known catchment characteristics within a larger region like a river basin. Since the hydrological model describes most of the relevant processes physically, most parameters can be derived directly from catchment characteristics utilizing a GIS. This

regionalization method was successfully applied to a rainfall runoff model and tested in seven gauged catchments in a river basin of 840 km².

Abrahart et al (1996) developed an application which divided a study basin into sub-basins for use in MEDRUSH, a GIS combined with distributed process model designed to simulate hydrologic and vegetative processes important in studying desertification. Each sub-basin contains a set of flow-strips, in which hydrologic simulations occur. The total output from each flow-strip in a basin is converted to water and sediment output for that basin. Each basin feeds its total output to the stream network, where information is accumulated in the downstream direction. The application may operate on basins up to 5000 km² in area.

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 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 Water Right Analysis

Package (WRAP) model, developed at Texas A&M University under the supervision of Dr. Ralph Wurbs, was chosen by the TCEQ as the new Water Availability Model for modeling the main river basins in Texas. The WRAP is a water allocation 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 (Wurbs, 2001).

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 TCEQ. The contract between the CRWR and the TCEQ for the WAM process began in 1997. Watershed parameters mentioned above have been determined for 23 river basins in Texas, including the binational Rio Grande/Bravo basin.

Hudgens and Maidment (1999) developed a set of ArcView GIS tools to calculate certain input parameters for the WRAP model based on geospatial data. The GIS tools were packaged as an ArcView 3 project file called WRAP 1117. The WRAP 1117 project file contains Avenue scripts linked to a series of menus and menu items. This toolset prepares the data for extraction of watershed parameters and then perform the data extraction. To prepare the stream network, a tool draws the stream network path taken across the DEM. Another 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. The drainage area value over a given point is simply the number of cells accumulated to that point, times the area of each cell. A weighted flow accumulation is used to determine the average curve number and mean annual precipitation over a given point. Thus, those three parameters are calculated for every single cell over the extent of the DEM, and the value for a given control point is found by picking up the grid cell value for the cell underneath that control point. The connectivity of control points is determined by identifying the next downstream control point in the stream network. Once the parameters are calculated for all control points, the results are then input to the WRAP model (Hudgens and Maidment, 1999).

The WRAP 1117 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 raster size (Hudgens, 1999). So even though this methodology provides useful tools for performing watershed analysis, scalability problems arise when it is applied to large river basins or using a better raster resolution; e.g. in basin with more than 150 million in a raster dataset, processing demands may exceed a computer and software capabilities.

Mason (2000) developed and revised a procedure to create watershed parameters from GIS data and completed parameter sets for six river basins in Texas. The method works well for small datasets, but when using 30-meter DEM data, the grids for some of the remaining WAM basins are too large to efficiently apply the existing procedures necessitating a new approach for developing watershed parameters for these large basins.

Gopalan (2003), Whiteaker (2004), and the author developed a new hydro data model called WRAPHydro specifically for the WRAP model. WRAPHydro utilizes a GIS to store geospatial inputs required to calculate parameters for WRAP such as drainage area, average Curve Number, and average precipitation referred to specific control points previously defined. WRAPHydro data model is considered as an ArcHydro-based Preprocessing data model and provides a very organized and structured platform to work on. The process becomes more systematic and easy to manage by dividing it in three parts: base data acquisition, preprocessing and actual parameter development on raster and vector side. Gopalan applied the WRAPHydro data model and the WRAPHydro toolset developed by Tim Whiteaker (2004) to determine watershed parameters for the

Guadalupe Basin, which cover 15,462 square miles, or roughly 17 million raster cells at a 30 meter by 30 meter cell size. As a test case, this basin was divided in four hydrological subregions, with an outlet called HydroJunction on the stream network for each watershed. The accumulation and consolidation tools were used to attribute HydroJunctions with total upstream drainage area. This work also validated the division of a basin into sub regions for a more efficient processing of parameters. The values obtained by this regionalization technique for upstream area for each control point were compared with the USGS area values and it was observed that they were similar.

2.4 PROPOSED CONTRIBUTIONS

One of the basic proposed contributions of this research is to introduce a GIS framework that can enable geographic information integration in a seamless and flexible way. This integration considers spatial and temporal information included in a standard relational data base implemented in GIS that is applied in basins larger than 100, 000 km².

Another proposed contribution is the development and application of a raster-network regionalization technique. This methodology allows a large river basin to be divided into hydrological distinct subregions where raster analyses may be performed in a feasible manner.

The enhancement to the time series component of the ArcHydro data model developed at the Center for Research in Water Resource (CRWR) of the University of Texas at Austin is considered another important contribution. With

this improvement, a relational database implemented in GIS would be able to store and manage millions of records related to some geographic features.

Sharing time series data with a data storage system is another proposed contribution. A toolset is developed and implemented in GIS to transfer million of records automatically from the ArcHydro data model toward a Data Storage System (DSS) file. The communication is established in both directions.

The development of a data model framework for storing water quality parameters is another proposed contribution. This framework is designed in Visio 2000 and exported as a schema in a Microsoft Access file in order to be applied to any empty relational database, generating automatically the structure and relationships of the water quality data model.

Chapter 3: Description of the case study area

3.1 GEOGRAPHY AND HYDROLOGY

The Rio Grande originates in the San Juan Mountains of southern Colorado. Flowing 858 kilometers from its headwaters and through the state of New Mexico, it enters Texas about 12 kilometers northwest of El Paso and then continues 2034 kilometers to the Gulf of Mexico (Patino et al, 2004). Figure 3.1 shows the total length of the river, as well as the political division of the Rio Grande/Bravo basin that includes the Hydrologic Unit Cataloging (HUCs) on the U.S.A. side and Cuencas and sub-Cuencas on the Mexican side.

The Rio Grande is the fifth longest river in North America (2892 Km), and among the 20 longest rivers in the world. The river carries little water compared to other rivers of its length. For this reason, it has been classified by the Encyclopedia of Water in the West (2002) as an exotic stream, which means that it tends to shrink in size as it flows downstream. This is typical of rivers that pass through arid regions. Most precipitation in the basin falls at either end of the river, as snow near its headwaters or as rain near its mouth.

The river collects rain, snowmelt and spring water from an area about 557,722 square kilometers including closed basins. The whole basin includes three states on the U.S. side (Colorado, New Mexico, and Texas), and five states on the Mexican side (Chihuahua, Coahuila, Durango, Nuevo Leon, and Tamaulipas). From the basin area, 225,380 Km² lies on the Mexican side and 242,994 Km² on the U.S. side, without considering closed basins (Patino et al, 2004)

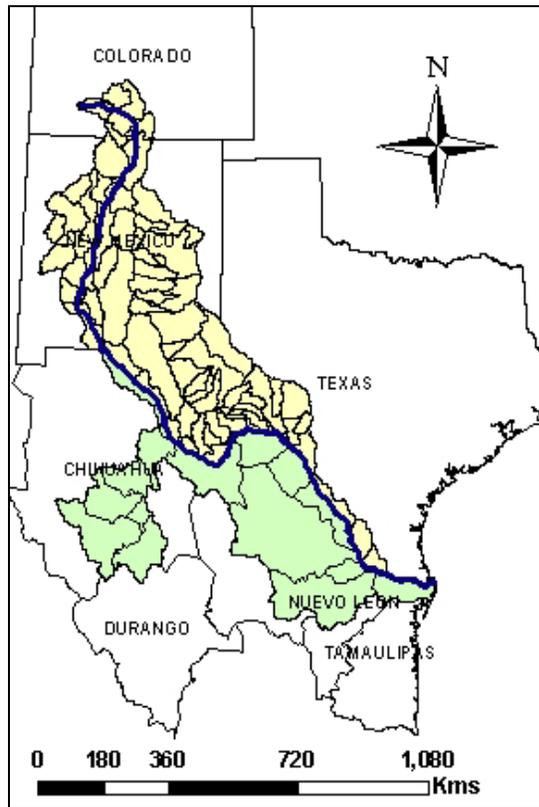


Figure 3.1: Political division of the Rio Grande/Bravo basin

Traditionally the Rio Grande/Bravo basin has been divided in two sub basins, the Upper Rio Grande Basin that includes Colorado, New Mexico, and part of Texas, and the Lower Rio Grande Basin (LRGB) that includes parts of the state of Chihuahua, Durango, Coahuila, Nuevo Leon, Tamaulipas, and Texas. The LRGB, from El Paso/Ciudad Juarez to the Gulf of Mexico, including the Rio Conchos and Pecos sub-basins, is the case study area for this research. This area encompasses the drainage of all major tributaries downstream of El Paso and Ciudad Juarez. The portion of the basin that lies in this study area is known in Mexico as the Cuencas Del Rio Bravo del Norte.

A part of the Rio Grande basin lies within North America's largest desert, the Chihuahua Desert. Mexico irrigates about 1.1 million acres in the basin, while the United States irrigates about 993,000 acres. Only 98,000 acres of irrigated land in the Rio Grande basin lie upstream from Texas (The Alliance for the Rio Grande Heritage et al, 2000). The Conchos, San Pedro, San Rodrigo, Alamos, and San Juan Rivers are the primary tributaries in Mexico. The Pecos and Devil Rivers are the principal tributaries to the river in Texas (Figure 3.2).

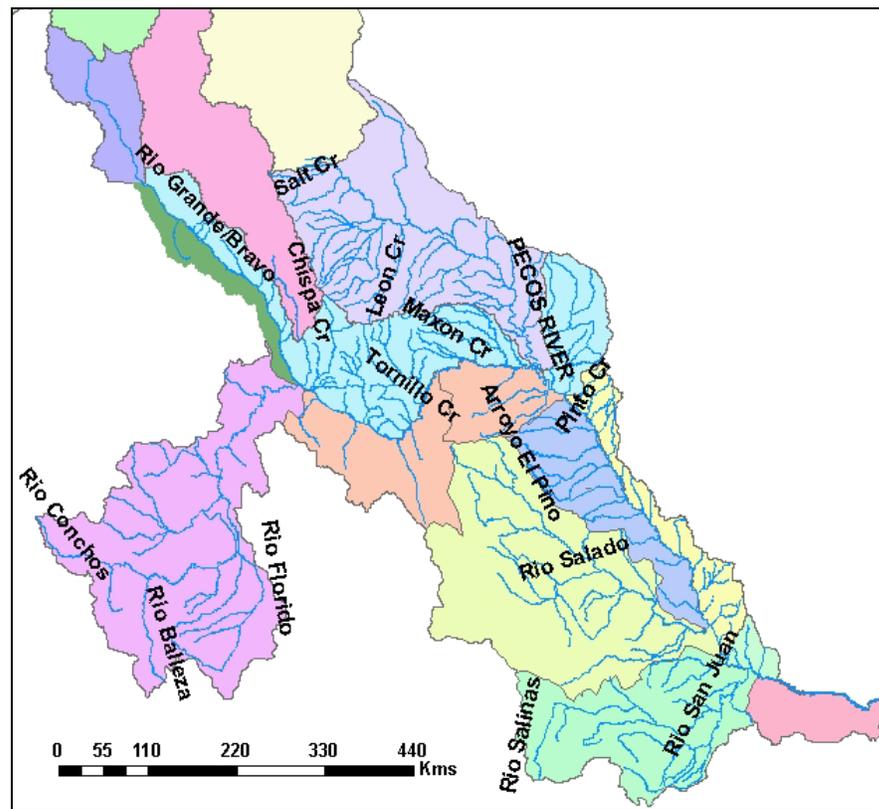


Figure 3.2: The primary tributaries in the Rio Grande/Bravo basin

The Rio Grande/Bravo basin is considered an arid to semi-arid region, dominated by agriculture and with limited supplies of both surface and groundwater. Average rainfall in the basin ranges from 200 – 900 millimeters with the highest values in the upper basin of the Rio Conchos (Patino et al, 2004). The Rio Conchos enters to the Rio Grande/Bravo near Presidio, Texas, just upstream of Big Bend National Park and Ojinaga, Mexico; in a region of mountains and canyons. The basin ranges from arid and suitable for crops, to semi-arid and hospitable to some crops only. Along the entire river, water lost through evaporation exceeds water gained from precipitation. The Lower Valley serves as temporary or permanent home for hundreds of bird species, and the river contributes vital fresh water to its gulf estuary (Tate, 2002). According to values reported by the Mexican National Water Commission in 2003, in most part of Mexico the precipitation occurs during the summer season. It is very low during the rest of the year (Table 3.1). These average values were generated using a record period from 1941 – 2001.

Administrative region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
I Península de Baja California	20	16	13	4	1	1	13	33	38	12	10	20	181
II Noroeste	22	18	11	4	4	15	88	92	50	22	15	27	368
III Pacífico Norte	29	15	8	5	9	65	173	181	140	49	23	34	731
IV Balsas	12	6	5	10	39	167	187	185	197	91	19	11	929
V Pacífico Sur	10	7	7	17	66	207	201	208	253	108	25	10	1 119
VI Río Bravo	14	12	8	16	28	45	65	73	77	36	14	15	403
VII Cuencas Centrales del Norte	12	7	4	9	21	49	75	70	70	30	11	12	370
VIII Lerma-Santiago-Pacífico	20	8	5	6	18	138	227	228	216	81	19	15	981
IX Golfo Norte	20	14	18	35	68	112	109	119	154	72	25	20	766
X Golfo Centro	58	44	40	52	89	238	279	268	324	214	108	74	1 788
XI Frontera Sur	60	48	51	79	198	348	293	328	419	307	115	74	2 320
XII Península de Yucatán	40	25	26	36	84	167	155	165	198	136	65	41	1 138
XIII Valle de México	10	5	9	23	54	134	160	155	135	60	15	7	767
Country	26	18	15	19	40	103	138	137	141	74	32	29	772

Table 3.1: Average monthly precipitation in mm for the Mexican administrative regions

3.2 TREATIES AND WATER RIGHTS

Mexico and the United States have two treaties, signed in 1906 and 1944, and various cooperative regulations that govern allocation of the water resources they share. The two nations compromised in 1906 Convention for the Equitable Division of the Waters of the Rio Grande for irrigations purposes, in which Mexico agreed to the development of Elephant Butte Dam that was completed in 1916 in New Mexico, and the United States committed to providing Mexico with 74 million cubic meters annually of the waters of the Rio Grande/Bravo, and specified a monthly schedule with which this water was to be delivered to Mexico's Acequia Madre above Ciudad Juarez, Mexico (IBWC, 2004). The U.S. constructed Elephant Butte dam to facilitate these deliveries. It is important to note that this agreement contains a provision specifying that in the event of drought, water deliveries to Mexico may be reduced in the same proportion as delivery to U.S. users in that stretch of the river is reduced.

The volumes specified in the treaty are so small that fulfilling them posed no apparent problems for the first 30 years the Convention was in force. The records registered from 1924 to 1937 showed that nearly one third of the river's average flow of 709.3 million cubic meters was left over after all U.S. and Mexican consumption. When the U.S. Caballo dam and American canal were opened in 1938, water users on the U.S. side suddenly were able to take 80 percent of the river at once. The U.S. Bureau of Reclamation regulates the amount of water released from Caballo and Elephant Butte reservoirs in New Mexico, about 100 miles upstream from El Paso/Ciudad Juarez.

Water for use on the U.S. side of the border is diverted into the American Canal at El Paso, 326 million cubic meters annually; while Mexico diverts part of the remainder through the Acequia Madre, 63 million cubic meters. The Mexican canal is empty from mid-September through mid-March as the initial river flow drops to less than 12.3 million cubic meters per month. However, the United States continues to divert an average of 9.3 million cubic meters per month during this period. For the rest of the year, Mexico takes an average of 10.7 million of the 19.6 million cubic meters per month remaining in the river after diversion by the United States. The Acequia Madre does have the capacity to carry more water, but only if the flow is consistently high. Otherwise, Mexico is limited day-to-day and month-to-month by the amount of water diverted by the United States two miles upstream.

Unusually, during high-water years when Mexico should have gotten more water, it did not. Has the United States been intentionally holding Mexico's allotment to no more than the level called for in the 1906 Convention? Or has Mexico not been taking the water even though it has been available? A little of both! The U.S. practice of not sharing extra water with Mexico began soon after the opening of the American Canal and its diversion dam in 1938. Mexican officials attribute these cases to the fact that the Acequia Madre Canal is old and small; during days of extremely high flow, Mexico has to let water go undiverted because the canal is full to capacity. Even if the United States were to practice more equitable apportionment of the river, Mexico would have to expand the

capacity of the Acequia Madre Canal in order to capture additional water (Eaton and Hurlbut, 1996).

Whereas surface water allocation is governed by a bilateral agreement, groundwater use is limited only by the ability of each side to pump it to the surface. The once rich aquifers in the El Paso/Ciudad Juarez area are being depleted so quickly that severe and chronic shortages are likely to occur within the next 40 years.

The city of El Paso Texas has already begun to implement conservation measures to delay future groundwater shortages. Actually, the water consumption is falling 1 percent per year, but withdrawals in Ciudad Juarez are increasing by about 5 percent every year as the city tries to keep pace with its rapidly expanding population. Both cities take water from the same aquifer system, so the speed with which Ciudad Juarez extracts water will affect the amount of water available for El Paso (SCERP, 2002).

In 1944, the United States of America and Mexico signed a new treaty establishing cooperative regulation and apportionment of the Rio Grande from Fort Quitman to the Gulf of Mexico. The pact establish two international reservoirs, Amistad reservoir, completed in 1968 with a total controlled capacity of 6.5 billion cubic meter, and Falcon reservoir, completed in 1953, with a capacity of 4.9 billion cubic meters, located 128 kilometers below Laredo, Texas. These dams and other water projects controlled the floods and allowed farming to the flourish along the river. According to this treaty, each country receives half of the water in the main stem of the Rio Grande, and full use of the waters in their

tributaries (US Department of State, 1946). However, there was an important exception to this last agreement: the treaty provides that one-third of the flow reaching the main channel of the Rio Grande/Bravo from the Rio Conchos, San Diego, San Rodrigo, Escondido and Salado and the Las Vacas Arroyo is allocated to the United States, provided that this third shall not be less, on average in cycles of five consecutive years, than 431 Mm³/year (350,000 acre-feet per year). The vast majority of this water comes from the Conchos basin, as flow in the other tributaries is minimal during much of the year. In exchange, Mexico receives 1,846 Mm³ (1.5 million acre-ft) from the Colorado River further west on the international border. In case of drought, deficits from Conchos deliveries can be made up over the following five-year period. As a result, the United States holds rights to 58 percent of the Lower Rio Grande/Bravo water, with the remaining 42 percent going to Mexico.

About 98 percent of all Laredo's water needs -municipal and industrial as well as agricultural- are currently supplied by surface water. Laredo will be able to find enough water to meet municipal needs by purchasing water rights from agricultural users upstream, but this acquisition is expected to contribute to the irrigation shortfall predicted by 2040. Due to the growing population, and without conservation measures in the McAllen/Reynosa area, water quantity problems could become severe. McAllen's population is growing by 3 percent annually, while Reynosa is growing by 2.5 percent (Eaton, 1996). Quantity problems in the Brownsville/Matamoros area are similar to those faced by McAllen/Reynosa. Groundwater is generally not a feasible alternative to surface water because the

region's aquifers are highly saline, recharge slowly, and are susceptible to subsidence.

Diversions from the river below Falcon dam go primarily to agriculture. Mexico relies on the Anzalduas channel dam near Hidalgo and Reynosa to divert the bulk of its appropriation to an irrigation canal system. Both Mexico and the U.S. divert about the same amount of water from the river. Water management infrastructure efficiency is low in this zone, because of the infrastructure and the natural conditions of the earthen Anzalduas canal, and because the largest irrigation district (250,000 ha) in northwestern Mexico is located in this area.

Despite the tremendous economic growth that has taken place in the region since the treaties were signed, the two operative international agreements governing water allocation in the Rio Grande basin continue to be the 1906 convention and 1944 treaty.

3.3 PROBLEMATIC AND CURRENT CONDITIONS

The Rio Grande/Bravo is a transboundary water source shared by the United States and Mexico. At this time, Mexico is in the process of improving its ability to develop and implement efficient management plans for the water in the Rio Grande/Bravo basin, taking into account the new developments in Mexican water law and the existing infrastructure and methods of application and distribution of water. A continually increasing population, serious problems related to lack of sanitation and clean water, as well as regular high investments in infrastructures which are not achieving their objectives, are likely to force governments at various levels to search for alternative approaches, other than

relying only on engineering solutions through supply management alone. The institutions concerned are aware that successful water resources management requires a long term planning process from technical, economic, political, social, and environmental viewpoints. Table 3.2 shows the population and the municipalities identified in the administrative region Rio Bravo and reported by the Mexican National Water Commission (CNA, 2003)

Administrative region	Surface (thousands of Sq Km)	Population in millions (Until Dec 2001)	Population density 2001 (hab/km ²)	Municipalities until 2002
I Península de Baja California	146	3.06	21	10
II Noroeste	205	2.40	12	79
III Pacífico Norte	152	3.88	26	51
IV Balsas	119	10.26	86	422
V Pacífico Sur	77	4.02	52	358
VI Rio Bravo	380	9.73	26	141
VII Cuencas Centrales del Norte	202	3.83	19	83
VIII Lerma-Santiago-Pacífico	190	19.42	102	327
IX Golfo Norte	127	4.79	38	154
X Golfo Centro	105	9.30	89	443
XI Frontera Sur	102	6.03	59	139
XII Península de Yucatán	138	3.35	24	124
XIII Valle de México	16	20.07	1 222	115
Country	1 959	100.14	51	2 446

Table 3.2: Population and municipalities in the Rio Bravo region

In addition, some decisions about water management are only partially supported, causing alterations in the global ecosystem. For this reason it is necessary to improve the administration and management of water in this watershed. This requires an assessment of water availability and the means to manage it appropriately for agriculture, industry and other services, also taking into account ecosystem preservation. Table 3.3 shows some reference values about the water availability in the Rio Bravo administrative region on the

Mexican side and reported by the CNA. Users must consider other factors to calculate water right permits or feasibility of a new project.

Many specialists have accepted Swedish hydrologist Malin Falkenmark's threshold of water stress for a region or country as less than 1,700 m³ of renewable runoff per person per year and water scarcity as 1,000 m³/person/year (Falkenmark, 1989). Rio Bravo below water stress index of 1700 m³/person/year (Table 3.3).

Administrative region	Naturalized Flows (Mm ³)	Average recharge of aquifers (Mm ³)	Average naturalized availability (Mm ³)	Population until 2001 (habitants)	Avg Naturalized availability per hab (m ³ /hab)
I Península de Baja California	3 012 ^(a)	1 413	4 425	3 062 644	1 445
II Noroeste	5 459	2 498	7 957	2 387 111	3 333
III Pacífico Norte*	21 879	2 581	24 460	3 883 887	6 298
IV Balsas	24 944	3 967	28 911	10 260 389	2 818
V Pacífico Sur	31 468	1 667	33 135	4 023 604	8 235
VI Rio Bravo	9 204	5 063	14 267	9 728 346	1 467
VII Cuencas Centrales del Norte	4 729	2 094	6 823	3 827 186	1 783
VIII Lerma Santiago Pacífico*	29 652	7 156	36 808	19 418 978	1 895
IX Golfo Norte	22 355	1 274	23 629	4 787 779	4 935
X Golfo Centro	98 930	3 615	102 545	9 301 075	11 025
XI Frontera Sur*	139 004	16 934	155 938	6 034 090	25 843
XII Península de Yucatán*	1 348	25 148	26 496	3 353 753	7 900
XIII Valle de México	1 996 ^(b)	1 809	3 805	20 072 335	190
Country	393 980	75 219	469 199	100 141 177	4 685

Table 3.3: Water availability in 2001 on the Mexican side of the Rio Grande/Bravo basin

According to the Monograph No. 2 published by the Southwest Center for Environmental Research and Policy (SCERP), repeated usage of river water for irrigation in the Rio Grande/Bravo basin has degraded the quality of the water by increasing the salinity. During periods of high discharge, the water quality meets water standards and can be used the basin. However, during periods of flow discharge, including the non-irrigation season (October-March) and droughts, the

salinity increases to the point that the water is not longer usable for domestic purposes.

Recent drought conditions have increased tensions over water sharing in the Rio Grande basin. Several areas of conflict and possible negotiated remedies have been identified, but there is a lack of data available to use in analysis of alternative solutions to these problems. Figure 3.3 depicts the water uses in the Rio Grande/Bravo basin on the Mexican side.

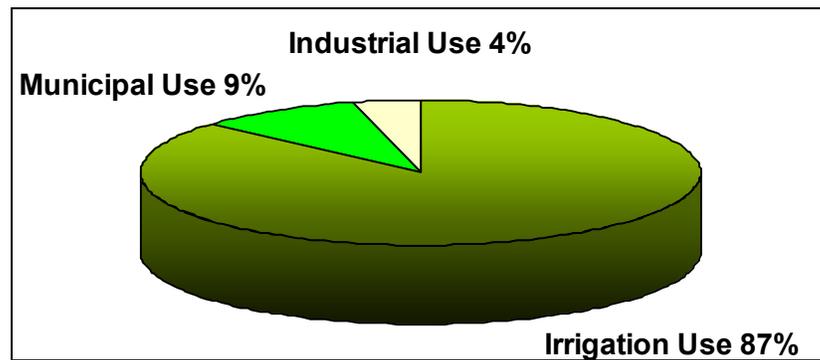


Figure 3.3: Water uses in the Rio Bravo basin estimated in 2001

Chapter 4: Methodology

4.1 RELATIONAL DATABASE FOR LARGE BASIN SCALE

The Center for Research in Water Resources (CRWR) of the University of Texas at Austin, the Mexican Institute of Water Technology (IMTA), the National Water Commission (CNA) of Mexico, with support from the Texas Commission on Environmental Quality (TCEQ) and the North American Development Bank (NADBANK) have cooperated in order to build a binational hydrologic information system, which can be used to support hydrologic analysis and modeling in the Rio Grande/Bravo basin (Patino et al, 2004). This dataset consists of an ArcHydro-based Geographic Information System and relational data base containing geographic, hydrologic, hydraulic and related data for the basin from the United States and Mexican sides, as shown in Figure 4.1. It will assist in developing bi-national cooperation between Mexico and the United States concerning water in this basin, providing accurate and reliable data necessary for analysis and resolution of water resources issues. Information collected in the project from both Mexican and U.S. agencies did not have the same features and presented some errors, especially in the river system dataset. This information has been processed and re-projected in order to use the same characteristics for the whole basin, creating several classes of data features (feature classes) contained in a geographically referenced database (i.e., a geodatabase). The concept of regionalization is introduced in order to divide the basin into several hydrological subregions, so grid cell-based (or raster) data sets were decomposed into smaller,

more manageable sizes to avoid computer memory and processing time difficulties when the geodatabase was developed.

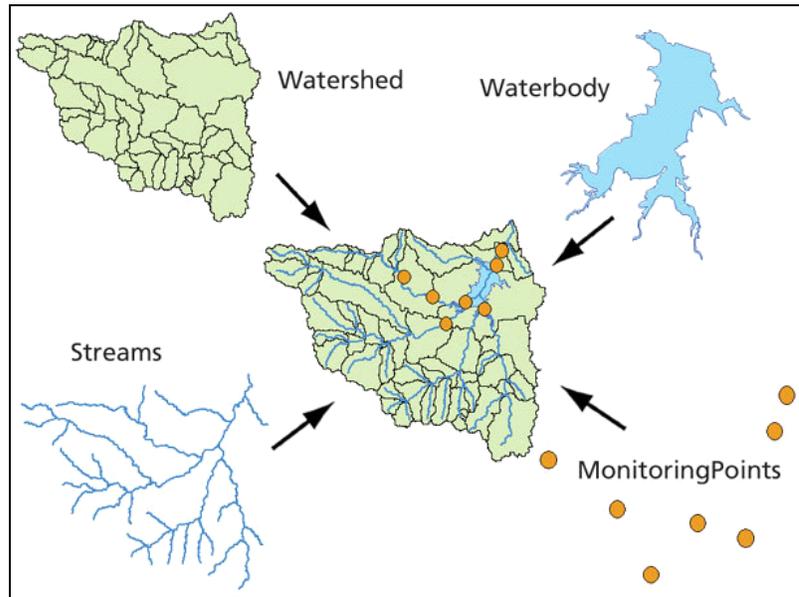


Figure 4.1: Relational integration of thematic layers in the ArcHydro data model (Maidment, 2002)

4.2 DATA COLLECTION

4.2.1 Geographic information

Hydrological information was obtained from Mexican and U.S. agencies for this research. The political boundaries, river network, water bodies and gauging stations on the Mexican side were collected from the National Water Commission (CNA), the Mexican Institute of Water Technology (IMTA), the University of Ciudad Juarez (UACJ), the Comision Internacional de Limites y Aguas (CILA), and the National Institute of Geography and Information (INEGI). The information for the U.S. side was obtained from the U.S.

Geological Survey (USGS), the Texas Commission on Environmental Quality (TCEQ), the International Boundary Water Commission (IBWC), and the Texas Natural Resources Information System (TNRIS), among others agencies. This original information came in several formats, so it had to be manipulated and transformed in order to generate the feature classes that would be part of the feature datasets within the relational database. Also, errors were found in some of the hydrological information such as incorrect positions of some monitoring and control points, disconnected river reaches, incorrect location of some water bodies, so it had to be edited in order to fix these errors using the ArcGIS software. Part of the original geographic information is shown in Figure 4.2.

The Mexican agencies usually use the Geographic Coordinate System and Lambert projection to create their geographic information. The Albers equal area projection was proposed for this project in order to preserve the areas for hydrological modeling. The Datum chosen was the NAD Datum 1983 that is the standard datum accepted around the world; the Geographic Coordinate System corresponds to the GCS_North_American_1983, while the Central Meridian is located at -103 degrees, near the center of the basin.

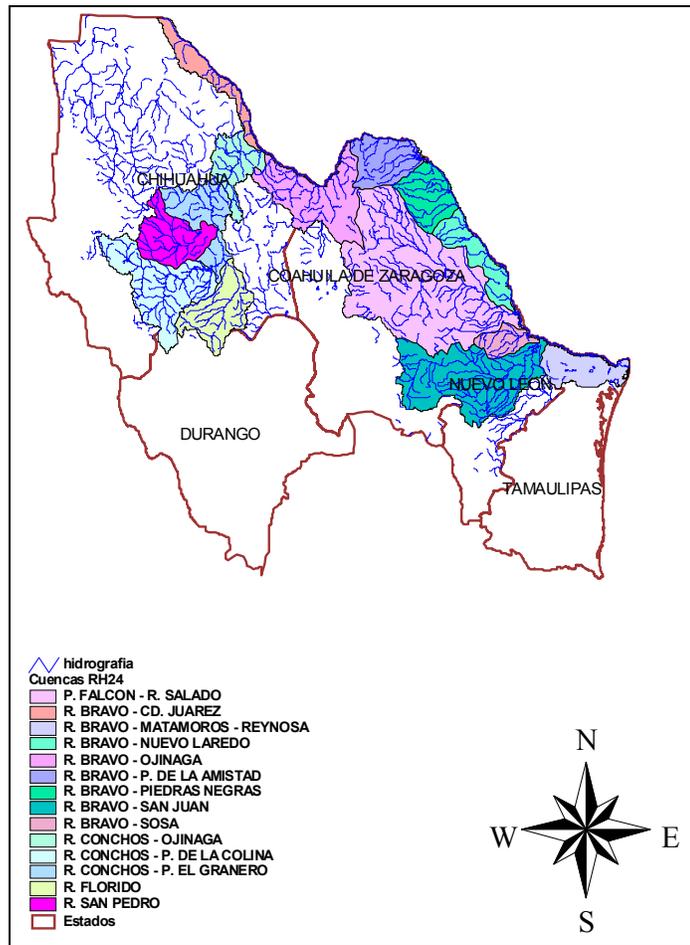


Figure 4.2: Cuencas, Sub Cuencas and original hydrography of the Rio Bravo basin on the Mexican side

4.2.2 Obtaining time series data for the basin

Temporal information was collected from the most important American and Mexican agencies to be included in the Rio Grande/Bravo basin geodatabase. Unfortunately it was generated in a different format by each agency. Climatic and hydrological time series data were collected and imported from the BANDAS, ERIC (on the Mexican side), and NWIS (on the U.S. side) systems corresponding

to monitoring points located in the Rio Grande/Bravo basin. Average annual precipitation was obtained from 230 climatic stations located on the Mexican side. Around 2100 control points among water rights, hydrometric stations, water diversions, return flow points, etc., were identified in the whole basin. Almost five million records related to these points will be included in the geodatabase (Figure 4.3)

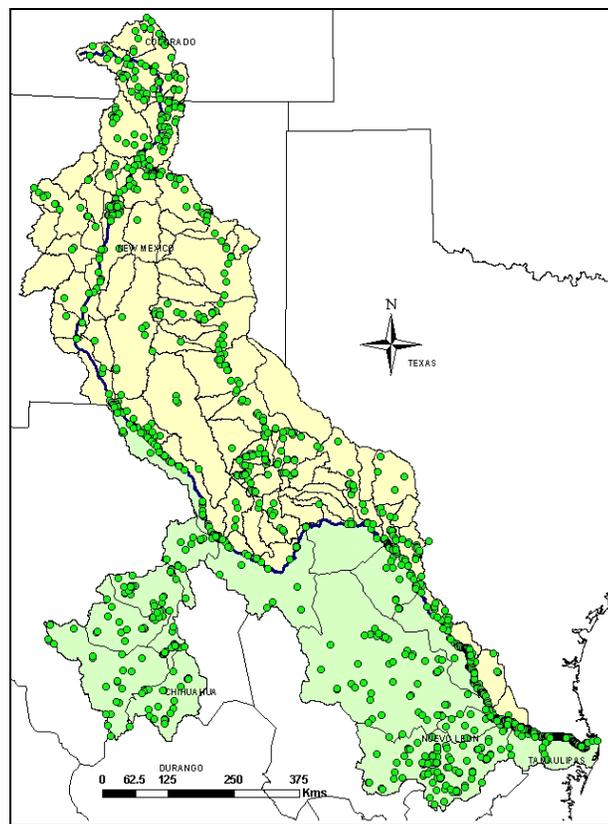


Figure 4.3: Control Points identified in the Rio Grande/Bravo basin

The data collected from the original sources are included in Table 4.1, as well as some of the data characteristics.

Description of data	Mexico	USA
Political boundaries. States included in the Rio Grande basin. Source: U.S. Department of Transportation. Scale: 1:250K. Original format: GIS shapefile	Available	Available
Basin Delineation. HUCs and Mexican Cuencas. Source: USGS for the U.S. side (1:100K as GIS coverage); IMTA, INEGI, CNA, and UACJ for the Mexican side (1:250K as GIS shapefile)	Available	Available
Hydrography. Stream network. Source: USGS for U.S. (Scale 1:100K as GIS coverage). IMTA, CNA, INEGI, and UACJ for the Mexican side (Scale 1:250 K as GIS shapefile).	Available	Available
Water Bodies and dam locations. Source: USGS- HUCs for the U.S. side (1:100K as GIS coverage). IMTA, CNA, INEGI, and UACJ for the Mexican side (1:250K as GIS shapefile)	Available	Available
Monitoring point's location. Source: USGS, TCEQ, and IBWC for the U.S. side (original format: Excel table). CNA, IMTA, and CILA for the Mexican side as hydrometric and climatic stations (Original format: dbase tables).	Available	Available
Historical hydrometric information (time series). Sources: National Water Information System (NWIS) and the IBWC for the U.S. side (1940 – 2000). CNA, IMTA, and CILA for the Mexican side. Part of this information is included in the BANDAS software developed by the CNA that includes 67 hydrometric stations located in the Rio Grande/Bravo basin on the Mexican side.	Available	Available
Climatologic information (time series). Sources: USGS and PRISM for the U.S. side. IMTA and CNA for the Mexican side. This information is included in the ERIC System (230 climatic stations on the Mexican side operating until 2002.)	Available	Available
Digital Elevation Model (DEM). Source: USGS for the U.S. side. Resolution: 30 m of cell size (seamless format). Source on the Mexican side: INEGI. Cell size: 104 m	Available	Available
Control Points (Include water rights, return flow points, diversions, etc). This information was obtained from the TCEQ on the U.S. side; and from the CNA for the Mexican side. This information was available as a shapefile in ArcView 3.2	Available	Available

Table 4.1: Summary of the original data collected for the Rio Grande/Bravo basin

4.3 DEVELOPMENT OF THE GEOSPATIAL DATABASE

The development of a watershed-scale database is fundamental to analyzing water resource management problems in the basin. Even though separate research efforts have been carried out on each side of the river, there has not been an integral database that includes data from both sides of the Rio Grande/Bravo basin. As in many watersheds, knowledge and information available about the Lower Rio Grande/Bravo basin is fragmented, disjointed, incomplete, and sometimes inaccurate. Integrated management of a river basin requires the development of models that are used for many purposes, e.g., to assess risks and possible mitigation of droughts and floods, manage water rights, assess water quality, and simply to understand the hydrology of the basin. For this purpose a database is needed from which models can access the various data needed to describe the systems being modeled (Figure 4.4). In other words, a database from which models read input data and to which they write output data. In order for this concept to work, however, it must have a standard design.

ArcGIS uses an object-oriented data model called the geodatabase data model. This data model gives the features in the GIS datasets custom behaviors and the possibility to create relationships between features. In general, a geodatabase model provides a standardized framework into which various types of data can be loaded. Once created, the geodatabase is a Microsoft Access file called an ArcGIS personal geodatabase.

The recently developed ArcHydro data model facilitates access to hydrologic information by models (Maidment, 2002). This model consists of a

geographic database (geodatabase) to describe an integrated collection of geographic information. Geodatabases are managed using ArcGIS software and can store and retrieve virtually any type of spatially and temporal reference data with high performance in a multi-user and single-user environment. Geodatabases manage all the basic geographic data types, including simple feature vector data types as points, lines, and polygons, as well as more advanced features that use rules for defining relationships, topologies, and behaviors of features. Also, historical information related to gage, water quality or climatologic stations can be included in the geodatabase, so user can have an integration of temporal and geographic information in the same structure.

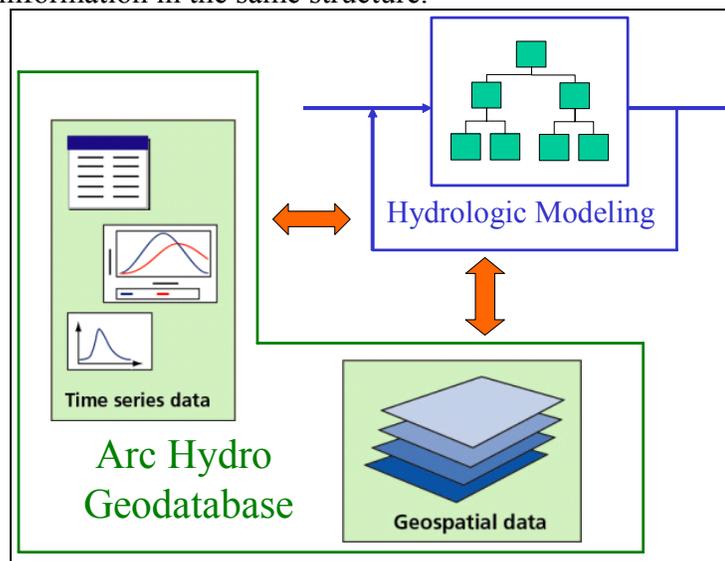


Figure 4.4: Hydrologic Information System (Maidment, 2002)

Creating the ArcHydro geospatial database for the entire Rio Grande/Rio Bravo basin represents the first major attempt to establish a more complete understanding of the basin as a whole, using both Mexican and U.S. geospatial

and temporal data for water resources. It is possible to obtain from the database information about climatology, water availability, water uses, hydraulic infrastructure, and drainage in the basin that are included as feature classes within the relational database (Figure 4.5). These data will permit models to calculate the state of water availability under different climatic and development scenarios and management plans in the future.

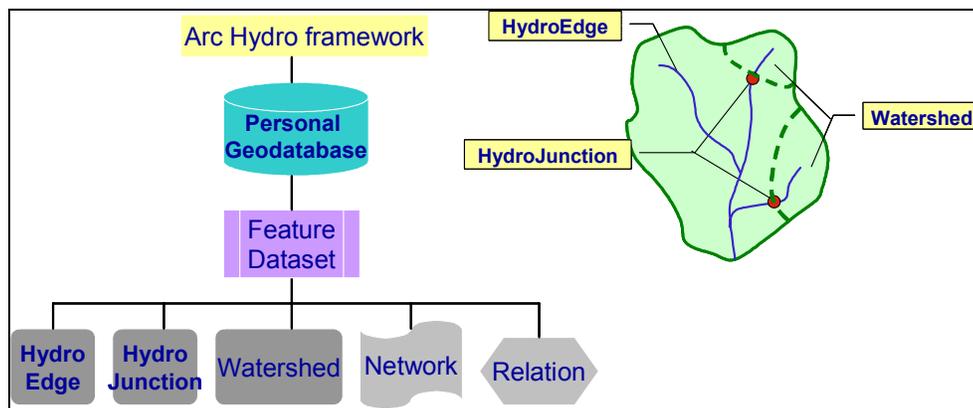


Figure 4.5: ArcHydro data model for water resources

4.4 DESCRIPTION OF THE ARCHYDRO DATA MODEL COMPONENTS

ArcHydro is an ArcGIS-based system designed to support water resources applications. It consists of two main components:

- ArcHydro Data Model framework
- ArcHydro Tools implemented in GIS

These two components provide basic database design and set of tools that facilitate analyses often performed in the water resources area (ESRI, 2005). The ArcHydro data model provides the initial functionality that can be extended by

adding to its database structures and function required by a specific task or application. The main components of the ArcHydro data model are described below.

- **MonitoringPoints:** are locations where water is measured, such as stream gages, climatic gages, water quality stations, or any other point of interest for the users.
- **Waterbodies.** This feature class includes all the significant ponds, lakes, dams, bay, and wider rivers that are represented as a polygon in the water system.
- **Watersheds.** This feature includes the drainage areas contributing flow from the land surface to the water system. These drainage areas can be generated from the digitized maps or indirectly from a digital elevation model.
- **HydroEdges** are the river network describing the map hydrography of a basin. There are two types: flowlines, which trace water movement and shorelines, which form the interface between land and water.
- **HydroJunctions.** This feature class includes a set of points located over the river segments in the geometric network. These points are representing the original monitoring points, which are kept at their original positions. For this reason they would be considered as virtual points participating directly in a geometric network.

Several relationships are established among the feature classes within the geodatabase as are shown in Figure 4.6

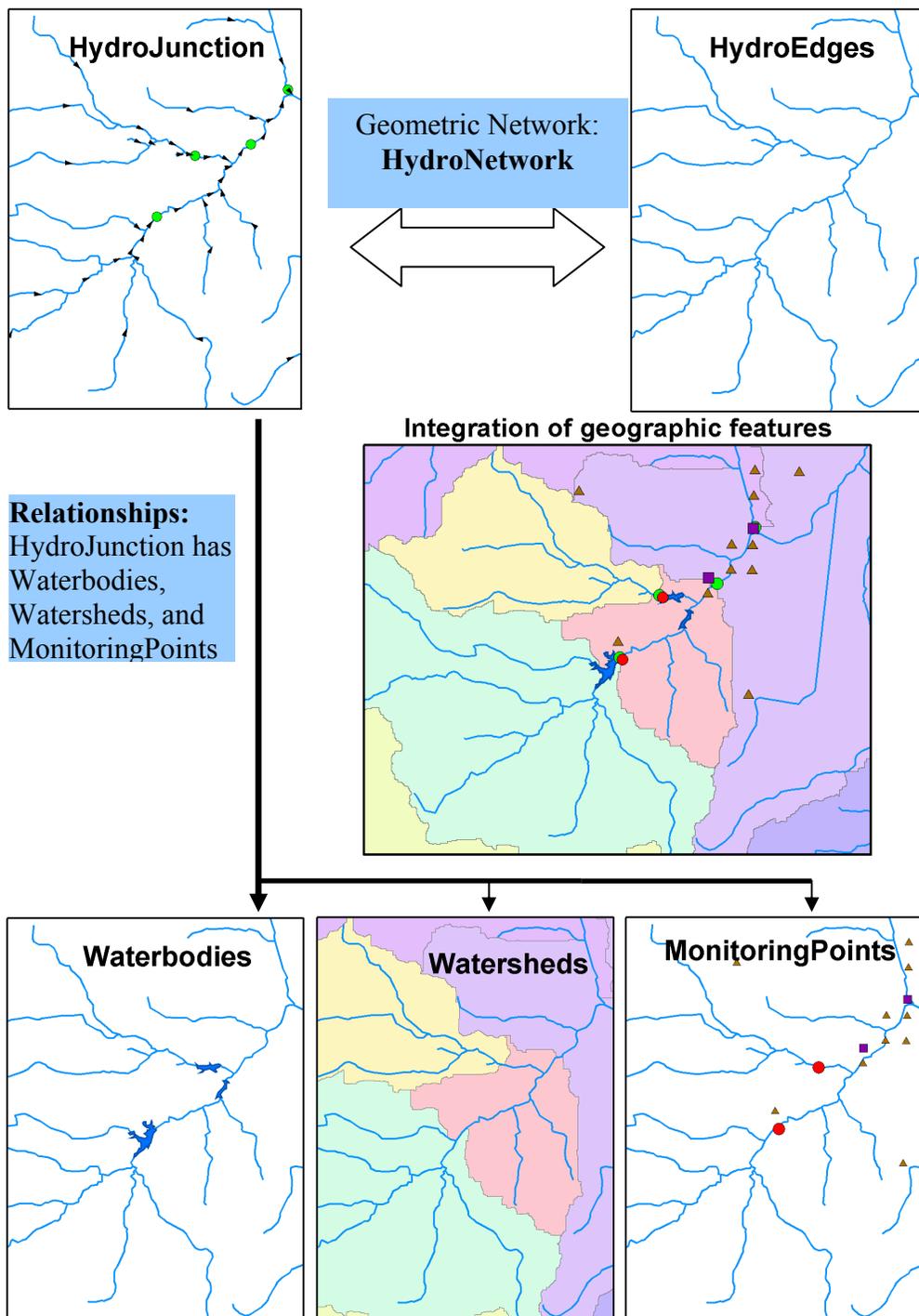


Figure 4.6: ArcHydro data model components

4.5 CLIPPING OR MERGING THE DATA SETS DEPENDING ON THEIR ORIGINAL EXTENT

In constructing the geodatabase for the Rio Grande/Bravo basin, data distributed on a national or state level had to be clipped; while data distributed at a county or Hydrologic Cataloging Unit level, had to be merged into a single and larger data set. Because the original DEM for Mexico existed for the whole country with a grid size of 104 m, it had to be clipped and resampled on a 30 m grid based on the basin boundaries. With respect to the USGS DEM for the U.S. side, the original seamless tiles are projected using the GCS_1983 and a grid resolution of 28.3 m; so they had to be reprojected and resampled to match the projection and characteristics chosen for the project. The result of this step is shown in Figure 4.7.

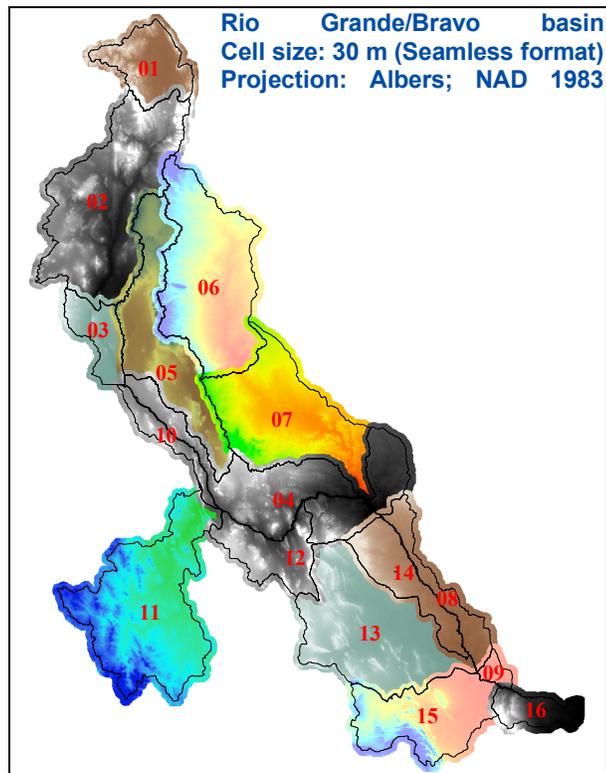


Figure 4.7: Clipped DEMs for the basin including a 10 Km buffer

The full process to project and clip a DEM for the Rio Florido that is a sub basin of the Rio Conchos is described in the appendix A.

4.6 IMPORTING DATA INTO A GEODATABASE

This step included the processing of the available information into the ArcHydro Rio Grande/Bravo geodatabase using the software ArcGIS desktop version 8.3 and 9.0. Feature datasets were created within the binational geodatabase that include feature classes related to each type of information. The ArcCatalog, which is one of the main applications of the ArcGIS software, is used to generate these features.

A new geodatabase is created and the **New Feature Dataset** option is applied (Figure 4.8).

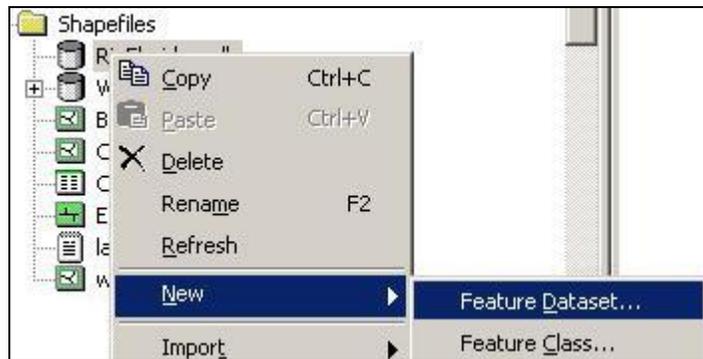


Figure 4.8: Creating new feature dataset within a personal geodatabase

A name is given to this new feature dataset and the projection and map extent properties are assigned using the “Edit” button in ArcCatalog. The coordinate system of the basin states covering the Rio Grande/Bravo basin is imported to the feature dataset. It is very important to import the largest geographic characteristic into the feature dataset first; otherwise several errors will be generated when new larger geographic information is added to this feature dataset.

Now it is possible to import all remain geographic information into the feature datasets created before. More details about importing GIS shapefiles and coverages into a personal geodatabase are described in the Appendix B.

4.7 APPLYING REGIONAL HYDROIDS

By definition, HydroIDs are unique identifiers for geographic features within a relational database that conform to the ArcHydro data model. Each feature, regardless of the feature class it belongs to, has a unique HydroID. This identifier is defined as a long integer and can reach a maximum value of 2,147,483,648.

The HydroID is the key to establishing relationships in the ArcHydro data model. All established relationship classes within ArcHydro use this key. The ArcHydro tools manage the HydroID directly, that is, the tools populate the HydroID automatically for any new feature that is created through the tools.

The implementation of HydroID assignment is based on two key premises:

- Simple implementation for a general user. The end user does not have to do anything, every element included in the feature classes will have a unique number assigned automatically, starting with 1 and incrementing by one for every element identified within the geodatabase.
- Complex or regional implementation. This option can be used by users who want control over HydroIDs in each feature class. The user has the ability to specify a starting point for assignment of HydroIDs according to predefined criteria.

A unique ten-digit identification number called the Regional HydroID was assigned to every object of each feature class according to the following classification in the Rio Grande/Bravo binational geodatabase:



The first digit (from left to right) indicates the hydrological region. Region 13 (Rio Grande) on the U.S. side was identified with the number 1, and number 2 identified region 24 (Rio Bravo) on the Mexican side. The next two digits are allocated for the hydrological subregion. Number 02 is assigned to the Rio Conchos basin. It is assumed here that all basins will have no more than 99 subregions. The basin is divided into 9 subregions on the U.S. side and 7 subregions on the Mexican side. The next two digits represent the type of geographic information being managed. The value 01 was assigned for the Control Point feature class, while the value 02 was assigned for edges (River network). The waterbody feature class was identified as 03, watershed as 04; and so on. The last five digits describe the feature number, with a maximum of 99,999 values. The Regional HydroID for the Rio Conchos basin is shown in Table 4.2 as an example. The original Mexican code was kept as a reference.

NAME	MEX_CODE	HydroID
R. CONCHOS - OJINAGA	24-J	2020400001
R. CONCHOS - P. EL GRANERO	24-K	2020400002
R. SAN PEDRO	24-N	2020400003
R. CONCHOS - P. DE LA COLINA	24-L	2020400004
R. FLORIDO	24-M	2020400005

Table 4.2: Regional HydroID for the Rio Conchos Basin

All HydroIDs for rivers lying within the Rio Conchos basin begin with the number 2 to indicate the Mexican side, 02 to indicate the Rio Conchos basin. After the regional identifier, the number 02 indicates that these features are edge features. So, each stream HydroID will be prefixed by 20202, and the last five digits will describe the number for every stream.

4.8 WRAPHYDRO DATA MODEL SCHEMA

A particular application of the ArcHydro data schema called WRAPHydro was applied to each of the Rio Grande/Bravo hydrological subregions in order to create the necessary fields required by the Water Right Analysis Package (WRAP) model. The WRAPHydro data model was derived from the ArcHydro model and is tailored specifically for the WRAP project developed jointly with the TCEQ (Gopalan, 2003). Previously mentioned, WRAP simulates management of water resources for evaluating existing water right permits, permit approvals for new water rights, and overall water management in Texas under a priority based water allocation system (Wurbs, 2001).

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. Figure 4.9 shows the WRAPHydro data model structure for the hydrological subregion 2402 corresponding to the Rio Conchos sub basin that is part of the Rio Grande/Bravo basin as an example.



Figure 4.9: WRAPHydro Data Model Structure

The “Region 2402” folder has a folder called “Grids” and a personal geodatabase called “WRAPHydro2402.mdb”. The right-hand part of Figure 4.9 represents the model structure when the whole basin is processed in one piece or after the results from all hydrological subregions have been generated and merged. The basin is processed either as a single unit or in parts by dividing it

into sub-basins. Each component of the WRAPHydro data model is described below.

- The “Grids” folder contains all the grids needed as a part of the process for developing watershed parameters.
 - BaseGrids folder. It contains all the grids that are required before any processing start. It includes the original DEM in a seamless format generated as an integer to reduce the file size. This DEM have a cell size of 30 m. The curve number (CN) and precipitation grids are also included in this folder as base grids.
 - PreProcess Grids. The terrain processing tools of the ArcHydro toolset are used to generate the flow direction raster “fdr2402” from the original DEM. These grids are used in conjunction with the feature classes in the preprocess dataset to define the basin boundary. The agree2402cm grid is obtained by reconditioning the rivers lying in the subregion 2402 to the original DEM. The mask2402 grid is a raster with all cells having unit value whose extent is equal to the extent of subregion 2402 including a buffer of 10 kilometers. BasinMask2402 is a grid with all its cells having unit value clipped to the basin feature class, without considering the buffer area.
 - WRAPHydro Grids. This folder includes all grids that are obtained for use in the final processing of parameters. The “WRAPcn2402” grid describes the original curve number grid clipped to

basinmask2402. The “WRAPfdr2402” is the flow direction grid clipped to basinmask2402, and the ‘WRAPpr2402” raster is the precipitation grid clipped to basinmask2402.

- The “WRAPHydro2402” geodatabase contains all the feature classes that are used in conjunction with the grid processing to obtain watershed parameters. Each feature class is described below.
 - ArcHdyroReg2402. This feature dataset is used to store all the final information after processing that would be included in the ArcHydro data model. It is assumed that the HydroEdge, which is generated from the WRAPEdge feature class, has been edited, checked for the inconsistencies mentioned before, and has the flow direction assigned. It is also assumed that the Watershed2402 feature class is the area defined by the ArcHydro and WRAPHydro tools during the watershed delineation process.
 - BaseData feature dataset. This feature dataset includes feature classes that are the raw data besides ArcHydro needs to begin the processing. Starting processing at this level creates a capability for base processing and then periodic updates. The BaseControlPoint feature class includes here is a point feature class that contains of all the control points at their original position in the corresponding hydrological subregion.
 - Preprocess feature dataset. After the base data is prepared, some preprocessing needs to be done before the data can be ready for

processing parameters. The “BufferWatershed” feature class is a polygon obtained from the original Hydrologic Unit Cataloging (HUC) for the American side or “Cuencas” and “SubCuencas” on the Mexican side of the basin. This polygon includes a buffer area of 10 Km drawn around it. The “WRAPFlowLine” is a line feature that includes all the river segments that lie within the “BufferWatershed” feature class. The “SnapControlPoint” is a point feature class that is the “BaseControlPoint” with all the features snapped to the right location on the geometric network. The “WRAPCatchment” is a polygon feature class that has been generated by delineating drainage areas for each stream segment in the “WRAPFlowLine” with a unique identifier HydroID. These catchments are used to define the basin boundary. The “Basin” is also a polygon feature class that is derived by dissolving only those catchments that define the boundary of the hydrological subregion under study. The “WRAPFlowLineNetwork” element is a complex network built with the “WRAPFlowLine” feature class. This is required to assign the flow directions for each flow line and delineate catchments for them. The “WRAPFlowLineHasWRAPCatchment” is one to one relation between the “WRAPFlowLine” and the “WRAPCatchment” elements. The HydroID of the “WRAPFlowLine” is related to the identifier “DrainID” of the “WRAPCatchment.”

- WRAPHydro feature dataset. This feature dataset contains all the data for which parameters need to be generated. It has four main feature classes. “ControlPoint” is a point feature class that is essential the “BaseControlPoint” element representing the original control points at their original positions. It might have more than one point at a single location. The “WRAPJunction” is also point feature class generated from the “SnapControlPoint” feature class by removing all coincident points, so it has just one virtual point at a location representing two or more original control points. The “WRAPEdge” is a line feature class including only those river segments that lie within the “Basin” feature class under study and described before. The “WRAPWatershed” is a polygon feature class including the watershed that has been delineated for each “WRAPJunction” element. The “WRAPNetwork” is a simple geometric network built using the “WRAPJunction” and “WRAPEdge” feature classes. The “WRAPJunctionHasControlPoint” is a one to many relationship between the “WRAPJunction” and the “ControlPoint” feature classes since more than one original control points could exist at the same location. The HydroID identifier of the “WRAPJunction” elements is related with the JunctionID identifier of the corresponding “ControlPoint.” This relationship is used for

transferring the hydrological parameters calculated to the original control points.

All of the fields created by the WRAPHydro schema were populated using the WRAPHydro tools developed at the CRWR (Whiteaker, 2004). These tools consist of a set of public domain utilities developed on top of the ArcHydro data model. The tools are accessed through the WRAPHydro toolbar, where they are grouped by functions into two menus and five buttons (Figure 4.10). The purpose of this toolkit is to process GIS data in order to calculate parameters used by WRAP and tabulated for each ControlPoint including: average curve number, average annual precipitation, total upstream drainage area, and next downstream ControlPoint.

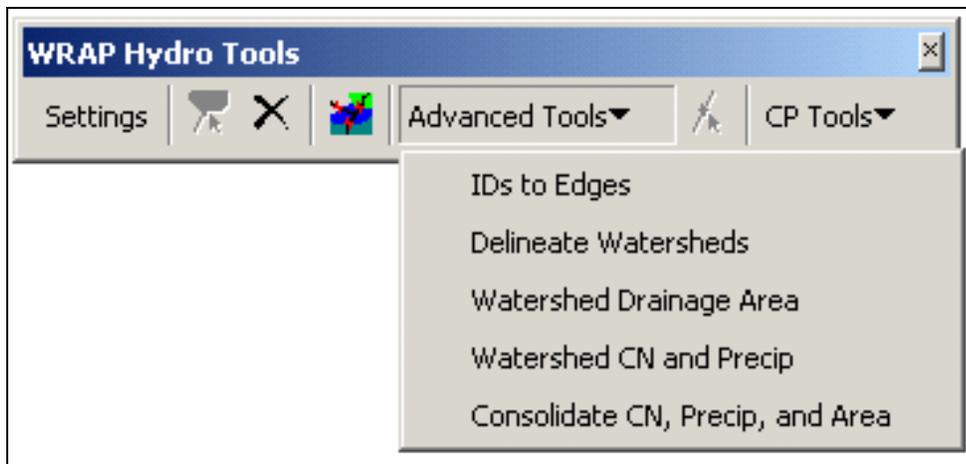


Figure 4.10: WRAPHydro Toolbar

4.9 PREPROCESSING

Once the base data is obtained, edited and fixed, the initial analysis area is defined for each hydrological subregion and some preprocessing needs to be done before some hydrologic parameters can be calculated.

4.9.1 Defining the basin boundary

For each hydrological subregion of the Rio Grande/Bravo basin, the HUCs or SubCuencas that make up the subregion were selected, including a 10 Km buffer around the HUCs called the BufferWatershed feature class. All the streams that lie within each subregion plus buffer were selected and exported to create the WRAPFlowLine feature class. HydroIDs were assigned for every element of the WRAPFlowLine feature class and used for delineating watersheds for all the stream segments (WRAPCatchment) in the corresponding hydrological subregion, selecting only those watersheds that are defined by the streams that lie within the subregion. A network is built using only the WRAPFlowLine as a simple network and the flow directions are assigning using the “FlowDir” attribute. The WRAPHydro Delineate Watershed tool is used for delineation. The setting for delineating watersheds with source layer as WRAPFlowLine and the source attribute as HydroID is shown in Figure 4.11.

