GEOGRAPHY & WATER:

BLANCO WATERSHED CHARACTERIZATION AND MODELING PROJECT, CFDA# 66-202

Part II Report 1: Blanco-San Marcos Watershed Modeling: Land Use & Land Cover Change and Its Impact on Streamflow and Non-Point Source Pollution

Final Report

PI: Andrew Sansom
Co-PI: Yongxia Xia
GIS and Database Specialist: Michael Clary
Remote Sensing and Land Use Modeling Specialist: Laura Parchman
Project Coordinators: Meredith Blount, Emily Warren
December 2010

Project Summary

The Blanco River headwaters originate in Kendall County, Texas and flow through Blanco and Hays Counties to the river's mouth at the confluence of the San Marcos River just southeast of the City of San Marcos. The joined river continues southeast, passing the City of Luling before it converges with the Guadalupe River and along its path is fed by numerous springs and seeps. Encompassed in the Guadalupe River basin, the Blanco River has a drainage area of over 1036 km^2.

The watershed ranks among the top five fastest growing populations in the United States. It is predicted that the population in the region will more than double in size by the year 2050. Population growth and urbanization have great impacts on the environment, transportation, and metropolitan infrastructure. Growth pressures from expanding population and development may also have significant impacts on the flow and quality of the river in the future.

Given this rapid economic development and urban expansion, it is imperative to characterize the land cover change in the region as it has been historically experienced. Recording, modeling and predicting the land use and land cover changes within the watershed is a primary step to understanding relationships between the land use and land cover (LULC) changes and related impacts on the watershed ecosystem within short-term and long-term timeframes. An assessment conducted in both spatial and temporal domains will provide an increased understanding of the relationships between LULC changes and consequent hydrological system impacts.

There were three research objectives associated with this project:

1) Characterize historic and current LULC attributes and dynamics in the Blanco River basin

2) Develop a simulation model of land use changes in the river basin, identify driving forces that are behind the land use change, and predict LULC changes using the simulation model for the years of 2025 and 2050

3) Simulate stream flow and non-point source pollution consequence scenarios based on current and future LULC change

This project utilized two Landsat 5 Images, October 1987 and October 2004, which were classified in a seven stage process to show land use and land cover for the study area. As expected, the two classes that showed significant increase were urban areas and grass/shrub. The two classes that decreased during this period were tree cover and agricultural land use.

The land use and land cover maps generated were then used to predict what the land use and land cover might be in the future. Maps were generated to determine the potential for particular land cover types to be converted to other types or land uses. As expected, all the land cover transactions from other land cover types to urban and urban land will likely happen around existing urban areas and along interstate highway I-35.

This project used Hydrological Simulation Program in Fortran (HSPF) to simulate watershed streamflow and non-point source pollutant loading. Two preliminary testing scenarios were performed to identify the impact of land cover change on the watershed in those twenty years using a selected sub-watershed simulation. The characterization process established an acceptable methodology for future applications and illuminated several important considerations. Although model simulation results provide some insight to hydrologic impacts of land cover change in the Blanco-San Marcos Basin, the initial results were not as expected. Overall, model outputs for varying years of land cover did not show significant changes on streamflow, runoff and zone storage. It appears that mean calibration of the model sacrificed resolution at the basin-wide scale. Additional modification to the models will allow for its inclusion in the San Marcos River Observation System and will be useful tool in long term watershed protection planning and management.

Table of Contents

List of Figures

List of Tables

1. Project Background

1.1 Blanco –San Marcos River Watershed

The Blanco River headwaters originate in Kendall County, Texas and flow through Blanco and Hays Counties to the river's mouth at the confluence of the San Marcos River just southeast of the City of San Marcos. The joined river runs southeast passing the City of Luling before it converges with the Guadalupe River and along its path, is fed by numerous springs and seeps.

The entire watershed is part of the Guadalupe River watershed with the HUC ID of 12100203 and includes parts of nine counties in Central Texas: Travis, Gillespie, Blanco, Hays, Kendall, Caldwell, Comal, Guadalupe and Gonzales. This area's population is among the fastest growing in the United States.

Human activities alter the environment of a river basin through land use choices such as road building and urban sprawl. Land use and land cover (LULC) change reflect the interaction between natural and human systems. To better understand the complexity that arises from the interaction of the two systems and their interrelationships, this project conducted an assessment of changes over the past twenty years on the Blanco River basin in Texas. A land use change, stream flow, and a non-point source pollution simulation model was also developed for the Blanco River watershed. The outcome of the land use change modeling will provide temporal and predictive information on urban growth and historical land use patterns in the area that can be used as inputs for a hydrological impact simulation model.

