

**GEODATABASES IN DESIGN:
A FLOODPLAIN ANALYSIS OF LITTLE KITTEN CREEK**

BY

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ABSTRACT

This study is an integration of GIS, the Arc Hydro data model and tools, and hydrologic models to solve land use planning issues in the Little Kitten Creek watershed, Riley County, Kansas. Every day designers plan and design in watersheds. These designs alter the land use cover and change the hydrologic regime. Generally the design and development process does not consider upstream/downstream impacts on water quality and quantity. As a result development often increases flooding and water pollution.

With the advent of the geodatabase, and the Arc Hydro geodatabase data model, designers have a flexible new tool for rapid simulation of a watershed. Arc Hydro allows the incorporation of traditional hydrologic data into linked modeling software together enabling users a “one-stop” approach for assimilating and modeling water resource systems. Once hydrologic data is in the Arc Hydro format it can be incorporated into assessment models, such as the Map to Map model.

This case study assessed the floodplain analysis capabilities of the Map to Map model in the Little Kitten Creek (HUC 14) watershed. Steps to accomplish this goal were: data collection (digital and field surveys) and processing, geodatabase construction, linking the geodatabase with hydrologic modeling programs and, analysis of land uses within the watershed using the Map to Map model with the intent to produce flood maps based on land use changes.

Key Words: Arc Hydro, flood plain analysis, map to map, landscape architecture

DEDICATION

This document is dedicated to my wife, Heidi, for she has taught me how to dream

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Introduction

A landscape can be defined as a reflection of natural systems, social systems and dynamic [Laurie, 95]. A landscape architect's domain is found in facilitating a harmonious interaction between natural and social systems for a desired outcome or dynamic. A vital aspect of the natural systems aspect of landscape is water. How water moves through landscapes, the quantity, and quality profoundly impact their function, design and aesthetic considerations.

All landscapes are part of a hydrologic system commonly defined by watersheds, or areas of land whose surface water drains to a single point. Watersheds contain complex networks of streams, rivers and lakes. Every design decision made in a landscape alters the hydrologic network and ultimately the hydrologic cycle. Designs implemented throughout a watershed impact the hydrologic regime, changing the amount of water, chemistry, sediment load, water temperature and debris in the network. Landscapes in lowlands and watershed outlets are affected by choices planners and designers make upstream, whether that is flooding or lack thereof.

No matter where the site, the impact of designing on the land alters the hydrologic regime. Therefore it is crucial to analyze the hydrology of a site pre-design and to be able to predict how design implementation will affect the hydrologic system. Additionally, the ability to analyze future watershed development impacts in a watershed system and on a conceptual design could prevent costly repairs and/or replacements of built works in the future. Being able to design landscapes with this analysis could greatly improve a landscape architect's achievement of harmonious system interactions,

while adhering to the professional responsibility to maintain the public health safety and welfare.

To understand the impacts of site design concepts within the context of future development scenarios, data on existing and planned land use, and hydrologic modeling tools must be readily available and easily accessed by designers and planners. The development of geographic information systems (GIS), and geoportal environments serving national to local geospatial data currently in use by planners and designers, can provide necessary data resources and tools to describe and analyze hydrologic system data. Developments in geospatial relational geodatabase technology, coupled with a geodatabase schema for hydrologic systems, development of hydrologic tools for GIS called Arc Hydro and advances in ArcGIS® software (by ESRI) provide a method for organizing, analyzing and visualizing a virtual hydrologic system. Given the hydrologic geodatabase model and relationship structure, links with scalable hydrologic modeling tools and applications can be made to model hydrologic systems and test development impacts within watersheds.

The Map to Map geoprocessing model automates the process of calling data stored in the standardized hydrologic geodatabase to populate parameters required in hydrologic modeling tools along with GIS layers derived from NOAA NEXRAD Doppler estimates of precipitation to create an estimate of flooding with a watershed. This geoprocessing model was created by David Maidment at the University of Texas to “develop a Flood Simulation System on top of the Arc Hydro Data Model that will streamline the simulation process, manipulation and generation of modeling outputs

needed for flood inundation mapping in flood assessment studies and mitigation” [Robayo, 05].

In Manhattan, Kansas, there is a trail system designed by a local landscape architect that encircles the city, allowing citizens to walk and bike through the countryside, neighborhoods and riparian corridors. The trail has both recreational and cultural value as it is the only direct visual and physical connection to the Kansas River due to levees which visually and physically separate the city and river. The Linear Trail



Figure 1 - Wildcat Creek choked with debris

and system connects people to the natural environment, as well as to the heritage of the community as the first settlers arrived via boat on the Kansas River.

One very strong human connection to natural systems of the area exists along Wildcat Creek (Kansas River watershed) section of the trail. As illustrated in Figure 1, people cross Wildcat Creek on their trail expeditions, and almost every year this pedestrian bridge is inundated with flood water and debris—a serious public health, safety and welfare issue. One

could initially say that the bridge was designed with inaccurate consideration of flood volumes. However, analysis of land use changes in the watershed upstream, indicates that increased development upstream contributes to increased flows. Either way, the bridge and trail design puts humans at risk and impedes use of the trail resource. As

demonstrated in Figure 1, planners and designers are not always successful in creating harmonious interactions between natural and social systems in this case for the purpose of recreation.

The professional responsibility of landscape architects to protect the public health, safety and welfare necessitates an understanding of how designs will alter the hydrology of not only the site, but an entire watershed. Recent advances in GIS technology allow new tools for watershed analysis which facilitate the question of this study, which is to answer: can the Map to Map geoprocessing model produce flood simulations and impact on development in the lower section of the Little Kitten Creek watershed under different planning and design scenarios in the currently undeveloped upper half of the Little Kitten Creek watershed?

Background

The Little Kitten Creek watershed is located on the western edge of the city of Manhattan, Riley County, Kansas, in the Flint Hills Ecoregion.

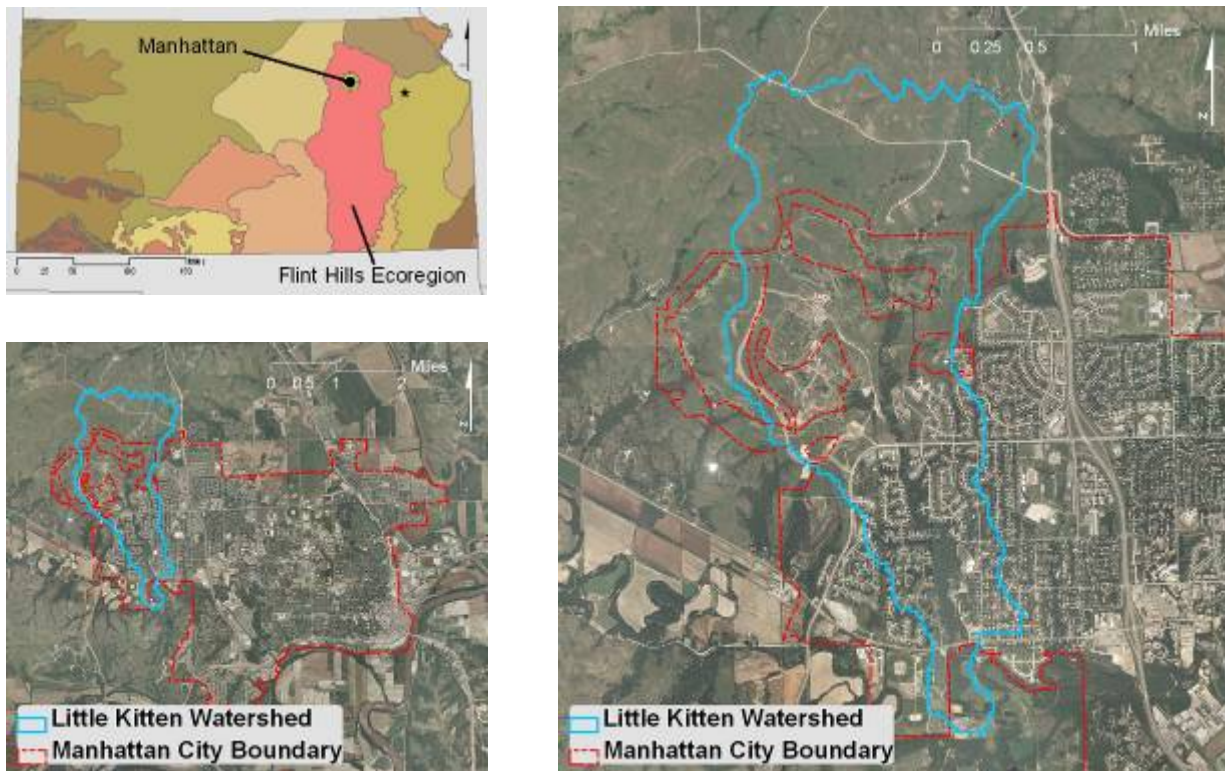


Figure 2 - Location map of Little Kitten Watershed [Data Sources: EPA Ecoregions; City of Manhattan, KS; Image Data: 2005]

Flint Hills Ecoregion

The following is the EPA level IV description of the Flint Hills Ecoregion:

“The Flint Hills ecoregion is the largest remaining intact tallgrass prairie in the Great Plains. This region is characterized by rolling hills composed of shale and cherty limestone, rocky soils, and by humid, wet summers. Average annual precipitation ranges from 28 to 35 inches. The Flint Hills

marks the western edge of the tallgrass prairie. Erosion of the softer Permian limestone has left the more resistant chert (or flint) deposits, producing the hilly topography and coarse soils of the area. This rocky surface is difficult to plow; consequently, the region has historically supported very little cropland agriculture. The natural tallgrass prairie still exists in most areas and is used for range and pasture land. However, some cropland agriculture has been implemented in river valleys and along the periphery of the Flint Hills, especially in the northwest corner where the topography is more level. This northwest edge is transitional between the cherty, rocky soils of the Flint Hills (28) and the silty, loamy, loess-formed soils of the Smoky Hills” [EPA Ecoregions, 06].

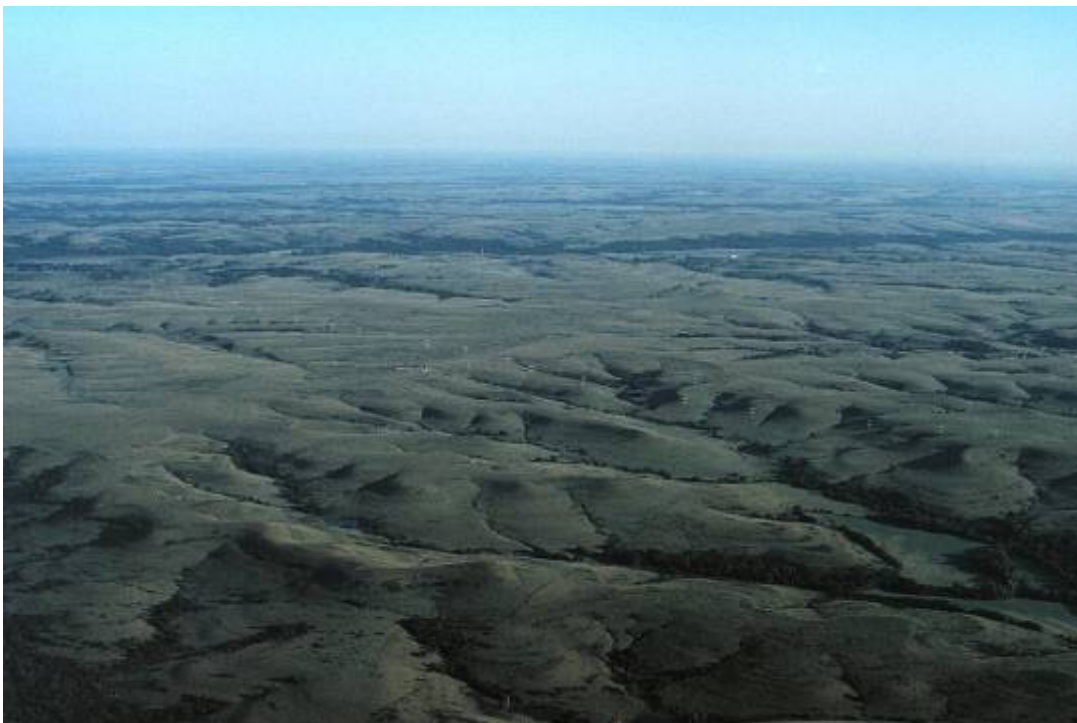


Figure 3 - The Flint Hills (Source: EPA Ecoregions, 2006)

The characteristics of Flint Hills Ecoregion define much of the physical, climatic, and biological components of the Little Kitten Creek watershed.

Geologic Origins

One distinguishing characteristic of the Flint Hills is the landscape form known as a cuesta. In the Flint Hills region cuestas consist of alternating layers of limestone and shale that have been slightly tilted (Figure

3). Erosion shapes the cuestas as water erodes soft layers of shale faster than the hard limestone. This process leaves a layer of limestone at the tops of cuestas.

Another result of the hard limestone layers are shallow soils. As the roots of prairie

vegetation weave through the soil, they are often stopped by limestone and shale.

Shallow soils combined with the fact that the limestone in the Flint Hills has high chert content have spared the Flint Hills from the plow. River bottoms have deeper soils and are less chert laden and therefore these areas were and are used for crop agriculture.

The pattern of ranching in the uplands and row cropping in the bottomlands still holds today.

The geology of the Flint Hills impacts the Little Kitten Creek watershed in many ways. The uplands of the watershed are defined by the native grass laden cuestas. As water falls on these forms it permeates into the shallow soils and there encounters an impenetrable shale layer. As water cannot pass through this layer it is forced to run horizontally underground and reappear downhill as a seep or spring. The water that



Figure 4 - Cuesta forms that dominate the Flint Hills [Kansas Geological Survey, 06]

does not infiltrate the surface flows into the many ephemeral streams found in the headwaters. Further downstream the water table rises to supply baseflow water for perennial streams found in riparian areas.



Figure 5 - Severly entrenched section of Little Kitten Creek.
[Source: authors personal collection]

The shallow, high clay and silt soils of the Flint Hills are highly erodible, yet are largely shielded from the forces of wind and water when covered with prairie and riparian vegetation. Therefore most of the erosion that occurs in undisturbed areas comes from in-channel erosion of

the stream banks and bed surface. Erosion of the stream banks causes the stream channel to slowly migrate back and forth along the floodplain. However, when vegetation is removed for agriculture or development, the increased peak flows of water quickly erode the riparian soils high in clay and silt. As peak flows increase channels react by becoming severely entrenched as illustrated in Figure 5.

Climate

The U.S.D.A. describes the Flint Hills climate as “a continental climate that is characterized by warm to hot summers, cold winters, abundant sunshine, moderate winds, low to moderate humidity and a pronounced peak in rainfall late spring and during the first half of summer. The county (Riley) is in the region of prevailing westerlies...” (USDA, 1975). Weather data for Manhattan, Kansas from 1971 to 2000

reports average highs of 93 F in the hottest month (July) and average low of 16.1 F in the coldest month (January); annual averages range from 67.5-42.3 F. Annual precipitation is 34.8 inches with 5.08 inches in May and 0.86 inches in January (see Appendix A).

Being situated in the Great Plains, most of the water that impacts the Little Kitten Creek watershed comes directly from rainfall events. Storms can blow in following the Jet Stream from the west as well as roll up from the Gulf of Mexico. Fortunately a majority of these storms hit in the late spring and early summer when vegetation can protect the soil from erosion. However flooding can and does occur when heavy rains fall on saturated soils and previously swollen creeks and rivers. Urban and agricultural land uses decrease the ability of the watershed to infiltrate water. As seen in Figure 1, this excess water leads to flooding, which impacts the public health, safety and welfare.

Settlement

Early American settlers described Kansas and the Flint Hills as a harsh place filled with extremes. Kansas Senator John James Ingalls said “The stranger [to Kansas], if he listened to the voice of experience, would not start upon his pilgrimage at any season of the year without an overcoat, a fan, a lightning rod, and an umbrella” [Ingalls, 04]. An early 20th century reporter stated “[Kansas is] a state like nothing so much as some scriptural kingdom- a land of floods, droughts, cyclones, and enormous crops, of prophets and plagues. Speaking specifically about the flooding characteristics of Kansas Horace Greeley claimed “Water runs off these rolling prairies so rapidly that a stream which a three-year-old child might ford at night will be running water enough to float a steamboat before morning” [Greeley, 05]. These extremes in weather and

climate made life tough during the era of American settlement in Kansas. These extremes still present challenges for us today.

Manhattan, Kansas

In 1853 Fort Riley, a U.S. Army outpost, was established eight miles from present day Manhattan and served to protect trading routes. Two years later Manhattan, Kansas was settled in April 1855 by New England settlers led by Isaac Goodnow at the confluence of the Big Blue and Kansas rivers. When in 1861 the State of Kansas entered the Union, Isaac Goodnow successfully petitioned to establish one of the first land-grant institutions now known as Kansas State University (KSU). These two organizations, KSU and Fort Riley have played major roles in shaping the history of the region. Their roles still heavily influence the town as many troops stationed at Fort Riley live in Manhattan and roughly half of the 50,000 residents are students at KSU, not to mention faculty and staff [City of Manhattan, 07].

Recently increases in troop numbers at Fort Riley are having drastic effects in Manhattan. Within six years there is a proposed increase of an additional 9,000 troops (not including families of those troops) at the Fort. Many of these additional soldiers will choose to live in Manhattan, and the effects of the increase have already been felt. The housing market is coming under pressure as evidenced by the 30% average increase in county property assessments in 2006 [Williams, 06] and the many new housing developments (Figure 6).

As previously mentioned, the impact of replacing permeable prairie and riparian vegetation with impermeable roof tops and roads, as well as trading deep rooted grass species with shallow rooted grasses greatly alters the hydrologic regime. Specifically

these alterations increase the peak flows of streams which leads to greater erosion and flooding. The Little Kitten Creek watershed is a microcosm for the greater Manhattan area of the challenges that development imposes on hydrology.

New Residential Development in Manhattan

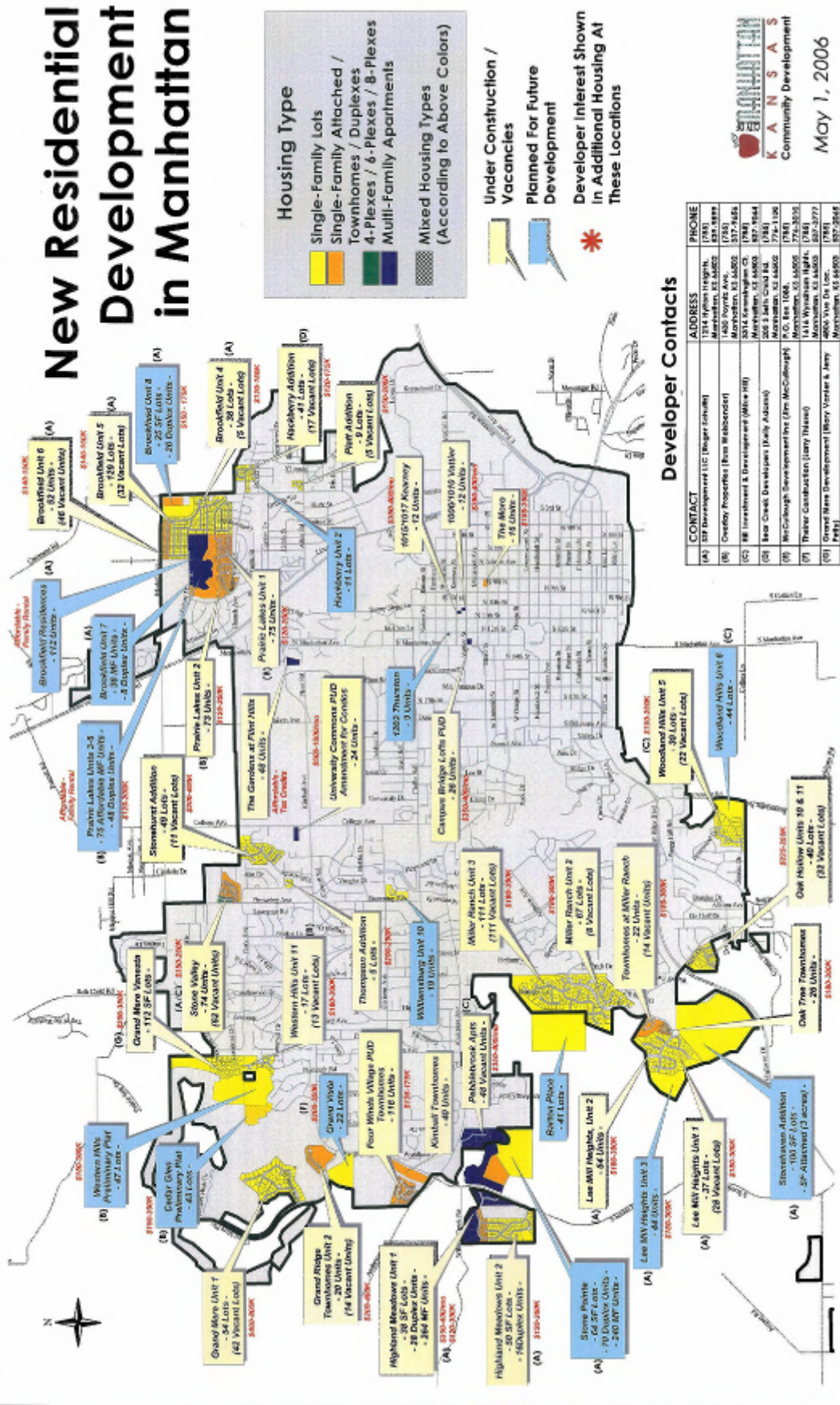


Figure 6 - Recent and proposed development in Manhattan, Kansas. (Source: Riley County, 2006)

Little Kitten Creek Watershed

Little Kitten Creek is a 1,900 acre watershed located on the western edge of Manhattan, Kansas. It is also part of the Lower Wildcat Creek watershed, hydrologic unit code (HUC-14) 10270101020070, and part of the Kansas River watershed (HUC 4) and subsequent Missouri River watershed (HUC 2) as illustrated below. The main channel of the watershed, Little Kitten creek, is a perennial stream that is fairly stable when compared to other nearby urban stream of similar size.

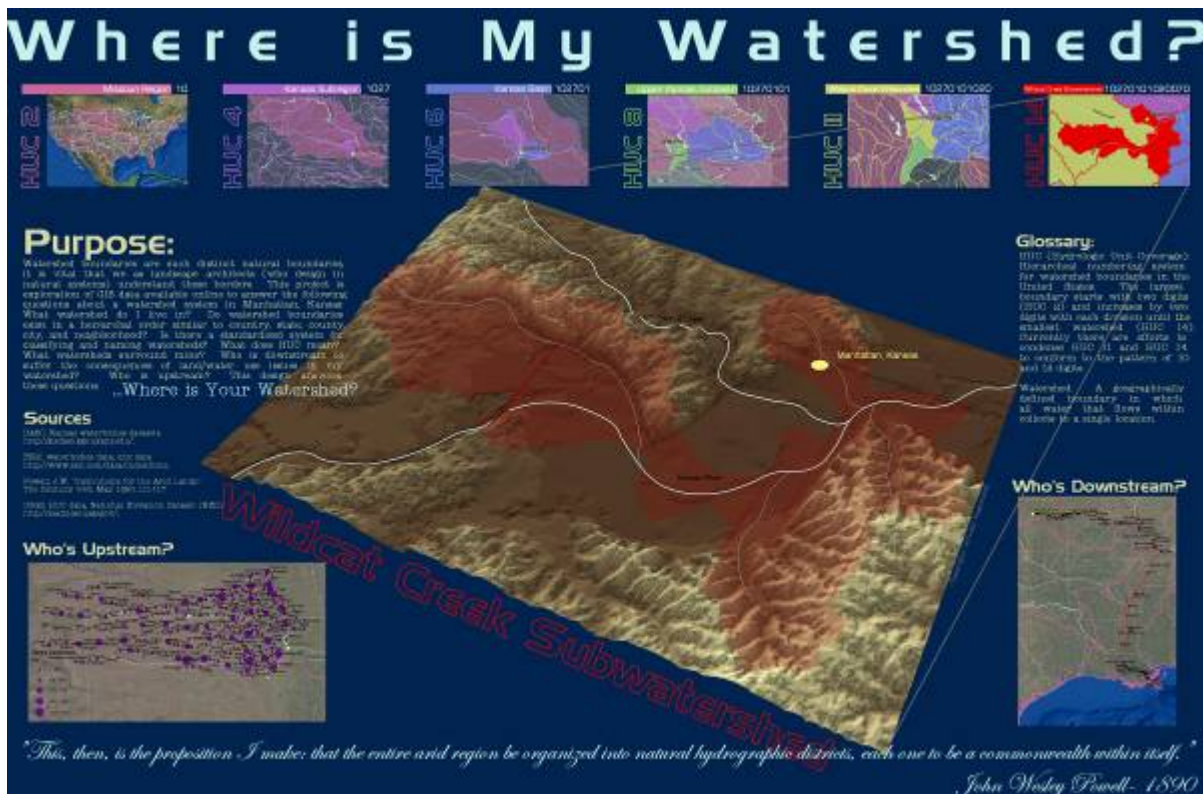


Figure 7 - Explanation of the HUC System for Manhattan, KS, (click to enlarge) [Source: Author]

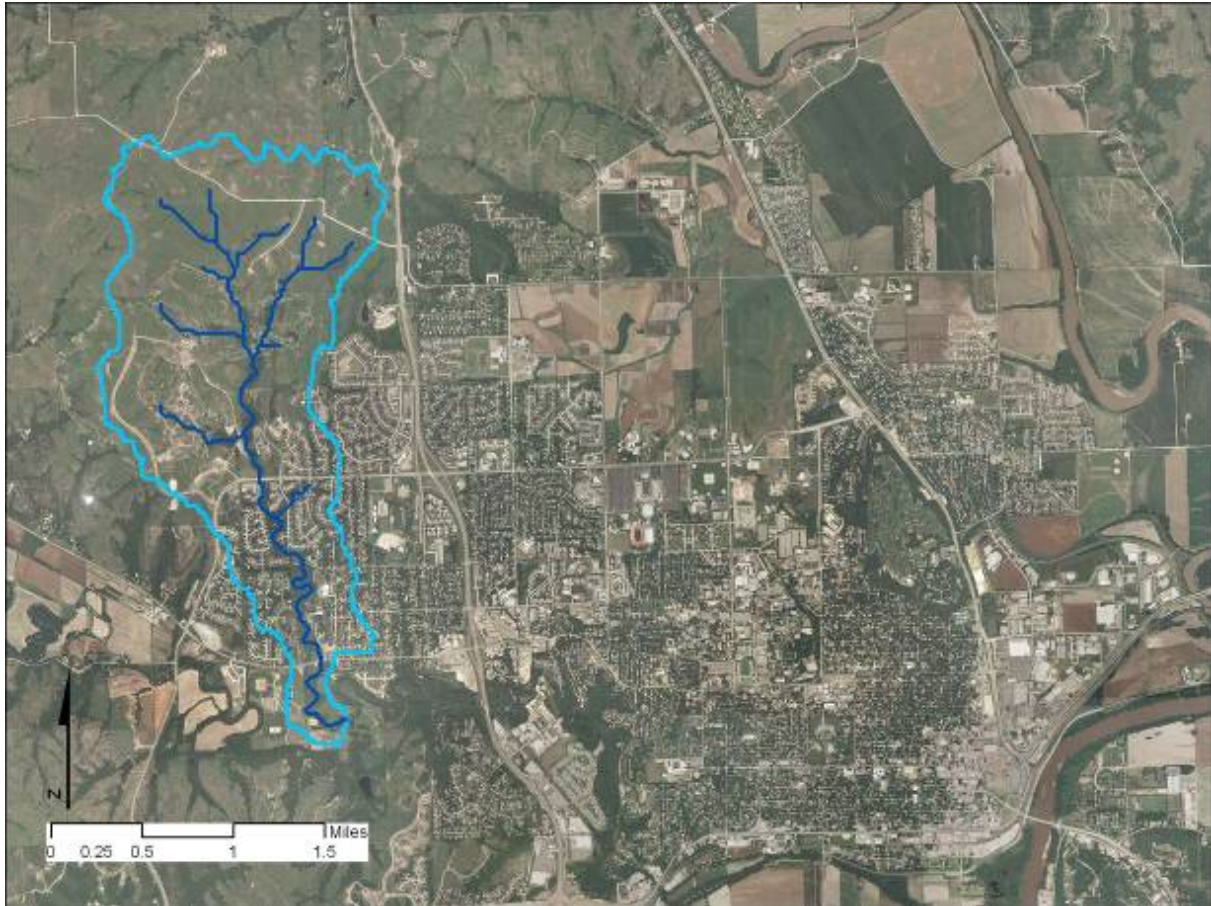


Figure 8 - Little Kitten Creek watershed; the lower end of the watershed is developed and the headwaters are currently undergoing development [Map source: Author, Image source: Riley County, 05]

At first glance the watershed can be easily divided into two distinct catchments: a lower catchment whose dominant land cover is single family residential and an upper catchment which has until very recently been used as native prairie pasture land (see Figure 8). The watershed was chosen for study because it is a typical Flint Hills watershed at the urban fringe currently under increasing development pressure and the hydrology is feeling the development pressure with high potential for downstream/lower watershed flooding of previously developed land.

The main stem of the watershed, Little Kitten Creek, is a fairly stable meandering creek that starts its journey in the upper reaches of the watershed, near a highpoint

locally known as Top-of-the-World. When rain falls it is met at Top-of-the-World by drought tolerant plants of the short grass prairie: Little Bluestem, Sideoats Gramma, Compass Plant, White Sage and the soils of the Benfield-Florence complex. Some water infiltrates the ground where it falls, while the rest flows over alternating layers of limestone and shale. Before the water collects into the channel, it infiltrates the Wymore-Kennebec soil complex that is infused with the roots of the plants of the tall grass prairie: Indian grass, Switchgrass, Big Bluestem, Goldenrod, Indigo Plant, Pale



Figure 9 - Little Kitten Creek in close proximity to single family residences

Purple Coneflower, Sumac, Rough Leaf Dogwood, and the occasional Cottonwood. When enough water concentrates more water loving plants grow: Prairie Cord Grass, sedges and trees that define riparian zones begin to appear. Red Oak, White Oak, Burr

Oak, Chinquapin Oak, Hackberry, Common Honeylocust and clumps of Junipers form a canopy over the channel and the floodplain filled with Buck Brush, Poison Ivy, Wild Plum, and Elderberry.

The water, now freely flowing, is halfway through the watershed when the urban landscape appears with streets and culverts that constrain the floodplain and channel down to a few dozen feet. Intermittent houses appear with turf grass yards sometimes reaching all the way to waters edge. Some of the houses are distant, out of the floodplain, while other houses with residents seeking a view of the meandering channel are only a few feet away (Figure 9). Under the protected canopy of this riparian habitat song birds of all kinds can be heard and seen, a vibrant flash of Oriel, the beautiful show and song of the Cardinal, and of course the Robin and European Starling. As the last of the houses fade, the channel loses much of the meandering and deeply incises. Steep banks with scattered patches of concrete rip rap constrict the gully while the water passes through a golf course and large city park which completes this portion of the journey as it enters Wildcat Creek; bound for the Gulf of Mexico via the Kansas, Missouri, and Mississippi.

Little Kitten Creek Watershed Hydrologic Soils Groups (HSG)

Created by the USDA Natural Resource Conservation Service as a standard soil dataset the HSG is used as part of the TR-55 program. Each soil type is classified according to the engineering properties, specifically the rate at which water enters the soil at the soil surface, known as the infiltration rate. The HSG also incorporates the rate at which water moves through the soil. These soil characteristics are classified into four groups: A, B, C, and D.

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

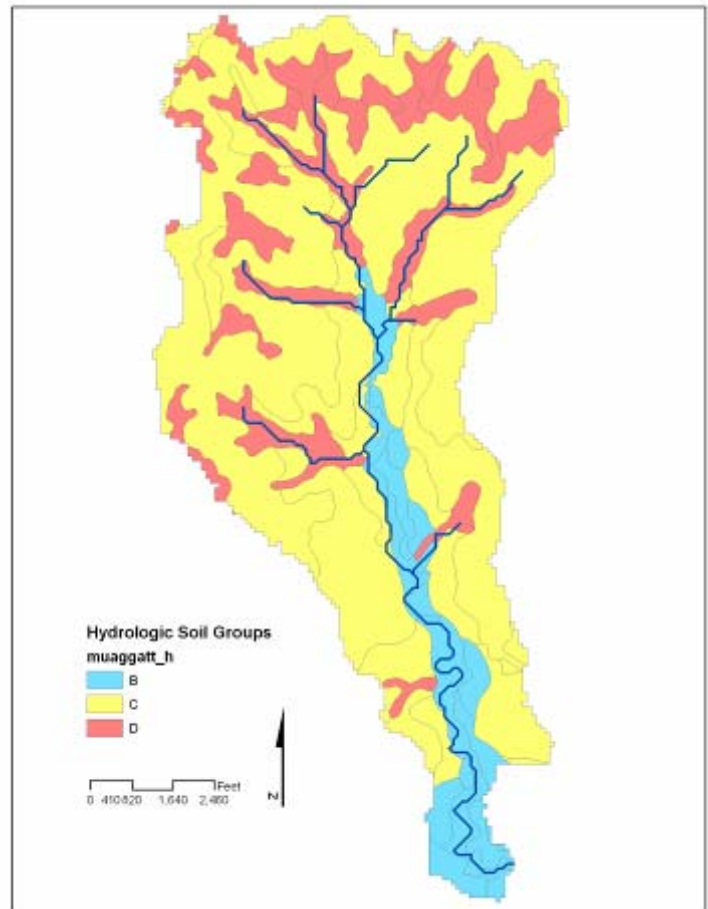


Figure 10 - Hydrologic Soil Groups [Data Source: NRCS Web Soil Survey

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Land Cover

For the purpose of this study the watershed was subdivided into four major land cover classifications: native prairie pasture, woodland, single family residential (SFR), and open space parkland (golf course). There are other land covers that do not exactly fit within one of the classifications, but for this purpose of this study they are negligible. Land cover classification data came from the Riley County GIS office.

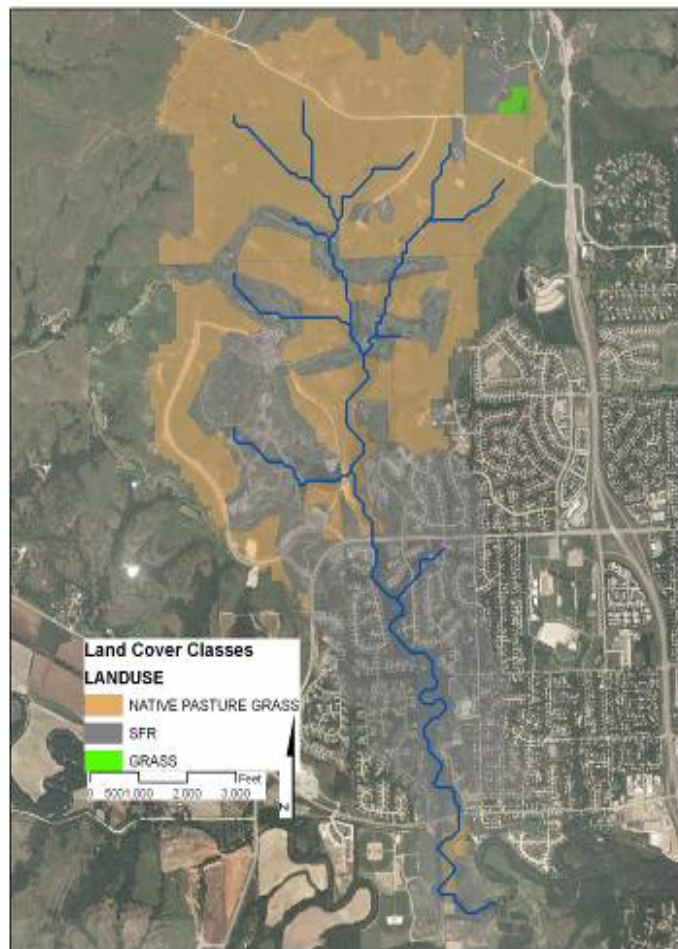


Figure 11 - Land cover classes overlaid aerial photo
[Data Source: Riley County, KS; Image date 2005]

The upper reaches of the watershed are comprised mostly of native tall grass and short grass prairie. Shrubs such as rough leaf dogwood and sumac can be found where there is sufficient water and where burning has not occurred recently. There are 958.31 acres of native prairie pasture located throughout the watershed.

Woodlands cover can be found in the riparian area immediately surrounding ephemeral and perennial streams. This area is largely undisturbed because of the recognition of value of this habitat for stabilizing stream banks and channels. In this particular watershed there are approximately 14 acres of woodlands held communally by the Sharingbrook Homeowners Association as a common green space. Individual landowners have also left woodlands as they occupy the floodplain. Overall woodlands consist of 173.96 acres.

In the north eastern corner of the watershed there is a small patch of turf grass maintained by a private landowner. Overall this 5.64 acre patch has little influence on the watershed as a whole.

The north central portion of the watershed is dominated by a golf course that is in the process of being surrounded by single family residential housing. Currently, 338.78 acres of the watershed are dedicated to this use. A more traditional 35.72 acre park with sports fields and golf courses is located at the outlet of the watershed.

The lower half of the watershed is dominated by single family residential. Of the 379.42 acres there are three densities of housing: ¼ acre lots, ½ acre lots, and 1 acre lots. For entry into the TR-55 model the different densities were averaged as ½ acre lots for the entire SFR section.

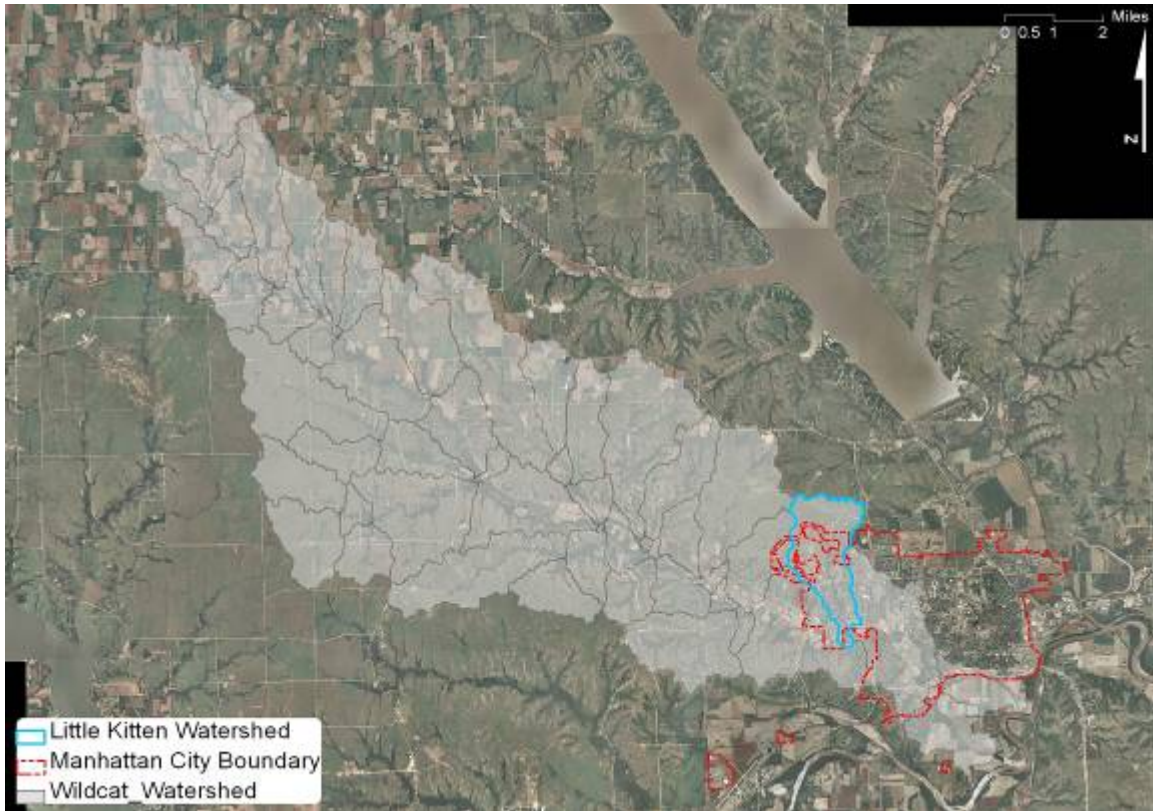


Figure 12 - Little Kitten Creek Watershed within Wildcat Creek Watershed [Data Sources: City of Manhattan, KS; Image Data: 2005]

Little Kitten Creek is situated on the current edge of the city of Manhattan. For residents living in the watershed this urban fringe relationship is a double edged sword. The beneficial aspects of living on the edge affords home owners direct contact and aesthetic views of farmland and natural areas. The fact that these characteristics are desirable encourages new development, which in turn creates a new urban edge, engulfing the previous natural edge. As the percentage of impervious surface increases

with development in Little Kitten Creek, so does the impact on the hydrology of the entire Wildcat Creek watershed.

Basic Hydrology

As water falls to the earth in a rain storm, water drains as a sheet; some percolates into the soil adding to the groundwater, and some collects and forms streams. Eventually the surface water and ground water end in a river, lake or ocean. The water is then heated by the sun and is evaporated back into the atmosphere ready to fall again as rain or snow as illustrated in Figure 11. In Manhattan, Kansas most water in streams comes from storm events, with very little influence from winter snow melt. Main factors that determine how much of the water percolates to ground water and how much collects into streams are land cover and soil type.

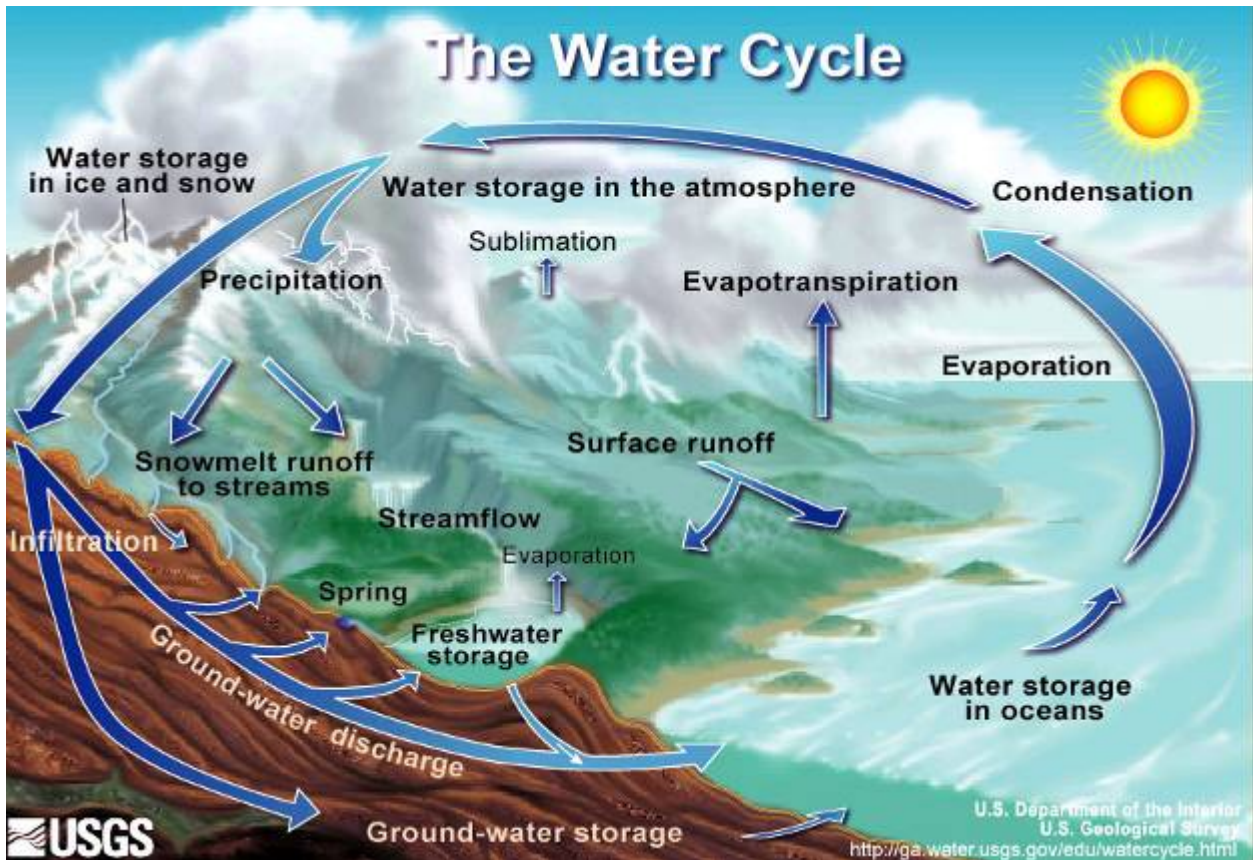


Figure 13 – The Hydrologic Cycle [USGS, 07]

Modeling Hydrology

In attempts to quantify the hydrologic cycle many models have been created to simulate hydrologic processes and physical characteristics of this system. Of interest to this study are the HEC suite of models created by the U.S. Army Corps of Engineers.

HEC [Hydrologic Engineering Center]

The complexity and impact of the hydrologic cycle has led to the development of models that attempt to simulate hydrologic processes so as to understand how the alteration landscapes is impacted. One group responsible for the development of many prevalent models used today is the U.S. Army Corps of Engineers (Corps) at the

Hydrologic Engineering Center (HEC). The history of the USACE's HEC dates to the 1960's. In 1964, engineers who started working for the Corps following WWII were beginning to come on retirement age. In order to prevent the loss of expertise and knowledge this cohort possessed HEC was created. Initially HEC set out to train upcoming engineers and set out to develop the suite of HEC software. Early versions of software dealt with watershed hydrology, river hydraulics, reservoir analysis for conservation, and the stochastic stream flow generation program [United States Army Corps of Engineers, 05]. Of these programs this study will utilize Hydrologic Modeling System (HMS) and River Analysis System (RAS).

HMS [Hydrologic Modeling System]

As part of the most recent suite of software produced by the Corps, HEC-HMS is used to calculate precipitation and runoff volumes of watersheds. The program is able to model "large river basin water supply and flood hydrology, and small urban or natural watershed runoff, useful for decisions where an understanding of water volume is essential such as future urbanization impact [United States Army Corps of Engineers, 06]. The program outputs hydrographs (which show the relationship between flow volume versus time, with special attention given to the peak flow) ready for use in other programs, such as HEC-RAS.

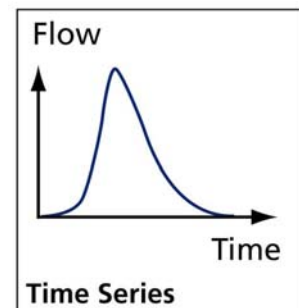


Figure 14 - Typical hydrograph [Maidment, 02]

GeoHMS

This extension of HMS is for use with ArcView GIS. GeoHMS analyzes digital terrain data to create a digital watershed with drainage paths and watershed

boundaries. This data is then prepped for import into HEC-HMS. The benefit of this program is that it greatly reduces the amount of time necessary to complete an HMS model because it builds the digital watershed from data nationally available in a GIS format.

RAS [River Analysis System]

The HEC-RAS software was developed by the Corps as part of the “Next Generation” phase [U.S. Army Corps of Engineers, 06]. As part of this software HEC-RAS receives input data of water runoff calculations, in the case of this study from the HEC-HMS produced hydrographs, and applies that information to compute a three dimensional flood volume. Necessary information to complete the model consists of river channel information such as cross sections, culverts, bridges and other surface feature data.

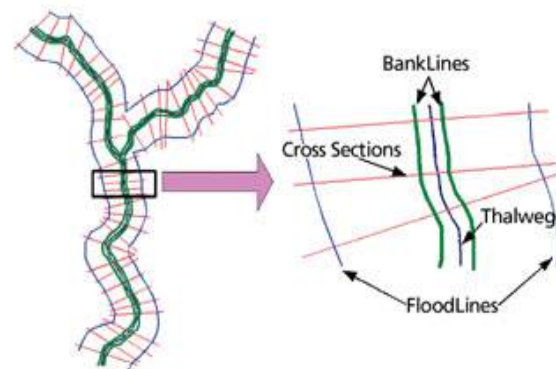


Figure 15 - HEC-RAS utilizes topographic data found in cross sections. [Maidment, 02]

GeoRAS

A new addition to the HEC-RAS suite of software was released fall of 2005. This program allows generation of surface data information from existing GIS data such as digital elevation models and exports this information into the RAS program thereby streamlining the model creation in a process similar to GeoHMS.

TR-55 [Technical Release 55]

Technical Release 55 (TR-55) is a computer program that presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable in small watersheds, especially urbanizing watersheds, in the United States. First issued by the Soil Conservation Service (now known as the Natural Resource Conservation Service or NRCS) in January 1975, TR-55 incorporates current NRCS procedures. This revision includes results of recent research and other changes based on experience with use of the original edition. Limits on inputs of the program include NRCS type distributions, 24-hour duration rainfall, 10 subwatersheds, minimum 0.1 hour and maximum 10-hour time of concentration. Used in tandem with HEC-RAS, TR-55 was used to calculate the time of concentration (T_c) by evaluating the infiltration rates of the various land cover types and the channels that collect the runoff.

GIS and Hydrology

Geographic Information Systems (GIS) have the unique ability to process and handle attribute as well as location data. There are four main components that make up a GIS: hardware, software, trained users and spatial data. Hardware consists of a computer workstation including input devices, monitors, storage etc. GIS software typically runs on Microsoft Windows based personal computers, but some will also work with UNIX based systems. Two popular GIS software packages are ArcGIS a commercially available program from ESRI and a freeware program called GRASS maintained by Baylor University.

A Brief History of GIS

Beginning in the 1970's GIS was used for natural resource management issues such as land-use planning, natural hazard assessment, wildlife habitat analysis and timber management. Recent developments in GIS have led to additional uses such as crime mapping and analysis, emergency planning, land records management, market analysis, utility management, and transportation planning [Chang, 05].

The most widely used GIS software packages are ArcInfo and ArcView created by ESRI in Redlands, California. ArcInfo dealt with points, lines, polygons (vector data), tabular attributes, raster or grid surfaces, and triangulated irregular networks (TIN). In the early 90's ArcView was added to the lineup of programs, initially developed for simple storage and viewing, but later was modified to perform simple spatial analysis and modeling [Maidment, 02]. In the early 2000's ESRI reengineered the software and developed the ArcGIS suite of programs. This program came with different degrees of functionality based on user needs. One major development was the way in which the software handled the data; the program migrated toward an object oriented framework. This allows the software to be customized within a basic framework, using information technology and software engineering standards [Maidment, 02].

Another major development in the ArcGIS suite was the advent of the geodatabase. The geodatabase is a spatially referenced relational database that allows spatial features and data about features to be related. The geodatabase deals with the same data types that ArcInfo does: points, lines, polygons, tabular data, rasters, and TINs. The difference is that within a geodatabase features with different data types (points, lines and polygons) can be stored in a single collection called a feature dataset.

Feature datasets allow relationships to exist between features. As an example, a point representing a stream gauge can be related to a line representing a stream and both be related to a polygon representing a watershed area within a single feature dataset.

Another advantage is that the data within a geodatabase is organized in one file location by a database file: a Microsoft Access file or enterprise database. This greatly enhances the portability and use of data.

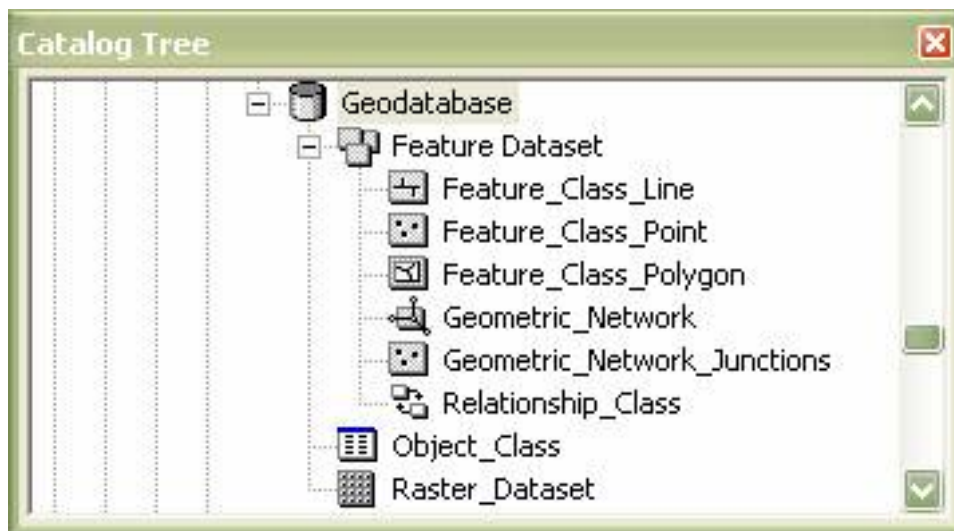


Figure 16 - Hierarchy of a geodatabase

The hierarchy of a geodatabase starts with the geodatabase itself which consists of a Microsoft Access .mdb file or enterprise geodatabase such as Oracle, Informix or DB2. Within the geodatabase, feature datasets are created to store features that are related to one another. One unique and useful aspect of the feature dataset is that it establishes a geographic boundary for the data found within the feature dataset (all data coordinates within the feature dataset must be within this geometric boundary). Feature datasets contain feature classes which consist of point, line, and polygon feature classes, geometric networks (which model linear networks), geometric network junctions (location where segments of a geometric network intersect), relationship

classes (which stores relationships between entities in two object or feature classes), and object classes (which is a table with a behavior) [Zeiler, 99]. Geodatabases also store tabular object classes or tables of attributes about features, raster datasets, tin datasets and terrain datasets in ArcGIS 9.2.

Advances in relational databases and computing technology are facilitating the development and use of GIS to create virtual models of spatial features that more closely match physical relationships of real world phenomenon, such as a watershed. Using the geodatabase framework, data models are being developed to more accurately represent relationships between real world phenomena in standardized formats.

Hydro Data Model

The adoption of the object oriented approach to GIS, allowed the creation of a customized hydrologic data model (or schema). Hydro is the data model framework created jointly by teams at ESRI and the Center for Research in Water Resources at the University of Texas at Austin available at the following url:

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

David Maidment, leader of the team at the University of Texas summed up the Hydro data model best: “Arc Hydro is a data structure that supports hydrologic simulation models, but it is not itself a simulation model. Hydrologic simulation is accomplished by exchanging data between Arc Hydro and an independent hydrologic model, by constructing a simulation model attached to Arc Hydro using a dynamic linked library, or by customizing the behavior of Arc Hydro objects” [Maidment, 02]. The data model is composed of five main datasets: network, drainage, channel, hydrography, and time

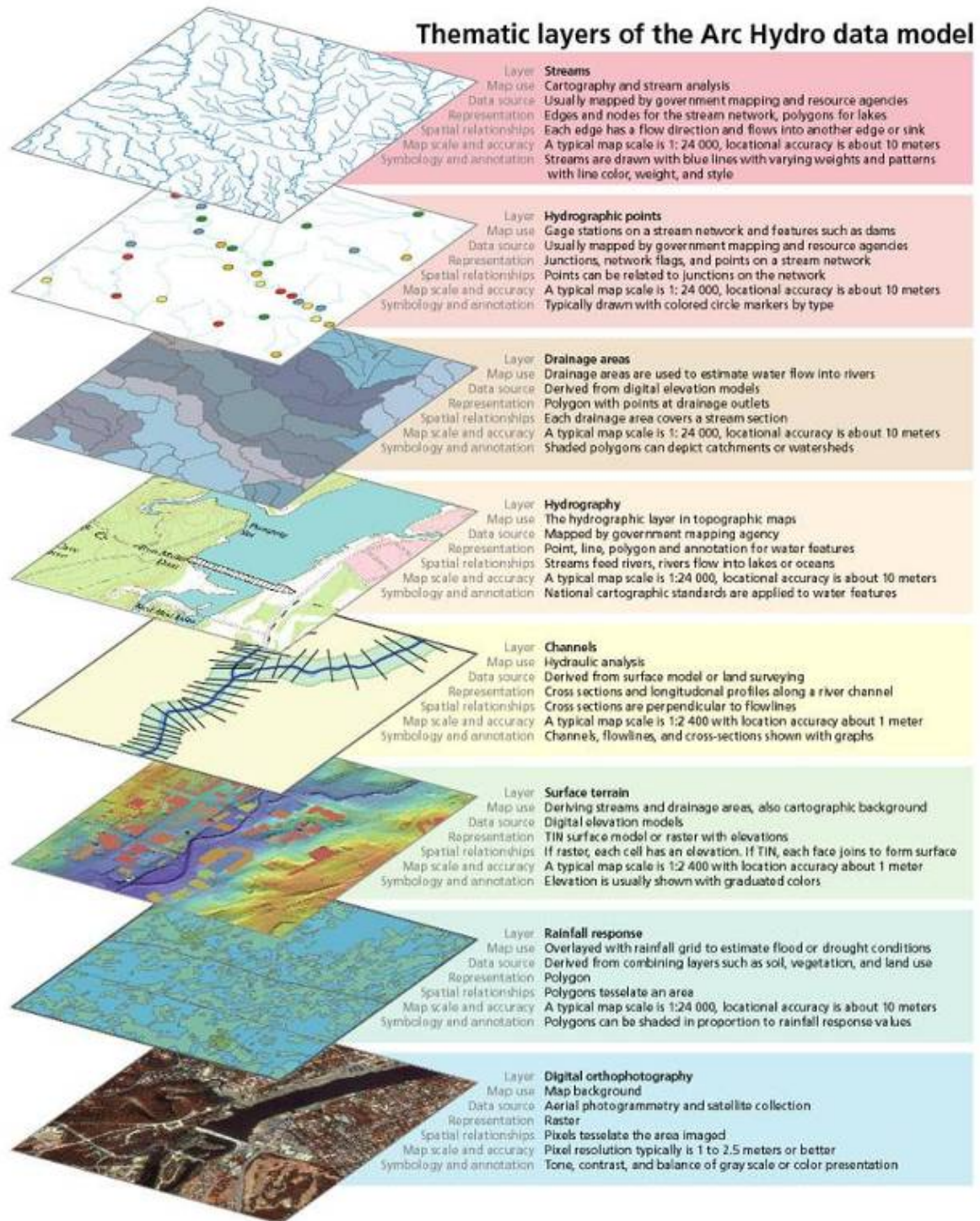


Figure 17 - A graphic depiction showing map layers of the Arc Hydro data model [Maidment, 02]

series illustrated as traditional GIS thematic layers in Figure 17 and in overview form in Figure 18.

ArcGIS Hydro Data Model

<http://arconline.esri.com/arconline/datamodels/water.cfm>

<http://www.crrw.utexas.edu/giswr>

*GIS in Water Resources
Consortium*

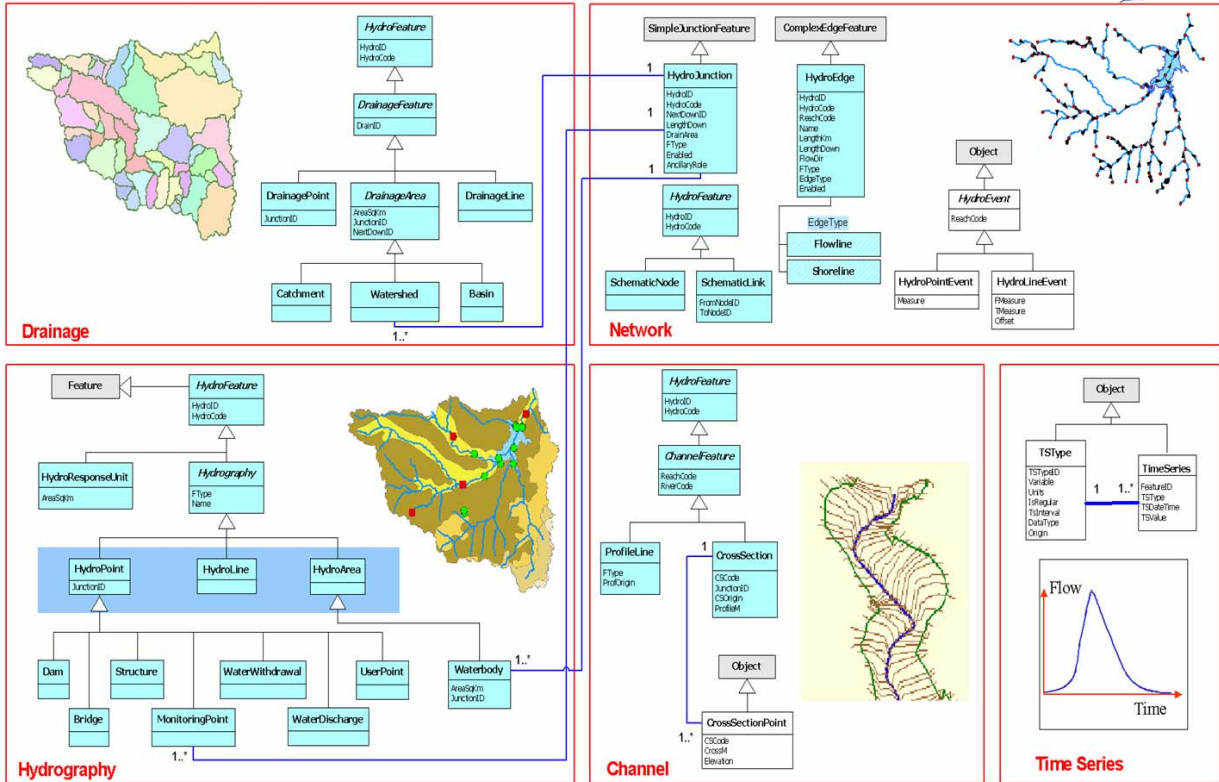


Figure 18 - Overview of Arc Hydro Data Model [Maidment, 02]

Network

Called the “backbone” of Hydro, hydro networks are the edges and junctions of a hydrologic system. Integral to this network is the topology of the system, i.e. which direction water flows in a stream. Hydro junctions establish between stream reaches and points of connectivity with waterbodies, stream gauges and other features. Hydro

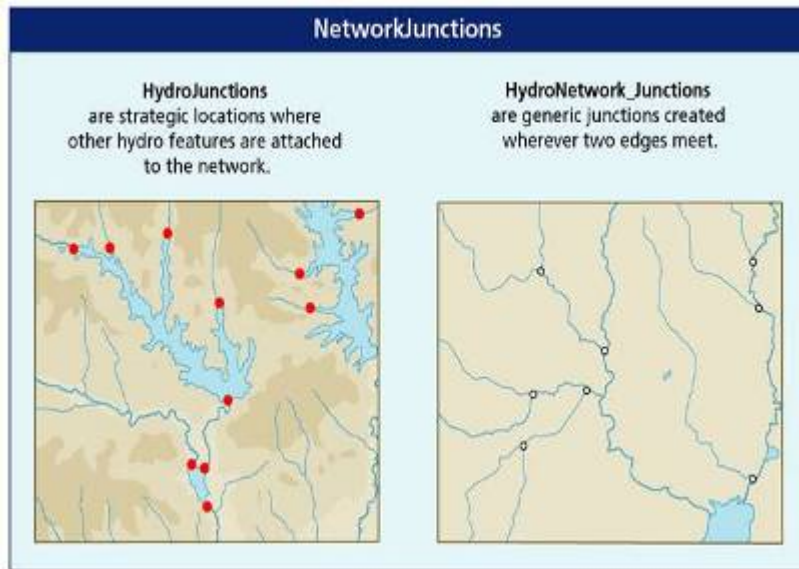


Figure 19 - Hydro junctions and hydro network junctions mark the location and relationship between members of the hydro network (Source: Maidment,

network junctions establish the location of convergence points of stream reaches and create upstream/downstream relationships.

Drainage

When water falls to the earth land surface topography determines the direction water moves. Water not infiltrated in the soil flows as a sheet over the landscape surface, collects into stream reaches, which increase in size until ultimately the water reaches an ocean or until it evaporates. DEM's (digital elevation models) are a raster or cell based method of



Figure 20 - DEM of Little Kitten Creek Watershed

representing 3D landscape topography. Each cell in the raster represents a surface area with the values of each cell representing elevation. Figure 20 is a DEM of Little Kitten Creek, the lighter cells represent the highest elevations in the DEM and the darker cells represent the lowest elevations. The resolution, or cell size of rasters varies from high resolution (<10m x 10m) to lower resolution (>30M x 30m). Higher resolution DEMs more accurately represent the land surface, but they are only available in limited areas (see U.S.G.S. Seamless Data Server <http://seamless.usgs.gov/> for availability).

DEMs are used to derive stream networks and watershed boundaries. Each cell of the DEM is analyzed to identify which direction water will flow off the cell, and once a specified number of cells flow to a cell a stream is formed. Once the streams are formed, each area that contributes to stream flow can be delineated as catchments.

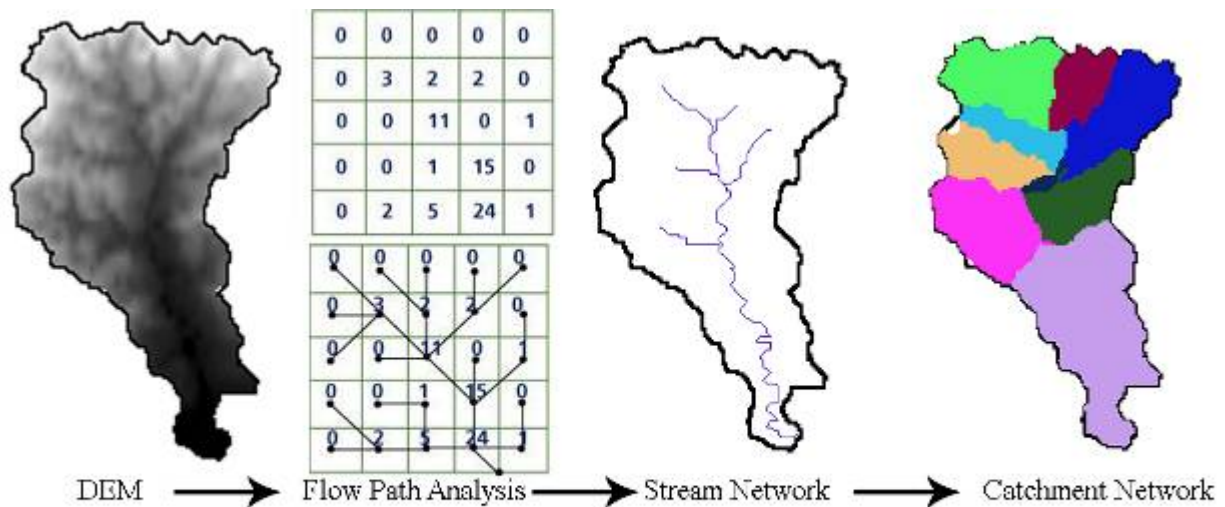


Figure 21 - Drainage systems comprised of a stream network, catchment network which are derived from a DEM.

Channel

In Arc Hydro, the channel itself is composed of a network of cross section lines representing the three dimensional land surface. On smaller streams these cross sections are derived from field measured surveys, and at larger scales they can be derived from high resolution DEMs. Cross sections are used in river morphology to understand erosion and depositional trends. Flood based models use cross sections to determine the extent of water during flood events.

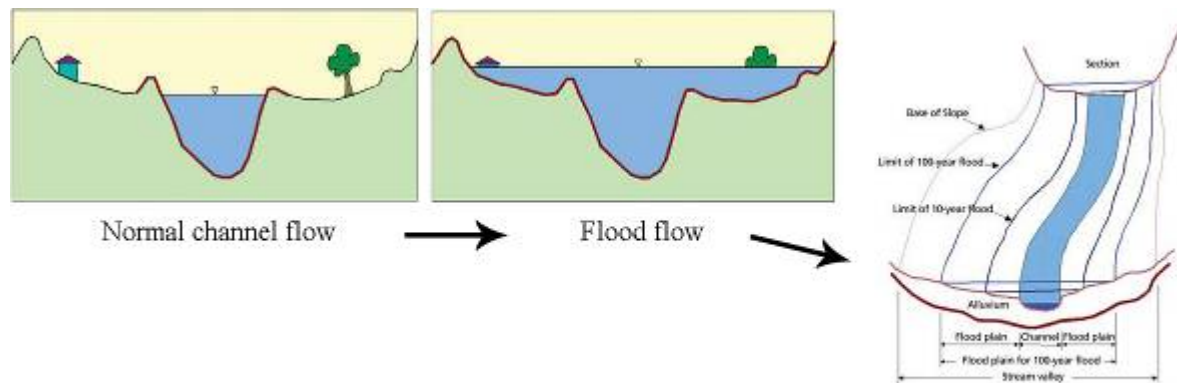


Figure 22 - Channel cross sections used to visualize normal and flood flows, as well as model a three-dimensional cross section network [Maidment, 02]

Hydrography

Hydrography is a geographic or map representation of spatial position of all types of water features. Such features include not only streams, rivers and lakes, but also swamps, wetlands, and structures such as dams, locks and bridges. Various classification systems exist and because of this various theories are used to organize the data. Hence there are multiple ways in which maps depict these features. The Hydro data model provides a framework to organize and classify hydrographic features illustrated in Figure 17. Applying the data model allows these geographic features to be relatable to each other and to a watershed or catchment area. The geodatabase and

Hydro schema utilizes existing data commonly available as points, lines, and polygons in ArcInfo coverages and shapefiles and easily incorporates the data into feature datasets in a geodatabase using automated processes.

Time Series

Many streams throughout the United States are monitored with stream gauging stations which collect data on precipitation and stream flows. This data can now be downloaded (<http://seamless.usgs.gov/>) and related to spatial data at hydro junctions in the Hydro geodatabase. Arc Hydro provides a spatial temporal framework that may be incorporated into hydrologic models. This spatial temporal framework, new to GIS, allows a spatial representation of storm events through time. Modelers can now apply this feature to flood analysis by using time series data to calculate total discharge into rivers from a storm event, not just at the end of the storm, but during the storm. This is an important feature because most storm events produce the highest amounts of rainfall at the beginning of the storm. Understanding this factor is critical when modeling flood events. [Maidment, 02].

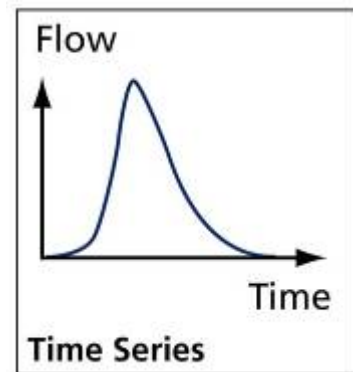


Figure 23 - Typical hydrograph showing flow is highest at the beginning of a storm (Maidment, 2002)

Arc Hydro organizes hydrologic networks, drainage features, river channels, hydrography, and time series features related them to each other in a standardized manner. This standardized organization provides a common language among users of hydrologic data and models, and it also allows for cross communication between hydrologic models.

Modeling Hydrology and Hydrologic Events in GIS using the Map to Map Model

The Map to Map model was created by David Maidment's team at the University of Texas' Center for Research in Water Resources (CRWR). This model incorporates the ArcHydro data model and takes advantage of the standardized nature of the data model allowing the Map to Map model to serve as the central hub of a rapid floodplain analysis [Robayo, 05]. Originally the model was built to be able to create the next generation of FEMA flood maps. Future developments of the model will incorporate groundwater aspects as well as real time flood forecasting with live connection to NEXRAD rainfall data. The model is run using the Model Builder program in ArcCatalog from the ArcGIS suite.

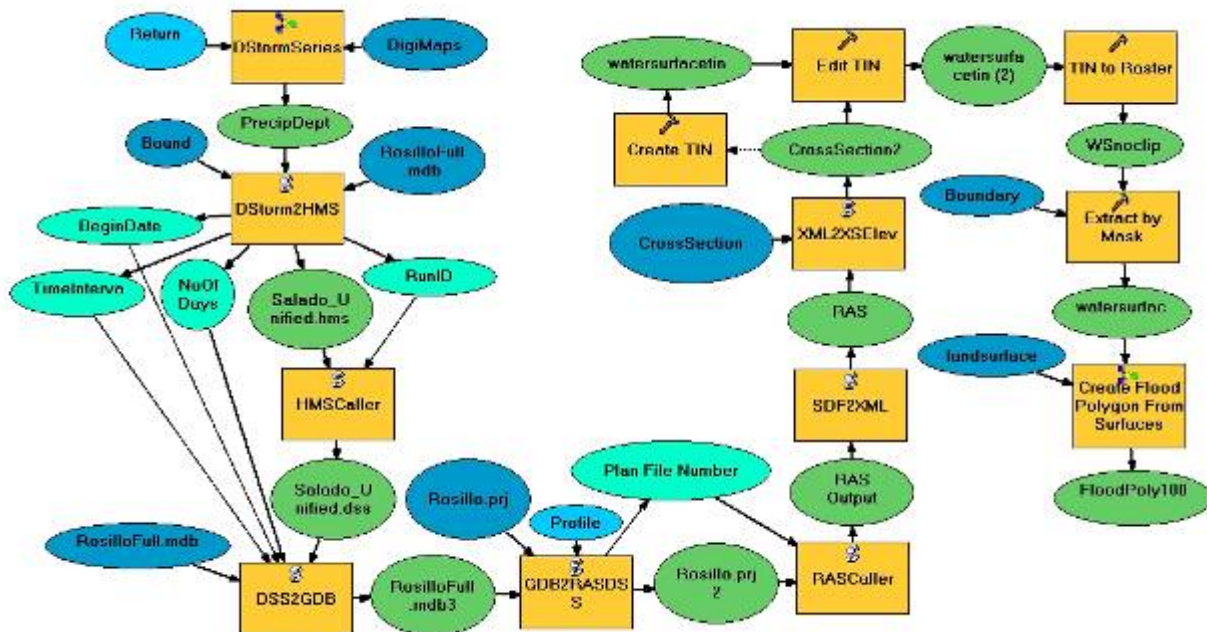


Figure 24 - The Map to Map model. Blue circles represent inputs, yellow squares are processes, and green circles are outputs [Maidment, 04]

User generated inputs of the model deal with hydrology, topography/bathymetry, land use, and soils. The model uses customized Visual Basic scripts to call on external hydrologic models (HEC-HMS, HEC-RAS), and then incorporates data from those models back into the ArcHydro geodatabase. Floodplain maps based on the inputs from the external models are created in the GIS. Once the initial framework of the geodatabase for a watershed is created it is then possible to run various scenarios for rapid assessment of impacts from various events such as severe storms or changes in land use.

