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Arc Hydro Data Model for Ethiopian Watersheds

by

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Thesis

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Arc Hydro Data Model for Ethiopian Watersheds

Approved by

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December 2005

Abstract

Arc Hydro Data Model for Ethiopian Watersheds

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The University of Texas at Austin, 2005

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Abstract

Ethiopia is endowed with a substantial amount of water resources. The country's renewable surface and ground water amounts 123 and 2.6 billion cubic meters per annum, respectively, but its distribution shows high temporal and spatial variation. The Ministry of Water Resources of Ethiopia (MoWR) planned to develop a digital hydrologic data model that supports management of the country's water resources. The purpose of this project is to use the Arc Hydro data model organize and manage water resource data in Ethiopia. To accomplish this, raw Shuttle Radar Topographic Mission (SRTM) data was processed and a 90m*90m Digital Elevation Model (DEM) was created. Second, drainage lines and watersheds were created using the Arc Hydro tools. Third, six hydro administrative regions were identified based on the flow direction of the streams. This project has shown that Arc Hydro is an effective tool for storing and analyzing hydrologic information for very large areas.

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CHAPTER 1: INTRODUCTION

1.1 Background

Ethiopia, with a total area of 1.13 million square kilometers, has a total population of 63.5 million (CIA, 2004). The economy of the country is highly dependent on agriculture, which in turn is dependent on the availability of seasonal rainfall. The country's renewable surface and ground water amounts to 123 and 2.6 billion cubic meters per annum respectively but its distribution shows high temporal and spatial variation. Furthermore, rainfall is highly variable across the country, from season to season, and from year to year. This temporal variation of rainfall subjects the country to frequent droughts and famine. Ethiopia is also the source of nearly 85% of the Nile River.

The Ministry of Water Resources (MoWR) of Ethiopia is the sole responsible agency for the distribution and conservation of water resources in the country. The MoWR signs international agreements related to Transboundary Rivers in accordance with the law. The department of Transboundary Rivers in the MoWR provides a policy advisory on strategies and legal matters pertaining to negotiation with the riparian states, particularly with Sudan and Egypt. The departments of Basin Study and Hydrology have a huge amount of basin resource potential and hydrological data respectively. The hydrology department also possesses large amounts of datasets related to river flow, sediments, and other hydrological characteristic of the major Rivers in the country. Most of the study output is in the form of classical paper report format that is difficult to manage. Thus, the Ministry of Water Resources (MoWR) planes to develop a digital hydrologic data model that supports management of the countries water resources. The

Arc Hydro data model can be used to support the MoWR plan to develop a digital hydrologic data set.

Arc Hydro, which is developed by the Center for Water Resources (CRWR) at the University of Texas at Austin, is a geospatial and temporal data model for water resources designed to operate within ArcGIS. Arc Hydro opens the way to building hydrologic information systems that synthesize geo-spatial and temporal water resource data to support hydrologic analysis and modeling (Maidment 2002). The purpose of a geographic information system (GIS) is to provide a spatial framework to support decisions for the intelligent use of earth's resources and manage the manmade environment.

1.2 Study Objectives

This project is aimed at developing a geodatabase to build hydrologic information systems for Ethiopian watersheds and modeling of the rivers. The geodatabase will consist of an Arc Hydro-based geographic information system and relational database containing hydrologic, hydraulic and related data for Ethiopian watersheds. Generally this project will have the following outputs: -

0. Generate a 90*90 m cell Digital Elevation Model (DEM) of Ethiopia from SRTM data.
0. Develop a prototype Arc Hydro data model for Ethiopia water sheds
0. Represent the drainage system into appropriate Basins, Watersheds, and Catchments
0. Represent stream flows using time series attribute tools

1.3Thesis outline

Chapter 2 is literature review about the Arc Hydro data model, the Ethiopia Water system and the Hydro-politics in East Africa. Chapter 3 discusses the different data archives collected and used for this project. Chapter 4 discusses how 90m digital elevation data was obtained and processed. Chapter 5 how the Blue Nile watershed was delineated using the terrain analysis tool in Arc Hydro. Chapter 6 describes the Geodatabase design and Arc Hydro framework for Blue Nile Basin. The last chapter describes the project summary and conclusions.

CHAPTER 2: LITERATURE REVIEW

Previous chapters provided background information about the importance of this study and the primary objectives of this project. This chapter provides a review of geographic location of Ethiopia and previous water resource studies conducted in Ethiopia.

2.1 The study area

Ethiopia is located in the Horn of Africa and is bordered on the north and northeast by Eritrea, on the east by Djibouti and Somalia, on the south by Kenya, and on the west and southwest by Sudan (Figure 2.1). The country has a high central plateau that varies from 1,800 to 3,000 meters (6,000 ft.-10,000 ft.) above sea level, with some mountains reaching 4,620 meters (15,158 ft.). Elevation is generally highest just before the point of descent to the Great Rift Valley, which splits the plateau diagonally. A number of rivers cross the plateau-most notably the Blue Nile flows from Lake Tana. The plateau gradually slopes to the lowlands of Sudan on the west and Somali-inhabited plains to the southeast.

The climate is temperate on the plateau and hot in the lowlands. At Addis Ababa, where the elevation ranges from 2,200 to 2,600 meters (7,000 ft.-8,500 ft.), maximum temperature is 26^{o} C (80^{o} F) and minimum temperature is 4^{o} C (40^{o} F). The weather is usually sunny and dry with the short rains occurring February to April and the heavy rain begin in mid-June and ending in mid-September (US Department of State, 1998).

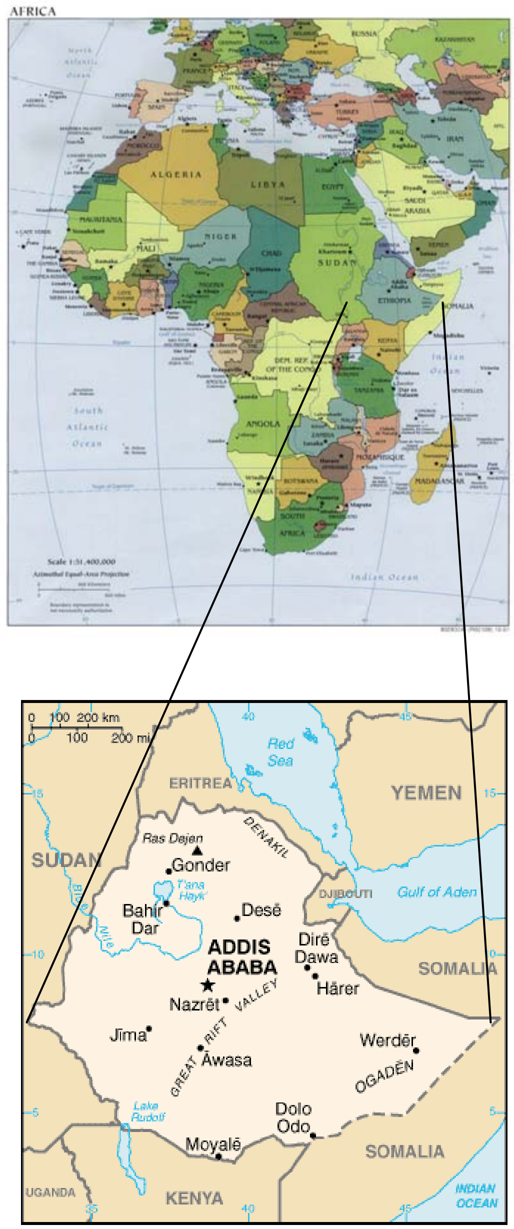


Figure 2.1 Location of Ethiopia (PCL 2000)

2.2 Water Resources of Ethiopia

Ethiopia is endowed with a substantial amount of water resources. The surface water resource potential is impressive but little developed. The country possesses twelve major river basins (FAO, 2005), which form four major drainage basins (table 2.1):

- ❖ The Nile Basin (including Abbay or Blue Nile, Baro-Akobo, Setit-Tekeze/Atbara and Mereb) covers 33% of the country and drains the northern and central parts westward.
- ❖ The Rift Valley (including Awash, Denakil, Omo-Gibe and central lakes) covers 28% of the country.
- ❖ The Shebelle-Juba basin (including Wabi-Shebelle and Genale-Dawa) covers 33% of the country and drains the southeast mountains towards Somalia and the Indian Ocean.
- ❖ The North East Coast (including the Ogaden and Gulf Aden basins) covers 6%of the country.

Integrated development master plan studies and related basin surveys, undertaken at the end of the 1990s, indicate that the aggregate annual runoff from Ethiopian river basins is about 122 x $10^9 km^3$ (table 2.2). Abay, Baro-Akobo and Omo-Gibe basins account for about 76% of the total runoff from an area of only 32% of the total area of the country. Most of the rivers in Ethiopia are seasonal and about 70% of the total runoff takes place during the months of July-August. Dry season flow originates from springs, which provide base flows for small-scale irrigation. The ground water potential of the country is estimated to be 2.6 billion cubic meters. Intense rainfall sometimes causes flooding particularly along the Awash River and in the lower Baro-Akobo and Wabe-Shebelle river basins, causing damages on standing crops and infrastructure (FAO, 2005).

Table 2.1 Area and runoff by river basin for Ethiopian water system (MoWR 2002)

Major Drainage	River Basin	Area (10^4 m^2)	% of total Area (%)	Annual Runoff (km^3/yr)	% of Total Runoff (%)
system		**(10^4 m^2)**	**(%)**	**(km^3/yr)**	**(%)**
Nile Basin		**36,881,200**	**32.4**	**84.55**	**69**
	Blue Nile	19,981,200	17.6	52.6	42.9
	Baro-Akobo	7,410,000	6.5	23.6	19.3
	SetitTekeze/Atbara	8,900,000	7.8	7.63	6.2
	Mereb	590,000	0.5	0.72	0.6
Rift Valley		**31,764,000**	**27.9**	**29.02**	**23.7**
	Awash	11,270,000	9.9	4.6	3.7
	Denakil	7,400,000	6.5	0.86	0.7
	Omo-Gibe	7,820,000	6.9	17.96	14.7
	Central Lake	5,274,000	4.6	5.6	4.6
Shebelli-Juba		**37,126,400**	**32.7**	**8.95**	**7.3**
	Wabi-Shebelli	20,021,400	17.6	3.15	2.6
	Genale-Dawa	17,105,000	15.1	5.8	4.7
North East Coast		**7,930,000**	**7**	**0**	**0**
	Ogaden	7,710,000	6.8	0	0
	Gulf of Aden	220,000	0.2	0	0
Total		**113,701,600**	**100**	**122.5**	**100**

Ethiopia has several lakes (about 7,000 km^2), a number of saline and crater lakes as well as several wetlands. All lakes, except Lake Tana, which is the source of Abbay River in the Nile Basin, are found in the Rift Valley and among these lakes only Zway has freshwater while others are saline. Rising of Lake Tana and Lake Awassa after intense rainfall is creating concerns to the city of Bahir Dar and Awassa respectively.

Large wetlands serve as source of water for large rivers, flood retention and groundwater recharge (FAO, 2005).

Table 2.2 water sources and use in Ethiopia (FAO, 2005)

Renewable water resources	**Year**	**Value**	**Unit**
Average precipitation		848	mm/yr
Total actual renewable water resources		122	10^9 m^3/yr
Total actual renewable water resources per inhabitant	2004	1,685	m^3/yr
Total dam capacity	2002	2,458	$10^6 m^3$
Water withdrawal			
Total Water withdrawal	2002	5,558	$10^6 m^3$/yr
-irrigation +livestock	2002	5,204	$10^6 m^3$/yr
-domestic	2002	333	$10^6 m^3$/yr
- industry	2002	21	$10^6 m^3$/yr
-per inhabitant	2002	86	m^3
-as % of total actual renewable water resources	2002	4.6	%

Ethiopia has many small, medium and large reservoir dams constructed for hydropower generation, irrigation and drinking water supply. Small dams are less than 15 m high and have a capacity of less than 3 million m^3. The height of the medium and large dams in Ethiopia is 15 -30 m and their capacity ranges from 4 to 1,900 million m^3. Totally, there are nine medium and large dams, with a total capacity of almost 3.5 km^3. Two large dams are used for hydropower generation only, one dam is used for irrigation and supply and hydropower generation, two dams are used for irrigation supply only and the remaining four supply to the Addis Ababa city and Gonder town.

2.3 Transboundary Waters and the Nile Basin Initiatives

(Gulilat, 2002) described that 75% of the rivers, which originates in highlands of Ethiopia, cross the borders and feed neighboring countries. These Transboundary Rivers, particularly the Nile Tributaries (Abbay, Tekeze, and Baro-Akobo) are also source of conflict with the down stream riparian countries like Sudan and Egypt. Ethiopia also contributes 86% of the Nile water.

There are ten countries that make up the Nile River Basin. Some of the countries have only a small part of their area within the basin, whilst others are virtually entirely within the Basin (Figure 2.2). All the countries contribute differently to the basin and have different needs for the water and other resources of the basin (NBI, 2005). International efforts and policy direction have brought together the partners in the Nile basin under the umbrella of the Nile Basin Initiative (NBI) (Gulilat, 2002). The Nile Basin Initiative created and prepared a Strategic Action Program, which consists of two sub-programs: the Shared Vision Program (SVP) and the Subsidiary Action Program (SAP). SVP is to help create an enabling environment for action on the ground through building trust and skill, while SAP is aimed at the delivery of actual development projects involving two or more countries. Projects are selected by individual riparian countries for implementation and submitted to the Council of Ministers of the Nile Basin Initiative for the approval (FAO, 2005).

Figure 2.2 Nile basin riparian countries (NBI 2005)

CHAPTER 3: METHODOLOGY

The previous chapters gave background information about the objective of the research and discussed previous water resource studies done in Ethiopia. This chapter discusses details of data used for applying Arc Hydro tools for Ethiopian Watersheds.

3.1Geographic Information Systems (GIS) Data

GIS is a system of computer software, hardware, data and personnel to help manipulate, analyze and present information that is tied to a spatial location (ESRI,2005):-

- *Spatial location* –a geographic location
- *Information* – visualization of analysis of data
- *System* – linking software, hardware and data
- *Personnel*- a thinking explorer who is key to the power of GIS

GIS data about major streams, major basins and waterbodies of Africa were obtained from the Food and Agricultural Organization (FAO) GeoNetwork. GeoNetwork allows for easily sharing geographically referenced thematic information between different FAO Units, other United Nations (UN) Agencies, Non-Governmental Organizations (NGO's) and other institutions.

3.1.1 MAJOR AFRICA'S STREAMS

Stream data of Ethiopian watersheds were obtained from FAO GeoNetwork (FAO, 1998). This digital data layer is a 1: 5, 000, 000 shapefile with the rivers of Africa that was digitized in 1994 for the United Nations Environmental Program (UNEP) and Food and Agricultural Organization (FAO) Desertification Assessment and Mapping Project.

The dataset consists of the following information:

- GIS generated codes (FNODE_, TONODE_, AFRIVLL_)
- a code to describe the hydrological rank of the river starting with rank 1 for the most upstream contributories and counting downstream according to Strahler's stream order method (RNK)
- a code to show the hydrological regime (1 = perennial, 2 = intermittent)
- a code that combines the two codes in one value (CODE, first digit RNK, second digit REGIME)

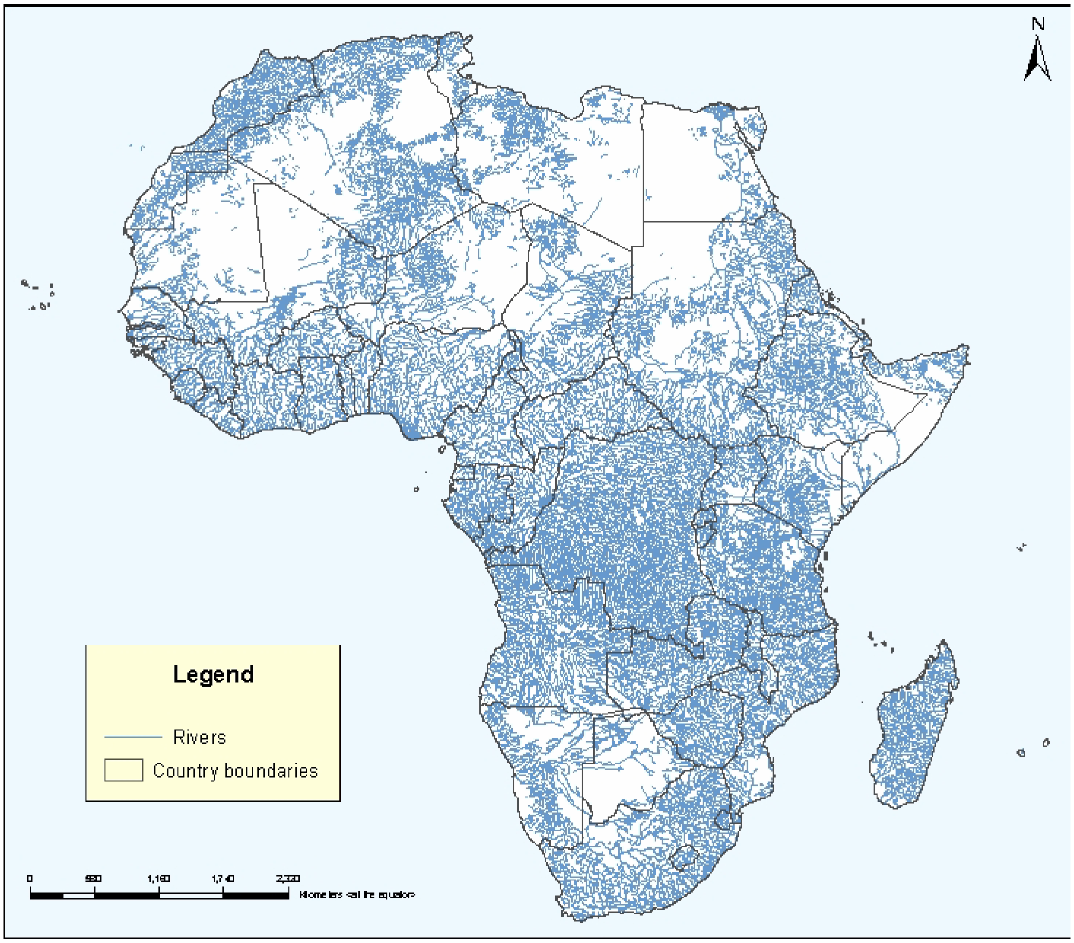


Figure 3.1 Rivers in Africa (FAOa, 2000)

3.1.2 MAJOR DRAINAGE BASINS

GIS data on major drainage basins were obtained from FAO GeoNetwork (FAO, 1998). The dataset divides the African continent according to its hydrological characteristics (Figure 3.2) and consist of the following information:

- numerical code and name of the major basin (MAJ_BAS and MAJ_NAME)
- area of the major basin in square km (MAJ_AREA)
- numerical code and name of the sub-basin (SUB_BAS and SUB_NAME)
- area of the sub-basin in square km (SUB_AREA)
- numerical code of the sub-basin towards which the sub-basin flows (TO_SUBBAS)

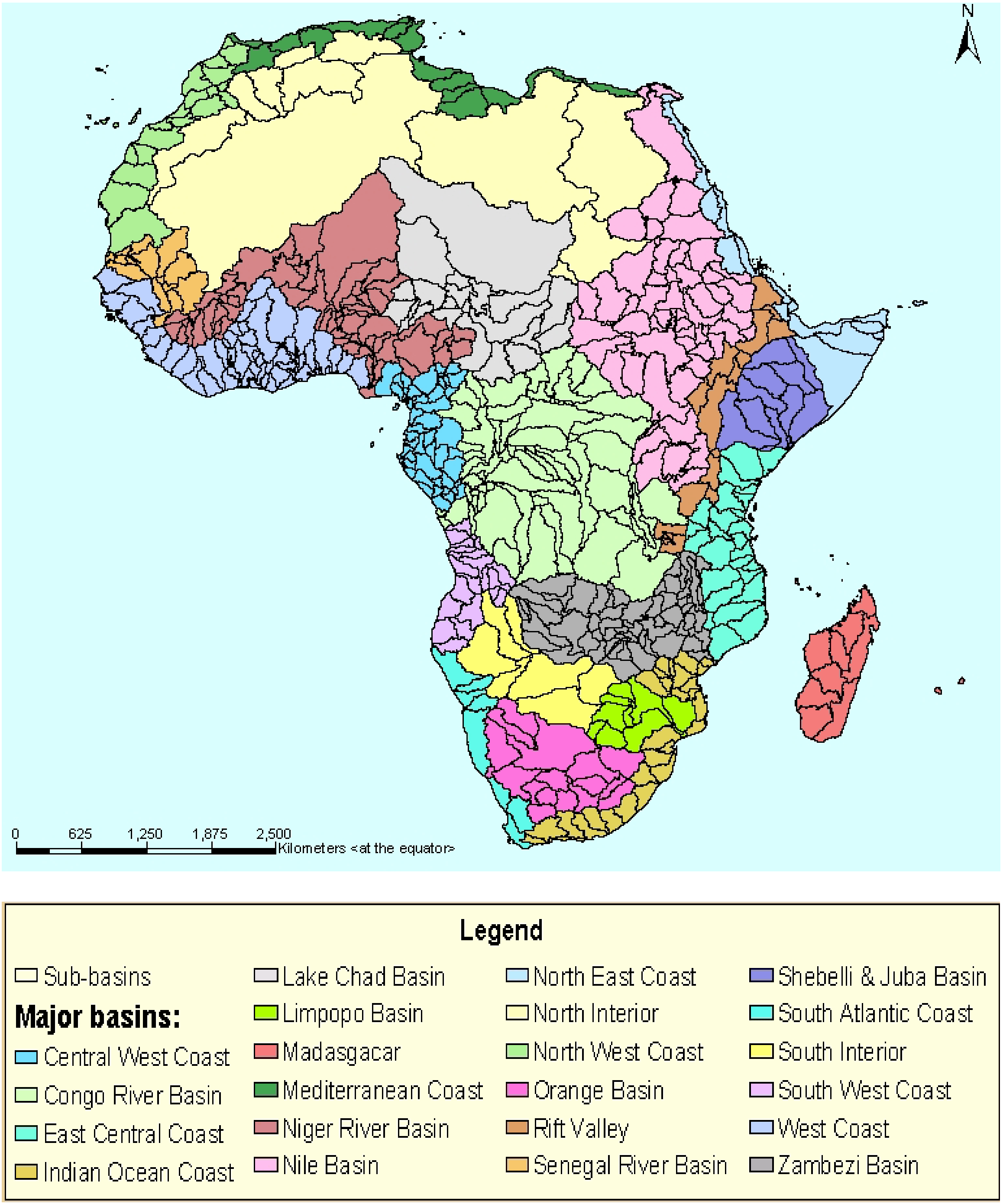


Figure 3.2 Hydrological Basins in Africa (FAOb, 2000)

3.1.3 INLAND WATER BODIES OF AFRICA

The Shape file of inland water bodies in Africa was obtained from FAO GeoNetwork (FAO, 1998). This dataset originates from the Digital Chart of the World 1:1000000. The water bodies for Africa have been characterized as lake, lagoon, reservoir etc.) . The data layer presented contains all the water bodies that had a name and were not characterized as river. The dataset consists of the following information:

- GIS generated codes (FID, AF_WTR_ID)
- Area of waterbody (SQKM)
- Name of waterbody (NAME_OF_WA)
- Type of waterbody (TYP_OF_WA)

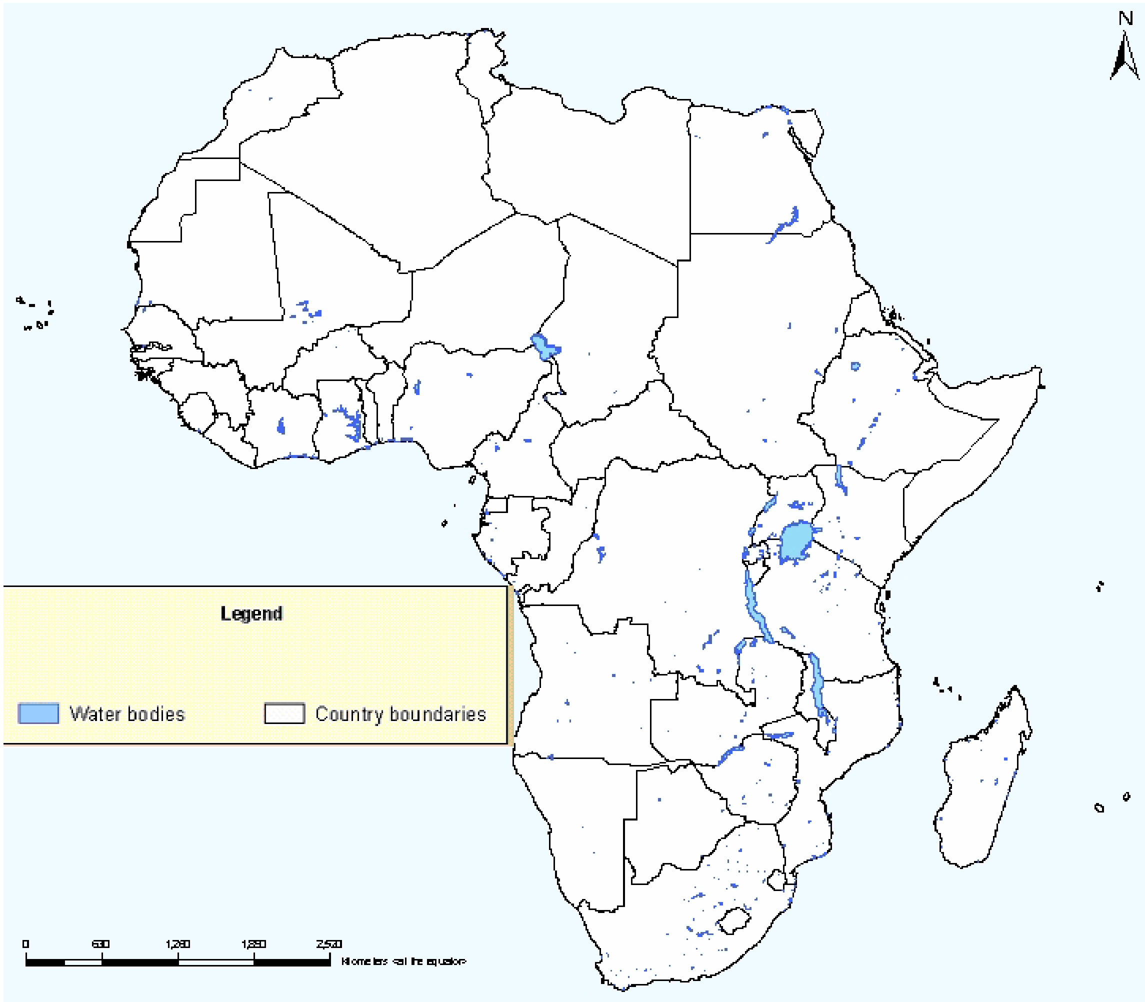


Figure 3.3 Inland water bodies in Africa (FAOc, 2002)

3.1.4 CREATING AND ADDING ETHIOPIA'S OUTLINE SHAPEFILE

The shapefile of Ethiopia's outline was created from Environmental System Research Institute (ESRI's) World Basemap Data. Basemap data are used to create maps of geographic features such as country boundaries, city points, rivers, roads, railroads, and airports. The World Basemap Data includes data layers from a variety of ESRI products, including Arc Atlas, Arc World, and digital map of the World. ESRI assembled selected data layers from these sources into a Spatial Database Engine (SDE) database to provide a continuous display of basemap data from a small-scale global display to a medium-scale regional display.

The Data Downloader opens the ESRI World Basemap; Ethiopia's shapefile was selected by entering Ethiopia in the search box and using the Zoom and Pan Tools to adjust the area. This action displays the Select windows layer. The default is all available layers. All layers include: Countries and Regions (Data and Maps), Major Rivers (Arc Atlas), Water Bodies (Arc Atlas), Major Highways (Arc Atlas), and Major Cities (Arc World). Then the Major Rivers, Water Bodies and Countries layers were checked and the other two layers were unchecked. Then the Download file was clicked to retrieve the shape file for Ethiopia and Ethiopia's shape file was retrieved as shown in figure 3.4.

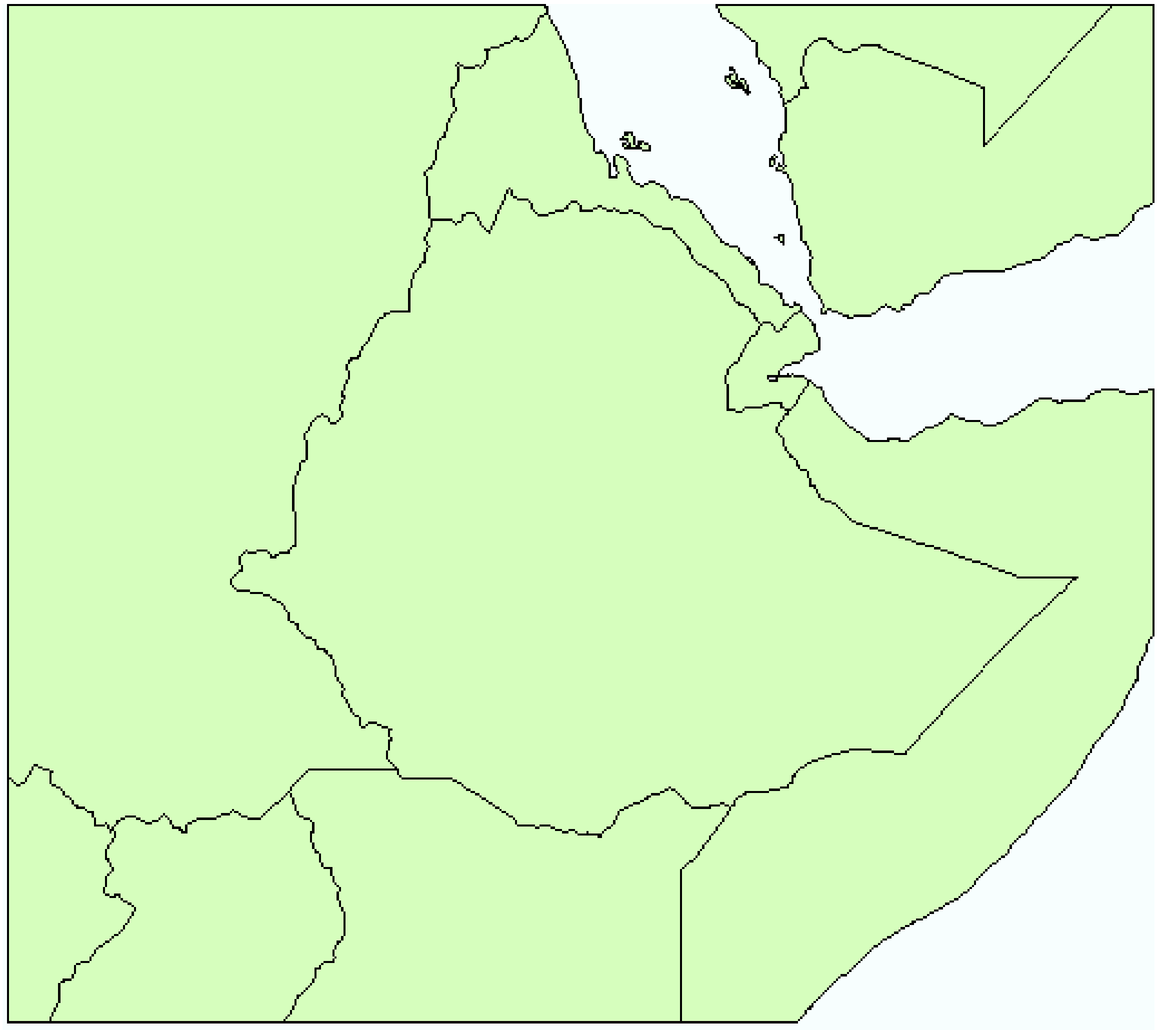


Figure 3.4 Shape of Ethiopia and its neighboring countries (ESRI, 2005).