Land use and land cover in the watershed are becoming increasingly punctuated with areas of urban concentration. In 2002, the population density in Blanco County was 12 persons per square mile and in Hays County, about 144 persons per square mile (United States Census Bureau, 2002). The population has increased by 41% in Blanco County and 49% in Hays County between 1990 and 2000. Specific population growth, density and related demographic data are given in Section II of this report. Major communities in the watershed include Blanco, Wimberley, Luling, Lockhart and Kyle. The total population in these communities increased from 48,475 in 1990 to 62,044 in 2000. Kyle is currently one of the fastest growing cities in Texas having grown from 5,314 recorded residents in the 2000 US Census to over 28,000 in 2009. The growth rate within the watershed is an average 21.87% (United States Census Bureau 2010). San Marcos is at the center of the Austin-San Antonio metropolitan area along the IH-35 corridor. The fastest growing communities are Wimberley and Kyle with average annual growth rates of 3.68% and 5.81% respectively (2000-2010). The expanding population and related development have, and will continue to affect land use patterns. The continued growth and urbanization will also have great impact on the watershed function, especially with regard to non-point source pollution.

Given the continuing economic development and urban expansion, it is imperative to characterize the land cover changes in the region as they have occurred in recent history. Recording, modeling and predicting the land use and land cover changes within the watershed is a primary step to understanding relationships between the land use and land cover changes and their related impacts on water quality and quantity for both short-term and long-term timeframes. An assessment conducted in both spatial and temporal domains will provide an increased understanding of the relationships between LULC changes and consequent hydrological system impacts.

1.2 Objectives of the Blanco-San Marcos Watershed Modeling Study

The three main research objectives associated with this project were to:

1. Characterize historic and current land use and land cover attributes and dynamics in the watershed in the form of a decision support system that will auto-generate reports for selected drainages.
2. Classify satellite images to show land use/land cover and identify changes in the river basin seeking to identify driving forces that are behind the land use change, and predict future land use and land cover using a neural network based model for the years 2020 and 2050.
3. Provide input for the stream flow and non-point source pollution modeling process.

The initial proposed study area included the Blanco River watershed and was then expanded to encompass the entire San Marcos watershed. As a result, the research area increased threefold from the initial 277,950.1 acres to the current 864,439.97 acres. The number of sub-drainages changed from 3 to 11 (Figure 1).

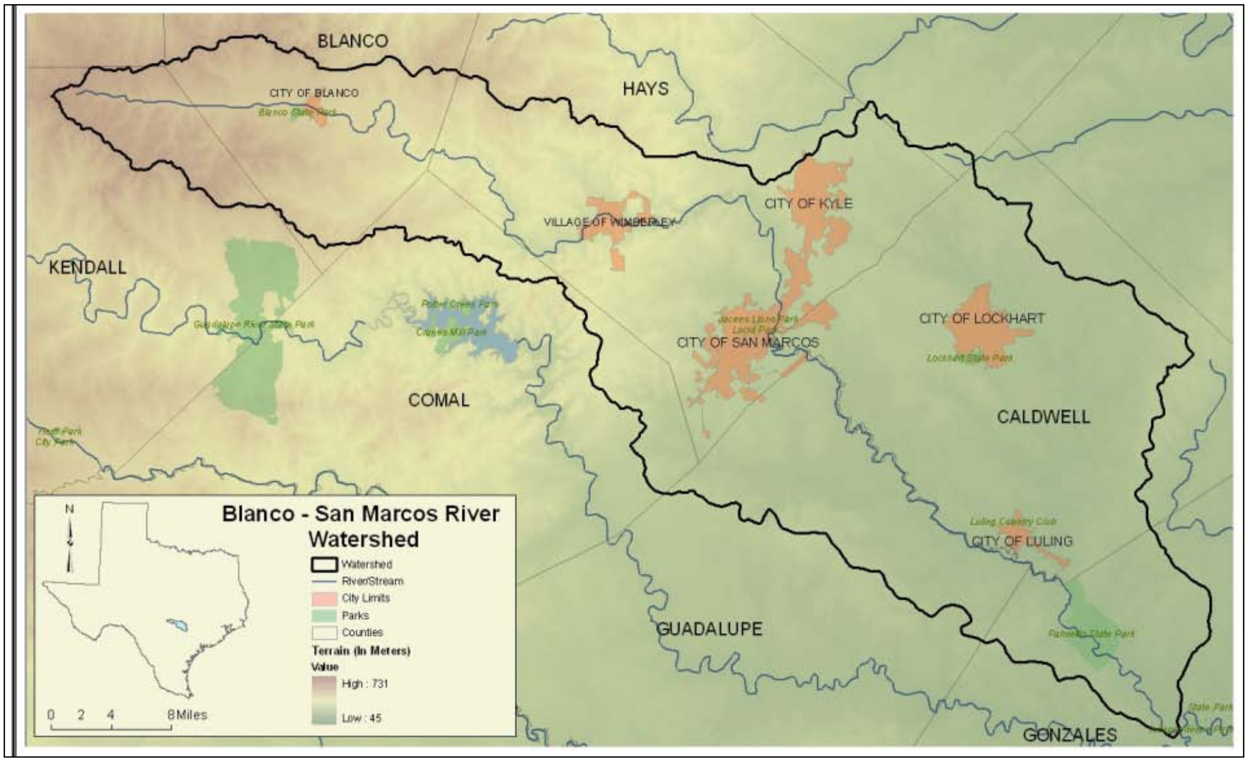

Figure 1 Initial Proposed Study Area and the Current Study Area.

The ultimate goal for this research project was to provide scientific information that regional resource management planners in the area can use to optimize the use of the land to ensure that an ecologically sustainable water supply is maintained. This report summarizes the data input into the watershed characterization tool and provides examples of the types of output generated by the tool.