Methodology

This case study utilizes the Map to Map model, originally developed for Rosillo Creek, Texas, to analyze the hydrologic impacts of continued development in the Little Kitten Creek watershed on existing development. The case study involved investigation of the implementation of the model on Rosillo Creek in Texas, data collection for Little Kitten Creek, assembly of a geodatabase and implementation of the Arc Hydro data model, creation of hydrologic models using HEC and TR-55 which are called in the run of the Map to Map geoprocessing model to determine flood extent in the 3D terrain model based on existing land use and then comparing to proposed land use changes in a second model run.

To accomplish the goal of implementing the Map to Map model it is first necessary to collect data of Little Kitten watershed and apply the Hydro data model. From this data a basic geodatabase is created using the data preprocessing tools in ArcMap. Now in the geodatabase format the data is preprocessed for the Hydro Data Model, and further manipulated to fit the Hydro schema. Basic HEC-RAS, HEC-HMS,

and TR-55 models complete the data preparation. Once the data for the watershed is in the Hydro data model format with the Hydro schema applied, the Map to Map model can be implemented. The Map to Map model combines geographical information systems (GIS), a hydrologic geodatabase utilizing the Hydro schema, TR-55, HEC-RAS and HEC-HMS hydrologic models to predict stormwater flooding based on changes in land use. The goal of this case study was to demonstrate if the Map to Map model could accurately predict flooding in the Little Kitten Creek watershed and ultimately to show the usefulness of the Map to Map model as utilized in planning and design processes to improve landscape assessment and intervention and potentially solve life cycle design challenges related to hydrologic system.

To accomplish these goals a framework geodatabase, or computer model of Little Kitten Creek was built that facilitates analysis and prediction of water resources in the watershed using Arc Hydro and other hydrologic models. Some of the specifics that the model will address are: water volumes, flooded area, and how different land covers alter these factors. The hydrologic framework and analysis of Little Kitten Creek watershed can also demonstrate how GIS can be used by landscape architects and communities to better understand water resources and the effects of development on natural and cultural resources within the watershed. The geodatabase framework implemented in this study can be directly shared with planners and designers on future projects as it can be added to existing web-based community GIS resources.

The Map to Map model requires six input datasets of the study area prepared prior to implementing the model to produce a floodplain map. These datasets are (1) a Hydro based geodatabase of Little Kitten Creek, (2) a HEC-RAS project file, (3) a

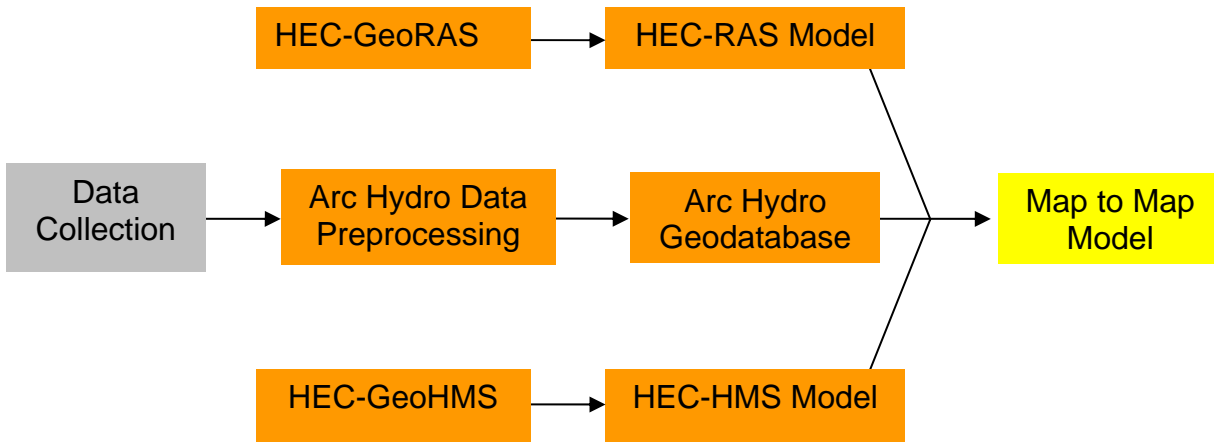


Figure 25 - Overview of methods necessary to complete Map to Map Model

HEC-HMS project file, (4) time of concentration, obtained from TR-55 model, (5) high resolution cross sections, and (6) a rainfall raster. Figure 25 overviews the process used to complete this study:

Data Collection

To facilitate use of the Map to Map data model one intent of this study was to create flood maps of Little Kitten Creek using data publicly and freely available for downloading from nationally available geoportals. GIS datasets are available from the United States Geological Survey (USGS) for the required thematic layers shown in Figure 17. Table 1 (next page) illustrates the data types and sources for standard datasets.

Table 1 - Data needed for Pre Processing Steps

Data Collection		
	Source	Resolution
Elevation Data	USGS NED – http://seamless.usgs.gov/	30 meter
Hydrologic Data	USGS NHD – http://nhd.usgs.gov/	Medium
Cross Section Data	Survey	< 10 meter

Elevation data was downloaded from the USGS Seamless data server in a grid or raster format with 30 meter resolution, meaning pixel sizes represent a 30 x 30 meter ground location. This resolution worked fine for the purpose of general delineation of the watershed. However, a finer resolution 10 meter data set available for some parts of the United States, but not this study area, would be preferred. Figure 26 illustrates the 30 meter NED DEM for the Little Kitten Creek Watershed.

Medium resolution hydrologic data was downloaded from the NHD server in a geodatabase format. Medium resolution was used because high resolution was not available for this watershed. The specific feature of interest the U.S.G.S. NHD dataset was the Flowline, which represents the stream networks. Again it is possible to use a higher resolution file, but at the time of this study it was not readily available for downloading. Figure 27 illustrates the NHD medium resolution hydrology data for the Little Kitten Creek Watershed.

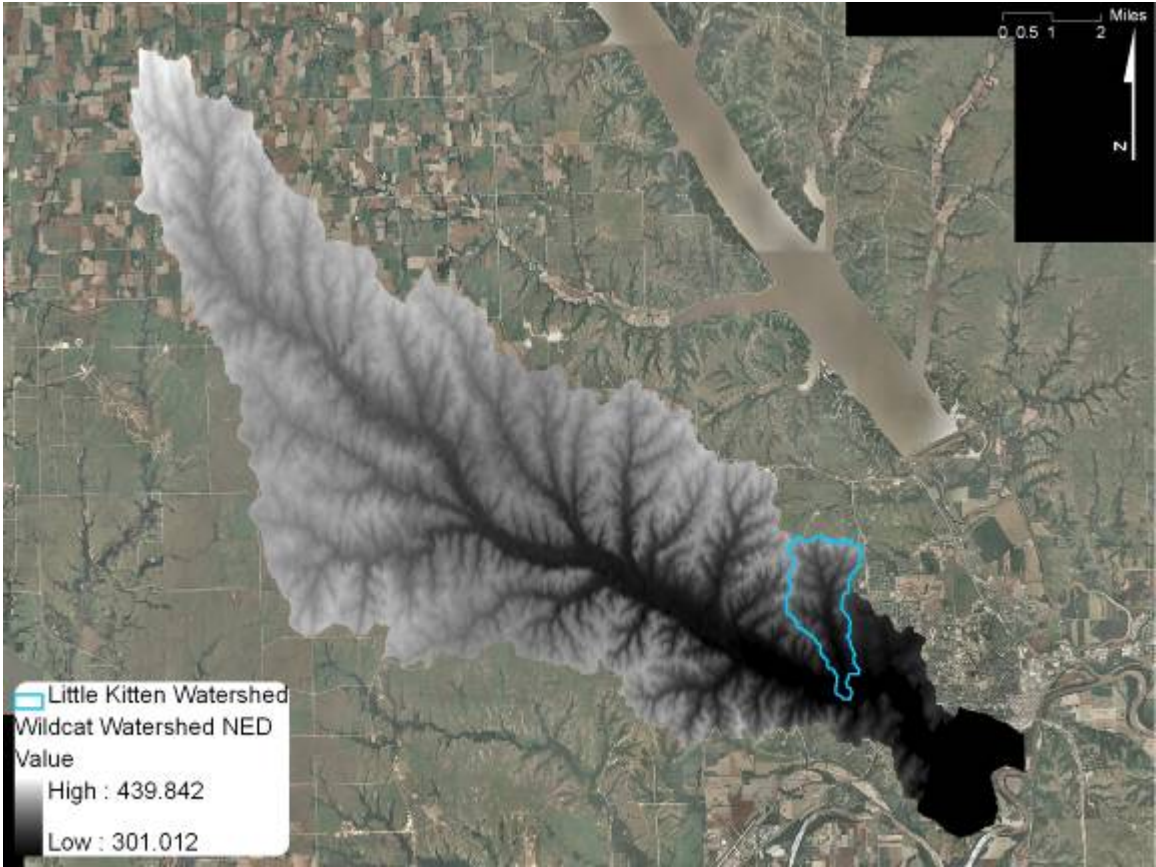


Figure 26 - Little Kitten Creek and NED data from the USGS Seamless Dataserver

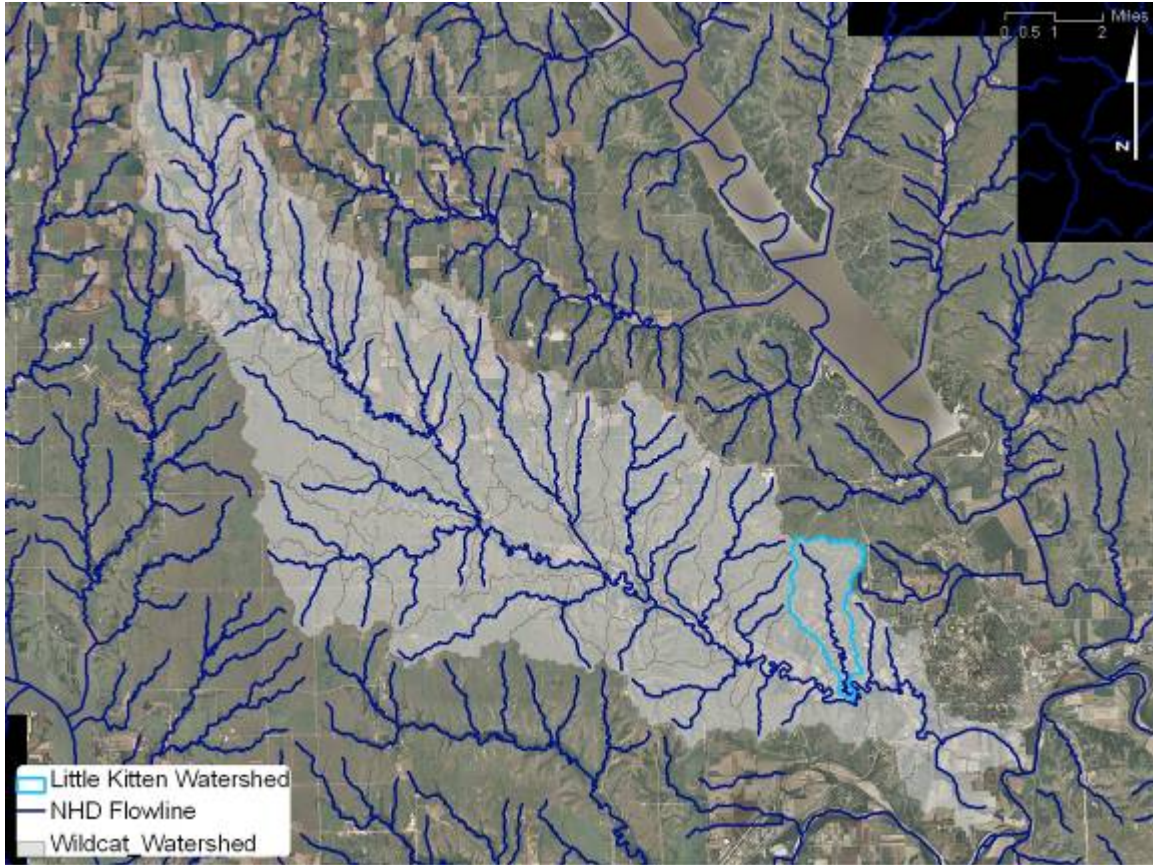


Figure 27 - Little Kitten Creek and NHD Data (Flowline)

Geodatabase Preparation

The hydrologic geodatabase created for the Little Kitten Creek watershed is essentially a model attempting to digitally replicate physical features and properties such as topography, stream networks and watershed boundaries and how water collects in, and flows through, the stream network. This computer model allows a representation of reality that can be use to simulate various design decisions and the hydrologic consequence of each.

Earlier in the paper we followed a rain drop on a journey through the watershed, all the way from when it fell in the uplands, flowed into a stream and ran down to the

bottomlands and outlet point. Similarly as this digital watershed is created, water will follow the journey of a real raindrop through a virtual model.

Data Preprocessing

The Arc Hydro geodatabase is a spatially referenced database that establishes hydrologic relationships between data features. Because these relationships are specific, data input into the geodatabase (raw elevation, hydrography, and cross section data) must be processed to fit the format required by the Map to Map model and the Arc Hydro schema. The coordinate system and projection used in the study was GCS North American 1983. The output extent is a rectangular geographic boundary required by the geodatabase that was set to include the entire watershed to avoid geodatabase processing errors.

With the output extent established the raw data relevant to the study was processed into the geodatabase. To process the raw NHD and NED data, Terrain Preprocessing tools were used, see Figure 28. These Terrain Preprocessing tools were added as toolbar to the ArcGIS program. Figure 29 illustrates the process and results of preprocessing steps with a brief discussion of specific preprocessing tools used and the outputs necessary for this study following. For specific methods used for the preprocessing reference either the tutorials found in Appendix B or the GISHydro 2006 website (<http://www.cwr.utexas.edu/gis/gishydro06/>).



Figure 28 - Arc Hydro terrain preprocessing tool bar

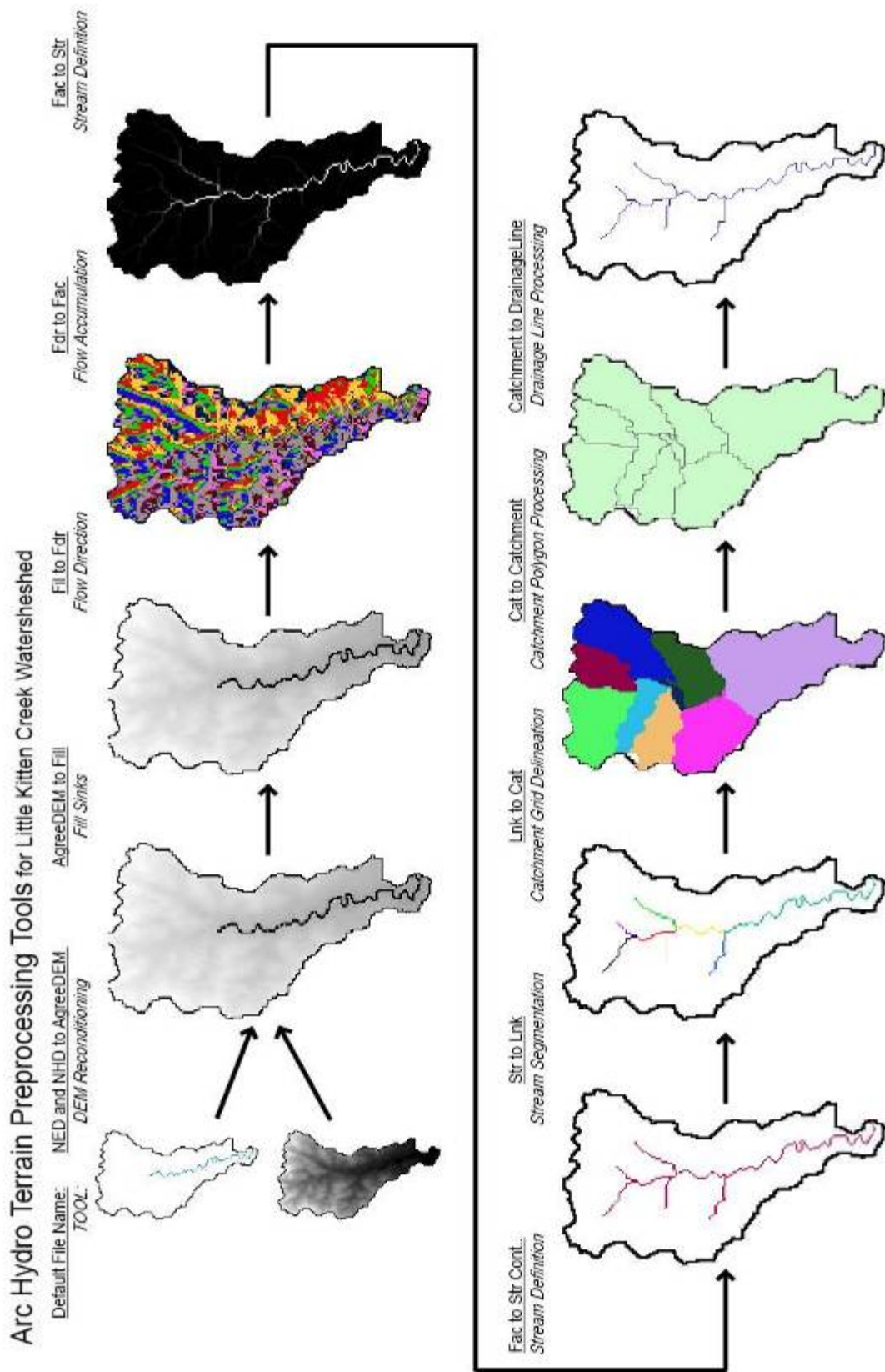
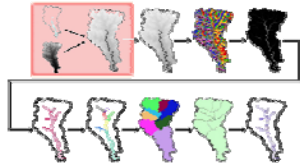


Figure 29 – Arc Hydro Terrain Preprocessing Tools

DEM Reconditioning



Before the digital raindrop starts the journey two datasets, NED and NHD data, are joined combined to accurately represent where water will flow. This is done by using the DEM reconditioning tool to “burn in” the NHD flowline data into the NED. This step exaggerates the stream channel flowline so that the location of the stream channel is clearly identified. With this step complete the NED surface, although not vertically accurate, will correctly show the location of known stream channels. This step is necessary because the 30 m resolution of the NED data available for this area is too coarse and only allows the largest rivers to be adequately illustrated. The topography of smaller channels is lost because the 30 m cell size of the NED is too large given the actual Little Kitten Creek stream channel width of 5 to 30 feet. It was therefore necessary for this study to modify the DEM by emphasizing within the data the location of the stream bed. Results of the “burn-in” process are shown in Figure 30. Note: after the reconditioning, it is not recommended to use the reconditioned NED for elevation relevant processes because the reconditioning renders the NED inaccurate in this aspect.

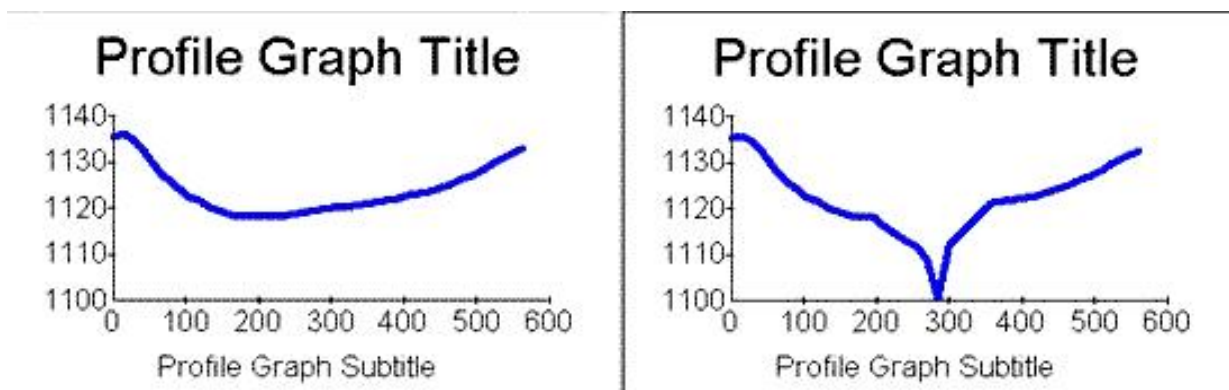


Figure 30- Profile of NED that has had the stream channel “burned into” the surface [Maidment 02]

Fill Sinks



One more step is required to prepare the NED surface before it is ready for the raindrop. This step fills in any low data values

that form depressions or low spots found in the surface so the digital water can flow unimpeded across the surface. Conversely rises or peaks in the data are also removed to allow water flow in the digital model. If left unmodified both the depressions and peaks would prevent accurate calculation of how much water would accumulate and where it would flow. It should be noted that this process creates a NED surface that is not topographically accurate.

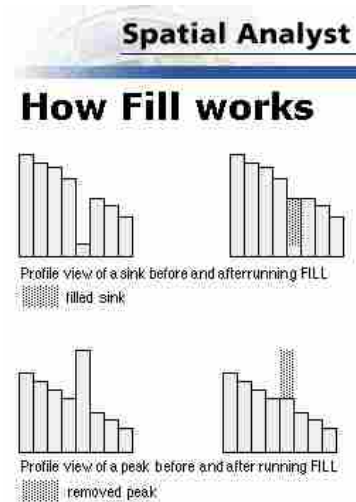


Figure 31 – Fill Sinks step fills low spots and removes peaks found in the elevation surface [Maidment, 02]

Flow Direction



The surface is now ready for the digital rain. Each cell on the surface of the NED has an elevation value associated with it.

Each cell is also surrounded by cell by know elevation. So as the digital rain falls onto the surface this process calculates where water will flow from one cell to the next. For example in Figure 32 when rain falls on the cell in the middle that has an

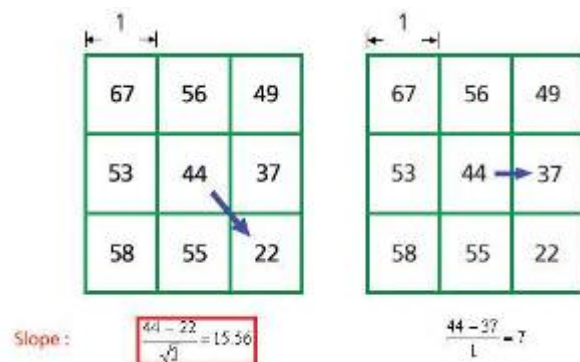
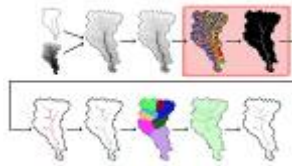


Figure 32 - Flow direction evaluated on a cell by cell basis, with flow direction moving from cells of higher elevation to those of lower elevation [Maidment, 02]

elevation of 44 the lowest elevation cell is the cell with an elevation of 22. This process is repeated for each cell. Now the model knows which way is downhill, and it is commonly known that water flows downhill.

Flow Accumulation



Once flow direction of the digital water on the surface is calculated, the flow accumulation tool can

determine amounts of cells flowing onto one another and which cells accumulate water to define a stream or flowline.

For example, in Figure 33 the black lines represent the flow

direction, or which way is downhill, and each cell is given a number based on how many cells flow into it. As a result the higher the number the cell the more digital water will accumulate in that location.

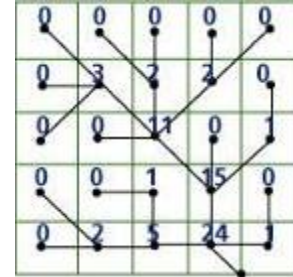


Figure 33 - Flow accumulation is determined by the total number of cells contributing to down stream cells [Maidment, 02]

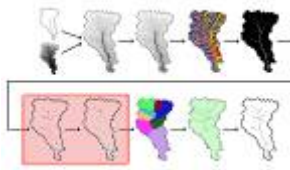
Stream Definition



Using the flow accumulation cell values the stream definition tool generates a new raster map of the watershed with locations of high water accumulation and identifies it as a stream. The user

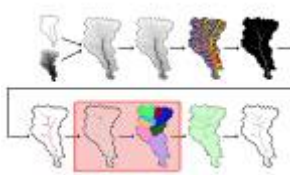
defines the total number of cells required to start a stream. For the Little Kitten Creek watershed of the stream channels were started in cells that had an accumulation value of 1000. That means 1000 cells will contribute digital water to that cell. This number is somewhat arbitrary because even in the physical world it is difficult to pinpoint exactly where a stream channel starts. See Figure 29.

Stream Segmentation



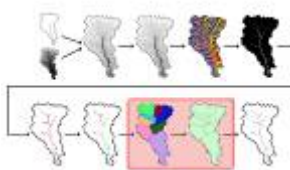
As the name implies this tool creates a new map that identifies each individual segment or reach within the stream network based on the flow accumulation result. See Figure 29.

Catchment Grid Delineation



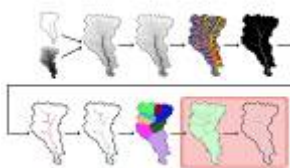
With each stream segment defined this step creates a map of catchments. Each catchment is all the area that drains into a single stream segment. Up to this point the preprocessing steps are essentially complete, the only steps left are to convert the grid based data into vector format. See Figure 29.

Catchment Polygon Processing



The catchment polygon processing step converted the cell based catchment grids into polygon based areas, or vectorized them. See Figure 29.

Drainage Line Processing



After the catchment grid is vectorized, the streams, still in raster format, are converted to continuous lines using the drainage line processing tool. See Figure 29.

With the data preprocessing complete, the geodatabase of the watershed now models the terrain surface and stream locations with accurate representation of the catchments. The digital raindrop will now fall on a catchment and be directed to a stream segment, or reach, in the digital watershed.

Preprocessing for the Arc Hydro Data Model

The terrain preprocessing yields data derived from the DEM and NHD representing a digital watershed with stream segments and catchments prepared for a preliminary geodatabase format prior to applying the Arc Hydro framework schema. The next step is to ensure file names and data formats exactly match the Arc Hydro geodatabase schema to enable the schema wizard to automatically populate a template geodatabase with the preprocessed data. Network tools refine the preliminary geodatabase creating network junctions and a geometric network and are explained below.

Network Junctions

Using the drainage line data derived from the NED/NHD preprocessing steps, junction features (points) are where branches of the stream network start, intersect, and end are built with the Geometric Network tool in ArcCatalog.

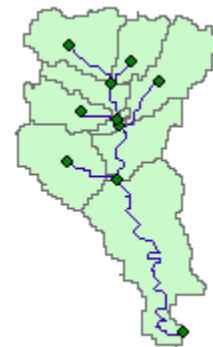


Figure 34- Network Junctions

Geometric Network

Next the geometric network tool is applied to create a “topologically connected set of edges and junctions. A geometric network is a type of graph that represents a one-dimensional network, such as a utility or transportation system” [Maidment, 02]. In the case of this study the one dimensional network is the stream network. The geometric network tool connects the stream segments, keeping track of points-where they start, end, and intersect each other and places each stream segment within a catchment. The geodatabase is now a model that will convey the digital water that falls in a catchment to the stream located in that catchment then down to be combined with water from adjacent catchments then on to the watershed outlet.

With the geometric network created the streams are then linked together and the digital raindrop can now flow from one stream segment to the next. The last step in this portion of the project is the creation of a highly accurate model (<10m resolution) of the stream channel itself. For a more detailed account of the process reference the Data Model Files- Tutorial One in Appendix C.

Arc Hydro Schema

Once the terrain data was preprocessed and the network tools applies the Arc Hydro Schema is implemented using the Schema Wizard Tool in ArcMap. The Schema Wizard Tool applies the Arc Hydro Schema to the newly created geodatabase. The schema establishes critical relationships and links between elements of the geodatabase. Specific relationships are in the network of streams and flow directions. To apply the Schema, refer to the schema application tutorial found in the Arc Hydro Data Model Files in the appendix. When applying the schema it is necessary to

exercise good GIS craftsmanship, following exactly the steps described, especially the use of terms and names of feature classes to be converted to the new schema. It is also necessary to establish an output extent that spatially encompasses the entire study area. For a complete list of relationships established for the geodatabase, refer to the ArcGIS Hydro Data Model in Appendix D.

Cross Sections

Cross section data is necessary for the digital model to accurately represent the topography of the stream channel itself used by the model to determine where water is located in 3D as it collects and moves through the watershed. During the study it was



Figure 35 - Surveying the channel of Little Kitten Creek

discovered that the 30 m resolution NED data was insufficient to locate and accurately represent the stream channel. Collecting data sufficiently accurate for cross section generation required the use of a field survey of the stream channel and the floodplain.

For this study a 1/3 mile section of the creek in the bottom half of the watershed was chosen to be surveyed. This section was chosen because the reach was relatively similar to most of Little Kitten Creek and the channel was observed to be in a state of balance, neither degrading nor filling in. The channel at this location also demonstrated little of the degraded gully like characteristics typical of urban streams in the region. This location was also chosen because existing single family homes were located in or near the flood plain and therefore more likely to be affected by potential stormwater increases resulting from upstream development. Upon speaking with residents of these homes many homes in this area had flooded.

Equipment for this survey included a Leica TC407 Total Station with a Carlson Explorer data logger. The survey was georeferenced using backsights to locally established benchmarks used by the city of Manhattan (Appendix E). Once the instrument was placed and backsighted points were collected at critical breakpoints cross sections of the creek including the floodplain, top of right bank, bottom of right bank, right edge of water, thalweg, and then the corresponding breakpoints on the left side of the creek. Cross section data points were collected at all major changes in direction of the channel, and every 30-50 feet. Collected points were downloaded and preprocessed using Carlson Xport and Autodesk Land Desktop (Appendix F). The survey point features were then added from the AutoCAD dwg file to ArcMap, and

converted to a point shapefile. Figure 36 illustrates survey data points, breaklines for banks and thalweg and surface model.

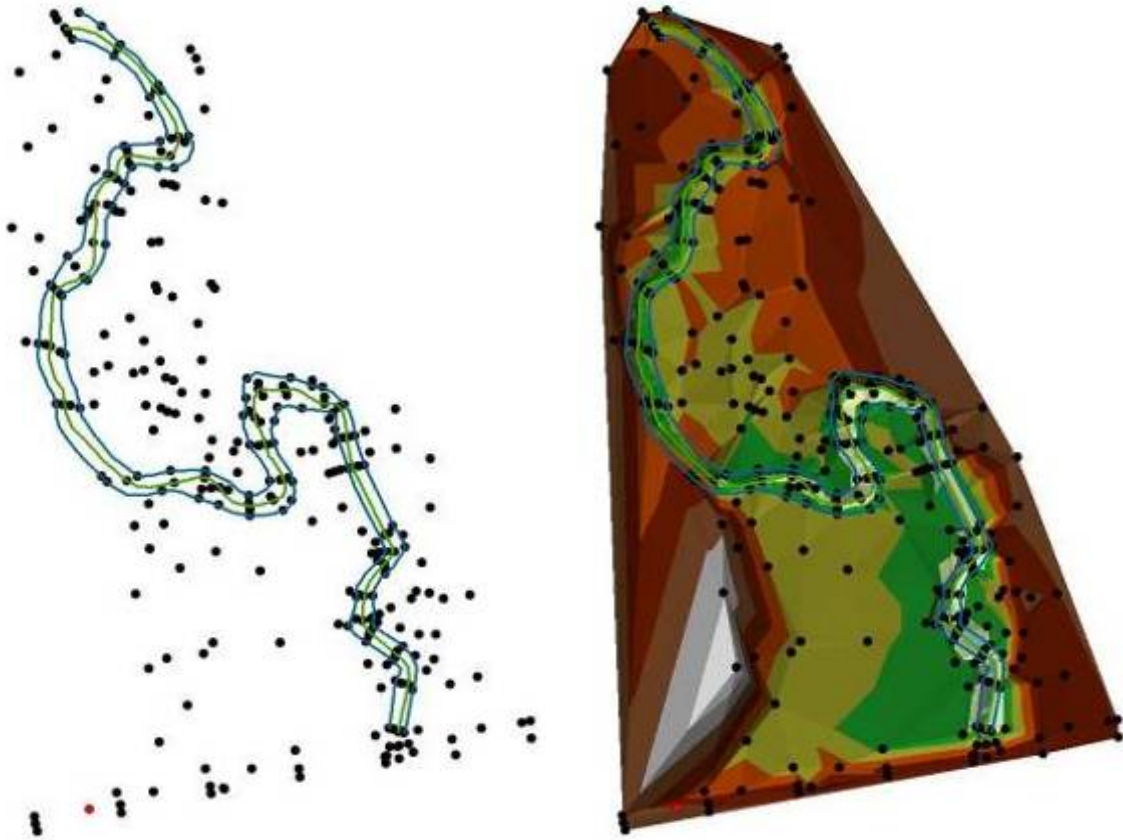


Figure 36 - Image on left: Survey points with banklines (blue) and thalweg (green); Image on right: TIN surface derived from survey points using bank and thalweg as breaklines in TIN surface generation

Using the 3D Analyst extension in ArcGIS the shapefile was used to create a three dimensional TIN (triangulated irregular network) surface. To create a more accurate surface of the stream channel itself breaklines of the right and left banks as well as the thalweg were created. Breaklines were derived from the survey points collected in the field at the left and right banks as well as at the thalweg. These breaklines were then integrated into the TIN and illustrated with green lines in Figure 36.

To create the actual cross section lines the data was exported for use in ArcView 3.2. This step was necessary because the tool to create the cross sections (HEC-GeoRAS) is only compatible with ArcView 3.2. Conversion of the TIN surface to a raster surface was necessary as the HEC-GeoRAS program extracts the elevation data

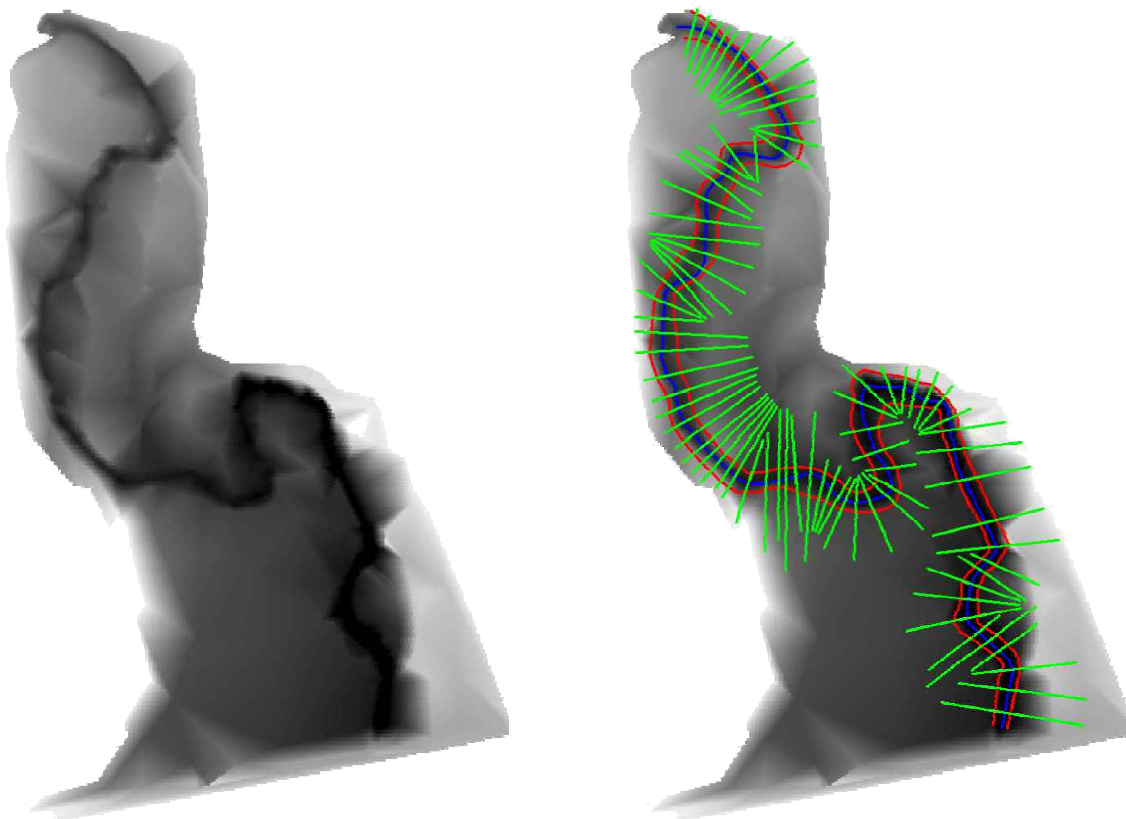


Figure 37 - Left: elevation raster derived from TIN; Right: manually digitized cross sections and profile lines

for the cross sections from a raster surface, not a TIN. Again using the spatial analyst extension the TIN surface is converted into a raster or grid. Over this raster surface two dimensional cross section lines are manually digitized perpendicular to the channel along the length of the surveyed section. The lines are placed at and even interval and every location where the channel changes direction.

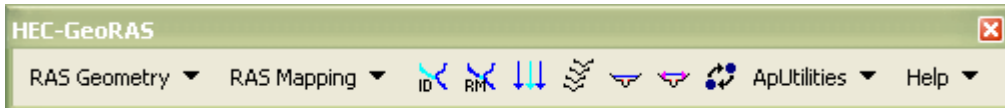


Figure 38 - HEC-GeoRAS toolbar in ArcMap

The goal of placing the lines being to accurately capture the 3D characteristics of the channel. From the 2 dimensional cross section lines and raster surface the HEC-GeoRAS tool creates the three dimensional cross sections. The cross sections can then be combined with the rest of the data required by the HEC-RAS program. Figure 40 on the following page illustrates 3D cross sections created by the HEC-RAS application.

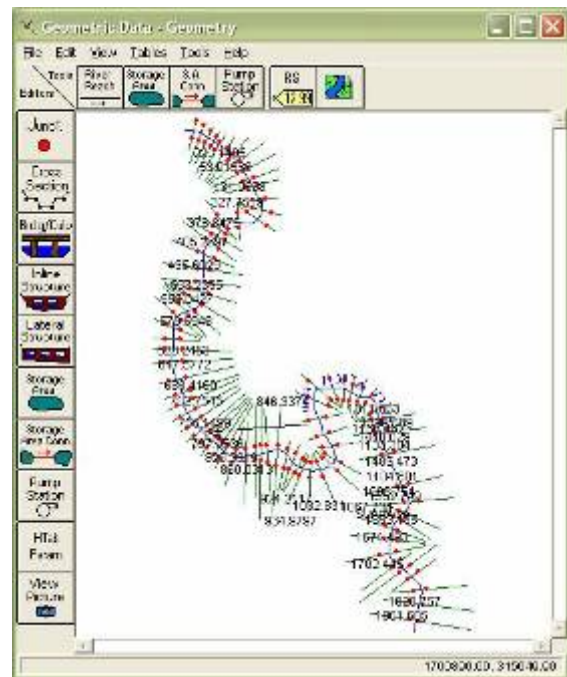


Figure 39 - HEC-RAS model of Little Kitten Creek

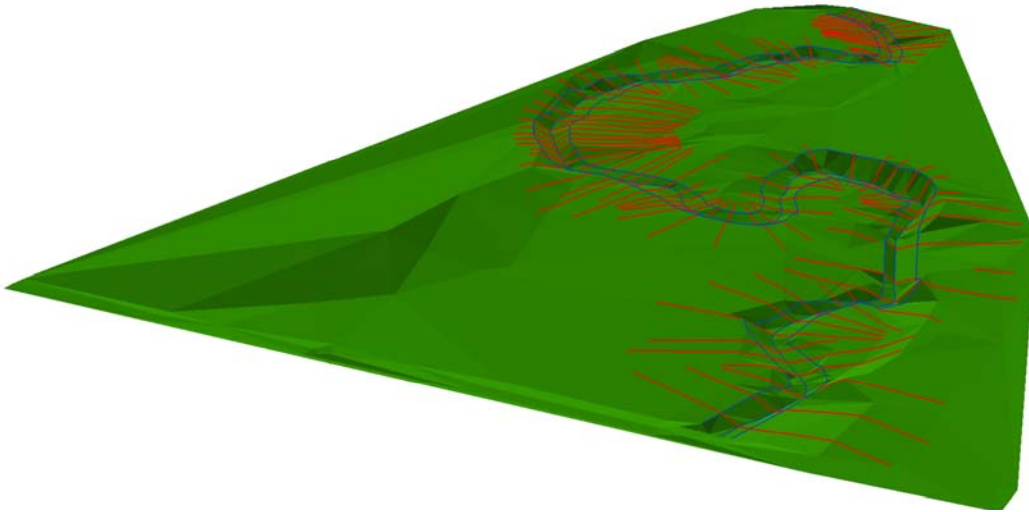


Figure 40 - Three dimensional TIN with cross sections on surface ready for import into HEC-RAS

HEC-RAS Implementation

The HEC-RAS program analyzes the topography and water volume to show the location of flooded areas. With the three-dimensional cross section lines, flowpath and bank lines created in the GIS, the data is imported into HEC-RAS using the import to HEC-RAS command. All the necessary attributes are created automatically either during the import or during the GIS preparation of the data. Once the HEC-RAS project is complete the file is saved to the C:\ drive in the “rasproj” folder. This step is necessary because Map to Map searches for the HEC-RAS project file in this exact folder. Once the RAS file is located, customized scripts in the Map to Map model then call on it to run in the background and produce a floodplain map.

HEC-HMS Implementation

To create the HEC-HMS file for Little Kitten Creek data the file is prepared and exported from ArcView 3.2 using the GeoHMS toolbar. Preparing the data using the

GeoHMS toolbar creates essentially the same data as the Terrain Preprocessing tool from the ArcHydro toolbar (fill grid, flow direction grid, flow accumulation grid, stream grid, stream segmentation, watershed grid, watershed polygon, stream segment vector, watershed accumulation). Features unique to the HEC-HMS program that are derived from and created from the GIS data include: centroidal flow path, hms points, hms connections. To ensure cross communication between

programs data fields with nomenclature unique to HEC-HMS are also created. With the data and nomenclature created the data is lumped and exported, making it ready for import into HEC-HMS.

Prior to unpackaging the GeoHMS file, an HMS project directory is created where the prepared data is imported to create the HMS basin model file.

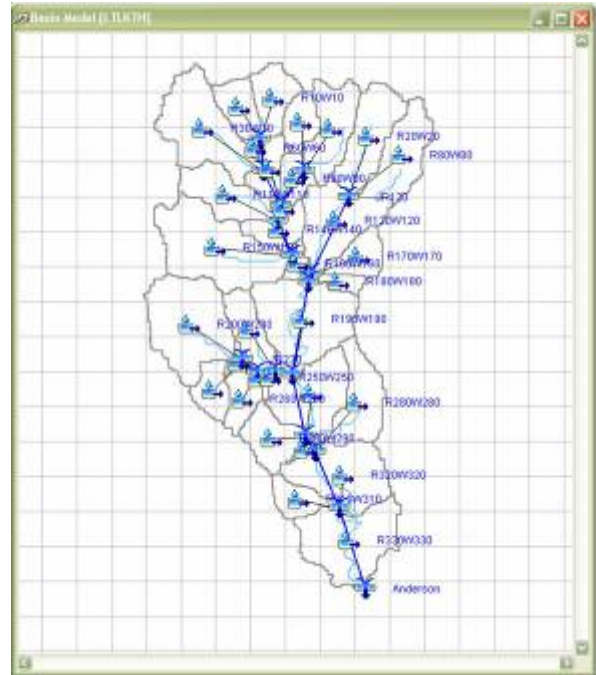


Figure 41 - HMS model of Little Kitten creek watershed

Land Use

Little Kitten Creek watershed has four major land cover types: single family residential, parks (community parks, golf courses), woodlands, and range or pasture land. In the watershed there are 19 sub-watersheds or catchments, each with various land uses and different land cover types. Land cover types are divided and delineated based on the catchments boundaries in which they are found. To calculate the impact of land cover on the hydrology of the watershed the TR-55 model was implemented.

TR-55

The purpose of using TR-55 was to calculate the time of concentration (T_c) for the watershed. To accomplish this four data types were necessary: Hydrologic Soils Groups, by the Natural Resource Conservation Service (NRCS), land cover classes (obtained as a shapefile from Riley County), the watershed boundary, channel geometry, and the watershed area which was derived from the NED during the data preprocessing.

The TR-55 uses land cover classifications such as native pasture grass, single family residential, and turf grass combined with the infiltration rates of soil types to determine

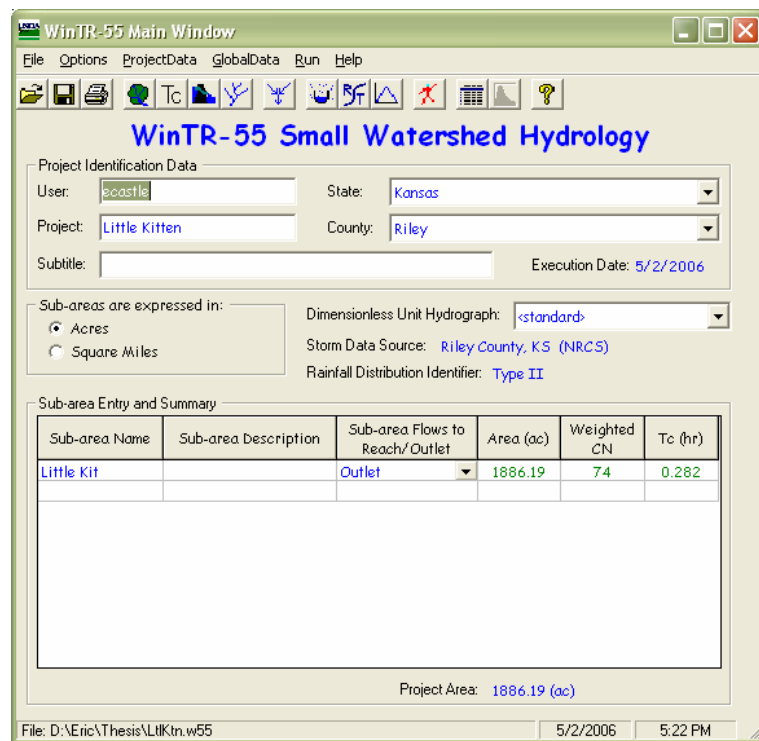


Figure 42 - TR-55 for Little Kitten Creek showing area and time of concentration (T_c)

the time of concentration.

Time of concentration is a measure of how long it takes for water travel from the top of the watershed to the bottom. This is important because as the time of concentration decreases (meaning the faster water gets from top to bottom) the higher the water volume at the watershed outlet. And water moves faster over paved and impervious surfaces such as roofs and roads than it does through native vegetation. The time of concentration provides a measurable variable that changes as land cover is altered.

As the Map to Map model is implemented to analyze alternative development scenarios, time of concentration is the dependent variable that allows comparison. Changes in time of concentration enable the Map to Map model to show variability in flood extents for development scenarios.

Soils by Land Cover

The soils data and land cover data were then combined and used in the process of calculating the Tc. Each land cover type was broken down into how many acres were in each of the soil classifications (A,B,C, or D). Figure 43 at right is an overlay of hydrologic soil groups and land uses for the watershed which was input into TR-55 as illustrated in Figure 44.

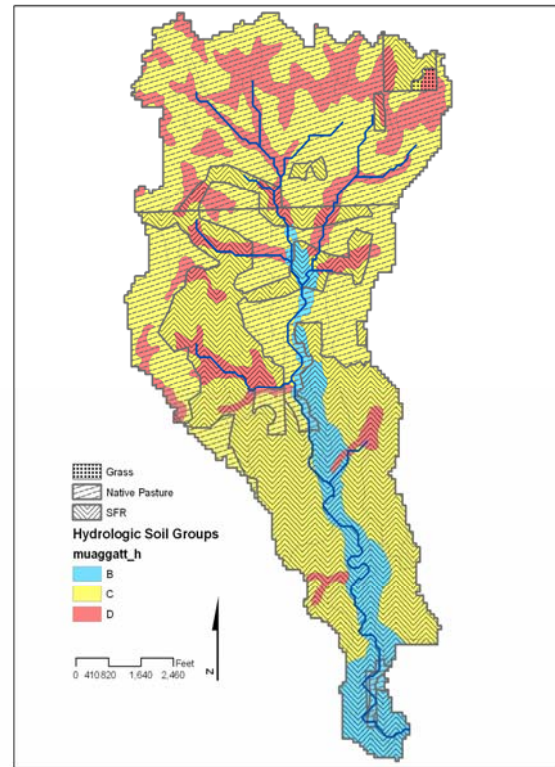


Figure 43 - Hydrologic Soil Groups with Land Cover Overlay

Land Use Details

Sub-area Name: Little Kit

Land Use Categories: Urban Area Developing Urban Cultivated Agriculture Other Agriculture Arid Rangeland

Area (Acres) for Hydrologic Soil Groups

Cover Description	Condition	Area (Acres) for Hydrologic Soil Groups							
		A	CN	B	CN	C	CN	D	CN
FULLY DEVELOPED URBAN AREAS (Veg Estab.)									
Open space (Lawns, parks etc.)									
Poor condition; grass cover < 50%		68		79		86		89	
Fair condition; grass cover 50% to 75%		49		69		79		84	
Good condition; grass cover > 75%		39	35.720	67	243.070	74	95.710	80	
Impervious Areas:									
Paved parking lots, roofs, driveways									
		98		98		98		98	
Streets and roads:									
Paved; curbs and storm sewers		98		98		98		98	
Paved; open ditches (w/right-of-way)		83		89		92		93	
Gravel (w/ right-of-way)		76		85		89		97	
Dirt (w/ right-of-way)		72		82		87		89	
Urban Districts Avg % Imperv									
Project Area(ac)	Summary Screen	Sub-Area		Weighted CN:					
1886.19	<input checked="" type="radio"/> Off <input type="radio"/> On	Area (ac) 1886.19		74		Help Cancel Accept			

File: D:\Eric\Thesis\LI\Kitn.w55 5/2/2006 10:59 PM

Figure 44 - TR-55 land cover type by soil classifications

Rainfall Data

To produce the floodplain map the Map to Map model requires a rainfall raster for a storm event. The Map to Map model was originally designed to produce flood maps based on design storms for 5, 10, 50, 100 year storm events. For this study the interest was not in flood maps for particular storm events, but rather for the impact of development on flood volumes. This type of analysis is dependent on land cover, and not rain volume, therefore it was not necessary to run the analysis using different storm events, but rather with different land cover values. To accomplish this using the Map to Map model it was necessary to simulate a continuous rainfall event that would be applied to various land use scenarios. For the study a 7 inch rainfall (100 year storm event) was chosen for the entire Little Kitten watershed area. To create this situation in the model a continuous value raster is created where each 30m x 30m cell had a cell value of 7. The raster simulates a 7 inch rain over the entire watershed and allowed for variations in land use to become evident through the analysis.

Implementation of the Map to Map Model

With the six necessary datasets compiled (Arc Hydro based geodatabase, HEC-RAS project file, HEC-HMS project file, time of concentration, obtained from TR-55 model, high resolution cross sections, and a rainfall raster) the next step incorporates the data into the Map to Map model run. The model was originally created for the Rosillo Creek watershed in Austin, Texas. To make the model run complex Visual Basic scripts were built into the model, these scripts called on that allow the model to communicate with the HEC-RAS and HMS programs. Because of this complexity, the approach taken used the existing model configurations and naming conventions rather

than recreate the scripts and file pathways to fit my data. As an example the model was originally created for the Rosillo Creek watershed in located in Texas, therefore the geodatabase is named RosilloFull.mdb instead of Little Kitten geodatabase.

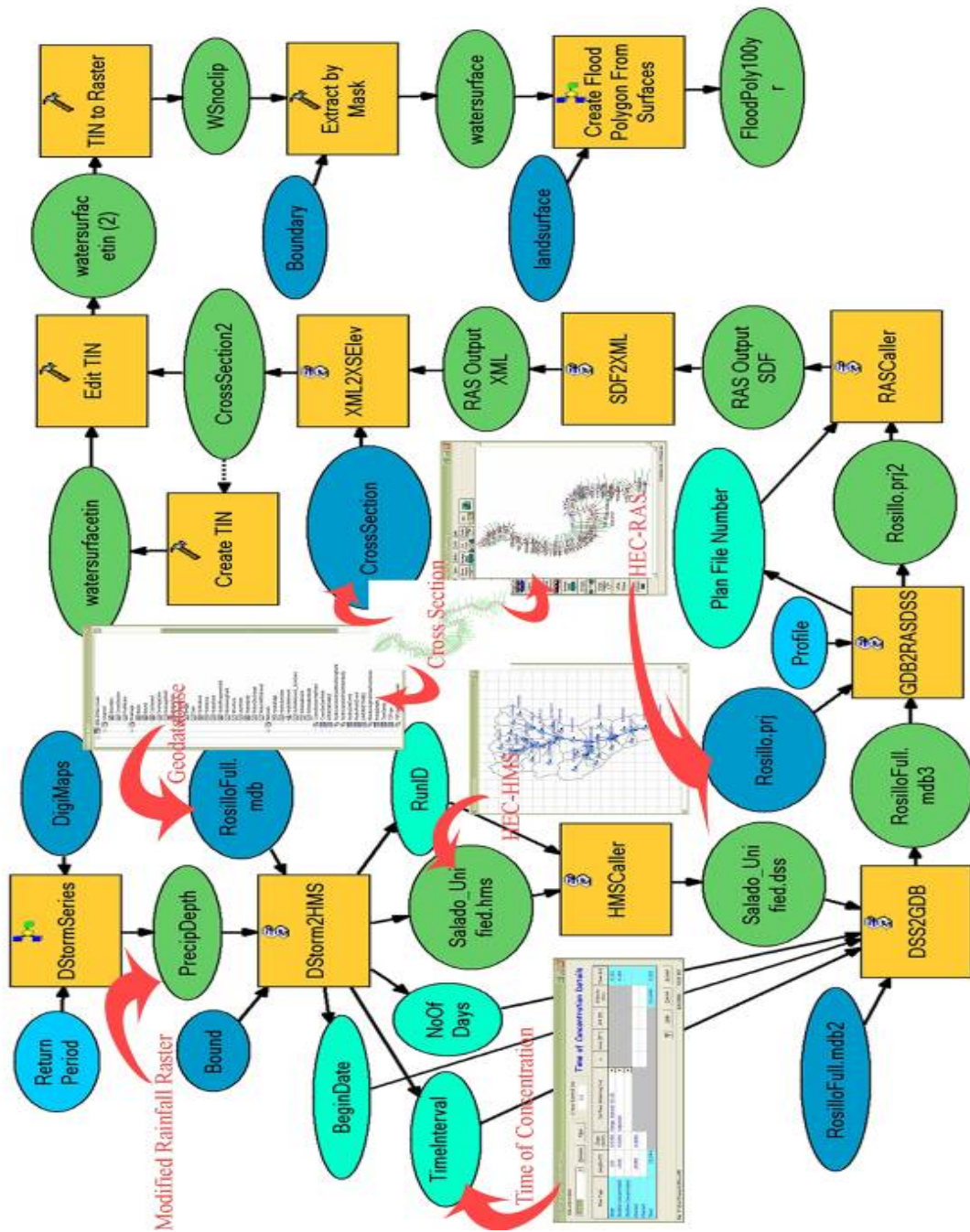


Figure 45 - Six datasets necessary to run the Map to Map model

The Map to Map model recognized the Little Kitten Creek geodatabase, now named RosilloFull.mdb and processed it as is would the original geodatabase as they both used the Hydro schema.

Highlights of protocol for setting up the model as described by Strassberg include: copying the Map to Map model and data directly of the C:\\ drive, copying the HEC-RAS and HMS models into the respective program root folders, and registering the DLL's of the customized scripts [Strassberg, 04].

Analysis

To evaluate the impact of development on stormwater volume, two different land use scenarios were to be evaluated. One was the existing land use scenario with the upper half of the watershed largely undeveloped, with native prairie and pasture grasses and a Tc of 0.282 hours calculated by TR-55. The second scenario was a hypothesized development of the entire upper end of the watershed from native pasture grass to single family residential and a residential golf course development. The outcome of that scenario produced a Tc of 0.122 hours.

Time of Concentration Summary

With the soils and land cover data combined and input into the model, the result in Tc was 0.282 hours, or 16.92 minutes. So with the current land use scenario and a two year rainfall event of 3.3 inches, water that falls in upper most reaches of the watershed will travel 0.282 hours or 16.92 minutes to reach the outlet. This time is important because indicates the highest volume of water in the stream for the particular rain event.

Table 2 - TR-55 results from current land use scenario:

Name	Description	Reach Area(ac)	RCN	Tc
Little Kit		Outlet 1886.19	74	.282
Total area: 1886.19 (ac)				

The second scenario, or developed scenario, changed all the native pasture grass area to urban residential, with an average ½ acre lots. With all other variables remaining the same this change in land use changed the Tc from the previous 0.282 hours to 0.122 hours or 7.32 minutes, a 70% change in Tc.

Table 3 - TR-55 results from development scenario 2:

Name	Description	Reach Area(ac)	RCN	Tc
Little Kit		Outlet 1885.99	75	.122
Total area: 1885.99 (ac)				

Once the first land use scenario was completed the data was input into the Map to Map model and run for analysis. However the model could not fully run as stream gauging data is required in the GDB2RASDSS processing step (Figures 45 and 46) to calibrate the model. This aspect of the model was not known at the outset of the case study. Time series data is collected using stream gauges on streams and is available for many streams and rivers from the U.S.G.S.. This stream does not however have a stream gauge and it is beyond the scope of this study to install gauges and collect this data. The possibility of creating the data from other sources was investigated but not available in time to complete this study. The missing data also prevented the full analysis of the second scenario as well.

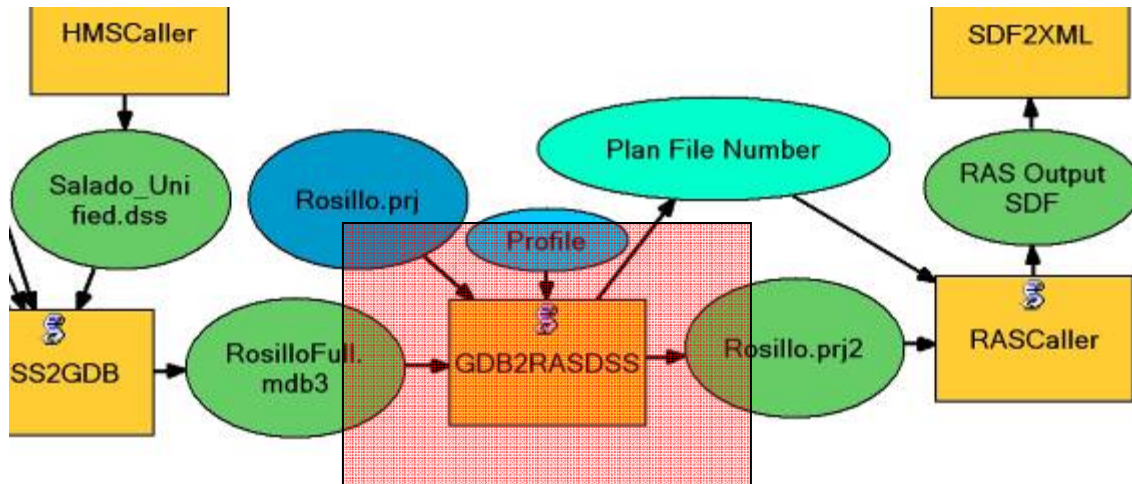


Figure 46 – Missing “time series data” message appeared during the GDB2RASDSS processing step

Conclusions

As designers impact the hydrology of watersheds they work in, it is vital to grasp an understanding of the volume, location and intensity of water through the system. It is even more important to know the impacts designs will have the system prior to design implementation. This paper has explored how the Map to Map model can assist in understanding the hydrology of the Little Kitten Creek watershed, located on the western portion of Manhattan, Kansas. The Map to Map model is a new method that relies on a standardized hydrologic geodatabase to connect to hydrologic models and visualize flood events in maps and 3D virtual landscape models. To accomplish floodplain simulation the model also calls on external hydrologic models: HEC-RAS, HEC-HMS, and TR-55. The outputs of these models input into the hydrologic geodatabase representing the watershed were hoped to produce post development flood maps and cross sections of Little Kitten Creek watershed. The Map to Map model

would have been able to provide the comparison of pre and post-development scenarios had stream gauging data been available.

Understanding of the hydrology allows landscape architects and other designers to make more appropriate design decisions and prevent flooding problems like the one on Wildcat Creek illustrated in Figure 1. This information would allow city planners and managers a quantifiable measure by which to influence developers into dealing with storm water onsite and formulate policy to improve design and implementation of new development. Likewise homeowners in the lower half of the Little Kitten Creek watershed could use the information to demonstrate to city officials that legislation is needed to protect their property from being flooded as a result of upstream development.

The steps to complete this project began with collecting necessary data of the watershed. One goal of this step was to utilize data that was free and publicly available. Elevation and hydrologic data was free and available from U.S.G.S websites, however the cross section creation process requires data at 10 meter resolution or greater that was not freely available for the study area. The cross section data could be extracted from High Resolution 10 meter NED elevation data available for some areas in the U.S. As with this study, cross section data of sufficient resolution can be obtained from a field survey.

Once the elevation, hydrologic, and cross section data are collected, they are processed through the Arc Hydro toolset which derived a higher detailed stream network and sub-watersheds, or catchments, network junctions, a geometric network,

cross sections and combined these data into a geodatabase ready for the Hydro schema implementation.

Implementation of the Hydro schema establishes critical relationships between all the data in the geodatabase. Users of the Hydro data model should use good GIS craftsmanship, following exactly the steps described, especially the use of terms and names of feature classes to be converted to the new schema. It is also necessary to establish an output extent that spatially encompassed the entire study area and to remember to establish the output extent when first creating the geodatabase as it cannot be changed once the geodatabase has been created.

HEC models used by Map to Map modeled the hydrology of the watershed. HEC-RAS modeled the volume of water and used cross section and stream channel data from the field survey. It is important to note that this data had to be exported from the GIS using Arc View 3.2 rather than ArcGIS 9.1 because the tool would only work in the 3.2 version. HEC-HMS modeled the stream network using data exported from ArcGIS 9.1 using the HEC-GeoRAS tool.

The HEC-RAS model requires a time of concentration method to calculate the volume of water, specifically the peak flow volume. The TR-55 model uses inputs of soil type, land cover data, flow path and channel dimensions all stored in the geodatabase. Time of concentration values calculated were: 16.92 minutes for the current land use and 7.32 minutes for the developed scenario for Little Kitten Creek.

With all inputs complete and implemented in the Hydro geodatabase, the Map to Map model can be run to determine flood effects. Rather than rewriting all the complex custom scripts for the Map to Map model, the Little Kitten Creek geodatabase was

renamed RosilloFull.mdb. This renaming allowed the model to process the Little Kitten data without having to redo complex programming work. The DStormSeries process of the Map to Map model also called for rasterized precipitation data representing over 80 different design storms for the site such as the 1 year 2 day, 1 year 2 hour, 1 year 3 hour, etc.... The purpose of this study was to understand the impact of land use change on storm water volumes and location, not to analyze the impact of various rainfall events, therefore, a single surface with constant rainfall over the entire watershed was used and should be an effective means for this type of study. The output of the DStormSeries process was a storm water volume, this output was mimicked in this case study to represent a 10 year storm event of 7 inches.

The model ran smoothly until the GDB2RASDSS processing step. This process combined the data in the geodatabase with the HEC-RAS data to get volume and spatial extent of the water in the 3D digital landscape. The process would not fully run because the HEC-RAS model was missing time series data needed to calibrate the model. To acquire this data it is necessary to install a gauging station on Little Kitten Creek or obtain temporal data from manual recordings of stream flow using a community mapping network, or other means. Because of the critical nature of this data for the HEC-RAS model to be properly calibrated, it was not possible to complete the full run of the Map to Map model which would have provided a flood map for both pre and post development scenarios that could have been compared.

Therefore, to answer the question posed in the introduction of this paper “can the Map to Map geoprocessing model produce flood simulations of developed parcels in the lower section of the Little Kitten Creek under different development scenarios in the

currently undeveloped upper half of the Little Kitten Creek watershed?”, the answer is no, at least not without stream gauge data. However the model is at a point that should this data become available, it can be input into the HEC-RAS model and the Map to Map model can then be run to produce flood maps for the watershed.

Another model used to calculate storm water based on various land use scenarios is the L-THIA model (Long-Term Hydrologic Impact Assessment) developed by the E.P.A. and maintained by Purdue University. This model is either run through Arc View 3.x or through the Web, with relatively few inputs: such as State, County, land use, and hydrologic soil type. The Little Kitten Creek watershed was analyzed using this model, evaluating both land use scenarios of the current development and future development. The L-THIA model is used to calculate runoff volumes as well as non-point source pollutants, giving the results in a yearly output. The total annual runoff volume for the site is 55.02 acre feet for the current land use scenario and 66.57 acre feet for the post development scenario.

Recommendations

Generally the Map to Map model is a viable tool for larger watersheds (HUC 8 scale) requiring less accurate topographic data readily available for the entire United States and commonly having USGS stream gauging stations. For watersheds smaller than the HUC 8 scale (HUC 11 or 14), I would not recommend using the Map to Map model as data collection would be time consuming and costly. As more highly detailed elevation data such as LIDAR or digital survey data become available for entire watersheds, the Map to Map model becomes more viable. Many cities already have HEC-RAS and HMS models built which could also be used with Map to Map to improve

efficiency of model implementation. I would recommend using other watershed modeling programs such as the L-THIA model because the model is simple to learn, quick to acquire necessary data, and can be integrated with GIS.

(<http://www.ecn.purdue.edu/runoff/>). However the L-THIA model does not give flood volumes in 3D which Map to Map does. Of course if you have the detailed elevation data of less than 10 meter resolution and stream gauge data, then the Map to Map model would be appropriate.

Effective use of the Map to Map model depends on these factors: GIS, HEC-RAS and HMS user competency, data availability, and to some extent scale of the watershed. The Map to Map model uses techniques on the edge of current GIS technology, so proficiency in the basics is highly recommended to save time and resources. Proficiency in HEC programs is also useful especially if the RAS and HMS datasets are not already built for the watershed of study. Larger watersheds in and impacting cities already have these datasets built up, at which point they can be simply included into the model with minimal modification.

The most difficult data to obtain for this watershed (and for most small watersheds) was the stream gauge, and cross section data. The U.S.G.S maintains many stream gauges in the U.S. (<http://waterdata.usgs.gov/nwis/rt>), but if the watershed does not have one it is necessary to either install one, collect data manually for temporal calibration or use a different model. Cross section data can be obtained by traditional survey, boat mounted sonar, and for some streams LIDAR data might be appropriate. Again if this data exists for the watershed of interest then the process is greatly simplified.

Future Research

There are three recommended areas for future research. The first is to install a gauging station along Little Kitten Creek and collect time series data for the watershed. This would enable the Map to Map model to fully run and produce a floodplain map . A complete Map to Map model of Little Kitten Creek watershed would also allow comparative analysis of planning and design scenarios.

Second, the Map to Map model for Little Kitten Creek watershed can be utilized in a community mapping scenario. Interested parties would access the model and input their data and get outputs all via the internet.

Third, there is much room for the integration of design, planning and engineering. The Map to Map model could be used to integrate the specialties of each discipline to create safer, more functional, and more aesthetic places. Specific possibilities include integration of TMDL (Total Maximum Daily Load, or more simply water pollution amounts) into the Map to Map model. Using the model to evaluate the effectiveness of storm water BMP's, such as rain gardens, bioswales and constructed wetlands is another promising area.

Ultimately the Map to Map model is built upon a GIS framework that is extremely flexible and can be customized to meet a variety of needs. When data availability allows for complete execution of the model there is great potential to rapidly assess hydrologic consequences of land use changes in watersheds. This will facilitate designers, city officials, and concerned citizens the ability to provide increased protection of the public health, safety and welfare.

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Appendix A

Weather data for Manhattan, Kansas. Souce Mary Knapp, Kansas State Climatologist.

NORMAL VALUES (1971-2000)													
Manhattan	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
Avg. Max (oF)	39.5	46.8	57.5	67.9	77.5	87	93	90.8	82	70.7	54.5	43	67.5
Avg. Min (oF)	16.1	21.5	31.4	42.2	52.5	62	67	65.1	56	43.2	30.2	20	42.3
Avg. Mean (oF)	27.8	34.2	44.5	55.1	65	75	80	78	69	57	42.4	31	54.9
Precip (In)	0.86	1	2.59	3.07	5.08	5.2	4.1	3.27	3.7	2.77	2.1	1.1	34.8
Snow (In)	4.8	4.9	3.4	0.9	0.1	0	0	0	0	0.2	1	3.7	18.8
Heat DD (base 60)	1153	864	637	315	106	7	0	4	48	265	679	###	5120
Cool DD (base 60)	0	0	0	17	106	298	461	405	163	15	0	0	1465

Appendix B

Arc Hydro Tools - Tutorial

Version 1.1 Final - September 2005

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Introduction

The purpose of this tutorial is to illustrate, step-by-step, how to install Arc Hydro and use the major functionality available in the tools. This is a hands-on document focusing on how, not why. There is little discussion on implementation or internal operation of a tool. This document is targeted to an experienced water resources ArcGIS user who wants to learn how to use the tools. The online help provides more detail on the way the tools operate.

Objective

In this tutorial, the user will perform drainage analysis on a terrain model. The Arc Hydro tools are used to derive several data sets that collectively describe the drainage patterns of a catchment. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data are then used to develop a vector representation of catchments and drainage lines. Using this information, a geometric network is constructed. Utility of Arc Hydro tools is demonstrated by applying them to develop attributes that can be useful in hydrologic modeling. To accomplish these objectives, the user is exposed to important features and functionality of Arc Hydro tools, both in raster and vector environment.

Getting Started

Software Requirements

- ArcGIS 8.3 or higher (Note: Arc Hydro is fully functional for ArcInfo and ArcEditor only – limited functionality is available with ArcView – see note below)
- Spatial Analyst extension
- XML Parser version 3.0 or 4.0 (MSXML 3.0 or MSXML 4.0) – 4.0 recommended
- Water Utilities Application Framework (ApFramework)

Note: Using Arc Hydro with ArcView

The Arc Hydro tools require ArcInfo/ArcEditor 8.3 or higher with the Spatial Analyst extension. Since ArcView allows only limited editing (simple features), not all functions are available with ArcView. In particular, the following functions require ArcInfo/ArcEditor:

- Hydro Network Generation
- Calculate Length Downstream for Edges
- Calculate Downstream for Junctions
- Find Next Downstream Junctions
- Store Flow Direction
- Set Flow Direction

The following tables summarize the requirements (ArcEditor/ArcInfo and Spatial Analyst) for each function in Arc Hydro.

