An Algorithm to Delineate Coastal Watersheds for TMDL Development

by

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Thesis

Presented to the Faculty of the Graduate School
of The University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science in Engineering

The University of Texas at Austin
May 2001

An Algorithm to Delineate Coastal Watersheds for TMDL Development

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Acknowledgements

First and foremost, I would like to thank my parents, Jennifer and Stephen Samuels, for their unconditional love, unwavering support, and infinite patience. You have made me the person I am today and I cannot thank you enough. I also thank my brother and sister, Michael and Ivy, for the fun, laughter, and listening they have always provided me. Thank you to my boyfriend Ben for brightening my life every day.

My gratitude also goes to my advisor, Dr. David Maidment, as well as Dr. Francisco Olivera, and Dr. Desmond Lawler for their guidance, wisdom, and encouragement during my graduate career at the University of Texas. Thank you to the Texas Natural Resource Conservation Commission for their funding, and to William Saunders for his personal assistance throughout this research effort.

Lastly, I thank all my friends. My Gator friends, especially Kathy, Kim, Jessica and Mike – thank you for the long distance phone calls, laughter and caring. My UT friends – especially Sarah, Melissa, Dave, Kevin, Susan, Tim, Rashi, Joey, Alisa and Jordan – thank you for making Austin feel like my home. I will always appreciate the fun we had together. Thanks to the rest of the students at CRWR and EWRE, past and present, for their help, support and good times.

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The University of Texas at Austin, 2001
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Urbanization, industry and agriculture affect the water quality of the Texas, specifically the bays adjacent to the coast. Thus, the Texas Natural Resources Conservation Commission (TNRCC) has designated Water Quality Management segments partitioning Texas bays and estuaries into distinct waterbodies with individual water quality issues. Similarly, the TNRCC has designated river segments as water quality management segments with unique water quality concerns. This thesis studies water quality management segments in Basin Group C in Texas, composed of the Trinity-San Jacinto Coastal Basin, the Neches-Trinity Coastal Basin, the San Jacinto-Brazos Coastal Basin, the San Jacinto River Basin and numerous bays and estuaries associated with these basins. An algorithm was developed to determine watersheds for the Water Quality Management segments, consisting of procedures to create a hydrography network, process digital elevation models and produce realistic watershed boundaries.

Additionally, this thesis highlights considerations when dealing with coastal regions. Four main issues resulted in approximately 75% of the watershed boundary discrepancies analyzed: contributing area to the Intracoastal Waterway in the Neches-Trinity Coastal Basin, short-circuiting due to cell size scale, unclassified Intracoastal Waterway flow direction in the San Jacinto-Brazos Coastal Basin, and waterbody representation. These inconsistencies were resolved with further editing and enhancement of the surface water drainage network.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Our nation’s lifestyle thrives on a close proximity to water. The four largest cities in the United States, namely New York, Los Angeles, Chicago and Houston, lie along the shoreline of a waterbody, be it a lake, gulf, bay or ocean. Agriculture, industry and urbanization depend on healthy waterbodies and waterways, yet the expansion of these institutions threaten to destroy the very water which nurtures them. In the United States, approximately 40% of assessed waters fail to meet water quality standards set by their governing agencies (EPA, 2000). This amounts to 20,000 river segments, lakes and estuaries, or 300,000 miles of rivers and shorelines and 5 million acres of lakes (EPA, 2000). These impaired waters endanger a majority of the population: 218 million citizens choose to live within 10 miles of these waterbodies (EPA, 2000). The combination of these factors shows the importance of shoreline and coastal regions and the significance of their drainage systems to many aspects of everyday life.

1.1.1 History of the TMDL Program

The government has recognized the need to rectify the impending water quality deterioration for the past several decades. In 1972, the Clean Water Act (CWA) was passed containing Section 303(d). This section required States to develop “pollution budgets” to restore water quality to waterbodies that failed or were predicted to fail their specified water use (EPA, 2000). The responsibility to create these budgets was placed in the hands of states, territories, authorized tribes, and the Environmental Protection Agency’s (EPA) Office of Water.

The formal name of the pollution budget is Total Maximum Daily Load (TMDL) allocation and implementation. TMDL is defined as “the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards”. This maximum amount is allocated among point and nonpoint pollutant sources. Therefore, a TMDL is an assessment of the maximum amount of a specific pollutant each source can discharge into a waterbody before the waterbody exceeds its water quality standards. TMDL allocations must include a factor of safety and a consideration of seasonal variation in their maximum load calculation (EPA, 2000).

1.1.2 TMDL in Texas

In the State of Texas, the Texas Natural Resource Conservation Commission (TNRCC) administers the development of TMDLs. They establish the water quality standards and measurement thresholds mentioned in the TMDL definitions for the State. These standards differ based on the usage of the waterbody. *Chapter 307*: *Texas Surface Water Quality Standards* (TNRCC, 2000) specifies four categories of uses for a waterbody and the water quality criteria to accompany each use. The four uses and their corresponding standards are:

1) Aquatic Life Support – "The standards associated with this use are designed to protect aquatic species. Those standards establish optimal conditions for the support of aquatic life and define indicators used to measure whether these conditions are met. Some pollutants or conditions that may violate this standard include low levels of dissolved oxygen, or toxics such as metals or pesticides dissolved in water" (TNRCC, 1997).
2) Contact Recreation – "The standard with this use measures the level of certain bacteria in water to estimate the relative risk of swimming or other water sports involving direct contact with the water and the bacteria and viruses in it" (TNRCC, 1997).
3) Public Water Supply – "The standards associated with this use indicate whether a water body is suitable for use as a source for a public water supply system using only conventional surface water treatment" (TNRCC, 1997).
4) Fish Consumption – "The standards associated with this use are designed to protect the public from consuming fish or shellfish that may be contaminated by pollutants in the water. The standards identify levels at which certain toxic substances dissolved in water pose a significant risk

> that these toxics may accumulate in the tissue of aquatic species" (TNRCC, 1997).

Each of these waterbody uses carries specific criteria and standards for indicators of water quality. These indicators act as the pollutants and can include metals, organics, fecal coliform bacteria, dissolved oxygen and dissolved solids (TNRCC, 1997).

The TNRCC formally maintains the TMDL initiative by regularly monitoring and assessing waterbodies for their specific use criteria. The results are published in the Clean Water Act Section 305(b) Report, *The State of Texas Water Quality Inventory* for the State of Texas. This document describes to what degree each waterbody meets the water quality standards for its specified uses, determined in *Chapter 307*: *Texas Surface Water Quality Standards.* Any waterbody in the Section 305(b) Report that does not meet the standards set for its use at the present time, or is predicted not to meet the standards in the near future is then placed on *The State of Texas List of Impaired Water Bodies,* corresponding to the Clean Water Act Section 303(d) List. In addition to these failing waterbodies, the 303(d) List also contains any waterbody that has clean-up activities planned in the next two years. This list serves as the foundation of TMDL development; any water body on the Section 303(d) List must have a TMDL developed for it and implemented within 10 years (TNRCC, 1997). A draft portion of the Texas 2000 Clean Water Act Section 303(d) List can be found in Appendix A.

1.2 WATERSHED ACTION PLANS

A Watershed Action Plan is the structure used to develop the TMDL. Each impaired waterbody is managed in the context of its watershed, or “the geographic area in which water, sediments, and dissolved materials drain into a common body of water” (TNRCC, 1997). The watershed action plan is then “a quantitative assessment of water quality problems and contributing pollutant sources, along with an implementation plan that identifies responsible parties and specifies actions needed to restore and protect a water body” (TNRCC, 1997). The processes involved in forming a watershed action plan are: targeting the specific pollutants, reviewing current information and collecting new data from monitoring programs, developing watershed and water quality models and devising management alternatives. Figure 1.1 illustrates this cycle of a watershed action plan and TMDL development in a priority watershed.

Figure 1.1 Watershed Action Plan Schematic (TNRCC, 1997)

Phase 5, the implementation step of the watershed action plan, consists of various rules, restrictions and practice suggestions. Examples of methods to reduce discharges to the TMDL set forth by the TNRCC are: making wastewater permit limits more strict by requiring additional treatment or new technology, requesting farmers and ranchers to use alternate practices to prevent fertilizers, pesticides and manure from traveling into waterbodies, or requiring cities to manage and treat runoff from their streets (TNRCC, 1999).

1.3 STUDY AREA

In order to develop the TMDL and implementation plan, the TNRCC develops geospatial databases of information about the watersheds of these impaired water quality management segments. These watersheds are grouped in five basin groups, A through E, for water quality planning purposes. Figure 1.2 illustrates the basin groups.

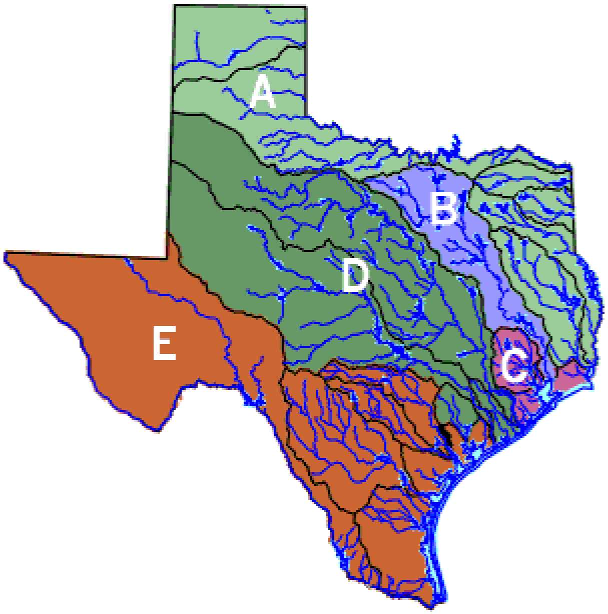


Figure 1.2 TNRCC Water Quality Planning Basin Groups (TNRCC, 2000)

Watershed delineation and data collection was initiated on Basin Group B in Texas, the Trinity River basin. This work was performed by Kimberley Davis and Jona Finndis Jonsdottir at the Center for Research in Water Resources at the

The University of Texas at Austin. This thesis will describe the procedures and efforts to delineate watersheds in Basin Group C in Texas. Figure 1.3 displays the location of the study area.

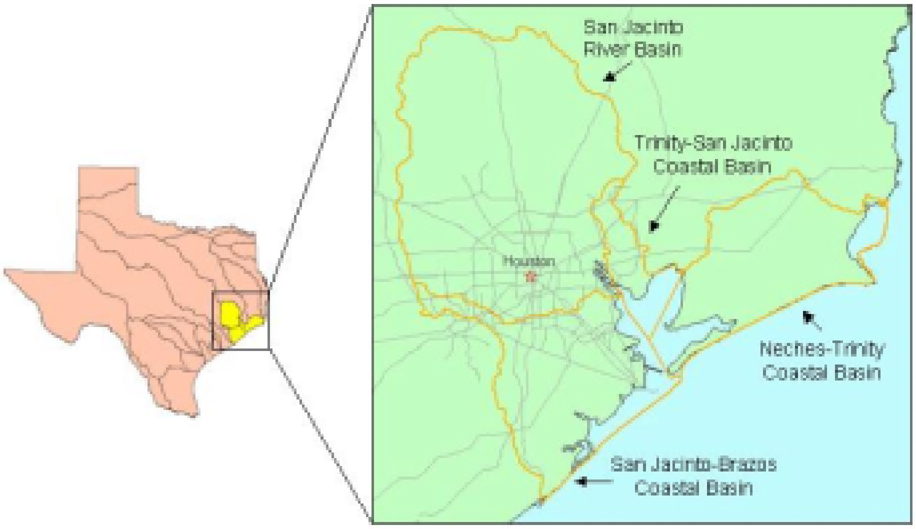


Figure 1.3 Basin Group C in Texas, as defined by the TNRCC

Basin Group C presents a unique twist on the work already accomplished on watershed delineation for TMDL development in Texas. Basin Group C contains not only a river basin but also is composed of three coastal basins and numerous bays and estuaries. Coastal basins are areas where the water and runoff drain directly into the Gulf of Mexico rather than traveling into or through a prominent Texas river. The basins in Basin Group C are: the San Jacinto river basin, the Trinity-San Jacinto coastal basin, the Neches-Trinity coastal basin, and the San Jacinto-Brazos coastal basin. Within this area, there are 55 water quality management segments, waterbodies listed on the 305(b) List. Of these 55 segments, 21 are bays or estuaries.

1.4 OBJECTIVES OF THIS THESIS

The TNRCC has commissioned work to be done by CRWR to determine the watersheds of the 55 water quality management segments in Basin Group C in order to proceed with watershed action plans. Many studies and procedures have been made on delineating watersheds and this practice is common among GIS in Water Resources users. However, areas of little to no terrain slope present a challenge to these established guidelines. In fact, current standards postpone determining procedures for these areas. In the *Federal Standards for Delineation of Hydrologic Unit Boundaries* Draft, no method is described. Instead a note indicates, “due to the unique qualities of the nation’s coastlines, specialized guidelines are presently being developed for these areas, and will be incorporated into these standards when finalized” (USDA, 2000).

The objective of this thesis is to apply the traditional strategy of delineating watersheds, and modify this procedure to consider the complications of the coastal drainage areas. Rather than delineating watersheds to points on a river network, an algorithm is developed for delineating watersheds in coastal and low-lying regions with little to no slope by studying the area draining to a length of river or a waterbody. Additionally, guidelines are presented on how to determine watersheds of waterbodies such as bays or estuaries. The procedures used to develop the geospatial database for TMDL development and the watershed action plan approach are also explained.

1.5 STRUCTURE OF THIS THESIS

This thesis describes the work involved in creating a general procedure for watershed delineation along the Texas coast. Following this introduction, a literature review is performed to find historical information on the issues encountered when delineating watersheds in areas of low slope. Additionally, coastal geomorphology is investigated to find the scientific basis behind the digital data sources and results. This information is found in Chapter 2. Chapter 3 describes the data used throughout the procedures of this research, as well as the data sources and metadata. The data are incorporated in the discussion of the general procedure of watershed delineation in Chapter 4. Modifications to traditional methods and definitions are highlighted. Chapter 5 describes the results from the procedures. As expected with any results, iterations were made to reconcile complications in the general procedure. Solutions to these problems and subsequent results are then presented. Chapter 6 culminates with the conclusions reached from the results and procedures.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The coast has been a constant source of research and speculation as to its development and its influence on the surrounding area. A great deal of analysis has been written about drainage processes in coastal regions and regions of low slope. These papers are reviewed to gain insight into problems that arose and solutions recommended. Then, the science behind the coastal issues, the factors which cause the complications, are explored through the framework of geomorphology.

2.2 PREVIOUS STUDIES

Many studies have been performed at the Center for Research in Water Resources (CRWR) with implications that apply to the coastal environment. This research provided a foundation for the thought process on the procedures of watershed delineation along the coast. The results of these analyses are presented.

2.2.1 Integration of Vector Hydrography

Typical automated watershed delineation efforts are raster-based: using grids of elevation values of an area (Digital Elevation Models – DEMs), analyzing the changes in elevation to find in which direction water from each grid cell flows, and accumulating the number of upstream cells. Looking at the flow accumulation, DEM stream paths are identified using the assumption that the largest flow accumulation is found in the defined channels. However, this process assumes that the topographic relief is significant enough to induce a drainage pattern over the landscape. In the case of the coastal region, the relief is so slight that it is referred to as flat, with little to no slope whatsoever.

Nevertheless, many attempts have been made to determine digitally computed drainage paths directly from digital elevation models. Melancon (1999) and Saunders (1996, 1999) both report that the grid-delineated streams and the actual streams (from digital line data that is described further in Chapter 3) vary greatly in areas of low relief. This is attributed to little defining terrain in the region, in which the elevation values do not change significantly or at all from cell to cell. Therefore, the flow direction is calculated over an area of equal elevation (Melancon, 1999; Saunders, 1996).

In addition to the inaccurate stream network, this issue carries through to the delineated watersheds. Saunders (1999) encountered problems where the watershed boundary intersected the vector hydrography stream network. This was caused by a difference between derived streams from the DEM and the actual stream hydrography. Mason (2000) found the same issue in his study of the San Jacinto basin. For USGS gage 8076000, which has a slope of 0.00075 m/m, the watershed boundary was erratic and unnatural in appearance. Yet, when consulting with a topographic map, no contours were present in the area to compare to the computer delineation. The area was so flat that it was impossible to determine if the unusual watershed boundary was correct.

A method to avoid this discrepancy is described as “burning in” the vector hydrography stream network to the DEM. Essentially, the stream network created from inspection of maps and aerial photography is organized in a vector format. This stream network is then overlaid on the digital elevation grid, and wherever the stream network coincides with a grid cell, that elevation is frozen. Any grid cell not coincident with the stream network is raised by a fixed value. The landscape then appears to have canyons where the vector stream network flows. Burning in the network and the differences between vector and raster data is further described in Chapters 3 and 4.

Burning in the stream network also helps to eliminate the problem known as “short circuiting”. Short circuiting is when the drainage path is distorted from the known location of streams and tributaries because it follows the DEM path of least gravitational resistance (Saunders 1999). Short circuiting is very common in areas near the coast where the slope is generally flat. Also, it occurs when the vector hydrography scale is too intricate for the digital elevation model, and the flow path is distorted because of nearby burned in cells. When these cells are adjacent to each other, flow may jump from one path to another incorrectly. The erroneous flow path is than transmitted through the flow direction grid to the flow accumulation grid. The result is again a derived stream network that differs from the accepted stream network. A solution to short circuiting from cell size and scale is to manually alter the stream network where paths appear too close together. However, this procedure is not recommended because a domino effect can occur and other features could be affected by the change as well. But, in the instance that more accurate DEMs are not available, no other recourse is possible (Mason, 2000).

The results of integrating the vector hydrography by burning in the network are seen in comparisons of watersheds for USGS gages. Saunders (1996) compared gage drainage areas reported by the USGS with delineated watersheds after the stream network was burned in to the DEM. The areas matched fairly accurately; however, the largest errors were seen for gages in the flattest areas and the least error occurred at the most inland gages (Saunders, 1996). Mason (2000) also compared USGS drainage areas with delineated watersheds. This study found a direct correlation between the slope of the area and the percent difference between calculated areas. For slopes greater than 0.002 m/m, the absolute difference was less than or equal to 1%. For slopes less than 0.002 m/m, a steep increase in the percent difference was found. Most of these gages with slopes less than the threshold were located in the San Jacinto basin. Furthermore, the gages were within 75 miles of the coast (Mason, 2000).

2.2.2 Recommended Procedures

Through these previous studies, procedures were devised to aid in delineating these watersheds. These procedures relate to both the vector stream network and the digital elevation model.

Saunders describes various editing recommendations for the stream network. First, lakes and isolated streams should be removed. Then instream lakes should be replaced with a centerline and braided streams should be substituted with a main channel. Marsh channels through barrier islands, pipelines, shipping channels, and islands within the Intracoastal Waterway should be eliminated (Saunders, 1996). The coastline should also be removed from the stream network because only arcs that represent drainage paths to outlets of the watershed should be included. The main stem of the drainage paths should also extend to the edge of the DEM. For coastal watersheds, that corresponds to a path from the mouth of a river out into open water (Saunders, 1999).

Several recommendations also exist referring to the digital elevation models. In coastal areas, DEMs with smaller scale, such as 10 meter cell size, are recommended for use (Mason, 2000). However, their computer processing time increases dramatically, and this is not currently practical. In dealing with larger celled DEMs, Saunders presents discussions of a procedure that introduces a small elevation gradient in flat areas leading towards a cell with a known flow direction. The integer values in the DEM cells are replaced by floating point values that slowly transition to the defined grid cell in the flow direction grid. Hellweger developed this procedure as an AML (Arc Macro Language) named *Agree*, and Reed reported on its application (Saunders, 1999).

Relating specifically to coastal applications, Melancon (1999) indicated several modifications that must be made to the DEM. First, negative values cannot be handled by the ArcInfo software; therefore, an additional processing step to remove the negative values must occur. Also, the ocean should act as an infinite sink for any flow. Hence, the ocean must be represented by NO DATA values in the DEM for watersheds along the coast to be delineated properly (Melancon 1999). Through these previous studies, many results can be applied to the efforts presented in this thesis for coastal watershed delineation.

2.3 COASTAL ZONE GEOMORPHOLOGY

The problems and procedures detailed all relate to various topographic issues in the coastal region. Therefore, it is necessary to consider how the topography was established. The resource used to study this evolution was the *Environmental Geologic Atlas of the Texas Coastal Zone – Galveston-Houston Area* (Fisher *et al.*, 1972), developed by the Bureau of Economic Geology at the University of Texas at Austin. The Texas Coastal Zone is located from the inner continental shelf to approximately 40 miles inland and encompasses all estuaries, tidally influenced streams and bounding wetlands. The Coastal Zone is divided into seven specific areas: Beaumont-Port Arthur, Galveston-Houston, Bay City-

Freeport, Port Lavaca, Corpus Christi, Kingsville and Brownsville-Harlingen; this thesis focuses on the Galveston-Houston area. The entire Texas Coastal Zone is illustrated in Figure 2.1.

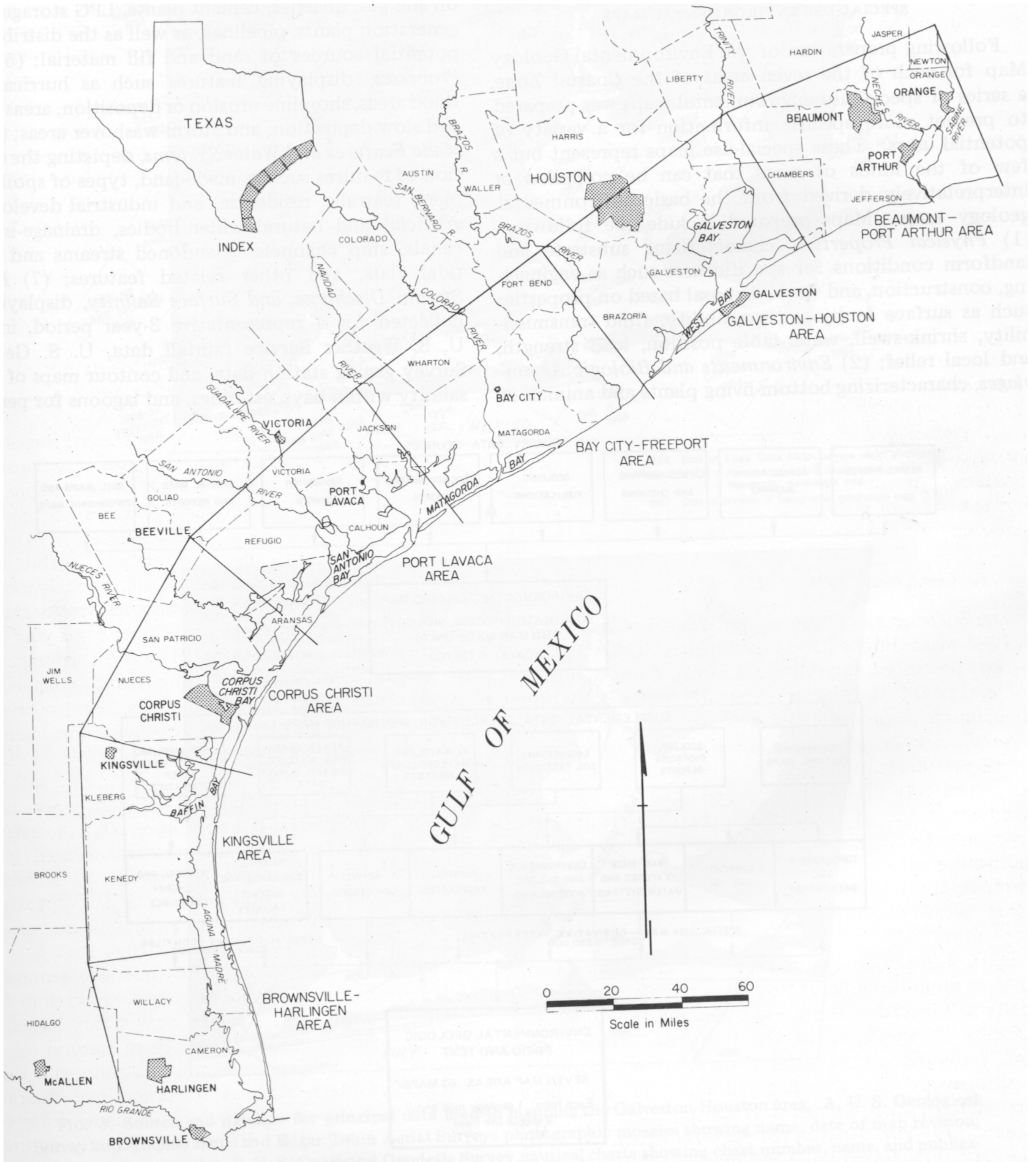


Figure 2.1 Texas Coastal Zone, partitioned into 7 areas (Fisher *et al.*, 1972)

The Galveston-Houston area covers about 2,903 square miles, of which 2,268 square miles is land. The general characteristic is a gently inclined slope gulfward of 5 ft/mile or less. It has primarily low relief, with the highest elevation of about 90 ft above mean sea level (MSL) that occurs mainly at Hoskins Mound, Barbers Hill, and the Blue Ridge State Prison Farm. The higher elevation topographic features are a result of salt domes. Two major river valleys transverse this region, the Trinity and the San Jacinto, as well as several valleys of minor headward eroding streams, such as Cedar Bayou, Buffalo Bayou, Clear Creek, Dickinson Bayou, Chocolate Bayou and Bastrop Bayou. The majority of the area is covered by extensive marshes, less than five feet above MSL, which stretch along West Bay, East Bay, the Trinity River delta and the lower Trinity River valley. Figure 2.2 is a schematic representation of the different geological environments of deposition that have been active along the Texas Gulf Coast over long periods of time (Fisher *et al.*, 1972).

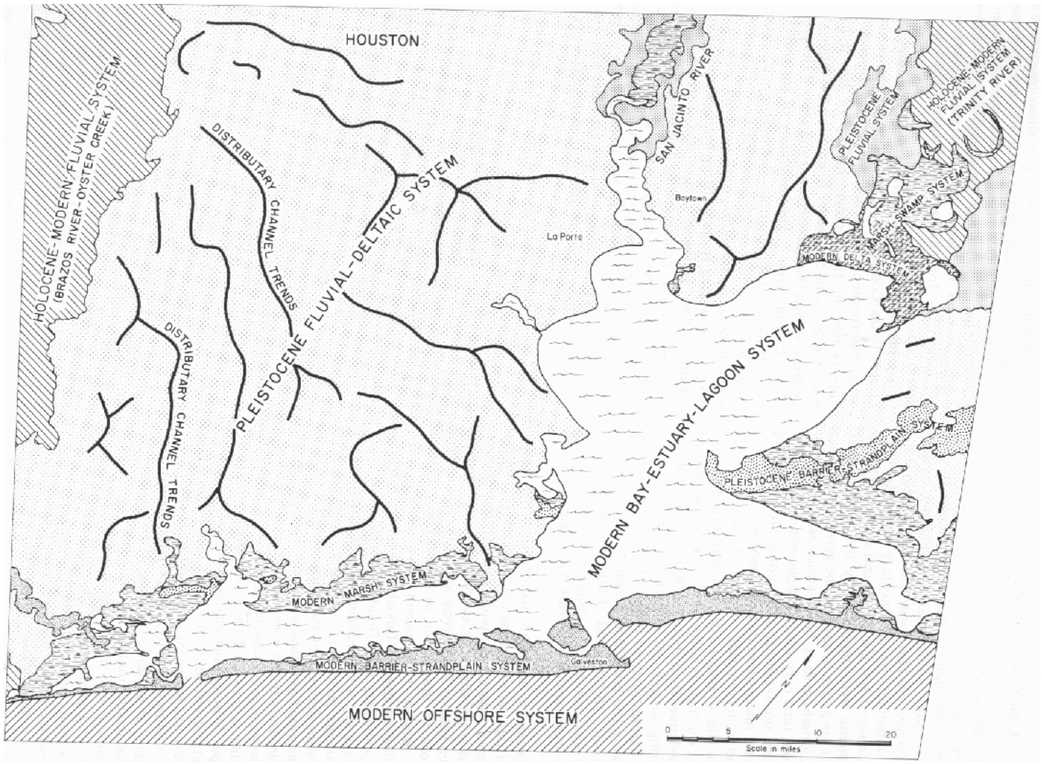


Figure 2.2 Natural Systems defined by environmental mapping in the Galveston-Houston area (Fisher *et al.*, 1972)

In order to evaluate the complex coastal zone as it exists today, it is necessary to study its geologic history. The *Environmental Geologic Atlas of the Texas Coastal Zone* states “the present Coastal Zone is, therefore, but one frame in a kaleidoscope of changing rivers, shifting beaches, and subsiding plains. Past geologic events and current geologic processes join in characterizing the nature of the *total* coastal environment, as well as to point inevitably to future changes that man must learn to understand, predict, and manage.” The factors affecting current processes include soils, wildlife, vegetation, groundwater, and natural resources. All of these components are influenced by the ancient geologic systems and must be considered to thoroughly understand and manage the present day Coastal Zone. Fisher *et al.* (1972) divide the geologic history of the area into three main time segments: Pleistocene, Holocene and Modern. Pleistocene age deposits originated over 30,000 years Before Present (B.P.) during glacial and interglacial cycles. Holocene age deposits originated after the final glacial period of the Pleistocene, approximately 18,000 to 4,500 years B.P. Modern deposits are the evolving systems that have been developing from 4,500 years B.P. to the present (Fisher *et al.*, 1972).

2.3.1 Pleistocene Depositional Systems

The Pleistocene is composed of at least four main glaciation cycles interspersed with interglacial episodes. Pleistocene depositional systems therefore exhibit the effects of recurring glaciation and melting. The later interglacial periods caused great amounts of sediment to be carried from upstream areas of Texas to broad embayments along the Gulf coast. Sand and mud were deposited in point bars along shifting meandering streams and in levees along vegetated river banks respectively. Meandering streams evolved seaward into distributary streams that emptied and deposited into the stream mouth, forming delta lobes and increased land encroachment into the Gulf bays. Rivers abruptly shifted course to send water along a more direct path with a higher gradient and shorter distance. The original distributary stream paths were than abandoned, only to be reused when the bays filled with sediment from overextension of the delta lobes. As the deltas extended further seaward, they encountered barrier islands, some of which were up to 58,000 years old. The deltas proceeded to bury these low sand bodies and islands. At the end of the Pleistocene, glaciation again occurred and the sea level dropped. Rivers no longer deviated from their course, and instead eroded into older fluvial and deltaic deposits, creating broad scalloped shaped valleys such as the Trinity and San Jacinto river incised valleys. The rivers then formed deltas along new shorelines located miles out onto the Continental Shelf (Fisher *et al.*, 1972).

The processes that occurred to cause Pleistocene depositional systems are still evident today. Several coastward trending pieces of older deltaic distributary channels can be seen in the coastal uplands, as inferred by the presence of higher elevation levee deposits. The abandoned delta distributary channels, later occupied by smaller streams, are now present as either abandoned meanders or loops. Because the loops are usually filled with mud, the abandoned courses now pond water in the form of oxbow lakes (Fisher *et al.*,1972). Many of these lakes can be observed in the coastal regions of Basin Group C. The areas between the distributary channels and inland from the delta lobes that infringe on the bays are broad flat areas of mud and clay substrates, as well as other associated sediments. These sediments correspond to interchannel floodplain or overbank deposition during the Pleistocene and comprise the largest geologic component of the Texas Coastal Zone (Fisher *et al.*, 1972).

Several sand bodies are also located inland of the shoreline. These sand bodies are believed to be the present day portrayal of the ancient Pleistocene barrier islands. East of Galveston Bay, the ridge forming Smith Point and extending northeastward through the Double Bayou area is considered to be a Pleistocene sand body. Figure 2.3 displays the ridge formed inland of the coastline due to Pleistocene barrier-strandplain sands. Additionally, the areas west of Galveston Bay, south of Dollar Bay and on either sides of Chocolate Bay display similar ridges. These ridges are slightly elevated, typically about 10 feet above local relief (Fisher *et al.*, 1972).