1.3 Watershed Delineation

The Blanco-San Marcos River Watershed was first delineated into eleven sub-watersheds. The threshold of this delineation is 50 square miles (mi^2). Figure 2 delineates the sub-watersheds, and Table 1 lists and describes the major water uses for each sub-watershed. All subsequent activities and analyses are based on these eleven sub-watersheds.

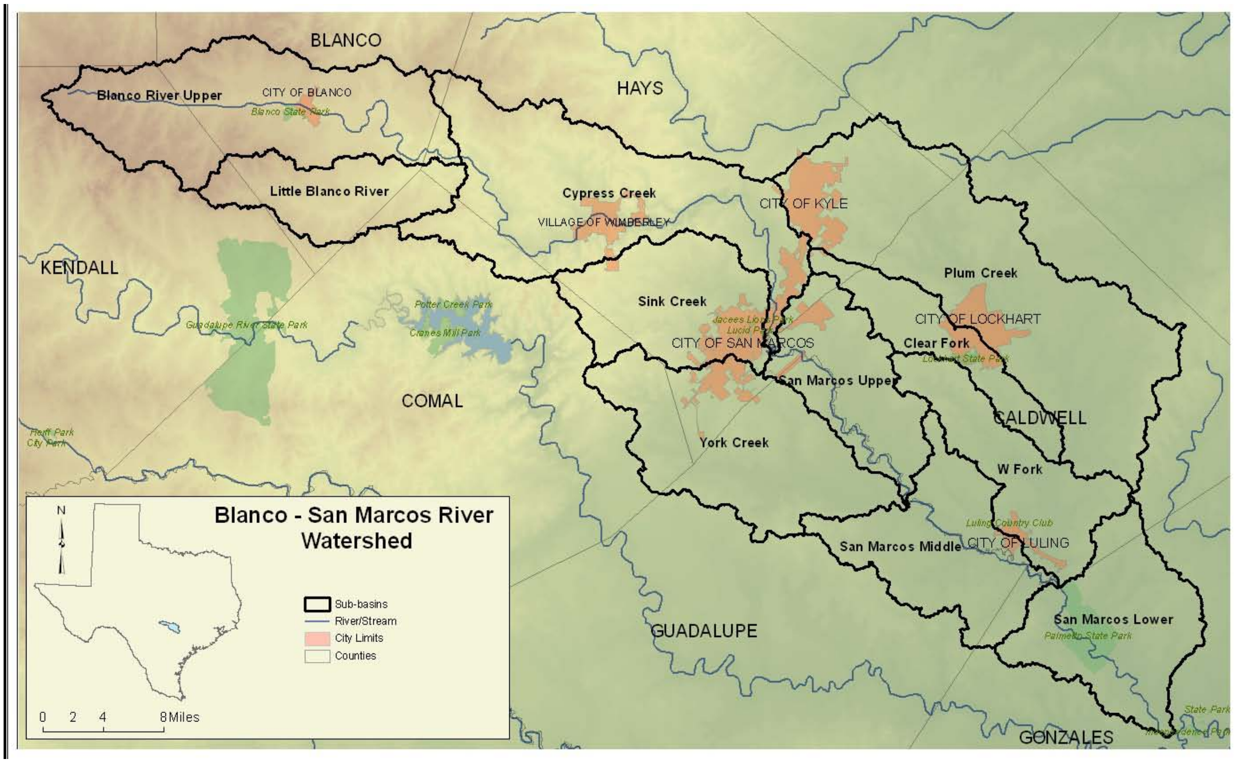

Figure 2 Sub-watersheds Delineated for Study.

Table 1 Sub-Watersheds in the Blanco-San Marcos Watershed.

Drainage Name	Area (acres)	Area (mi^2)	Description
Upper Blanco River	107,356.66	167.74	This drainage contains the city of Blanco and has a state recreation area along the Blanco River. Dinosaur tracks can be found in the dry river banks. Uses: aquatic life, contact recreation, fish consumption and public water supply.
Cypress Creek	126,925.48	198.32	This drainage contains the city of Wimberley and the city of Wood Creek. There are spring-fed recreation spots such as Blue Hole and Jacob's Well. Uses: aquatic life, contact recreation, fish consumption and public water supply.
Plum Creek	159,660.34	249.46	This drainage contains the cities of Kyle, Lockhart, Niederwald and Uhland. Recreation includes the Lockhart City Park and the Caldwell County Fair Grounds. Uses: aquatic life, contact recreation, and fish consumption.