3.1.5 SUMMARY OF GIS DATA AND SHAPE FILES

All the GIS data for Ethiopia was clipped out from Figures 3.1, 3.2, 3.3 and 3.4 in ArcGIS desk top and layered as shown in Figure 3.5. The basins shape file protruded out side of Ethiopia's political boundary since some of the basins are shared between

Ethiopia and its neighboring countries. The streams shape files showed all the streams from Hydro1k. HYDRO1k, developed at the U.S. Geological Survey's (USGS) Earth Resource and Observation System (EROS) Data Center, is a geographic database providing comprehensive and consistent global coverage of topographically derived data sets with a spatial resolution of 1 km (USGS,2003). The water bodies shape file showed all the lakes in Ethiopia that lies in the rift valley system except Lake Tana.

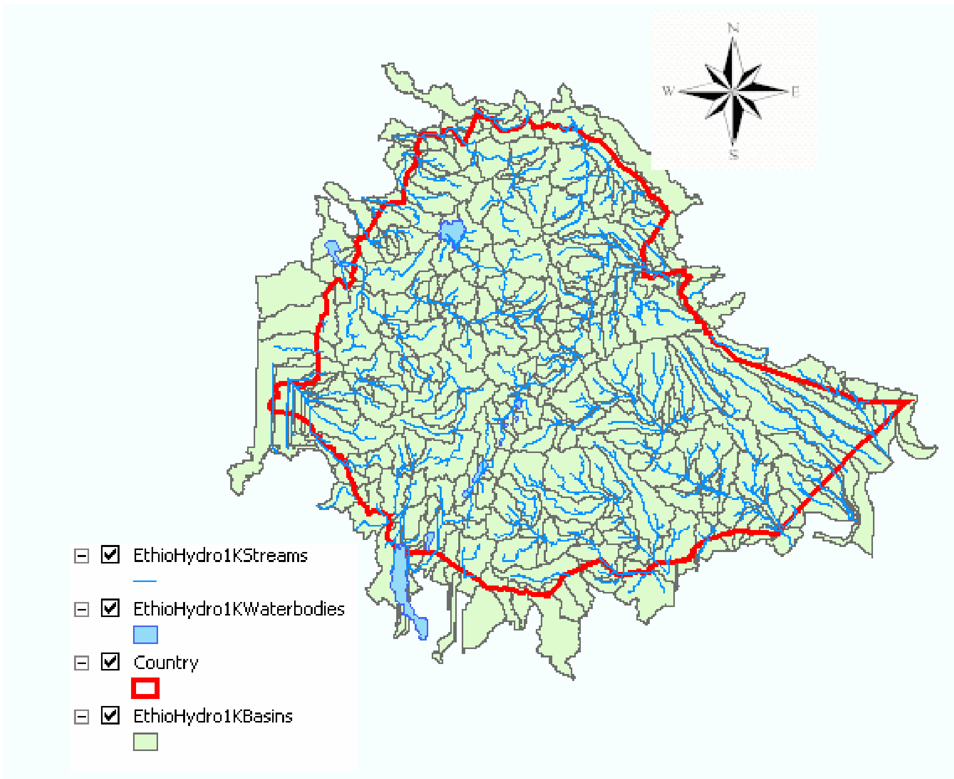


Figure 3.5 Ethiopia Country's boundary, Streams, Water Bodies and Basins from Hydro1K.

CHAPTER 4: GETTING DIGITAL ELEVATION DATA

4.1 Shuttle Radar Topography Mission (SRTM)

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. The data are published in 1-arc second (30 m resolution) grids for the US and 3 arc second (90 m resolution) grids for the rest of the globe from 56^{o} S - 60^{o} N latitude.

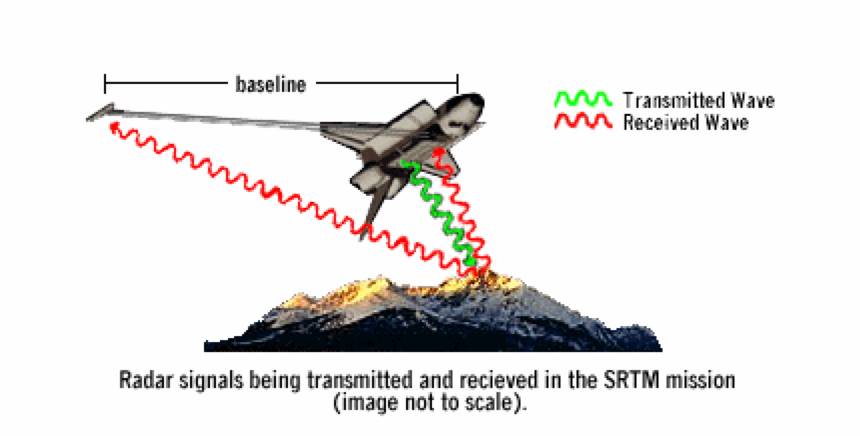


Figure 4.1 Illustration of interferometry on the Endeavour (JCP, 2005)

Two radar data sets were collected at the same time separated by 60 m, the distance between the main antenna and the outboard antenna (Figure 4.1). Knowing the distance between the two antennas and the differences in the reflected radar wave signals, accurate elevation of the Earth's surface was calculated.

4.2 Obtain SRTM data

There are several sources available from which SRTM data can be obtained, including:

NASA (raw data): ftp://e0mss21u.ecs.nasa.gov/srtm/

USGS (somewhat corrected data): http://seamless.usgs.gov/

CGIAR (No Data holes filled): http://srtm.csi.cgiar.org/

The Consortium for Spatial Information (CIS), an initiative of the many geospatial scientists with in the Consultative Group for International Agriculture Research (CGIAR), site is the best data source since Data holes are filled and the data are ready for use. The CGIAR-CSI GeoPortal provided SRTM 90m Digital Elevation Data for the entire world as shown in Figure 4.2. However, they are not provided in a "seamless" data format and several tiles must be mosaiced together. The DEM files are available for down load as 5 degree * 5 degree tiles in geographic coordinate system - WGS84 datum.

These files are available for download in both Arc-Info ASCII format, and as GeoTiff, for easy use in most GIS and Remote Sensing software applications.

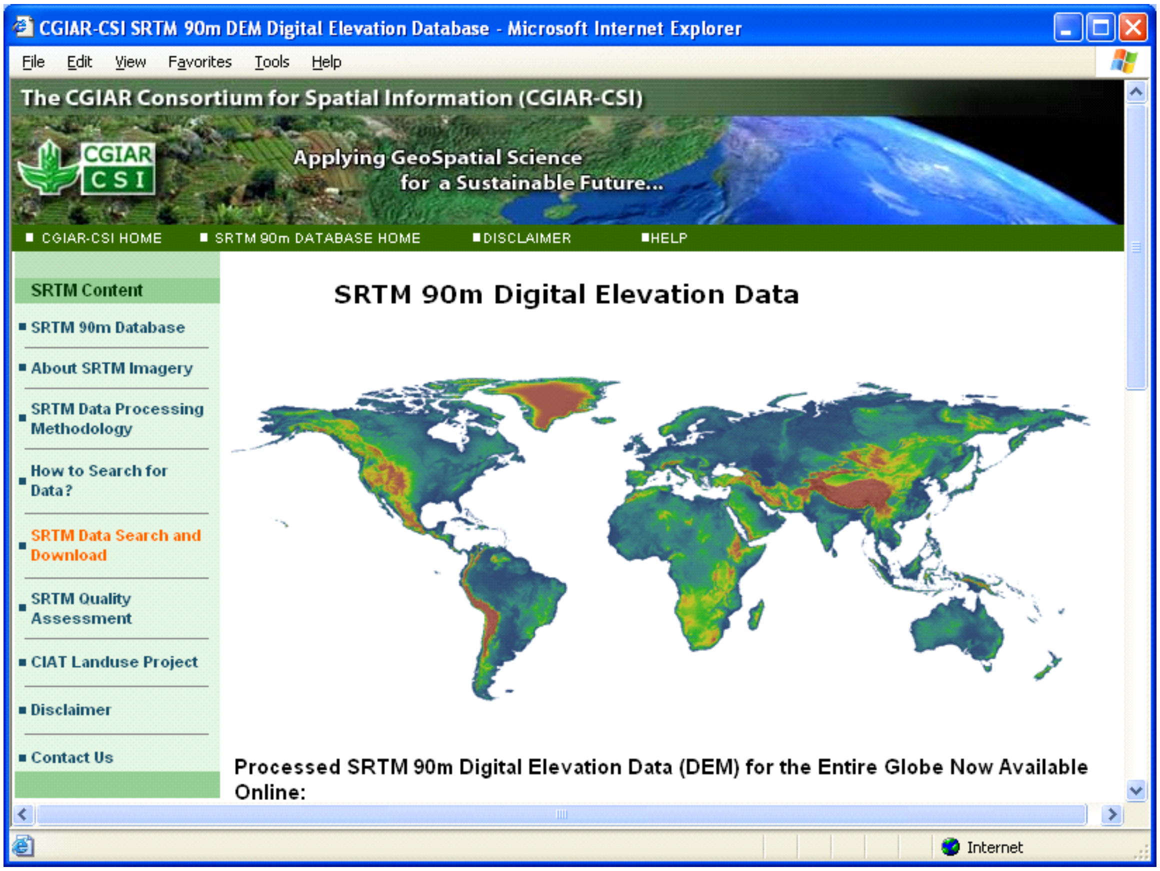


Figure 4.2 Processed SRTM 90m Digital Elevation Data (DEM) for entire globe (CGIAR, 2005)

From Figure 4.2 selecting **SRTM Data Search and Download** and then **entering** the Latitude and Longitude of choice will allow choose SRTM data of interest. This yields the world map divided in to 60 rows and 72 columns as shown in Figure 4.3.

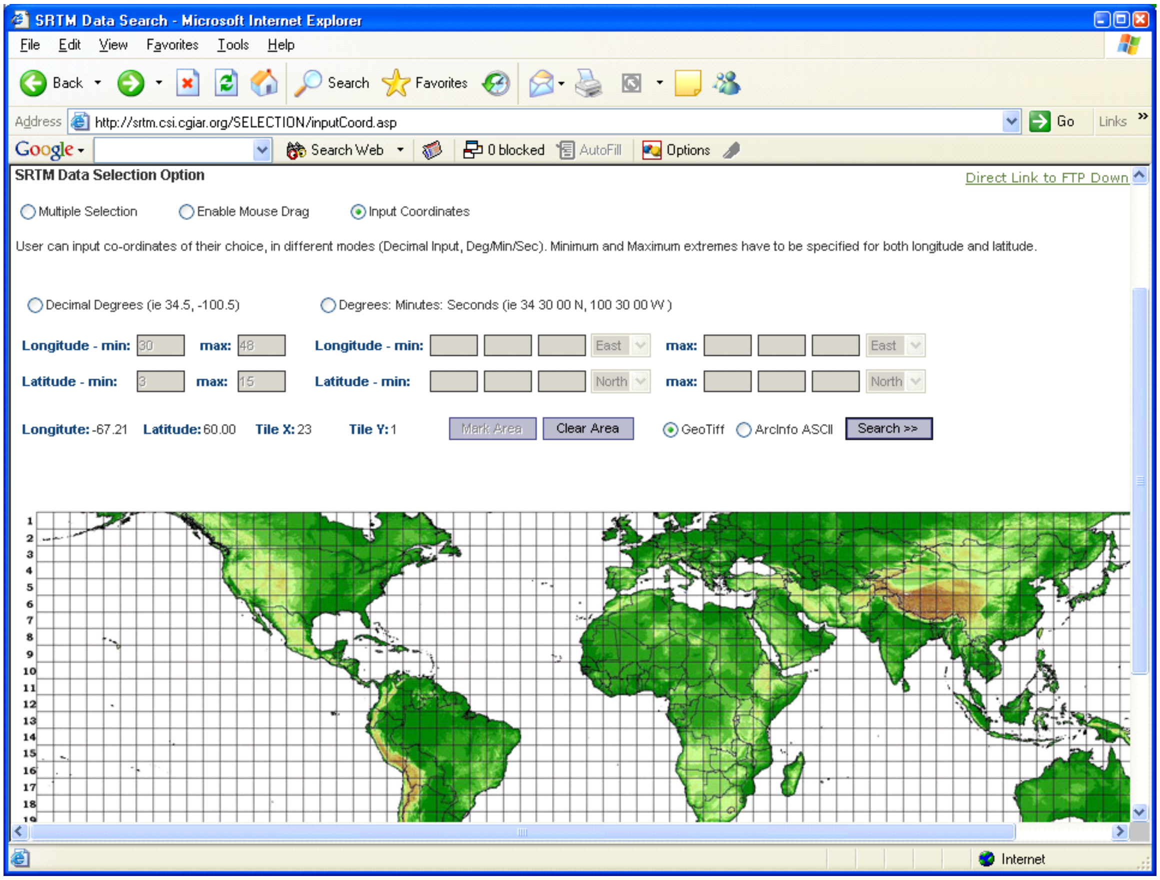


Figure 4.3 SRTM data search page in Microsoft Internet explorer (CGIAR,2005)

To select SRTM data for Ethiopia, enter the coordinates: 30-48° Longitude and 3-15° Latitude. Then select **Search**. This will select 12 tiles that can be readily downloaded as shown in Figure 4.4. The SRTM data from this option is in GeoTiff format.

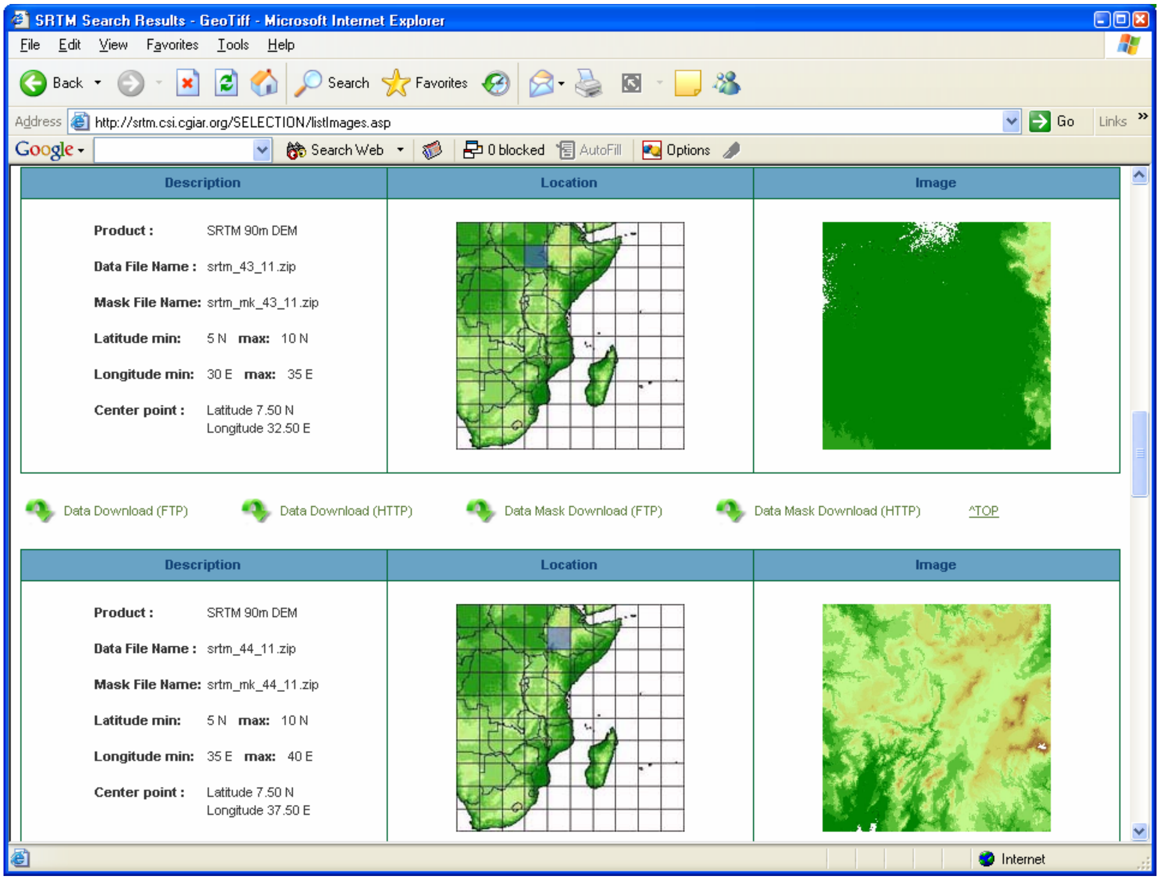


Figure 4.4 SRTM search results in GeoTiff format (CGIAR, 2005)

Alternatively, it is possible to select **Direct Link to FTP Download** and select and download all the tiles at once. In this case, Arc info ASCII option is checked instead of GeoTiff. This option is relatively time consuming and used to down load SRTM data for Ethiopia.

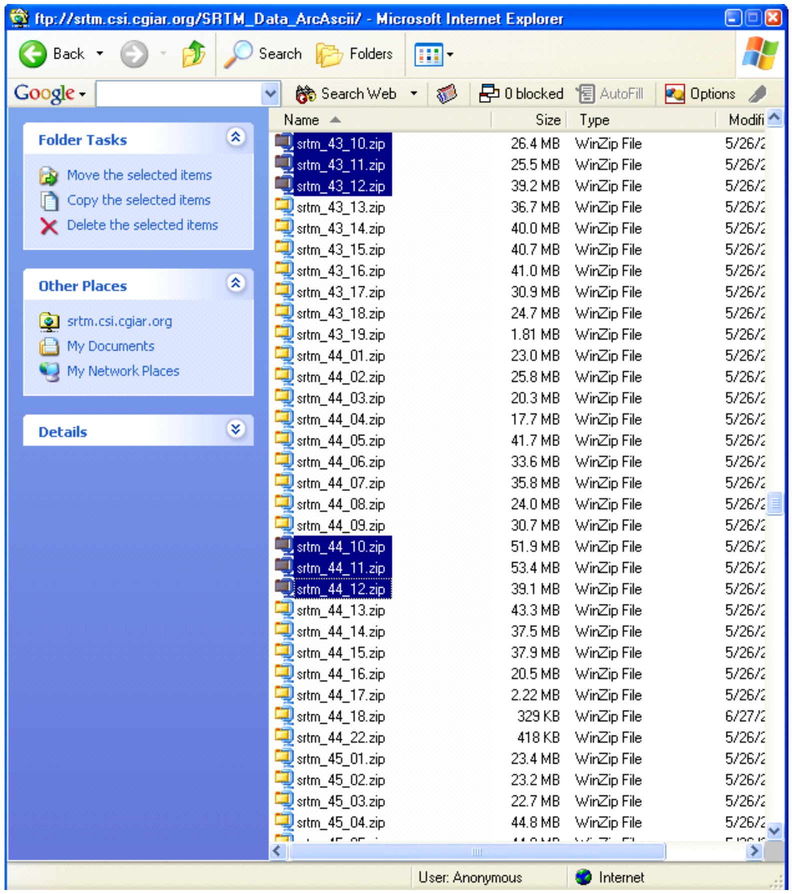


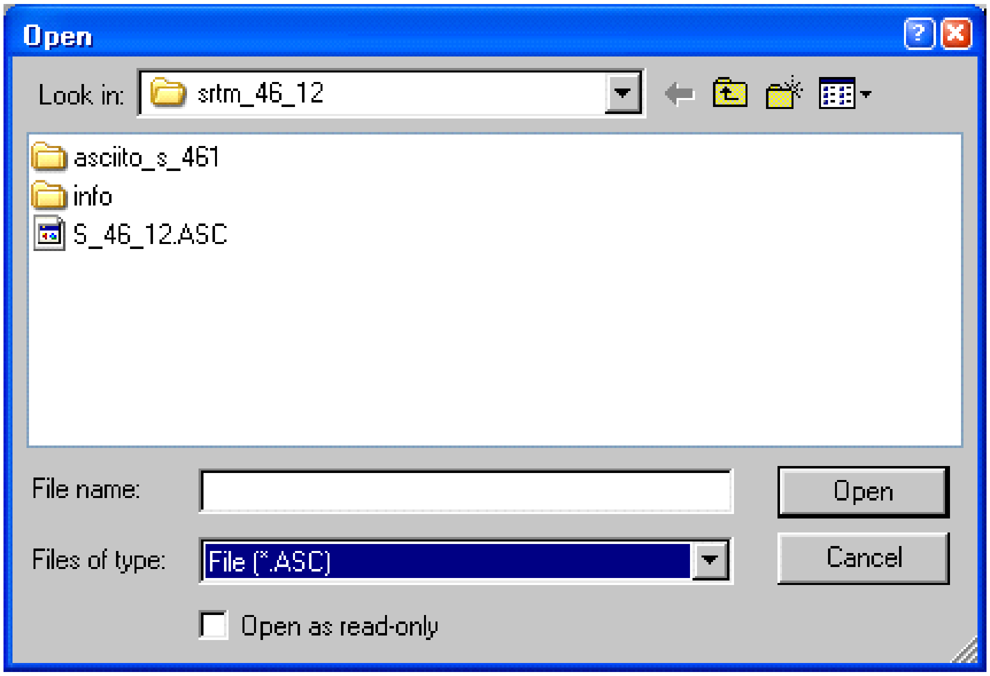
Figure 4.5 SRTM Data zip files in ASCII format (CGIAR, 2005)

Right clicking and selecting **Copy to Folder**, will select the folder where the SRTM zip files for selected coordinates to be downloaded. For instance, to download all the data for Ethiopia, the following zip files were selected: srtm_43_12.zip,srtm_44_12.zip,srtm_45_12.zip,srtm_46_12.zip, srtm_43_11.zip, srtm_44_11.zip,srtm_45_11.zip,srtm_46_11.zip,srtm_43_10.zip, srtm_44_10.zip, srtm_45_10.zip and srtm_46_10.zip as shown in Figure 4.5.

4.3 Convert ASCII to Raster Grids

The zip files from Figure 4.5 were unziped and the tiles from the downloaded files were saved in separate directories. In order to display the raster grids in ArcMap the following tool was used to convert **ArcASCII format:**

ArcMap: ArcToolbox: Conversion Tools: To Raster: ASCII to Raster



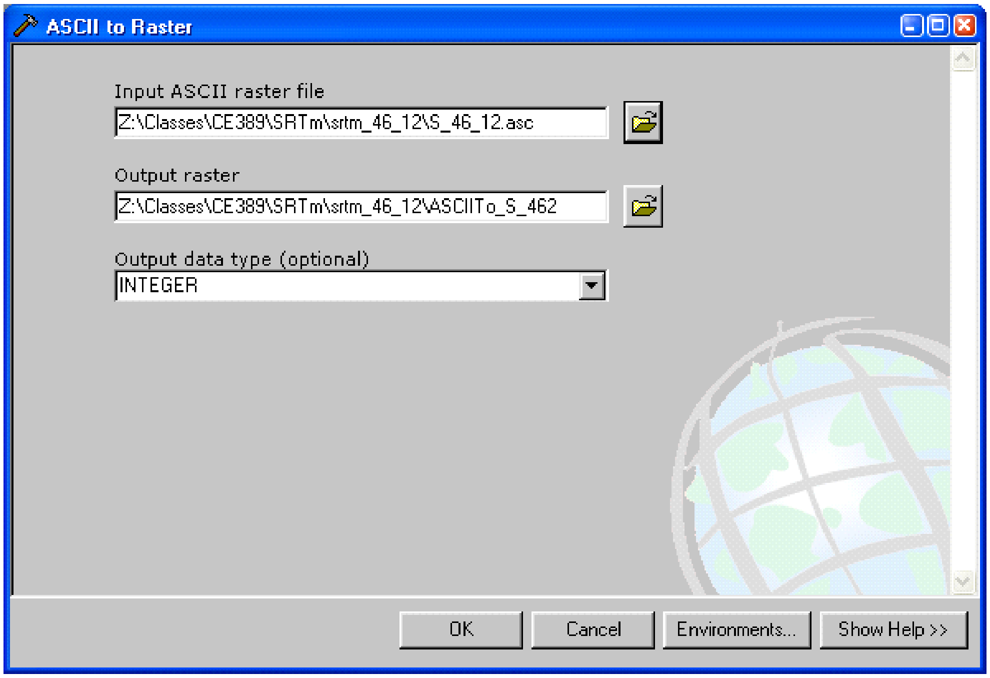


Figure 4.6 Converting files from ASCII to raster format.

After processing each of the four downloaded tiles, we have the result shown in Figure 4.7.

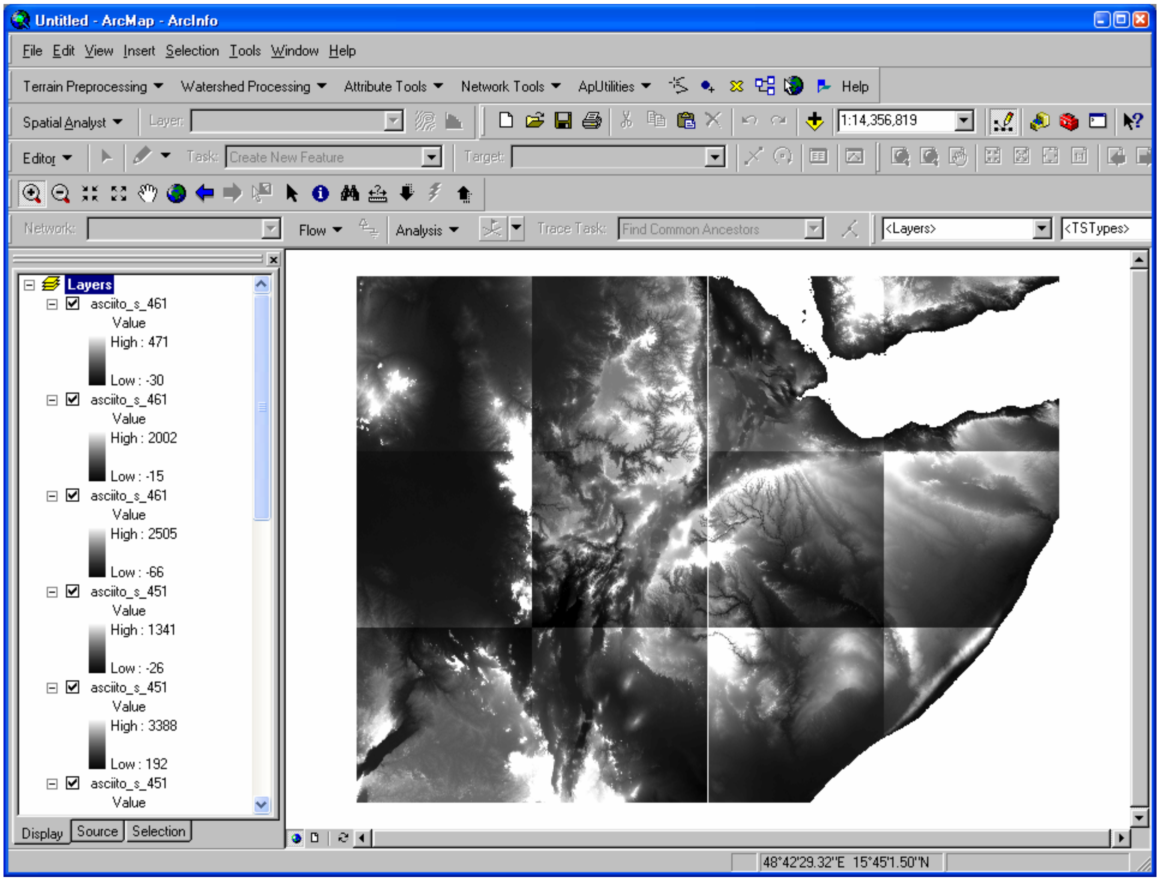


Figure 4.7 Tiles of rasters for SRTM 90m.

4.4 Mosaic Multiple Grids

Since there are 12 tiles Ethiopia, all the tiles were mosaiced together into a larger grid using ArcToolBox (in ArcCatalog or ArcMap). The following command will mosaic all the grids from N3E030 to N15E048 into a single grid :

ArcMap: ArcToolbox: Data Management Tools: Raster: Mosaic_to_New_Raster

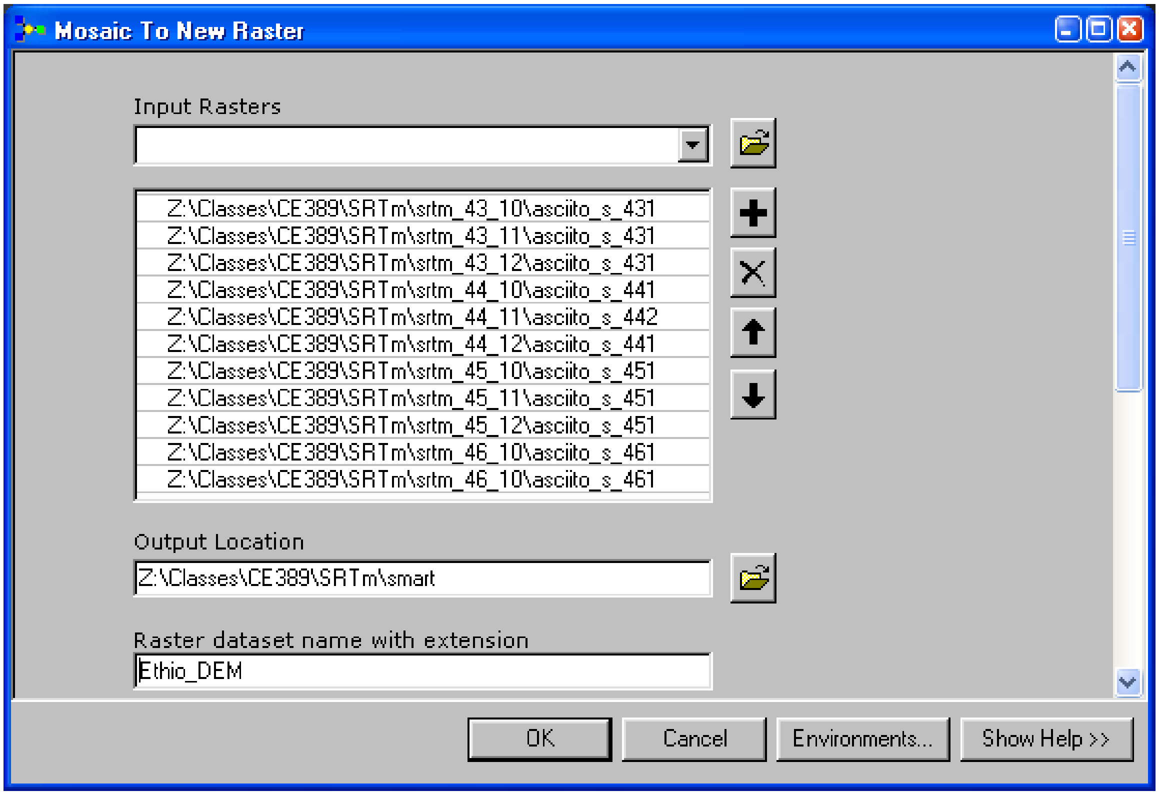


Figure 4.8 Mosiac to raster dialog box

Finally, the resulting DEM was added to the display. A single tile for the whole region as shown in Figure 4.8.