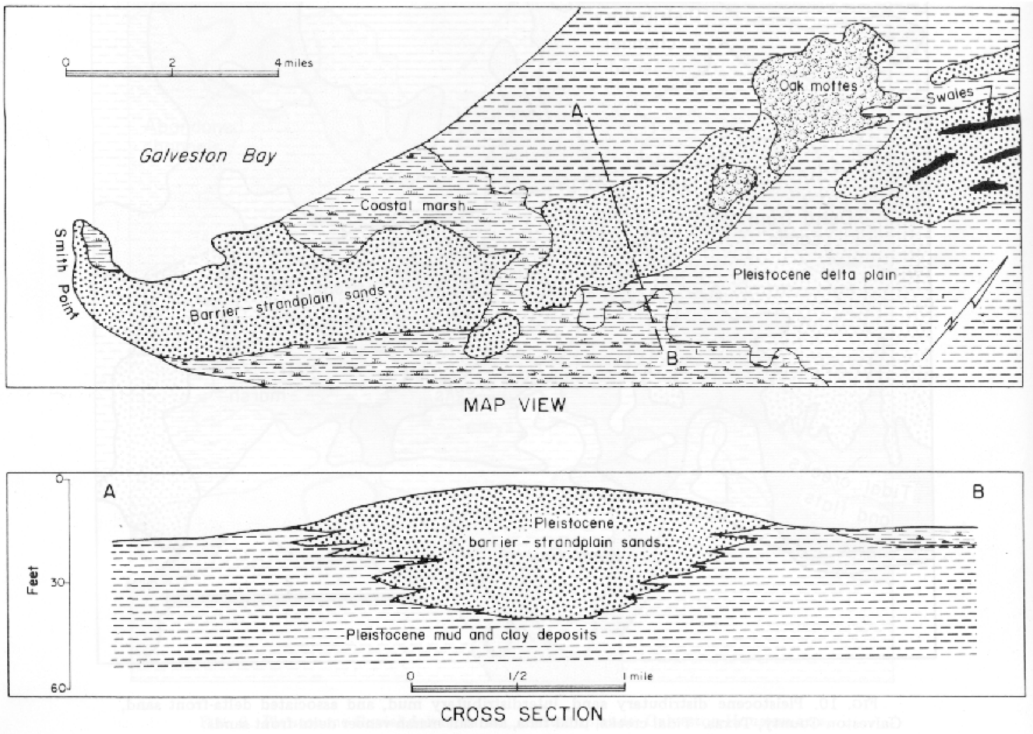


Figure 2.3 Pleistocene barrier-strandplain sands, Smith Point area (Fisher *et al.*, 1972)

2.3.2 Holocene-Modern Depositional Systems

The Holocene and Modern deposits are linked together because of common representations of geologic processes in today's landscape. Many geologic units, features of significant environmental character, can be attributed to both the late Holocene and early Modern times. However, the geologic history of each time period differs. The Holocene Epoch is depicted as a time of great fluctuation in which the sea level began its last great rise after the final Pleistocene glaciation when melted waters reached the ocean. As the sea level rose, the rivers continued to meander within the filling valleys. Mud sheets and large point bars were deposited by the rivers as they meandered toward the coast. The Trinity and San Jacinto river valleys continued to fill and eventually drowned to form the Trinity and Galveston Bays (Fisher *et al.*, 1972).

Modern history relates the changes that occurred when the sea level reached a somewhat constant state at the present level. Five main changes were initiated during this Modern time. Eroding sediment from drowned valleys began to fill the deeper parts of the Trinity and San Jacinto estuaries, continuing the formation of the modern Trinity and Galveston Bays from the inundated Trinity and San Jacinto river valleys. The bayhead deltas began to also fill the upper end of the estuaries. Headward erosion due to excessive rainfall and runoff continued in streams located in areas of Pleistocene mud deposits, such as Chocolate Bayou, Clear Creek, and Cedar Bayou. East and West Bays grew as elongated lagoons behind the barrier island of Bolivar Peninsula. Bolivar Peninsula, Galveston Island, Follets Island and other sand bodies were formed by spit and shoreface deposition from the deltaic sediments that traveled southwestward by longshore currents and shoreward by wind-generated waves. Marshes began developing over the Pleistocene delta deposits and bays that were filled by storm flooding. At a filled depth of 1-2 feet, marine grassflats and marsh plants sprouted and accelerated the trapping of sediments (Fisher *et al.*, 1972).

These changes are reflected in the present-day systems shown on the Environmental Geology Map. Abandoned meandering channels of the Trinity, Brazos, and San Jacinto rivers have evolved into topographic lows on the river floodplains. Again, these channels are now seen as narrow, sinuous loops and oxbow lakes that trap water. Point bars have formed along the current meandering streams, appearing as large deposits of sand and bedload along the inner curve of the loops and meanders. Also adjacent to the modern channels are levee deposits caused by frequent overbank flooding. The overflow from the river banks leads to fine grained muds and silts resting just outside the river channels, resulting in a topographic high directly next to the river channels (Fisher *et al.*, 1972).

The current barrier-strandplain-chenier system is also influenced by the geologic past. The beach area is comprised of a forebeach that gently slopes seaward and a back-beach that slopes either seaward or locally away from the sea. The forebeach and back-beach are separated by a berm up to five feet high, which can influence the sloping of the back-beach. The sand bodies also contain a beach ridge area, which is a series of subparallel ridges and swales oriented with the barrier island. Each ridge depicts a former shoreline location. The ridges are also 5-10 feet above MSL. The remainder of the barrier island/sand body features are covered by vegetated barrier flats or wind-tidal flats (Fisher *et al.*, 1972). Figure 2.4 depicts the Modern barrier-beach system around Galveston Island.

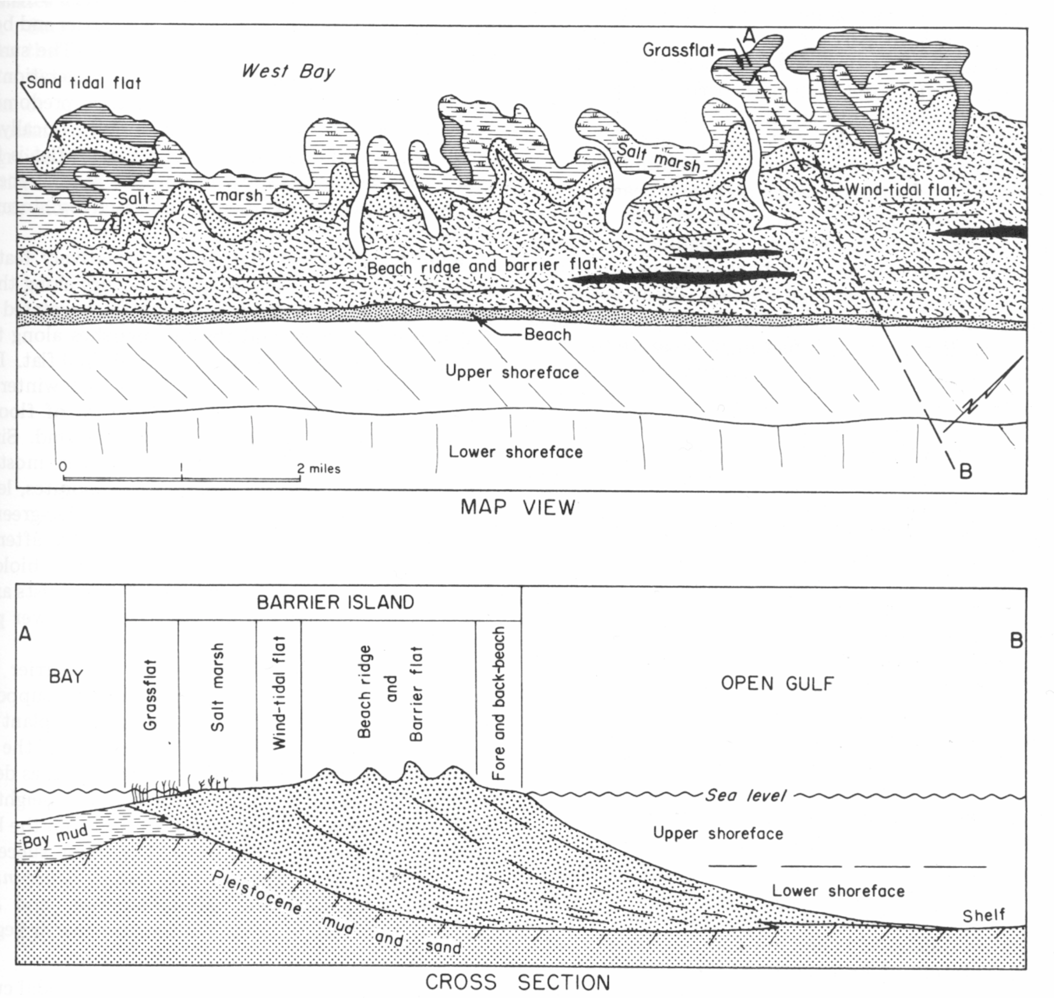


Figure 2.4 Modern barrier-bar environment and facies, Galveston Island (Fisher *et al.*, 1972)

The marsh-swamp environment distinguishes the Texas Coastal Zone from the rest of the state due to its unique characterization. Modern marshes and swamps are found at elevations usually less than 5 feet above MSL. The substrate is perpetually wet and the water table is permanently high. Swamps and marshes are typically formed on top of flood-tidal deltas, back sides of barrier islands and sand bodies, mainland shorelines, abandoned tidal creeks and channels, and fluvial floodplains, and therefore, comprise the majority of the Texas Coastal Zone. Adjacent to the marshes and swamps are the bays, estuaries and lagoons, covering a 553 square mile area of the Galveston-Houston coastal zone. Included in the bay system are Galveston and Trinity Bays, coastward trending lagoons such as East and West Bays, and smaller waterbodies such as Christmas and Drum Bays, shown in Figure 2.5. The shape and morphology of these bays represent ancient depositional and erosion topography (Fisher *et al.*, 1972).

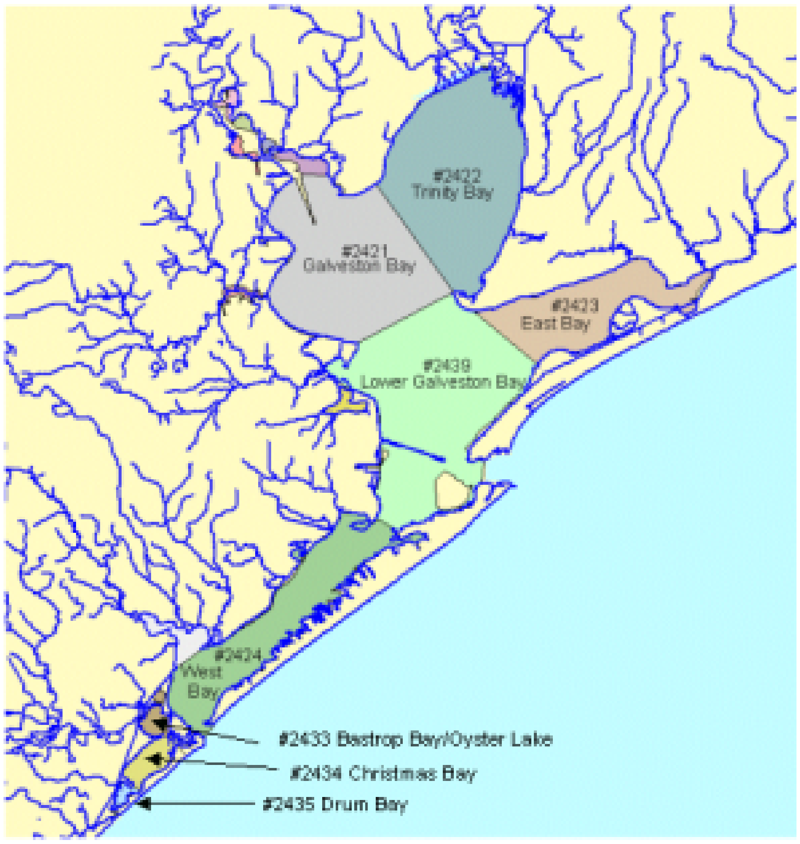


Figure 2.5 Reference Map of Basin Group C Bays

2.4 CONCLUSION

The geomorphology of the Texas Coastal Zone creates the foundation for complex topography of the region. The existence of so many abandoned channels and ridges, formed by ancient geologic events, produces the complicated drainage patterns seen in the landscape. The looping and undefined stream paths discussed in previous research as causing problems in watershed delineation are primarily caused by these Pleistocene and Holocene-Modern geologic systems. Therefore, understanding these issues and ascertaining remedies in the digital delineation environment is necessary.

CHAPTER 3: DATA DESCRIPTION

3.1 INTRODUCTION

The procedures and research presented in this thesis focus on the availability, detail and accuracy of the digital data utilized. This chapter describes the data involved in delineating watersheds for a coastal environment in the context of TMDL development. It also displays the various digital data layers collected as part of the geospatial database for each TMDL segment. Additionally, map projections are crucial in dealing with digital data. The more prominent map projections used in this work are also described.

3.2 DATA DESCRIPTION

Watershed delineation requires many forms of digital data such streamlines and elevation data, as well as topographic information to ensure accuracy of the data retrieved from public agencies. The following datasets are described based on their use in the research presented:

- National Hydrography Dataset
- TNRCC Water Quality Management Segments
- Digital Raster Graphic Maps
- National Elevation Dataset

Then, the 44 different geospatial data layers requested by the TNRCC are listed with accompanying metadata sources.

3.2.1 National Hydrography Dataset

The core of any GIS in Water Resources application is a surface water drainage network. The framework of the network for this research lies in the National Hydrography Dataset (NHD). The NHD is “a comprehensive set of digital spatial data that encodes information about naturally occurring and constructed bodies of water, paths through which water flows, and related entities” (USGS, 2000). This dataset holds base cartographic information in the form of two types of data layers, routes and regions, each with distinct ways of representing the data. The “route” layers encompass the linear surface water drainage network and consist of the route.reach and route.drain themes. Route.drain divides the network into the types of network features such as stream/river, canal/ditch, artificial path, and pipeline. Route.reach divides the network differently, defining numbered river reaches that can be used for linear referencing. The “region” layers correspond to areal hydrographic waterbody features. Region.wb contains the waterbody features such as sea/ocean, lake/pond, reservoir and others. Region.reach contains those waterbodies that represent waterbody reaches, reaches that delineate the boundary of specific waterbody features, and are labeled with a Reach Code. More information about the characteristics and attributes of the NHD is presented in Appendix B in the form of an interactive and educational exercise. Figure 3.1 illustrates the various data layers present in the NHD coverage.

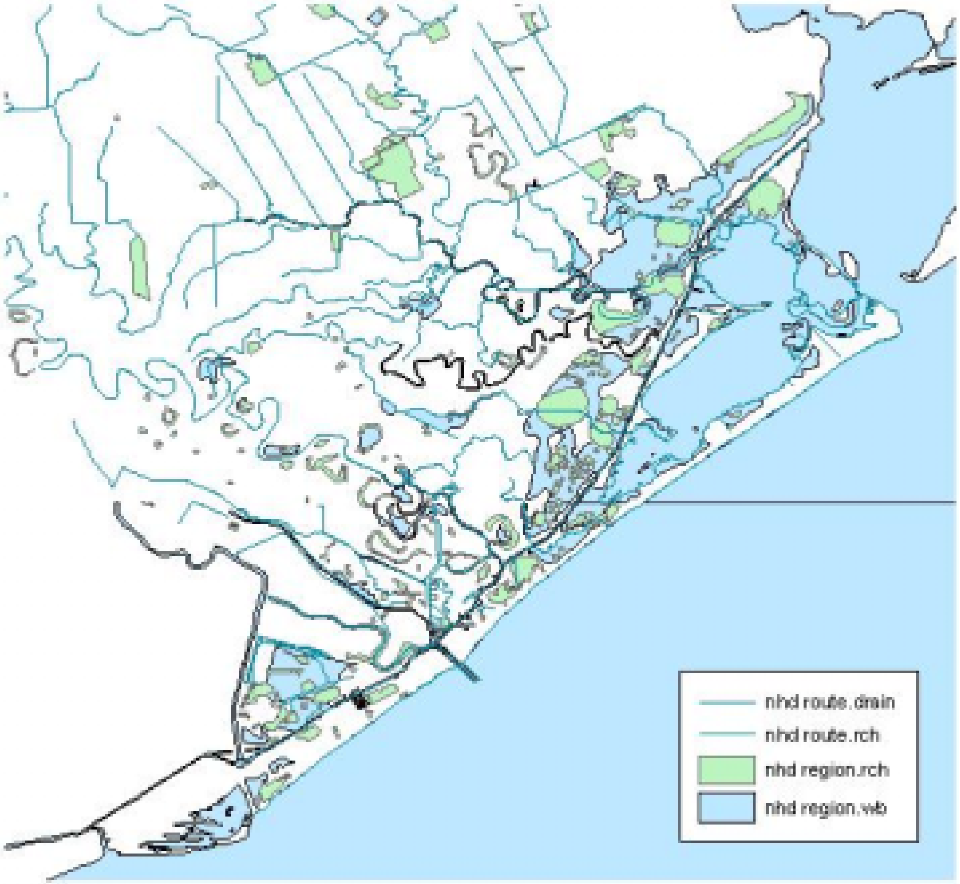


Figure 3.1 Data Layers in the NHD coverage

The NHD is derived from many sources, primarily Digital Line Graph 3 files and Reach File Version 3 data. Digital Line Graph 3 (DLG-3) data originates from USGS topographic maps and unpublished source material. It provides the designation and classification of the NHD line features, with the exception of connectors and artificial paths through waterbodies. DLG-3 data is distributed in the UTM projection with the North American Datum of 1927 at a scale of 1:100,000. Reach File Version 3 (RF3) data was developed by the U.S. Environmental Protection Agency (EPA) also from 1:100,000 scale Digital Line Graph data. RF3 data furnished the first classification of reach codes and flow direction on streamlines and positions of geographic names. The DLG-3 data was converted to features and merged with the RF3 data to build reaches (USGS, 2000).

The NHD is distributed by hydrologic cataloging unit in geographic coordinates. The horizontal datum used is the North American Datum of 1983. Areas and Lengths were obtained from the Albers Equal Area projection. Any elevation references are with respect to the National Geodetic Vertical Datum of 1929 (USGS, 2000).

3.2.2 TNRCC Water Quality Management Segments

The watersheds delineated for this project correspond directly to a TNRCC Water Quality Management segment, also known as a designated segment. The procedure by which these segments are chosen is explained in Chapter 1. The final chosen segments are in the form of a unique identifier with a description of the water quality issue and the location of the segment, found in *Chapter 307: Texas Surface Water Quality Standards* (TNRCC, 2000). This description is then converted to a digital representation of the segment, which was used in this research. The segments signify either a stream or a waterbody. A stream is considered “a flowing surface water feature such as a river, creek, canal, or navigation channel”. Narrow streams are characterized by a single centerline while wider streams are displayed as their right and left bank lines. Waterbodies are defined as “surface water features with areal extent; i.e., lakes, reservoirs, bays, estuaries and a portion of the Gulf of Mexico” (TNRCC, 1999). Boundaries are also produced that indicate where multi-segment waterbodies such as Galveston Bay separate into distinct segments (TNRCC, 1999).

Three main sources were used by the TNRCC to compile the TNRCC Designated Stream Segments digital data layers. Using the description from Chapter 307, the initial draft of the streams and waterbodies was extracted from TIGER/Line 92 data. The TIGER line files were obtained from the U.S. Census Bureau and were published in 1992. Missing spatial data was added to the streams and waterbodies by digitizing the absent segments from Texas Department of Transportation (TxDOT) County Maps and U.S. Army Map Series Map Sheets (TNRCC, 1999).

The designated stream segments layer has an accuracy based on the three different scales of source data used. The TIGER files are at a 1:100,000 scale, the TxDOT County Maps are at a 1:63,360 scale and the U.S. Army Map Sheets are at a 1:250,000 scale. Therefore, the horizontal accuracy ranges between 32 meters and 127 meters. The water quality management segment data layer obtained from the TNRCC is in the Texas State Mapping System (TSMS)

Lambert projection, described later in this chapter. Figure 3.2 shows the TNRCC designated stream segments for Basin Group C (TNRCC, 1999).

Figure 3.2 TNRCC Designated Streams and Waterbodies

3.2.3 Digital Raster Graphics Maps

In comparing the TNRCC water quality management segments to the NHD data, discrepancies were noticed. Additionally, the coastal areas require enhanced detail on occasion to capture the true nature of the surface water flow. Digital Raster Graphic Maps (DRGs) were utilized to provide this accuracy. DRGs are scanned images of USGS topographic maps and display natural and constructed features of the Earth’s surface. Natural features include mountains, valleys, lakes and rivers. Constructed features include roads, boundaries, and canals. Characteristic of topographic maps are the contour lines that indicate the three dimensional terrain on a two dimensional surface (USGS, 1999). The topographic map is scanned on a high-resolution scanner at a minimum of 250 dots per inch. The scanned image is then georeferenced to fit theoretical Universal Transverse Mercator (UTM) coordinates based on the published map’s graticle ticks. The finished file, the DRG, is then compressed into about 8 megabytes as a TIFF image (USGS, 2000).

DRGs and topographic maps are available at many scales. The scale used for this research was 1:24,000, the equivalent of a 7.5-minute quadrangle map. This scale corresponds to a ground resolution of 8 square feet per pixel. The DRG is distributed in UTM projection with the datum of the source map, typically NAD 1927. The accuracy of a DRG with respect to a paper topographic map is approximately the same. Paper maps have error due to paper shrinking and stretching while the DRG contains error in the manual matching of the scanned image to the control graticle ticks (USGS, 2000). Figure 3.3 displays an example of a DRG used in this study.

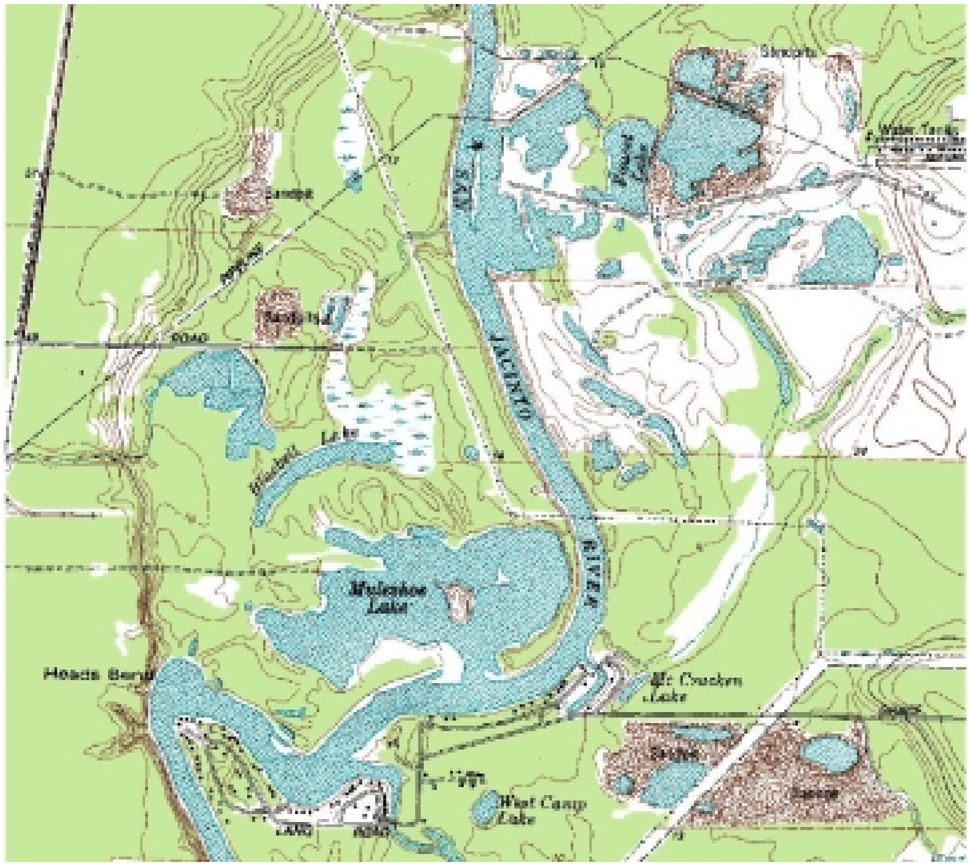


Figure 3.3 Digital Raster Graphics Map

In the author's experience of comparing the National Hydrography Dataset to the Digital Raster Graphic maps, the NHD, while comprehensive, still neglects to include all significant streams, especially important in such a flat area. In general, the NHD contains main stream stems but does not incorporate the minor tributaries of every river reach. Additionally, many streams in the NHD end prematurely where the DRG indicates that the stream continues further in the landscape. These issues were resolved through editing of the NHD to obtain a more thorough network. A complete description of this procedure is found in Section 4.2.2.

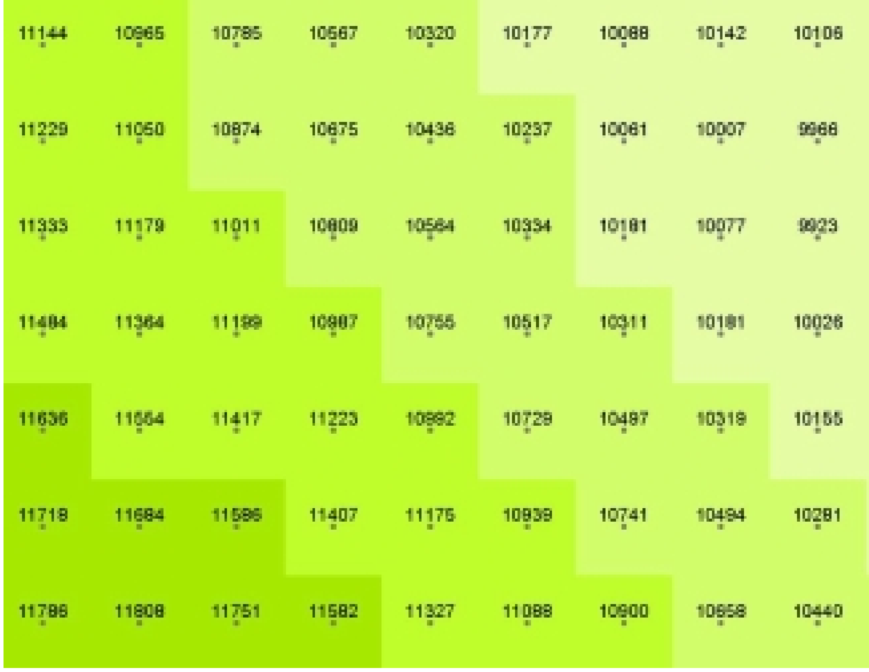
3.2.4 National Elevation Dataset

Digital elevation models (DEMs) are essential to watershed delineation because gravity drives flow. A DEM is array of elevation values for the ground at a regularly spaced interval (USGS, 1996). The DEMs used for this study were obtained from the National Elevation Dataset (NED). The NED is a compilation of over 50,000 files of DEM data, merged into a seamless dataset with a consistent projection and datum. The projection of the distributed NED is geographic coordinates with the North American 1983 datum. The elevation values are referenced to the North American Vertical Datum of 1988 (USGS, 1999).

The DEMs used to assemble the National Elevation Dataset are typically produced from cartographic and photographic sources. Cartographic information was gathered from maps of scale 1:24,000 through scale 1:250,000. The topography found on the maps is digitized and then interpolated to take the standard grid format and spacing. Photographic information is processed into the DEM format by manual and automated correlation. The elevations are gathered and these raw elevations are then weighted based on spot heights during an interpolation process to achieve the matrix form and desired interval spacing (USGS, 1996).

Because the NED is composed of various DEMs, the final product contains production artifacts and requires edge matching. Artifacts are removed from the NED by a “mean profile filtering” algorithm which isolates elevation deviations which cause banding in the DEM. The data was then merged together to form the 7.5 minute panels. Small pieces of data were missing from the panels, and a bilinear interpolation algorithm was employed to fill these voids. Any discontinuity caused by merging two DEMs of different quality, scale or source was rectified. Spikes in elevation were replaced by an interpolated value while offsets were corrected by matching the DEM to fit along the edge and correspond with the slope (USGS, 1999).

The NED has a resolution of 1 arc-second, or approximately 30 meter interval spacing, leading to 30 meter cells with unique elevation values. This data is the most accurate currently available for the state of Texas. The NED is retrieved in tile format, in which each tile name is the (x,y) coordinate of the upper left corner of the tile. For example, the upper left corner of dem9530 is at (95^{o}W, 30^{o}N). The elevation information is given in floating point meters; however, for computation speed, the decimals were converted to integer by multiplying by 100 to maintain accuracy. Therefore the elevation values shown in any subsequent figures are in centimeters. Figure 3.4 displays the NED in grid form as 30 meter cells as well as the unique elevation values in matrix format.



11144	10965	10785	10567	10320	10177	10088	10142	10106
11229	11050	10874	10675	10436	10237	10061	10007	9966
11333	11179	11011	10809	10564	10334	10181	10077	9923
11484	11364	11199	10987	10755	10517	10311	10181	10026
11636	11564	11417	11223	10992	10729	10487	10319	10155
11718	11684	11596	11407	11176	10939	10741	10494	10281
11786	11808	11751	11582	11327	11088	10900	10658	10440

Figure 3.4 Digital Elevation Model with point elevations

3.2.5 Geospatial Database Data Layers

As part of the contract with the TNRCC to delineate watersheds for the water quality management segments in Basin Group C, a geospatial database was compiled. The various data in the geospatial database is used in determining and allocating the TMDL, as well as for administrative functions. The data layers generally pertain to four categories: hydrology (e.g. TMDL segments, NHD, Hydrologic Cataloging Unit boundaries), coverages (e.g. STATSGO and

SSURGO soil coverages, land use layers, vegetation layers), point layers (e.g. discharge points, USGS gage locations, locations of hydraulic structures), and political/munipal information (e.g. county boundaries, city boundaries, transportation networks). The purpose of this data is to facilitate the Watershed Action Plan used by the State in implementing the TMDL clean-up activities. Therefore, each of the data layers exists as part of a regional Basin Group C database and in a geodatabase specific to each water quality management segment watershed. Table 3.1 identifies the data layers included in the geodatabase, their source agency and the website at which they can be obtained or their metadata is located.

Data Layer	**Source Agency**	**Website**
30 m DEM	USGS	http://edcnts12.cr.usgs.gov/ned/default.htm
30 m Flow Direction Grid	CRWR	N/A
30 m Flow Accumulation Grid	CRWR	N/A
Surface Water Quality Segments	TNRCC	www.tnrcc.state.tx.us/gis/metadata/ segments_met.html
STATSGO soil coverage	NRCS	www.ftw.usda.gov/stat_data.html
SSURGO soil coverage	NRCS	www.ftw.nrcs.usda.gov/ssur_data.html
NHD	USGS	nhd.usgs.gov
National Land Cover Data	EPA	www.epa.gov/mrlc/nlcd.html
Municipal and Industrial Dischargers	TNRCC	www.tnrcc.state.tx.us

NWS Weather Stations	EPA-BASINS	www.epa.gov/ost/basins
NWS Weather Areas	EPA-BASINS	www.epa.gov/ost/basins
USGS Flow Gage Locations	USGS	txwww.cr.usgs.gov
Dam Locations	TNRCC	www.tnrcc.state.tx.us
County Boundaries	TNRIS	ftp://204.64.181.200/pub/GIS/boundary/state
City Boundaries	TNRCC	www.tnrcc.state.tx.us
TXDOT State-Maintained Roadways	TNRCC	www.tnrcc.state.tx.us
Major Highways	TNRCC	www.tnrcc.state.tx.us
Texas Major Roads	TNRCC	www.tnrcc.state.tx.us
Hydrologic Cataloging Unit Boundaries	EPA-BASINS	www.epa.gov/OST/basins/metadata/hydunits.htm
Watershed Data Management Stations	EPA-BASINS	www.epa.gov/OST/basins/metadata/wdm.htm
Public Drinking Water Supply Locations	TNRCC	www.tnrcc.state.tx.us/gis/metadata/pwss_met.html
Surface Water Quality Monitoring Stations	TNRCC	www.tnrcc.state.tx.us
National Sediment Inventory Stations	EPA-BASINS	www.epa.gov/OST/basins/metadata/nsi.htm
Superfund (National Priority List) Sites	EPA-BASINS	www.epa.gov/OST/basins/metadata/cerclis.htm
Toxic Release Inventory Sites	EPA-BASINS	www.epa.gov/OST/basins/metadata/tri.htm
Federal and State Congressional Districts	TLC	ftp://ftp1.capitol.state.tx.us/research/ftp/pub
National Climatic Data Center (NCDC) Precipitation Gage Locations	NCDC	www.ncdc.noaa.gov
Solid Waste Landfill Locations	TNRCC	www.tnrcc.state.tx.us/gis/metadata/landfill_met.html

Council of Government Regions	TNRCC	www.tnrcc.state.tx.us
Surface Water Rights Diversion Points	TNRCC	www.tnrcc.state.tx.us/gis/metadata/ watright_met.html
Ecoregions	EPA-BASINS	www.epa.gov/OST/basins/metadata/ ecoreg.htm
TNRCC Service Regions	TNRCC	www.tnrcc.state.tx.us/gis/metadata/ regions_met.html
TNRCC Class B Land Application Sites	TNRCC	www.tnrcc.state.tx.us
Permitted Industrial & Hazardous Waste Sites	TNRCC	www.tnrcc.state.tx.us/gis/metadata/ pihw_met.html
Aquifers	TWDB	www.twdb.state.tx.us/data/GIS/gis_toc.htm
Vegetation Layer	WetNet	www.glo.state.tx.us/wetnet
Air Quality Monitoring Stations	TNRCC	www.tnrcc.state.tx.us/gis/metadata/ airmon_met.html
TIGER files	TNRCC	www.tnrcc.state.tx.us

Table 3.1 Geospatial Database Data Layers

The acronyms of the source agencies in Table 3.1 refer to Center for Research in Water Resources (CRWR), United States Environmental Protection Agency (EPA), U.S. EPA Better Assessment Science Integrating Point and Nonpoint Sources (EPA-BASINS), National Climatic Data Center (NCDC), Natural Resources Conservation Service (NRCS), Texas Legislative Council (TLC), Texas Natural Resource Conservation Commission (TNRCC), Texas Natural Resources Information System (TNRIS), Texas Water Development Board (TWDB), United States Geological Survey (USGS), and Texas Wetland

Information Network (WetNet). The flow direction and flow accumulation grids were created at CRWR and are not available on the Internet.

Once these data layers were collected and the watersheds delineated, the data was clipped by the final watershed boundaries to participate in the regional and individual geodatabases. Section 4.7 discusses the clipping procedure.