Little Blanco River	43,667.96	68.23	This sub-watershed is in the northwestern portion of the basin in a relatively unpopulated area south of the Blanco River, joining the Blanco upstream from the Cypress Creek confluence.
Sink Creek	60,425.25	94.41	This sub-watershed contains a large portion of San Marcos. There are many spots along the river for recreation. Texas State University is also within this drainage.
Clear Fork	34,780.69	54.34	This narrow sub-watershed is located north of the Upper San Marcos between Plum Creek and West Fork Creek with drainage in the Cities of Lockhart and Uhland.
Upper San Marcos River	51,905.70	81.1	This sub-watershed includes portions the City of San Marcos. This sub-watershed includes the confluence of the Blanco River into the San Marcos River. There are many spots along the river for recreation.
Middle San Marcos River	66,941.57	104.59	This sub-watershed contains portions of Luling. There are many spots along the river for recreation.
Lower San Marcos	68,511.26	107.04	This sub-watershed is located at the southernmost portion of the watershed near the San Marcos River's mouth/confluence with the Guadalupe River.
York Creek	91,016.45	142.21	This sub-watershed is located southwest of the Upper San Marcos Reach and includes San Marcos area development.
West Fork	53,248.61	83.2	This drainage includes much of the City of Luling.
Total	**864,439.97**	**1,350.64**	

2. Blanco Watershed Characterization Tool

This section describes the report auto-generated by the Watershed Characterization Tool. Approximately six months of effort were devoted to the development and modification of the Watershed Characterization Tool for the study area. Utah State University's WRIA- Decision Support System (DSS) provided the framework for the development of this tool (Utah State University, 2008). The WRIA- DSS includes three large models- surface water quality, surface water quantity, and instream flow/fish habitat, in addition to other functions. The result is a simulation model with a user-interface that can analyze water quality and quantity data, display data, and create scenarios. However, since the WRIA-DSS was developed for watersheds in Washington State, most of the code was rewritten to fit the geographic focus of this project. Annual climate change, annual stream flow change, impervious land cover, and well maps are examples of data and information added to the original watershed characterization tool. Graphics and tables were generated at the sub-watershed level, and data were assembled from various sources. Figure 3 shows the interface of this tool.

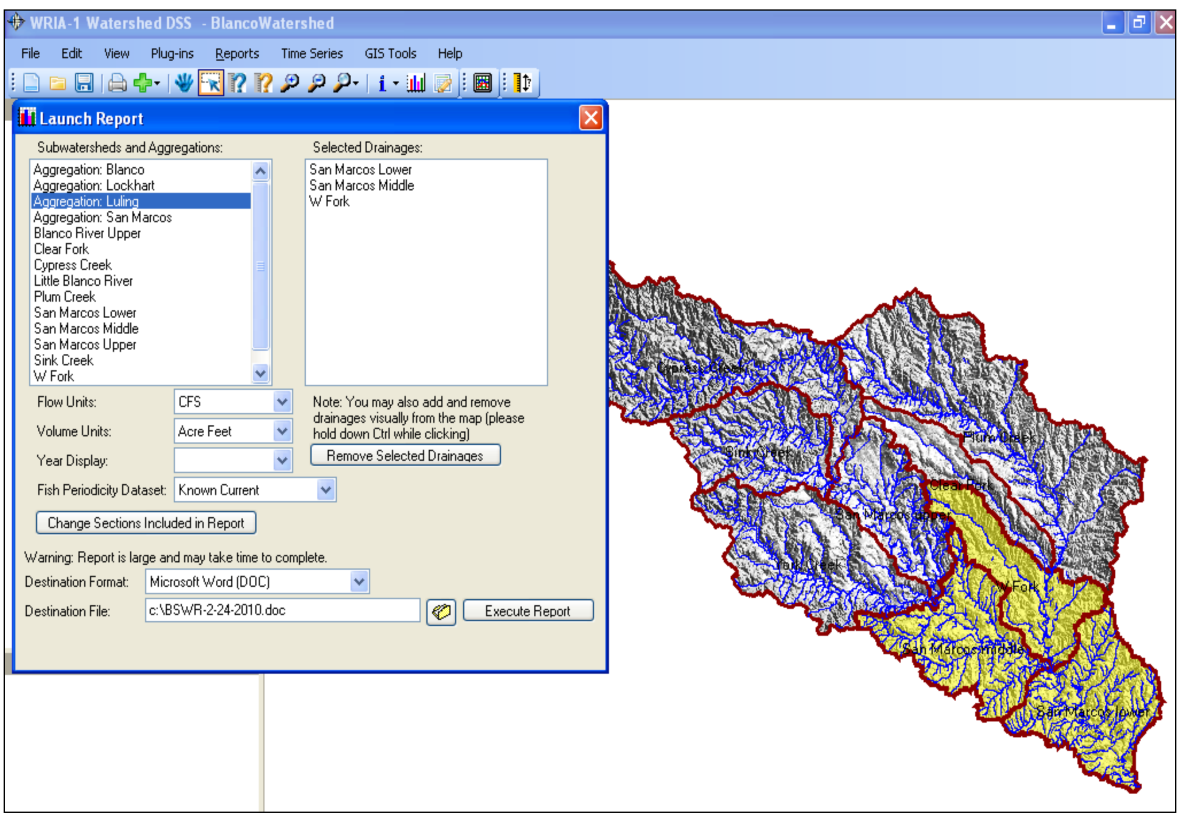

Figure 3 Blanco-San Marcos Watershed Characterization Tool Interface Example.

Since it is impossible to show all of the data that were used as inputs to the Blanco Watershed Characterization Tool, this section provides overview of the data that were used as inputs for the tool. It also includes several examples of detailed data at the sub-watershed level used in the Tool. It also includes outputs and examples of analyses that water resources managers can conduct with the Tool.