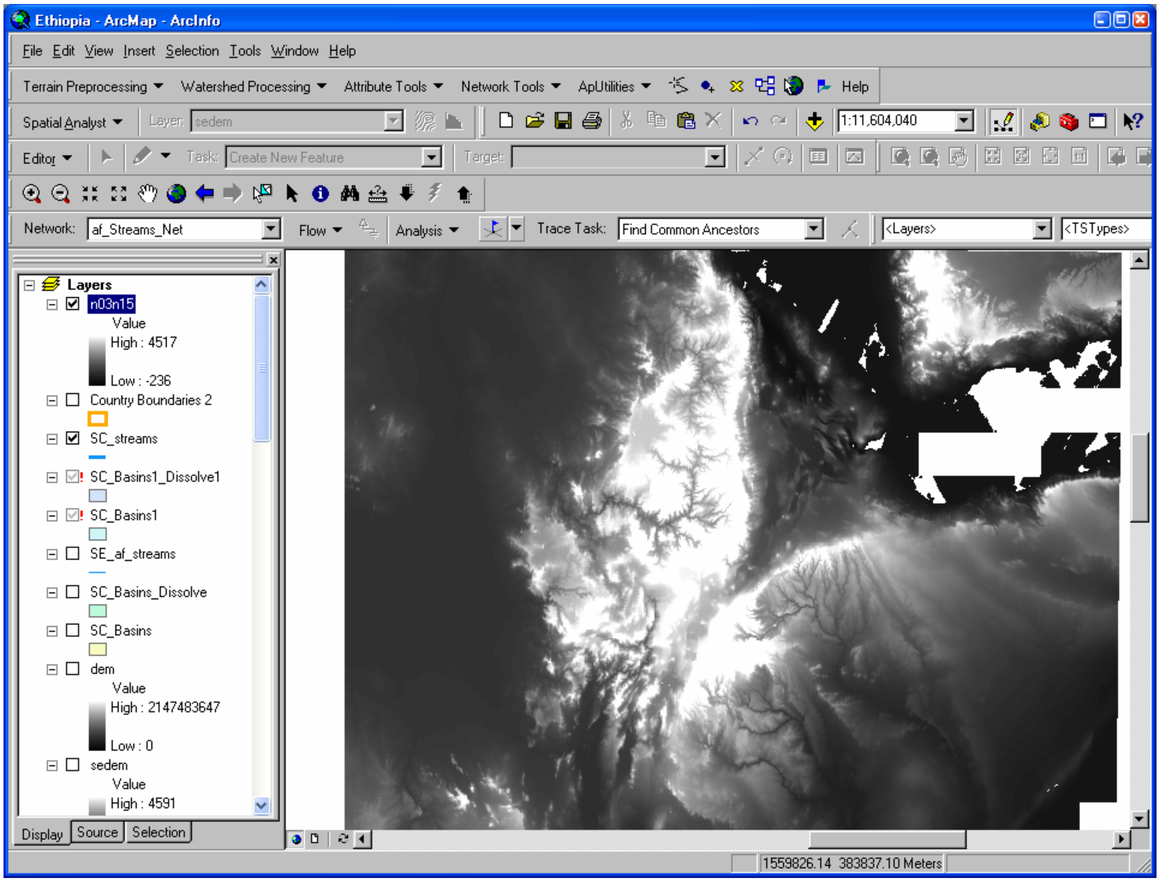


Figure 4.9 Mosaiced DEM of Ethiopia and its surroundings

4.5 Remove "NoData" Values from DEM

One of the problems that arises during mosaicing multiple grids together is that you can receive no-data values at the seams between the grids as shown in Figure 4.7. Cells with NoData value are those cells for which a valid value is not known such as a cell past the edge of a quadrangle. NoData and "0" (zero) are not the same- 0 is a valid cell value. These NoData areas will cause significant problems later during the terrain processing procedures and they must be patched.

This problem can be fixed by resetting the NoData values for the DEM grid in ArcView GIS using the following three methods:

0. For small holes, the NoData value can be set to zero using the following command to fill the holes:

ArcMap: Spatial Analyst: Raster Calculator:

Con (isnull ([raster]), 0, [raster])

2. For medium sized holes of NoData, the following command averages the values surrounding NoData and fills the holes:

ArcMap: Spatial Analyst: Raster Calculator:

Con(isnull([raster]), focalmean([raster] , rectangle, 5, 5), [raster])

This procedure had to be repeated several times to fill all of the holes. The resulting raster is in the floating-point format and it needs to be converted back to integer using the following command:

ArcMap: Spatial Analyst: Raster Calculator: Int([raster])

Then, the resulting grid is made **permanent** as follows:

ArcMap: Right Click on Grid: Make Permanent

3. Finally, larger holes, like in Denakil depression, can be filled by resampling from the old 1 km data from the following site:

http://edcdaac.usgs.gov/gtopo30/hydro/readme.asp#RasterDataFormats

The 1 km grid had to be transformed from “*.bil” form to a regular ARC/INFO grid with the command IMAGEGRID. IMAGEGRID does not support conversion of signed image data, therefore the negative 16-bit image values will not be interpreted correctly.

ARC: imagegrid [input bil file name] [in grid]

After running IMAGEGRID, an easy fix was accomplished using the following formula in GRID:

GTOPO30 Raster = con (in_grid >= 32768, in_grid - 65536, in_grid)

Clipping your basin DEM [Basin DEM Raster], and the 1 km DEM [GTOPO30 Raster], using the mask (see below) and the larger DEM

[Clipped_Basin_DEM_Raster] = Mask * [Basin_DEM_Raster]

[Clipped_GTOPO30_Raster] = Mask * [GTOPO30_Raster]

Resample the 1 km DEM **[Clipped GTOPO30 Raster] to** 90 m DEM using the following command:

Arc Toolbox: Raster: Resample ([Clipped_GTOPO30_Raster],

use cell size of your DEM)

Make it permanent with the name **[resample GTOPO30 Raster]**

Finally, fill the NoData in your DEM **[GTOPO30 Basin DEM Raster]** with the 1 Km DEM 90m data [resample GTOPO30 Raster]

ArcMap: Spatial Analyst: Raster Calculator:

Con(isnull([Clipped_Basin_DEM_Raster]),

[Resample_GTOPO30_Raster],

[Clipped_Basin_DEM_Raster]

Figure 4.8 final result of resampling

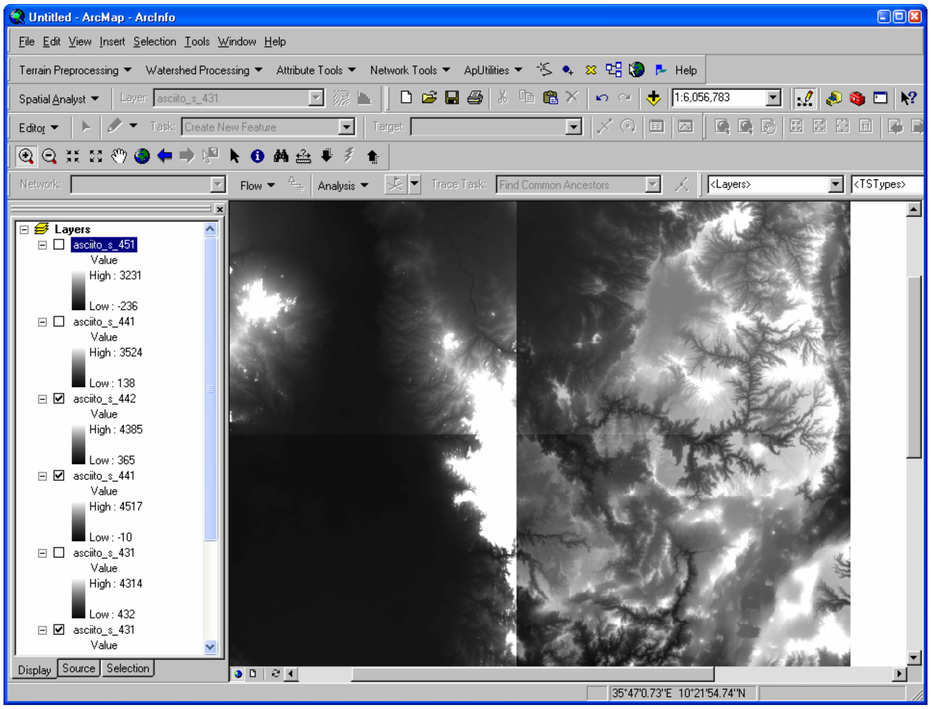


Figure 4.10 Seams at the boundary of quadrangle.

4.6 Define the Spatial Reference for the Grids

Spatial Reference provides the description of the reference frame for, and the means to encode, coordinates in a data set. Since the Spatial Reference of the gridsdiscussed in the previous section has yet been defined, it should be defined as follows :

ArcCatalog: Right Click on Grid: Properties Scroll down to "Spatial Reference"

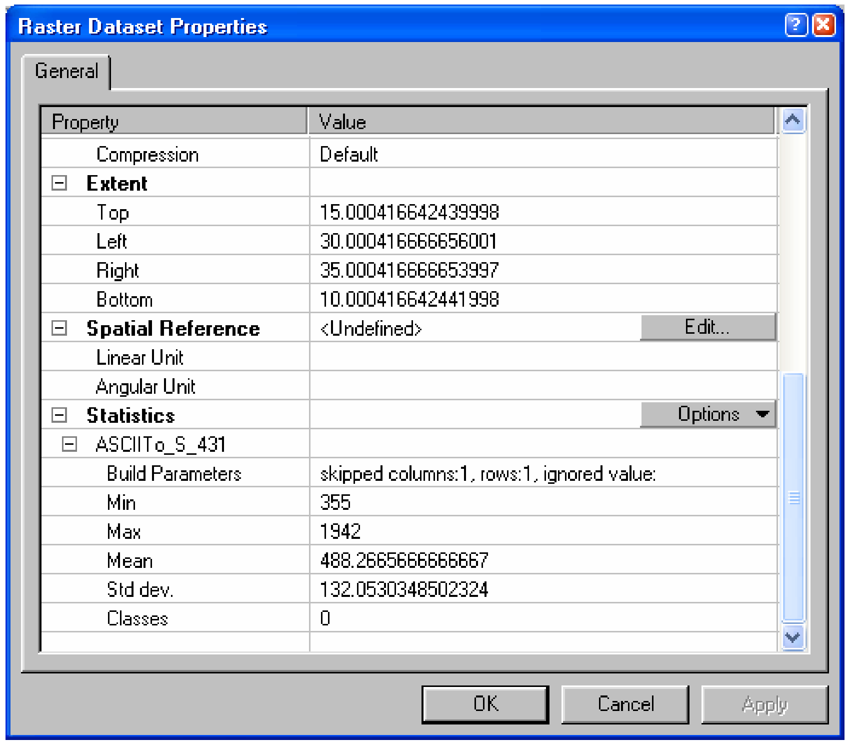


Figure 4.11 Raster dataset properties

Make sure the Define the “coordinate system interactively” option is selected.

Click **Next**.

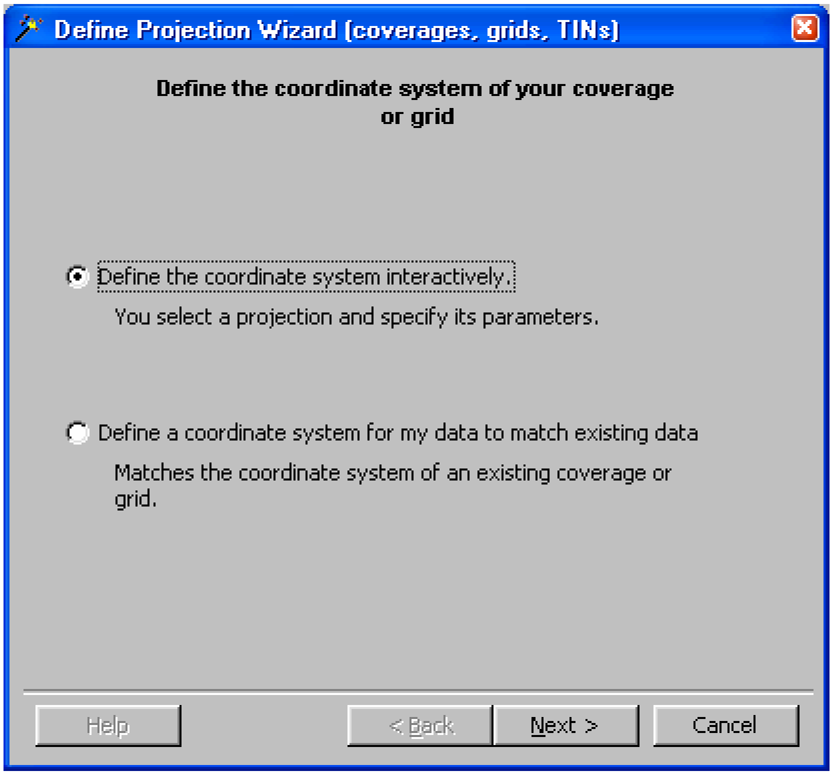
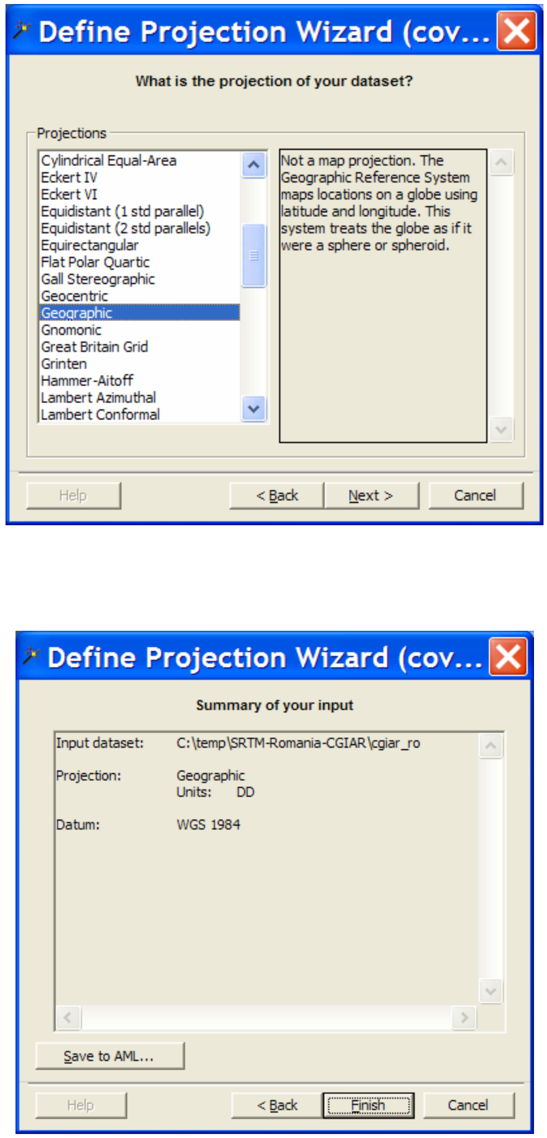


Figure 4.12 Define projection wizard

Select the **Geographic** projection with **decimal degrees** (DD) and a **WGS-1984** datum. This is not a map projection. The Geographic Reference System maps locations on a globe using latitude and longitude. This system treats the globe as if it were a sphere or spheroid.



Figures 4.13 Define projection wizard dialog boxes

Review the summary of the coordinate system that will be assigned to the grid. If you want to change an entry, go back through the wizard by clicking the Back button. Click Finish if you want to use this coordinate system. The coordinate system and its parameters appear in the Raster Properties dialog box. Click OK in the Raster Dataset

Properties dialog. This procedure defined the spatial reference of the Raster Dataset as shown in the following diagram.

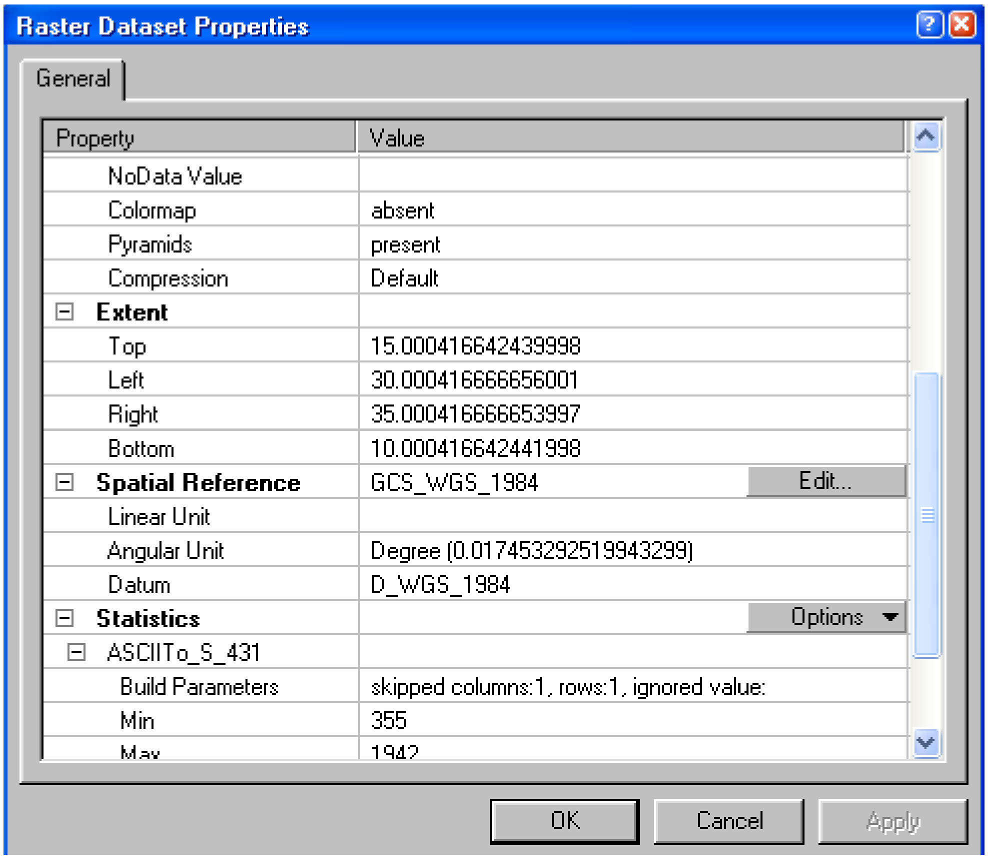


Figure 1.14 Raster dataset properties dialog box

4.7 Project Grids

Project the grids into your working projection with the appropriate cell size (e.g., 90m at the equator) as follows:

ArcMap or ArcCatalog: ArcToolbox: Data Management: Projections and Transformations: Raster: Project Raster

For this research, the Albers system was chosen as the Coordinate system in order that areas and distances are computed correctly later. The Albers System has the following properties

The Cell size: 92.076753327191767 m

Projection: Albers

Parameters:

False_Easting: 0.000000

False_Northing: 0.000000

Central_Meridian: 25.000000

Standard_Parallel_1: 20.000000

Standard_Parallel_2: -23.000000

Latitude_Of_Origin: 0.000000

Linear Unit: Meter (1.000000)

Geographic Coordinate System:

Name: GCS_WGS_1984

Angular Unit: Degree (0.017453292519943299)

Prime Meridian: Greenwich (0.000000000000000000)

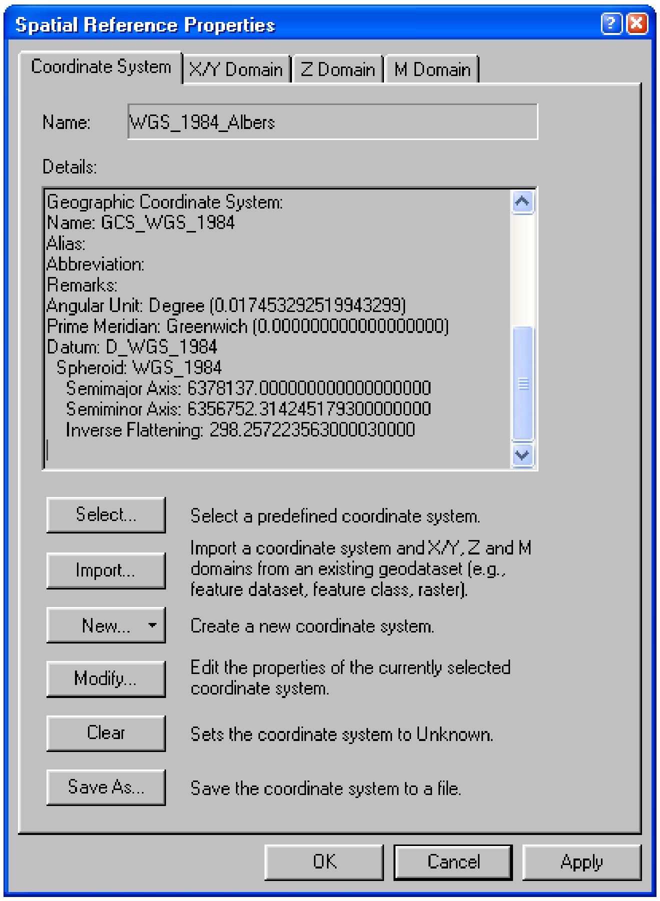
Datum: D_WGS_1984

Spheroid: WGS_1984

Semimajor Axis: 6378137.000000000000000000

Semiminor Axis: 6356752.314245179300000000

Inverse Flattening: 298.257223563000030000



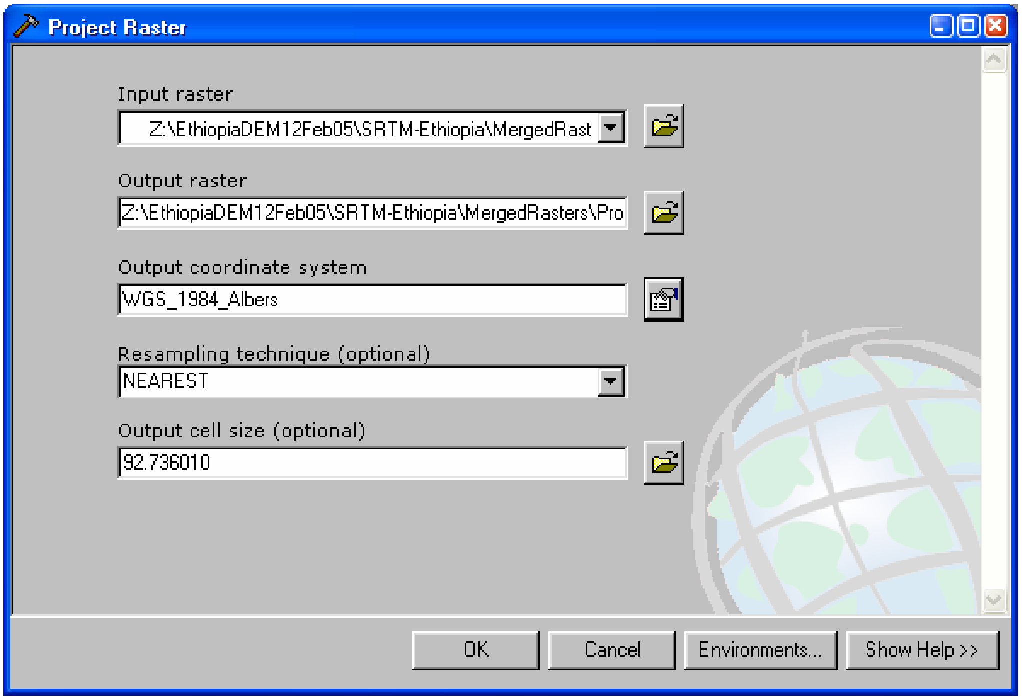


Figure 4.15 Project Raster dialog box

Click **OK** and the result is calculated

Open ArcMap. Find and display the new grid as shown in Figure 4.15.

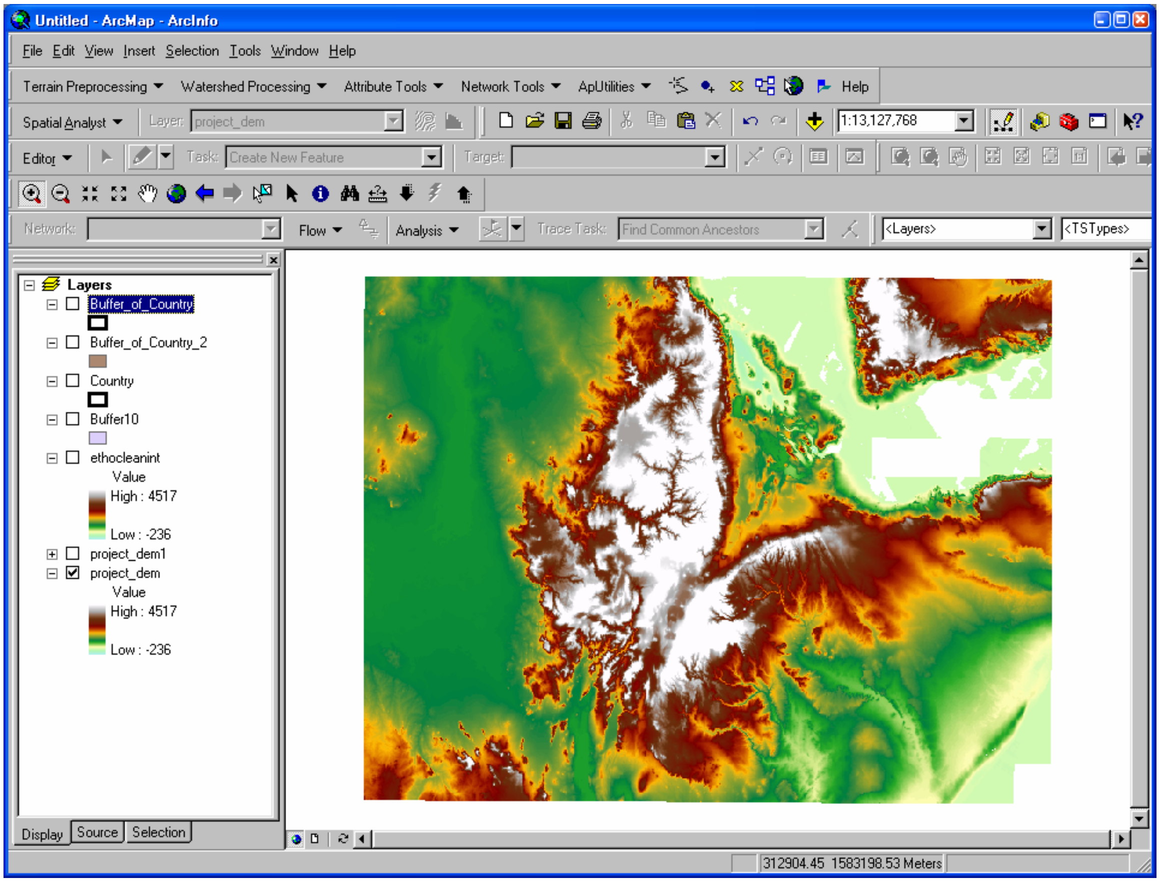


Figure 4.16 Regional DEM after projection

4.8 Make Buffer for Area of Interest

Create a new Geodatabase for the project: **Ethiopia_GDB.mdb.** Also, create a new FeatureDataset named **Base** in the new Geodatabase, with the same coordinate system as the Projected DEM from the previous section.

Export the Ethiopia country boundary polygon from the NEW_DEM Coverage into the Base FeatureDataSet, name it Ethiopia _Boundary.

Display the **Ethiopia_Boundary** polygon on the map.