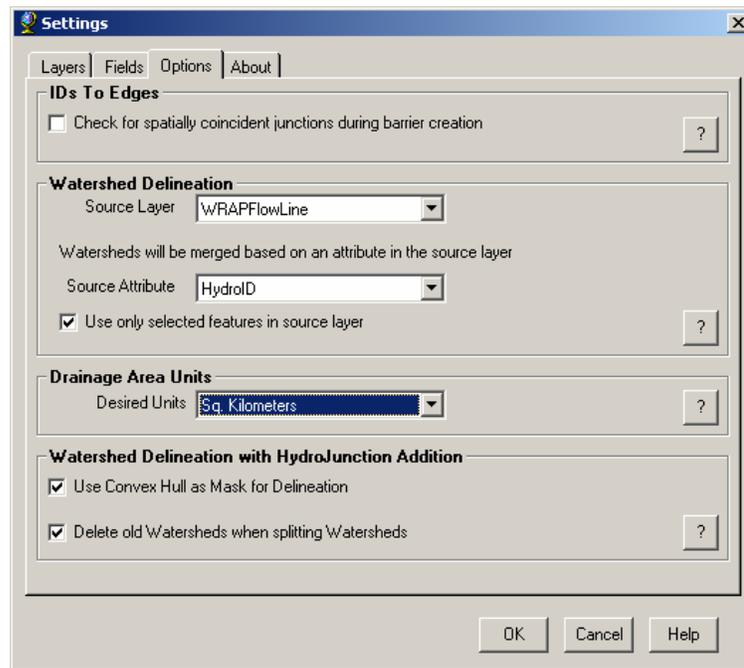


Figure 4.11: Settings window for WRAPCatchment delineation

The DrainID field of the delineated catchments was populated by the HydroIDs of the WRAPFlowLine segment draining to it. In Figure 4.12 the black text are the DrainID of the WRAPCatchment and the blue ones correspond to the HydroIDs of the lines they are draining to.

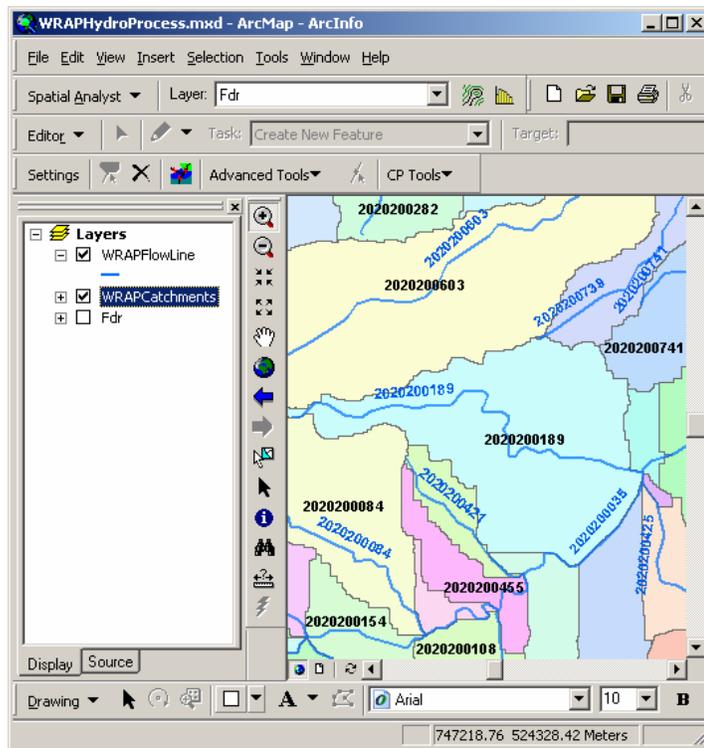


Figure 4.12: Populating DrainID of the WRAPCatchment

Thus, there is a one to one relationship between the WRAPFlowLine and the WRAPCatchment feature classes. Hence a relationship WRAPFlowLineHasWRAPCatchment is created. To select all the WRAPCatchments that make up the basin, first all the streams that lie in the basin should be selected. The original HUCs and Cuencas are used as reference and all the features in WRAPFlowLine that completely lie within this area are selected by location or using the trace upstream option of the ArcHydro tools based on the geometric network created previously. 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 (Figure 4.13).

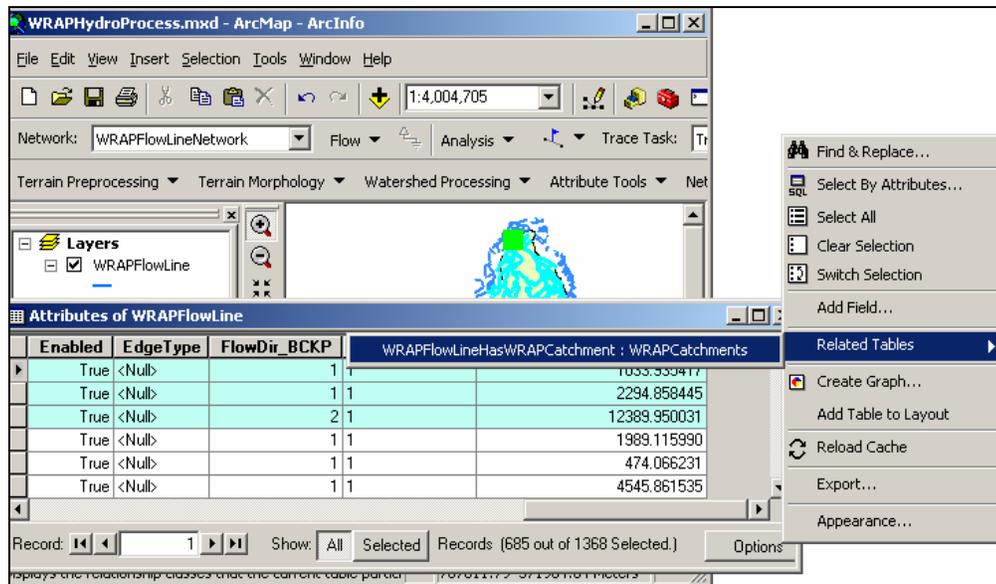


Figure 4.13: Selecting catchments to define the basin

The selected catchments are the 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 equal to one for example. Appendix C includes more details about the basin boundary delineation.

4.9.2 Clipping the grids

Once the basin boundary is defined, a Digital Elevation Model (DEM) of the buffered area is clipped and processed using the ArcHydro Terrain Analysis tool in order to get the flow direction raster of this basin (Figure 4.14). A raster mask of the basin must be created using the Spatial Analyst extension in ArcMap.

A mask is a grid that covers the hydrological subregion under study and all the cells in this mask have a unit value. For step by step procedure to clip grids refer Appendix A.

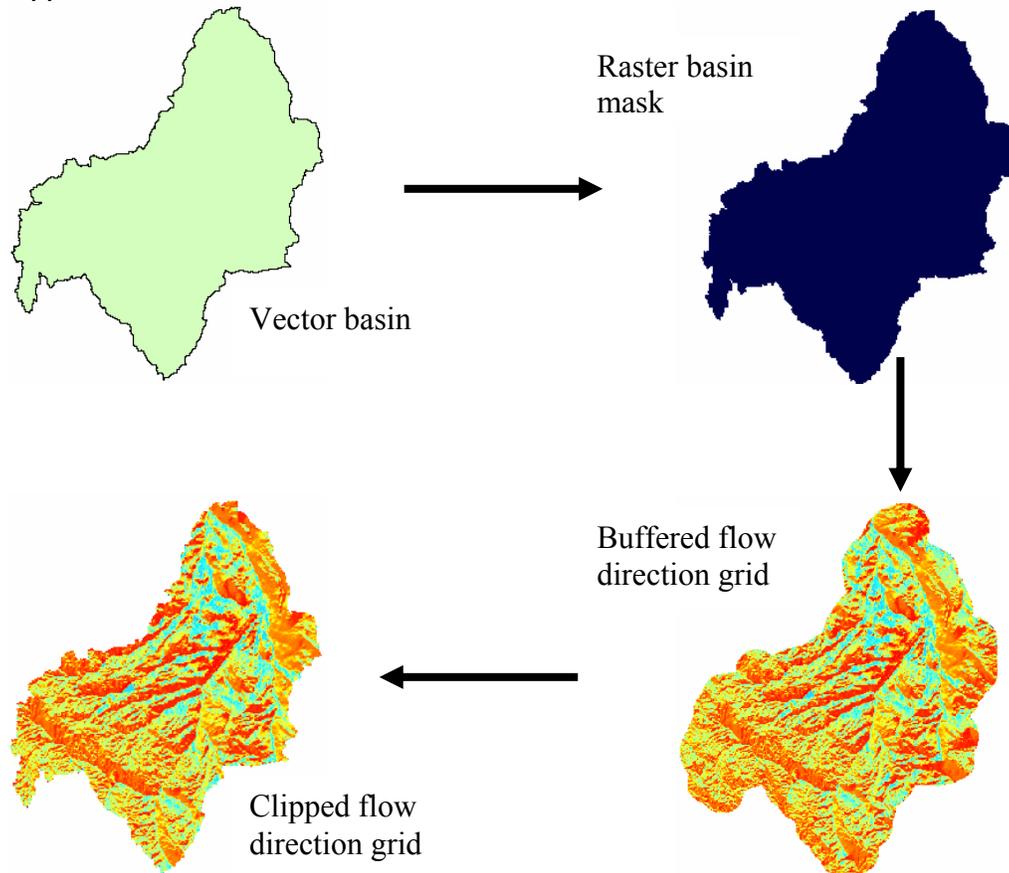


Figure 4.14: Clipping the flow direction grid

4.9.3 Snapping Control Points

Some Control points may be at a considerable distance from the streams. The original base control points are exported to create the SnapControlPoint feature class. The locations of points included in the SnapControlPoint feature class are corrected so that they lie within a distance of 100 m from the stream

segment to which they have to be snapped. The old geometric network is deleted and a new network is built using the WRAPFlowLine and the SnapControlPoint feature classes as a complex network. More details are included in the appendix C.

4.10 FINDING WATERSHED PARAMETERS

The topological connections of the edges and control points in a geometric network enables tracing of water movement upstream and downstream through streams, rivers, and water bodies. Relationships built from the control points connect drainage areas and point features such as diversion points to the HydroNetwork. This HydroNetwork allows calculation of the distance between any two points on a flow path. The parameters calculated in this research for every single hydrological subregion in the GIS environment 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

A new feature class called WRAPEdge was created using the HydroNetwork selecting all streams lying in the hydrological subregion (Figure 4.15). The BaseControlPoint features are exported to the ControlPoint feature class within the WRAPHydro feature dataset.

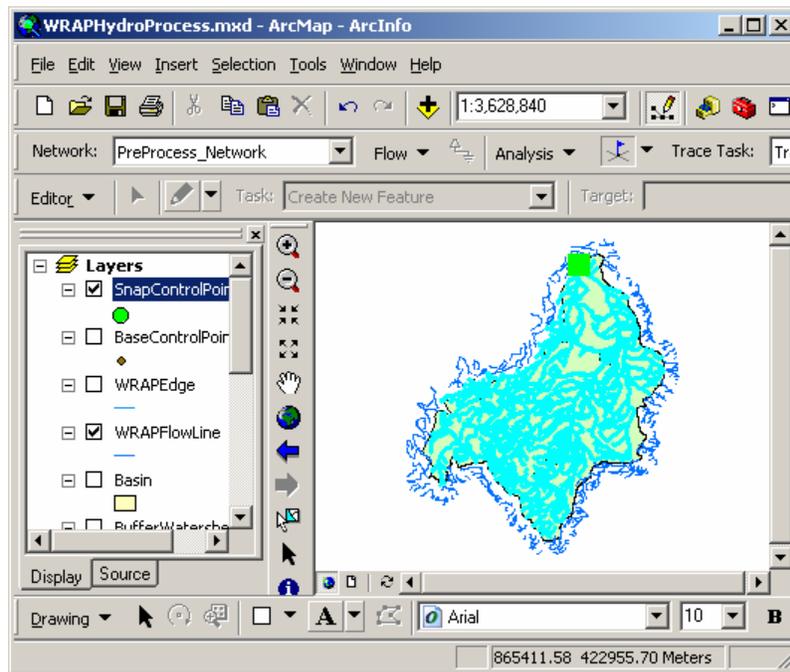


Figure 4.15: Creating the WRAPEdge feature class

4.10.1 Building the Network with the SnapControlPoint and WRAPFlowLine feature classes

As discussed in previous section, a new complex geometric network is created using the SnapControlPoint and the WRAPFlowLine feature classes. A snapped tolerance of 100 m is given. There are two reasons for why a snapped control point is not connected to the network: one, if the point is located more than 100 m away from the stream (edge), it would not have snapped to the network, and the second if it has coincident points. For the first case the snapped control points can be identified by placing a flag at the outlet of the basin and tracing upstream. Those points that are not participating in the network can be

identified easy as seen in Figure 4.16. Only those points participating in the network are selected.

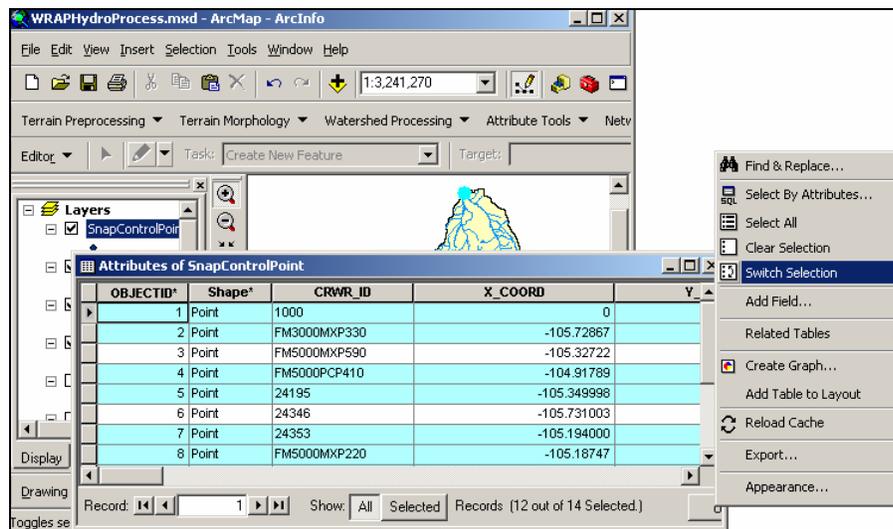


Figure 4.16: Snapped points out of the geometric network

All the selected points are exported to another feature class called WRAPJunction. The old network is deleted and a new network called WRAPNetwork is built using the WRAPEdge and WRAPJunction feature classes. Once the network is built the flow directions are assigned to the stream segments using the FlowDir attribute of the WRAPEdge feature class. More details about this process can be seen in the appendix C.

4.10.2 Loading Junctions

The WRAPEdge is considered as a single feature for creating the geometric network, so that the edges can be split at points where the WRAPJunctions are located. After the network is built and opened in ArcMap, it

can be seen that some of the streams 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 solve this problem the edges need to be split at points where junctions are located. More details are included in the appendix C.

4.10.3 Regional HydroID assignment

One of the first steps in calculating watershed parameters is to assign a unique identifier for every element included in the geodatabase. In the WRAPHydro process each WRAPJunction and WRAPEdge is identified by its regional HydroID rather than the public identifier assigned by an agency. The numbering convention used for the regional HydroIDs is discussed in section 4.7. It is recommended to follow the same numbering convention for all the hydrological subregions. The HydroID table manager of the ArchHydro tools is used to set the HydroID values for the WRAPJunction and WRAPEdge feature classes as it is shown in Figure 4.17.

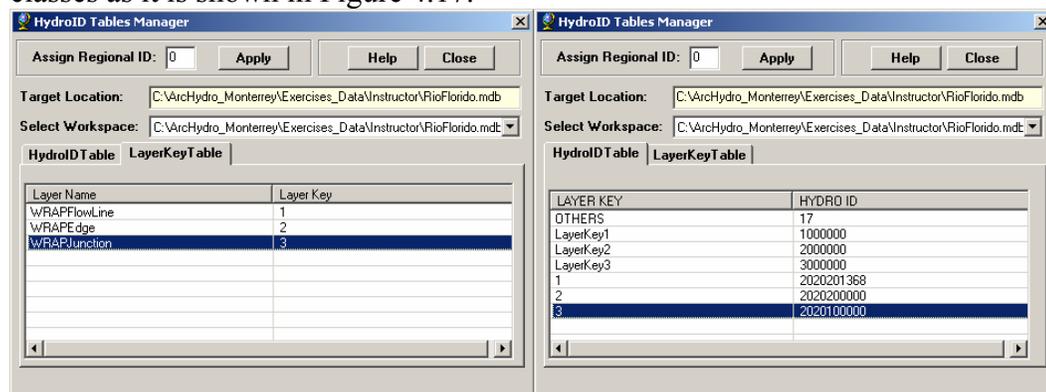


Figure 4.17: Assigning regional HydroIDs

4.10.4 Determining next downstream control point

This parameter is populated in the NextDownID field of the WRAPJunction feature class. It shows the connectivity of the junctions, indicating which junction is located immediately downstream of another. The Next Downstream Junction tool of the ArcHydro toolset is used to assign the HydroID of the next downstream junction to the NextDownID value of that junction. Any junction that does not have a junction downstream of it will have a value -1 in its corresponding NextDownID attribute. Thus, the outlet of the basin always has a NextDownID value equal to -1. In case that any other junction has a value -1, it means that this junction is not participating in the geometric network, so any parameter will not be calculated for it. Thus, this tool also helps to validate the location of all control points on the network. Figure 4.18 shows the WRAPJunction labeled with their HydroIDs and NextDownIDs.

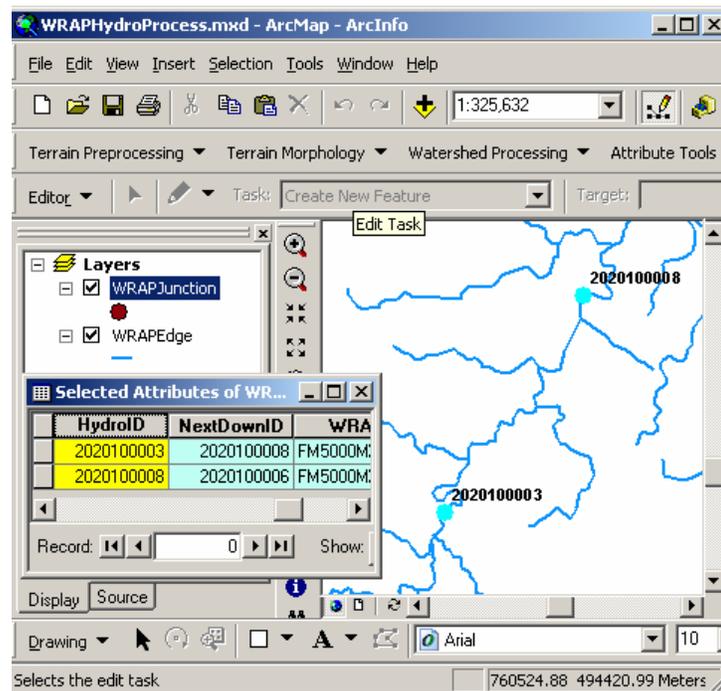


Figure 4.18: Determining next downstream junctions

4.10.5 Calculating length to outlet (LengthDown)

This parameter is populated in the LengthDown field in the WRAPJunction feature class. The Calculate Length Downstream for Junctions tool of the ArcHydro toolset is used to calculate the distance of each WRAPJunction from the outlet of the corresponding hydrological subregion. It calculates the total length by adding up the lengths of all segments that are located downstream of it. The Shape_Length field of the WRAPEdge feature class is used to specify the length of each edge in meters as is shown in Figure 4.19.

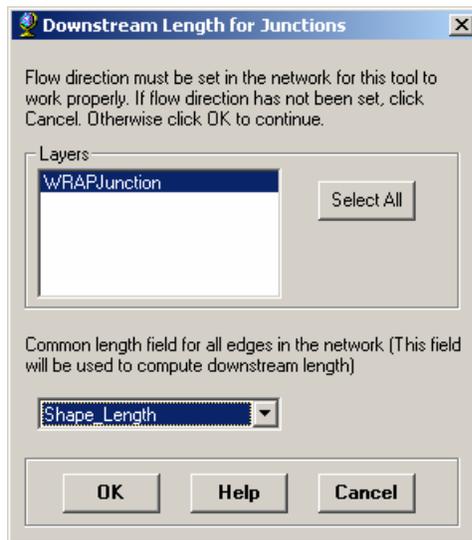


Figure 4.19: Input setting for calculating length downstream

As it can be seen in Figure 4.20, each of the downstream WRAPEdge Shape_Length values adds up to the value LengthDown for each of the junctions.

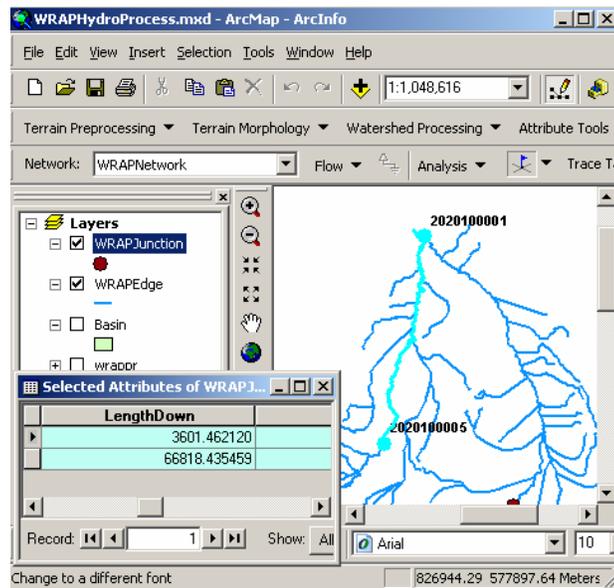


Figure 4.20: Length downstream for junctions

4.10.6 Upstream area delineation

In order to find the total drainage area for each control point, it is necessary to delineate the incremental watersheds that contribute to each junction, and then their value is accumulated moving downstream. The delineation process is done using the WRAPHydro toolset. The feature classes and grid names are specified in the layer tab in settings as shown in Figure 4.21, default fields are used in the fields tab and the WRAPEdge is specified as the source layer for delineation with the JunctionID identifier as source attribute in the options tab.

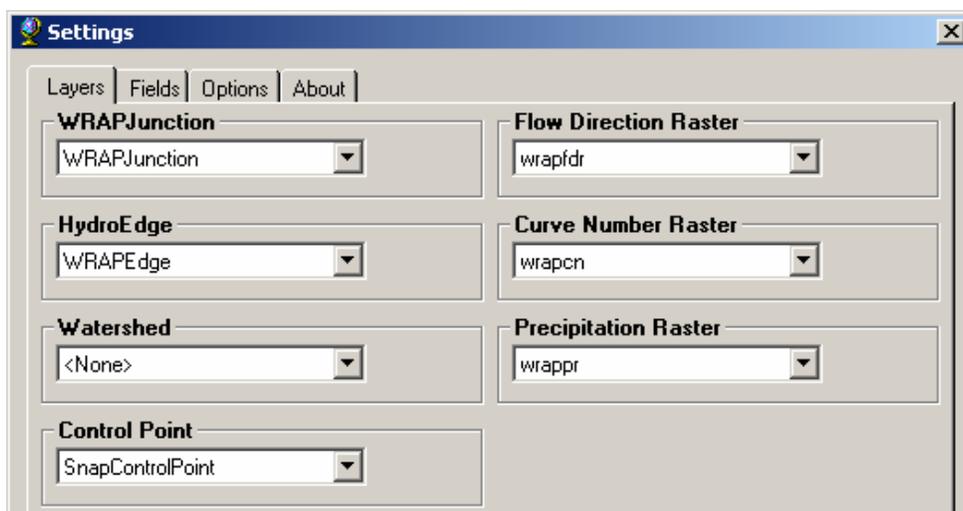


Figure 4.21: Settings for the WRAPWatershed delineation

The HydroIDs assigned previously to the WRAPJunction feature class are used to populate the JunctionID field of all segments in the WRAPEdge feature class flowing toward it. Thus, all streams between two junctions have the same JunctionID value (Figure 4.22). The Ids to edges tool in the WRAPHydro toolset is used to achieve this task.

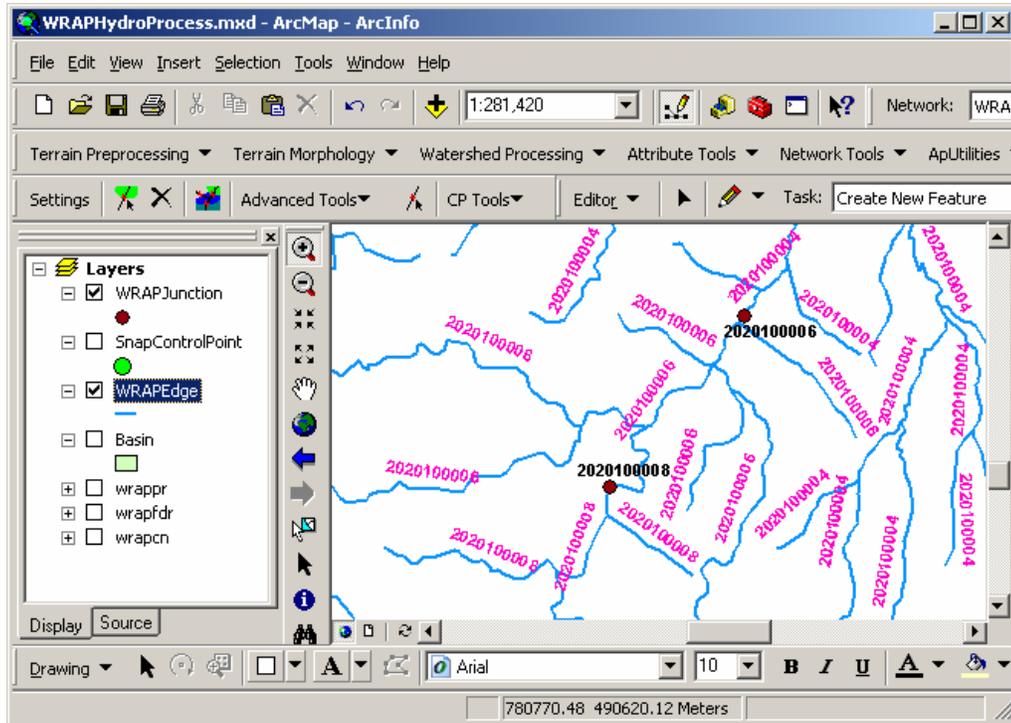


Figure 4.22: JunctionID for the river segments

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 flow direction raster and the river network as the input files, and this new feature class is called WRAPWatershed. The internal process creates a watershed for each value of JunctionID of edges. Thus, a watershed is created for each junction since all the edges between two junctions have the same JunctionID value. The DrainID field of the WRAPWatershed is populated with the JunctionID of the streams it is draining to. Figure 4.23 shows

the WRAPWatershed delineated for each WRAPJunction in the Rio Florido sub basin.

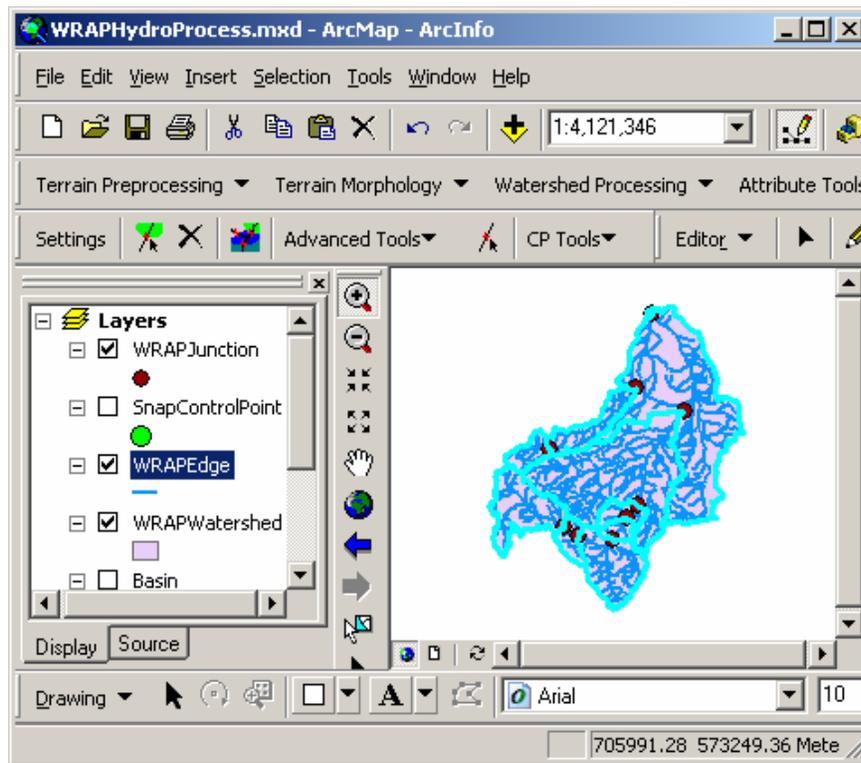


Figure 4.23: WRAPWatershed for each WRAPJunction

4.10.7 Watershed drain area, average curve number and average precipitation

Watershed drainage area, average curve number and average precipitation are calculated for each delineated watershed using the Advanced WRAPHydro tools (Figure 4.24). These values are populated in the DrainArea, AvgCN, and AvgPr fields in the WRAPWatershed feature class. The average value of Curve

Number and average annual precipitation for each watershed is the mean of all the cells within that area.

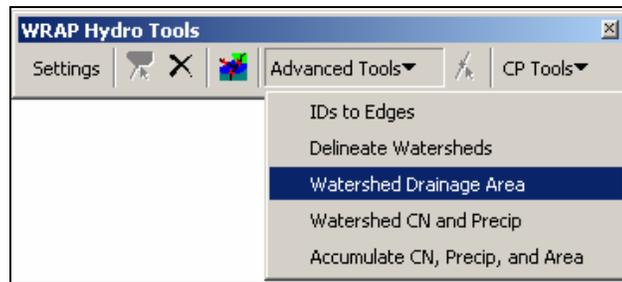


Figure 4.24: Advanced WRAPHydro tools

4.10.8 Consolidating attributes

Then once the incremental values for the drainage area, curve number and precipitation are determined for each watershed, these values are consolidated to add in the effects of all the area contributing to 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 DrainArea field in the WRAPJunction feature class. 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 4.25 and 4.26. Figure 4.25 shows three WRAPJunctions with HydroIDs 2020100009, 2020100007, and 2020100003 that are located in the Rio Conchos basin. For convenience they are referred to as junctions 9, 7 and 3 respectively. Similarly their corresponding WRAPWatershed with respective DrainIDs are shown and referred as watershed

9, 7, and 3 too. Remember DrainID of the WRAPWatershed are equal to the HydroID of WRAPJunction it is contributing to. As it can be seen, junctions 9 and 7 are both upstream of junction 3, so the effects of watershed 9 and 7 are consolidated in watershed 3. Figure 4.26 shows the attribute table for WRAPWatershed and WRAPJunction for the three junctions. The drainage area of junction 9 remains the same as that of its respective watershed because the only area that drains into it is from its own watershed. But the drainage areas of junctions 7 and 3 are the accumulated areas upstream of them. The average weighted curve number for any junction 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. Similarly the average weighted precipitation for any junction is calculated. Example for the junction 3 is shown below.

$$AvgCN_3 = \frac{(83.22 \times 1270.03) + (78.01 \times 306.32) + (78.00 \times 1257.76)}{2834.11} = 80.34$$

$$AvgPR_3 = \frac{(512.20 \times 1270.03) + (463.00 \times 306.32) + (465.57 \times 1257.76)}{2834.11} = 486.19$$

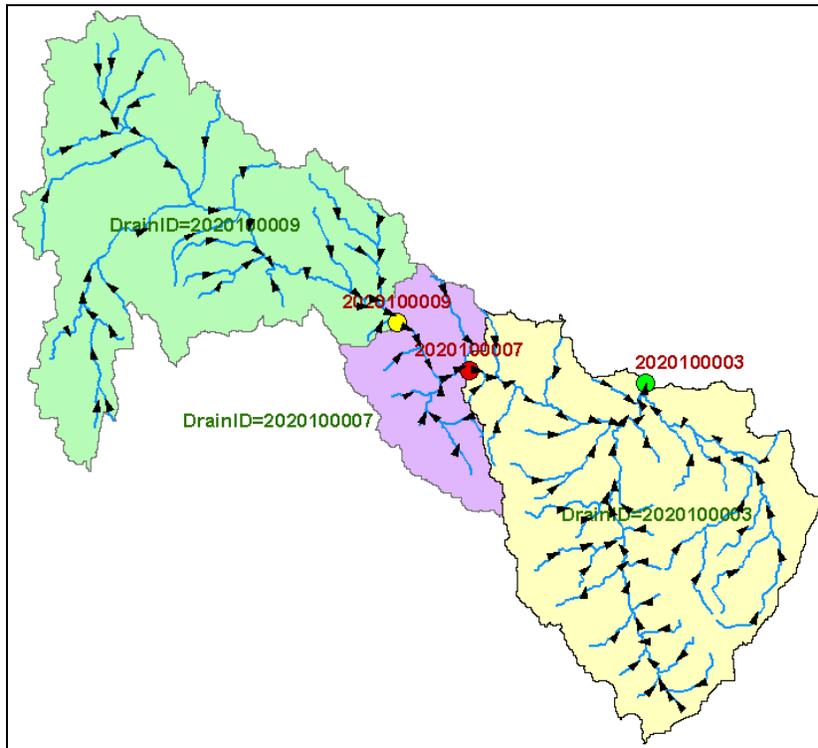


Figure 4.25: Consolidating information downstream for junctions

DrainID	DrainArea	AvgCN	AvgPr	Shape_Area
2020100009	1270.034098	83.222870	512.202454	1270034098.36045
2020100007	306.316800	78.010193	463.000214	306316800.374034
2020100003	1257.755394	78.000206	465.572327	1257755393.78009

HydroID	DrainArea	AvgCN	AvgPR	NextDownID	LengthDown
2020100009	1270.034098	83.222870	512.202454	2020100007	236852.558709
2020100007	1576.350899	82.209942	502.641465	2020100003	223812.953490
2020100003	2834.106293	80.341692	486.190456	2020100008	193389.008535

Figure 4.26: Values in WRAPWatershed and WRAPJunction

4.10.9 Copying attributes from WRAPJunction to ControlPoint

The last step in watershed parameterization is to copy the hydrological parameters from WRAPJunction to all the points including the coincident ones in the ControlPoint feature class. The “CP tools” in the WRAPHydro toolset is used to achieve this step (Figure 4.27)

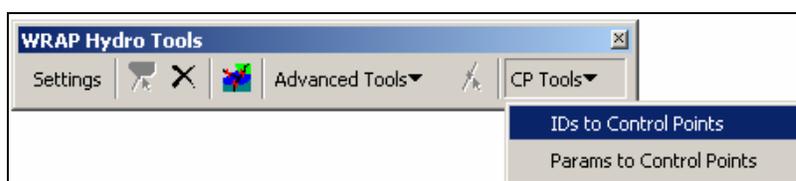


Figure 4.27: Tools for transferring hydrological parameters

The “Settings” form is used to specify layers, fields, and processing options to be used by various functions in the WRAPHydro toolset. The features in the ControlPoint need to be associated with WRAPJunction, but these features have not been snapped to the network to retain their original position, so the SnapControlPoint feature class in the PreProcess feature dataset is used to locate the correct WRAPJunction from features that are spatially coincident with them. Then, the “IDs to Control Points” tool is used to populate the HydroID of the WRAPJunction to the JunctionID of the SnapControlPoint based on spatial location. The SnapControlPoint feature is specified as the ControlPoint file in the settings and a JunctionID field is added to it (Figure 4.28)

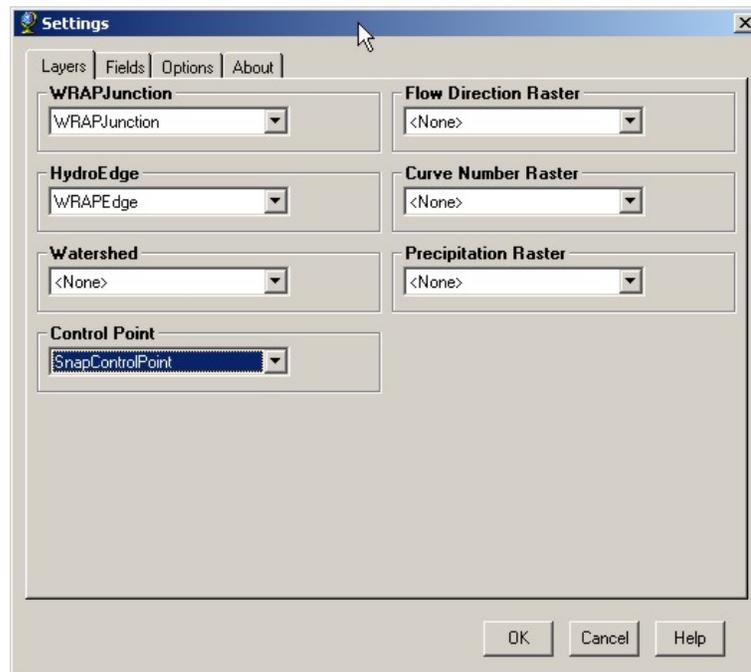


Figure 4.28: Layer settings for populating JunctionIDs

The SnapControlPoint attribute table is joined with the ControlPoint attribute table using the HydroCode, which is a public identifier, as the common field. The JunctionID values of the SnapControlPoint feature are copied to the JunctionID field of the ControlPoint feature class.

Thus, there is now a one to many relationship between the WRAPJunction and ControlPoint feature classes. The “Params to Control Points” tool is used to transfer the attributes from the WRAPJunctions to the original control points. For each match of HydroID in WRAPJunction with JunctionID in ControlPoint feature class, the respective attributes for drainage area, average curve number, and average precipitation are copied as it is. The NextDownID parameter is also determined to the control points. Before the WRAPHydro tools can calculate this

value, the HydroID values must be assigned to the ControlPoint feature class in case they do not exist yet. This process is detailed in Appendix C.

4.11 RASTER NETWORK REGIONALIZATION TECHNIQUE

When working with large basins like the Rio Grande/Bravo, is difficult, if not impossible, to process then entire raster data set as a whole. The computer processor might not be able to handle large dataset, especially the raster processing part. This is dealt with by dividing the basin into sub-regions and processing the sub-regional grids individually. The values obtained for each sub-basin can be cascaded downstream to get the final parameters for the entire basin. This way, overall drainage areas can be calculated by the ArcHydro accumulation function executed over the river network and related incremental drainage areas found from the sub-region raster analysis.

This research introduces a Raster-Network Regionalization Technique, which allows a large region to be divided into hydrological distinct subregions where raster analyses may be performed in a feasible manner. A summation of raster values over watersheds can be easily determined using the watersheds as distinct zones which define the area of analysis for the zonal statistics tool in ArcGIS. This tool calculates statistics such as mean, sum, max, and min for each zone by reading the values of cells within each zone and performing the necessary statistical operations. Thus, with this approach, accumulated grids whose cell values are influenced by all upstream cells are no longer needed. The only cells of a watershed that an analyst is interested in are the cells that lie directly over that watershed (Whiteaker, 2004).

Once attribute values have been determined for watersheds, these values can be transferred to outlet junctions, and then consolidated throughout the stream network in the vector domain. The watersheds become the basic processing unit with basin-wide coverage, while the raster coverage can be reduced to each individual watershed's extent. Thus, watersheds effectively replace grid cells as the "units" of analysis. This allows a basin or region to be divided into hydrological distinct subregions, in which the necessary raster analyses takes place.

The smaller size of the subregions permits faster raster processing, while results from raster analysis are stored on vector watersheds to be accumulated at the basin level. The Consolidation and Accumulation options from the WRAPHydro tools are then used to accumulate watershed parameters across the entire basin.

With the Raster-Network Regionalization technique, the weight of processing is changed from the raster side to the vector side, resulting in several benefits due to reduced processing time, since much of the processing occurs in the vector domain rather than in the raster domain. Data storage requirements are reduced, since accumulation grids no longer need to be created. Also, the remaining grids can be split into hydrological distinct regions defined by one or more watersheds. This allows for faster processing on the raster side, more modular data storage, and less raster reprocessing effort if data in a given watershed changes. Even the largest basin can now be processed with high-resolution raster data too.

4.11.1 Subdividing the basin

The Raster-Network regionalization technique has been successfully applied to the binational Rio Grande/Bravo basin for its analysis, which has a contributing area of over 468,000 square kilometers and is divided in 9 hydrological subregions on the U.S. side and 7 hydrological subregions on the Mexican side, according to the USGS and CNA classification respectively (Figure 4.29). Each subregion has its own unique identification numbers (HydroIDs) set up in such a way that when all 16 sub-regional geodatabases are merged the HydroIDs are also unique at the regional level.

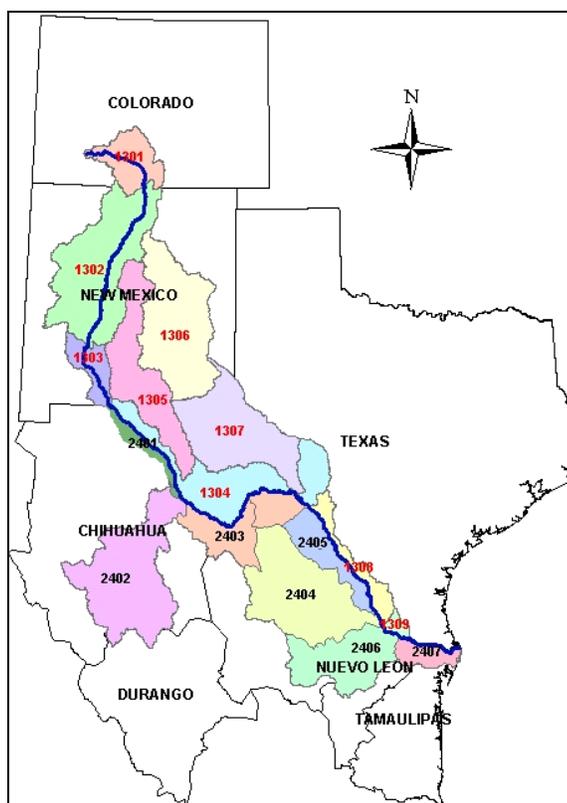


Figure 4.29: Hydrological subregions of the Rio Grande/Bravo basin

The methodology described in section 4.10 is applied. A 10 K m buffer is created for each of the 16 subregions 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 subregion to define its boundary. The precipitation, curve number and elevation grids are clipped to this mask. A network is built using the WRAPEdge and WRAPJunction feature classes for each subregion. Catchments are delineated for each JunctionID value of the WRAPEdge feature class, and watersheds are delineated for each HydroID value of the WRAPJunction feature class (Figure 4.30).

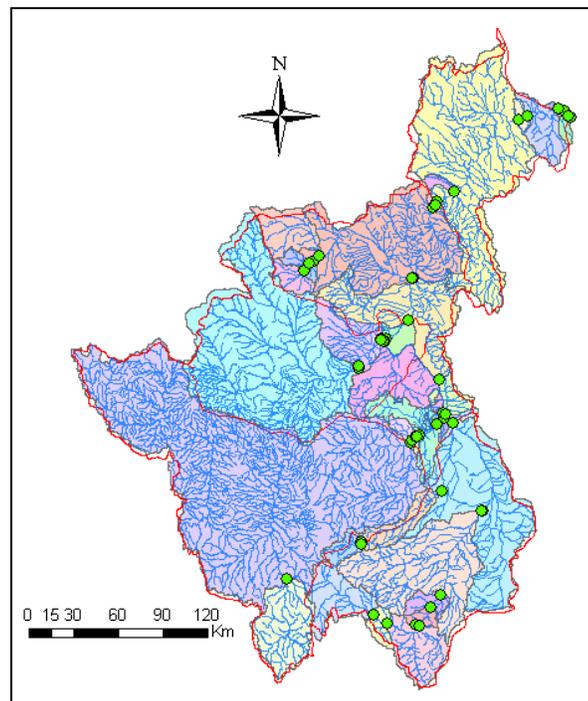


Figure 4.30: Rio Conchos basin delineation

4.11.2 Merging hydrological information from subregions

Once all the hydrological parameters have been calculated for every hydrological subregion, the results from the raster analysis of each subregion are merged on the vector side for determining the total drainage area flowing toward a specific control point, as well as its corresponding average precipitation, average curve number, and length downstream parameters.

The WRAPWatersheds for the 16 hydrological subregions of the Rio Grande/Bravo basin are delineated and the DrainID of the watersheds has been populated with the JunctionID of the WRAPEdge it flows to, which were populated with the HydroID of the NextDownstream WRAPJunction. Figure 4.31 shows the watersheds delineated for the seven hydrological subregions of the Rio Grande/Bravo basin on the Mexican side as an example, as well as the associated junctions and edges for each Watershed.

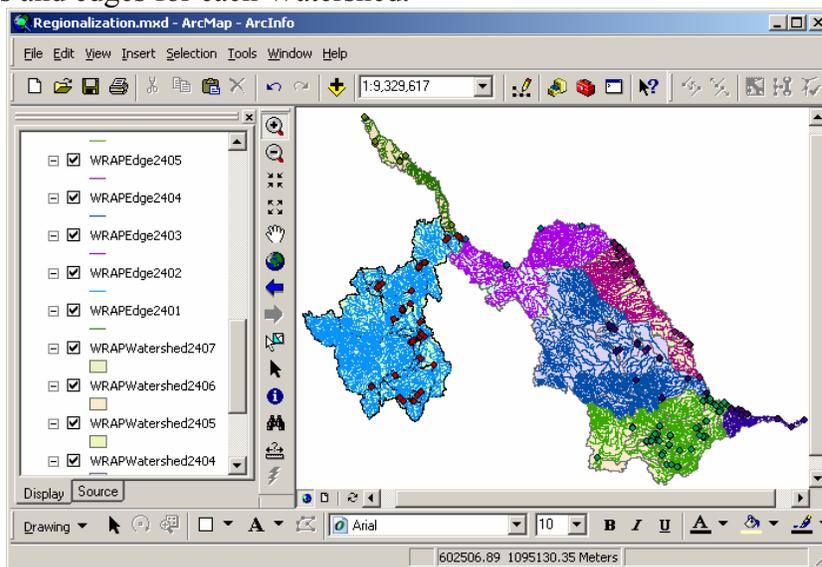


Figure 4.31: Hydrological information by subregions

The junctions, edges, and watersheds of all subregions are merged together in ArcGIS using the application ArcToolbox, exported into the feature dataset WRAPHydro and called WRAPJunction, WRAPEdge, and WRAPWatershed respectively according to the WRAPHydro data model schema described in section 4.8 (Figure 4.32). Refer appendix D for more details for merging process.

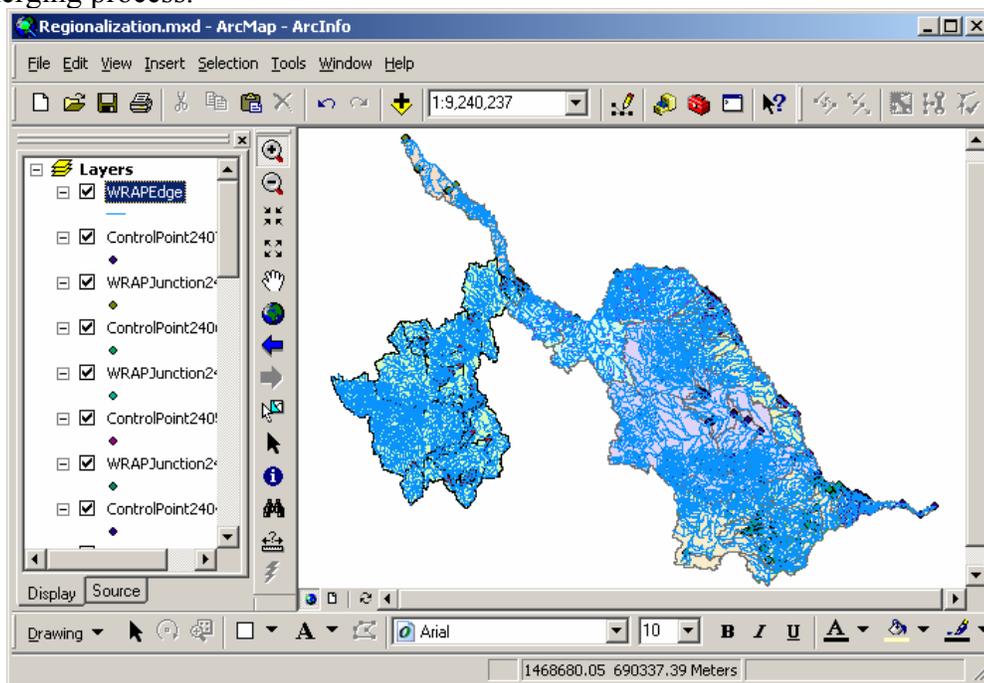


Figure 4.32: Hydrological information on the Mexican side

4.11.3 Updating the connectivity for the whole basin

After merging the hydrological information for the whole basin, it is necessary to update the NextDownID for the outlet of each hydrological subregion. A geometric network is built using the WRAPEdge as a simple edge and WRAPJunction feature class, 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 (Figure 4.33).

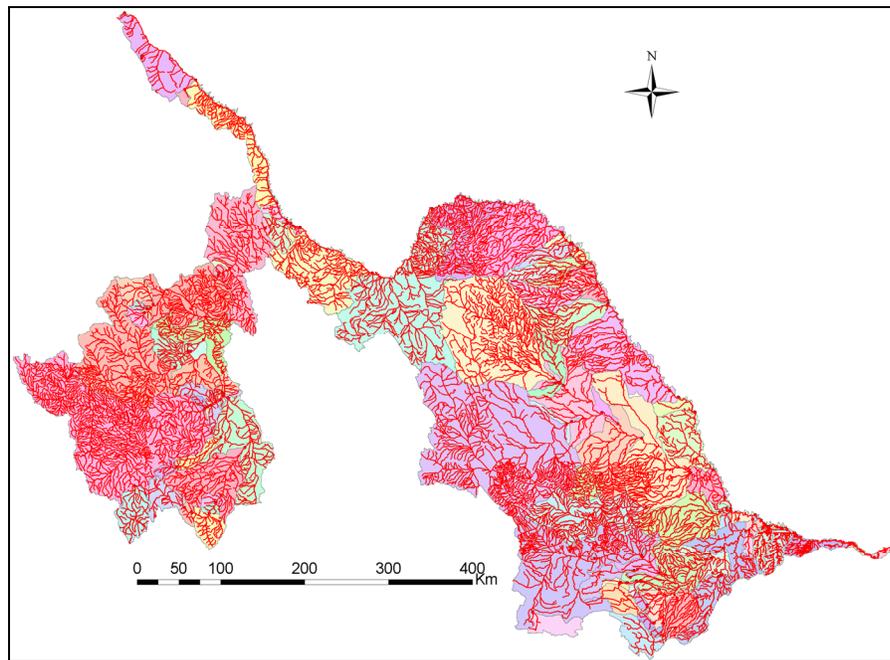


Figure 4.33: Tracing upstream in the Rio Grande/Bravo basin

Now the NextDownID can be assigned for the WRAPJunction at the outlet of each subregion. These points can be easily identified because they have a minus one unit value in their NextDownID field (Figure 4.34). Once all the outlets are selected, the “Find Next Downstream Junction” tool of the ArcHydro toolset is used to find the NextDownID for the selected junctions.

AncillaryRole	IsOnNetwork	NextDownID	DistBtwCP
None	1	-1	<Null>
None	1	-1	<Null>
None	1	-1	<Null>
None	1	-1	<Null>
None	1	-1	<Null>
None	1	-1	<Null>
None	1	-1	Amistad Dam
None	1	-1	<Null>
None	1	-1	<Null>
None	1	2010100001	186.004082
None	1	2010100001	192.974479
None	1	2010100003	81.421736
None	1	2010100003	60.741914

Figure 4.34: Junction at the outlet of each subregion

4.11.4 Consolidate the parameters for each junction

With the datasets merged and network connectivity established, parameters throughout the stream network can be now accumulated. The “Accumulate CN, Precip and Area” tool of the WRAPHydro toolset is used to consolidate the average curve number, average precipitation and drainage area for every WRAPJunction. Thus, the most downstream junction has the largest contributing drainage area (Figure 4.35).

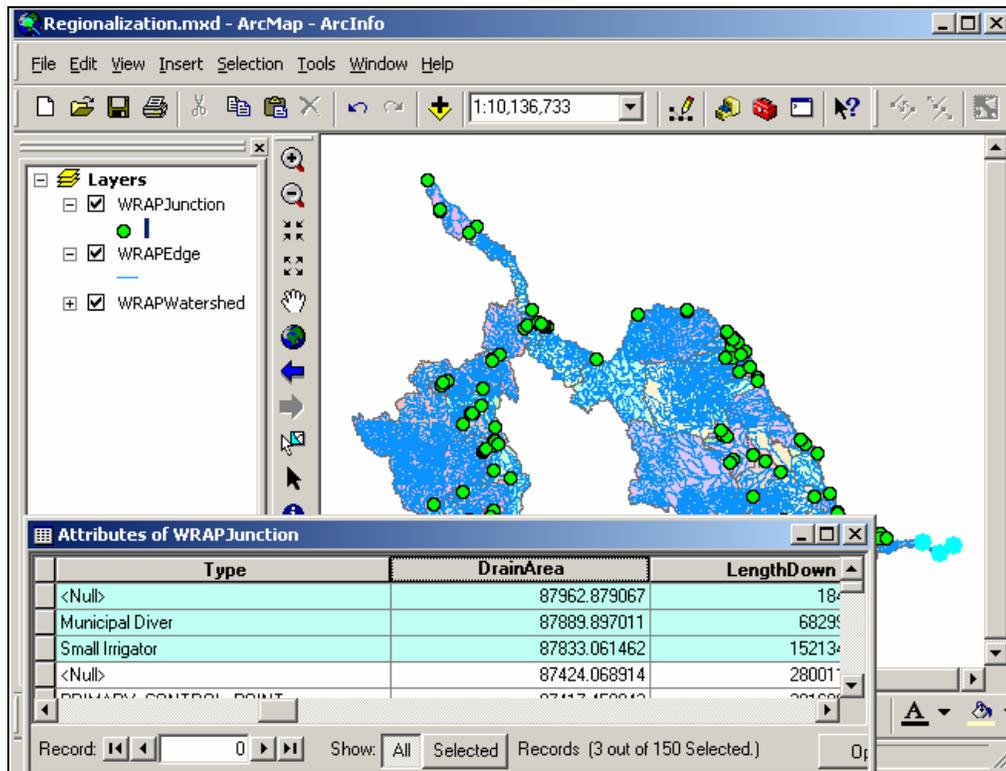


Figure 4.35: Total drainage area on the Mexican side

4.11.5 Assign new LengthDown parameter to WRAPJunction

Because the hydrological information has been integrated for the whole basin, it is needed to re-calculate the length down parameter for each WRAPJunction. The “Calculate Length Downstream for Junctions” tool of the ArcHydro toolset is used to achieve this task, and the “Shape_Length” attribute is selected as the common length field for all edges in the network. This field is used to compute the downstream length (Figure 4.36)

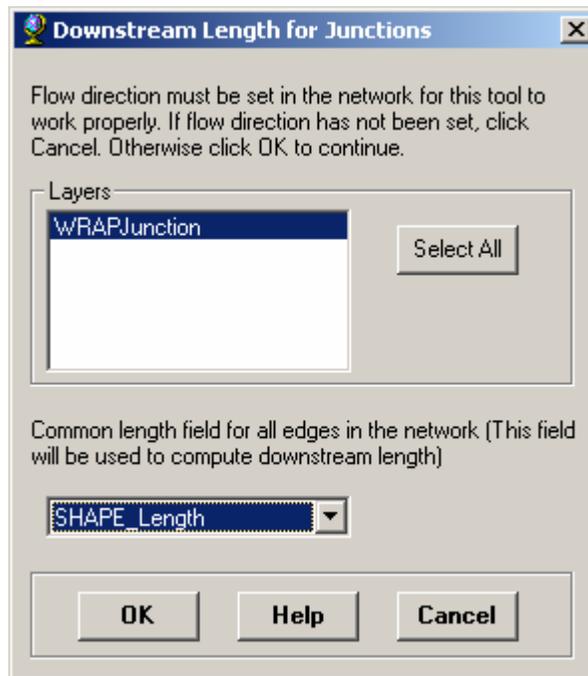


Figure 4.36: Settings for calculating length downstream for junctions

4.11.6 Copy the parameters to the original control points

Once all hydrological parameters have been re-calculated for the junctions in the whole basin, it is necessary to transfer these ones to the original control points included in the ControlPoint feature class. The “Params to Control Points” tool of the WRAPHydro toolset is used to copy the parameters from WRAPJunction to ControlPoint.

NextDownID, average curve number, average precipitation, and drainage area have now been populated for all original control points in the region. Refer appendix D for more details about this process.

4.12 SCHEMATIC NETWORK

A schematic network diagram was created for the Rio Grande/Bravo basin from El Paso, Texas through the Gulf of Mexico, as is shown in Figure 4.37. This schematic network is a simplification of the HydroNetwork that consists of separate point and line feature classes called Schematic-Node and Schematic-Link, respectively. The schematic network is an abstract representation of the elements to which hydrologic or water management models can be applied, and it provides a simplified view of the connectivity of the river network and the control points. This kind of network is useful as a visual check to make sure that the hydrologic elements needed for a model are correctly linked in the landscape (Maidment, 2002)

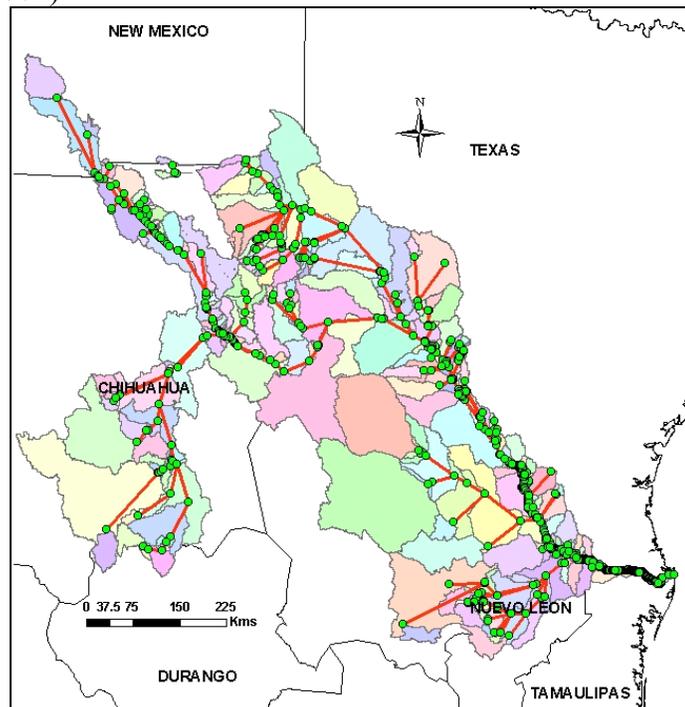


Figure 4.37: Schematic network of the Rio Grande/Bravo basin

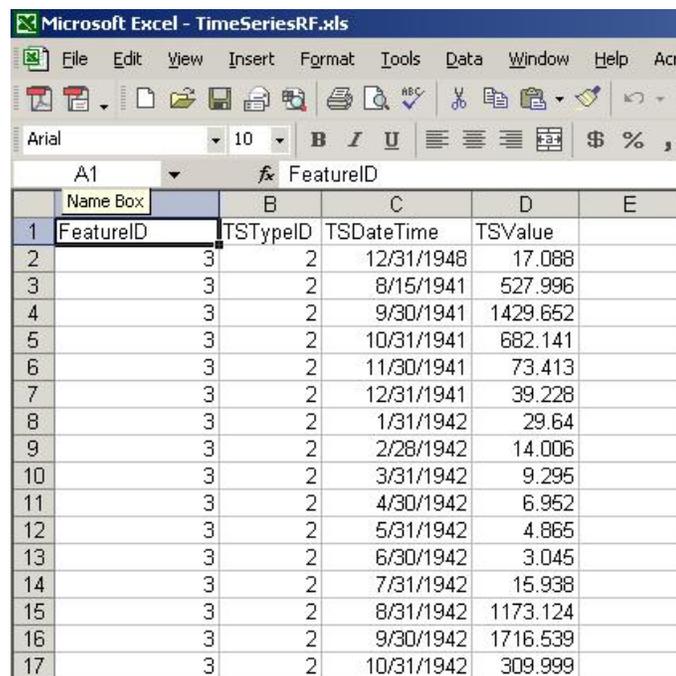
Typically, Watersheds and HydroJunctions are used to create the schematic network. The JunctionID attribute on a Watershed stores the HydroID of the HydroJunction that serves as the outlet for that Watershed. The NextDownID attribute of a HydroJunction stores the HydroID of the next downstream HydroJunction. Thus, the HydroID is a key attribute allowing the linking of schematic features. With these attributes, connectivity is established between Watersheds and HydroJunctions. From this connectivity, a schematic network representing those features may be created.

The schematic network is composed of two feature classes: SchemaNode and SchemaLink, representing schematic nodes and schematic links, respectively. A schematic node represents a hydrologic feature, such as a watershed or a junction in the stream network. Schematic nodes are typically created from polygon or point features, with a node being located at the centroid of its related polygon feature or at the same location as its related point feature. The schematic nodes contain a field called FeatureID, which stores the HydroID of the source feature that is represented by the schematic feature. Refer appendix D for more details on how to create the schematic network in ArcGIS.

Chapter 5: Time Series Management

The ArcHydro data model integrates spatial and temporal data in a hydrologic context within a GIS. ArcHydro's time series structure is used in this research for time series display and analysis.

There are several ways to load time series data into a geodatabase but the best way is to generate a text file with the required ArcHydro format (any text file with a tab separated value format including the headings), that is, the text file must be an Access compatible file that includes the headings for each record. This text file can be generated in Excel, using the ArcHydro structure shown in Figure 5.1



The screenshot shows a Microsoft Excel spreadsheet titled "TimeSeriesRF.xls". The spreadsheet contains a table with the following data:

FeatureID	TSTypeID	TSDateTime	TSValue
3	2	12/31/1948	17.088
3	2	8/15/1941	527.996
3	2	9/30/1941	1429.652
3	2	10/31/1941	682.141
3	2	11/30/1941	73.413
3	2	12/31/1941	39.228
3	2	1/31/1942	29.64
3	2	2/28/1942	14.006
3	2	3/31/1942	9.295
3	2	4/30/1942	6.952
3	2	5/31/1942	4.865
3	2	6/30/1942	3.045
3	2	7/31/1942	15.938
3	2	8/31/1942	1173.124
3	2	9/30/1942	1716.539
3	2	10/31/1942	309.999

Figure 5.1: ArcHydro time series structure

The first row describes the attributes of the ArcHydro time series table. The FeatureID value corresponds to the HydroID of its corresponding monitoring point. The TSTypeID field describes the variable users are recording. Monthly runoff in cubic meter per second is identified with number 2 as an example in this research. TSDateTime describes when the value was recorded, while the TSValue field contains the value recorded. This file is save using text tab delimited format to import it into the geodatabase. More details about how to import historical records into a geodatabase in GIS are described in appendix E.