Terrain Preprocessing	Requires ArcInfo/ArcEditor	Requires Spatial Analyst
DEM Reconditioning		X
Build Walls		X
Fill Sinks		X
Flow Direction		X
Flow Accumulation		X
Stream Definition		X
Stream Segmentation		X
Catchment Grid Delineation		X
Catchment Polygon Processing		X
Drainage Line Processing		X
Adjoint Catchment Processing		
Drainage Point Processing		X
Longest Flow Path for Catchments		X
Longest Flow Path for Adjoint Catchments		X
Slope		X
Slope greater than 30		X
Slope greater than 30 and facing North		X
Weighted Flow Accumulation		X

Terrain Morphology	Requires ArcInfo/ArcEditor	Requires Spatial Analyst
Drainage Area Characterization		X
Drainage Boundary Characterization		X
Drainage Connectivity Characterization	X	X

Watershed Processing	Requires ArcInfo/ArcEditor	Requires Spatial Analyst
Batch Watershed Delineation		X
Batch Subwatershed Delineation		X
Drainage Area Centroid		
Longest Flow Path		X
Longest Flow Path for Watersheds		X
Longest Flow Path for Subwatersheds		X
Construct 3D Line		
Smooth 3D Line		
Flow Path Parameters from 2D Line		
Flow Path Parameters from 3D Line		

Attribute Tools	Requires ArcInfo/ArcEditor	Requires Spatial Analyst
Assign HydroID		
Generate From/To Node for Lines		
Find Next Downstream Line		
Calculate Length Downstream for Edges	x	
Calculate Length Downstream for Junctions	x	
Find Next Downstream Junction	x	
Store Area Outlets		
Consolidate Attributes		
Accumulate Attributes		
Display Time Series		
Transfer ID		
Transfer Value		
Compute Local Parameters		x
Compute Global Parameters		x

Network Tools	Requires ArcInfo/ArcEditor	Requires Spatial Analyst
Hydro Network Generation	x	
Node/Link Schema Generation		
Store Flow Direction	x	
Set Flow Direction	x	

Buttons and Tools	Requires ArcInfo/ArcEditor	Requires Spatial Analyst
Flow Path Tracing		x
Point Delineation		x
Batch Point Generation		
Assign Related Identifier		
Global Point Delineation		x
Trace By NextDownID Attribute		

Setting up the Arc Hydro Tools

As indicated in the software requirements, the Arc Hydro tools require ArcGIS 8.3 or higher, the Spatial Analyst extension, XML Parser 3.0 or 4.0, and the Water Utilities Application Framework (ApFramework). XML Parser 3.0 was already required for the versions of Arc Hydro previously released – so if you have an older version of Arc Hydro, you should already meet the requirement for the XML Parser. However we recommend the installation and use of MSXML 4.0 to ensure compatibility with the Arc Hydro based water resources applications.

Installing XML Parser 4.0

This needs to be done independently from the Arc Hydro installation. MSXML 3.0, that meets the requirement, should be on your computer if you already had Arc Hydro installed. However, you may want to upgrade to MSXML 4.0 if you plan to use extensions to Arc Hydro such as GeoRas that requires 4.0.

Check the version(s) of the XML Parser installed on your computer

Open the registry editor:

- Start\Run...
- Type Regedit in the Run window to open the registry editor

Browse to the following locations in the editor:

- *HKEY_LOCAL_MACHINE\SOFTWARE\Classes\Msxml2.DOMDocument\CurVer*

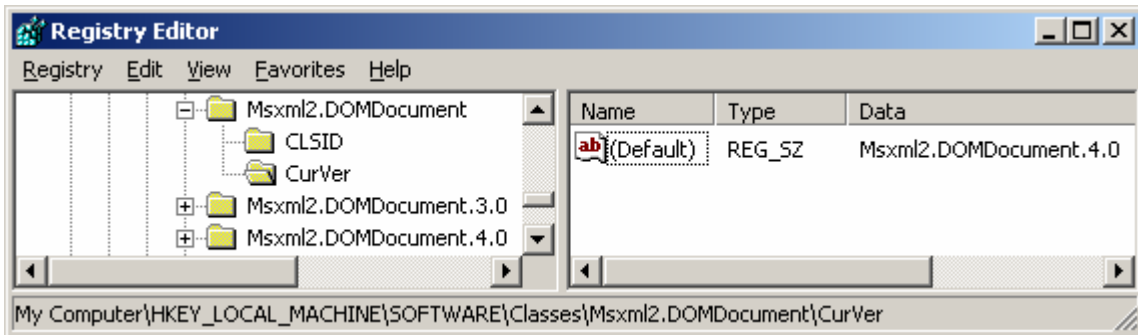
(Note: this location indicates the version of the XML Parser that is used by default – if this location does not exist, then neither MSXML 3.0 nor MSXML 4.0 are installed.)

- *HKEY_LOCAL_MACHINE\SOFTWARE\Classes\Msxml2.DOMDocument.3.0*

This location exists only if MSXML 3.0 is installed.

- *HKEY_LOCAL_MACHINE\SOFTWARE\Classes\Msxml2.DOMDocument.4.0*

This location exists only if MSXML 4.0 is installed.



The following table summarizes the actions that are required, depending on the existence/value of these keys. Again, MSXML 3.0 meets the current Arc Hydro requirements. The upgrade to 4.0 is optional, but recommended since other Arc Hydro extensions (GeoRas) require 4.0.

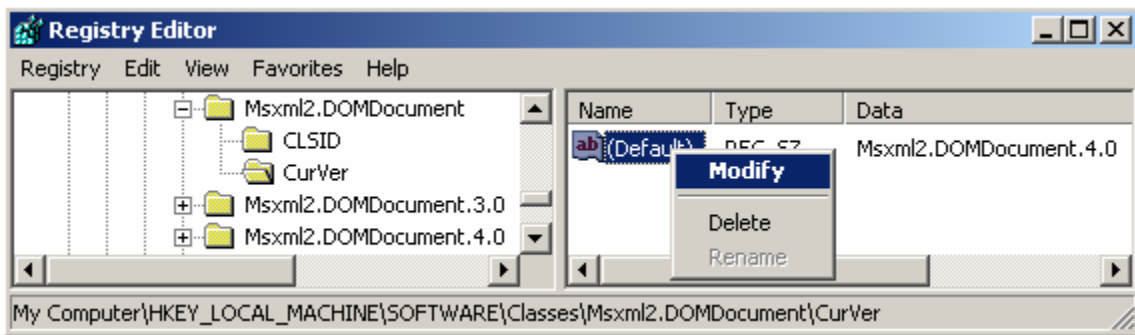
Mxml2.DOMDocument	Mxml2.DOMDocument.3.0	Mxml2.DOMDocument.4.0	Action Required
Not found – no XML Parser installed	Not found – MSXML 3.0 not installed	Not found – MSXML 4.0 not installed	Install 4.0
CurVal = Mxml2.DOMDocument.3.0 – Default version is 3.0	Found - MSXML 3.0 installed	Not found	Optional upgrade to 4.0: install 4.0 + set CurVal to 4.0
CurVal = Mxml2.DOMDocument.3.0 – Default version is 3.0	Found - MSXML 3.0 installed	Found - MSXML 4.0 installed	Optional modification of default version to 4.0: set CurVal to 4.0
CurVal = Mxml2.DOMDocument.4.0 – Default version is 4.0	Found or not found	Found - MSXML 4.0 installed	None

If you determine that no action is required, then you may proceed to the Arc Hydro install, and skip the rest of the section.

How to install MSXML 4.0 and make it the default version

This installation is a 3 steps process (the files needed for the install may be downloaded from ESRI ftp site – see instructions below):

- run mxml.msi, to setup the XML Parser
 - if this install fails, then run InstMsiW.exe, to setup the Microsoft installer needed to install the XML Parser. You may need to reboot your machine after the install. Then rerun mxml.msi, to setup the XML Parser
- check in the registry that the default version is 4.0 by browsing to the key *HKEY_LOCAL_MACHINE\SOFTWARE\Classes\Mxml2.DOMDocument\CurVer*
 If data does not point to 4.0 then edit the key by right-clicking on Default, clicking Modify and editing so that it reads Mxml2.DOMDocument.4.0.



Installing the Water Utilities Application Framework

Once the XML Parser requirement is met, you may proceed with the installation. Arc Hydro needs to be installed on top of the Water Utilities Application Framework (ApFramework). In previous versions of Arc Hydro, the framework was installed together with Arc Hydro. It now has its own installation setup that needs to be run before the Arc Hydro setup. This is the general framework used by Arc Hydro and other applications such as GeoRas or GeoHMS. The Framework files are always installed

under C:\Program Files\ESRI\WaterUtilsCommon\ApFramework or C:\Program Files\ESRI\WaterUtilsCommon\ApFramework9.

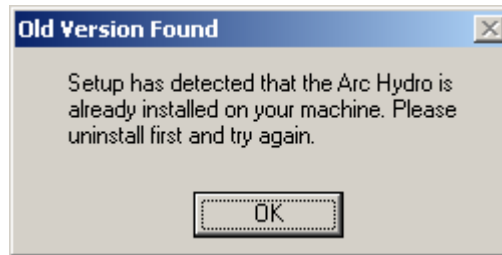
Installing Arc Hydro

Once the Water Utilities Application Framework requirement is met, you may proceed with the installation of Arc Hydro by running the Arc Hydro setup. The tools are installed by default under C:\Program Files\ESRI\ArcHydro or C:\Program Files\ESRI\ArcHydro9.

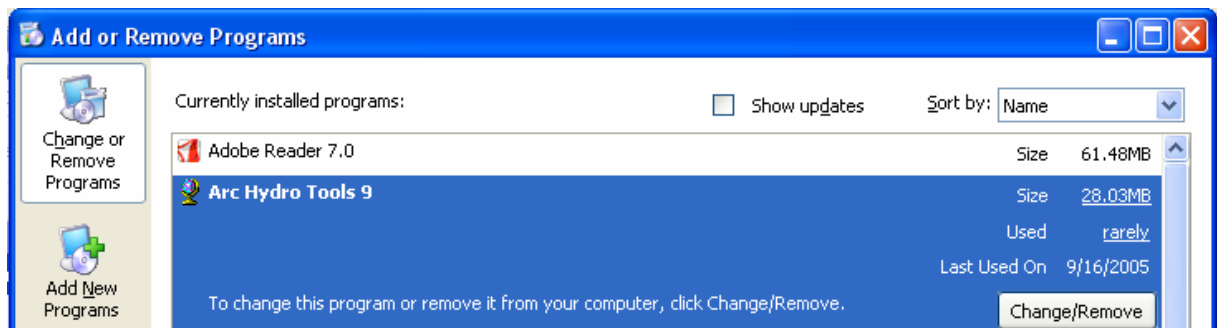
1. Run the Arc Hydro setup

Run the setup, setup.exe, by double-clicking on the file or using Add/Remove Programs.

Note: if a previous version of the Arc Hydro tools is already installed, the following window will be displayed.

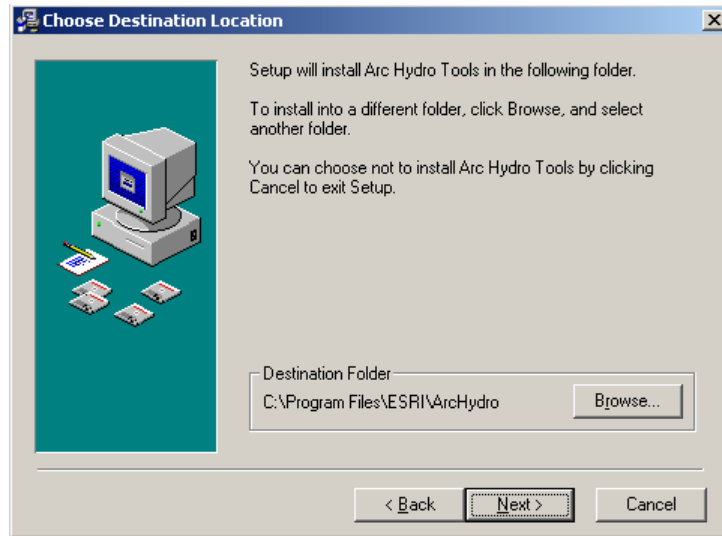


To uninstall the previous version, use the function Add/Remove Programs in the Control Panel, select Arc Hydro Tools and click Change/Remove. Then follow the instructions from the Wizard to remove the tools.



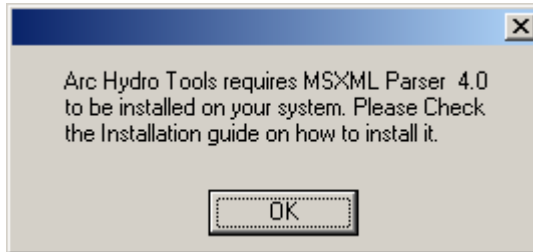
Check the location where the tools were installed and make sure it is empty. If some of the Arc Hydro tools dlls are still in the bin directory (e.g. ArcHydroTools.dll, TimeSeriesManager.dll, WSHPTools.dll), unregister and delete these files before proceeding with the installation of the new version.

After double-clicking the setup, browse to the desired installation location: the Arc Hydro files will be installed in the bin directory under the destination folder: C:\Program Files\ESRI\ArcHydro or C:\Program Files\ESRI\ArcHydro9.



- Follow the instructions to complete the setup.

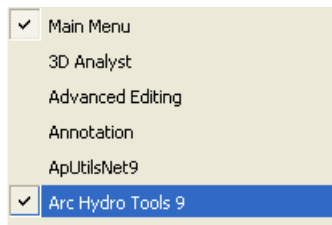
Note: if the setup cannot find the MSXML Parser 4.0 on your computer the following message will be displayed.



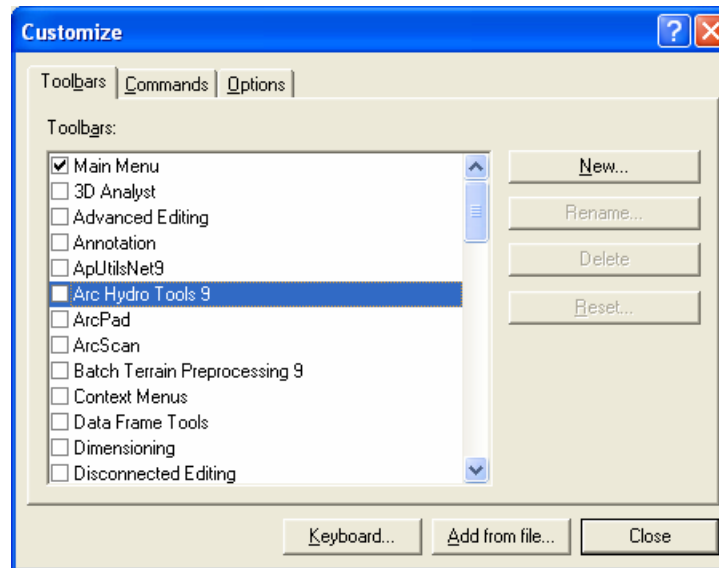
As discussed in the section Installing XML Parser 4.0, the XML Parser 3.0 satisfies the requirement and version 4.0 is not required but is recommended (see previous section for additional information).

2. Open ArcMap and load Arc Hydro tools

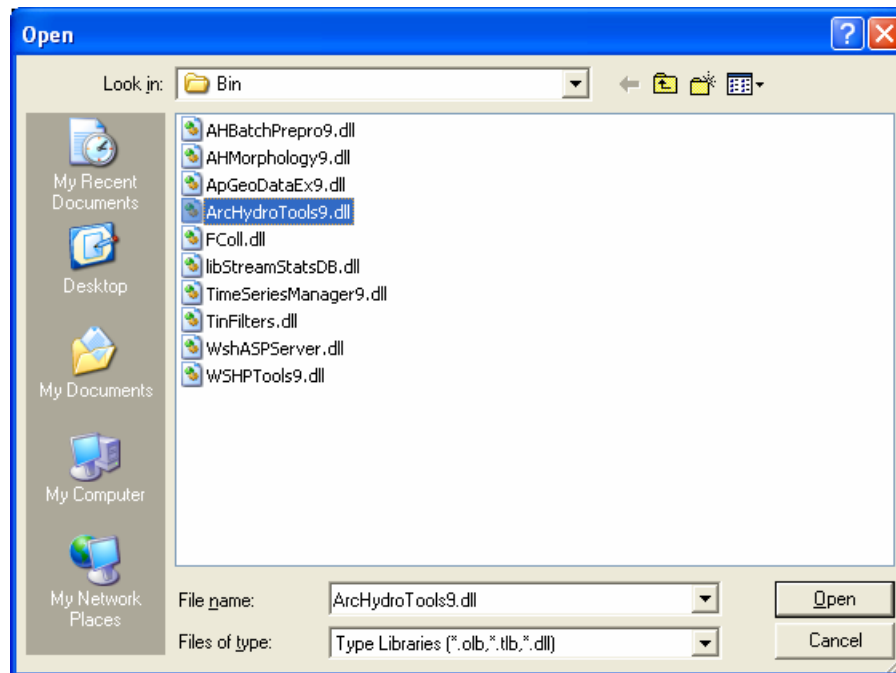
- Open ArcMap. Create a new empty map, and save it as ArcHydro.mxd (or any other name).
- Right click on the menu bar to pop up the context menu showing available tools.



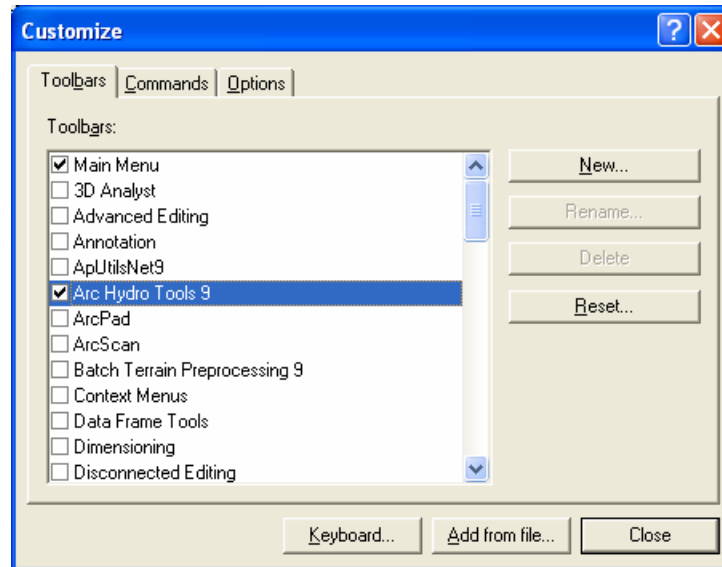
- If the Arc Hydro Tools menu does not appear in the list, click on “Customize”.



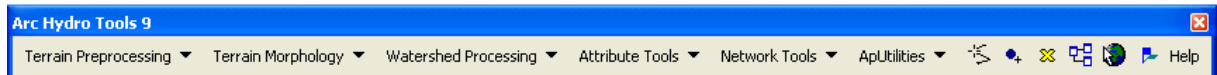
- In the Customize dialog that appears, click on the “Add from file” button.
- Navigate to ArcHydroTools.dll or ArcHydroTools9.dll (installed by default under c:\Program Files\ESRI\ArcHydro\bin or c:\Program Files\ESRI\ArcHydro9\bin), and click on “Open” to select the file.



- A dialog box will appear informing that the tools have been added to ArcMap. Click “Ok”.
- Check the box next to Arc Hydro Tools to turn it on. Click on “Close” button. You should now see the Arc Hydro tools added to ArcMap.



- The Arc Hydro Tools toolbar is shown below.



Note

It is not necessary to load the Spatial Analyst, Utility Network Analyst, or Editor tools because Arc Hydro Tools will automatically use their functionality on as needed basis. These toolbars need to be loaded though if you want to use any general functionality that they provide (such as general editing functionality or network tracing).

However, the Spatial Analyst Extension needs to be activated, by clicking Tools>Extensions..., and checking the box next to Spatial Analyst.

Dataset Setup

The existing data to be used in an Arc Hydro project can be stored in any geodatabase and loaded in the map. Rasters (Grids) used in the tools need to be stored on the disk, not in a geodatabase. The data created with the Arc Hydro tools will be stored in a new geodatabase that has the same name as the stored project (unless pointed to an existing geodatabase) and in the same directory where the project has been saved. By default, the new raster data are stored in the subdirectory with the same name as the dataset in the map (under the directory where the project is stored). The location of the vector, raster, and time series data can be explicitly specified using the function ApUtilities>Set Target Locations.

1. Load the terrain data

- Click on the  icon to add raster data.

Note: raster (grid) data cannot be stored in a geodatabase: they must be stored in a directory.

- In the dialog box, navigate to the location of the data, select the raster file (e.g. “dem”) and click on the “Add” button.
- The added file is listed in the Arc Map Table of contents.

Terrain Preprocessing

Terrain Preprocessing uses DEM to identify the surface drainage pattern. Once preprocessed, the DEM and its derivatives can be used for efficient watershed delineation and stream network generation.

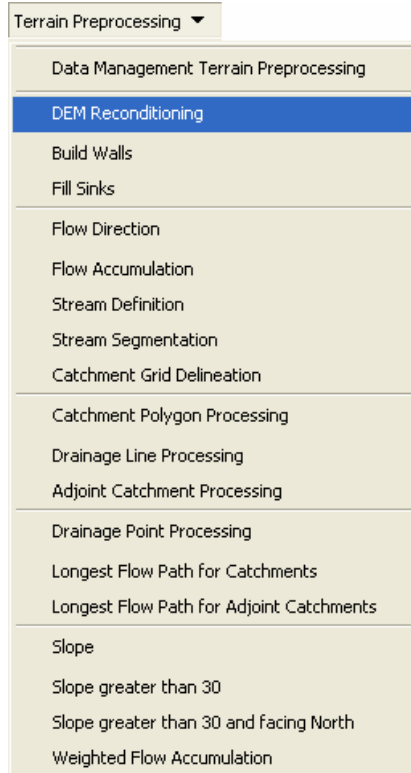
The steps in the Terrain Preprocessing menu should be performed in sequential order, from top to bottom. All of the preprocessing steps from Flow Direction down to Adjoint Catchment Processing must be completed before Watershed Processing functions can be used. DEM reconditioning, Build Walls and Fill Sinks might not be required, depending on the quality of the initial DEM.

1. DEM Reconditioning (optional)

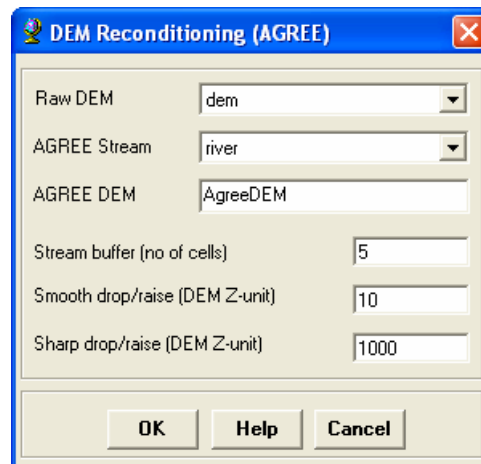
This function modifies a DEM by imposing linear features onto it (burning/fencing). It is an implementation of the AGREE method developed at the University of Texas at Austin in 1997. For a full reference to the procedure refer to the web link <http://www.ce.utexas.edu/prof/maidment/GISHYDRO/ferdi/research/agree/agree.html> .

The function needs as input a raw dem and a linear feature class (e.g. river to burn in) that both have to be present in the map document.

- Select **Terrain Preprocessing | DEM Reconditioning**.



- Select the appropriate input dem and linear feature (streams to burn in). The output is a reconditioned Agree DEM (default name AgreeDEM).



- Enter a Stream buffer: this is the number of cells around the linear feature for which the smoothing will occur.
- Enter the Smooth drop/raise value: this is the amount (in vertical units) that the linear feature will be dropped (if the number is positive) or the fence extruded (if the number is negative). This value will be used to interpolate the DEM into the buffered area (between the boundary of the buffer and the dropped /raised vector feature).

- Enter the Sharp drop/raise value: this is the additional amount (in vertical units) that the linear feature will be dropped (if the number is positive) or the fence extruded (if the number is negative). This results in additional burning/fencing on top of the smooth buffer interpolation and needs to be performed to preserve the linear features used for burning/fencing.
- Click OK. Upon successful completion of the process, the “AgreeDEM” layer is added to the map.

2. Build Walls (optional)

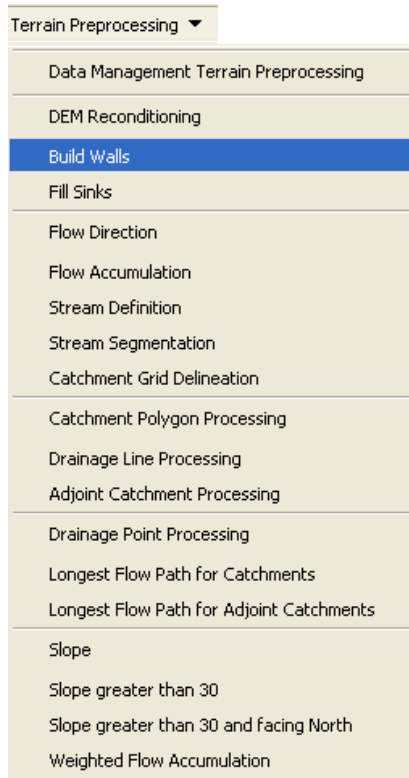
This function allows “building” walls in the input grid. Two types of walls may be created:

- Outer walls – based on an input polygon feature class (Outer Wall Polygon)
- Inner walls – based on an input polygon, line or point feature class (Inner Wall Feature)

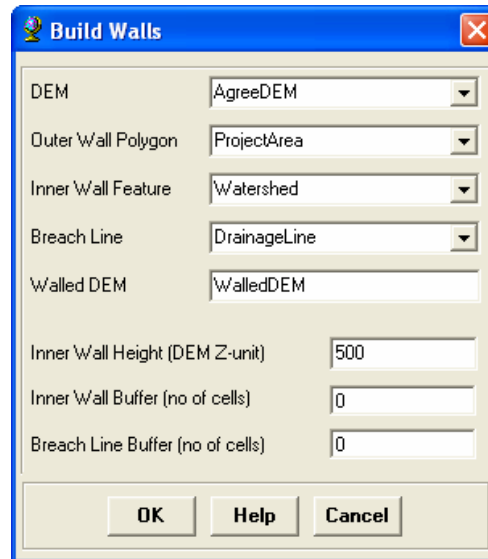
Both types may be built at the same time, but at least one must be selected.

In addition, a Breach Line feature class may be provided as input, to ensure that they are “breaches” in the walls allowing the water to flow out.

- Select **Terrain Preprocessing | Build Walls**



- Confirm that the input for DEM is “DEM” (or “AgreeDEM” after using DEM Reconditioning). The output is the Walled DEM layer, named by default “WalledDEM”.

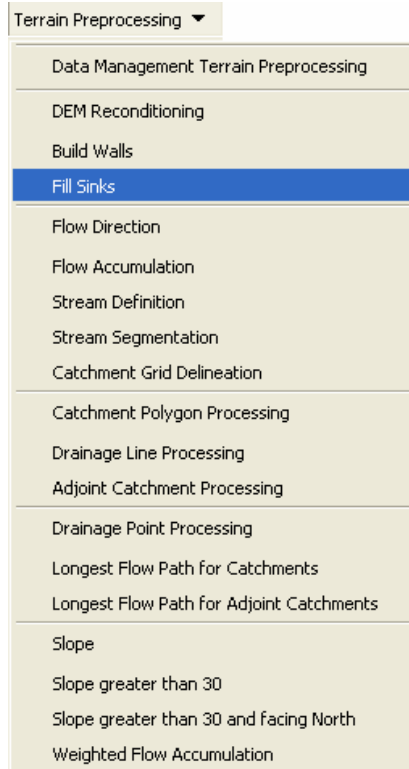


- Select the Outer Wall Polygon (optional) to ensure that the outer boundary of the Catchment feature class matches a specific boundary.
- Select the Inner Wall Feature class (optional) to ensure internal watersheds/catchments boundary match specific input data.
- Select a Breach Line feature class that contains features crossing the walls so that the water can flow out.
- Enter the Inner Wall Height. The Outer Wall Height is twice this height.
- Enter a buffer (number of cells) for the Inner Walls. Default to 0, i.e. no buffer.
- Enter a buffer for the Breach Line. Default to 0, i.e. no buffer.
- Click OK. Upon successful completion of the process, the “WalledDEM” layer is added to the map.

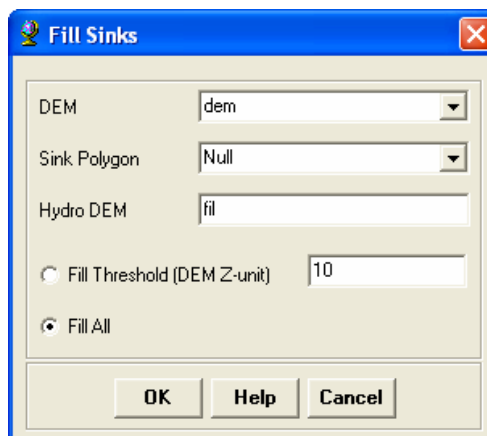
3. Fill Sinks (optional)

This function fills the sinks in a grid. If a cell is surrounded by higher elevation cells, the water is trapped in that cell and cannot flow. The Fill Sinks function modifies the elevation value to eliminate these problems.

- Select **Terrain Preprocessing | Fill Sinks**.



- Confirm that the input for DEM is “DEM” (or “AgreeDEM” after using DEM Reconditioning, or WalledDEM after using Build Walls). The input Sink Polygon is optional. If provided, it defines the areas that will not be filled (e.g. real sinks). The output is the Hydro DEM layer, named by default “Fil”. This default name can be overwritten.
- Select whether to fill all sinks or only the sinks, whose depth is lower than the threshold provided.
- Press OK. Upon successful completion of the process, the “Fil” layer is added to the map.

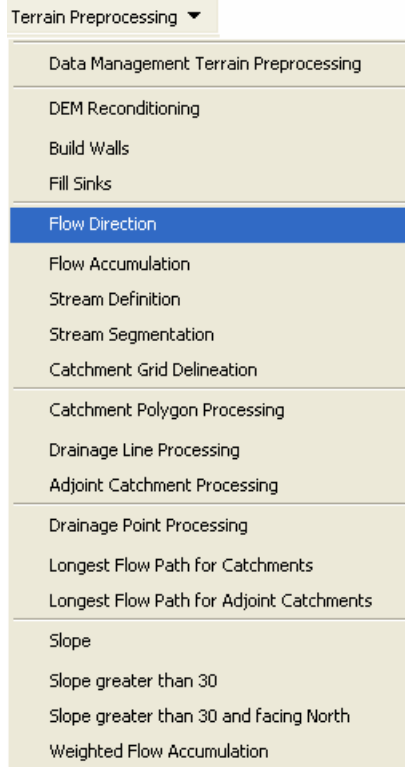


- Press OK. Upon successful completion of the process, the “Fil” layer is added to the map.

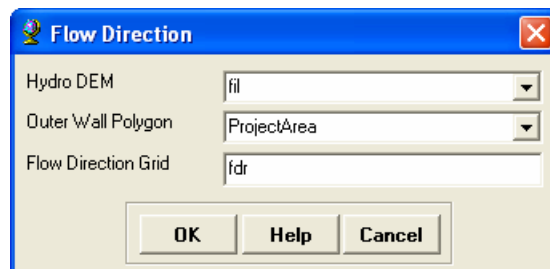
4. Flow Direction

This function computes the flow direction for a given grid. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.

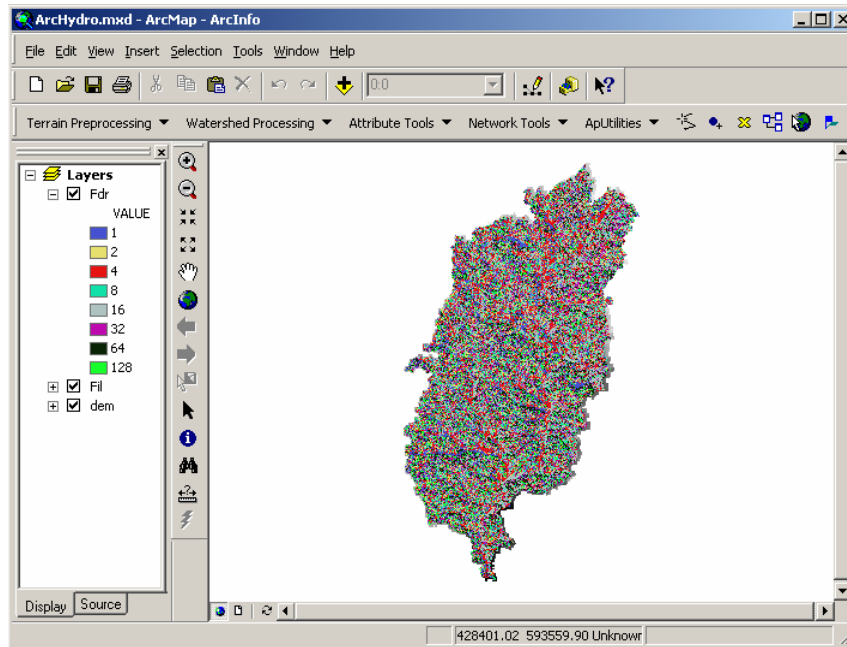
- Select **Terrain Preprocessing | Flow Direction**.



- Confirm that the input for Hydro DEM is “Fil”. The output is the Flow Direction Grid, named by default “Fdr”. This default name can be overwritten.
- If you have previously used the function Build Walls to fence in an external wall, you need to use again the Outer Wall Polygon to clip the Flow Direction grid correctly. Otherwise, leave this input to Null.



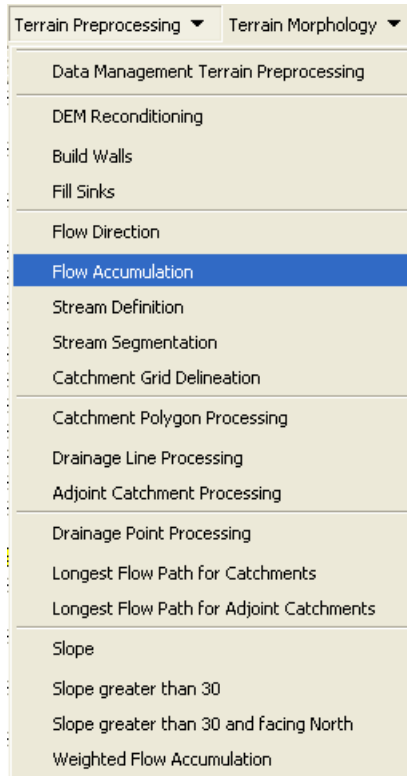
- Press OK. Upon successful completion of the process, the flow direction grid “Fdr” is added to the map.



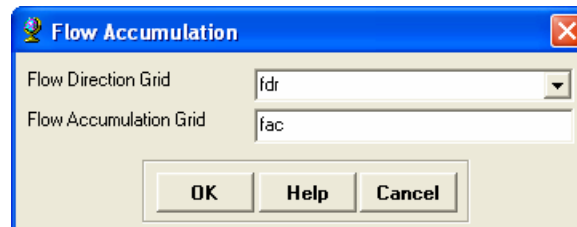
5. Flow Accumulation

This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid.

- Select **Terrain Preprocessing | Flow Accumulation**.



- Confirm that the input of the Flow Direction Grid is “Fdr”. The output is the Flow Accumulation Grid having a default name of “Fac” that can be overwritten.

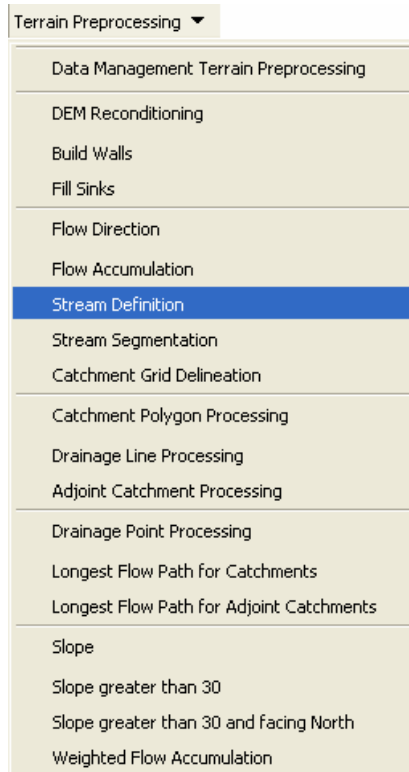


- Press OK. Upon successful completion of the process, the flow accumulation grid “Fac” is added to the map.

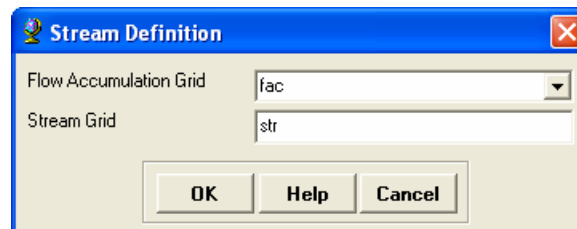
6. Stream Definition

This function computes a stream grid contains a value of "1" for all the cells in the input flow accumulation grid that have a value greater than the given threshold. All other cells in the Stream Grid contain no data.

- Select **Terrain Preprocessing | Stream Definition.**

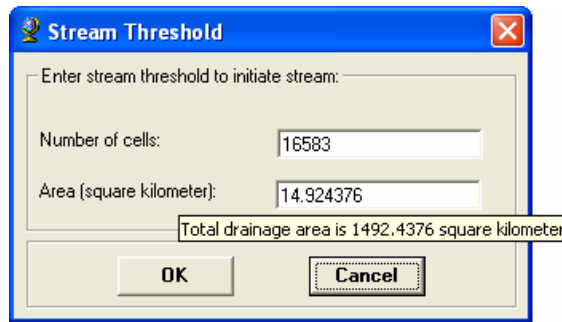


- Confirm that the input for the Flow Accumulation Grid is “Fac”. The output is the Stream Grid. “Str” is its default name that can be overwritten.



A default value is displayed for the river threshold. This value represents 1% of the maximum flow accumulation: it is the recommended threshold for stream determination. Note that these streams are used to prepare preprocessed data that will help speed up point delineation. These streams do not need to be meaningful or representative of existing streams. Any other value of threshold can be selected. Smaller threshold will result in denser stream network and usually in a greater number of delineated catchments, which may hinder delineation performance.

If the ground units have been set (otherwise Area will be grayed out), the threshold may also be set using the area in square kilometer. Check the online help (How to... Define ground unit and z-unit for more information on how to set the ground units).

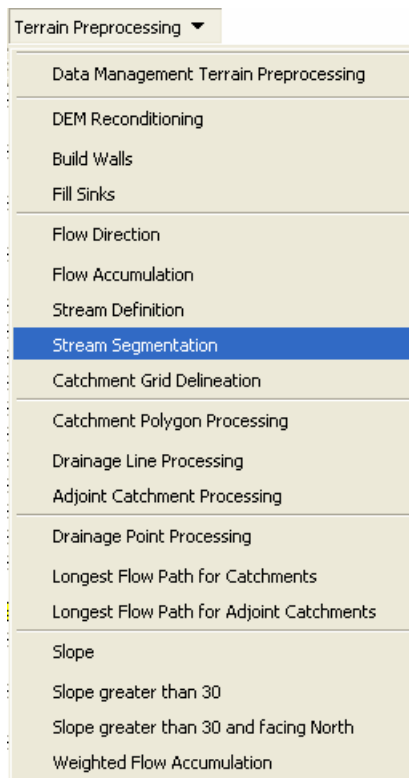


- Press OK. Upon successful completion of the process, the stream grid “Str” is added to the map.

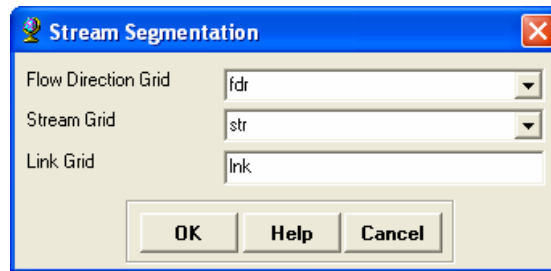
7. Stream Segmentation

This function creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment.

- Select **Terrain Preprocessing | Stream Segmentation**.



- Confirm that “Fdr” and “Str” are the inputs for the Flow Direction Grid and the Stream Grid respectively. The output is the Link Grid, with the default name “Lnk” that can be overwritten.

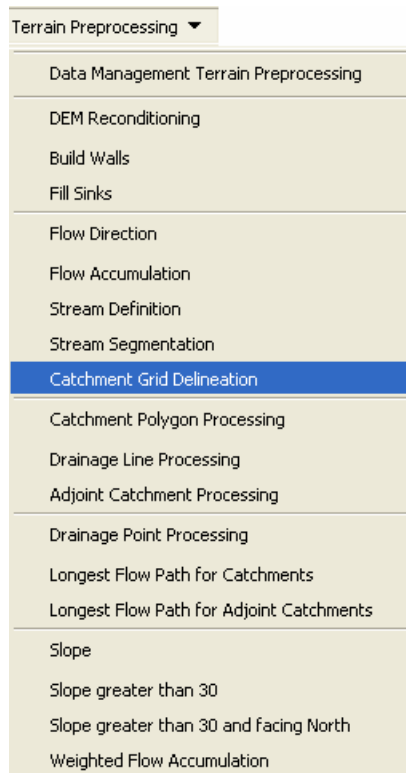


- Press OK. Upon successful completion of the process, the link grid “Lnk” is added to the map.

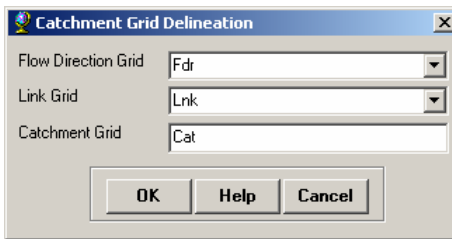
8. Catchment Grid Delineation

This function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid

- Select **Terrain Preprocessing | Catchment Grid Delineation**.



- Confirm that the input to the Flow Direction Grid and Link Grid are “Fdr” and “Lnk” respectively. The output is the Catchment Grid layer. “Cat” is its default name that can be overwritten by the user.

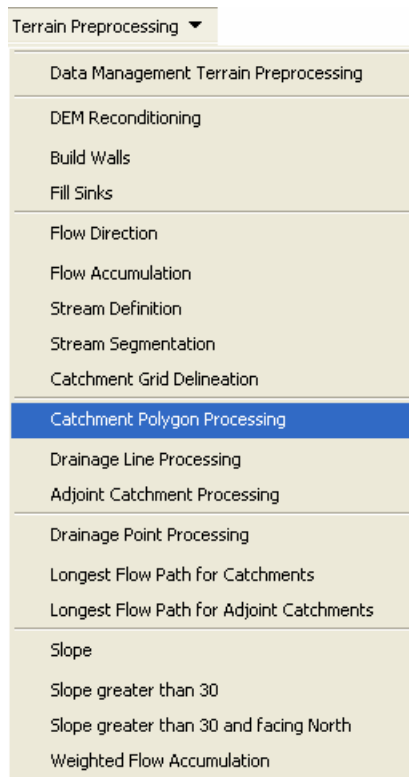


- Press OK. Upon successful completion of the process, the link grid “Lnk” is added to the map.

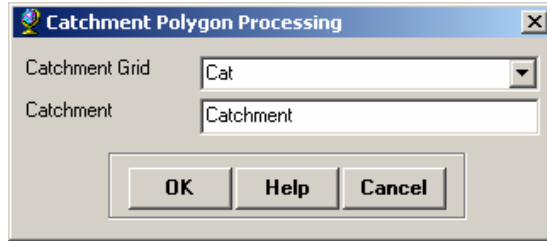
9. Catchment Polygon Processing

This function converts a catchment grid it into a catchment polygon feature.

- Select **Terrain Preprocessing | Catchment Polygon Processing**.



- Confirm that the input to the Catchment Grid is “Cat”. The output is the Catchment polygon feature class, having the default name “Catchment” that can be overwritten.



- Press OK. Upon successful completion of the process, the polygon feature class “Catchment” is added to the map.
- Open the attributes table of Catchment. The field GridID stores the grid value for the associated Catchment Grid. HydroID is a unique identifier that allows uniquely identifying features in the target geodatabase (i.e. the target vector workspace).

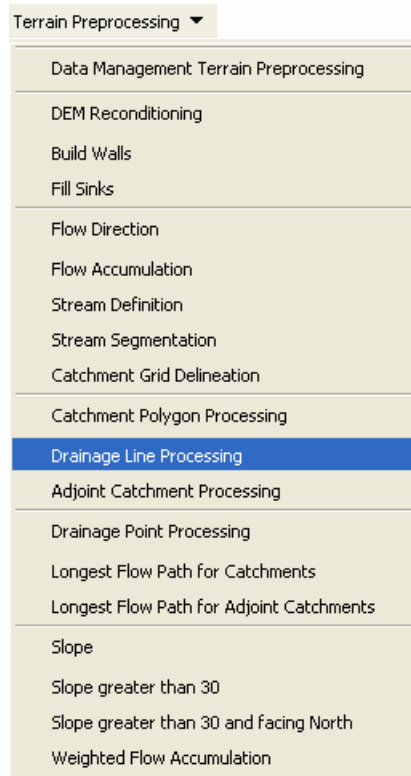
Shape*	OID*	Shape_Length	Shape_Area	HydroID	GridID
Polygon	1	36479.999918	26218800.038738	1	1
Polygon	2	31559.999814	16946100.014269	2	2
Polygon	3	13140.000097	4588200.010796	3	3
Polygon	4	27660.000038	10106100.047217	4	4
Polygon	5	25019.999957	21497399.982851	5	5
Polygon	6	20040.000011	13174200.024702	6	6
Polygon	7	24359.999917	11725200.015741	7	7
Polygon	8	33600.000006	32172299.979849	8	8
Polygon	9	26759.999934	21551399.975490	9	9
Polygon	10	24239.999924	18395099.991875	10	10

Record: 20 Show: All Selected Records (0 out of 53 Selected.) Options

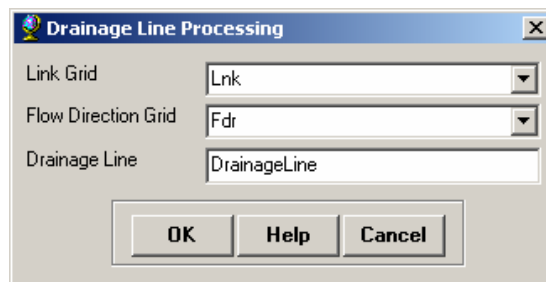
10. Drainage Line Processing

This function converts the input Stream Link grid into a Drainage Line feature class. Each line in the feature class carries the identifier of the catchment in which it resides.

- Select **Terrain Preprocessing | Drainage Line Processing**.



- Confirm that the input to Link Grid is “Lnk” and to Flow Direction Grid “Fdr”. The output Drainage Line has the default name “DrainageLine”, that can be overwritten.



- Press OK. Upon successful completion of the process, the linear feature class “Drainage Line” is added to the map.
- Open the attributes table of DrainageLine. GridID contains the HydroID of the corresponding Catchment. NextDownID contains the HydroID of the next downstream DrainageLine feature or “-1” if there are no downstream features.

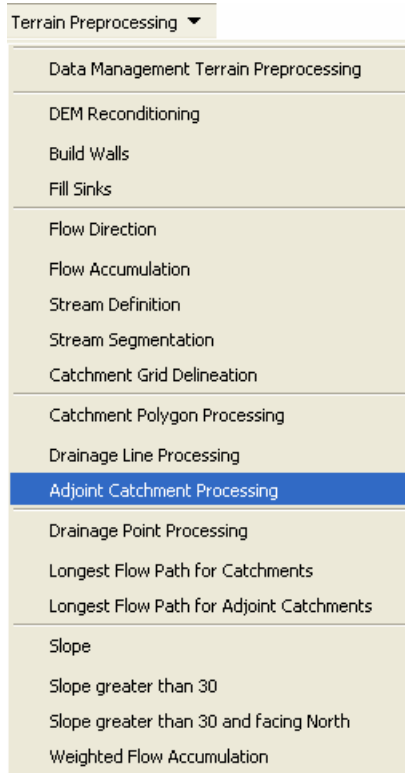
Shape*	OID*	Shape_Length	GridID	FROM_NOD	TO_NODE	HydroID	NextDownID
Polyline	1	6326.026012	1	1	2	54	56
Polyline	2	1635.182911	2	3	2	55	56
Polyline	3	3034.629881	3	2	5	56	57
Polyline	4	830.330104	4	5	4	57	-1
Polyline	5	5277.716385	5	6	5	58	57
Polyline	6	3744.777041	8	7	8	59	60
Polyline	7	4028.893947	6	8	6	60	58
Polyline	8	4249.188291	7	9	6	61	58
Polyline	9	1188.198115	10	10	9	62	61
Polyline	10	1565.954528	12	11	12	63	64

Record: 19 Show: All Selected Records (0 out of 53 Selected.) Options

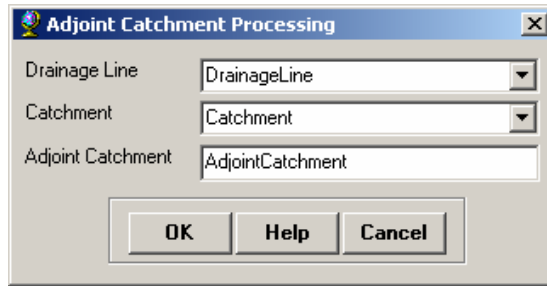
11. Adjoint Catchment Processing

This function generates the aggregated upstream catchments from the "Catchment" feature class. For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an "Adjoint Catchment" tag. This feature class is used to speed up the point delineation process.

- Select **Terrain Preprocessing | Adjoint Catchment Processing**.



- Confirm that the inputs to Drainage Line and Catchment are respectively "DrainageLine" and "Catchment". The output is Adjoint Catchment, with a default name "AdjointCatchment" that can be overwritten.



- Press OK. Upon successful completion of the process, the polygon feature class “Lnk” is added to the map.
- Open the attributes table of AdjointCatchment: HydroID is the unique identifier of the adjoint catchment and GridID contains the GridID of the catchment immediately downstream from the adjoint catchment.

Shape*	OID*	Shape_Length	Shape_Area	HydroID	GridID
Polygon	1	40440.000001	43164900.053007	107	3
Polygon	2	51539.999905	79488900.041519	108	13
Polygon	3	45540.000095	58288499.987401	109	22
Polygon	4	63119.999937	108263699.974872	110	15
Polygon	5	98040.000100	258779699.984452	111	9
Polygon	6	111360.000187	312503399.93979	112	6
Polygon	7	43080.000159	43336799.945011	113	26
Polygon	8	55200.000160	72854999.991575	114	33
Polygon	9	87179.999949	206917199.933838	115	31
Polygon	10	58379.999900	67703400.091926	116	45

- Open the attributes table of Catchment. Adjoint Catchment Processing has added the field NextDownID that contains the HydroID of the next downstream catchment (“-1” if there is no downstream catchment).

Shape*	OID*	Shape_Length	Shape_Area	HydroID	GridID	NextDownID
Polygon	1	36479.999918	26218800.038738	1	1	3
Polygon	2	31559.999814	16946100.014269	2	2	3
Polygon	3	13140.000097	4588200.010796	3	3	4
Polygon	4	27660.000038	10106100.047217	4	4	-1
Polygon	5	25019.999957	21497399.982851	5	5	4
Polygon	6	20040.000011	13174200.024702	6	6	5
Polygon	7	24359.999917	11725200.015741	7	7	5
Polygon	8	33600.000006	32172299.979849	8	8	6
Polygon	9	26759.999934	21551399.975490	9	9	6
Polygon	10	24239.999924	18395099.991875	10	10	7

- Open the attributes table of DrainageLine. Adjoint Catchment Processing has added the field DrainID that contains the HydroID of the catchment corresponding to the drainage line.

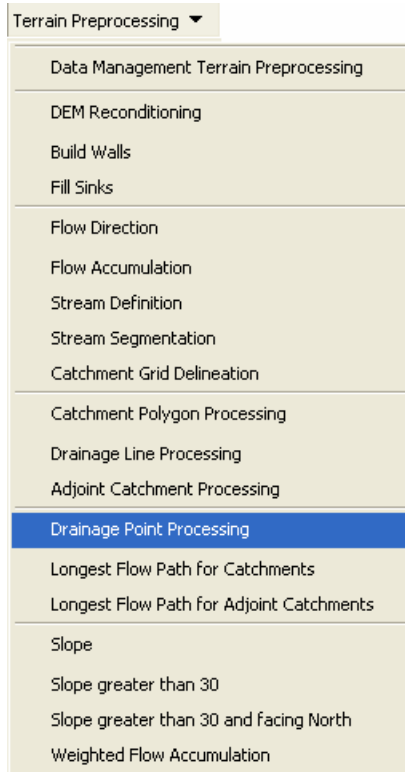
Shape*	OID*	Shape_Length	GridID	FROM_NOD	TO_NODE	HydroID	NextDownID	DrainID
Polyline	1	6326.026012	1	1	2	54	56	1
Polyline	2	1635.182911	2	3	2	55	56	2
Polyline	3	3034.629881	3	2	5	56	57	3
Polyline	4	830.330104	4	5	4	57	-1	4
Polyline	5	5277.716385	5	6	5	58	57	5
Polyline	6	3744.777041	8	7	8	59	60	8
Polyline	7	4028.893947	6	8	6	60	58	6
Polyline	8	4249.188291	7	9	6	61	58	7
Polyline	9	1188.198115	10	10	9	62	61	10
Polyline	10	1565.954528	12	11	12	63	64	12

Record: 18 Show: All Selected Records (0 out of 53 Selected.) Options

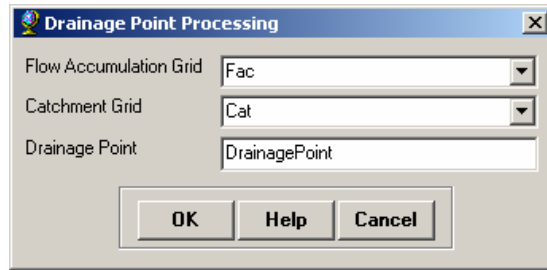
12. Drainage Point Processing

This function allows generating the drainage points associated to the catchments.

- Select **Terrain Preprocessing | Drainage Point Processing**.



- Confirm that the input to Drainage Line is “DrainageLine”, and the input to Catchment is “Catchment”. The output is Drainage Point, having the default name “DrainagePoint” that can be overwritten.



- Press OK. Upon successful completion of the process, the point feature class “DrainagePoint” is added to the map.
- Open the attributes table of DrainagePoint. HydroID is the unique identifier in the geodatabase. GridID is the value of the catchment grid draining to the drainage point. DrainID is the HydroID of the associated catchment.

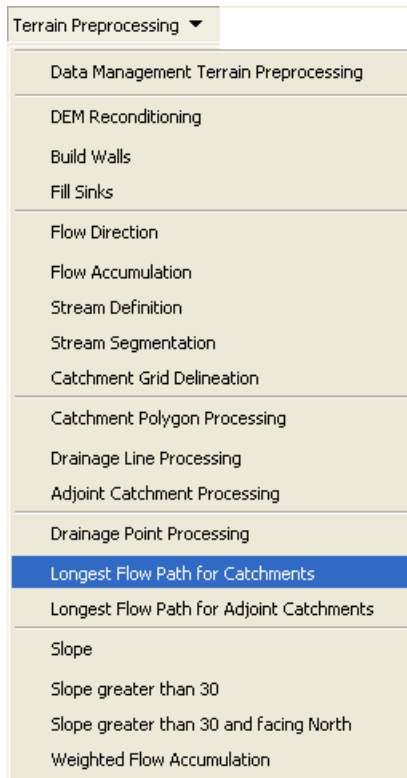
Shape*	OID*	HydroID	GridID	DrainID
Point	1	186	1	1
Point	2	187	2	2
Point	3	188	4	4
Point	4	189	3	3
Point	5	190	5	5
Point	6	191	6	6
Point	7	192	7	7
Point	8	193	8	8
Point	9	194	9	9
Point	10	195	10	10

13. Longest Flow Path for Catchments

This function allows generating the longest flow paths associated to the catchments. This is required to speed up the generation of Longest Flow Paths. If you do not plan to generate these types of features, you may skip this step as well as the next one.

Note: This function may be time-consuming.

- Select **Terrain Preprocessing | Longest Flow Path for Catchments**



- Confirm that the input to Flow Direction Grid is “Fdr”, and the input to Catchment is “Catchment”. The output is Longest Flow Path Catchment, having the default name “LongestFlowPathCat” that can be overwritten.



- Press OK. Upon successful completion of the process, the longest flow path for catchments feature class “LongestFlowPathCat” is added to the map.
- Open the attributes table of LongestFlowPathCat. HydroID is the unique identifier in the geodatabase. DrainID is the HydroID of the associated catchment. LengthDown is the length from the start of the flow path to the basin outlet in map units

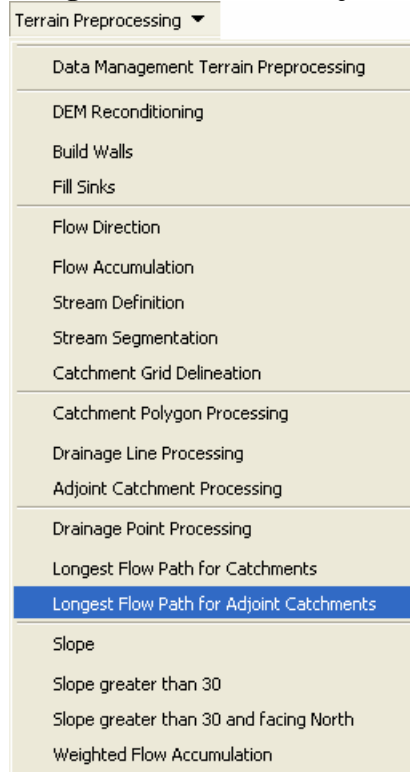
Shape*	OID*	Shape_Length	HydroID	DrainID	LengthDown
Polyline	1	12265.874537	239	1	16124.62
Polyline	2	11903.742426	240	2	15762.49
Polyline	3	4245.731577	241	3	5069.85
Polyline	4	6805.325732	242	6	12913.37
Polyline	5	10600.067040	243	8	20730.79
Polyline	6	8988.229425	244	12	30389.24
Polyline	7	9449.072483	245	5	10279.40
Polyline	8	8511.244539	246	9	18641.97
Polyline	9	7202.604989	247	13	24427.92
Polyline	10	8774.772740	248	4	8774.77

Record: 20 Show: All Selected Records (0 out of 53 Selected.) Opt

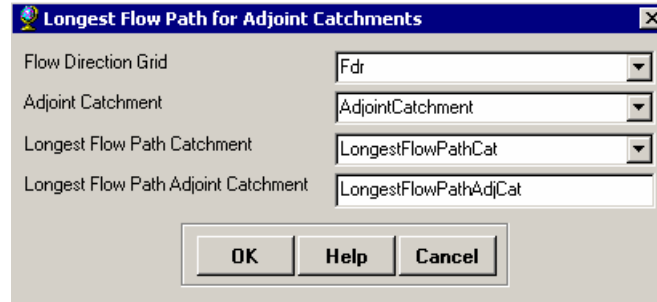
14. Longest Flow Path for Adjoint Catchments

This function allows generating the longest flow paths associated to the adjoint catchments.

- Select **Terrain Preprocessing | Longest Flow Path for Adjoint Catchments**



- Confirm that the input to Flow Direction Grid is “Fdr”, the input to Adjoint Catchment “AdjointCatchment” and the input to Longest Flow Path Catchment “LongestFlowPathCat”. The output is Longest Flow Path Adjoint Catchment, having the default name “LongestFlowPathAdjCat” that can be overwritten.



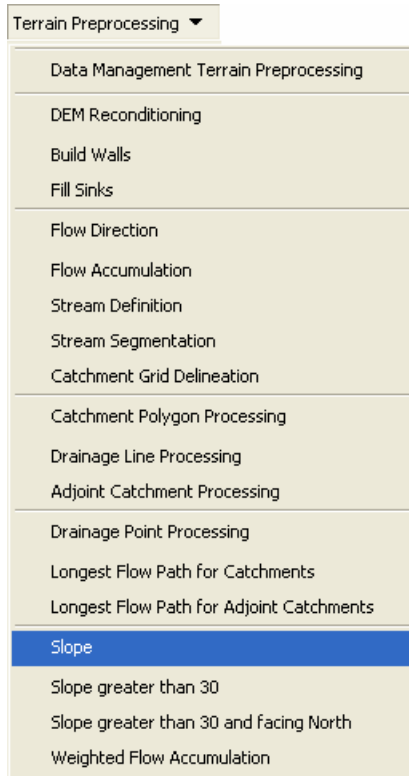
- Press OK. Upon successful completion of the process, the longest flow path for adjoint catchments feature class “LongestFlowPathCat” is added to the map.
- Open the attributes table of LongestFlowPathAdjCat. DrainID is the HydroID of the associated adjoint catchment.

Shape*	OID*	Shape_Length	DrainID
Polyline	1	12265.874537	107
Polyline	2	14340.321533	108
Polyline	3	9853.448121	109
Polyline	4	16141.053083	110
Polyline	5	27626.668995	111
Polyline	6	34715.045603	112
Polyline	7	9572.787806	113
Polyline	8	13288.372180	114
Polyline	9	18832.524837	115
Polyline	10	18256.311613	116

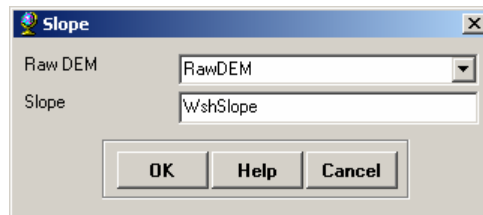
15. Slope

This function allows generating a slope grid in percent for a given DEM.

- Select **Terrain Preprocessing | Slope**.



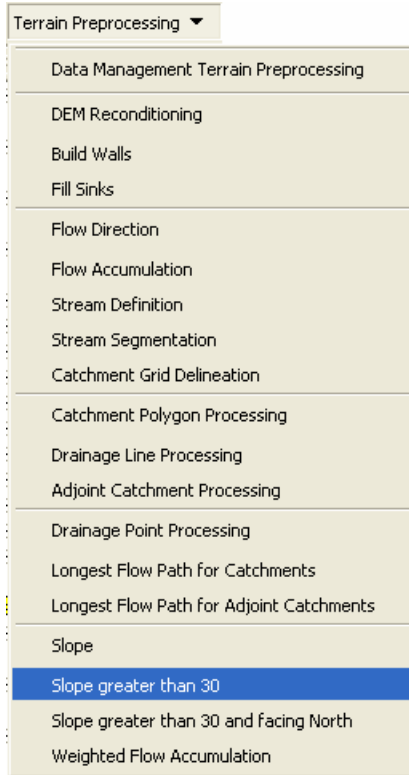
- Confirm that the input to Raw DEM is “RawDEM” (i.e. the unprocessed DEM). The output is the slope grid for that DEM, having the default name “WshSlope” that can be overwritten.



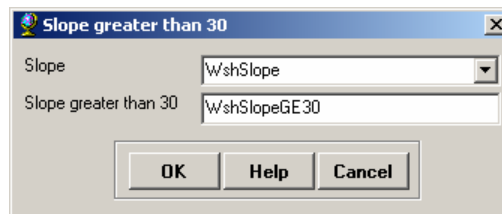
16. Slope greater than 30

This function allows generating a grid that characterizes all the cells having a slope greater than 30%. These cells have a value of 1, whereas all the others have a value of 0.

- Select **Terrain Preprocessing | Slope greater than 30**.



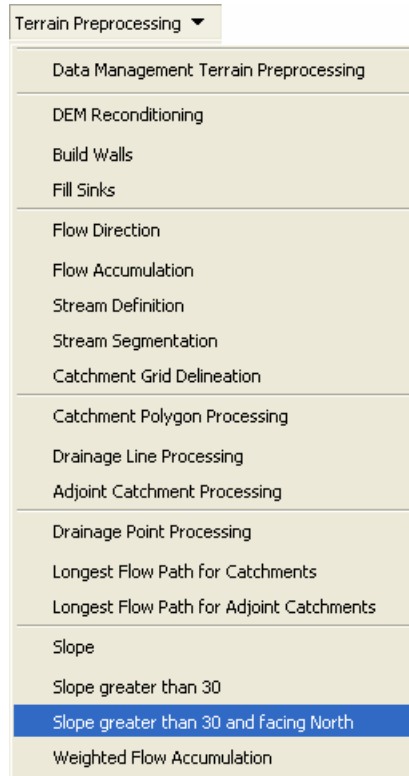
- Confirm that the input to Slope is the slope grid “WshSlope”. The output is a grid tagged “Slope greater than 30” in which all the cells having a slope greater than 30% have a value of 1, and all the others a value of 0.



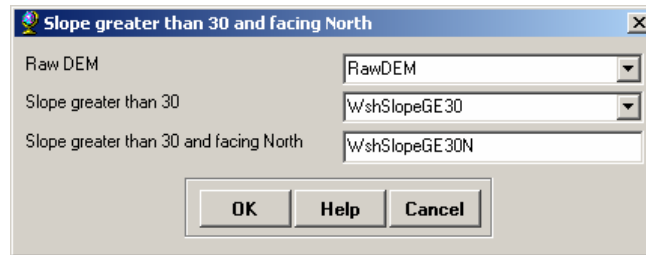
17. Slope greater than 30 and facing North

This function allows generating a grid that characterizes all the cells having a slope greater than 30% and facing North. These cells have a value of 1, whereas all the others have a value of 0.

- Select **Terrain Preprocessing | Slope greater than 30 and facing North**.



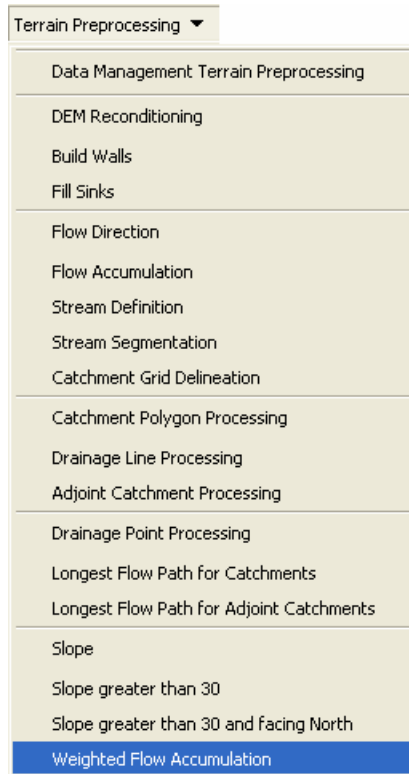
- Confirm that the input to “Raw DEM” is a DEM grid and the input to “Slope greater than 30” the grid computed for that DEM that characterizes the cells having a slope greater than 30%. The output is a grid (“Slope greater than 30 and facing North”) in which all the cells having a slope greater than 30% and facing North have a value of 1, and all the other cells a value of 0.



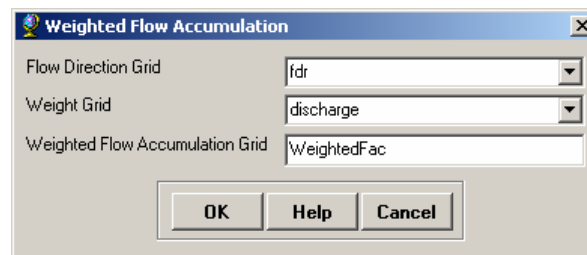
18. Weighted Flow Accumulation

This function computes a weighted flow accumulation grid. Each cell in the resulting grid contains the accumulated values from the weight grid of all the cells upstream of that cell.

- Select **Terrain Preprocessing | Weighted Flow Accumulation**.



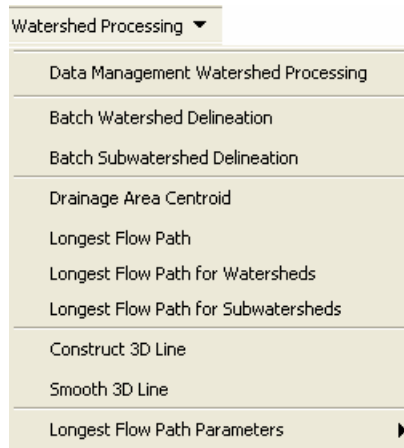
- Confirm that the input of the Flow Direction Grid is “Fdr”. Select a weight grid containing the value you want to accumulate (e.g. discharge grid containing the discharge generated in each cell – this grid may be computed by multiplying a runoff coefficient grid by a precipitation grid). The output is a Weighted Flow Accumulation Grid having a default name of “WeightedFac” that can be overwritten.



- Press OK. Upon successful completion of the process, the weighted flow accumulation grid “WeightedFac” is added to the map.

Watershed Processing


The steps in Terrain Preprocessing need to be performed before the watershed delineation functions may be used. The preprocessing functions partition terrain into manageable units to allow fast delineation operations.




1. Batch Watershed Delineation

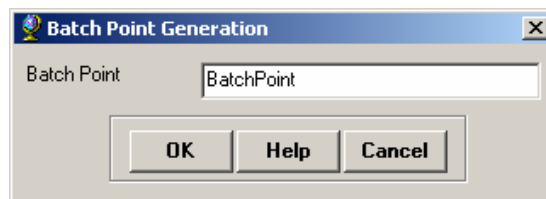
This function performs a batch watershed delineation for points in an input Batch Point feature class. This point feature class must contain four required fields:

- Name
- Descript
- BatchDone
- SnapOn

The Arc Hydro tool Batch Point Generation  may be used to interactively create the Batch Point feature class.

To create the Batch Point input file

- Click on the icon  in the Arc Hydro Tools toolbar.
- Confirm that the name of the batch point feature class is “BatchPoint”.



The BatchPoint feature class will be added to the Table of Contents.

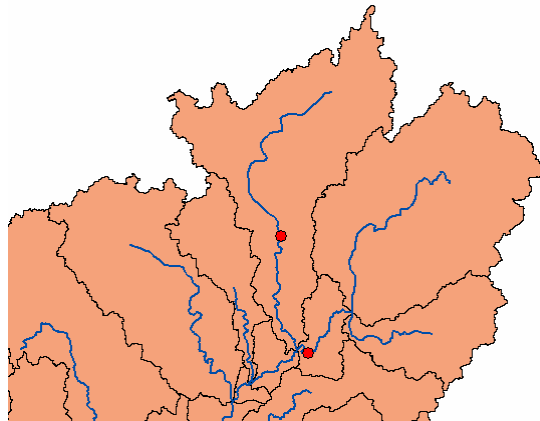
- Click with the mouse on the to create a point on the map. The following form is displayed:

The dialog box titled "Batch Point Generation" has a "Point Definition" section with the following fields:

- Name: Name 1
- Description: Description 1
- BatchDone: 0 (dropdown menu)
- SnapOn: 1 (dropdown menu)

Buttons for "OK" and "Cancel" are located at the bottom.

- Fill in the fields Name and Description. Both are string fields. The BatchDone option indicates whether the Batch Watershed Delineation function will perform a delineation for that point (0: delineate, 1: do not delineate). The SnapOn option indicates whether the Batch Watershed Delineation function will try to snap the point to the closest stream. Select the options shown above.
- Create another point, and fill in the Name and Description.



- Open the attribute table of BatchPoint. BatchDone = 0 means that Batch Point Delineation will process the 2 points.

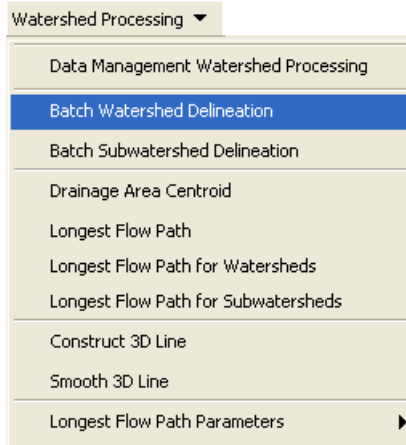
The attribute table titled "Attributes of BatchPoint" contains the following data:

Shape*	OID*	Name	Descript	BatchDone	SnapOn
Point	1	Name 1	Description 1	0	1
Point	2	Name 2	Description 2	0	1

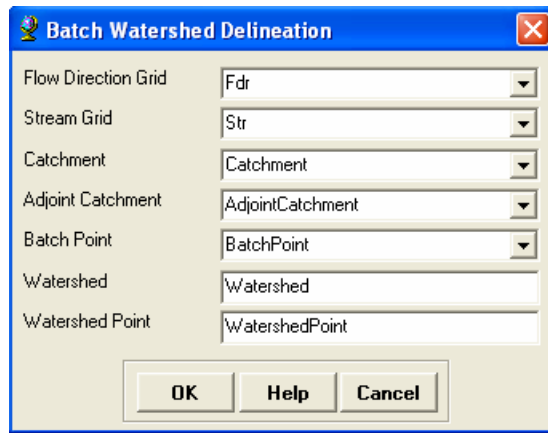
Record navigation controls show record 2 of 2. Show: All Selected. Records (0 out of 2 Selected.)

To perform a batch watershed delineation

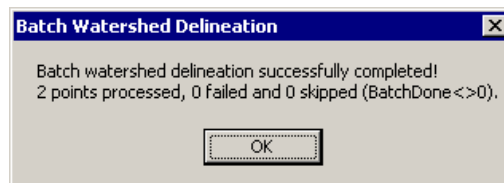
- Select **Watershed Processing | Batch Watershed Delineation**.



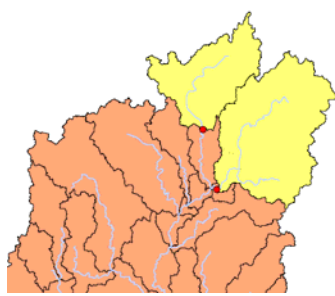
- Confirm that “Fdr” is the input to Flow Direction Grid, “Str” to Stream Grid, “Catchment” to Catchment, “AdjointCatchment” to AdjointCatchment, and “BatchPoint” to “Batch Point”. For output, the Watershed Point is “WatershedPoint”, and Watershed is “Watershed”. “WatershedPoint” and “Watershed” are default names that can be overwritten.



- Press OK. The following message box appears on the screen, indicating that 2 points have been processed.



The delineated watersheds are shown below.



- Open the attributes table of Batch Point. BatchDone now contains the value 1 that indicates that the watershed associated to each point has been delineated. If an error occurs during delineation, the field BatchDone will be updated with the value -1.