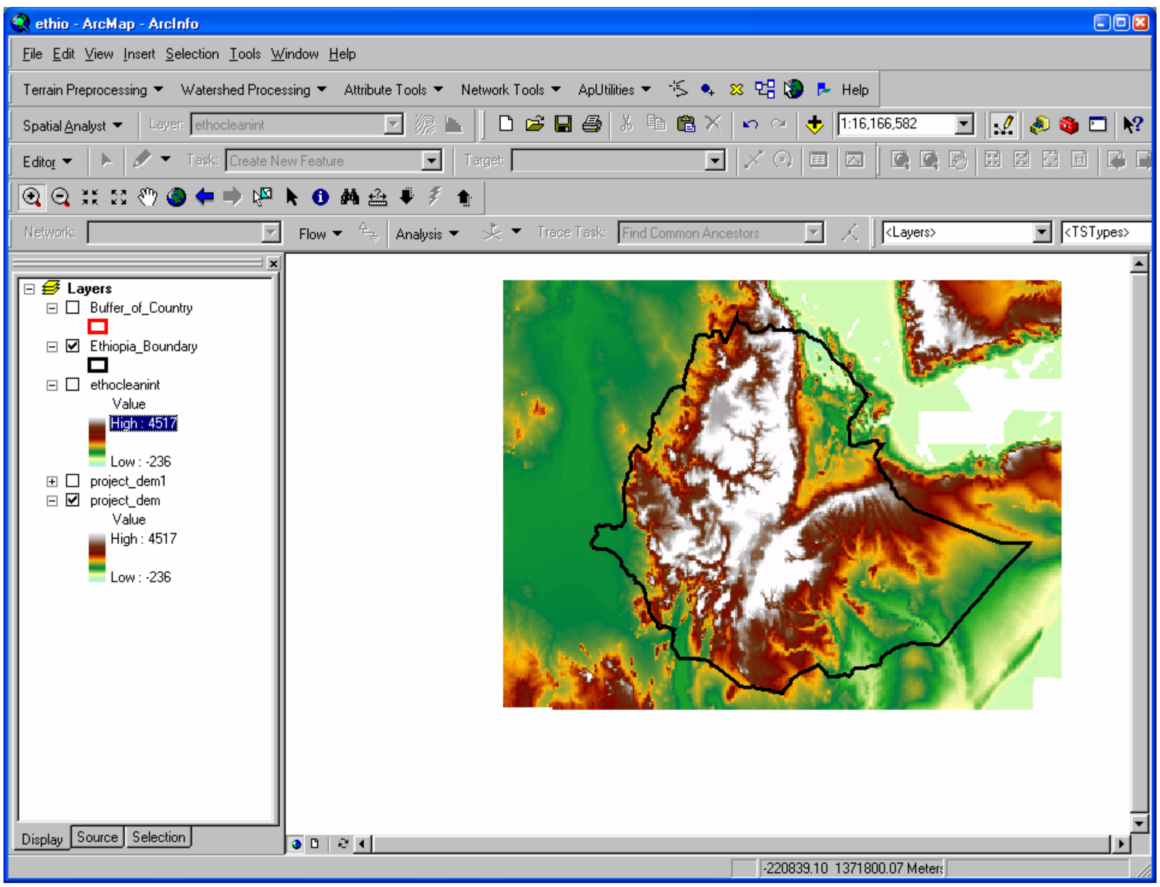


Figure 4.17 Regional DEM and Ethiopia country boundary

Create a 50-km buffer polygon [**Buffer_of_Ethiopia_Boundary**] around the boundary using buffer wizard as follows:

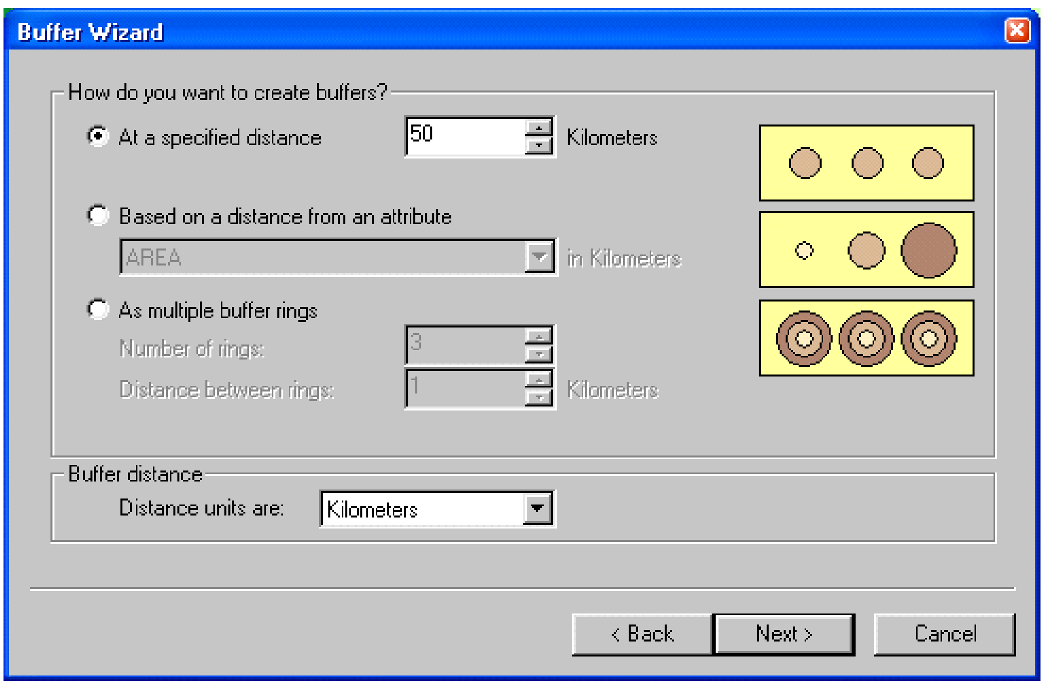
ArcMap: Tools: Buffer Wizard

Distance: 50 km

Dissolve: yes

Outside and include inside

Location and name: eg., "[Buffer_of_Ethiopia_Boundary]"



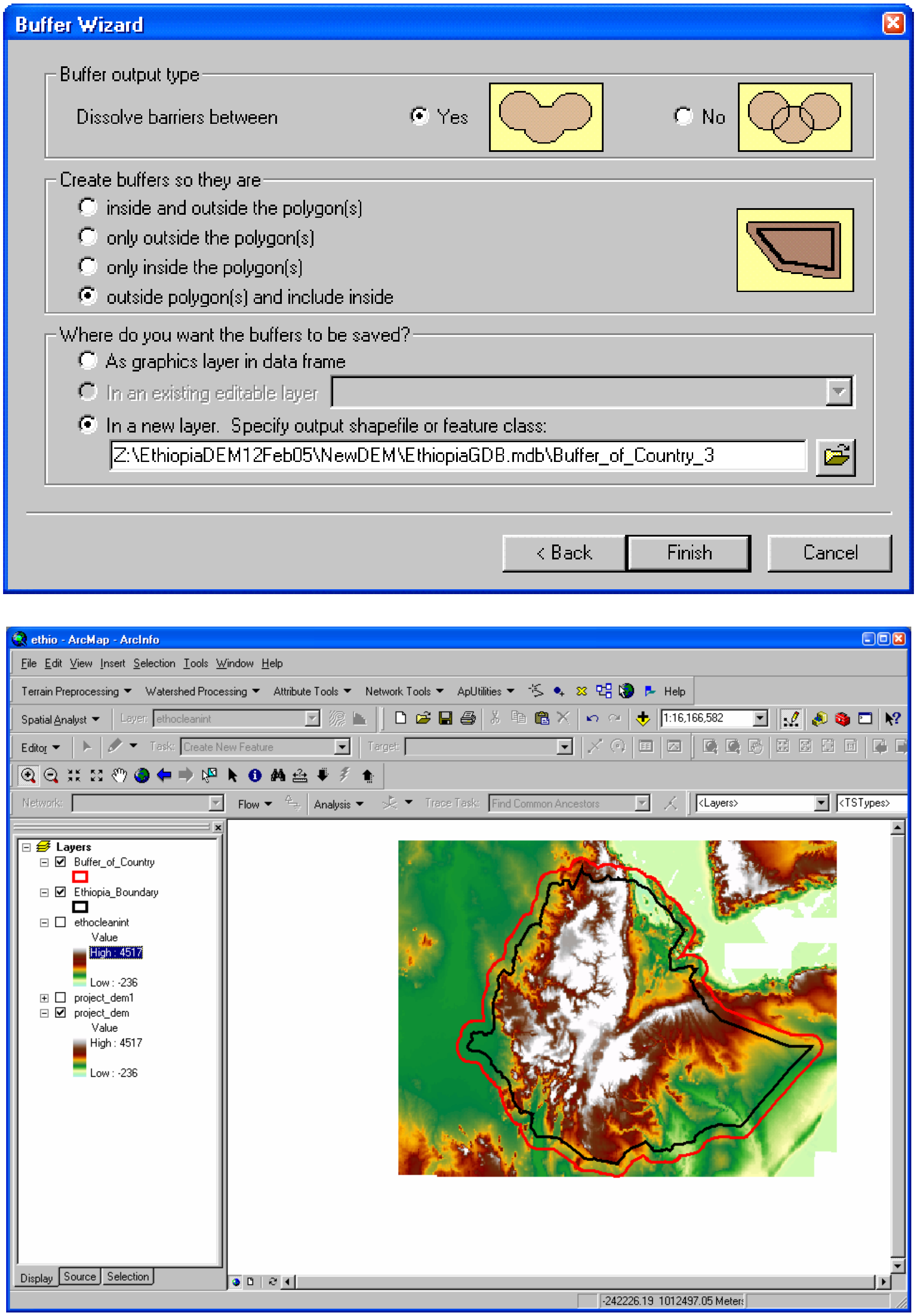


Figure 4.18 Buffer wizards dialog box

Add a field of “One” to [**Buffer_of_Ethiopia_Boundary**]

ArcMap: Select [Buffer_of_Ethiopia_Boundary]: Right Click: Open Attribute Table

Attribute Table: Options: Add Field: Name [One]: Short Integer

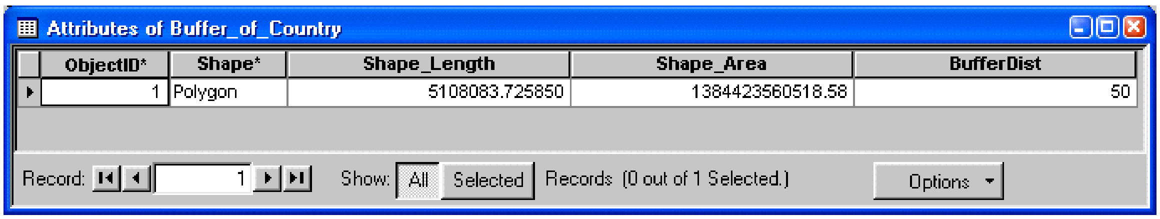
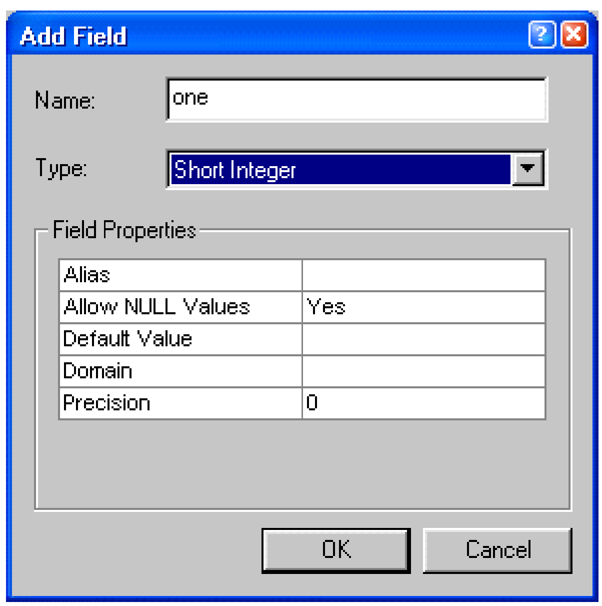


Figure 4.19 Attribute table of Buffer of Ethiopia with field one

Attribute Table: Select Field [One]: Right Click: Calculate Values

Calculate Values: Value of One = 1



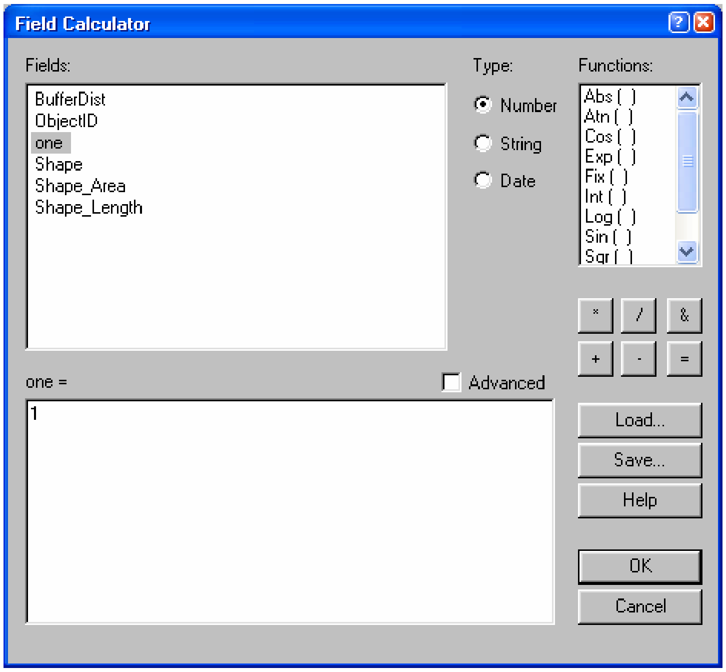


Figure 4.20 Field Calculator dialog box

Create a raster [Buff_Raster] from [**Buffer_of_Ethiopia_Boundary**] using the following commands:

ArcMap: Spatial Analyst: Convert: Features-to-Raster

Input Feature: [Buffer_of_Ethiopia_Boundary]

Attribute to Use: [One]

Cell size = 92.076753327191767

Location and name: eg., "[Buff_Raster]"

Clip your basin DEM raster [Dem] to the area of the [Buff_Raster] by multiplying the rasters:

ArcMap: Spatial Analyst: Raster Calculator

[Buff_Raster] * [Dem]

Make the temporary raster permanet.

CHAPTER 5: WATERSHED AND STREAM NETWORK DELINEATION

5.1 Introduction

The previous chapter discussed how elevation data could be obtained from SRTM data for Ethiopia. This chapter illustrates how to use the major functionality available in the Arc Hydro tools for Raster analysis and perform drainage analysis on a terrain model using the Digital Elevation Model of Ethiopia and Hydro 1 K streams. The Arc Hydro tools are used to derive several data sets that collectively describe the drainage patterns of the catchment. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data will then be used to develop a vector representation of catchments and drainage lines from selected points.

5.2 Hydro Administrative regions of Ethiopia

Based on the flow direction of the streams, the country is divided into six hydro administrative regions:

- The Blue Nile region (BN)
- The South West region (SW)
- The South Central region (SC)
- The South East region (SE)
- The Rift Valley region (RV)
- The North East-West region (NEW)

Since the Blue Nile region is the source of nearly 85 % of the Nile water and vigorously erodes the country's fertile soil, water shed and stream network delineation is shown for this region. But, a similar procedure was followed for the rest of five hydro administrative regions to develop the stream network delineation for the whole country.

5.3 Setting up the Arc Hydro tools

The Arc Hydro Toolset is a suite of tools that 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 Arc Hydro tools were installed from Center for Research in Water Resources (CRWR) web site (http://www.crwr.utexas.edu/gis/gishydro04/index.htm).

The existing data for the Blue Nile (BN) basin, including bn_dem1 and BN hydro 1k streams, were added into ArcMap document and saved before the analysis of the dataset using Arc Hydro tools as shown in Figure 5.1. The procedure of getting the blue Nile Basin DEM is explained in Appendix A. Similar procedure was used to obtain the DEM for the rest of the Hydro Administrative regions.

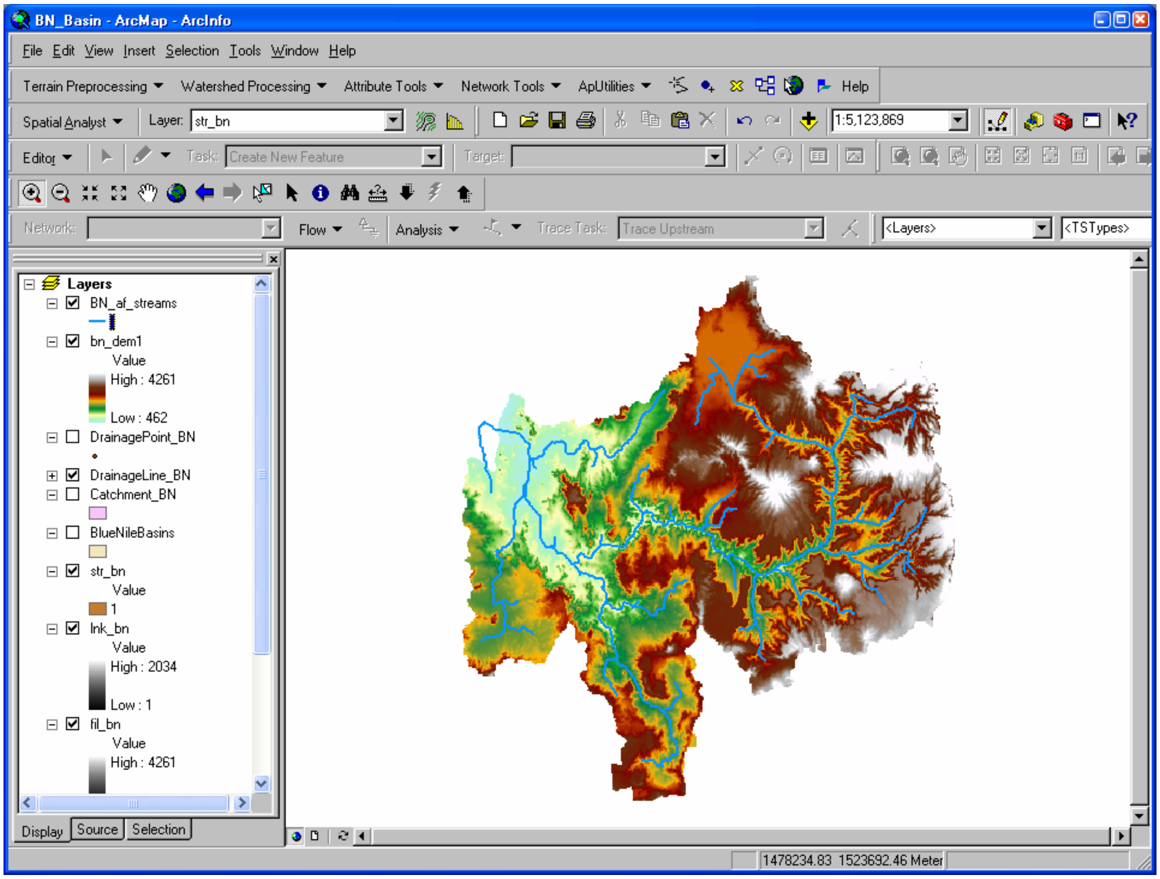


Figure 5.1 the outline of Blue Nile DEM and hydro 1k streams

5.4 Terrain Processing

The purpose of terrain preprocessing is to perform an initial analysis of the terrain and to prepare the dataset for further processing. Once preprocessed, the DEM and its derivatives can be used for efficient watershed delineation and stream network generation.

All the steps in the Terrain Preprocessing menu were performed in sequential order, from top to bottom. All of the preprocessing had to be completed before Watershed Processing functions could be used (Maidment, 2004).

5.4.1 DEM RECONDITIONING

The DEM Reconditioning function (Terrain Preprocessing menu) modifies Digital Elevation Models (DEMs) by imposing linear features onto them (burning/fencing). This function is an implementation of the AGREE method developed by Ferdi Hellweger at the University of Texas at Austin in 1997.

5.4.2 FILL SINKS

The Fill Sinks function (**Terrain Preprocessing** menu) fills 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. This function produced a Hydro DEM where sinks didn’t exist (Figure 5.2).

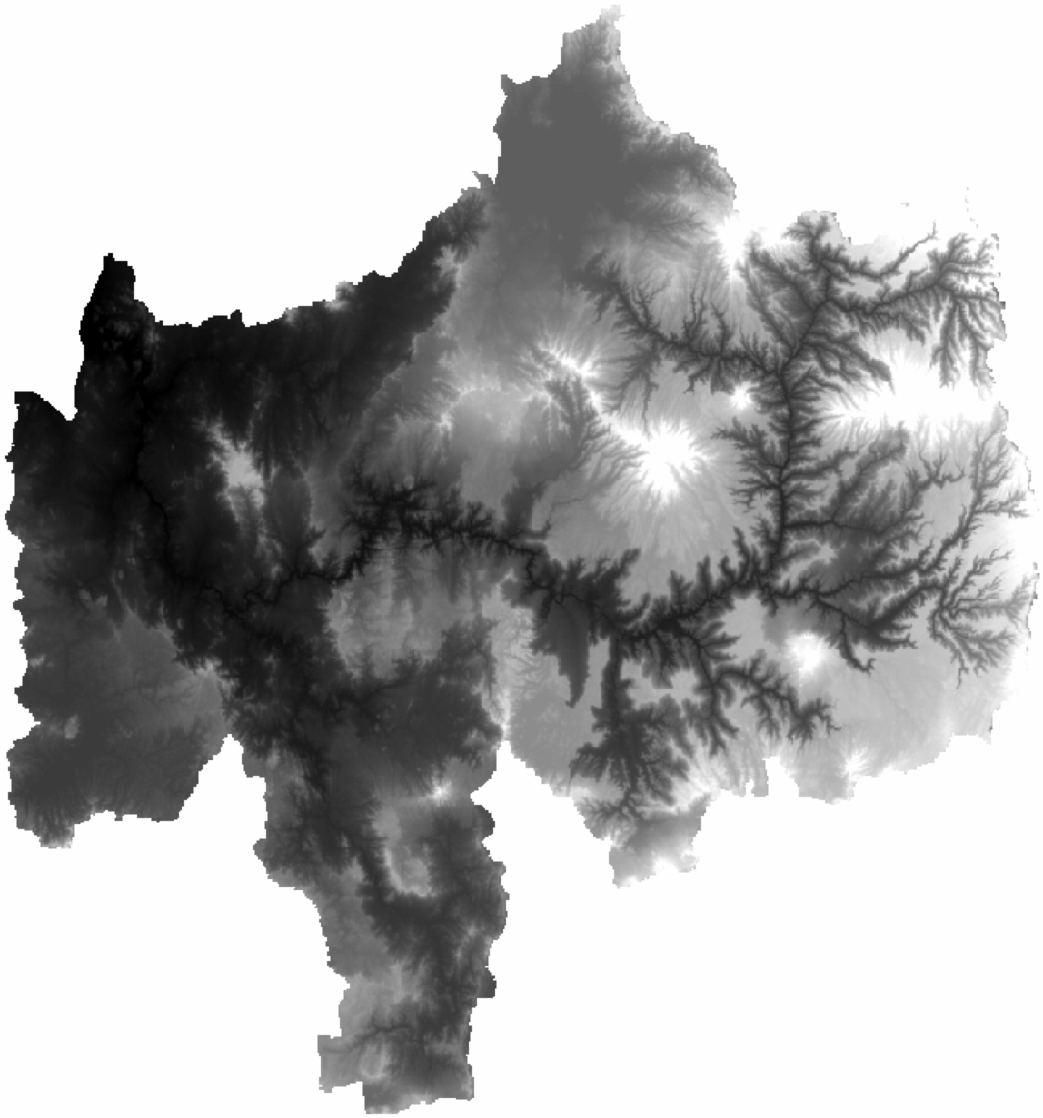


Figure 5.2 Blue Nile DEM after sinks have been filled

5.4.3 FLOW DIRECTION

This function computes the flow direction in a given grid by using "Fil_bn" hydro DEM as an input (Figure 5.3). The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.

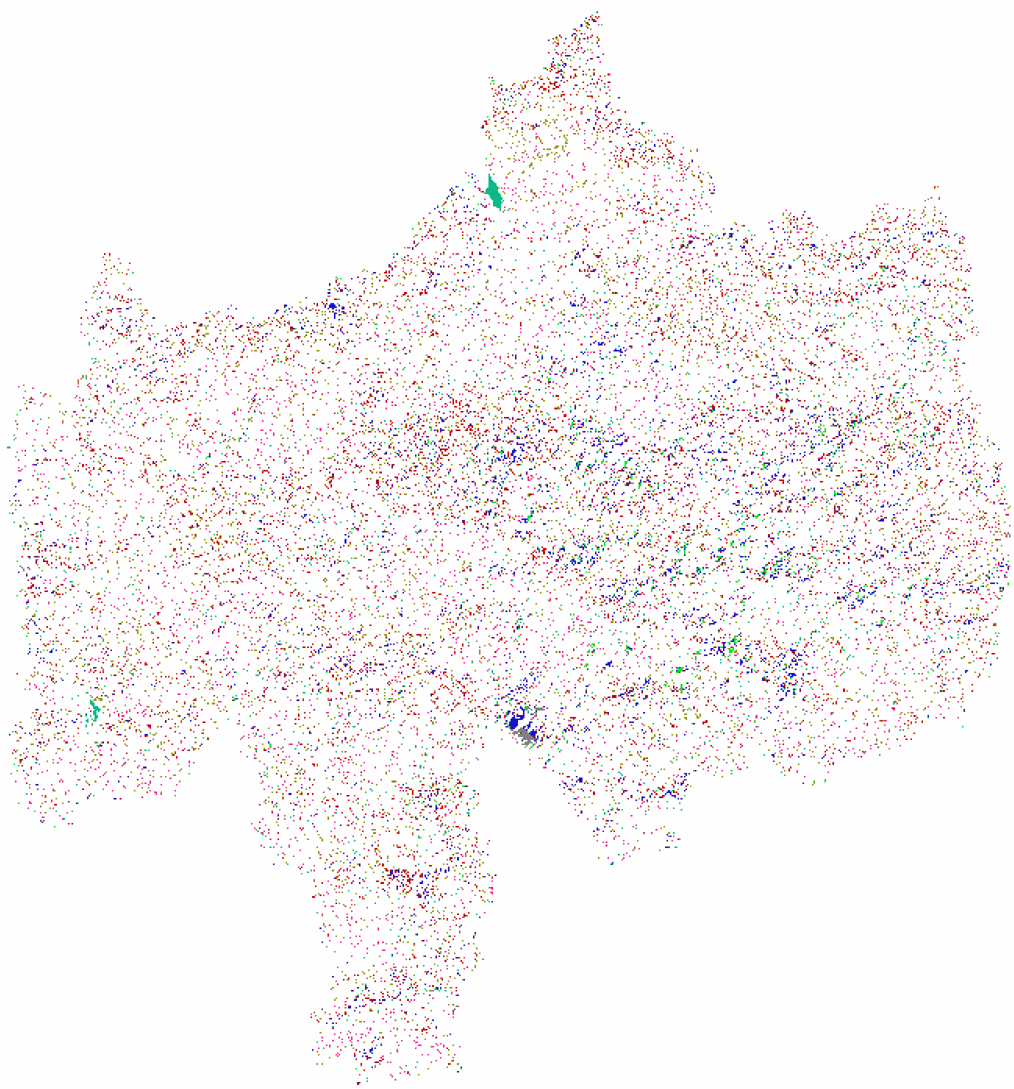


Figure 5.3 Flow direction grids for Blue Nile Basin

4.3.3 FLOW ACCUMULATION

This function takes the flow accumulation grid as an input. It computes the associated flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid as shown in Figure 5.4.

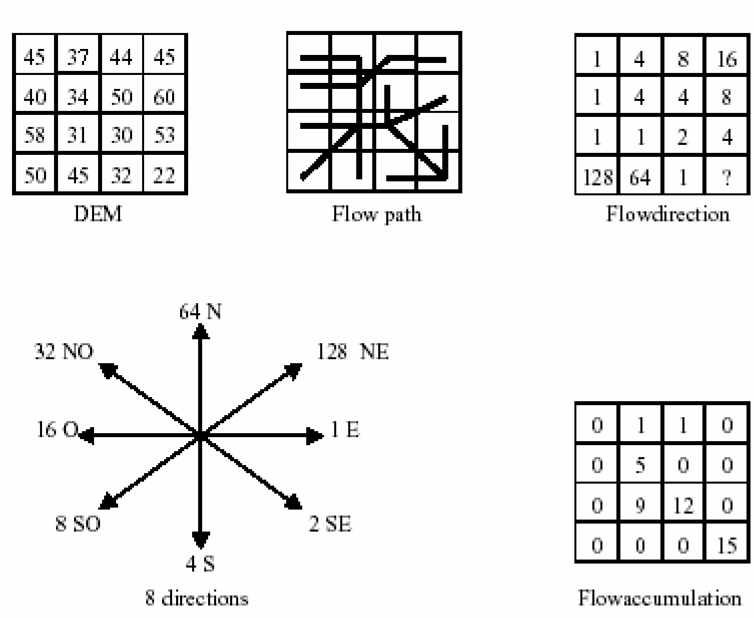


Figure 5.4 Flow direction and Flow accumulation models (Source Arc Hydro help)

The output of flow accumulation grid is shown in Figure 5.5.

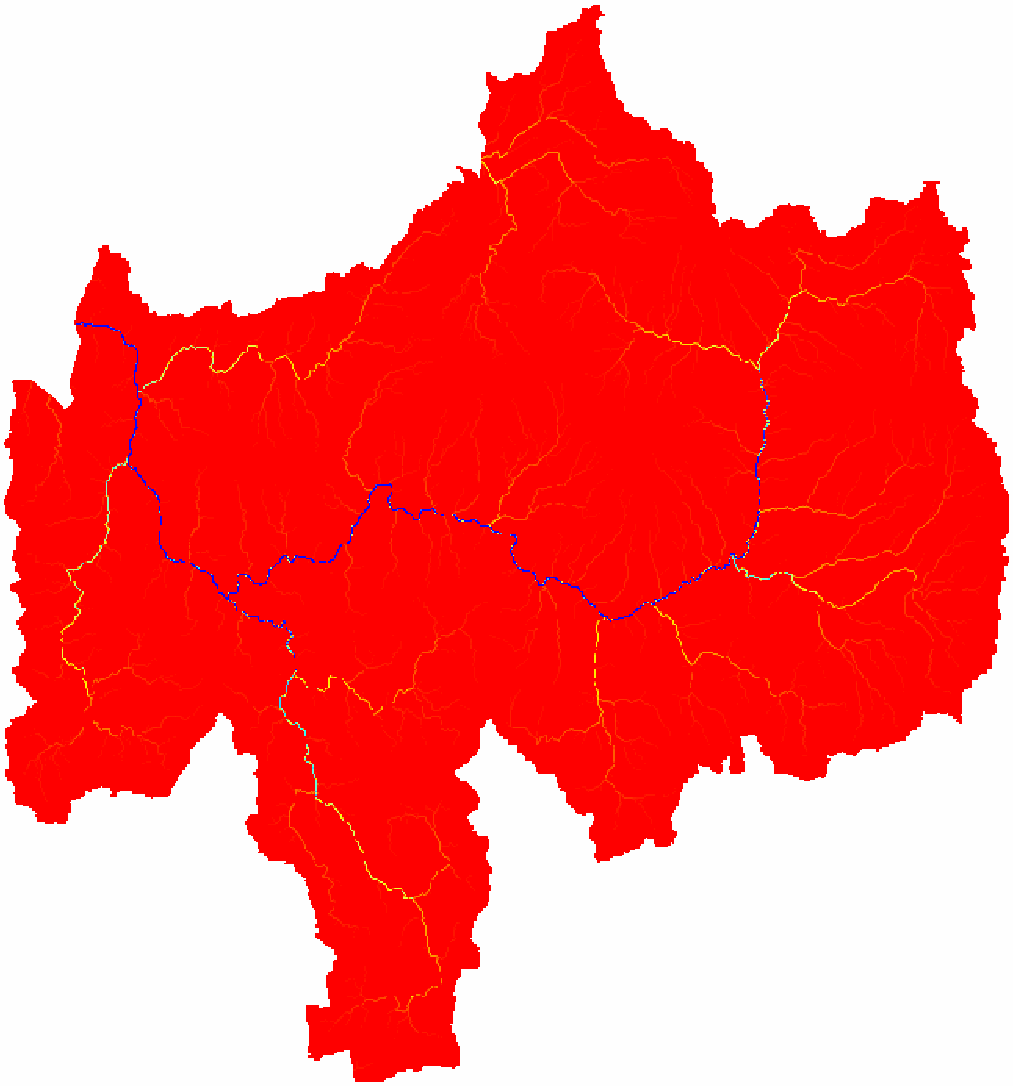


Figure 5.5 Flow accumulation grids for Blue Nile Basin

4.3.3 STREAM DEFINITION

This function takes the flow accumulation grid as an input and generates a Stream Grid for a user- defined threshold (Figure 5.6). The resulting stream grid contains a value of "1" for all the cells in the input grid that have a value greater than the given threshold. All other cells in the Stream Grid contain no data.