5.1 IMPORTING THE TIME SERIES RECORDS INTO THE GEODATABASE

The ArcHydro time series format is applied to all the time series data, around five million records, in order to include and relate them to the monitoring and control points inside the Rio Grande/Bravo geodatabase. The time series standard format of the ArcHydro schema was changed, adding one more table called TSGroup that contains information related to the agency from which the data is derived (Patino et al, 2004). Tables 5.1 and 5.2 describe the agencies and variables included in the geodatabase.

OBJECTID*	TSTypeID*	Variable	Units	IsRegular	TSInterval	DataType	Origin
1	1	Daily Streamflow	cms	True	1Day	Average	Recorded
2	2	Monthly Streamflow	cms	True	1Month	Cumulative	Recorded
3	3	Real Time Streamflow	cms	True	15Minute	Instantaneous	Recorded
4	4	Stage	m	True	1Day	Average	Recorded
5	5	Daily Runoff Volume	Million of m3	True	1Day	Average	Recorded
6	6	Monthly Runoff Volume	Million of m3	True	1Month	Cumulative	Recorded
7	7	Daily Precipitation	mm	True	1Day	Cumulative	Recorded
8	8	Monthly Precipitation	mm	True	1Month	Cumulative	Recorded
9	9	Evaporation	mm	True	1Month	Cumulative	Recorded
10	10	Storage	Million of m3	True	1Month	Average	Recorded
11	11	Volume-Demand	Million of m3	True	1Month	Cumulative	Recorded
12	12	Volume-IN	Million of m3	True	1Month	Cumulative	Recorded
13	13	Volume-OUT	Million of m3	True	1Month	Cumulative	Recorded
14	14	Daily Storage	Million of m3	True	1Day	Average	Recorded
15	15	Inflow	cms	True	1Month	Average	Recorded
16	16	Outflow	cms	True	1Month	Average	Recorded
17	17	NaturalizedFlows	Million of m3	True	1Month	Cumulative	Generated

Table 5.1: Variables included in the geodatabase

OBJECTID	FeatureID	Agency	GroupID*
1	1	CNA	1
2	2	IBWC	2
3	3	IMTA-BANDAS&SICLIM	3
4	4	USGS	4
5	5	TCEQ	5
6	6	CILA	6
7	7	Other	7

Table 5.2: Agencies participating to create the geodatabase

Users can select a specific monitoring point within the geodatabase and several relationships have been established for it, so they can identify the agencies from which the temporal data was derived, as well as the type of variable. The Rio Conchos runoff to the Rio Grande/Bravo is shown in Table 5.3

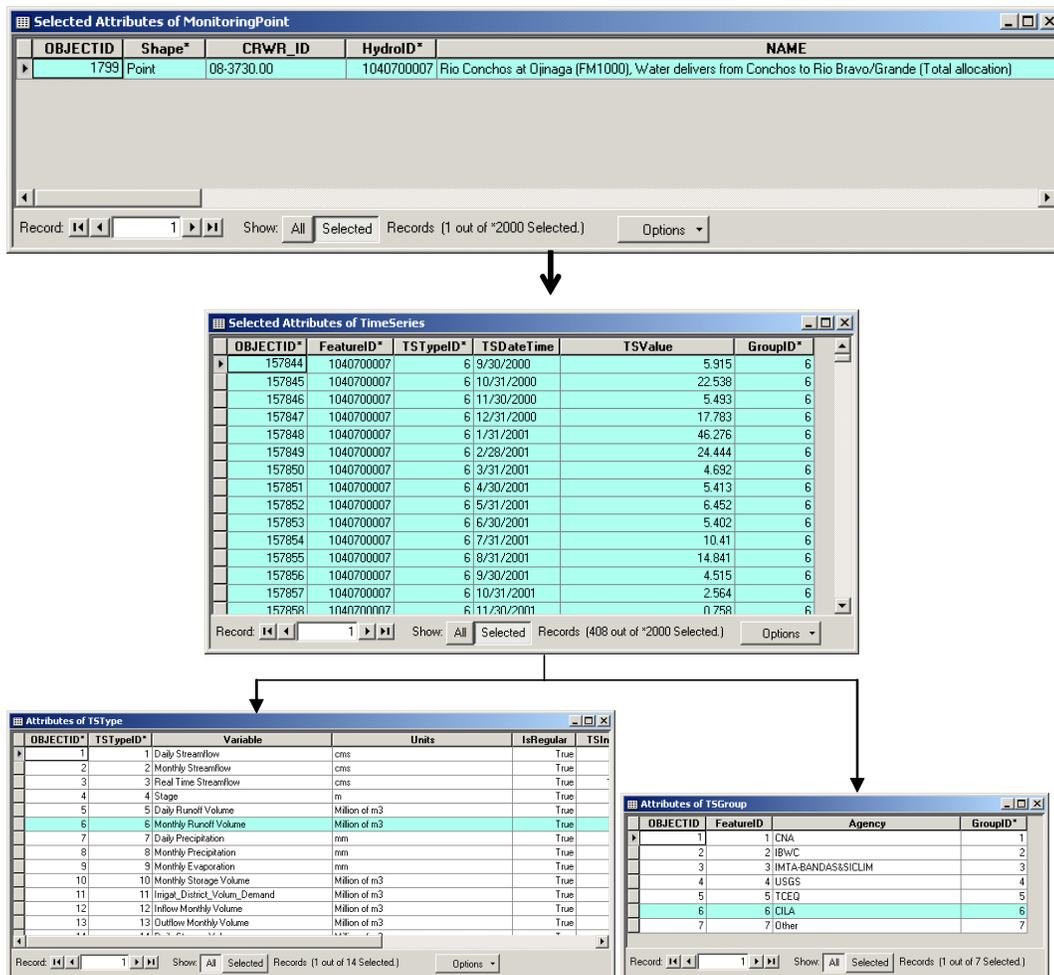


Table 5.3: Monthly runoff at the gage station Rio Conchos - Ojinaga

Also, a time series viewer developed by John Goodall (2004) at the CRWR was applied in order to plot the behavior of the temporal information. The information related to runoff from the Rio Conchos to the Rio Grande/Bravo is shown in Figure 5.2. The total discharge to the Rio Grande identified by the identification number (HydroID) 1040700007 is displayed in this graph. The

regional HydroIDs 2020100051 and 2010100005 correspond to the discharge to the Rio Grande from Mexico and the U.S. respectively.

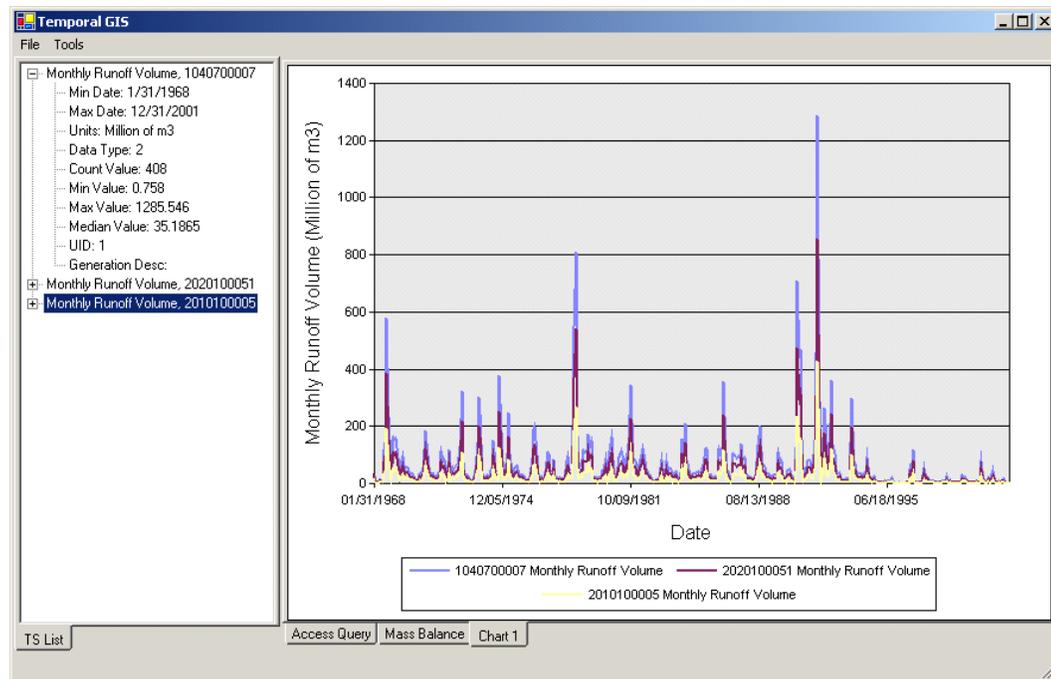


Figure 5.2: Monthly runoff volume from the Rio Conchos to the Rio Grande/Bravo

5.2 EXCHANGE OF TEMPORAL INFORMATION

A tool called DSSHydro tool for transferring around two million of historical records from an ArcHydro geodatabase into a HEC-DSS file and back to a geodatabase is being developed in this research for using with USACE HEC models. This tool consists of a set of public domain utilities developed in Visual Basic. The DSSHydro toolbar operates in the ArcGIS ArcMap environment, and is comprised of four commands to transfer the temporal information (Figure 5.3).

This tool utilizes an object library and objects classes within the geodatabase structure called DSS Time Series Catalog (DSSTSCatalog) that contains all relevant records and descriptors to automatically transfer the time series (Teasley et al, 2004). Full help documentation for the tool, as well as the tool itself, may be downloaded from ftp://ftp.crwr.utexas.edu/pub/outgoing/PATINOC/DSS_Executables/

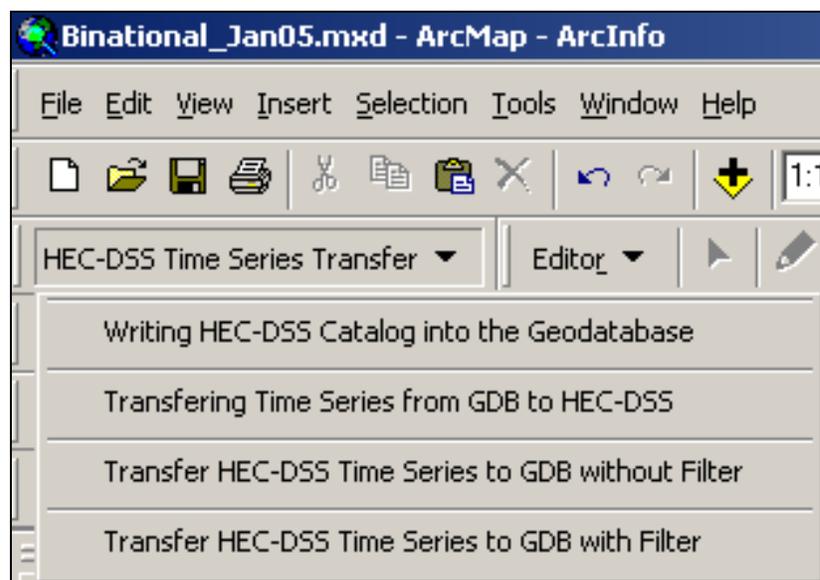


Figure 5.3: DSSHydro Tools

The original ArcHydro Time Series framework is modified to create automatically the DSSTSCatalog table inside the ArcHydro structure when the ArcHydro schema is applied to a geodatabase. This table contains all necessary fields that are used as the descriptors to create the HEC-DSS files (Figure 5.4).

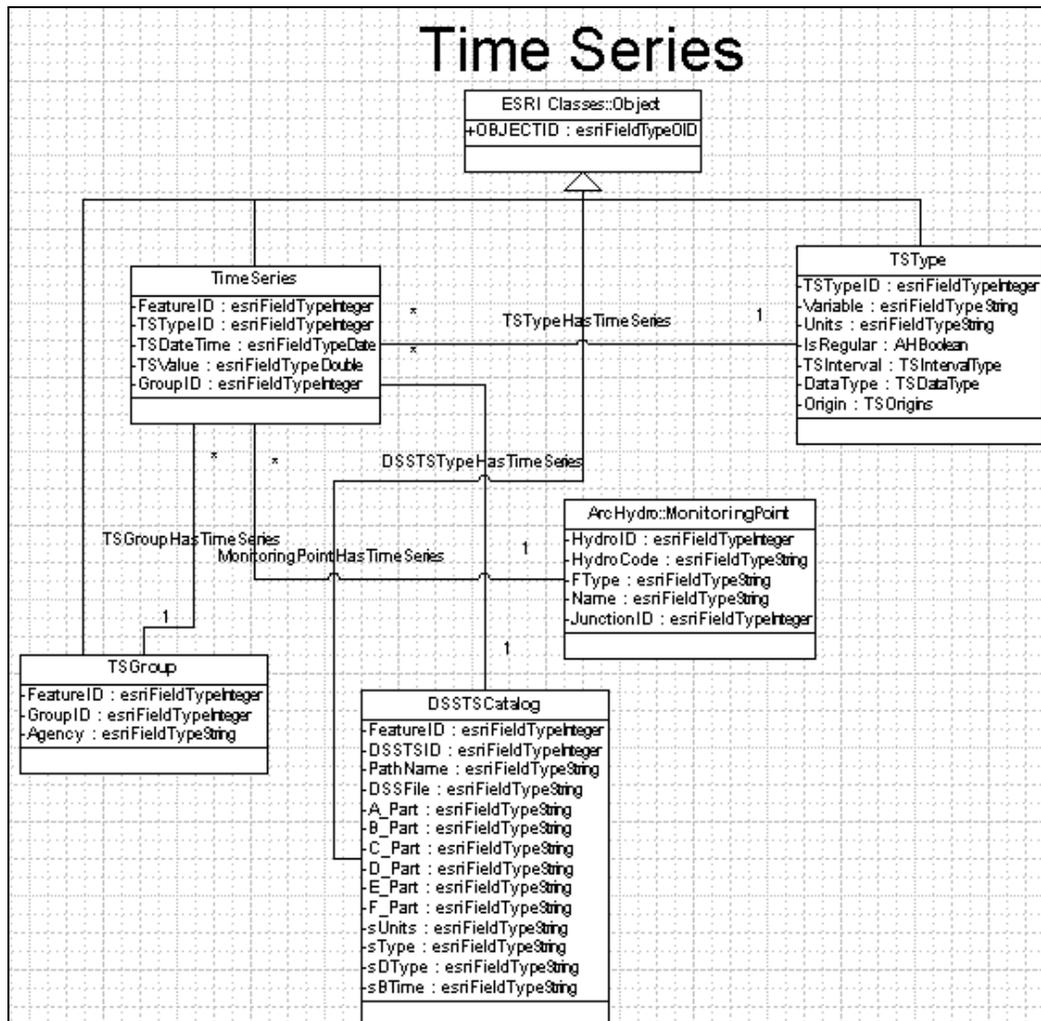


Figure 5.4: Modified ArcHydro Time Series Framework

The DSSTSCatalog, which is created previously by the ArcHydro schema, is populated automatically in a geodatabase using the “Writing DSS Catalog into the geodatabase” option included in the DSS Hydro toolbar. This function takes the temporal information from the Time Series and the TSType tables included in

the ArcHydro geodatabase. The TSType table must have the structure shown in Table 5.4 in order to be able to transfer the temporal information.

OBJECTID*	TSTypeID*	Variable	Units	IsRegular	TSInterval	DataType	Origin
1	1	Daily Streamflow	cms	1	17	4	1
2	2	Monthly Streamflow	cms	1	19	2	1
3	3	Real Time Streamflow	cms	1	7	1	1
4	4	Stage	m	1	17	4	1
5	5	Daily Runoff Volume	Million of m3	1	17	4	1
6	6	Monthly Runoff Volume	Million of m3	1	19	2	1
7	7	Daily Precipitation	mm	1	17	2	1
8	8	Monthly Precipitation	mm	1	19	2	1
9	9	Evaporation	mm	1	19	2	1
10	10	Storage	Million of m3	1	19	4	1
11	11	Volume-Demand	Million of m3	1	19	2	1
12	12	Volume-IN	Million of m3	1	19	2	1
13	13	Volume-OUT	Million of m3	1	19	2	1
14	14	Daily Storage	Million of m3	1	17	4	1
15	15	Inflow	cms	1	19	4	1
16	16	Outflow	cms	1	19	4	1
17	17	NaturalizedFlows	Million of m3	1	19	2	2

Table 5.4: TSType table in the ArcHydro structure

Robayo’s work (2005) considers a similar structure for converting a NEXRAD rainfall map time series into a flood inundation map. Once the precipitation records have been reassigned to the watersheds they are transferred from geodatabase time series tables to HEC-DSS binary format based on the HEC-DSS Time Series Type table containing the needed arguments for the transfer process. Some computer applications in the form of script tools were developed to transfer the data from the HEC-DSS system into the predefined Arc Hydro table (transferring around five thousand records), while a more robust HEC-DSS time series “bridge” application implemented directly in the ArcMap environment is designed in this research to transfer millions of records in just one step considering many variables.

The DSSTSCatalog is the object class table within the geodatabase that contains the information related to the DSS data and its pathname, and represents the key step in transforming a time series from a geodatabase into the HEC-DSS format. The DSS pathname consists of six parts in the following format:

/A/B/C/D/E/F/

Where

- A - Group name for the data such as a watershed name, study name or any identifier which allows the records to be recognized as belonging to a group.
- B – The location identifier for the data. The location identifier may be a site name or organization ID such as a USGS gage ID or the HydroID of the monitoring point.
- C - The parameter of the data such as flow, precipitation, storage, evaporation, etc.
- D - the start date of the time series, and
- E - The time interval for regular data or the block length for irregular interval data.
- F - An optional descriptor that can be used for additional information about the data.

Once the DSSTSCatalog is created, the temporal information contained in the ArchHydro time series table is transferred from the geodatabase to the HEC-DSS format using the “Transferring Time Series from GDB to HEC-DSS” option

of the DSS Hydro toolbar. These HEC-DSS files will be used for simulation purposes (Figure 5.5).

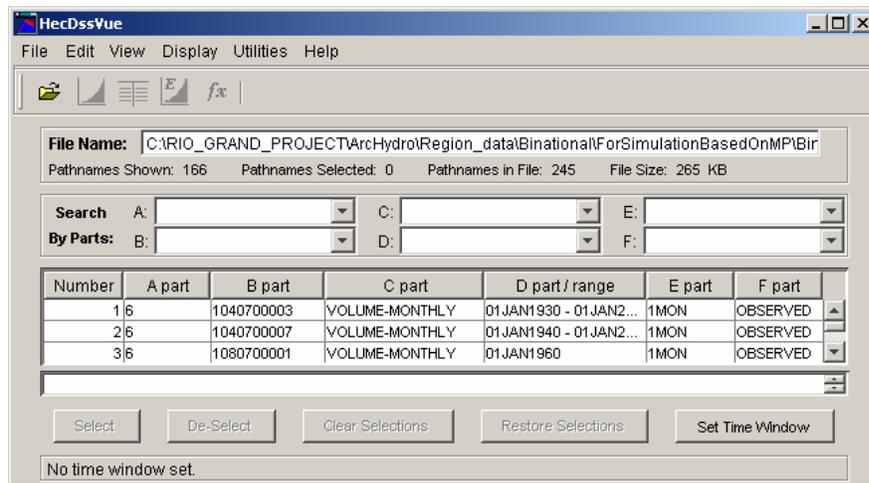


Figure 5.5: HEC-DSS files

After the simulation has been completed in any HEC model, it is necessary to transfer back the time series results from the HEC-DSS files to the geodatabase. The “Transfer HEC-DSS Time Series to GDB” option of the DSS Hydro toolbar is used to perform this task. There are two options for exchanging temporal information; one of them uses a filter for transferring time series just related to one specific point, whereas another one is used to transfer all records contained in the HEC-DSS files (Figure 5.6).

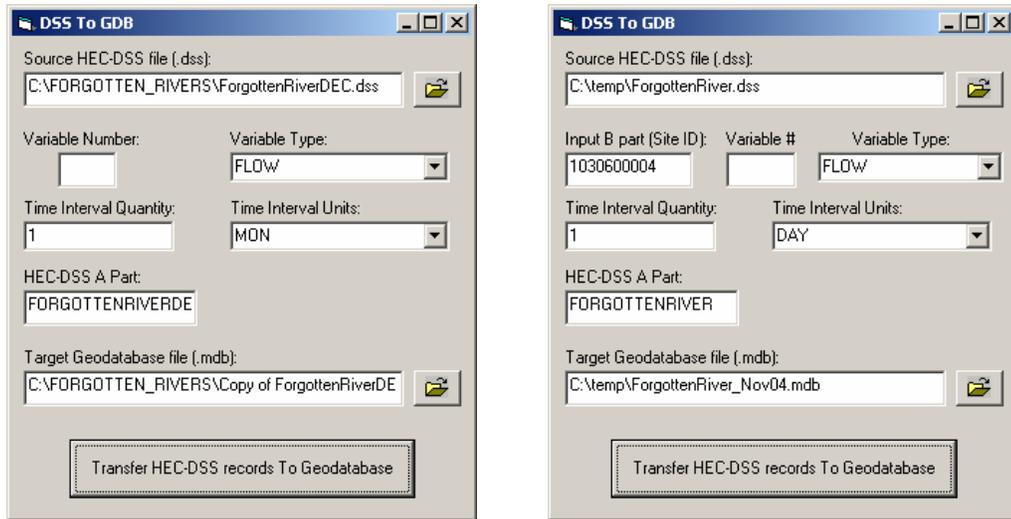


Figure 5.6: Transferring records from the DSS files

Figure 5.7 shows the whole process for transferring historical records between a geodatabase and the HEC-DSS files.

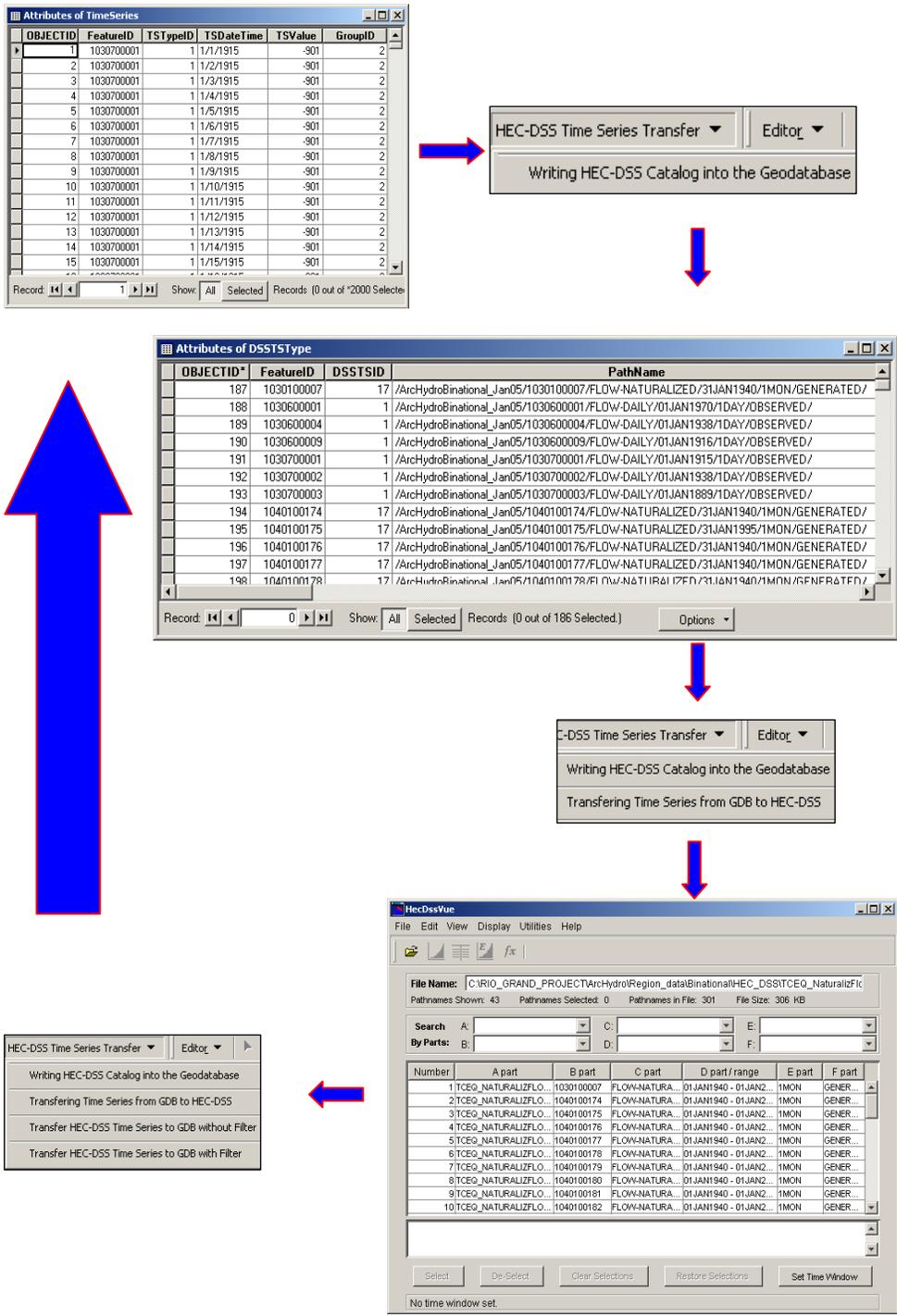


Figure 5.7: Time series transfer between the geodatabase and HEC-DSS

Chapter 6: Water Quality Data Model in GIS for the Rio Grande/Bravo Basin

6.1 OBJECTIVE

Development of a Water Quality Data Model (WQDM) based on a framework developed in Visio 2000 and exported as a schema in a Microsoft Access mdb file is another important objective of this research. This data model is implemented following criteria and parameters from the International Boundary Water Commission (IBWC), Texas Commission on Environmental Quality (TCEQ), United States Geological Survey (USGS), Environmental Protection Agency (EPA), Mexican National Water Commission (CNA), and the Mexican Natural Resources and Environmental Secretary (SEMARNAT). This georeferenced database includes spatial and temporal information, and can be implemented in a Geographic Information System (ArcGIS) following the ArcHydro data model structure developed at the Center for Research in Water Resources of the University of Texas at Austin (CRWR-UT). This relational database will be related to the Water Quantity Data Model for the Rio Grande/Bravo basin described in the previous sections.

6.2 METHODOLOGY

6.2.1 Data collection

Data regarding water quality control points and their corresponding historical information on the American side was collected from the International Boundary Water Commission. This info is classified in two parts; one of them is

included in the “IBWC Water Bulletins (http://www.ibwc.state.gov/EMD/Water_Bulletins/Water_Bulletins.htm)” and the other one is part of the “Texas Clean River Project (<http://www.ibwc.state.gov/CRP/monstats.htm>)”. The Clean River Project (CRP) is implemented by several agencies such as IBWC and TCEQ. All original data is included in excel spreadsheets and includes the period 1990 – 2000 in most cases. The rivers are classified by the TCEQ with a specific segment ID, which is preserved in the Water Quality Data Model (WQDM). These river segments are reported as shapefiles in the TCEQ website (<http://www.tnrc.state.tx.us/gis/ourmaps.html>). The waterbodies included in the WQDM were gathered from the TCEQ for the American side, preserving their classification criteria. The river segments, water quality control points and waterbody information on the Mexican side of the basin were collected from the CNA and SEMARNAT agencies.

6.3 DEVELOPING THE SCHEMA OF THE WATER QUALITY DATA MODEL (WQDM)

A water quality framework was created in Visio 2000 to produce a Rio Grande Water Quality UML file. This framework follows the ArcHydro data Model philosophy, but some changes were made to the attribute tables of the feature classes in order to meet criteria and parameters required by the TCEQ, EPA, USGS, IBWC, CILA, and CNA. Several new fields were included for preserving the original identifiers, codes, and names from the corresponding agency, in order to establish the link between the original format of the water

quality information and the WQDM structure implemented in this research. Also, more code tables associated with the river segments and water quality stations were added, in order to indicate which segments are impaired and which pollutants are responsible for the failure of those segments to meet water quality standards.

Once the Water Quality Data Model UML has been created, it must be exported as an Access mdb file to create the schema, which will be applied to a relational geodatabase in ArcCatalog (Figure 6.1).



Figure 6.1: Water Quality Data Model Framework

6.4 SPATIAL REFERENCE INFORMATION

The projection parameters used for the WQDM are the same as in the ArcHydro data model for the Rio Grande/Bravo basin.

6.5 ENTITY AND ATTRIBUTE INFORMATION

6.5.1 Feature Class: HydroEdge

This feature class depicts the official TCEQ Stream Segments for the State of Texas as listed in Title 30, Chapter 307 of the Texas Administrative Code (TAC), also known as the Surface Water Quality Standards on the US side, and the official CNA or SEMARNAT Stream Segments for the Mexican side of the Rio Grande/Bravo basin. These are streams and waterbodies that have been individually defined by the TCEQ and the other participating agencies and assigned unique identification numbers. Intended to have relatively homogeneous chemical, physical, and hydrological characteristics, a segment provides a basic unit for assigning site-specific standards and for applying water quality management programs of the agency. Both "classified" and "unclassified" segments have been included in this feature class.

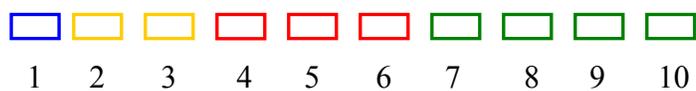
Classified segments, also referred to as *designated segments*, refer to water bodies that are protected by site-specific criteria. The classified segments are listed and described in Appendix A and C of Chapter 307.10 of the TAC. The site-specific uses and criteria are described in Appendix A. Classified waters include most rivers and their major tributaries, major reservoirs, and estuaries.

Unclassified waters are those smaller water bodies that do not have site-specific water quality standards assigned to them, but instead are protected by general standards that apply to all surface waters in the state. This feature class also identifies which segments and water bodies have been listed as impaired or

threatened in the final draft of the Texas 2000 Clean Water Act Section 303(d) List (effective August 31, 2000) for the U.S. side of the Rio Grande/Bravo basin.

An **impaired segment** is a water body which does not meet the standards set for its use, or is expected not to meet its use in the near future. The impaired code table associated with this feature class contains fields that indicate which segments are impaired and which pollutants are responsible for the failure of those segments to meet water quality standards. The hydrography described as HydroEdges in the Rio Grande/Bravo basin geodatabase for the water quantity developed in the CRWR is used to define these river segments within the WQDM.

- a. **Attribute: HydroID.** This is the unique 10 digit identification number assigned by the CRWR. This ID will be used to establish the topology in the geometric network. The HydroID for this element would be assigned as described below:



The first digit indicates the country where the element is located. The number 1 is used for the segments located on the US side, and 2 for the segments located on the Mexican side. The next two digits indicate the feature class within the geodatabase. Number 02 was assigned to the HydroEdge feature class, which contains the river segments. The next three digits correspond to the element number; and the last four digits describe the river segment classification from the

corresponding agency (TCEQ and EPA on the US side and CNA and SEMARNAT on the Mexican side).

- b. Attribute: HydroCode.** This is the public identification number assigned by the TCEQ, USGS, EPA, IBWC, or CNA.
- c. Attribute: ReachCode.** This field is added to store the ReachFile from the EPA
- d. Attribute: Name.** The name of the classified or unclassified segment as it appears in the Texas Surface Water Quality Standards on the US side, and as it appears in the National Water Commission (CNA) or the Natural Resources and Environmental Secretary (SEMARNAT) classification on the Mexican side.
- e. Attribute: LengthKm.** This field indicates the river segment length in Km
- f. Attribute: LengthDown.** This field indicates the distance of the river segment to the outlet of the Rio Grande/Bravo basin, usually calculated in kilometers based on the HydroEdge attribute LengthKm.
- g. Attribute: FlowDir.** This field indicates flow direction of each river segment
- h. Attribute: Agency_ID.** This is a unique digit identification number as it appears in the TCEQ, EPA, IBWC, CILA, CNA, SEMARNAT, etc., databases for every river segment. This ID is usually the same as the HydroCode attribute

- i. Attribute: SegmentClass. Classified:** River Segments or water bodies that are protected by site-specific criteria as outlined in the TCEQ Surface Water Quality Standards. **Unclassified:** Smaller water bodies that do not have site-specific water quality standards assigned to them, but instead are protected by general standards that apply to all surface water in the state.
- j. Attribute: SegmentType. Freshwater Stream:** Inland waters which exhibit no measurable elevation changes due to normal tides. **Tidal Stream:** Descriptive of coastal waters which are subject to the ebb and flow of tides. For purposes of standards applicability, tidal waters are considered to be saltwater. Classified tidal waters include all bays and estuaries with a segment number that begins with 1323xx for the Texas side, all streams with the word tidal in the segment name, and the Gulf of Mexico. **Reservoir:** Any natural or artificial holding area used to store, regulate or control water. **Estuary:** Regions of interaction between rivers and near shore ocean water, where tidal action and river flow create a mixing of fresh and salt water.
- k. Attribute: Location.** Verbal description indicating where the stream segment or water body begins and ends.
- l. Attribute: Basin.** This field describes the name of the basin. Rio Grande/Bravo basin is the official name within the WQDM

- m. Attribute: Region.** This field describes the region where the stream segment is located, according to the TCEQ classification on the Texas side and the CNA classification on the Mexican side
- n. Attribute: Impaired_Status.** Single-character field indicating whether or not the water body was impaired in the 2000 Surface Water Quality Standards effective on September 1, 2000. GIS Maps are available with results about impairing for 2000, but not for year 2002 in the TCEQ website (http://www.tnrcc.state.tx.us/water/quality/data/wmt/data_by_basin.html). These results will be updated for 2002 in the WQDM.
- o. Attribute: AgencImpairCode.** A one-digit numeric code from the agency indicating why the water body is listed as impaired. This attribute will be related with the Impaired_Code_Table through the CRWR_ImpairedCode attribute.
- p. Attribute: CRWR_ImpairedCode.** A small integer related to the impaired code from the agency. There will be established a relationship between this attribute and the Impaired_Code_Table to describe why the river segment or waterbody is considered as impaired.

A relationship is established between a river segment and its corresponding water quality monitoring station (Identified as a Monitoring Point within the geodatabase). Another relationship is established between the river

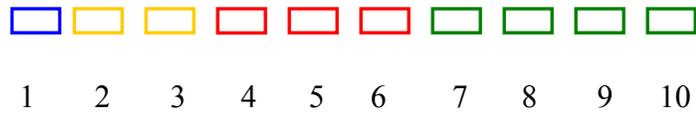
segments (HydroEdge) and the HydroJunction feature class. The HydroJunction is a virtual point representing a monitoring point in the geometric network.

6.5.2 Feature Class: Monitoring Point

This feature class shows all surface water quality monitoring being conducted by the TCEQ or under TCEQ contract for Fiscal Year 2005 on the Texas side, and all water surface water quality monitoring identified by the CNA and SEMARNAT on the Mexican side. Other types of water quality points such as treatment plants location, waste water discharges, and hazardous points will be included in this feature class within the WQDM. The water quality stations on the US side of the Rio Grande/Bravo basin were downloaded from the IBWC website (<http://www.ibwc.state.gov/CRP/monstats.htm>), where users can find the monitoring point locations considered in the IBWC-Clean River Project. To support coordinated monitoring, the TCEQ has developed guidance for site selection and for sampling requirements for routine, special study, and targeted monitoring. In this website http://www.tnrcc.state.tx.us/water/quality/data/wqm/coop_monitoring_2005.html TCEQ provides more documents as support for the statewide coordinated monitoring effort in Texas.

a. Attribute: HydroID.

The HydroID of a Monitoring Point indicates a unique feature identifier in the Water Quality Data Model. This ID becomes the key to establish many relationships between the monitoring point and other elements included in the WQDM. The HydroID for an element would be assigned as described below:



The first digit indicates the country where the element is located. The number 1 is used for the water quality points located on the US side, and 2 for the control points located on the Mexican side. The next two digits indicate the feature class within the geodatabase. Number 01 was assigned to Monitoring Point feature class, which contains the water quality control points. The next three digits correspond to the element number; and the last four digits describe the water quality river segment where the water quality control point is measuring according to the TCEQ and EPA classification on the US side and CNA or SEMARNAT on the Mexican side.

6.5.3 Feature Class: Waterbody

This feature class includes the water bodies, impaired or not, located on the Rio Grande/Bravo basin on both sides of the basin. Waterbodies are all the significant ponds, lakes, and bays in the water system. The American waterbodies were gathered from the USGS, EPA, and TCEQ, while the CNA and SEMARNAT provided the waterbodies information on the Mexican side.

6.5.4 Feature Class: Watershed

This feature class will include information related to the drainage areas contributing flow from the land surface to the water system. The watershed information on the Mexican side is collected from the CNA and SEMARNAT,

while this is being collected from EPA and TCEQ on the American side. The EPA manages water pollution using Total Maximum Daily Loads (TMDL) defined on watersheds draining to selected river segments or waterbodies, a different watershed layout than that used by the National Weather Service on the US. The WQDM is designed to allow any set of watersheds to be relationally connected to the hydro network, using the “area flows to a point on a line” concept to establish relationships between watersheds and HydroJunctions at their outlet location.

6.5.5 Feature Class: HydroJunction

This feature class includes a set of junctions located at the end of the river segments and at other strategic locations on the flow network. Usually the Monitoring Points, which preserve their original position, are represented by the HydroJunction on the flow network. HydroEdges and HydroJunctions are topologically connected in an ArcGIS geometric network, called the HydroNetwork and included as the backbone of the WQDM. Since HydroJunctions are topologically linked to the river segments (HydroEdges) in the geometric network, the combination of this network and the other relationships means that the classes in the WQDM framework are connected into an integrated data structure.

6.5.6 Time Series table

The inclusion time series data in the WQDM is not only to create a complete water quality data model for using the GIS environment, but also to

build a relational database that would be accessible to many water quality models that operate separately of the GIS. The temporal information is captured and stored in a variety of formats by each entity, so it is fundamental to have a standard design to manage large historical data sets. The original ArcHydro time series framework for surface water flow data was modified to have a large container in the GIS that allows storing the many more variables related to water quality data and includes millions of records. Under this concept, a user may acquire, store, or deliver an entire water quality data set, including time series data files from water quality stations, as well as the geographic element associated to it in a single geodatabase file.

6.5.7 TSGroup table

This table describes the entity that manages and publishes time series information. In this table users can identify where the information comes from, using a unique identifier for each agency. A relationship is established between the temporal information in the time series table and the Monitoring Point feature class using the FeatureID as the key.

6.5.8 TSType table

The TSType table contains an index of the types of time series data stored in the time series table. A relationship is established between the TSType table and the Time Series table using the TSTypeID as the key.

6.5.9 Impaired Code Table

This table is associated with the HydroEdge and WaterBody feature classes within the WQDM to indicate which river segments are impaired. The impaired code table contains fields to describe which pollutants are responsible for the failure of river segments to meet water quality standards.

6.5.10 Agency responsible table

This table describes which entity is in charge of the water quality stations. A relationship is established between the Agency responsible table and the Monitoring Point feature class using the AgenResp_Code attribute as the key.

6.6 TOPOLOGY AND RELATIONSHIPS AMONG THE FEATURE CLASSES

A geometric network called HydroNetwork is created to establish the topology among the elements within the WQDM. This HydroNetwork becomes the backbone of the WQDM structure, created from the river segments (HydroEdges) and the water quality monitoring stations (HydroJunctions). The topological connection of the HydroEdges and HydroJunctions in the WQDM enables tracing of water movement upstream and downstream through streams and waterbodies. Relationships built from the HydroJunctions connect drainage areas, waterbodies and any point features such as water quality stations or wastewater treatment plants to the HydroNetwork. Each relationship has a multiplicity, and all the relationships implemented are one-to-many. One-to-many multiplicity means that one HydroJunction may be associated with one or more features in the related class. For example, two HydroEdges (river segments) may drain into a single HydroJunction on a river network

6.7 DATA PROCESSING

6.7.1 Creating HydroEdges

The original river segments (including the waterbodies) on the US side were extracted from TIGER/Line 92 data to create the initial Designated Stream Segments layer. Where that layer was lacking, missing streams and new reservoirs were table-digitized from TxDOT "half-scale" county map sheets. The Mexican side of the Amistad and Falcon reservoirs and the outlying boundaries of the border lakes are "heads-up" digitized from a digital map created in the early 1980s by the Texas Water Commission (from 1:250,000 AMS map sheets). The hydrography described as HydroEdges in the Rio Grande/Bravo basin geodatabase for the water quantity was used to define these river segments within the WQDM (Figure 6.2). Fragmented segments were merged in ArcInfo so that each displayed segment was represented by only one record in the table.

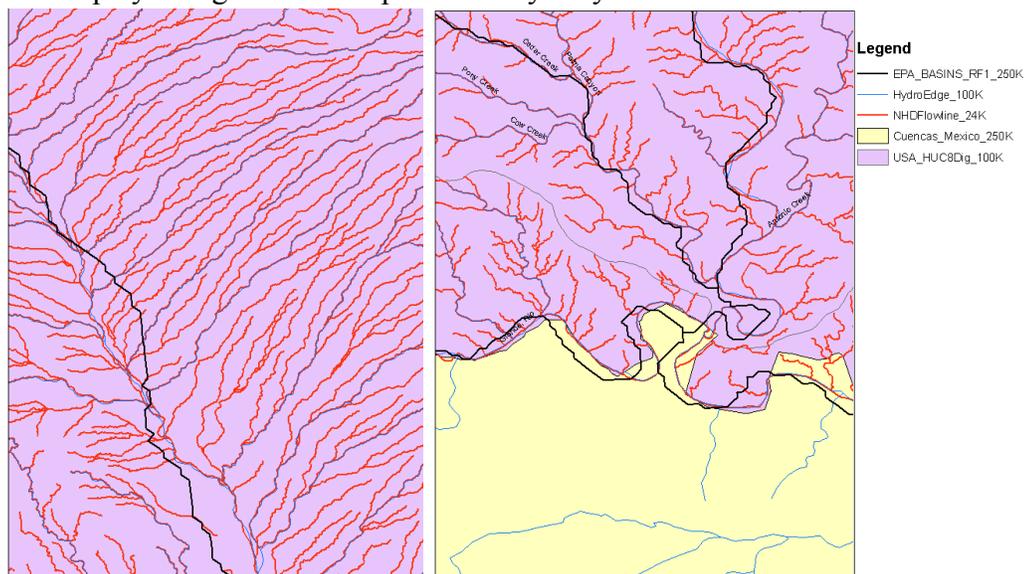


Figure 6.2: FlowLine resolution in the Rio Grande/Bravo basin

6.7.2 Creating Monitoring Points

Water quality stations, wastewater treatment plants, and other important control points are included in the WQDM as a feature class called Monitoring Points.

6.7.3 Creating the SnapControlPoint feature class

Because more than two monitoring points could be represented for just one HydroJunction in the geometric network, it is necessary to have a feature class called SnapControlPoint. The SnapControlPoint is a point feature class that represents all monitoring points with all the features snapped to the right location on the network. The HydroCode is the unique identifier to establish the relationship between the SnapControlPoint and the Monitoring Point feature class. The main purpose of this feature class is to exchange information about water quality parameters between the HydroJunctions participating in the geometric network and the monitoring points, which maintain their original position.

6.7.4 Creating HydroJunctions

Since more than one monitoring point can exist at the same location, it is fundamental to have one point on the geometric network representing all of them. These points participating directly in the network are known as HydroJunctions in the ArcHydro jargon. The HydroID is the key to establish the relationship between the HydroJunctions and the monitoring points. This unique value is assigned to the JunctionID value of the all monitoring points that are representing, so two or more monitoring points could have the same JunctionID.

6.7.5 Creating a geometric network

A geometric network is created using the SnapControlPoint and HydroEdge feature classes. All points in the SnapControlPoint feature class are snapped to the HydroEdge element. In order to avoid dividing the river segments into several parts, this geometric network is built with complex edges.

Also, the historical information related to the monitoring points is included in the time series table within the WQDM. The Unified Macro Language (UML) for the Water Quality Data Model can be downloaded from this ftp site: <ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/RioGrandeInfo/>

6.8 RESULTS AND VALIDATION

6.8.1 Final watershed delineation and connectivity in the Rio Grande/Bravo basin

Figure 6.3 shows the result of comparing the SubCuencas of the Rio Conchos basin defined by the Instituto Nacional de Estadística, Geografía e Informática of Mexico (INEGI)--represented by a red continuous line--and the watershed defined by the WRAPHydro Tools--represented by polygons. The SubCuencas were defined using a 1:250K scale topographic map, while the watersheds were calculated using the methods of this research from a 1:100K scale WRAPeEdge (from a digitized map) and a DEM grid size of 30 m. The points represent the related water rights, gage stations, and return flow control points.

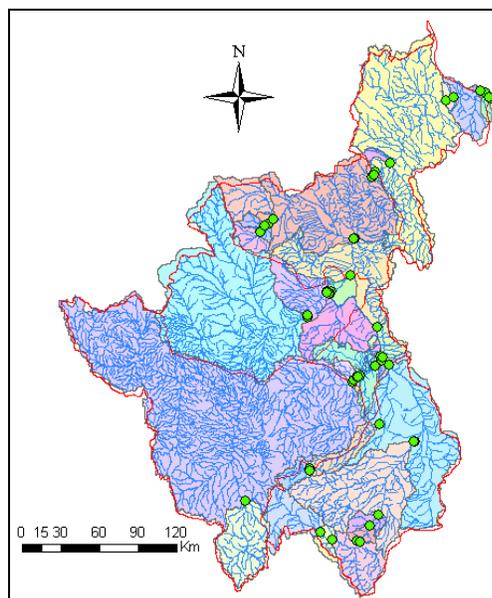


Figure 6.3: Rio Conchos basin delineation

Figure 6.4 shows the control points and main rivers in the portion of the Rio Grande/Bravo basin from El Paso/Cd. Juarez through the Gulf of Mexico. The connectivity among the river system, junctions and watersheds is shown in Figure 6.5.

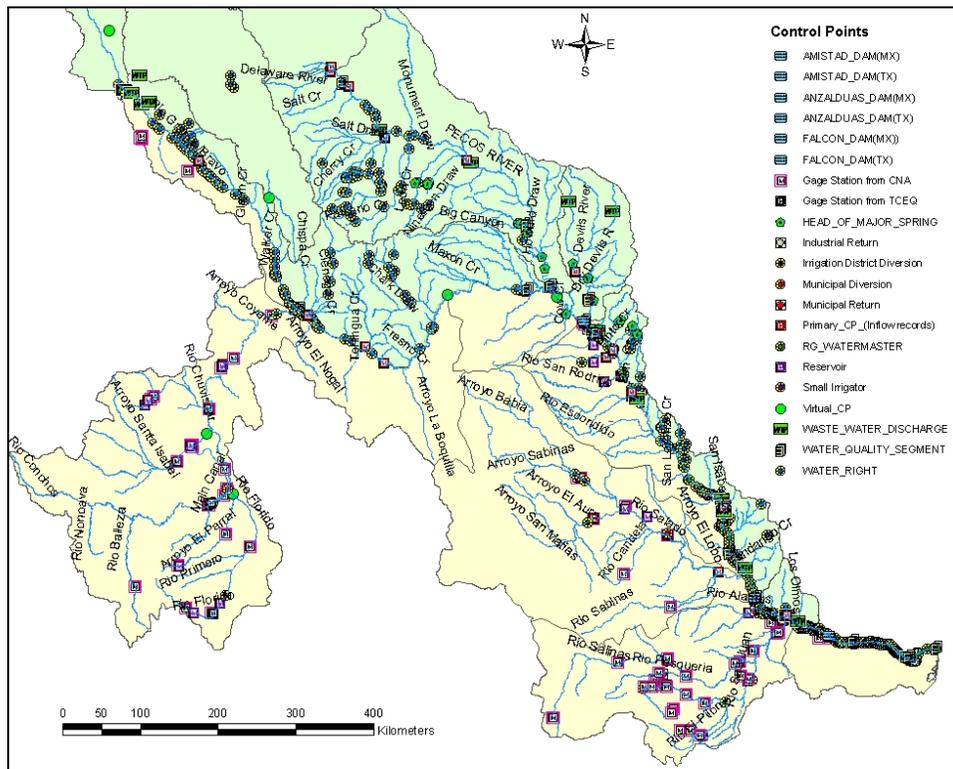


Figure 6.4: Control points and main rivers in the Rio Grande/Bravo basin

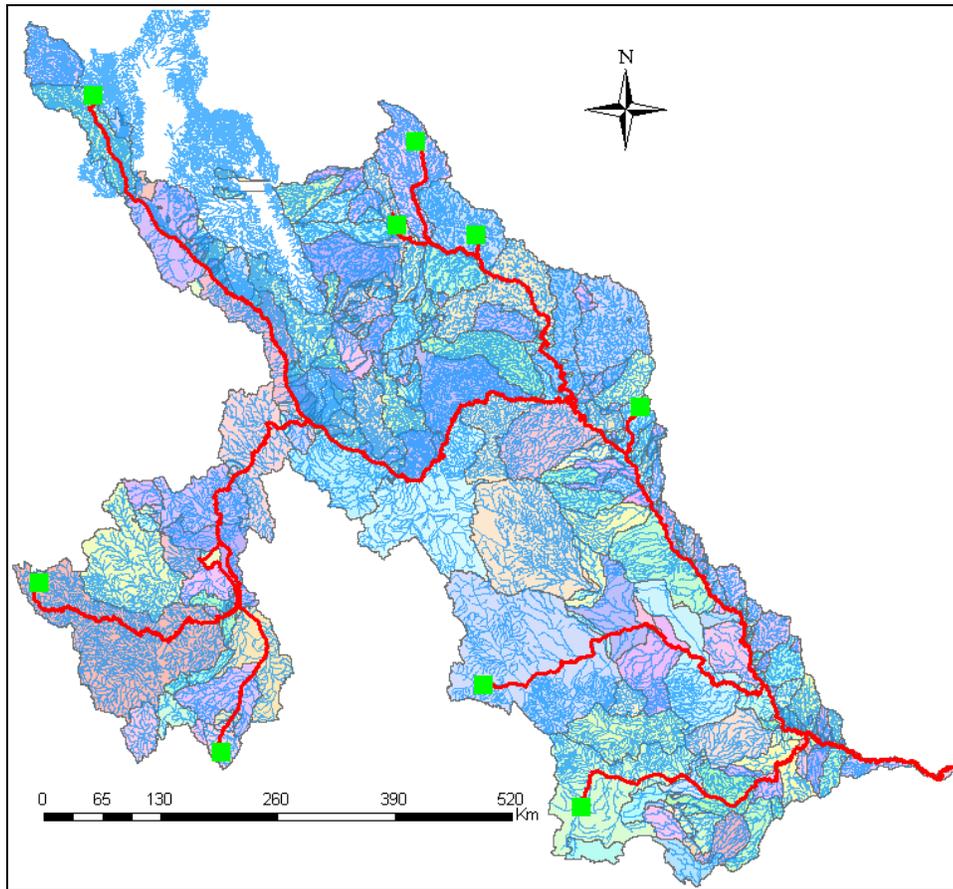


Figure 6.5: Connectivity in the Rio Grande/Bravo basin

6.8.2 Drainage areas comparison and validation

The results obtained for total upstream area for some stream gages from this research are compared to the USGS, IBWC, TCEQ, and CNA reported values for these stream gages located in the Rio Grande/Bravo basin. Figure 6.6 shows the drainage area values calculated from this research (red color) match very closely to the drainage values reported by the Mexican Institute of Water Technology (IMTA) and the CNA on the Mexican of this basin (see Table 6.1).

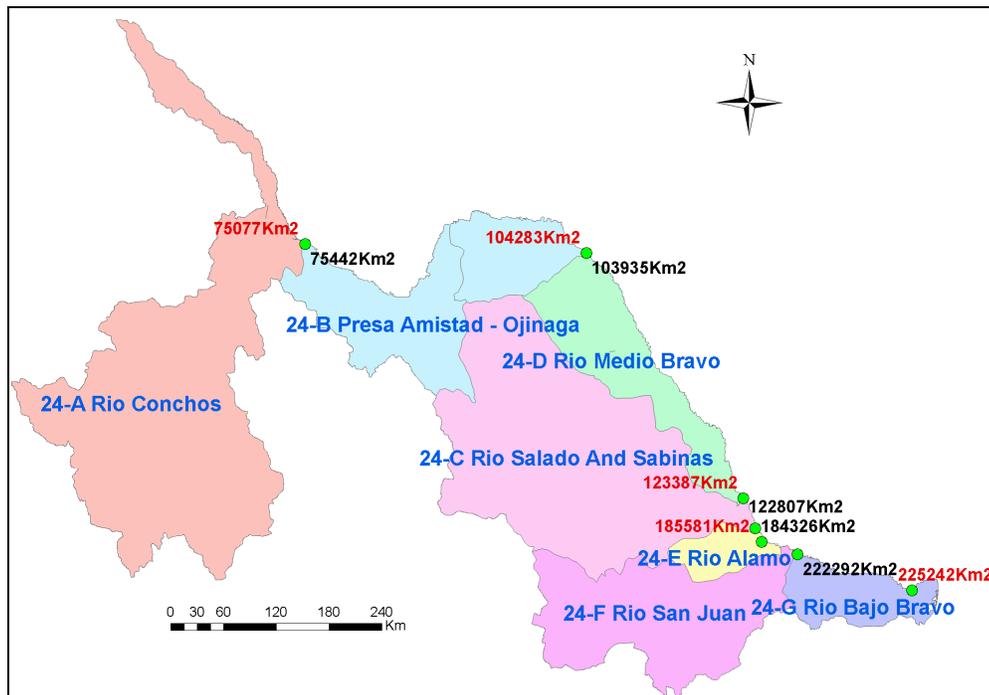


Figure 6.6: Drainage areas on the Mexican side of the Rio Grande/Bravo basin

The values reported on the Mexican side were determined by the technical subdirection of the CNA using a 1:250K scale topographic maps and satellite images (IMTA, 2001)

The biggest difference is found close to the outlet of the basin in the subcuena 24-G Rio Bajo Bravo, which corresponds for a CILA/IBWC gage station located downstream of Brownsville, Texas (Table 6.1). This difference of 2.76% is because the CNA/IMTA area includes a non contributing part of the subcuena called Soto La Marina.

Gage Name	CRWR Total Drainage Area on the Mexican side	Total drainage area by CNA/IMTA (SqKm)	Difference (%) between values from CRWR and CNA/IMTA
24-A Rio Conchos basin (CNA)	75,076.68	75,442	0.48
24-B Presa Amistad - Ojinaga - Gage Station from IBWC below la Amistad dam	104,282.99	103,935	-0.33
24-D Rio Bravo medio basin	123,387.09	122,807	-0.47
24-C rio Salado and Sabinas basin. Gage Station from TCEQ below Falcon Dam (DM1000)	185,581.00	184,326	-0.68
TCEQ Municipal return close to Miguel Aleman City below Rio Alamos in the 24-E rio Alamo basin	190,121.92	189,223	-0.48
Outlet of the 24-F rio San Juan basin	222,206.42	222,292	0.04
IBWC/CILA Gage station below Brownsville, Texas. Close to the outlet of the 24-G Bajo Bravo basin	225,241.99	231,644	2.76

Table 6.1: Difference in drainage areas on the Mexican side

Figure 6.6 shows and Table 6.2 reports the points where the drainage areas calculated with the methodology of this research are compared with the drainage areas reported by the USGS, IBWC, and TCEQ for the whole Rio Grande/Bravo basin. It can be seen that the biggest difference of around 4,000 square kilometers is found in the gage station located at Fort Quitman (point number 2). This difference is because the drainage area value reported by the USGS for this station considers part of the closed basin located in the hydrological subregion 1305, which does not contribute to the Rio Grande/Bravo basin. In general, the difference between the drainage areas calculated for every control point in this research and the values reported by the official agencies of both countries of this basin is less than 3% (see Tables 6.1 and 6.2).

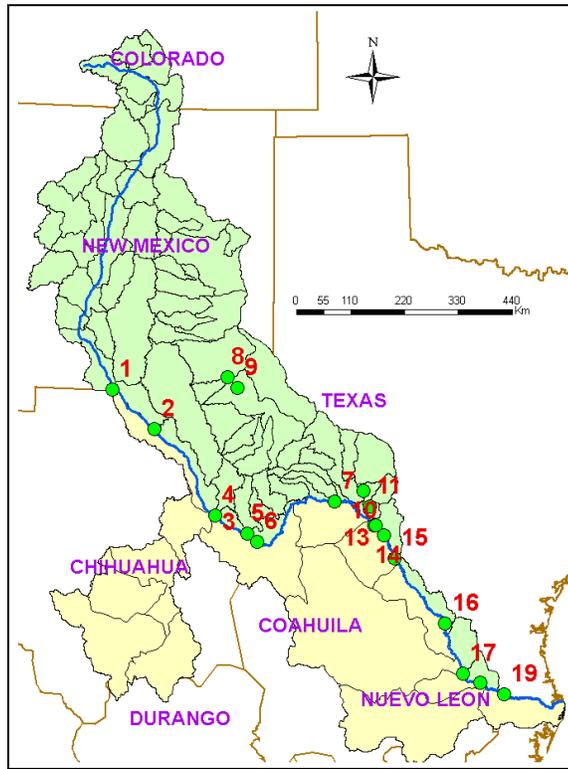


Figure 6.7: Points for drainage area comparison

Gage	Gage Name	CRWR Total Drainage Area of the Rio Grande Basin (SqKm)	IBWC/USGS Total Drainage Area of the Rio Grande Basin (SqKm) from TCEQ	Difference (%) CRWR Vs IBWC/USGS
1	RG @ EL PASO	70,464.45	70,464	0.00
2	RG @ FORT QUITMAN	78,488.88	82,699	5.09
3	ALAMITO @ PRESIDIO	4,021.94	3,894	-3.29
4	RG BL CONCHOS	164,038.91	163,977	-0.04
5	TERLINGUA NR TERLINGUA	2,820.81	2,770	-1.83
6	RG @ JOHNSON RANCH	174,718.38	175,423	0.40
7	RG @ FOSTER RANCH	208,672.68	209,031	0.17
8	PR @ RED BLUFF	50,586.73	50,587	0.00
9	PR @ ORLA	54,697.86	54,910	0.39
10	DEVILS NR JUNO	7,180.56	7,068	-1.60
11	DEVILS @ PAFFORD	10,102.30	10,252	1.46
12	RG @ DEL RIO	332,099.05	327,294	-1.47
13	SAN FELIPE NR DEL RIO	120.44	119	-1.13
14	PINTO NR DEL RIO	612.94	645	4.92
15	RG @ PED NEGR	341,530.93	329,596	-3.62
16	RG @ LAREDO	355,162.42	343,229	-3.48
17	RG BL FALCON	425,313.67	412,331	-3.15
18	RG BL RG CITY	462,357.51	451,402	-2.43
19	RG BL ANZALDUAS	466,939.35	455,933	-2.41

Table 6.2: Difference of drainage areas for the whole Rio Grande/Bravo basin

6.8.3 Discrepancy of the hydrologic data in the upper Rio Grande/Bravo basin

The river network reported by the Environmental Protection Agency (EPA) and the USGS was reviewed and edited in the upper area of the Rio Grande/Bravo basin as part of the hydrologic analysis for creating the water quality data model. Some discrepancies have been identified in the information from the RF1 stream network used by EPA and the river network reported by the USGS. For example, the Costilla Creek river, which is located between Colorado and New Mexico (Figure 6.8), and lies in the subregion 1302 according to the NHD classification, is an important tributary to the Rio Grande according to the USGS (red line), but it is flowing to nowhere according to the RF1 system (1:500K, purple line).

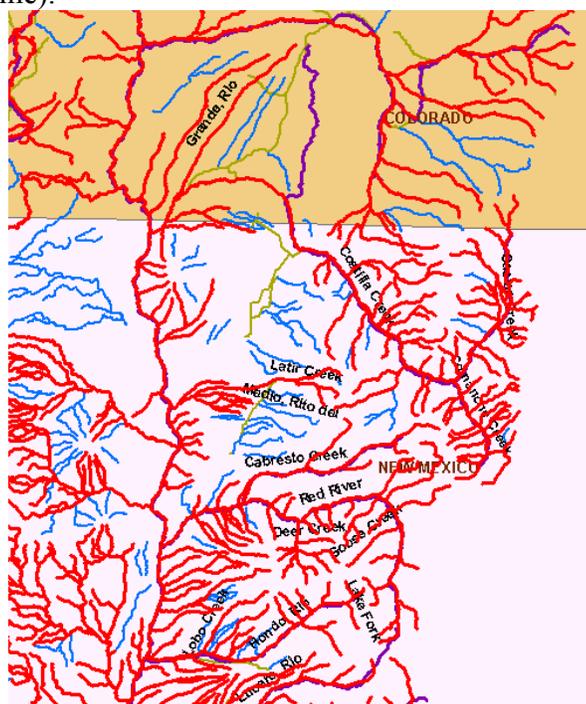


Figure 6.8: Comparison between RF1 and NHD river network

Figure 6.10 shows the comparison of the river network from RF1 (pink lines) and the NHD (blue lines) version after the last one is edited.