2.1. Social Economic Conditions Output Examples

This section provides overview of the total population, population category and economic activities of the study area that were used as inputs for the tool. It also includes several examples of detailed data at the sub-watershed level used in the tool.

The Blanco watershed has witnessed some of the fastest economic growth in the country with an average annual growth rate of at least 2.68%. The city population data listed below in Table 2 are from the 1990 US Census (TSLAC 2010).

Table 2 City Population from 1990 Census.

City Name	Total Population
Blanco	1238
San Marcos	28743
Wimberley	2403
Luling	4661
Lockhart	9205
Kyle	2225

Table 3 lists the population from the 2000 census (US Census Bureau, 2002). Comparing the population changes between 1990 and 2000 demonstrates that Kyle and Wimberley are the two fastest growing communities on the watershed.

Table 3 City Population from 2000 Census.

City Name	Total Population
Blanco	1505
San Marcos	34733
Wimberley	3797
Luling	5080
Lockhart	11615
Kyle	5314

Figure 4 presents the boundary of cities and their extra-territorial jurisdictions in the watershed in 2007.

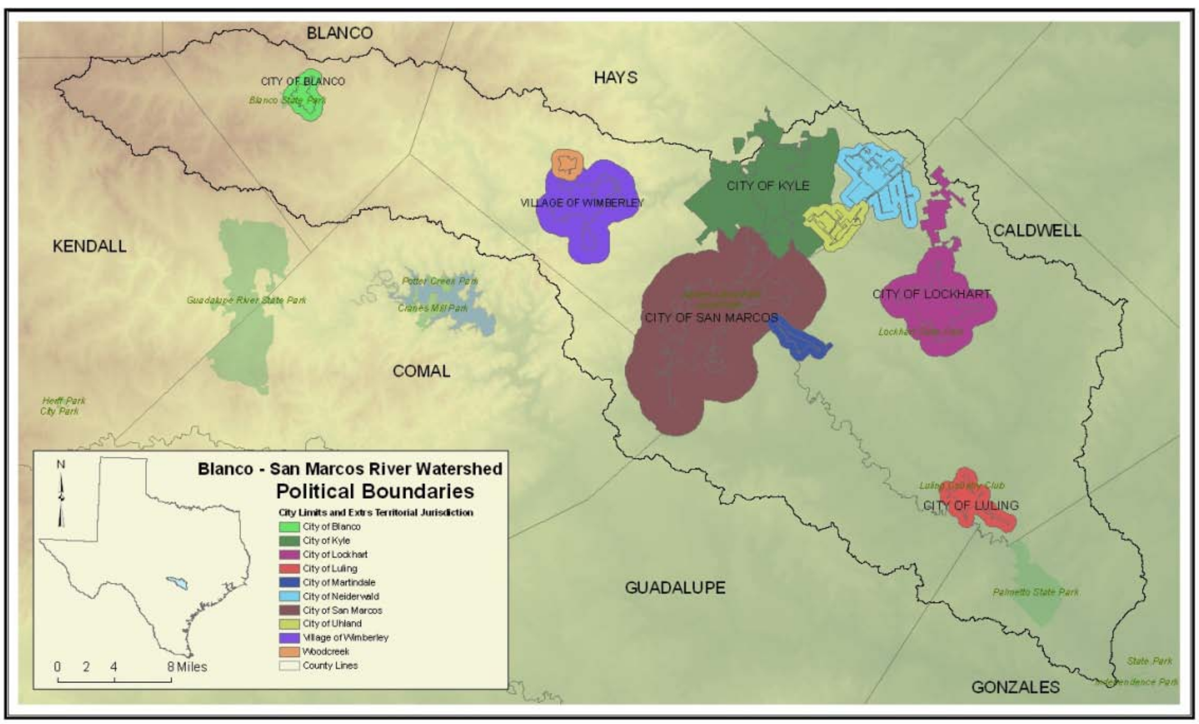

Figure 4 Watershed Cities and City ETJs, 2007.

Figure 5 shows population growth rates for these communities.