3.3 MAP PROJECTIONS AND COORDINATE SYSTEMS

Digital data essentially replicates paper maps, a two-dimensional representation of the earth. To accurately transform the curved shape of the earth to two-dimensional space, map projections are used. Many map projections exist with corresponding advantages and limitations. The *Albers Equal Area* projection retains correct earth surface areas that are important for hydrologic applications. Local angles and correct shape are maintained when using the *Lambert Conformal Conic* projection. These are both conic projections that more truly characterize East-West land areas than North-South areas. The data presented in this research is in the Albers Equal Area projection (Maidment, 1999).

In addition to map projections, coordinate systems differ between digital data sources. A coordinate system is the (x,y) location system for the map. Three different coordinate systems were used in conjunction with map projections for this project.

3.3.1 Texas State Mapping System

In 1992, the Department of Information Resources (DIR) and the Texas Geographic Information Council (TGIC) adopted a standard statewide coordinate system for all digital data relating to Texas (Shackelford, 2000). The coordinate system parameters were designed to portray a statewide coverage of Texas without any gaps and with a pleasing shape. The coordinate system, named the Texas State Mapping System (TSMS), is a Lambert Conformal Conic projection in which standard parallels are located at 1/6 from the top and bottom of the state. An Albers Equal Area projection was derived from the TSMS Lambert projection for hydrologic applications (Maidment, 1999). The parameters of TSMS Albers are shown in Table 3.2. Most of the data initially retrieved for this research came in the TSMS Albers or Lambert projection.

Projection	Albers Equal Area
Central Meridian (Longitude of Origin)	-100 00 00
Reference Latitude (Latitude of Origin)	31 10 00
1st Standard Parallel	27 25 00
2nd Standard Parallel	34 55 00
False Easting	1,000,000
False Northing	1,000,000
Datum	NAD 83
Units	Meters
Ellipsoid	GRS 80

Table 3.2 TSMS Albers Projection Parameters

3.3.2 Texas Centric Mapping System

Inspection of the TSMS Coordinate System reveals that the parameters are not exact decimal coordinates and can be hard to work with. In April 1999 the Statewide Mapping Work Group of the DIR and TGIC again convened to determine a new statewide coordinate system. The new system was designed to overcome the hassles inherent in the TSMS system while remaining as cartographically sound as the former system. The Statewide Mapping Work Group proposed the Texas Centric Mapping System (TCMS) in both Lambert Conformal Conic and Albers Equal Area projections with more workable parameters (Shackelford, 2000). The TCMS System was adopted by the TGIC in May 2000 and its use has become encouraged for data deliverables for state funded projects. Therefore, the data handled and produced by this research is in the TCMS Albers Equal Area projection. The parameters are shown in Table 3.3.

Projection	Albers Equal Area
Central Meridian (Longitude of Origin)	-100 00 00
Reference Latitude (Latitude of Origin)	18 00 00
1st Standard Parallel	27 30 00
2nd Standard Parallel	35 00 00
False Easting	1,500,000
False Northing	6,000,000
Datum	NAD 83
Units	Meters

Table 3.3 TCMS Albers Projection Parameters

3.3.3 Universal Transverse Mercator

The Digital Raster Graphics maps mentioned in Section 3.2.3 are displayed in the Universal Transverse Mercator (UTM) coordinate system. This coordinate system is composed of zones where each zone is 6^{o} wide and has a central meridian. These zones go from pole to pole and cover the earth from East to West. Basin Group C is located in Zone 15. The parameters of UTM Zone 15 are shown in Table 3.4.

Projection	Transverse Mercator
Central Meridian (Longitude of Origin)	-93 00 00
Reference Latitude (Latitude of Origin)	00 00 00
Scale Factor	0.9996
False Easting	500,000
False Northing	0
Datum	NAD 83 or NAD 27
Units	Meters
Ellipsoid	GRS 80

Table 3.4 UTM Zone 15 Projection Parameters

3.4 CONCLUSION

Investigation into the data used in this research is essential to perform any manipulation or procedures. The production of the information is useful in determining scale and accuracy, while the projection furnishes the knowledge of how to view specific data with respect to other layers of data. These digital layers are gathered then manipulated and processed as described in the following chapters.

CHAPTER 4: PROCEDURE

4.1 INTRODUCTION

GIS users in Water Resources have developed a general procedure for delineating watersheds using several types of digital data. Many of these steps are universal; however, variations occur in the process because of the flat nature of the area. The methods outlined here contain both universal routines and specific tasks performed for this research. Most of these unique practices are with respect to the TNRCC water quality management segments, both river reach and particularly waterbody. The first step presented is building a surface water drainage network to represent the flow in the area. Next the TNRCC segments are distinguished in the network. A discussion about the definition of a watershed and its application to a waterbody is then presented. Terrain analysis follows with two distinct procedures dependent upon the type of waterbody watershed desired. The final efforts serve to present the watersheds more realistically, regardless of which type of waterbody watersheds were chosen. Once the watersheds are determined, the geospatial databases are compiled. The data layers presented in this chapter, capitalized and italicized, can be quickly referenced in Appendix E, which gives a brief description and its initial location in the text.

4.2 BUILDING A DRAINAGE NETWORK

4.2.1 Manipulating the NHD Data

The drainage network of the area was built using the route.reach data layer within the NHD coverage of the National Hydrography Dataset (NHD). Because of the flat nature of the coastal region, many canals and ditches exist which add complexity to the surface water system. These man-made water channels form many complicated loops in the flow network. A decision was made with the TNRCC initially to ignore these channels and loops and use an entirely natural stream network. Therefore, the canal/ditches were to be eliminated from the original network. Figure 4.1 displays the complicated surface water network from the route.drain data layer with the canals to be eliminated in green.

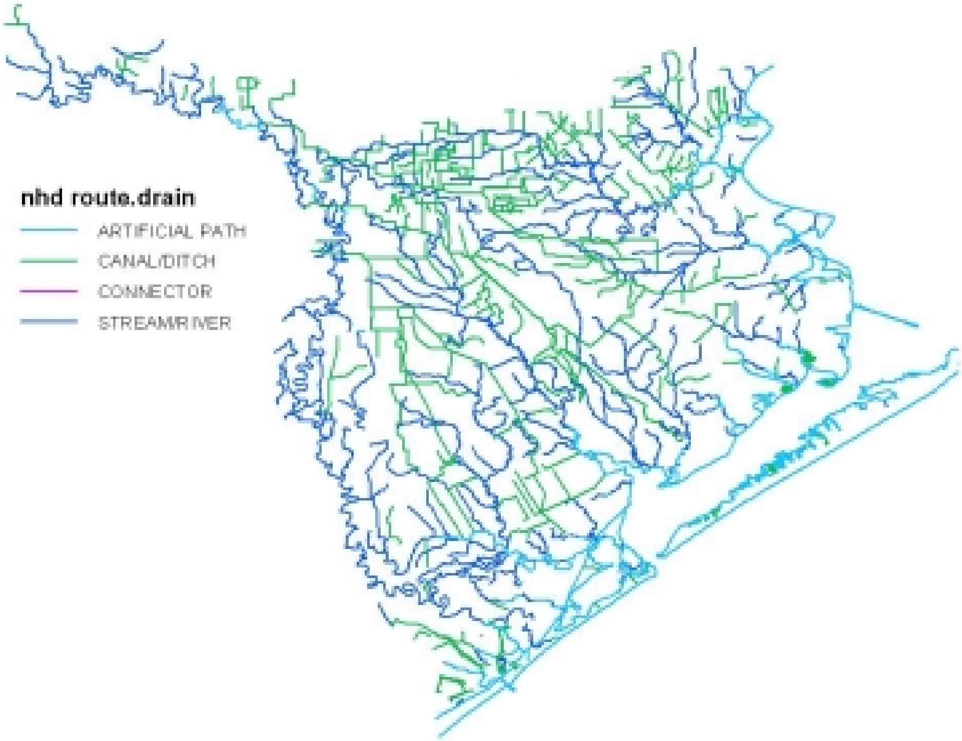


Figure 4.1 NHD route.drain layer for the San Jacinto-Brazos Coastal Basin

To achieve the simplification of this network, the route.reach and route.drain layers were both studied. Before any processing could occur, additional fields were added to both reach layers, route.reach and region.reach (the areal features), to be used in computations. The reach code field (*Rch_Code)*, which houses the unique identifier for any reach, is a string. The ArcView/ArcInfo system will not retain this string field as the identifier when performing functions. Therefore, a field (*RchCodeNo*) was added and calculated as *Rch_code.AsNumber* to convert the string field to a number field. Then a field was calculated as an abbreviation of the reach code (*RchCodeAbv)* because

ArcView will only process numbers less than 1000000. By subtracting the HUC (hydrologic unit code) number followed by six zeros from the *RchCodeNo* field, the reach number is left. For example: the Rch_code of a reach is 12040203000149. The *RchCodeAbv* field is calculated as "[RchCodeNo] – 12040203000000", resulting in a value of 149. When using multiple HUCs for a basin, as in this case, care must be taken in retaining a number that implies which HUC a reach originated in and avoids duplication of Reach Code abbreviations. The method used was to add in a unique number representing each HUC, multiplied by 100000, to the *RchCodeAbv* field when calculated. Table 4.1 lists the HUCs in Basin Group C and their corresponding distinct identifiers. Therefore, in HUC 12040203, reach number 0000149, the abbreviation was 300149. Figure 4.2 illustrates the fields added and the results from these calculations.

HUC No.	**Basin**	**Unique Identifer**
12040201	Neches-Trinity	1
12040202	Neches-Trinity	2
12040203	Trinity-San Jacinto	3
12040204	San Jacinto-Brazos	4
12040205	San Jacinto-Brazos	5
12040101	San Jacinto	6
12040102	San Jacinto	7
12040103	San Jacinto	8
12040104	San Jacinto	9

Table 4.1 HUC Identifier Convention

RCH_CODE	RCHCODENO	RCHCODEABV
12040205000071	12040205000071	500071
12040205000327	12040205000327	500327
12040205000326	12040205000326	500326
12040205000530	12040205000530	500530
12040205000497	12040205000497	500497
12040204001108	12040204001108	401108
12040205000059	12040205000059	500059
12040205000328	12040205000328	500328
12040205000323	12040205000323	500323
12040205000322	12040205000322	500322
12040205000058	12040205000058	500058

Figure 4.2 Reach Code field calculations

To eliminate the canal/ditches from the network, the route.drain layer was queried using the Ftype field for a dataset containing all types of features except canal/ditch. With these features selected, the route.reach layer was made active and using select by theme, all the features of route.reach that “have their center in” the selected features of the route.drain layer were chosen. These reaches were converted into a new theme. This result is the natural stream network seen in Figure 4.3, the starting point for the drainage network to be used. An alternate procedure to obtain the natural stream network is to join the attribute tables of route.drain and route.reach. The route.drain table acts as the source table with the “Rch_com_id” field and route.reach acts as the destination table with the “Com_id” field. Then, the Ftype attribute is transferred to the route.reach dataset while the tables are joined. A query was then made for all types of features except canal/ditch. Again, the natural stream network is the selection, as seen in Figure 4.3.

Figure 4.3 Natural Stream Network for the San Jacinto-Brazos Coastal Basin

4.2.2 Editing the Network

Further accuracy and detail was obtained in the surface water network with manual editing. The main tool used for editing was the Digital Raster Graphic maps (DRGs). The drainage network was placed over these maps and compared for discrepancies. Many types of inconsistencies occurred: tributaries that were not attached to the main stream, dangling streams that are not connected to the network at all, streams running through land not seen on the map, and gaps in the network. Additionally, some loops in the network were noticed with the comparison to the DRGs. Also, the TNRCC water quality segments were overlaid on the network to ensure correlation between the NHD and the segment location. Any conflicting locations were resolved by studying the DRGs.

These manual corrections were incorporated into the network mainly by vertex editing or merging reaches not present in the initial selection back into the network. These methods maintained the integrity of the attributes that accompany the NHD. Vertex editing employs a tool in ArcView in which a line is reshaped by moving, adding or deleting vertices (ESRI, 1998). The attributes of the line remain the same, but the shape changes. Figure 4.4 shows the steps involved in vertex editing of the red line. An hollow arrow indicates the tool, which changes to a crosshair over a vertex. Holding down the left mouse button over the vertex allows the vertex to be moved to the new desired location. This editing feature was mainly used to move parts of a stream over the location shown on the DRG. The Geoprocessing Wizard was used to merge canals originally eliminated from the network back into the network once the DRGs were consulted for their significance.

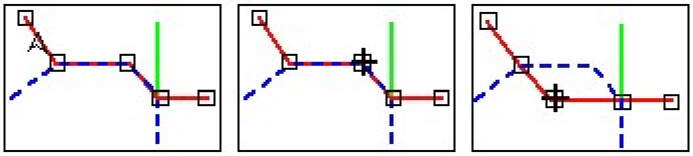


Figure 4.4 Vertex Editing (ESRI, 1998)

In other editing situations, a new line was drawn in by hand and lacked any associated property information. Isolated reaches, random streams not connected to any main stem, were also eliminated during this process.

The final network was then "cleaned" in ArcInfo to ensure the connectivity. The *clean* command creates an output coverage with correct polygon or arc-node topology. It searches for and corrects any geometric coordinate errors and then builds arcs or polygons with feature attribute information (ESRI, 2000). The form of the command is as follows (note – names in all capital letters are user-specified data names):

```
Arc:  clean NETWORK NETWORK_CL 0.000001 0.000001 line
```

in which *NETWORK* is the final network and *NETWORK_CL* is the product of the clean function. The 0.000001 values represent recommended values for the dangle length and the fuzzy tolerance, respectively. The dangle length is the minimum length allowed for dangling arcs in the cleaned coverage. A dangling arc is an arc with the same identifier on the left and right sides of an intersection, and ends with a dangling node. Dangling nodes are described in the next paragraph. The fuzzy tolerance is the minimum spacing between arc vertices in the cleaned coverage (ESRI, 2000). Line indicates what type of output coverage is desired, line or polygon. In this case, a line network was necessary; however, later in this chapter the clean command was performed on polygons and the "poly" parameter was chosen instead.

After cleaning, the cleaned network must be checked for dangling nodes, which indicate stream connectivity. Lines or arcs are determined by a set of vertices and nodes. The nodes are the endpoints of the arc. Arc-node topology is correct when all arcs share nodes. Three different types of nodes exist: normal, pseudo, and dangling. Normal nodes connect endpoints of multiple arcs. Pseudo nodes connect the end of one arc to the beginning of another. Dangling nodes do not connect to any other node. Dangling nodes at can frequently occur through the network editing process when arcs are added. Many times, an arc would be added to the network, but not connected to another vertex or node; therefore, the endpoint of that arc would be dangling, ruining the arc-node topology. The method used in this study to check the stream connectivity employed the ArcView 3.2 project file "wrap1117.apr". In wrap1117.apr, tools named " Show Dangling Nodes" and "Erase Interior Dangling Node" are present. With the "Show Dangling Nodes" tool, the dangling nodes in the current view are found and indicated by a red point. Each node can be looked at specifically, and if appropriate, the "Erase Interior Dangling Node" tool can be used. This tool splits the original arc at the intersection and creates a normal node in its place (Hudgens, 1999). A more thorough explanation of the clean function, dangling nodes and wrap1117.apr can be found in *Geospatial Data in Water Availability Modeling* by Bradley Hudgens at http://www.crwr.utexas.edu/reports/1999/rpt99-4.shtml.

An illustrative example of editing is provided below. Figure 4.5 shows three types of edits that were made to the network. The orange reaches represent streams that were added to the network. First, the stream on the top was a main canal path that was considered significant after visual inspection and thus was added back to the network by merging. Second, the middle tributary was not connected to the main stream stem in the NHD. The DRG indicated that they were indeed connected to the main flow path and vertex editing corrected this error. Lastly, the orange reach on the bottom was added to the network to maintain consistency with the TNRCC water quality management segment (the dashed purple line). The DRG confirmed that a stream was present and it was manually added to the network.

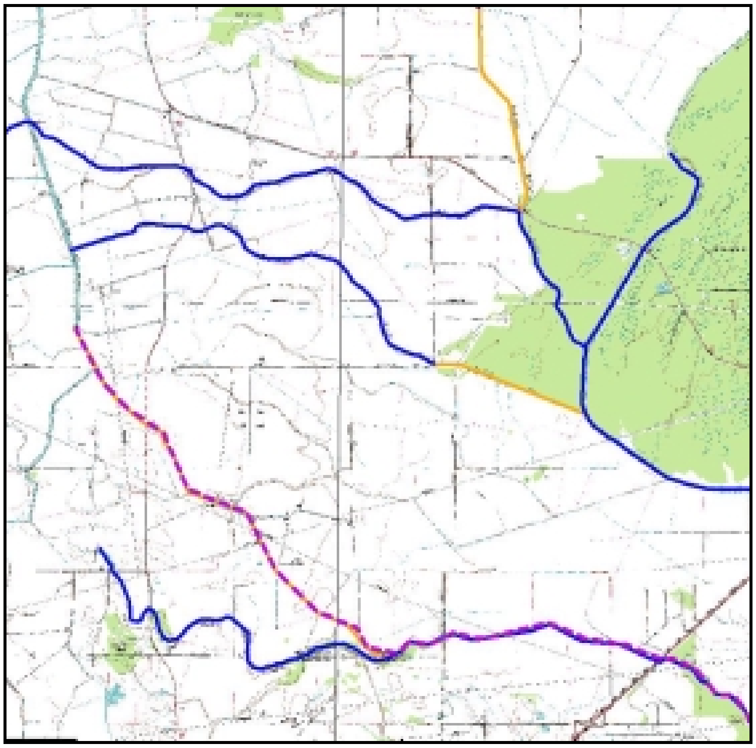


Figure 4.5 Edits to the network in the Neches-Trinity Coastal Basin

4.2.3 Determining Waterbodies on the Network

In addition to streams, the surface water drainage network is also comprised of waterbodies such as lakes, ponds, wide streams and reservoirs. Other waterbodies of interest may be bays or oceans that abut the region being considered. In some instances, these waterbodies are incorporated into the drainage network to be used for watershed delineation. The study area for this research focuses heavily on the waterbodies with water quality issues such as bays and estuaries along the coastline and specific lakes. These waterbodies were provided as part of the TNRCC water quality management segment coverage. Other waterbodies on the network can be determined from the NHD region.reach data layer.

From the region.reach layer, features were selected by theme that "contain the center of" the stream network previously described and constructed. This selection captured all of the lake/pond waterbodies that are considered "significant" and which lie on an NHD artificial path. The term significance is defined in Appendix E of *The NHD Concepts and Contents* (USGS, 2000). For "insignificant" lake/pond features, those less than 10 acres in area, no separate artificial path is delineated in the NHD. Therefore, this methodology for determining lake/pond waterbodies on the network also ignored "insignificant" waterbodies. Figure 4.6 displays the waterbodies that accompanied the water quality management segments as well as the selected lake/ponds of the NHD for the Trinity-San Jacinto Coastal Basin.

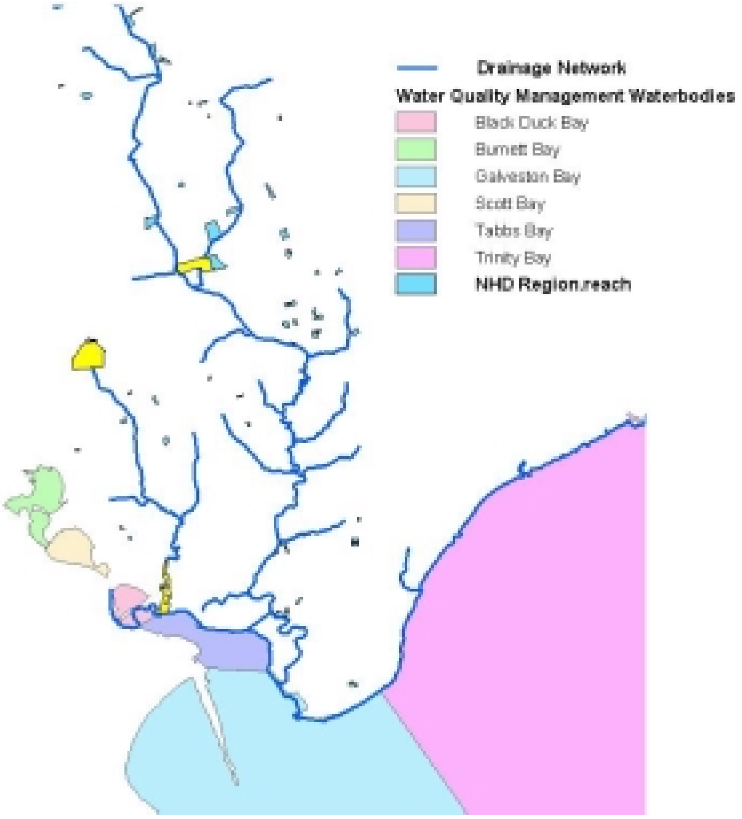


Figure 4.6 Waterbodies on the Suface Water Drainage Network in the Trinity-San Jacinto Coastal Basin. Lake/Ponds selected from the NHD Region.reach in yellow.

4.3 WATERBODY WATERSHEDS

A watershed is typically defined as “the natural unit of land upon which water from direct precipitation, snowmelt, and other storage collects in a (usually surface) channel and flows downhill to a common outlet at which the water enters another water body such as a stream, river, wetland, lake, or the ocean” (Black, 1991). Furthermore, many hydrologists believe that “unless a watershed discharges directly into the ocean, it is part of one that does, and may be referred to as a subwatershed" (Black, 1991). While this definition applies to most land-surface water interactions, it neglects the portion of the watershed that is not a "subwatershed", the portion of the watershed that does drain directly into the ocean without collecting in any defined channel to arrive there. In this thesis, this area is referred to as the *waterbody watershed*. This term relates to all waterbodies: lakes, reservoirs, and most importantly, bays, estuaries and oceans. Its definition derives from the following definition of the watershed, "the area of land draining into a stream at a given location" (Chow *et al.*, 1988). Rather, a *waterbody watershed* is the area of land draining into a waterbody at any given location, not limited to a single outlet point. This definition is illustrated in Figure 4.7, which shows the watershed for the waterbody Tabbs Bay, TNRCC segment #2426. The area in green is the area of land that drains into Tabbs Bay without draining into any other channelized TNRCC designated stream segment. From this evaluation, a general watershed definition can be concluded. A watershed can generically be defined as an area that drains to a set of water features. This definition considers the accepted view of a watershed, which drains to a point, and the consideration of a waterbody watershed that drains to a line or area.

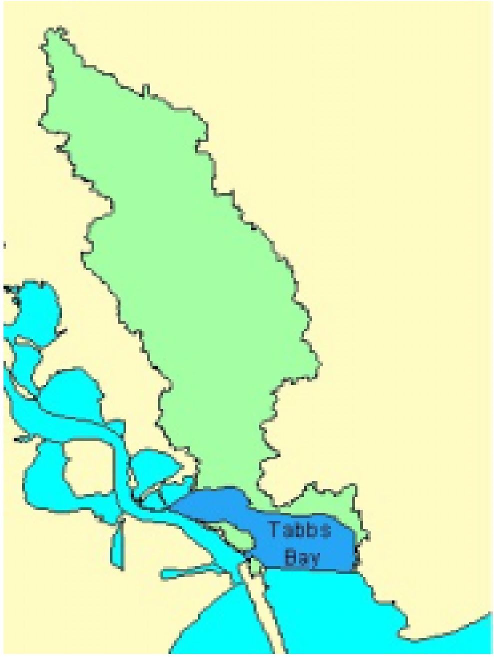


Figure 4.7 Initial Waterbody Watershed Definition

This definition refers specifically to the area of land that drains into the waterbody. It is imperative to also consider the waterbody itself and its contribution to the watershed. A waterbody is defined generically as "any collection of water, whether it be on the surface or below the water table" and these water collections are then partitioned into "ground water storage" or "depression storage" for surficial waterbodies (Black, 1991). Because the waterbody provides storage for the runoff and could be included as a depression land feature, there is an argument for the inclusion of the waterbody in the waterbody watershed. Any rainfall that falls on the waterbody does add to the water stored and supplies additional water to the flow from that waterbody.

Therefore, another definition for a waterbody watershed ensues: “the area of land draining into a waterbody at any given location and the waterbody itself”. This definition further parallels the definition for a watershed of a stream as the stream itself is included in its watershed. Figure 4.8 displays the waterbody watershed for Tabbs Bay that does include the bay.

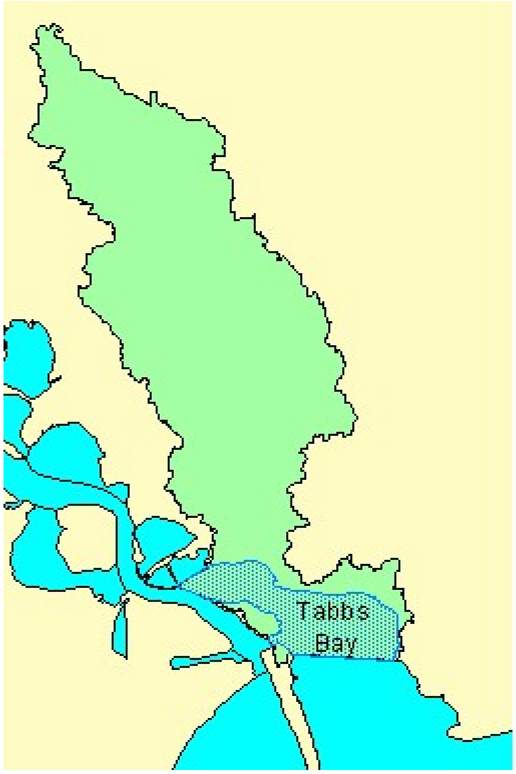


Figure 4.8 Waterbody Watershed for Tabbs Bay, including the waterbody itself

4.4 CREATING THE OUTLET GRID

Traditionally, watersheds are delineated from outlet grids consisting of outlet points. These outlet points are the most downstream points of interest along a stream for which it is desired that a drainage area be assessed, as mentioned in the first watershed definition presented above. Typically, they are determined through DEM terrain analysis that is described more thoroughly in the following section.

In this study, drainage areas were assessed for entire lines and areas, representing the TNRCC water quality management segments of streams and waterbodies. Therefore, the outlet grid, rather than being points, consists of zones of cells. The difference between the outlet grids can be seen in the translation between vector and raster data in Figure 4.9.

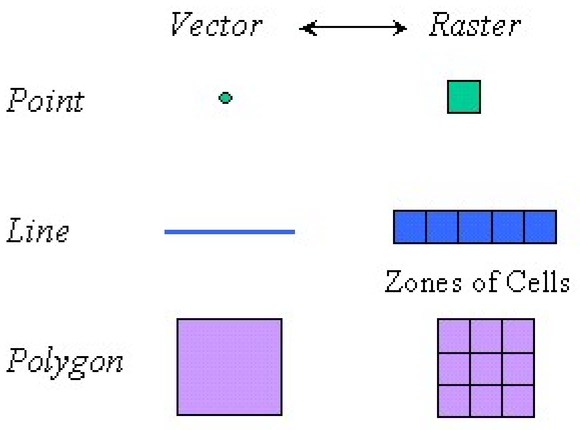


Figure 4.9 Vector-Raster Data Translation (Maidment, 1999)

The outlet grid was created by selecting the segments, both river reach and waterbody and merging their respective grids together. But before the two types of segments were converted to grids, the river reach segments had to lie coincident with the surface water drainage network. This correspondence was necessary for correct flow direction to be established in the DEM. To accomplish this goal, the river reach segment numbers were manually input into a new field named "*SegmentNo*" of the appropriate reaches in the surface water network. Figure 4.10 illustrates the river reach segments and the corresponding network selections with the segment number as an attribute for the San Jacinto River Basin.

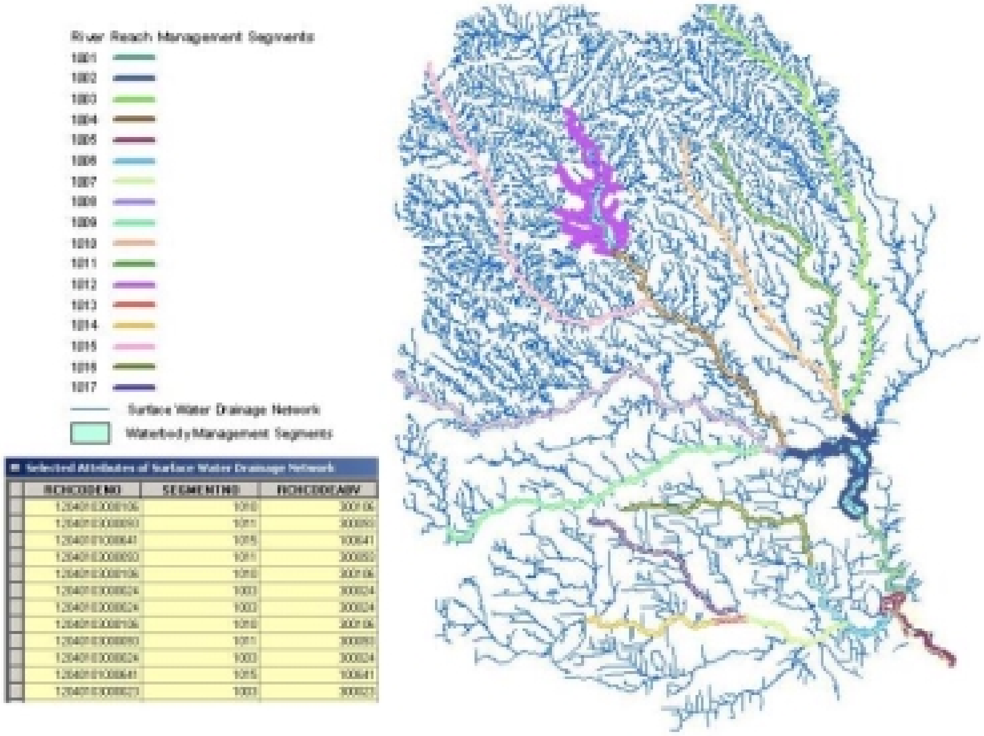


Figure 4.10 Network Reaches that coincide with a TNRCC management segment are attributed with that segment number

Once the segments are located on the network, the outlet grid, indicating the locations for watershed delineation, was created. First, the reaches in the network that comprised a segment were selected and converted to a grid. Second, the areal features that represented segments, e.g. lakes and bays, were converted to a grid of the same extent. Both grids carried a field that contained the segment number that uniquely identified the outlet cells as the conversion field. Next, the grids were merged in ArcInfo Workstation Grid using the following command:

Grid: OUTLETGRID = merge (POLYSEG_GRID, REACHSEG_GRID) in which *POLYSEG_GRID* was the grid of the lakes and bays and *REACHSEG_GRID* was the grid of the reach segments. The *POLYSEG_GRID* took precedence over the *REACHSEG_GRID* to minimize any overlapping between the reaches and the areas. Figure 4.11 shows the outlet grid for the entire Basin Group C. With this outlet grid, the watersheds were delineated.

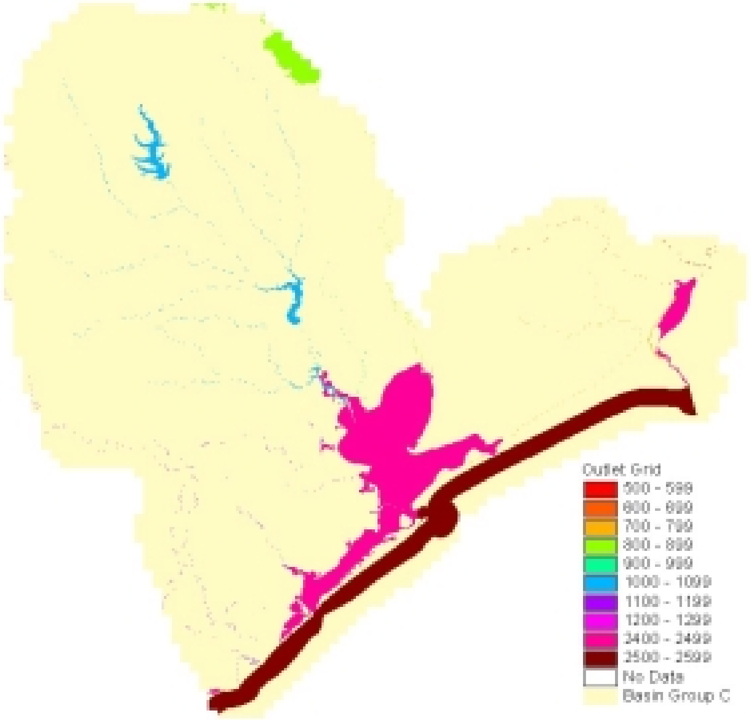


Figure 4.11 Outlet Grid for Basin Group C

4.5 DELINEATING WATERSHEDS EXCLUDING WATERBODIES

This thesis thoroughly studies the watersheds of waterbodies such as Tabbs Bay in Section 4.3. Procedures are outlined for the watershed delineation steps that deal with the definition of a watershed presented in literature and carries over to the different types of waterbody watersheds described. Watershed delineation procedures are presented for waterbody watersheds that exclude the waterbody. The TNRCC requested waterbody watersheds that include the waterbody itself, and the changes in the procedure are then offered.