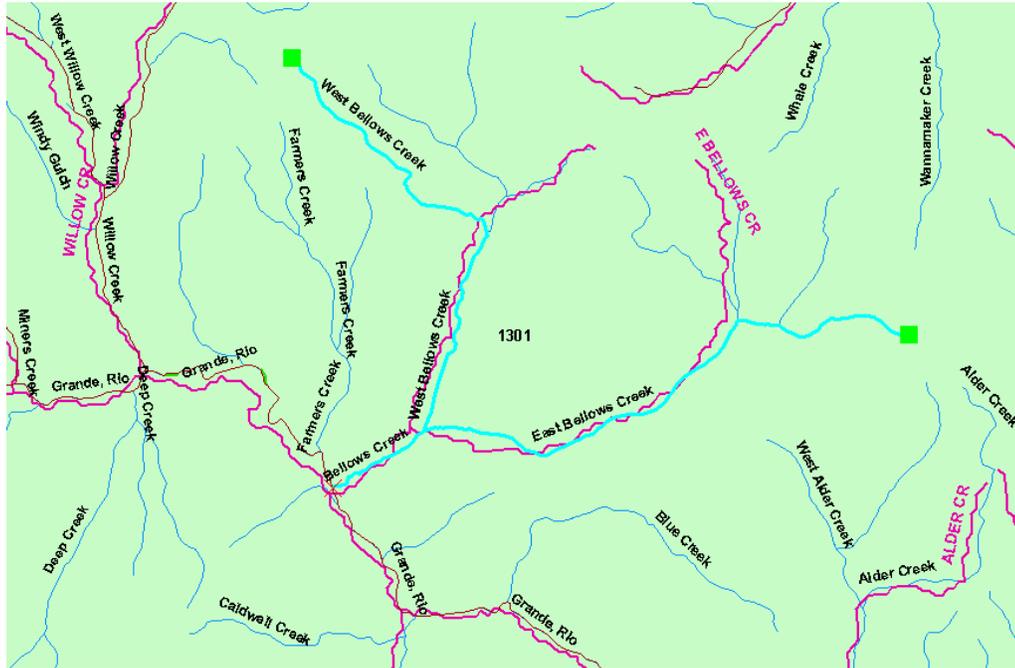


Figure 6.10: Comparison between the RF1 and edited NHD streams

Chapter 7: Conclusions and results

7.1 RESEARCH CONTRIBUTIONS

7.1.1 Development of a basin-scale database

The development of a relational database in GIS containing geographic, hydrologic, hydraulic and related data for the binational Rio Grande/Bravo basin is one of the most important of this contribution research. This integral geodatabase includes information from both sides of the basin, and was implemented using the ArcHydro data model framework. The geodatabase was developed in response to Minute 308 of the International Boundary Water Commission which states that it is very important to have a watershed-scale database to support projects that increase data exchange related to the management of hydrological information systems. This relational database is a tool that can assist in promoting bi-national cooperation between Mexico and the United States concerning water in the Rio Grande basin, providing accurate and reliable data necessary for analysis and resolution of water resources issues. The first part of this research collected the hydrologic information from both Mexican and American agencies. Unfortunately this information did not have the same characteristics and accuracy in both sides, so it had to be edited, reprojected, and fixed in order to get unified criteria for the geodatabase.

This geodatabase has been made available to Mexican and U.S. federal, state, and local organizations and represents the first major attempt to establish a more complete understanding of the basin as a whole, using both Mexican and U.S. data.

7.1.2 Development and application of a Raster-Network Regionalization Technique

One of the main purposes of this research was to develop and apply an operational method for the automated parameterization of large basins. There are a number of potential advantages to using automated digital terrain analysis techniques to derive parameters and variables for hydrologic models. The principle advantage is the speed and reproducibility with which the parameterization task can be accomplished. The development of a Raster-Network Regionalization technique for large basins utilizing raster-based analysis at the subregional scale in an efficient method is one of the most important contributions of this research. This methodology allows large regions to be divided into hydrological distinct subregions where raster analyses may be performed in a feasible manner. The results from each subregion are stored as attributes on vector data. The vector data are then merged, and appropriate values accumulated to obtain hydrologic parameter values for points of interest along the stream network, such as the drainage area, average Curve Number, average precipitation, and distanced from monitoring points to the basin outlet. The results from each subregion are stored as attributes on vector data. This technique uses the vector stream network as the pillar for the integration of subregions into a single region. The ArcGIS Hydro Data model was used to provide attributes with which to establish connectivity, as well as tools to perform the attribute accumulation. Also, this methodology helped to verify the validity of dividing a basin for processing without compromising on the accuracy of the parameter values determined. The Raster-Network Regionalization technique can also be

applied at a local level when high resolution data, such as LIDAR data, are available. These data are so dense they typically preclude raster analysis over a relatively small area. In conclusion, this technique takes advantage of using automated digital terrain analysis techniques to parameterize watersheds over a range of scales. This can only be done rapidly and systematically using automated methods.

The Raster-Network Regionalization technique has been successfully applied for the binational Rio Grande/Bravo basin, which has a contributing area of over 468,000 km² using high-resolution DEM. The drainage area for each control point is determined using the proposed technique and compared to reported stream gage contributing areas from the U.S. Geological Survey (USGS) and the National Water Commission (CNA) of Mexico. This comparison of the drainage areas for DEM-delineated watersheds to reported U. S. Geological Survey values validates the methodology for subdividing large basins into hydrologic subregions.

Non-contributing drainage areas such as depressions where the runoff is trapped were not considered in the Rio Grande/Bravo basin analysis.

A powerful conclusion from this research is that regional HydroID assignment is critical to the success of regionalization. The HydroID enables the connection between features in the landscape, including the connection of watersheds to outlet junctions, as well as the connection of junctions with next downstream junctions. Also, it allows the integration of subregions into regions,

through the update of the NextDownID in the most downstream junction in each region.

The main difference in processing watershed parameters using any traditional method and the Raster Network Regionalization technique used here is that in the traditional methods, raster data are used both for determining the local values as well as upstream accumulated values of the watershed parameters, whereas the technique reported here uses a combination of raster and vector data to find these parameters. The local areas are derived from raster and all the other values are determined in a vector environment.

In summary, the Raster Network Regionalization technique used here reduces dramatically the problems found by the traditional methods for watershed parameterization in GIS when processing large regions.

7.1.3 Enhancement of the ArcHydro time series component

The enhancement to the time series component of the ArcHydro Data Model to better storage and management of large amount of records using the same schema is another contribution of this research. One more table called TSGroup that contains information related to the agency from which the data is derived was added to the original ArcHydro structure. In this way, users can select a specific monitoring point within the geodatabase and several relationships have been established for it, so they can identify the sources from which the temporal data were derived, as well as the type of variable. This time series format is more robust and can handle millions of records distributed in dozens of variable types. This new framework was applied to the Rio Grande/Bravo basin

geodatabase to improve the management of temporal information gathered from U.S. and Mexican agencies. Around five million records collected from U.S. and Mexican agencies were manipulated and included in the Rio Grande/Bravo basin geodatabase.

7.1.4 Sharing time series data with a data storage system

A methodology for transferring temporal data between the ArcHydro data model and the HEC Data Storage System (HEC-DSS) is another contribution of this research. A GIS toolset called DSSHydro tool for transferring historical records from an ArcHydro geodatabase into a HEC-DSS file and back to a geodatabase was developed in this research for using with USACE HEC models. This tool consists of a set of public domain utilities developed in Visual Basic. The DSSHydro toolbar operates in the ArcGIS ArcMap environment, and is comprised of four commands to transfer the temporal information. Also, the communication between the geodatabase and the HEC-DSS is executed in two directions.

7.1.5 Development of a water quality data model framework

The development of a Water Quality Data Model (WQDM) framework for storing water quality data is another contribution of this research. This data model was developed in Visio 2000 and exported as a schema in an Access mdb file. The framework was implemented following criteria and parameters from the IBWC, TCEQ, USGS, EPA, CNA, and the SEMARNAT. This relational database includes spatial and temporal information from both sides of the Rio

Grande/Bravo basin, and was implemented in a Geographic Information System (ArcGIS) following the ArcHydro data model structure. The WQDM is related to the Water Quantity Data Model for the Rio Grande/Bravo basin developed during this research, and it is proposed as a standard framework for water quality data management in Mexico and the United States.

7.1.6 ArcHydro training courses and technology transfer

In order to implement the geodatabase and the proposed regionalization technique in this research, training and implementation were provided for Mexican and U.S. counterparts. Five ArcHydro training courses were held in English and Spanish at CRWR in Austin Texas, Mexico City, Valencia Spain, El Paso Texas, and Monterrey Mexico. The course materials were developed in English and Spanish and can be downloaded from ftp://ftp.crwr.utexas.edu/pub/outgoing/PATINOC/ArcHydro_Monterrey/

The binational Rio Grande/Bravo basin Geodatabase represents a tool that can assist in promoting bi-national cooperation between Mexico and the United States concerning water in the Rio Grande basin. It has been exposed in several forums and has been accepted by the main agencies in both sides of this basin as the most robust and standard structure to manage water information. Also, the IBWC and CILA are pushing to implement and update continuously this system in their office.

The Raster-Network Regionalization technique implemented in this research becomes the most robust technique for raster-based analysis combined with the vector environment known until today. It reduces dramatically the

problems found when the terrain analysis must be achieved for a large basin using the traditional manual techniques. For this reason, the technique used in this research for the watershed parameterization is being now implemented in other countries as Romania, Spain and Mexico.

The time series component of the Rio Grande/Bravo basin geodatabase solves the problematic about how to manage a huge amount of historical records coming from several sources, and represents one of the most robust structures embedded in a personal relational database known until today.

7.2 FOLLOW ON RESEARCH

7.2.1 Addition of water quality data to the Rio Grande/Bravo geodatabase

The Rio Grande/Bravo geodatabase has been created and it is available for use by water management agencies within the U.S. (EPA, TCEQ, IBWC) and Mexico (CNA, SEMARNAT, IMTA, INEGI, and CILA), and these agencies have shown great interest in its use. In order to satisfy the demand from the water management agencies, preliminary water quality parameters need to be added to the Rio Grande/Bravo geodatabase based on the results of the previous development. These activities are left for further research:

- Obtain the water quality time series data from original sources and document the data;
- Create additional HydroJunctions along the river network wherever points of interest are located (i.e., water quality monitoring locations);
- Create the river segments following the EPA and SEMARNAT/CNA criteria on the American and Mexican side respectively. 1: 100 K scale

would be used to create these segments on the American side and 1:50 K on the Mexican side;

- Generate the time series of the water quality parameters for the whole Rio Grande/Bravo basin;
- Apply the Water Quality Data Model framework designed in this research;
- Verify the relationships between HydroJunctions and water quality stations for which time series exist (i.e., water quality records); and
- Verify the relationships among outlet HydroJunctions, watersheds, waterbodies, and river segments defined according to the EPA and SEMARNAT classification.

7.2.2 ArcHydro training course and technology transfer

Even though five ArcHydro training courses have been held in English and Spanish in the USA, Mexico and Spain for transferring the relational geodatabase concept and the Raster-Network Regionalization technique, there is a real demand to achieve at least one more training course, so the course materials are being continuously updated. Also, entail installation of the updated Rio Grande/Bravo geodatabase at the IBWC, TCEQ, CNA, CILA, and IMTA needs to be achieved to ensure implementation not just data development.

7.2.3 Connection of the Rio Grande/Bravo basin geodatabase to the WEAP model

Physical assessment of the opportunities to improve water management in the bi-national Rio Grande/Bravo basin is a project currently achieved by a

consortium of universities and non governmental organizations from Mexico and the United States. Identification of water management scenarios that would provide mutual benefits to all stakeholders, physical assessment and modeling of these scenarios are proposed in the hydrologic planning phase of this project. The Water Evaluation and Assessment Program (WEAP) developed by Tellus Institute, Cambridge, MA was chosen for modeling because it incorporates both hydrology and mass balance analysis, having its origin as a water management model. The inputs into the model are hydrological parameters as well as water management/operational decision-making factors. It incorporates climatic time-series and allows the allocation of water in different time increments and at different points.

Creation of a pilot application of WEAP which reads and writes data from an ArcHydro data model for a simplified version of a Rio Grande/Bravo basin model is another activity left for further research.

Appendix A: Rio Florido Base Grids

Prepared by Carlos Patino

Center for Research in Water Resources – University of Texas at Austin

July 2005

GOALS OF THE EXERCISE

This exercise is intended for you to manipulate the raster dataset of the Rio Conchos basin collected from the Mexican National Institute of Statistics, Geography, and Informatics (INEGI). In this section you will learn how to project and clip and DEM for the Rio Florido that is a sub basin of the Rio Conchos.

COMPUTER AND DATA REQUIREMENTS

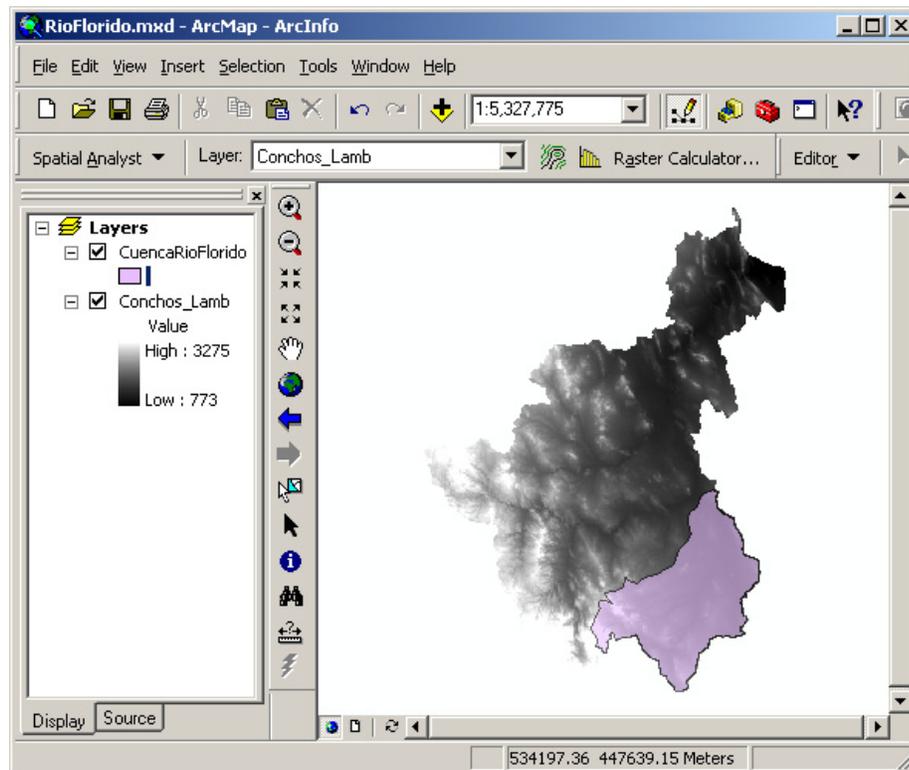
To carry out this exercise, you need to have a computer, which runs **ArcInfo** version of ArcGIS with the Spatial Analyst extension. The following data are needed:

- A DEM for the Rio Conchos basin located on the Mexican side of the Rio Grande/Bravo basin. This DEM has an original cell size resolution of 104 m.
- Watershed boundary feature class of the Rio Florido (1:250K). This watershed appears as a feature class within the Geodatabase RioFlorido.mdb in the folder ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_Data/Participant/

For your convenience the final results are located in the folder ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_Data/Instructor/

GETTING STARTED

- Open ArcCatalog and change the original name of the DEM in case it includes just numbers, as the DEM collected from the USGS. Close ArcCatalog.
- Open the ArcMap and add the Rio Conchos DEM. You can see that the original projection is Lambert Datum NAD27, and it has a grid cell size of 104 m.



1. **Change the projection parameters from Lambert to the Albers equal area.** The Albers equal area projection was chosen as the official parameter to build the binational Rio Grande/Bravo basin geodatabase. The parameters for this projection are as follows:

Albers Equal Area Projection
False Easting: 1000000
False Northing: 1000000
Central Meridian: -103
Standard Parallel 1: 27.41666666
Standard Parallel 2: 34.91666666
Latitude of Origin: 31.16666666
GCS North American 1983
Datum: D North American 1983
Prime Meridian: 0

To do this task, open the ArcWorkstation and use the project grid option

- Start ArcInfo by clicking Start-Programs-ArcGIS and ArcWorkstation
- At the arc prompt, change the working directory to \ArcHydro_Monterrey\Exercises_Data\Participant; to where you need to copy the information downloaded from ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/, and then type grid. This starts something called grid. With grid, we can perform raster operations. At the grid prompt, type Conchos_Alb =

projectgrid (conchos_lmb, #, nearest) to project this original DEM. The # symbol means the input projection has been defined. Nearest neighbor assignment is the resampling technique of choice for categorical data since it does not alter the value of the input cells. Once the location of the cell's center on the output raster dataset is located on the input raster, nearest neighbor assignment will determine the location of the closest cell center on the input raster, and assign the value of that cell to the cell on the output raster.

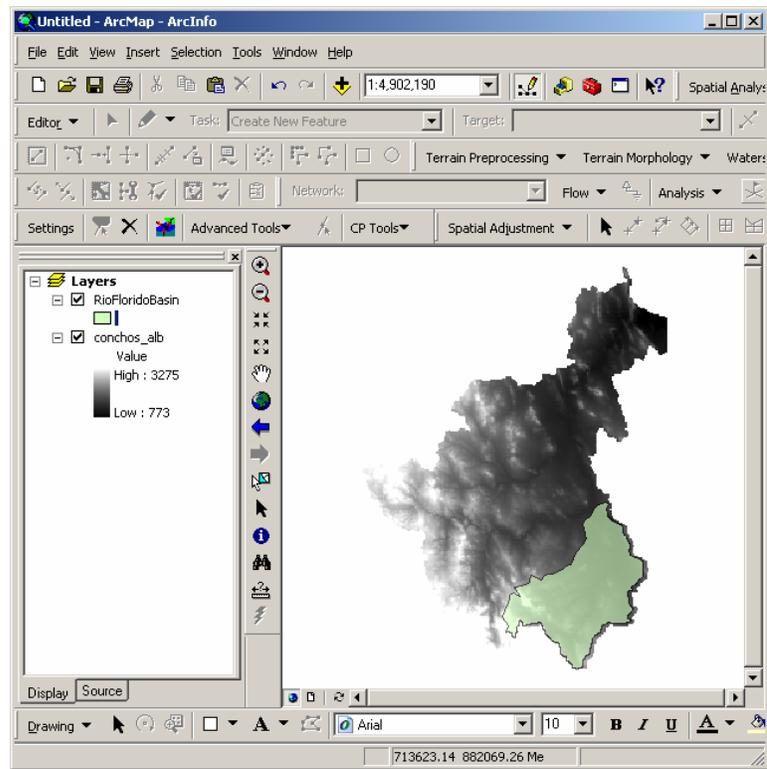
- Type the parameters for your new projection. When finished, your screen should look like the image below.

```

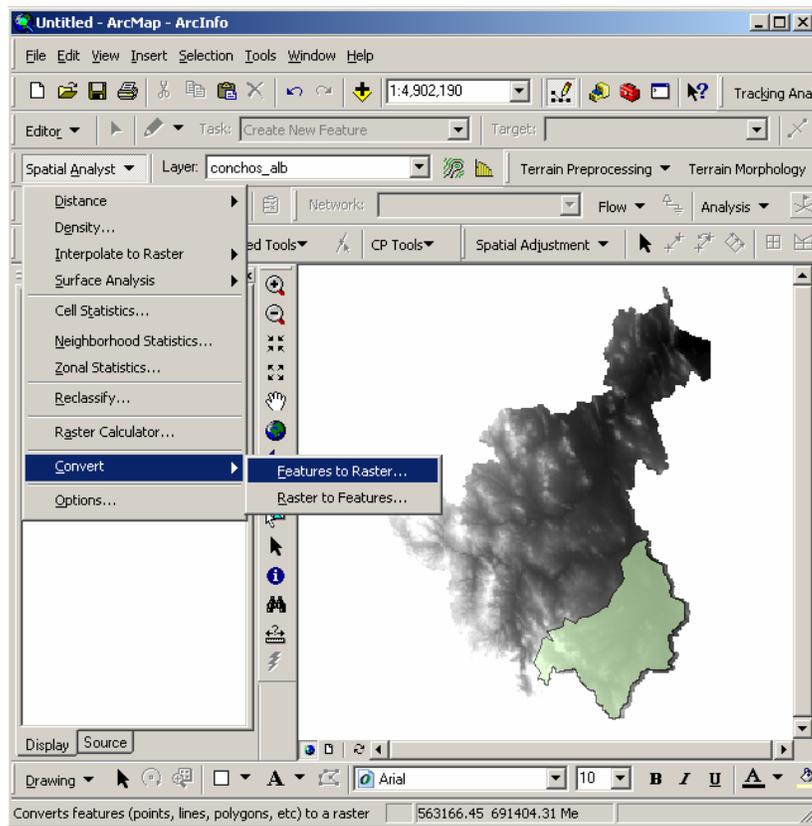
Arc
GRID 9.0 (Fri Mar 5 16:09:26 PST 2004)
Grid: Conchos_Alb = projectgrid (conchos_lmb, #, nearest)
*****
* The INPUT projection has been defined. *
*****
Use OUTPUT to define the output projection and END
to finish.

Project: output
Project: projection albers
Project: unit meters
Project: datum nad83
Project: parameters
1st standard parallel [ 0 0 0.000 l: 27 25 0
2nd standard parallel [ 0 0 0.000 l: 34 55 0
central meridian [ 0 0 0.000 l: -103 0 0
latitude of projection's origin [ 0 0 0.000 l: 31 10 0
false easting (meters) [ 0.00000 l: 1000000
false northing (meters) [ 0.00000 l: 1000000
Projectgrid: end
Inversibility is 100 per cent
Project...
Grid:
  
```

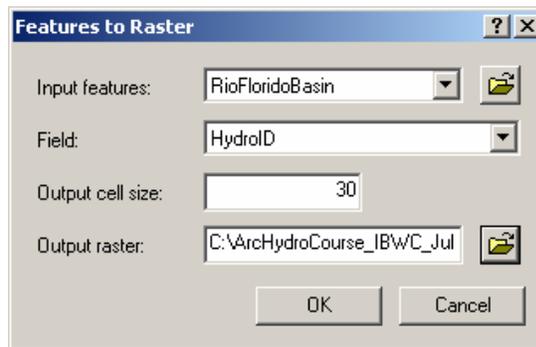
2. Open ArcMap and add the projected DEM as well as the Rio Florido basin located on the \ArcHydro_Monterrey\Exercises_Data\Participant. You can check that the units are now in meters.



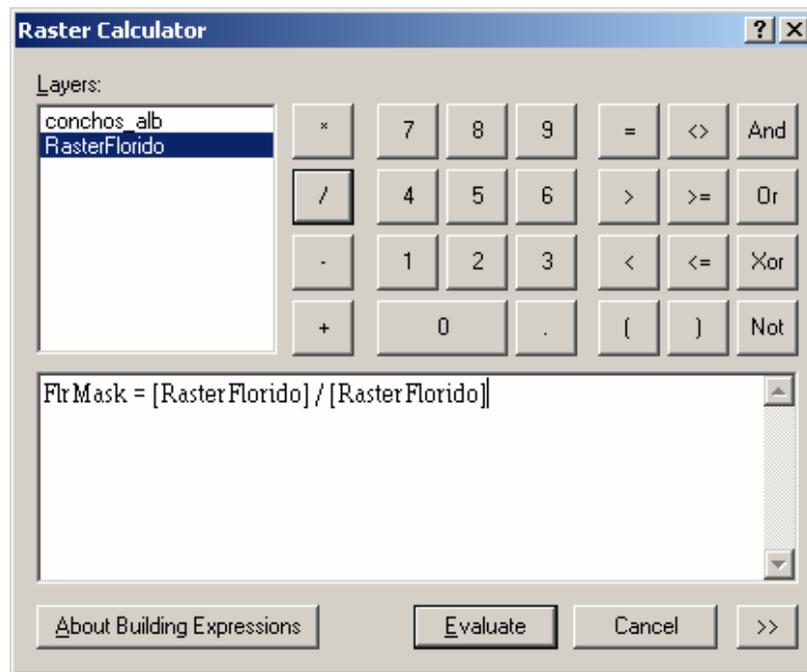
3. Create a raster for the Rio Florido sub basin, using the Convert-->Features to Raster menu item within the Spatial Analyst menu.



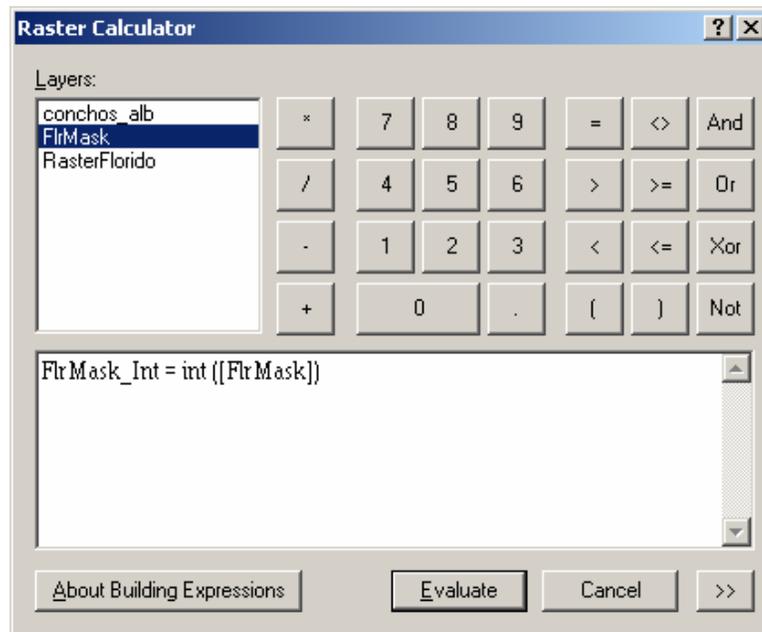
Input the next raster parameters. Because the DEM cell size is 30 m for the whole basin, the output cell size for the raster should be consistent with this one. Select the RioFloridoBasin feature class in the input features field, and choose the “HydroID” in the field. The Field could be any field as long as it does not have a zero value record, and an output raster is specified (e.g. “RasterFlorido”). This is going to create a raster with its cells having the value of the field “HydroID”. When finished, the window should look like the one below.



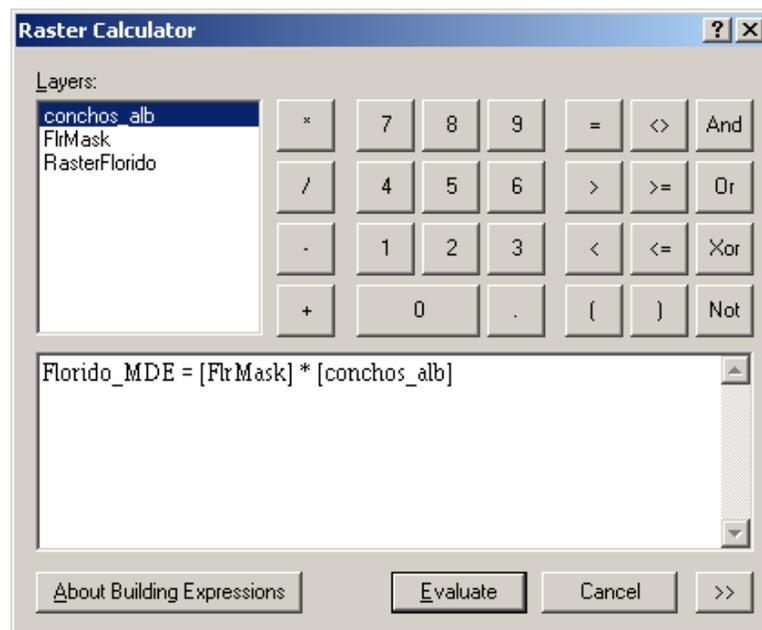
4. After you create the raster, you will create a mask for the Rio Florido basin using the raster calculator in the Spatial Analyst menu.



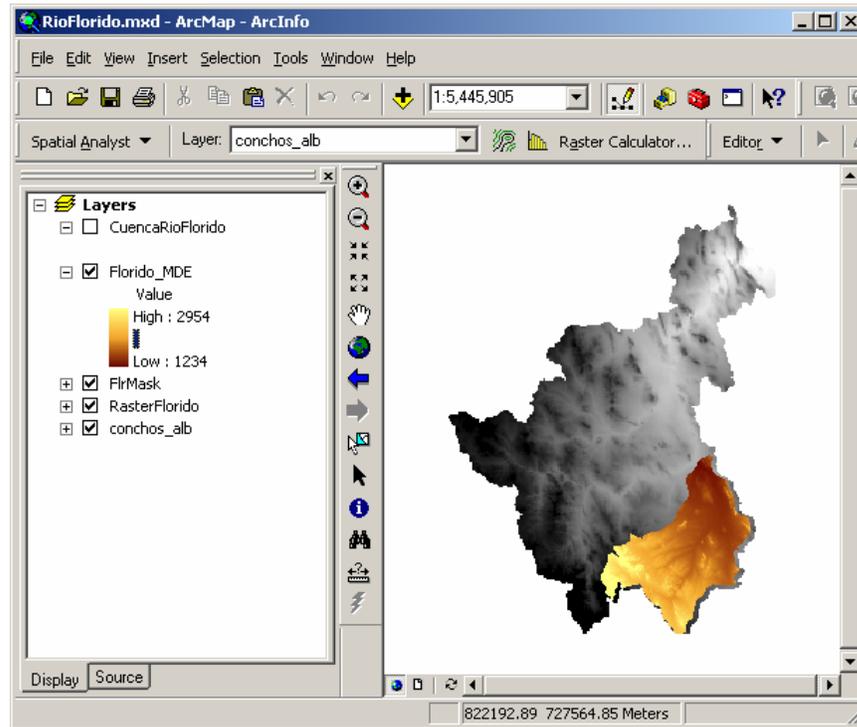
5. In order to reduce the Rio Florido Mask size, you can change it as an integer, using the raster calculator too



6. Now, you will be able to clip the Rio Florida basin DEM, using the Rio Florida mask and the projected DEM (Conchos_alb) into the raster calculator



Congratulations!!! You have projected, and clipped a DEM for the Rio Florido basin.



Appendix B: Geodatabase and Shapefiles

INTRODUCTION

In this section you will build a **basemap** of geographic and streamflow data for a watershed using the Rio Florido Basin in Northern Mexico as an example. The base map comprises

- Basin's watershed boundaries, streams and waterbodies from shapefiles.
- A **geodatabase** to hold all these data layers and create relationships inside the geodatabase.
- A point **feature class** of stream gage sites by inputting latitude and longitude values for the gages in an Excel table that is added to ArcMap and the geodatabase

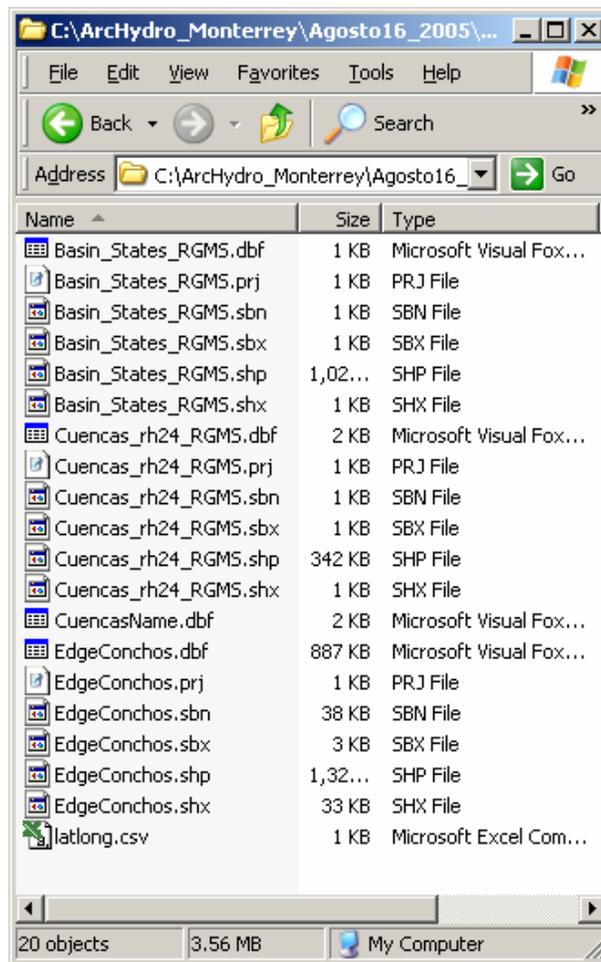
The needed files are located in the Course directory from ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_

Data/Participant

The files include shapefiles of:

- **Administrative polygons** (State or Country) – needed to get the extent of the study area. These are often available from local government information systems, the Digital Chart of the World, or the GeoCommunities website (www.GeoCommunities.com);
- **Basin boundary polygons** – needed to get identify the basin of interest plus a surrounding buffer zone. These are often available from local government information systems, or the Hydro1K website; and

- **River lines** – needed to recondition a Digital Elevation Model (DEM) of the study area and serve as the main river network. These are often available from local government information systems, or the Hydro1K website. Sometimes, these lines are not available and must be estimated directly from the DEM.



The files:

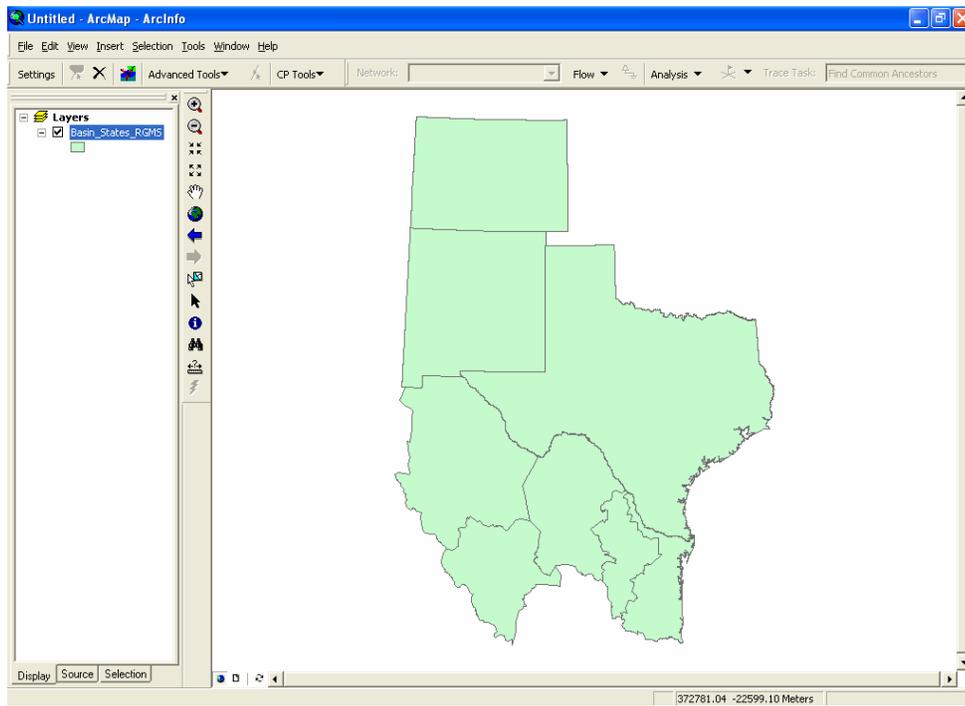
- Basins_States_RGMS.*,
- Cuencas_rh24_RGMS_*,
- EdgeConchos.*, and
- Latlong.csv

are files that define the **Basins_States**, **Cuencas**, **EdgeConchos** Shapefiles, and the Excel table to create the gage stations.

STREAM AND WATERSHED DATA

The geospatial data files defining the states which contain the Rio Grande/Bravo basin are located in the Shapefiles **Basin_States**. The drainage areas, and rivers for the Mexican side of the Rio Grande/Bravo basin are contained in the shapefiles **Cuencas**, and **EdgeConchos**. Note that each shapefile is comprised of various files and therefore, it is easy to make errors when copying these files to another location. In general, it is recommended that when you want to copy the geospatial data files from one place to another in your workspace, you need to use the **ArcCatalog** to copy all of the files rather than using Copy in Windows Explorer.

Open **ArcMap** and add the Shapefile **Basin_States** to the map:



Recolor the themes if you wish. Move the cursor to the lower left corner of the display, and you'll see the coordinates changing at the bottom of the map display. The coordinates shown here are (374,808; -24168). If you move the cursor to the upper right of the corner of the rectangle, you will find (1,924,726; 2,122,886). You now have the reference coordinates for the Basin States.

CREATING A GEODATABASE

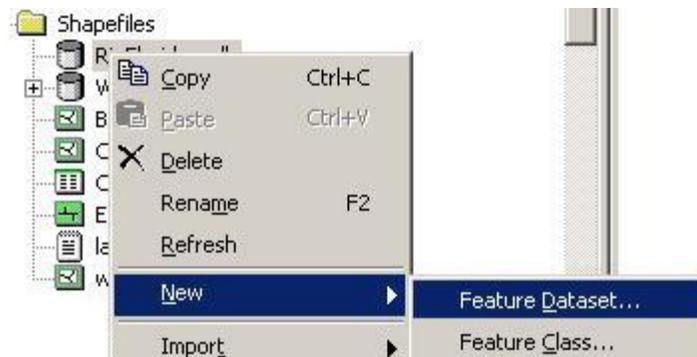
ArcGIS uses an object-oriented data model called the geodatabase data model. This data model gives the features in your GIS datasets custom behaviors and the possibility to create relationships between features. In general, a geodatabase model provides a standardized framework into which various types

of data can be loaded. Once created, the geodatabase is a Microsoft Access file called an ArcGIS personal geodatabase.

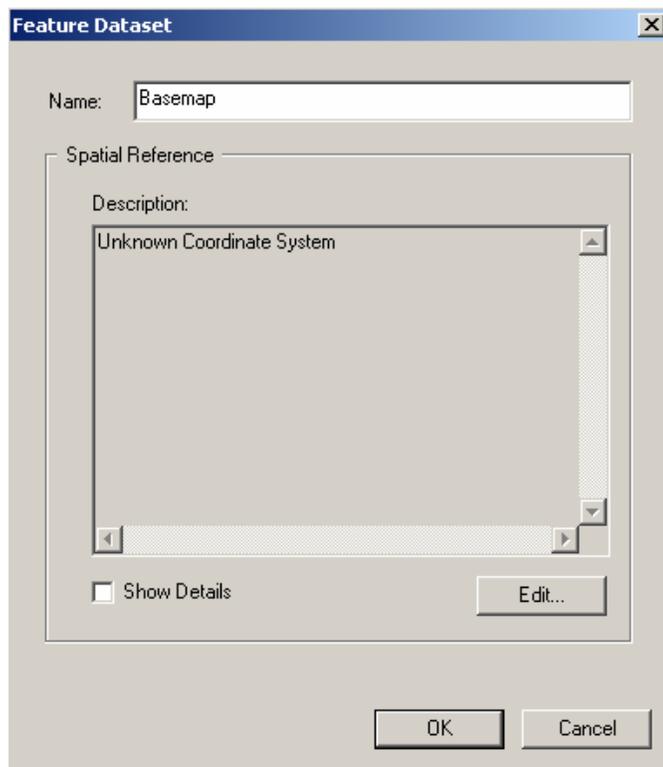
Close ArcMap and open **ArcCatalog**. Right click on the data folder, select **New / Personal Geodatabase**. Call the new geodatabase **RioFlorida**.



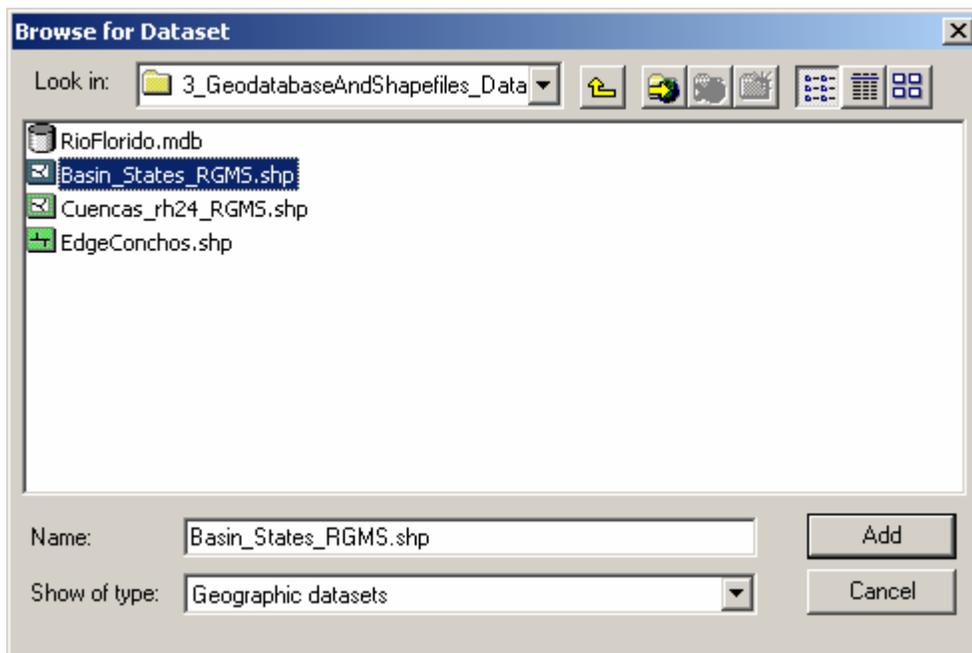
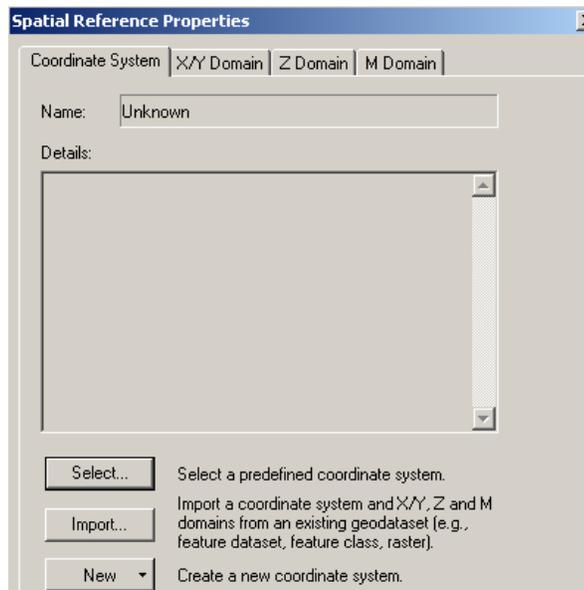
Right click on the geodatabase, and select **New Feature Dataset**.



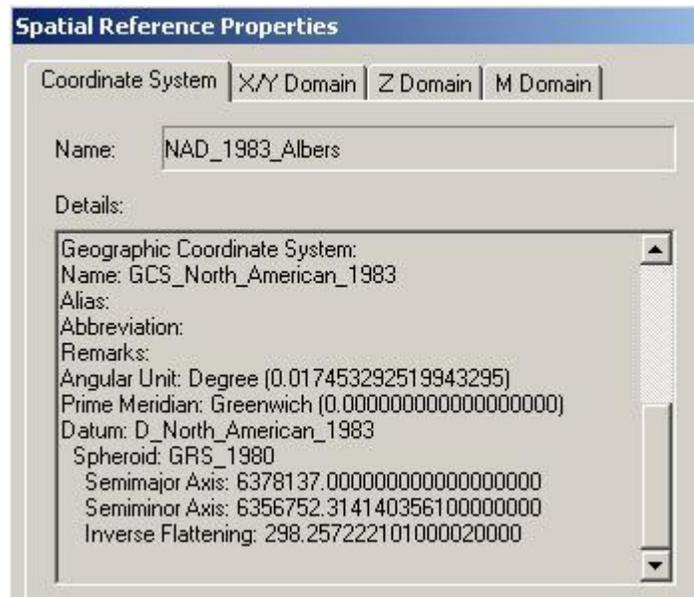
Name the new feature dataset **Basemap**, and select **Edit** to set the projection and map extent.



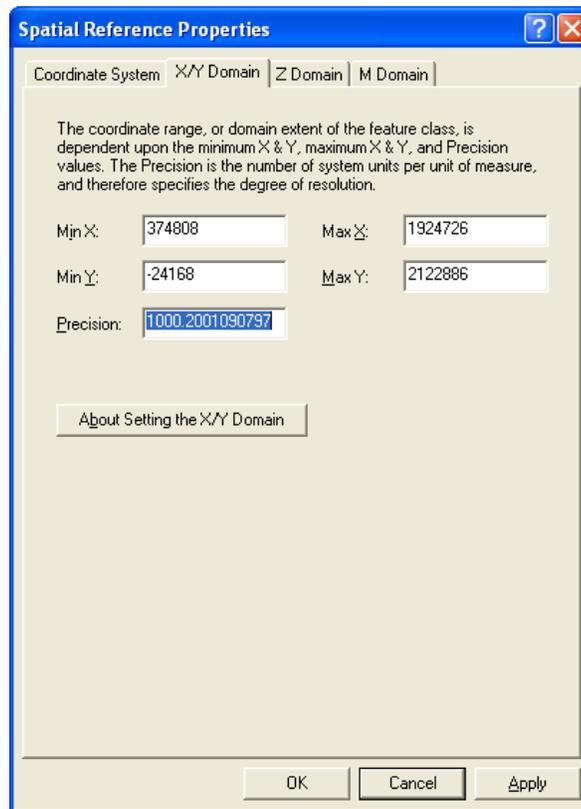
We will import the coordinate system from the Basin_States Shapefile. Select **Import** from the choices in the menu displayed and select the **Basin_States_RGMS** Shapefile.



You'll see that the coordinate system is now specified:



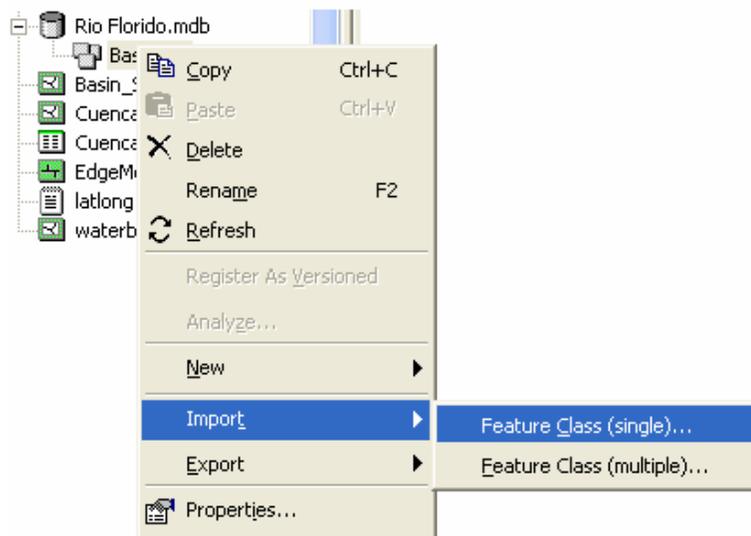
We'll enter the **X/Y Domain** definition from the coordinates that we found earlier in ArcMap: (**MinX, MinY**) = (374,808; -24168), (**MaxX, MaxY**) = (1,924,726; 2,122,886).



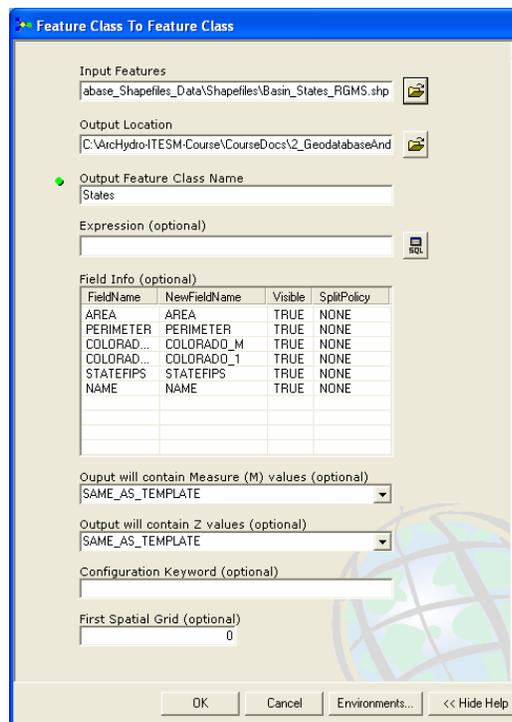
Hit **Apply** and **OK**, to finish setting the Spatial Reference Frame of the Feature Dataset.

IMPORTING DATA INTO A GEODATABASE

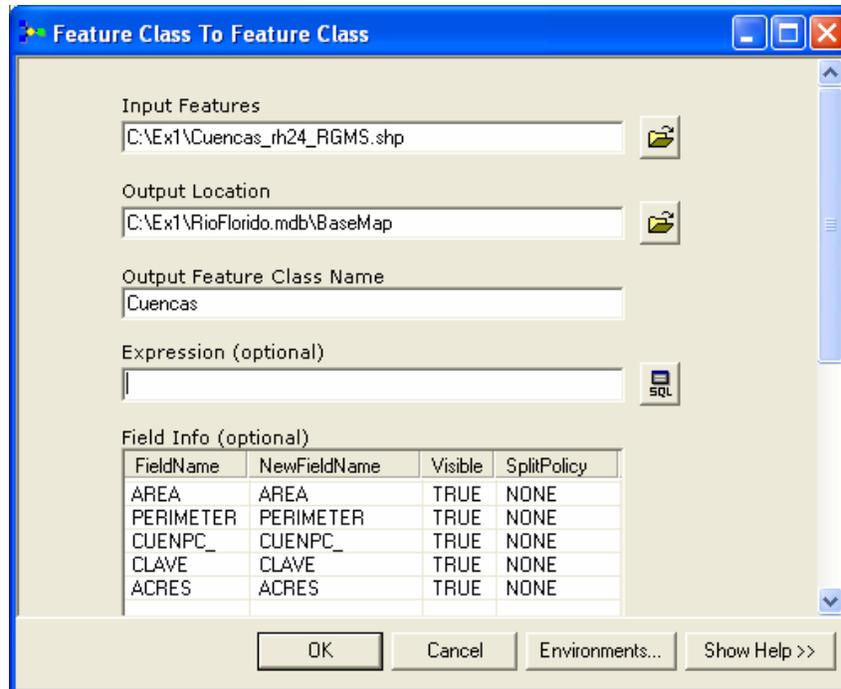
Now, you will import the shapefiles into the geodatabase RioFlorida. You will be importing the three shapefiles. You will first import the **Basin_States_RGMS** shapefile, since this file has the largest extent and the geodatabase will adopt the spatial reference of the first imported feature class. To import the shapefiles, right-click on your feature dataset and press **Import / Feature Class (single)** as shown below.



From the **Input Features** box browse for the shapefile **Basin_States_RGMS** and click to import it. Type the name **States** into the **Output Feature Class Name** field.



Repeat the above process to input the shapefile **Cuencas_rh24_RGMS**. Select the existing feature dataset **Basemap** and type in **Cuencas** as the name of this feature class.



Repeat the above steps once more for the shapefile **EdgeConchos**. Select the existing feature dataset **Basemap** and enter **EdgeConchos** as the new name of the feature class.

Here is the new feature dataset that you've just created with its three new feature classes included:



CREATING A POINT FEATURE CLASS OF STREAM GAGES

Now you are going to build a new Feature Class yourself of stream gage locations on the Rio Florido. We have prepared the file latlong.csv with the data for eight stream gages located on the main channel of our river:

GAGENO	LONGDEG	LONGMIN	LONGSEC	LATDEG	LATMIN	LATSEC	NAME
1	105	19	38	26	26	0	Rio Florido at San Antonio
2	104	55	4	27	8	31	Rio Florido at Cd. Jimenez
(FM50)							
3	105	21	0	26	26	28	San Antonio
4	105	11	15	26	37	36	103 Rio Florido
5	105	37	59	26	29	28	Puente FF.CC.
6	105	32	27	26	26	38	San Gabriel
7	105	14	57	26	32	53	Pico Del Aguila
8	104	55	5	27	8	10	Jimenez

- a. Define a table containing an ID and the long, lat coordinates of the gages

The coordinate data is in geographic degrees, minutes, & seconds. These values need to be converted to decimal degrees, so go ahead and perform that computation for the 8 pairs of longitude and latitude values. This is something that has to be done carefully because any errors in conversions will result in the stations lying well away from the Rio Florido. It is suggested that you prepare an Excel table showing the gage longitude and latitude in degrees, minutes and seconds, convert it to long, lat in decimal degrees using the formula

$$\text{Decimal Degrees (DD)} = \text{Degrees} + \text{Min}/60 + \text{Seconds}/3600$$

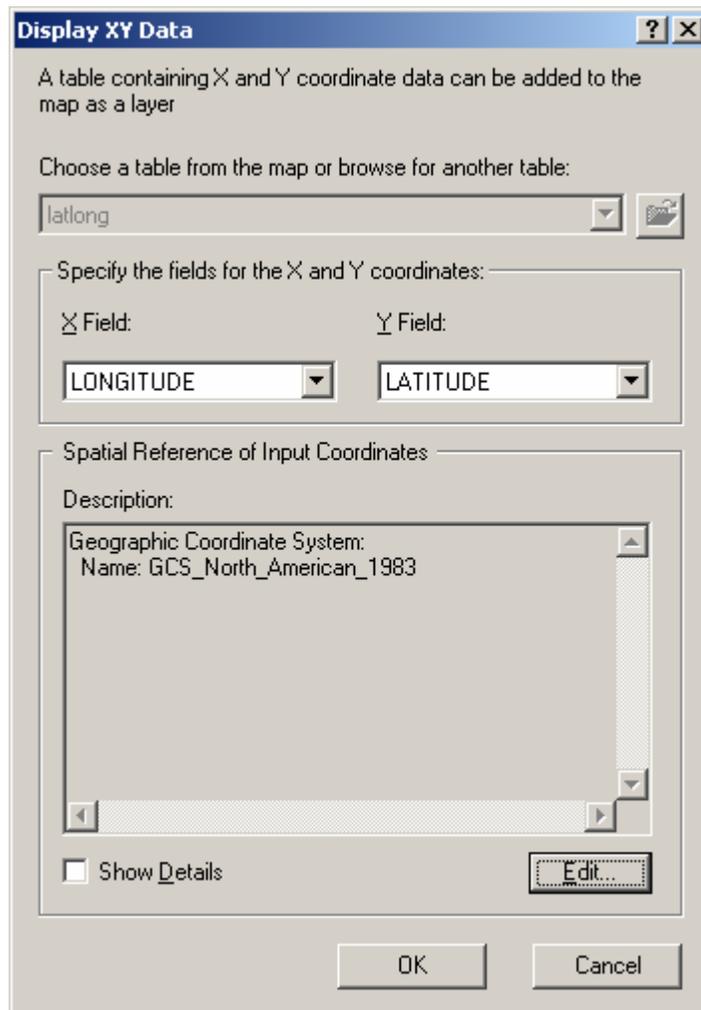
Remember that West Longitude is negative in decimal degrees. Shown below is a table that I created. **Be sure to format the columns containing the Longitude and Latitude data in decimal degrees (LongDD and LatDD) so that they explicitly have Number format with 4 decimal places using Excel format procedures.** Save the file as **latlong.dbf** as type (DBF4, dBASE IV) in

Excel. If you don't explicitly format your decimal degree columns, you'll find that you've lost significant figures after the decimal places when you incorporate the table latlong.dbf into ArcMap. Close Excel before you proceed to ArcMap.

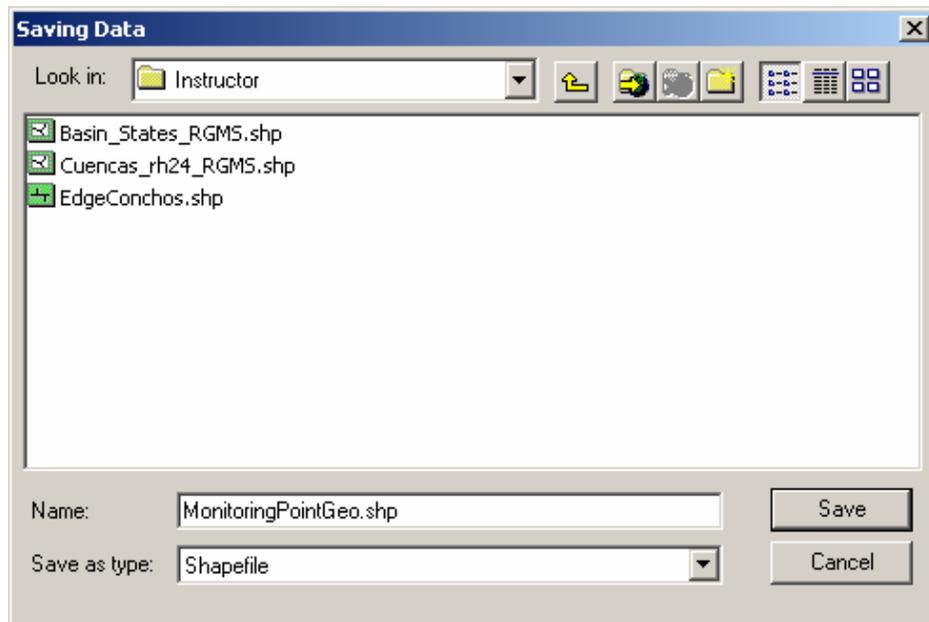
	B	C	D	E	F	G	H	I	J	K
1	LONGDEG	LONGMIN	LONGSEC	LATDEG	LATMIN	LATSEC	NAME	RIVER	LONGITUDE	LATITUDE
2	105	19	38	26	26	0	Rio Florido at San Anto	RIO FLORIDO	-105.3272	26.4333
3	104	55	4	27	8	31	Rio Florido at Cd. Jimer	RIO FLORIDO	-104.9178	27.1419
4	105	21	0	26	26	28	San Antonio	RIO FLORIDO	-105.3500	26.4411
5	105	11	15	26	37	36	103 Rio Florido	RIO FLORIDO	-105.1875	26.6267
6	105	37	59	26	29	28	Puente FF.CC.	RIO FLORIDO	-105.6331	26.4911
7	105	32	27	26	26	38	San Gabriel	RIO FLORIDO	-105.5408	26.4439
8	105	14	57	26	32	53	Pico Del Aguila	RIO FLORIDO	-105.2492	26.5481
9	104	55	5	27	8	10	Jimenez	RIO FLORIDO	-104.9181	27.1361

b. Creating and Projecting a Feature Class of the Gages

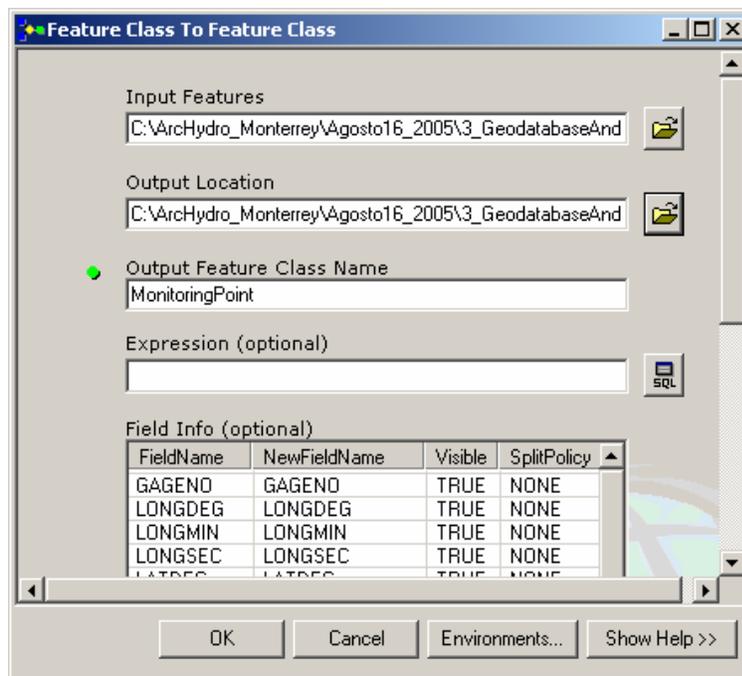
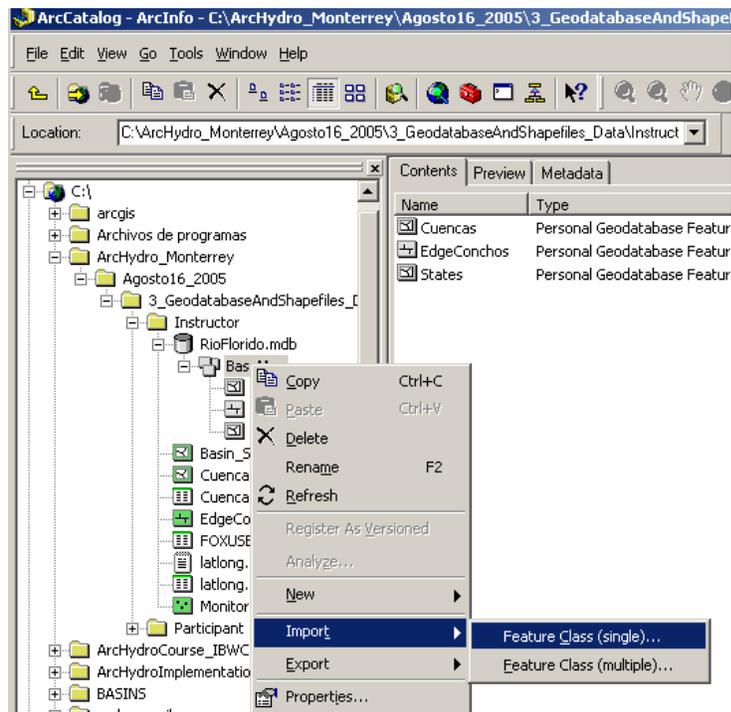
(1) Open ArcMap and add the latlong.dbf table created in Excel. Right click on the table and select Display XY Data ..., this will cause a window to appear. The correct X and Y fields are selected by ArcMap (Xfield = Longitude, Yfield = Latitude). Use Edit to Select the North American Datum of 1983 included in the Geographic Coordinates System → North America folder for the projection, and click OK to complete the process of transferring the table to an Event. An event is a point or line that is displayed using coordinates but is NOT an explicit point or line shapefile or feature class.



(2) Create a shapefile out of the XY Event by first right clicking on the latlong Event layer and press Data/Export... to export the data as a shapefile in your folder. Name this shapefile as MonitoringPointGeo.



Now, close Arc Map and use Arc Catalog to Import/Feature Class (Single) to import the MonitoringPointGeo shapefile to the Basemap feature dataset as MonitoringPoint feature class. The Albers projection is done on the fly as this export is happening!



Appendix C: WRAPHydro Process

1 Introduction

In this section, we apply the WRAPHydro process to the Rio Florido subbasin to give support to the integration of the results of WRAPHydro processing among all the Rio Grande/Bravo subbasins. The main phases involved in this process are Preprocessing, Watershed Parameterization, and Regionalization.