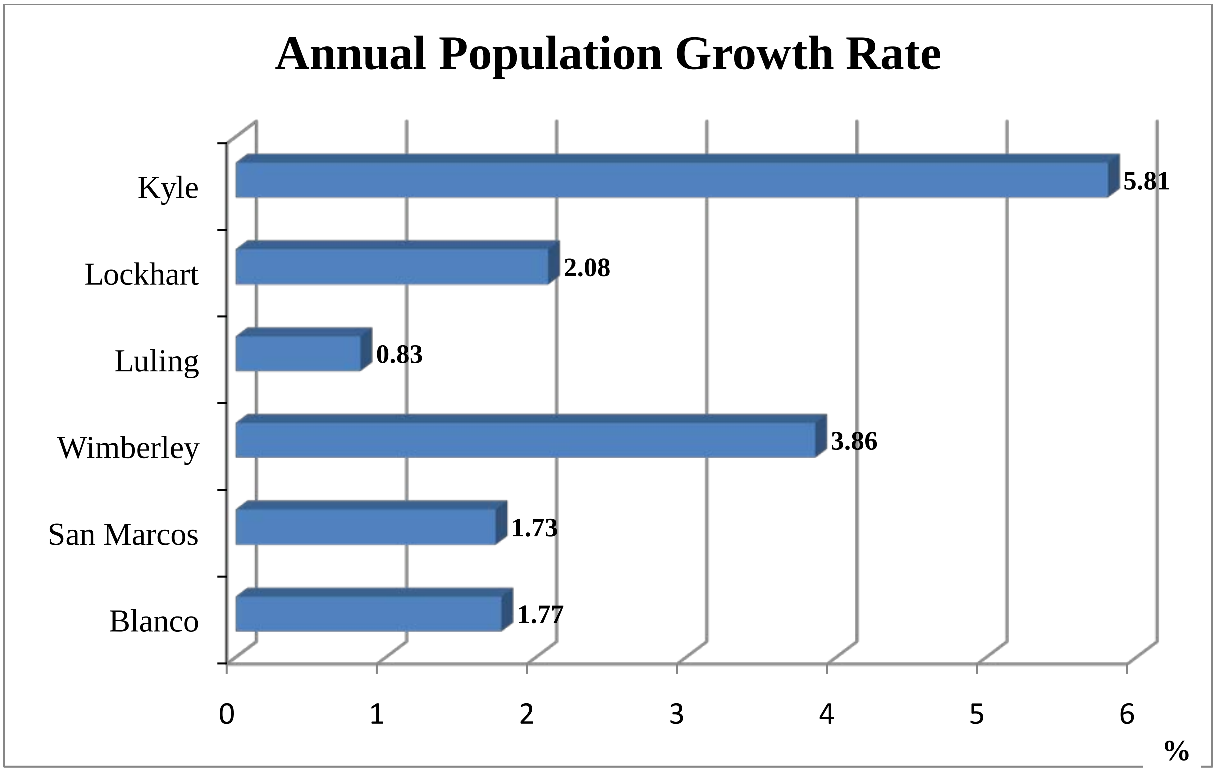

Figure 5 Average Annual Population Growth Rate in %, 1990-2000.

Based on information collected in the 2000 US Census, the two largest economic sectors in the basin are Management of Companies and Enterprises and Education Services. Figure 6 shows an example of the distribution of Economic Activities in the Cypress Creek watersheds.

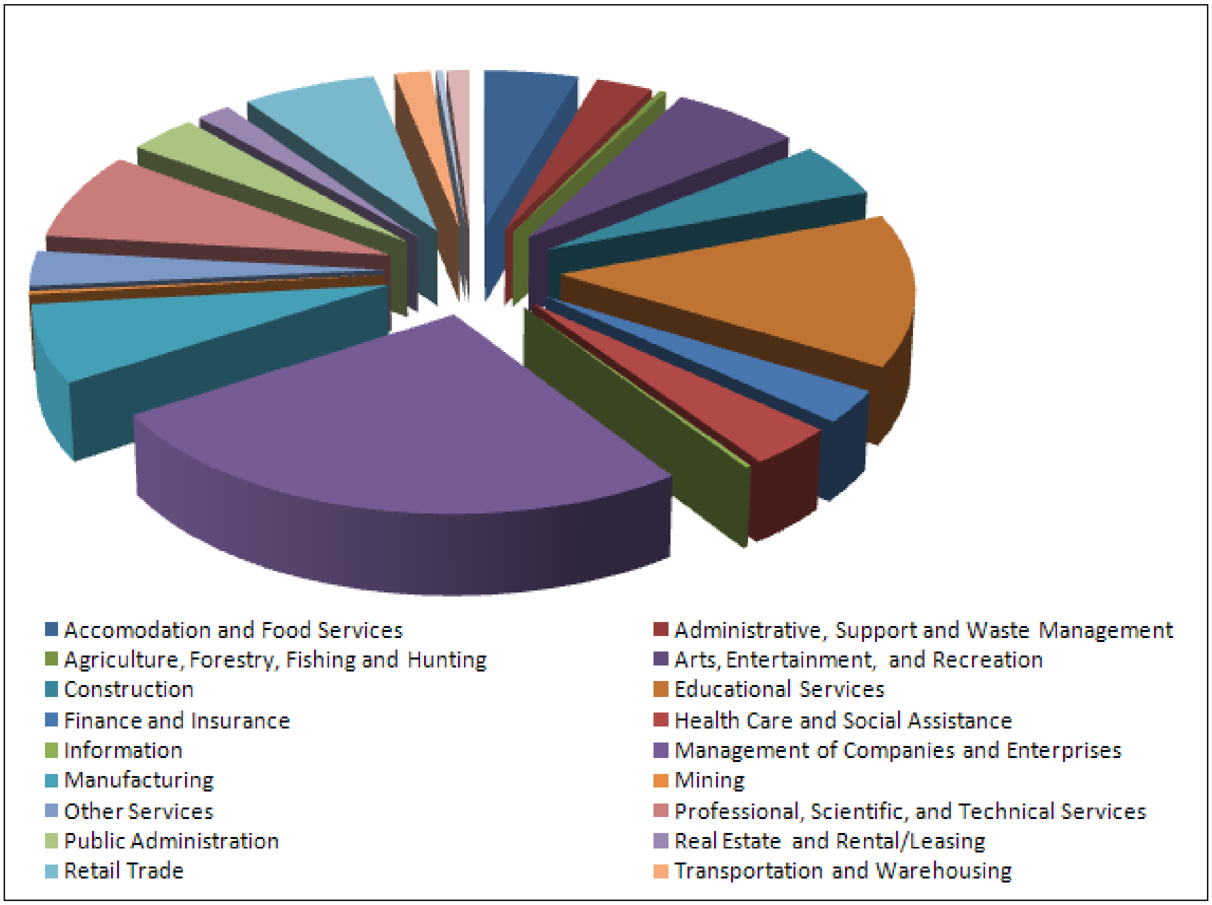

Figure 6 Distribution of Economic Activities in Cypress Creek Watershed.