Figure

5.6 Stream definition grids for Blue Nile basin

5.4.6 STREAM SEGMENTATION

The Stream Segmentation function creates a grid of stream segments that have a unique identification (Figure 5.7). 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.

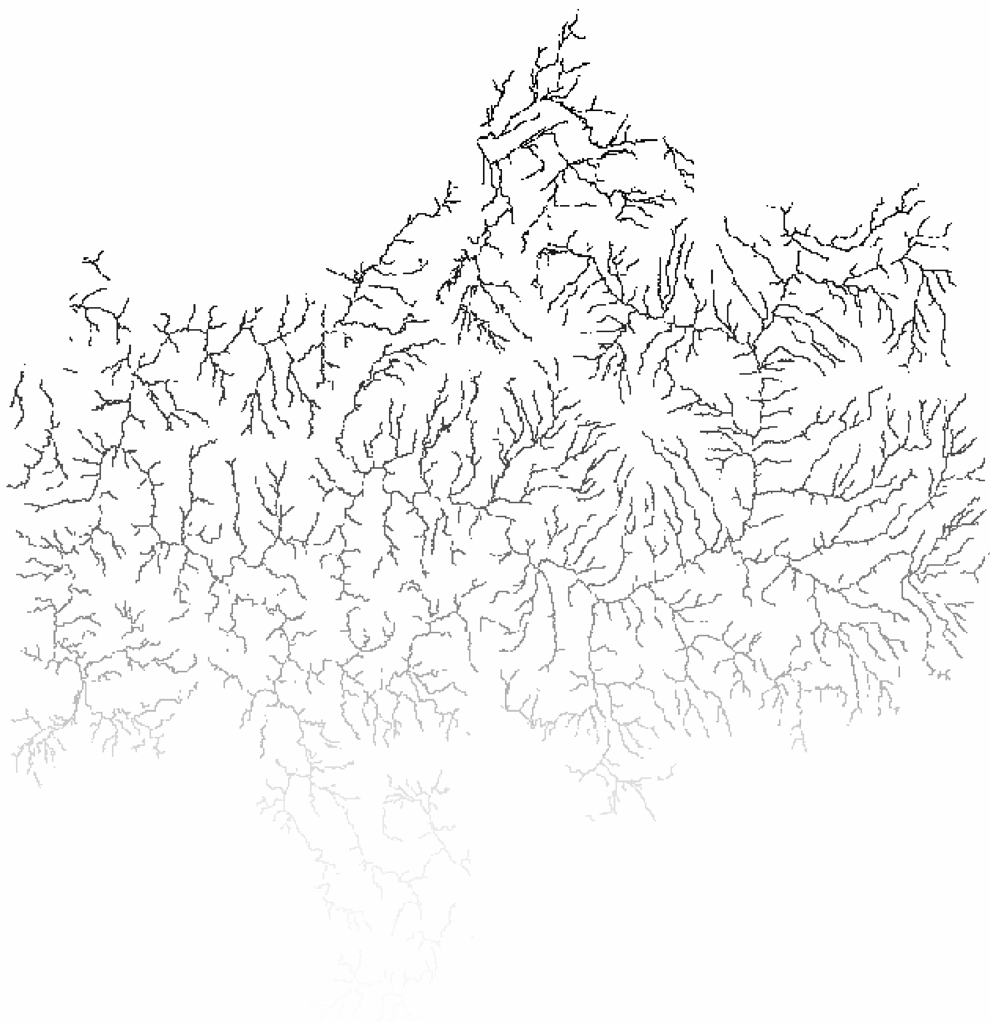


Figure 5.7 Stream segmentation grids for Blue Nile Basin

5.4.7 CATCHMENT GRID DELINEATION

The Catchment Grid Delineation 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. The output from catchment grid delineation is shown in Figure 5.8.

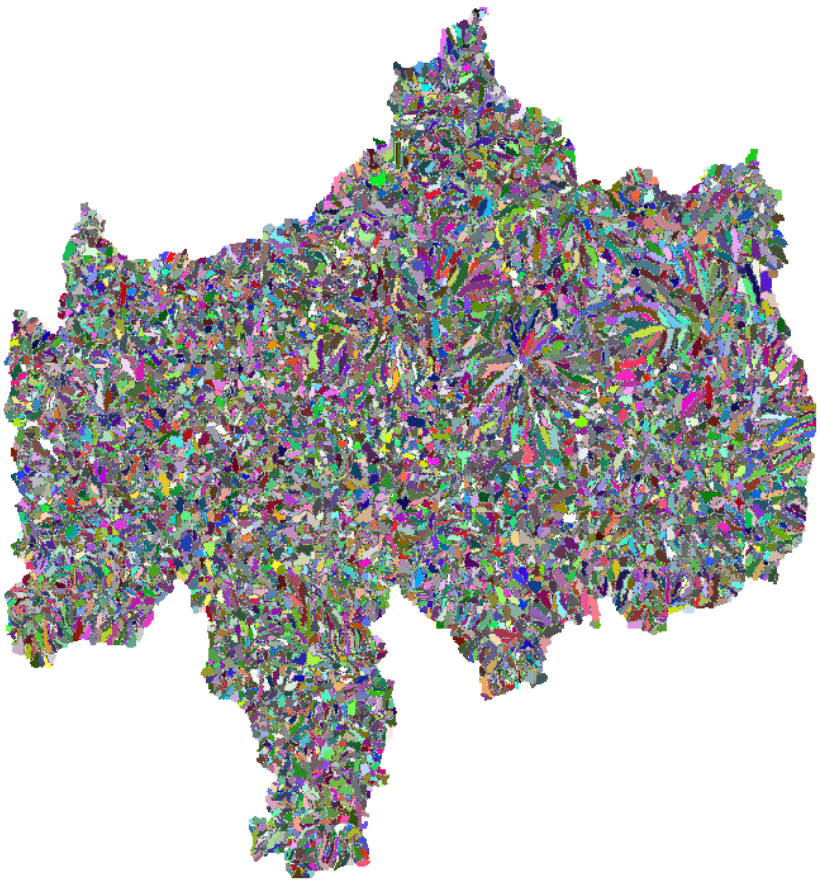


Figure 5.8 Catchment grid delineation grids for Blue Nile Basin

5.4.8 CATCHMENT POLYGON PROCESSING

The Catchment Polygon Processing function takes as input a catchment grid and converts it into a catchment polygon feature class. The adjacent cells in the grid that have the same grid code are combined into a single area, whose boundary is vectorized. The output from catchment polygon processing is shown in Figure 5.9.

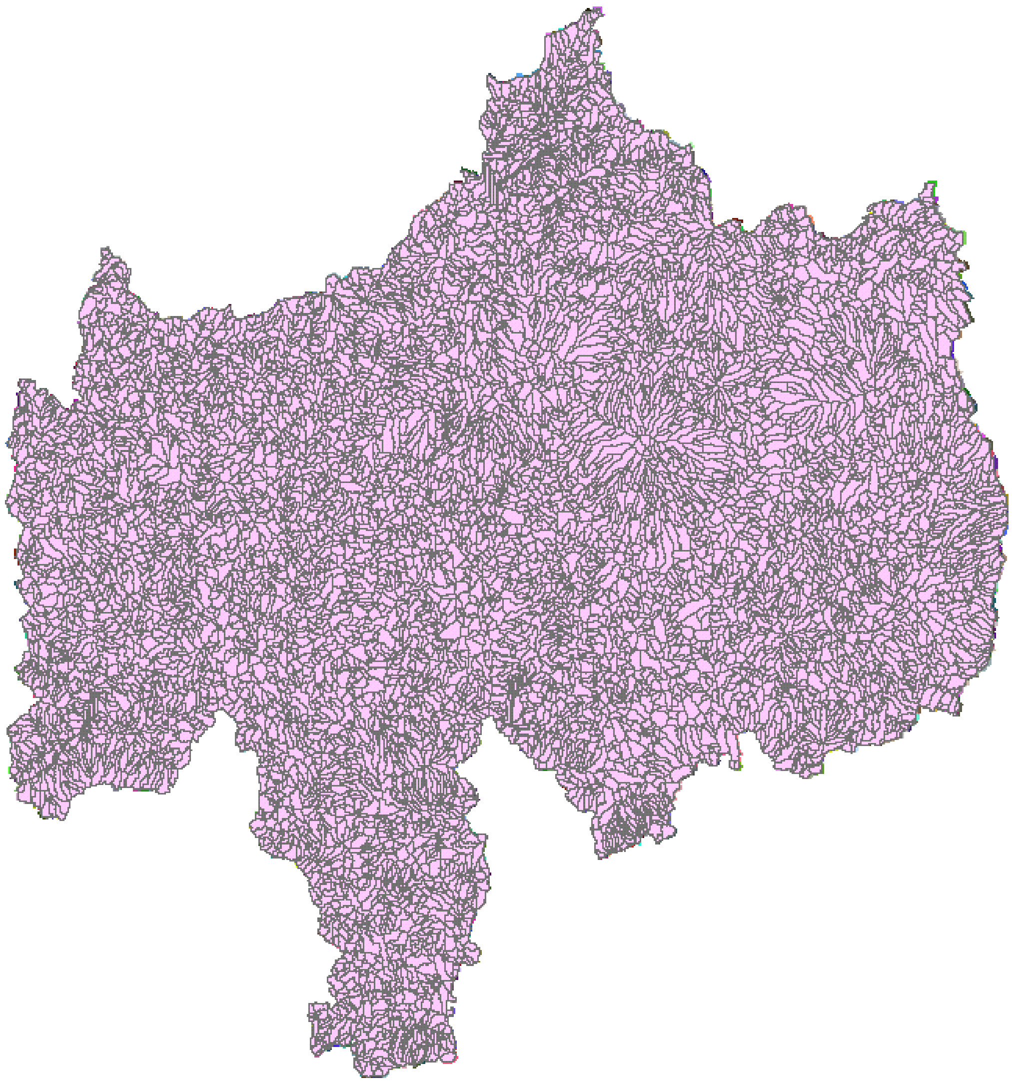


Figure 5.9 Catchment polygon processing grids for Blue Nile Basin

5. 4.9 DRAINAGE LINE PROCESSING

The Drainage Line Processing 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. The output from Drainage line processing command is shown in Figure 5.11.

Figure 5.10 Drainage line processing grid for Blue Nile basin

5.4.10 DRAINAGE POINT DELINEATION

This function generates the drainage points associated with the catchments. The fields created by this function are:

1. **HydroID**: Unique identifier of the drainage point in the Hydro database. System generated.
2. **GridID**: GridID of the catchment draining to the drainage point.
3. **DrainID**: HydroID of the catchment draining to this drainage point

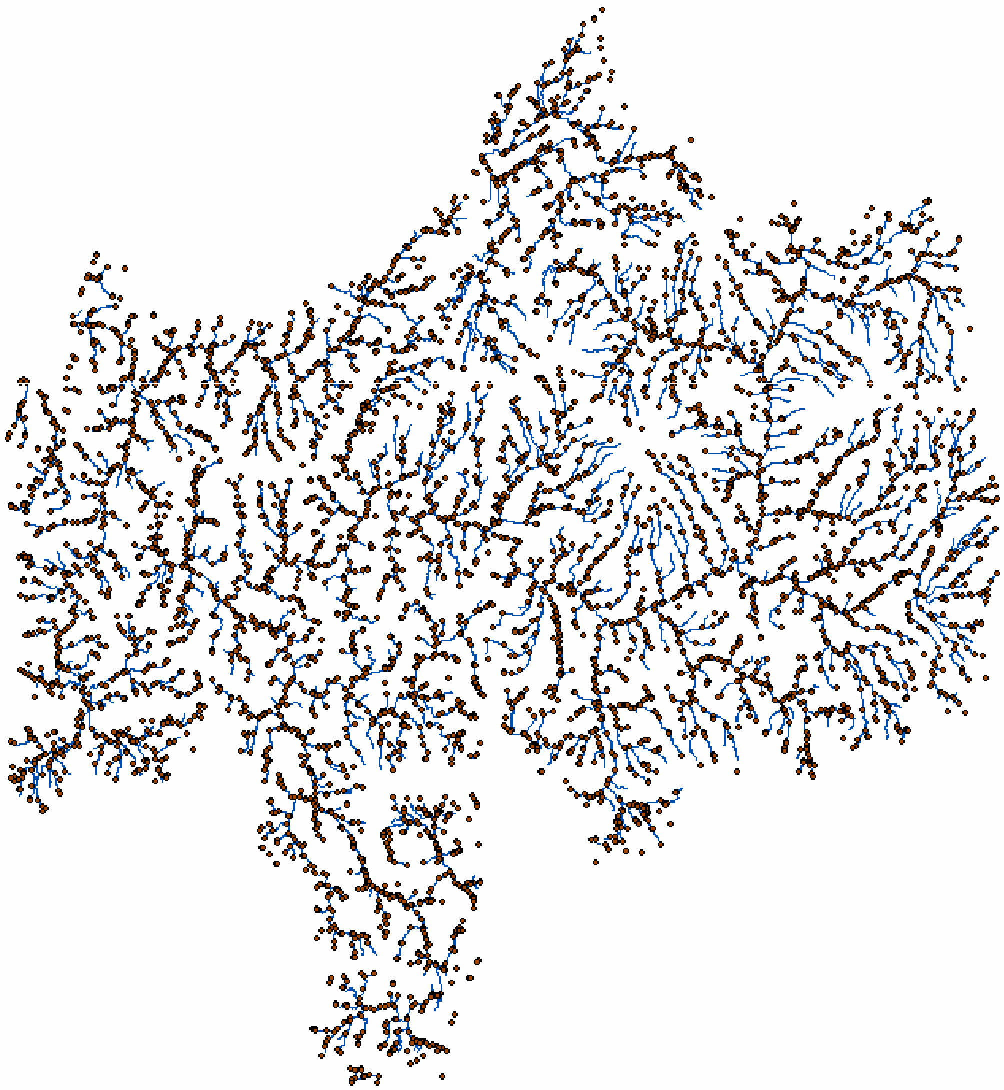


Figure 5.11 Drainage point processing grid for Blue Nile Basin

Similar procedures were followed to generate the catchments and streams lines for the other five Hydro Administrative regions of Ethiopia. The final output is shown in Figure 5.13.

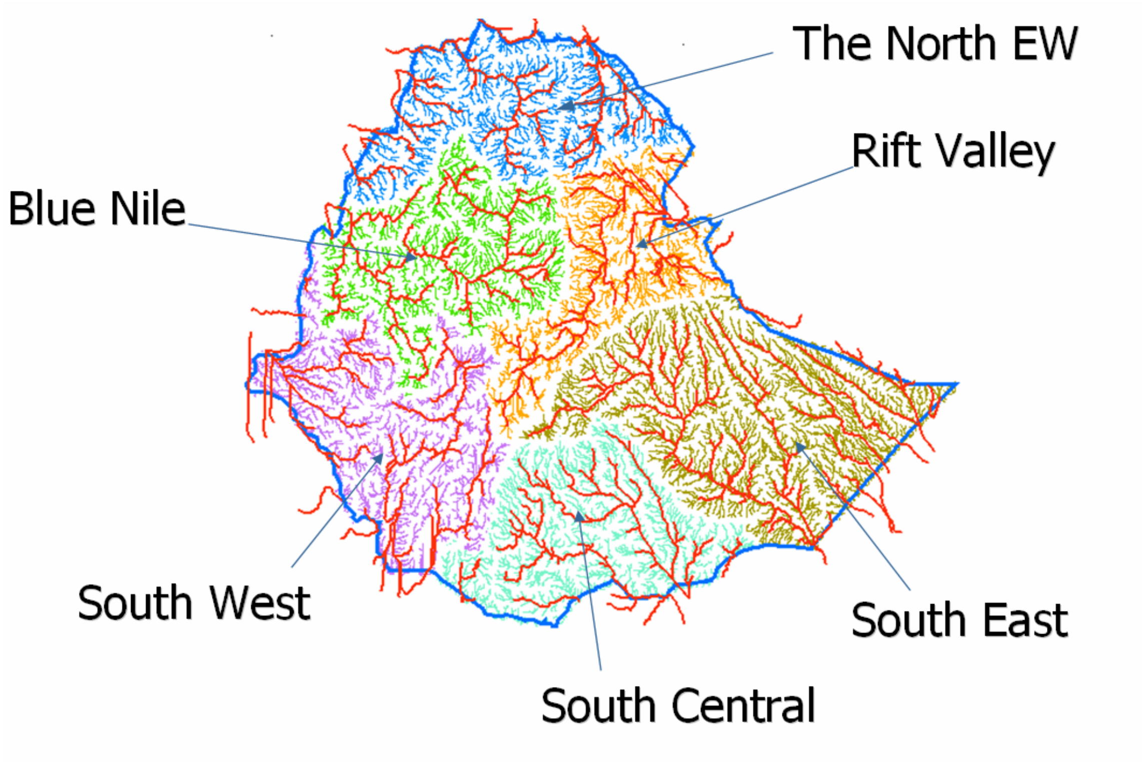


Figure 5.12 The six hydro administrative regions of Ethiopia and the associated streams.
The red lines show the Hydro 1k streams.

CHAPTER 6: ARC HYDRO DATA MODEL AND FRAMEWORK

6.1ArcGIS Hydro Data Model

The Arc Hydro framework provides a simple, compact data structure for storing the important geospatial data describing the water resource system (Maidment,2002). 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 Visio 2000. 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 are imported into the Arc Hydro format by applying the schema to an ArcGIS geodatabase.

The ArcGIS Hydro Data Model (Arc Hydro) 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 (Figure 6.1).

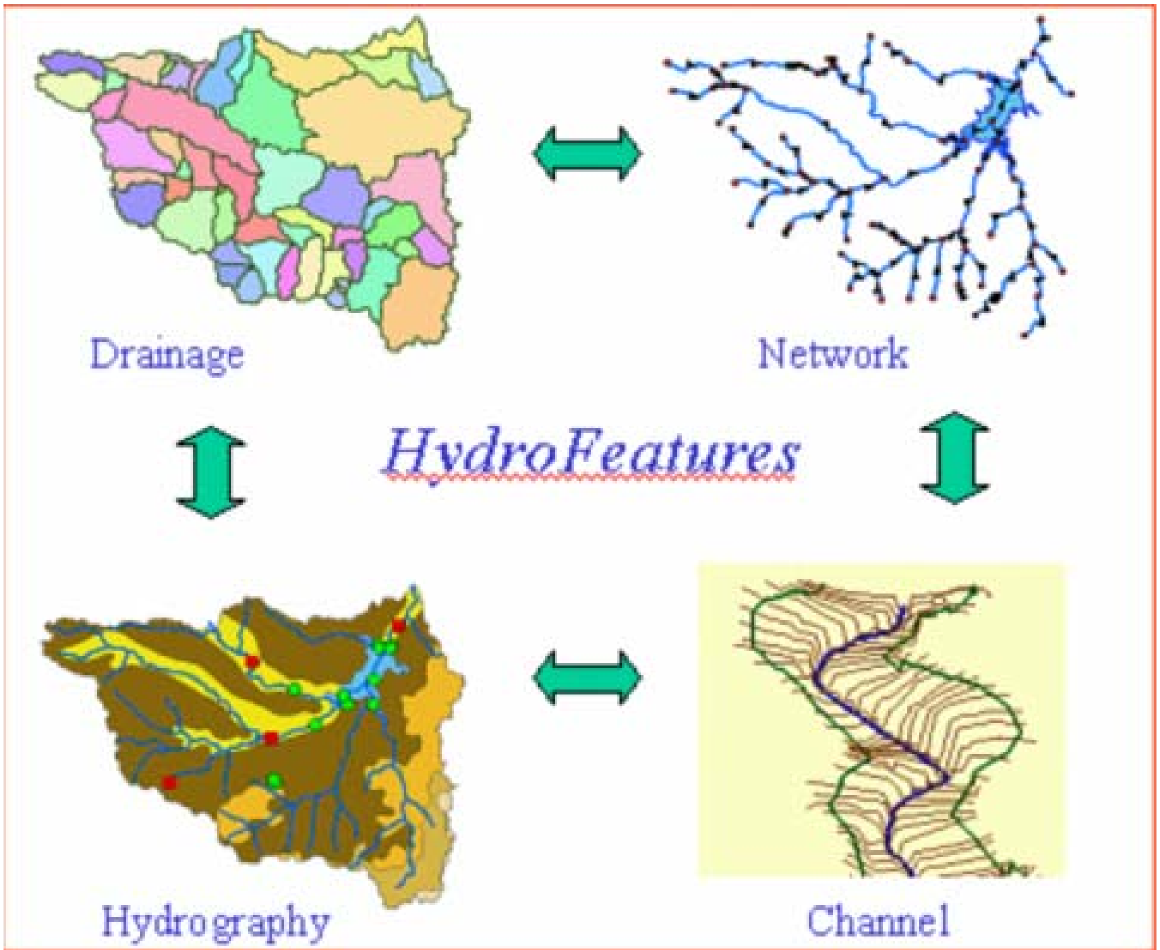


Figure 6.1 ArcGIS Hydro Data Model (Maidment, 2002)

6.2Geodatabase design

A Geographic Information System (GIS) database design is founded on geographic representations. For instance, entities can be represented as features (such as points, lines, and polygons); and continuous surfaces and imagery using raster. Arc Hydro features for this research were organized in a series of thematic layers. A thematic layer is a collection of common geographic elements, such as a road network, a collection of parcel boundaries, soil types, an elevation surface, satellite imagery for a certain data, or well locations (Arctur et al 2004). Before creating the Geodatabase for the Blue Nile Basin and for the rest of the Ethiopian basins a study was performed regarding the structure of the Geodatabase, the data that will be included in the Geodatabase and the different types of relationships among the features and attributes.

6.2.1 CREATING GEODATABASE

A simple personal geodatabase was created in Arc Catalog for each Ethiopian Hydro Administrative region after identifying the relation between the features classes and attributes. Once created, the geodatabase is a Microsoft Access file called an ArcGIS personal geodatabase.

Procedures:

- In the ArcCatalog tree (left window) navigate to the folder in which you will save your geodatabase (for example, Ethio-Geodatabase). Right click on the Ethio-Geodatabase folder and choose New -- Personal Geodatabase as shown in Figure 6.2.

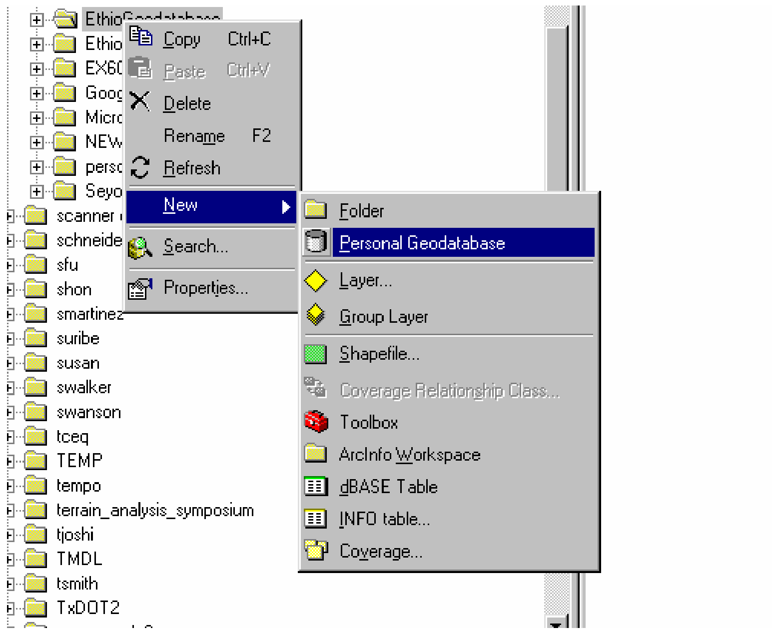


Figure 6.2 Creation of personal geodatabase

- Change the name of the new personal geodatabase. The default is "New Personal Geodatabase.mdb" so make it BlueNile to make it consistent with the Hydro Administrative region name. Similarly, generate a personal geodatabase for each hydro administrative region as shown in Figure 6.3. Be sure to leave the **.mdb** extension.

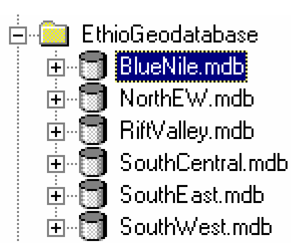


Figure 6.3 Personal geodatabases for each Hydro Administrative regions of Ethiopia

6.2.2 CREATING FEATURE DATASET

A “Feature Dataset” is a collection of related feature classes. Feature classes are organized in an integrated feature dataset for many purposes- primarily to manage spatial relationships among related feature classes (Arctur et al, 2004). The feature datasets created for each hydro-administrative area geodatabase are shown in Figure 3.3.

Procedures

- Right click on the newly created file in the ArcCatalog tree. Choose New -- Feature data set as shown in Figure 6.4.

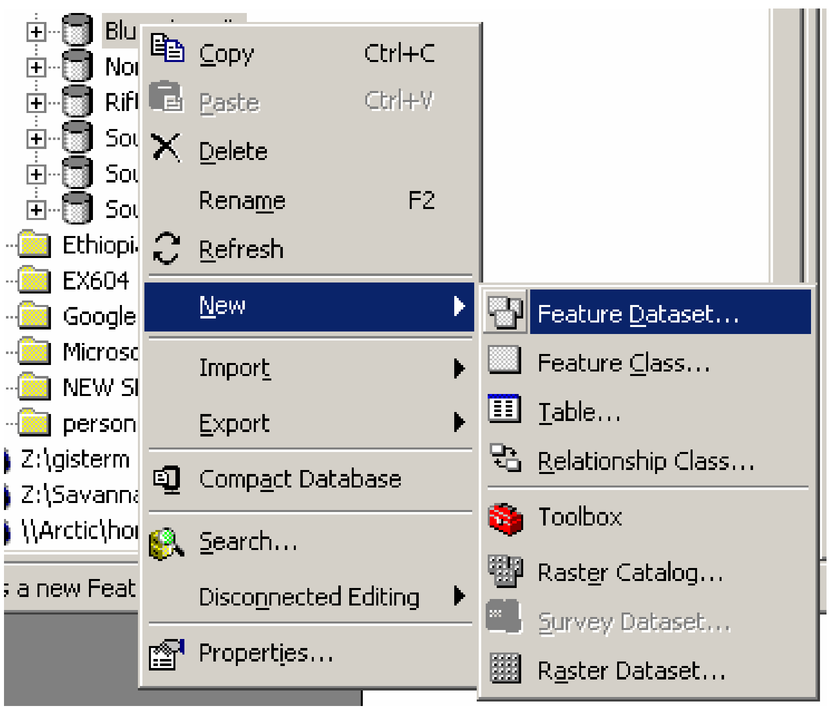


Figure 6.4 Creating a Feature Dataset

- Name the new feature dataset **Arc Hydro**, and select **Edit** to set the projection and map extent as shown in Figure 6.5.

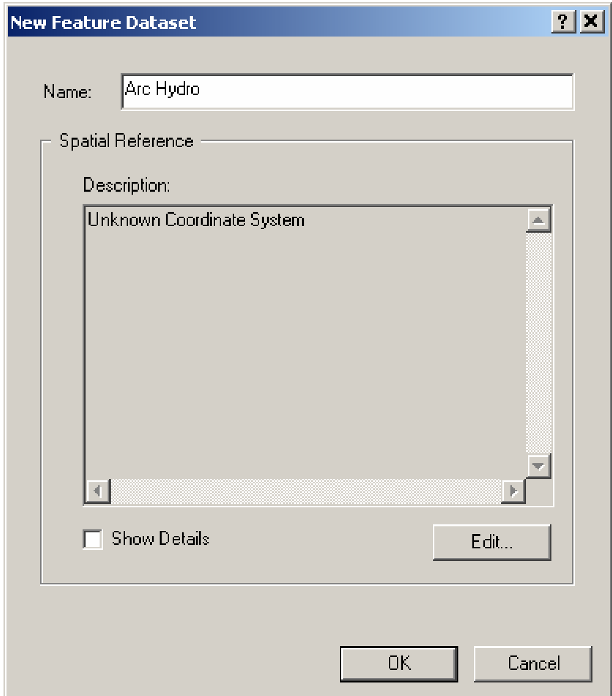


Figure 6.5 Geographic coordinate generation for new feature dataset

- Import the coordinate system of existing data, such as data from Hydro1K documents that were explained in chapter three (Figure 6.6).

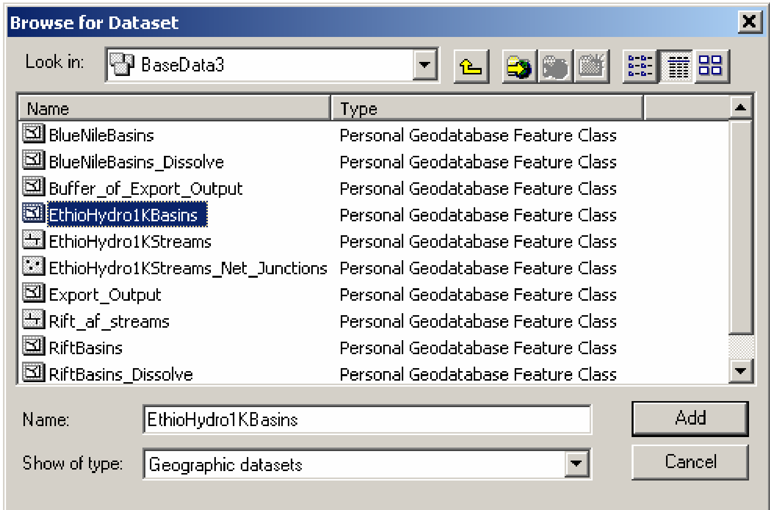


Figure 6.6 Geographic coordinates from Hydro 1K

- Finally, you will see that the coordinate system is specified. Then, Click OK

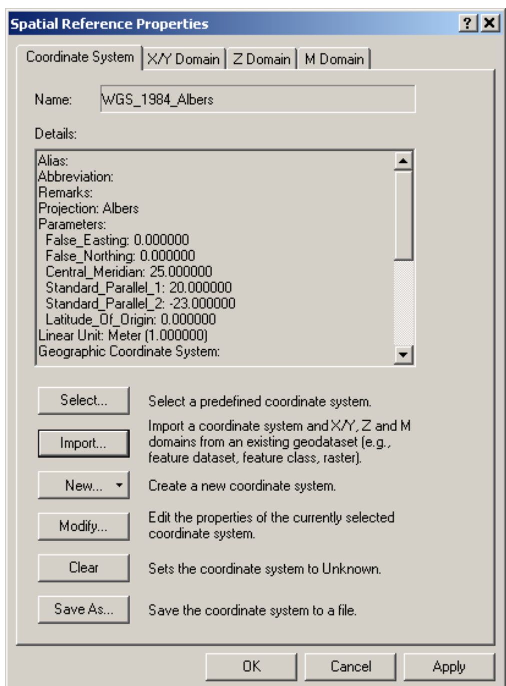


Figure 6.7 Albers Geographic coordinates from Hydro 1K.