After the base data are obtained, the initial analysis area is defined and some preprocessing is performed, which is required to calculate the final watershed parameters. The preprocessing basically deals with defining the basin boundary to set the analysis extent for any further processing.

Next, the ArcHydro and WRAPHydro tools are used to calculate watershed parameters for the Rio Florido subbasin. Once parameters have been calculated, the Regionalization technique is used to integrate the results with the other Rio Grande/Bravo subbasins on the Mexican side.

2 Computer and Data Requirements

To complete this section, you need to have a computer system running ArcGIS with an **ArcInfo** license and the Spatial Analyst extension active. The ArcHydro tools and WRAPHydro tools must be installed on the computer. The ArcHydro tools may be downloaded from the CRWR website at

<http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&mid=15>

The WRAPHydro tools may be downloaded from Dr. David Maidment's Student Homepages website at

<http://www.ce.utexas.edu/prof/maidment/grad/whiteaker/hydrotools.html>

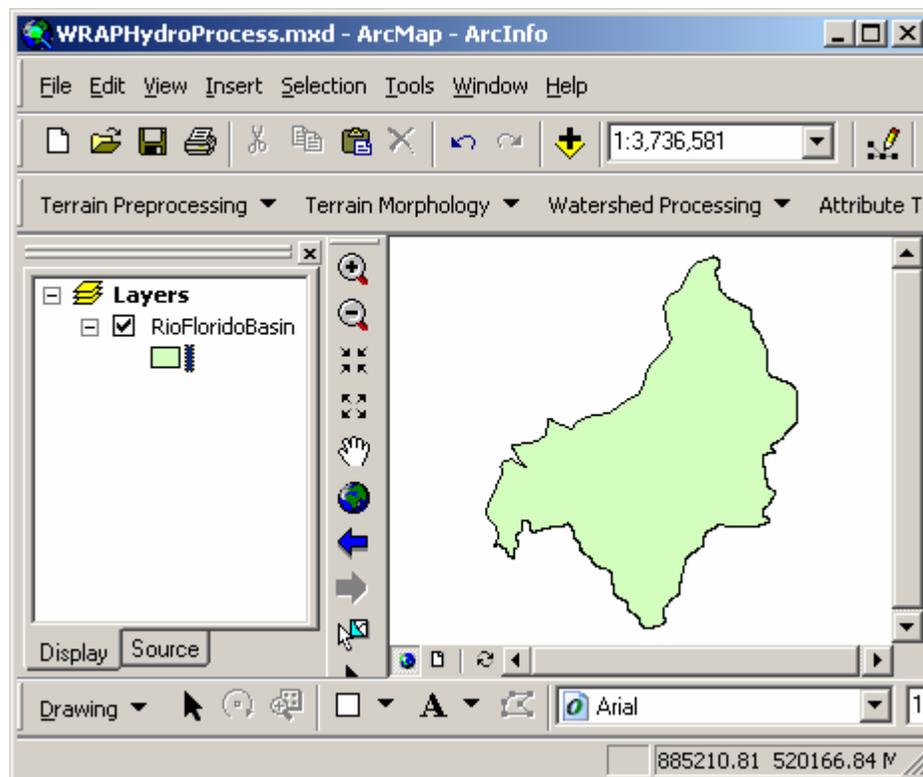
All data necessary for this exercise is located in the folder ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_Data/Participant/. Also, for your convenience the final results are located in the folder

ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_Data/Instructor/.

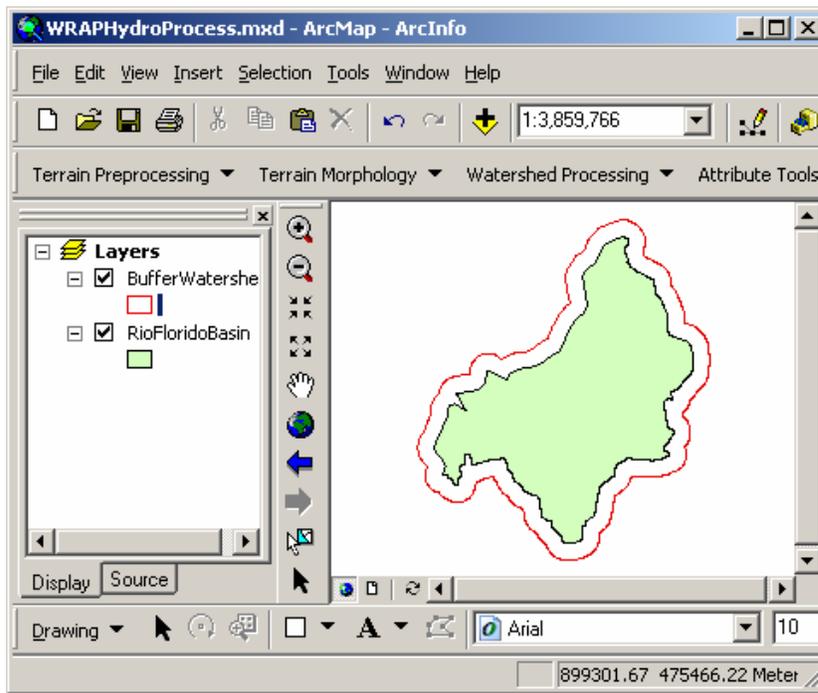
3 Preprocessing

Select the polygon corresponding to the Rio Florido basin.

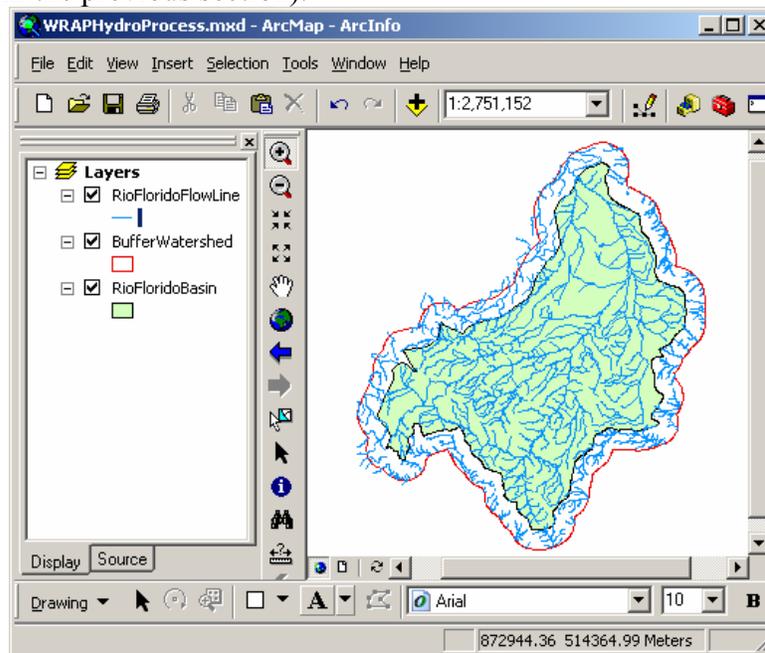
- Open ArcMap. Save the document as WRAPHydroProcess.mxd.
- Add the **RioFloridoBasin** to the Map.



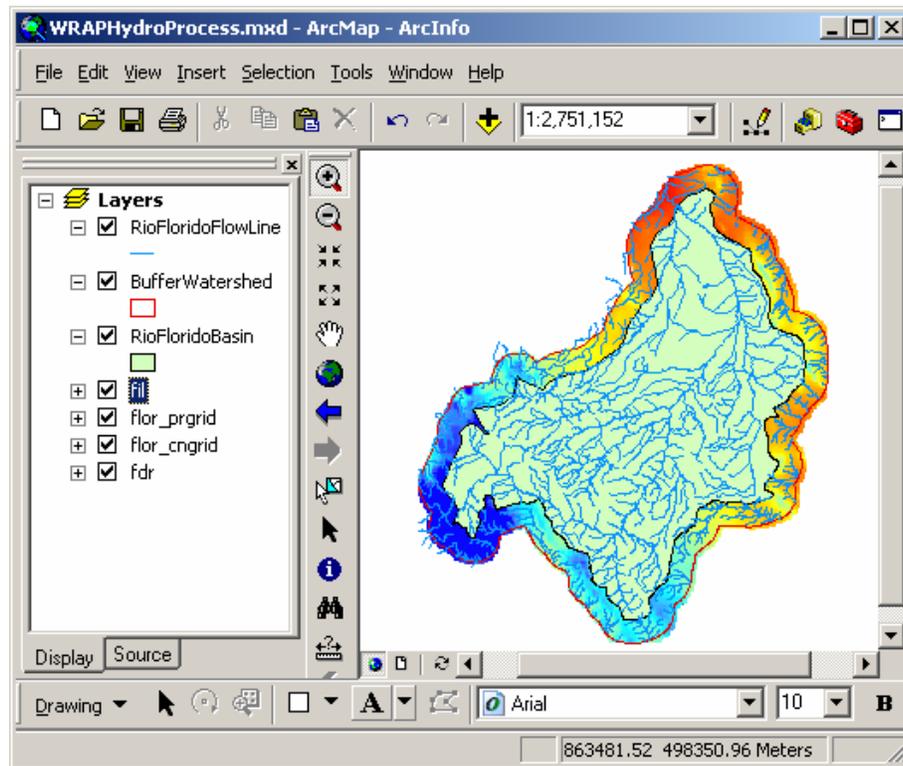
- Add the **BufferWatershed** to the map.



- Add the WRAPFlowline (this is the same as the RioFloridoFlowLines from the previous section).



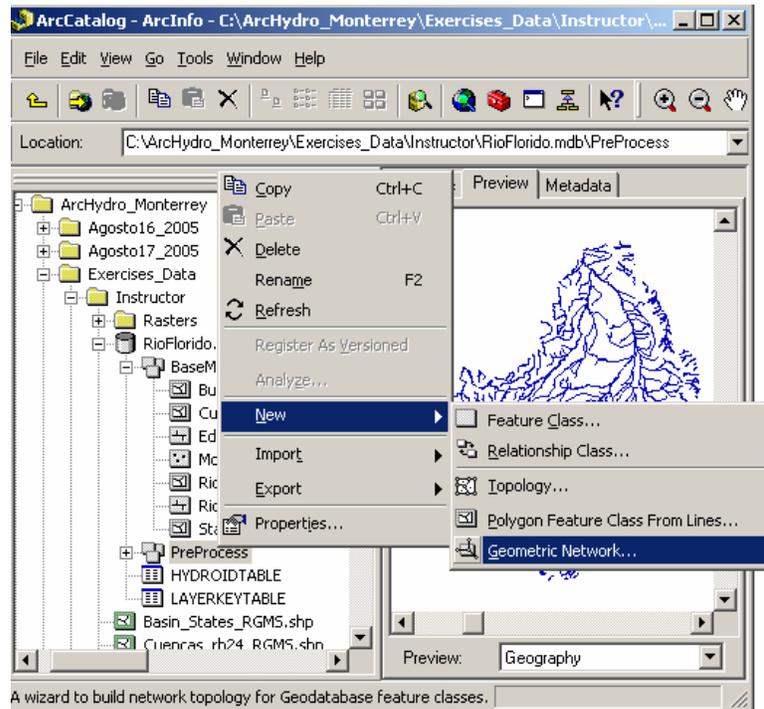
- Add the Filled DEM, the Flow Direction, Curve Number, and Precipitation rasters to the map. These are located in the directories \ArcHydro_Monterrey\Exercises_Data\Participant\Rasters\PreProcessGrids, and \ArcHydro_Monterrey\Exercises_Data\Participant\Rasters\BaseGrids (they are the same as the rasters from the previous section).



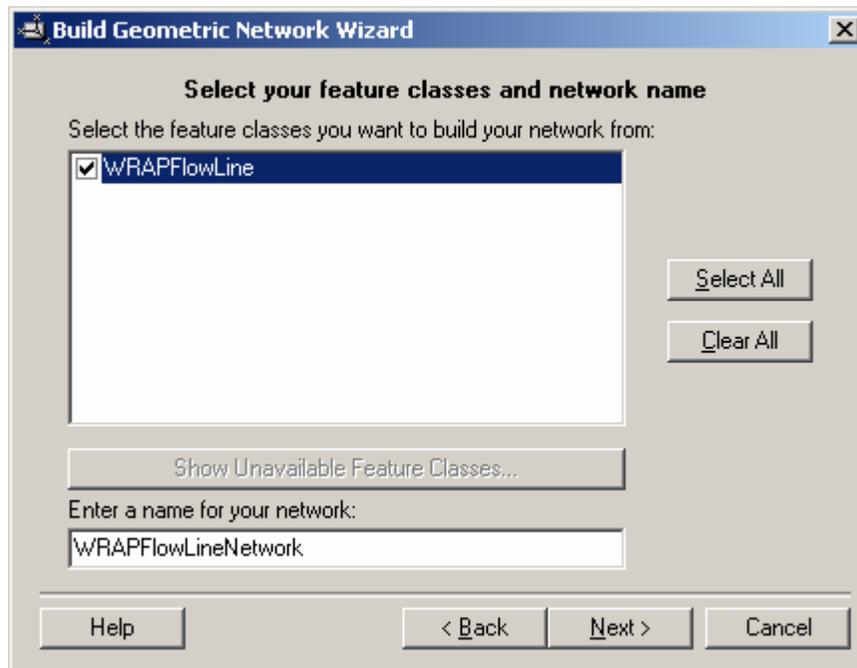
4 Build a network with WRAPFlowline as a complex edge.

- Save the ArcMap document, close ArcMap, and open ArcCatalog
- Right click on the RioFlorido.mdb Geodatabase and select **New: Feature Dataset**
- Name the new feature dataset: **PreProcess**
- **Import** the projection parameters from the BaseMap feature dataset
- **Export** the **RioFloridoFlowLine** from the **Basemap** to the **PreProcess** feature data set and name it **WRAPFlowLine**
- Right click on the PreProcess feature dataset inside the RioFlorido geodatabase.

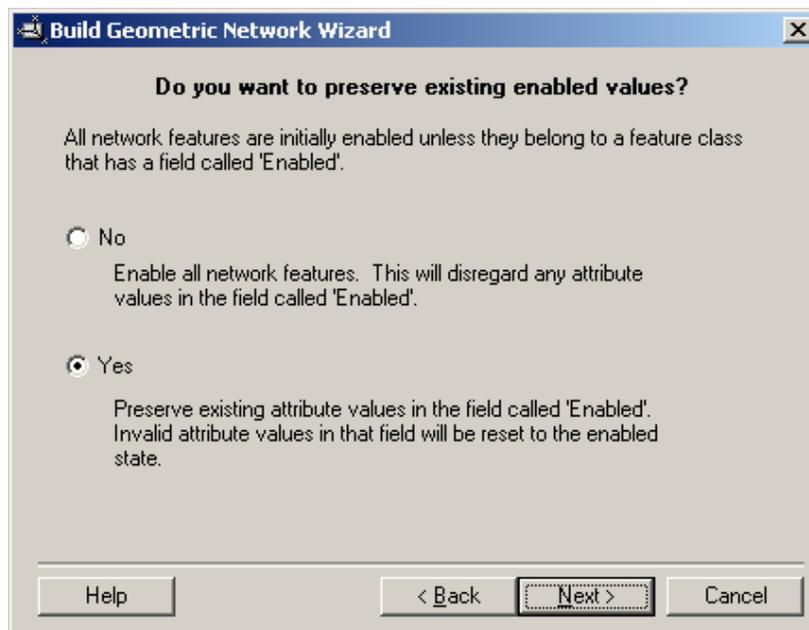
- Click **New:Geometric Network**. The Build Geometric Network Wizard opens.



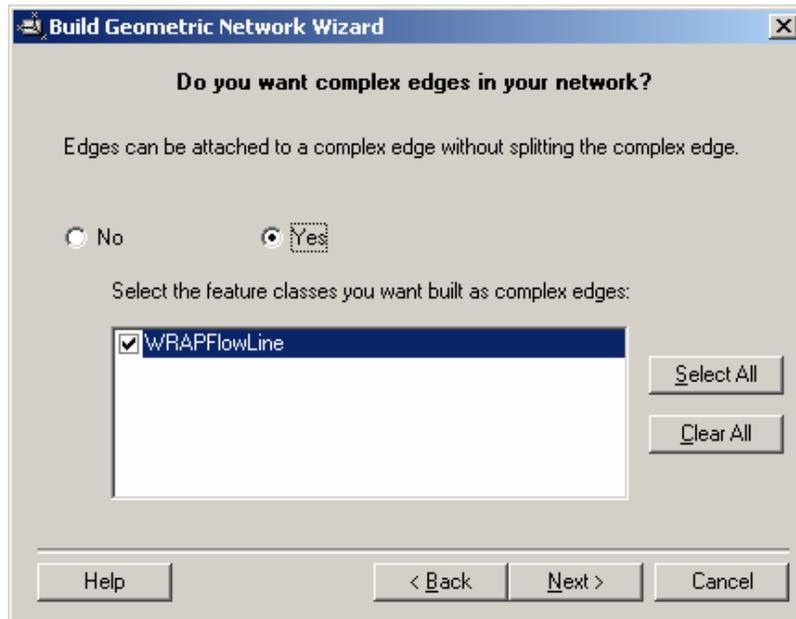
- Click Next to skip the first screen in the wizard.
- Make sure 'Build a geometric network from existing features' is selected and click Next.
- Choose the WRAPFlowline as the feature class to create the network from. Call the network WRAPFlowLineNetwork, and click Next.



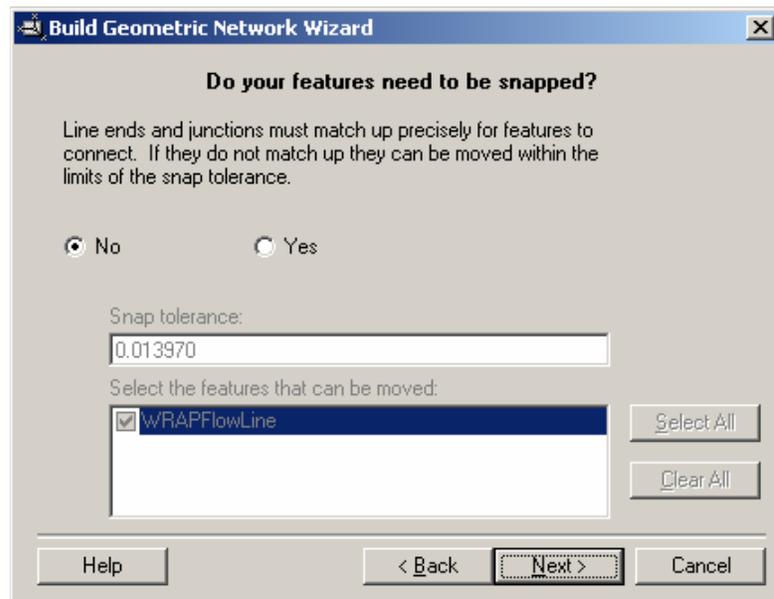
- Choose 'Yes' to preserve the existing enabled values, and click Next.



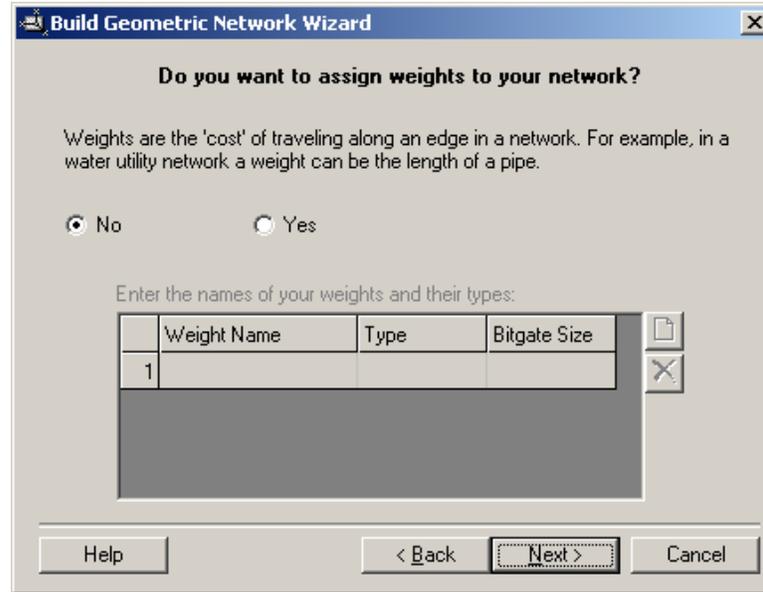
- Choose 'Yes' to build the geometric network with WRAPFlowLine as a complex edge, and click Next.



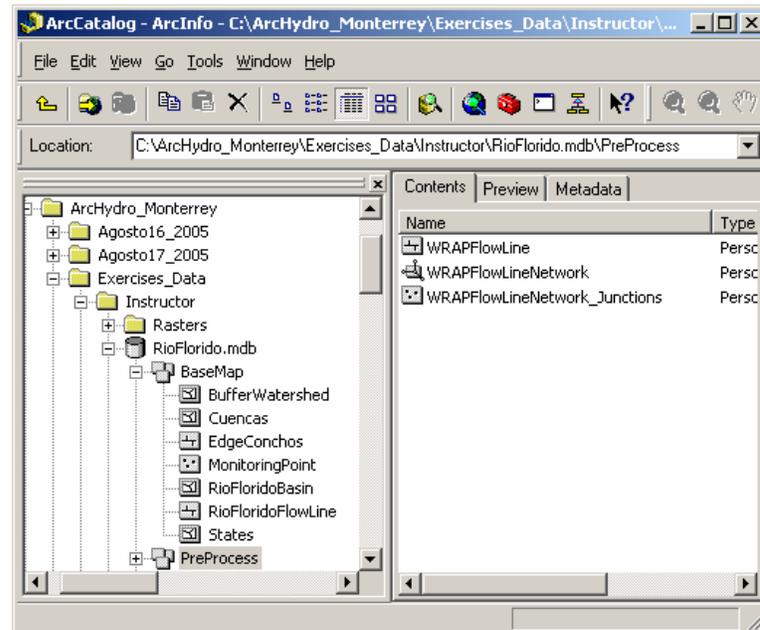
- Choose 'No', as the features do not need to be snapped. Click Next.



- Choose 'No' to not assign weights to the network, and click Next.



- Click 'Finish' to create the geometric network. When the process is completed, you will see a WRAPFlowLineNetwork icon and a WRAPFlowLineNetwork_Junctions icon in the PreProcess feature dataset.



5 Assign HydroIDs to the WRAPFlowLine edges.

The subbasins are identified by a ten digit integer HydroID. The first digit specifies the Rio Grande/Bravo basin side, defined as the number 1 for the US side and 2 for the Mexican side. The next two digits are allocated for the hydrological subregion. Number 02 is assigned to the Rio Conchos basin (It is assumed here that all basins will have no more than 99 subregions). The next two digits represent what type of geographic information being managed. It is assigned number 01 for control points, 02 for flow lines, 03 for water bodies, 04 for watersheds, and so on. The last five digits describe the number of the element, so each feature class may have 99,999 elements.

Regional HydroID Assignment for every feature class in the Geodatabase

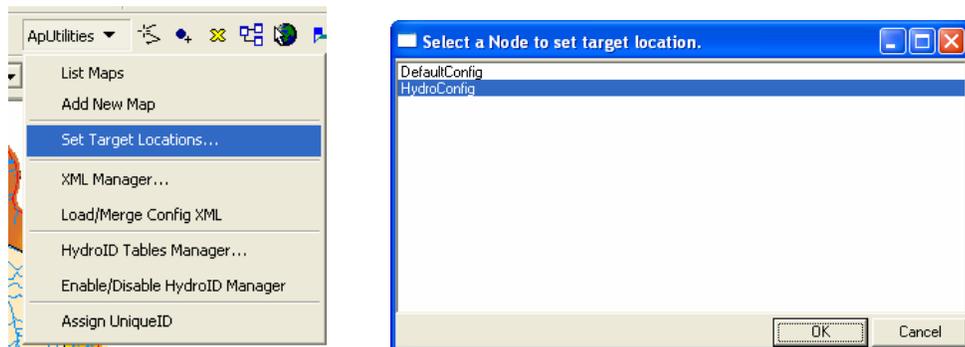


- 1st digit (**blue box**): Hydrological Region
- 2nd two digits (**yellow boxes**): Sub Region
- 3rd & 4th digits (**red boxes**): Feature Class
 - Control Point: 01
 - HydroEdge: 02
 - WaterBody: 03
 - Watershed: 04
 - And so on
- 5th – 9th digits (**green boxes**): Feature Number (1 - 99 999)

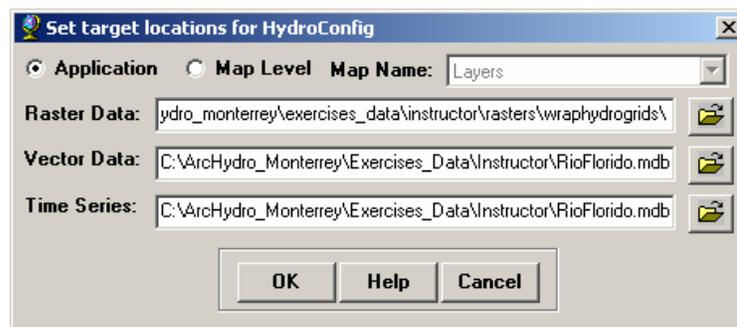
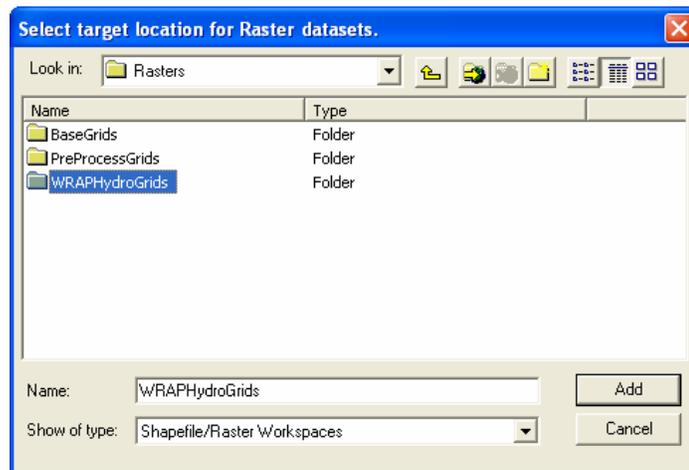
These WRAPFlowLines lie within the Rio Florido subbasin, so all HydroIDs for WRAPFlowLines will begin with the number 2 to indicate the **Mexican side**, 02 to indicate the **Rio Conchos basin**. After the regional identifier, the number 02 indicates that these features are **edge features**. So, each WRAPFlowLine HydroID will be prefixed by 20202, and the last five digits will describe the number for every stream.

Set Target Locations for HydroIDs

- Close ArcCatalog, and open the WRAPHydroProcess ArcMap document.
- Add **WRAPFlowLines** layer to the map and remove **RioFloridoFlowLines** from the map.
- Click the **Set Target Locations** in the **ApUtilities**. Then select **HydroConfig** from the next box.

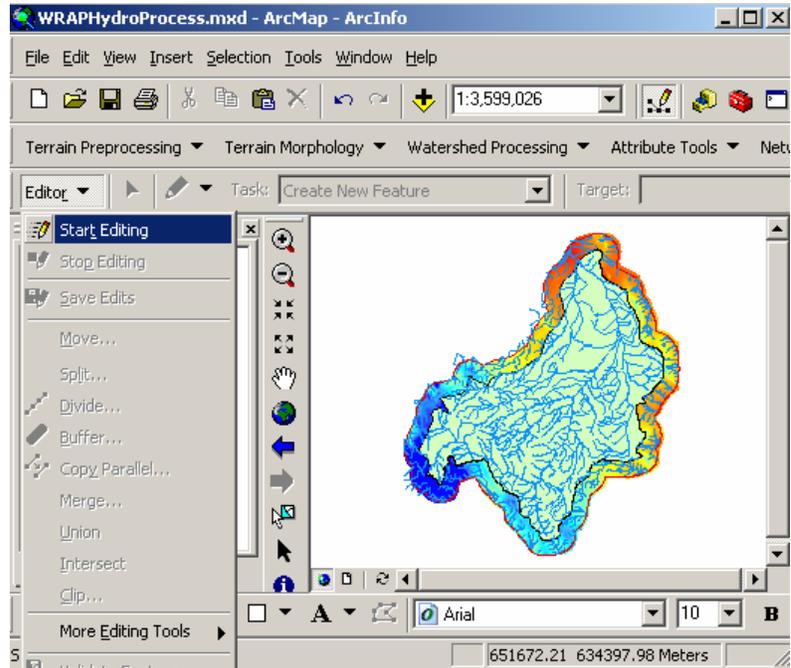


- Select **WRAPHydroGrids** as the target for **Rasters**; **RioFlorido.mdb** as the target for **Vectors** and **Time Series**.

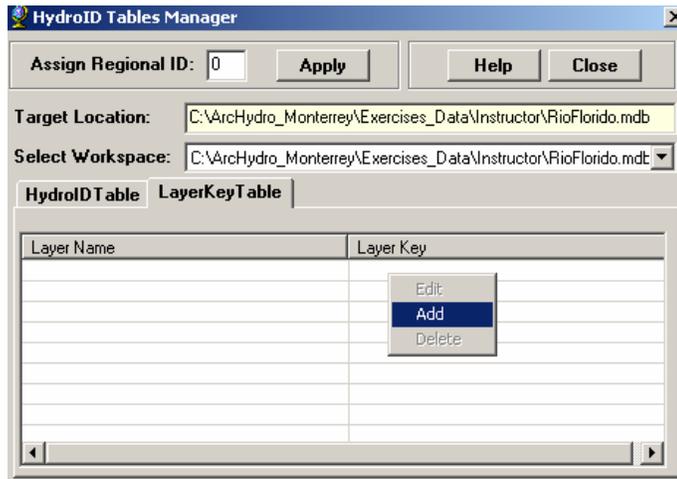


Set Starting HydroIDs for WRAPFlowLines

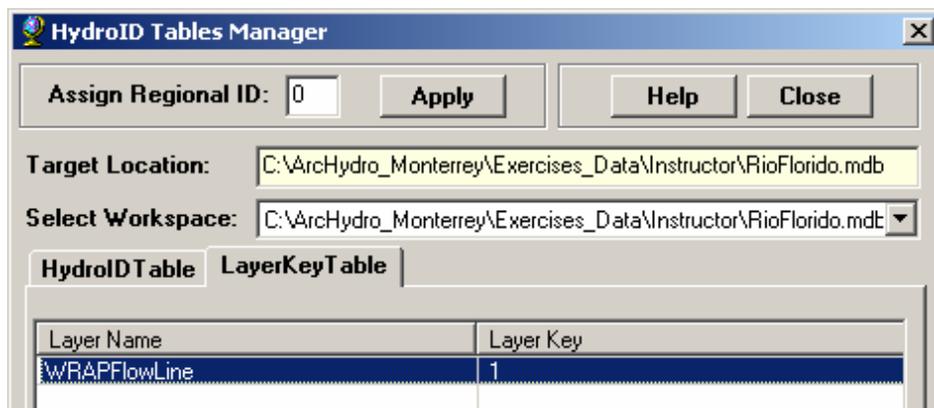
- Click the Editor Toolbar and click **Start Editing**. [hint: If the editor toolbar is not visible, add it by clicking View→Toolbars→Editor.]



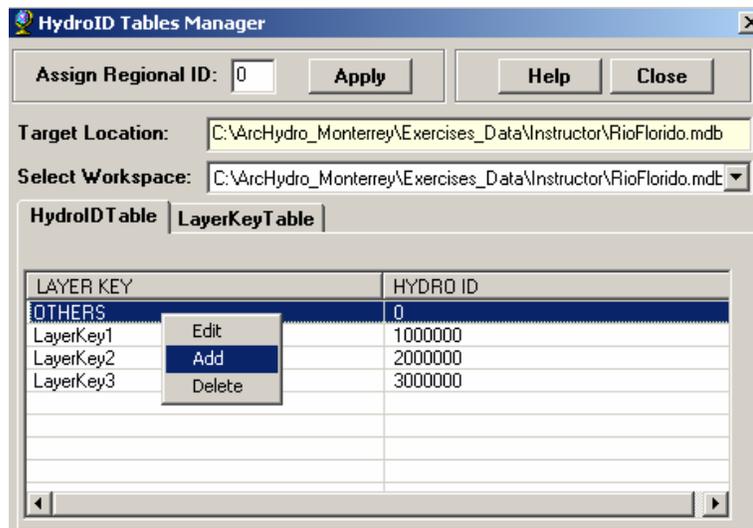
- Go to the **HydroID tables manager** in the ApUtilities menu of the ArcHydro toolbar.
- Open the HydroID Tables Manager located in the “AppUtilities” menu of the ArcHydro toolbar, and go to the **LayerKey Table** tab.
- Right click in the first blank under the words “Layer Name”, and click **Add**.



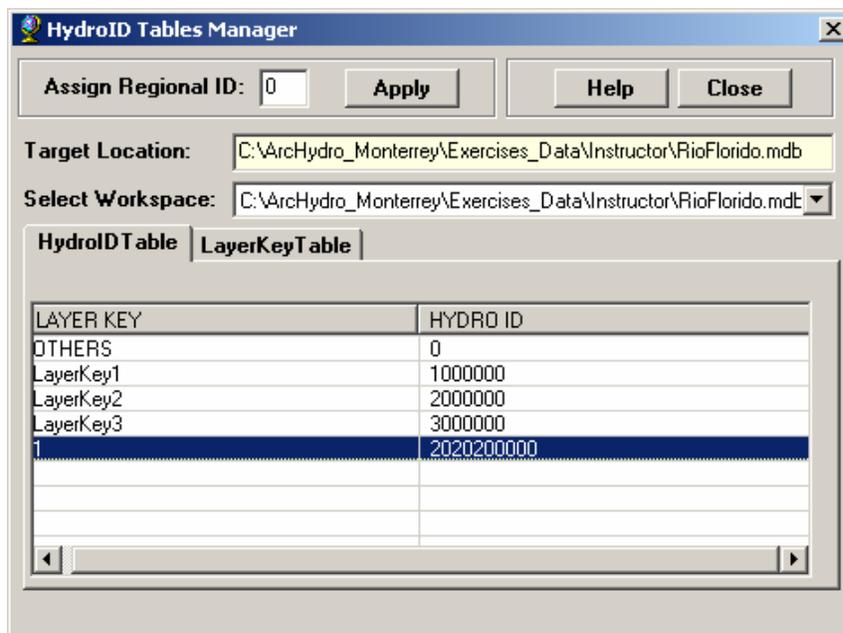
- Type WRAPFlowLine as the layer name, and 1 as the layer key. Click OK.



- Click on the **HydroID Table** tab to provide a HydroID starting point for the WRAPFlowLine layer key. To establish this key, right click on the word “OTHERS” under Layer Key and click **Add**.



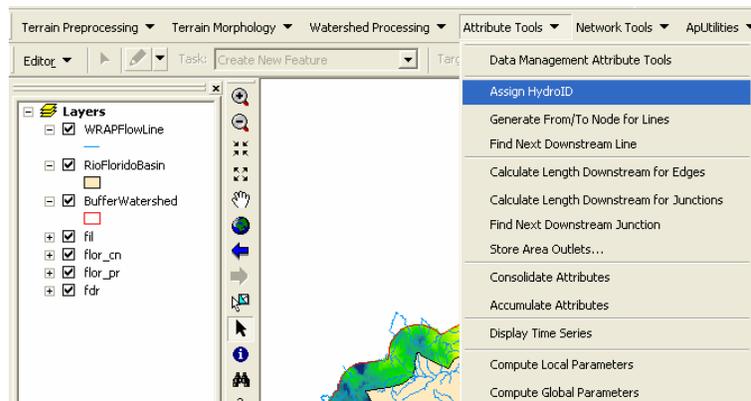
- Type 1 as the layer key, and 2020200000 as the HydroID. Thus, the first HydroID assigned to a WRAPFlowLine will be 2020200001; the second will be 2020200002, and so on. Click OK.



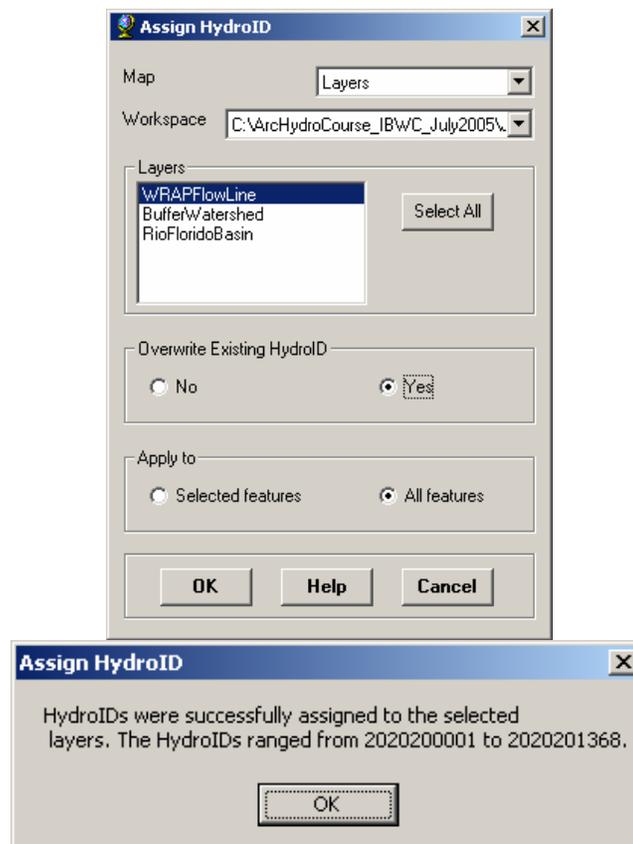
- Click **Close** to close the HydroID Tables Manager and stop the editing process.

Assign HydroIDs to WRAPFlowLines

- In the Attribute Tools menu of the ArcHydro toolbar, click **Assign HydroID**.



- Highlight the WRAPFlowline feature class, and click OK to assign HydroIDs to all WRAPFlowline features. When the tool finishes, the range of HydroIDs assigned is displayed. Notice that each HydroID is indexed by the hydrological sub region number (02) and the feature type (02).

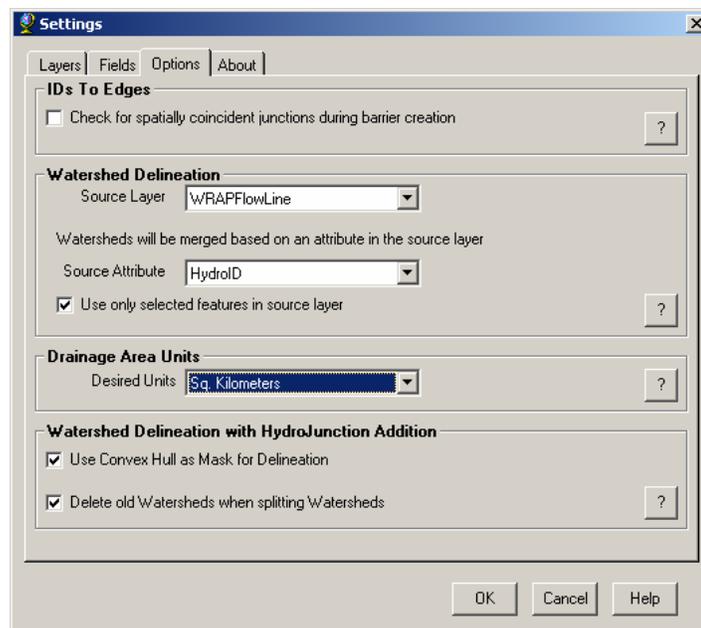


- Be sure that the Flow Direction grid appears at the **bottom** of the layers in the table of contents, otherwise you will receive errors when you try to assign the HydroIDs

WRAPHYDRO PROCESS APPLICATION

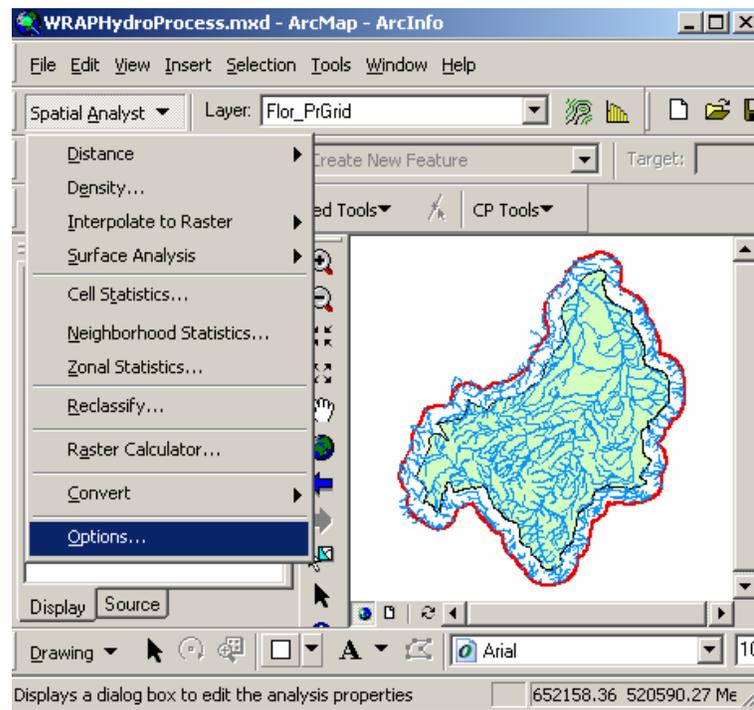
6 Delineate catchments for each stream segment in WRAPFlowline.

- In the WRAPHydro toolbar, click **Settings** to open the Settings form. This form is used to specify layer names, field names, and optional settings for use in WRAPHydro tools' operations.
- Click the **Options** tab on the Settings form.
- In the **Watershed Delineation** section, specify WRAPFlowLine as the source layer and HydroID as the source attribute. Then click OK.

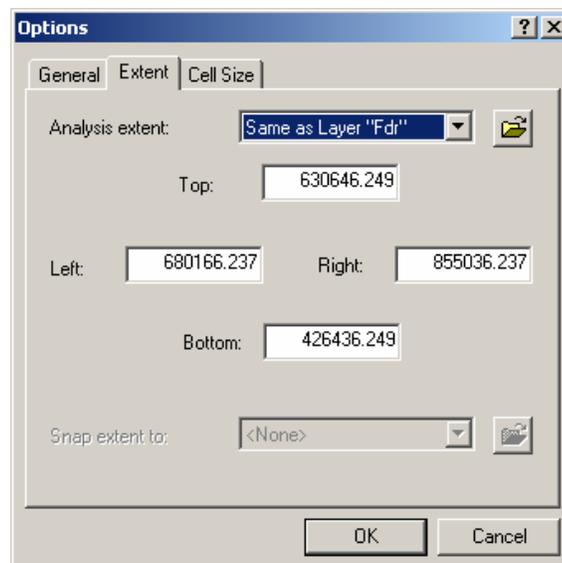


The WRAPHydro tools look at spatial analyst settings when performing raster operations. Therefore, the extent and cell size should be set in Spatial Analyst before delineating watersheds with the WRAPHydro tools.

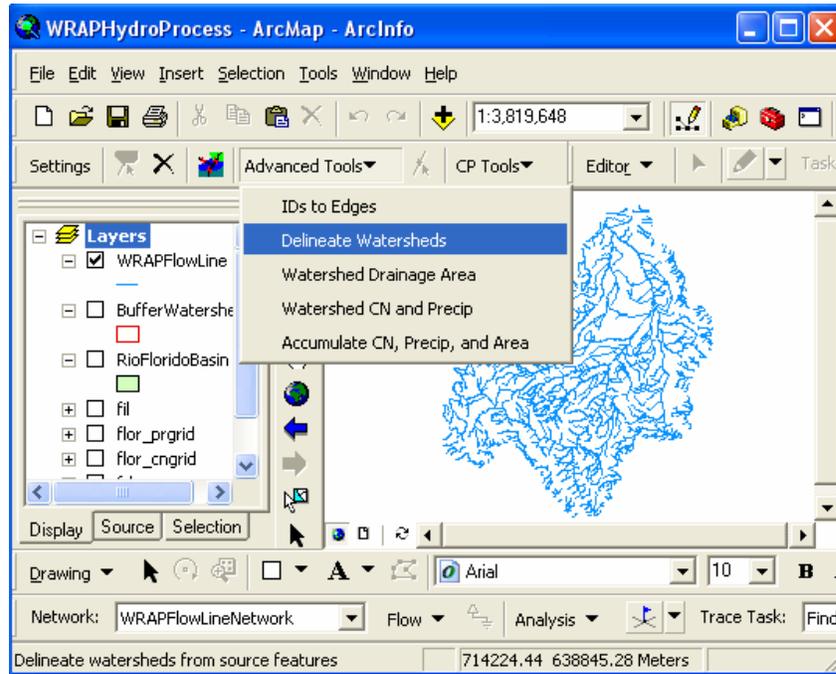
- Click Options in the Spatial Analyst toolbar. [hint: If the Spatial Analyst toolbar is not visible, click View→toolbars→Spatial Analyst.]



- Click the Extent tab, and then set the analysis extent to **Same as Layer “fdr”**. Then click the Cell Size tab and set the analysis cell size to **Same as Layer “fdr”**.
- Click OK.



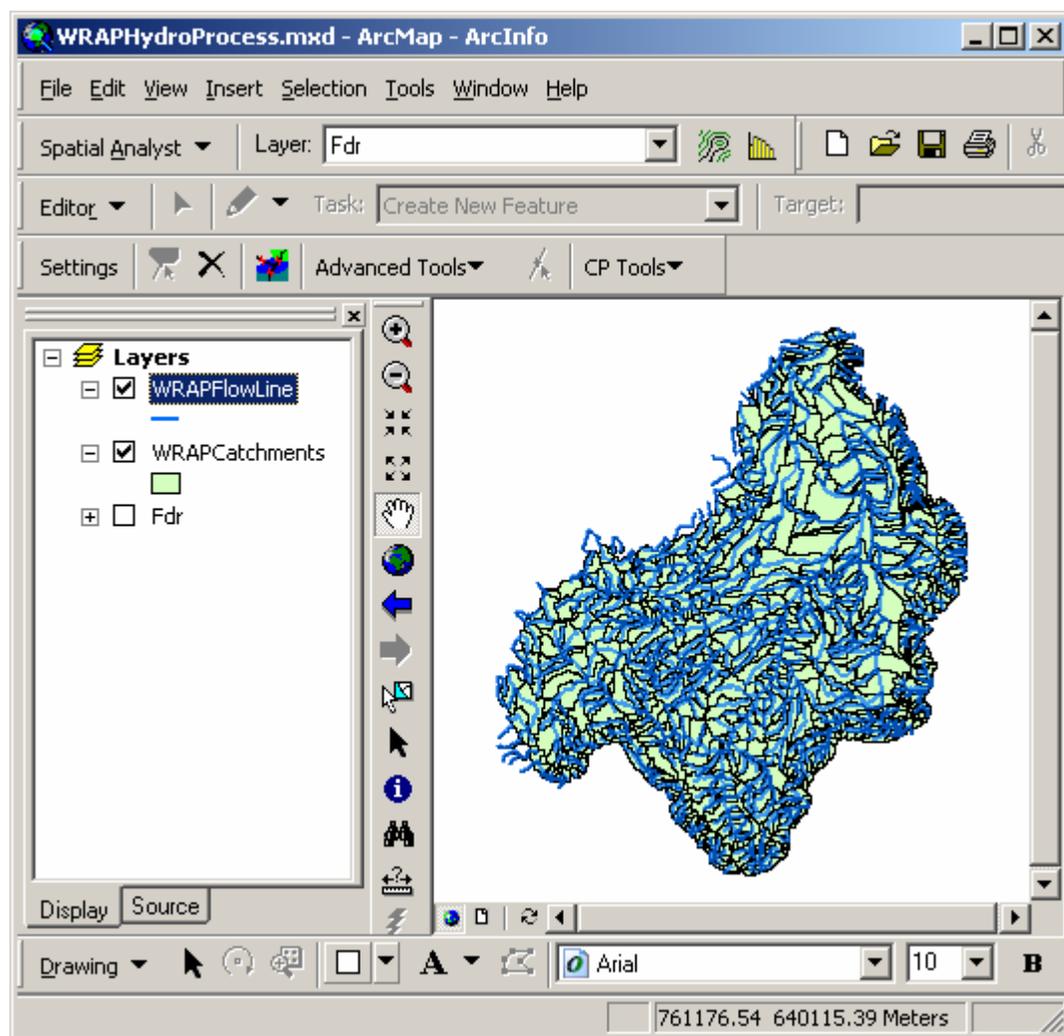
- In the Advanced Tools menu of the WRAPHydro tools, click **Delineate Watersheds**.



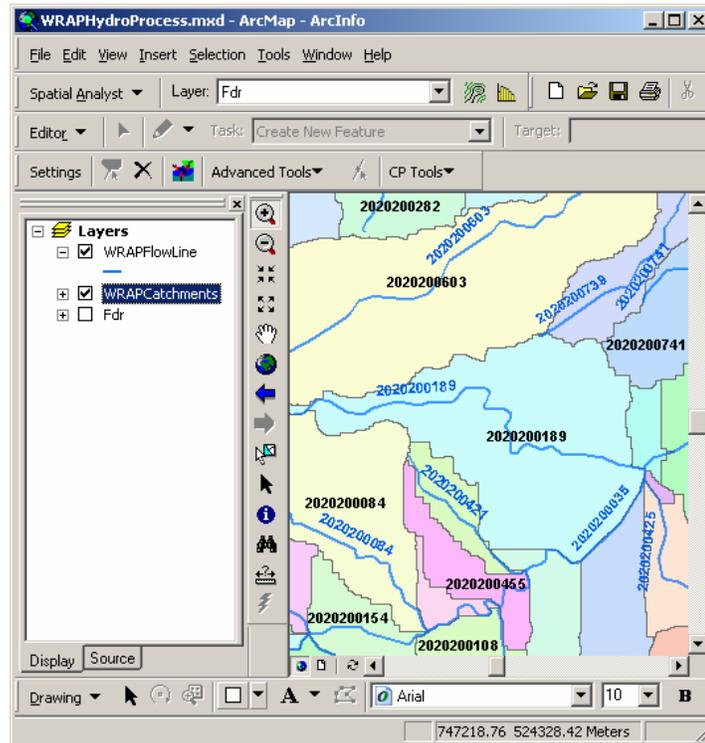
- Save the output watersheds as WRAPCatchments into the Preprocess feature dataset.



The WRAPHydro tools read the inputs from the Settings form and delineate watersheds. In this case, a WRAPCatchment are created for every WRAPFlowLine feature.

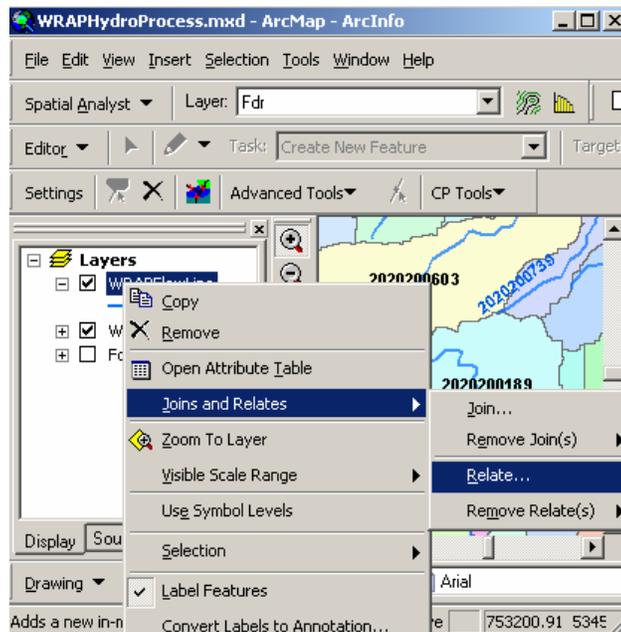


- Check that each delineated watershed has a field DrainID which is equal to the HydroID of the Stream it drains to.

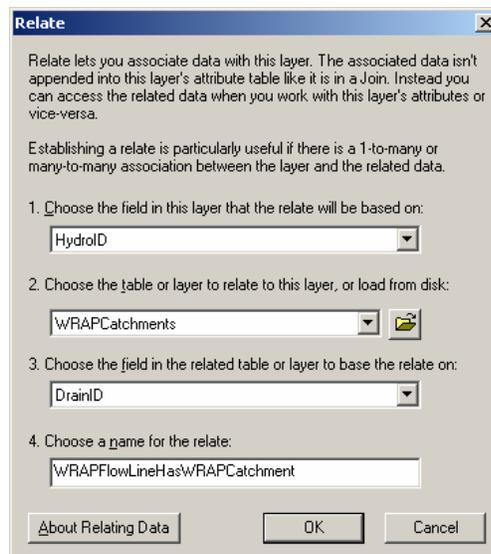


7 Build a relationship between WRAPFlowline and WRAPCatchment.

- In the ArcMap table of contents, right click the WRAPFlowLine feature layer, click **Joins and Relates**, and then click **Relate**.



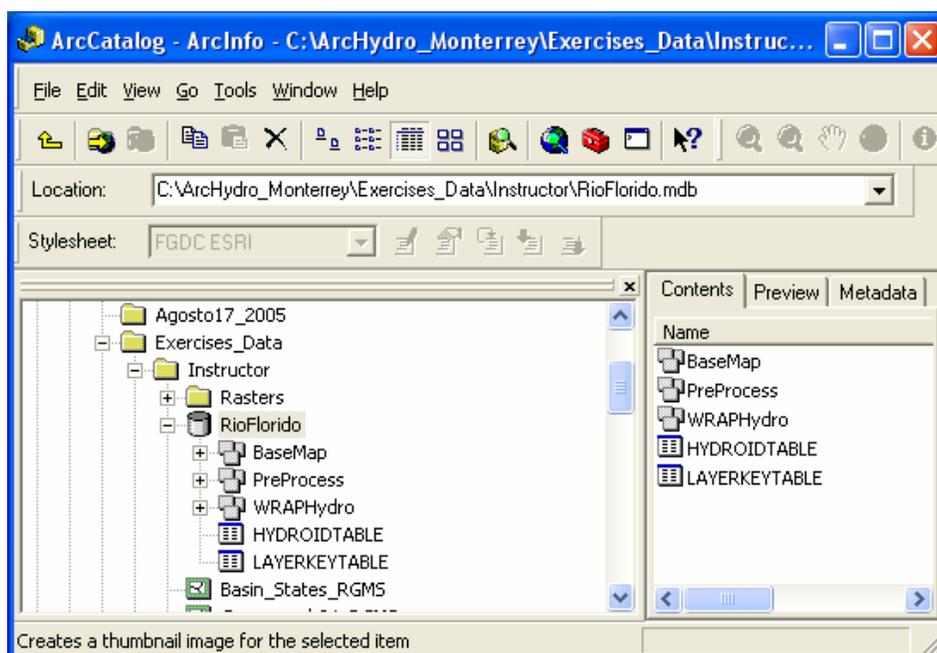
- Choose HydroID as the field in WRAPFlowLine that relate will be based on.
- Choose WRAPCatchments as the layer to relate to WRAPFlowLine.
- Choose DrainID as the key field in WRAPCatchments.
- Type WRAPFlowLineHasWRAPCatchment as the relate name.
- Click OK to create the relationship.



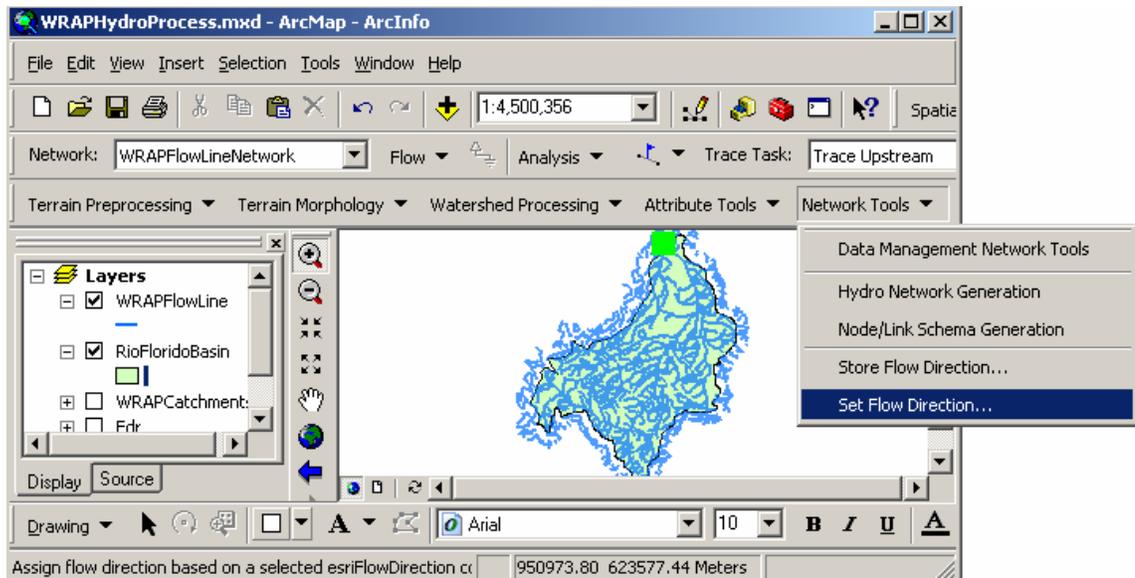
8 Select streams in the basin and export them to WRAPeEdge

Select all the streams that make up the basin and export them to WRAPeEdge in the WRAPHydro feature dataset.

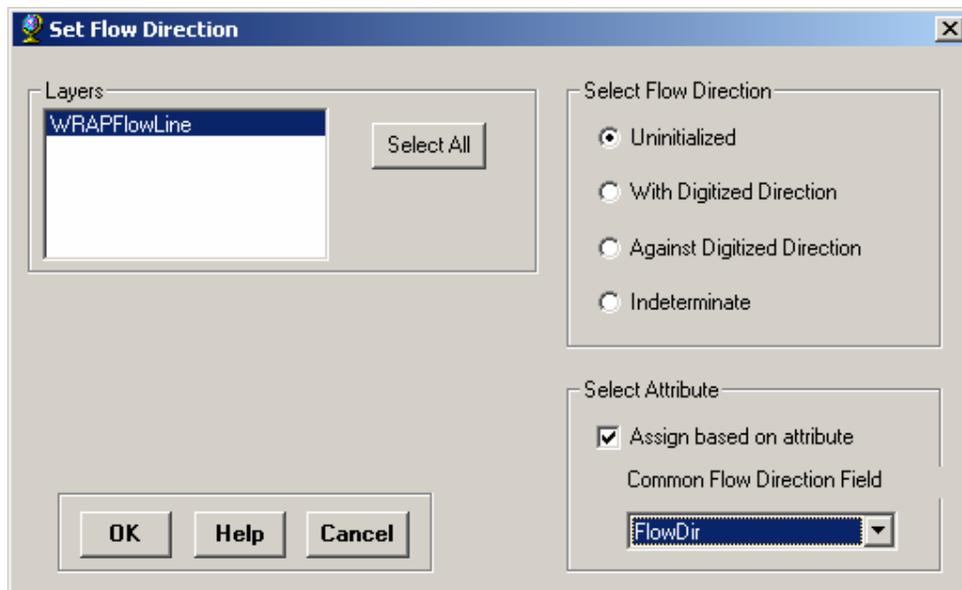
- Close ArcMap and open ArcCatalog.
- Create a new Feature Dataset in the RioFlorido.mdb Geodatabase called WRAPHydro with the same geographic properties as the PreProcess feature dataset.

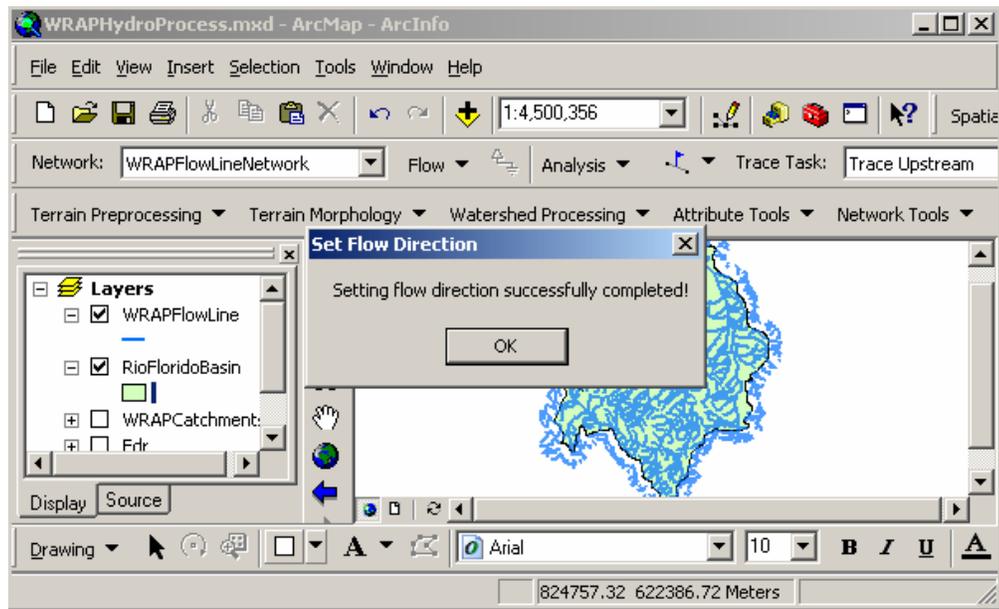


- The flow direction for every FlowLine must be assigned as the first step. Go to the “Network Tools” menu of the ArcHydro toolbar and choose the “Set Flow Direction” option.