Figure 7 shows the average family size across the watershed at the census track level. Since the watershed and the census tracks are not exactly the same, it is important to note here that some of the census tracts extend beyond the watershed boundaries. Census track data used were with the best fit for the watershed.

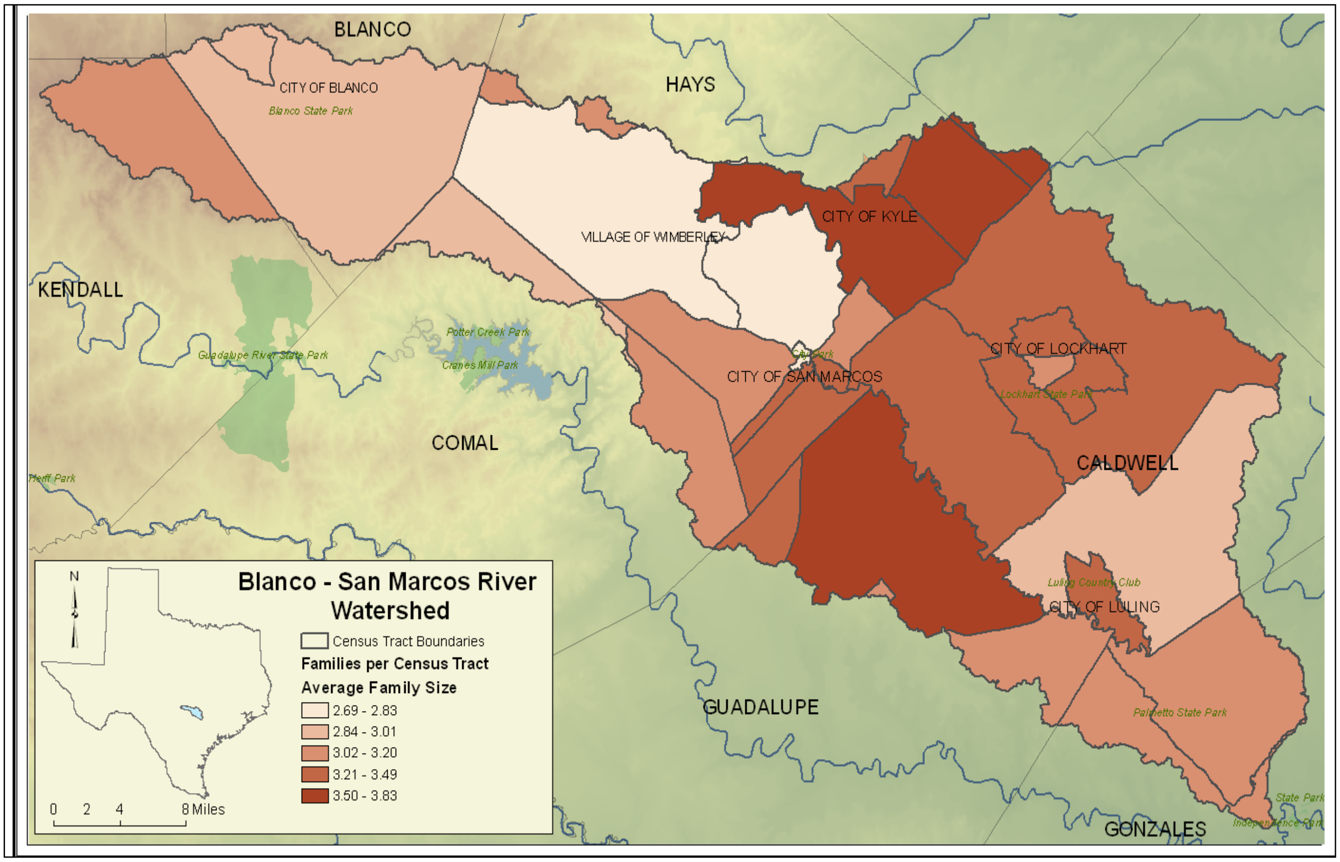

Figure 7 Average Family Size per Census Tract, 2000.

2.2. Climate Output Examples

In order to understand climate trends, the climate section of the Blanco Watershed Characterization Tool reports monthly average as well as annual changes over the last 50 years. What follows are examples of the type of data that were used as inputs for the Tool. In addition, we have included examples of the types of analyses that water resources managers can conduct with the Tool.