Shape*	OID*	Name	Descript	BatchDone	SnapOn
Point	1	Name 1	Description 1	1	1
Point	2	Name 2	Description 2	1	1

Record: 1 Show: All Selected Records (0 out of 2 Selected.)

- Open the attributes table of WatershedPoint and Watershed. WatershedPoint and Watershed are related to BatchPoint through the Name field. The DrainID in WatershedPoint is the HydroID of the corresponding Watershed.

Shape*	OID*	HydroID	DrainID	Name	Descript
Point	1	366	365	Name 1	Description 1
Point	2	368	367	Name 2	Description 2

Record: 2 Show: All Selected Records (0 out of 2 Selected.)

Shape*	OID*	Shape_Length	Shape_Area	HydroID	Name
Polygon	1	223199.998264	480177001.17264	365	Name 1
Polygon	2	70080.001122	105052500.255113	367	Name 2

Record: 2 Show: All Selected Records (0 out of 2 Selected.)

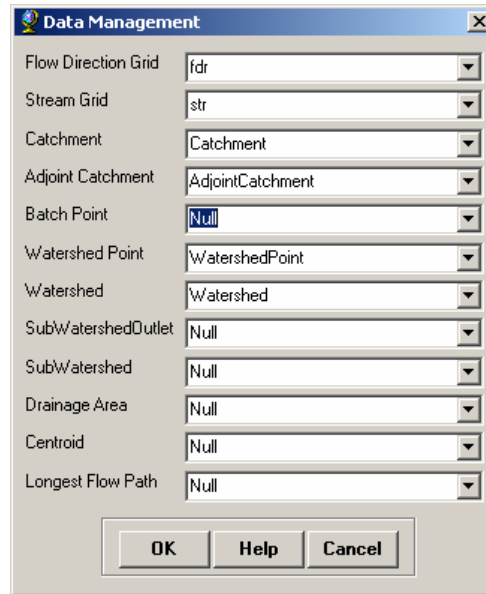
Note: New watershed and watershedpoint features will be appended to the feature classes.


2. Batch Subwatershed Delineation

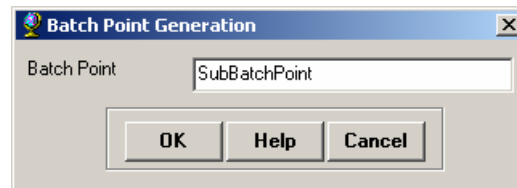
This function allows delineating subwatersheds for all the points in a selected Point Feature Class. Input to the batch subwatershed delineation function is a point feature class with point locations of interest. The Batch Point Generation function can be used to interactively create such a file.

To create the input Point Feature Class

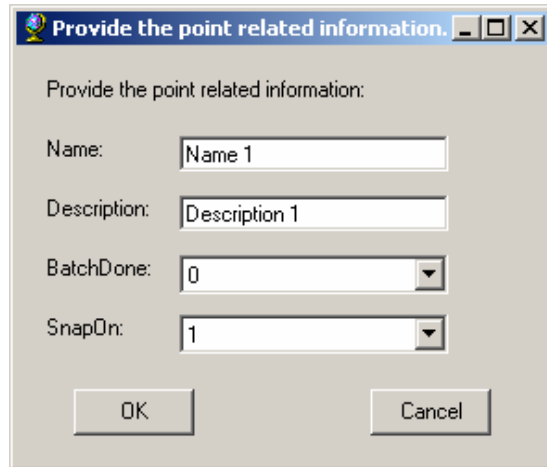
- Reset the tag BatchPoint by selecting Watershed Processing/Data Management, and setting BatchPoint to Null. Click OK.



- If you previously used BatchPoint, which is the default name for the Batch Point feature class, the function will automatically use BatchPoint and not prompt for it. In this case, you need to change the default name in the XML to be able to reset Batch Point:
 - Select ApUtilities>XML Manager...
 - Browse to the node HydroConfig>TemplateView>ApLayers>ApLayer(BatchPoint).
 - Right-click this node and select EditAttributes.
 - Change the name from BatchPoint to BatchPointDefault for example and click OK.
 - Close the XML Manager.
- Click on the icon  in the Arc Hydro toolbar to activate the Batch Point Generation tool and click with the mouse on the map at the location of the new point to generate.
- Enter "SubBatchPoint" for the Batch Point feature class. Click OK.

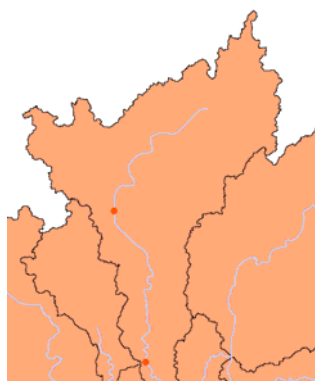


- Fill in the fields Name and Description in the form.

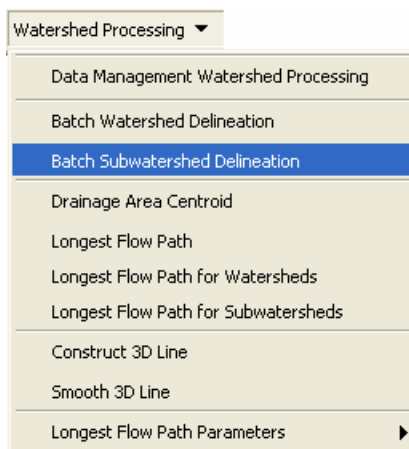


The BatchDone and SnapOn options are used in batch subwatershed delineation in the same way as in batch watershed delineation.

- Create another point on the map. Fill in the name and description.

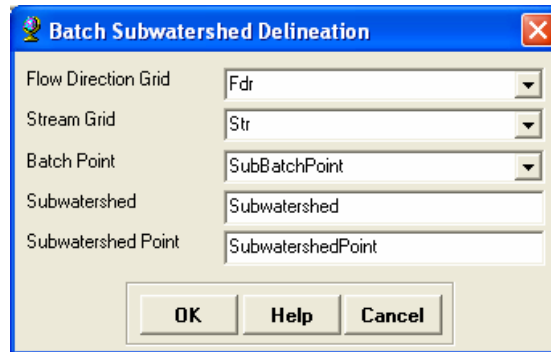


- Select **Watershed Processing | Batch Subwatershed Delineation**.

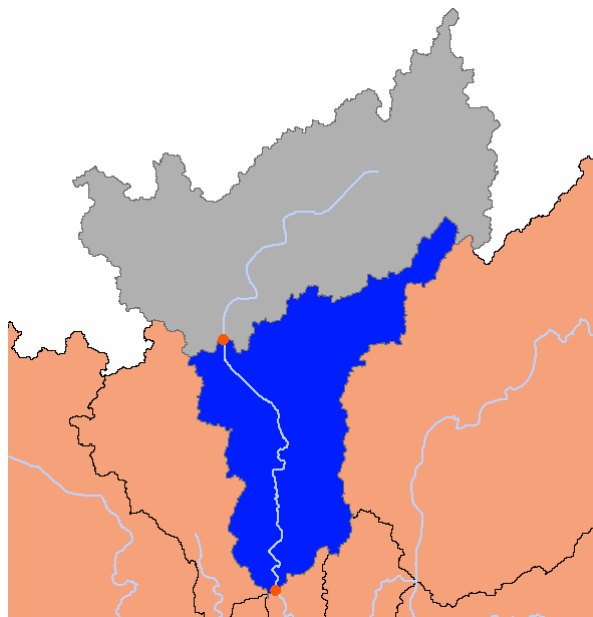


- Confirm that the input to the Flow Direction Grid is “Fdr”, to the Stream Grid {“Str”) and to the Batch Point feature class “SubBatchPoint”. The output Subwatershed is named by default

“Subwatershed” and the output Subwatershed Point “SubwatershedPoint”. These names may be overwritten.



- Press OK. The delineated subwatersheds are shown below.



Notes:

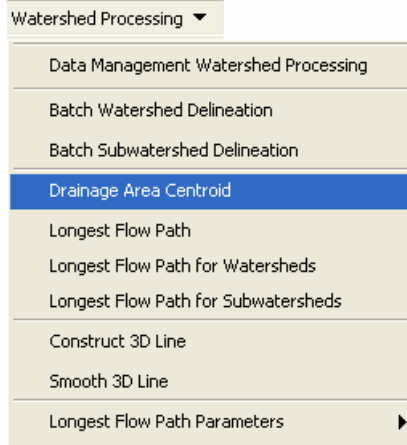
The function will delineate only the SubBatchPoint features having BatchDone=0.

The old Subwatershed and Subwatershed Points records will be deleted each time a new delineation is performed, since for subwatersheds the number of points to delineate has an impact on the result.

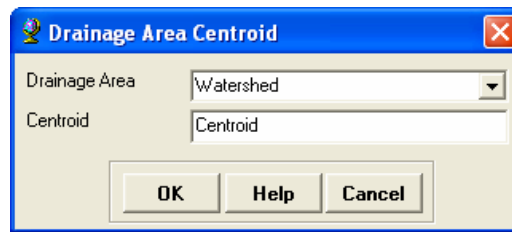
3. Drainage Area Centroid

This function generates the centroid of drainage areas as centers of gravity. It operates on a selected set of drainage areas in the input Drainage Area feature class. If no drainage area has been selected, the function operates on all the drainage areas.

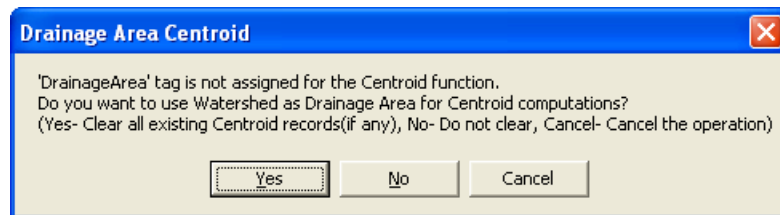
- Select **Watershed Processing | Drainage Area Centroid**.



- Confirm that the input to Drainage Area is “Watershed”. The output of Centroid is “Centroid”. “Centroid” is a default name that can be overwritten.

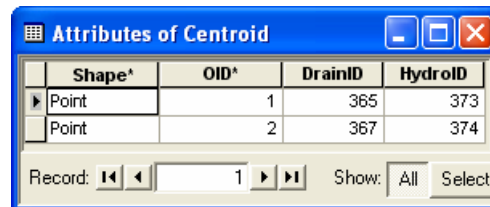


- Press OK to calculate the centroids for the catchments. The following message box is displayed on the screen.



- Select Yes to set “DrainageArea” to Watershed for the Centroid: this parameter allows linking the source drainage area to the centroids.

The DrainID in the Attributes table of Centroid is the HydroID of the corresponding Drainage Area feature.



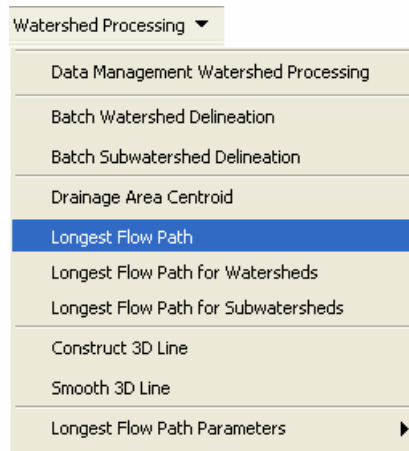
Shape*	OID*	Shape_Length	Shape_Area	HydroID	Name
Polygon	1	223199.998264	480177001.17264	365	Name 1
Polygon	2	70080.001122	105052500.255113	367	Name 2

Record: 2 Show: All Selected Records (0 out of 2 Selected.)

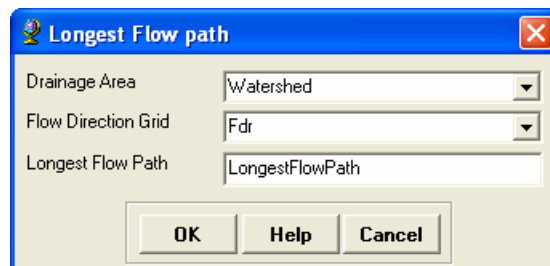
4. Longest Flow Path

This function identifies and computes the length of the longest flow path in a selected set of drainage areas (e.g. any polygon feature class). If no drainage area has been selected, the function processes all the drainage areas.

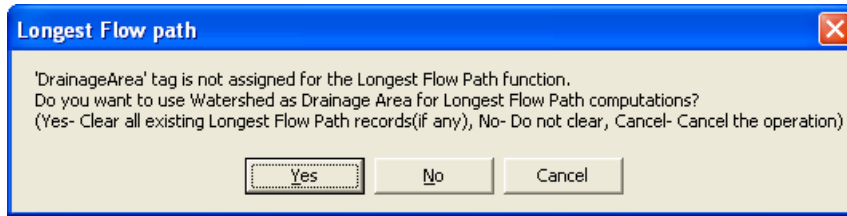
- Select one of the Watershed features.
- Select **Watershed Processing | Longest Flow Path**.



- Confirm that the input to the Flow Direction Grid is “Fdr”, and the input to Drainage Area is “Watershed”. The output of Longest Flow Path is “LongestFlowPath”. “LongestFlowPath” is a default name that can be overwritten.

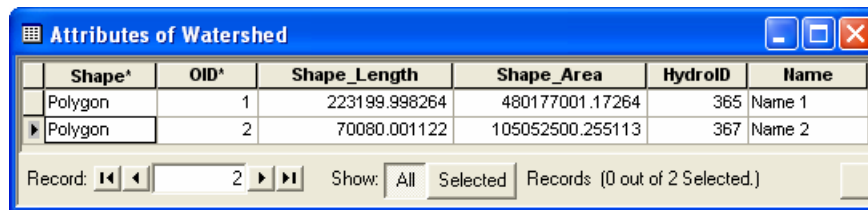
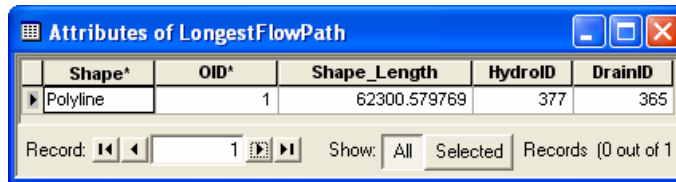


- Press OK to calculate the longest flow path.
- The message box below appears on the screen. Select Yes to relate the flow paths to the source Drainage Area feature class.



- Upon completion of the operation the LongestFlowPath linear feature class is added to the map.

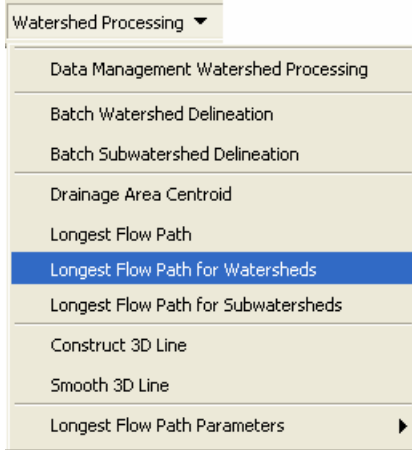
The DrainID in the Attributes table of Longest Flow Path is the HydroID of the associated Drainage Area feature.



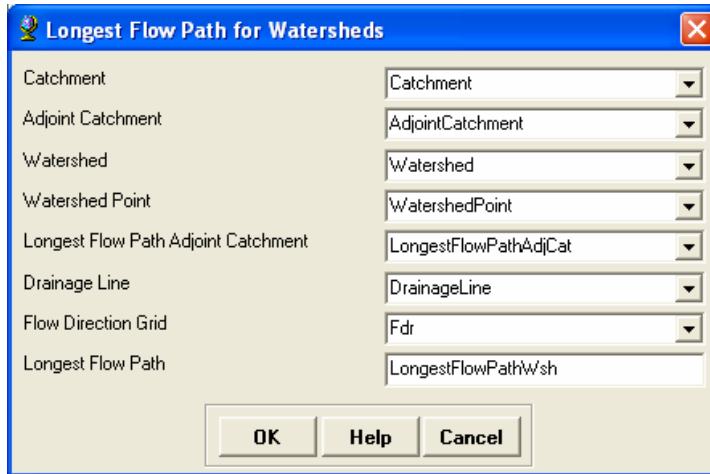
5. Longest Flow Path for Watersheds

This function generates the longest flow paths for input watersheds more efficiently than the previous function because it relies on preprocessed data to speed up the process.

- Select one of the Watershed features.
- Select **Watershed Processing | Longest Flow Path for Watersheds**.



- Confirm the inputs to Catchment, Adjoint Catchment, Watershed, Watershed Point, Longest Flow Path Adjoint Catchment, Drainage Line and Flow Direction Grid. Rename the output Longest Flow Path “LongestFlowPathWsh” not to overwrite the feature previously created. Click OK.



The DrainID in the Attributes table of LongestFlowPathWsh is the HydroID of the associated watershed.

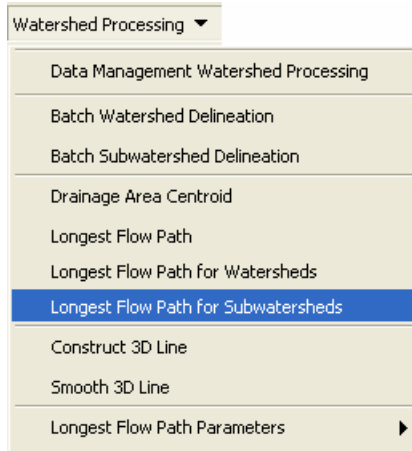


6. Longest Flow Path for Subwatersheds

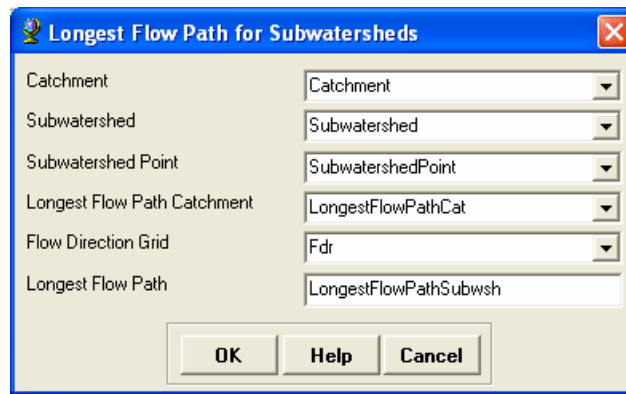
This function generates the longest flow paths for input subwatersheds more efficiently than the Longest Flow Path function because it relies on preprocessed data to speed up the process.

- Select one of the Subwatershed features.

- Select **Watershed Processing | Longest Flow Path for Subwatersheds**.



- Confirm the inputs to Catchment, Subwatershed, Subwatershed Point, Longest Flow Path Catchment and Flow Direction Grid. Rename the output Longest Flow Path “LongestFlowPathSubwsh”. Click OK.



The DrainID in the Attributes table of LongestFlowPathSubwsh is the HydroID of the associated subwatershed.

Shape*	OID*	Shape_Length	HydroID	DrainID
Polyline	1	46162.465139	383	381

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

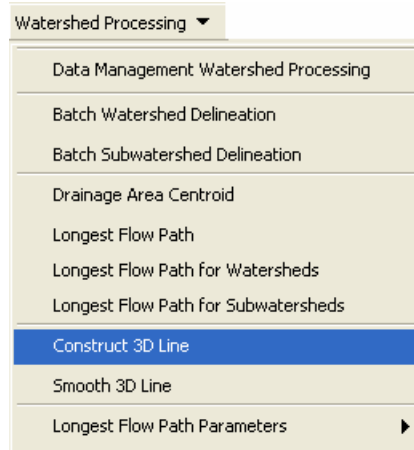
Shape*	OID*	Shape_Length	Shape_Area	HydroID	Name
Polygon	3	212340.007209	425469594.81435	381	Name 1
Polygon	4	56519.999567	54681298.870217	382	Name 2

Record: 1 Show: All Selected Records: (0 out of 2 Selected.)

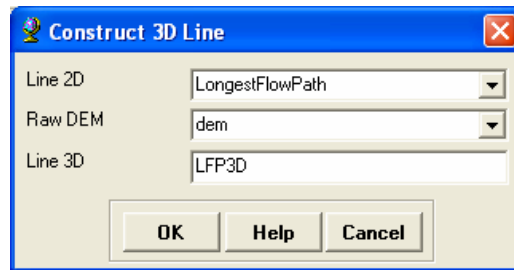
7. Construct 3D Line

This function allows building the 3D (z-aware) lines corresponding to a selected set of 2D lines by extracting elevations from an input DEM. Elevations are stored in the X/Y unit of the input DEM.

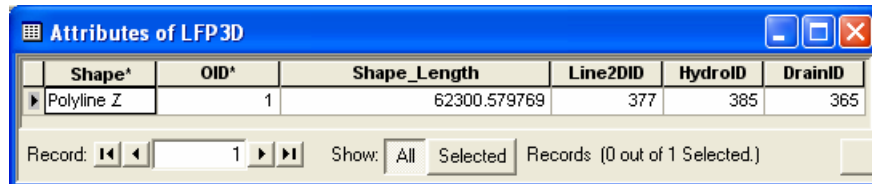
- Select on the previously created Longest Flow Path feature stored in the LongestFlowPath feature class.
- Select **Watershed Processing | Construct 3D Line**.



- Select LongestFlowPath as input Line 2D feature class and dem (i.e. the unprocessed dem) as Raw DEM. The output is Line 3D is called by default Line3D. Rename the output LFP3D and click OK.



The 3D Line (Polyline Z shape) corresponding to the selected input 2D Line (Polyline shape) is generated. It contains the same attributes as the input line as well as the Line2DID attribute, which stores the HydroID of the associated 2D line.



Shape*	OID*	Shape_Length	HydroID	DrainID
Polyline	1	62300.579769	377	365

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

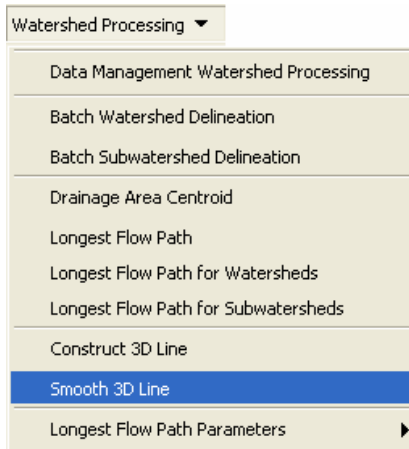
Note:

The 3D Line has more vertices than the 2D Line so that z values are known along the line and not only at the vertices of the 2D Line.

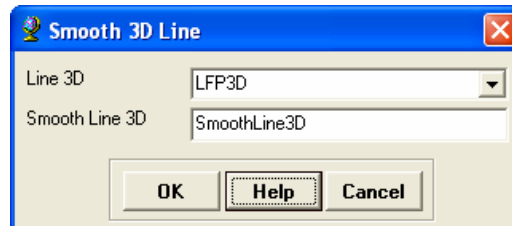
8. Smooth 3D Line

This function smoothes a 3D line oriented in the downstream direction. Smoothing is performed linearly along each line feature.

- Select **Watershed Processing | Smooth 3D Line**.



- Select the input 3D Line feature class containing features to smooth and enter a name for the output line. Click OK.



The Smooth Line 3D (Polyline Z shape) corresponding to the selected input 3D Line is generated. It contains the same attributes as the input line as well as the Line3DID attribute, which stores the HydroID of the associated 3D line.

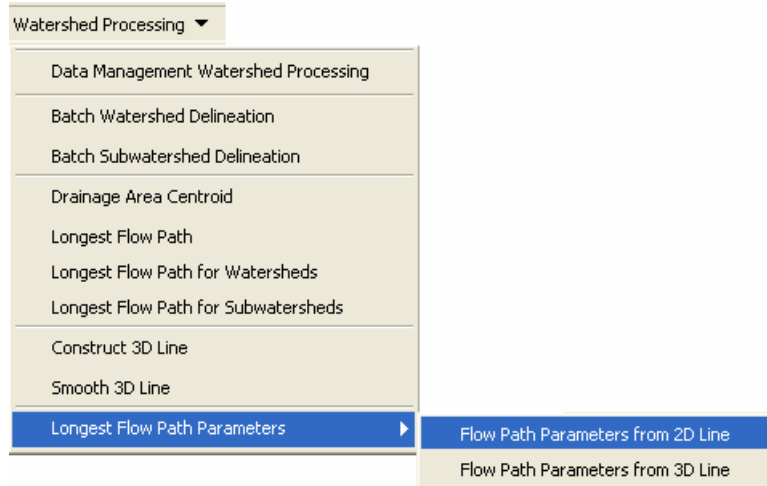
Shape*	OID*	Shape_Length	Line3DID	Line2DID	HydroID	DrainID
Polyline Z	1	62300.579769	385	377	386	365

Shape*	OID*	Shape_Length	Line2DID	HydroID	DrainID
Polyline Z	1	62300.579769	377	385	365

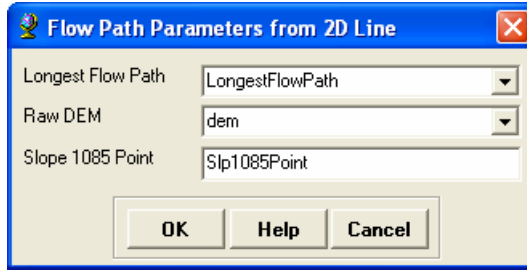
9. Flow Path Parameters from 2D Line

This function computes the longest flow path length, the slope and 10-85 slope, and the 10-85 points associated to the longest flow paths features. The slopes values are stored in the Longest Flow Path feature class. This function works on the selected longest flow paths features or on all the features if none are selected. Elevations are extracted from the input dem.

- Select the longest flow paths to process.
- Select **Watershed Processing | Longest Flow Path Parameters | Flow Path Parameters from 2D Line**.



- Confirm that the input to the elevation grid Hydro DEM grid is the “RawDEM” dem, and the input to the Longest Flow Path is “LongestFlowPath”. Enter a name for the output Slope 1085 Point feature class. Click OK.



The function computes the following parameters:

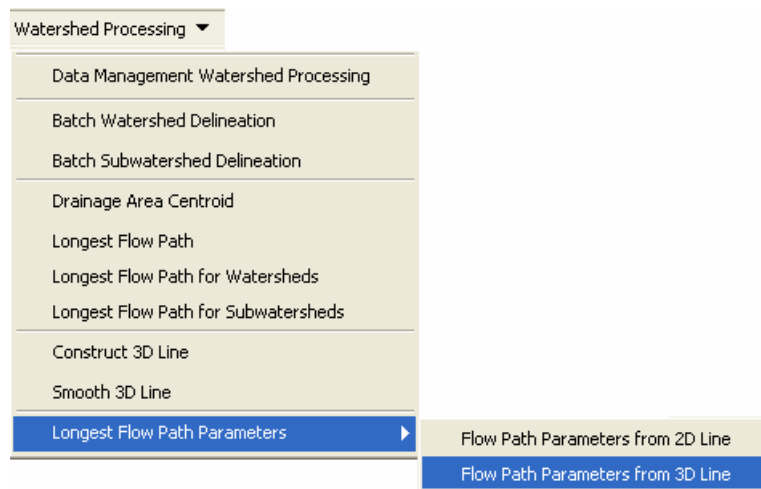
- LengthMi: Length of longest flow path feature in miles.
- SlpFM: Slope in feet per mile.
- Slp1085FM: 10-85 slope in feet per mile.
- Slp: Dimensionless slope.
- Slp1085: Dimensionless 10-85 slope.
- ElevUP: Upstream elevation in meters.
- ElevDS: Downstream elevation in meters.
- Elev10: Elevation at 10% along the flow path from the outlet in meters.
- Elev85: Elevation at 85% along the flow path from the outlet in meters.

The function also creates the 10-85 points associated to each flow path and stores their elevation in meters.

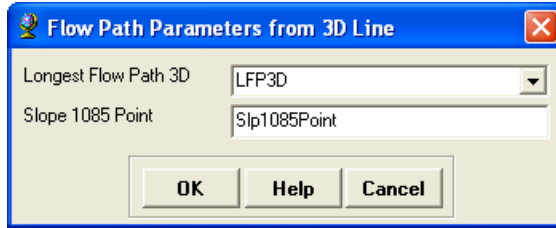
10. Flow Path Parameters from 3D Line

This function computes the same parameters as the previous function by reading elevations from the 3D lines instead of the input DEM.

- Select **Watershed Processing | Longest Flow Path Parameters | Flow Path Parameters from 3D Line**.



- Select the input Longest Flow Path 3D feature class (LFP3D) and enter a name for the output Slope 1085 Point feature class. Click OK.



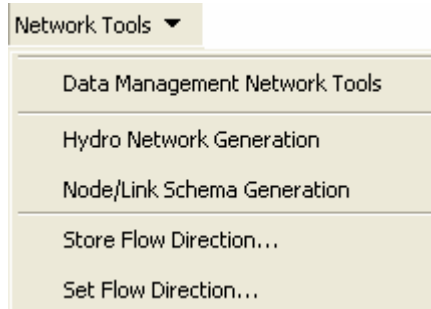
The function computes the slopes and generates the 10-85 points associated to the longest flow path features processed.

The "Attributes of LFP3D" window displays a table with 12 columns and one data row. Below the table is a navigation bar with record navigation buttons, a "Show:" dropdown set to "Selected", and a status indicator "Records (0 out of 1 Selected.)".

Line2DID	HydroID	DrainID	LengthMi	SlpFM	Slp1085FM	Slp	Slp1085	ElevUP	ElevDS	Elev10	Elev85
377	385	365	38.720	9.58	8.02	0.00181	0.00152	412	299	305	376

Network Tools

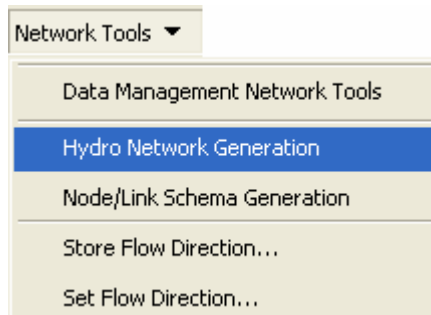
If the dataset already has the geometric network with Hydro Edges and Hydro Junctions layers defined, you can directly use all the Attribute Tools. However, if you are coming from a raster environment as we are in this example, you will need to use the Network Tools to generate the geometric network before you can use some of the Attribute Tools.



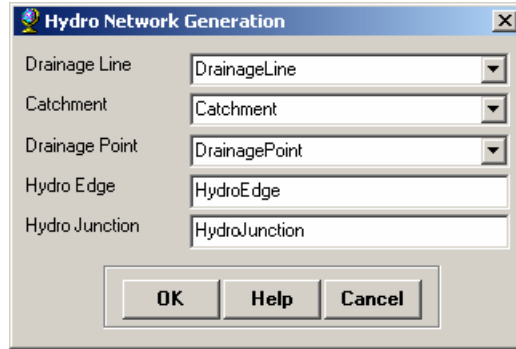
1. Hydro Network Generation

This function allows converting drainage features into network features, and creating the associated geometric network. It also creates a relationship class (HydroJunctionHasCatchment) between the new HydroJunction feature class (HydroJunction) and the Catchment feature class that will be used subsequently.

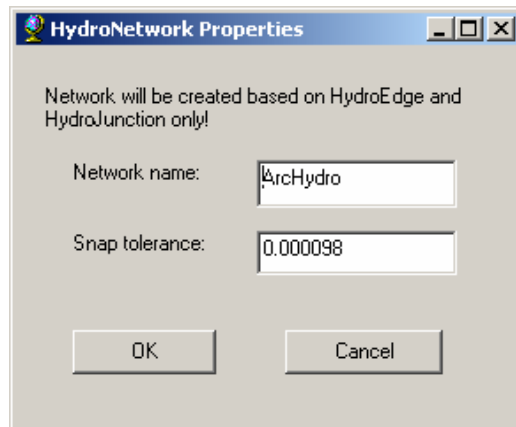
- Select **Network Tools | Hydro Network Generation**.



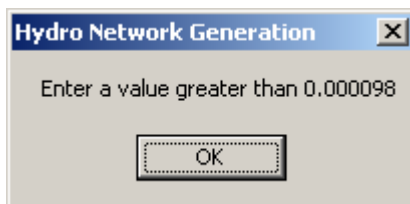
- Confirm that the input to Drainage Line is “DrainageLine”, to Catchment “Catchment”, and to Drainage Point “DrainagePoint”. The output Hydro Edge is named by default “HydroEdge”, and the output Hydro Junction “HydroJunction”. These names can be overwritten.



- Press OK. Upon the completion of the process, the following form appears. It shows the default network name and snap tolerance. The default value of snap tolerance is the minimum snap tolerance allowed needed to create the network. If a lower tolerance is entered, a warning message is generated.

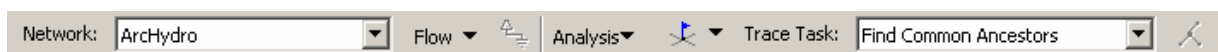


- Enter a lower tolerance. The following warning appears on the screen.




- Enter the minimum tolerance and click OK.

The network generated, named “ArcHydro”, is added to the Utility Network Analyst as shown below (the Utility Network Analyst toolbar needs to be loaded manually, if not present in the ArcMap document).



Sometimes even after the successful completion of the operation, the HydroEdge and HydroJunction

layer may not show in the map, and the network may not be added to the Utility Network Analyst. In such cases, you need to manually add these layers.

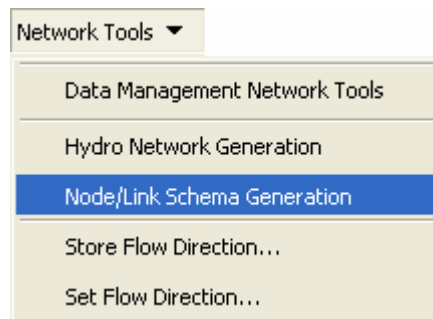
- To manually add these layers, click on the  icon to add data. Navigate to the location of data, and select the HydroEdge and HydroJunction layers to add them to the map (or select the network – this will load both layers).

2. Node/Link Schema Generation

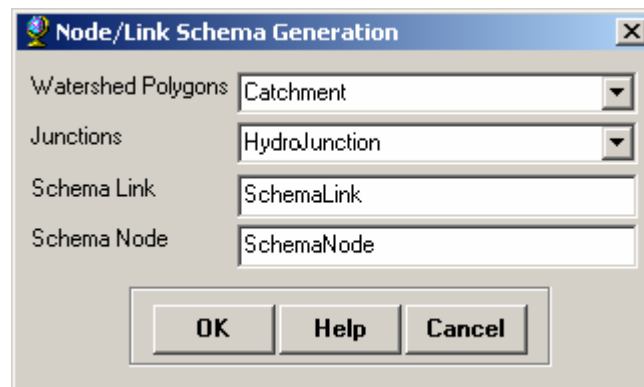
This function allows generating a node-link schema. The nodes are defined by the centers of the polygons representing basins and by points that represent locations of interest in the model. The points include basin outlets, river junctions, water intakes and other facilities.

The function requires that the relationship between the Watershed Polygons and their outlet be established through the JunctionID field, and the relationship between the Junctions and their next downstream junction be established through the NextDownID field.

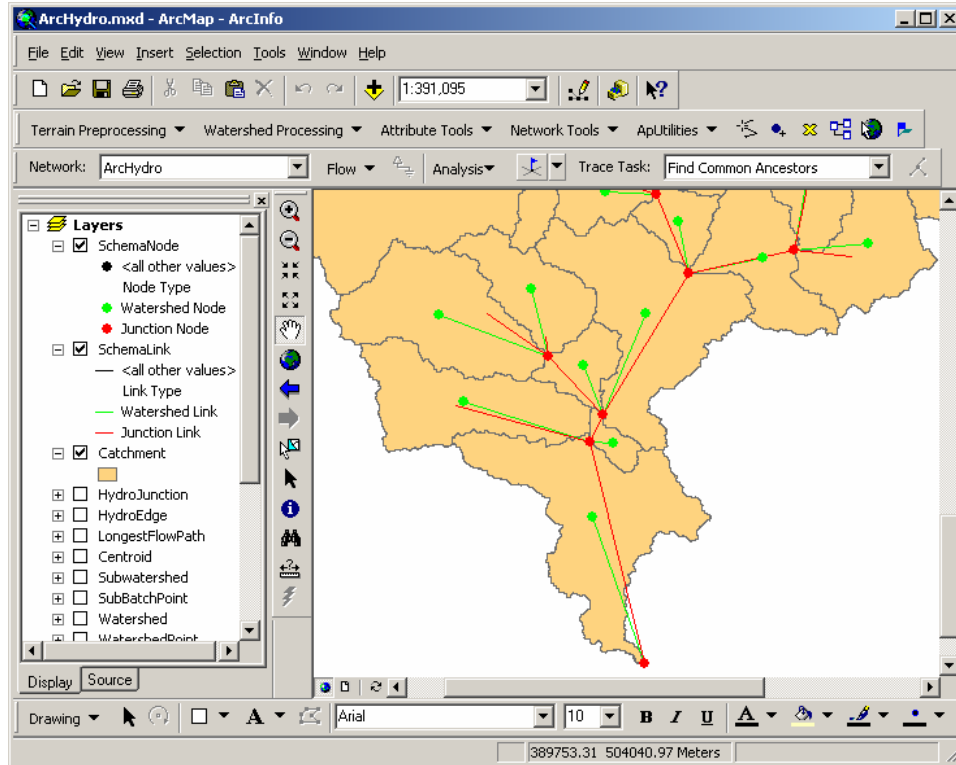
- Select **Network Tools | Node/Link Schema Generation**.



- Confirm that the input to Watershed Polygons is “Catchment” and to Junctions “HydroJunction”. The default names for the outputs, Schema Link and Schema Node, are respectively “SchemaLink” and “SchemaNode”. These names can be overwritten.



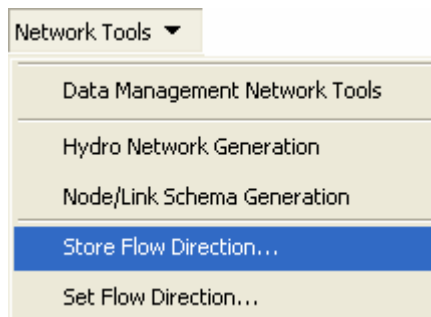
- Press OK. The links and nodes are generated as shown below.



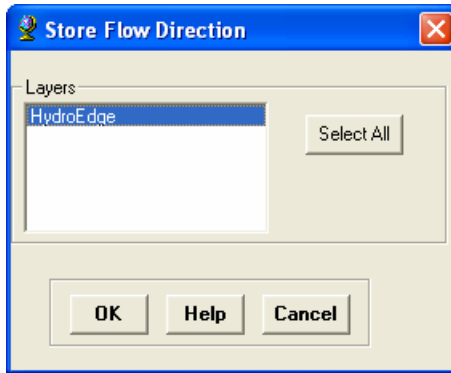
3. Store Flow Direction

This function reads the flow direction for a set of edges from the network and writes the value of the flow direction to a FlowDir field defined in the XML in the Edge Feature Class.

- Select **Network Tools | Store Flow Direction**.



- Select “HydroEdge” under Layers by clicking on the name or on Select All. Click OK.



- Press OK. The FlowDir field in the Hydro Edge feature class is populated with the specification of the flow direction for each feature.

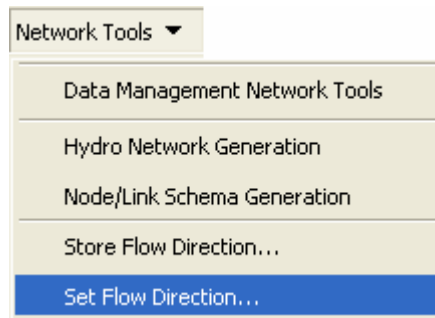
	OID*	Shape_Length	HydroID	ReachCode	FType	FlowDir	EdgeType	Enabled
▶	4	20625.977242	397	2	Synthetic Channel	WithDigitized	Flowline	True
	5	2301.578999	399	4	Synthetic Channel	WithDigitized	Flowline	True
	6	344.557952	401	6	Synthetic Channel	WithDigitized	Flowline	True
	7	10826.755433	403	9	Synthetic Channel	WithDigitized	Flowline	True
	8	32536.039220	406	1	Synthetic Channel	WithDigitized	Flowline	True
	9	8056.903721	407	7	Synthetic Channel	WithDigitized	Flowline	True
	10	10203.151310	410	5	Synthetic Channel	WithDigitized	Flowline	True

Record: 1 Show: All Selected Records (0 out of 61 Selected.) Options

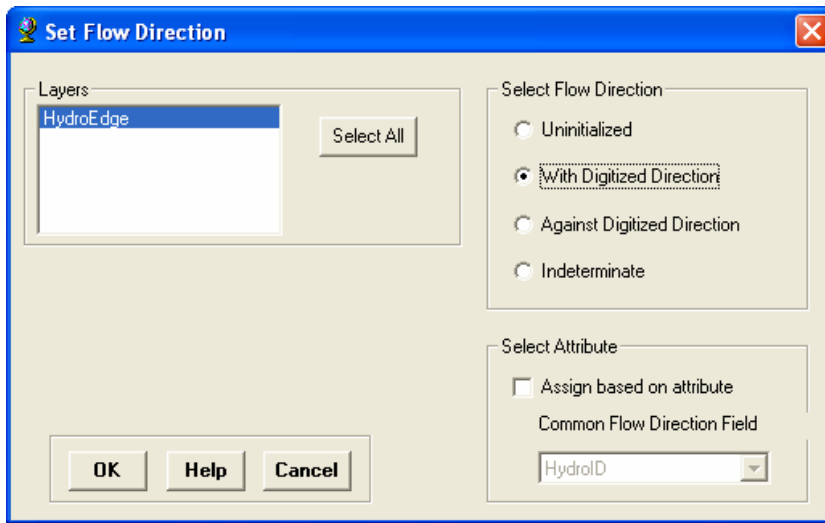
4. Set Flow Direction

This function sets the flow direction for selected edges in a network edge feature class. If no features are selected, the tool sets the flow direction for all the edges in the feature class.

- Select **Network Tools | Set Flow Direction**.



- Select “HydroEdge” under Layers and choose “With Digitized Direction” for the Flow Direction.



- Press OK. The flow direction is set for the Hydro Edge in the digitized direction.

Terrain Morphology

The Terrain Morphology menu contains 4 functions:

- Data Management Terrain Morphology
- Drainage Area Characterization
- Drainage Boundary Characterization
- Drainage Connectivity Characterization

The functions allow characterizing drainage areas volumes and drainage areas boundaries profile by using elevation extracted from a Grid (DEM) or a TIN, as well as creating network connectivity for non dendritic drainage areas (i.e. with pits).

1. Data Management Terrain Morphology

- Select Terrain Morphology | Data Management Terrain Morphology.

Data Management

Terrain
Select Terrain Model TIN GRID

TIN Null

GRID Null

Layers

Drainage Area Null

Drainage Line Null

Drainage Boundary Null

Hydro Edge Null

Hydro Junction Null

Boundary Drainage Line Null

Flow Direction Grid Null

Drainage Point Null

Exclusion Area Null

External Boundary Null

Tables

Elevation Area Volume Null

Elevation Width Area Null

Drainage Connectivity Null

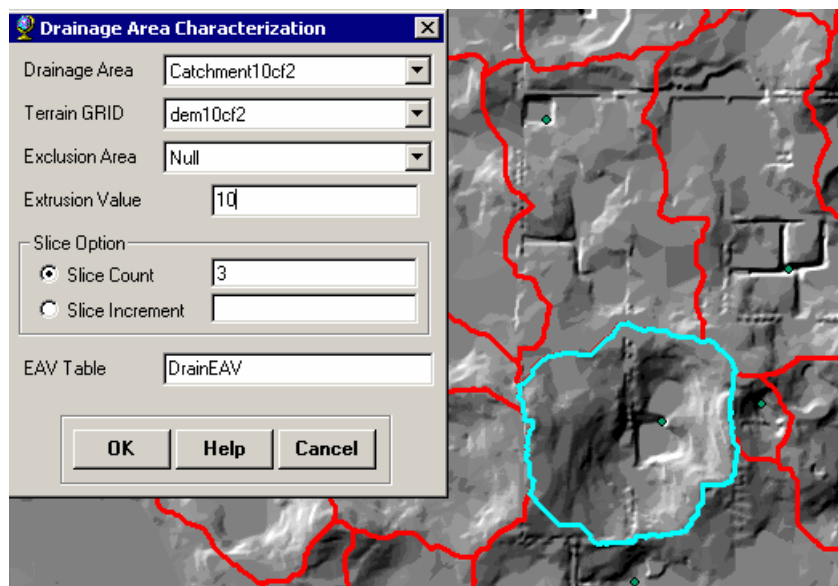
OK Help Cancel

- Select whether the elevation data is stored in a GRID or TIN by clicking on the corresponding radio button in the Data Management form. Click OK.

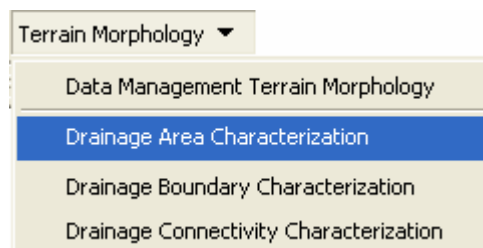
Note: when setting a layer, all fields defined for that layer in the XML are created. For example setting your drainage area layer to the “Drainage Area” tag will automatically create the fields DrainID, MinElev, MaxElev, IsPitted and IsDone. The fields will be added when running the characterization functions otherwise.

2. Drainage Area Characterization

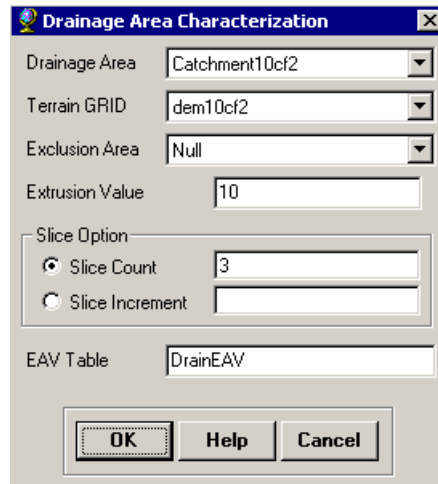
The Drainage Area Characterization tool computes the cumulative areas and volumes below a given elevation (top of slice). The tool works on a selected set, or on all features if there is no selected set. The function characterizes the area and volume for “slices” of the selected drainage areas. Note that selected areas that have already been processed will be reprocessed if they are selected or if there is no selected set.



- Select the drainage areas to characterize (all areas will be processed if there is no selection)
- Select Terrain Morphology | Drainage Area Characterization.



- Select the Terrain GRID (DEM) or TIN containing the elevation values. If the wrong type of elevation data is displayed, close the window and use the Data Management function to change the type of the elevation data required.



- Select the Exclusion Area feature class (optional) defining the areas that will not be characterized (i.e. areas and volumes contributing from these areas will be subtracted).
- Enter a positive extrusion value (optional – default to 0 (no extrusion)). If a positive value is specified, the function will create one additional record for a slice that ranging from the top elevation of the drainage area to the top elevation + extrusion value (may be required for modeling).
- Enter the number of slices to create for each drainage area or the incremental elevation to use to define the slices. Note that in addition to these slices, one initial slice will be created to characterize the bottom of the drainage area and, optionally, one additional slice may also be created if a positive extrusion value is specified.
- Enter the name of the output Elevation Area Volume (EAV) Table. This name defaults to DrainEAV. If the table already exists, records corresponding to areas already processed will be overwritten in the table, whereas records for newly processed areas will be appended.
- Click OK.

The function performs the following actions:

1. Check that the following fields exist in the attribute table of Drainage Areas and create these fields if not found:
 - MinElev: Minimum elevation of the drainage area.
 - MaxElev: Maximum elevation of the drainage area.
 - IsPitted: Indicate whether the drainage area has an internal pit. Must be populated before using the Drainage Boundary Characterization function and the Drainage Connectivity Characterization function.
 - IsDone: Indicate whether the drainage area was successfully processed (1) or not (-1) by the Drainage Area Characterization function

2. Check whether the output EAV Table exists and create the table if not found. The table is visible in the Source Tab in the Table of Contents of ArcMap. It contains the following attributes:
 - BottomElev: Bottom elevation of the slice (for grid, in linear unit).
 - TopElev: Top elevation of the slice (for grid, in linear unit).
 - SlcElev: Mid elevation of the slice (for grid, in linear unit). Equal to $(0.5 * (\text{TopElev} + \text{BottomElev}))$
 - CumArea: Area of the drainage area having an elevation that is less than or equal to the top elevation of the slice.
 - CumVolume: Volume of water needed to fill the associated drainage area up to the top elevation of the slice.

3. Check whether the output DrainEAV table already contains records associated to the drainage areas being processed and delete these records (i.e. old records will be overwritten). The FeatureID in the EAV table stores the HydroID of the drainage areas. For example the table below shows that the drainage area with HydroID 113 was previously processed since the DrainEAV table has records with FeatureID=113. If this drainage area is selected for processing, the associated record in the EAV table will be deleted so that the table gets updated with the most recent records.

Selected Attributes of Catchment10cf2

Shape*	OID*	Shape_Length	Shape_Area	HydroID	GridID	MinElev	MaxElev	IsPitted	IsDone
Polygon	113	6040.000042	1450000.007600	113	113	6	24.31	<Null>	1

Record: 1 Show: All Selected Records (1 out of 250 Selected.)

Attributes of DrainEAV

OBJECTID	FeatureID	BottomElev	TopElev	SlcElev	CumArea	CumVolume
1	113	6	6	6	38900	0
2	113	6	12.104	9.052	429600	1209440.5
3	113	12.104	18.207	15.155	1093100	5654834
4	113	18.207	24.311	21.259	1450000	13682541
5	113	24.311	34.311	29.311	1450000	28182540

Record: 1 Show: All Selected Records (1 out of 5 Selected.)

Check for records to overwrite in DrainEAV Table

4. Process each selected drainage area:
 - Update the following fields in the attributes table of the Drainage Area feature class:

Selected Attributes of Catchment10cf2

Shape*	OID*	Shape_Length	Shape_Area	HydroID	GridID	MinElev	MaxElev	IsPitted	IsDone
Polygon	113	6040.000042	1450000.007600	113	113	6	24.31	<Null>	1

Record: 1 Show: All Selected Records (1 out of 250 Selected.)

Update of Drainage Area feature class

- MinElev: Minimum elevation for the drainage area (for grid, in grid linear unit)

- MaxElev: Maximum elevation for the drainage area (for grid, in linear unit)
 - IsDone: Indicate whether the drainage area was successfully processed (1) by the Drainage Area Characterization function or not (-1). Note that this field is not used to filter drainage areas that need to be processed (i.e. the function will reprocess a drainage area even when IsDone is set to 1 or -1).
- Add records in the EAV table to characterize each slice of the drainage area:
 - a. The first slice that is created for each drainage area (highlighted in blue in the table below) characterizes the bottom of the drainage area. The slice has TopElev=BottomElev=SlcElev = minimum elevation of the drainage area (“6” in the example provided). CumArea indicates the area in the drainage area located at the bottom (38,900 square feet of the area has an elevation of 6 feet in the example provided). CumVolume is equal to 0 (there is no volume at the bottom). This slice is created in addition to the number of slices specified by the user or computed based on the incremental slice elevation value entered by the user.

OBJECTID	FeatureID	BottomElev	TopElev	SlcElev	CumArea	CumVolume
1	113	6	6	6	38900	0
2	113	6	12.104	9.052	429600	1209440.5
3	113	12.104	18.207	15.155	1093100	5654834
4	113	18.207	24.311	21.259	1450000	13682541
5	113	24.311	34.311	29.311	1450000	28182540

Initial EAV slice

- b. After creating the initial slice, the function then slices the drainage area using either the number of slices or the incremental slice elevation specified by the user in the form. Note: no slice will be created for flat drainage areas since these areas are totally characterized by the initial slice (the entire drainage area is located at the bottom and the volume is always 0). The function populates the elevation, area and volume characteristics for each slice. In the example used here, the user has requested 3 slices that correspond to the records 2, 3 and 4 in the DrainEAV table, with elevations ranging from the minimum (6 ft) to the maximum (24.31 ft) elevation of the drainage area.

Shape*	OID*	Shape_Length	Shape_Area	HydrolID	GridID	MinElev	MaxElev	IsPitted	IsDone
Polygon	113	6040.000042	1450000.007600	113	113	6	24.31	<Null>	1

OBJECTID	FeatureID	BottomElev	TopElev	SlcElev	CumArea	CumVolume
1	113	6	6	6	38900	0
2	113	6	12.104	9.052	429600	1209440.5
3	113	12.104	18.207	15.155	1093100	5654834
4	113	18.207	24.311	21.259	1450000	13682541
5	113	24.311	34.311	29.311	1450000	28182540

Incremental EAV slices

- CumArea: Area with an elevation less than or equal to the top elevation of the current slice. Note: for the top slice (highlighted) where TopElev=MaxElev (=24.31 in this example), CumArea (1,450,000) is the same as the total area of the drainage area (Shape_Area=1,450,000).
 - CumVolume: Total volume of water required to fill the drainage area up to the specified elevation.
- c. If a strictly positive extrusion value has been entered, one additional slice will be created (highlighted in blue in the table below) in addition to the number of slices specified by the user (or computed based on the specified incremental elevation). CumArea for this slice is the same as the total drainage area since the entire area is located under the extruded elevation. The extruded elevation is calculated by adding the extrusion value to the maximum elevation of the drainage area. CumVolume is calculated by adding to the cumulative volume of the top slice previously computed the incremental volume obtained by multiplying the total drainage area by the extrusion value. In the example below, an extrusion value of 10 feet is used.

OBJECTID	FeatureID	BottomElev	TopElev	SlcElev	CumArea	CumVolume
1	113	6	6	6	38900	0
2	113	6	12.104	9.052	429600	1209440.5
3	113	12.104	18.207	15.155	1093100	5654834
4	113	18.207	24.311	21.259	1450000	13682541
5	113	24.311	34.311	29.311	1450000	28182540

Extruded slice in EAV Table

5. After processing all selected features, the function will report the number of features that were successfully processed and the number that failed.

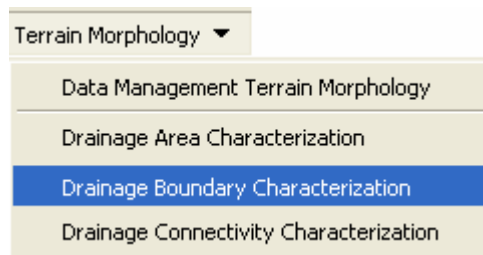
3. Drainage Boundary Characterization

The Drainage Boundary Characterization tool computes the width, perimeter and cross section area associated with slices of the boundaries of the drainage areas. The tool works on a selected set of drainage areas, or on all drainage areas if none are selected.

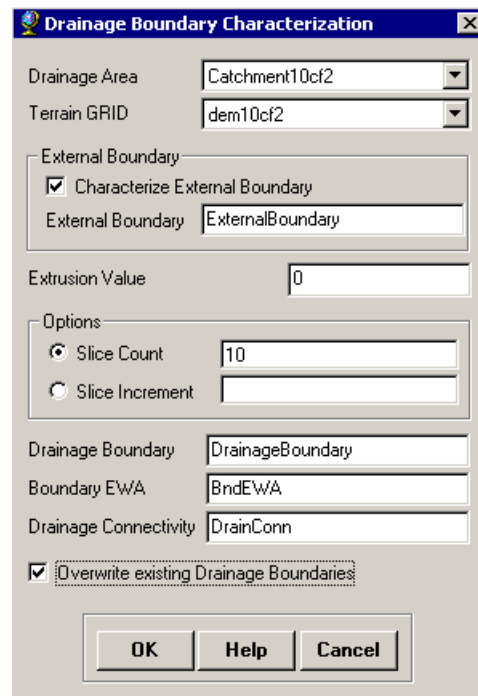
Note 1: Selected areas that have already been processed will be reprocessed only if the checkbox “Overwrite existing Drainage Boundaries” is checked.

Note 2: Drainage Areas with internal pits need to be characterized as such before running this function by setting the attribute “IsPitted” to 1 in the attributes table of the Drainage Area feature class. The Drainage Boundary Characterization tool is using the IsPitted field to indicate whether the drainage boundaries are next to at least one drainage area with a pit. This is important because only this type of boundaries will be processed by the Drainage Connectivity Characterization function.

- Select the drainage areas to process (all drainage areas will be processed if there is no selected set).
- Select Terrain Morphology | Drainage Boundary Characterization.



- Select the Terrain Grid or TIN storing the elevation



- Select whether to characterize the external boundaries.
- Enter an extrusion value (optional – default to 0 – no extrusion)

- Specify the number of slices to create or the incremental elevation used to define a slice.
- Enter a name for the output Drainage Boundary feature class that will store the 3D polylines representing the boundaries.
- Enter a name for the output Boundary Elevation Width Area table that will store the characteristics of the boundaries slices.
- Enter the name of the Drainage Connectivity table that will store information on the Drainage Areas associated with the new Drainage Boundaries.
- Check “Overwrite existing Drainage Boundaries” to recharacterize areas that have already been processed (otherwise these areas will not be reprocessed).
- Click OK.

The function performs the following actions:

1. If “Overwrite existing Drainage Boundaries” is selected, check whether there are records associated with the drainage areas being currently processed in the output Drainage Boundary feature class, Boundary EWA table and Drainage Connectivity table. Delete these records.
2. Create the drainage boundaries associated to the selected areas: each boundary line represents the intersection between 2 drainage areas. The Drainage Boundary feature class is a 3D polyline feature class that has the following structure:
 - HydroID: unique identifier of the drainage boundary in the geodatabase.
 - MinElev: minimum elevation along the boundary.
 - MaxElev: maximum elevation along the boundary.

Shape*	OID*	Shape_Length	HydroID	MinElev	MaxElev
Polyline Z	1	1720.000011	751	17	21
Polyline Z	2	420.000002	752	20	21
Polyline Z	3	240.000017	753	21	23.072
Polyline Z	4	509.999980	754	20	22
Polyline Z	5	729.999996	755	22	24
Polyline Z	6	2420.000034	756	13	22

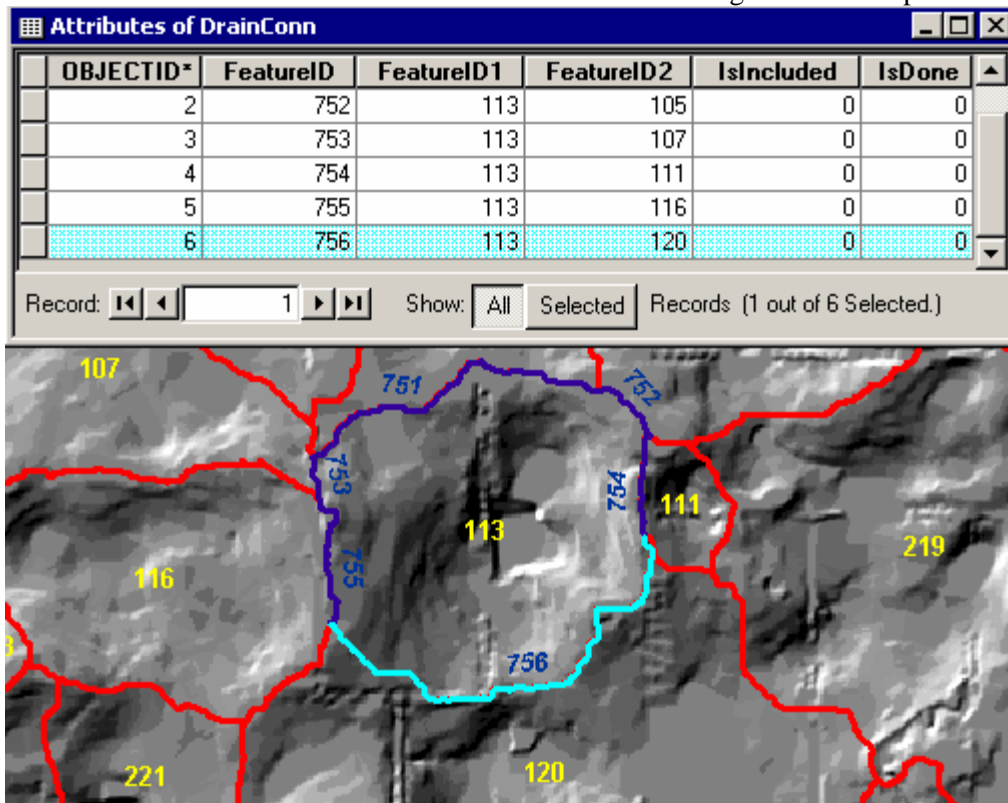
Drainage Boundary Attributes Table

3. Populate the Drainage Connectivity table with information on Drainage areas separated by the boundaries. The table has the following structure:
 - FeatureID: HydroID of the associated Drainage Boundary.
 - FeatureID1: HydroID of the first drainage area touching the boundary

- FeatureID2: HydroID of the second drainage areas touching the boundary.
- IsIncluded: Indicate whether at least one of the two drainage areas has an internal pit (IsPitted=1). Set to 1 in this case. *Note: only the drainage boundaries with IsIncluded=1 will be processed by the Drainage Connectivity Characterization tool.*
- IsDone: Indicate whether the associated Drainage Boundary has already been processed by the Drainage Connectivity Characterization tool. Populated with 0 by default. Updated to 1 by the Drainage Connectivity Characterization tool. *Note: the Drainage Connectivity Characterization tool will process only Drainage Boundaries having IsDone=0.*

The picture below shows that the drainage boundary feature with HydroID 756 separates the drainage areas with the HydroIDs 113 and 120. The highlighted record in the DrainConn shows the same thing: the record with FeatureID 756 (which is the HydroID of the associated boundary) is located between the drainage areas having HydroIDs equal to FeatureID1 (113) and FeatureID2 (120).

Note that IsIncluded=0 because IsPitted was not set to 1 for the drainage area before processing.



Drainage Boundary Connectivity

4. Populate the characterization table Boundary EWA that contains characteristics associated to slices of the boundaries. The table has the following structure:
 - BottomElev: Bottom elevation of the slice (for grid, in grid linear unit).
 - TopElev: Top elevation of the slice (for grid, in grid linear unit).
 - SlcElev: Mid elevation of the slice (for grid, in grid linear unit).
 - SlcWidth: Width of the water that covers the boundary line for the specified TopElev. Boundary that is exactly at the top elevation is not considered covered

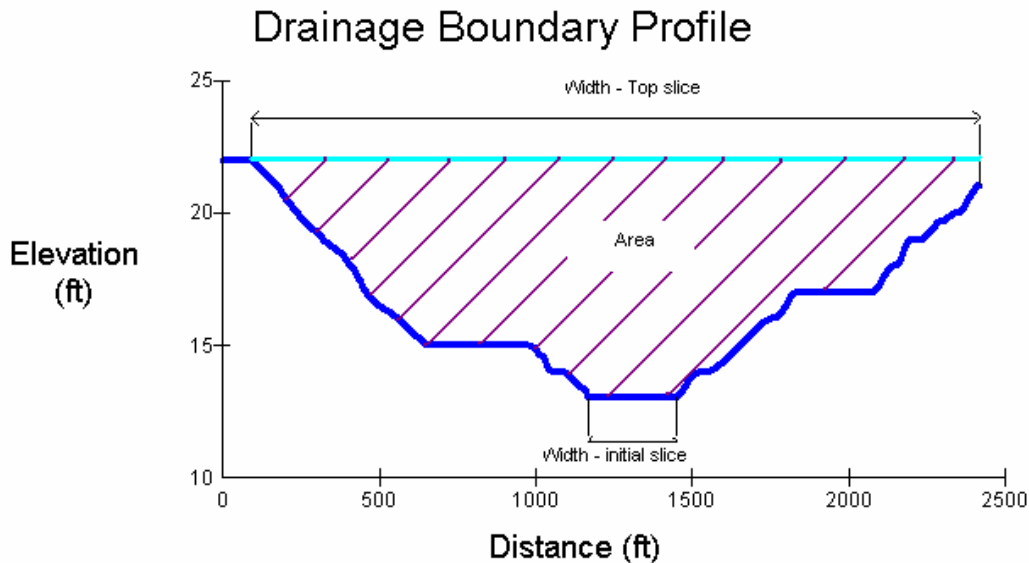
and is not included to compute the width, except when the boundary line is flat. In that case, the width is equal to the length of the boundary line.

- SlcArea: Area of the cross section of the boundary line that is below the TopElev and above the BottomElev of the slice.
- CumArea: Area of the cross section of the boundary line that is below the TopElev.
- SlcPerimeter: Wetted perimeter, equal to the sum of the length of the boundary line under the TopElev and the height of the water at the two ends of the boundary line segment.

OBJECTID*	FeatureID	BottomElev	TopElev	SlcElev	SlcWidth	SlcArea	CumArea	SlcPerimeter
26	756	13	13	13	240.000	0	0	240.0
27	756	13	16	14.5	1187.358	2024.4	2024.4	1187.4
28	756	16	19	17.5	1876.984	4770.8	6795.2	1877.1
29	756	19	22	20.5	2340	6464.6	13259.8	2341.1
30	756	22	32	27	2420	24200	37459.8	2441.1

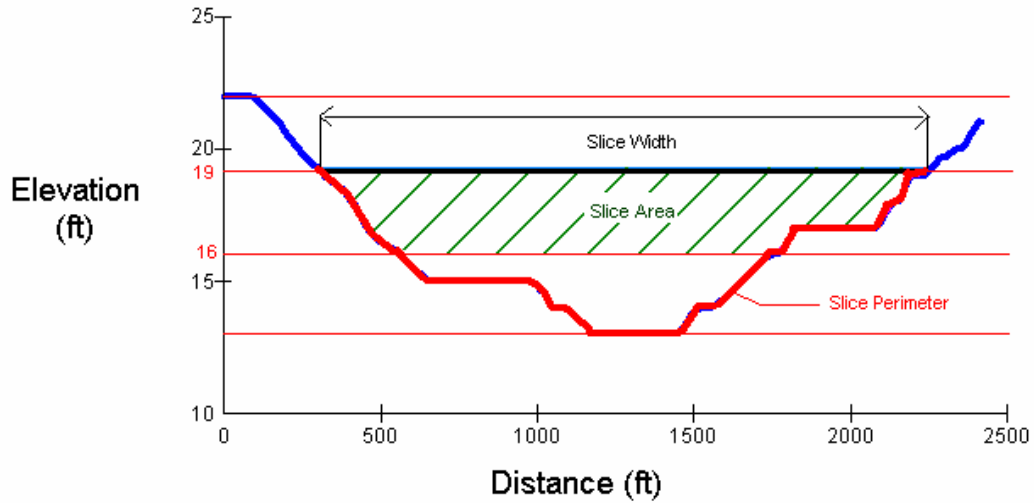
Boundary EWA Table

SlcWidth defines the length of the drainage boundary that is strictly below the top elevation of the current slice. The initial slice is an exception to this rule: the width of the initial slice is the length of the drainage boundary that is exactly at the top elevation of the slice. The highlighted records in the previous table define respectively the initial slice and the top slice (not the extruded slice). The last record in the table defines the optional extruded slice. Note that the width of the extruded slice is the same as the length of the associated drainage boundary, since the entire boundary is located below the top elevation of the extruded slice (32 ft, whereas the MaxElev of the drainage boundary is 22 ft).



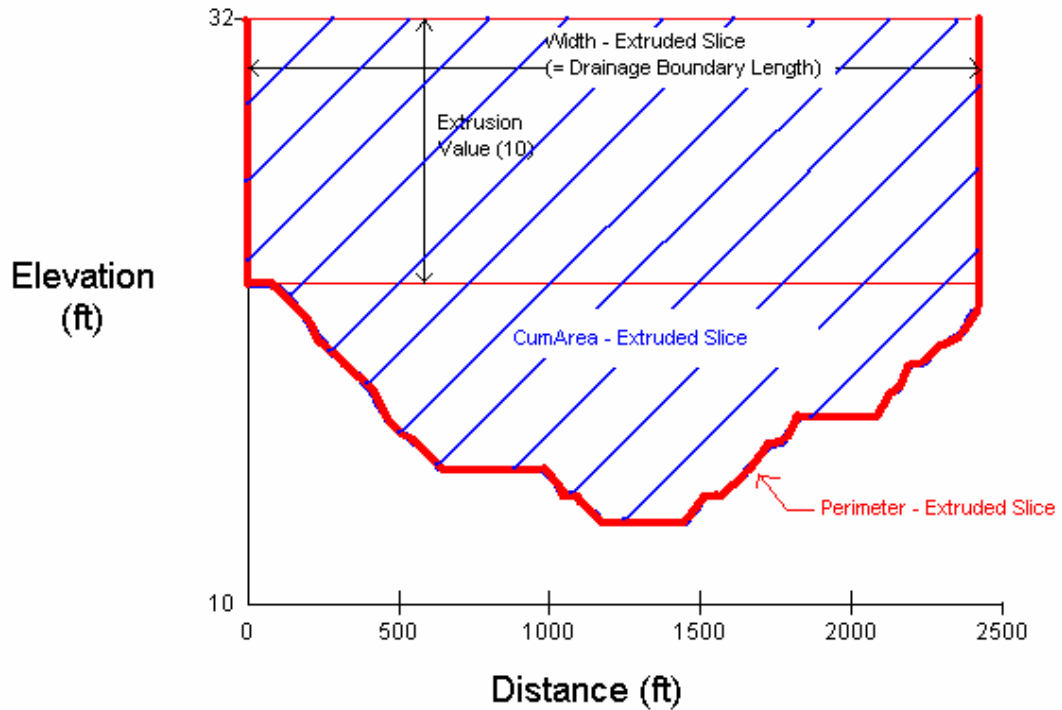
Drainage Boundary Profile (FeatureID 756)

Drainage Boundary Profile



Intermediate slice area, width and perimeter

Drainage Boundary Profile



Extruded slice Width, CumArea, and Perimeter

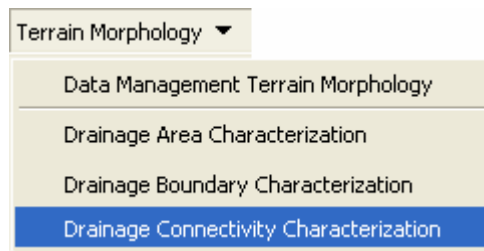
4. Drainage Connectivity Characterization

The Drainage Connectivity Characterization tool generates connectivity links for drainage areas with internal pits. This function complements the Hydro Network Generation tool that defines the connectivity for dendritic drainage areas. It generates HydroEdges and HydroJunctions. It also generates Boundary Drainage Lines that define links from a pitted drainage area with its neighbors. These lines correspond to the Drainage Lines in a dendritic network.

The function operates on a selected set of Drainage Boundary features or on all features if there are no selected features. Only drainage boundaries associated with pitted drainage areas and that have not been already characterized will be processed (i.e. IsIncluded=1 and IsDone=0 in the Drainage Connectivity table for the record associated to the boundary feature. FeatureID in the tables corresponds to the HydroID of the feature).

Note: Make sure that Catchment and Drainage Point are synchronized before starting the process (i.e. the DrainID in the DrainagePoint feature class corresponds to the HydroID in the Drainage Area feature class). For a drainage area with a pit, the DrainagePoint represents the internal pit.

- Select the Drainage Boundary features to process. The function will process all features if there is not selected set.
- Select Terrain Morphology | Drainage Connectivity Characterization.



- Select the input Flow Direction Grid, Drainage area, Drainage boundary (created with the Drainage Boundary Characterization function) and Drainage Point (created with the Drainage Point Processing function) feature classes, and the Drainage connectivity table (created with the Drainage Boundary Characterization function).
- Enter the names of the output HydroEdge, HydroJunction and Boundary Drainage Line. Note that the function will create the HydroEdge and HydroJunction feature classes if they have not been already created with the Hydro Network Generation function. However the function will not create the geometric network – this will need to be done manually in ArcCatalog.
- Click OK.

Drainage Connectivity Characterization Form

The function performs the following steps:

For each selected Drainage Boundary:

1. Retrieve the HydroID of the Drainage Boundary feature being processed
2. Retrieve the records associated to this drainage boundary in the Drainage Connectivity table that have not been processed yet (FeatureID = HydroID, IsIncluded=1 and IsDone=0). Note: IsIncluded is populated by the function Drainage Boundary Characterization based on the field IsPitted in the attributes table of the Drainage Area feature class. IsIncluded=1 means that at least one of the drainage areas separated by the boundary has an internal pit.

Note: To reprocess a boundary line you need to reset the attribute IsDone to 0 in the Drainage Connectivity table.

3. If the boundary has not yet been processed (IsDone=0), identify and retrieve the drainage areas on each side of the boundary
4. Identify the point on the boundary having the lowest elevation. If there is more than one point at that lowest elevation, the function will use the last point found along the drainage boundary.
5. Generate the flow path from the lowest point on the boundary into each of the two drainage areas.
6. Look for an existing HydroJunction associated with each drainage area. For dendritic drainage areas, the JunctionID field in the catchment feature class is populated with the HydroID of the associated Junction when the Hydro network is generated for the dendritic network. If a HydroJunction is found, move the To-Point of the flow path defined for that area to this HydroJunction. The From-Point for each flow path is the point previously characterized as the lowest point along the boundary.
7. If there is no existing HydroJunction, check whether the drainage area has a pit (IsPitted = 1). If it does, look for the associated Drainage Point and make it the To-Point of the flow path.