4.5.1 Preparing the DEM for the Area of Interest

The initial steps to delineate watersheds involve preparing the Digital Elevation Model (DEM) for processing. The first of these actions is to obtain the relevant DEM tiles from the National Elevation Dataset (NED) and merge them together. Next, the DEM was projected from its original geographic coordinates to the appropriate projection, TCMS Albers. The study area outline was then buffered by 10 kilometers to incorporate the surrounding drainage features that may influence the drainage paths within Basin Group C (*BUFFER*). This buffered outline was used to clip the DEM to a smaller extent. These tasks were all carried out in ArcInfo Workstation using the following commands:

```
Arc:  grid
Grid:  DEM_GEO = merge (DEM9530, DEM9531, DEM9630, DEM9631)
Grid:  quit
Arc:  project grid DEM_GEO DEM_ALB GEO2ALBERS.TXT
Arc:  shapearc BASINGRPC BASINGRPC
Arc:  build BASINGRPC
Arc:  buffer BASINGRPC BUFFER # # 10000 #
Arc:   grid
Grid:  setwindow BUFFER BUFFER
Grid: setcell 30
Grid:  CLIPDEM = selectpolygon (DEM_ALB, BUFFER, inside)
```

The file *GEO2ALBERS.TXT* is a projection file included in Appendix C. The study area outline, buffer and the two DEMs are shown in Figure 4.12.

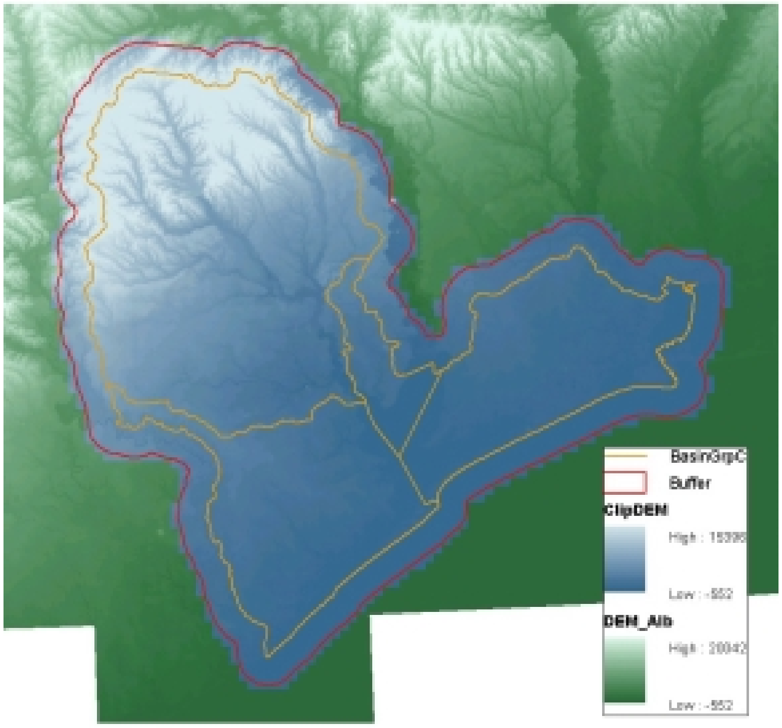


Figure 4.12 DEM for the Basin Group C study area

4.5.2 Conditioning the DEM for Negative Values

Inspecting the DEM for Basin Group C, negative elevation values, to a magnitude of 5.72 meters, were noticed. These values are present because of the construction method of the DEM. The elevation models are developed from contour maps and interpolation between the contours as detailed in Section 3.2.4, which probably lead to the negative values. DEM processing in ArcInfo/ArcView does not handle negative elevation values; therefore, these measures were corrected. The modification was made using the condition command in ArcInfo Workstation in which a conditional statement determines the new value of the elevation cell. The following command line was used:

Grid: DEM_CON = con (CLIPDEM > 0, CLIPDEM, 0)

in which any cell with a value less then zero was replaced with zero and all cells greater than zero retain their original value. Figures 4.13(a) and 4.13(b) illustrate the negative values at the coastline of San Jacinto River as an example. The original and conditioned DEM are both displayed, with the elevation values in centimeters.

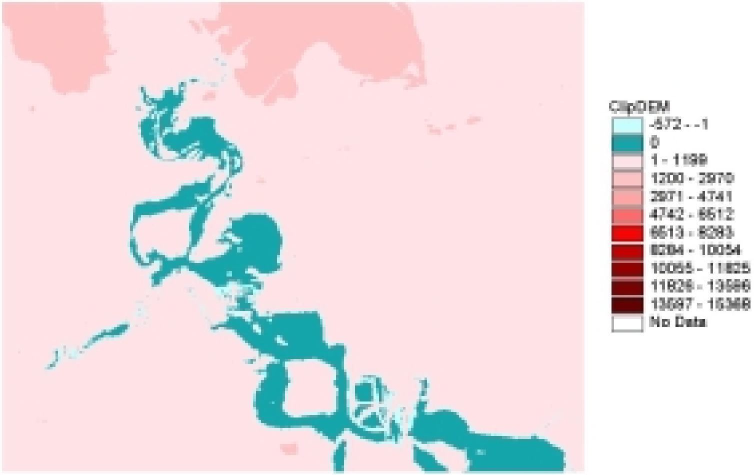


Figure 4.13(a) Negative Values of the DEM

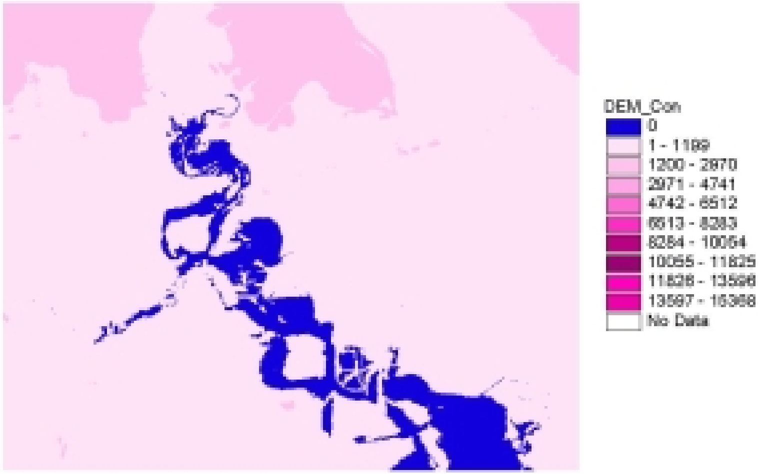


Figure 4.13(b) Zero Values in the DEM

4.5.3 Formatting the Ocean of the DEM

As noticed in the DEM in Figure 4.12, elevation values exist in the model where the ocean is present. If the waterbody watershed is not to include the waterbody in the ocean, the DEM should contain NO DATA values in that area. Then, that area would not participate in watershed delineation and would be a stopping point for flow through the network. Several steps were necessary to implement this format into the DEM.

First, a data layer containing the polygons of the Sea/Ocean features from the NHD was made. The Region.wb data layer was queried for an Ftype of Sea/Ocean, and that selection was exported to a new data layer. The new data layer, *SEAOCEAN*, was then clipped by the *BUFFER* using the Geoprocessing Wizard. In this clipped data layer, a new field was added named “Value” which was populated with zeros. The analysis extent and cell size were set to the *DEM_CON* and the clipped Sea/Ocean data layer was converted to a grid with the “Value” field as the grid-code, *SEAGRID.* In ArcInfo Workstation Grid, the *isnull* function was used on the new grid. This function returns a value of ‘1’ if the input cell value is NODATA and ‘0’ if it is not NODATA. In this case, the output grid *GRIDCALC1* contained values of zero where the Sea/Ocean was and values of one everywhere else. The ArcInfo Workstation commands for this function are as follows:

```
Grid:  setwindow DEM_CON DEM_CON
Grid:  setcell 30
Grid:  GRIDCALC1 = isnull (SEAGRID)
```

At this point, the analysis extent and cell size were set to the extent of *GRIDCALC1* and a map calculation was performed, dividing *GRIDCALC1* by itself, *GRIDCALC1/GRIDCALC1*. This output grid *GRIDCALC2* contained NODATA values where the Sea/Ocean existed and values of one elsewhere. Lastly, the original DEM, *DEM_CON* was multiplied by *GRIDCALC2* which resulted in *FORMAT_DEM*. *FORMAT_DEM* retained the original elevation values in all cells not in the Sea/Ocean and replaced the Sea/Ocean elevation values with NODATA, the desired result. Therefore, this DEM, shown in Figure 4.14 with the *SEAOCEAN* data layer laid on top of it, was used to delineate watersheds.

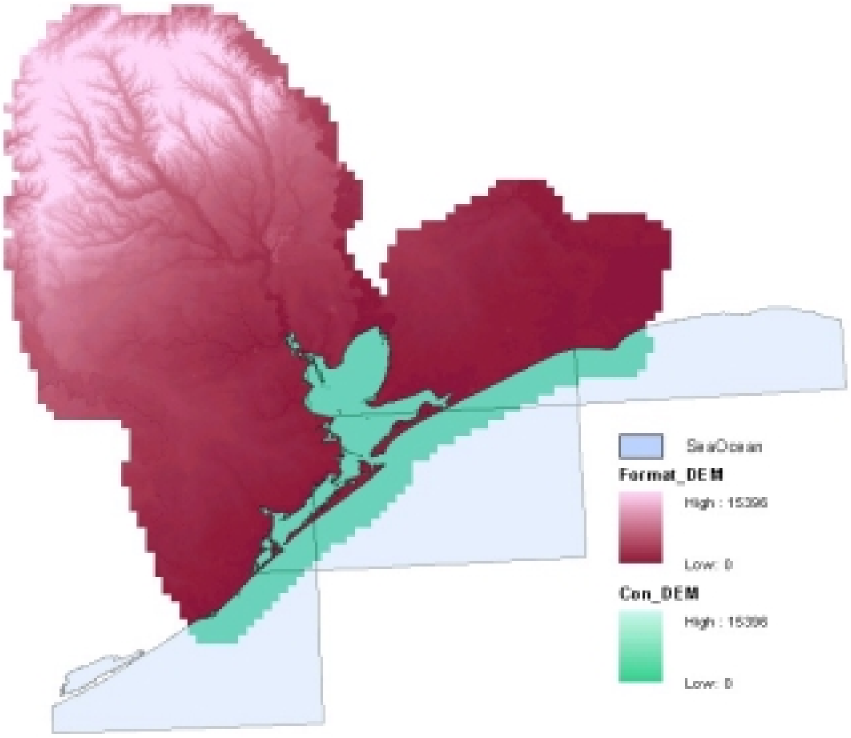


Figure 4.14 DEM formatted based on SeaOcean location

4.5.4 Processing the DEM

The next step in delineating watersheds was burning the stream network into the DEM. By burning in the network, the flow was forced to accumulate in the determined stream paths from vector hydrography rather than DEM derived artificial stream paths. Burning in the network consists of raising the DEM around the stream path by a predetermined constant amount, therefore creating canyons where the water will flow into and not exit. The burn streams process consisted of converting the edited stream network to a grid of single cell strings, assigning the DEM values to those cells, then adding a fixed value to all off-stream cells in the DEM (Saunders, 1999).

The network creation process was described earlier; however, this network was just for the study area considered. Similar to the DEM extent, the network must also be enhanced by including the drainage features for 10 kilometers outside the basin group boundary. Networks for the adjacent basins were obtained, either from other projects being studied at the Center for Research in Water Resources or from the National Hydrography Dataset. Networks from the NHD were manually created using the process described. These additional networks were merged to the base network using the Geoprocessing Wizard.

The coastal nature of the study area presented a variation in the procedure of burning in the network. Typically, the network would be burned directly into the DEM without further alteration. However, the coastline was characterized by streams in the network. The coastline would be included a second time because the waterbody along the coast was part of the outlet grid. The double representation would lead to confusion if the coastline and the TNRCC waterbody were not exactly coincident. To eliminate the possibility of this conflict, the coastline was deleted from the network to be burned into the DEM. In conjunction with removing the coastlines from the network, any tributary draining into the coast was extended past the coastline into the waterbody. Guidelines for integrating vector hydrography into a DEM specify that drainage paths to be burned in must extend to the edge of the corresponding DEM or open water in the case of coastal watersheds (Saunders, 1999). By extending the tributaries, the correct drainage path was ensured because the tributary would not stop short of the waterbody itself. The network to be burned in is illustrated in Figure 4.15.

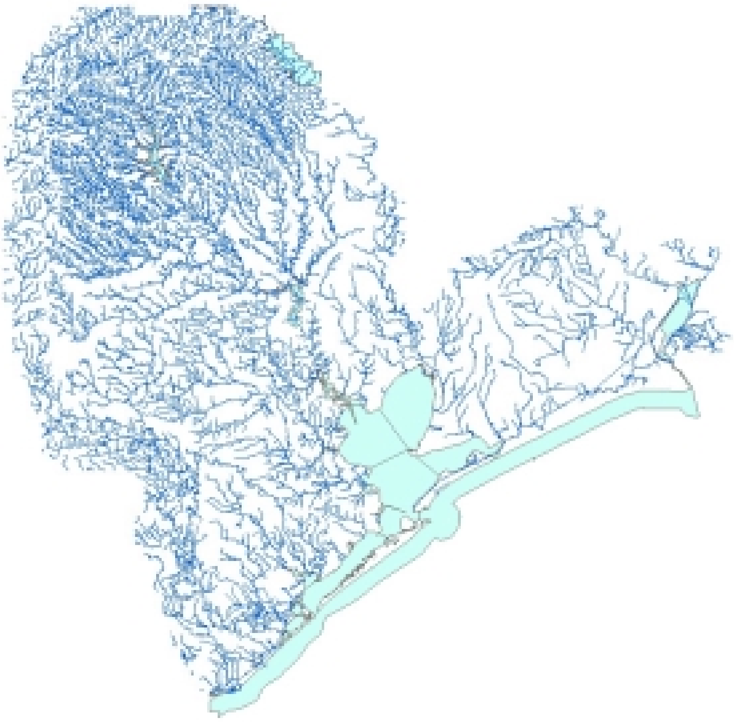


Figure 4.15 Network to be Burned In to the DEM

Using CRWR PrePro, an ArcView preprocessor that extracts information from digital spatial data or ArcInfo, the merged network was burned into the

DEM, in which the landscape was raised by 200 meters (Olivera, 1999). The increase in elevation must be greater than the highest point in the original DEM.

The remainder of the DEM processing takes place in ArcInfo Workstation. The burned DEM, *BURN_DEM*, was then filled and the flow direction was calculated. Finally, the flow accumulation grid was computed.

Filling the DEM consists of removing pits in the landscape. Technically, it "fills sinks or levels peaks in a continuous grid to remove small imperfections in the data" (ESRI, 2000). Sinks are filled in order to ensure that the derived drainage paths are continuous. Figure 4.16 exemplifies the process of filling sinks in ArcInfo.

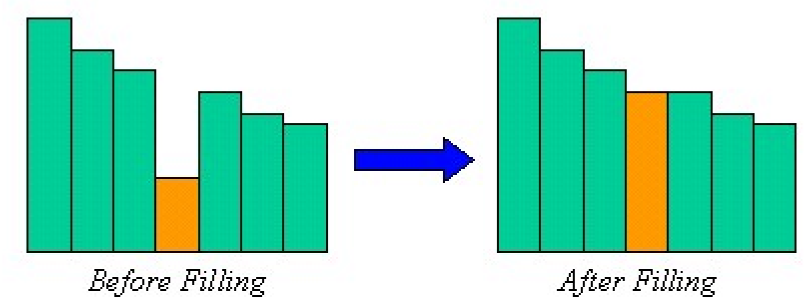


Figure 4.16 Filling Sinks (ESRI, 2000)

The flow direction function "creates a grid of flow direction from each cell to its steepest downslope neighbor" (ESRI, 2000). The convention followed in computing flow direction uses the Eight Direction Pour Point Method. With this method, an integer value is assigned to each of the eight surrounding neighbors of a cell. The cell with the steepest drop from the center cell is the direction of flow, and the center cell is assigned the integer code associated with the flow direction. Figure 4.17 displays the integer flow direction convention.

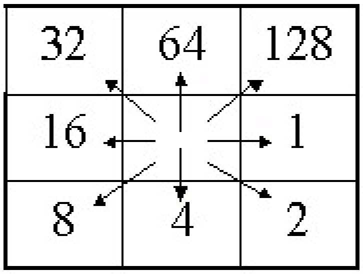
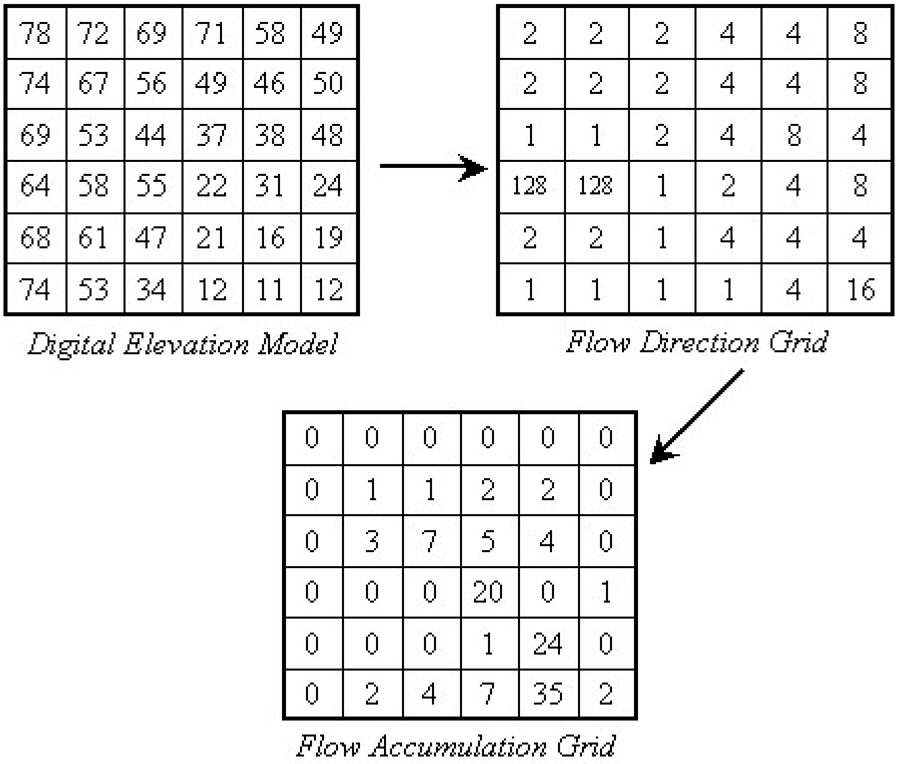


Figure 4.17 Eight Direction Pour Point Model convention

With a flow direction grid, a flow accumulation grid can be calculated. The flow accumulation function “creates a grid of accumulated flow to each cell, by accumulating the weight for all cells that flow into each downslope cell” (ESRI, 2000). It basically keeps a running total of how many cells are draining into a cell of interest. The flow accumulation can be used to find derived stream paths by following cells with a flow accumulation above a specified threshold. Figure 4.18 displays the transition from DEM to flow direction grid to flow accumulation grid.



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Digital Elevation Model

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

Flow Direction Grid

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

Flow Accumulation Grid

Figure 4.18 Flow Direction and Flow Accumulation Grid Functions (ESRI, 2000)

Once these intermediate grids are calculated, the watersheds were delineated using the *watershed* function, which calls for the flow direction grid, *FDR*, and the outlet grid. The outlet grid, *OUTLETGRID*, was created based on the method described earlier. With these grids, the watershed function "determines the contributing area above a set of cells in a grid", the outlet grid (ESRI, 2000). The flow direction function tells the direction of flow from one cell to another, until those cells reach a cell in the outlet grid. The following

ArcInfo Workstation commands were used to perform the watershed delineation process:

```
Arc:  grid
Grid:  setcell 30
Grid:  setwindow BURN_DEM BURN_DEM
Grid:  fill BURN_DEM FILL_DEM # # FDR
Grid:  FAC = flowaccumulation (FDR)
Grid:  WSH_GRID = watershed (FDR, OUTLETGRID)
Grid:  quit
```

4.5.5 Post-Processing the Watersheds

The watershed function yielded watersheds in grid form, *WSH_GRID,* with the grid-code equaling the appropriate segment number. These watersheds were converted to polygons using the *gridpoly* command, with the result of watersheds as polygons, *WSH_POLY*. However, this coverage had spurious polygons and sharp edges along the coastline where the grid cell size was inadequate for the intricacy of the coast. In order to smooth the edges and maintain the correct shape along the coast, the *SEAOCEAN* data layer was used again. The *erase* command in ArcInfo trims the overlapping area between the input coverage, watershed coverage *WSH_POLY* and the erase coverage, the *SEAOCEAN* coverage. The result was trimmed, more accurately shaped watersheds, *SMOOTH_WSH*. Figure 4.19 illustrates the jagged edge of the original polygon watersheds and the smoothed edges of the manipulated watersheds, achieved by using the *erase* command. The following ArcInfo Workstation commands were used to perform the process:

```
Arc:  gridpoly WSH_GRID WSH_POLY
Arc:  erase WSH_POLY SEAOCEAN SMOOTH_WSH
```

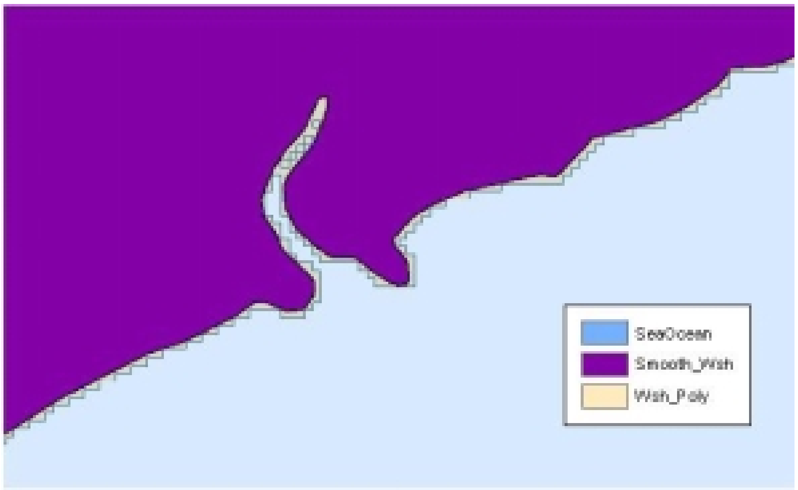


Figure 4.19 Smoothed Watershed Boundary using Erase Command

Significant islands presented a complication in smoothing the edges of the watersheds. The *SEAOCEAN* coverage had to be *cleaned* before it could be used properly in ArcInfo. During the cleaning process, polygon features were created as part of the *SEAOCEAN* coverage where the islands were located. Therefore, during the *erase* command, the islands were also erased with the jagged coastline. In order to maintain both the islands as part of the original watersheds and the smoothed coastlines, a few additional steps were taken. First, the island was selected from the cleaned *SEAOCEAN* coverage and converted to a new coverage, *ISLAND*. Then, the island was clipped out of the initial *WSH_POLY* coverage using the ArcInfo Workstation command:

Arc: clip WSH_POLY ISLAND ISLAND_WSH.

The output, *ISLAND_WSH*, was merged with the smoothed watersheds using Geoprocessing Wizard to yield *FINAL_WSH*. These data layers are exemplified in Figure 4.20 of the Bolivar Peninsula in the Neches-Trinity coastal basin. The Bolivar Peninsula was initially excluded in the smoothing of the coastline, but returned to the final watershed boundaries using this process.

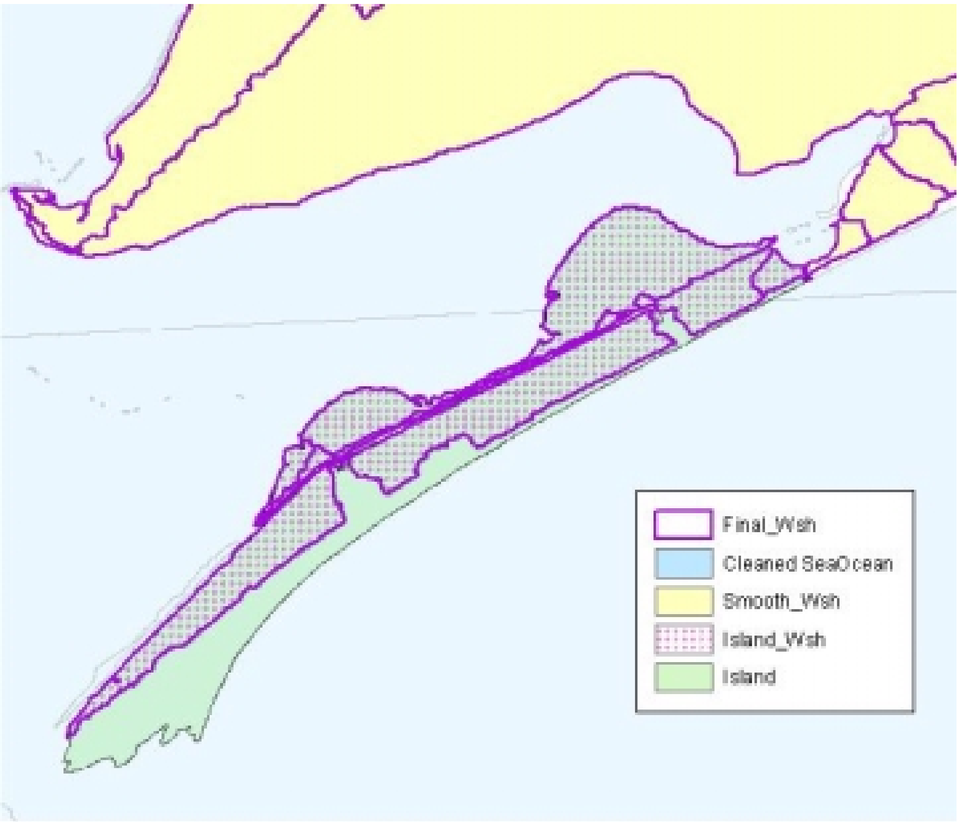


Figure 4.20 Returning the Bolivar Peninsula to the final watersheds

Spurious polygons still presented an issue for the smoothed watersheds. The problem was individual cells or areas connected to the watershed on a diagonal, which ArcInfo does not recognize as part of the whole watershed. Rather, these cells or areas are identified with a grid-code of –9999. Corrections to these problems were made manually on a case by case basis after inspection of the flow direction grid *FDR* and the adjacent watershed grid-codes. The –9999 grid-code was manually changed, which resulted in several polygons for each watershed code. The polygons were merged together using the dissolve function in Geoprocessing Wizard, with the grid-code as the attribute to dissolve by and adding the Area by Sum field. These watersheds, *WSH_DIS*, were the final watershed boundaries determined for the TNRCC.

4.5.6 Delineating Watersheds Including the Waterbody

The watershed delineation process for waterbody watersheds including the waterbody consists of the same methodology as that presented. However, inclusion of the waterbodies was much more straightforward than the prior procedure and several of the steps were omitted.

First, the DEM was not formatted for NODATA cell values. Because the watershed should include the waterbody, the cells in the ocean can have elevation values. These cells are coincident with cells in the outlet grid and therefore were automatically assigned to the watershed for that outlet grid-code. Second, the edges of the watershed along the coast were not smoothed. Again, the watershed included the waterbody and did not terminate at the coast. Therefore, no need existed for smoothing the edges. Third, islands did not pose a problem to the watershed because no erasing took place. The watershed and the waterbody were lumped together and the island was included in the watershed polygon because the waterbody surrounded it. Therefore, the procedures detailed in this section apply to watersheds including the waterbody with the exclusion of the steps mentioned.

4.6 REALISTIC WATERSHED BOUNDARIES

The final dissolved watershed boundaries represent the drainage area for each water quality management segment. These watersheds are to be used to distribute digital information to the public and private agencies modeling TMDL allocation. The nature of watershed delineation derived from a DEM led to boundaries with 30 meter right angles and a jagged appearance. A decision was made to *generalize* the boundaries, to reduce detail in the boundaries to obtain a more realistic appearance. It was believed that the public would be more accepting of a realistic watershed boundary as opposed to a jagged, stair step boundary. To accomplish the softening of the boundary, the *generalize* command in ArcInfo Workstation was used. The command is of the form:

```
Arc:  generalize WSH_DIS WSH_GEN 80 bendsimplify.
```

The command parameters are described as follows. *WSH_GEN* is the watershed coverage that has the relaxed boundaries. *Eighty, 80,* represents the weed tolerance, defined as the tolerance in coverage units used to remove unwanted detail within the arcs. *Bendsimplify* specifies the simplification operator. Two options exist for the simplification operator, pointremove or bendsimplify. Pointremove utilizes the Douglas-Peucker's algorithm for line simplification with enhancements; essentially it retains critical vertexes and connects them to form a simplified version of the line without any detail. Additionally, this method results in a line with sharp angles and spikes, the very problem that was being attempted to be rectified. Bendsimplify recognizes unnecessary bends in the original line and removes them, based on the weed tolerance. The final result from bendsimplify is more true to the original line, with a gentler appearance (ESRI, 2000). Figure 4.21 highlights the difference between the dissolved boundaries and the generalized boundaries.

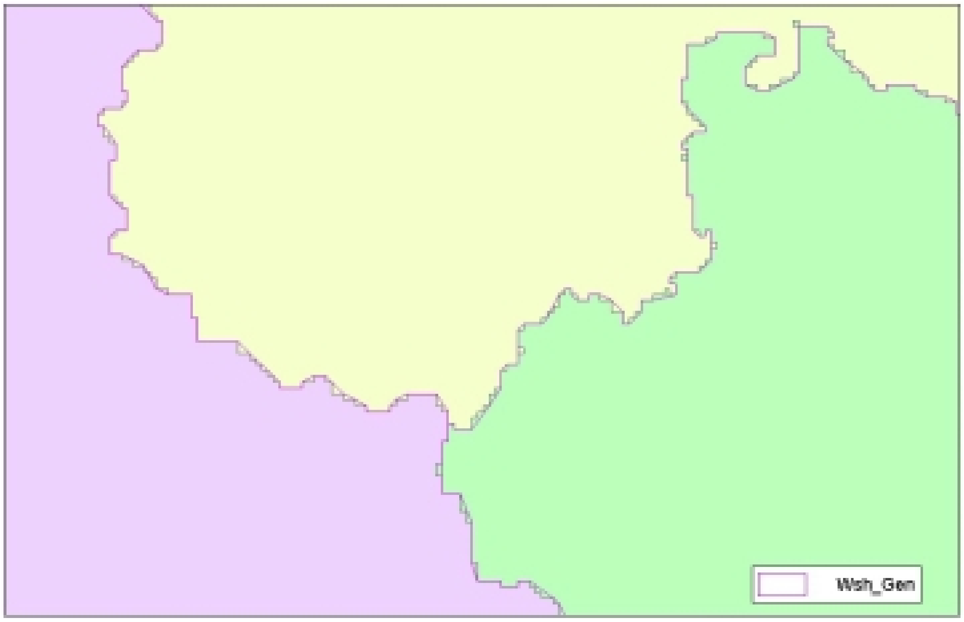


Figure 4.21 Generalized Watershed Boundaries

4.7 PARTITIONING GEOSPATIAL DATA

Once the realistic generalized watersheds were created, the corresponding geospatial databases were produced for each watershed. First, the data layers, listed in Table 3.1 in Section 3.2.5, were obtained from various sources. The main resource was the Internet. The specific source of each data layer is also present in the table. Once these data layers were retrieved, their metadata was studied to find their original projection. Each database had a common projection, TCMS Albers; however, most of the data layers were not initially in that projection. Therefore, the data layers were projected to the TCMS Albers projection in the ArcInfo Workstation domain.

Next, the data layers were attributed with the appropriate watershed number in which they fell. Two procedures were used, one for point data layers and one for lines and polygon coverages. For the point layers, a point data layer and the generalized watersheds were added to an ArcView project with the Geoprocessing Wizard extension. The “Assign data by location (Spatial Join)” geoprocessing option was used, in which the “theme to assign data to” was the point data layer and the “theme to assign data from” was the generalized watershed polygons. The attribute table of the point data layer was opened and a new field was added named “Grid_code”. The “Grid_code” field was then calculated as equal to the “Gridcode” field joined from the generalized watershed coverage. The edits to the table were saved, and the table was closed. Each point contained in the layer that was located within a watershed was attributed with that watershed gridcode.

For the polygon and line coverages, they too were added to an ArcView project with the Geoprocessing extension. The “Intersect two themes” geoprocessing option was used, in which the “input theme to intersect” was either a line or polygon coverage and the “overlay theme” was the generalized watershed polygons. The output coverage was named “wsh_*layername*” based on which data layer was being intersected. This output coverage was a polygon or line coverage with distinct polygons or lines for each feature with unique attributes and a unique watershed gridcode.

Once the features in the data layers were attributed with the appropriate watershed gridcodes, they were compiled into a large regional database and then partitioned into individual geospatial databases for each watershed. In order to partition the final 54 data layers in an efficient manner, automated programs were utilized. Shapefiles and coverages were separated by their watershed gridcode using an Avenue script named "ExportDataQuery", written by Tim Whiteaker, which can be found in Appendix D. To use this script, it was first necessary to create a main watershed data directory as the working directory, with a subfolder under this directory for each watershed gridcode, named by the gridcode. The data layer with the watershed attributes was then made active and the script was executed. The query field was then chosen, either "Grid_code" for point data layers or "Gridcode" for polygon and line data layers. The user then specifies the output name for the shapefile of the data layer, selected by the query field. The script then queries for all features with a watershed gridcode and coverts them to a new shapefile with the output name. The new shapefile is then saved in the subfolder named by its gridcode.