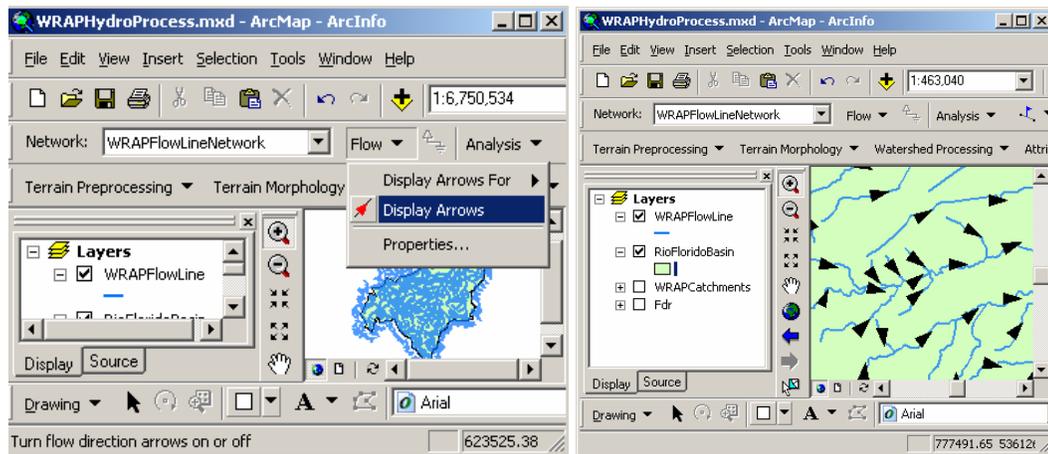


- Select the “WRAPFlowLine” feature class as the Layer input file. The flow direction for every stream is assigned based on the information of the “FlowDir” attribute. Click OK.



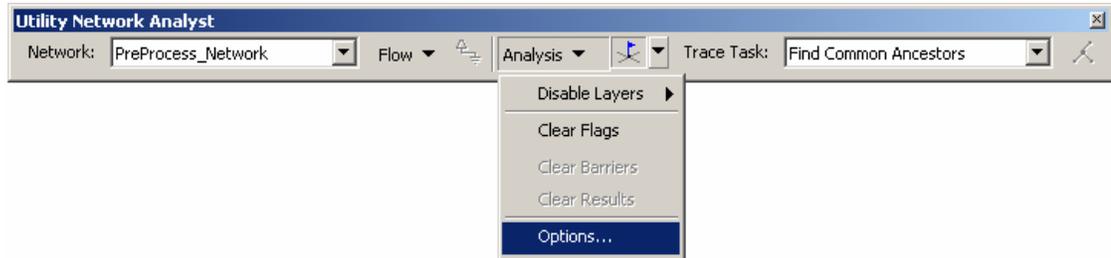


- Verify all flow directions were assigned correctly. In the Utility Network Analyst toolbar, click Flow→Display Arrows. [hint: If this toolbar is not visible, click View→Toolbars→Utility Network Analyst.]

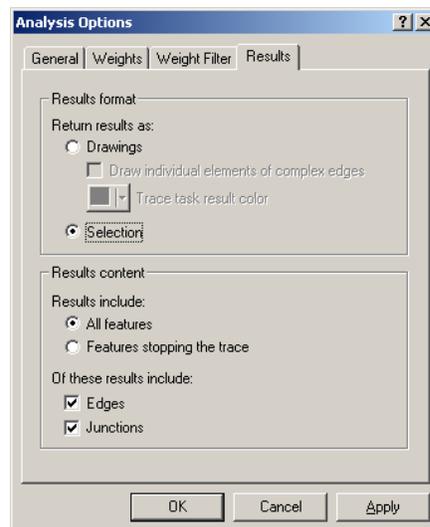


To select all the WRAPCatchments that make up the basin, first all the streams that lie in the basin should be selected. These streams are selected by placing a flag at the outlet of the basin, and then tracing upstream. But first, the Utility Network Analyst must be configured to return the results of the trace as a selection.

- In the Utility Network Analyst toolbar, click Analysis→Options.



- In the Results tab, click the option to return results as a **Selection**. Make sure that the results will include all features, including edges and junctions. Click OK.

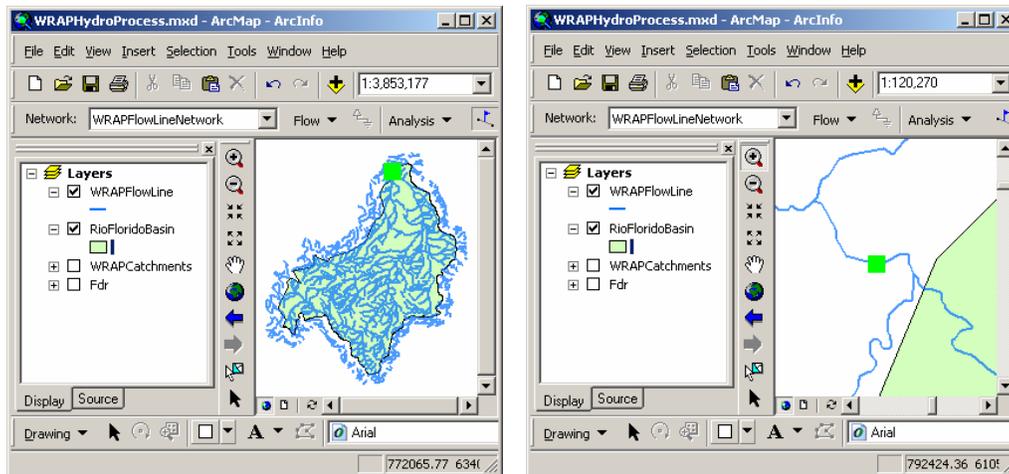


- Select the Add Edge Flag Tool from the Utility Network Analyst Toolbar.

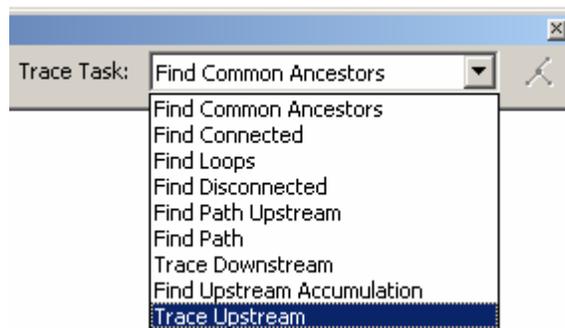


- Click on the Add Edge Flag tool .

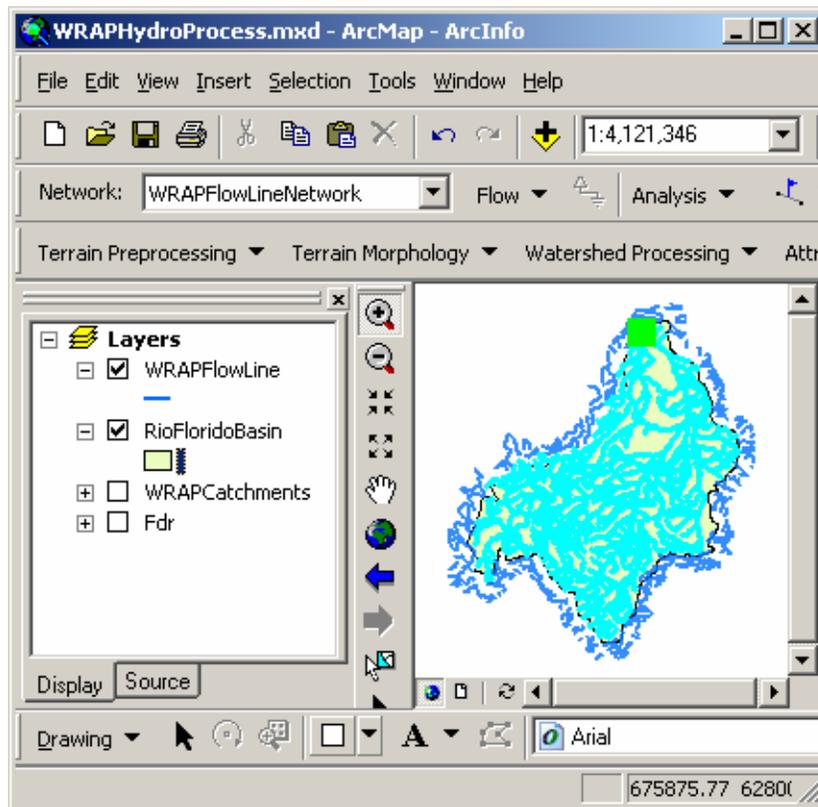
- Place a flag at the most downstream location in the Rio Florido basin, by clicking near the downstream end of the last edge in the basin. This location is shown in the image below. Note that this location is also just upstream of the most downstream FlowLine in the basin, because the WRAPFlowLine feature class includes a 10 Km buffer. The original polygon describing the Rio Florido subbasin can be added as a reference.



- Select Trace Upstream as the Trace Task in the Utility Network Analyst toolbar.



- Click the Solve  button on the Utility Network Analyst toolbar to perform the trace. All of the WRAPFlowLines that are on the stream network for the Rio Florido basin will be selected.

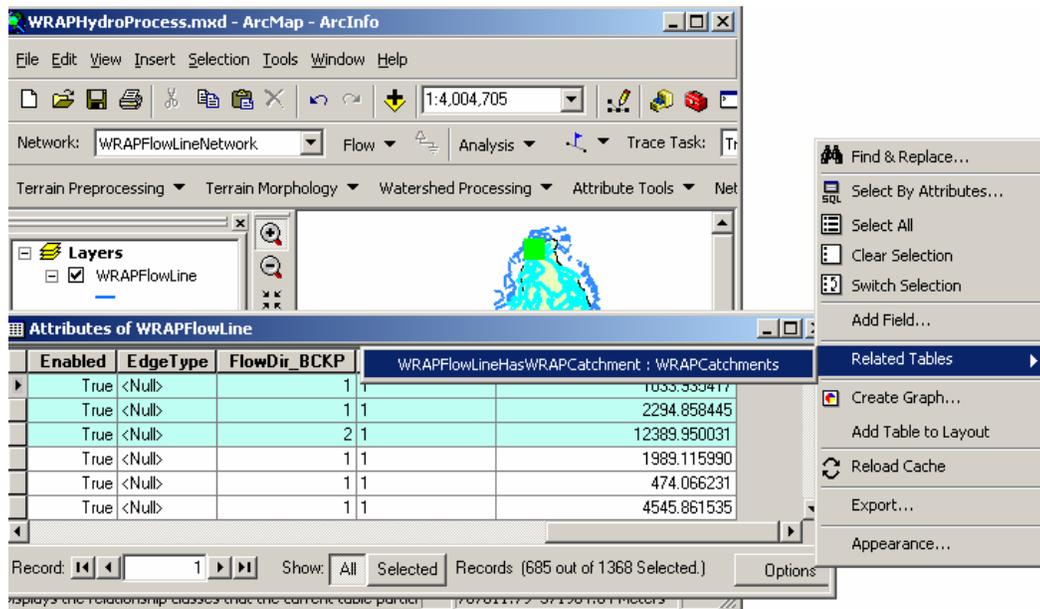


- Export the WRAPFlowLines to the WRAPHydro feature dataset, and call the result WRAPEdge.

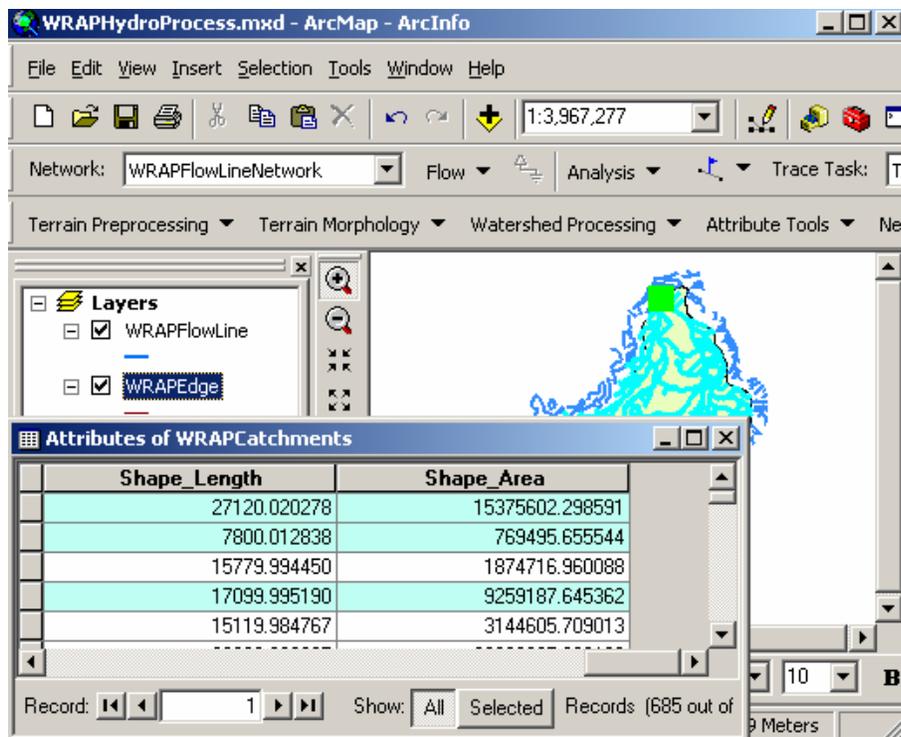
9 Select the catchments that drain to the selected streams.

Once all the required streams are selected, the related WRAPCatchments can be selected since a relationship exists between them.

- Right click on WRAPFlowLine in the ArcMap table of contents and click **Open Attribute Table**.
- Click **Options**→**Related Tables**, and select the relationship to WRAPCatchments.



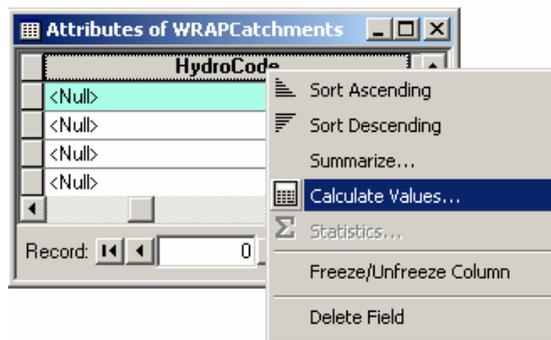
After a moment, the WRAPCatchments attribute table appears automatically, and the ones related to the selected WRAPFlowLines are now selected.



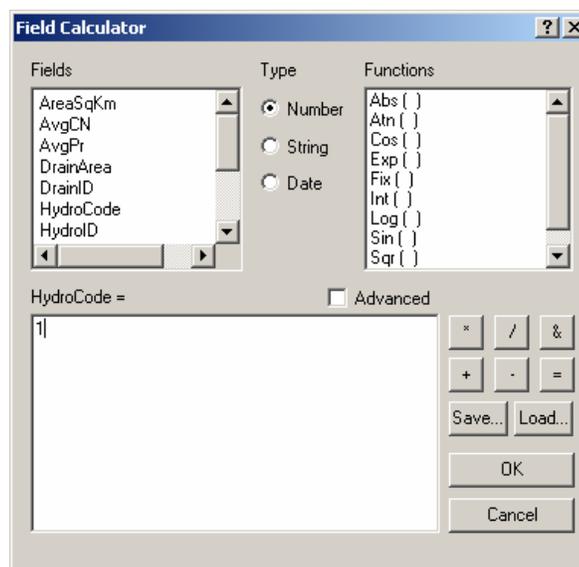
10 Dissolve the selected WRAPCatchments to 'basin'

Dissolve the selected WRAPCatchments to create a single polygon 'basin' which defines the boundary of the basin.

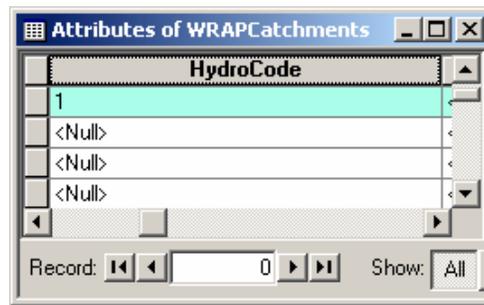
- In the attribute table for WRAPCatchments, right click the HydroCode field and click Calculate Values.



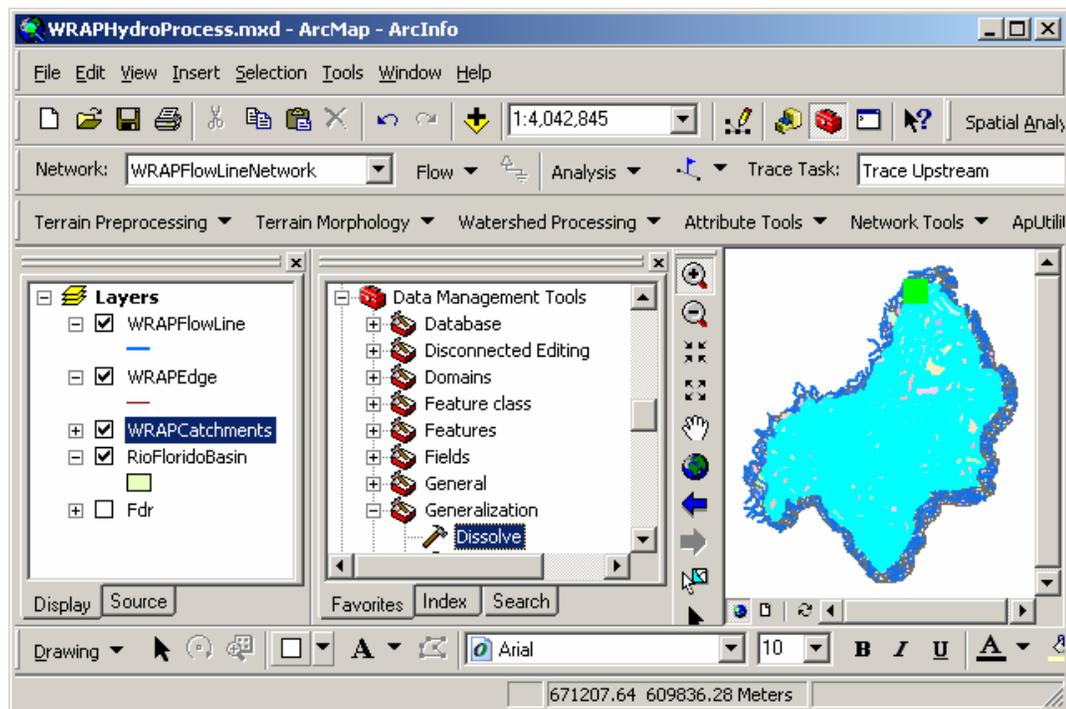
- Assign the number 1 to the HydroCode in the field calculator. The field calculator will only operate on selected WRAPCatchments.



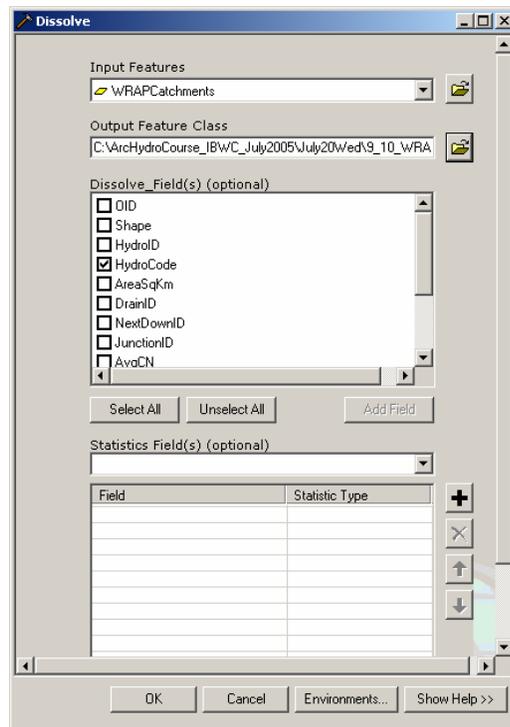
Now all selected WRAPCatchments have a HydroCode of 1.



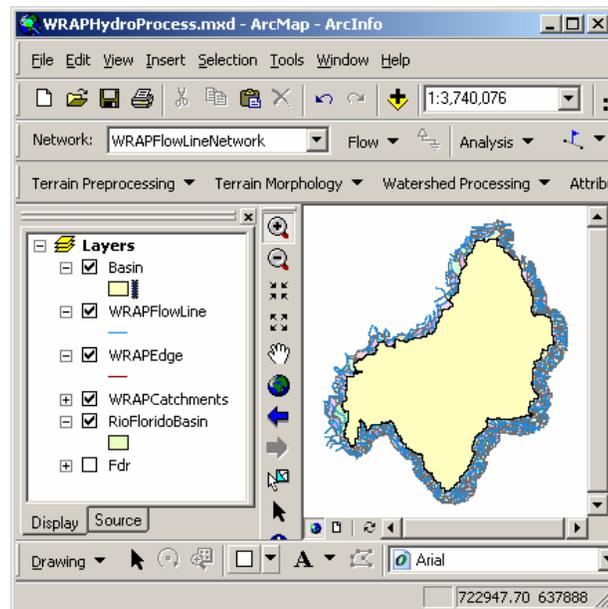
- Launch the ArcTool box application. Go to the **Data Management Tools**→**Generalization** →**Dissolve** option and click on it.



- Select the WRAPCatchments as the input layer. Export the result as a feature class to the PreProcess data set and call it “Basin”. Select the dissolve features based on the HydroCode attribute and click OK.



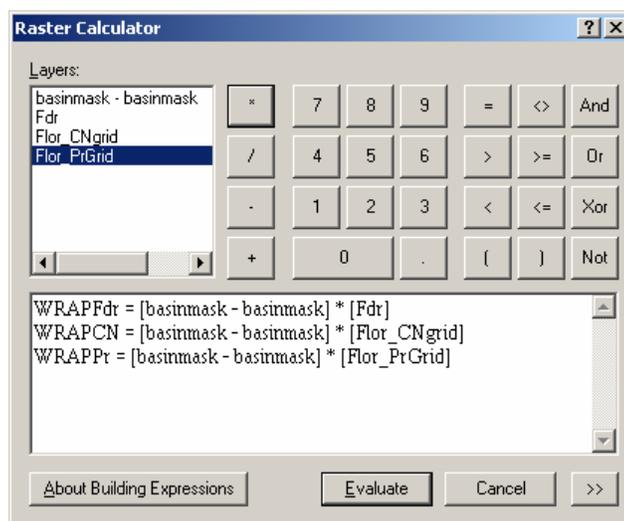
The Basin feature class now stores the Rio Florido Basin, as delineated using the available flow direction grid, “fdr”.



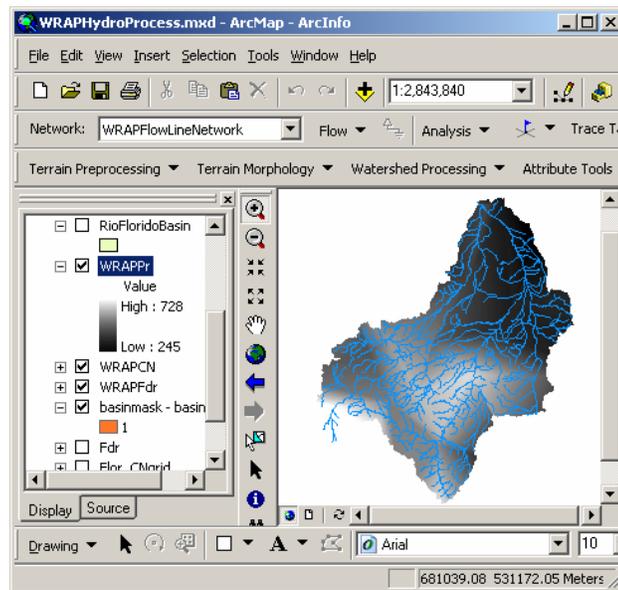
11 Create a mask of the “Basin”

Create a mask of the “Basin” feature class and clip the Fdr, the Curve Number and the Precipitation grid to it using the Spatial Analyst extension

- Apply the same methodology to create a mask of the **basin** feature class. Remember that this mask is grid that covers the analysis region and all the cells in the mask have a unit value. Call the result **BasinMask** and save it in the “PreProcessGrids” folder.
- Clip the Fdr, Flor_CNgrid, and Flor_PrGrid using the raster calculator of the Spatial Analyst extension. (If necessary, add those grids to the map document from the BaseGrids and PreProcessGrids folders.) Call the results WRAPFdr, WRAPCn, and WRAPPPr, and save them in the WRAPHydroGrids folder.

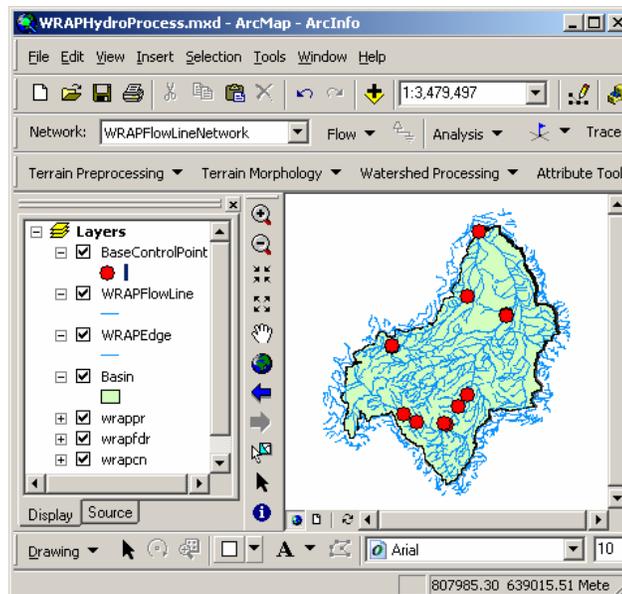


The grids used for WRAPHydro analysis have now been clipped to cover the Rio Florido Basin exactly.

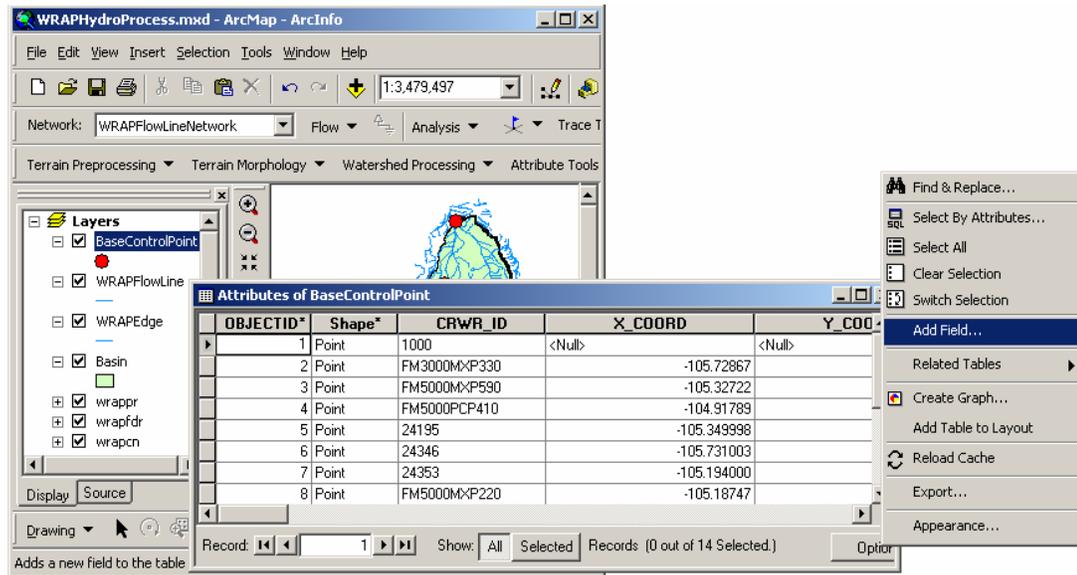


12 Copy BaseControlPoint to PreProcess

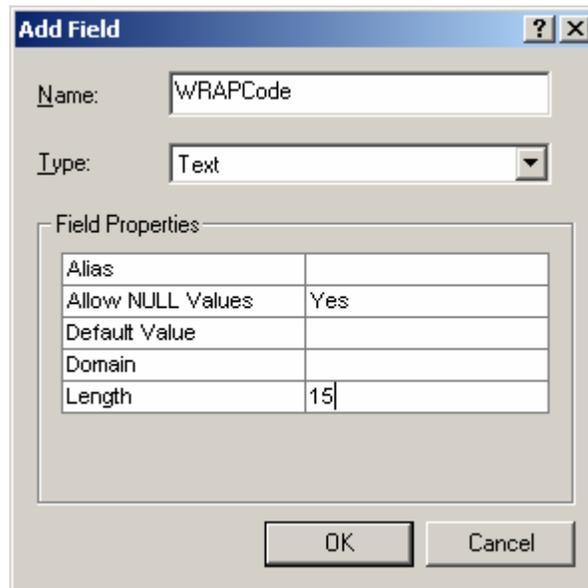
- Open ArcCatalog and export the **BaseControlPoint** shapefile to the **BaseMap** feature dataset as a new feature class and call it **BaseControlPoint**. Close ArcCatalog.
- Open your document WRAPHydroProcess.mxd in ArcMap and add the **BaseControlPoint** feature class.



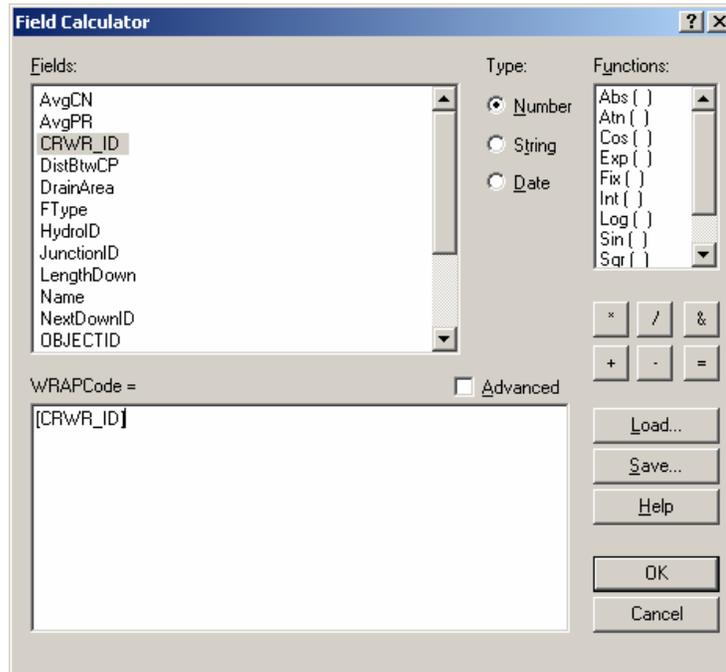
- Open the attribute table of BaseControlPoint, and click **Options**→**Add Field**.



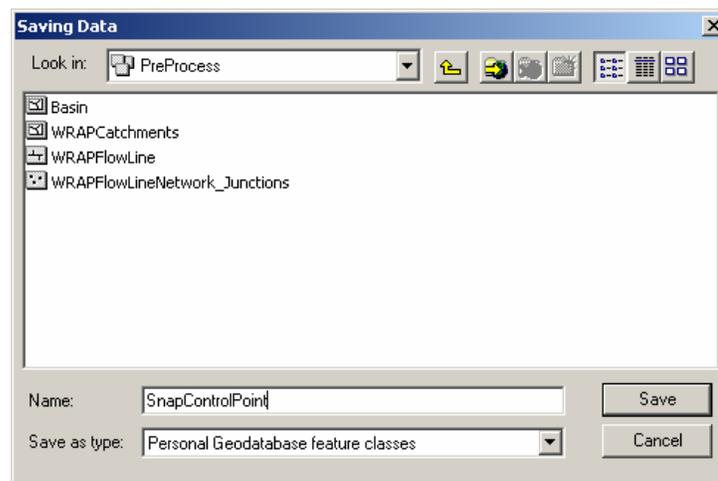
- Call the field WRAPCode, and make it of type Text (15 digits length). Click OK. We will use this field as an identifier key field later on.

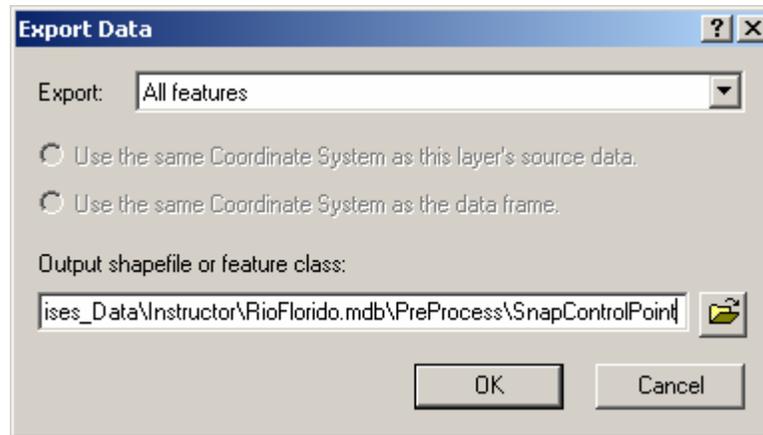


- Right click on the WRAPCode field, and click **Calculate Values**.
- Copy the values from the “CRWR_ID” field into WRAPCode using the field calculator.



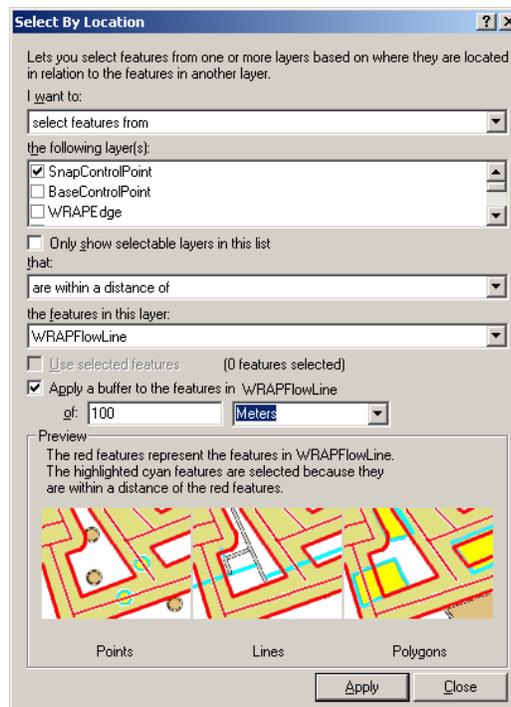
- Right click on the BaseControlPoint feature class and select **export data**.
- Call this new feature class SnapControlPoint and save it in the PreProcess feature dataset.





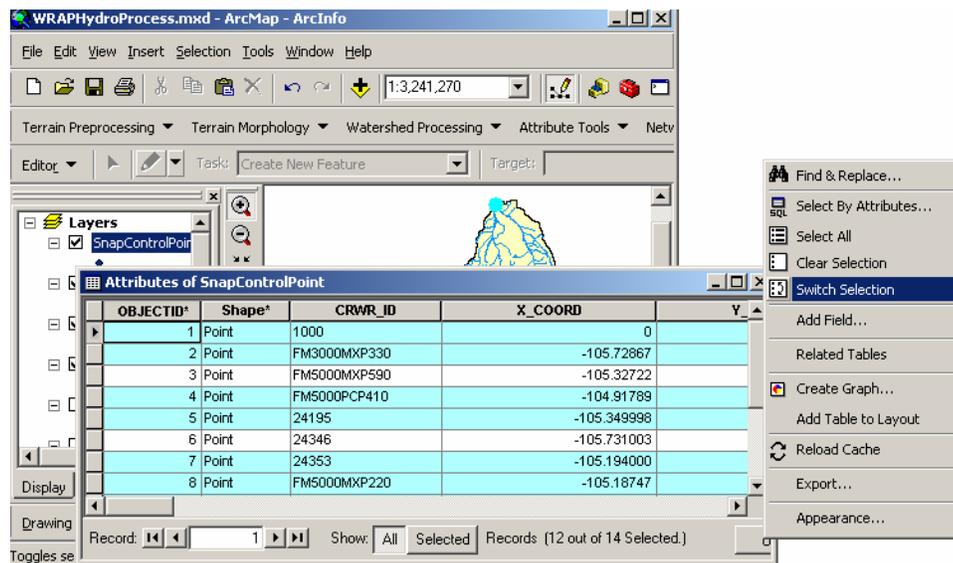
Change the location of SnapControlPoints so that they lie within 100 m from WRAPFlowlines.

- In ArcMap, start an edit session if one has not already been started.
- Use Select by Location to select SnapControlPoints located within 100 m of WRAPFlowLine.



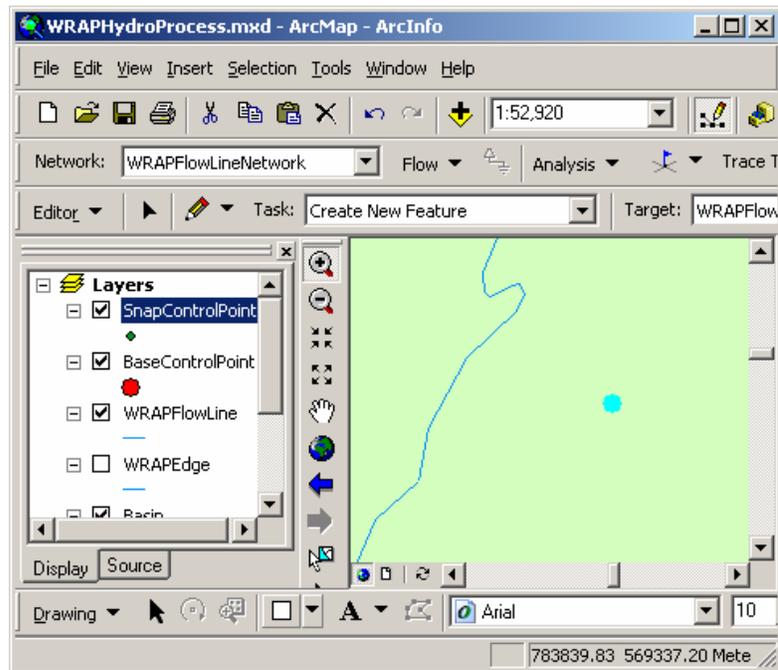
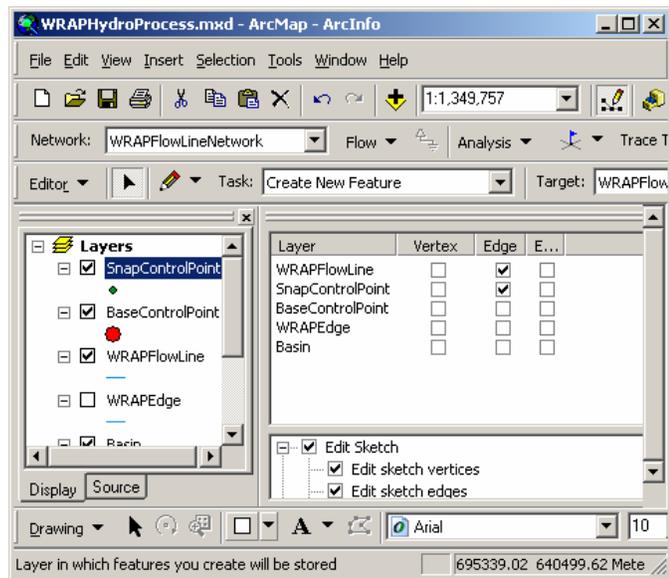
Now all of the SnapControlPoints within 100 m of WRAPFlowLine are selected. However, we want to isolate those points that are further than 100 m from WRAPFlowLine.

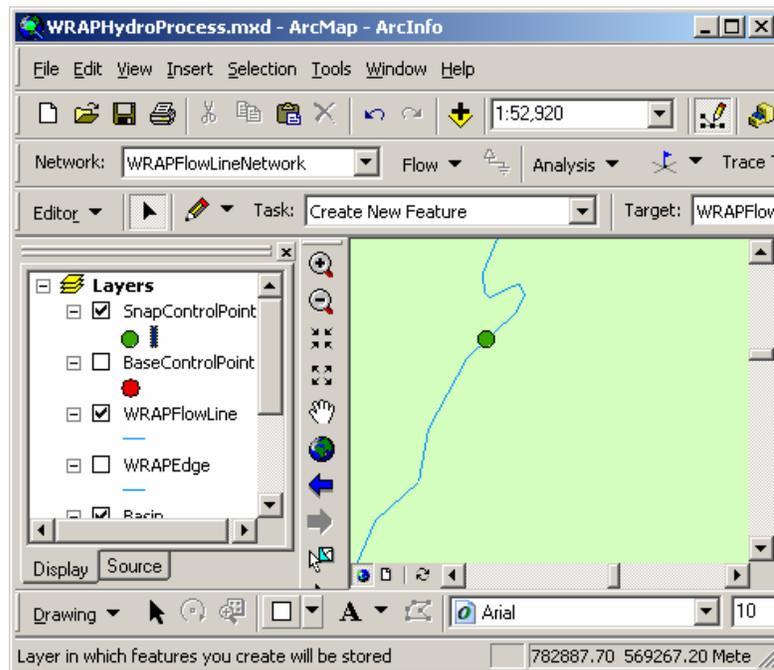
- Open the SnapControlPoint attribute table.
- Click Options → Switch Selection.



Now the SnapControlPoints further than 100 m from WRAPFlowLine are selected.

- Using the Edit Sketch tool, move any selected SnapControlPoints to within 100 m of the nearest WRAPFlowLine (or an otherwise appropriate location on the stream network). [hint: Set the snapping options in the Editor menu before moving the points, so that the points will snap to the edges of WRAPFlowLine.]

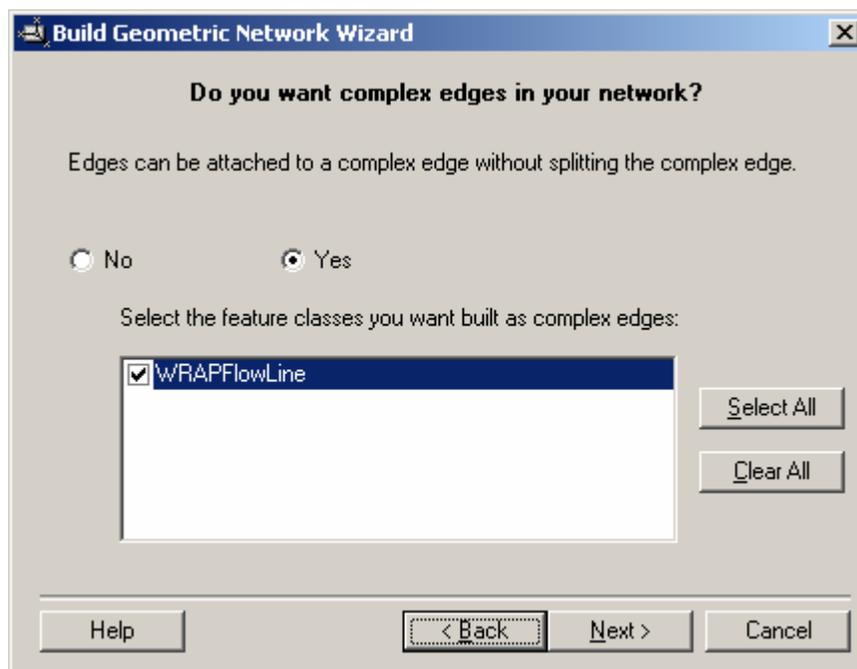
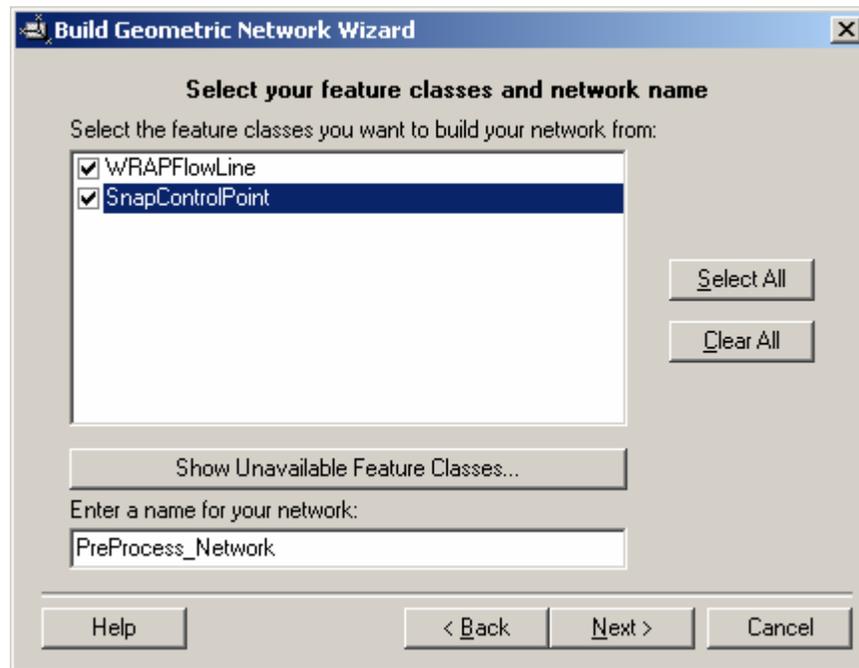




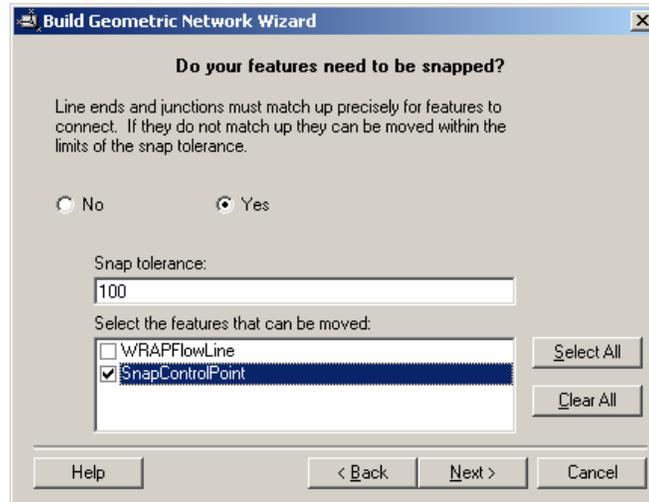
13 Build new network with SnapControlPoint and WRAPFlowline

Delete the old network and build a new one with SnapControlPoint and WRAPFlowline, and snap the junctions to the edges by giving a 100 m snapping tolerance.

- Save any edits, save ArcMap, and then close ArcMap.
- Open ArcCatalog. Right click on WRAPFlowLineNetwork in the PreProcess feature dataset and click **Delete** to delete the network.
- Create a new geometric network with SnapControlPoint and WRAPFlowLine feature class as a complex edge



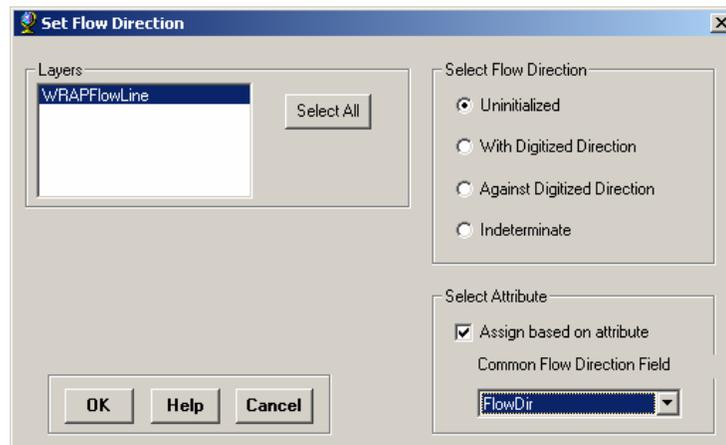
- Select the snap option and choose the SnapControlPoint feature class to be moved with a snap tolerance of 100.



- Do not specify any sources or sinks, or weights for the network. Click Finish to complete the Geometric Network Creation Wizard process. When completed, all SnapControlPoints should be snapped on top of a WRAPFlowLine.

14 Assign Flow Directions

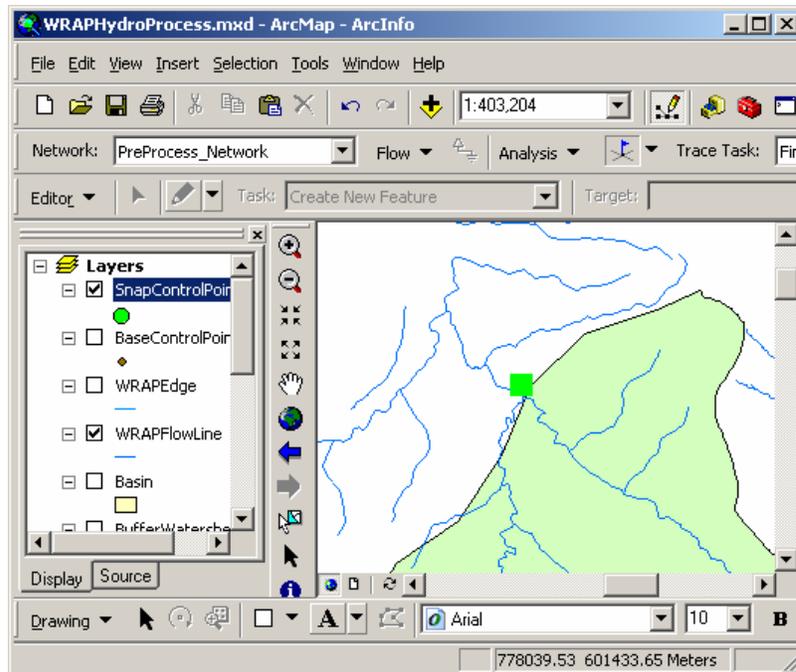
- Close ArcCatalog.
- Open the WRAPHydroProcess project in ArcMap
- In the ArcHydro toolbar, click **Network Tools** → **Set Flow Direction**.
- Select the WRAPFlowLine as the input for the Hydro Edge field.
- Assign the Flow direction based on the FlowDir attribute. Click OK.



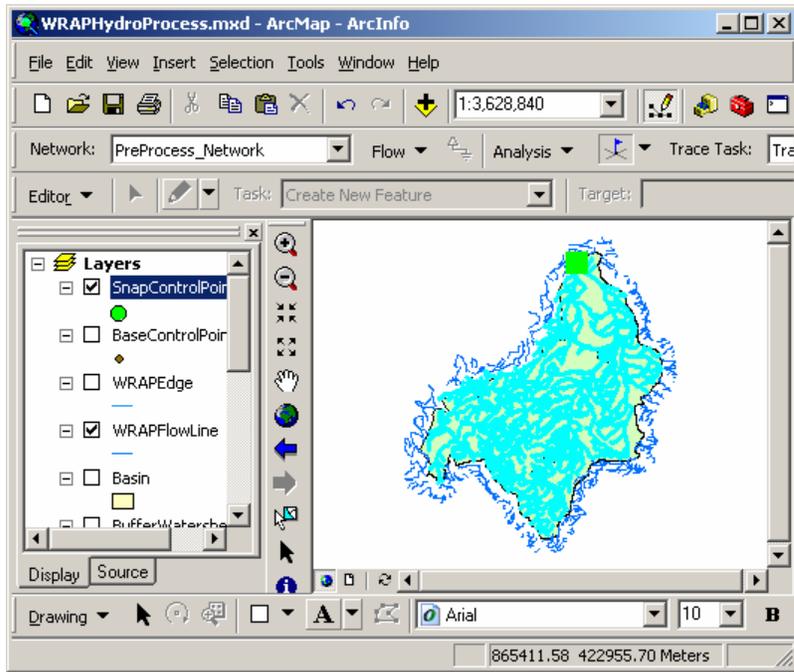
15 Trace Upstream to Select SnapControlPoints on Network

Do a “trace upstream” task to select SnapControlPoints on the stream network.

- Using the Utility Network Analyst toolbar, place a junction flag at the most downstream SnapControlPoint in the basin.



- In the Analysis→Options of the toolbar, make sure that the results of the trace will be returned as a feature selection.
- Choose Trace Upstream as the Trace Task.
- Click the Solve button to perform the upstream trace.



All network features upstream of the outlet of the Rio Florido basin are selected.

- Open the attribute table for SnapControlPoint.

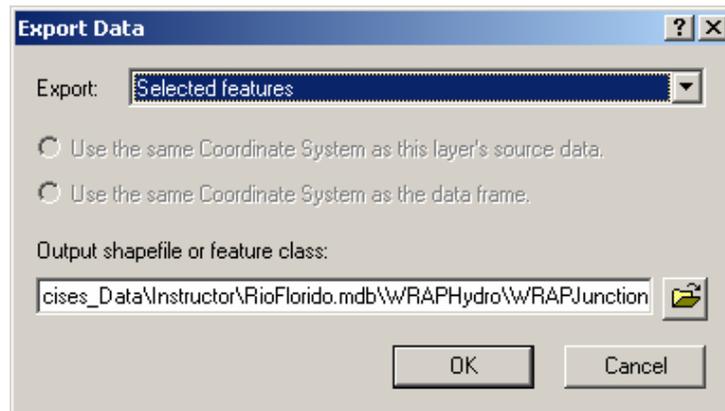
OBJECTID*	Shape*	CRWR_ID	X_COORD	Y_COORD	Type
1	Point	1000	0	0	Virtual_CP
2	Point	FM3000MXP330	-105.72867	26.92013	Reservoir
3	Point	FM5000MXP590	-105.32722	26.43324	Gage Station from TCEQ
4	Point	FM5000PCP410	-104.91789	27.14191	Primary_CP_(Inflow records)
5	Point	24195	-105.349998	26.441000	Gage Station from CNA
6	Point	24346	-105.731003	26.931999	Gage Station from CNA
7	Point	24353	-105.194000	27.254000	Gage Station from CNA
8	Point	FM5000MXP220	-105.18747	26.62664	Irrigation District Diversion

Notice that not all SnapControlPoints are selected. The reason for this is that some SnapControlPoints are spatially coincident with each other. In other words, some of the points lie directly on top of each other. When this happens, only one of those points can participate in the geometric network. So, if three points are in the same location on the network, only one will be selected in the trace upstream task.

Only the SnapControlPoints that are participating in the network will be exported to the WRAPJunction feature class. This ensures that a clean geometric network is created to operate on when calculating WRAP parameters.

16 Export selected SnapControlPoints to WRAPJunction

- Export the selected SnapControlPoints to a new feature class in the WRAPHydro dataset, and call it WRAPJunction.

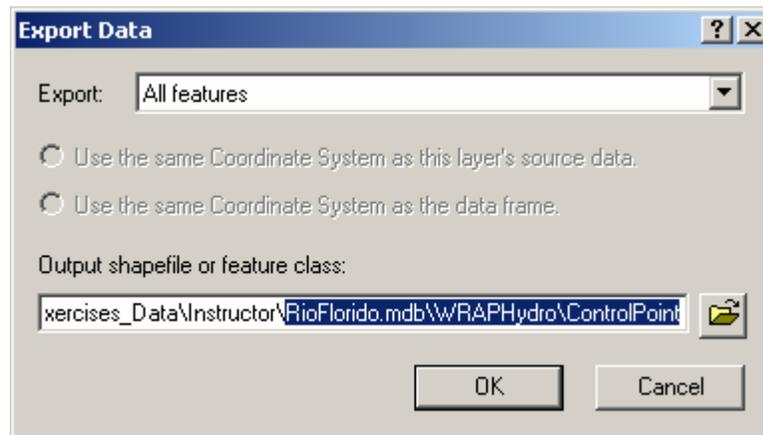


FINDING WATERSHED PARAMETERS

17 Export BaseControlPoint to ControlPoint

Export the BaseControlPoint file to WRAPHydro and call it ControlPoint.

- Export all features in the BaseControlPoint feature class to the WRAPHydro feature dataset, and call the new feature class ControlPoint.



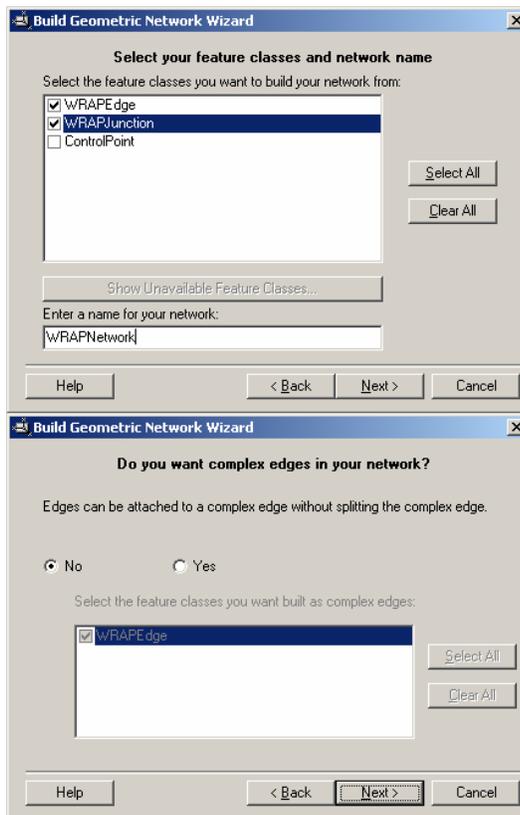
- Save edits, save the ArcMap document and close ArcMap.

18 Build WRAPJunction and WRAPEdge Network

Build a network with WRAPJunction and WRAPEdge, with WRAPEdge as a simple edge feature.

A new network called WRAPNetwork is created using the WRAPEdge and WRAPJunction. This network is built with WRAPEdge as a simple edge feature. Once the network is built the flow directions are assigned to the network using the FlowDir attributes in WRAPEdge.

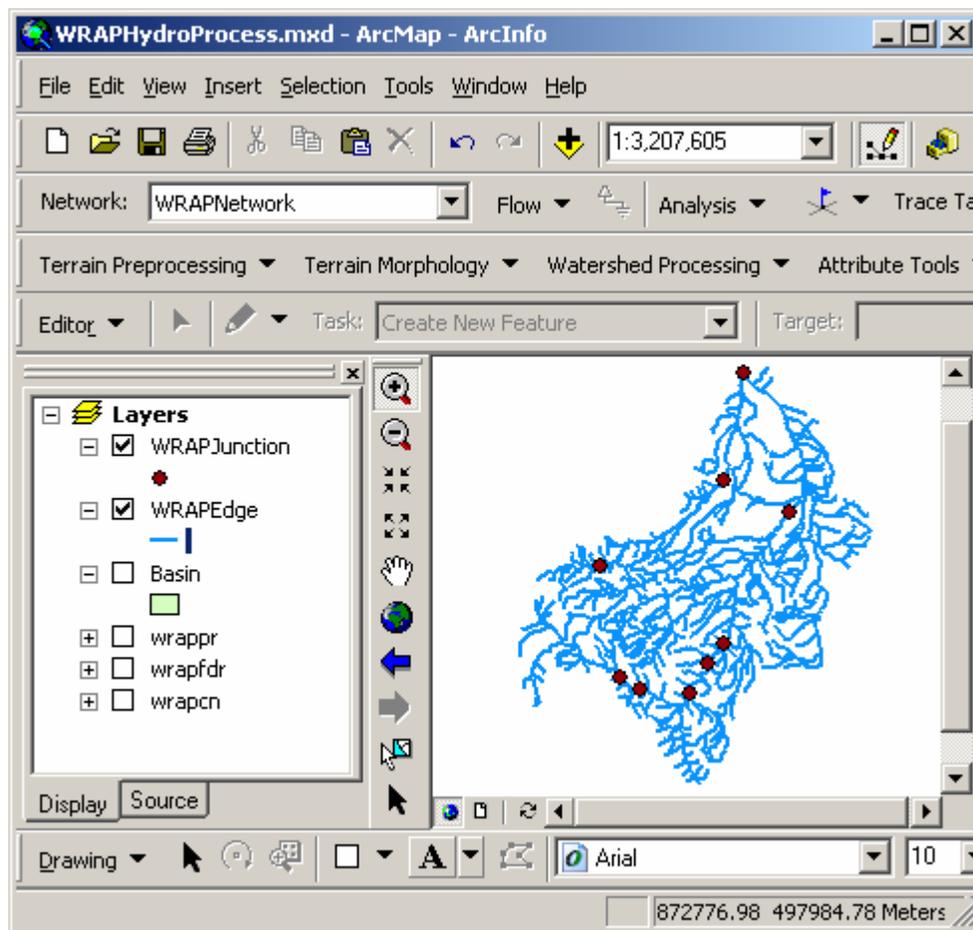
- Open ArcCatalog and create a new geometric network with WRAPJunction and WRAPEdge as a simple edge feature. Accept the defaults for the other network creation options.



- When the geometric network has been created, close ArcCatalog.

19 Make a copy of the WRAPJunction feature class

- Open your ArcMap document and add WRAPEdge and WRAPJunction to the map if necessary.



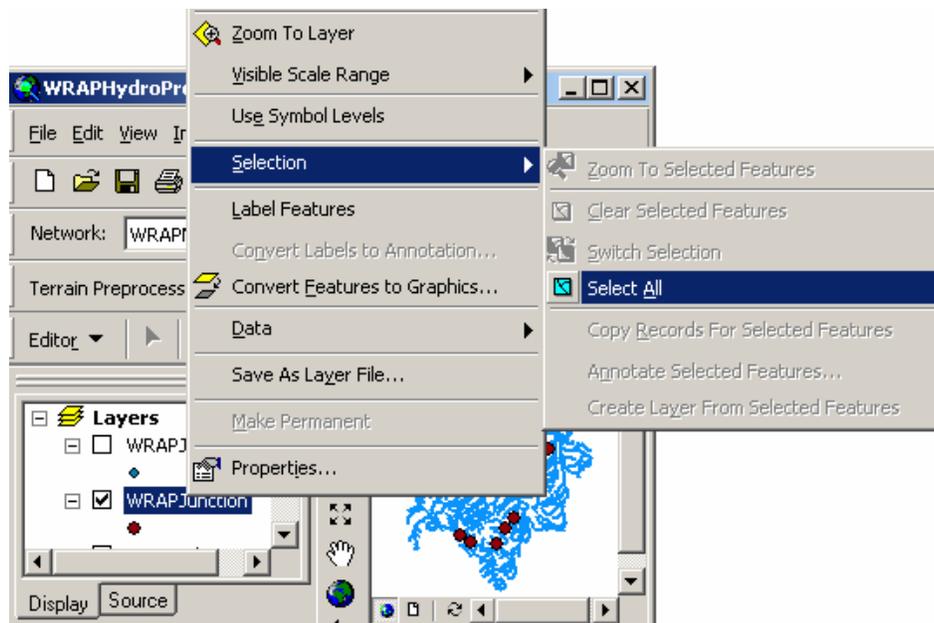
We will use WRAPEdges as the outlet zones for watershed delineation. Each watershed will eventually be related to the downstream WRAPJunction that the WRAPEdge flows to. However, currently some WRAPJunctions lie within the middle of a WRAPEdge. By building the geometric network with simple edges instead of complex edges, the edges will be split when new junction features are loaded into the middle of them. Therefore, we will “reload” the WRAPJunctions, automatically splitting any edges with WRAPJunctions in the middle.