8. Check whether a HydroJunction already exists at the location of the From-Point located on the boundary. If not, create the HydroJunction with the following attributes:
 - HydroID: unique identifier of the feature in the geodatabase.
 - NextDownID: HydroID of the next downstream junction. Set to Null.
 - FType: Boundary Node
 - SchemaRole: 1
 - AncillaryNode: 0
 - Enabled: 1

9. Check whether HydroJunctions already exist at the location of the two To-Points. If not, create the node(s) with the following attributes:
 - HydroID: unique identifier of the feature in the geodatabase.
 - NextDownID: HydroID of the next downstream junction. Set to -1 (no downstream junction) if IsPitted=1 for the corresponding drainage area.
 - FType: Sink Node
 - SchemaRole: 1
 - AncillaryNode: 0 (None)
 - Enabled: 1 (True)

10. Create HydroEdge of type "Boundary Link" to represent the link in the network. The Hydro Edge will be populated as follows:
 - HydroID: unique identifier of the HydroEdge in the geodatabase.
 - ReachCode: HydroID of the drainage area where the link is located.
 - FType: Boundary Link
 - FlowDir: 0 (Uninitialized)
 - EdgeType: 1 (Flowline)
 - Enabled: 1 (True)

Note: the Geometric network itself will not be created by the function if it does not already exist (May be created by Hydro Network Generation). In this case the network needs to be created manually in ArcCatalog.

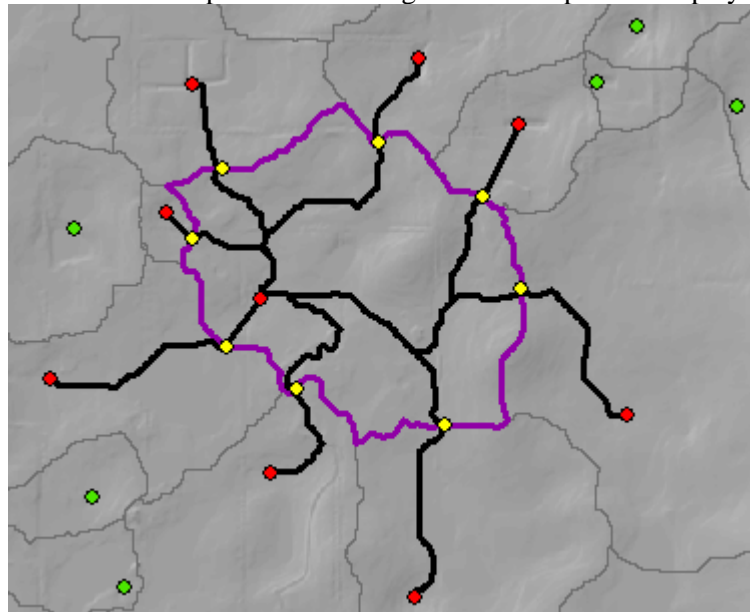
11. Create the Boundary Drainage Line associated to the link. The table has the following structure:
 - LinkID: HydroID of the associated Drainage Boundary.
 - DrainID: HydroID of the associated drainage area.

Shape*	OID*	Shape_Length	LinkID	DrainID
Polyline	2	1914.928266	1024	96
Polyline	4	952.340239	1025	105
Polyline	6	1624.339475	1026	107
Polyline	8	213.090642	1027	111
Polyline	1	613.090598	1024	113
Polyline	3	635.933284	1025	113
Polyline	5	932.550273	1026	113
Polyline	7	576.227690	1027	113
Polyline	9	950.920650	1028	113
Polyline	11	850.595897	1029	113
Polyline	10	983.506874	1028	116
Polyline	12	531.374827	1029	120

Record: 0 Show: All Selected Records (6 out of 12 Selected.)

Boundary Drainage Line Attributes table

The picture below shows an example of links and nodes created for one drainage area. The Drainage Boundary features that have been processed are displayed in purple. The generated Boundary Drainage Lines are displayed in black, sink nodes in red and boundary nodes in yellow. The drainage points that are located at the pit for the other unprocessed drainage areas with pits are displayed in green.

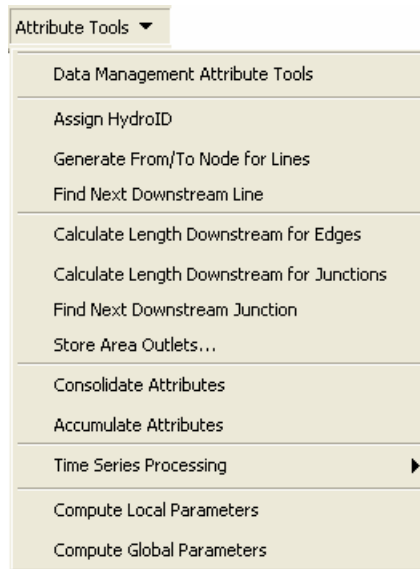


Links, sinks nodes and boundary nodes

- Set the attribute IsDone to 1 in the Drainage Connectivity table to indicate that the boundary line feature has been processed.

Attribute Tools

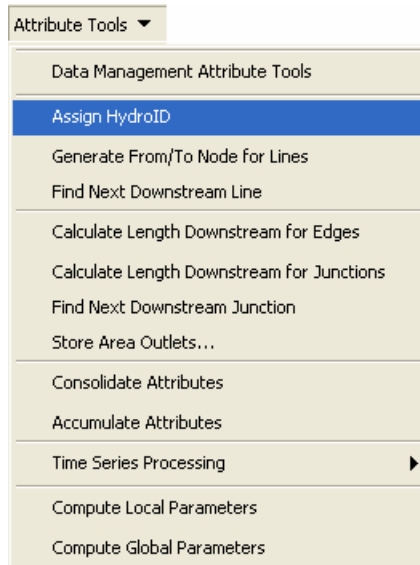
If your dataset already has the geometric network with HydroEdge and HydroJunction layers defined, you do not need to use the “Hydro Network Generation” tool. You can directly use the Attribute Tools.



1. Assign HydroID

In general, Assign HydroID should be used only for those feature classes that have not been generated with the Arc Hydro tools (e.g. importing a batch point file or a catchment layer digitized from source maps). This tool only creates HydroIDs for features in selected feature classes. It does NOT maintain attribute relations (For example, DrainID field of a catchment centroid contains the HydroID of the catchment in which the centroid resides. If the HydroID of the catchment is changed using the HydroID tool, the corresponding DrainID will not be changed).

- Open the attributes tables for “Centroid” previously created.
- Select **Attribute Tools | Assign HydroID**.



The Assign HydroID form shown below is displayed on the screen.



- Select the map/dataframe containing the layer “Centroid”. You should only have “Layers” available, unless you have several data framed in the ArcMap TOC.
- Select the workspace so that you can see the layer “Centroid”. If all the vector feature classes have been created in the same default workspace, you should have only one workspace available.

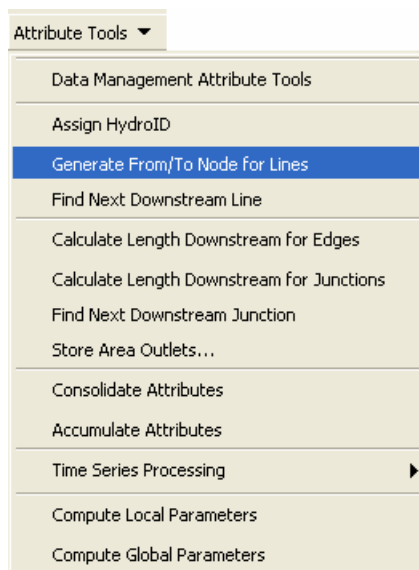
- Select “Centroid” in the list of layers available.
- Finally, select to overwrite the existing features, and to apply to all features. Click OK.

The function overwrites the HydroID fields in the “Centroid” layer.

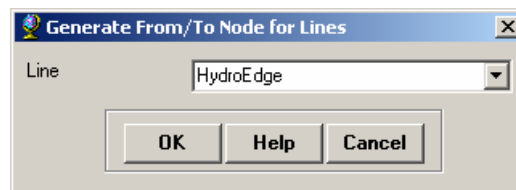
2. Generate From/To Node for Lines

This function creates and populates the fields FROM_NODE and TO_NODE in the selected input linear feature class.

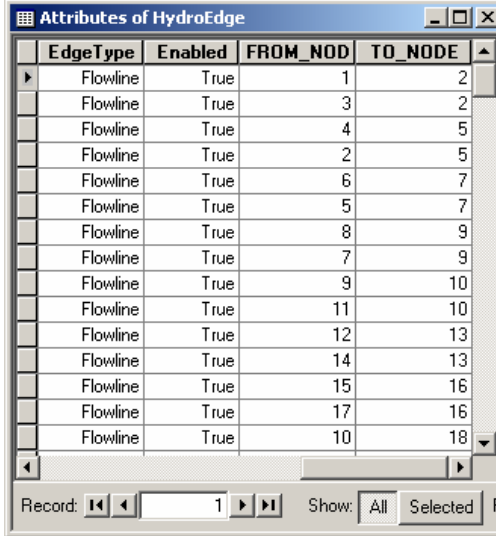
- Select **Attribute Tools | Generate From/To Node for Lines**.



- Confirm that the input of Line is “HydroEdge” (this tool will operate on any line feature class).



- Press OK. The fields FROM_NODE and TO_NODE are created and populated in the attribute table of “HydroEdge”.



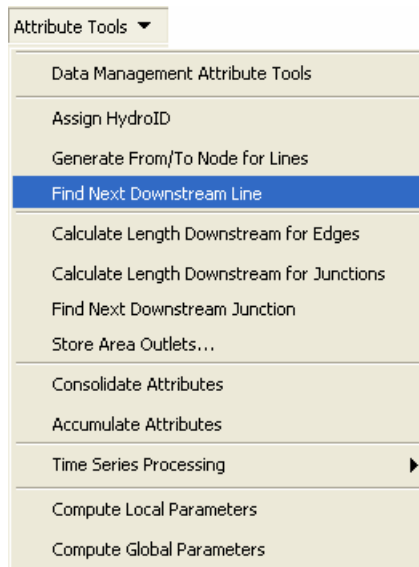
EdgeType	Enabled	FROM_NOD	TO_NODE
Flowline	True	1	2
Flowline	True	3	2
Flowline	True	4	5
Flowline	True	2	5
Flowline	True	6	7
Flowline	True	5	7
Flowline	True	8	9
Flowline	True	7	9
Flowline	True	9	10
Flowline	True	11	10
Flowline	True	12	13
Flowline	True	14	13
Flowline	True	15	16
Flowline	True	17	16
Flowline	True	10	18

Record: 1 Show: All Selected F

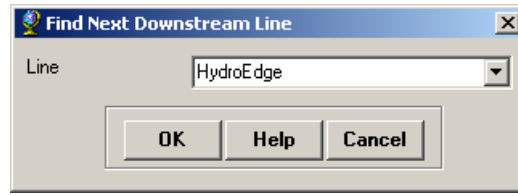
3. Find Next Downstream Line

This function finds the next downstream feature in a linear feature class based on the digitized direction. It creates and populates the field NextDownID with the HydroID of the next down feature.

- Open the Attributes table of “HydroEdge” and scroll all the way to the right.
- Select **Attribute Tools | Find Next Downstream Line**.



- Confirm that the input to Line is “HydroEdge”.



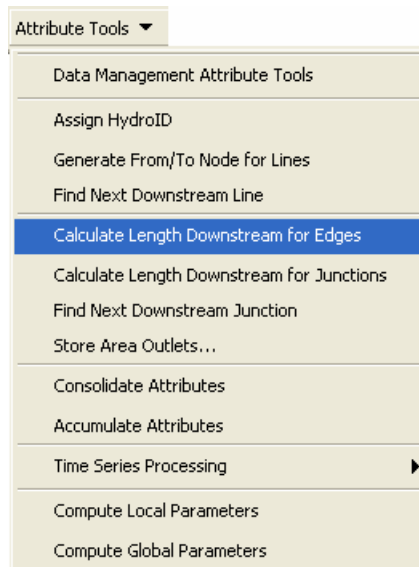
- Press OK. The field NextDownID is created and populated in the Attributes table of HydroEdge.

FROM_NODE	TO_NODE	NEXTDOWNID
1	2	325
3	2	325
2	4	331
5	4	331
6	7	335
4	7	335

4. Calculate Length Downstream for Edges

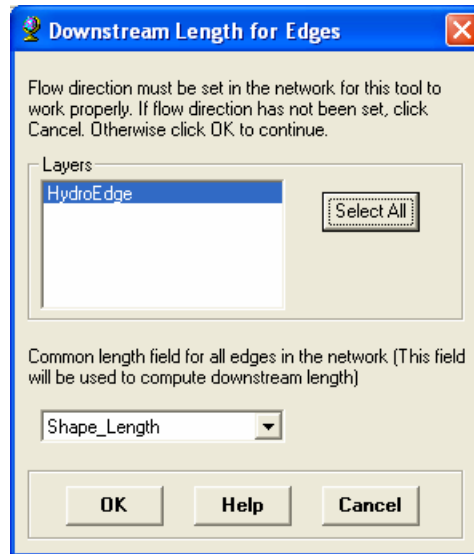
This function calculates the length from a network edge to the sink that the edge flows to, and populates the field LengthDown in that feature class with the calculated value.

- Select **Attribute Tools | Calculate Length Downstream for Edges**.



The tool requires the flow direction to be set in the input edge. The flow direction was automatically set by the function Hydro Network Generation, and set again with Set Flow Direction.

- Select “HydroEdge” under Layers and select the field containing the length for the edges (“Shape_Length”) from the drop down list.



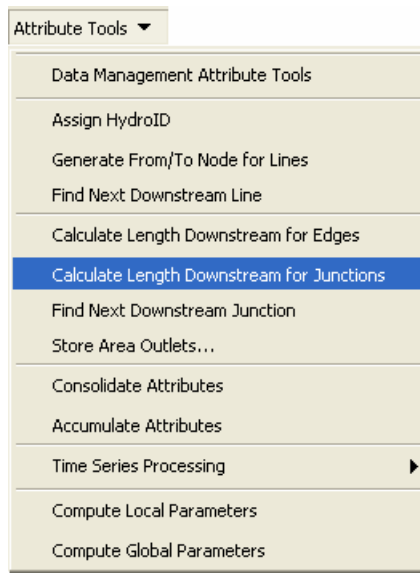
- Press OK. The field LengthDown is created and populated.

TO_NODE	NEXTDOWNID	LengthDown
2	325	141634
2	325	141634
4	331	141290
4	331	141290
7	335	133233
7	335	133233

5. Calculate Length Downstream for Junctions

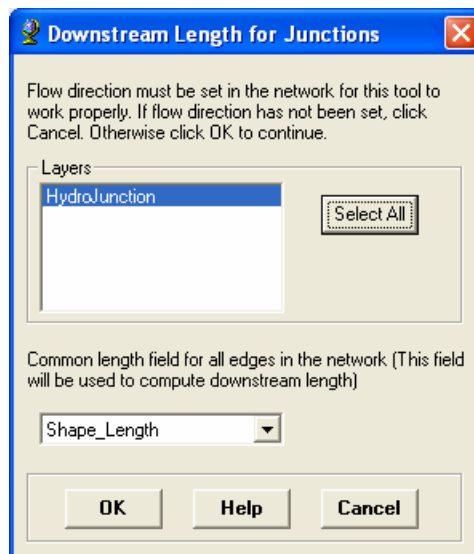
This function calculates the length from a network junction to the sink that the junction flows to, and populates the field LengthDown in that feature class with the calculated value

- Select **Attribute Tools | Calculate Length Downstream for Junctions**.



This function requires that the flow direction be set on the network.

- Select “HydroJunction” under Layers. Select the length field for each edge feature class in the network (Note: there is only one, “HydroEdge”). Select “Shape_Length” from the drop down list.



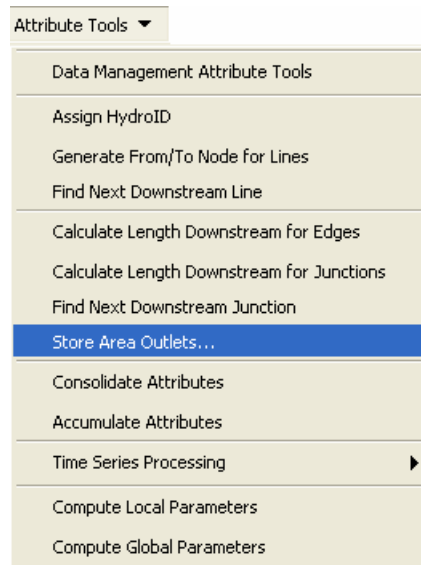
- Press OK. The field LengthDown is created and populated in the Attributes table of HydroJunction.

Enabled	AncillaryRole	LengthDown
1	0	162260
1	0	141634
1	0	143936
1	0	141290
1	0	152116

6. Find Next Downstream Junction

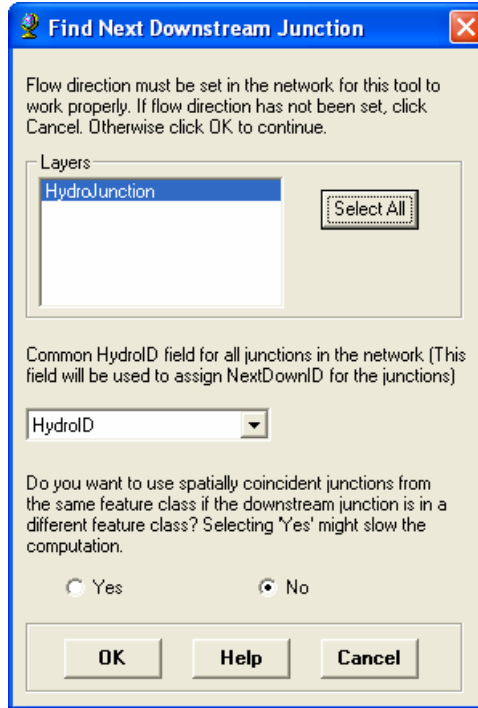
This function finds the next downstream junction in a junction feature class based on the flow direction set in the network, and assigns the HydroID of this downstream feature to the NextDownID field in the feature class.

- Select **Attribute Tools | Find Next Downstream Junction**.



The function requires the flow direction to be set in the geometric network

- Select “HydroJunction” under Layers.
- Select “HydroID” as the common HydroID field in the network.
- Check “No” to skip checks for spatially coincident junctions.
- Click OK.



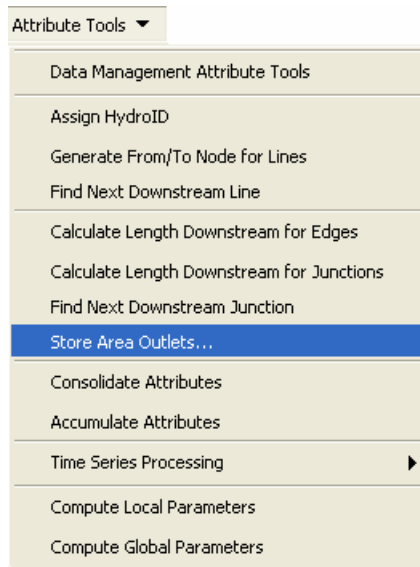
The calculated next downstream ID of junctions is stored in the NextDownID field in the attribute table of “HydroJunction”.

Shape*	OID*	HydroID*	NextDownID
Point	1	319	320
Point	2	320	324
Point	3	322	320
Point	4	324	329
Point	5	326	324

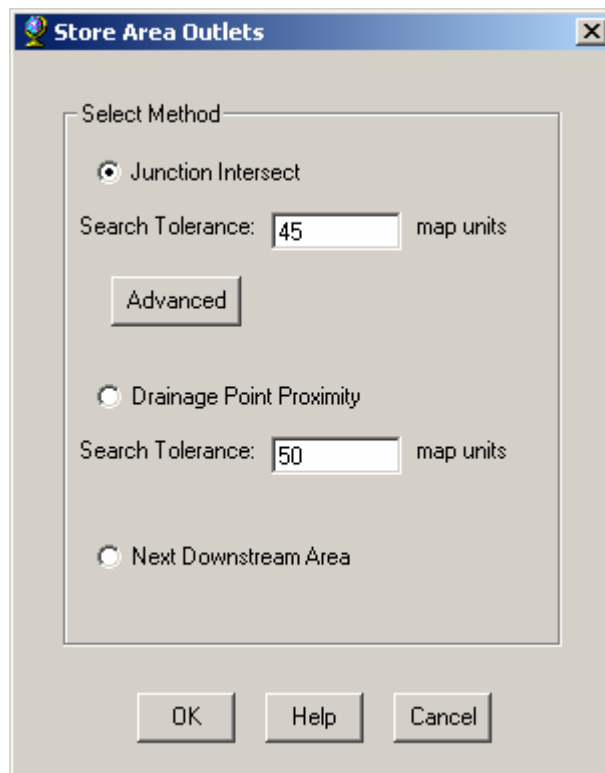
7. Store Area Outlets

This function locates the outlet junctions for a selected set of areas and assigns the HydroID of the junction to the JunctionID field in the corresponding area feature class. If no features are selected, the tool runs on all records. The JunctionID field is created if it does not already exist in the area feature class.

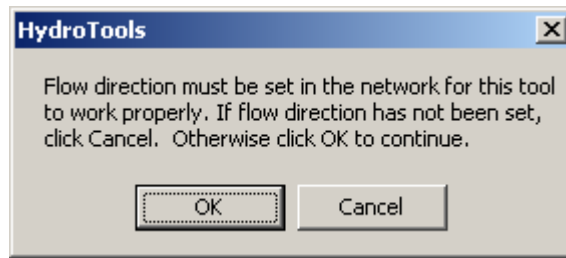
- Select a few polygons in the Catchment Feature Class.
- Select **Attribute Tools | Store Area Outlets**.



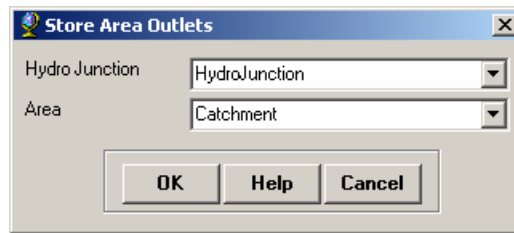
- A form showing 3 options of determining the store area outlets will appear. Select the “Junction Intersect” method. Enter “45” map units as search tolerance.



- You will be asked to verify if you have set the flow direction on the network. Press OK as you have already set the flow direction on HydroEdges.



- Confirm that the input of Hydro Junction is “HydroJunction, and Area Layer is “Catchment”.



- Press OK. The outlet for each selected catchment is stored in the “JunctionID” field of the catchment attribute table.

The "Attributes of Catchment" table displays the following data:

	Hydroid	GridID	DrainID	NextDownID	JunctionID
▶	163	1	1	8	383
■	164	2	2	5	380
■	165	3	3	11	387
■	166	4	4	9	385
■	167	5	5	8	383
■	168	6	6	17	391
■	169	7	7	5	380
■	170	8	8	9	385
■	171	9	9	11	387
■	172	10	10	13	388
■	173	11	11	13	388
■	174	12	12	18	394
■	175	13	13	22	396
■	176	14	14	23	398
■	177	15	15	17	391
■	178	16	16	18	394
■	179	17	17	22	396
■	180	18	18	30	407

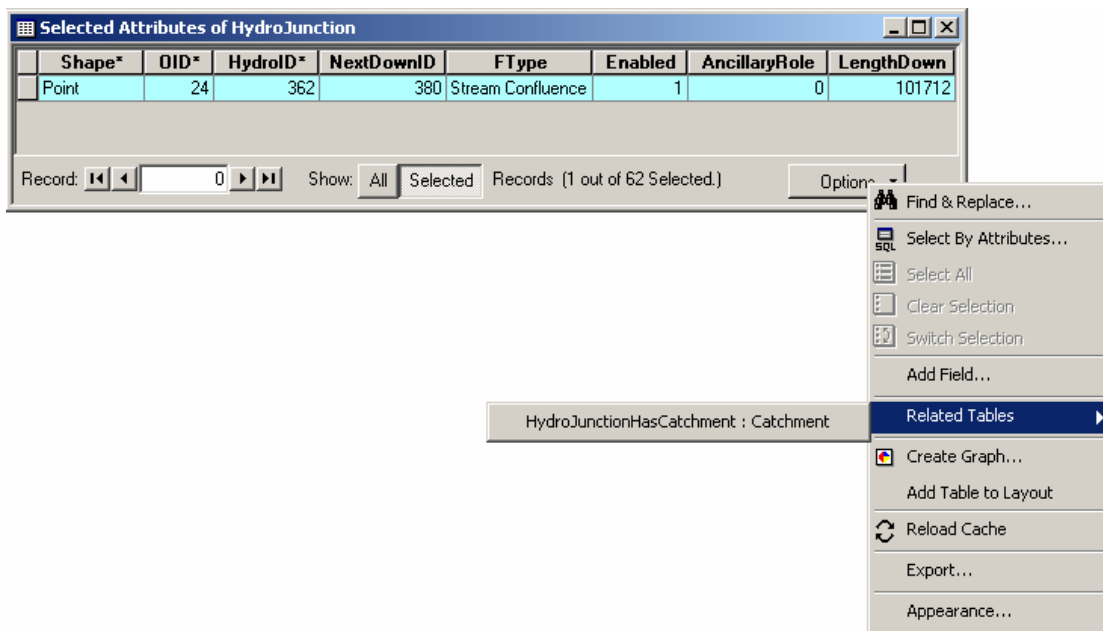
At the bottom of the table, there is a "Record:" field with navigation arrows and a value of "1", a "Show:" dropdown menu set to "All", and a "Records (0 out of 54 Se" label.

8. Consolidate Attributes

This function allows consolidating the source attribute in the source layer based on a relationship between the source layer and the target layer. Only layers having relationships may be selected as target or source layer. The source has to be different from the layer and related to it.

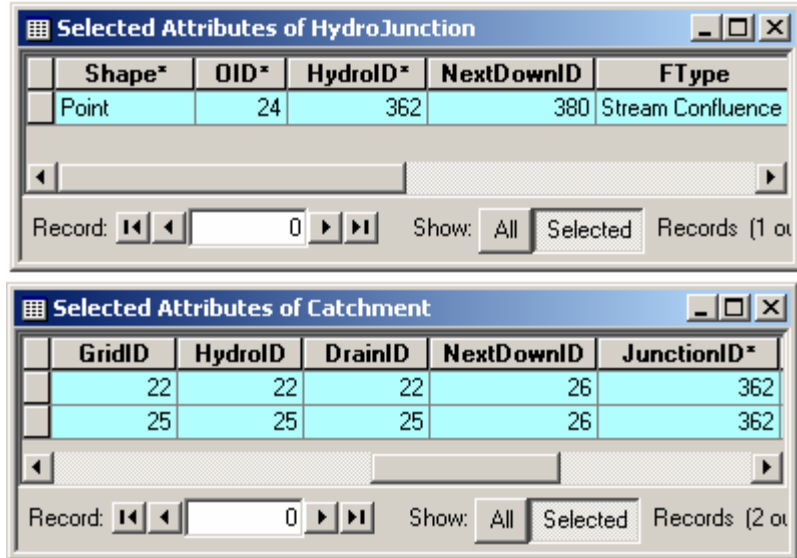
For example, the function may be used to calculate the total area of all the catchments related to each Hydro Junction.

- Select one Hydro Junction on the map and open the Attribute table of HydroJunction. Select Show Selected.
- Select Options>Related Tables>HydroJunctionHasCatchment

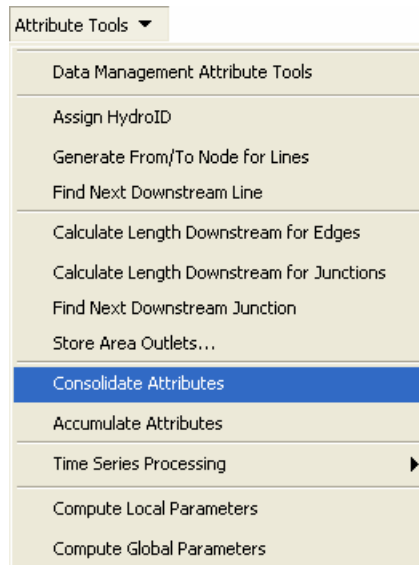


HydroJunctionHasCatchment is a relationship class between the HydroJunction and the Catchment feature classes. The JunctionID in Catchment relates to the HydroID in HydroJunction.

The Attribute table of Catchment displays the Catchments related to the selected HydroJunction.



- Clear the selection.
- Select **Attribute Tools | Consolidate Attributes**.



The following form pops-up:

Consolidate Attributes

Target for Consolidation

Target Feature Layer: HydroJunction

Target Field: ConsolidatedArea

Use selected features only

Source for Consolidation

Source Feature Layer: Catchment

Source Field: Shape_Area

Consolidation Type

Sum Average Min Max

Count Median Mode Standard Deviation

Weighted Average by Field: OBJECTID

OK Help Cancel

- Select “HydroJunction” as the target layer.
- Enter “ConsolidatedArea” as target field. The function will create this field in the target layer, “HydroJunction”.
- Select “Catchment” as the source layer.
- Select “Shape_Area” as the source field, which will be consolidated.
- Select “Sum” as the consolidation operation, and press OK.

The function uses the relationship class to retrieve the Catchments associated to a particular Hydro Junction, sums their areas, and stores the result in the field “ConsolidatedArea” in the Attributes table of “HydroJunction”.

Shape*	OID*	Hydroid*	NextDownID	FType	ConsolidatedArea
Point	57	429	433	Stream Confluence	163245600.467946
Point	58	431	429	<Null>	0
Point	59	433	437	Stream Confluence	170459100.006173
Point	60	436	437	<Null>	0
Point	61	437	440	Stream Confluence	105363900.221778
Point	62	440	-1	Drainage Outlet	145065600.267587

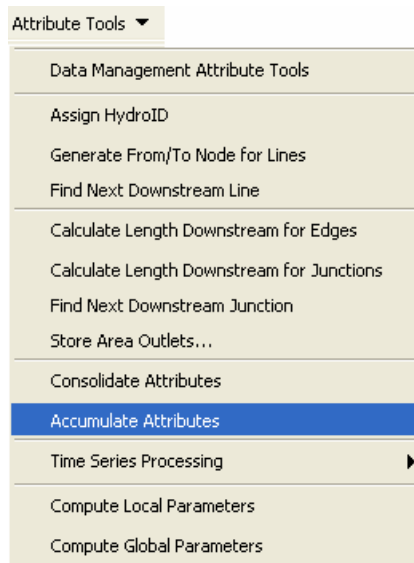
Record: 0 Show: All Selected Records (0 out of 62 Selected.)

9. Accumulate Attributes

This function allows accumulating attributes of target features located upstream of source features. Target features may either belong to the source feature class, or to a layer related to the source feature class. Upstream target features are related by performing a trace on the target feature class or on a related feature class. Two types of trace may be used: based on a geometric network; based on the NextDownID attribute.

For example, this function may be used to calculate the total area draining to each Hydro Junction.

- Select **Attribute Tools | Accumulate Attributes**.



The following form is displayed on the screen.

Accumulate Attributes

Trace Type

Network Layer: HydroJunction

Feature Layer with NextDownID: SchemaNode

Next Down ID Field: OID

Use selected features only

Source for Accumulation

Source Feature Layer: Catchment

Source Field: Shape_Area

Accumulation Type

Sum Average Min Max

Count Median Mode Standard Deviation

Weighted Average by Field: OBJECTID

Target for Accumulation

Target Feature Layer: HydroJunction

Target Field: AccumulatedArea

OK Help Cancel

- Select “HydroJunction” as the Network layer to use for the trace.
- Select “Catchment” as the Source layer and “Shape_Area” as the source field.
- Select “Sum” as the Accumulation operation.
- Select “HydroJunction” as the Target layer and type AccumulatedArea for Target field.
- Click OK.

For each Hydro Junction being processed, the function performs a trace to locate all the upstream Hydro Junctions. It locates all the catchments (source features) related to these junctions, sums their areas, and stores the resulting value in the “AccumulatedArea” field in the Attribute table. This field contains the total upstream area for each Hydro Junction.

HydroID*	NextDownID	FType	ConsolidatedArea	AccumulatedArea
431	429	<Null>	0	0
433	437	Stream Confluence	170459100.006173	4580404202.0749
436	437	<Null>	0	0
437	440	Stream Confluence	105363900.221778	4675254302.20393
440	-1	Drainage Outlet	145065600.267587	4820319902.47152

Record: [Navigation icons] 0 [Navigation icons] Show: All Selected Records (0 out of 62 Selected.)

10. Display Time Series

This function allows displaying the values of a parameter associated with a feature in a target feature class over time.

For example, this function may be used to display the variation of one parameter (e.g. rainfall) over time in the 2 batch watersheds previously delineated (refer to Batch Watershed Delineation to delineate these watersheds if needed).

- Create the input tables

Copy the tables TimeSeries and TSTypeInfo from the Arc Hydro data model into your current working workspace. If you cannot find the tables, then you can create them directly in ArcCatalog, with the following structures:

TimeSeries

- FeatureID – Long: Unique ID (HydroID) of the feature to which the measurement is associated
- TSTypeID – Long: Parameter type.
- TSDateTime – Date: Date of the measurement
- TSValue – Double: Measurement value.

TSTypeInfo (note: only the two fields listed are used by the function)

- TSTypeID – Long: Parameter type.
- Variable – Text: Name of the parameter.

- Populate the tables

Add the TimeSeries and TSTypeInfo tables into ArcMap.

Open the Watershed feature class and take note of the HydroIDs of the features (e.g. 365 and 367).

Shape*	OID*	Shape_Length	Shape_Area	HydroID	Name
Polygon	1	223199.998264	480177001.17264	365	Name 1
Polygon	2	70080.001122	105052500.255113	367	Name 2

Record: 2 Show: All Selected Records (0 out of 2 Selected.)

Start editing.

Open the TSTypeInfo and enter at least the type (TSTypeID) and the name of the parameter (Variable).

OBJECTID*	TSTypeID*	Variable	Units	IsRegular	TSInterval	DataType	Origin
5	1	Precipitation	Inches	True	1Hour	Step-Cumulative	Recorded

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

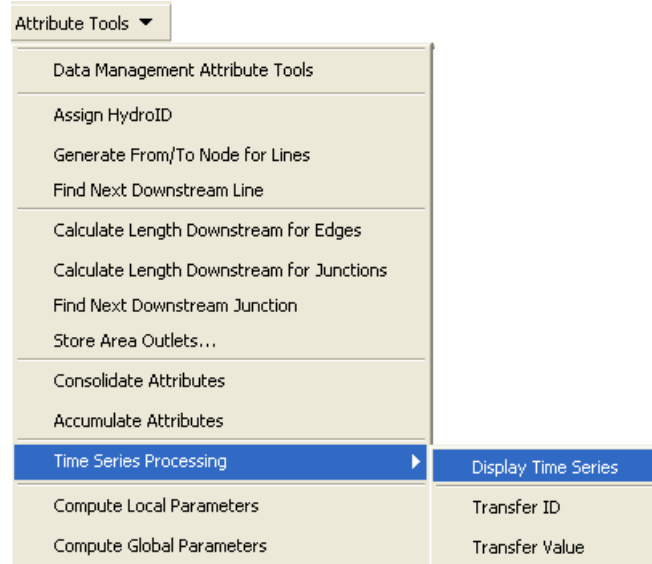
Open the TimeSeries table and enter 5 measurements for each feature. Stop editing.

OBJECTID*	FeatureID	TSTypeID*	TSDateTime	TSValue
1	365	1	1/1/2005 8:00:00 AM	0.01
2	367	1	1/1/2005 8:00:00 AM	0.02
3	365	1	1/1/2005 9:00:00 AM	0.05
4	367	1	1/1/2005 9:00:00 AM	0.07
5	365	1	1/1/2005 10:00:00 AM	0.1
6	367	1	1/1/2005 10:00:00 AM	0.12
7	365	1	1/1/2005 11:00:00 AM	0.15
8	367	1	1/1/2005 11:00:00 AM	0.17
9	365	1	1/1/2005 12:00:00 PM	0.16
10	367	1	1/1/2005 12:00:00 PM	0.2

Record: 2 Show: All Selected Records (0 out of 10 Selected.)

To use the Display Time Series function

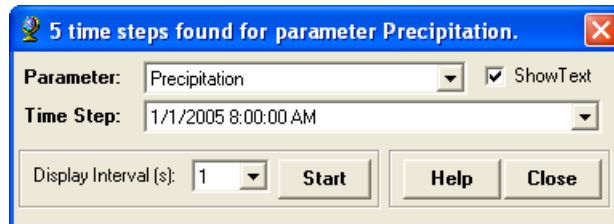
- Select **Attribute Tools | Time Series Processing | Display Time Series**.



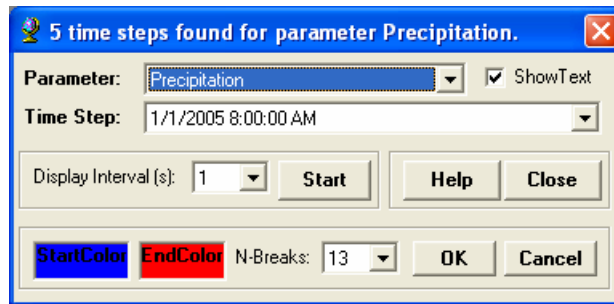
- Select Watershed as the target layer to display (TS DISPLAY) and TimeSeries as the Time Series Table.



The following window appears on the screen. It indicates that 5 time steps have been found for the selected parameter, precipitation. The value displayed on the screen corresponds to the selected time step. When Show Text is checked (default), the parameter and time step are displayed on the map.



Note also that the legend associated with the target layer is automatically modified to use graduated colors. You can select the colors and the number of breaks by right-clicking the Start button: the window expands then as follows:



Modify the legend as needed, and click OK to implement the changes in the Table of Contents.

Note that you can also modify the format of the number in the XML by editing the parameter `NumberFormat` in the XML under the node `FrameworkConfig/HydroConfig/ProgParams/ApFunctions/ApFunction(TimeSeriesDisplay)`. You still need to click OK to update the legend.

To display the variations of the precipitation over the 5 time steps, click on Start. The Display Interval, in seconds, allows modifying the time each time step is being displayed.

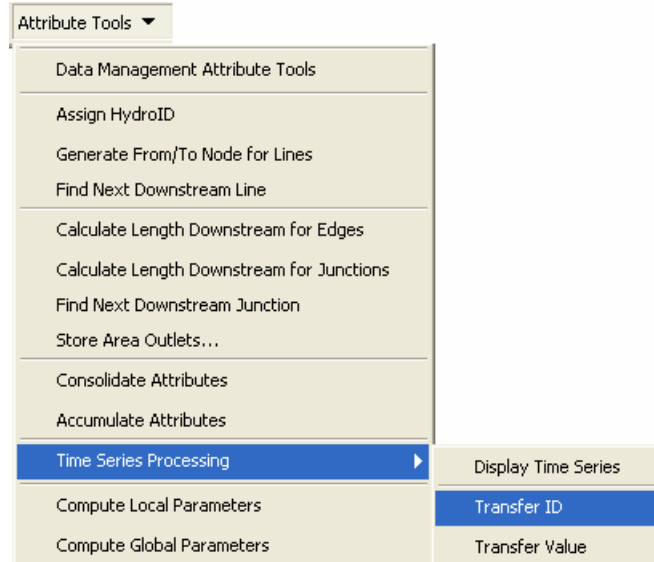
11. Transfer ID

This function allows establishing a relationship between a source feature class having an existing Time Series table and a target feature class that needs to be linked to time series data. This function requires first the creation of an intersect layer that is built by intersecting the source and the target feature class.

- Make ArcToolbox visible in ArcGIS.
- Browse to Analysis Tools>Overlay>Intersect and double-click Intersect.
- Select the layers “Catchment” and “Watershed” as input features.
- Rename the output CatWshIntersect and click OK.

The Intersect layer is generated by intersecting the layers “Catchment” and “Watershed”, and added into ArcMap.

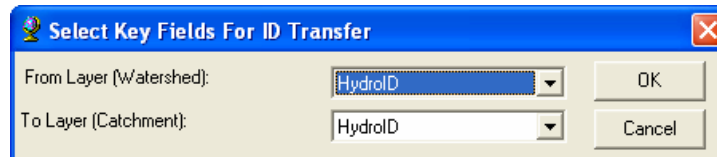
- Select **Attribute Tools | Time Series Processing | Transfer ID**.



- Select “Watershed” as From Layer, “Catchment” as To Layer and “CatchWshIntersect” as Intersect Layer. Click OK.



- Select HydroID as key fields for ID transfer for both “Watershed” and “Catchment”.



The function stores in the Intersect Layer the unique identifiers from the source and target feature classes, as well as the ratios of each intersect feature’s area to the area of the corresponding source and target features.

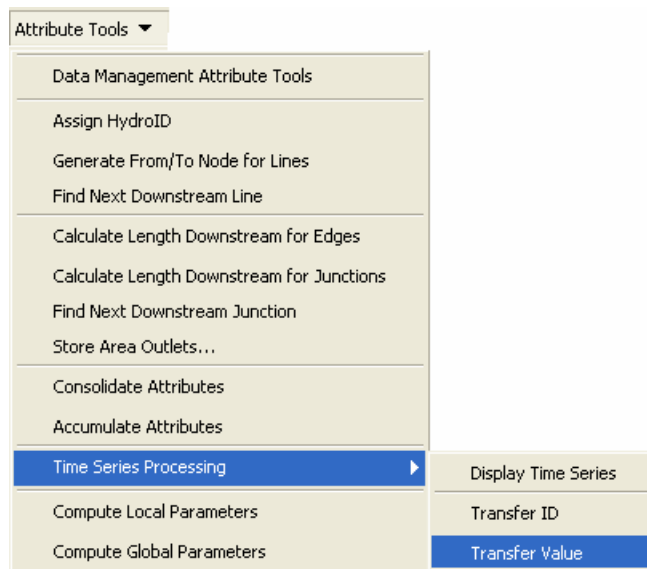
Shape_Length	Shape_Area	KEYFROM	KEYTO	PCTFROM	PCTTO
93480.002691	91259100.078335	365	14	0.19005	1.00000
54059.999308	54539100.067901	365	17	0.11358	1
88800.005244	100395000.265142	365	21	0.20908	1.00000
113700.001951	158480998.968229	365	27	0.33005	1
60000.006228	75502801.854474	365	36	0.15724	0.58934
70080.002146	105052499.026312	367	40	1.00000	0.79784

Record: 1 Show: All Selected Records: (0 out of 6 Selected.)

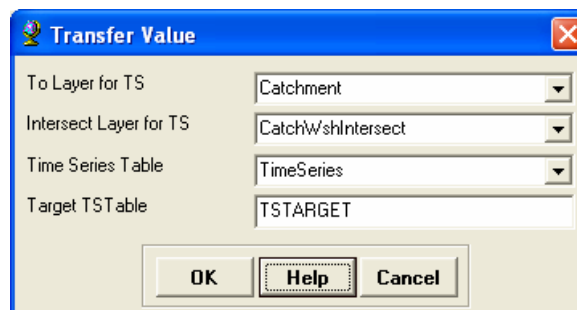
12. Transfer Value

This function allows generating a Time Series table for a polygon feature class based on an existing polygon feature and its associated Time Series table.

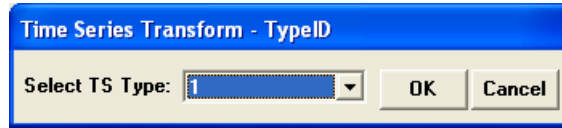
- Select **Attribute Tools | Time Series Processing | Transfer Value**.



- Select “Catchment” as To Layer, “CatchWshIntersect” as Intersect Layer, “TimeSeries” as source Time Series table and “TSTARGET” as target Time Series table. Click OK.



- Select “1” (Precipitation) as the Time Series type to transfer. Click OK.



The function generates the target Time Series table that can now be used with the function Display Time Series.

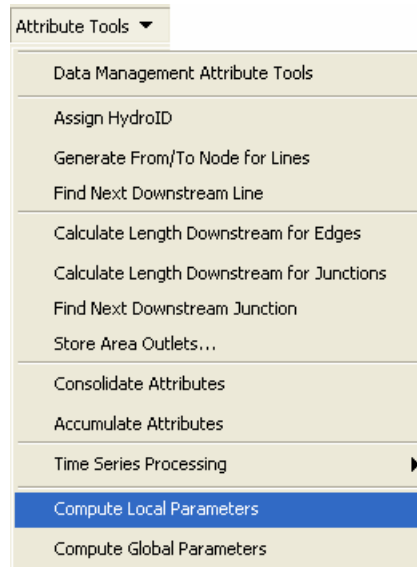
Note:

The value –0.01 in the target Time Series table indicates the Catchment features with no data for the corresponding time step.

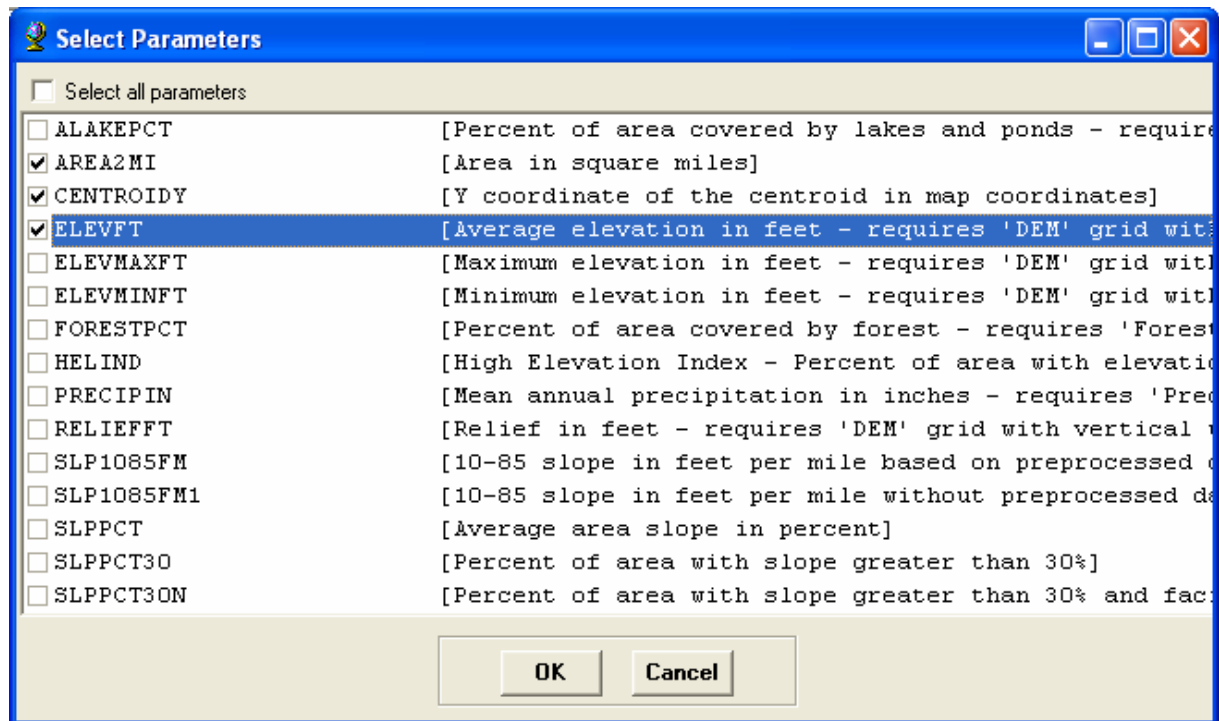
13. Compute Local Parameters

This function allows retrieving area characteristics (e.g. average elevation, area, etc.) for selected polygon feature(s) in the input Drainage Area polygon feature class and storing them in the attributes table of the polygon layer (Note: if no features are selected then parameters will be extracted for all the features in the input polygon feature class). Examples of parameters that may be extracted are:

- Area in square miles
 - Average elevation in feet
 - Maximum elevation in feet
 - Minimum elevation in feet
 - Relief (Difference between the maximum and the minimum elevations) in feet
 - Average slope in percent
 - Percentage of a given type of land cover (e.g. forest)
 - Mean precipitation in the unit of the precipitation grid (e.g. inches).
-
- Select **Attribute Tools | Data Management Attribute Tools**.
 - Reset the layer tagged as “Drainage Area” to Null. Click OK.
 - Select **Attribute Tools | Compute Local Parameters**.



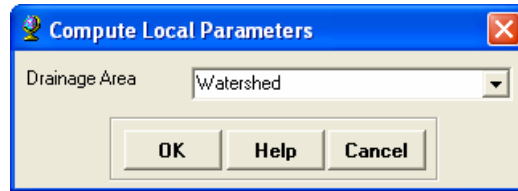
- Uncheck “Select all parameters” and then check AREA2MI and ELEVFT to select the parameters that will be extracted. Click OK.



Note: The Raster Target dataset, if not set, needs to be set for the HydroConfig node by using the function ApUtilities>Set Target Locations.

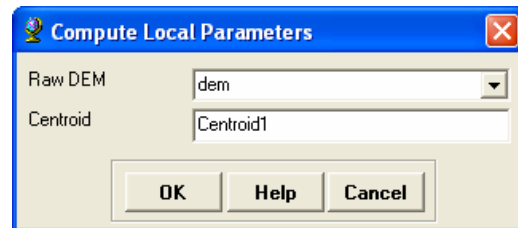
The function requires that both the ground units and the z unit be set for the DEM (refer to How to... Define ground unit and z-unit in the online help).

- Select “Watershed” as Drainage Area and click OK.



The function then prompts for the layer(s) needed to compute the selected parameters. Raw DEM is required to compute the average elevation. A centroid feature is generated when the function calculates the Y-coordinate of the centroid.

- Select “dem” for the Raw DEM and “Centroid1” for the output Centroid feature class (since “Centroid” already exists). Click OK.



The function computes the specified parameters (average elevation, Y-coordinate of the centroid) for the input watershed features and stores the results in the attribute table. The function also generates the “Centroid1” feature class and adds it into the Table of Contents.

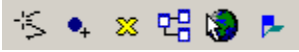
Notes:

- Units may need to be set for Raw DEM (Ground units and z-units) and the Drainage Area Layer (z-units). Refer to the online help for additional information on how to set these units.


14. Compute Global Parameters

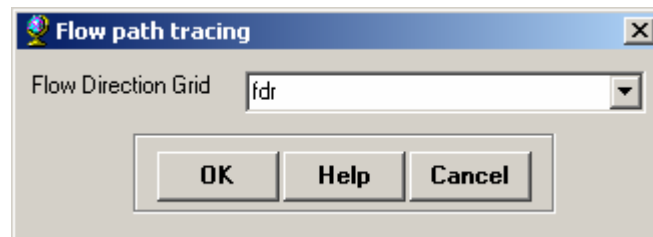
The preprocessing steps required by this function are described in the document Global Point Delineation with EDNA Data and in the online help. Once these steps have been performed, the function is used in the same way as the function Compute Local Parameters.

Buttons and Tools

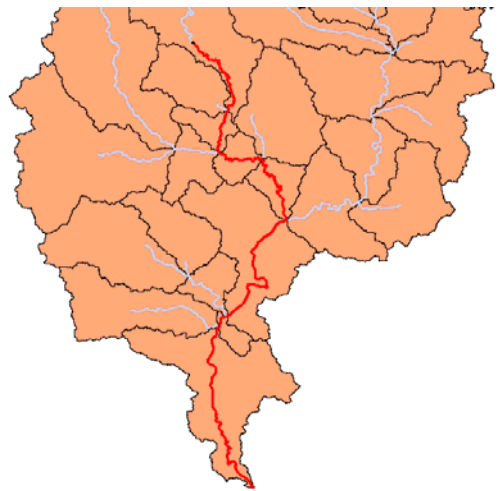


1. Flow Path Tracing


- Click on the icon  in the Arc Hydro toolbar.
- Confirm, if prompted, that the input Flow Direction Grid is “Fdr”. If not, it means that the Flow Direction Grid is already set.

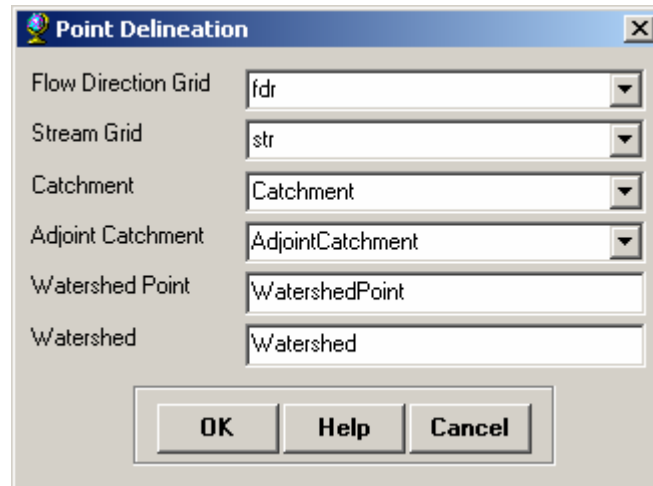


- Click your mouse at any point to determine the flow path. The flow path defines the path of flow from the selected point to the outlet following the steepest descent.

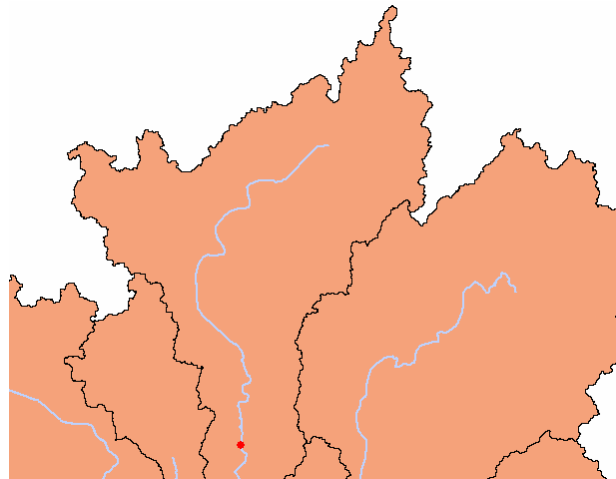


2. Point Delineation

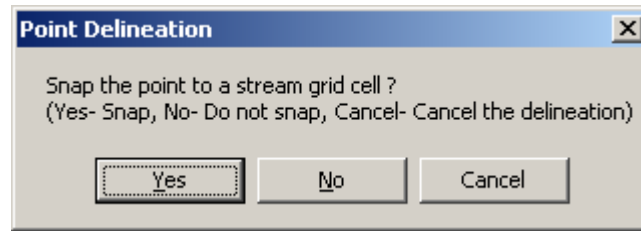
- Click on the icon  in the Arc Hydro toolbar.
- Confirm, if prompted, that the input Flow Direction Grid is “Fdr”, the input Stream Grid “Str”, the input Catchment “Catchment”, and the input Adjoint Catchment “AdjointCatchment”. The output Watershed Point is “WatershedPoint”, and the output Watershed is “Watershed”. “WatershedPoint” and “Watershed” are default names that can be overwritten by the user. You will not be prompted for the layer if they are already set.



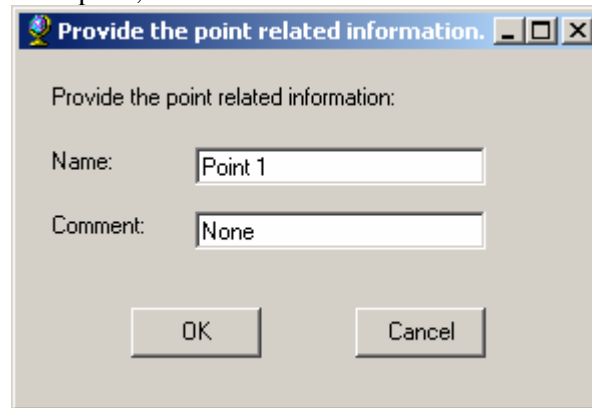
- Create a point by clicking with the mouse on the map.



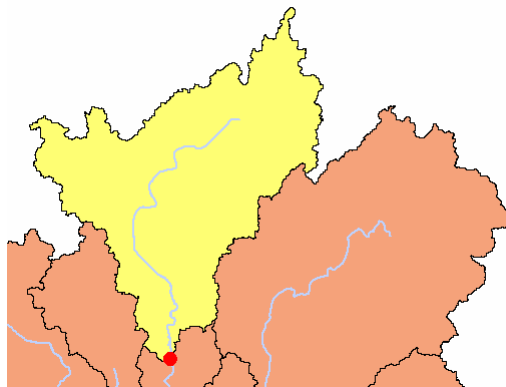
- Press OK to snap the point to a stream grid cell (this form will not be presented if the point is already on the stream).



- After the delineation is complete, fill in the name and comment as shown below in the form.




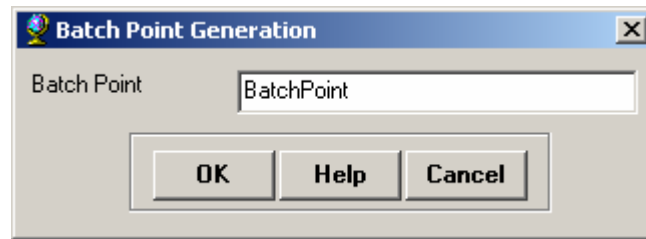
The delineated watershed is shown below.



3. Batch Point Generation

This function creates the Batch Point feature class that is used as input to the function Batch Watershed Delineation in the Watershed Processing menu.

- Click on the icon  in the Arc Hydro Tools toolbar.
- Confirm, if prompted, that the name of the batch point feature class is “BatchPoint”.



- Click with the mouse to create a point on the map. The following form is displayed:

- Fill in the fields Name and Description. Both are string fields. The BatchDone and SnapOn options can be used to turn on (select 1) or off (select 0) the batch processing and stream snapping for that point. Select the options shown above.

The Batch Point feature class is created if needed, and this layer stores the new point.


4. Assign Related Identifier

This function allows updating an attribute for a target feature with the value of a related attribute in a source feature.

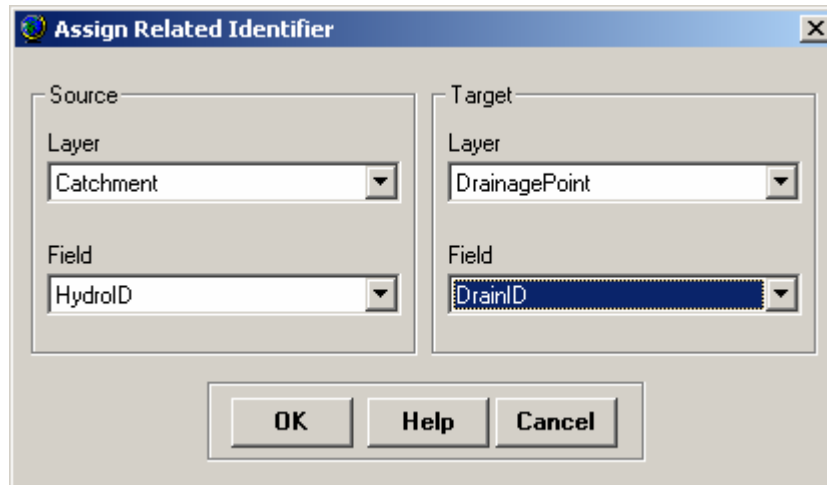
Considering for example the layers “Catchment” and “DrainagePoint”: the field “DrainID” in DrainagePoint is the HydroID of the Catchment where the point is located.

- Select one Catchment and use the function Assign HydroID to overwrite its HydroID.

The DrainID in the DrainagePoint feature class for the point located in that watershed is not correct anymore. It can be corrected in the following way using the Assign Related Identifier function:

- Click on the icon  in the Arc Hydro toolbar.
- Select Catchment/HydroID as the source layer/field.

- Select DrainagePoint/DrainID as the target source/field.




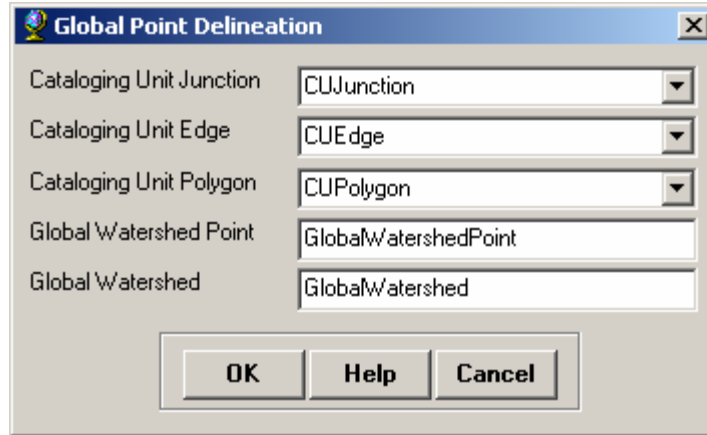
- On the map select the Drainage Point located in the catchment previously selected.
- Right-click the catchment and select Assign Attribute.

The DrainID of the drainage point is updated with the value of the new HydroID in the associated Catchment

5. Global Point Delineation

The preprocessing steps required by this function are described in the document Global Point Delineation with EDNA Data and in the online help. Once these steps have been performed, the function is used in the following way:

- Click on the icon  in the Arc Hydro Tools toolbar.
- Uncheck Select all parameters and click OK.
- Select a point in the map to perform the global delineation.
- Select the Catalog Unit Junction and Edge feature classes, as well as the Catalog Unit Polygon feature class to use as input.
- Select the output names for the Global Watershed Point and the Global Water. “GlobalWatershedPoint” and “GlobalWatershed” are default name that can be overwritten.



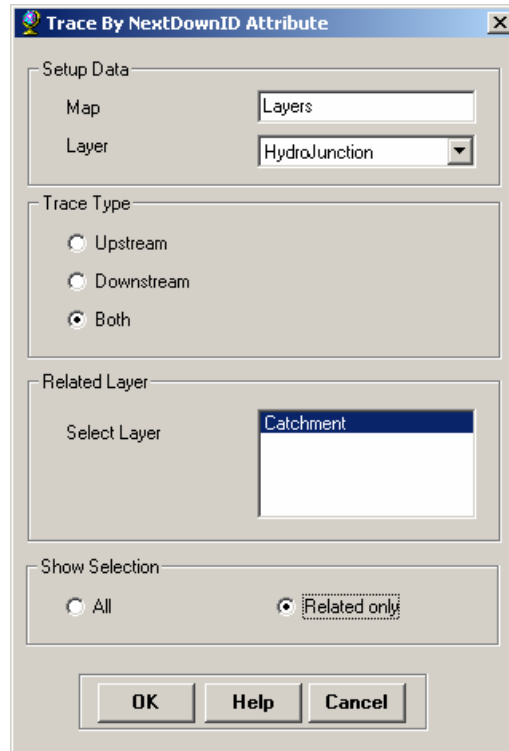
The function delineates the global watershed for the selected point by performing a local delineation in the Catalog Unit where the point is located, and merging the result the Catalog Units polygons located upstream.

6. Trace By NextDownID Attribute

This function allows performing a trace on a feature class based on the NextDownID attribute. Only layers having the attribute "NextDownID" may be traced. The trace may be performed upstream, downstream or in both directions. The function allows displaying the features related to the result of the trace. It may be used for example to display the catchments located upstream and/or downstream of a specific junction.

- Click on  in the Arc Hydro Tools toolbar.

The following form is displayed on the screen:



- Select “HydroJunction” as the layer on which to perform the trace.
- Select “Both” as Trace Type.
- Select “Catchment” as the Related Layer.
- Select “Related Only” under Show Selection.
- Click OK.
- Click on the map on a Hydro Junction from which to perform the trace. Make sure that “HydroJunction” and “Catchment” are visible.

The function shows as a selection the catchments related to the Hydro Junctions located upstream and downstream from the selected Hydro Junction.

Appendix C

Arc Hydro: GIS for Water Resources

Data Model Files

The ArcGIS Hydro data model provides a data structure for a large variety of water resources features, namely hydrography, drainage features, channels, networks, and time series. As such, many classes exist in Arc Hydro which may not be required in smaller applications. Therefore, three versions of Arc Hydro are provided with this CD: the full Arc Hydro model, the Arc Hydro Framework, and the Framework with Time Series. The Framework model contains the five most commonly used Arc Hydro classes, while the Framework with Time Series model contains the Arc Hydro time series classes in addition to the classes in the Framework model. Below you will find the following files associated with each of the three versions of Arc Hydro:

[UML \(.vsd\)](#)

[Repository \(...Schema.mdb\)](#)

[Shell \(...Shell.mdb\)](#)

[Diagram \(.ai\)](#)

[Tutorial on how to Apply Schema](#)

UML (.vsd)

The UML (Unified Modeling Language) is a Visio 2000 drawing containing the classes and relationships of Arc Hydro. The UML is used to create the repository, from which the Arc Hydro schema can be applied to geodatabases. The UML itself is not required to use Arc Hydro, as long as you already have a repository created from the UML (repositories are included with this CD). Customized versions of Arc Hydro can be created by modifying the UML and exporting the UML to a new repository. (See ArcGIS desktop help to learn how to create and edit UML diagrams.) The Visio 2000 software is required to view the UML.

*Download ~~the~~ UML here**

[Full Model](#) - [Framework Model](#) - [Framework with Time Series Model](#)

* Please note: For Oracle users, potential problems with the uppercase/lowercase naming convention used in the standard UML listed above can be avoided by using a UML with only uppercase names. Alternative UMLs for each of the three models with only uppercase names have been created for Oracle users.

Download the all uppercase UML here

[Full Model](#) - [Framework Model](#) - [Framework with Time Series Model](#)

Repository (...Schema.mdb)

The repository is a Microsoft Access database (.mdb) that contains the Arc Hydro schema, or blueprint of classes and relationships. By connecting to the repository through ArcCatalog (as described in Chapter 9 of the Arc Hydro book), the Arc Hydro schema can be applied to a geodatabase, converting that geodatabase into an Arc Hydro geodatabase.

*Download the Arc Hydro Schema here**

[Full Model](#) - [Framework Model](#) - [Framework with Time Series Model](#)

* Please note: For Oracle users, potential problems with the uppercase/lowercase naming convention used in the standard Arc Hydro schema listed above can be avoided by using a schema with only uppercase names. Alternative schemas for each of the three models with only uppercase names have been created for Oracle users.

Download the all uppercase Arc Hydro Schema here

[Full Model](#) - [Framework Model](#) - [Framework with Time Series Model](#)

Shell (...Shell.mdb)

For each version of Arc Hydro, this CD includes a shell geodatabase. The shell is created by

applying the Arc Hydro schema to an empty geodatabase. This process creates an empty class in the geodatabase for each class in Arc Hydro, as well as creating Arc Hydro relationships and coded value domains.

Download the Shells here

[Full Model](#) - [Framework Model](#) - [Framework with Time Series Model](#)

Diagram (.ai)

An Adobe Illustrator diagram of each version of Arc Hydro is included for visualization purposes. Use the diagram as a quick reference as to what each Arc Hydro model contains.

Download the Diagrams here

[Full Model](#) - [Framework Model](#) - [Framework with Time Series Model](#)

Tutorial (.html)

A html page tutorial of how to apply the Framework with Time Series Model has been included. The tutorial, used as class exercises at the University of Texas at Austin, is broken into three sections. Use the tutorial to better understand how apply the Arc Hydro schema to a geodatabase.

Download the Applying the Schema Tutorials here

[Part 1](#) - [Part 2](#) - [Part 3](#)

[back](#)

Applying the ArcGIS Hydro Data Model: Part 1

CE 394K GIS in Water Resources University of Texas at Austin Fall 2001

Prepared by: Reem Zoun, Kristina Schneider, Tim Whiteaker, and David Maidment

Covered in Part 1

- [Introduction to the ArcGIS Hydro Data Model and Arc Hydro Framework](#)
- [Objectives of the Exercise](#)
- [Computer and Data Requirements](#)
- [Procedure for the Assignment](#)
 1. [View your data in ArcMap and ArcCatalog](#)
 2. [Prepare your Data for Schema Application](#)
 - A. [Create Centerline](#)
 - B. [Create Waterbody](#)
 - C. [Create Network Junctions](#)
 - D. [Create Geodatabase and Import Data](#)
 - E. [Create Geometric Network](#)

Covered in Part 2

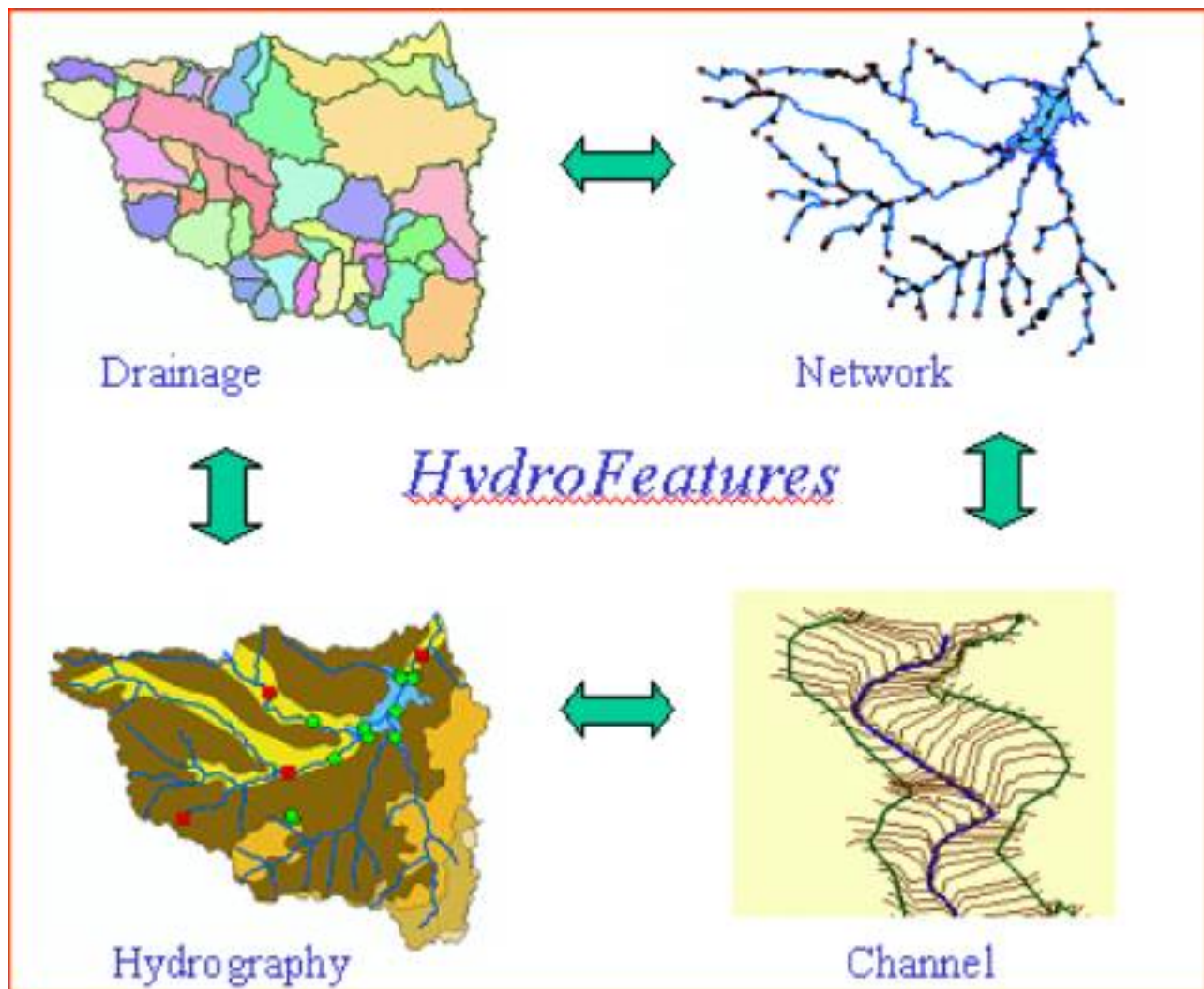
3. Applying the Schema
 - A. Add Schema Creation Wizard to ArcCatalog
 - B. Connect to the Repository
 - C. Selecting Features
 - D. Set Properties of Feature Classes
 - E. Create the Schema
4. Applying Tools
 - A. Add the Arc Hydro tools to ArcMap
 - B. Apply the Arc Hydro tools
 - I. Assign HydroID
 - II. Calculate Length Downstream
 - III. Find Next Downstream Junction
 - IV. Store Area Outlets
 - V. Consolidate Attributes
 - VI. Store Flow Direction

Introduction to the ArcGIS Hydro Data Model and Arc Hydro Framework

The ArcGIS Hydro Data Model (Arc Hydro) is an ArcGIS geodatabase model. It provides a standardized framework into which various types of water resources data can be loaded. In this manner the data forms an integrated water resources modeling and mapping database.

A geodatabase model is generated in a series of steps, beginning with the definition of classes and attributes in a Unified Modeling Language (UML) diagram created in the Visio 2000 drawing system. The second step is to export the diagram to a Microsoft repository format, which is an equivalent tabular structure, or schema, for loading into Microsoft Access (personal geodatabase) or other relational data servers (enterprise geodatabase). Finally, the data is imported into the Arc Hydro format by applying the schema to an ArcGIS geodatabase. Additional instructions for generating a schema in ArcCatalog can be found in the ArcGIS help files and in the book, *ArcObjects Developer's Guide* (shipped with ArcGIS).