Grids were partitioned using an AML named "ClipGrids", also found in Appendix D. Four grids were integrated into the geospatial database: the burned and filled DEM, the flow direction grid, the flow accumulation grid and the land use/land cover grid. The grids were clipped based on the individual generalized watershed already separated and found in a subfolder by gridcode.

The AML converts the generalized watershed to a coverage, then clips the four grids to that coverage and saves them as grids of smaller extent in that gridcode subfolder.

4.8 CONCLUSION

The procedures described in this chapter portray the work that was performed for the watershed delineation study and geospatial database development for TNRCC designated stream and waterbody segments. They can be categorized into a few main tasks: building a hydrography network, creating the outlet grid, processing the DEM, editing the final watersheds for completeness and compiling the geospatial data. The methods are generally applicable to any watershed delineation situation and more relevant for watershed delineation of waterbodies. Several additional steps are depicted which are specific for waterbody watersheds that exclude the waterbody; however, these steps are highlighted for their exclusion in the case of delineating watersheds that include the waterbody.

CHAPTER 5: RESULTS

5.1 INTRODUCTION

The procedures described in Chapter 4 yield watersheds in polygon form. These watersheds correspond one to one with a TNRCC designated water quality management segment, explained in Chapter 3. As in every research effort, final results must first go through several iterations before achieving the accepted product. The first and last iterations of watersheds and the review process between them are detailed here.

5.2 FIRST ITERATION WATERSHEDS

The methods depicted in Chapter 4 were followed to arrive at the first iteration of watersheds for the TNRCC. At this point in the research, watersheds that excluded the waterbodies were derived, as it was prior to the first review process with the TNRCC. Figure 5.1 displays the delineated watersheds for the 55 designated segments in the Basin Group C area.

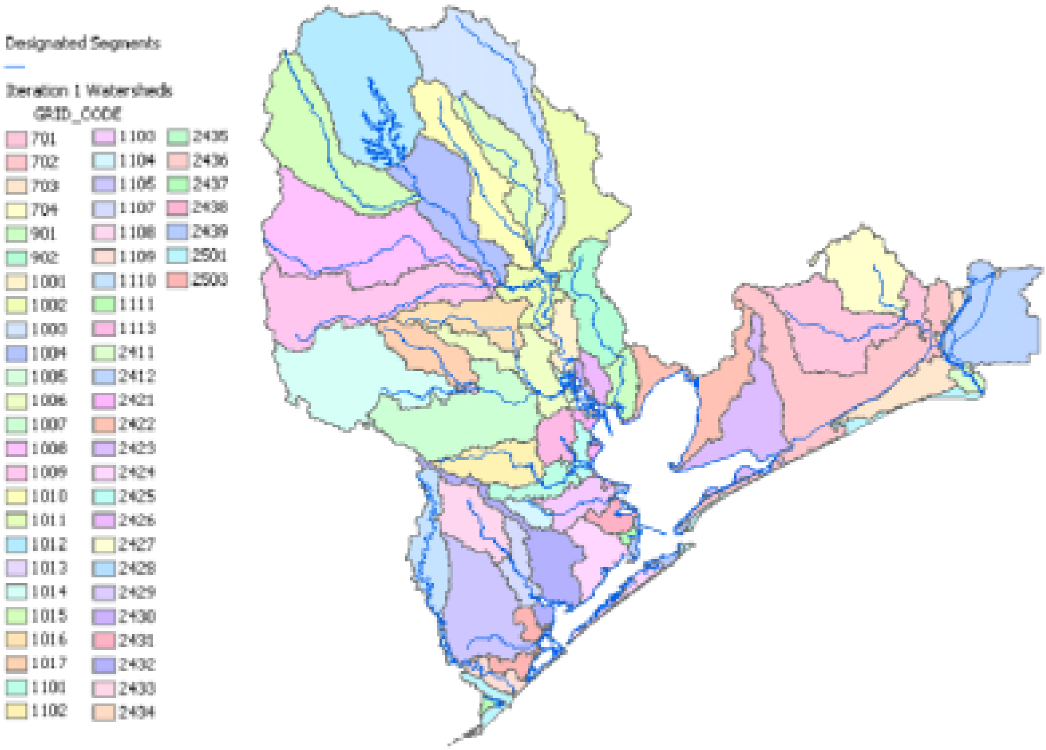


Figure 5.1 First Iteration Delineated Watersheds

In the legend in Figure 5.1, the watershed grid_code refers to the Segment ID. The segment IDs relate to the basin numbers. The segment ID consists of four numbers, the first two equaling the basin number and the last two uniquely identifying the segment. The following basins in Basin Group C correspond to the following numbers: Neches-Trinity coastal basin = 7, Trinity-San Jacinto coastal basin = 9, San Jacinto river basin = 10 and the San Jacinto-Brazos coastal basin =11. The bays and estuaries along the coast of Texas correlate to a number of 24. The Gulf of Mexico relates to a segment ID of 2501. Therefore, the grid_codes of interest are those starting with 7, 9, 10, and 11. Additionally, a selection of the bays and estuaries are included in the research, specifically numbers 2411, 2412, and 2421-2439. The Gulf of Mexico, 2501, is included in the final results of the first iteration to show which area drains directly into the Gulf rather than first flowing through a different designated waterbody.

An area is included the final results of the first iteration with a grid_code of 2503. This grid_code was implemented by the author to account for area that flows directly into the Intracoastal Waterway in the San Jacinto-Brazos coastal basin bypassing any other segment. In this basin, the Intracoastal Waterway is not yet "classified" and is not included on the 305(b) list. This area was passed on to the TRNCC to obtain an official decision of where to attribute this land.

Table 5.1 indicates the watershed grid_code and its area in square kilometers. This table is included as a reference tool to compare with future iteration results.

GRID_CODE	Area (sq km)	*GRID_CODE*	Area (sq km)	*GRID_CODE*	Area (sq km)
701	724.17	*1014*	918.51	*2423*	503.90
702	1083.42	*1015*	856.04	*2424*	293.48
703	272.68	*1016*	331.06	*2425*	74.31
704	438.92	*1017*	284.58	*2426*	80.77
901	142.02	*1101*	147.83	*2427*	13.83
902	384.87	*1102*	290.94	*2428*	4.32
1001	157.24	*1103*	186.22	*2429*	9.31
1002	808.57	*1104*	77.73	*2430*	18.74
1003	1018.67	*1105*	619.42	*2431*	83.52
1004	570.28	*1107*	164.12	*2432*	393.78
1005	30.91	*1108*	307.27	*2433*	6.93
1006	355.33	*1109*	94.23	*2434*	10.79
1007	801.26	*1110*	327.60	*2435*	4.13
1008	1141.17	*1111*	19.56	*2436*	3.69
1009	844.38	*1113*	148.43	*2437*	16.36
1010	559.74	*2411*	57.77	*2438*	3.26
1011	407.51	*2412*	618.66	*2439*	56.93
1012	1165.51	*2421*	55.47	*2501*	196.91
1013	12.46	*2422*	446.48	*2503*	122.82

Table 5.1 First Iteration Watershed Areas

5.3 REVIEW PROCESS

Once the first iteration of delineated watersheds were complete, the TNRCC reviewed the boundaries against their GIS coverages, topographic maps, and personal knowledge of the area. The comments of the TNRCC revealed discrepancies in the digitally delineated watersheds. Figure 5.2 highlights the discrepancies with purple circles.

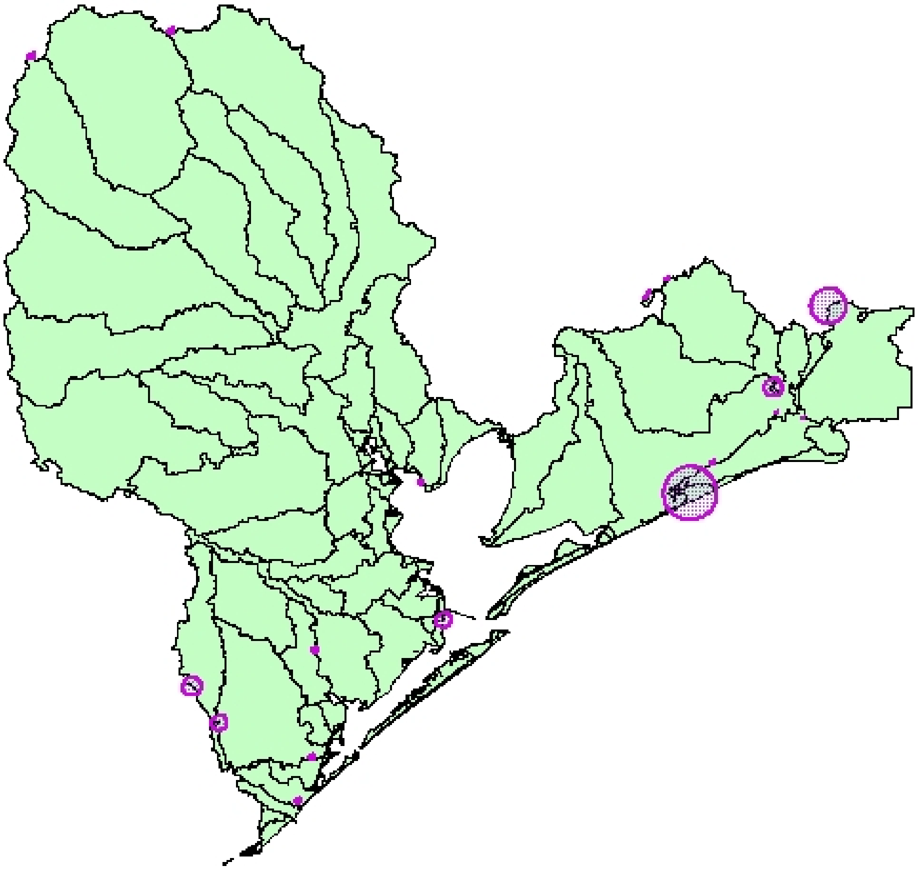


Figure 5.2 Discrepancies in the first iteration of watersheds

These disparities could be characterized as four main issues of concern: the contributing area to the Intracoastal Waterway in the Neches-Trinity coastal basin, short circuiting of the flow due to an intricate network in a larger scale grid, the “unclassified” Intracoastal Waterway flow direction in the San Jacinto-Brazos coastal basin and the representation of waterbodies in the landscape. These four issues are further described and solutions presented. The new watershed boundaries for the entire Basin Group C are then presented in Section 5.4.

5.3.1 Contributing Area to the Intracoastal Waterway in the Neches-Trinity Basin

In the lower portion of the Neches-Trinity coastal basin, a land mass separates the Gulf of Mexico and the Intracoastal Waterway (ICWW). The term land mass may not even be appropriate to describe this area; rather, it is a conglomeration of lakes, swamps and marshes. Therefore, no distinct drainage paths could be determined from the topographic maps with any real accuracy. Initially, the NHD was assumed to be correct and the network in that area was left unedited. Figure 5.3 presents an overview of the area under discussion.

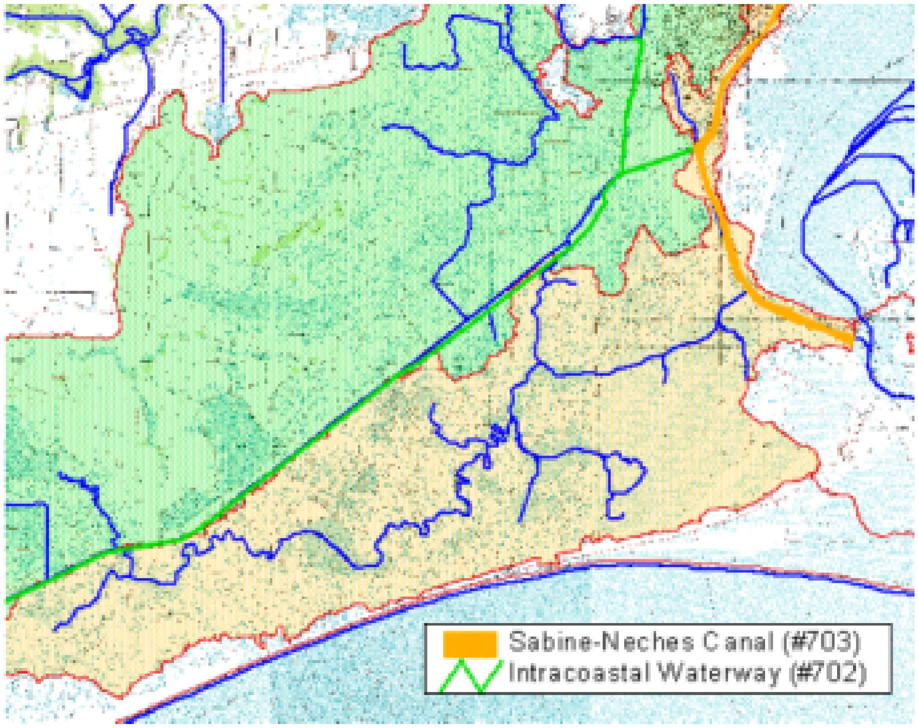


Figure 5.3 Overview of the Intracoastal Waterway area in the Neches-Trinity coastal basin

Upon watershed delineation, the DEM forces the majority of the area between the Gulf of Mexico and the Intracoastal Waterway to drain into the Sabine-Neches Canal, Segment #703, rather than the ICWW (Segment #702). Because the area is so flat, this result was disputed. TNRCC reviewers have personally investigated the area to determine the actual flow directions over the marshy area. The results of their study indicated that the majority of the area actually drains to the ICWW and not the Sabine-Neches Canal. Therefore, the hydrography of the area was manually altered to relate their findings into the network.

First, the ICWW was connected to the east end of Salt Bayou and to Star Lake. Second, the network was split between Johnson Lake and Keith Lake. Third, the network was also split just west of Clam Lake. With these modifications, the looping that attempted to replicate the marsh land of the area was eliminated. It was replaced by distinct drainage paths acting as tributaries that lead exclusively to either the Sabine-Neches Canal or the ICWW. These specific changes were made based on the recommendations of the TNRCC. The edits made to address these issues are shown in Figures 5.4-5.7. The results of these changes are described in Section 5.4.

Figure 5.4 Connection between the ICWW and Salt Bayou

Figure 5.5 Connection between the ICWW and Star Lake

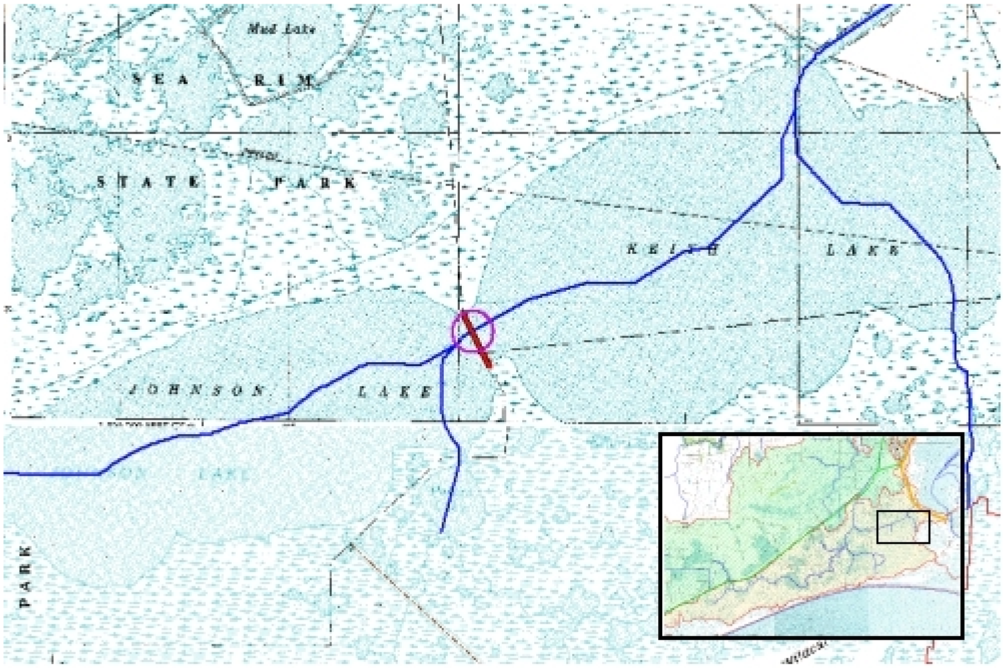


Figure 5.6 Split between Johnson Lake and Keith Lake

Figure 5.7 Split between Salt Bayou and Clam Lake

5.3.2 Short-Circuiting due to Cell Size Scale

Saunders (1999) warns against using hydrography data and digital elevation models of different scales, as errors may occur when the two data layers are integrated. These errors did occur in the first delineation of watersheds in the form of short-circuiting. When vector data is converted to raster data, any cell which contains a portion of the vector data is included in the new representation. The cell size of the raster data is 30 meters. Therefore, when the distance between two streams in the hydrography data layer is less than 30 meters, the two streams merge in the grid and create errors in the resultant grids.

In several instances in this study, the watersheds are distorted because flow was falsely attributed to a stream that does not actually receive it. This is because the network data burned in to the DEM contained instances in which the distance between streams was less than 30 meters. Therefore, the cells combined, and the elevation of these burned in cells was very similar. When the flow direction was computed, the flow traveled down the wrong path, leading to a more pronounced flow in the incorrect channel. This can be identified in the flow accumulation grid. The watersheds then reflect the erroneous flow in their boundaries. An example of a flawed watershed is presented.

The watershed for the Hillebrandt Bayou (Segment #704) has an irregular hook protruding from its west side, as seen in Figure 5.8. This hook is the contributing area to a tributary that drains into a main stem that leads into this segment. However, the remaining tributaries that flow into the same main stem are not included in the overall watershed.

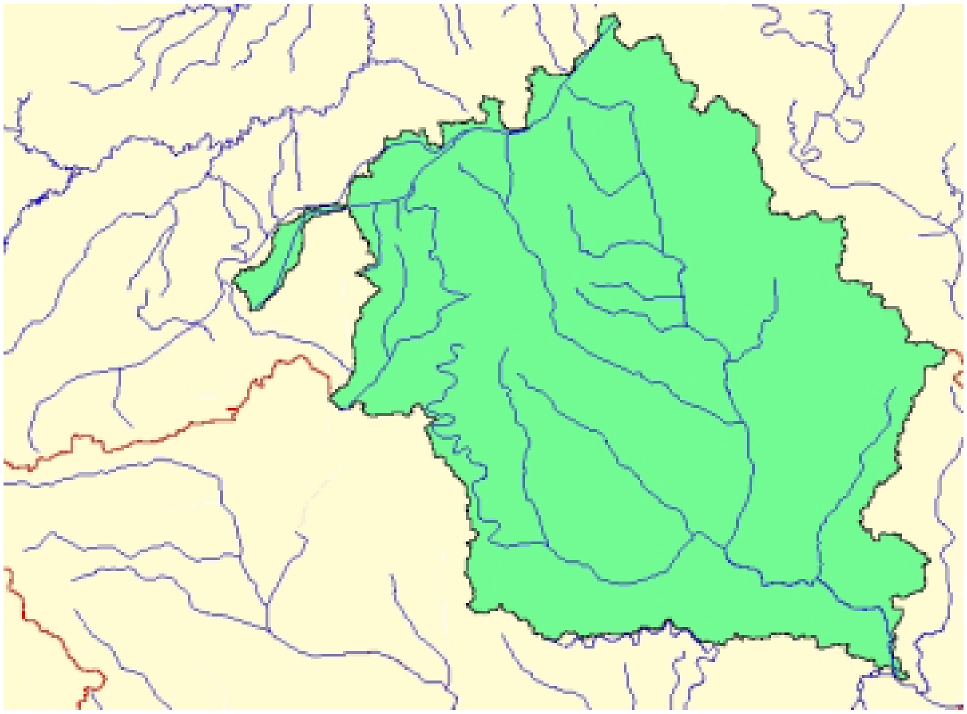


Figure 5.8 First Iteration Hillebrandt Bayou Watershed

Inspection of the flow accumulation grid displays the jump in flow from a stream that is not part of the segment stream system to a tributary that is part of the segment stream system by means of cell connection. Therefore, the flow is short-circuiting without traveling through the entire stream route. Manual editing of the network rectified this problem. The three streams that lie very close to the tributary were trimmed back to a distance greater than the 30 meter threshold.

Although this method is not recommended, lack of more intricate DEMs leave it as the only choice at this time. By increasing the distance, the cells do not coincide and the flow becomes channeled in the appropriate direction. Figure 5.9 shows the three streams within 30 meters of the tributary mentioned.

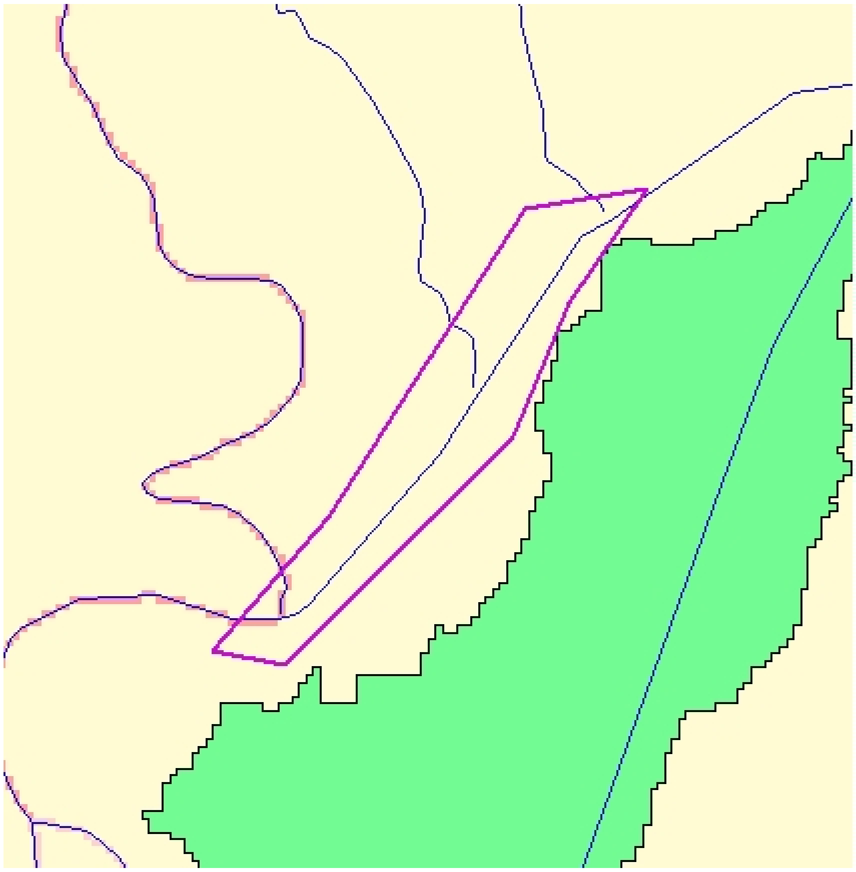


Figure 5.9 Flow Accumulation Grid with Short-circuiting Flow

5.3.3 Unclassified Intracoastal Waterway Flow Direction

In the San Jacinto-Brazos coastal basin, the Intracoastal Waterway is "unclassified", which means it is not yet included on the Section 305(b) list. Therefore, it is not a TNRCC designated segment and a watershed was not delineated for this artificial stream. However, much of the landscape in this area does flow directly into the ICWW and was manually attributed a code of 2503, shown in Figure 5.10. This area was then studied by the TNRCC as to how to partition this area to classified TNRCC designated segments.

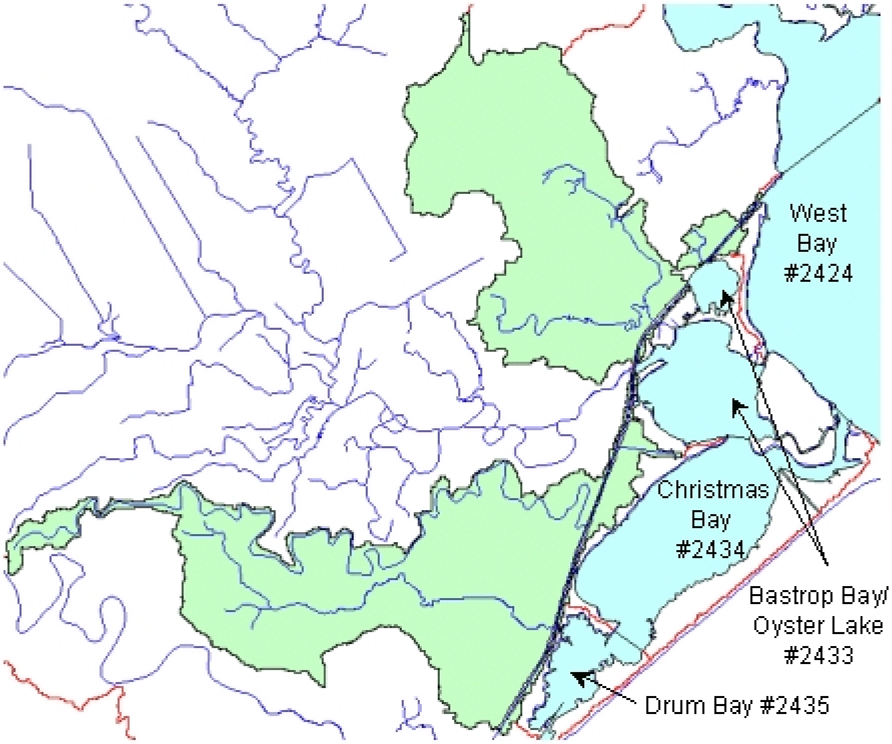


Figure 5.10 Drainage Area to the unclassifed Intracoastal Waterway

This area was broken into several pieces, with each piece contributing to a classified segment watershed. These watersheds receiving the area are Bastrop Bay/Oyster Lake (Segment #2433), West Bay (Segment #2424) and Drum Bay (Segment #2435). The area was split by modification of the drainage network. These modifications included removing pieces of the network, moving intersections, and splitting streams. The main alterations are described below.

In order to force the flow to follow the correct path into Bastrop Bay/Oyster Lake, two main modifications were made. The flow was split between Oyster Lake and West Bay. This split attempted to divert some of the flow into West Bay and the rest into Oyster Lake. The location is located on Figure 5.11. Also, the intersection of the Intracoastal Waterway and the incoming segment, Bastrop Bayou Tidal (#1105) was moved into the Bastrop Bay waterbody. This relocation forced flow accumulating in the Intracoastal Waterway to empty into Bastrop Bay rather than to travel past it and further accumulate in the ICWW until it reaches the outlet into the Gulf of Mexico. The intersection of note is shown in Figure 5.12.

Figure 5.11 Split in Network between Oyster Lake and West Bay

Figure 5.12 Intersection of ICWW, Bastrop Bay and Bastrop Bayou Tidal

Similar modifications were made to partition portions of the area into Drum Bay and Bastrop Bay. A stream representing the Intracoastal Waterway between two confluences was chosen as the ridge location dividing the area. However, instead of splitting the stream into two distinct pieces with a small gap, the entire stream between the confluences was removed. This allowed the DEM to dictate where the exact ridge location was between the confluences rather than it being manually decided. Then, above the ridge line, flow is towards Bastrop Bay and on the other side of the ridge, flow is towards Drum Bay. Figure 5.13 notes the stream that was removed from the network (the stream with the circle).

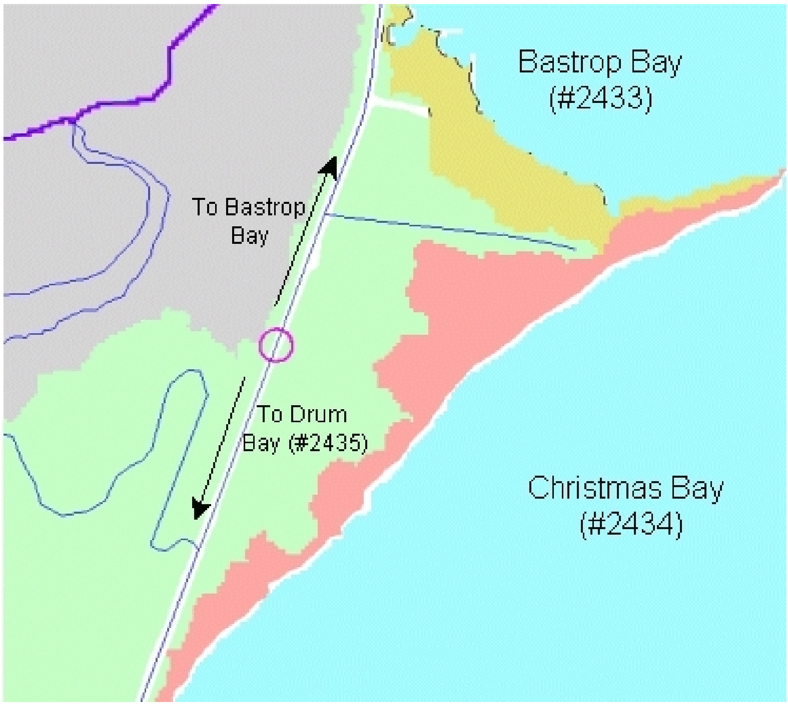


Figure 5.13 Stream Removed from Intracoastal Waterway

An intersection of the Intracoastal Waterway and the Drum Bay waterbody also needed to be moved in order for the flow to transmit correctly. Again, the intersection was not physically on top of a raster cell in the waterbody, so the ICWW flow continued past Drum Bay into the Gulf. This intersection was moved to coincide with the waterbody. The intersection is shown in Figure 5.14.

Figure 5.14 Intersection of Intracoastal Waterway and Drum Bay

With these changes in the network, the area attributed to 2503 (the fictitious segment) is separated into areas that contribute to a TNRCC designed segment.

5.3.4 Waterbody Representation in Watershed Delineation

Waterbodies presented a constant issue for coastal watershed delineation. They result in two different delineation procedures dependent on whether the bay/estuary waterbody is included in the watershed. In the initial watershed delineation (watersheds excluding the waterbody), the bay and estuaries were removed from the DEM. Thus, the segment number was input into the coastline adjacent to the bay or estuary. In some cases, the coastline did not follow the waterbody defined by the TNRCC exactly. Another problem encountered during the initial watershed delineation dealt with waterbodies in the network. While the method to determine which waterbodies lie on the network was described in Section 4.2.3, their inclusion was not implemented into the network to be burned into the DEM. Hence, in several locations, a waterbody was bisected by a watershed boundary.

To correct the inconsistent coastlines and waterbodies, the method to delineate watersheds including the waterbody was followed. The outlet grid was created as described. These two steps ensured that the watershed included all of the TNRCC water quality management segment waterbody.

To prevent the division of a waterbody by a watershed boundary, two options existed. An option that should be pursued is burning the waterbody into the DEM as well as the stream network. Because this would involve an additional processing step, which relates to a more time-consuming procedure, this option was not employed. Rather, artificial streamlines that run through the waterbody were added to the network. As in the case of Harris Reservoir, the stream network abuts the waterbody, but does not include an artificial path going through the waterbody. When the watersheds were delineated, the watershed for the segment of the area, Oyster Creek Above Tidal (Segment #1110), bisected the reservoir. The watershed boundary can be seen in Figure 5.15.

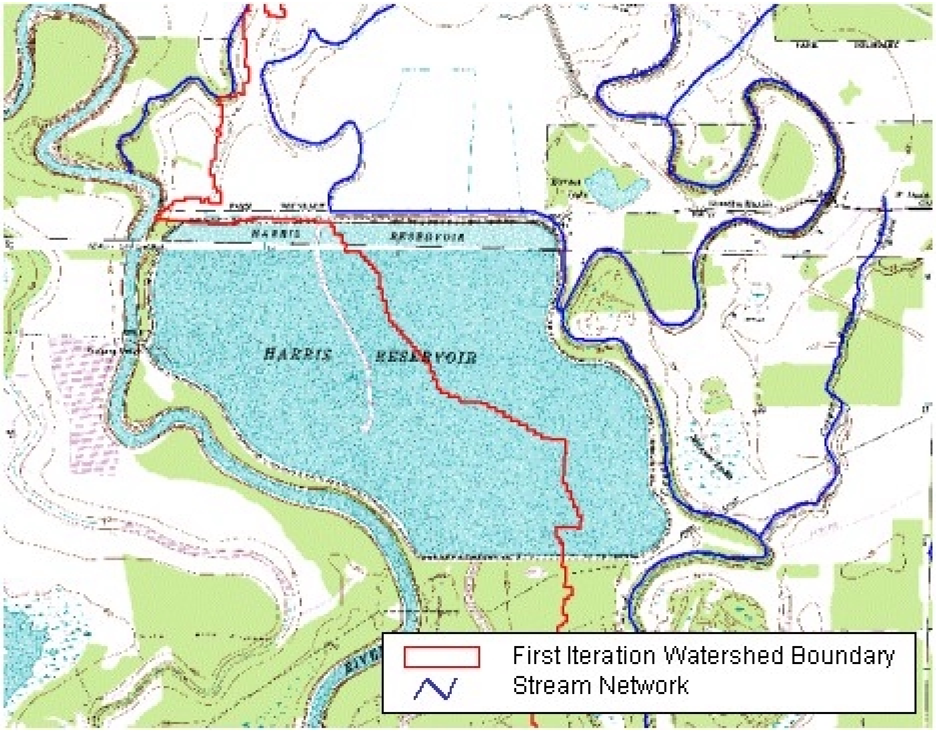


Figure 5.15 Harris Reservoir bisected the Oyster Creek Above Tidal Watershed

To correct this error, artificial paths were added to the network that represent the shoreline of the reservoir and flow lines through the reservoir.