- **Export** all data from the WRAPJunction feature class to a feature class called **WRAPJunction_copy**, in the WRAPHydro feature dataset.

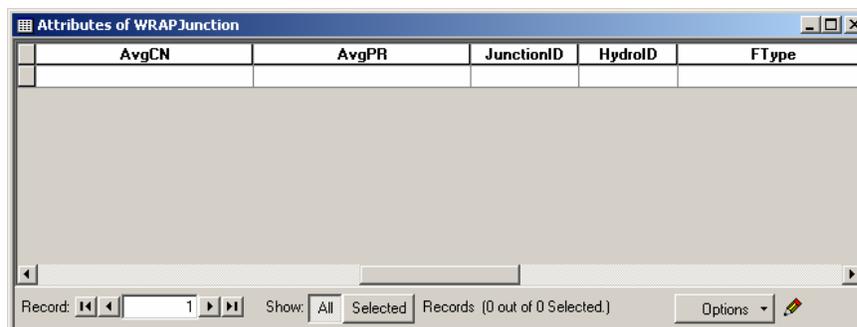
20 Delete WRAPJunction features and load back from ‘copy’

Delete all the features from WRAPJunction and load the features back from the 'copy' file using the Load objects command.

- From the Editor menu, click **Start Editing**.
- **Right click** on the WRAPJunction layer in the ArcMap table of contents, click **Selection**, and then click **Select All**.



- Delete all selected features by pressing the Delete key on the keyboard, or by clicking the Edit menu (next to the File menu) and clicking Delete. All WRAPJunctions will be deleted.

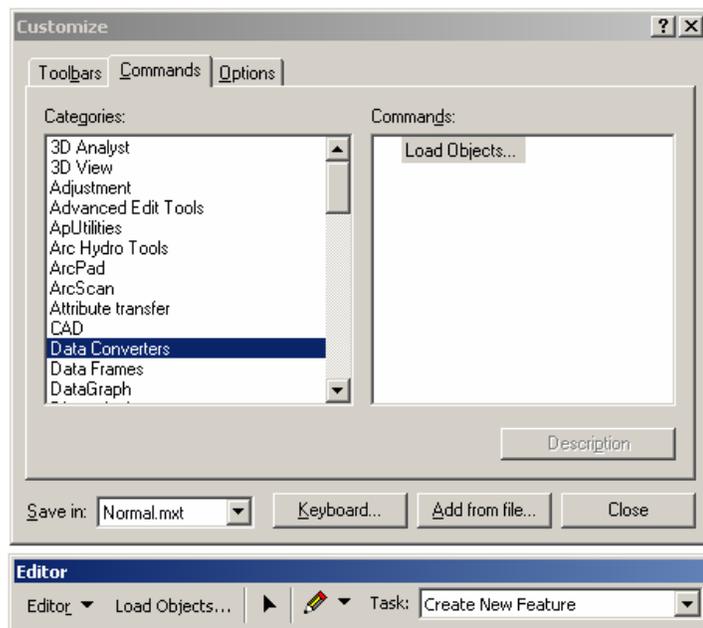


- Make sure the WRAPJunction feature class is the target in the Editor toolbar.

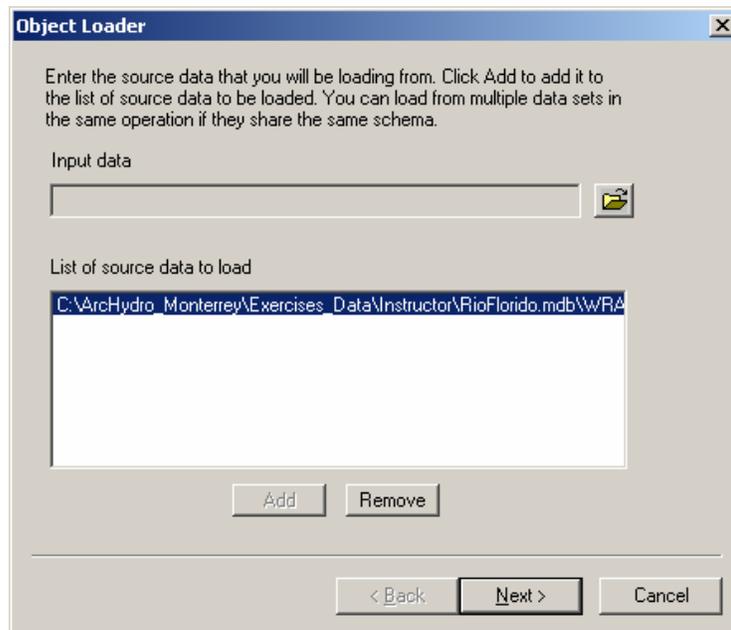


The Load Objects button is a standard ArcGIS tool that is enabled when an edit session is open.

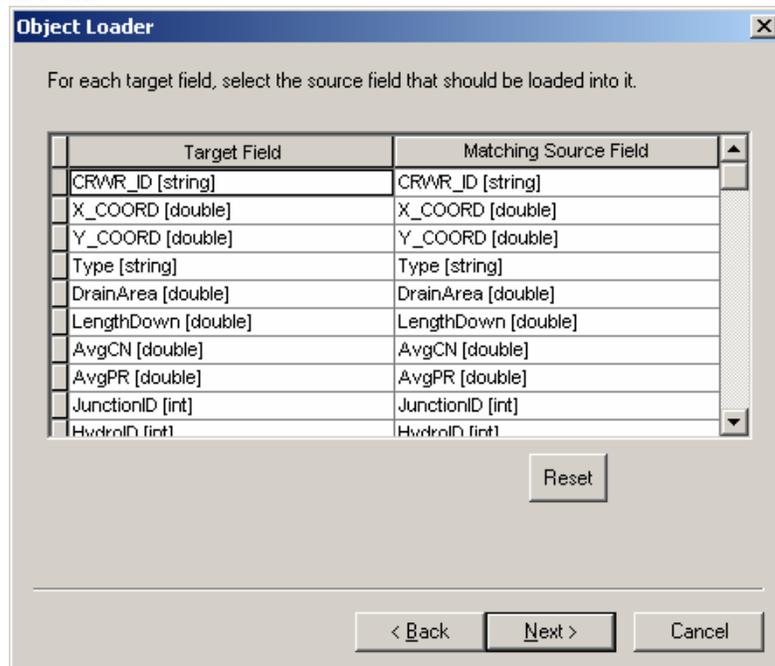
- If necessary, add the Load Objects button to the Editor Toolbar. If the Load Objects button does not appear on the screen, add it to the map by clicking Tools→Customize, then click the Commands tab, click the Data Converters category, and finally drag the Load Objects command onto the Editor Toolbar.



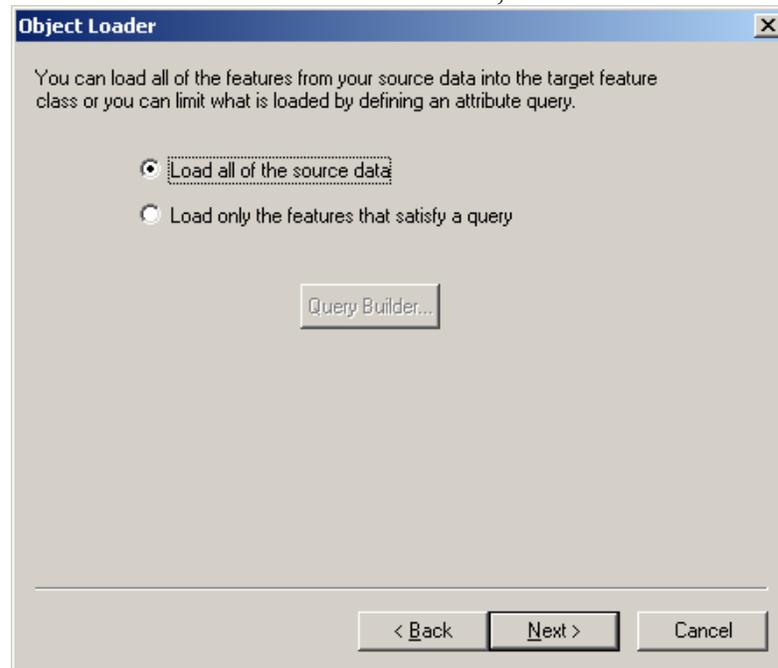
- Click the **Load Objects** button.
- Click the folder  button and then browse to **WRAPJunction_Copy** and click Open.
- Click Add to add this data source.



- Click Next.
- The WRAPJunction and WRAPJunction_copy have the same fields, so click Next.



- Choose to load all of the data source data, then click Next.



- The data do not need to be snapped or validated, so click “Next” and then “Finish” to load the data. Now all junctions should be back!

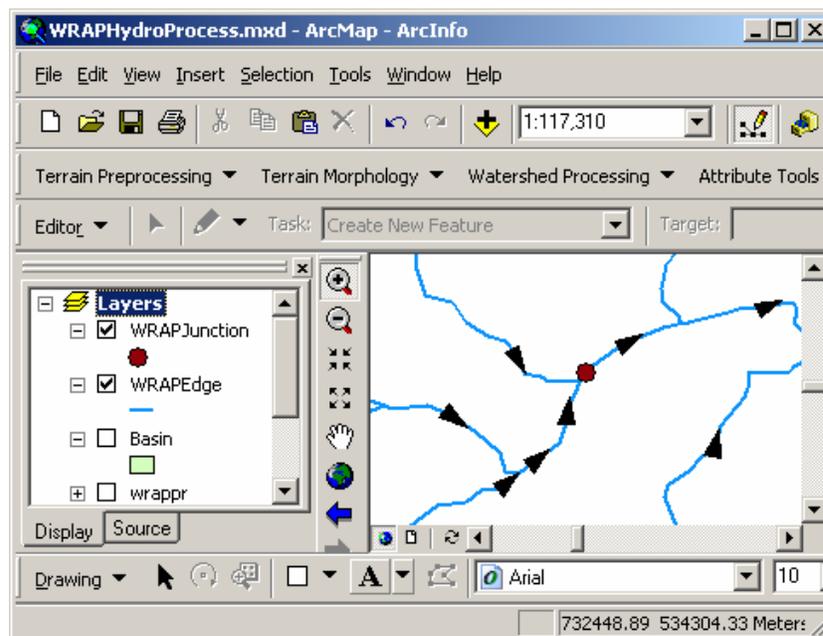
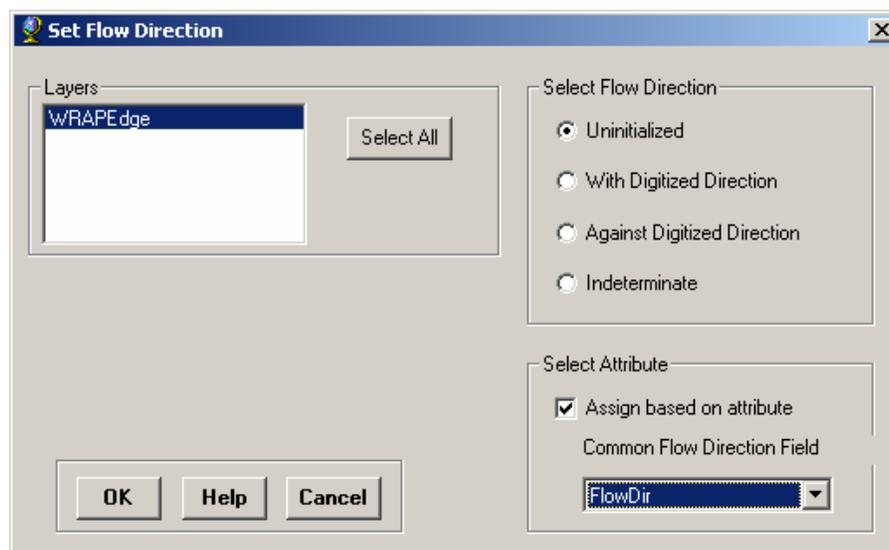
Attributes of WRAPJunction				
OBJECTID*	Shape*	CRWR_ID	X_COORD	Y_COORD
10	Point	1000	<Null>	<Null>
11	Point	FM3000MXP330	-105.72867	
12	Point	FM5000MXP590	-105.32722	
13	Point	FM5000PCP410	-104.91789	
14	Point	24353	-105.194000	2
15	Point	FM5000MXP220	-105.18747	
16	Point	FM5000MXP560	-105.54073	
17	Point	FM5000MXP520	-105.24908	
18	Point	24282	-105.633003	2

Record: 1 Show: All Selected Records (0 out of 9 Selected.) Options

21 Set Flow Directions

After loading the Junctions the flow directions have to be set for the WRAPEdges.

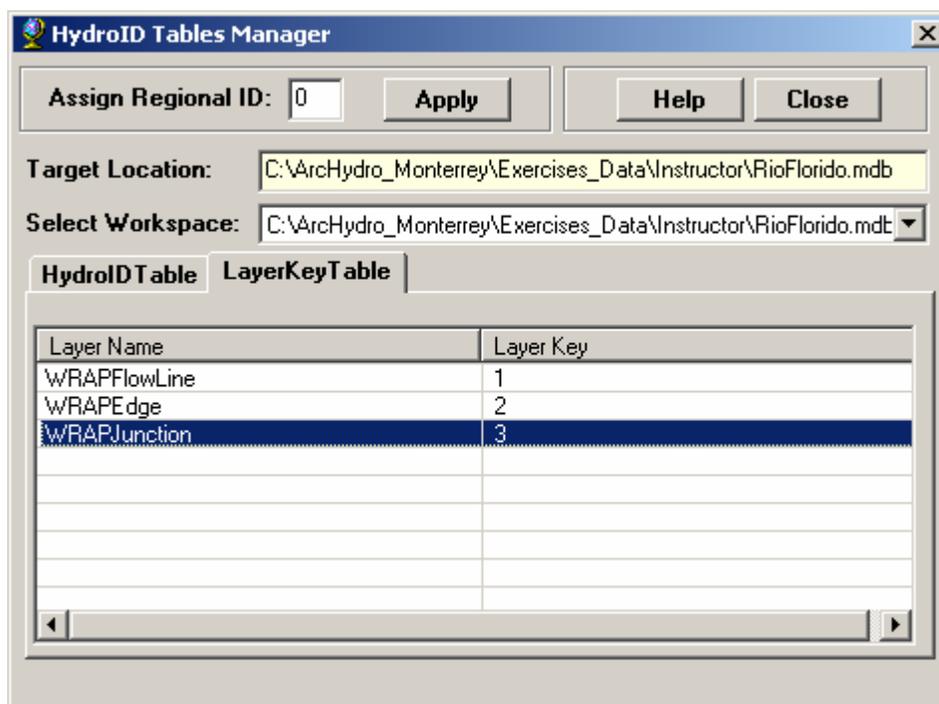
- Use the Set Flow Direction tool from the ArcHydro tools to set flow direction for WRAPEdge based on the FlowDir attribute.



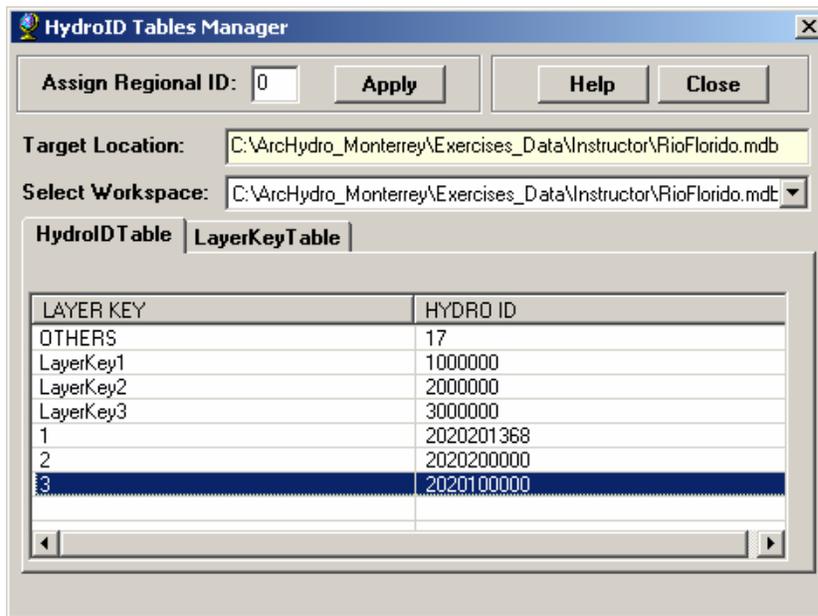
22 Set the HydroIDs for Junctions and Edges

Use HydroID tables manager to set the HydroID values for Junctions and Edges.

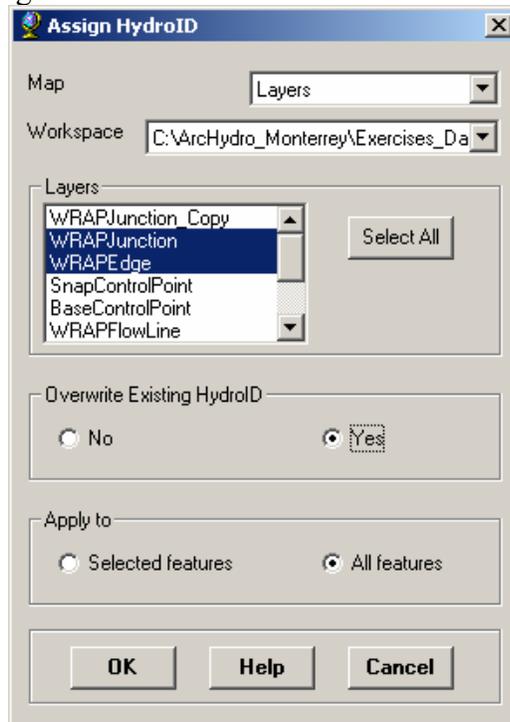
- If necessary, click Editor→Start Editing to start an edit session.
- Open the HydroID Tables manager in the ArcHydro tools.
- Go to the Layer key option and add the WRAPEdge and WRAPJunction feature classes as the layer key numbers 2 and 3, respectively.



- Go to the “HydroID table” button and assign the HydroID for the keys 2 and 3. This HydroID will have 10 digits. The first one corresponds to the country (2 for the Mexican side of the Rio Grande/Bravo basin). The Rio Florido is located in the Rio Conchos basin, identified as the hydrological subregion number 02. The next two digits identify the type of geographic element. Number 01 will be assigned for the junctions (WRAPJunctions), while number 02 is assigned for the edges (WRAPEdge). The last five digits will describe the feature number.



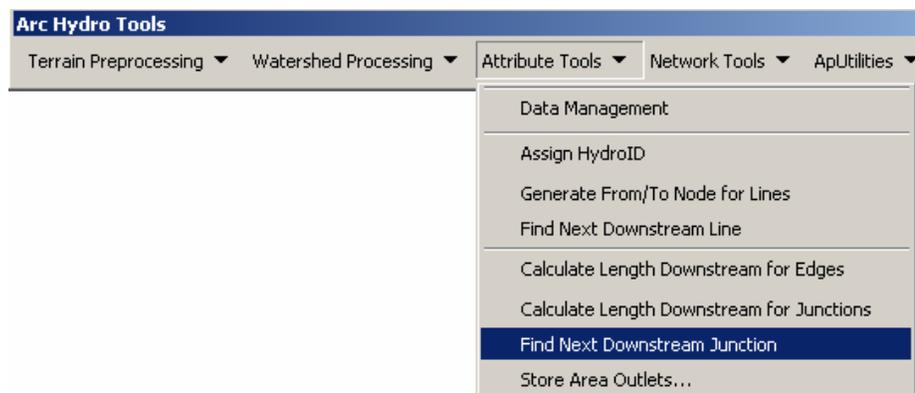
- Click **Assign HydroID** from the Attribute Tools menu in the ArcHydro tools.
- Overwrite existing HydroIDs and apply it to all features in WRAPJunction and WRAPEdge.



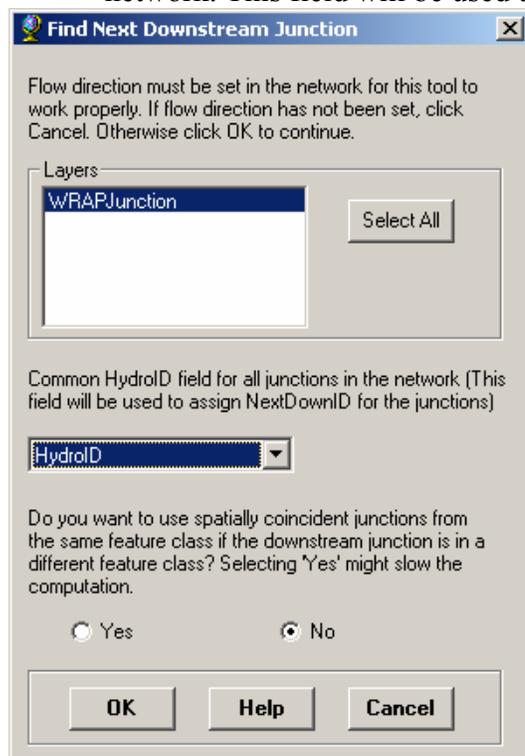
23 Determine NextDownID

Determine the Next Downstream ID for every WRAPJunction

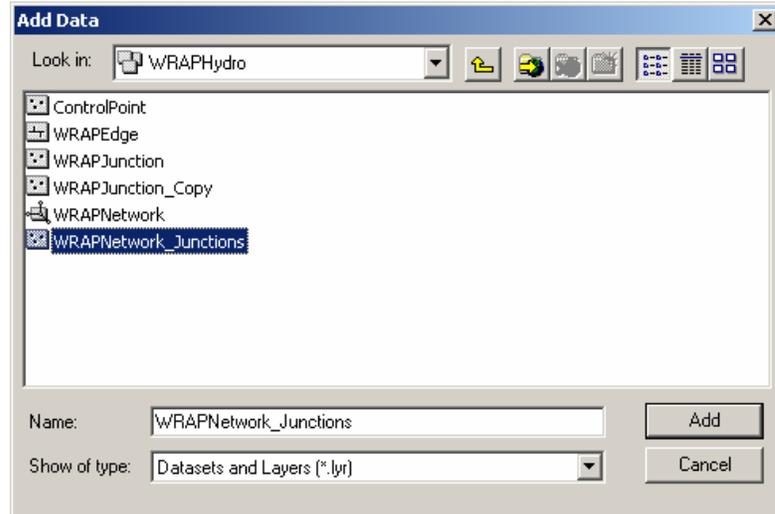
- In the Attribute Tools menu of the ArcHydro tools, click Find Next Downstream Junction.



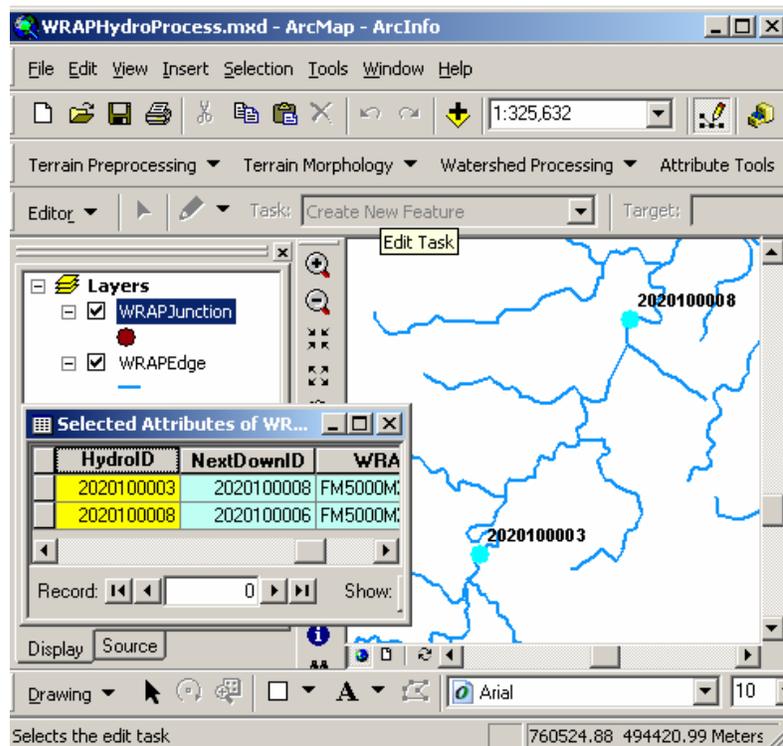
- Select WRAPJunction as the HydroJunction input and click OK. The HydroID identifier is used as the common field for all junctions in the network. This field will be used to assign NextDownID for the junctions.



- If the HydroID option does not appear as the common field, add the “WRAPNetwork_Junctions” element from the WRAPHydro Feature dataset



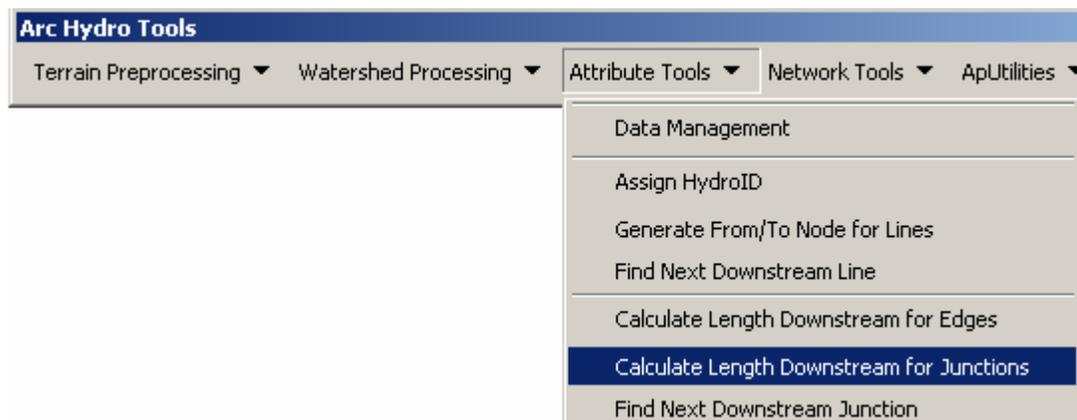
- Assign the HydroIDs for the “WRAPNetwork_Junctions” feature class. Do not worry about the regional HydroIDs for this step.
- Remove the WRAPNetwork_Junctions feature class from your document, and try again to calculate the NextDownID for the WRAPJunctions.
- The NextDownID field of the WRAPJunction attribute table has been populated. This value points to the HydroID of the NextDownID in the stream network.



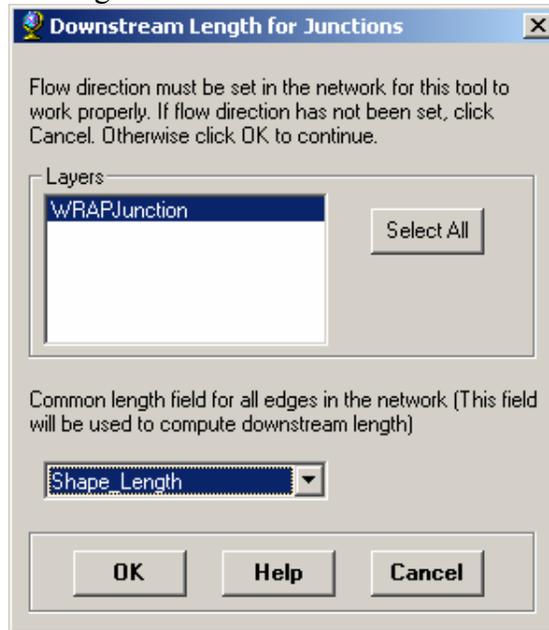
24 Calculate LengthDown

Calculate the Length to Outlet of every WRAPJunction.

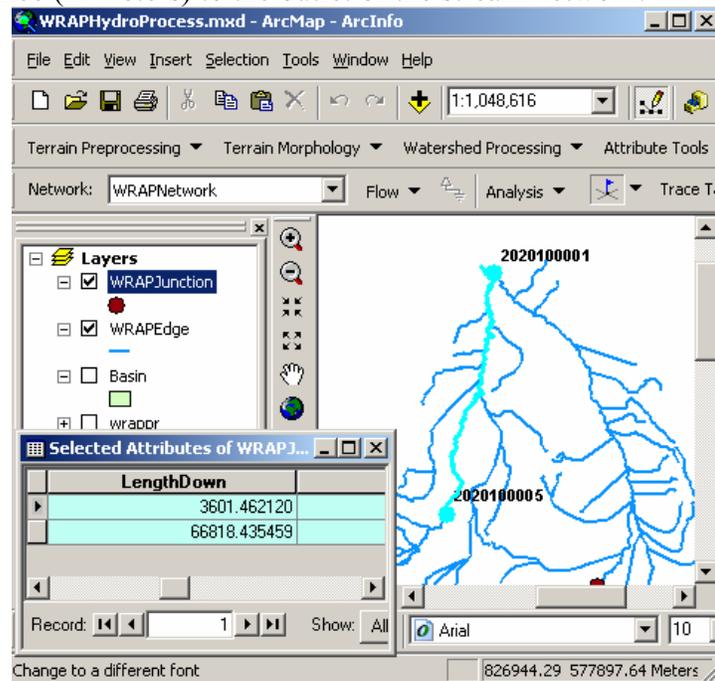
- In the Attribute Tools of the ArcHydro toolset, click **Calculate Length Downstream for Junctions**.



- Choose WRAPJunction as the HydroJunction. Select the Shape_Length field for WRAPEdge and click OK.



- The LengthDown field of the WRAPJunction has been populated with the distance (in meters) to the outlet of the stream network.



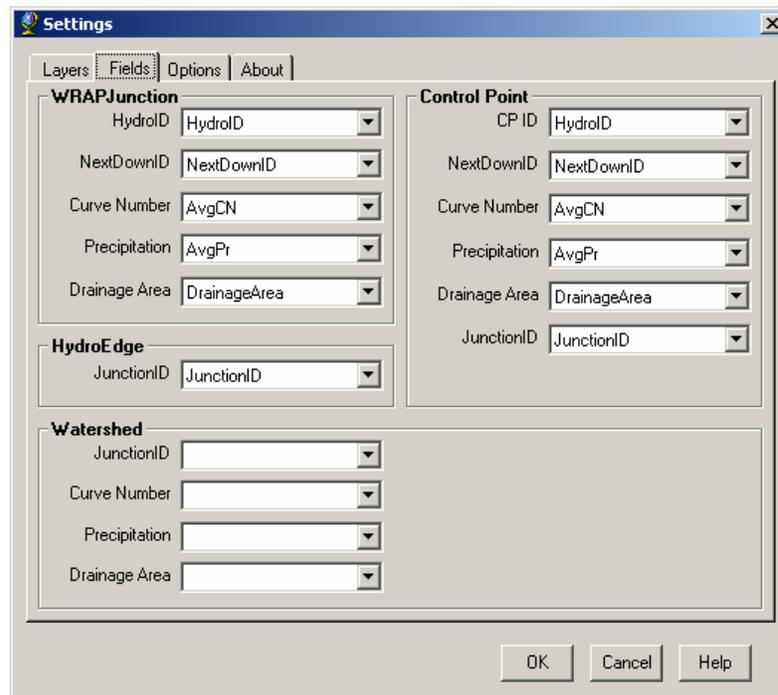
25 Assign JunctionIDs

Assign JunctionIDs to WRAPeEdge.

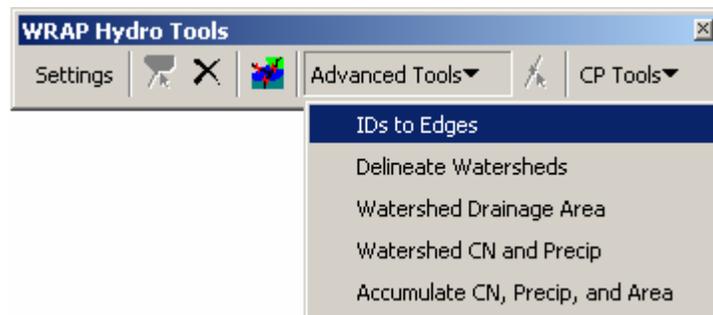
- Click **Settings** on the WRAPHydro Tools toolbar to display the Settings form.
- In the **Layers** tab, select WRAPJunction as the WRAPJunction layer, WRAPeEdge as the HydroEdge layer, and SnapControlPoint as the ControlPoint layer.



- In the **Fields** tab, for the **WRAPJunction** layer, select HydroID, NextDownID, AvgCN, AvgPr, and DrainageArea as the HydroID, NextDownID, Curve Number, Precipitation, and Drainage Area fields, respectively.
- For the Control Point fields, select HydroID as the CP ID field, and JunctionID as the JunctionID field. For the remaining fields, use the same names as for the WRAPJunction layer.
- For the HydroEdge layer, select JunctionID as the JunctionID field. Click OK to close the Settings form.

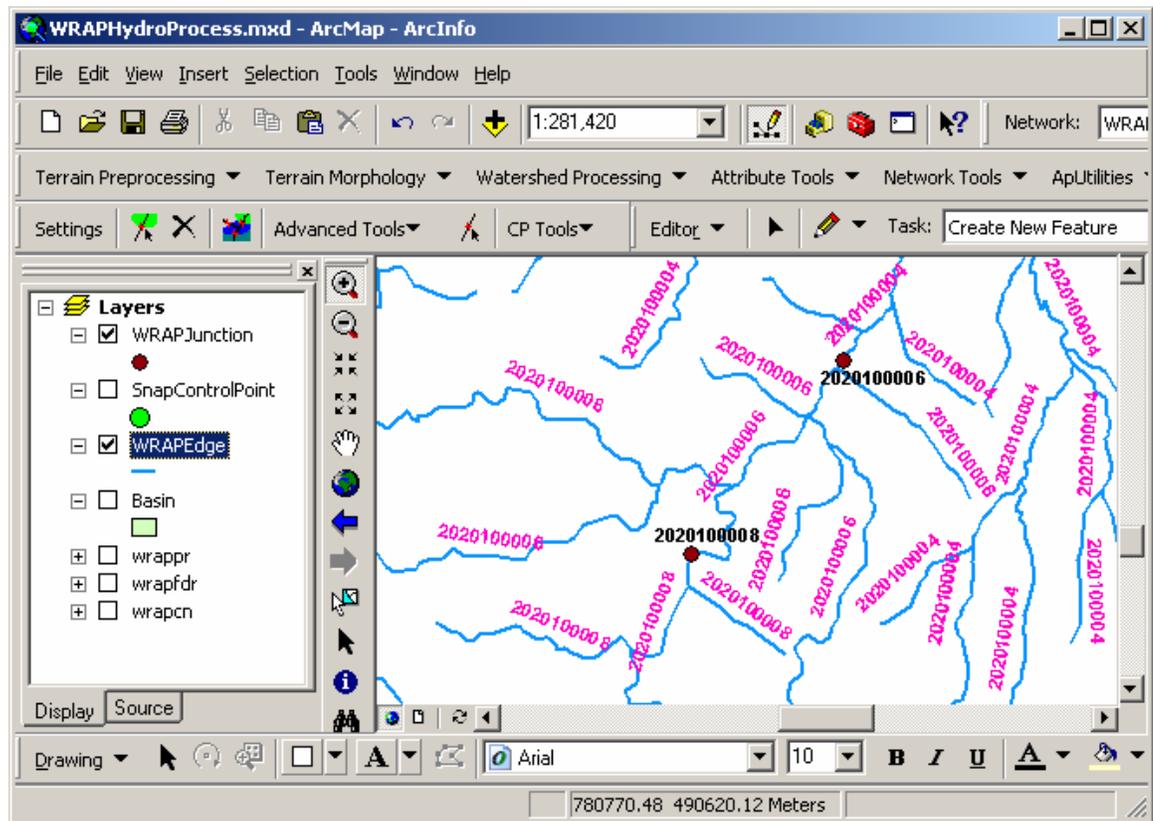


- Make sure no features are selected.
- In the Advanced Tools menu of the WRAPHydro tools, click IDs to Edges.



- Click OK when given the reminder that flow direction must be set.
- Click **Yes** to assign IDs for all features.

All the Edges between two junctions now have the same JunctionID (which is the HydroID of the downstream junction).



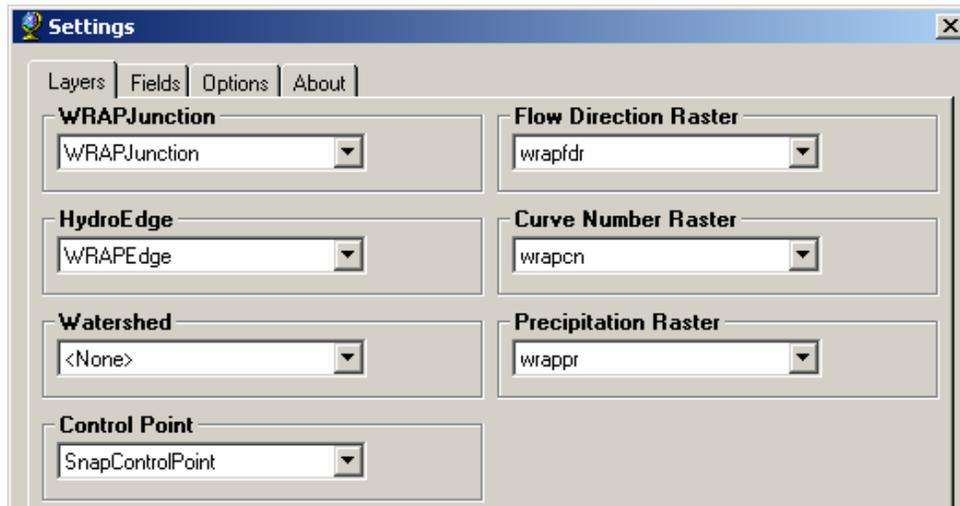
26 Delineate the upstream area for each WRAPJunction

Delineate the upstream area for each WRAPJunction using WRAPEdge and WRAPfdr.

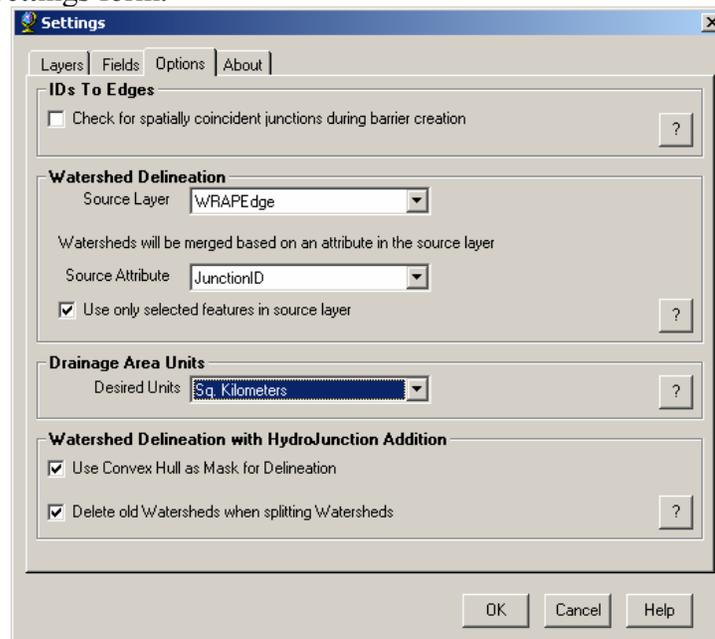
Once all the JunctionIDs are populated, the Delineate Watersheds tool in the WRAPHydro toolset is used to delineate watersheds for each junction. The watersheds are delineated using the WRAPFdr flow direction grid and the WRAPEdges as the outlet zones. The output is called WRAPWatershed. For each value 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 drains to. Thus, each WRAPWatershed is already attributed with the HydroID of its outlet junction.

- Open the Settings form for the WRAPHydro Tools.

- Select wrapfdr as the Flow Direction Raster, wrapcn as the Curve Number Raster, and wrappr as the Precipitation Raster.



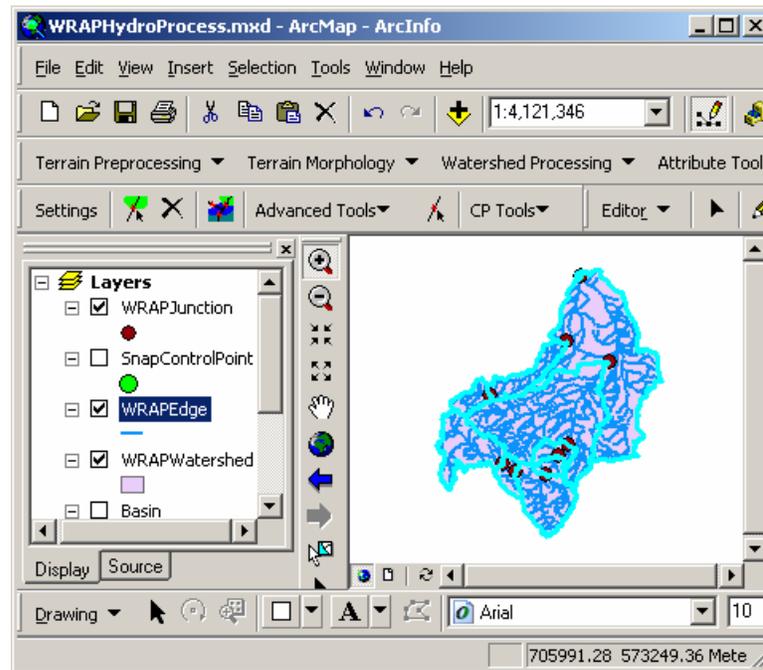
- Click the **Options** tab.
- In the Watershed Delineation section, select WRAPEdge as the Source Layer and JunctionID as the Source Attribute. Select Square Kilometers as the desired units in the “Drainage Area Units” option. Click OK to close the Settings form.



- In the Advanced tools of the WRAPHydro toolset, click **Delineate Watersheds**.
- Save the output watersheds as WRAPWatershed in the WRAPHydro feature dataset.



One WRAPWatershed has now been delineated for each WRAPJunction.



27 Calculate the Area, CN and Precip for each WRAPWatershed

Calculate the Watershed Drain Area, Average Curve Number and Average precipitation for each WRAPWatershed

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.

- Open the Settings form of the WRAPHydro tools.
- Make sure that WRAPWatershed appears as the Watershed layer, and that all of the fields for Watershed have been filled in.

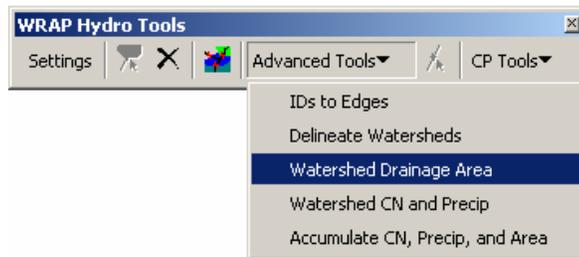
The screenshot shows the 'Settings' dialog box with the following configuration:

- WRAPJunction:** HydrolD (HydrolD), NextDownID (NextDownID), Curve Number (AvgCN), Precipitation (AvgPR), Drainage Area (DrainArea)
- Control Point:** CP ID (HydrolD), NextDownID (NextDownID), Curve Number (AvgCN), Precipitation (AvgPR), Drainage Area (DrainArea), JunctionID (JunctionID)
- HydroEdge:** JunctionID (JunctionID)
- Watershed:** JunctionID (JunctionID), Curve Number (AvgCN), Precipitation (AvgPr), Drainage Area (DrainArea)

- Click the **Options** tab in the Settings form. Verify that the desired **Drainage Area Units** are in square kilometers. Click OK to close the Settings form.

The close-up shows the 'Drainage Area Units' section with a dropdown menu set to 'Sq. Kilometers'.

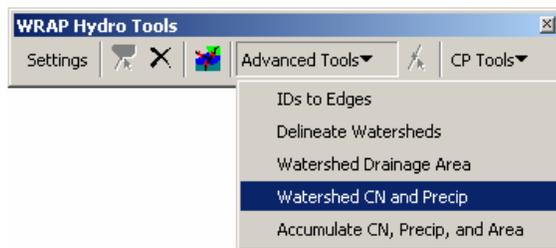
- In the Advanced tools in the WRAPHydro toolset, click **Watershed Drainage Area** to calculate the drainage area for each WRAPWatershed.



The DrainArea field of the WRAPWatershed feature class has been populated.

AvgCN	AvgPr	DrainArea
<Null>	<Null>	12.791709
<Null>	<Null>	212.649301
<Null>	<Null>	306.083727
<Null>	<Null>	329.256008
<Null>	<Null>	364.089612
<Null>	<Null>	721.594789
<Null>	<Null>	1256.253281
<Null>	<Null>	1270.425600
<Null>	<Null>	4095.554110

- In the Advanced tools in the WRAPHydro toolset, click **Watershed CN and Precip**.



The AvgCN and AvgPR fields of the WRAPWatershed feature class have been populated.

AvgCN	AvgPr	DrainArea
81.993172	23.150145	12.791709
78.019157	25.293777	212.649301
78.010201	22.838732	306.083727
79.361534	25.941017	329.256008
90.824608	24.009254	364.089612
89.626694	26.383791	721.594789
78.000206	26.589668	1256.253281
83.222580	21.903437	1270.425600
83.586075	25.923716	1095.554110

28 Consolidate Area, Curve Number, and Precip for each WRAPJunction

Consolidate the Watershed Drain Area, Average Curve Number, and Average Precipitation for each WRAPJunction

- Copy the DrainID values to the JunctionID field in the WRAPWatershed feature class using the field calculator.

DrainID	NextDownID	JunctionID	AvgCN	AvgP
0	<Null>	0	81.993172	
2020100008	<Null>	2020100008	78.019157	
2020100007	<Null>	2020100007	78.010201	
2020100006	<Null>	2020100006	79.361534	
2020100002	<Null>	2020100002	90.824608	
2020100005	<Null>	2020100005	89.626694	
2020100003	<Null>	2020100003	78.000206	
2020100009	<Null>	2020100009	83.222580	
2020100004	<Null>	2020100004	83.586075	

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.

- In the Advanced tools of the WRAPHydro toolset, click **Accumulate CN, Precip and Area**.



A message will appear listing which parameters were successfully calculated when the tool finishes.



The drain area values were added downstream and were stored in the DrainArea field in the WRAPJunction. The curve number and precipitation values were populated in the AvgCN and AvgPR fields in the WRAPJunction by taking a weighted average of the respective values over each watershed.

The image shows a table window titled "Attributes of WRAPJunction". The table has three columns: "AvgCN", "AvgPR", and "DrainArea". There are 9 rows of data. At the bottom, there is a "Record:" field with a value of "0" and a "Show:" dropdown menu set to "All". The status bar indicates "Records (0 out of 9 Selected.)".

AvgCN	AvgPR	DrainArea
81.990729	26.482725	13539.307532
90.824608	24.009254	364.089612
80.343394	24.082713	2832.762608
82.011758	25.208425	7470.222327
90.028420	25.587478	1085.684401
80.101139	24.340335	3374.667917
82.210582	22.085027	1576.509327
80.181102	24.167277	3045.411909

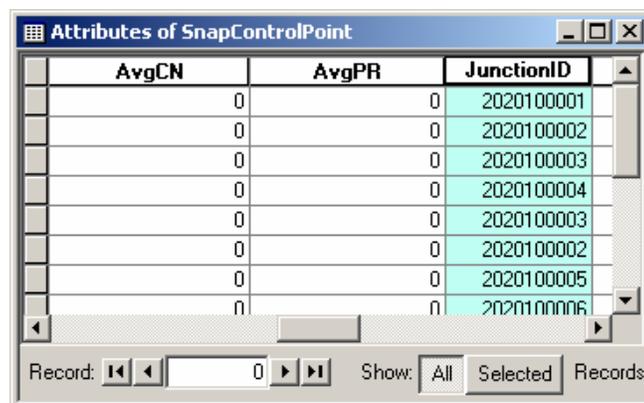
29 Assign JunctionID to SnapControlPoint.

The last step in parameter development is to copy the attributes from WRAPJunction to all the points including the coincident ones in the ControlPoint feature class.

- Open the Settings form of the WRAPHydro tools. Verify that SnapControlPoint is specified as the Control Point layer, and that all fields have been filled in for SnapControlPoint and WRAPJunction.
- In the CP Tools menu of the WRAPHydro tools, click IDs to Control Points.



Each SnapControlPoint now is attributed with the HydroID of the WRAPJunction that lies directly underneath it.

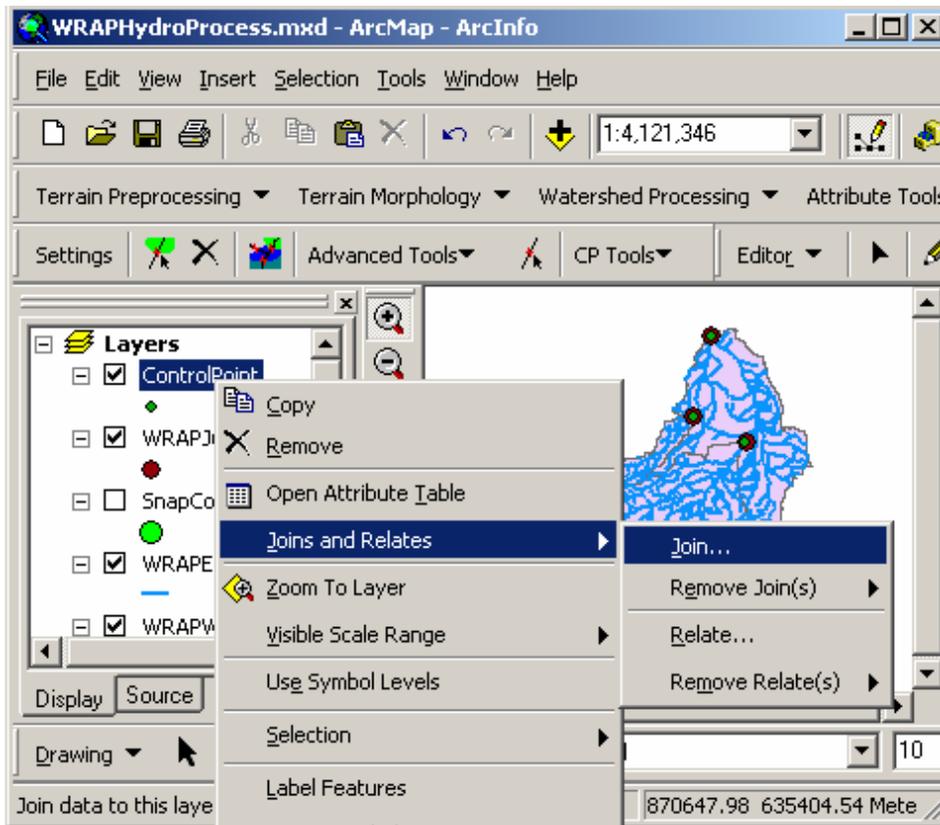


AvgCN	AvgPR	JunctionID
0	0	2020100001
0	0	2020100002
0	0	2020100003
0	0	2020100004
0	0	2020100003
0	0	2020100002
0	0	2020100005
0	0	2020100006

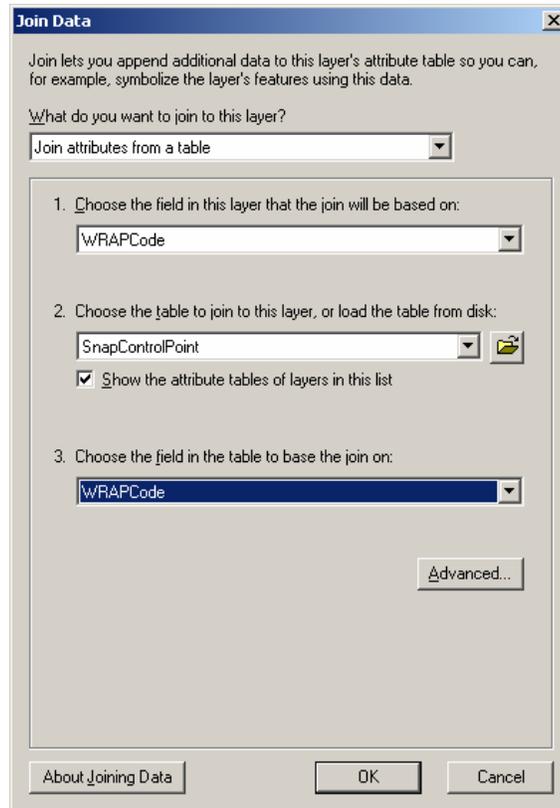
Ultimately, the features in the ControlPoint need to be associated with WRAPJunctions. The SnapControlPoint from the previous step is used because it is easier to locate the correct WRAPJunction from features that are spatially coincident with them. Next, we assign JunctionID values to the corresponding ControlPoints, which are not necessarily spatially coincident with WRAPJunctions.

Each SnapControlPoint and ControlPoint is attributed with a value called WRAPCode. This value is the same for corresponding features between the two features classes.

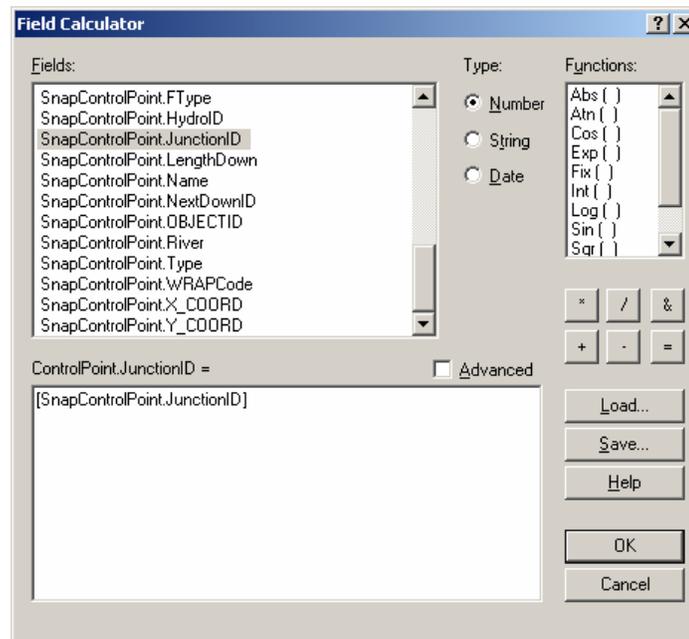
- Right click on the ControlPoint feature layer and create a new join with the SnapControlPoint layer.



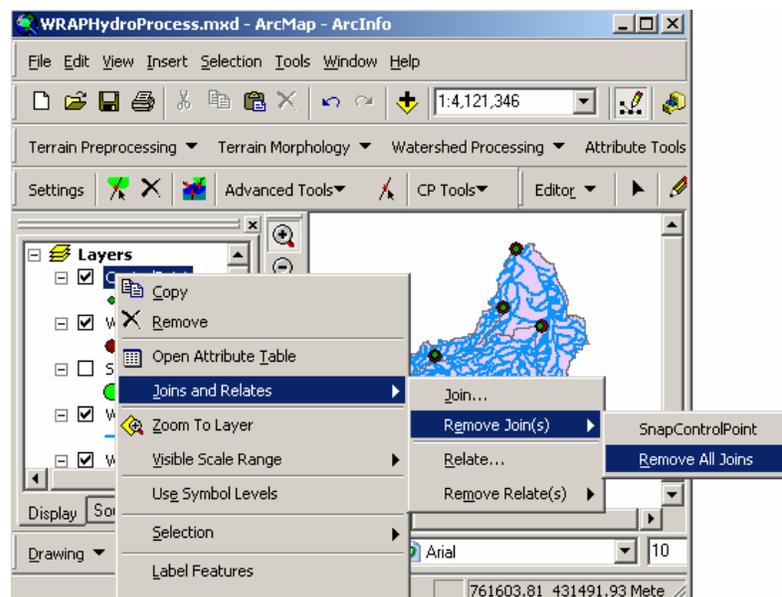
- Use WRAPCode as the common attribute between both layers.



- Once the join has been created, open the ControlPoint attribute table.
- Copy the JunctionID values from the SnapControlPoint feature class to ControlPoint using the field calculator.



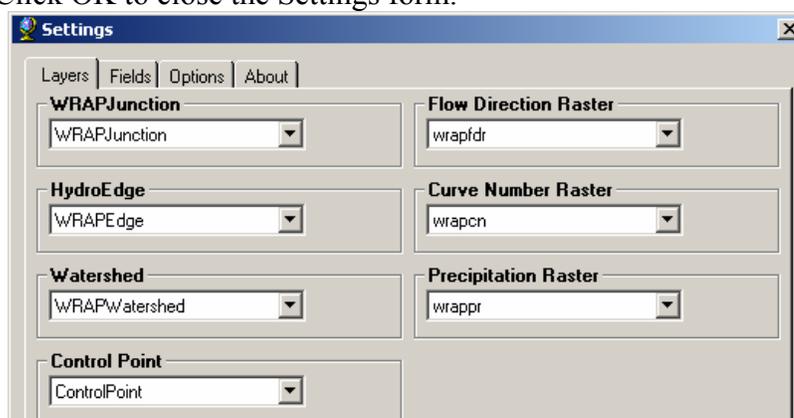
- Remove the join by right clicking on the ControlPoint layer, clicking Joins and Relates, Remove Join(s), and finally Remove All Joins.



30 Copy parameters from WRAPJunction to ControlPoint.

There now exists a one to many relationships 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 Drain_Area, AvgCN and AvgPR values are copied to ControlPoint.

- Update the Settings form of the WRAPHydro tools so that the Control Point layer is now set as ControlPoint (instead of SnapControlPoint). Verify that all fields for Control have been filled in by clicking the Fields tab. Click OK to close the Settings form.

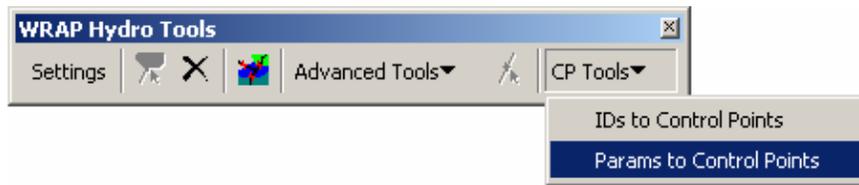


One of the parameters required by WRAP is the NextDownID for Control Points. Before the WRAPHydro tools can calculate this value, we must assign HydroIDs to ControlPoints in case they do not exist yet.

- Use the ArcHydro tools to assign HydroIDs to the ControlPoint feature class. Overwrite any existing IDs.

Note that own ID can be used, instead of HydroID, as the ControlPoint identifier. To do so, simply change the HydroID field (and perhaps the NextDownID field) for the Control Point layer in the Settings form of the WRAPHydro tools.

- In the CP Tools of the WRAPHydro toolset, click **Params to Control Points**.



Finally the Control Point feature class parameters have been populated!!!

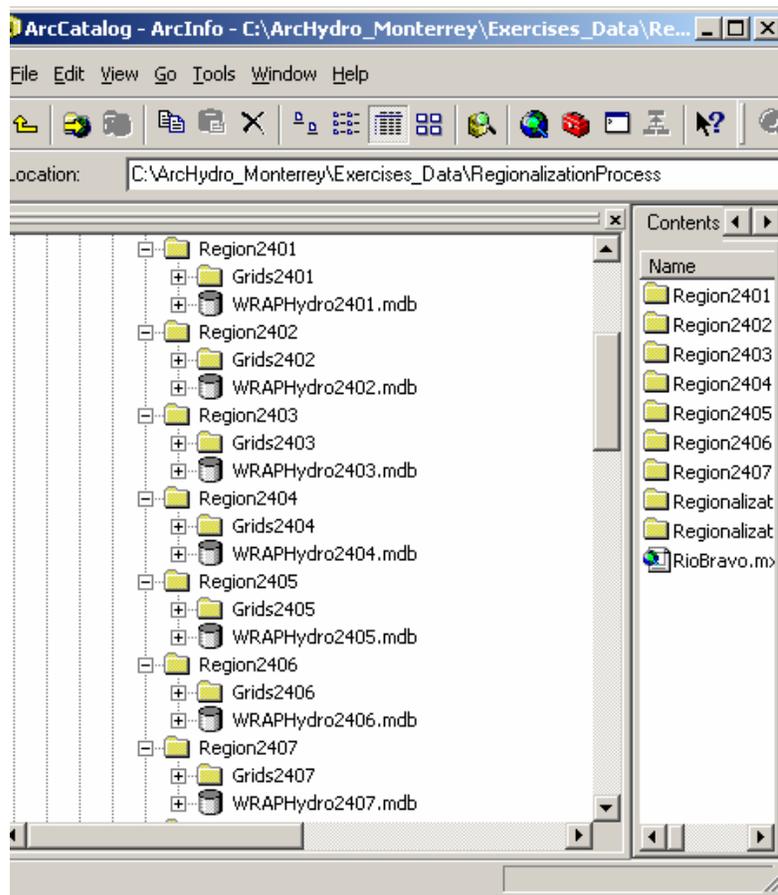
The image shows the ArcMap interface with the 'WRAPHydroProcess.mxd' map. The 'Layers' panel shows 'ControlPoint' and 'WRAPJunction' layers. The 'Attributes of ControlPoint' table is displayed below the map, showing a table with columns: DrainArea, AvgCN, AvgPR, JunctionID, HydroID, and NextDownID. The table contains several rows of data, with the first row highlighted in light blue.

DrainArea	AvgCN	AvgPR	JunctionID	HydroID	NextDownID
13539.307532	81.990729	26.482725	2020100001	2020100026	-1
7470.222327	82.011758	25.208425	2020100004	2020100002	2020100026
7470.222327	82.011758	25.208425	2020100004	2020100015	2020100026
3374.667917	80.101139	24.340335	2020100006	2020100037	2020100002

Record: 0 Show: All Selected Records: (1 out of 14 Selected.) Options

Appendix D: Regionalization process in Rio Grande/Bravo basin

The regionalization technique allows a large region to be divided into hydrologically distinct subregions where raster analyses may be performed in a feasible manner. In the previous exercise, you calculated WRAP parameters for the Rio Florido basin, a subbasin of the Rio Conchos basin. In this exercise, you will combine the results from raster processing of the other Rio Grande/Bravo subbasins and calculate WRAP parameters for the entire Rio Grande/Bravo basin. Because the WRAP Process has been already completed for a subregion (in the previous exercise), it is required to repeat that effort for the other six Rio Grande/Bravo subbasins. The required raster and vector processing, up through the point where WRAPWatersheds have been attributed with WRAP parameters, have been already completed for this exercise. The Rio Grande/Bravo basin folder, as shown below, has these data organized into separate folders for each region, with a single WRAPHydro geodatabase in the Rio Grande/Bravo basin folder itself.