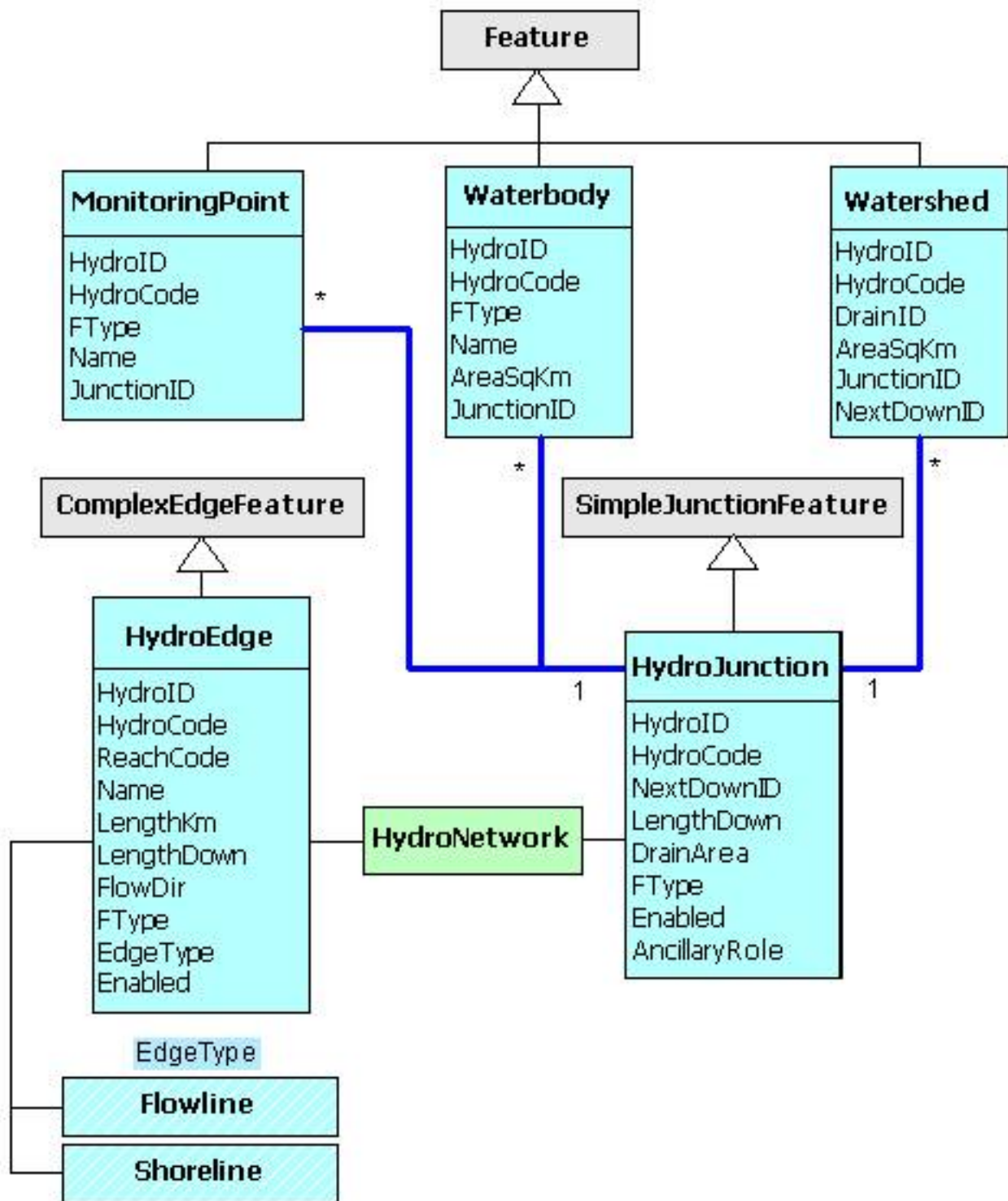
The ArcGIS Hydro Data Model stores data in four feature datasets, each corresponding to one of the main domains of the UML analysis diagram: **Hydrography** (map hydrography and associated data inventories), **Drainage** (drainage areas derived from digital elevation models or manually digitized), **Channel** (3-D profile and cross-section representation of stream channels), and **Network** (a geometric network representation of the connectivity of the surface water features of the landscape). Associated with these four feature datasets are a set of object tables for additional information, such as events defined on the river network, and time series of monitoring data.



To apply Arc Hydro, you simply apply the **schema**. One of the goals of this exercise is to apply a schema to a dataset. However, the Arc Hydro model, with four feature datasets, is a bit complicated if just used to demonstrate how to apply a schema.

The **Arc Hydro Framework** schema was created to provide a slimmed down version of the Arc Hydro model to provide practice in applying data models. Arc Hydro attempts to capture the majority of water resources data available, while Arc Hydro Framework's goal is to represent the most commonly used feature classes and relationships.

Arc Hydro Framework consists of one feature dataset called ArcHydro. The feature dataset contains only five feature classes: **MonitoringPoint**, **Waterbody**, **Watershed**, **HydroEdge**, and **HydroJunction**. MonitoringPoint represents point features from map hydrography and inventory sources used to collect water resources data. Waterbody represents area features from map hydrography. Watershed is a polygon feature class, which contains any subdivision of the landscape into drainage areas. HydroEdge and HydroJunction form a geometric network called HydroNetwork. The UML diagram below shows the relationships that create the schema.



Objectives of the Exercise

- To take regularly available geospatial data for hydrology and prepare it in the format needed for inclusion in a data model.
- To apply the Arc Hydro Framework schema to these data.
- To run a set of Arc Hydro tools to fill in the attributes contained in the schema.

In this exercise, you'll learn editing skills for linear and areal features, and also how to create new lines and polygons as part of existing feature classes.

Computer and Data Requirements

- ArcGIS 8.1
- 35 MB of disk space

Data Files:

ArcHydroFrameworkSchema.mdb	MS Repository for Arc Hydro
Albstat Shapefile	Point shapefile which contains gaging stations
Rf1guad Shapefile	Line shapefile showing the path of the river.
Hucguad Shapefile	Polygon shapefile representing watersheds derived for the Guadalupe basin.
CreatePolyFromLines.txt	VBA script for creating polygons from closed polylines

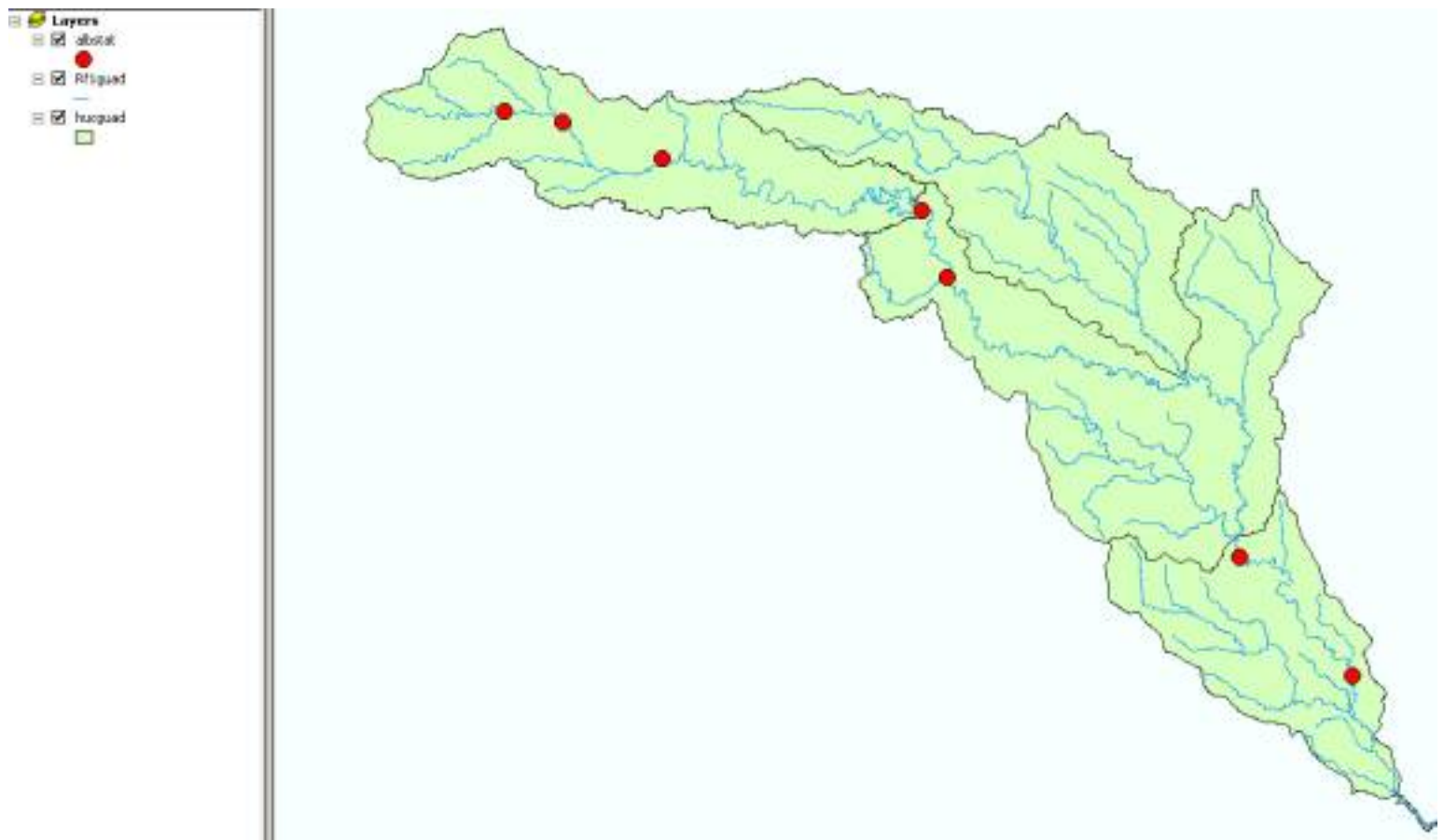
These files are attached to this exercise as [ArcHydro.zip](#).

Procedure for the Assignment

1. View your data in ArcMap

(1) Open ArcMap.

(2) Navigate to the directory with your data. Add the **Albstat**, **Rf1guad** and **Hucguad** shapefiles to the data frame. Explore the dataset by looking at the attributes for each class and visualizing them separately. These are the same files that you prepared for the Guadalupe Basin in exercise 2 of the course.



(3) Close ArcMap, you don't need to save the data.

2. Prepare your Data for Schema Application.

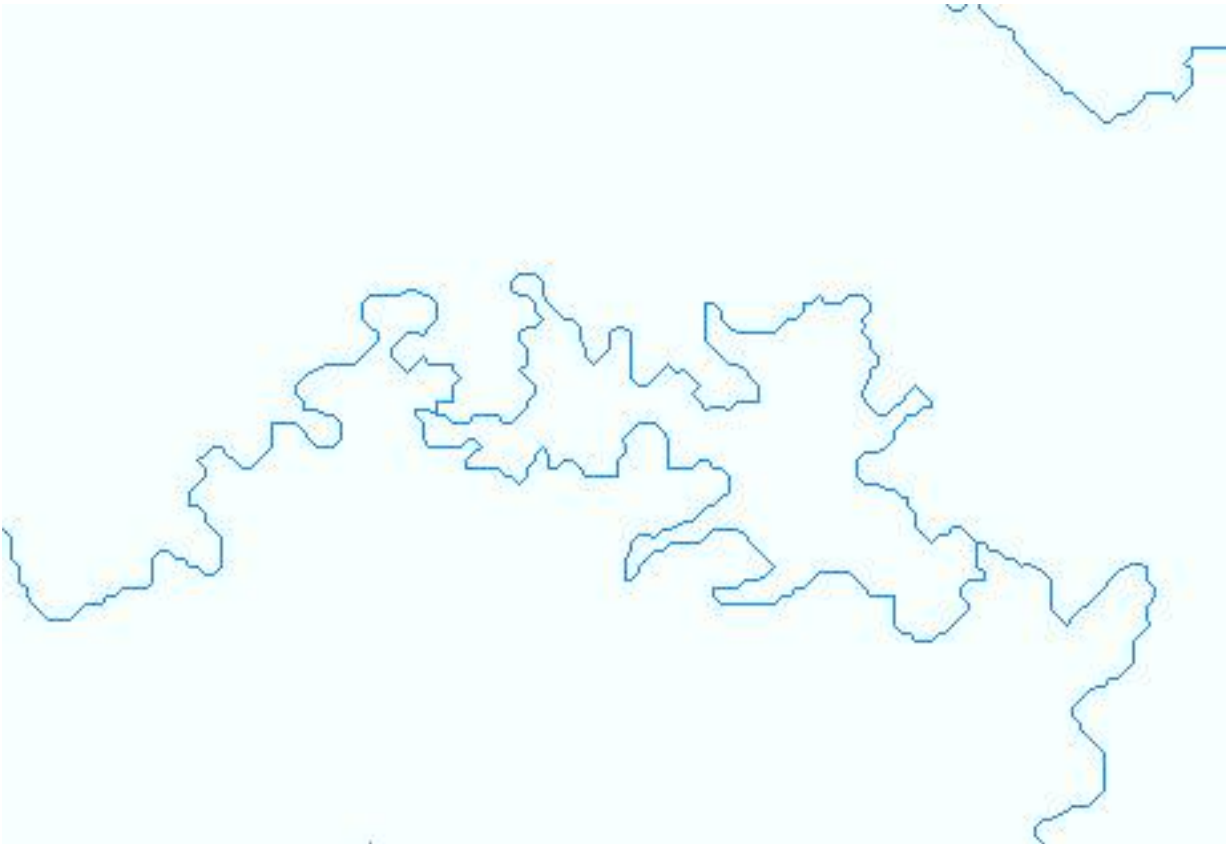
The Arc Hydro Framework schema contains 5 feature classes and at present we have data for only 3 of them: MonitoringPoint (Albstat.shp), Watershed (Hucguad.shp) and HydroEdge (Rf1guad.shp). In this part of the exercise, we are going to create the data for the other two feature classes, Waterbody and HydroJunction. The first thing we'll do is to create a centerline through Canyon Lake.

A. Create Centerline

(1) Open ArcMap and add 'Rf1Guad' shapefile to your dataframe.

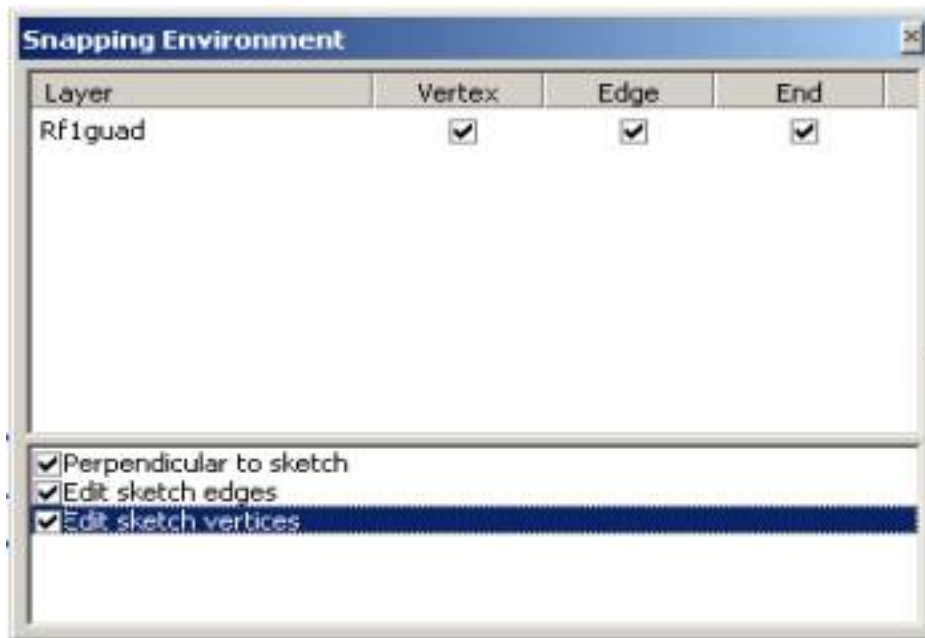
(2) Zoom into the area where the Guadalupe River goes around Canyon Lake to show the shape of the reservoir. We are going to create a centerline through Canyon Lake to form a complete network for Guadalupe River.

Canyon Lake



(3) Go to **Tools/Editor Toolbar** and the Editor toolbar will appear. On the Editor toolbar go to Editor/Start Editing.

(4) Go to **Editor/Snapping** and the Snapping Environment dialog will appear. Click all the options on for Rf1guad. It should appear as the dialog below after you have turned them on.



(5) Close the Snapping Environment dialog.


(6) Zoom into the Canyon Lake area and click on the Create New Feature icon on the Editor Toolbar (the little pencil).

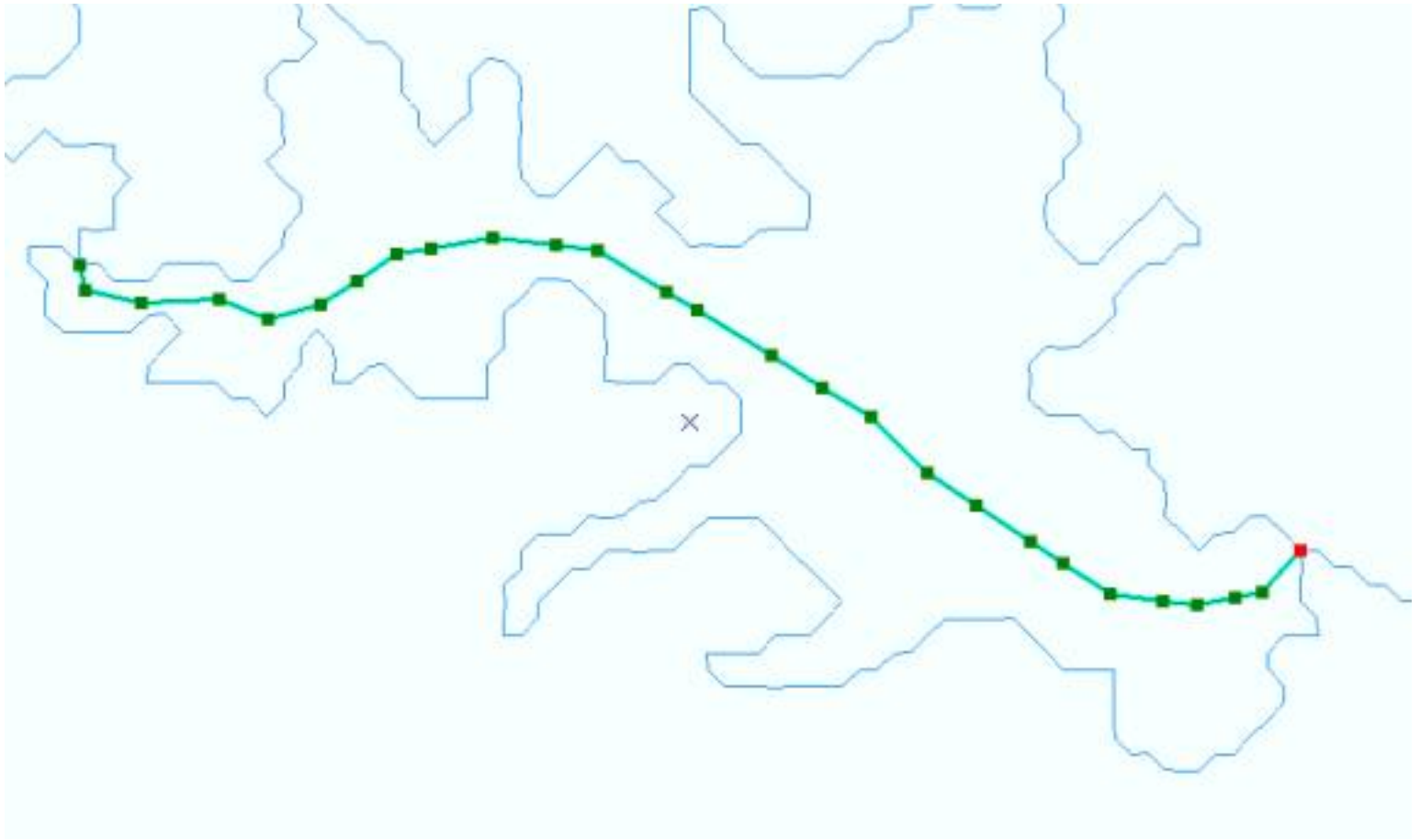


(7) Snap at the intersection of Guadalupe River and the reservoir and the continue clicking through the middle of the reservoir to create a centerline. When you reach the end, double click. You should end up with a centerline in the middle of Canyon Reservoir. *Note: If you cannot create a centerline because the cursor always snaps to the boundary of the lake, try decreasing the snap tolerance by clicking **Editor/Options...** and adjusting the Snapping tolerance.*

(8) Use the **Editor/Save Edits** to save the edits that you've made. If you don't like the centerline you created, use **Editor/Stop Editing** to terminate the editing session and do not Save Edits, and then restart the Edit session and redo the centerline. To modify an existing feature without retracing it, use Task: **Modify feature** in the toolbar shown above and use



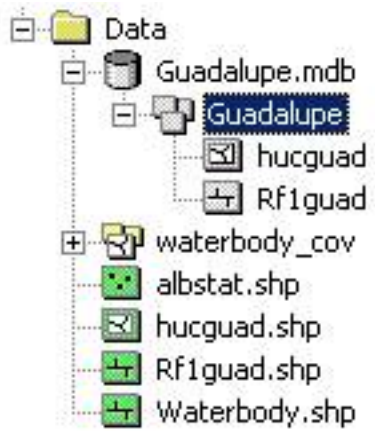
the  next to the Create New Feature icon to select and edit the features you want to alter.



B. Create Waterbody

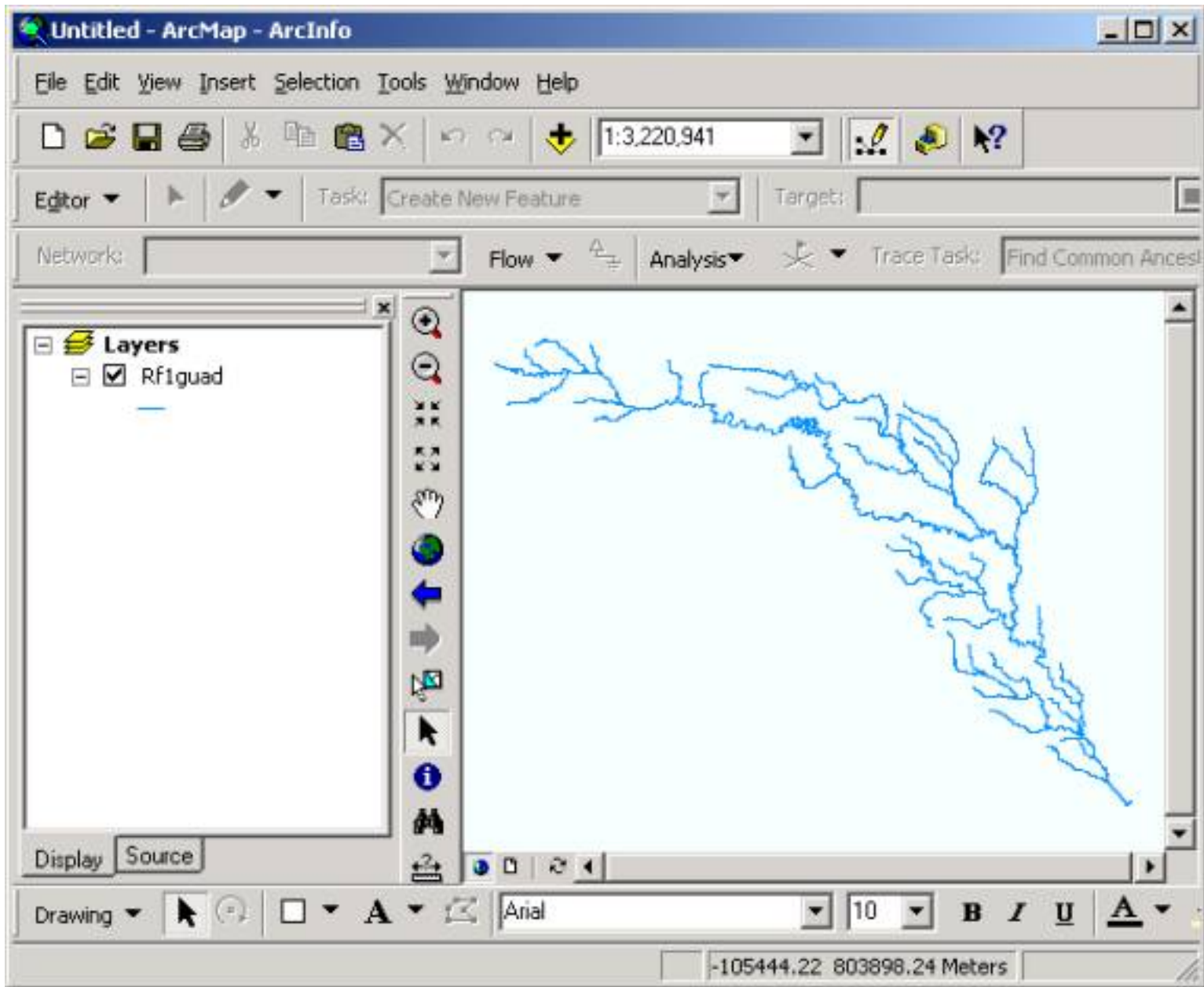
Now we are going to take the lines that trace the shoreline of Canyon Lake and make them into a polygon to form a Waterbody.


- (1) Go to **ArcCatalog**, create a new geodatabase called **Guadalupe.mdb**, and import into it the shapefile **hucguad.shp**, naming the feature dataset Guadalupe, and then import **rf1guad.shp** into this feature dataset. If you go to the Properties of the Guadalupe feature dataset, you'll see that it has the albers projection of the Guadalupe data that you used in exercise 2 earlier in the course. The hucguad.shp file was imported here to make sure that the extent of the feature dataset was large enough to cover all the region of interest. It's really the rf1guad river reaches that we are interested in working with.



Next we are going to create the Waterbody in ArcMap. Because only one ArcGIS application can access a geodatabase at a time, we must first close ArcCatalog.

- (2) Close ArcCatalog. Open ArcMap and add Rf1guad from the Guadalupe geodatabase that you just created.



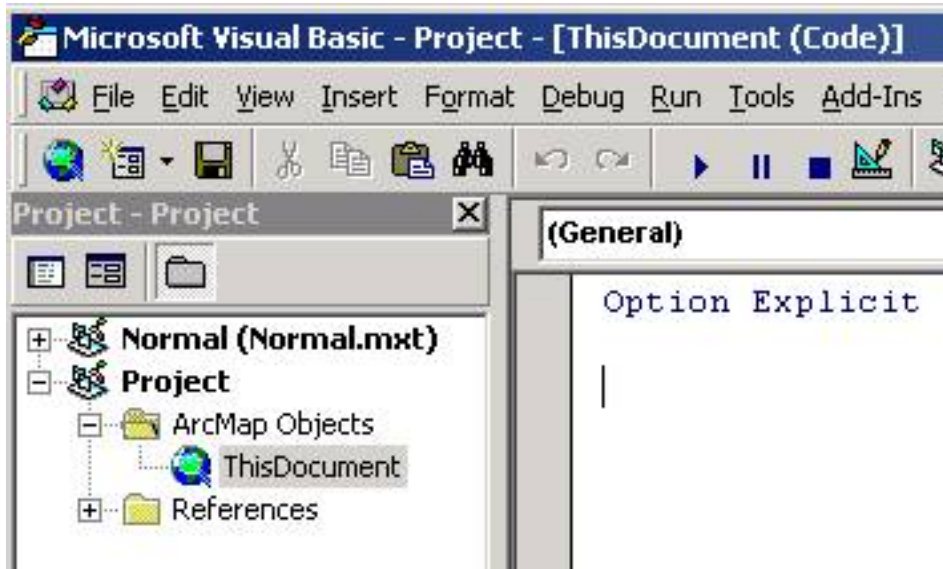
(3) Click on the Edit  button on the editor toolbar. Select the shorelines of the Canyon Lake by clicking on them using shift key. Use the **Editor/Merge** command to merge the two shorelines into a single feature.

(4) **Save edits and Stop editing.**

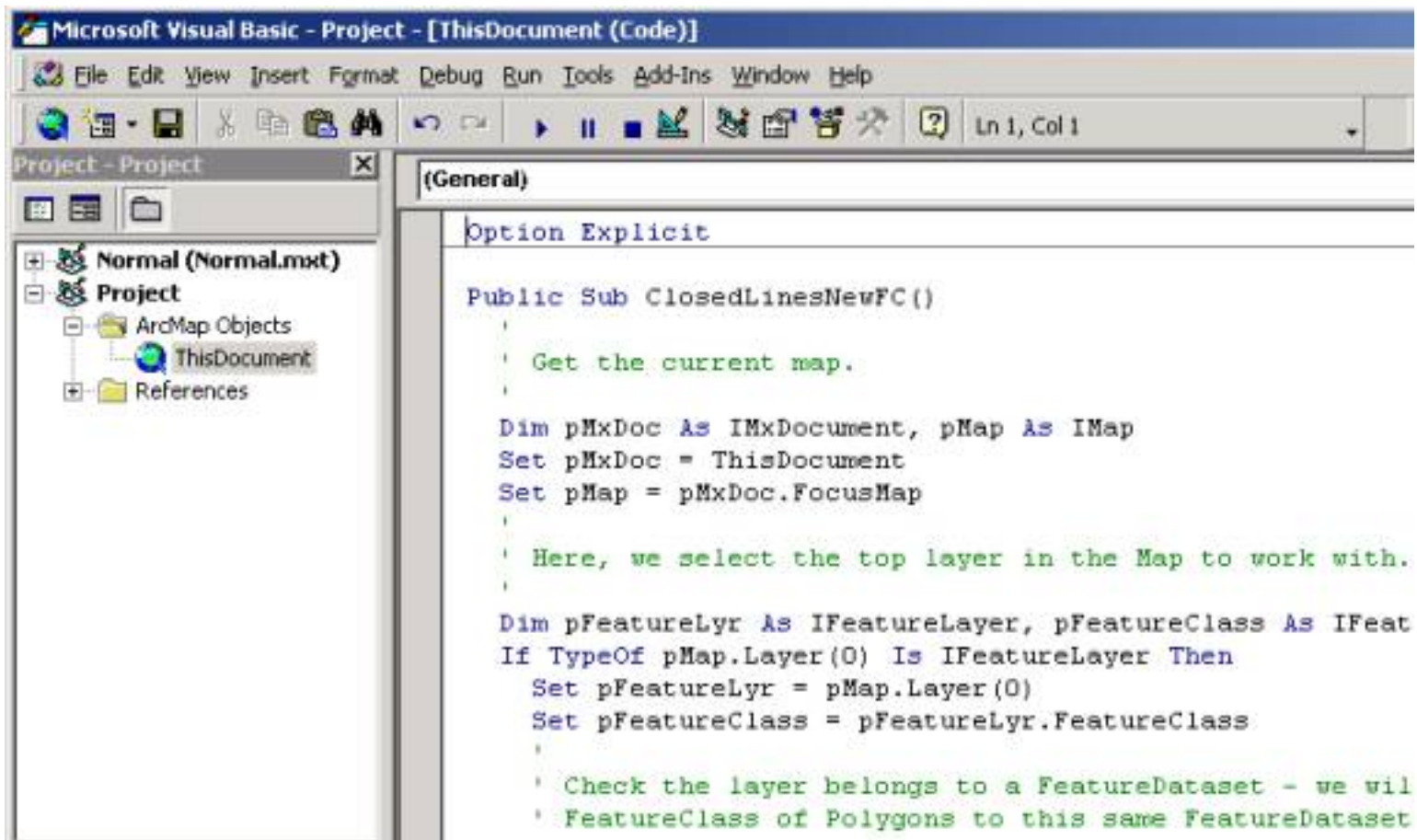
Now we add some Visual Basic code to convert the polylines forming Canyon Lake into a polygon feature class.

(5) Make sure that Rf1guad is the only layer in the map. Open the Visual Basic Editor by clicking **Tools/Macros/Visual Basic Editor**. The VBA environment window for ArcMap opens up.

- (6) Open the code window for **ThisDocument** by expanding the project window items until **ThisDocument** appears, and then by double clicking on **ThisDocument**. (You may or may not have the words “Option Explicit” at the top of the code window. The code that we will use will work either way.)

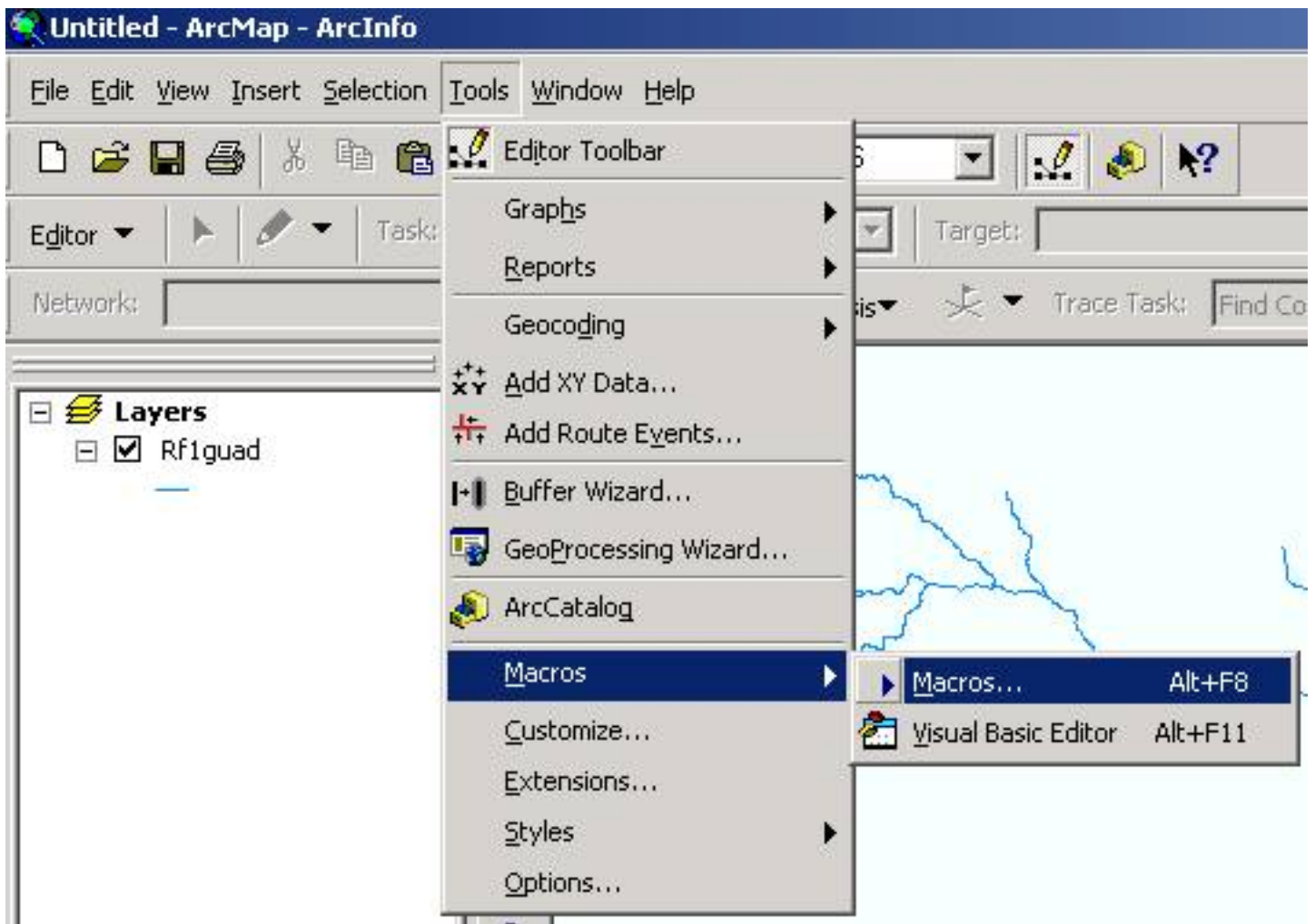


- (7) Open CreatePolyFromLines.txt from the ArcHydro.zip file included with this exercise. Make sure the **Word Wrap** option **IS NOT** checked. This option can usually be found under the **Format** menu. *Note: For helpful macros and extensions (including CreatePolyFromLines), look in arcexe81\ArcObjects Developer Kit\Samples.*
- (8) Copy all of the text in CreatePolyFromLines.txt, and paste it into the code window. If you have the words “Option Explicit” at the top of the code window, paste the CreatePolyFromLines code below the words “Option Explicit”.



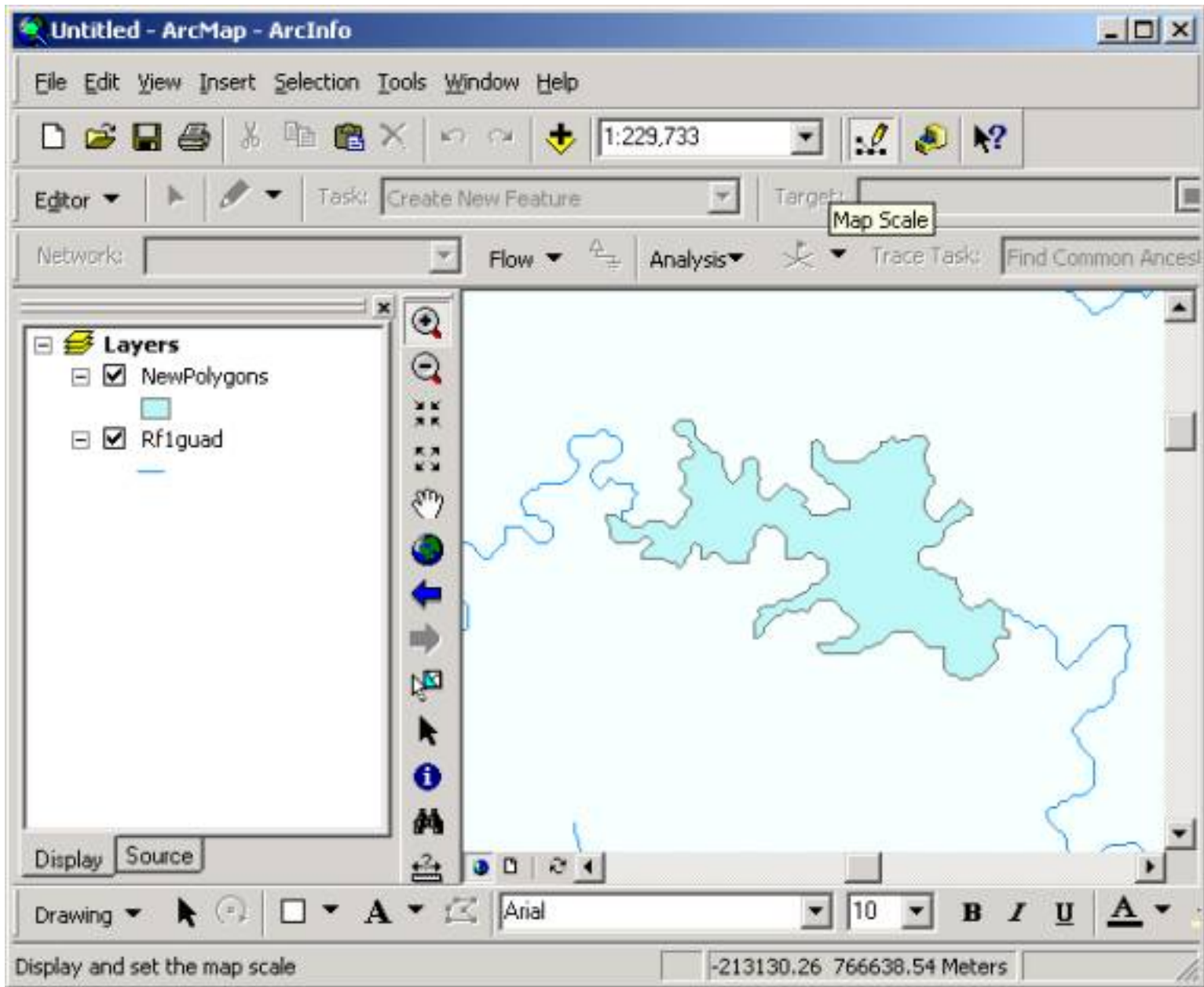
(9) Close the VBA window.

(10) Now it's time to run the macro. In ArcMap, click **Tools/Macros/**.



(11) In the Macros window, highlight ClosedLinesNewFC and click **Run**.

A new feature class called NewPolygons is created in the Guadalupe geodatabase and added to ArcMap.



Now that the Waterbody has been created, we can delete the shorelines of Canyon Lake.

(12) Clear any selected features and turn off NewPolygons.

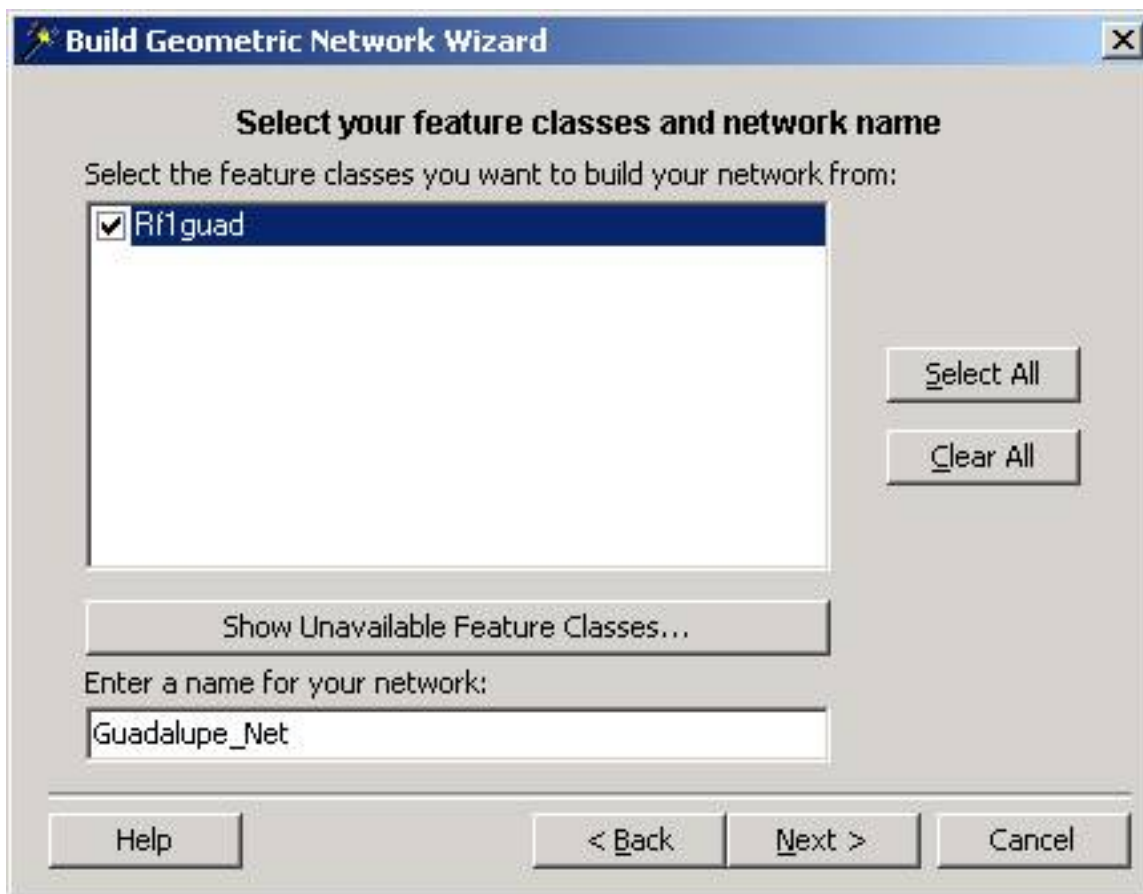
(13) Go to **Editor/Start Editing**. Set the **Task** as **Modify feature** and Target as **Rf1guad** on the Editor Dialog box. Select the canyon reservoir shoreline and delete it. This creates a simple network through the lake rather than parallel paths around its edges.

(14) Go to **Edit/Save Edits** and **Stop Editing**. Exit ArcMap. You don't need to save changes.

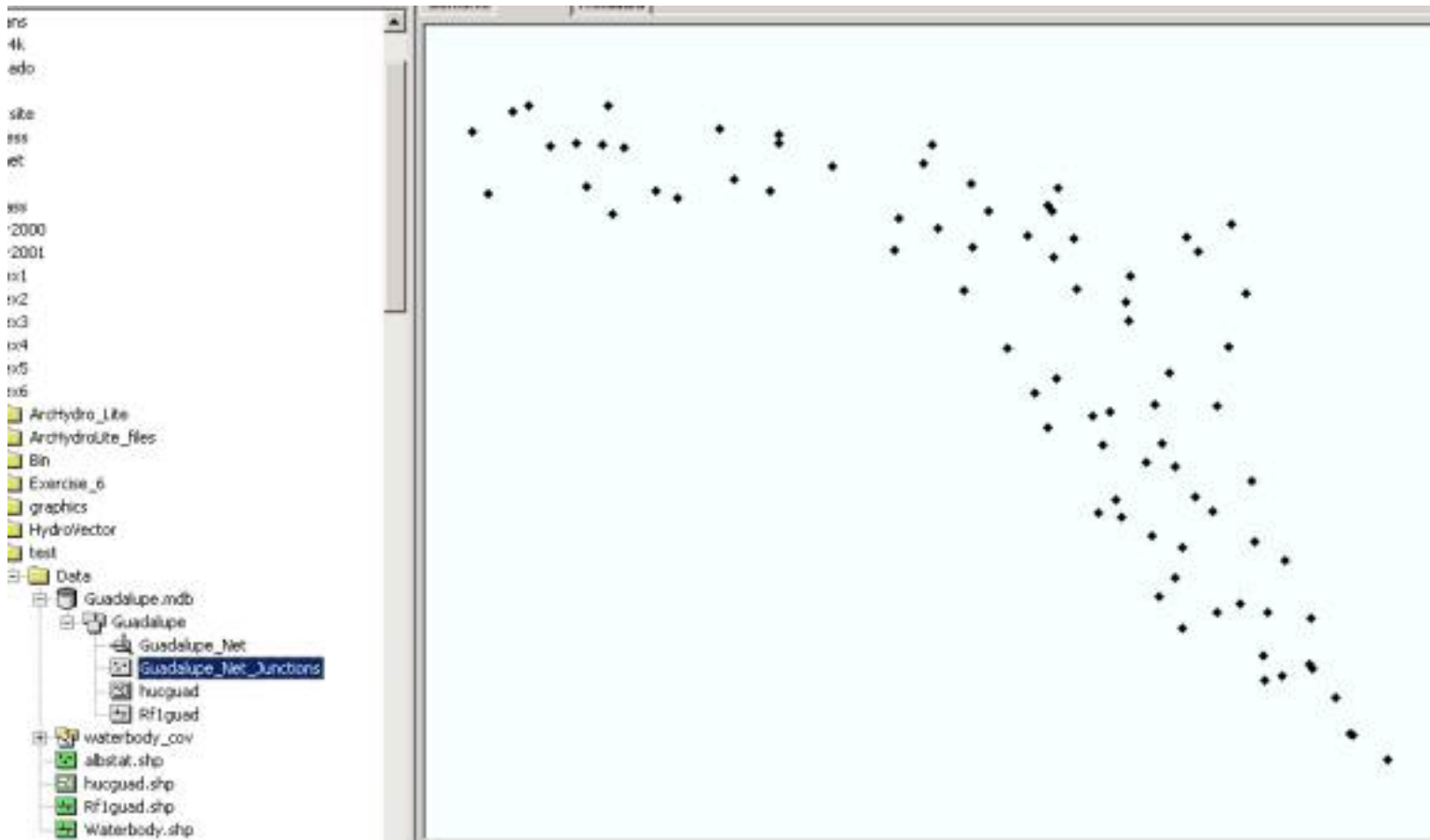
C. Create network junctions

Now, we are going to create junctions for our network using the geometric network builder.

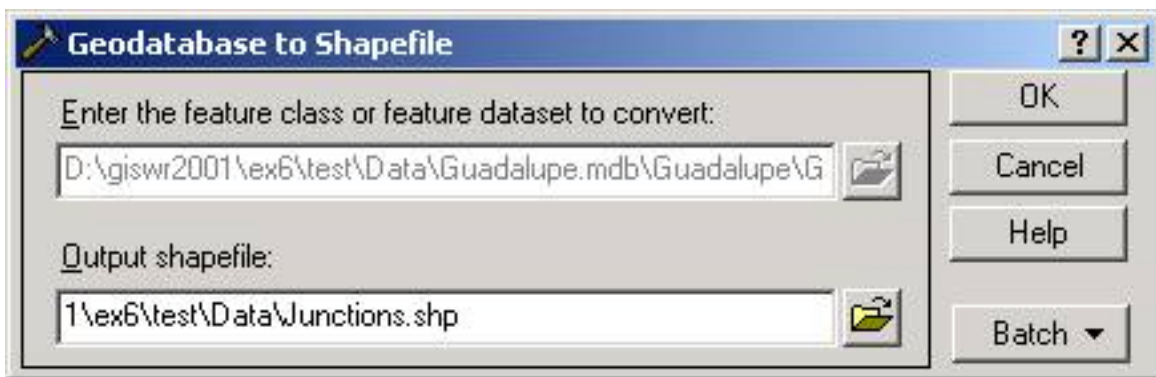
- (1) Open ArcCatalog.
- (2) In the Guadalupe feature dataset, Create a new geometric network, Building with Existing Features, Select **Rf1guad** as the feature class and **Guadalupe_Net** as the network to be created. Do not use Complex Edges in the network. Do not snap features. Do not assign weights to the network.



Once you've got the network created, you'll see that you've added a new feature class called **Guadalupe_Net_Junctions**, which is created during the network building process to link the lines in the Guadalupe network. These are called **ESRI Generic Junctions**. We are now going to transform them into Junctions for use in the Arc Hydro data model.



- (3) In ArcCatalog, right click on **Guadalupe_Net_Junctions** and use Export/Geodatabase to Shapefile to create a new shapefile called **Junctions.shp**.



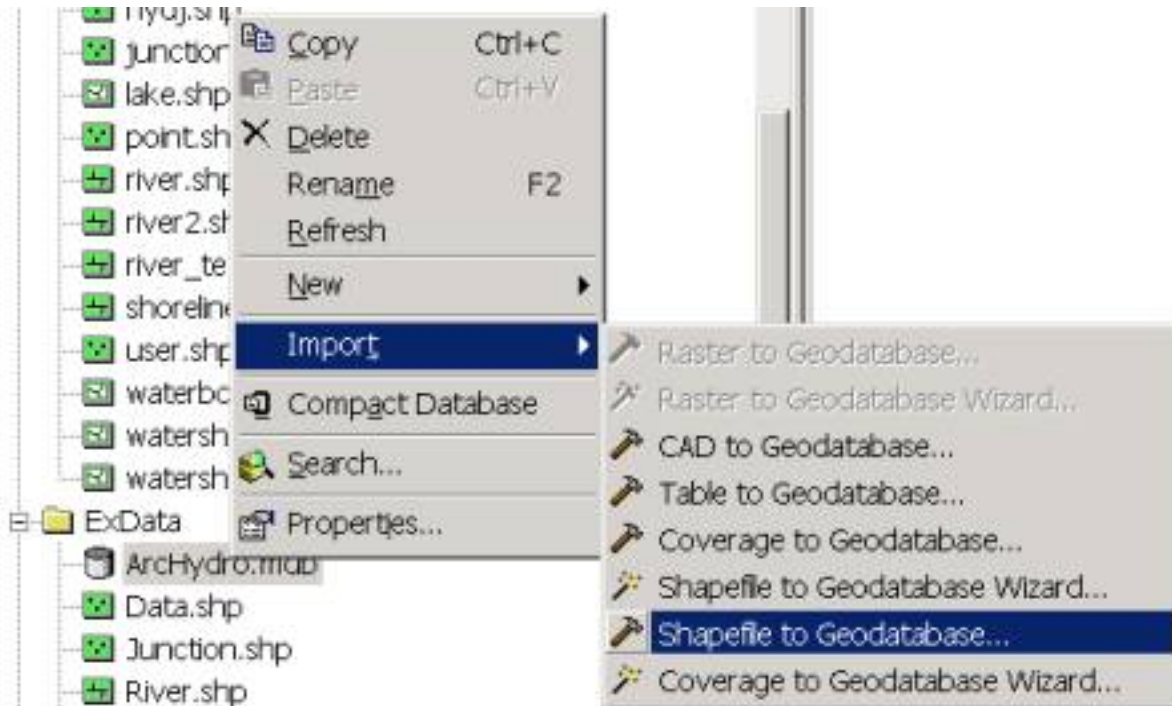
- (4) Export the **NewPolygons** feature class to a new shapefile called **Waterbody.shp**.

D. Create Geodatabase and Import Data

When applying the Arc Hydro schema, it works best when you have a geodatabase with feature classes already in it with the correct class names. So lets create that now.

(1) Open ArcCatalog. Right click on the data folder, press **New/Personal Geodatabase**. Call the new geodatabase **ArcHydro**.

(2) Now, you will import your shapefiles into the geodatabase. Right-click on your geodatabase and press **Import/Shapefile to Geodatabase**.

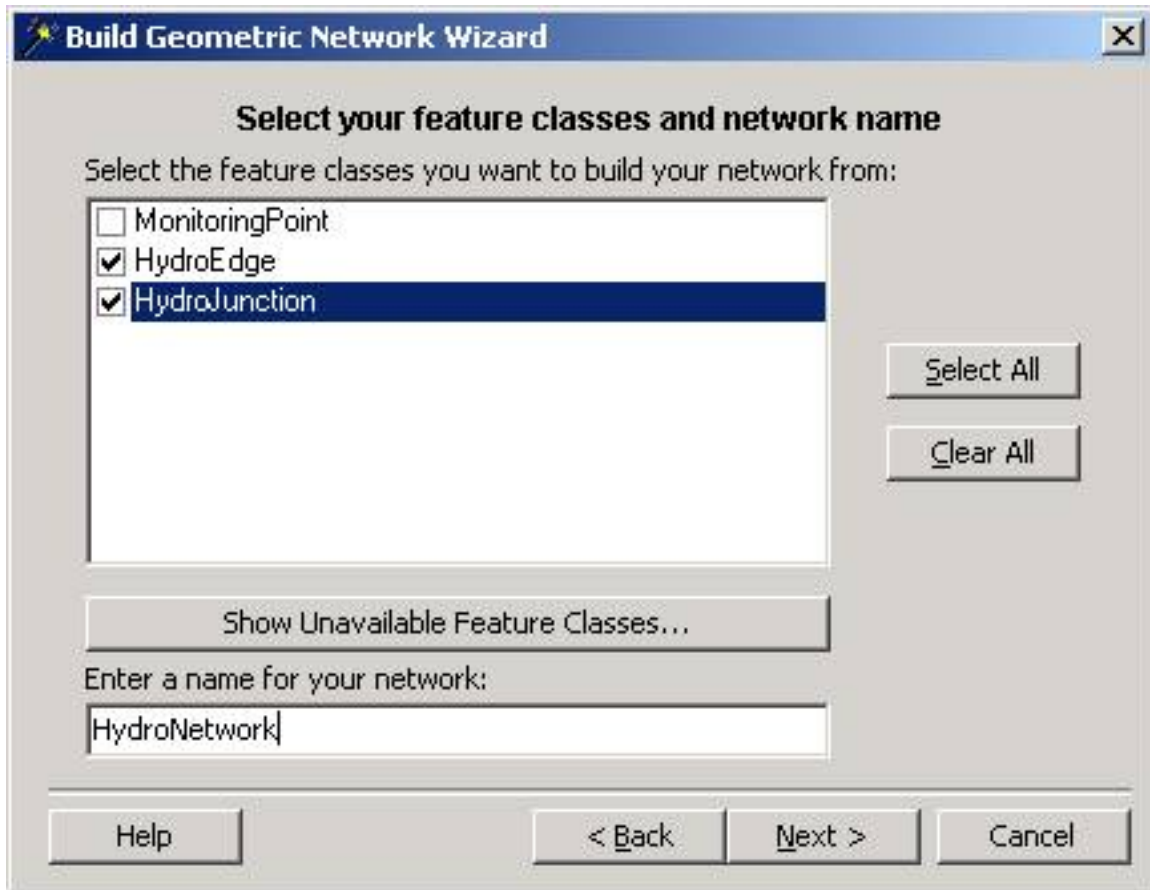


You will be importing all of your shapefiles. First, you must navigate your data folder in the Input shapefile box. Choose the hucguad shapefile, since this file has the largest extent. Type in ArcHydro as the name for your new feature dataset and Watershed as the name of new feature class. You will repeat the above process until the remaining shapefiles are added. It is important to note that each feature class should have the name assigned to it in Arc Hydro Framework. See the table below for the corresponding information.

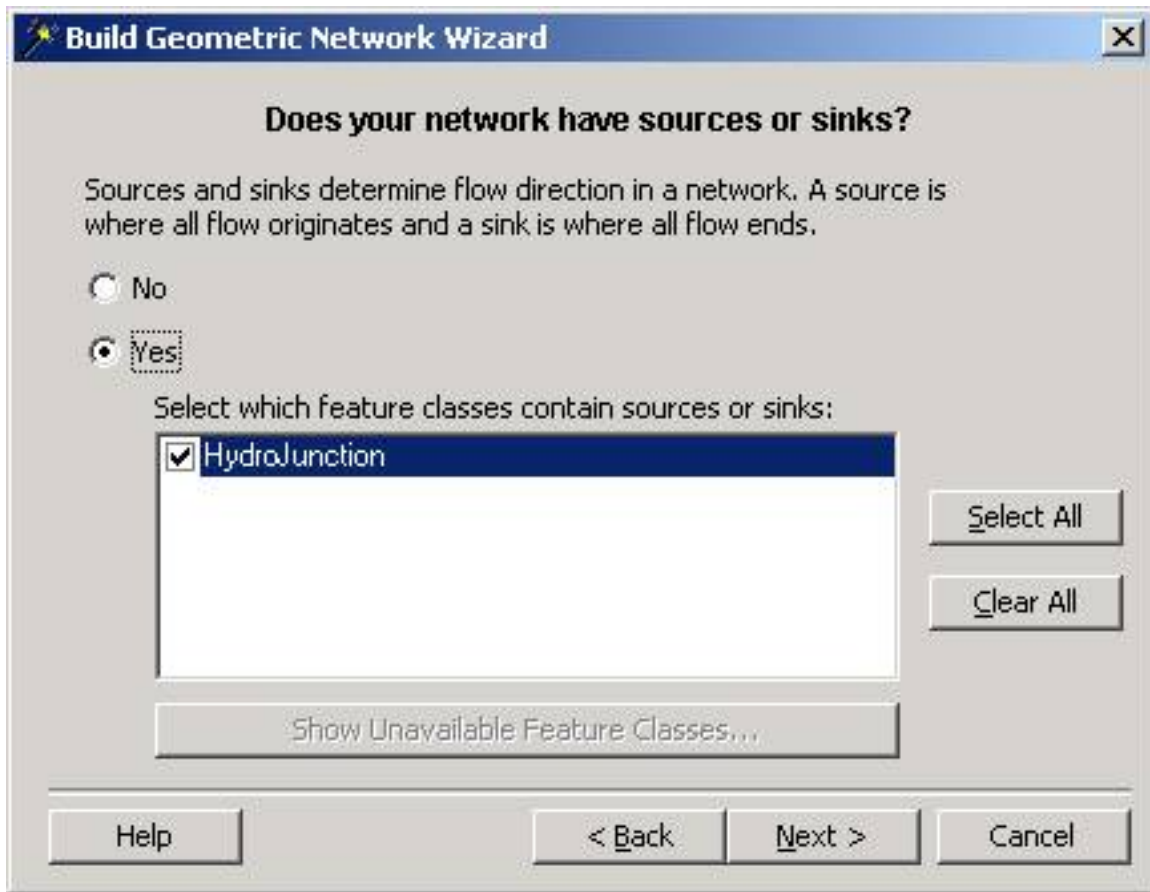
Shapefile	Arc Hydro Framework Feature Class
hucguad	Watershed
albstat	MonitoringPoint
Junction	HydroJunction
Rf1guad	HydroEdge
Waterbody	Waterbody

E. Create Geometric Network

(1) The next step is to create your geometric network, HydroNetwork. Right-click on the feature dataset Arc Hydro and press **New/Geometric Network**. Press **Next** on the first screen and then select **Build a geometric network from existing features** on the second screen. In third screen, select the HydroJunction and HydroEdge files to be part of the network.

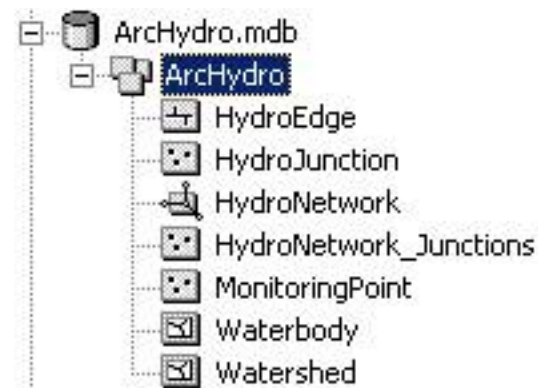


Also, name the network **HydroNetwork**. This is an important step since the schema will only accept a network with the same name as in the model description. Click **No** to enable all features in the network on the fourth screen. Click **Next**. You will be asked if your network has complex edges, select **Yes** and HydroEdge. Click **Next**. In the sixth screen, select **No** since your features do not need to be snapped and click **Next**. You will be asked if your network will have sources or sinks, in the seventh screen. Click **Yes** and select **HydroJunction**.



Press **Next**. You will be asked if you would like to assign weights to the network, answer **No** and click **Next**. Finally, press **Finish** to create the geometric network.

Your geodatabase should look like this.



In summary, the important factors to remember when preparing your data for schema application are the following:

1. Assign the appropriate Arc Hydro Framework name to your feature datasets, feature classes, and feature attributes allows for automatic recognition by the schema creation wizard.

2. Create the network (HydroNetwork) with HydroEdge and HydroJunction. HydroEdge will be a complex edge and HydroJunctions will contain sinks. Each point in the HydroJunction does not have to be a sink but all HydroJunctions will have the option of becoming a sink.

Ok, super duper, you've now created your input data sets!

In the next part of the exercise, we'll apply the Arc Hydro Framework schema and the Arc Hydro tools.

Note: In some situations, it's better to only import generic junctions that have some significance into the HydroJunction feature class, while leaving the remaining junctions as generic junctions. However, in this exercise, no such distinction is made between generic junctions; therefore, all generic junctions were loaded into the HydroJunction feature class.

Applying the ArcGIS Hydro Data Model, Part 2

CE 394K GIS in Water Resources University of Texas at Austin Fall 2001

Prepared by: Reem Zoun, Kristina Schneider, Tim Whiteaker, and David Maidment

Covered in Part 1

- Introduction to the ArcGIS Hydro Data Model and ArcHydro Framework
- Objectives of the Exercise
- Computer and Data Requirements
- Procedure for the Assignment
 1. View your data in ArcMap and ArcCatalog
 2. Prepare your Data for Schema Application
 - A. Create Centerline
 - B. Create Waterbody
 - C. Create Network Junctions
 - D. Create Geodatabase and Import Data
 - E. Create Geometric Network

Covered in Part 2

3. [Applying the Schema](#)
 - A. [Add Schema Creation Wizard to ArcCatalog](#)
 - B. [Connect to the Repository](#)
 - C. [Selecting Features](#)
 - D. [Set Properties of Feature Classes](#)
 - E. [Create the Schema](#)
4. [Applying Tools](#)
 - A. [Add the Arc Hydro Tools to ArcMap](#)
 - B. [Apply the Arc Hydro tools](#)
 - I. [Assign HydroID](#)
 - II. [Calculate Length Downstream](#)
 - III. [Find Next Downstream Junction](#)
 - IV. [Store Area Outlets](#)
 - V. [Consolidate Attributes](#)
 - VI. [Store Flow Direction](#)

This portion of the Arc Hydro exercise assumes that you've already prepared the data for schema

application and you have available a set of prepared files in an ArcHydro geodatabase. This file is attached here as a point of departure for this portion of the exercise. Application of the Arc Hydro tools requires a completely connected geometric network, which the attached file [ArcHydroPart2.zip](#) contains. These are also stored in the LRC on `/class/maidment/giswr2001/archydro`.

These files are:

ArcHydroTools_v1_Beta2: a zip file that contains the ArcHydroTools.dll (may be hidden from view) and the Arc Hydro Tools documentation explaining what the tools are and how to use them

ArcHydro.mdb: the geodatabase you'll use in this exercise (pictured below)

ArcHydroFrameworkSchema.mdb: the schema that will be applied this geodatabase

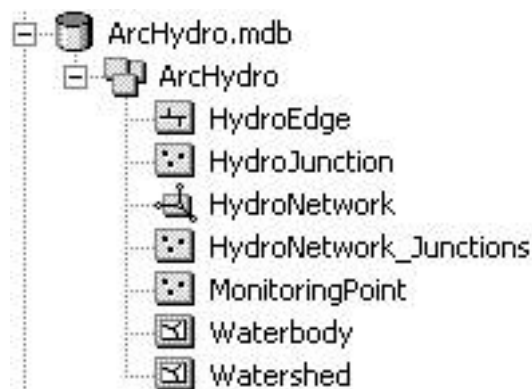
ArcHydroAfterSchema.mdb: the result of applying the schema (as a backup in case you have trouble with doing this)

ArcHydroAfterTools.mdb: the result of applying the ArcHydro tools (as a backup in case you have trouble with doing this)

This portion of the exercise also requires that you have available and have installed the **Arc Hydro** tools. The setup file for these tools can be obtained from the attached zip file. The tools should already be working in the computers in ECJ 3.400 but if you need to install them, simply run setup.exe in the attached zip file.

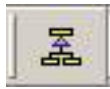
Ok, lets get started!!!

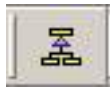
What you are beginning with is a draft **ArcHydro.mdb** database that looks like this:



3. Applying the Schema

A. Add the schema creation wizard to ArcCatalog



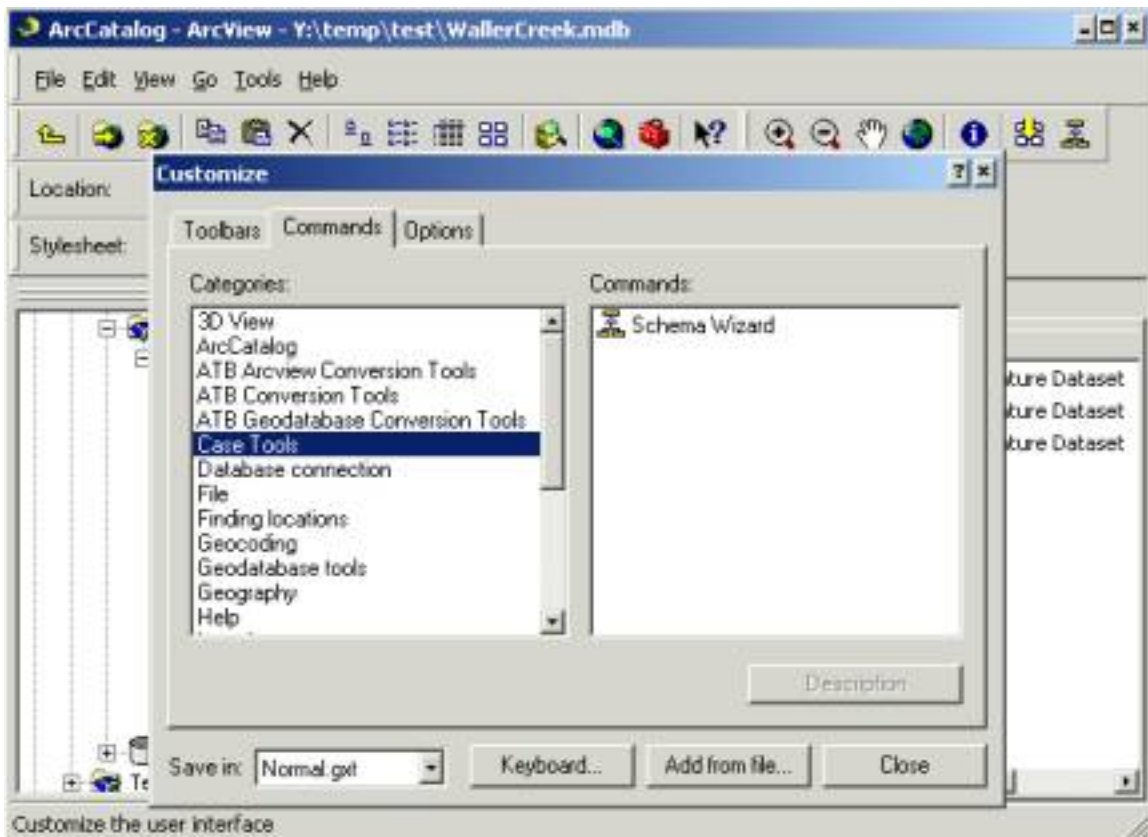
If the schema creation wizard  has already been added to ArcCatalog, skip to step 3.B, Connect to the Repository.

(1) Right click in the gray area in ArcCatalog where the buttons are and click *Customize*. You can also click *Customize* under the **Tools** menu.

(2) Click the *Commands* tab.

(3) If “Case Tools” appears in the categories list, skip to step (4) of this section. If “Case Tools” is not in the categories list, click “Add from file” and browse to the Bin directory where ArcGIS was installed (**/arcexe81/bin**). Select **SchemaWiz.dll** and click *Open*, then click **OK**. If you don’t see the **SchemaWiz.dll** in /arcexe/bin, it may still be there but invisible. Use **Tools/Find File** in Windows Explorer to locate the file, and then register the .dll using **RegCat.exe**, which is also located in /arcexe81/bin (This may also be invisible). Use Tools/Find File to locate RegCat.exe, right click on it and create a shortcut on your desktop. Drag the **SchemaWiz.dll** file onto the **RegCat.exe** shortcut and you’ll be prompted with a dialog to define where to register the .dll. Select ArcMap, ArcCatalog and ArcTools. Now, when you go to the Categories list you will see that the Case Tools option is available and the Schema Wizard icon is visible.

(4) Click “Case Tools” in the categories list.



(1) Drag the *Schema Wizard* command onto a toolbar.

(2) Click **Close**.

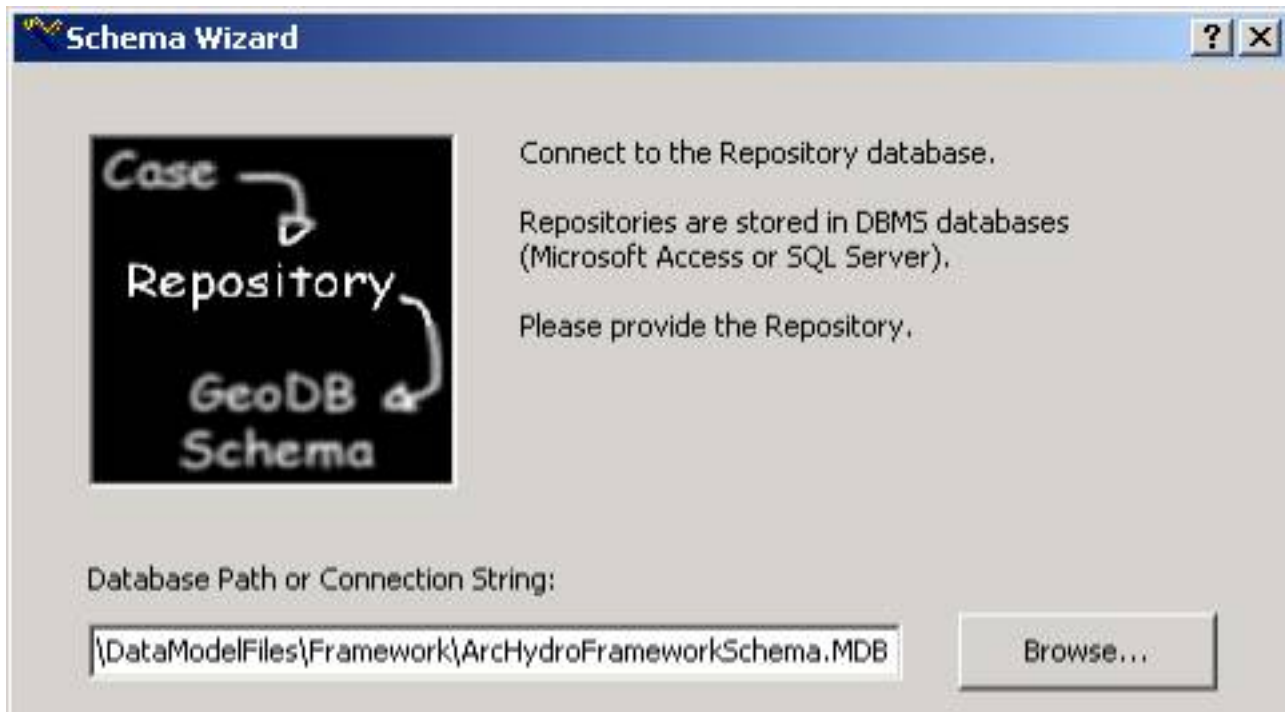
B. Connect to the Repository

(1) In the ArcCatalog tree, click the ArcHydro geodatabase to which you will apply the schema, so that it opens and you can see the feature dataset it contains.