These artificial paths are an accepted method of representing waterbodies in a dendritic network by the GIS in Water Resources community. Once this network is burned into the DEM, any area draining to the shorelines or paths will be associated with the Oyster Creek Above Tidal watershed. The added artificial paths are seen in Figure 5.16.

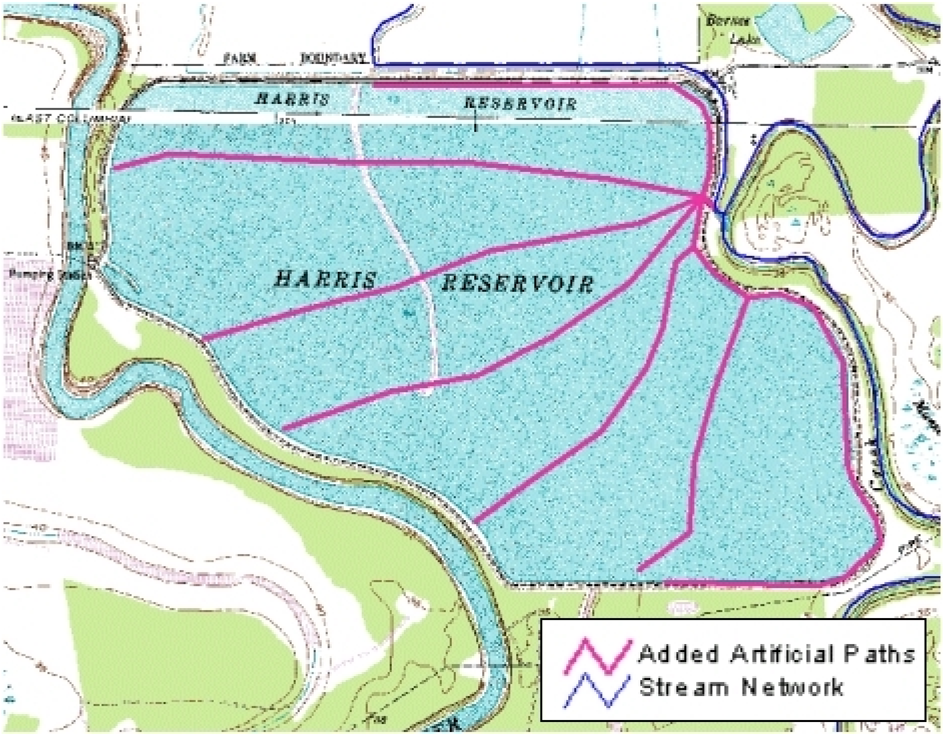


Figure 5.16 Artificial Paths added to Network for Harris Reservoir

Using this method, inland waterbody issues are resolved. Bay and estuary waterbody issues are corrected by including them in the watershed.

5.4 FINAL ITERATION WATERSHEDS

All results in a research setting go through numerous iterations before reaching a final product that meets the standards for deliverables. In the instance of this research, several iterations were made. The changes detailed in the previous section were implemented into the network, which necessitated re-processing the DEM and again performing all the grid and watershed functions. The results were again assessed, and more edits were made.

Of the changes discussed, all but one was effective while new problems arose. Most of the new problems can be attributed to the four main issues described, mainly short-circuiting. The one ineffective solution was the split in the network to divert flow from the Intracoastal Waterway in the San Jacinto-Brazos coastal basin to West Bay and Oyster Lake, shown in Figure 5.11. Despite various efforts and trials for locations of the split, the drainage area continued to flow entirely into Oyster Lake rather than divide between the two waterbodies. After several attempts, a decision was made that the result would stand as is; the drainage direction and path should not be brutely forced if the digital elevation model resists it. Until more detailed DEMs are available, the watershed boundary would remain as delineated.

Another significant change from the first iteration of watersheds was the inclusion of the waterbody in the watershed for the bays and estuaries. As portrayed in Chapter 4, the procedure for delineating watersheds including the waterbody is slightly different than those originally produced. Also, the desired projection of the final watersheds was changed from TSMS Albers to TCMS Albers that led to reprojecting many of the data layers. Once these modifications were incorporated into the process, the final delineated watersheds were produced. These watersheds are found in Figure 5.17.

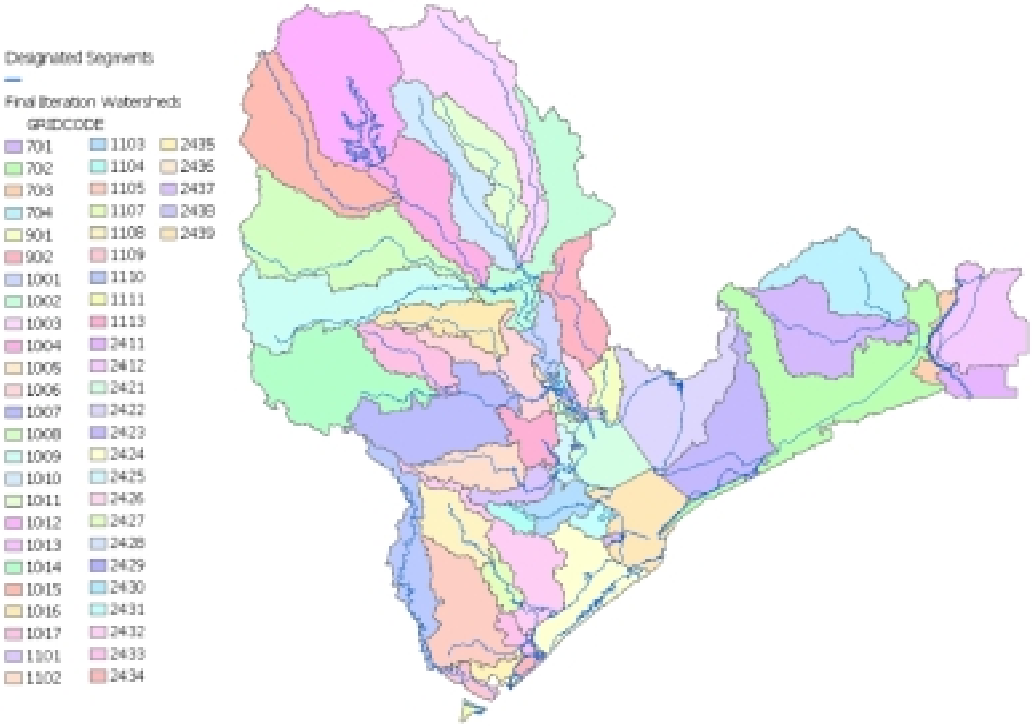


Figure 5.17 Final Iteration Delineated Watersheds

Because the figure cannot drastically show the difference between the first and final iteration, the calculated drainage areas are used for comparison. These areas are shown in Tables 5.2 and 5.3.

Segment No.	Initial Area (sq km)	Final Area (sq km)	% Difference	Reason
701	724.17	669.86	7.50%	5
702	1083.42	1295.65	-19.59%	1
703	272.68	87.09	68.06%	1
704	438.92	576.18	-31.27%	2
901	142.02	143.53	-1.06%	
902	384.87	388.60	-0.97%	
1001	157.24	161.02	-2.41%	
1002	808.57	779.02	3.65%	
1003	1018.67	1016.79	0.18%	
1004	570.28	572.36	-0.37%	
1005	30.91	45.34	-46.71%	3
1006	355.33	362.56	-2.03%	
1007	801.26	762.35	4.86%	
1008	1141.17	1137.79	0.30%	
1009	844.38	845.81	-0.17%	
1010	559.74	560.30	-0.10%	
1011	407.51	405.95	0.38%	
1012	1165.51	1164.86	0.06%	
1013	12.46	12.24	1.73%	
1014	918.51	920.82	-0.25%	
1015	856.04	856.39	-0.04%	
1016	331.06	331.96	-0.27%	
1017	284.58	291.04	-2.27%	
1101	147.83	140.89	4.70%	
1102	290.94	290.54	0.13%	
1103	186.22	186.02	0.11%	
1104	77.73	73.78	5.08%	5
1105	619.42	582.55	5.95%	4
1107	164.12	114.02	30.53%	2
1108	307.27	307.20	0.02%	
1109	94.23	72.66	22.89%	3
1110	327.60	417.09	-27.32%	4
1111	19.56	19.31	1.27%	
1113	148.43	190.20	-28.14%	5

Table 5.2 Drainage Area Comparison of Basin Segment Watersheds

In Table 5.2, the drainage areas are shown for the basin segment watersheds: the watersheds of segments which lie in the Neches-Trinity, Trinity-San Jacinto, San Jacinto-Brazos or San Jacinto basins. These do not include the bay and estuary watersheds. The two iterations of watersheds are presented: the initial iteration area as “Initial Area” and the final iteration area of the generalized watersheds as “Final Area”. The percent difference between the two iteration areas is then given as “% Difference”. This is calculated as (“Initial Area” – “Final Area”) / “Initial Area”. Therefore, a negative percent difference indicates a gain in area from the initial to final iteration and a positive percent difference indicates a loss in area from the initial to final iteration.

Of the 34 watersheds presented in Table 5.2, eleven watersheds have an absolute value percent difference in area over 5%. When investigating the cause for the increase or decrease in area, given as “Reason”, most watersheds fell into the four issues described in Section 5.3. The key for the “Reason” column corresponds as follows:

1. Contributing Area to the Intracoastal Waterway in the Neches-Trinity Basin
2. Short-Circuiting due to Cell Size Scale
3. Unclassified Intracoastal Waterway Flow Direction
4. Representation of Waterbodies

5. Other, meaning changes in the DEM, looping, additional of a significant canal, etc.

For the other 23 watersheds, the minor error can be explained by variations in the DEM from resampling during the projection process, the generalization of the boundary and other small changes in the network.

Segment No.	Initial Area (sq km)	Waterbody Area (sq km)	Adjusted Initial Area (sq km)	Final Area (sq km)	% Difference	Reason
2411	57.77	5.22	62.99	160.83	-155.34%	1
2412	618.66	102.89	721.55	591.83	17.98%	5
2421	55.47	299.12	354.59	356.27	-0.47%	
2422	446.48	317.52	764.00	753.85	1.33%	
2423	503.90	149.12	653.02	644.32	1.33%	
2424	293.48	195.44	488.92	495.29	-1.30%	
2425	74.31	5.87	80.19	76.45	4.66%	
2426	80.77	10.19	90.96	91.85	-0.99%	
2427	13.83	5.23	19.06	19.27	-1.11%	
2428	4.32	3.11	7.44	6.00	19.35%	4
2429	9.31	3.78	13.10	13.22	-0.91%	
2430	18.74	5.41	24.15	25.17	-4.22%	
2431	83.52	8.39	91.91	77.83	15.32%	5
2432	393.78	21.06	414.84	460.77	-11.07%	2
2433	6.93	13.09	20.01	76.04	-279.90%	3
2434	10.79	23.37	34.15	36.66	-7.34%	3
2435	4.13	5.34	9.47	77.92	-722.83%	3
2436	3.69	0.55	4.24	4.52	-6.55%	4
2437	16.36	1.17	17.53	14.74	15.89%	4
2438	3.26	0.94	4.20	3.89	7.45%	4
2439	56.93	362.42	419.35	463.20	-10.46%	4
2501	196.91	n/a	n/a	n/a		
2503	122.82	n/a	n/a	n/a		

Table 5.3 Drainage Areas Comparison of Waterbody (Bay and Estuary) Segment Watersheds

In Table 5.3, the drainage areas are compared for the bay and estuary segment watersheds in the same fashion. However, instead of comparing the initial area to the final area, an adjusted initial area was used. The “Adjusted Initial Area” was calculated as the “Initial Area” + “Waterbody Area”. The waterbody areas are the calculated areas of the waterbodies from the TNRCC data. The percent difference is then calculated the same as for Table 5.2 with the “Initial Area” replaced by the “Adjusted Initial Area” to reveal the differences in watershed iterations not due to the waterbody inclusion in the watershed.

Of the 21 watersheds for bays and estuaries, twelve also have a percent difference greater than 5%. The disparity between the adjusted initial and final areas can also be accounted for with the five reasons explained. The greater ratio of watersheds with differences stems from the fact that two of the four main issues for review dealt with the bays and estuaries.

When examining the sum of the areas for all the watersheds, essentially the area of Basin Group C, the total adjusted initial area is 20,308 sq km while the final area is about 20,232 sq km. The percent difference between these two values is 0.38%. While this percentage is within the margin of error, it can still be rationalized. The initial areas included area in the Basin Group C boundary defined by the TNRCC that drained directly into the Gulf of Mexico, segment number 2501. For the final areas, the Gulf of Mexico was not considered since it was not included in the Basin Group C segments (numbers 7xx, 9xx, 10xx, 11xx and certain 24xx segments). Therefore, this area was not counted in the final areas and accounts for the discrepancy.

5.5 CONCLUSION

As seen from the initial watershed boundaries, the review process, and the analysis of the final watershed boundaries, four main issues plagued watershed delineation in Basin Group C: contributing area to the Intracoastal Waterway, shortcircuiting due to the cell size and network scales, unclassified Intracoastal Waterway drainage areas and the representation of waterbodies during watershed delineation. These four topics account for the majority of discrepancies between the initial and final watersheds. Specifically, 17 out of the 23 watersheds, 74%, with a percent difference in drainage area greater than 5% can be attributed to these four issues. Therefore, the factors behind these issues must be addressed in research dealing with coastal watershed delineation.

CHAPTER 6: CONCLUSIONS

This thesis presents a detailed account of the steps taken to obtain watersheds for a coastal environment in the context of TMDL development. Specifically, watersheds were delineated for the 55 water quality management segments designated by the TNRCC for Basin Group C in Texas. This basin group is located around the Houston area and contains the Neches-Trinity coastal basin, the San Jacinto-Brazos coastal basin, the Trinity-San Jacinto coastal basin, the San Jacinto river basin, and several bays and estuaries along this coastline. The distinguishing factor of this work is its focus on the watersheds of the waterbodies, the bays and estuaries. Additionally, the slight to flat slope of the area necessitated modifications in the traditional watershed delineation methods.

Initially, a surface water drainage network was created for the entire Basin Group C area. The network was derived from the National Hydrography Dataset and underwent manual inspection and editing when compared to the Digital Raster Graphic maps of the USGS. Then, the departure from typical watershed determination occurred. The definition of a waterbody watershed was developed, which was also used to apply to a stream segment. Specifically, a waterbody watershed is characterized as the area of land draining into a waterbody at any given location. This carries over to the stream in that the watershed is then the area of land draining into a stream at any location, rather then a specific location such as an outlet.

With this definition of a watershed, the corresponding outlet grid was created. Rather than containing outlet points converted to outlet cells in a grid, the entire stream or waterbody was converted to form the outlet grid. This ensures a correct watershed boundary in such a flat area. When using only an outlet point, the flat nature of the region could cause flow direction to bypass the one specific outlet location, whereas using the entire stream or waterbody assures that any flow that reaches the stream at any point is included in the watershed.

The digital elevation model was then processed for watershed delineation. Two procedures are described: for watersheds that excluded the waterbody and for watersheds that included the waterbody. The method of waterbody exclusion was more encompassing, with the inclusion method omitting several of the steps. Many recommendations of prior coastal studies were implemented, such as conditioning the DEM to remove any negative values, and replacing the sea/ocean area of the DEM with NO DATA cells to act as sinks. Also, the drainage network created was burned into the landscape, and the DEM was filled. The flow direction and flow accumulation grids were calculated. Using the flow direction grid and outlet grid, the watersheds for the TMDL designated segments were delineated. The watersheds were then post-processed to yield a one-to-one relationship between the generalized watersheds and the water quality management segments.

Four main concerns were raised during the watershed delineation process: contributing area to the Intracoastal Waterway in the Neches-Trinity coastal basin, short-circuiting due to the cell size, flow direction of the unclassified Intracoastal Waterway, and waterbody representation. These four main issues have underlying implications that must be addressed in all coastal delineation efforts.

The overall lesson from these issues is that detailed data, digital, paper or personal knowledge, is essential to work along the coast. Digital elevation models provide the basis for establishing flow direction and creating watershed boundaries. However, the coastal region is too flat to be accurately represented in a 30 meter cell size grid. The streams and flow paths are too densely clustered or too undefined through marshes and swamps and lead to short-circuiting. The two complications that dealt with the Intracoastal Waterway reinforce the importance of personal knowledge of the area. Without having personal accounts of the direction of flow, it would have been impossible to delineate watersheds in those areas with any real accuracy. When dealing with a swamp/marsh area with undefined drainage paths on the maps, hands-on information is the only reliable source. Finally, waterbody inclusion and representation encompasses all of these issues. Inclusion of the bays and estuaries in the watersheds reduced the amount of pre-processing of the DEM and post-processing of the watersheds. Lakes and ponds were represented as flow paths through the waterbody, which caused short-circuiting in some instances.

By realizing these issues, this study has resulted in many recommendations for future coastal work. First, the most detailed digital elevation model should be used. LIDAR (Light Detection and Ranging) determined elevation models and 10 meter DEMs should be considered if processing power and time is available. Second, lakes and ponds should be included on the network, as opposed to artificial paths through them. The new ArcGIS Hydro data model has several feature classes and relationships that should allow for this possibility to be easier in the future. In addition to lakes and ponds in the network, a great deal of Basin Group C is swamp and marsh, a unique combination of land and lake. A method should be considered to hydrologically and hydraulically represent swamps and marshes as waterbodies in the landscape. By characterizing the swamps as a waterbody, the need for personal knowledge of the area is reduced. However, this requirement will always remain paramount in coastal watershed delineation and must be stressed emphatically.

Another recommendation deals with the tedious editing process necessary to implement the user specified flow direction along the Intracoastal Waterway. The new ArcGIS Hydro data model also contains capabilities to traverse along the hydrography network. These options are reliant upon the flow direction of the network. Flow direction is set dependent upon the location of sinks and sources or based on the digitized direction. A new tool, developed by Tim Whiteaker at CRWR, allows the user to assign flow direction as indeterminate, with digitization, against digitization or uninitialized. This tool should be studied for its usefulness in assigning and storing known flow direction along the surface water drainage network. This could possibly replace the trial and error editing procedure employed for this research. The user can assign the flow direction along reaches in the network and save them for future use, processing, and travel along the network.

The final recommendation deals with a new outlook on the state’s tessellation of the landscape. Texas is currently divided into 15 river basins and 8 coastal basins. These basins are used to coordinate water quality management activities. Therefore, the water quality management segments are attributed by Segment ID to the planning basin in which they are located. However, when studying the partitioning of the landscape by designated segment watersheds, the areas and basin boundaries are vastly different, as shown in Figure 6.1.

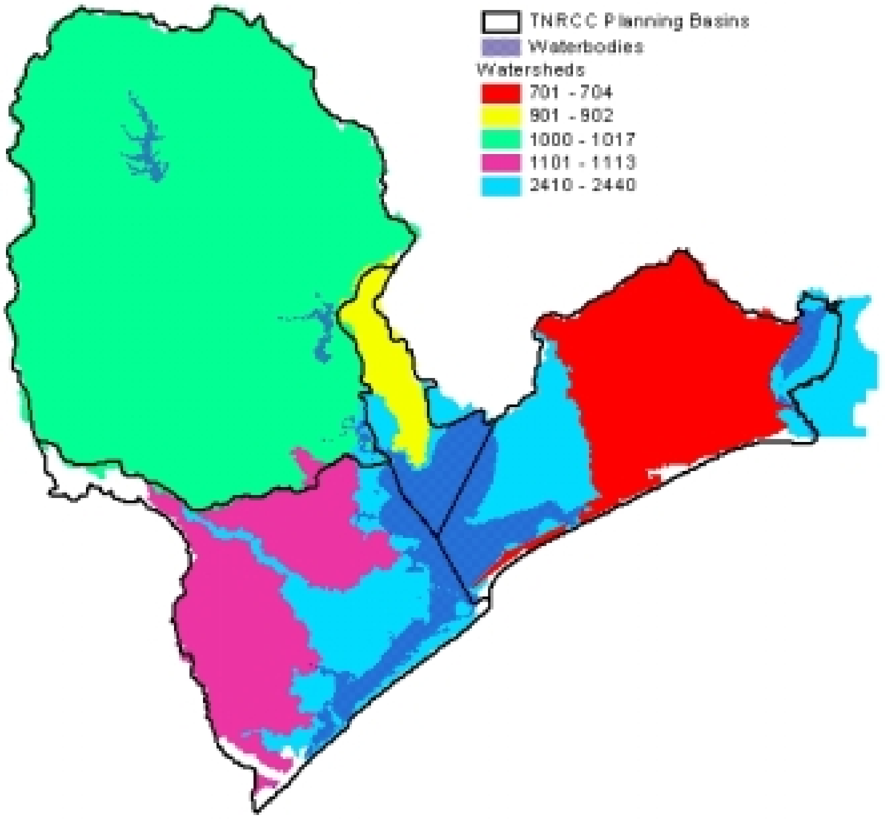


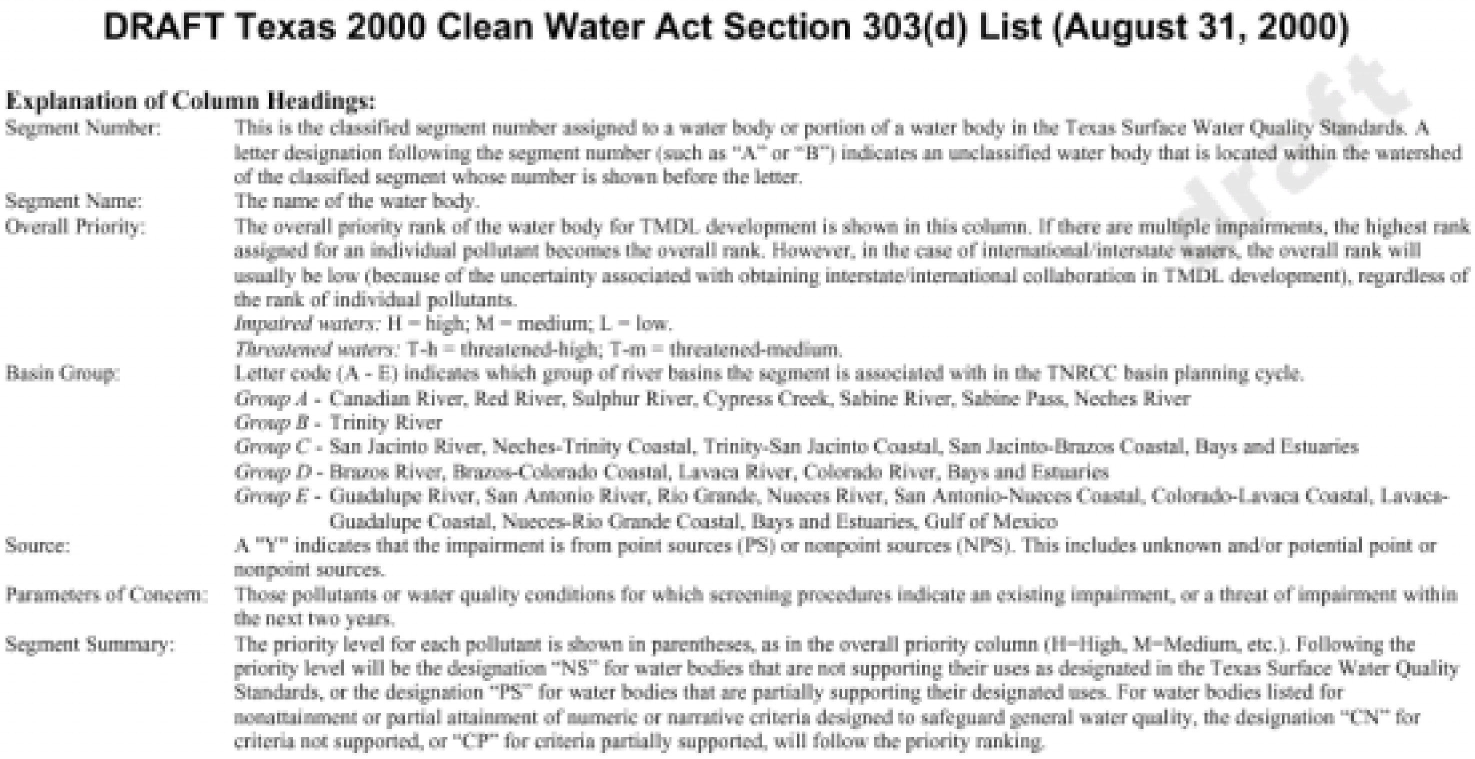
Figure 6.1 TNRCC Planning Basin Boundaries

The black boundaries indicate the current planning basin boundaries. The watersheds are symbolized by their respective Segment ID, in which the first or first two numbers reflect which basin they are located in: 7 = Neches-Trinity, 9 = Trinity-San Jacinto, 10 = San Jacinto, 11 = San Jacinto-Brazos, and 24 = Bays and Estuaries. The obvious conclusion is that a great deal of area now included in the coastal basins actually drains directly to a bay, estuary, or into the Gulf of Mexico without first traveling through a segment in the basin. In the San Jacinto-

Brazos Basin, the basin is actually divided by land which is attributed to the bays rather than the basin. These watersheds that correlate directly to water quality management segments should be studied further for possible implementation as new water quality planning units.

APPENDIX A: TEXAS 2000 CLEAN WATER ACT SECTION 303(D) LIST

The following appendix contains the Draft copy of the Texas 2000 Clean Water Act Section 303(d) List, posted August 31, 2000. The list is part of the document *Texas 2000 Clean Water Act Section 303(d) List and Schedule for Developing Total Maximum Daily Loads*, found at the website http://www.tnrcc.state.tx.us/water/quality/00_303d.html. The list entries included are the designated segments in Basin Group C. The entire list is available at http://www.tnrcc.state.tx.us/water/quality/00_303dlist.pdf.



DRAFT Texas 2000 Clean Water Act Section 303(d) List (August 31, 2000)

Explanation of Column Headings:

Segment Number:	This is the classified segment number assigned to a water body or portion of a water body in the Texas Surface Water Quality Standards. A letter designation following the segment number (such as "A" or "B") indicates an unclassified water body that is located within the watershed of the classified segment whose number is shown before the letter.
Segment Name:	The name of the water body.
Overall Priority:	The overall priority rank of the water body for TMDL development is shown in this column. If there are multiple impairments, the highest rank assigned for an individual pollutant becomes the overall rank. However, in the case of international/interstate waters, the overall rank will usually be low (because of the uncertainty associated with obtaining interstate/international collaboration in TMDL development), regardless of the rank of individual pollutants. *Impaired waters:* H = high; M = medium; L = low. *Threatened waters:* T-h = threatened-high; T-m = threatened-medium.
Basin Group:	Letter code (A - E) indicates which group of river basins the segment is associated with in the TNRCC basin planning cycle. *Group A* - Canadian River, Red River, Sulphur River, Cypress Creek, Sabine River, Sabine Pass, Neches River *Group B* - Trinity River *Group C* - San Jacinto River, Neches-Trinity Coastal, Trinity-San Jacinto Coastal, San Jacinto-Brazos Coastal, Bays and Estuaries *Group D* - Brazos River, Brazos-Colorado Coastal, Lavaca River, Colorado River, Bays and Estuaries *Group E* - Guadalupe River, San Antonio River, Rio Grande, Nueces River, San Antonio-Nueces Coastal, Colorado-Lavaca Coastal, Lavaca-Guadalupe Coastal, Nueces-Rio Grande Coastal, Bays and Estuaries, Gulf of Mexico
Source:	A "Y" indicates that the impairment is from point sources (PS) or nonpoint sources (NPS). This includes unknown and/or potential point or nonpoint sources.
Parameters of Concern:	Those pollutants or water quality conditions for which screening procedures indicate an existing impairment, or a threat of impairment within the next two years.
Segment Summary:	The priority level for each pollutant is shown in parentheses, as in the overall priority column (H=High, M=Medium, etc.). Following the priority level will be the designation "NS" for water bodies that are not supporting their uses as designated in the Texas Surface Water Quality Standards, or the designation "PS" for water bodies that are partially supporting their designated uses. For water bodies listed for nonattainment or partial attainment of numeric or narrative criteria designed to safeguard general water quality, the designation "CN" for criteria not supported, or "CP" for criteria partially supported, will follow the priority ranking.

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
0701	Taylor Bayou Above Tidal	L	C	Y	Y	depressed dissolved oxygen	In the lower 25 miles of the segment, dissolved oxygen concentrations are occasionally lower than the criterion established to assure optimum conditions for aquatic life (L/PS).
0704	Hillebrandt Bayou	L	C	Y	Y	depressed dissolved oxygen	Dissolved oxygen concentrations are occasionally lower than the criterion established to assure optimum conditions for aquatic life (L/PS).
0901	Cedar Bayou Tidal	M	C	Y	Y	pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).
0902	Cedar Bayou Above Tidal	L	C	Y	Y	pathogens, total dissolved solids	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS). The average concentration of total dissolved solids exceeds the criterion established to safeguard general water quality uses (L/CN).
1001	San Jacinto River Tidal	M	C	Y	Y	dioxin in blue crab and catfish tissue, pathogens	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS). Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).
1005	Houston Ship Channel/San Jacinto River Tidal	M	C	Y		dioxin in blue crab and catfish tissue	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in 1990 due to elevated concentrations of dioxin in blue crabs and catfish (M/NS).

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
1006	Houston Ship Channel Tidal	H	C	Y	Y	dioxin in blue crab and catfish tissue, copper in water, toxicity in ambient sediment, toxicity in ambient water, thermal modifications	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS). Within the Patrick Bayou Tidal area, the average dissolved copper concentration exceeds the criterion established to protect aquatic life from chronic exposure (H/NS). Within the Patrick Bayou Tidal area, significant effects in ambient water toxicity tests sometimes occur, indicating that conditions are not optimum for aquatic life (H/NS). Within the Patrick Bayou Tidal area, significant effects in ambient sediment toxicity tests occasionally occur, indicating that conditions are not optimum for aquatic life (H/PS). Within the Patrick Bayou Tidal area, water temperature sometimes exceeds the criterion established to safeguard general water quality uses (H/CN).
1007	Houston Ship Channel/Buffalo Bayou Tidal	M	C	Y	Y	dioxin in blue crab and catfish, toxicity in ambient sediment	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in 1990 due to elevated concentrations of dioxin in blue crab and catfish tissue (M/NS). Within the Vince Bayou Tidal area, significant effects in ambient sediment toxicity tests occasionally occur, indicating that conditions are not optimum for aquatic life (M/PS).
1008	Spring Creek	M	C	Y	Y	depressed dissolved oxygen, pathogens	In the portion upstream from the Kuykendahl Road bridge, dissolved oxygen concentrations are sometimes lower than the criterion established to assure optimum conditions for aquatic life (M/NS). Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
1009	Cypress Creek	M	C	Y	Y	pathogens, total dissolved solids	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS). The average concentration of total dissolved solids exceeds the criterion established to safeguard general water quality uses (M/CN).
1013	Buffalo Bayou Tidal	M	C		Y	pathogens, copper in water	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS). Average dissolved copper concentrations exceed the criterion established to protect aquatic life from chronic exposure (M/NS).
1014	Buffalo Bayou Above Tidal	L	C	Y	Y	pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).
1016	Greens Bayou Above Tidal	L	C	Y	Y	pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).
1017	Whiteoak Bayou Above Tidal	L	C	Y	Y	pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).
1101	Clear Creek Tidal	M	C	Y	Y	carbon disulfide, chlordane, trichloroethane, and dichloroethane in fish and crab tissue, pathogens	The fish consumption use is not supported in an 8.3-mile portion upstream of SH 3 in Clear Creek Tidal, based on a no-consumption advisory issued by the Texas Department of Health in 1993 due to elevated concentrations of dichloroethane, trichlororethane, carbon disulfide, and chlordane in fish and crab tissue (L/NS). Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
1102	Clear Creek Above Tidal	L	C	Y	Y	carbon disulfide, chlordane, dichloroethane, and trichloroethane in fish and crab tissue, pathogens	The fish consumption use is not supported, based on a no-consumption advisory issued by the Texas Department of Health in 1993 due to elevated concentrations of dichloroethane, trichlororethane, carbon disulfide, and chlordane in fish and crab tissue (L/NS). In the lower 25 miles of the segment, bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).
1103	Dickinson Bayou Tidal	M	C	Y	Y	depressed dissolved oxygen, pathogens	Downstream from IH 45 southeast of Dickinson to one-half mile downstream of SH 3, dissolved oxygen concentrations are occasionally lower than the criterion established to assure optimum conditions for aquatic life (M/PS). Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).
1104	Dickinson Bayou Above Tidal	L	C		Y	pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).
1108	Chocolate Bayou Above Tidal	L	C		Y	pathogens, total dissolved solids	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS). The average concentration of total dissolved solids exceeds the criterion established to safeguard general water quality uses (L/CN).
1109	Oyster Creek Tidal	M	C		Y	pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).
1110	Oyster Creek Above Tidal	M	C	Y	Y	depressed dissolved oxygen, pathogens	In the lower 25 miles of the segment, dissolved oxygen concentrations are sometimes lower than the criterion established to assure optimum conditions for aquatic life (M/NS). In the same 25 miles, southwest of the City of Angleton in Brazoria County, bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
1113	Armand Bayou Tidal	H	C	Y	Y	depressed dissolved oxygen, pathogens	In the upper two miles of the segment, dissolved oxygen concentrations are sometimes lower than the criterion established to assure optimum conditions for aquatic life (H/NS). Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (M/NS).
2421	Upper Galveston Bay	M	C	Y	Y	dioxin in blue crab and catfish tissue, pathogens	The fish consumption use is not supported in the 22 square miles from Red Bluff Point to Five Mile Cut Marker to Houston Point and north to Morgan's Point, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in September 1990 due to elevated concentrations of dioxin in blue crab and catfish tissue (M/NS). Based on Texas Department of Health shellfish maps, 55% of the bay (59.5 square miles of the outer perimeter) does not support and 19% of the bay (20.6 square miles of the area adjacent to the nonsupporting area) partially supports the oyster water use due to potential contamination by human pathogens (L/NS/PS).
2422	Trinity Bay	L	C		Y	pathogens	Based on Texas Department of Health shellfish maps, 69.3% of the bay (90.2 square miles of the outer perimeter) does not support and 13.8% of the bay (17.9 square miles of the area adjacent to the nonsupporting area) partially supports the oyster water use due to potential contamination by human pathogens (L/NS/PS).
2423	East Bay	L	C		Y	pathogens	Based on Texas Department of Health shellfish maps, 22.1% of the bay (11.5 square miles at the east end of the bay near East Bay Bayou and Intracoastal Waterway) does not support the oyster water use due to potential contamination by human pathogens (L/NS).