PROCEDURE FOR REGIONALIZATION:

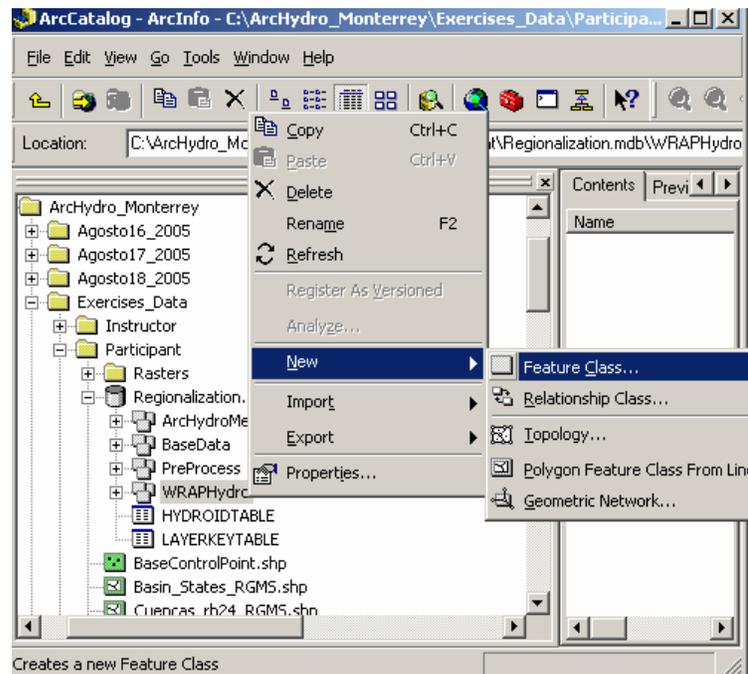
(The following steps, steps 1 through 5, have been completed before for applying the regionalization process.)

1. **Grids for each hydrologic subregion are processed separately with a 10 Km buffer as already done for the Rio Florido subbasin.**
2. **Basin boundary is created and preprocessing is done for each subregion similar to previous method.**
3. **An outlet is placed at the most downstream location of each subregion.**
4. **WRAPWatersheds draining to each WRAPJunction are delineated for each subregion.**
5. **Parameters are calculated for each WRAPWatershed.**

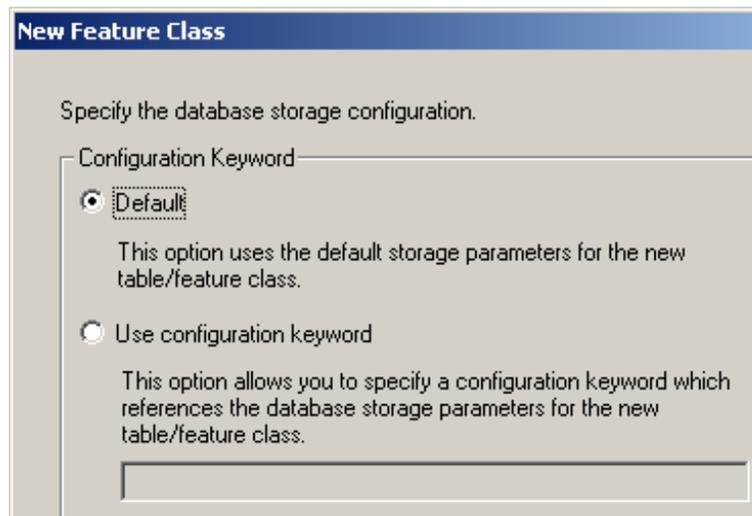
With parameters calculated for each WRAPWatershed, it is possible now to merge the vector data and accumulate the parameters throughout the entire stream network.

All data necessary for this exercise is located in the folder ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_Data/RegionalizationProcess/.

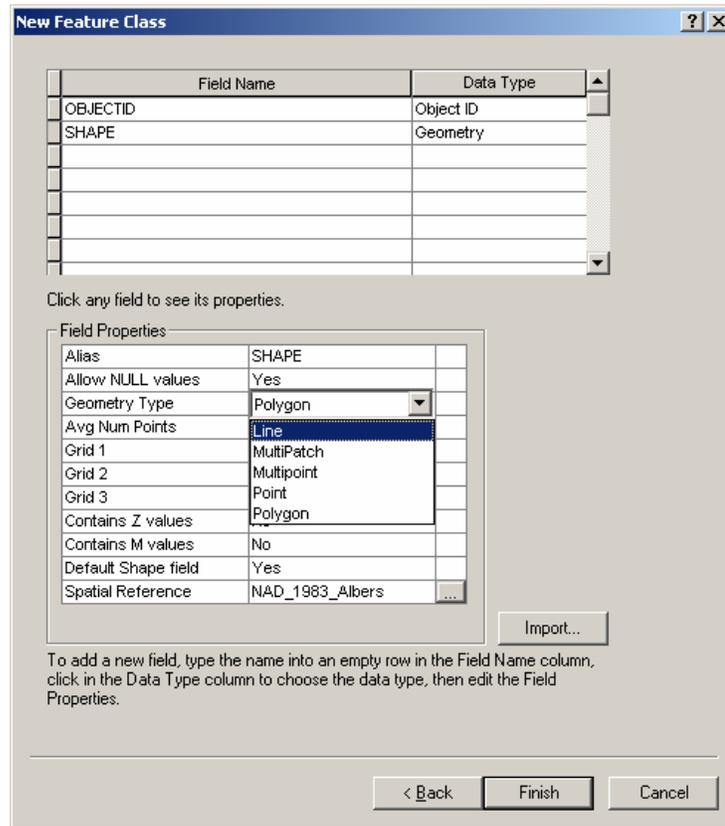
6. **WRAPEdges, WRAPJunctions, ControlPoints and WRAPWatersheds of all the regions are merged and exported to the WRAPHydro geodatabase.**
 - Create a new empty feature class in the Regionalization geodatabase, inside the WRAPHydro feature dataset.
 - Open ArcCatalog and right click on the WRAPHydro feature dataset. Select New → Feature Class and named it WRAPEdge.



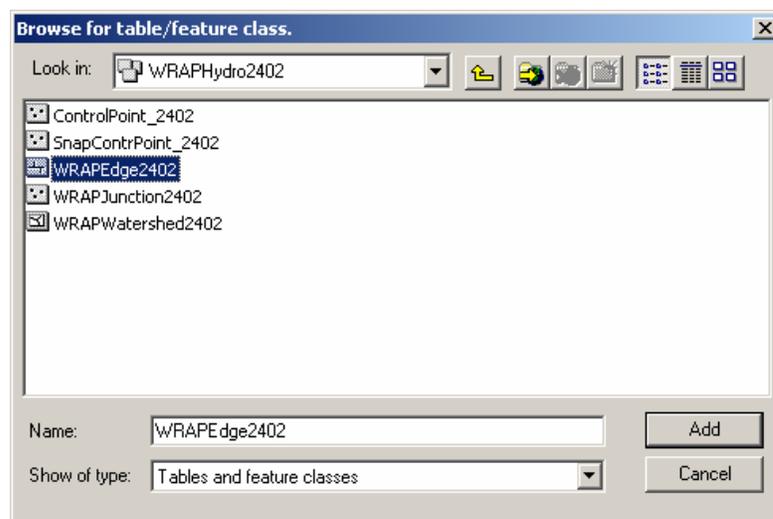
- Choose the option to use the default storage parameters for the new table/feature class. Click Next.



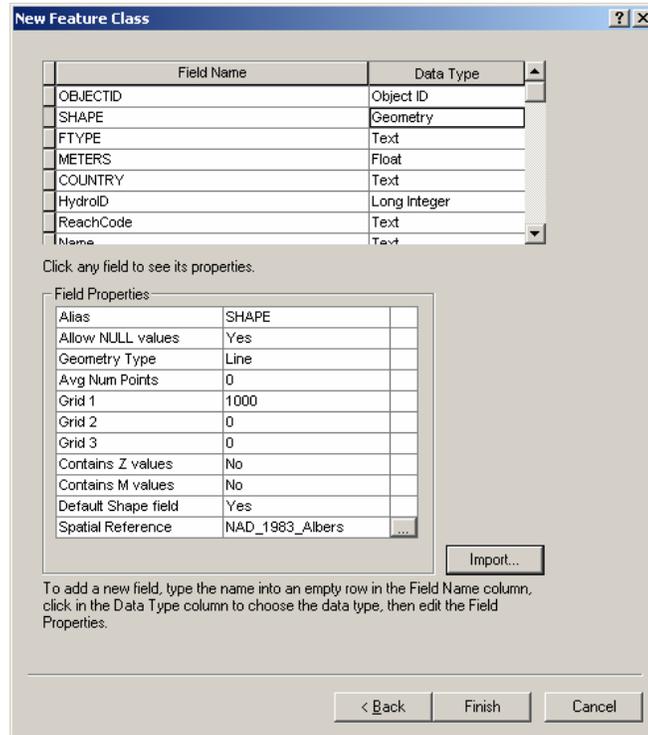
- Go to the geometry properties and select it as a Line instead of a Polygon



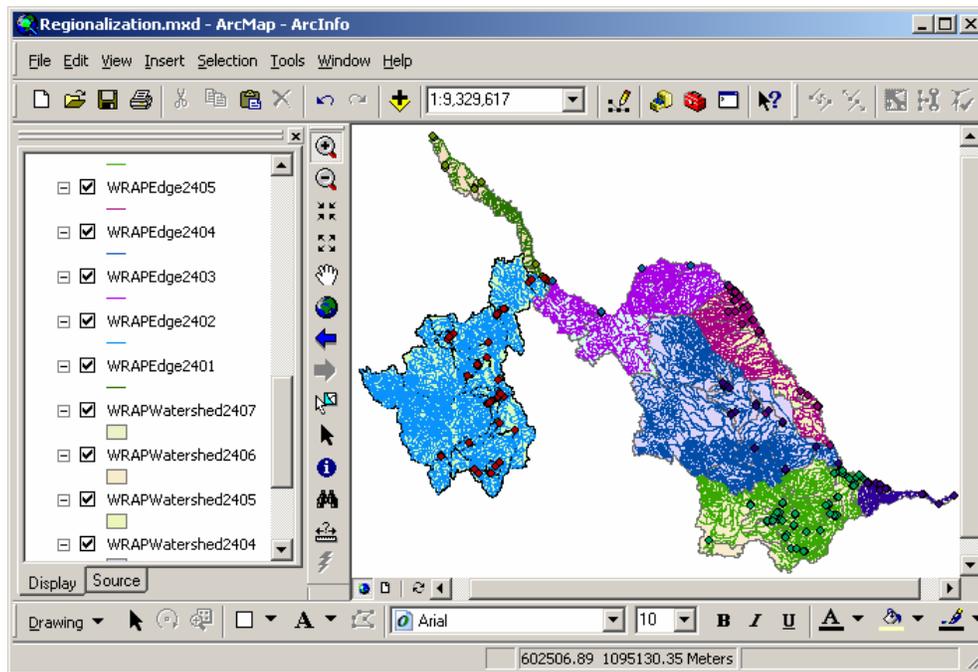
- Import the attribute fields from any WRAPEdge of the hydrologic sub regions.



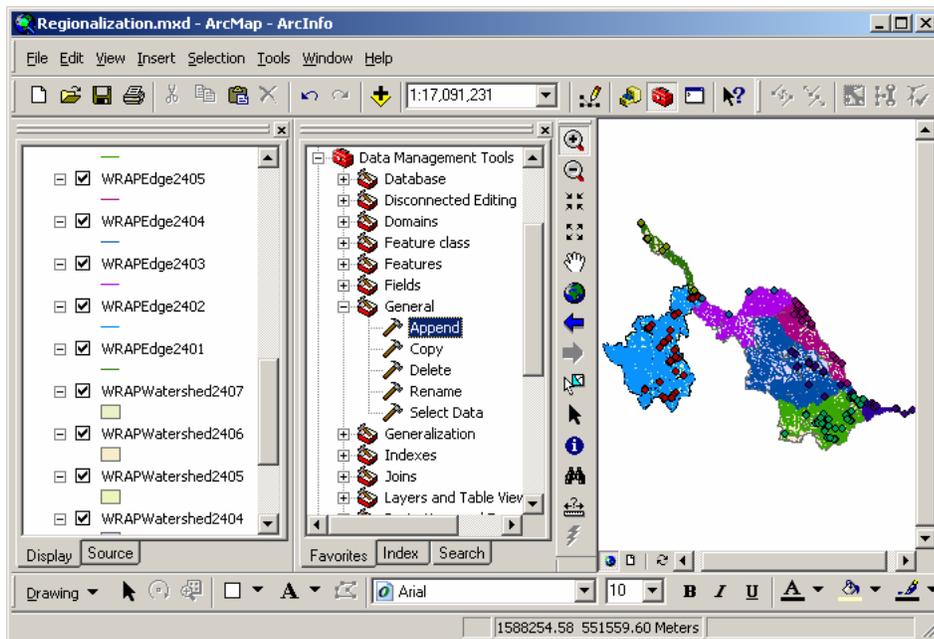
- Click on the “Finish” button to complete the process



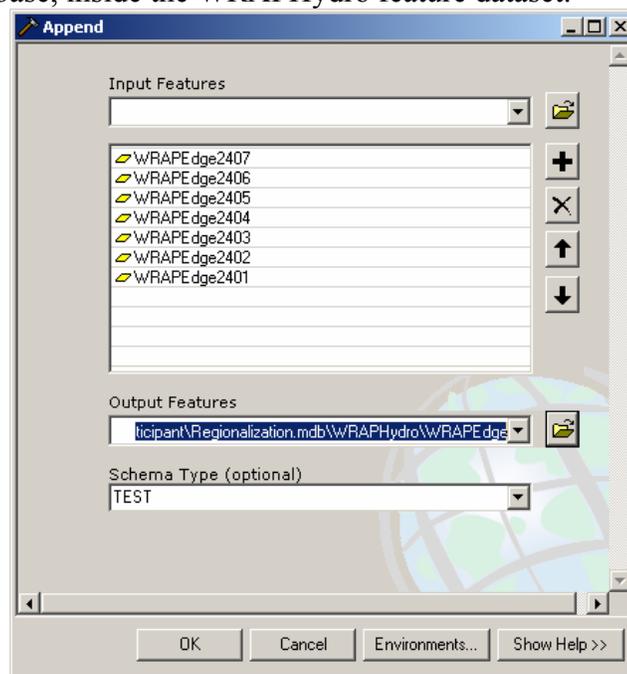
- Apply the same procedure to create an empty feature class in the WRAPHydro feature dataset for the WRAPJunction and ControlPoint features as a point and the WRAPWatershed feature as a polygon.
- Open ArcMap and add all WRAPEdges, WRAPJunctions, ControlPoints and WRAPWatersheds for each sub region. Save your document as “**Regionalization.mxd**”



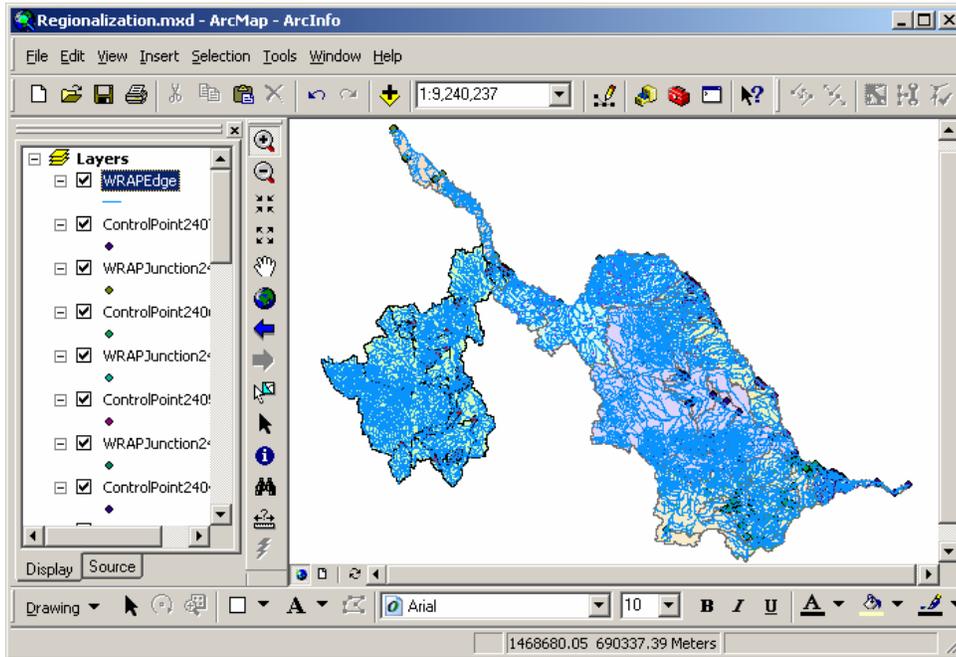
- Merge all WRAPEdges into one by using the “Append” tool included in the Data Management Tools of the Arc Toolbox application as shown below. This function appends multiple input features to a target feature class. [Hint: All the same feature classes must have the same attribute fields, otherwise an error will appear]



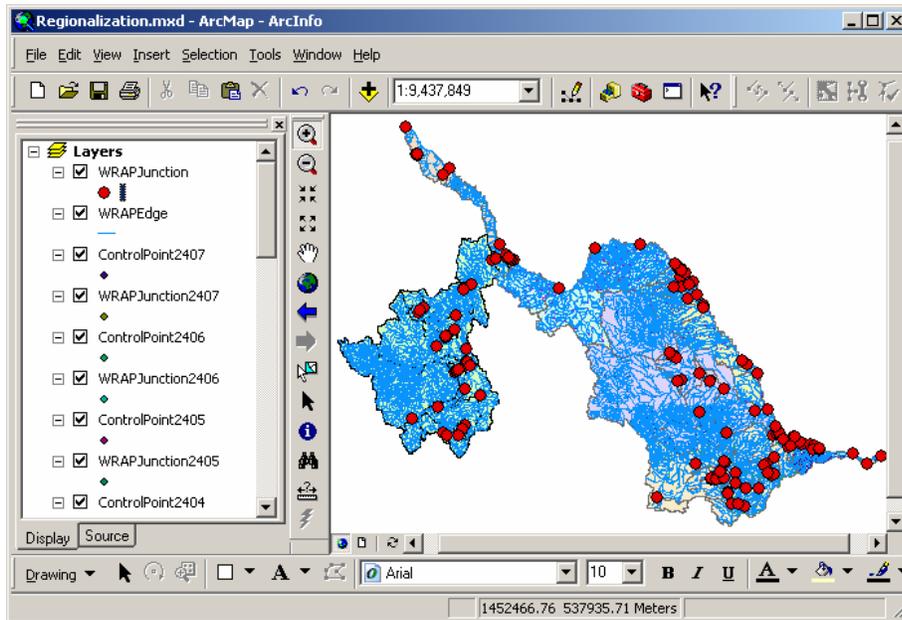
- Select all WRAPEdge layers in the table of content of ArcMap and drag them as the input features of this append process. Chose the empty WRAPEdge feature class created before as the output feature and click OK. Remember this empty feature class is in the Regionalization geodatabase, inside the WRAPHydro feature dataset.



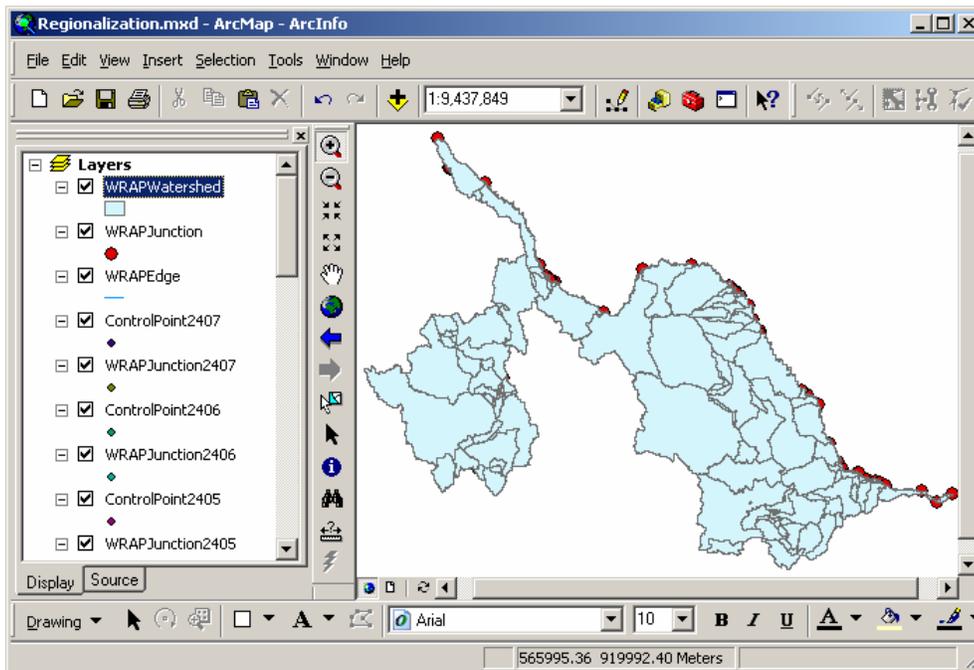
- Final results after merging all WRAPEdges are shown below.



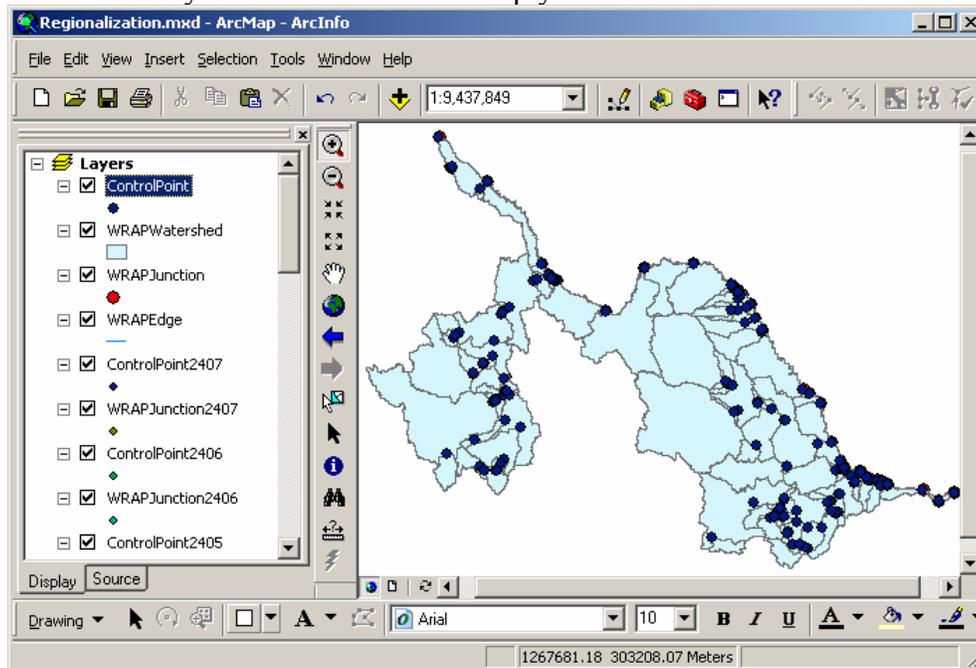
- Merge all WRAPJunctions for each sub region using the “Append” tool. Save this result in the Regionalization geodatabase, inside the WRAPHydro feature dataset→ empty WRAPJunction feature class.



- Merge all WRAPWatersheds for each sub region using the “Append” tool. Save this result in the Regionalization geodatabase, inside the WRAPHydro feature dataset→ empty WRAPWatershed feature class.



- Merge all ControlPoints for each sub region using the “Append” tool. Save this result in the Regionalization geodatabase, inside the WRAPHydro feature dataset→ empty ControlPoints feature class.



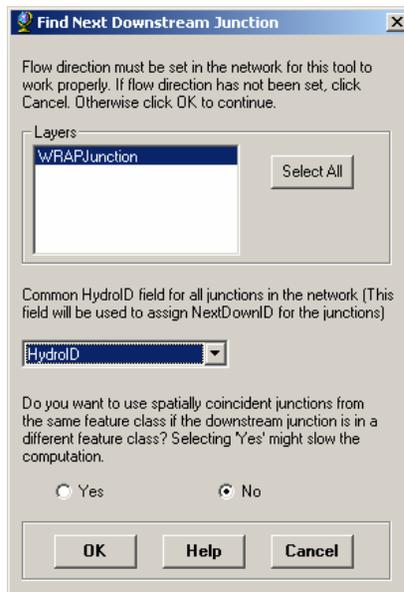
7. NextDownID is updated for the outlet of each subregion

- First a geometric network must be built.
 - Save edits, save the ArcMap document, and close ArcMap.
 - Open ArcCatalog.
 - Create a new geometric network using the WRAPEdge as a simple edge and WRAP Junction. Follow the steps as it is known.
- Next, in order to assign NextDownID, flow direction must be assigned.
 - Close ArcCatalog. Open the ArcMap document.
 - Use the ArcHydro tools to **Set Flow Direction** using the FlowDir attribute of WRAPEdge.
- Now the NextDownID can be assigned for each WRAPJunction.
 - Open the WRAPJunction attribute table and select the outlet of each subregion. These points have a minus one unit value in their NextDownID field.

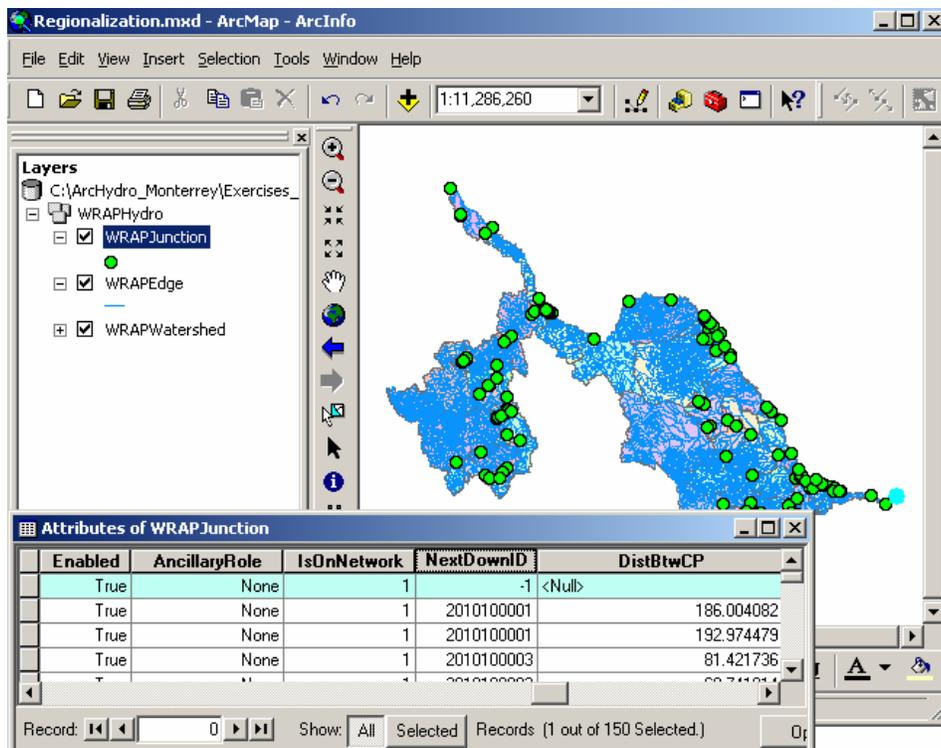
AncillaryRole	IsOnNetwork	NextDownID	DistBtwCP	
None	1	-1	<Null>	<Null>
None	1	-1	<Null>	<Null>
None	1	-1	<Null>	<Null>
None	1	-1	<Null>	<Null>
None	1	-1	<Null>	Amistad Dam
None	1	-1	<Null>	<Null>
None	1	-1	<Null>	<Null>
None	1	2010100001	186.004082	<Null>
None	1	2010100001	192.974479	<Null>
None	1	2010100003	81.421736	<Null>
None	1	2010100003	60.741914	<Null>

Record: 0 | Show: All Selected | Records (7 out of 150 Selected.) | Options

- Use the **Find Next Downstream Junction** tool from the ArcHydro tools to find the NextDownID for the selected WRAPJunctions.
 - The WRAPNetwork_Junctions feature class must be added to the ArcMap document. This feature class was created automatically when the geometric network was established in the WRAPHydro feature dataset.
 - Assign the HydroID identifier for the WRAPNetwork_Junctions elements. Otherwise the ArcHydro tools will not recognize the HydroID field of the WRAPJunction feature class in order to find the NextDownID for the WRAPJunction with -1 value.
 - The WRAPNetwork_Junctions feature class can be removed from the layers.
 - Go to the “Attribute Tools” of the ArcHydro tools and apply the “Find Next Downstream Junction” option to the selected WRAPJunctions. The HydroID is assigned as the common field for all junctions in the network.

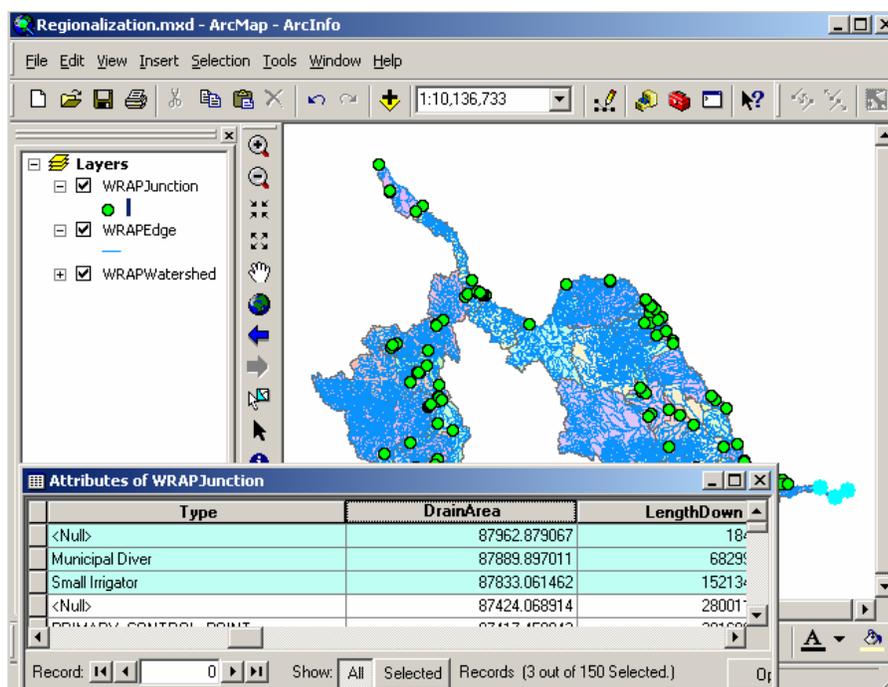


With the datasets merged and network connectivity established, parameters throughout the stream network can be now accumulated. Clear selected features.



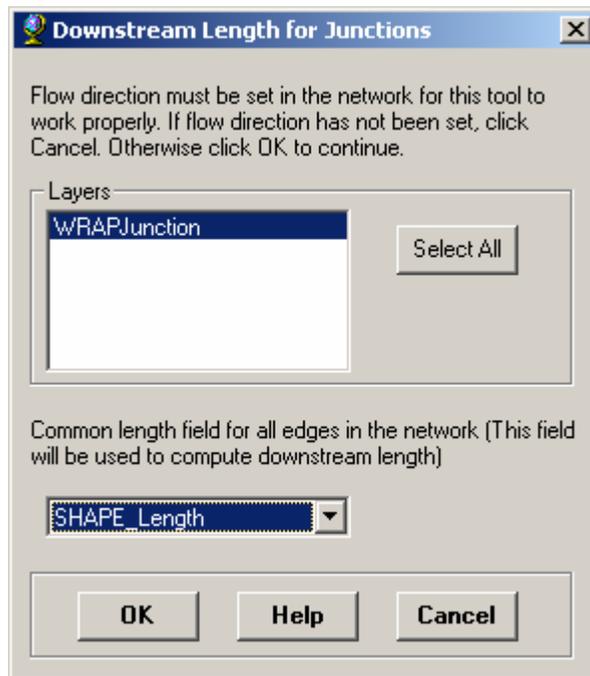
8. Consolidate the parameters for each WRAPJunction.

- Click the Settings button on the WRAPHydro toolbar.
- Select the merged WRAPWatershed as the Watershed layer, and the merged WRAPJunction as the WRAPJunction layer. Make sure that the correct fields have been selected for these two layers in the Fields tab. Click OK to close the Settings form.
- In the Advanced Tools menu of the WRAPHydro tools, click **Accumulate CN, Precip, and Area**. Remember all drainage areas for each hydrological subregion were calculated in square miles.



9. Assign LengthDown to WRAPJunction.

- Use the ArcHydro tools to **Calculate Length Downstream** for WRAPJunction. Select the “Shape_Length” attribute as the common length field for all edges in the network. This field will be used to compute the downstream length.



10. Copy the parameters to ControlPoint.

- If necessary, add the ControlPoint feature class for the entire region to the map.
- Set ControlPoint as the Control Point layer in the Settings form of the WRAPHydro tools. Make sure that Control Point's fields have been filled in on the Fields tab of the Settings form. Close the Settings form.
- Use the "Params to Control Points" tool in the WRAPHydro toolbar to copy the parameters from WRAPJunction to ControlPoint.

NextDownID, average curve number, average precipitation, and drainage area have now been populated for all ControlPoints in the region.

11. Copy LengthDown to ControlPoint.

The WRAPHydro tools do not copy the LengthDown values to the Control Points. These values may be copied by using a table join.

- Right click on ControlPoint in the ArcMap table of contents and create a new join with WRAPJunction. The JunctionID of ControlPoint matches the HydroID of the corresponding WRAPJunction.
- Open the attribute table for ControlPoint.
- Use the field calculator to copy the LengthDown values from WRAPJunction to ControlPoint.

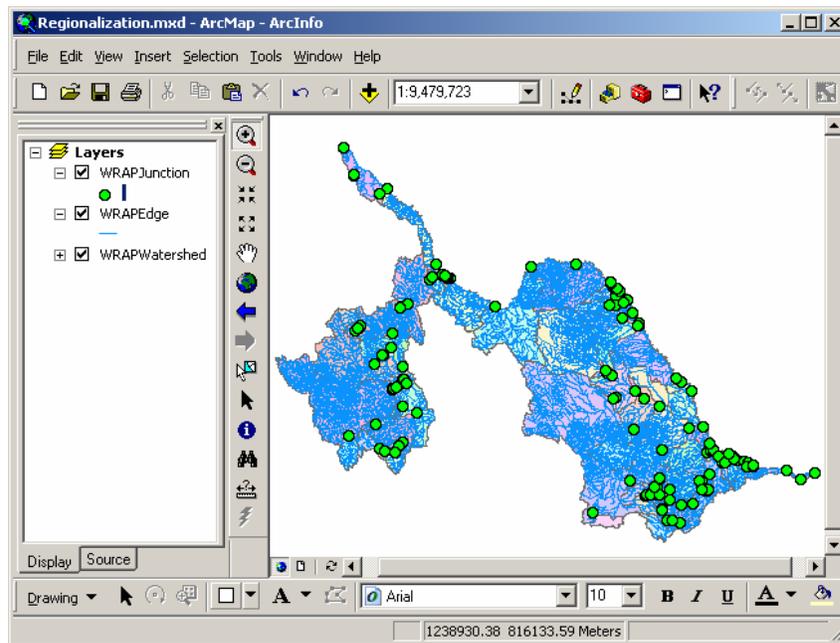
Control Points for the Rio Grande/Bravo basin on the Mexican side have now been attributed with all of the parameters necessary for WRAP analysis.

The last step in this exercise is to build a schematic network. A schematic network is useful for seeing the connectivity between features in the landscape.

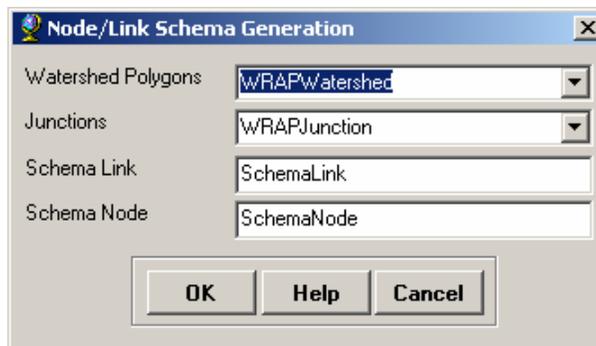
12. Create a Schematic network

This function allows generating a node-link schema. These nodes are representing the centers of the WRAPWatersheds and the WRAPJunctions. This function requires that the relationship between the WRAPWatersheds and their outlet identified by the WRAPJunctions be established through the JunctionID – HydroID fields and the NextDownID of the WRAPJunctions must be established through the NextDownID field.

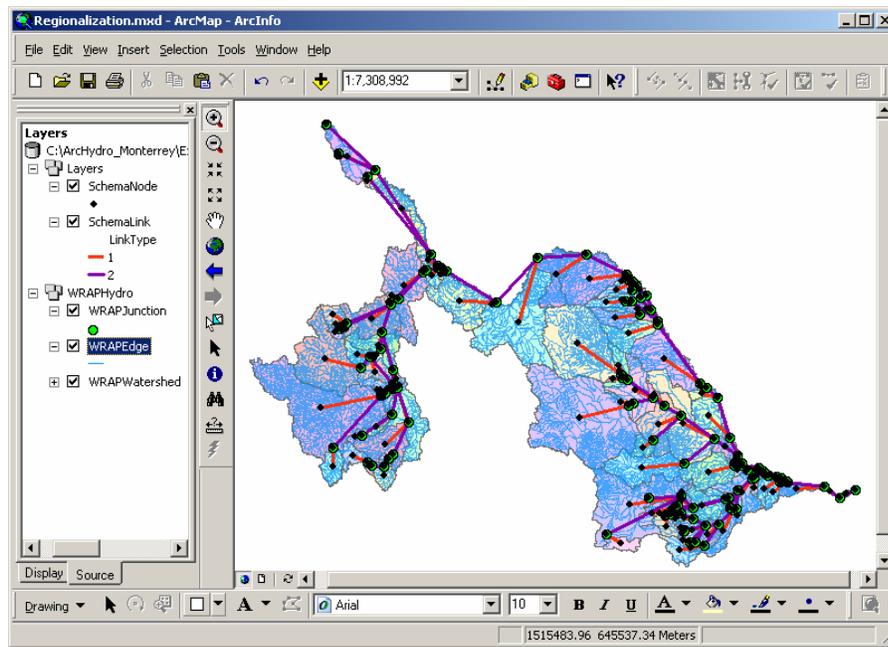
For this exercise, the only map layers you need are WRAPJunction, WRAPEdge, and WRAPWatershed.



- Assign a HydroID for every WRAPWatershed of the Rio Grande/Bravo basin.
- Apply the Node/Link schema generation tool in the Network Tools menu of the ArcHydro toolset.
- Select the WRAPWatershed as the Watershed Polygons, the WRAPJunction as the Junctions and click OK



The schematic network has now been created. The schematic network connects the WRAPWatersheds and WRAPJunctions in a node/link network.

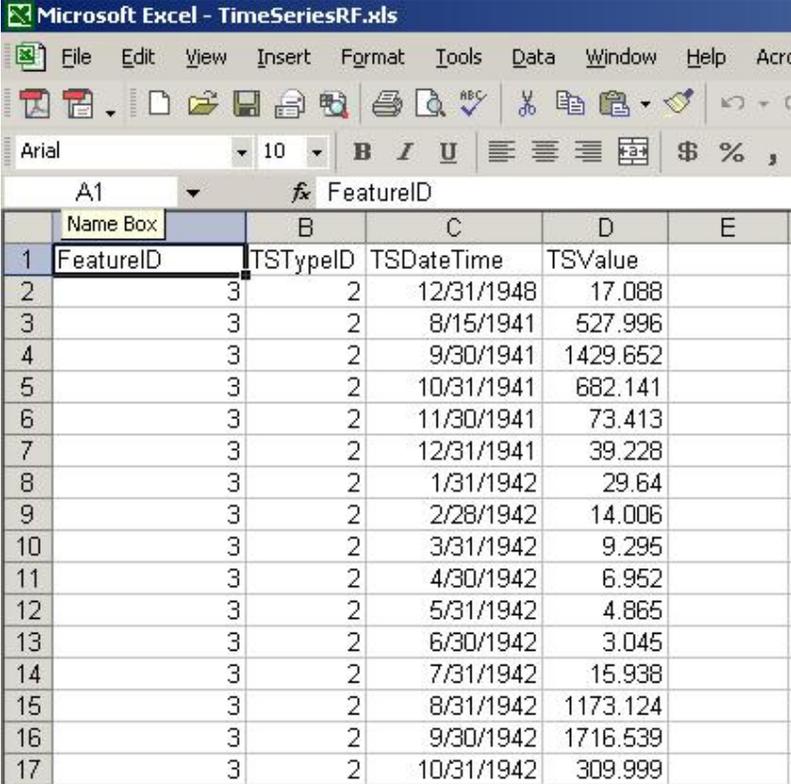


Congratulations! The Regionalization process for the Rio Grande/Bravo basin has been completed now. Give yourself a pat on the back, and a gold star.

Appendix E: Adding Time Series into the Geodatabase

In order to add the time series into the ArcHydroRioFlorida geodatabase you need to use a txt file generated in tab delimited format that contains historical information of the hydrometric stations (ftp://ftp.crwr.utexas.edu/pub/outgoing/patinoc/ArcHydro_Monterrey/Exercises_Data/Participant/).

1. Open Excel. Go to the folder where you saved the file TimeSeriesRF.xls and open it. This file contains the hydrometric stations located on the Rio Florida basin.

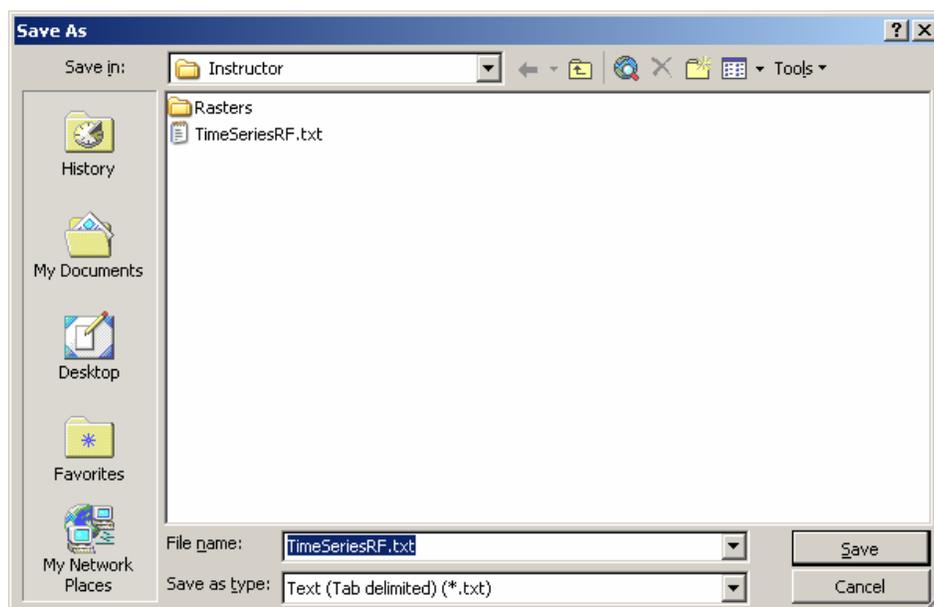


The screenshot shows a Microsoft Excel spreadsheet titled "TimeSeriesRF.xls". The spreadsheet contains a table with the following data:

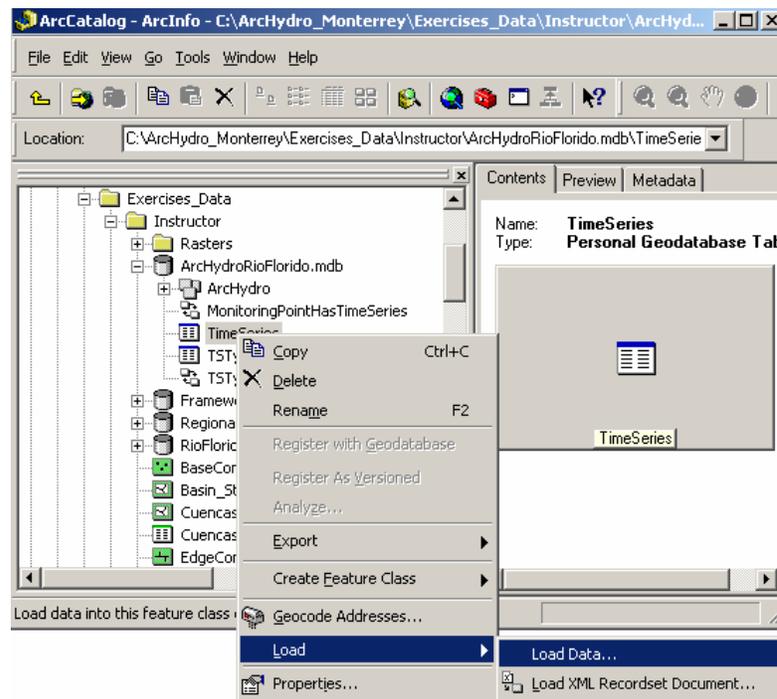
	Name Box	B	C	D	E
1	FeatureID	TSTypeID	TSDateTime	TSValue	
2		3	2	12/31/1948	17.088
3		3	2	8/15/1941	527.996
4		3	2	9/30/1941	1429.652
5		3	2	10/31/1941	682.141
6		3	2	11/30/1941	73.413
7		3	2	12/31/1941	39.228
8		3	2	1/31/1942	29.64
9		3	2	2/28/1942	14.006
10		3	2	3/31/1942	9.295
11		3	2	4/30/1942	6.952
12		3	2	5/31/1942	4.865
13		3	2	6/30/1942	3.045
14		3	2	7/31/1942	15.938
15		3	2	8/31/1942	1173.124
16		3	2	9/30/1942	1716.539
17		3	2	10/31/1942	309.999

The first row describes the attributes of the ArcHydro time series table. The FeatureID value corresponds to the HydroID of its corresponding monitoring point. The TSTypeID field describes the variable you are recording. Monthly runoff in cubic meter per second is identified with number 2 in this exercise. TSDateTime describes when the value was recorded, while the TSValue field

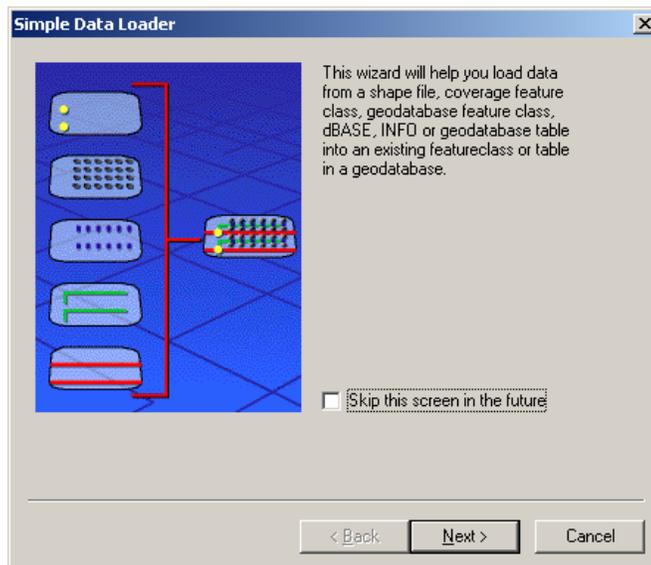
contains the value recorded. Go to the Excel application and save this file as text tab delimited format as it is shown below, in order to import it into the ArcHydroRioFlorida geodatabase later.



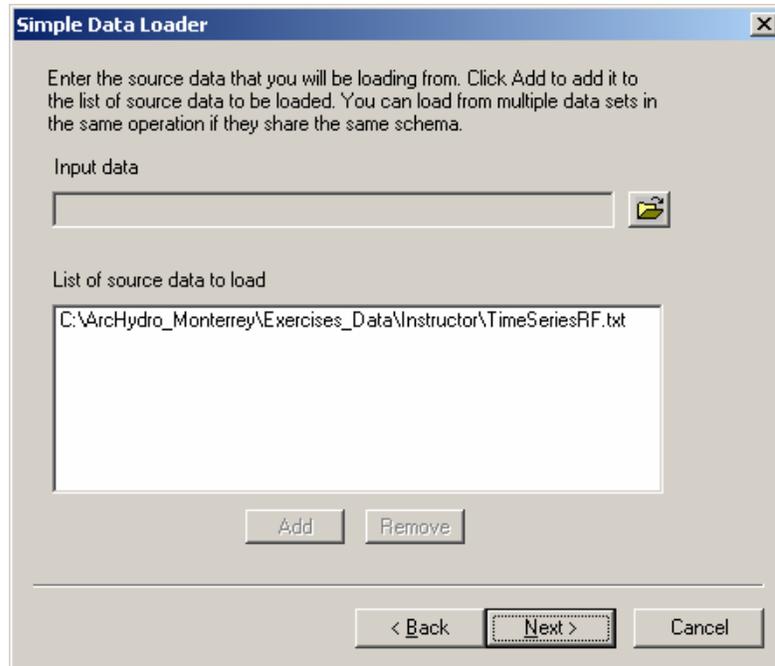
Now open ArcCatalog and go to the folder where you saved the ArcHydroRioFlorida geodatabase. Right click on the Time Series table, which should be empty, and select the “Load Data” option.



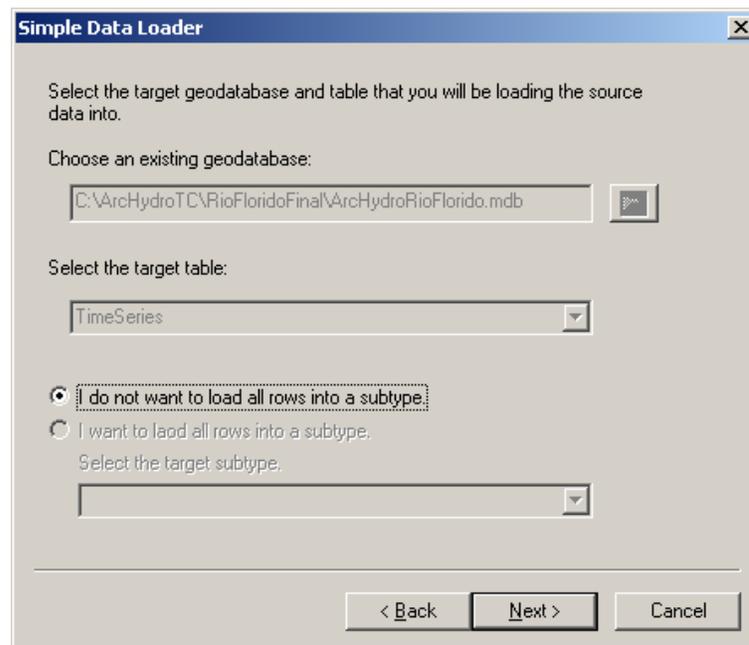
The Simple Data Loader option will appear now.



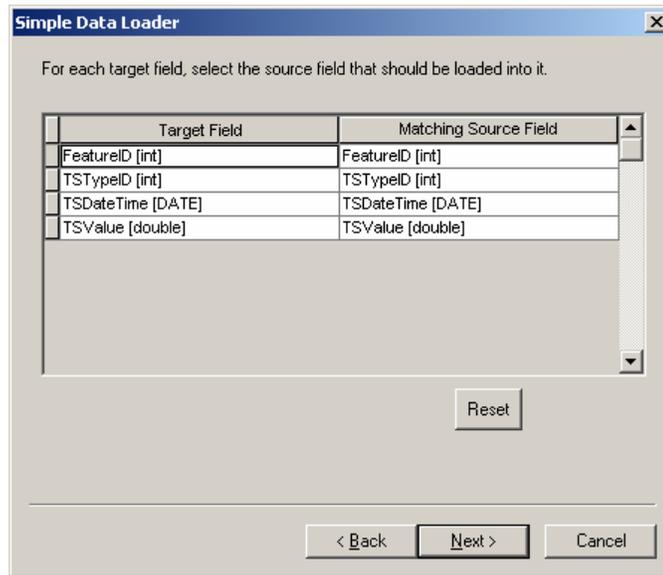
Click the next button and go to the folder where you saved the TimeSeries.txt. Select it and click Add button.



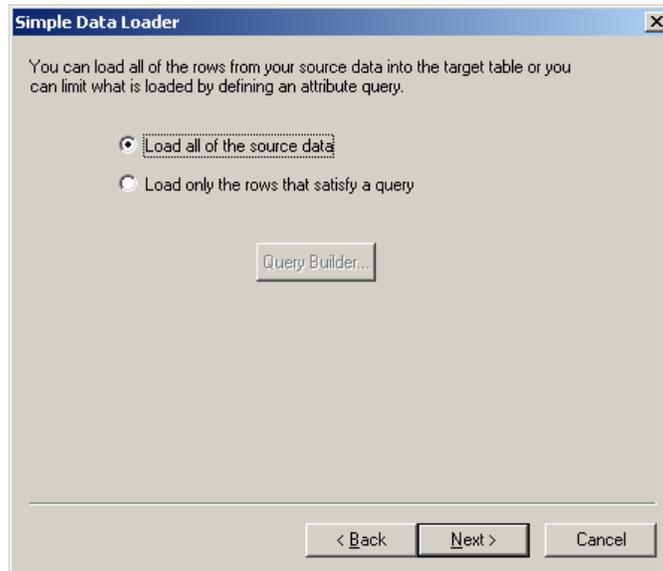
Click on the Next button and this window will appear.



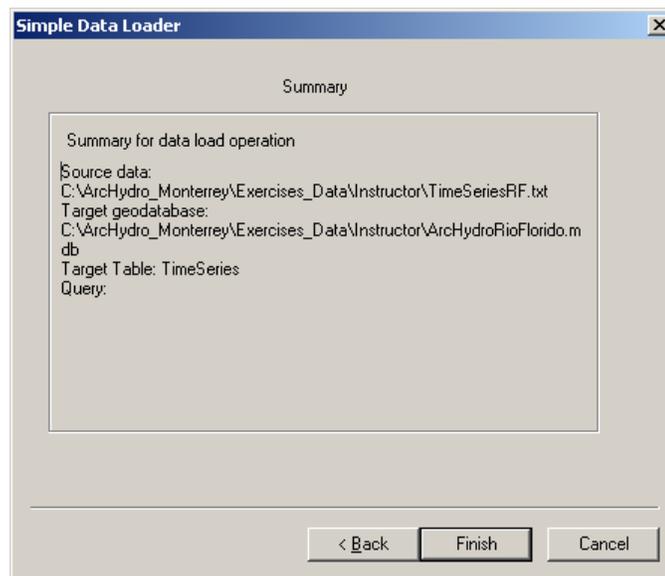
Click on the Next button in order to match the attributes of the time series table. Review carefully that all attributes are the same in both tables.



Click on the Next button. The next screen gives you the possibility to download all data or just some of records that satisfy a specific query. Select the “Load all of the source data” option.

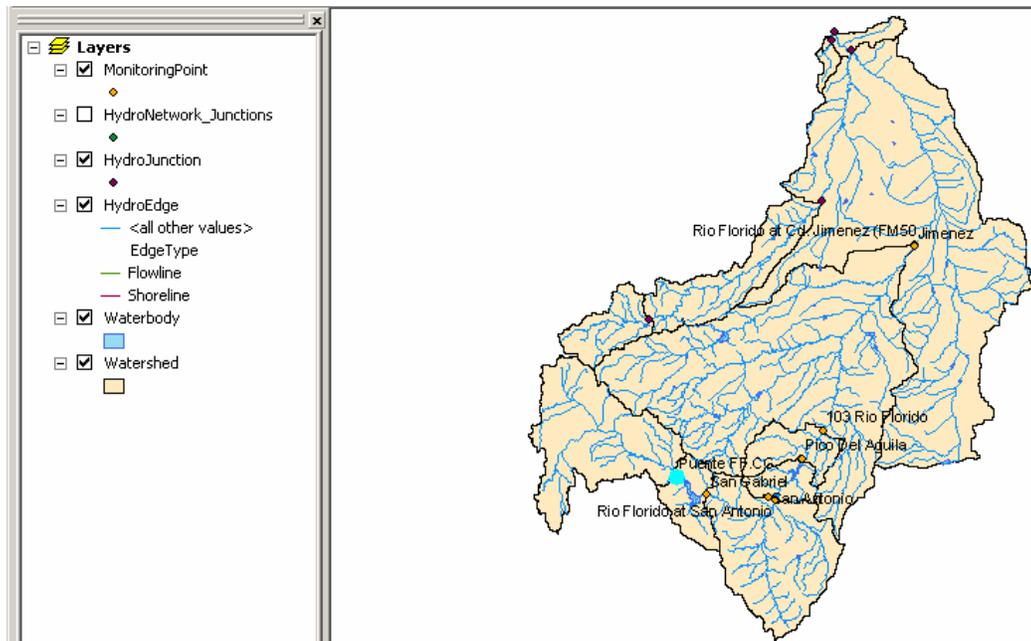


Click on the Next button. Now you will see a summary of the process. Click on the Finish button to download the records into the ArcHydro time series table.

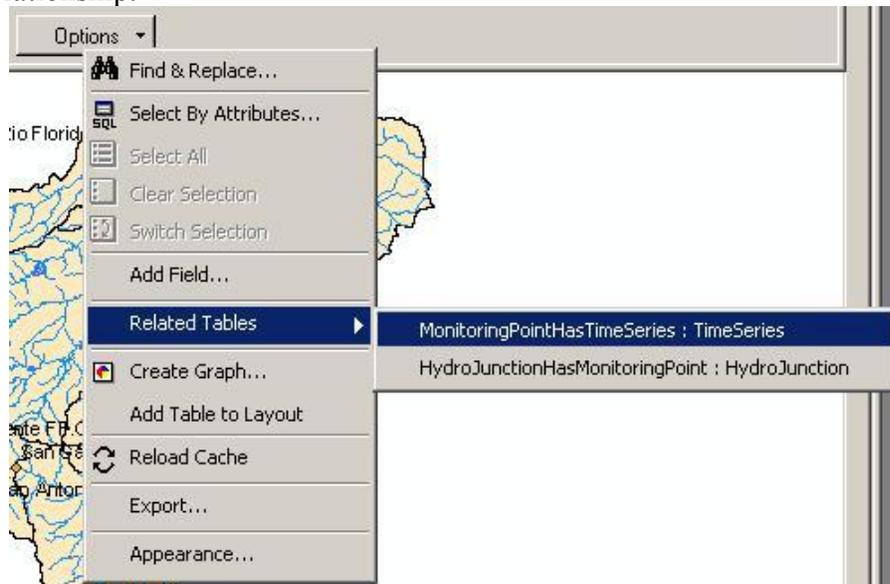


Check that the records contained in the time series table of the ArcHydroRioFlorida geodatabase are the same as in the original Excel table.

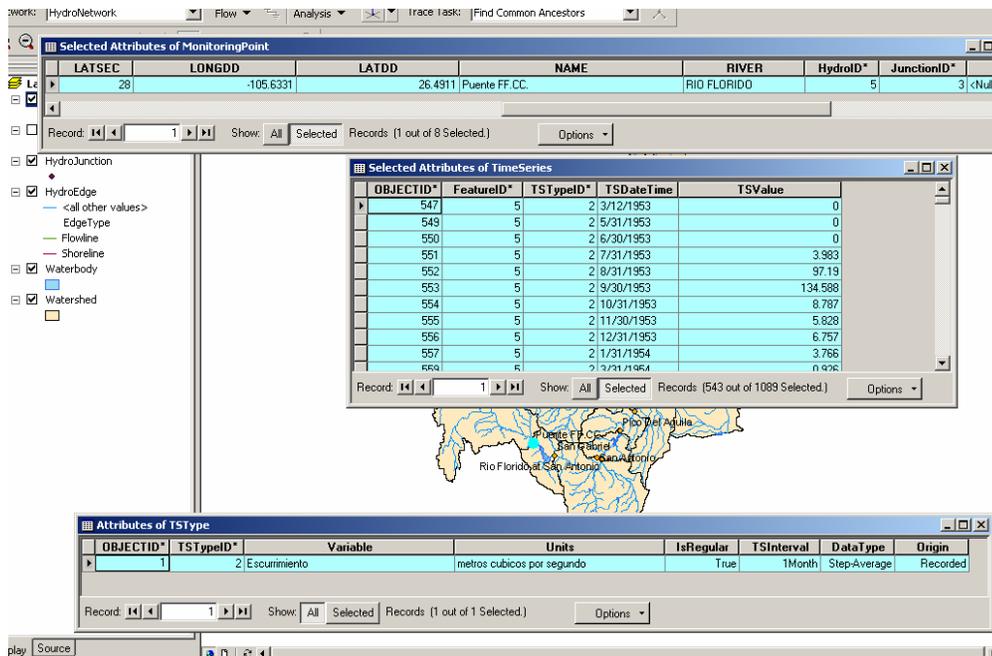
- Now **open** ArcMap to create a new document and **add** the Watershed, WaterBody, and the MonitoringPoint feature classes. **Set** the labels for the MonitoringPoint feature class based on the "NAME" attribute. **Select** the MonitoringPoint called Puente FF.CC, as it is shown in the picture below.



- Open the attribute table of the MonitoringPoint feature class and click on the “Selected” button located at the bottom of this table. You will see just the selected element (Puente FF.CC.) that has the value 5 as its HydroID.
- Click on the “Options” button of the attribute table and go to the “Related Tables” option. Select the MonitoringPointHasTimeSeries: TimeSeries relationship.



- Now you will see the Time Series table for the selected monitoring point. Click on the “**Selected**” button of the attribute table to check the records for the hydrometric station Puente FF.CC (Remember that its HydroID is the number 5). Click on the “**Options**” button to see the attributes of this time series table and select **Related Tables> TSTypeHasTimeSeries: TSType** option. The next screen will be displayed.



Congratulations!!! You have imported time series records from a txt file into the ArcHydro data model

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