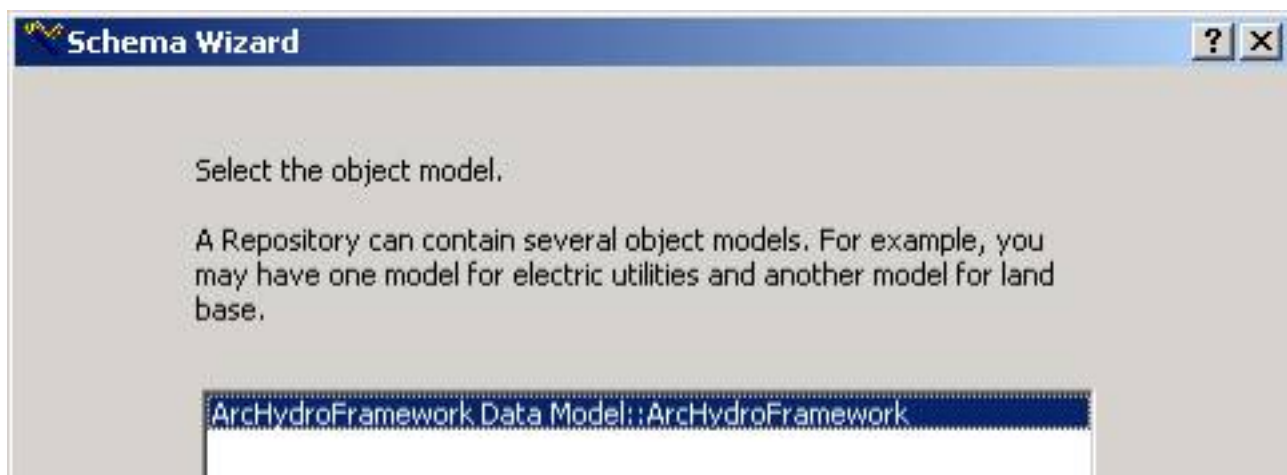
(2) Click the Case Schema Creation button to launch the Schema Creation Wizard. You may get a message saying that this action requires an ArcGIS or ArcEditor version of ArcGIS. In that event, go to **Programs/ArcGIS/Desktop Administrator** and set the seat to ArcGIS or ArcEditor.



(3) Click **Next** to skip the introduction step, and then click **Browse** to select the repository database (in this exercise, **ArcHydroFrameworkSchema.MDB**). Ignore User Name and Password Requirement if asked for. Click **Next** to continue.

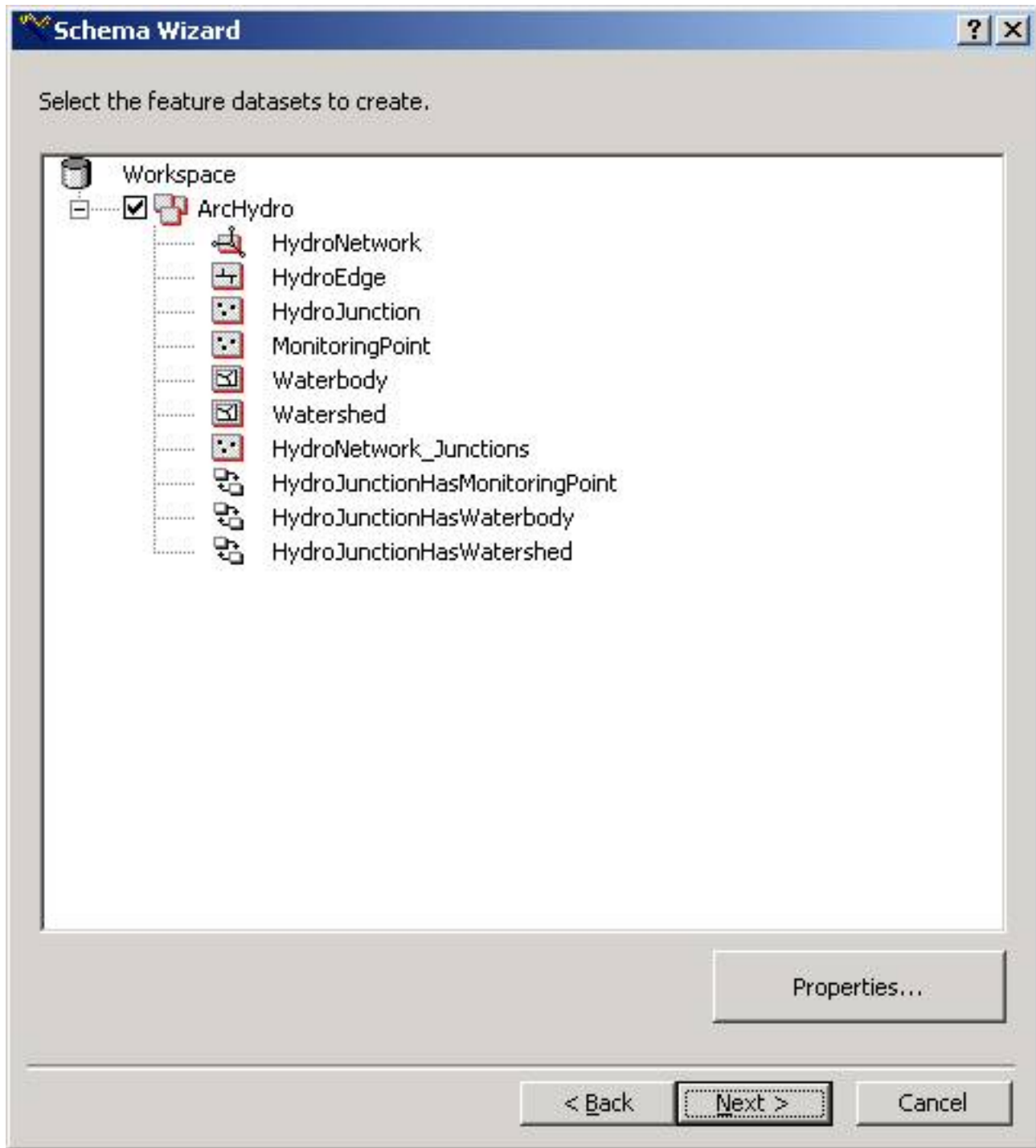


(4) Click the name of the object model in the repository for which you want to generate schema (**ArcHydroFramework Data Model:: ArcHydroFramework**).



(5) Click **Next**. This process may take a few minutes. A screen might appear asking you if you would like to use default values or values from a previous run. Select to use the default values. Press **Next**.

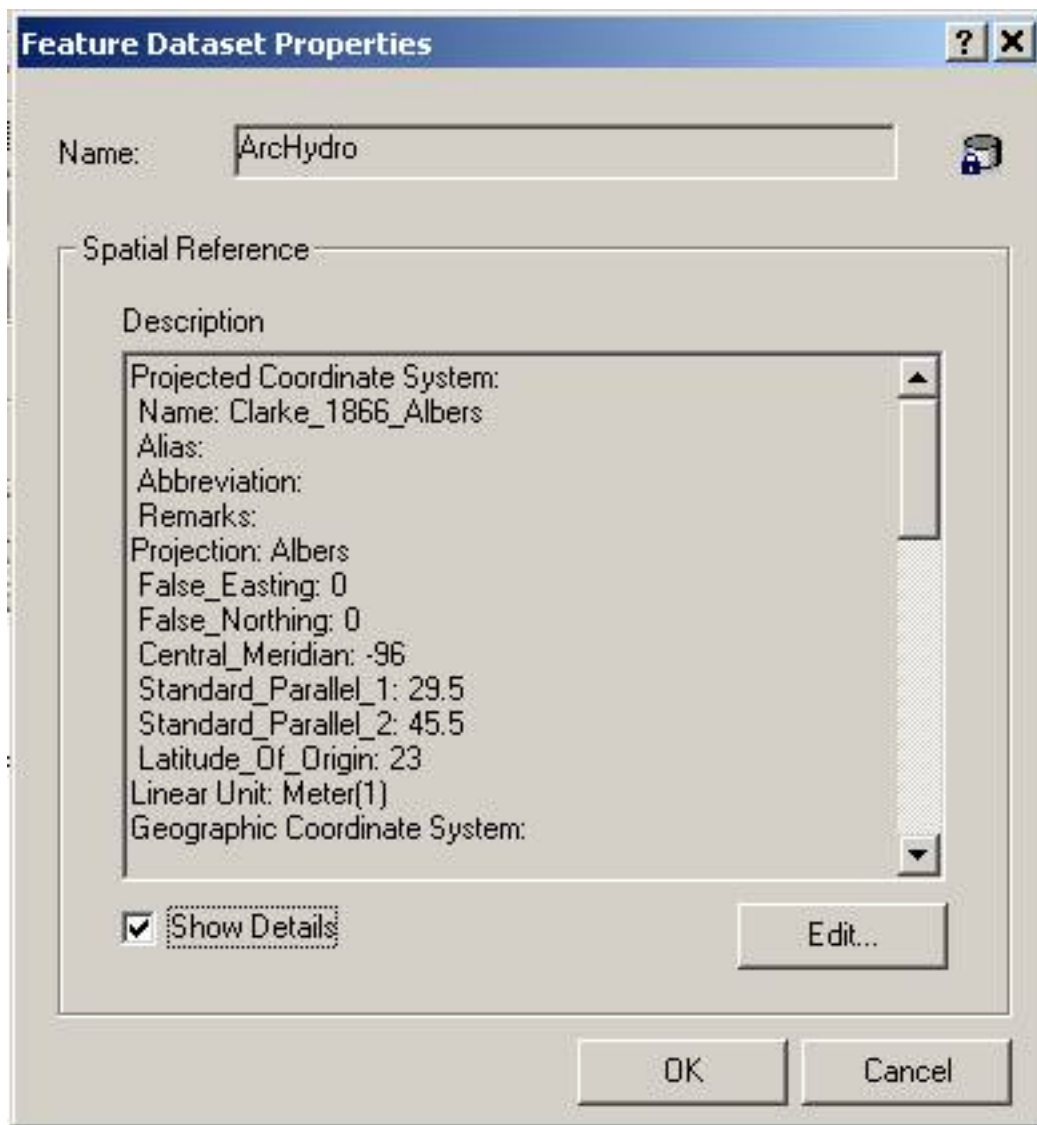
A tree-view of the schema represented in the model is displayed. Using this tree-view, you will now select the object classes (tables), feature datasets, and feature classes from your UML model for which you want to generate schema. The feature classes, highlighted with red, have been detected by the schema creation wizard since they have the correct Arc Hydro Framework name.



C. Select Feature Datasets

(1) Click on the ArcHydro feature dataset and then click **Properties**.

(2) On the Feature Dataset Properties window click **Show Details** to show the spatial reference information. Note that the spatial reference for that feature dataset has already been set (and that it coincides with the reference for the existing feature dataset).



(3) Click **OK** to close the properties window.

D. Set properties of feature classes

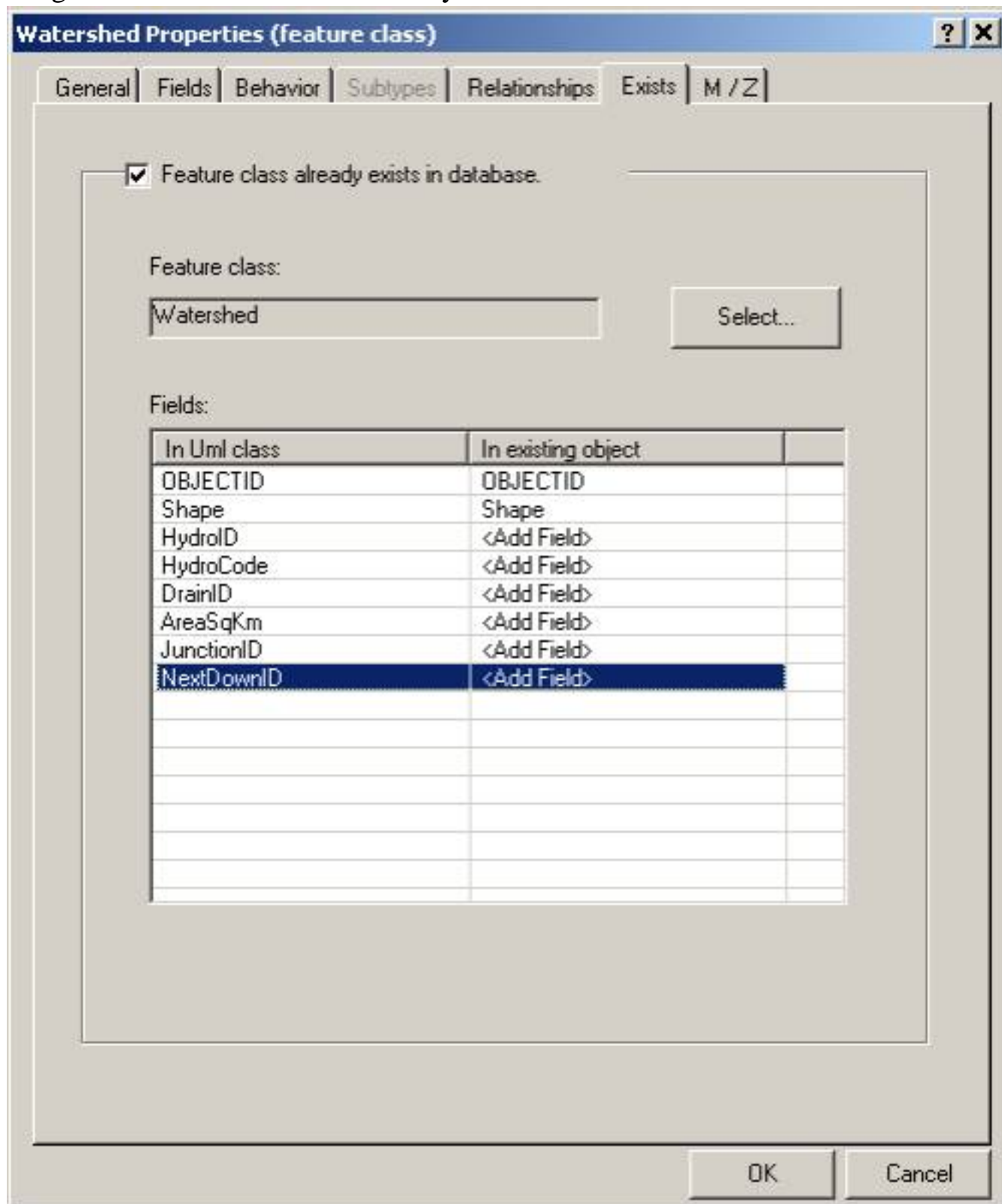
(4) Double Double-Click on “Watershed” and a dialog box for Watershed Properties will appear.

(5) Click on the *Exists* tab. Note near the top of the window that there is a check mark by “Feature class already exists in database” and the Watershed is listed in the Feature Class box. In this window you will match fields that were defined in the UML model to those that already exist in the Watershed feature class.

(6) In the “In existing object” column, click on “click to select” in the HydroID row. HydroID does not currently exist in the Watershed feature class; so select <Add Field> to add the field from the dropdown menu bar that is presented.

(7) Repeat step (6) for all unmatched UML classes.

Your Dialog box should look like this after you have matched all fields:



(8) Click OK and you will go back to Schema Wizard.

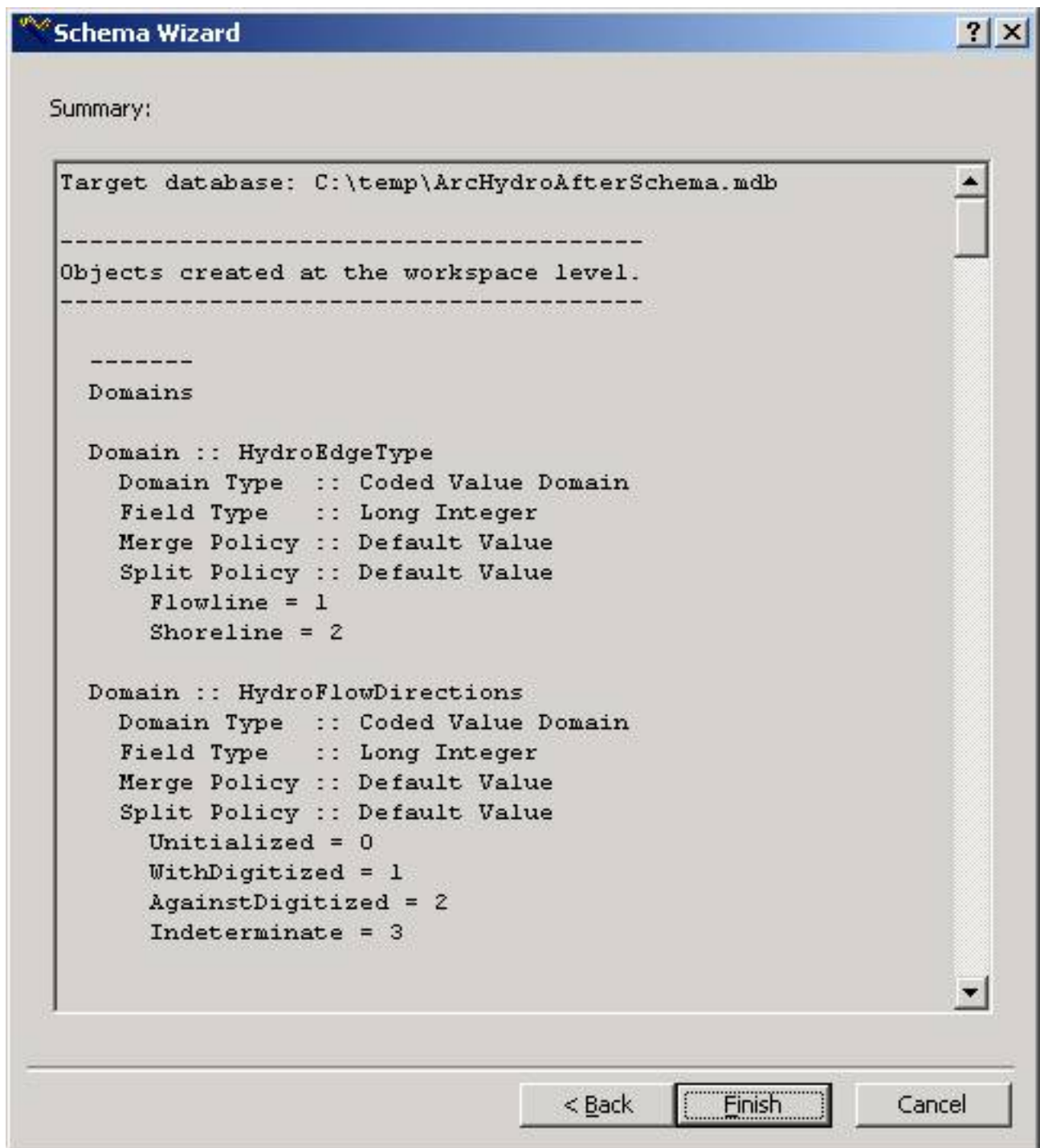
- (9) Repeat steps 4, 5, 6, 7 & 8 for all feature classes in ArcHydro. You should have <Add Field> for any unmatched fields in all existing classes. Don't worry about the HydroNetwork_Junctions class since it is empty and we don't need it.
- (10) Click OK to return to the Schema Wizard.

E. Create the schema

Once you have connected to the repository and selected the classes from your UML model for which you want to generate schema, the last part of the Schema Wizard is to actually create the schema in the geodatabase.

- (1) Click **Next**.

At this point, you could review the options you specified in the Schema Wizard. If you wanted to change anything, you would click **Back** and change the appropriate parameters.



(2) Click Finish to generate the schema in the geodatabase. The generation may take a while. Say No to if you wanted to see the log file (or Yes if you wanted to see the log file!).

Congratulations! You have generated a schema!

View the feature classes that you've just worked on in ArcMap. Open the attribute tables and

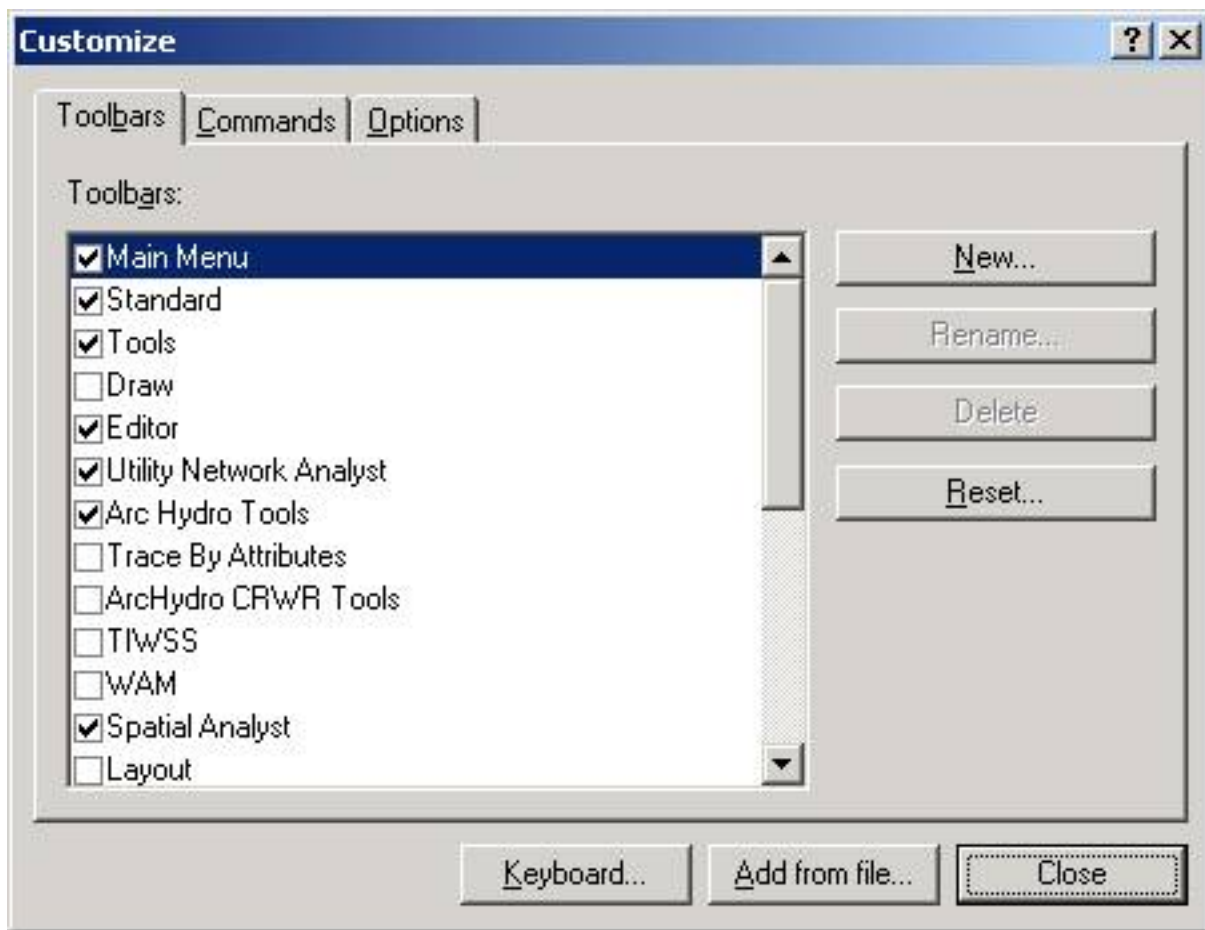
you'll see that what you have done is to create a series of additional attributes at the right hand end of your attribute tables --- these are the standard Arc Hydro attributes.

To be turned in: Make a table that lists the five feature classes: HydroEdge, HydroJunction, MonitoringPoint, Waterbody and Watershed and list the attributes that were added to these feature classes by the process of applying the ArcHydro schema.

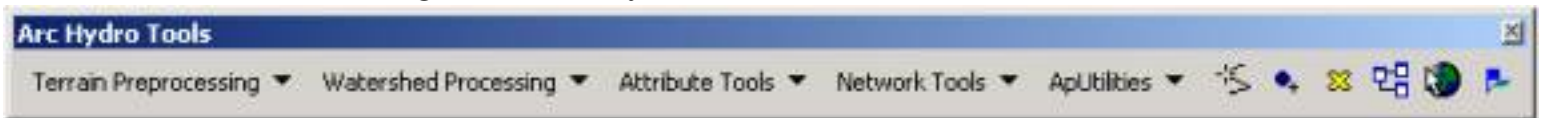
4. Applying Tools

A. Add the Arc Hydro Tools to ArcMap

1. Right click in the gray area in ArcMap where the buttons are and click *Customize*. You can also click *Customize* under the **Tools** menu. Click the *Toolbars* tab.
2. If 'Arc Hydro Tools' appears in the toolbars list, skip to step 3 of this section. If 'Arc Hydro Tools' is not in the categories list, click "Add from file" and browse to the directory where the Arc Hydro Tools were installed (c:\Program Files\ESRI\ArcHydro\Bin by default). Select **ArcHydroTools.dll** and click *Open*, then click **OK**. The Arc Hydro Tools will appear on your Toolbars list now.
3. Click on the boxes for Editor, Utility Network Analyst and Arc Hydro Tools. You will need all three of these tools to apply the Arc Hydro Tools.



4. All three of the toolbars will appear on the screen. You can drag it onto the top of the screen or leave it floating. The Arc Hydro Tools toolbar looks like this:

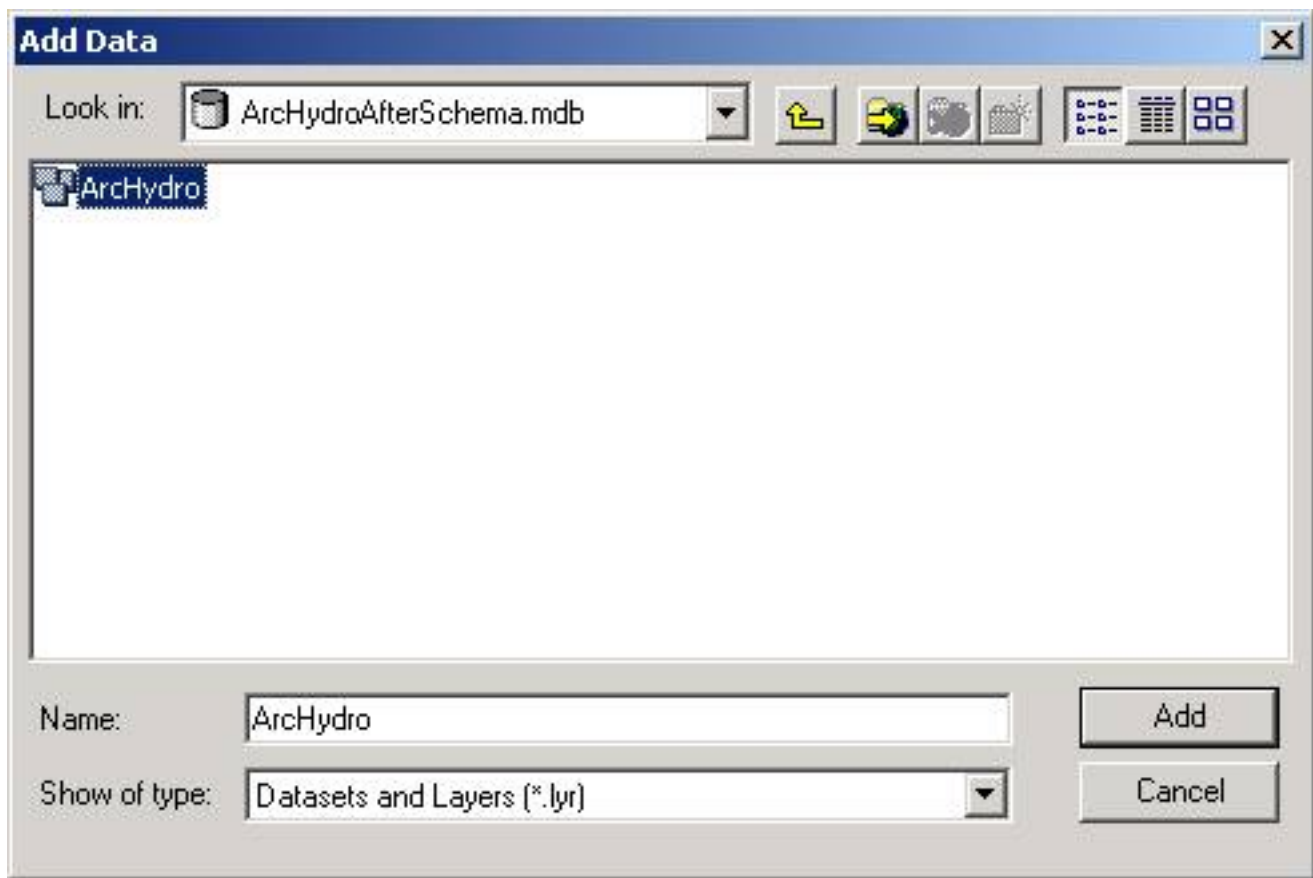


5. Click **Close** to close the customize window.

B. Apply the Arc Hydro Tools

The Arc Hydro tools can determine values for Arc Hydro attributes.

1. Add all of the feature classes in the ArcHydro feature dataset to ArcMap. You can do this by selecting the ArcHydro feature dataset and clicking **Add**, as shown below.



If you open the attribute tables of HydroJunction, you will find that the last few columns of the table is blank. We will use Arc Hydro Tools to calculate the values for some of these columns in HydroJunction and the other feature classes.


2. Go to **View/Toolbars** and click the Editor Toolbar on if it is not already active. On the Editor Toolbar click on **Editor/Start editing**.

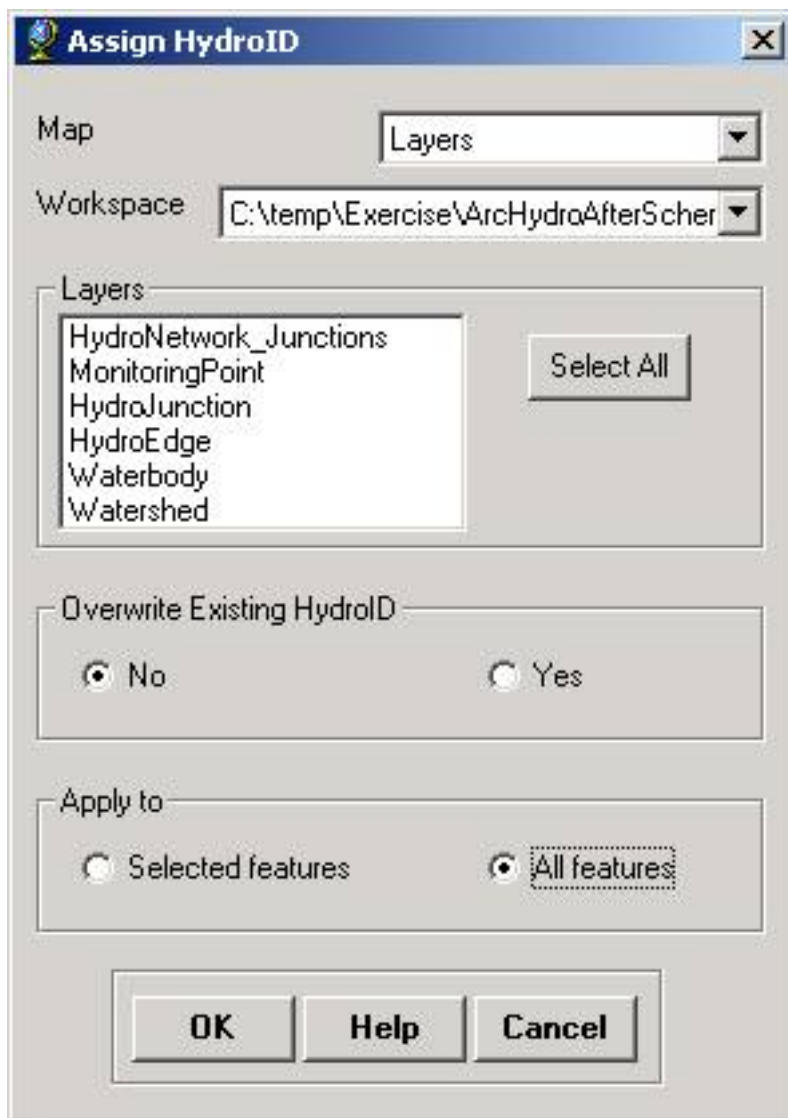
I. Assign HydroID:

This tool assigns the HydroID values to the junctions and edges.

3. Right click on HydroJunction and **Open Attribute Table** for HydroJunction. You will find HydroID* column with <null> values in it.

4. In the Attribute Tools menu of the Arc Hydro Tools toolbar, click on **Assign HydroID**

. A dialog box appears with some options for assigning HydroID.



Click **Select All** to select all of the layers in the map. Then click **OK**. If prompted to save edits, click 'Yes'. When the tool is finished, a message box appears displaying the range of HydroIDs that were assigned.

5. Open the attribute table of HydroJunction if necessary. You will find that the values of HydroID are now populated. The Assign HydroID tool has assigned HydroID values to all feature classes in the Arc Hydro Framework geodatabase. The HydroIDs begin with 1 and increment by 1 for each feature to which an ID is assigned. Each ID is unique within the geodatabase. See 'Arc Hydro HydroID_v1.0 Beta2.doc' in the ArcHydroTools_v1_Beta2.zip file for more information about the HydroID and how to customize it.

Your HydroJunction attribute table should look similar to this.

OBJECTID*	SHAPE*	Enabled	AncillaryRole	Hydroid*
1	Point	True	None	8
2	Point	True	None	9
3	Point	True	None	10
4	Point	True	None	11
5	Point	True	None	12
6	Point	True	None	13
7	Point	True	None	14

Record: 0 Show: All Selected Records (0 out of 88 S)

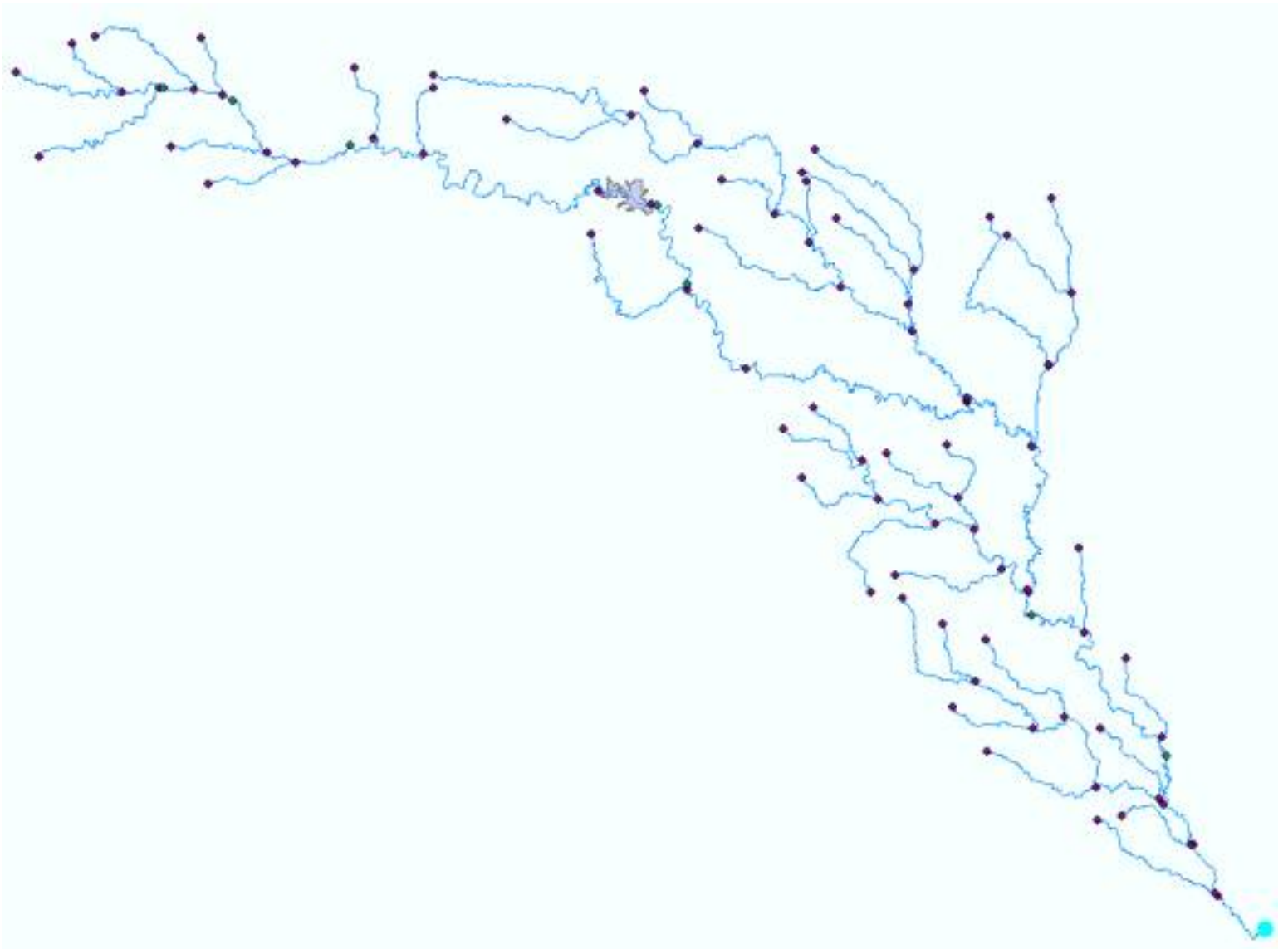
6. Close the attribute table.


II Calculate Length Downstream:

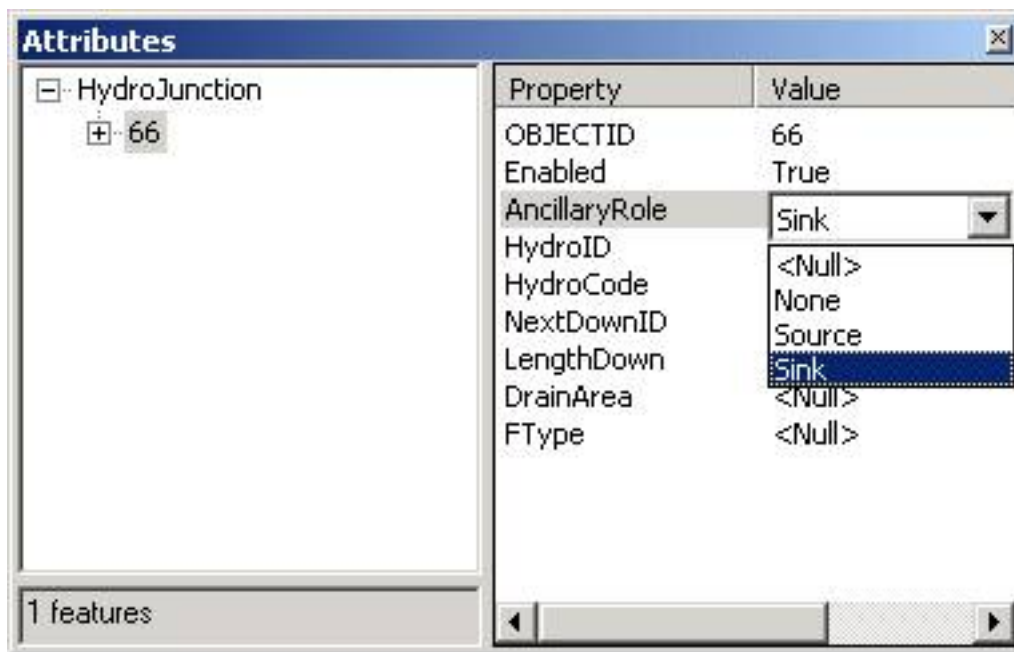
The Length Downstream Tool can calculate the downstream length from any junction or edge.

7. Save the ArcMap file and call it 'Network_Tools'.

8. You will have to set the flow direction of edges in your network before you can apply the Calculate Length Downstream tool. Click on **Editor/Start editing**. Select the most downstream junction on your network as shown in the picture below:



9. Click the **Attributes**  button on the Editor toolbar. The Attributes dialog box for the selected HydroJunction will appear. Set the ancillary role of the selected junction to sink.



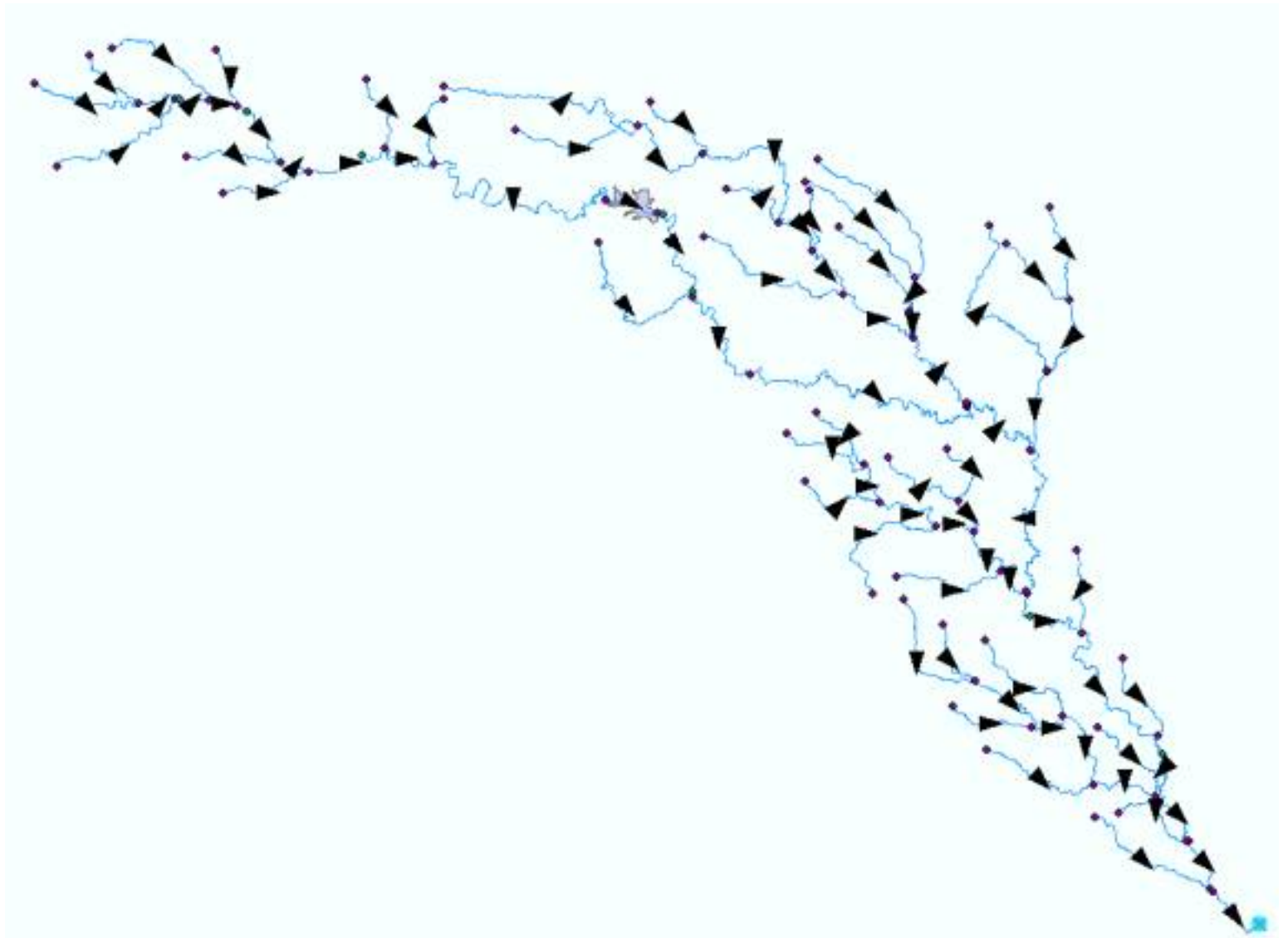
10. Close the attributes dialog box.

11. Click on the Set Flow Direction  button.

12. Go to **Flow/Display Arrows For** and click on the HydroEdge box. Click on **Flow/Display Arrows**.

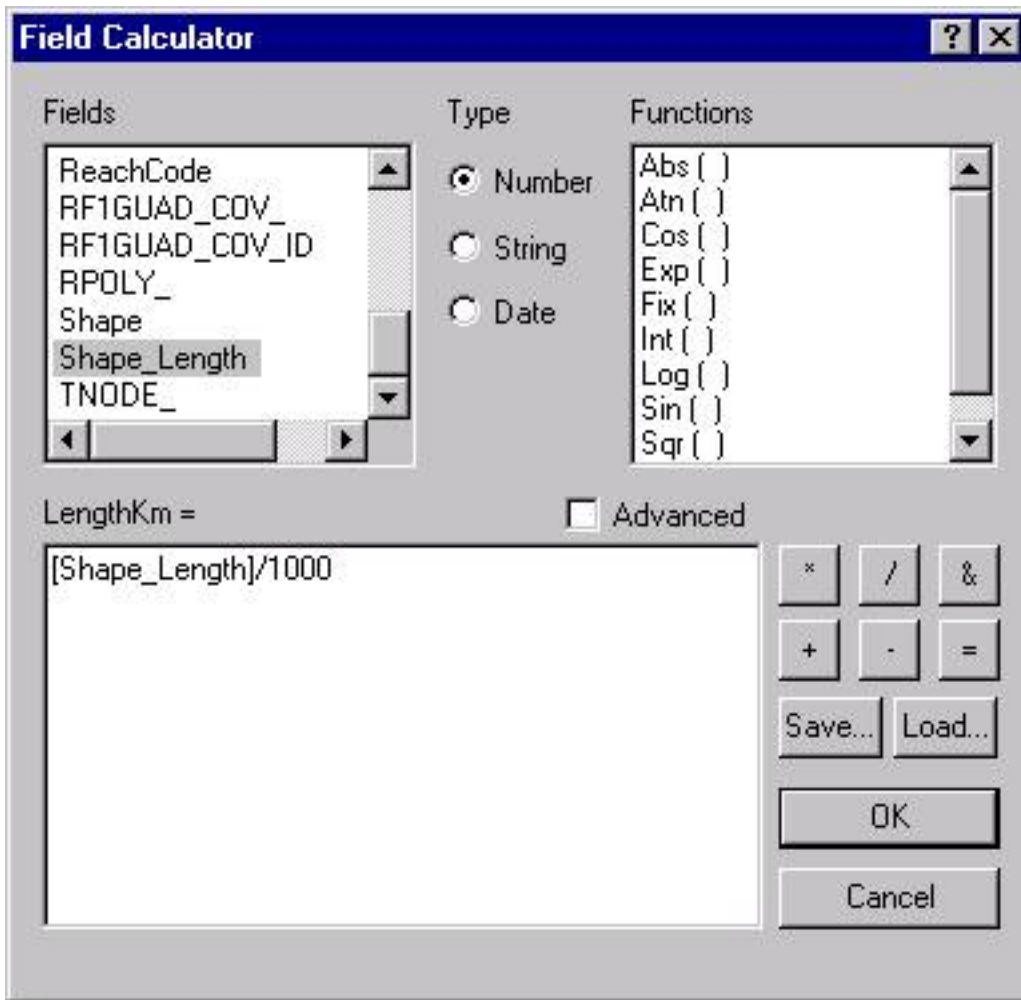


Your Network should look like the following diagram. If the network edges upstream of Canyon Lake are not shown with directions, it means that you need to build the Rf1guad shape file as a coverage and import that into the Arc Hydro geodatabase, rather than working with the Rf1guad shapefile imported into the geodatabase.



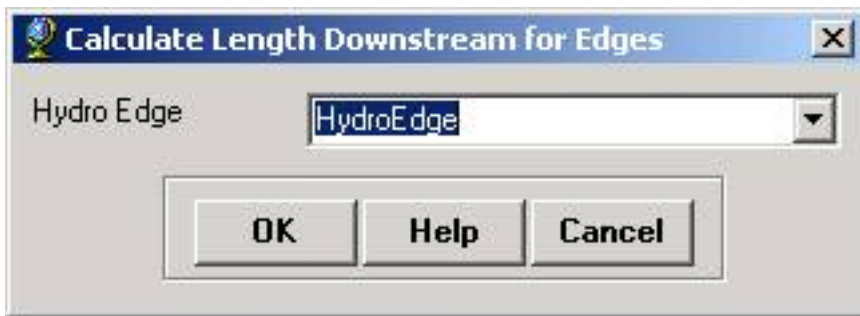
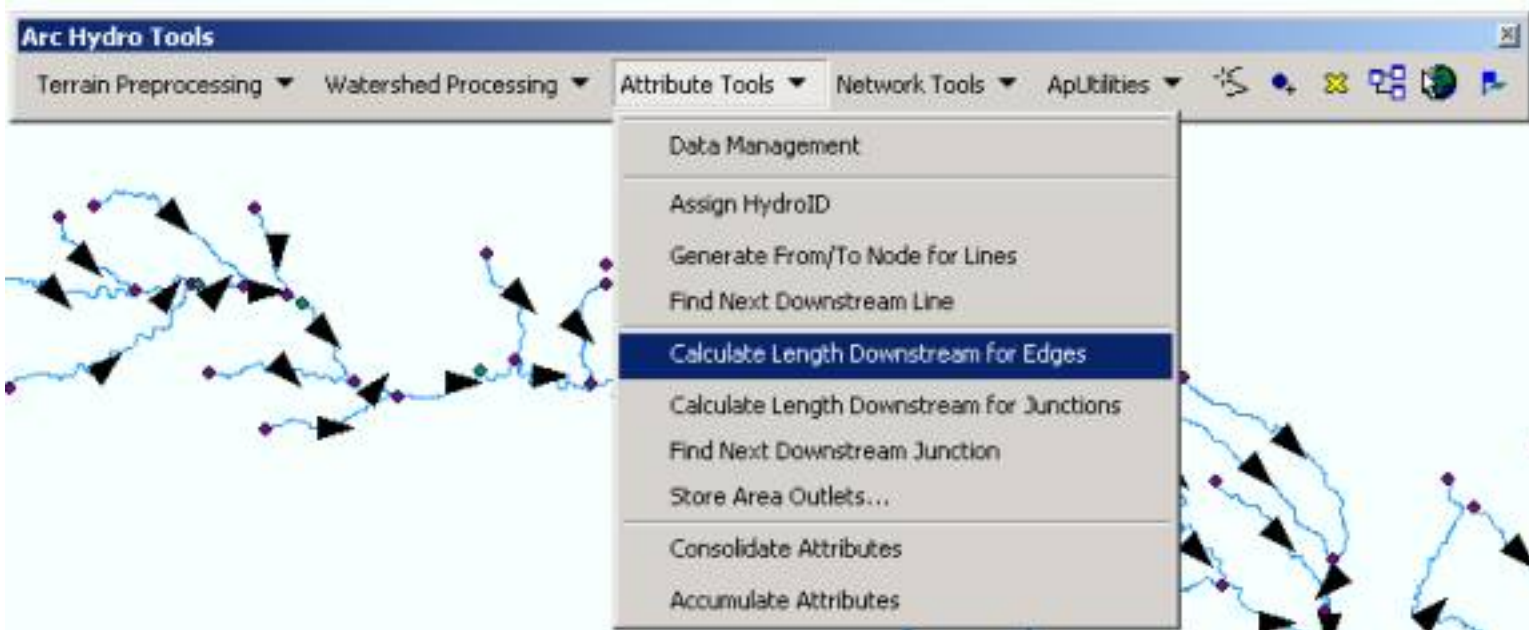
13. You can remove the display of arrows by clicking on **Flow/ Display Arrows** again or leave the arrows on as you wish.

14. Now we are going to determine the values of the LengthKm attribute. Open the attribute table for HydroEdge, right click on the LengthKm field, and open the Field Calculator. Set the result equal to **Shape_Length/1000** (Shape_Length is in meters)



15. Right click on HydroEdge and **Open Attribute Table** for HydroEdge. You will find LengthDown column with <null> values in it.

16. In the Arc Hydro Tools, go to **Attribute Tools/Calculate Length Downstream for Edges**. A message box appears warning the user that flow direction should be set before running this tool. We set flow direction in the previous steps, so click OK to proceed. Select HydroEdge for calculating Downstream Length and LengthKm for the Length Field. Click OK.



The values of downstream length from each edge will appear on the LengthDown column of the Attribute table. The table should look like this:

The screenshot shows a table window titled 'Attributes of HydroEdge'. The table has two columns: 'LengthKm' and 'LengthDown'. The data is as follows:

LengthKm	LengthDown
13.451646	415.125631
23.627885	561.384552
7.936794	561.384552
89.366863	428.577276
26.627228	569.321345
23.678495	537.706057
19.761917	517.944139
10.800000	500.000000

At the bottom of the table window, there are navigation controls: 'Record: 0' and 'Show: All Selected Records (0)'.

17. Close the Attribute Table of HydroEdge.
18. You will now calculate length downstream for HydroJunction. Right click on the HydroJunction layer and **Open Attribute Table** for HydroJunction. You will find LengthDown column with <null> values in it.
19. In the Arc Hydro Tools, go to **Attribute Tools/Calculate Length Downstream for Junctions**. A message box appears warning the user that flow direction should be set before running this tool. We set flow direction in the previous steps, so click OK to proceed. Select HydroJunction for calculating Downstream Length and LengthKm for the Length Field. Click OK.

The values of downstream length for HydroJunction will appear on the LengthDown column of the HydroJunction attribute table. Close the attribute table.

Now, let's figure out what you have been doing. Right click on the HydroJunction layer. Under Properties, Select the Labels tab. Place a check in "Label Features in this layer". Select LengthDown as the Label Field. Click OK. Similarly, set the Label Field of HydroEdge to LengthKm. You may alter the Text Symbol for the HydroEdge labels to Bold, to make the labels easier to distinguish from the HydroJunction labels. If you zoom in near the downstream outlet of the Guadalupe watershed, you should see something like the following diagram. The length downstream of the most downstream junction is 0 (this is where water flows into the Gulf of Mexico). The first river reach upstream of the outlet has length 17.72 km, so the LengthDownstream of the upstream junction is 17.72km, and so on for the succeeding upstream reaches and junctions. Pretty cool!!

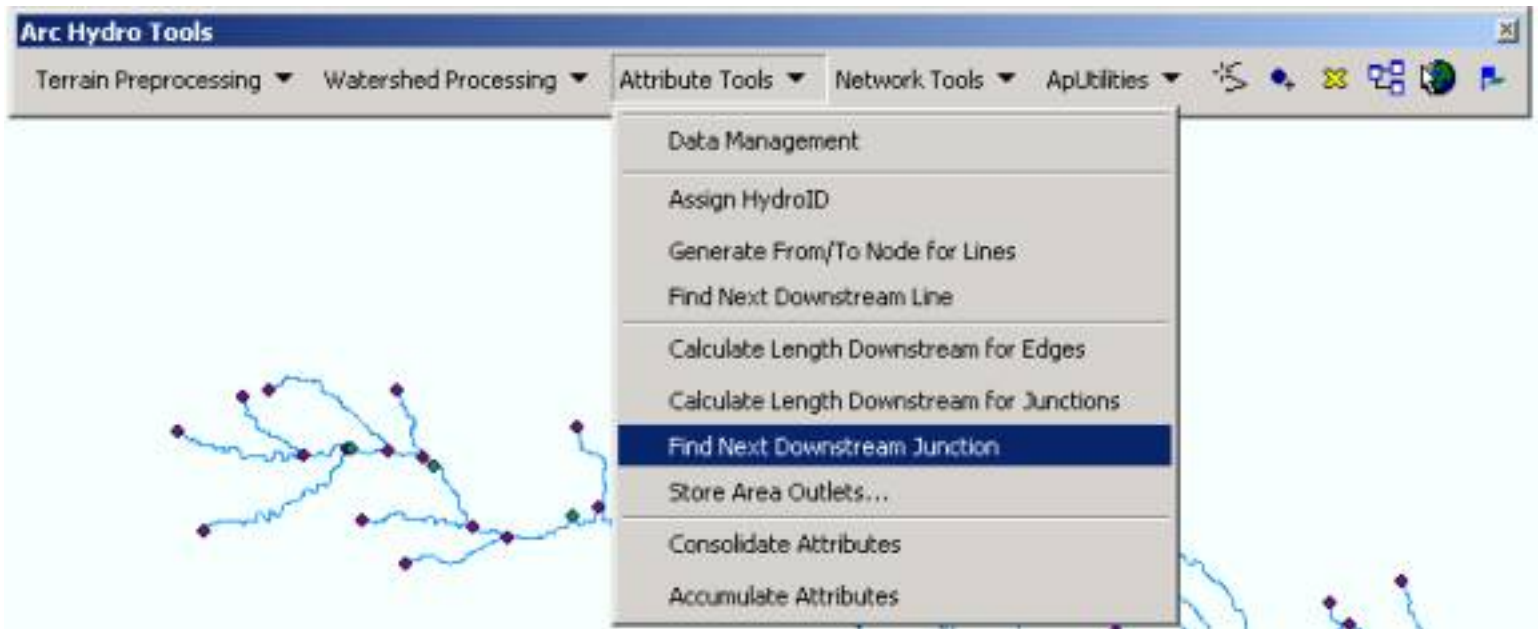


III Find Next Downstream Junction:

Find Next Downstream Junction tool uses the network to find the next downstream junction in a particular feature class, and assigns the HydroID of the downstream junction to the NextDownID field in the upstream junction.

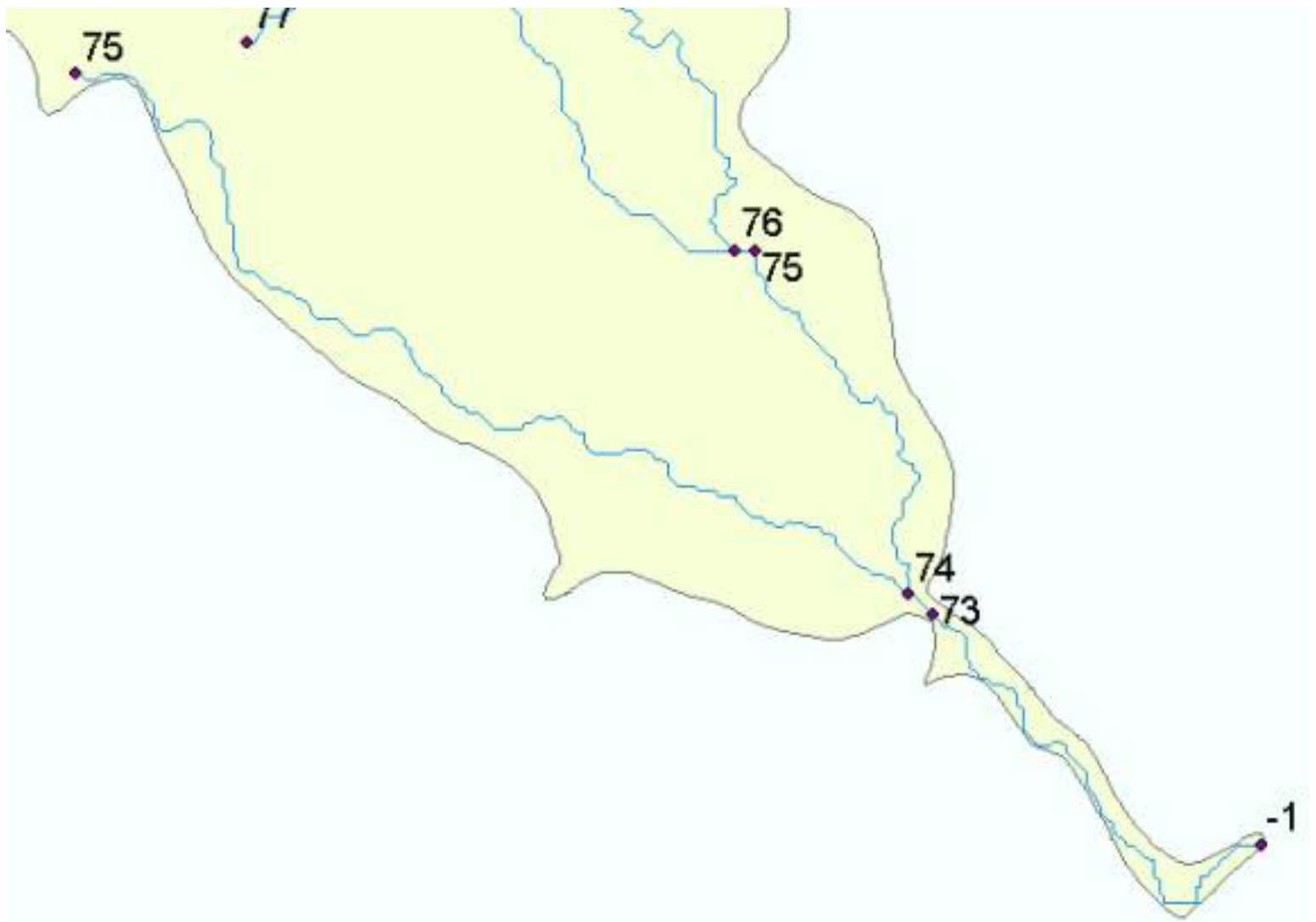
20. Right click on the HydroJunction layer and **Open Attribute Table**. You will find the NextDownID column with <null> values in it. We will use the *Find Next Downstream Junction* tool to populate this column.

21. In the Arc Hydro Tools, go to **Attribute Tools/Find Next Downstream Junction**. A message box appears warning the user that flow direction should be set before running this tool. Click OK to proceed. Select HydroJunction and click OK. When prompted to check for spatially coincident junctions, click No. (Checking for spatially coincident junctions is an advanced topic. See Arc Hydro Tools documentation for details.)



The values of HydroID for the next downstream junction for each junction will appear in the NextDownID column of the Attribute table. You will find value of -1 for the most downstream junction in the network. If the tool does not find a downstream junction for a particular feature, it assigns a value of -1 to the feature's NextDownID.

If you set the labels for HydroJunction to NextDownID and zoom to the basin outlet, you'll find a display similar to the following:



The most downstream HydroJunction has HydroID 73, which is the NextDownID of the next upstream junction (74). You can see that junction 75 is the NextDownID for two upstream junctions because it lies at a confluence in the river system.

IV. Store Area Outlets:

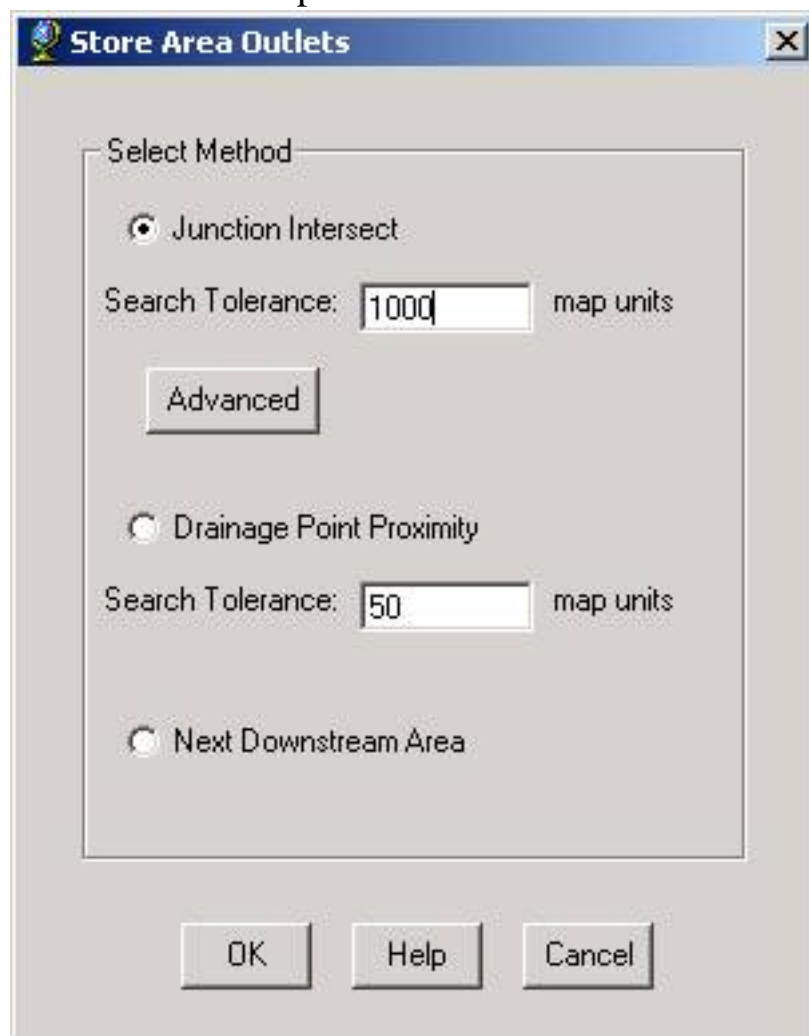
The Store Area Outlets Tool locates outlet junctions for a set of areas. It writes the HydroID of the outlet to the JunctionID field in the area feature class. If a JunctionID field does not exist in the area feature class, one will be created for you. The junction feature class must have a HydroID field of type Integer.

Note that the Junction Intersect method does NOT create junctions at the intersection of the areas and the network for you. The tool assumes that this step has already been done using the Geoprocessing Wizard or by some other means.

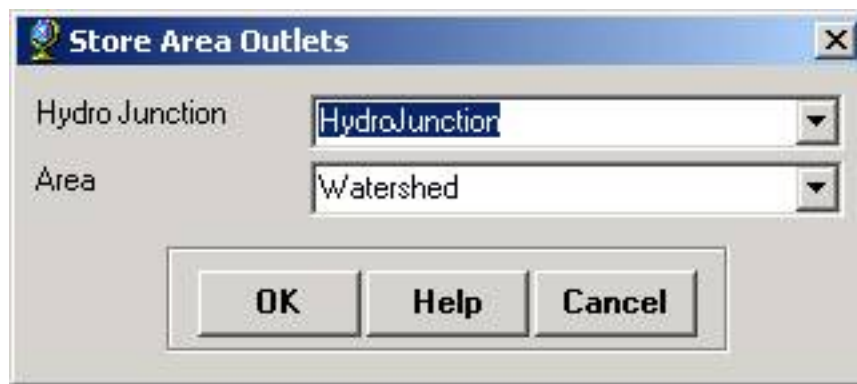
If an outlet could not be found for a given area after the execution of all specified methods, then a JunctionID of -1 is assigned for that area.

22. Right click on Watershed and **Open Attribute Table** for Watershed. You will find the JunctionID column with <null> values in it. We will use the *Store Area Outlets* tool to populate this column.

23. In the Arc Hydro Tools, go to **Attribute Tools/Store Area Outlets**. In the Store Area Outlets dialog box select **Junction Intersect** as the method and set the Search Tolerance to 1000 map units. A message box appears warning the user that flow direction should be set before running this tool. Click OK to proceed.



24. Select HydroJunction as the Hydro Junction Layer and Watershed as the Area Layer in the Layer dialog box. Click OK.



The tool will require a few seconds to calculate. The HydroIDs of the outlet junctions will be written in the JunctionID column in the Watershed attribute table.

The table should look like this:

AreaSqKm	JunctionID*	NextDownID
<Null>	31	<Null>
<Null>	67	<Null>
<Null>	58	<Null>
<Null>	73	<Null>

You can inspect the watersheds and outlets manually to make sure that outlets were correctly assigned.

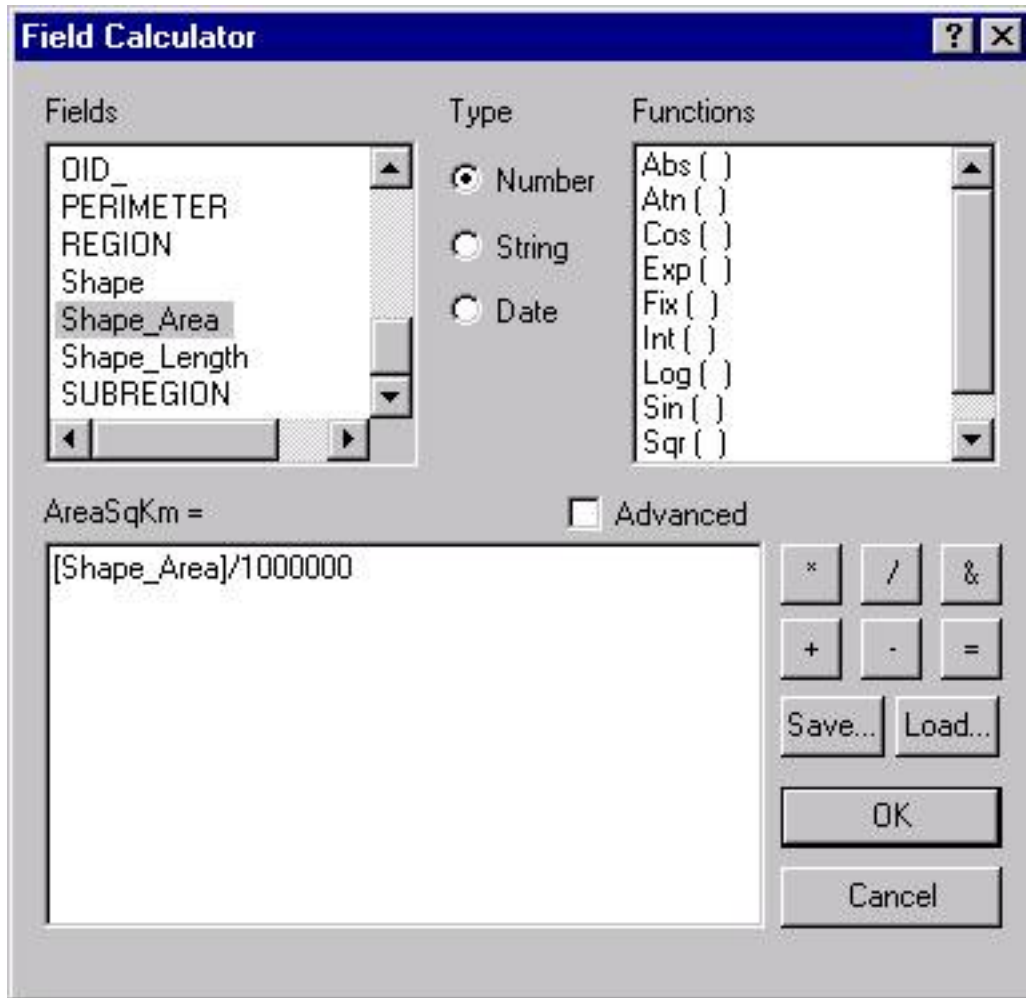
25. Close the attribute table.

V. Consolidate Attributes:

The Consolidate Attributes Tool summarizes values from an input feature layer to an output feature layer. Consolidation operations include sum, max, min, count, average, median, mode, standard deviation, and weighted average by field. We will use the Consolidate Attributes tool to find the incremental drainage area for each HydroJunction. The incremental drainage area for a HydroJunction is the area of the watersheds for which that HydroJunction serves as the outlet junction. Outlets were determined in Section IV: Store Area Outlets.