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
2424	West Bay	M	C		Y	copper (chronic), pathogens	In eight square miles near Carancahua Reef, the average concentration of dissolved copper exceeds the criterion established to protect aquatic life from chronic exposure (M/NS). Based on Texas Department of Health shellfish maps, 35.2% of the bay (24.4 square miles at the east end near Galveston and Texas City) does not support the oyster water use due to potential contamination by human pathogens (L/NS).
2426	Tabbs Bay	M	C	Y	Y	dioxin in fish and crab tissue, pathogens	Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS). The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS).
2427	San Jacinto Bay	M	C	Y		dioxin in fish and crab tissue	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in September 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS).
2428	Black Duck Bay	M	C	Y		dioxin in fish and crab tissue	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in September 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS).
2429	Scott Bay	M	C	Y	Y	dioxin in fish and crab tissue, pathogens	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in September 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS). Bacteria levels sometimes exceed the criterion established to assure the safety of contact recreation (L/NS).

Segment Number	Segment Name	Overall Priority	Basin Group	Source		Parameters of Concern	Segment Summary
				PS	NPS		
2430	Burnett Bay	M	C	Y		dioxin in fish and crab tissue	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in September 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS).
2432	Chocolate Bay	L	C	Y	Y	pathogens	Based on Texas Department of Health shellfish maps, the entire bay does not support the oyster water use due to potential contamination by human pathogens (L/NS).
2436	Barbours Cut	M	C	Y		dioxin in fish and crab tissue	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in September 1990 due to elevated concentrations of dioxin in catfish and blue crab tissue (M/NS).
2437	Texas City Ship Channel	L	C	Y		depressed dissolved oxygen	Dissolved oxygen concentrations are occasionally lower than the criterion established to assure optimum conditions for aquatic life (L/PS).
2438	Bayport Channel	M	C	Y		dioxin in blue crab and catfish tissue	The fish consumption use is not supported, based on restricted-consumption and no-consumption advisories issued by the Texas Department of Health in 1990 due to elevated concentrations of dioxin in blue crab and catfish tissue (M/NS).
2439	Lower Galveston Bay	M	C	Y	Y	copper (chronic), pathogens	The average dissolved copper concentration in water exceeds the criterion established to protect aquatic life from chronic exposure (M/NS). Based on Texas Department of Health shellfish maps, 43.5% of the bay (60.7 square miles of the outer perimeter, Galveston and Texas City) does not support and 9.9% of the bay (13.8 square miles of the area adjacent to the nonsupporting area) partially supports the oyster water use due to potential contamination by human pathogens (L/NS/PS).

APPENDIX B: NATIONAL HYDROGRAPHY DATASET EXERCISE

The following exercise was prepared by the author and David R. Maidment, of the Center for Research in Water Resources, University of Texas at Austin, in October 2000. The exercise included in this thesis is only part one of the entire exercise entitled *National Hydrography Dataset and Networks in ArcGIS 8.0*. To view the exercise in its entirety, see the webpage: http://www.ce.utexas.edu/prof/maidment/giswr2000/ex6/Exercise.htm. The data used in the exercise is available from the NHD website, as mentioned in the exercise. The study area is HUC #12040204, West Galveston Bay, a cataloging unit within the San Jacinto-Brazos coastal basin. The software used in this exercise is ArcMap. ArcMap is a program in the ArcGIS software package, distributed by ESRI.

National Hydrography Dataset and Networks in ArcGIS 8.0

Prepared by Victoria Samuels and David R. Maidment
Center for Research in Water Resources
University of Texas at Austin
October 2000

Contents

Goals of the Exercise

This exercise has two parts. **Part 1** introduces the user to map hydrography data depicting water features of the landscape, and specifically hydrography data from the National Hydrography Dataset. The user learns to symbolize and differentiate between the feature and reach data layers. The attributes accompanying the hydrography data are also described. The study area selected for this exercise is HUC #12040204, West Galveston Bay. This area is located on the Southeast coast of Texas near Houston.

Computer and Data Requirements

To carry out this exercise, you need to have a computer that runs ArcInfo 8.0 (with ArcMap and ArcCatalog). In order to download the National Hydrography Dataset data, you need internet access. The data files used in the exercise consist of ArcInfo coverages. All of the data being used is in the Geographic projection, NAD 83 datum.

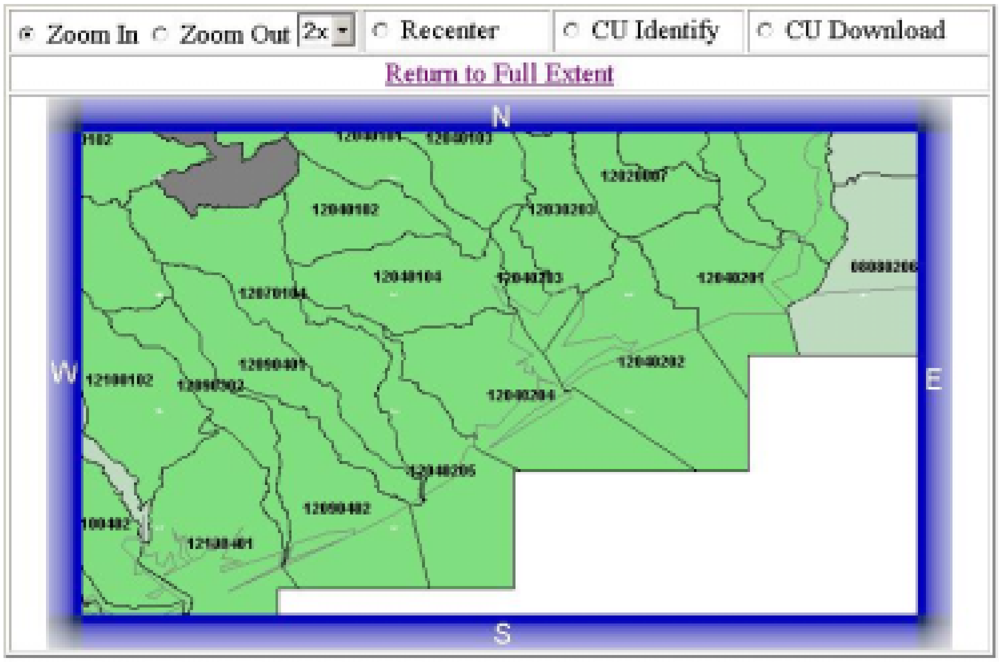
Part 1: The National Hydrography Dataset

Obtaining National Hydrography Dataset Data

The National Hydrography Dataset (NHD) is a substantial set of digital data and contains information about the surface water drainage network of the United States. The data consists of naturally occurring and constructed bodies of water, natural and artificial paths which water flows through, and related hydrographic entities. The NHD is distributed by the United States Geological Survey (USGS) and is available to the public for download.

The NHD is available at the website http://nhd.usgs.gov. At this web site, click on the **Data** tab on the left side of the screen and then click on the first bullet, **Obtaining NHD Data**. The NHD is organized by Hydrologic Cataloging Unit (HUC). You will see a map of the United States in which you can zoom in and navigate to the HUC of interest. Another option is using the FTP site to obtain the data. The data you will be using is for HUC #12040204. The first method described is downloading the NHD using the map.

Zoom in several times on Eastern Gulf Coast of Texas near the Louisiana border (the divide between green and light green HUCs). Eventually zoom in to where you can differentiate between HUCs and their number.



When you can distinguish HUC #12040204 (the third green HUC to the left after the border between green and light green HUCs), change the radial button at the top of the map to **CU Download** and click on HUC #12040204. Fill out the **NHD Download** screen information and **Continue**. Click **Yes** to the Security Warning and click **Download** on the Download page. Navigate to the location you want to place the 12040204 file, and click **OK** to the **Successful Download** window. You should now have the **12040204.tgz** file, a compressed folder with the NHD data.

Another way to download the data is to use the FTP site, if the HUC number is known. You want HUC #12040204, and can precede directly to the FTP site without manipulating the map. From the initial window with the map of the United States, click on the **FTP** link under the map. Scroll down the list to the **12040204.tgz** link, click on it, then **Save this file to a disk**. Navigate to the directory you want to place the data. Now you have the NHD data for HUC #12040204.

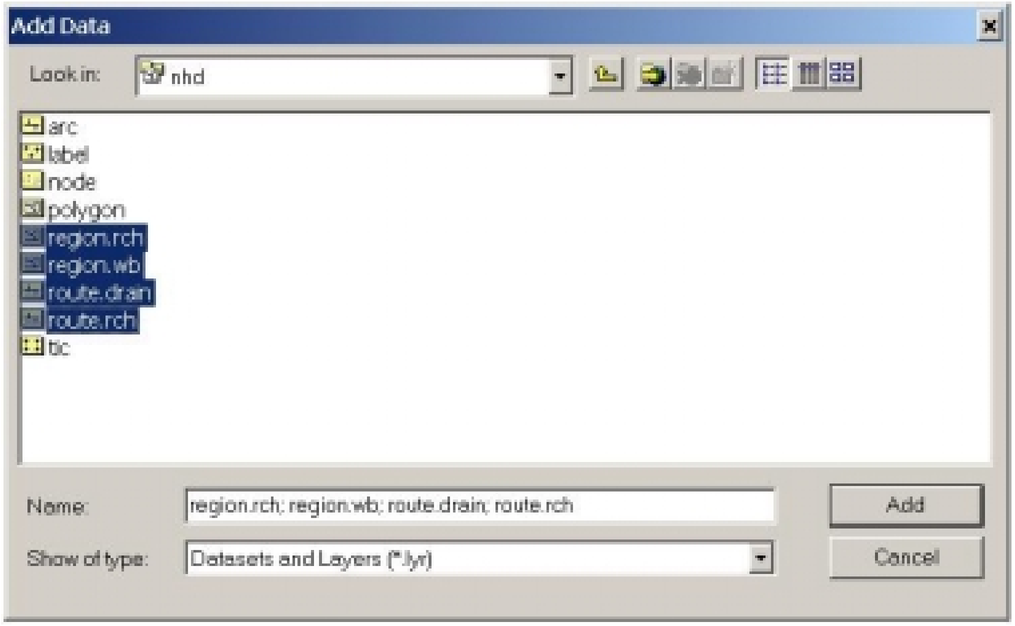
Structure of the National Hydrography Dataset

Unzip the 12040204.tgz file using the Windows utility Winzip. Extract the file to the 12040204 folder. Click **Yes** to the Winzip window asking if Winzip should decompress 12040204.arc.tar to a temporary folder. In Windows Explorer, navigate to the second 12040204 folder. Please note that using Winzip for uncompressing the NHD files has some limitations not important to this exercise. These limitations are important if you want to append or join NHD files for several adjacent HUC units. In that event, use the uncompression software provided on the NHD website.

The NHD is organized as three ARC/INFO coverages, many related INFO tables, and text files containing metadata. The **nhd** coverage contains the line and polygon features. This coverage has line, polygon and node topology, which together is network topology. The **nhdpt** coverage contains point features related to the hydrography. The third coverage, **nhdduu**, contains metadata and information about sources and updates of the hydrographical information. The spatial elements of the surface water network are found in the **nhd** and **nhdpt** coverages.

Viewing and Inspecting NHD Feature Classes

NHD data can be inspected using ArcView 3. This exercise goes on to use the Network capabilities of ArcInfo 8, so we'll view the data in ArcMap instead. Open a new empty map in **ArcMap** and **Add Data**. Browse to the second 12040204 folder, then to the **nhd** folder. Note the different elements in the **nhd** coverage. Arcs, nodes, and polygons are the typical spatial elements originally in ArcInfo. The NHD forms groups of arcs or polygons as single entities and labels them as *routes* or *regions*, respectively. Add the **region.rch**, **region.wb**, **route.drain**, and **route.rch** data layers.



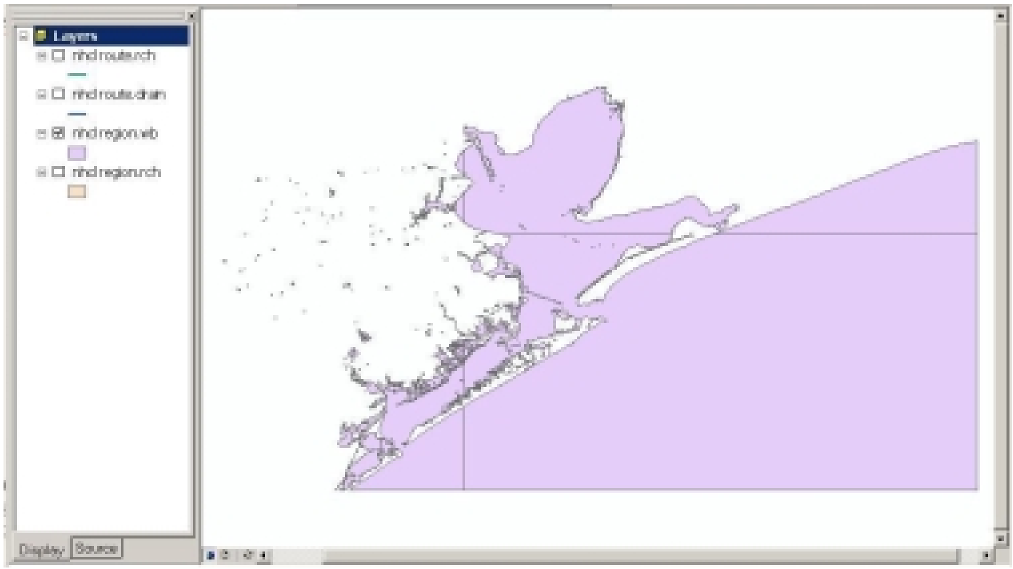
Look in: nhd

Name: region.rch; region.wb; route.drain; route.rch

Show of type: Datasets and Layers (*.lyr)

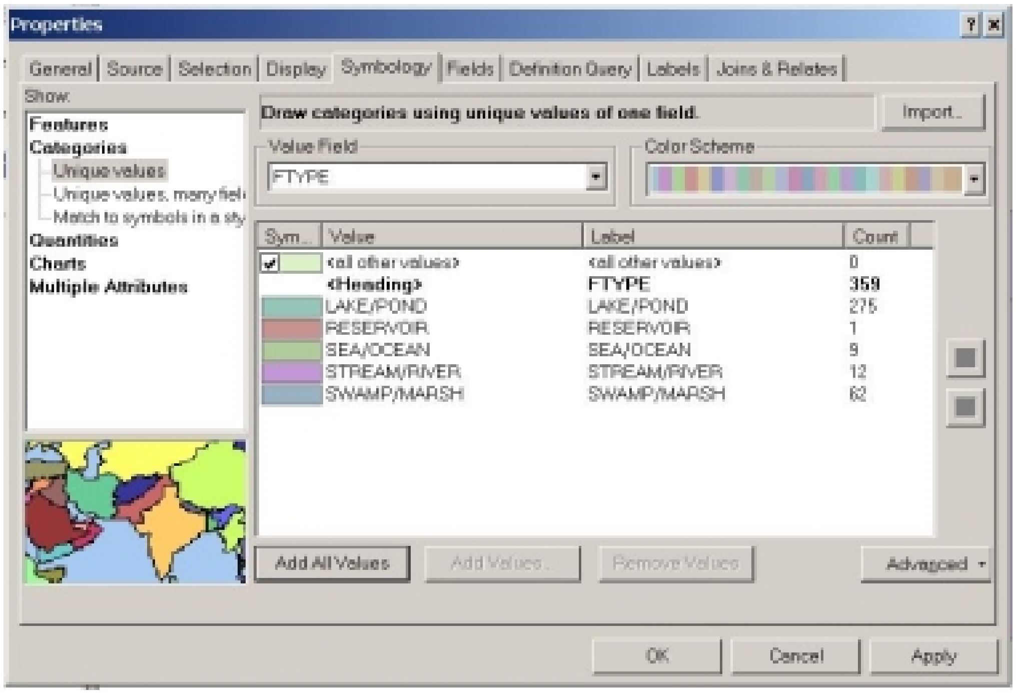
Waterbody Features

Now turn off (remove the check in the box) for all layers except **region.wb**. This theme contains the areal hydrographic features representing waterbodies. They are organized in "regions" (a group of polygons) because one waterbody may be composed of many polygons.



The region.wb layer depicts *waterbody features*. These can be of the following types (not all of which are present in this particular HUC unit): *Area of Complex Channels, 2-D Canal/Ditch, Estuary* (in the next release of NHD), *Ice Mass, Lake/Pond, Reservoir, Sea/Ocean, Swamp/Marsh, 2-D Stream/River, Playa* and *Wash*. To classify the feature types uniquely within the region.wb layer, doubleclick on the nhd region.wb data layer name, and go to the **Symbology** tab.

To symbolize each type of waterbody uniquely, click on **Categories** and highlight **Unique values**. From the **Value Field** dropdown menu, select **FTYPE**. Then click on **Add All Values**. This adds all the different values of Ftype present in this data layer to the legend and symbolizes them differently. For each feature class, the Ftype attribute describes what type of feature an element is. The Fcode attribute is a coded value for that type.

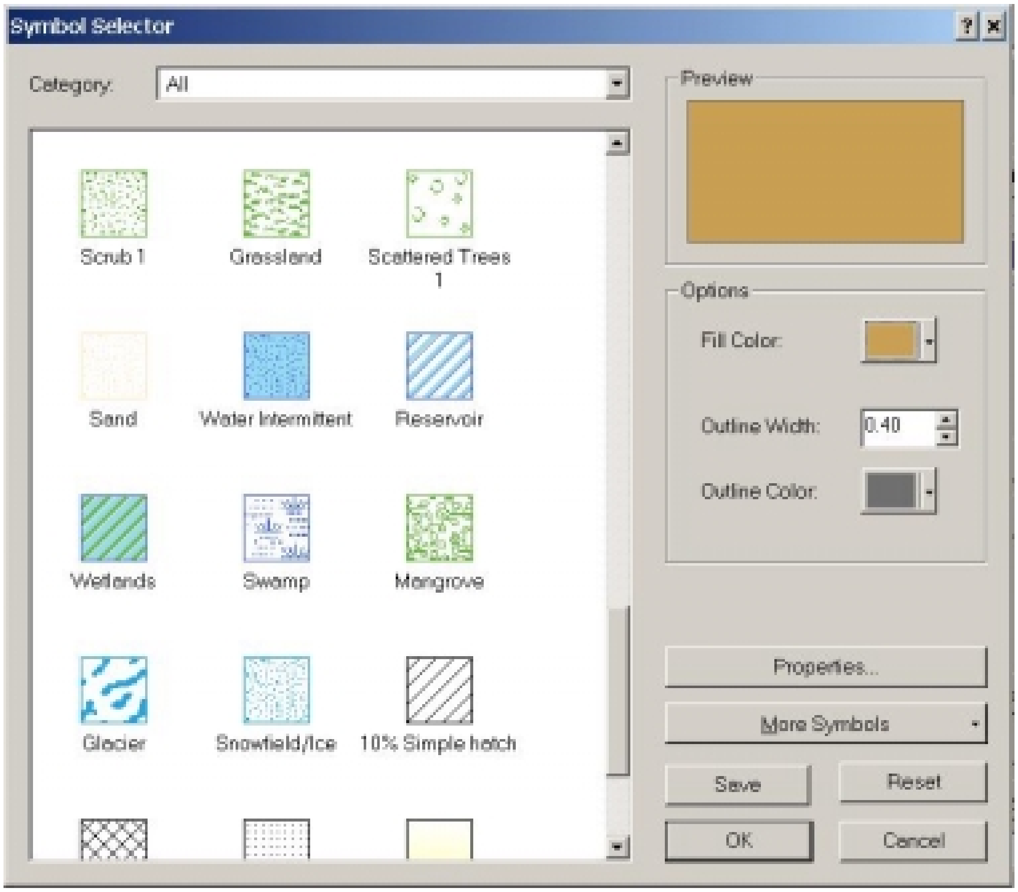


Draw categories using unique values of one field.

Value Field: FTYPE

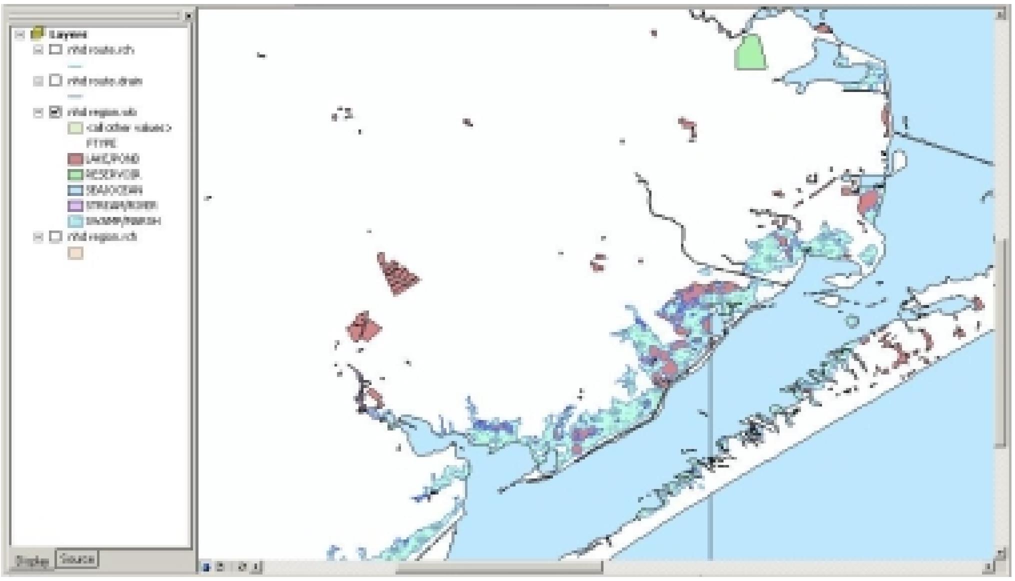
Sym...	Value	Label	Count
☑ ■	<all other values>	<all other values>	0
	<Heading>	**FTYPE**	**359**
■	LAKE/POND	LAKE/POND	275
■	RESERVOIR	RESERVOIR	1
■	SEA/OCEAN	SEA/OCEAN	9
■	STREAM/RIVER	STREAM/RIVER	12
■	SWAMP/MARSH	SWAMP/MARSH	62

Choose each type of waterbody to look differently. To change all of the Ftype legends at once, change the color ramp from the **Color Scheme** dropdown menu. You can change the individual types by clicking on the color box next to the type name. ArcMap has preset legend styles contained in the symbology options. These preset styles store different industry's standards of representing certain spatial data. These include waterbodies, transportation ways, signage, etc. Double click on the color box of **Swamp/Marsh**. Scroll down on the **Symbol Selector** window, and select **Swamp**.



To make the background color of the Swamp filled in and easier to see on the map, click on **Properties**. On the **Picture Fill** tab, change the background color to be a color as opposed to white. Leave the foreground color as blue, or change it as you would like. Click **OK** and click **OK** to close the **Symbol**

Selector window. Change any additional Waterbody types to look as you would like. Click **OK** and close the **Layer Properties** window. **Save your ArcMap project** using File/Save As in the Main ArcMap Menu bar.



Zoom in on various areas on the map to see the boundaries between lakes, swamps, oceans and streams.

In addition to the Ftype attribute, the region.wb data layer contains other descriptive information. **Right Click on the nhd region.wb** data layer and **Open the Attribute Table**. The fields of interest for the region.wb data layer are:

- FTYPE - the type of waterbody feature, in text form.
- FCODE - a numeric value coding the type and values of the characteristics of the waterbody feature. The first three digits describe the feature type,

the last two digits describe the characteristics associated with that feature type.

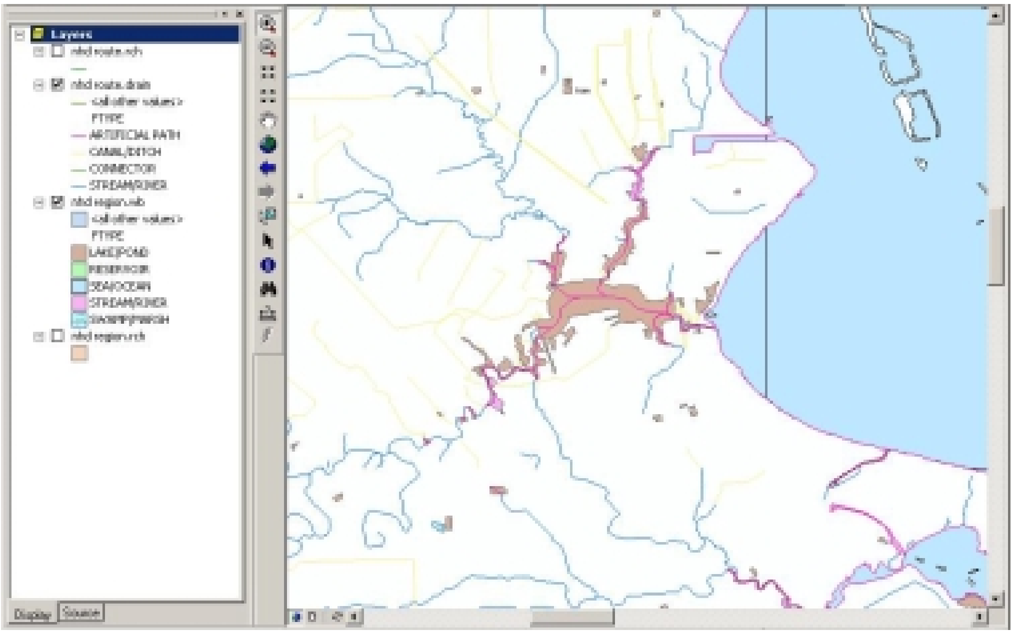
- ELEV - the elevation of the waterbody, in meters above the vertical datum. In the initial release, most of the elevations are not known, and therefore contain the value -9998 to indicate it is unspecified. A value of -9999 indicates the elevation attribute is not appropriate for this feature and is therefore not applicable.
- STAGE - the height of the water surface which is the basis for the elevation. The possible values of stage are: Average Water Elevation, Date of Photography, High Water Elevation, Normal Pool, or Spillway Elevation.
- SQ_KM - the area of the feature in square kilometers.
- GNIS_ID - the Geographic Names Information System (the Federal Government primary source for identifying official names) eight-digit identifier for the name of the entity.
- NAME - the text waterbody name according to the Georgraphic Names Information System.

Additional attributes are identifiers. One identifier common to all of the NHD region and route data layers is the COM_ID. This is a unique identifier given to each NHD feature or reach. In this data layer it is called the WB_COM_ID. The COM_ID, or common identifier is a 10 digit number which is distinct for each feature within all of the NHD. It is used as a reference to relate the various data layers as will be seen later in the exercise. An additional attribute, RCH_COM_ID, will be discussed later as well. Close the Attribute Table.

Drainage Network Element Features

Zoom out to the entire extent and turn on (place a check in the box next to) the **route.drain** theme. This layer encompasses the entire linear surface water drainage network. The feature types which can be represented in this layer are: *Stream/Rivers, Canal/Ditches, Pipelines, Artificial Paths* that run through the waterbodies described earlier, and *Connectors*. As described above, these linear features are grouped together as routes rather than simple lines because several lines may comprise one route. Symbolize all values uniquely based on Ftype, as you did in the previous section.

Observe the artificial paths which run through the waterbodies of the region.wb layer. Zoom in on the lake in the upper right corner of the basin.



Notice the artificial paths running through the lake/pond and 2-D stream/river features. Coastlines bordering the sea/ocean are also considered artificial paths. The artificial path immediately changes to a stream/river when it exits the waterbody. These artificial paths represent flow paths where there is realistically no actual channel. Using these artificial paths aids in performing network tasks which you do later in this exercise. Without the artificial paths and connectors, the network would have breaks at waterbody features.

Also notice the large number of canals and ditches compared with the number of natural streams in the area. Because this area is so flat and near the coast, the natural streams are insufficient to carry away storm water flow and a constructed drainage ditch and canal system exists to supplement the natural streams.

In addition to the Ftype attribute, the route.drain data layer also contains other descriptive information. Rightclick on the nhd route.drain data layer and Open Attribute Table. The fields of interest for the route.drain data layer are:

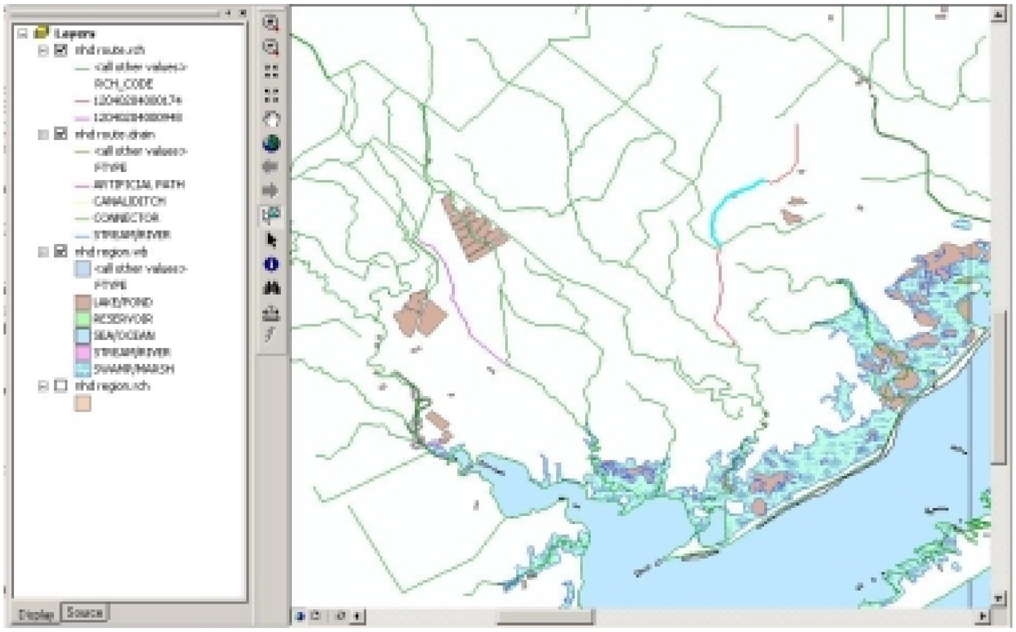
- COM_ID - the unique common identifier for each element.
- FTYPE - the type of waterbody feature, in text form.
- FCODE - the numeric value coding the type and values of the characteristics of the waterbody feature.
- METERS - the length of the feature in meters.
- WB_COM_ID - the unique identifier of the waterbody from the **region.wb** theme through which the artificial paths run. In the initial release of the NHD, this field is populated with -9998 for applicable routes and -9999 for routes that do not have a corresponding waterbody.

Reach Network Features

Now, zoom back out and turn on the **route.rch** layer. This is the linear drainage network as well, broken up into different pieces called *reaches*. A reach is a collection of surface water features with similar hydrologic characteristics. Reaches can be either pieces of stream/rivers, or portions of lake/ponds. There are three types of reaches: *transport, coastline,* and *waterbody*. The transport and coastline reaches are found in the **route.rch** data layer, while the waterbody reaches are found in region.rch data layer which will be studied next. A fourth type of reach, shoreline reach, has not be developed yet. Reaches are used as tools to geocode information about a linear or areal surface water feature because of their identifying attributes.

Transport reaches represent the path of water moving across the drainage network. Coastline reaches represent the coastline of the Atlantic, Pacific, or Artic Ocean, the Great Lakes, the Gulf of Mexico, or the Caribbean Sea. They are used to reference the location of the ocean in respect to the drainage network. Coastline reaches are only composed of artificial paths.

Now, let's look at how several features in the **route.drain** layer can comprise one element in the **route.rch** layer. Each reach element in route.rch is given a unique identifier, called the Reach Code. The Reach Code is a 14 digit number with two parts: the first eight digits are the Hydrologic Cataloging Unit code for the Unit in which the reach is located, and the second six digits are a unique number assigned to each reach arbitrarily. You will symbolize two of these reaches uniquely to look at their composition. Double-click on the **route.rch** layer, click on **Categories** and highlight **Unique values**. Change the **Value Field** dropdown menu to **RCH_CODE.** Click on **Add Values...** and click **Yes** to the warning about exceeding 50 unique values. Highlight reaches **12040204000174** and **12040204000948** by holding down the **Control** key to select the second choice. Click **OK**. Change these colors to something bright and noticeable. Zoom in to the area containing both these reaches (the bottom left of the screen).