The spatial properties dialog box has the following components:

- **Coordinate system**

The coordinate system of a dataset identifies its projection and datum. The coordinate system and datum should be set to be the same as any data intended to be loaded into the dataset. This information allows ArcMap and other applications to represent your data in the correct place relative to other data. Unlike the rest of the Spatial References, the coordinate system information can actually be changes after it has been established; this doesn't reproject the data.

- **XY domain**

The XY Domain, or Extent, of a dataset is the range of X and Y coordinates values that it will store. This permanently defines the area in the dataset that can contain features; in a sense it defines the edge of the world with respect to the dataset. No features can have coordinate values that are greater or less than these values. Features that exceed these limits can't be loaded or digitized in to the dataset.

- **Precision**

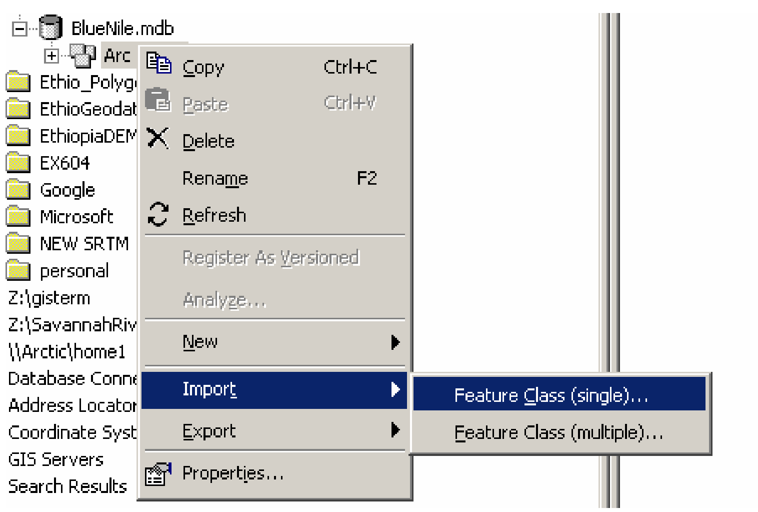
The precision is the number of internal geodatabase storage units allocated to each Coordinate System unit.

6.3.3 IMPORTING FEATURE CLASSES INTO THE GEODATABASE

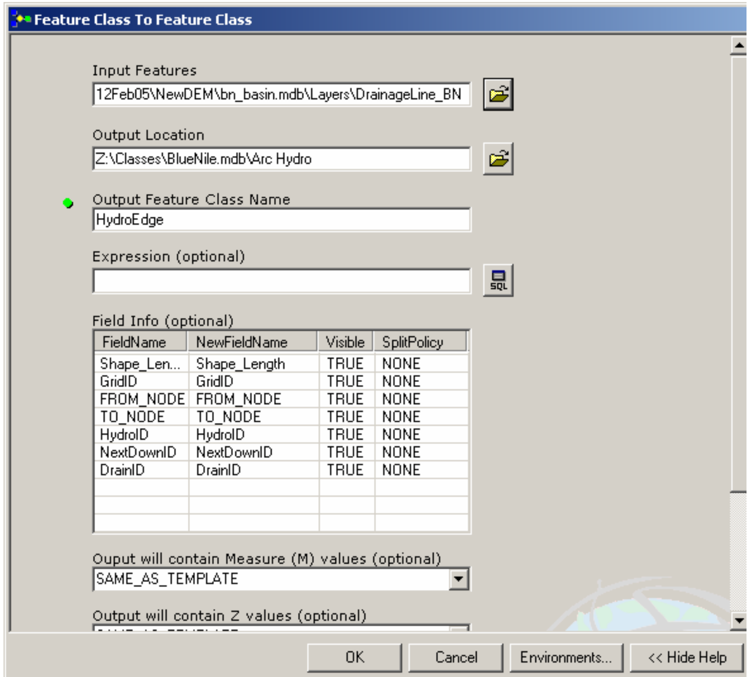
A feature class is a collection of feature representing the same geographic elements, such as rivers, water bodies, or catchment areas. All the features in a feature class have the same spatial representation (for example, point, line, or polygon) and share a common set of descriptive attributes (Arctur et al, 2004). Individual features in a feature class can also share spatial relationship with other features. For Examples, adjacent polygons share boundaries according to well -defined integrity rules (such as that Hydro Administrative region can't overlap one another).

The feature classes created in chapter five and those obtained from other sources, such as those explained in chapter three were imported to the geodatabase as follows:

- Right-click on your feature dataset and press **Import → Feature Class (single)…** as shown in Figure 6.8 and name is **Hydro Edge**.



a



b

Figure 6.8 a and b. Importing feature Class to geodatabase

Similarly, other feature classes, such as monitoring points, watershed, and water body were imported to the feature dataset for each Hydro Administrative regions.

6.4 Building an Arc Hydro Geodatabase and Geometric Network

To apply the schema to the empty geodatabase created in section 6.2, **right-click on the geodatabase and select Import/XML Workspace Document** as shown in Figure 6.10.

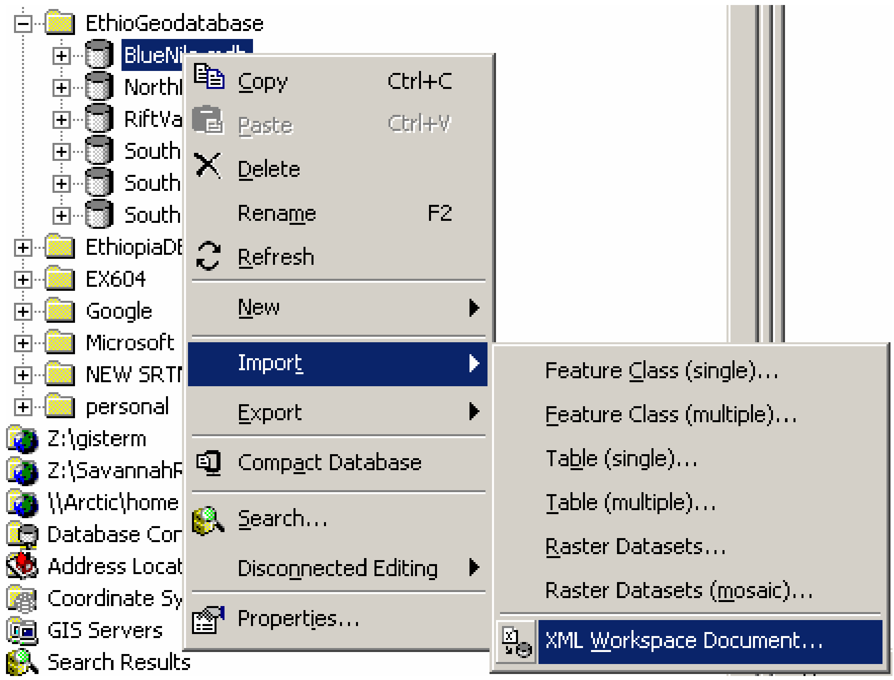


Figure 6.10 Importing XML workspace document

- Click Schema only option and import hydro framework schema from CRWR website (figure 6.11).

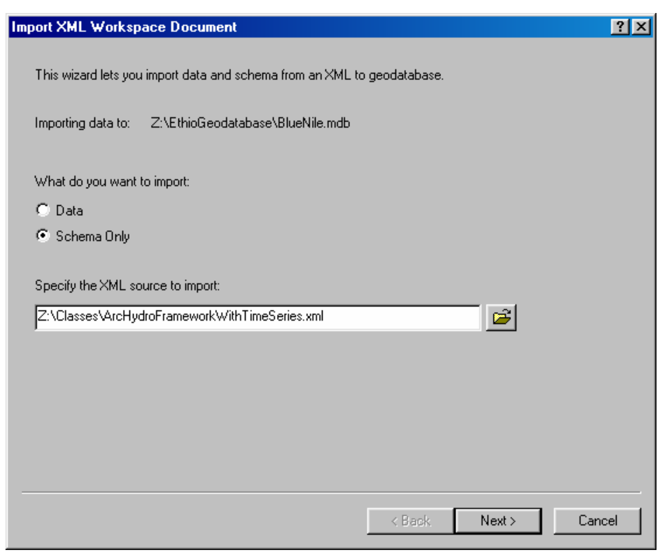


Figure 6.11 Importing XML workspace Document

Press Next and then Finish. Refresh Arc Catalog and you will see the result shown in Figure 6.17.

Arc Hydro Framework for the Blue Nile basin consists of one feature dataset called ArcHydro. The feature dataset contains only five feature classes: **MonitoringPoint**, **Waterbody**, **Watershed**, **HydroEdge**, and **HydroJunction**.

- **HydroEdge** and **HydroJunction** (Figure 6.12 and 6.13 respectively) form a geometric network called HydroNetwork (Figure 6.14).
- **MonitoringPoint** represents point features from map hydrography and inventory sources used to collect water resources data.
- **Waterbody** represents area features from map hydrography (Figure 6.15) and contains water bodies obtained from Hydro 1K.
- **Watershed** is a polygon feature class, which contains any subdivision of the landscape into drainage areas

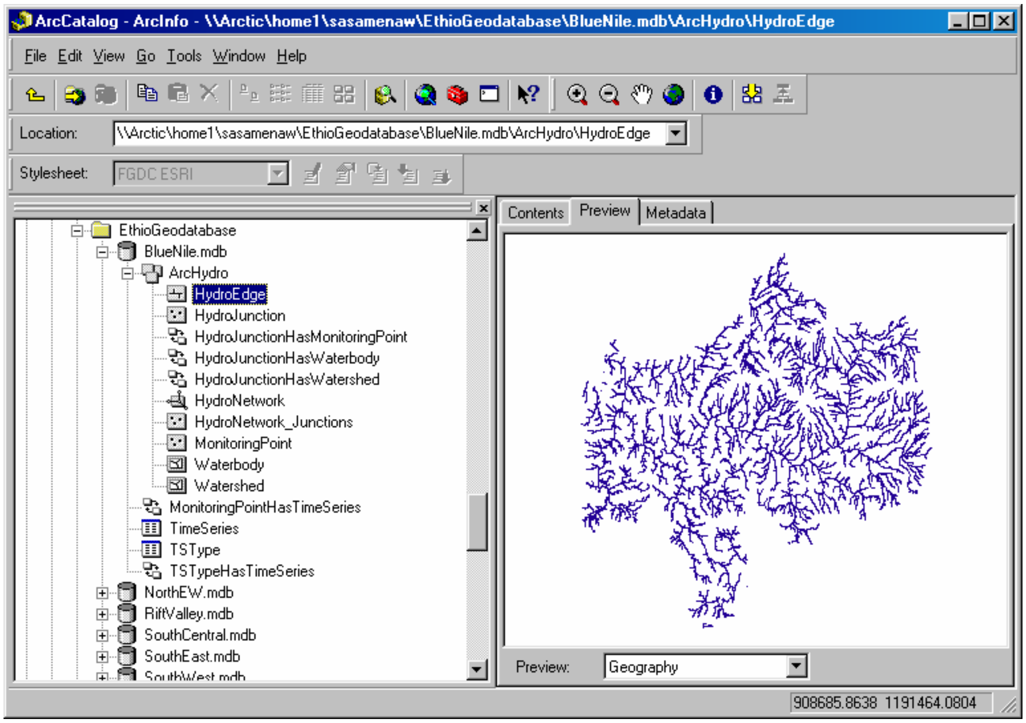


Figure 6.12 HydroEdge feature class for Blue Nile Basin

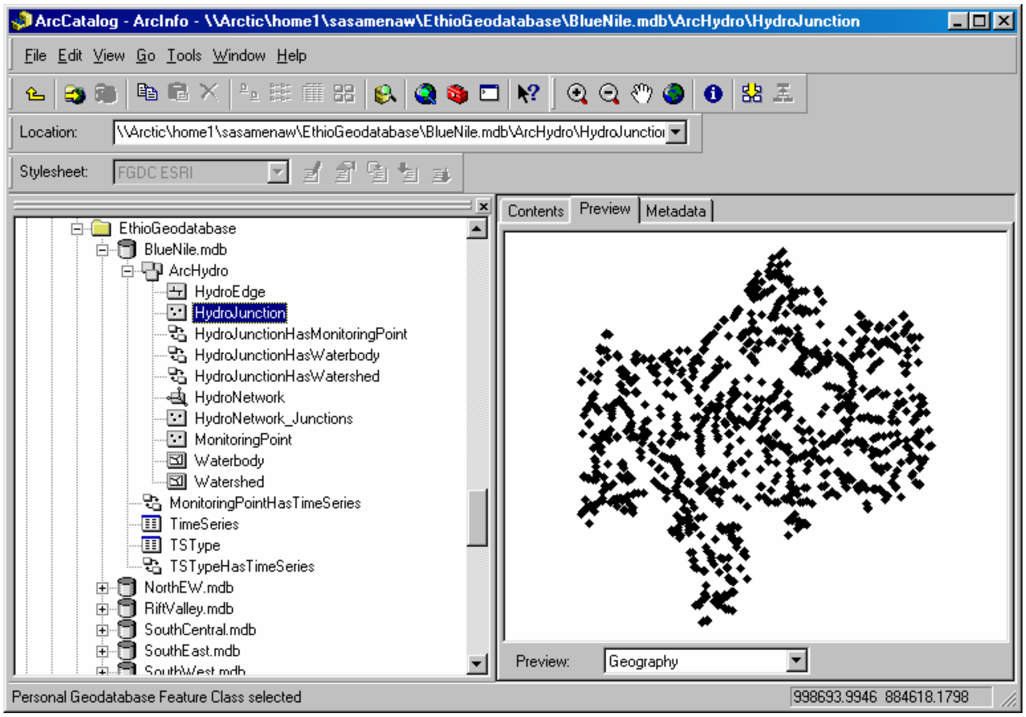


Figure 6.13 HydroJunction feature class for Blue Nile Basin

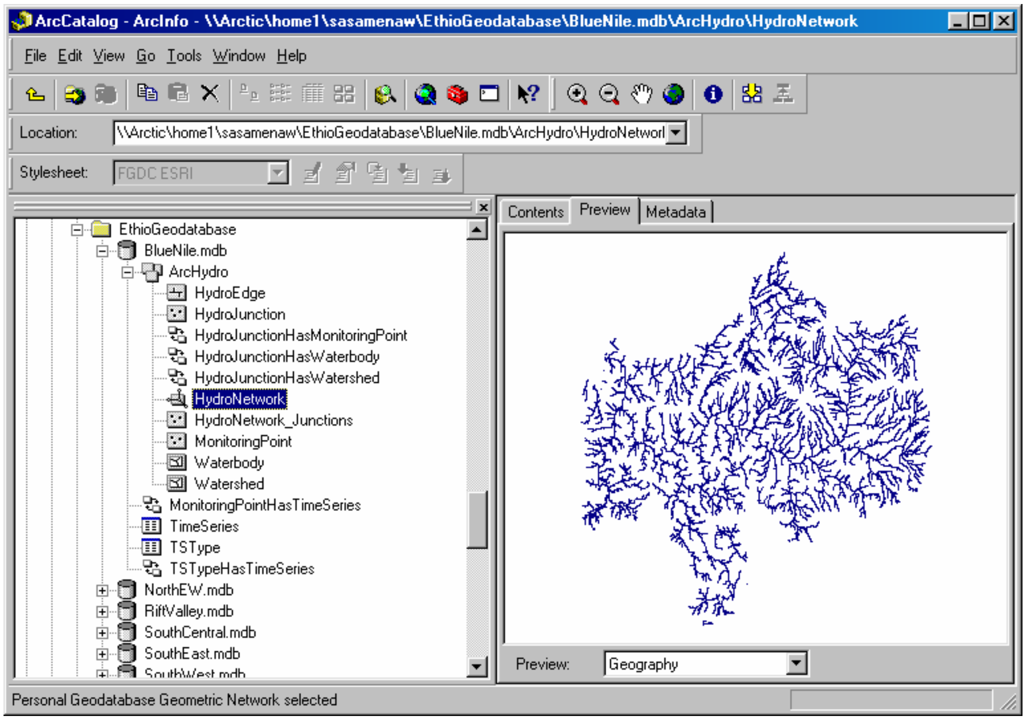


Figure 6.14 HydroNetwork feature class for Blue Nile Basin

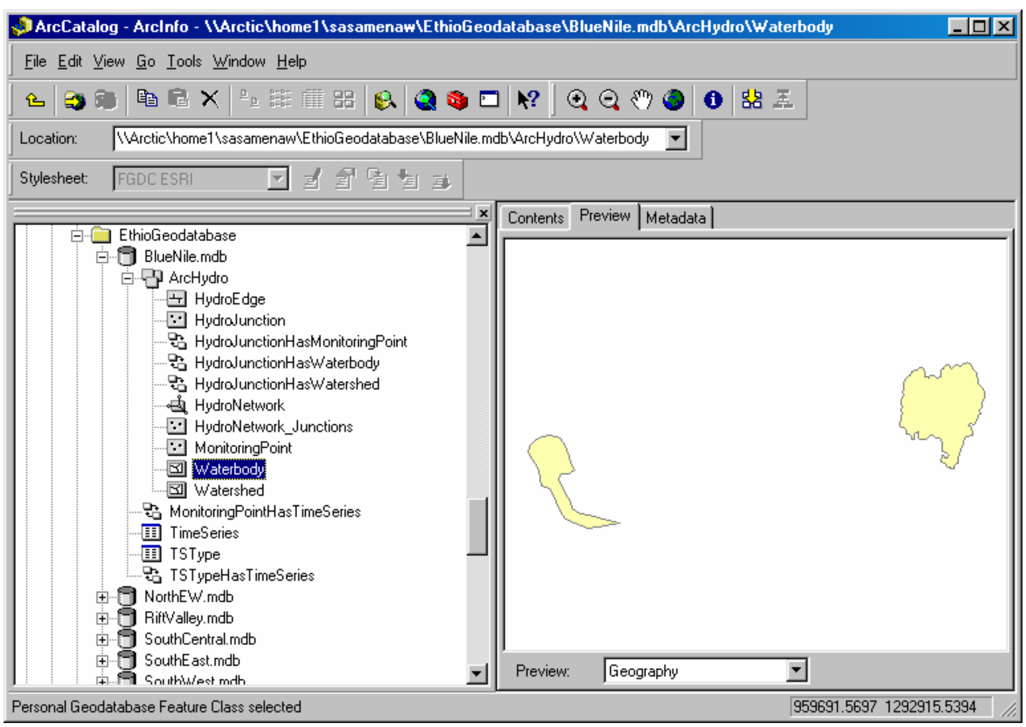


Figure 6.15 Waterbody feature class for Blue Nile Basin

Finally, a hydro geometric network was created for Blue Nile basin and the rest of Ethio-Hydro Administrative regions following the same procedure explained in Appendix A. The output of the hydro geometric network is added in Blue Nile basin geodatabase and is shown in Figure 6.16.

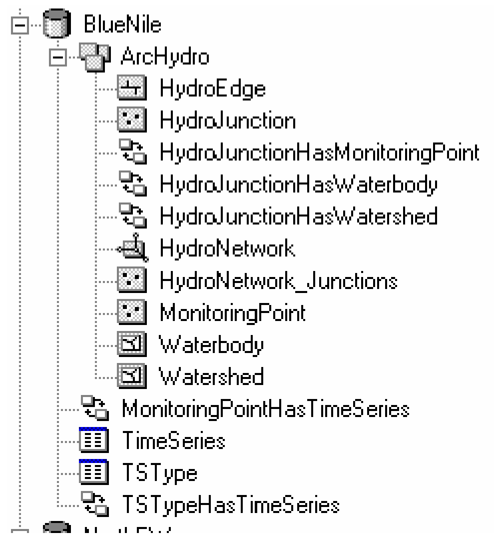


Figure 6.16 Arc Hydro Framework with Hydro Geometric Network for Blue Nile basin

CHAPTER 7: CONCLUSION AND RECOMMENDATION

7.1 Project Summary

This project examined the possibility of using the Arc Hydro data model for Ethiopian Watersheds. Initially, existing Geographic Information data on Ethiopian were collected from Food and Agricultural organization (FAO) and Environmental System Research Institute (ESRI) Web achieves. Then, the Shuttle Radar Topographic Mission (SRTM) data was obtained from the Consultative Group for International Agriculture Research (CGIAR) web achieves and those data were processed to get 90 m Digital Elevation Data (DEM) for Ethiopia. Once those data were collected and processed, the country was divided into six Hydro-Administrative namely: Blue Nile, Rift valley, South East, South Central, South West and North East-West region by tracing upstream of streams crossing the country. Then, a Geodatabase containing five feature dataset was created for each of the Hydro-Administrative regions in the country. Finally, a geometric network was created and an Arc Hydro Schema was applied for each Geodatabase.

7.2 Project Conclusion

A number of conclusions were drawn from this project. Some of them are:

1. The Arc Hydro data model is a very useful tool for organizing hydrologic information data for a very large area like Ethiopia (national scale). Thus, this project serves as a springboard for using the Arc Hydro data model for managing Ethiopia's water resources.

2. This project has shown that the Arc Hydro Framework is a very useful tool for managing GIS hydrological data for Ethiopian watersheds. It could also enable the Ministry of Water Resources of Ethiopia (MoWR) the ability of addressing streams, tracing upstream and downstream on the streams network.

3. The Arc Hydro Time Series Component provides a means for storing spatially and temporally irregular measurements including stream flow and monitoring point measurements. Unfortunately, it was difficult to acquire stream flow and monitoring point data for Ethiopia and those components of the Arc Hydro were not included in this project.

7.3 Future Work

The ability to query by time and location is important to studying hydrologic data. It is of interest, for example, to be able access all stream gauges, rainfall gauges, and water quality data in Ethiopia and incorporate with Arc Hydro Framework developed in this project. The time series object class in Arc Hydro data model could also help store hydrological temporal event data for Ethiopian watersheds.

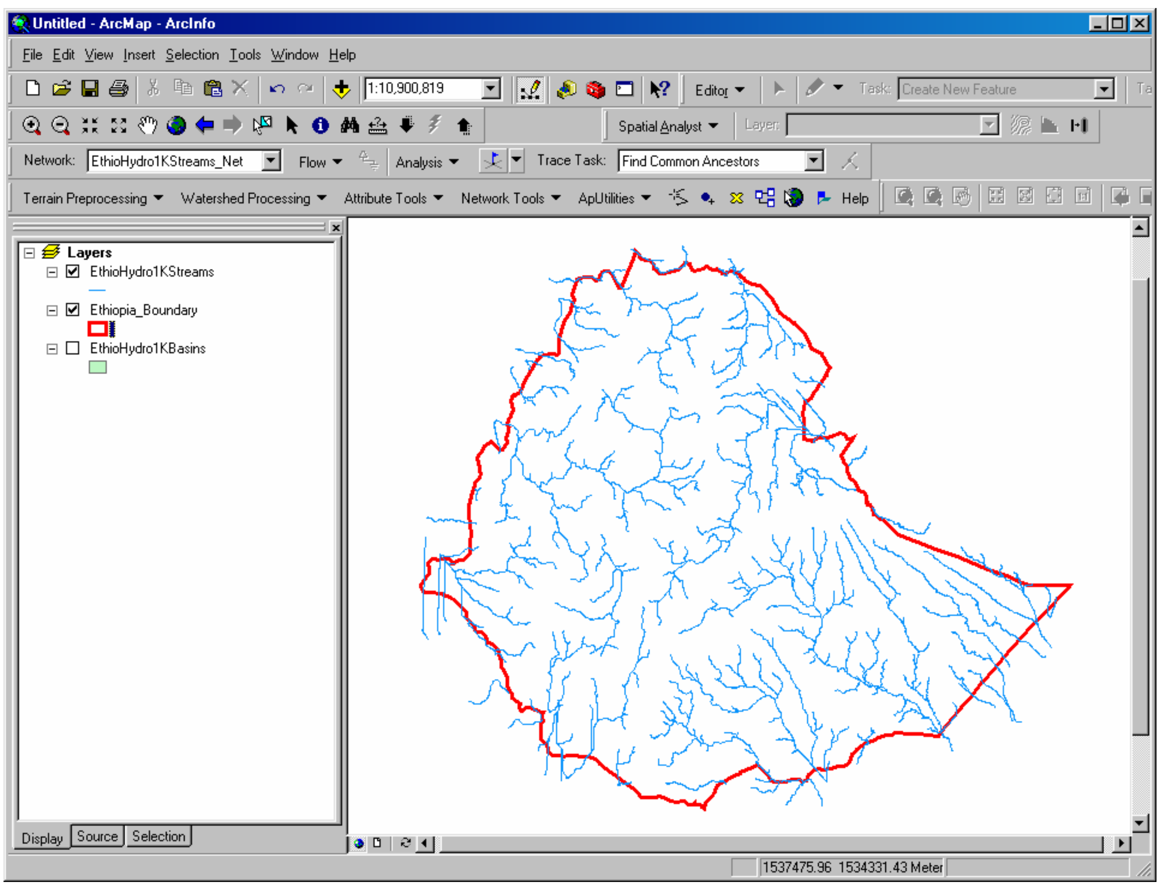
APPENDIX A

Steps for preparing the Regional Data and Data preparation for building a geometric network

The following procedures explain how the regional data were obtained for the Blue Nile Basin. A similar procedure was pursued to acquire the regional data for the other Hydro Administrative regions in Ethiopia.

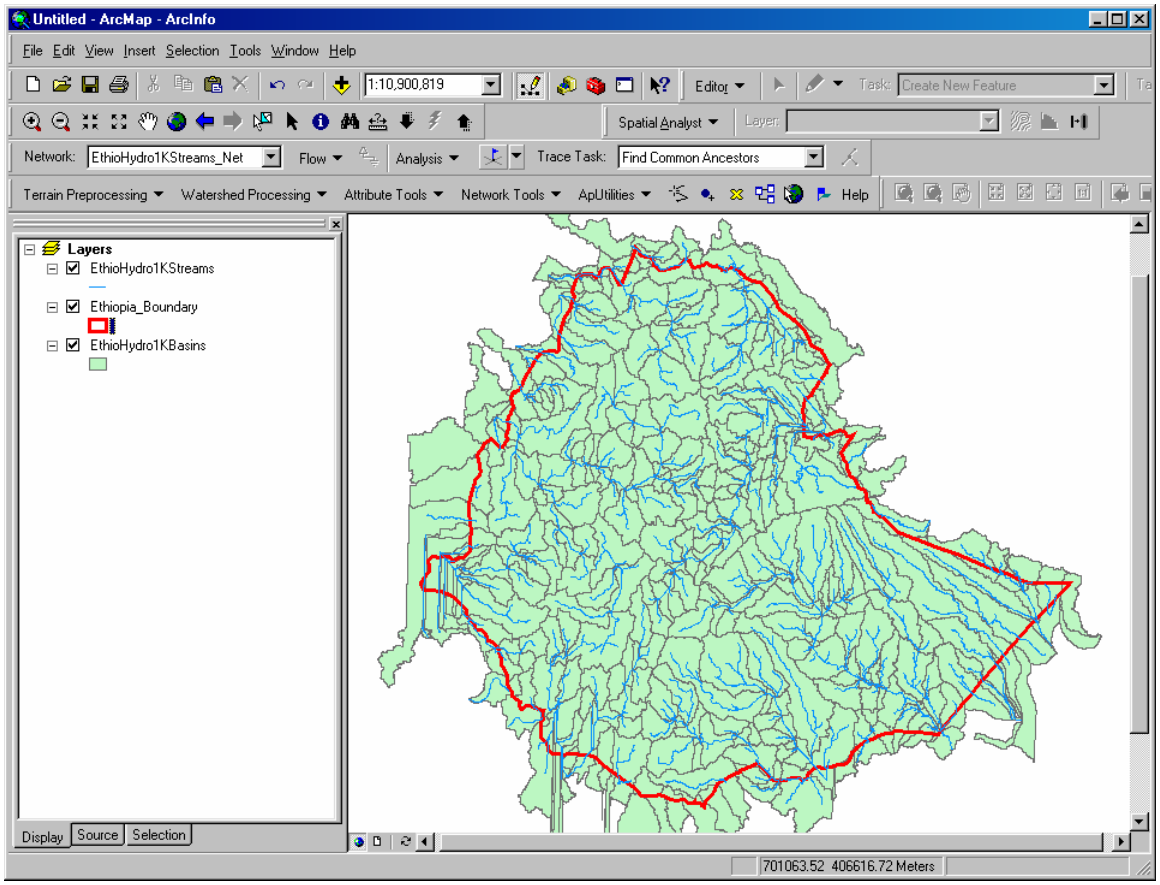
- Display EthioHydro1K Streams accessed from USGS server

< http://lpdaac.usgs.gov/gtopo30/hydro/>



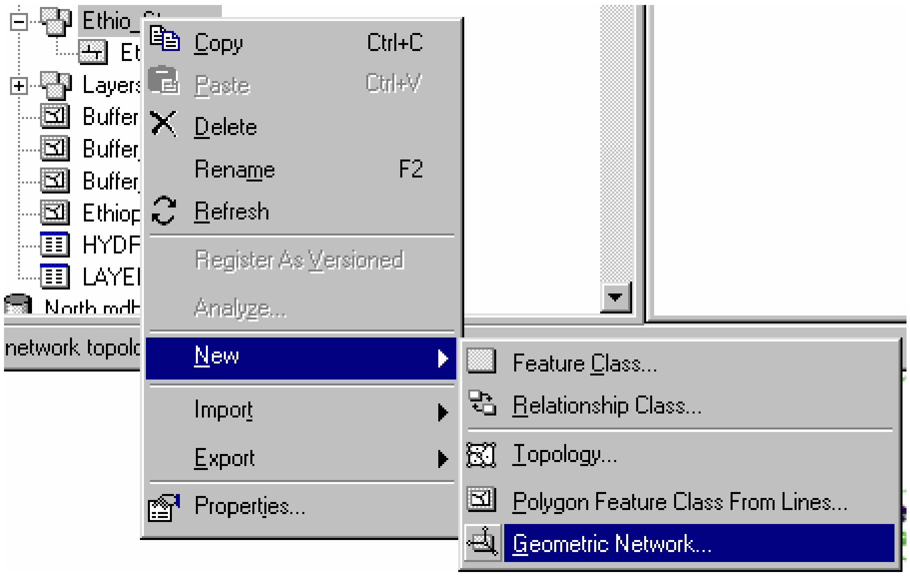
- Display **EthioHydro1KBasins** accessed from USGS server

http://lpdaac.usgs.gov/gtopo30/hydro/

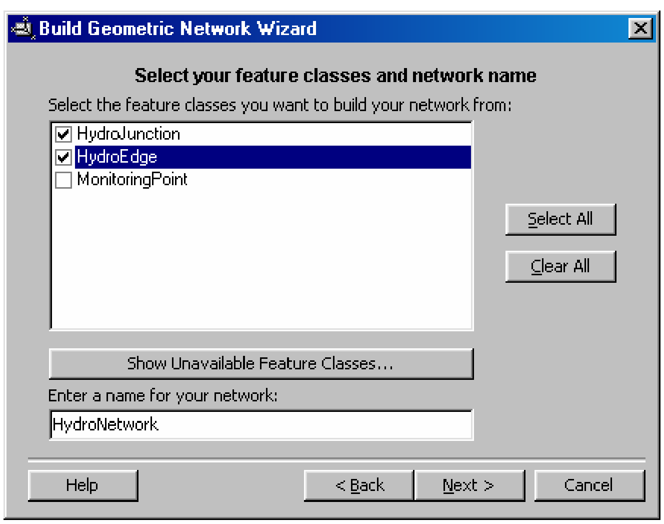


Create a Geometric Network

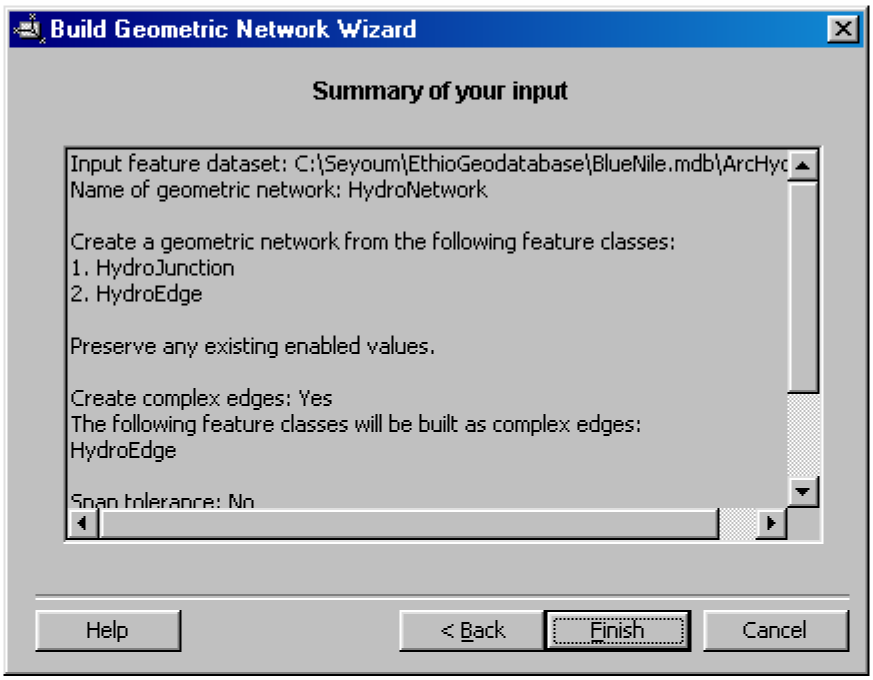
- Open ArcCatalog and navigate to EthioGeodatabase data folder
- In the Blue Nile Geodatabase and ArcHydro feature dataset right click select **New** and **Geometric Network..**.