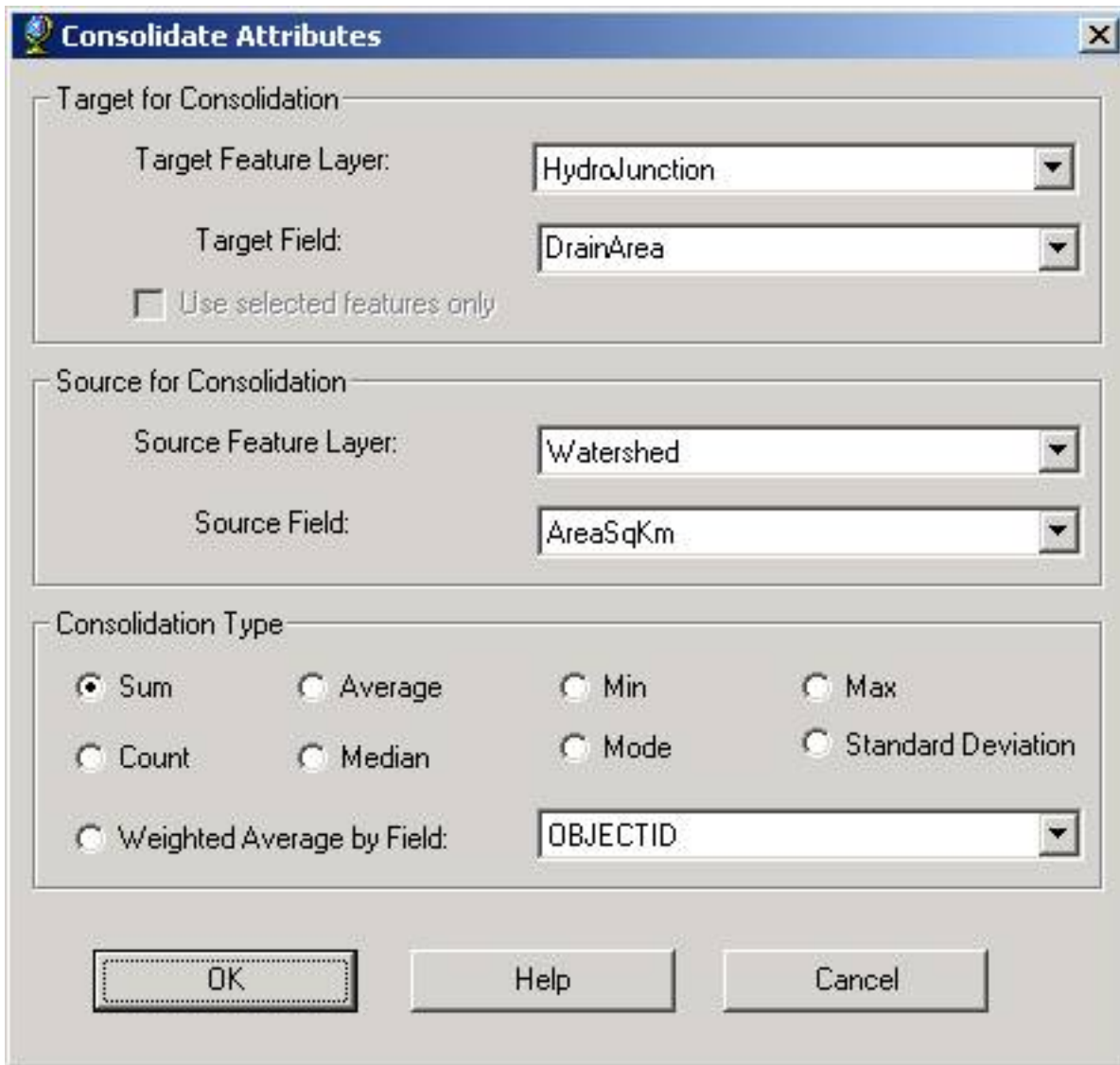
26. Let's populate the AreaSqKm attribute of the Watershed feature class. Open the

attribute table for Watershed if necessary. Right click on the AreaSqKm attribute, and open the field calculator. Set the result for AreaSqKm to Shape_Area/1000000, as shown:



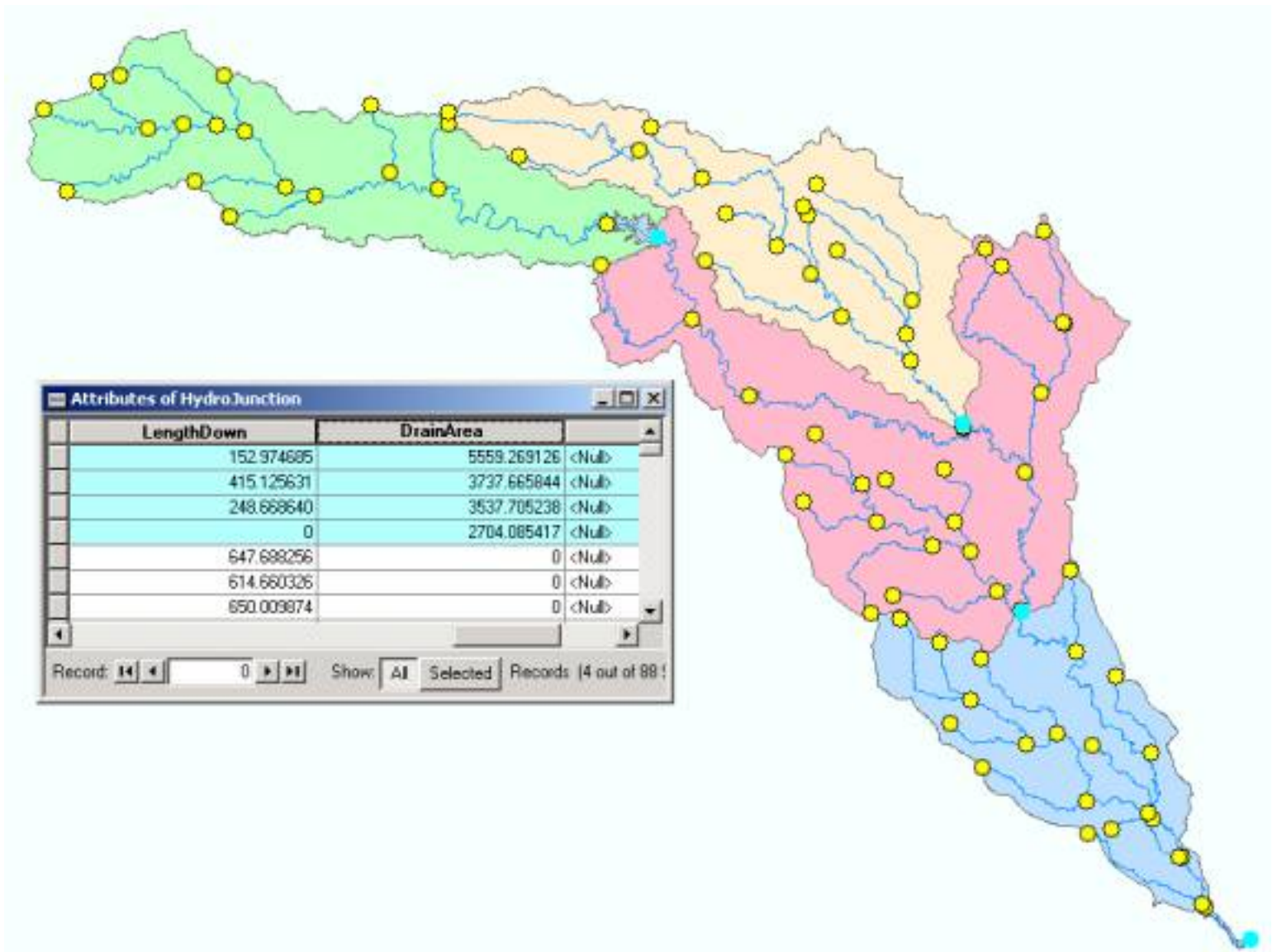
27. Right click on HydroJunction and **Open Attribute Table** for HydroJunction. You will find DrainArea column with <null> values in it. We will use the *Consolidate Attributes* tool to populate this column.

28. In the Arc Hydro Tools, go to **Attribute Tools/Consolidate Attributes**. The Consolidate Attributes dialog box appears. Select HydroJunction as the Target Feature Layer, and DrainArea as the Target Field. Select Watershed as the Source Feature Layer, and AreaSqKm as the Source Field. Select Sum as the Consolidation Type, and click OK. The completed dialog box is shown below. Click OK.



For each HydroJunction, the tool will find the Watersheds that drain to that junction (if any). The tool then sums the AreaSqKm values from those watersheds and assigns that value to that HydroJunction's DrainArea. Thus, each HydroJunction now knows the AreaSqKm value of all Watersheds for which that HydroJunction serves as the outlet.

29. Inspect the attribute table of HydroJunction to verify that DrainArea values have been calculated. The outlet Junction for each watershed should have the drainage area of that watershed, while all other HydroJunctions should have a DrainArea value of zero.



30. Close the attribute table.

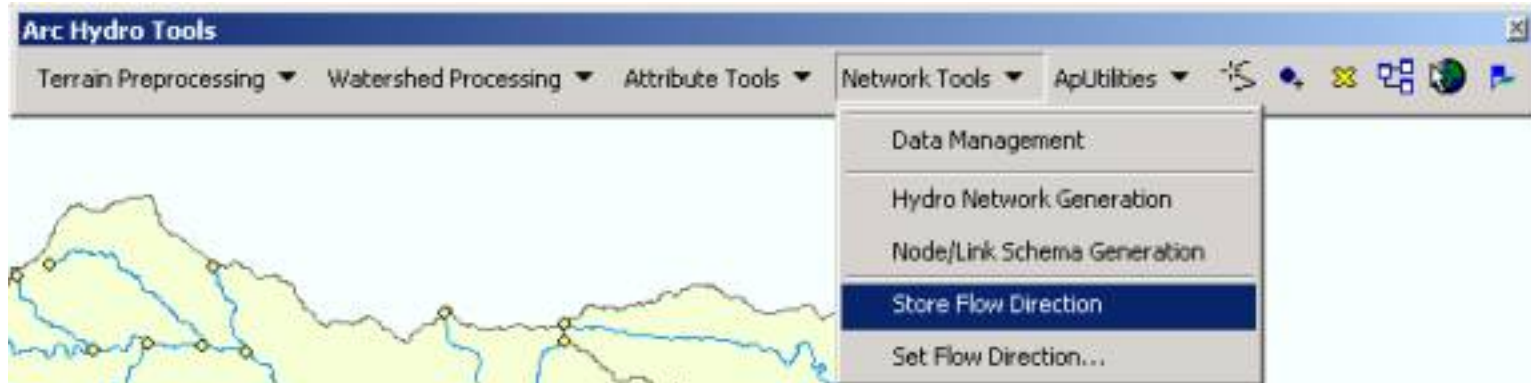
VI. Store Flow Direction:

The Store and Set Flow Direction Tools use the network to store or assign flow directions of edges. The tools work on a selected set of edges or the entire set if no edges are selected.

The *Store Flow Direction* Tool reads flow direction for edges from the network and writes those values to the edge attribute table.

31. Right click on HydroEdge and **Open Attribute Table** for HydroEdge. Move to the FlowDir column in the Attribute Table. It will have <null> values in it. We will use the *Store Flow Direction* tool to populate this column.

32. In the Arc Hydro Tools, go to **Network Tools/Store Flow Direction**.



33. Select HydroEdge as Hydro Edge Layer to store flow direction in the dialog box. Click OK.

The values of Flow Direction will appear on the FlowDir column of the Attribute table. The table should look like this:

The screenshot shows the 'Attributes of HydroEdge' dialog box. It contains a table with three columns: LengthDown, FlowDir, and FType. The FlowDir column contains the value '1' for all rows, and the FType column contains '<Null>'. The table has 10 rows of data.

LengthDown	FlowDir	FType
415.125631	1	<Null>
561.384552	1	<Null>
561.384552	1	<Null>
428.577276	1	<Null>
569.321345	1	<Null>
537.706057	1	<Null>
517.944139	1	<Null>
569.321345	1	<Null>
587.891252	1	<Null>
603.685856	1	<Null>

Record: 0 Show: All Selected Records (0 out of 87)

The **Set Flow Direction** tool assigns flow direction to edges. You may assign flow direction based on the selected esriFlowDirection constant, or you may assign flow direction based on values in a field in the edge layer. The values in the field must correspond to esriFlowDirection constants. The tool works on a selected set of edges or the entire set if no edges are selected. There is no need to use the Set Flow Direction tool in this exercise, since flow direction was already assigned using the Utility Network Analysis toolbar. The Set Flow Direction tool is most useful for setting flow direction in loops in the network. Edges in loops are assigned a flow

direction of 'Indeterminate' by the Utility Network Analysis toolbar, so the Set Flow Direction tool can be used to give these edges a defined flow direction.

You have just applied all the Arc Hydro Tools!

To be turned in: What is the drainage area (km²) for each of the four watersheds and for the drainage basin as a whole? Which feature classes are connected by relationships in the data model? What attributes are used as the key fields in these relationships?

GO to [Home Page](#)

Applying the ArcGIS Hydro Data Model: Part 3

CE 394K GIS in Water Resources University of Texas at Austin

Prepared by: Tim Whiteaker and David Maidment

Covered in Part 1

- Introduction to the ArcGIS Hydro Data Model and Arc Hydro Framework
- Objectives of the Exercise
- Computer and Data Requirements
- Procedure for the Assignment
 1. View your data in ArcMap and ArcCatalog
 2. Prepare your Data for Schema Application
 - A. Create Centerline
 - B. Create Waterbody
 - C. Create Network Junctions
 - D. Create Geodatabase and Import Data
 - E. Create Geometric Network

Covered in Part 2

3. Applying the Schema
 - A. Add Schema Creation Wizard to ArcCatalog
 - B. Connect to the Repository
 - C. Selecting Features
 - D. Set Properties of Feature Classes
 - E. Create the Schema
4. Applying Tools
 - A. Add the Arc Hydro tools to ArcMap
 - B. Apply the Arc Hydro tools
 - I. Assign HydroID
 - II. Calculate Length Downstream
 - III. Find Next Downstream Junction
 - IV. Store Area Outlets
 - V. Consolidate Attributes
 - VI. Store Flow Direction

Covered in Part 3

5. [Applying the FrameworkWithTimeSeries Schema](#)
6. [Retrieving Time Series Data](#)
 - A. [Loading the NWIS tool into ArcMap](#)
 - B. [Using the NWIS tool](#)

This portion of the Arc Hydro exercise extends the Arc Hydro geodatabase to support time series data. This portion assumes that you have already prepared data and applied the ArcHydroFrameworkSchema as described in the previous portions of the exercise. The attached zip file, [ArcHydroPart3.zip](#), serves as a point of departure for this portion of the exercise.

The files included in ArcHydroPart3.zip are:

FrameworkWithTimeSeriesSchema.mdb: the framework schema with time series classes

ArcHydroAfterTools.mdb: the geodatabase after schema and Arc Hydro tools have been applied

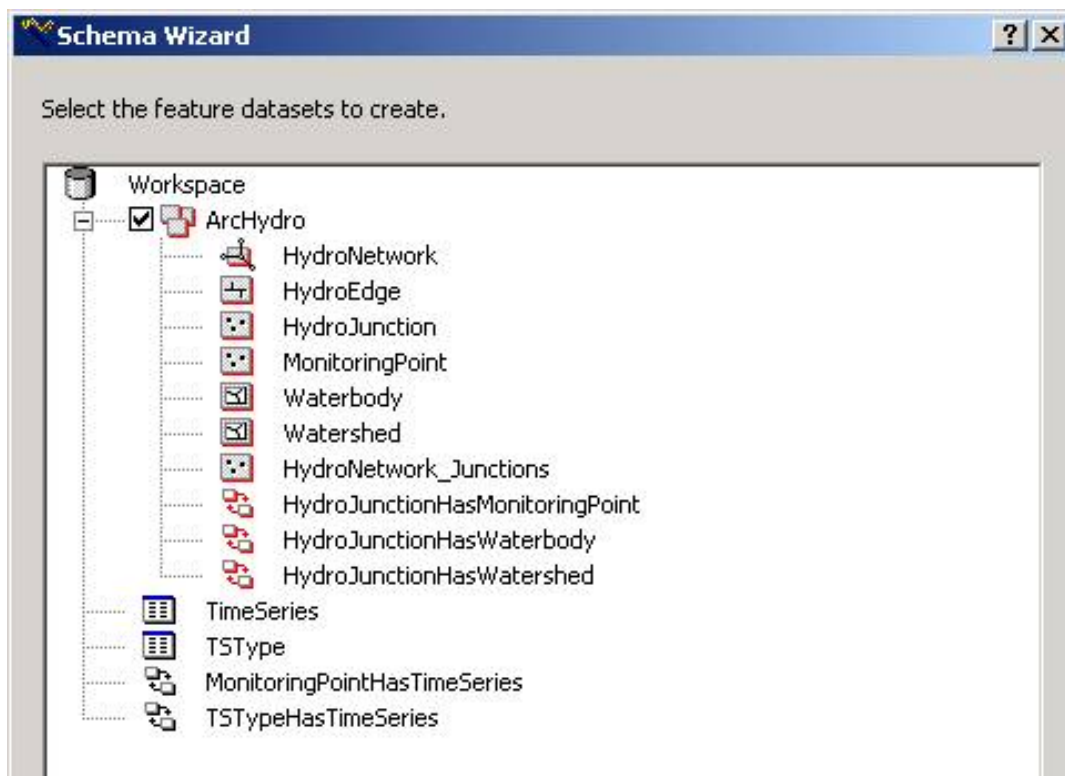
Nwis.zip: zip file containing NWIS dll and documentation (source files and additional sample data are included for your benefit, but are not required for this exercise)

ArcHydroAfterNWIS.mdb: the geodatabase after the NWIS tool has been applied

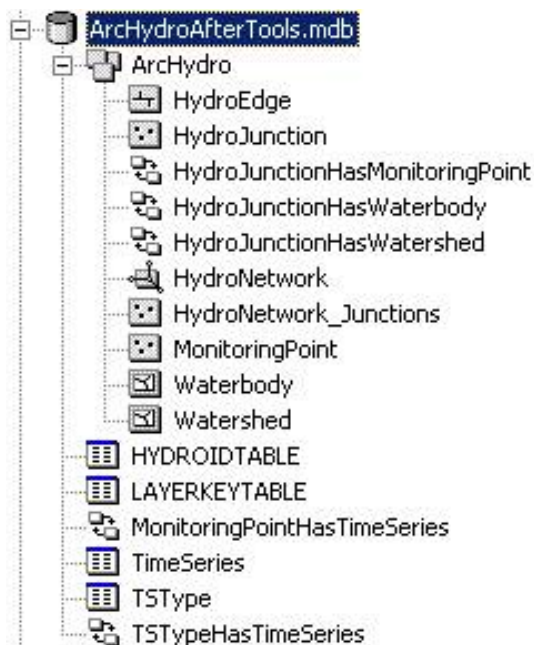
5. Applying the FrameworkWithTimeSeries Schema

In this portion of the exercise, we will retrieve time series data from the Internet and store that data in our Arc Hydro geodatabase. First, we need to prepare our geodatabase to store the time series data. We will do this by applying the FrameworkWithTimeSeries Schema, which contains the same structure as the ArcHydroFrameworkSchema, but with the addition of time series classes and relationships. We will use the ArcHydroAfterTools geodatabase for this exercise.

- (1) Close all instances of ArcMap that contain data from our Arc Hydro geodatabase. This is required to free up the geodatabase for editing by ArcCatalog.
- (2) Open ArcCatalog.
- (3) Click the *Schema Creation Wizard* and apply the FrameworkWithTimeSeriesSchema schema, using the same procedure from Part 2 of the exercise, to the ArcHydroAfterTools geodatabase. Note that most of the classes and relationships in this schema already exist in the geodatabase, but that two new time series classes (TimeSeries and TSType) and their relationships will be added from the schema.



When the schema creation wizard is finished, the geodatabase will contain the same structure as before but with the addition of the Arc Hydro time series classes.



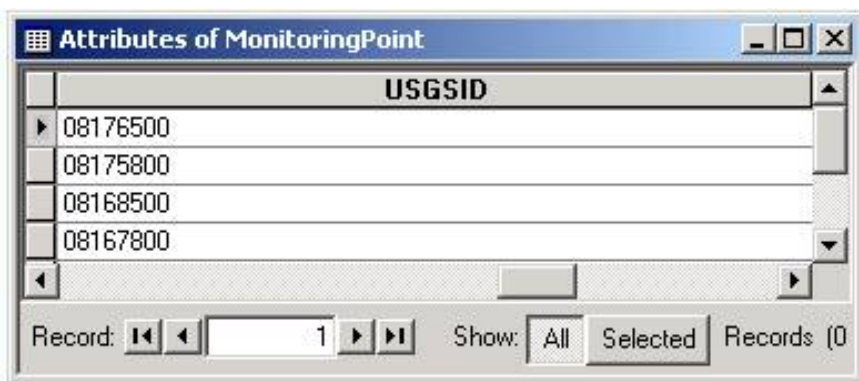
The TimeSeries table stores the time/value pairs of time series data, while the TSType table stores descriptive information about the categories of time series data stored in the TimeSeries table.

6. Retrieving Time Series Data

For this exercise, we will retrieve daily streamflow data from the USGS National Water Information System (NWIS). Normally, one can retrieve the data by going to the USGS web page and navigating through various web pages. But for this exercise, we will retrieve the data automatically from within an ArcMap application, without ever having to open up a web browser. We will do this with the NWIS tool.

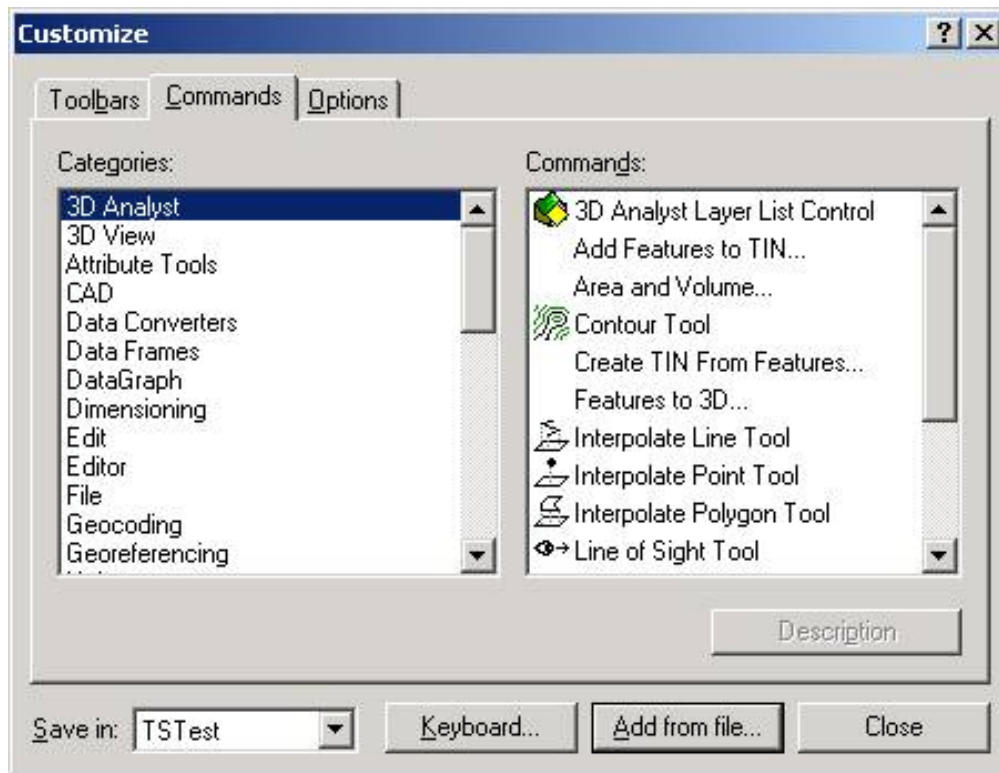
A. Loading the NWIS tool into ArcMap

1. Close ArcCatalog.
2. Open ArcMap. From our Arc Hydro geodatabase, add the MonitoringPoint feature class to ArcMap. Open the attribute table for MonitoringPoint. Note that the USGSID field contains USGS gage numbers. Each number is a universal index that uniquely identifies each USGS stream gage.

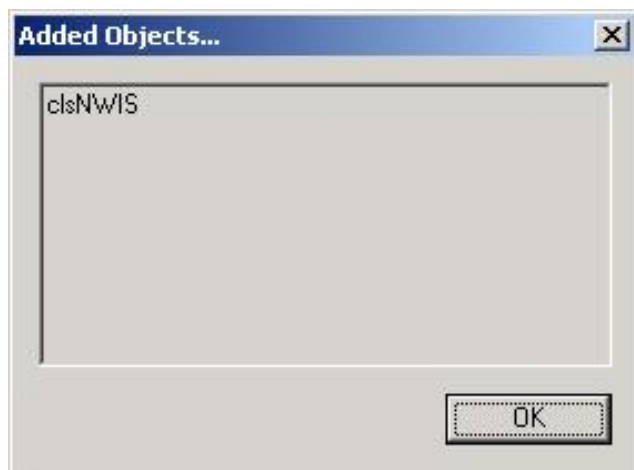


3. Extract NWIS.dll from the Nwis.zip file included with this exercise (attached in ArcHydroPart3.zip).
4. Click **Tools/Customize**. Click the *Commands* tab in the Customize window, and then click **Add from**

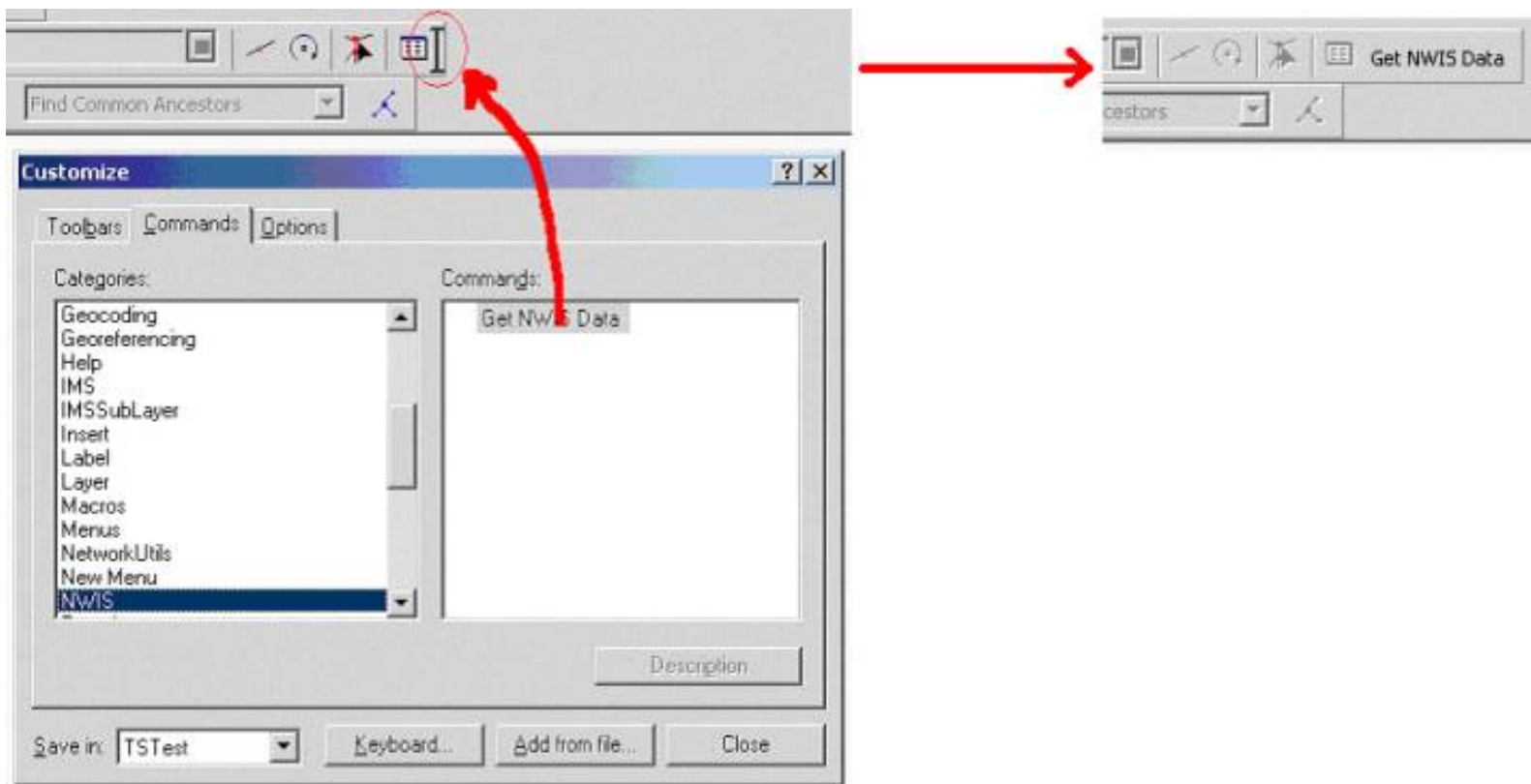
file.



5. Navigate to NWIS.dll, and click **Open**. A window appears showing that clsNWIS was added. Click OK.



If necessary, click on 'NWIS' in the Categories pane of the Customize window. The Get NWIS Data command appears in the Commands pane. To add this button to ArcMap, click on 'Get NWIS Data' with the left mouse button. While holding down the left mouse button, drag the Get NWIS Data button next to another button in the gray area where all the commands and tools are in ArcMap. When you see the insertion cursor (looks like a capital I,) that means that tool can be placed in that location. Release the left mouse button to drop the tool in that location. Then close the Customize window. The Get NWIS Data button is now ready for use.



B. Using the NWIS Tool

6. Click **Get NWIS Data**. In the NWIS Data Retrieval window, select MonitoringPoint as the layer, USGSID as the USGS Site Number field, and HydroID as the Feature ID field. Then click OK.
7. Enter a period of record to retrieve (you can accept the default for this exercise).
8. In the Select Table dialog box, choose the TimeSeries table from our Arc Hydro geodatabase and click **Save**. This is the table where we will store the USGS time series data.
9. Input 1 as the TSTypeID. The TSTypeID identifies categories of time series data, e.g. rainfall data might have a TSTypeID of 3, while streamflow data might have a TSTypeID of 1. The TSTypeID will link each time series record to a row in the TSType table, which provides descriptive information about categories of time series data.

The tool will now go to the NWIS web site and attempt to retrieve the requested time series data. The tool ignores IDs for which no USGS gage exists. If the available data on the USGS web site isn't sufficient to cover the entire period of record requested by the user, the tool will only retrieve the available data from the web site. When the tool is finished, a message box appears providing some information about the tool's processing time.

10. In the ArcMap table of contents, note that the TimeSeries and TSType tables have been added to the map document. Open these tables and inspect the data. They should look like this:

Attributes of TSType					
OBJECTID*	TSTypeID*	Variable	Units	IsRegular	TSInterval
1	1	Daily Streamflow	cfs	True	1Day

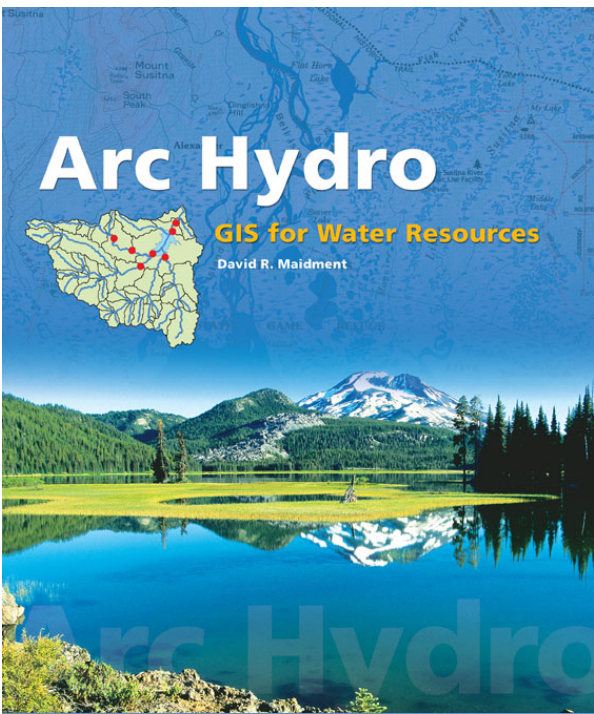
Record: 0 Show: All Selected Records (0 out of 1 Selected.) Options ▾

Attributes of TimeSeries					
OBJECTID*	FeatureID*	TSTypeID*	TSDateTime	TSValue	
1	1	1	8/1/1998	453	
2	1	1	8/2/1998	411	
3	1	1	8/3/1998	389	
4	1	1	8/4/1998	389	
5	1	1	8/5/1998	569	
6	1	1	8/6/1998	515	
7	1	1	8/7/1998	387	
8	1	1	8/8/1998	386	
9	1	1	8/9/1998	455	

Record: 0 Show: All Selected Records (0 out of *2000 Selected.) Options ▾

Note how the TSType table describes the time series data as Daily Streamflow, in units of cfs, at regular intervals, etc.

Congratulations! You have now completed this portion of the exercise.



[Introduction](#)

[Chapter Figures](#)

[Arc Hydro Tools](#)

[Sample Data](#)

[Data Model Files](#)



Arc Hydro: GIS for Water Resources

Introduction to CD-ROM

The information on this CD-ROM supplements the book *Arc Hydro: GIS for Water Resources* by providing electronic files to help you implement Arc Hydro. The CD-ROM has four main components:

- **Chapter Figures** -- each of the images from the book is here presented as a Powerpoint slide, with one slide set per book chapter so that you can use these images in your own presentations about Arc Hydro
- **Arc Hydro Tools** -- these files and documentation allow you to implement the Arc Hydro toolset in ArcMap and contain a tutorial to guide you through application of the toolset.
- **Sample Data** -- several sample datasets are provided to illustrate various aspects of implementation of Arc Hydro, primarily to the San Marcos and Guadalupe basins in Texas.
- **Data Model Files** -- these files include the Unified Modeling Language (UML) diagrams for the Arc Hydro data model in Visio format, the repository, the shell geodatabase, and a detailed tabular representation of the resulting features and objects for each component of the data model.

We have endeavored to make these files as self-explanatory and error-free as possible, but if you find errors in them or points where the information should be improved, please contact Christine Dartguenave at ESRI, Redlands at cdartiguenave@esri.com.

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Arc Hydro: GIS for Water Resources

Chapter Figures

The figures from *Arc Hydro: GIS for Water Resources* are included on this CD-ROM. For each chapter, there is a Powerpoint file (.ppt) with one picture (.jpg) per slide. The Powerpoint files can be downloaded for each chapter from the links below.

[Chapter 1 - Introduction](#)

[Chapter 2 - Conceptual Framework](#)

[Chapter 3 - HydroNetwork](#)

[Chapter 4 - Drainage System](#)

[Chapter 5 - River Channels](#)

[Chapter 6 - Hydrography](#)

[Chapter 7 - Time Series](#)

[Chapter 8 - Hydrologic Modeling](#)

[Chapter 9 - Model Implementation](#)

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Arc Hydro: GIS for Water Resources

Arc Hydro Tools

The Arc Hydro Toolset

The Arc Hydro Toolset is a suite of tools which facilitate the creation, manipulation, and display of Arc Hydro features and objects within the ArcMap environment. The tools provide raster, vector, and time series functionality, and many of them populate the attributes of Arc Hydro features. The .zip file below contains the Arc Hydro Tools setup file as well as several documents describing what the tools are and how to use them.

download the Arc Hydro Toolset here:

[Arc Hydro Tools v 1.0 Beta 2](#)

The NWIS Tool

NWIS is the USGS National Water Information System. The NWIS tool reads USGS gage ID's from gage stations on your map and retrieves stream discharge information from NWIS for a specified period of record. The tool then processes the data and builds a time series table to store the data.

download the NWIS tool here:

[NWIS Tool](#)

[back](#)

Arc Hydro: GIS for Water Resources

Sample Data Sets

These sample datasets provide examples of information structured in Arc Hydro format.

[San Marcos River Basin](#)

[Guadalupe River Basin](#)

[Global Delineation Setup](#)

San Marcos River Basin

The San Marcos basin is an 8-digit hydrologic cataloging unit within the Guadalupe Basin in Texas for which both raster and vector Arc Hydro data are presented on this CD-ROM. You can use these data as a sample data set to exercise all the Arc Hydro tools.

Download the San Marcos River Basin sample data here

[Geodatabase \(.mdb\)](#)

[Flow Direction Grid \(.zip\)](#)

[Flow Accumulation Grid \(.zip\)](#)

Guadalupe River Basin

The Guadalupe Basin comprises four 8-digit hydrologic cataloging units for which an Arc Hydro dataset with supporting data for all the main components of Arc Hydro, including channels and time series. The Full Arc Hydro Data Model schema was applied to this geodatabase.

Download the Guadalupe River Basin sample data here

[Arc Hydro Geodatabase \(.mdb\)](#)

Global Delineation

Global delineation is a special Arc Hydro procedure for delineating watersheds in large basins using a combination of raster and vector data. The sample data contained here are for hydrologic cataloging units in the Arkansas-White-Red basin in Oklahoma.

Download the Global Delineation data here

[Global Delineation Setup](#) <-- No data provided

[back](#)

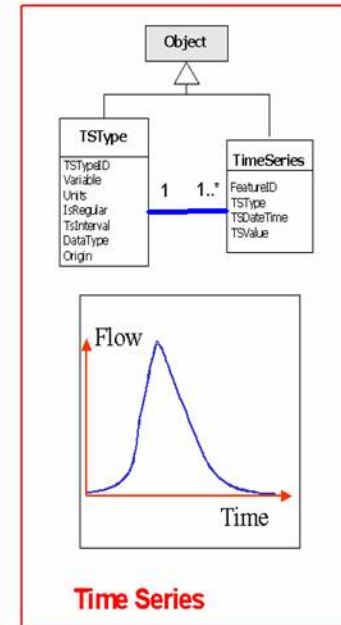
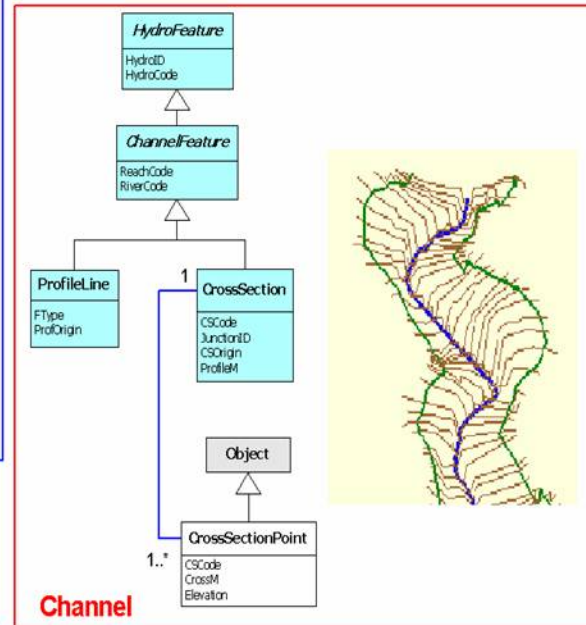
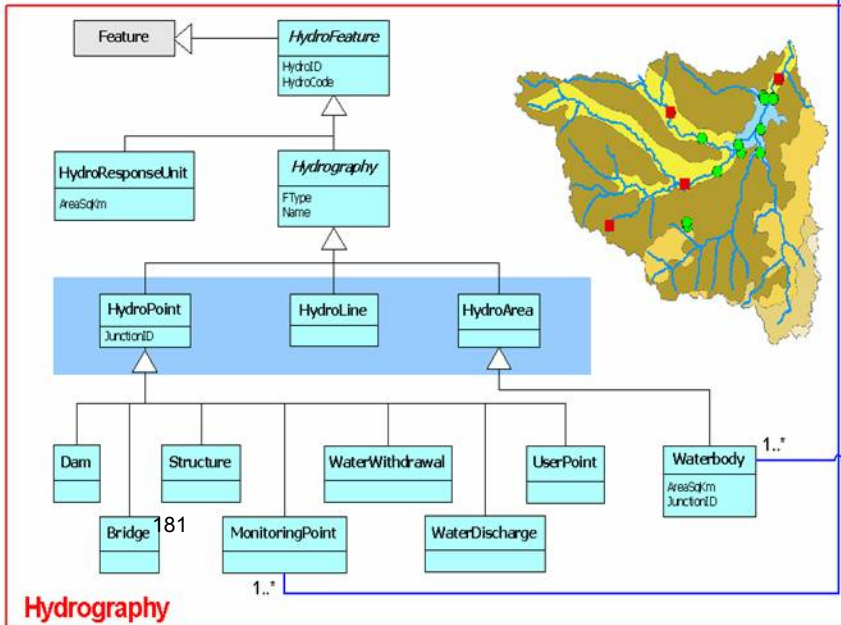
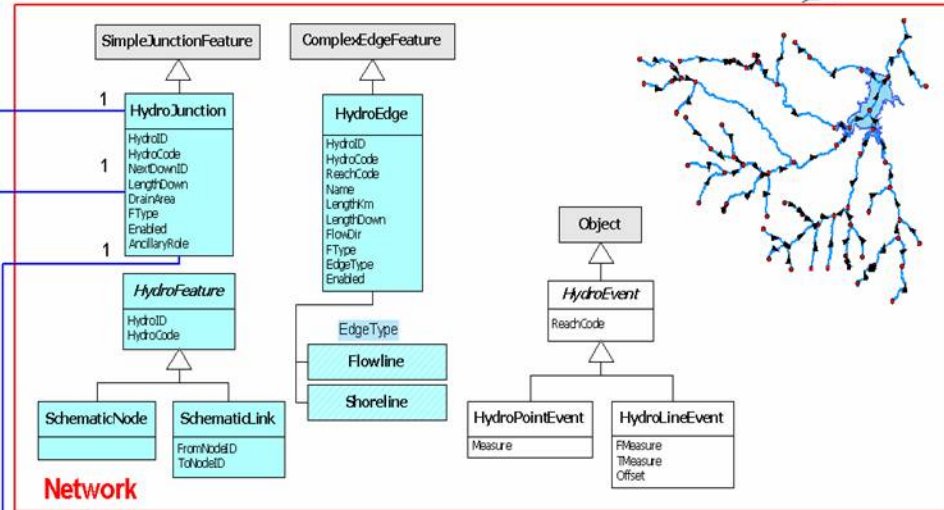
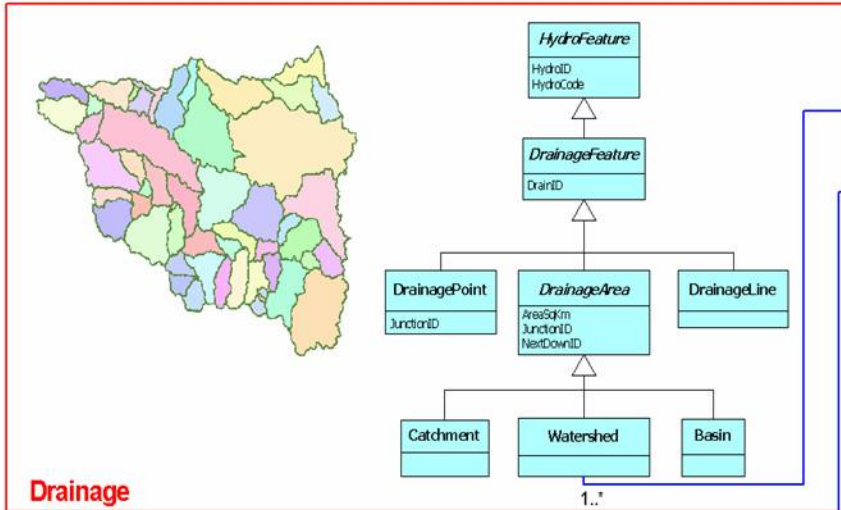
Appendix D

ArcGIS Hydro Data Model

<http://arconline.esri.com/arconline/datamodels/water.cfm>

<http://www.cwr.utexas.edu/giswr>

GIS in Water Resources Consortium



Appendix E

Benchmarks 2004

BM# City	Benchmark Location	Elevation		Street		Coordinates(NAD 83)	
		(ft)NGVD 29	(ft) NAVD 88	North-South	East-West	Northing	Easting
001M	Disk at East end of North headwall on box culvert along Marlatt Ave. East of the Swine, Dairy and Poultry Teaching and Research entrance rd. 600' ± West of Denison Ave. NW of the KSU 580 low frequency transmitter tower.	1049.626	1050.03	Denison	Marlatt	325549	1712301
002M	Destroyed(2003) Headwall Conc. Box 1/2 mile south of Marlatt	1066.539	1066.943	College	Marlatt	322818	1709521
003M	Disk at West end of North headwall of concrete box on Marlatt Ave. 550' ± East of intersection of Marlatt and College Ave., 105' ± SE to P.P., 15' N of centerline of Marlatt	1067.691	1068.095	College	Marlatt	325507	1710310
004M	Disk in center of South headwall of concrete box culvert on Marlatt 250' ± East of Browning centerline, 16' South of Marlatt centerline, 76' E.S.E to power pole.	1115.053	1115.457	Browning	Marlatt	325408	1707091
005M	Disk 8' North of the South end of the West headwall of the concrete box culvert on Browning Ave. 35.4' North of centerline of Lawrence Rd. 28' West of Browning centerline.	1093.298	1093.702	Browning	Lawrence	322644	1706862
006M	Disk on East end of north headwall of concrete box culvert on Kimball Ave. 87' ± West of the centerline of the southbound off ramp for K-113. 44.5' ± North of Kimball Ave. centerline. At the SE corner of Candlewood Shopping Center.	1113.981	1114.385	K-113(Seth Childs)	Kimball	319993	1704085

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
007M	Destroyed(unknown) Disk in North end of concrete retaining wall at the SE corner of the Kimball Ave and Hudson Ave intersection. 69' South of Kimball centerline and 16' East of Hudson centerline.	1213.961	1214.365	Hudson	Kimball	-	-
008M	Disk in center of North headwall of concrete box culvert on Kimball Ave. over Little Kitten Creek. 225' ± East of Westbank Way, 43.9' North of Kimball centerline	1122.973	1123.377	Westbank Way	Kimball	319919	1699762
009M	Disk in North end of concrete box culvert on Kimball Ave. 47' East of Kimball centerline 106.5' ± North of Grand Mere Pky centerline.	1189.679	1190.083	Grand Mere Pky	Kimball	319247	1698410
010M	Disk in concrete bank lining at South end of concrete retaining wall on Hudson Ave. 110' North of Dickens Ave. centerline, 18.5' East of Hudson centerline, and 0.5' South of end of retaining wall.	1160.716	1161.12	Hudson	Dickens	317386	1701735
011M	Disk at NW corner concrete street inlet 29' North of Anderson Ave centerline, 56' East of Meadowbrook In., 6' East of Fire Hydrant.	1053.215	1053.619	Meadowbrook	Anderson	314681	1703643
012M	Disk in center of North headwall of double box culvert on Anderson Ave. at Little Kitten Creek crossing. 141.5' West of Windsong Ln., and 47' North of Anderson Ave. centerline.	1063.879	1064.283	Windsong	Anderson	314633	1701286
013M	Disk in entrance to Twin Oaks Softball Complex, Anneberg Park. 41' East of chain link fence, 1' East of the edge of the concrete service road, and 30.5' South of Twin Oaks entrance walkway centerline. 60' North of pay phone.	1060.499 (1060.625)	1060.903	Anneberg	Twin Oaks	313894	1699939

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
014M	Disk in South headwall of concrete box culvert on Anderson Ave. 3.5' East of West edge of South headwall, 20' South of Anderson centerline, and 92' West of Pebblebrook Cir(Cumberland Rd).	1075.953	1076.357	Pebblebrook	Anderson	314680	1698636
015M	Disk in NW corner of street inlet box at the North West corner of the intersection of Candlewood Dr. and North Candlecrest Cir. 20' North of Candlewood drive centerline and 38' West of Candlecrest Cir centerline.	1160.716	1161.12	Candlewood	North Candlecrest	323316	1703452
016M	Disk at West side of West of two flag pole bases. At West side of Manhattan Fire Dept. Headquarters, 110' east of Denison Ave. centerline, and 214.7' North of North curb of Kimball Ave.	1105.119	1105.523	Denison	Kimball	320546	1713258
017M	Destroyed(1996)- Disk NE corner area inlet at SE corner of Kimball and College	-	-	College	Kimball	-	-
018M	Disk at Northwest corner of storm sewer junction box at Northeast corner of Kimball Ave. and Browning Ave. 39.5' East of Browning centerline and 57' North of Kimball centerline	1104.591	1104.995	Browning	Kimball	320077	1706959
019M	Disk at Northwest corner of street inlet box on North side of Gary St. South of residence of 3412 Gary. 19.4' North of Gary centerline and 77' West of Effingham centerline.	1160.806	1161.21	Effingham	Gary	322610	1702793
020M	Disk on center of South end of street inlet box on the east side of Little Kitten Ave. 17.6' East to Little Kitten Ave. centerline and 410' South to Stephen Ct. centerline.	1134.348	1134.752	Little Kitten	Stephen	321029	1699769

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
021M	Disk at Northeast corner of street inlet box at East end of Cul-De-Sac of Erin Cir. 26' North of Erin Cir. Centerline. 19.2' WNW of telephone pedestal #1317			Sharingbrook	Erin	316425	1699779
022M	Disk at Southeast corner of street inlet box on East side of Westbank Way, 17.7' East of Westbank Way centerline and 53.5' North of Deandra Ln. extended centerline.			Westbank Way	Deandra	318488	1699676
023M	Disk at Southeast corner of street inlet box South of Blue Hills Rd. 51.1' East of N. Manhattan Ave. centerline and 17.3' South of Blue Hills Rd. centerline.	1141.244	1141.648	N. Manhattan	Blue Hills Rd.	320809	1715852
024M	Disk at West end of North end of headwall 7'X5' box 65' West of southbound Tuttle Creek Blvd centerline and 147' North of westbound Kimball Ave. centerline.	1049.958	1050.362	Tuttle Creek Blvd	Kimball	321664	1716939
025M	Disk at center of headwall at the East end of 14" concrete pipe. 30' East of northbound Tuttle Creek Blvd centerline and +_95' South of Walters Dr. centerline	1041.966	1042.37	Tuttle Creek Blvd	Walters	324645	1715440
026O	Destroyed(Unknown) Disk NE corner traffic signal SW corner of Claflin and College.	-	-	College	Claflin	-	-
027O	Disk at Southwest corner of street inlet box on the West side of College Ave. 27.3' West of College centerline and +_ 120' North of Hobbs St. centerline.	1113.062	1113.466	College	Hobbs	318326	1709568

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
028O	Disk at Northeast corner of concrete base of traffic signal at the Southeast corner of the intersection of Browning Ave. and Hobbs Dr. at the Northwest corner of Marlatt Elementary School. 27.2' East of Browning centerline and 22.1' South of Hobbs centerline.	1094.558	1094.962	Browning	Hobbs	318003	1706985
029O	Disk in limestone rock outcropping on the East side of Browning Ave. +_ 32' East of Browning centerline and +_100' North of Claflin centerline	1110.424	1110.828	Browning	Claflin	316189	1707025
030O	Disk at Southeast corner of street inlet box on Anderson Ave. 25.2' North of Anderson centerline and 37.4' West of Woodland Dr. centerline.			Woodland	Anderson	315276	1708495
031O	Disk at South end of a concrete retaining wall on the west side of concrete steps on the north side of Anderson Ave. and on the South side of Lee Elementary School. 33'+_ North of Anderson Ave. centerline and 123'+_ East of Westview Dr. centerline			Westview Dr.	Anderson	313759	1710909
032S	Disk at Southeast corner of a concrete flag pole base near the main entrance to Manhattan High School West Campus. 59'+_ North of Poyntz Ave. centerline and 75'+_ West of Pine Dr. centerline	1142.733	1143.05	Pine	Poyntz	311298	1711900
033S	Disk at the Southwest corner of a concrete sign base of the Sunset Zoo main entrance. 17.6' North of Oak St. centerline and 215'+_ West of Summit Dr. centerline.			Summit	Oak	310761	1710994
034R	Void(Out of ROW) Disk at center of the North edge of a 4' X 9' Boulder. 41'+_ North of Juniper Dr. and 59'+_ East of Stagg Hill Rd. centerline.			Stagg Hill	Juniper	305292	1708010

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
035R	Disk at Northeast corner of street inlet box 26' ± East of Davis Dr. centerline and 73' ± North of Stagg Hill Rd. centerline.			Davis	Stagg Hill	304210	1706117
036R	Disk at Southwest corner of the concrete base of a telephone pedestal near the intersection of Fort Riley Blvd and Warner Park Road. ± 69' West of the Warner Park Rd centerline and ± 60' North of the centerline of the West bound lane of Fort Riley Blvd.			Warner Park	Fort Riley Blvd		
037R	Disk in exposed rock layer ± 0.2 miles from the entrance of Warner Park Rd entrance to Warner Park and Southeast of the intersection of the West spur of the park road and an entrance to a parking area. ± 34' South of spur centerline and ± 54.7' East of the parking area entrance centerline. 14.6' SSE to a shiner in a 42" Cedar tree and 21.5' West to a split 60" Cedar tree.			Warner Park			
038M	Disk at Northwest corner of concrete base of a telephone pedestal #8041. 46.7' East of Denison Ave centerline, and 0.45 miles South of Marlatt Ave.	1083.444	1083.848	Denison	Marlatt	323010	1713123
039C	Disk at Northeast corner of concrete base of a telephone pedestal #R8084. +_38' South of Anderson Ave centerline and +_76' East of entrance to Blueville Nursery at 4539 Anderson Ave. and +_0.1 miles West of Claflin Rd centerline			Claflin	Anderson	316363	1696468
040R	Disk at Southeast corner of street inlet box Northeast of the West Dartmouth Rd and Amherst Ave intersections. ± 23' East of Dartmouth centerline and ± 35' North of Amherst centerline.			Dartmouth	Amherst	310256	1705413

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
041R	Disk at center of West retaining wall behind and North of a stone street sign at the North side of Bethany Dr. and Bethany Cir. ± 16' North of Bethany Dr. centerline and ± 30' West of Bethany Cir. Centerline.			Bethany Cir.	Bethany Dr.	312187	1704759
042S	Disk at Northwest corner of a concrete storm sewer junction box manhole. ± 31' South of Fort Riley Blvd centerline, ± 40' North of Frontage Rd. and ± 38' West of Delaware Ave. centerline.			Delaware	Fort Riley Blvd		
043S	Disk at the Southwest corner of a street inlet box ± 18' West of Manhattan Ave. centerline and ± 65' South of Fort Riley Blvd. Centerline.	1018.623	1018.94	Manhattan	Fort Riley Blvd	309376	1715787
044I	Disk at the Southwest corner of concrete traffic signal base at the Southeast corner of Fort Riley Blvd and Juliette Ave. 35.4' South of Fort Riley Blvd. centerline and 39.8' East of Juliette centerline.	1018.98	1018.777	Juliette	Fort Riley Blvd	309418	1718647
045I	Disk at West end of a concrete retaining wall 1.5' North of Manhattan Train Depot. ± 250' East of 2nd St. centerline and ± 95' South of Yuma St.	1014.894	1014.691	2nd St	Yuma	309756	1721126
046I	Disk at the center of the North headwall of a box culvert running under U.S. Highway 24 and at the South side of Jon Murdock Auto Dealership(600 McCall Rd). ± 23' North of Frontage Rd. centerline and ± 411' West of McCall Rd and U.S 24 intersection.			Enoch	Frontage	314834	1724495

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
047I	Disk at the Southwest corner of a concrete traffic signal base at the Southeast corner of Tuttle Creek Blvd. And U.S. Highway 24. +_34' South of East bound U.S. 24 centerline and +_46' East of South bound Tuttle Creek Blvd.	1013.281	1013.078	Tuttle Creek Blvd	U.S HWY 24	311500	1721686
048T	Disk at Northeast corner of concrete light pole base. Second light pole East of entrance to the Manhattan Waste Water Treatment plant on the South side of the entrance drive and North of the chain link fence. 48' South and 5' West of the Southwest corner of the main office of the treatment plant.			Sewage Treatment Plant Rd.		313617	1726575
049M	Disk at Southeast corner of street inlet box South of Harvey Dr. +_22' Southeast of Harvey Dr. centerline and +_45' Northeast of Columbine Ct. centerline.	<i>1012.257</i>	<i>1012.661</i>	Columbine Ct.	Harvey	319034	1722610
050M	Disk at Northwest corner of storm sewer junction box at Southwest corner of Casement Rd. and Allen Rd. +_26.5' West of Casement centerline and +_24.4' South of Allen centerline. Northeast corner of 2031 Casement Rd (School District Shop).	1020.652	1021.056	Casement	Allen	320362	1721099
051M	Destroyed(2003) Disk on West wing wall of the North side of the west side of a twin Concrete box under Casement RD. ± 16' West of Casement centerline and ± 75' North of Brookmont Dr.	1019.027	1019.431	Casement	Brookmont	323293	1721016
052M	A disk at the Northwest corner of a street inlet box South of Butterfield. ± 17.7' South of Butterfield Rd. centerline and ± 42.6' West of Buttonwood Dr.	<i>1018.444</i>	<i>1018.848</i>	Buttonwood	Butterfield	322845	1719627

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
053M	Disk 12' South of the North edge the hubguard of a concrete triple box under Butterfield Rd. 15.6' East of Butterfield Rd. centerline and ± 30' South of Mission Ave centerline.	1027.428	1027.832	Butterfield	Mission	323267	1717510
054M	Disk at Southeast corner of a street inlet box at the Southwest corner of Spain Dr. and Blueberry Dr. 19.3' South of Spain centerline and ± 35' West of Blueberry centerline.	1011.912	1012.316	Blueberry	Spain	321517	1723222
055R	Disk at Southwest corner of a concrete storm sewer junction box. 21.7' East of Ridgewood centerline and +_590' South of Allison Ave. Between the addresses of 720 and 722 Ridgewood.			Ridgewood	Allison	306248	1707633
056F	Disk at Northwest corner of a concrete traffic signal base at the Northwest corner of 17th St. and Poyntz Ave. 25.5' North of Poyntz centerline and 39.0' West of 17th centerline.	1043.141	1043.458	17th	Poyntz	311368	1713909
057J	Destroyed(1999) Disk at Northeast corner of a street inlet box along the North side of Anderson Ave. 25.7' North of Anderson centerline and 62.9' East of Denison Ave. centerline.			Denison	Anderson	-	-
058K	Disk at Northeast corner of a street inlet box at the Northwest corner of the intersection of Juliette Ave. and Fremont St. 24.3' West of Juliette centerline and 24.0' North of Fremont centerline.			Juliette	Fremont	312904	1718581
059K	Disk at Southeast corner of a street inlet box on the East side of Juliette Ave. 15.2' East of Juliette centerline and ± 164' North of Ratone St. centerline.			Juliette	Ratone	316085	1718617

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
060M	Disk at Southeast corner of a street inlet box on the East side of Tuttle Creek Blvd. 30.5' East of the centerline of the North bound lane of Tuttle Creek Blvd. and ±225' South of Casement Rd. centerline			Tuttle Creek Blvd	Casement	317838	1719774
061M	Destroyed(1995) Disk at Southwest corner of a street inlet box on the South side of Allen Rd. 18.0' South of Allen and ±301' West of Sloan St. centerline. At the residence of 705 Allen.			Sloan	Allen	-	-
062K	Destroyed(1995) Disk at West end of the North headwall of a twin box culvert under Bluemont Ave. ±43' North of Bluemont centerline and ±62' West of Frontage Rd.			Frontage	Bluemont	314102	1720811
063K	Disk at Northwest corner of a concrete landing at the bottom of a concrete stairway. Located on the East side of the old low level pumping station building at the water treatment plant. ±106' West of the centerline of the Southbound lanes of Tuttle Creek Blvd, and ±29' South of the North water treatment plant entrance road centerline.			Tuttle Creek Blvd	Thurston	315902	1720165
064M	Destroyed() Disk in a rock outcropping on the West side of N. Manhattan Ave. ±30' West of Manhattan Ave. centerline and ±193' South of Baker's Way centerline and directly West of the American Institute of Baking.			Manhattan	Baker's Way	318665	1715769
065S	Disk at the Southwest corner of a concrete telephone pedestal base, #417G. ±27' South of Collins Lane centerline and ±31' East of the centerline of the 1st street of Northcrest #2 Mobile Home Park			S. Manhattan	Collins	304195	1714463

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
066M	Disk set in concrete with rebar 0.5' below ground surface. 2.6' East of the back of curb, 18.2' East of Londondery St. centerline, 9.7' Southwest of center of sanitary sewer manhole, and ±398' North of Plymouth Dr.			Londondery	Plymouth	321505	1700737
067M	Destroyed() Disk set in concrete with rebar 0.4' below ground surface. ±55' East of Kimball Ave centerline, 6.8' West Southwest of the Northwest corner of Lot 1, 69.1' North Northwest of the PI of Lot 1, Paragon Point Subdivision, and 0.2 miles North of Anderson Ave centerline.	1178.831	1179.235	Kimball	Anderson	-	-
068M	Disk set in concrete with rebar 0.5' below ground surface. 52.1' East of Kimball Ave. centerline, 10.3' West of North-South barb wire fence, and 68.1' South of the PI on the West line of lot 70, Paragon Pointe, Phase III subdivision. ±0.6 miles North of Anderson Ave. ±78' South of centerline of Berkshire Rd.	1213.476	1213.88	Kimball	Berkshire Cir	318302	1698360
069T	Disk set in concrete with rebar, 0.5' below ground surface. East of Shop Quick at address of 473 U.S. Highway 24, in the median of Hwy 24, 22.8' South of the Westbound lanes of Hwy 24, and 46.3' East of Frontage Rd. centerline.			Frontage	U.S HWY 24	313543	1723428
070T	Destroyed() Disk set in concrete with rebar, 0.6' below ground surface. Southeast corner of Kretchmer and Levee Dr. 21.0' South of Levee centerline and 56.0' East of Kretchmer.			Kretchmer	Levee	-	-

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
071T	Disk set in concrete with rebar, 0.7' below ground surface. Southeast of Levee Dr. and Hayes Dr. 22.0' South of Levee Dr. centerline and 63.5' East of Hayes Dr. centerline.			Hayes	Levee	315997	1721932
072S	Disk set in concrete with rebar, 0.6' below ground surface. 46.5' South of S. Manhattan Ave. centerline, 781' South of the South end of the bridge over Wildcat Creek, 26.0' North Northwest of the North side of a power pole, 1.0' East of a North-South barbwire fence, and 0.35 miles South of Fort Riley Blvd.	1009.426	1009.743	S. Manhattan	Pottawatomie	307757	1715695
073S	Disk set in concrete with rebar, 0.5' below ground surface. 27.3' East of S. Manhattan centerline, 5.2' North of a telephone/cable TV pole, 42.8' South of a drive entrance to the East, East of 942 S. Manhattan Ave. and ±0.2 miles North of Collins Rd. centerline.			S. Manhattan	Collins	305370	1715802
074M	Disk set in sidewalk. ±39' East of College centerline and ±65' South of Kimball centerline.	1099.256	1099.66	College	Kimball	320072	1709604
075M	Disk at Southwest corner of street inlet box on Walters Dr. 18.55' East of Walters Dr. centerline and 48.3' South of Butterfield Rd.	1024.41	1024.814	Walters	Butterfield	324586	1717379

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
076M	Disk at Southwest corner of street inlet box +_15' East of the Wyndham Heights Rd. centerline, Southeast of the entrance of Wyndham Heights subdivision.	1183.075	1183.479	Wyndham Heights Kimball	Anderson	316797	1698104
077M	Disk at center of street inlet box on Pinewood Dr. ± 17.4' East of Pinewood centerline and ± 52.3' North of Meadowood Dr. centerline.			Pinewood	Meadowood	323486	1704907
078M	Disk in Southeast corner of concrete street inlet box between 2501 and 2511 Tiana Ter. 38.5' from the center of the cul-de-sac, 74.0 to sanitary sewer manhole between 2510 and 2501 Tiana Ter., 55.7' to water meter of 2511 Tiana Ter., and ± 240' East of Tamarron Ter.	1086.825	1087.229	Tamarron Ter	Tianna Ter	322430	1708282
079M	Disk in Northeast corner of concrete inlet box between 2608 and 2600 Snowbird Dr. 37.6' to center of cul-de-sac, 58.8' to water valve in street, 44.8' to Water meter of 2600 Snowbird, and ± 303' East of Hillview centerline.	1097.754	1098.158	Hillview	Snowbird	321129	1708274
080M	Disk at East end of concrete wingwall at Southeast corner of concrete box under St. Matthews Dr. ± 24.2' Northeast of St. Matthews centerline and ± 167' Northwest of Hillview centerline.	1073.835	1074.239	St. Matthew	Hillview	322061	1708610

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BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
081M	Disk in Northeast corner of concrete street inlet box on Corporate Dr. 25.7' West of Corporate Dr. centerline, 28.7' to sanitary sewer manhole on South side of Corporate Dr. and 70.9' to a Fire Hydrant on the North side of Corporate Dr.			Wildcat Creek	Corporate		
082M	Disk at Southwest corner of a Triple concrete storm box under Vinewood Drive. ±39' West of Vinewood centerline and ±105.2' South of Willow Grove Rd. centerline.	1082.245	1082.649	Vinewood	Willow Grove	323240	1708136
083M	Disk at East end of South concrete bridge buttress. ±26.2' East of College Ave. centerline and ±0.16 miles North of Hillview Dr. centerline.	1066.483	1066.887	College	Hillview	322789	1709558
084M	Disk on West end of North concrete wingwall on the East side of a triple concrete box under Casement Rd. ±15.6' East of Casement centerline and ±64.5' North of Brookmont Dr. centerline.	1017.945	1018.349 1008.349	Casement	Brookmont	323285	1721050
085M	Disk at center of South headwall of a concrete box under Anderson Ave. ±59.0' South of Anderson centerline and ±280' West of Scenic Dr.	1077.437	1077.841	Scenic Dr. Kimball Ave	Anderson	320133	1696628
086M	Disk in concrete retaining wall ±1' East of the Northeast corner of a concrete golf cart tunnel under Grandmere Pky. ±37.6' North of Grandmere Pky. centerline and ±381.5' East of Heartland Dr.	1245.446	1245.85	Heartland Dr.	Grandmere Pky	315672	1697156

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
C-338	Disk in concrete monument North of Moore Hall. 156' South of Claflin and 79' East Northeast of the Northwest corner of the Hall and 21.5' North of the North side of the Hall.	1065.11	1065.58	N. Manhattan	Claflin	316991	1715313
KSU	South of Seaton Hall	1065.14	1065.61	17th	Mid Campus	314449	1714565
C-115	East of Fairchild Hall	1074.62	1075.09	Mid Campus	Vattier	314744	1714009

All BM ending in	To adjust to NAVD 88
F are referenced to USGS BM C-370	0.317
I are referenced to USGS BM FF-115	-0.203
K are referenced to USGS BM FF-115	-0.203
M are referenced to USGS BM Y-111	0.404
O are referenced to USGS BM Y-111	0.404
S are Referenced to USGS BM C-370	0.317

Legend:

- Bold** Adjusted Elevation
- italics* non-looped elevation
- underline project elevation

Non City BM

BM #	Location	(ft)NGVD 29	(ft) NAVD 88	N-S Street	E-W Street	Northing	Easting
USGS							
Y-111	3" Brass disk in concrete monument. 30' North of Marlatt Rd CL and +_660' East of Potomac Rd. <i>Destroyed</i>	1030.346	1030.75	Tuttle Creek Blvd	Marlatt	325184	1715184
FF-115	3" Brass disk in concrete retaining wall on the West side of the North doors to the Federal Building at 4th and Houston.	1018.413	1018.21	4th	Houston	310891	1719897
C-370	Steel rod under protective cap. Intersection of Yuma and 16th street. 89' west of 16th street centerline and 44' North of Yuma centerline.	1025.323	1025.64	N. Manhattan	Yuma	309790	1714244
D-115	Disk in concrete monument. 13' South of South curb of Vattier street and 33' West of West curb of N. Manhattan Ave.	1026.865	1027.36	N. Manhattan	Vattier	314266	1715749
K-263	3" brass disk in rail bridge abutment +_100' Southeast of Fort Riley Blvd. In the top of the Southeast end of the Southwest Abutment.	1027.252	1027.64	Poliska	Fort Riley Blvd	307715	1710969
R-114	Disk in wall of Riley county court house. .5' east of the south entrance to the court house set vertically in the wall.	1020.36	1020.82	5th	Poyntz	311292	1719655
P-370	Steel rod under protective cap. +_25 miles west of the intersection of K-18/K-113 and +_75' north of the center of the west bound lanes of K-18.	1120.37	1121.12	K-113	K-18	307348	1706879
Q-370		1008.48		K-177	Fort Riley Blvd		
N-370		1027.27		W. end of Stagg Hill	Fort Riley Blvd		
B-338	Destroyed	1020.88	1021.24				
MMA-2	Disk at the Manhattan Airport 18.6' North of the West corner of the old rock hanger.	1042.65	1043.13	Aiport Rd	K-18	296632	1691082
M-370	Steel Rod under protective cap. .1 mile southeast of K-18 on Wildcat Creek Rd. 45' East of railroad track		1041.33	Wildcat Creek Rd	K-18	293416	1688816
KSU							
D-338	Disk in concrete monument Northeast of Goodnow Hall. 118' South of Claflin centerline and 71' West of Denison centerline.	1084.11	1084.58	Denison	Claflin	316149	1713279

Appendix F



SUMMARY OF SCENARIOS

State: Kansas

County: Riley

Land Use	Hydrologic Soil Group	Current	acres Scenario 1	Scenario 2
Grass/Pasture	B	35.7	35.7	0
Grass/Pasture	C	243.0	0	0
Grass/Pasture	D	95.7	0	0
Low Density Residential	C	358.9	601.9	0
Low Density Residential	D	20.4	116.1	0
Grass/Pasture	C	696.3	696.3	0
Grass/Pasture	D	262.0	262.0	0
Forest	B	173.9	173.9	0

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft)

Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.08	0.08	0
Grass/Pasture	4.63	0	0
Grass/Pasture	4.68	0	0
Low Density Residential	17.57	29.47	0
Low Density Residential	1.91	10.88	0
Grass/Pasture	13.29	13.29	0
Grass/Pasture	12.83	12.83	0
Forest	0	0	0
Total Annual Volume (acre-ft)	55.02	66.57	0

Avg. Annual Runoff Depth (in)			
Current	Scenario 2		Scenario 3
0.35	0.42		0
Avg. Runoff Depth by Landuse			
Land Use	Hydrologic Soil group	Curve Number	Runoff Depth (in)
Grass/Pasture	B	61	0.03
Grass/Pasture	C	74	0.23
Grass/Pasture	D	80	0.59
Low Density Residential	C	80	0.59
Low Density Residential	D	85	1.13
Grass/Pasture	C	74	0.23
Grass/Pasture	D	80	0.59
Forest	B	55	0
Average Annual Rainfall Depth (in)			19.77

NONPOINT SOURCE POLLUTANT RESULTS			
Nitrogen (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.169	0.169	0
Grass/Pasture	8	0	0
Grass/Pasture	8	0	0
Low Density Residential	87	146	0
Low Density Residential	9	53	0
Grass/Pasture	25	25	0
Grass/Pasture	24	24	0
Forest	0	0	0

Total	161.169	248.169	0
Phosphorous (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.002	0.002	0
Grass/Pasture	0.126	0	0
Grass/Pasture	0.127	0	0
Low Density Residential	27	45	0
Low Density Residential	2	16	0
Grass/Pasture	0.362	0.362	0
Grass/Pasture	0.349	0.349	0
Forest	0	0	0
Total	29.966	61.713	0

Suspended Solids (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.242	0.242	0
Grass/Pasture	12	0	0
Grass/Pasture	12	0	0
Low Density Residential	1963	3292	0
Low Density Residential	213	1216	0
Grass/Pasture	36	36	0
Grass/Pasture	34	34	0
Forest	0	0	0
Total	2270.242	4578.242	0

Lead (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.001	0.001	0
Grass/Pasture	0.063	0	0
Grass/Pasture	0.063	0	0
Low Density Residential	0.430	0.722	0
Low Density Residential	0.046	0.267	0
Grass/Pasture	0.181	0.181	0
Grass/Pasture	0.174	0.174	0
Forest	0	0	0
Total	0.958	1.345	0

Copper (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.002	0.002	0
Grass/Pasture	0.126	0	0
Grass/Pasture	0.127	0	0
Low Density Residential	0.430	0.722	0
Low Density Residential	0.046	0.267	0
Grass/Pasture	0.362	0.362	0
Grass/Pasture	0.349	0.349	0
Forest	0	0	0
Total	1.442	1.702	0

Zinc (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.001	0.001	0

Grass/Pasture	0.075	0	0
Grass/Pasture	0.076	0	0
Low Density Residential	3	6	0
Low Density Residential	0.417	2	0
Grass/Pasture	0.217	0.217	0
Grass/Pasture	0.209	0.209	0
Forest	0	0	0
Total	3.995	8.427	0

Cadmium (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0	0	0
Grass/Pasture	0.012	0	0
Grass/Pasture	0.012	0	0
Low Density Residential	0.035	0.060	0
Low Density Residential	0.003	0.022	0
Grass/Pasture	0.036	0.036	0
Grass/Pasture	0.034	0.034	0
Forest	0	0	0
Total	0.132	0.152	0

Chromium (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.001	0.001	0
Grass/Pasture	0.094	0	0
Grass/Pasture	0.095	0	0
Low Density Residential	0.100	0.168	0

Low Density Residential	0.010	0.062	0
Grass/Pasture	0.271	0.271	0
Grass/Pasture	0.262	0.262	0
Forest	0	0	0
Total	0.833	0.764	0

Nickel (lbs)

Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Low Density Residential	0.478	0.803	0
Low Density Residential	0.052	0.296	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Forest	0	0	0
Total	0.53	1.099	0

BOD (lbs)

Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.121	0.121	0
Grass/Pasture	6	0	0
Grass/Pasture	6	0	0
Low Density Residential	1221	2047	0
Low Density Residential	132	756	0
Grass/Pasture	18	18	0
Grass/Pasture	17	17	0

Forest	0	0	0
Total	1400.121	2838.121	0

COD (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Low Density Residential	2370	3975	0
Low Density Residential	258	1468	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Forest	0	0	0
Total	2628	5443	0

Oil & Grease (lbs)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Low Density Residential	81	136	0
Low Density Residential	8	50	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Forest	0	0	0
Total	89	186	0

Fecal Coliform (millions of coliform)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0.220	0.220	0
Grass/Pasture	11	0	0
Grass/Pasture	11	0	0
Low Density Residential	4353	7300	0
Low Density Residential	473	2697	0
Grass/Pasture	32	32	0
Grass/Pasture	31	31	0
Forest	0	0	0
Total	4911.22	10060.22	0
Fecal Strep (millions of coliform)			
Land Use	Current	Scenario 1	Scenario 2
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Low Density Residential	12189	20442	0
Low Density Residential	1326	7552	0
Grass/Pasture	0	0	0
Grass/Pasture	0	0	0
Forest	0	0	0
Total	13515	27994	0

These results were generated by the L-THIA (Long-Term Hydrologic Impact Assessment) model at

"http://www.ecn.purdue.edu/runoff/lthianew"