Both of these reaches are composed of multiple drain feature elements. To see the grouping of network elements in one reach, go to the **Selection** menu and drag down to **Set Selectable Layers**, check nhd route.drain and uncheck the other layers. Using the **Select Features** button, click on one of the reaches. Notice how only a portion of the reach becomes highlighted. This is only one of the network elements that make up the one reach. Reach 12040204000174 is made up of three distinct features and reach 12040204000948 is made up of 2 different feature elements. The drain features composing each reach and that corresponding reach are linked together through the RCH_COM_ID in the

route.drain layer. In the route.drain layer, the RCH_COM_ID is the COM_ID identifier of the reach which the network element is part. Using the **Identify** tool, click on the selected portion of the reach. Swith back and forth on the left side menu in the **Identify Results** box between **nhd route.rch** (the name of the reach) and **route.drain** (the type of feature). Note that the COM_ID for Reach 12040201000174 is 1568586 and the RCH_COM_ID for all three drain features that comprise it is also 1568586.

Location: (-95.099549 29.309030)

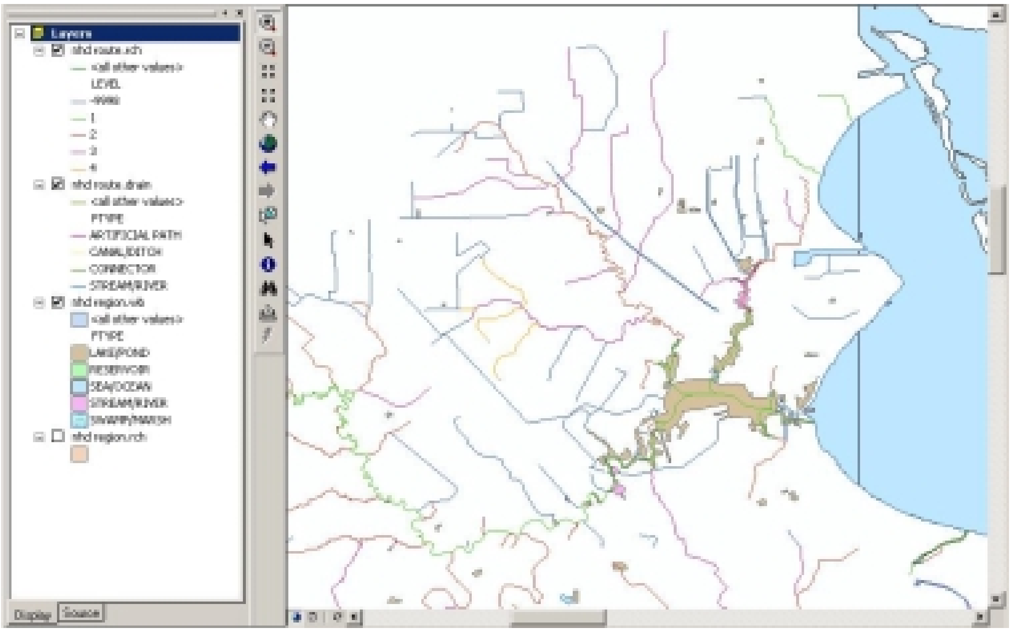
Property	Value
FID	1206
Shape	
DRAIN#	1206
DRAIN-ID	1210
COM_ID	1566314
RCH_COM_ID	1568586
WB_COM_ID	-9999
FTYPE	STREAM/RIVER
FCODE	46004

Location: (-95.099549 29.309030)

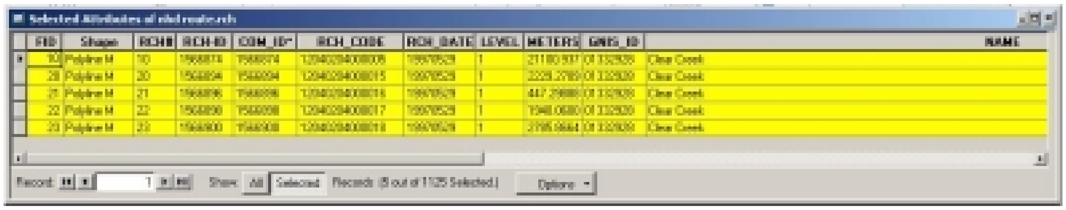
Property	Value
FID	860
Shape	
RCH#	860
RCH-ID	1568586
COM_ID	1568586
RCH_CODE	12040204000174
RCH_DATE	19970529
LEVEL	2
METERS	12104.790039

Another important attribute in **route.rch** is **Level**. The Level attribute characterizes the stream level of each reach. The level is determined by first identifying the endpoint or sink of the surface water drainage network, and working backwards by the flow relationships. The lowest level (one) is assigned to reaches which flow into the endpoint and to upstream transport reaches which trace the main flow of water back to the head of the stream. The level is then increased by one for reaches which terminate at the main flow path, i.e. reaches which are tributaries to the main flow path. This procedure continues to assign a level attribute to all reaches. If a reach has a level of -9998, the level for that reach is currently undefined. Either the reach is isolated and not connected to the network, or the level is not yet determined. Most of the canals in this area of of level -9998 since their complex nature does not allow a flow direction to be defined. Additionally, the coastline reaches are also -9998 level because they do not have a specified flow direction.

Go to the **Selection** menu and **Clear Selected Features**. Go to the **Symbology** tab of the **nhd route.rch Properties** and change the **Value Field** to **LEVEL**. Add all the values and choose a **Color Scheme** that displays the levels clearly and vibrantly. Zoom to **Full Extent** (the globe button on the **Tools** toolbar) and then again zoom into the area by the lake. Notice all four level values as well as the level value -9998. These Levels are not the same classification scheme for rivers that we examined in Exercise 4, where level 1 was most upstream, and the numbers increased going downstream. In the NHD classification scheme the numbers start low near the coast and increase going upstream.



Go to the **Selection** Menu and go to **Set Selectable Layers**. Change the selectable layer from **nhd route.drain** to **nhd route.rch**. Using the **Select Features** tool on the **Tools** toolbar, select the lines in the lake. Notice how all the line features within the lake are selected as a single reach. Because all these internal drain elements contain the same hydrologic characteristics, they are considered one reach. Select a few of the upstream level one segments flowing into the lake. Open the attribute table of **nhd route.rch** and click **Selected** for **Show ... Records**.


Selected Attributes of nhd route.rch

FID	Shape	RCH#	RCH-ID	COM_ID*	RCH_CODE	RCH_DATE	LEVEL	METERS	GNIS_ID	NAME
10	Polyline M	10	[illegible]	[illegible]	[illegible]	19970529	1	[illegible]	[illegible]	Clear Creek
20	Polyline M	20	[illegible]	[illegible]	[illegible]	19970529	1	[illegible]	[illegible]	Clear Creek
21	Polyline M	21	[illegible]	[illegible]	[illegible]	19970529	1	[illegible]	[illegible]	Clear Creek
22	Polyline M	22	[illegible]	[illegible]	[illegible]	19970529	1	[illegible]	[illegible]	Clear Creek
23	Polyline M	23	[illegible]	[illegible]	[illegible]	19970529	1	[illegible]	[illegible]	Clear Creek

Each of the selected streams has a level of one, which is the main flow path from the bordering bay. The **nhd route.rch** data layer also has the attributes of **GNIS_ID** and **NAME** as in the region.wb data layer. All of these reaches make up a part of Clear Creek, which is referenced by the GNIS as 01332928. An additional attribute of note of the route.rch layer is the **RCH_DATE**. This the date that the Reach Code (RCH_CODE) was first assigned. The additional attributes will be discussed later. Clear the selected features.

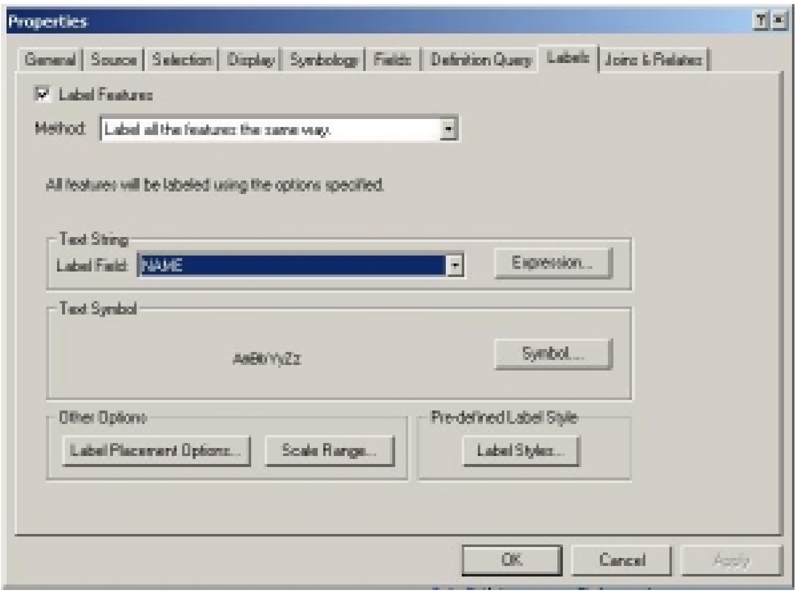
Waterbody Reach Network Features

The final layer you will look at is the waterbody reach data layer. Turn on the **nhd region.rch** layer, and highlight its name. Click and drag the data layer to above the region.wb data layer. These polygons are regions which represent waterbody reaches. These regions are composed of one or more regions found in region.wb. Just as transport and coastline reaches allow for information to be linked to the linear network features, waterbody reaches allow for information to be attached to areal features. In this first release of the NHD, waterbody reaches are only defined for lake/pond features in region.wb. For these lake/pond areas, it is possible for both a transport and waterbody reach to be defined; the transport reach represents the artificial path of flow through the lake while the waterbody reach describes the area.

Go to the **Symbology** tab of the **Properties** of region.rch and symbolize the data layer by RCH_CODE. Click on the minus sign next to the region.rch layer name in the Display Table of Contents to shorten the legend list. The attributes of nhd region.rch are:

- COM_ID - the unique common identifier for each element.
- RCH_CODE - the 14-digit code which identifies each reach.
- RCH_DATE - the date the Reach Code was assigned.
- SQ_KM - the area of the waterbody reach region in square kilometers.
- GNIS_ID - the GNIS identifier for the waterbody, if appropriate.
- NAME - the GNIS name of the waterbody, if appropriate.

It is possible to view those waterbodies that have names assigned by the Geographic Naming Information System. Right-click on the region.rch layer name. Go **Properties**, then go to the **Labels** tab. Change the dropdown **Label Field:** menu to **NAME**. Make sure the "Label Features" box is checked. Click **OK**.



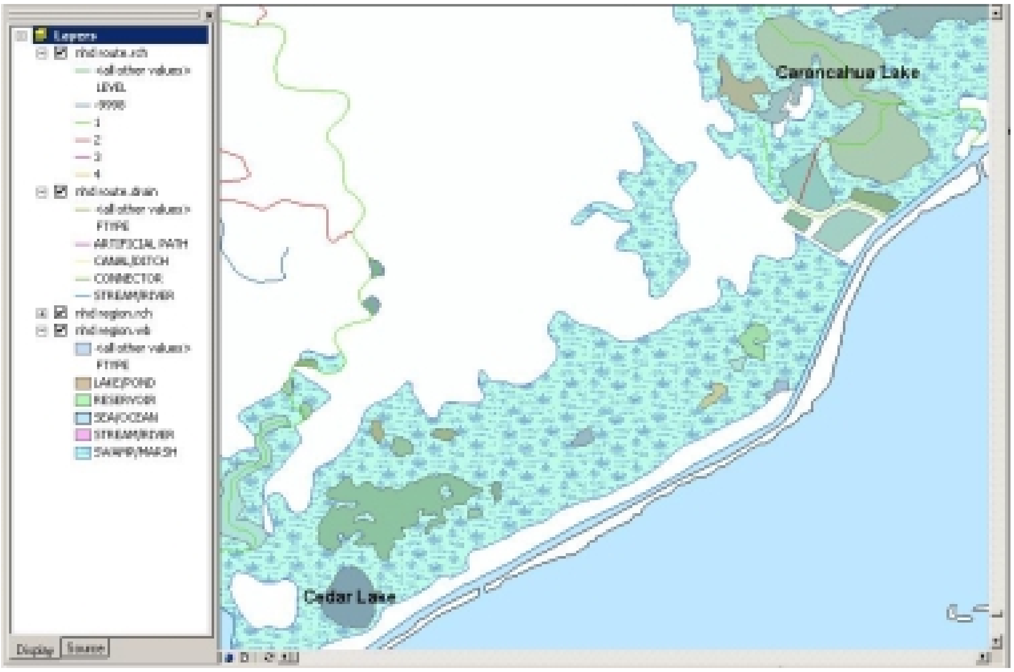
☑ Label Features

Method: Label all the features the same way.

All features will be labeled using the options specified.

Label Field: NAME

Right-click again on the region.rch data layer. Go to the Label Features option. Now all the waterbody reach regions that have names assigned by the Geographic Naming Information System are shown. Zoom in on Carancahua Lake and Cedar Lake. You can change the appearance of the labels from the **Labels** tab of the **Properties**, and make the text larger and darker. The relationship between the route.drain and route.rch data layers also exist between the region.wb and region.rch data layers through the RCH_COM_ID. Check the different attributes of COM_ID and RCH_COM_ID using the Identify tool for Caranchahua and Cedar Lakes.



Other National Hydrography Dataset Layers

In addition to the layers described above, the National Hydrography Dataset contains hydrographic features which do not necessarily play a role in the network. These features are known as *Landmarks* and are found in the NHD as route.lm and region.lm in the nhd coverage folder for lines and areas and as the nhdpt coverage for points.

The attributes of these landmark layers are shown in the table below. The attributes are all found in other data layers and their description can be found earlier in this exercise.

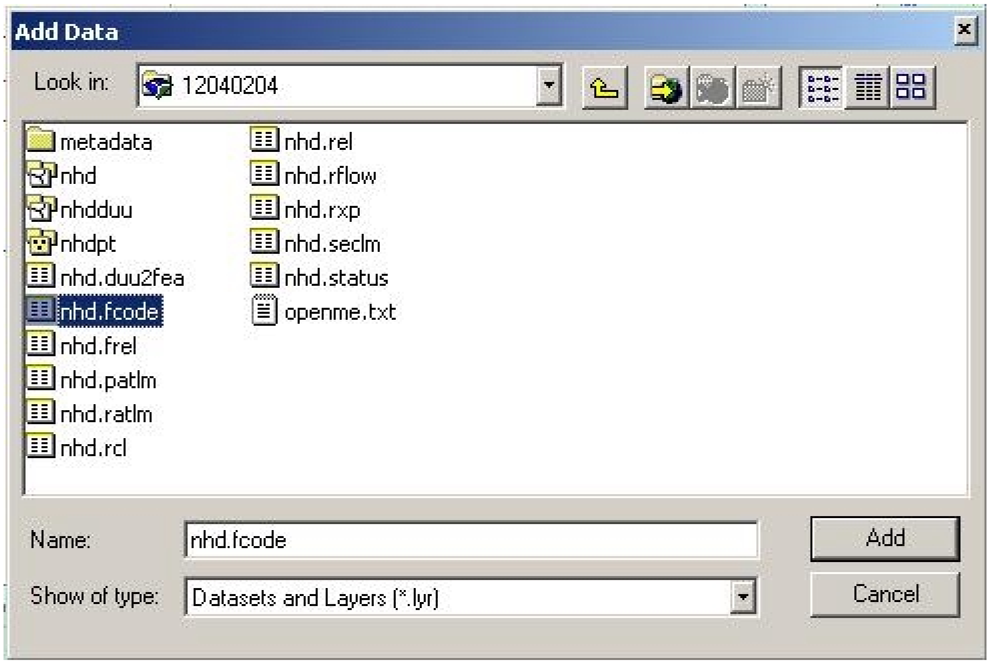
Region.lm	***Route.lm***	***Nhdpt***
COM_ID FTYPE FCODE ELEV STAGE SQ_KM GNIS_ID NAME	COM_ID FTYPE FCODE METERS GNIS_ID NAME	COM_ID FTYPE FCODE GNIS_ID NAME

For the FTYPE for each data layer, the options are diverse and encompass many types of hydrologic landmark feature. The types of feature for each data layer are listed below:

Region.lm	***Route.lm***	***Nhdpt***
Area to Be Submerged Bay/Inlet Bridge (2-D) Dam/Weir (2-D) Foreshore Hazard Zone Inundation Area Lock Chamber (2-D) Special Use Zone Submerged Stream Spillway Rapids (2-D)	Bridge (1-D) Dam/Weir (1-D) Gate (1-D) Lock Chamber (1-D) Nonearthen Shore Rapids (1-D) Reef Sounding Datum Line Special Use Zone Limit Tunnel Wall Waterfall (1-D)	Fumarole Gaging Station Gate (0-D) Geyser Lock Chamber (0-D) Mudpot Rapids (0-D) Rock Spring/Seep Waterfall (0-D) Well

Different features may be represented in multiple dimensions, such as Rapids, which can be present in all three data layers. Many of these types of features have multiple subtypes which is characterized in the FCODE attribute.

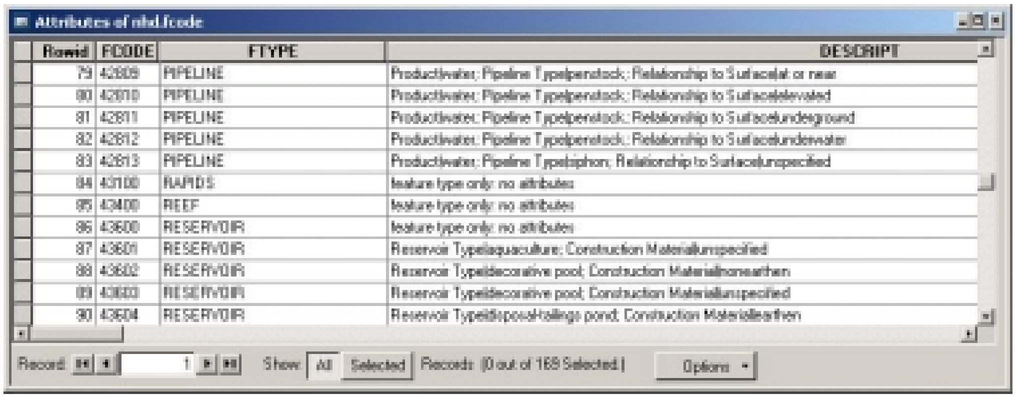
The first three digits of the FCODE indicate the feature type and the last two digits describe the distinct characteristics. To look at the different types of characteristics associated with each FTYPE and to determine the meaning of the FCODE, you will load a table that comes with the NHD data. Click on the Add Data button and navigate up to the root 12040204 folder and add **nhd.fcode**.



Name: nhd.fcode

Show of type: Datasets and Layers (*.lyr)

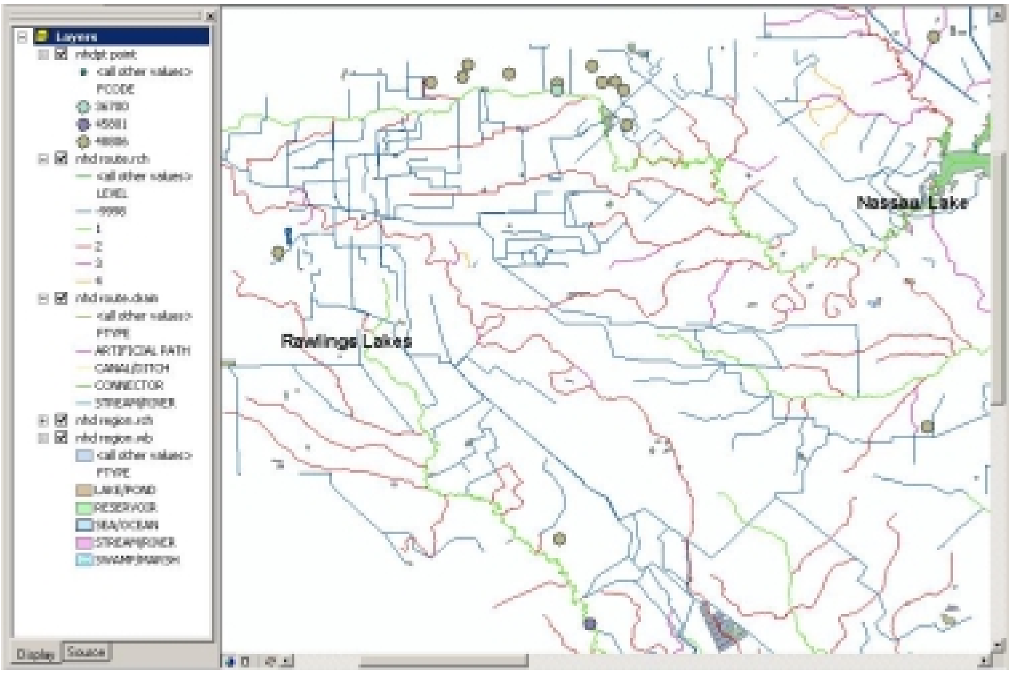
The Table of Contents should have switched to the **Source** tab with the table **nhd.fcode** at the bottom. Right-click on nhd.fcode and go to **Open**. The table lists the various FCODE values, the FTYPE text that accompanies that FCODE, and the description of the FCODE which highlights the differences between them. Notice how many different subtypes of each one feature type that exists.



Rowid	FCODE	FTYPE	DESCRIPT
79	42809	PIPELINE	Product|water; Pipeline Type|penstock; Relationship to Surface|at or near
80	42810	PIPELINE	Product|water; Pipeline Type|penstock; Relationship to Surface|elevated
81	42811	PIPELINE	Product|water; Pipeline Type|penstock; Relationship to Surface|underground
82	42812	PIPELINE	Product|water; Pipeline Type|penstock; Relationship to Surface|underwater
83	42813	PIPELINE	Product|water; Pipeline Type|siphon; Relationship to Surface|unspecified
84	43100	RAPIDS	feature type only: no attributes
85	43400	REEF	feature type only: no attributes
86	43600	RESERVOIR	feature type only: no attributes
87	43601	RESERVOIR	Reservoir Type|aquaculture; Construction Material|unspecified
88	43602	RESERVOIR	Reservoir Type|decorative pool; Construction Material|nonearthen
89	43603	RESERVOIR	Reservoir Type|decorative pool; Construction Material|unspecified
90	43604	RESERVOIR	Reservoir Type|disposal-tailings pond; Construction Material|earthen

Record: 1 Show: All Selected Records (0 out of 169 Selected.)

There are no linear or areal landmark features for the area studied in this exercise. However, there are landmark points. Add the data layer **nhdpt** from the folder 12040204. Right-click on the **nhdpt point** data layer and **Zoom to Layer**. Symbolize the nhdpt layer uniquely based on FCODE. Look up what each FCODE means in the nhd.fcode table to determine what each type of point is.



You have now thoroughly inspected the feature data from the National Hydrography Dataset. Save this map and exit ArcMap. Additional information about the NHD can be found at http://nhd.usgs.gov/techref.html in the documents:

- *NHDinARC Quickstart*
- *Concepts and Contents*
- *Introducing the NHDinARC*

APPENDIX C: PROJECTION FILE

The following file is the projection file *GEO2ALBERS.TXT*, referred to in Chapter 4. This projection file is for use in the Arc Workstation module of ArcInfo. The input file is in geographic coordinates and the output file is in Texas Centric Mapping System (TCMS) Albers projection.

GEO2ALBERS.TXT

```
input
projection geographic
datum NAD83
spheroid GRS1980
units dd
parameters
output
projection albers
datum NAD83
spheroid GRS1980
units meters
parameters
27 30 0
35 0 0
-100 0 0
18 0 0
1500000
6000000
end
```

APPENDIX D: DATA PARTITIONING TOOLS

Developing the geospatial databases for the individual watersheds, described in Section 4.7, required a massive effort: separating 54 large data layers into 55 smaller components, with each component corresponding to a watershed. This “cookie-cutter” process was made more efficient and less time consuming with the use of an ArcView script, *ExportDataQuery* written by Tim Whiteaker, and an AML, *ClipGrids.* The text for these two programs are included here.

EXPORTDATAQUERY SCRIPT

```
'-----------------------------------------------------------------
-----------
'Name:  ExportDataQuery
'
'This script finds all unique values for a query field, and then
'for each value, exports the records from the theme that have
'that value to a shapefile in a directory below the working
'directory.  The subdirectory must already be created and must
'have a name equal to the value in the query field.  The name of
'each produced shapefile is a generic name specified by the user
'input.
'
'User inputs:  Query field
'              Generic output filename
'
'Produces:  A series of shapefiles based on querying unique
'values in a field
'
'Requirements:  There must be an active theme in the view
'               Subdirectories with names corresponding to each
'                 value in the query field
'               The working directory must be set
'
'Author:  Tim Whiteaker - 3/2/2001
'-----------------------------------------------------------------
-----------




'-------------------------
'----Determine inputs-----
'-------------------------

theproject=av.getproject
theview=av.getactivedoc

if (theView.GetActiveThemes.Count = 0) then
   msgbox.error("No Theme Selected", Script.The.GetName)
   exit
end

'---------------------------
'---Set working directory---
```

```
'---------------------------

theWorkDir = theproject.GetWorkDir
theWorkDir.SetCWD


'------------------------------
'---Get pointers to the data---
'------------------------------

'Get the active theme
thmThemeIn = theview.GetActiveThemes.Get(0)

'Get FTab for active theme
inFTab=thmThemeIn.GetFTab

'Get fields for active theme
inFldLst = inFTab.getfields

'Get gridcode field
inFieldList = inFTab.getfields
gField=msgbox.choice(inFieldList,"Identify query field","Query
Field")
'gField = inFTab.FindField("gridcode")
'exit if no field selected
if (gField=nil) then
    msgbox.info("No field selected.  Exiting.","")
    inFTab.DeActivate
    inFTab = nil
    exit
end

'Create output generic filename
nameStr = MsgBox.Input("Enter generic filename for output
files","Input Filename","")
'nameStr = "test"

'-------------------------------------
'---Get unique values for gridcode---
'-------------------------------------

'Create the list of unique values
uniqueList = List.Make
for each record in inFTab
    if (inFTab.ReturnValue(gField, record) > 0) then
        uniqueList.Add(inFTab.ReturnValueString(gField, record))
    end
end
'Remove duplicates
```

```
if (uniqueList.Count > 0) then
    uniqueList.RemoveDuplicates
else
    msgbox.info("No values found in field.  Exiting.","")
    exit
end


'-------------------------------------
'---Create shapefile for each record---
'-------------------------------------

for each gridcode in uniqueList

    '-----------------------------------------
    '---Select based on gridcode attribute---
    '-----------------------------------------

    'Create bitmap to hold selection
    myBitmap=inFtab.GetSelection
    myBitmap.ClearAll

    'Create the query
    q1 = "(["+gField.asstring+"] = "+gridcode.asstring+")"
    inFTab.Query(q1, myBitmap, #VTAB_SELTYPE_NEW)


    '-----------------------------
    '---Create output filename---
    '-----------------------------
    outName =
theWorkDir.asstring+"\"+gridcode.asstring+"\"+nameStr
    outFName = outName.AsFileName

    if (inFTab.GetNumSelRecords > 0) then

        '-----------------------
        '---Save selected set---
        '-----------------------

        inFTab.ExportClean(outFName,True)

        '-------------------------------
        '---Add the theme to the View---
        '-------------------------------

        ' Create the SourceName
        theSrc = SrcName.Make(outFName.asstring+".shp")
```

```
        ' Use the SourceName to make a theme
        aTheme = Theme.Make(theSrc)

        ' Add the theme to the view
        theview.AddTheme(aTheme)

        ' Set a new name for the theme
        aTheme.SetName(nameStr+"_"+gridcode.asstring)

    end
end 'for each gridcode in uniqueList

'Cleanup
inFTab = nil
av.PurgeObjects
```

CLIPGRIDS.AML

```
w s:\watershed_data\1101
shapearc wsh_gen wsh_gen
build wsh_gen poly
grid
gridclip s:\basingroupc\fill_ dem fill_dem cover wsh_gen
gridclip s:\basingroupc\fdr fdr cover wsh_gen
gridclip s:\basingroupc\fac fac cover wsh_gen
gridclip s:\basingroupc\landuse landuse cover wsh_gen
q
/*
w s:\watershed_data\1102
shapearc wsh_gen wsh_gen
build wsh_gen poly
grid
gridclip s:\basingroupc\fill_ dem fill_dem cover wsh_gen
gridclip s:\basingroupc\fdr fdr cover wsh_gen
gridclip s:\basingroupc\fac fac cover wsh_gen
gridclip s:\basingroupc\landuse landuse cover wsh_gen
q
/*
w s:\watershed_data\1103
shapearc wsh_gen wsh_gen
build wsh_gen poly
grid
gridclip s:\basingroupc\fill_ dem fill_dem cover wsh_gen
gridclip s:\basingroupc\fdr fdr cover wsh_gen
gridclip s:\basingroupc\fac fac cover wsh_gen
gridclip s:\basingroupc\landuse landuse cover wsh_gen
q
/*
w s:\watershed_data\1104
shapearc wsh_gen wsh_gen
build wsh_gen poly
grid
gridclip s:\basingroupc\fill_ dem fill_dem cover wsh_gen
gridclip s:\basingroupc\fdr fdr cover wsh_gen
gridclip s:\basingroupc\fac fac cover wsh_gen
gridclip s:\basingroupc\landuse landuse cover wsh_gen
q
/*
/*Continue for each watershed gridcode
&return
```

APPENDIX E: DATA DICTIONARY

Chapter 4 describes the procedures undertaken for this watershed delineation effort. Many file names are referenced in capitalized italic font. This data dictionary presents a quick reference as to what each data layer refers to and where the initial reference to the data layer is located.

File Name	**Data Description**	**Type**	**Section**
BASINGRPC	shapefile of study area	polygon	4.5.1
BUFFER	*BASINGRPC* area buffered by 10 kilometers	polygon	4.5.1
BURN_DEM	DEM with the stream network for the *BUFFER* area “burned in”	grid	4.5.4
CLIPDEM	*DEM_ALB*, clipped to the extent of *BUFFER*	grid	4.5.1
DEM_ALB	*DEM_GEO*, projected to TCMS Albers	grid	4.5.1
DEM_CON	*CLIPDEM* conditioned for any cell with a negative value to be replaced with zero	grid	4.5.2
DEM_GEO	Merged DEM from tiles *DEM9530, DEM9531, DEM9630, DEM9631* in geographic coordinates	grid	4.5.1
DEM9530	DEM of the 7.5 minute tile with upper left coordinate (-95,30)	grid	4.5.1
DEM9531	DEM of the 7.5 minute tile with upper left coordinate (-95,31)	grid	4.5.1
DEM9630	DEM of the 7.5 minute tile with upper left coordinate (-96,30)	grid	4.5.1
DEM9631	DEM of the 7.5 minute tile with upper left coordinate (-96, 31)	grid	4.5.1
FAC	flow accumulation grid calculated from *FDR*	grid	4.5.4
FDR	flow direction grid calculated from *BURN_DEM*	grid	4.5.4
FILL_DEM	*BURN_DEM* with sinks in landscape “filled in”	grid	4.5.4
FINAL_WSH	Island watersheds *ISLAND_WSH* and smoothed watersheds *SMOOTH_WSH* merged together	polygon	4.5.5
FORMAT_DEM	Grid of same extent as *GRIDCALC2* with NODATA values where the *SEAOCEAN* is located and the original elevation value everywhere else	grid	4.5.3

GEO2ALBERS.TXT	projection file to convert from geographic coordinates to TCMS Albers	text	4.5.1
GRIDCALC1	grid of same extent as *SEAGRID* with zeroes where the *SEAOCEAN* is located and ones everywhere else	grid	4.5.3
GRIDCALC2	grid of same extent as *GRIDCALC1* with NODATA values where the *SEAOCEAN* is located and ones everywhere else	grid	4.5.3
ISLAND	island polygons selected from the cleaned *SEAOCEAN* polygons	polygon	4.5.5
ISLAND_WSH	*ISLAND* polygon watersheds	polygon	4.5.5
NETWORK	Edited hydrography network, derived from the NHD	line	4.2.2
NETWORK_CL	*NETWORK* cleaned in ArcInfo Workstation for correct topology	line	4.2.2
OUTLETGRID	outlet cells for watershed delineation	grid	4.4
POLYSEG_GRID	TNRCC designated segment polygons converted to grid	grid	4.4
REACHSEG_GRID	TNRCC designated stream segments converted to grid	grid	4.4
SEAGRID	*SEAOCEAN*, converted to a grid with zero values where the sea/ocean polygons are located	grid	4.5.3
SEAOCEAN	sea/ocean polygons selected from the NHD region.wb for the area	polygon	4.5.3
SMOOTH_WSH	polygon watersheds (*WSH_POLY)* with smooth edges along the coast	polygon	4.5.5
WSH_DIS	final watersheds *FINAL_WSH* dissolved resulting in one polygon for each gridcode	polygon	4.5.5
WSH_GEN	*WSH_DIS* with softened, generalized boundaries	polygon	4.6
WSH_GRID	watersheds in grid format, calculated from *FDR* and *OUTLETGRID*	grid	4.5.4
WSH_POLY	watersheds in polygon format, converted from *WSH_GRID*	polygon	4.5.5

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