Click **Next** on the Geometric Network Wizard options until you get to Selecting the feature classes and network name. Select **HydroEdge and HydroJunction** as your network feature classes. Change the network name to **HydroNetwork.**

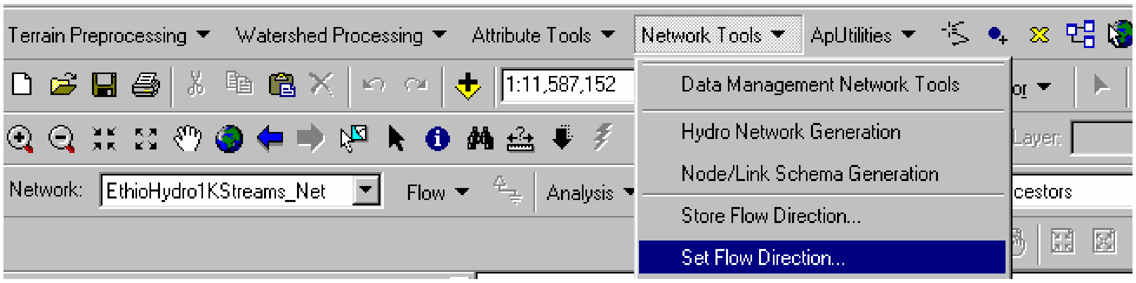


Continue through the wizard and accept all the defaults **EXCEPT** say **yes** when it asks if you want **complex edges** in the network. When you finish you'll see that you've created a new geometric network, **HydroNetwork**, which includes a set of generic network junctions called **HydroNetwork_Junctions** whose function is to provide geometric connectivity between the HydroEdge features.



Generating Flow on the Network

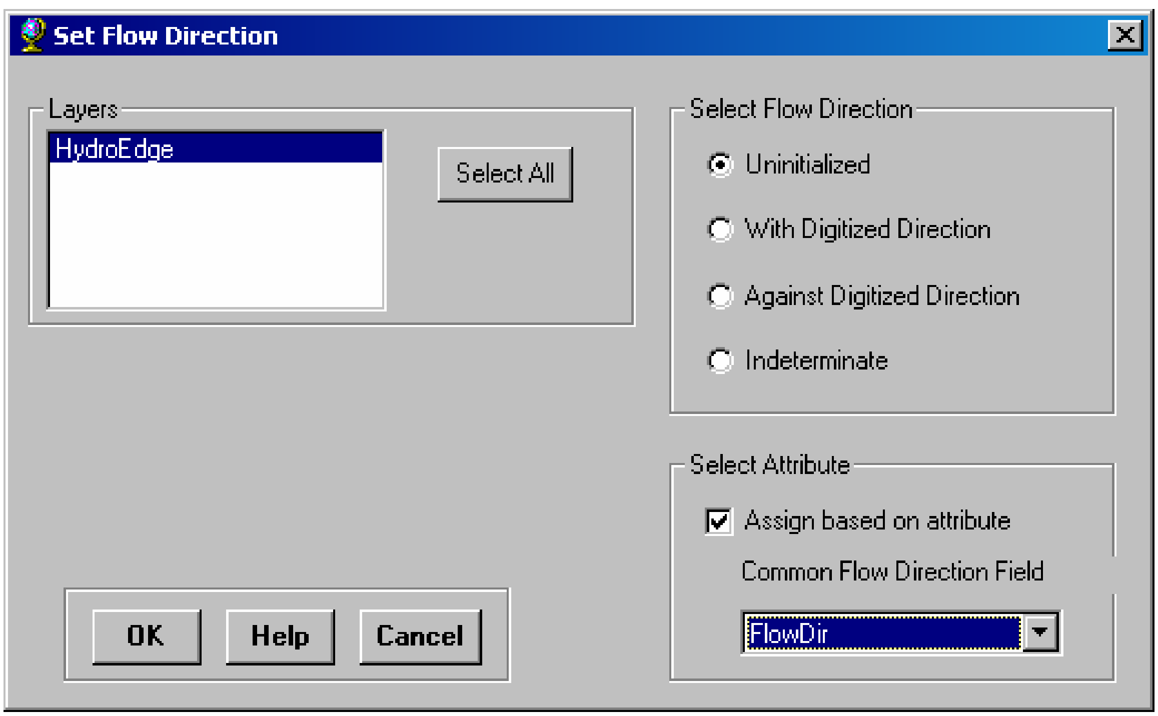
- In Arc Hydro toolbar in Arc Map document click **Network tools** and **set flow direction.**



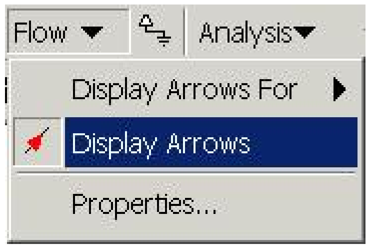
- You will see the **Set Flow Direction** dialog box. This will enable to set the flow with the following criteria:

esriFDUninitialized	**0**	Uninitialized
esriFDWithFlow	**1**	In the direction of digitization of the edge
esriFDAgainstFlow	**2**	Opposite to the direction of digitization of the edge
esriFDIndeterminate	**3**	Indeterminate flow direction

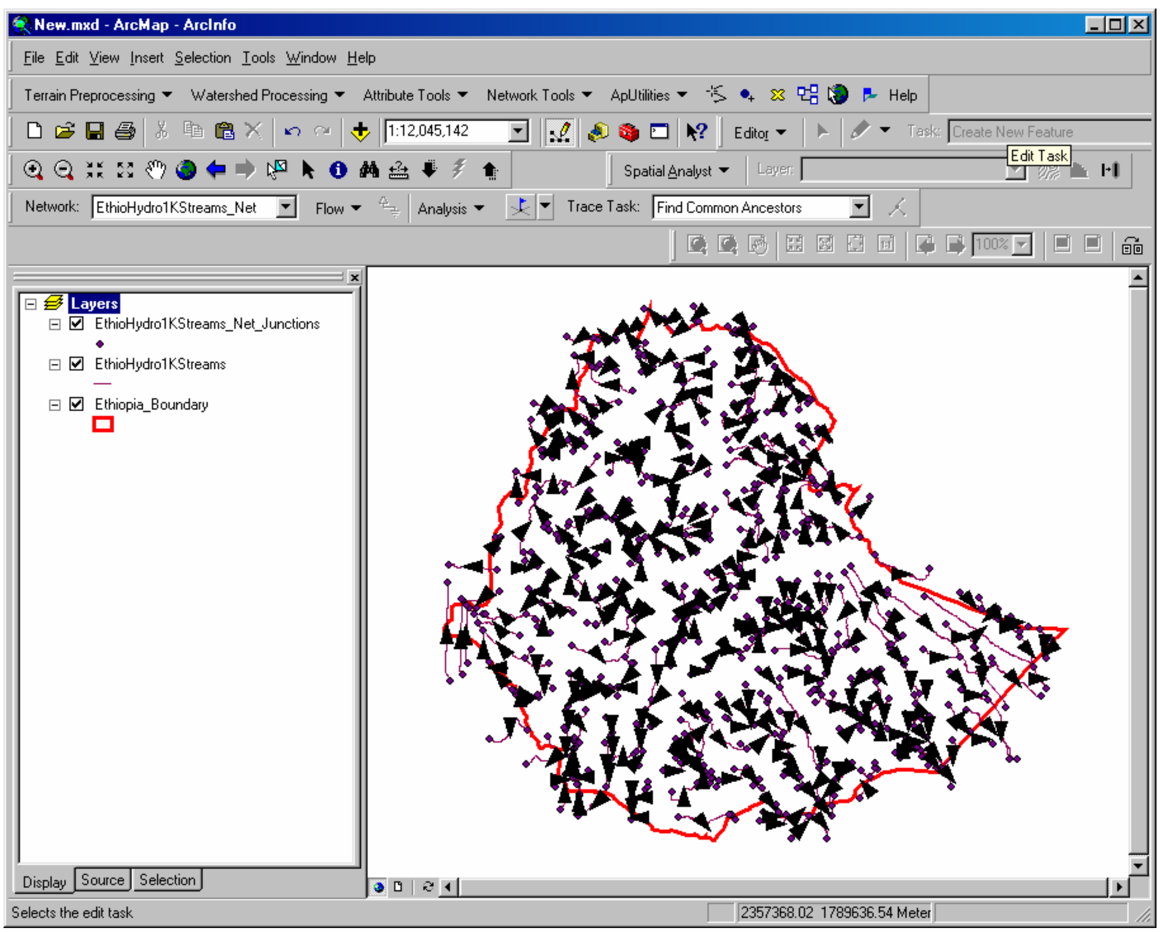
The default option is initialized and agrees with that condition and click **OK**.



- To view the flow set on the network click on the **Flow** dropdown menu and go to **Display Arrows**. The arrows may not all appear and only some black circles may appear. The software is still not foolproof when displaying the arrows. If you have a problem, try turning on and off display arrows, and that may work.

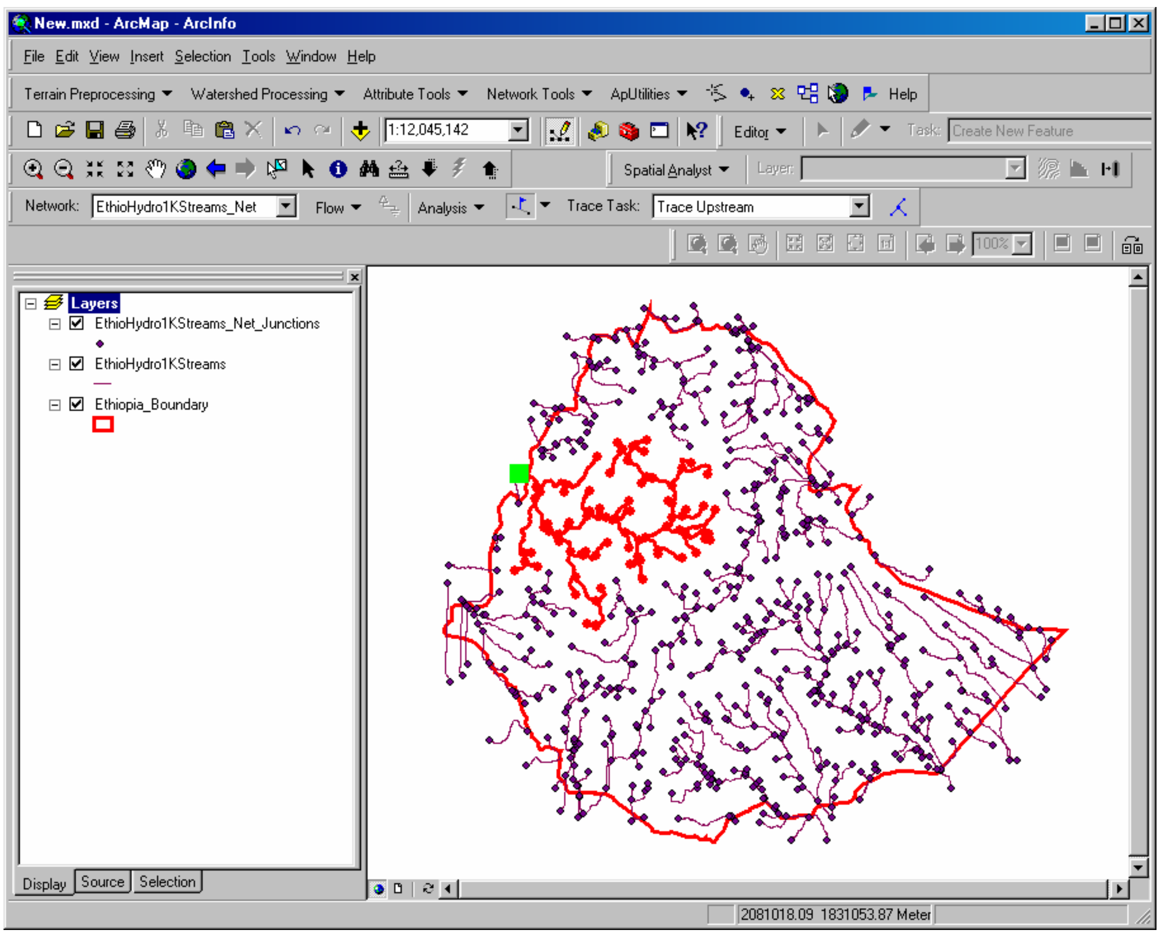


The picture below shows how the arrows should appear. Turn on your **HydroNetwork_Junctions** feature class.

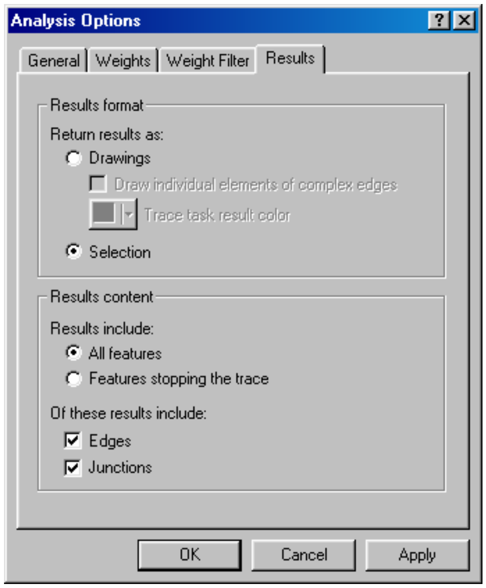


Set the **Trace Task** to **Trace Upstream**. 

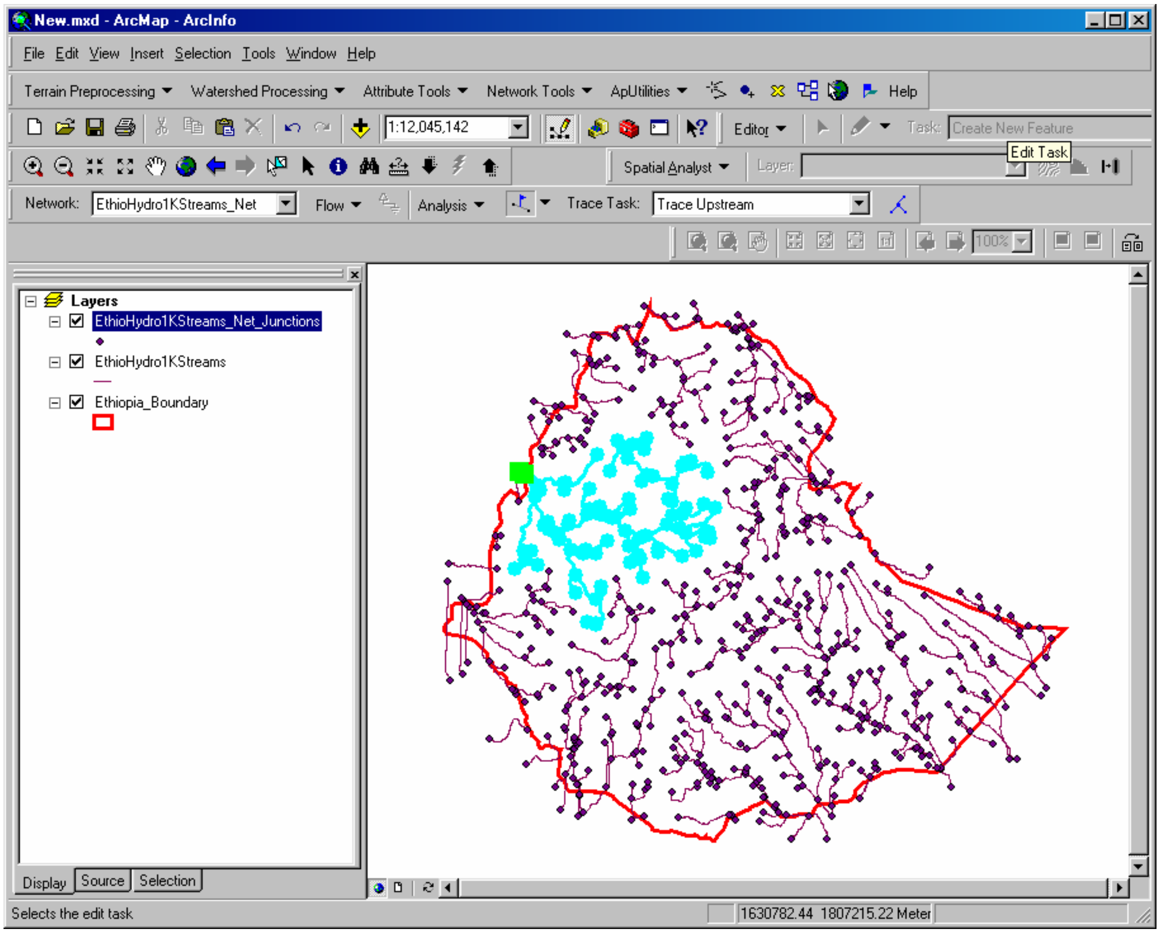
To delineate the Blue Nile streams at the western side of the country and use the **Solve tool**  also on the Utility Network Analyst to run the trace upstream process. This procedure will turn Blue Nile streams red indicating that all reaches are upstream of the outlet junction as shown in the following figures.



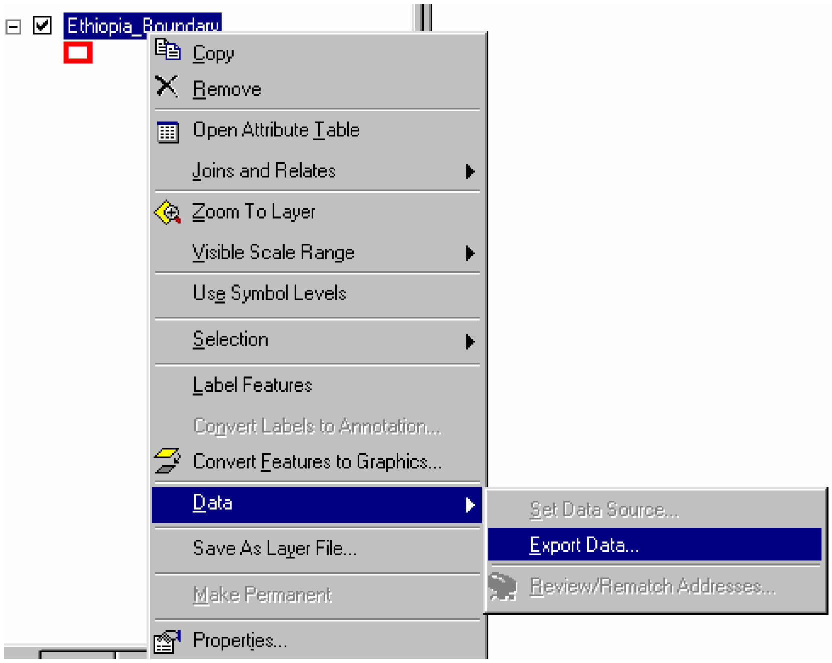
- Next open the Options window **Analysis/Options**. Under the **Results tab**, change the results format the **Selection**



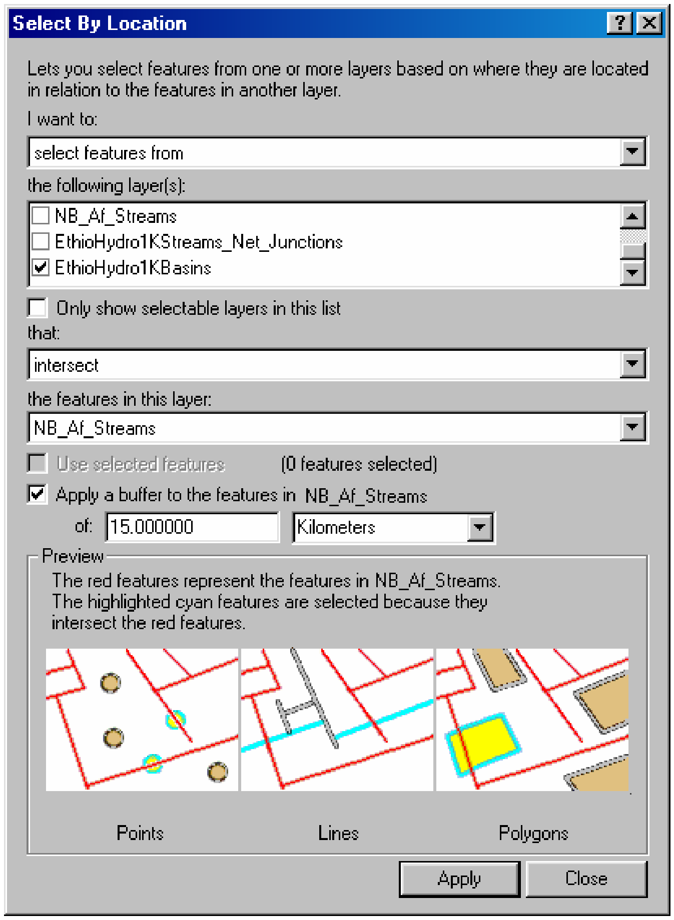
- Select streams from **EthioHydro1K**. **Place a flag** on an edge in the network and press the **Solve button.** Thus, you will see the result shown in the following figure.



- Export the selected them to a feature class as NB_af_Streams



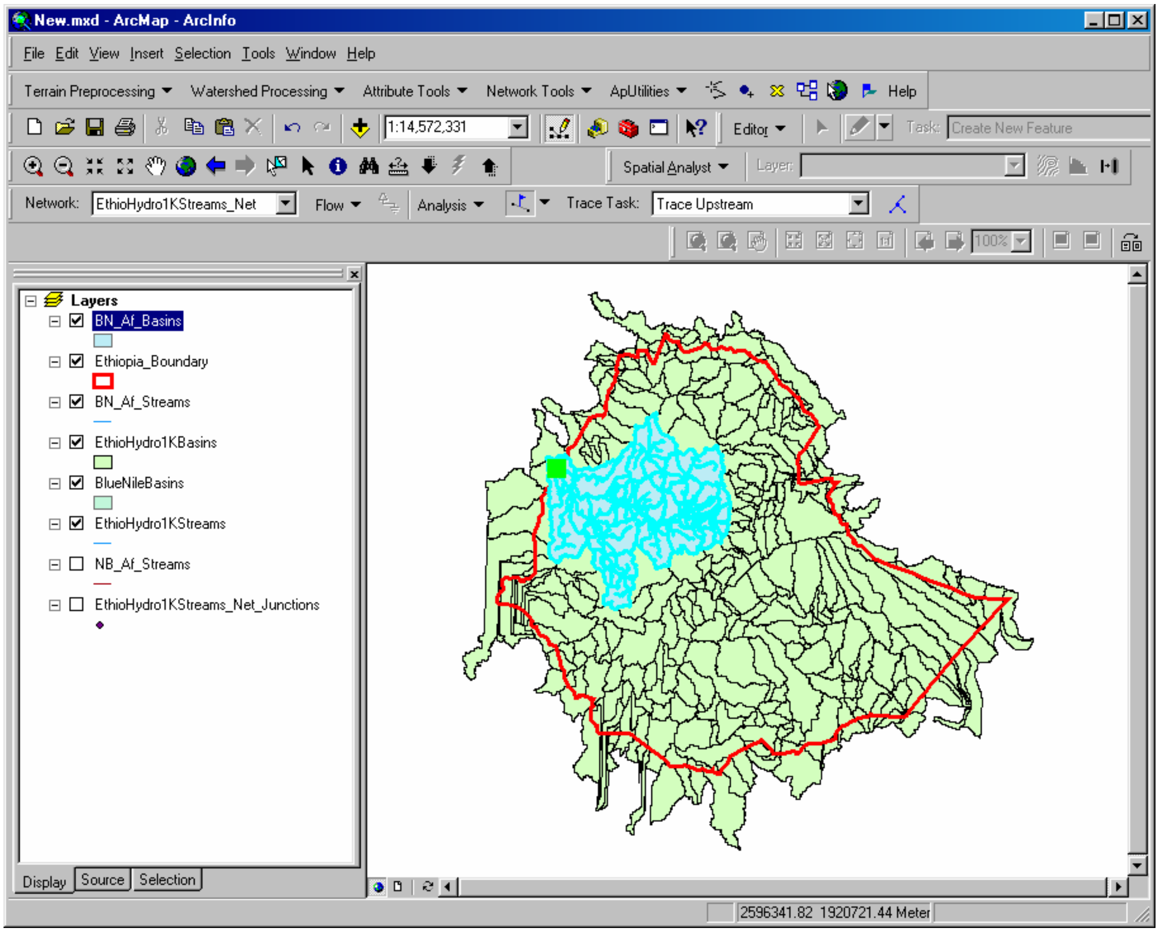
- Click Selection from the menu bar and Click →Select by Location.
- Select basins from **EthioHydro1K** , using NB_Af_Streams with a 15 km buffer.



- Click Apply

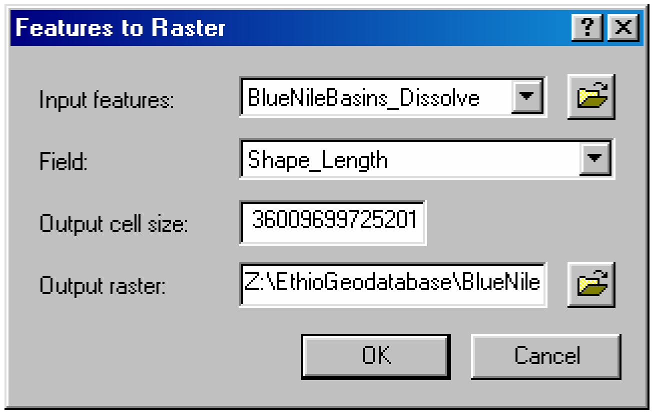
This will select Ethiopia Hydro 1K basins that will intersect the streams within the Blue Nile Basin as shown in the flowing figure.

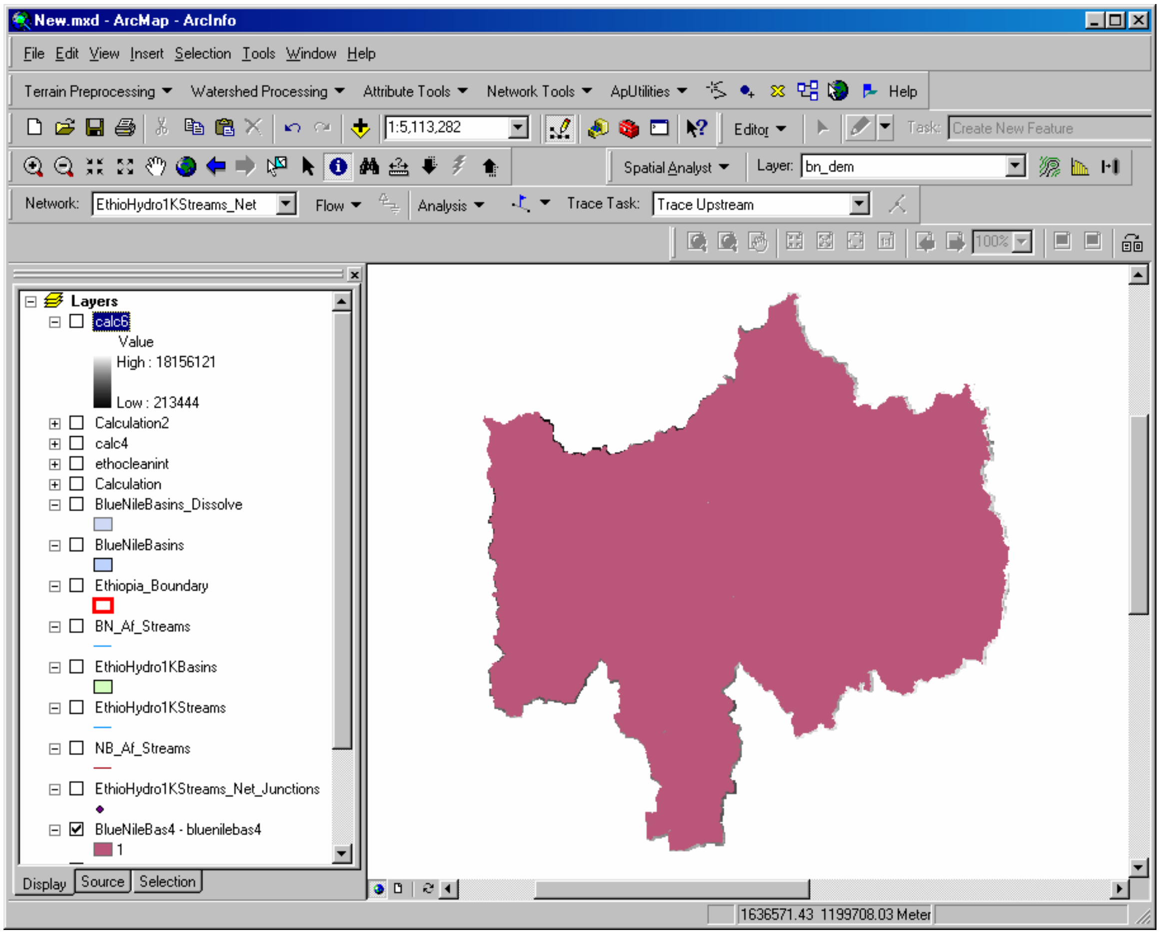
- Export the selected feature class as BN_Af_Basins



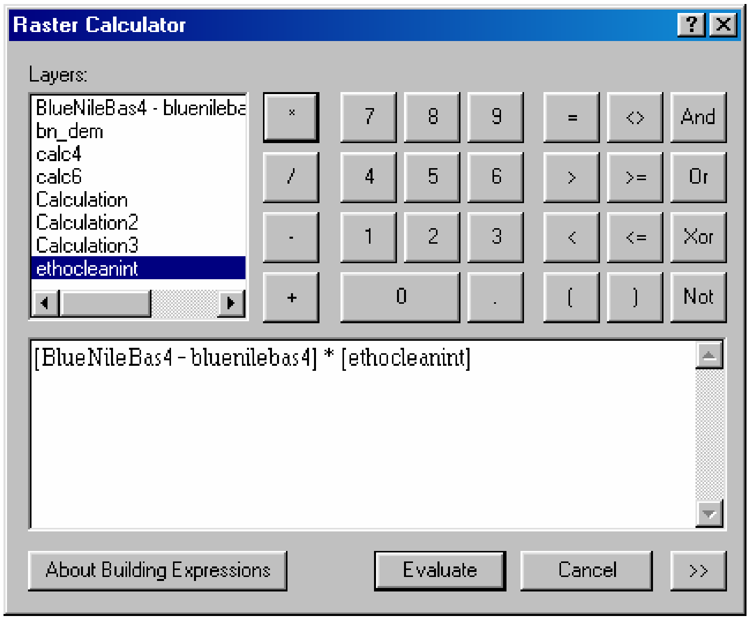
- Dissolve basins into a single polygon BN_af_Dissolve
- Right Click BN_af_Dissolve feature class and open the attribute table.
- Add field named "One" to BN_Basins_Dissolve and give it the value 1

- Spatial Analyst – Convert Feature to Raster (BN_Basins_Dissolve, field One, Cell size from DEM)



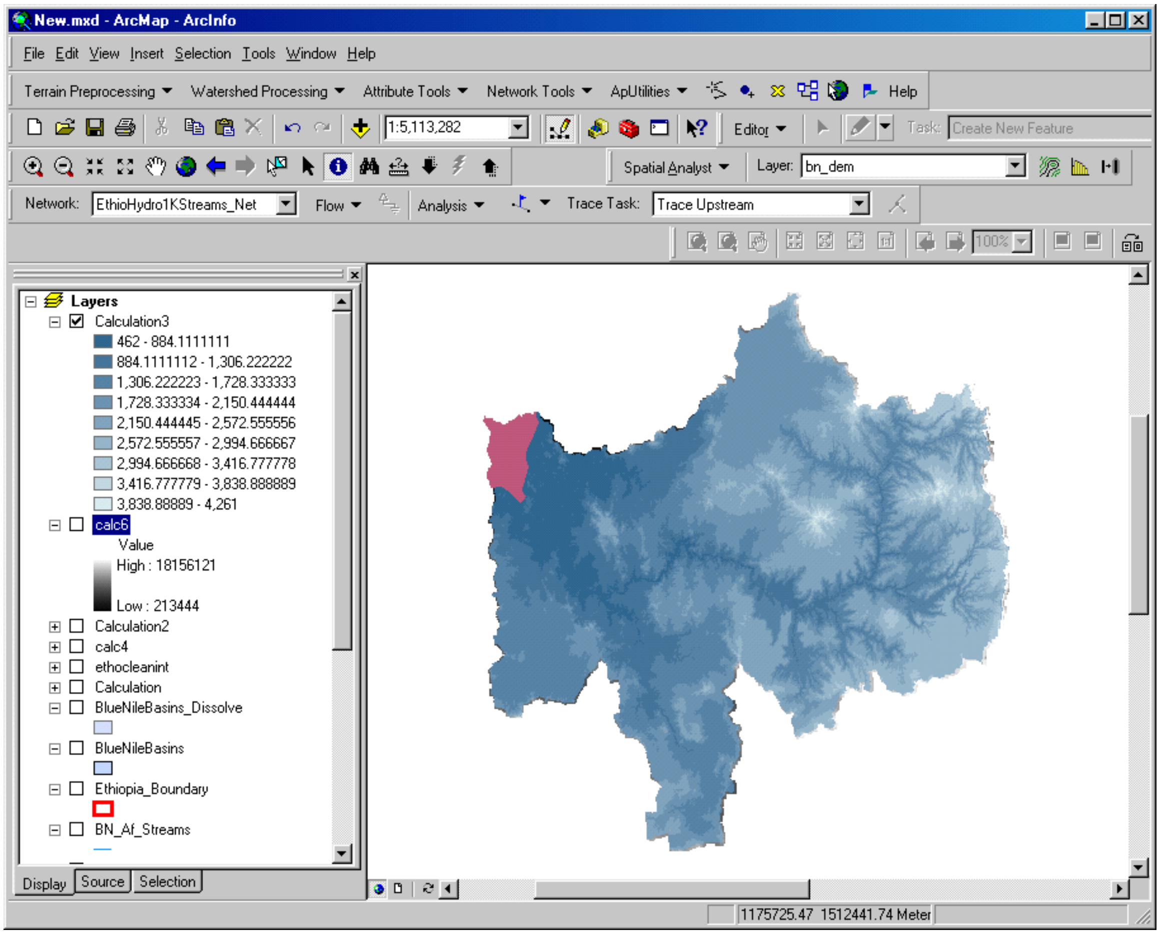


- Multiply new raster of 1’s times DEM to get buffer DEM



- Clip Ethiopia_DEM to basin: Ethiopia_DEM * Raster_of_1

The out put is shown in the following Figure.

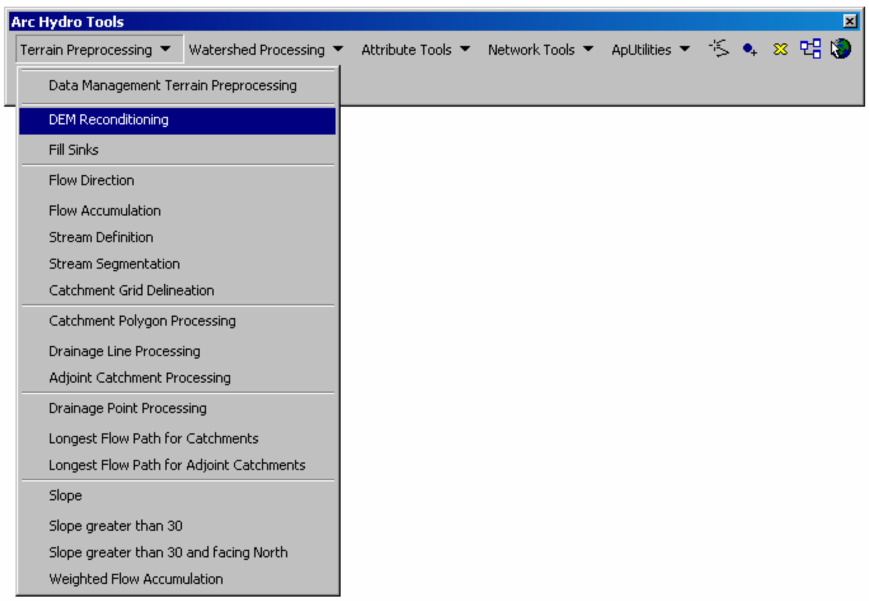


- Make permanent the resulting grid from the above procedure

Similarly, the DEM for the rest of five Hydro Administrative regions was obtained for terrain analysis.

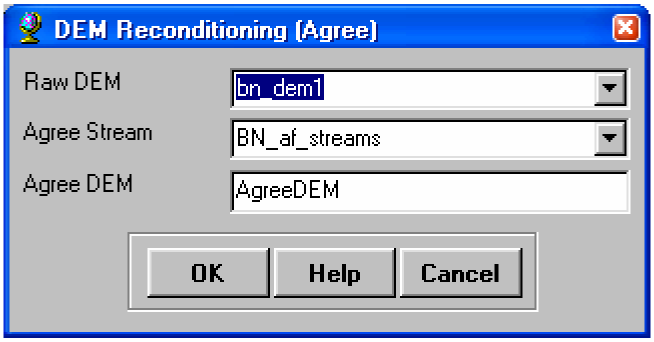
APPENDIX B

The following procedure shows how terrain analysis was performed in Arc Hydro tools to obtain stream lines and catchments for each Hydro Administrative regions. The Blue Nile basin was used as demonstration.

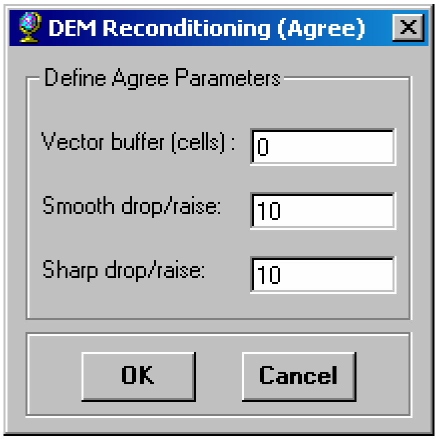


The function needs inputs of **bn_dem1** and **bn_af_streams** and the default output will be **AgreeDEM.**

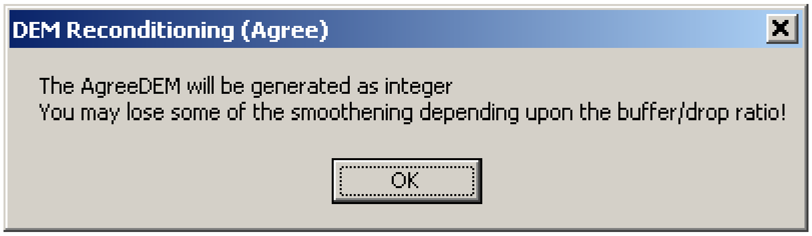
Input	**Output**
"bn_DEM1" Grid	"Agree DEM" Grid
"bn_af_Streams" Featuredataset	



After initiating the function accept the default reconditioning parameters shown below.

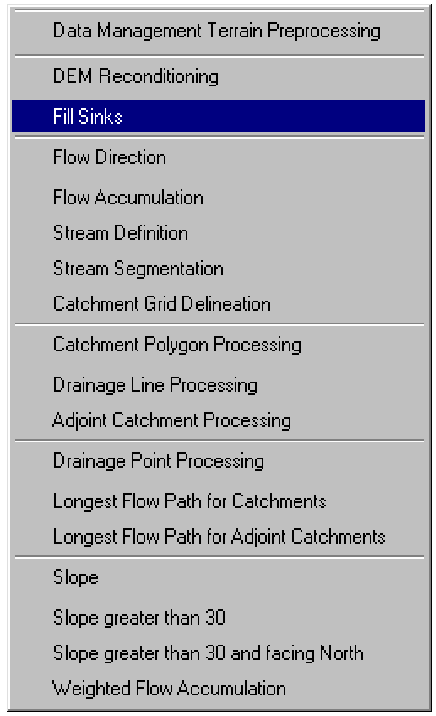


Click **OK** the flowing warning.

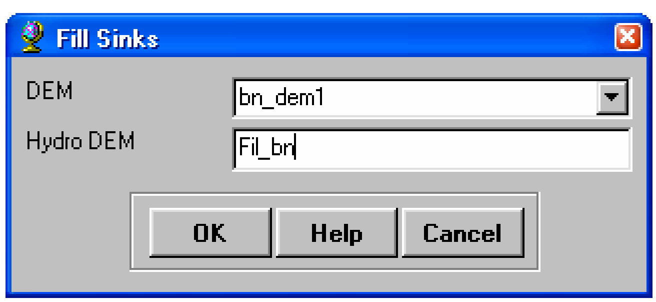


Finally, the reconditioned AGREE DEM was processed with the Fill Sinks function to make sure that the potential sinks in the stream were removed.

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

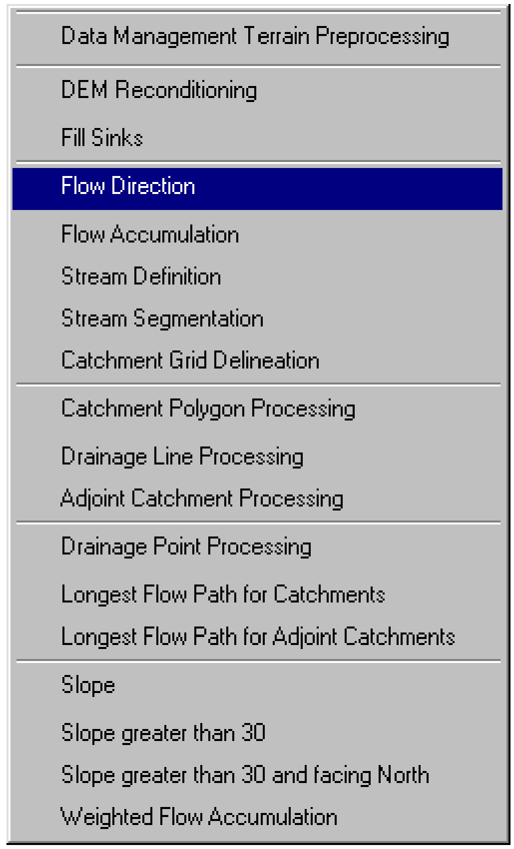


- Confirm that the input for DEM is bn_dem1. The default Hydro DEM is "Fil" but for this project Fil_bn is selected.

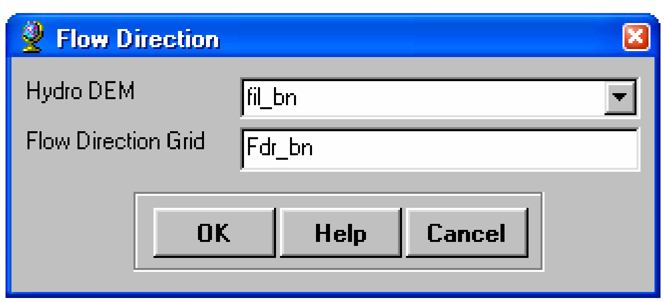


The "Fil_bn" Hydro DEM layer is shown below.

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

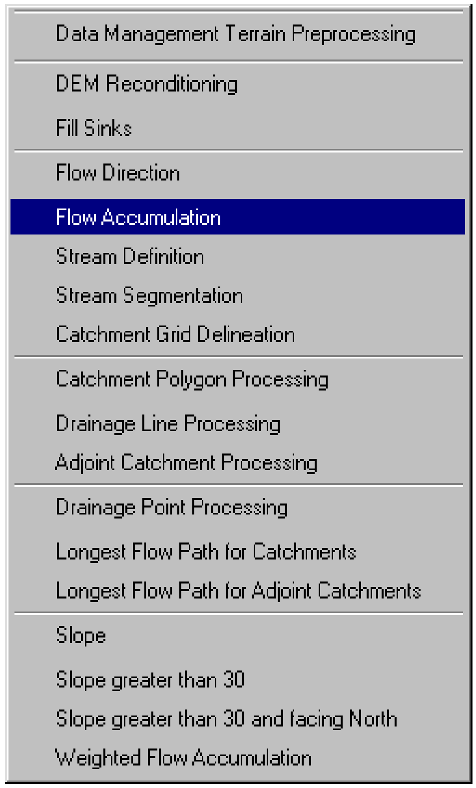


- Confirm that the input for Hydro DEM is "fil_bn". The output is the Flow Direction named by "Fdr_bn".

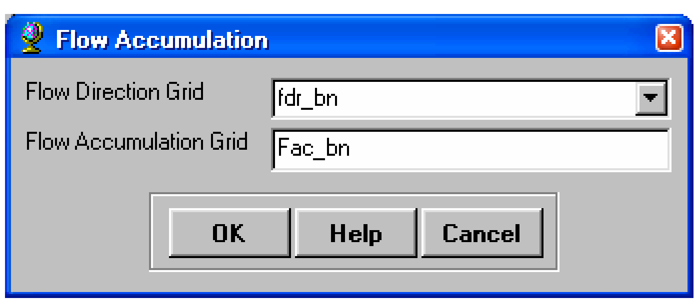


- Press OK. Upon successful completion of the process, the flow direction grid "Fdr" is added to the map.

- Select **Terrain Preprocessing | Flow Accumulation**

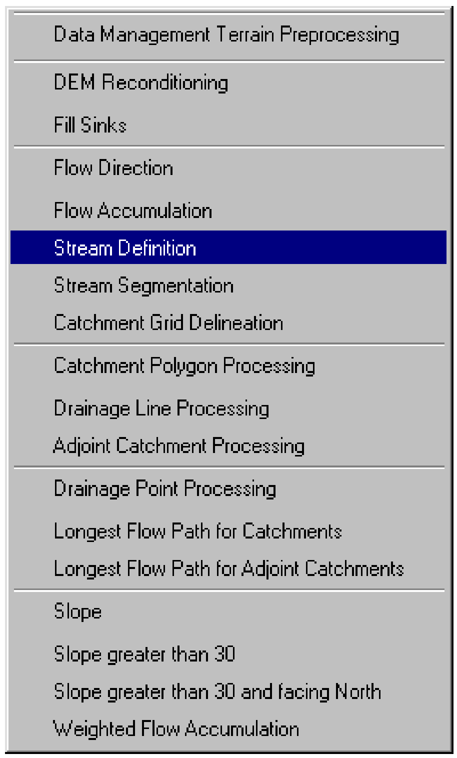


- Confirm that the input of the Flow Direction Grid is "Fdr". The output is the Flow Accumulation Grid having a default name of "Fac" that can be overwritten



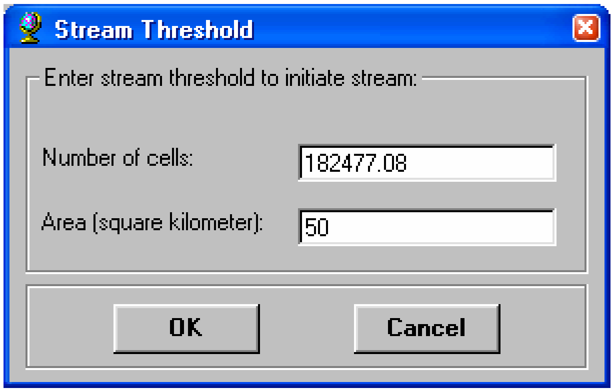
- Press **OK**. Upon successful completion of the process, the flow accumulation grid "Fac" is added to the map.

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

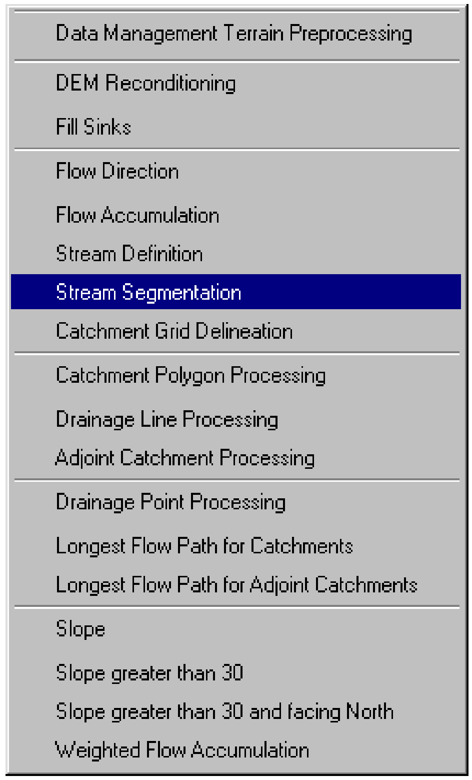


- Confirm that the input for the Flow Accumulation Grid is "***Fac***". The output is the Stream Grid. "***Str***" is its default name that can be overwritten.

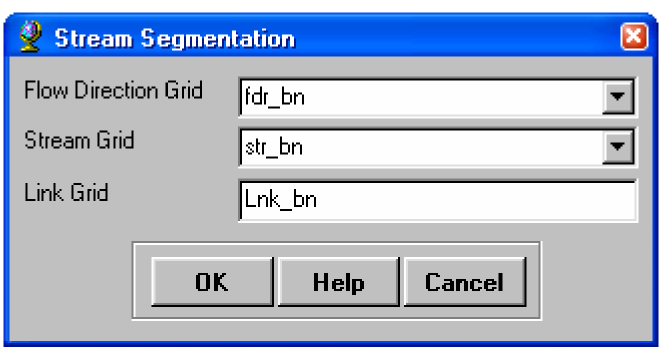
A default value is displayed for the river threshold. This value represents **1%** of the maximum flow accumulation: it is the recommended threshold for stream determination. However, any other value of threshold can be selected. Smaller threshold will result in denser stream network and usually in a greater number of delineated catchments. For the project a threshold value of 50 square kilometers of area was defined.



- Press ***OK***. Upon successful completion of the process, the stream grid "***Str***" is added to the map.
- Select **Terrain Preprocessing | Stream Segmentation**

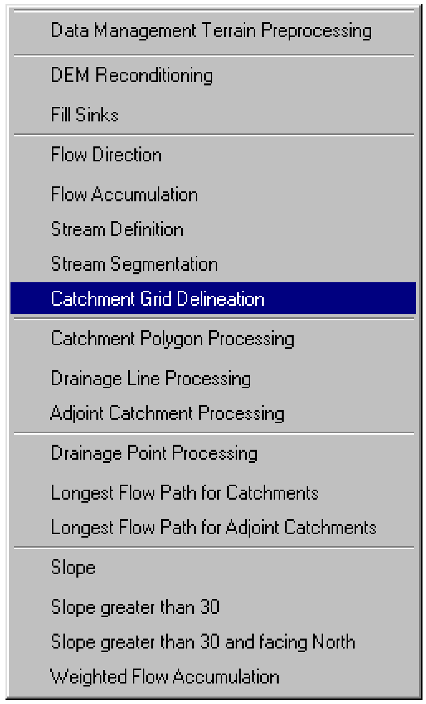


- Confirm that "***Fdr***" and "**Str**" are the inputs for the Flow Direction Grid and the Stream Grid respectively. The output is the Link Grid, with the default name "***Lnk***" that can be overwritten.

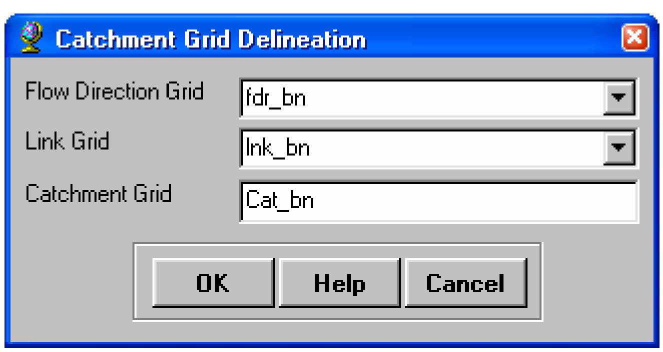


- Press ***OK***. Upon successful completion of the process, the link grid "***Lnk***" is added to the map.

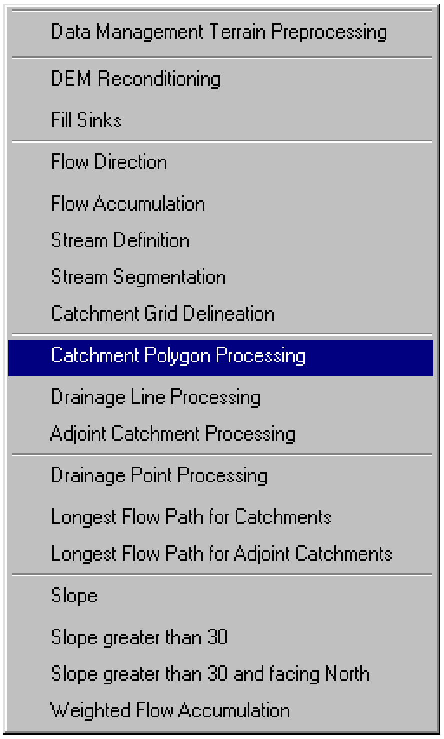
- Select **Terrain Preprocessing | Catchment Grid Delineation**



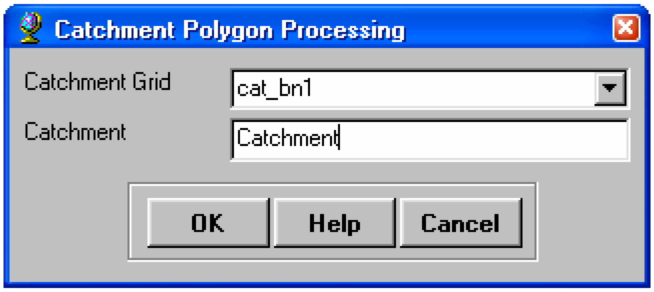
- Confirm that the input to the Flow Direction Grid and Link Grid are "***Fdr***" and "***Lnk***" respectively. The output is the Catchment Grid layer. "***Cat***" is its default name that can be overwritten.



- Press ***OK***. Upon successful completion of the process, the Catchment grid "***Cat***" is added to the map.
- Select **Terrain Preprocessing | Catchment Polygon Processing**.

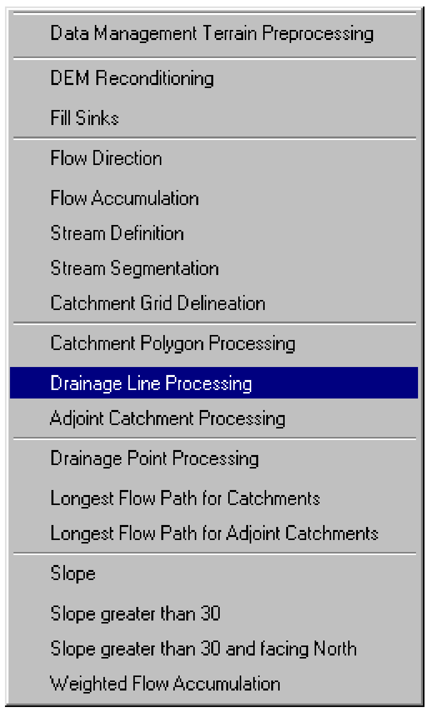


- Confirm that the input to the CatchmentGrid is "***Cat***". The output is the Catchment polygon feature class, having the default name "Catchment" that can be overwritten.

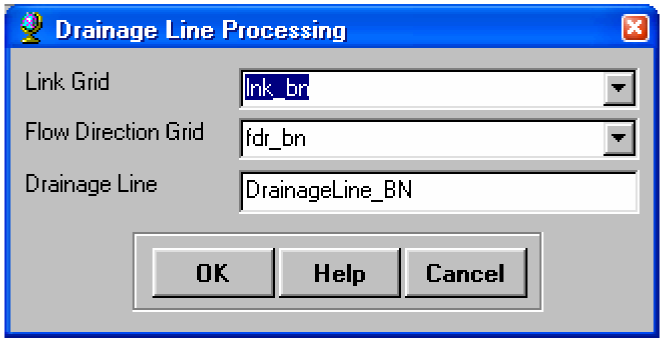


- Press ***OK***. Upon successful completion of the process, the polygon feature class "Catchment" is added to the map.

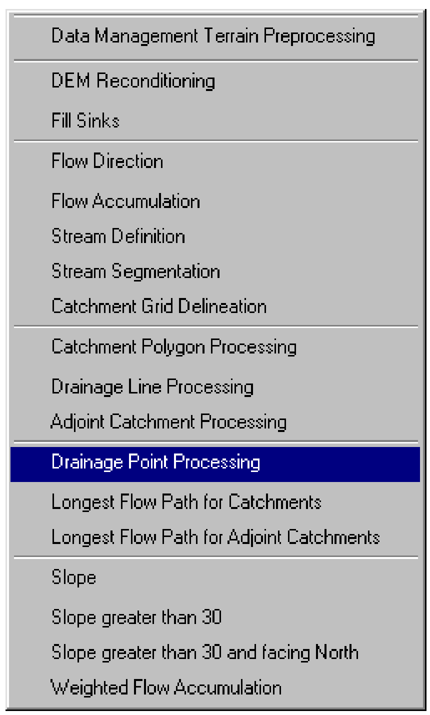
- Select **Terrain Preprocessing | Drainage Line Processing**



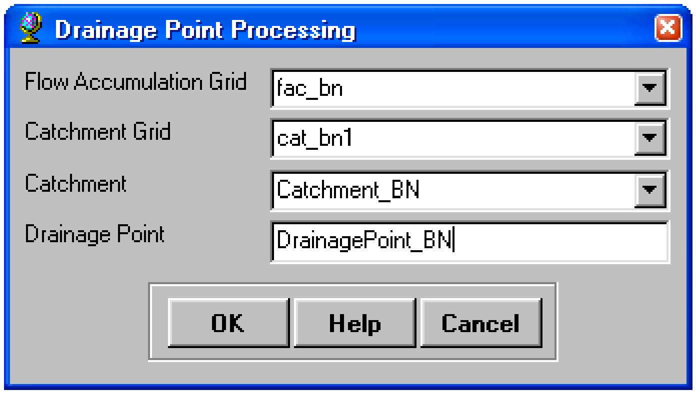
- Confirm that the input to Link Grid is "***Lnk***" and to Flow Direction Grid "***Fdr***". The output Drainage Line has the default name "***DrainageLine***" that can be overwritten.



- Press **OK**. Upon successful completion of the process, the linear feature class "DrainageLine" is added to the map.
- Select **Terrain Preprocessing | Drainage Point Processing**.



- Confirm that the input flow accumulation grid is "***fac***", the catchment grid is "***cat***" 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.

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