Using data from weather station 410832 in Blanco, Figures 8 through 11 present annual average values of temperature and precipitation in the last 50 years. Analysis of the data show that 1954, 1956, 1990, 1998, 1999, and 2004 have the highest annual average temperatures, while the most precipitation was recorded in 2004-2005. Evaluation of data indicated that 1954 to 1956, 1986 to 1988, and 2004 to 2006 showed the highest temperature variations in the data set. The recorded climate data capture the extremes experienced in this region, which can be obscured by the average temperature and precipitation values.

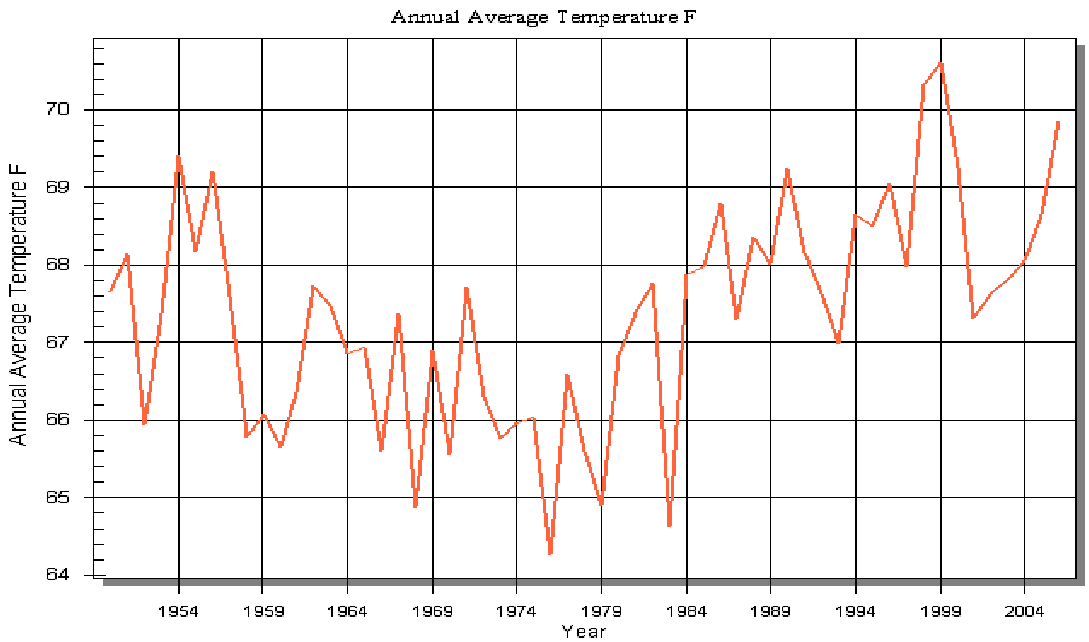

Figure 8 Annual Average Temperature Trend, Blanco station 410832 (1954-2004).

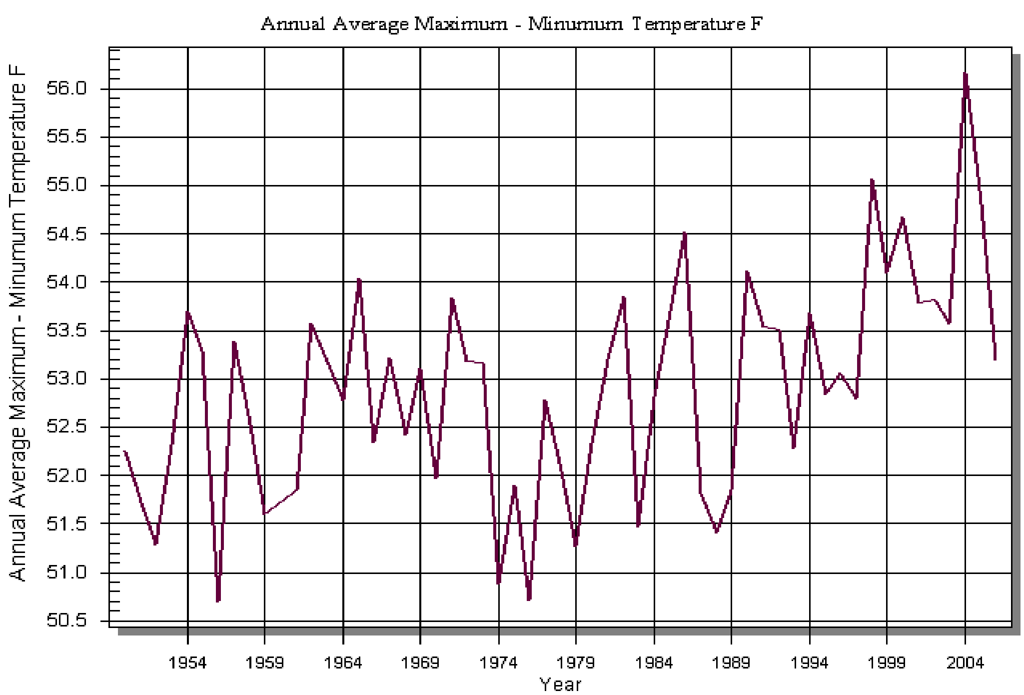

Figure 9 Annual Average Temperature Variation, Blanco station 410832 (1954-2004)

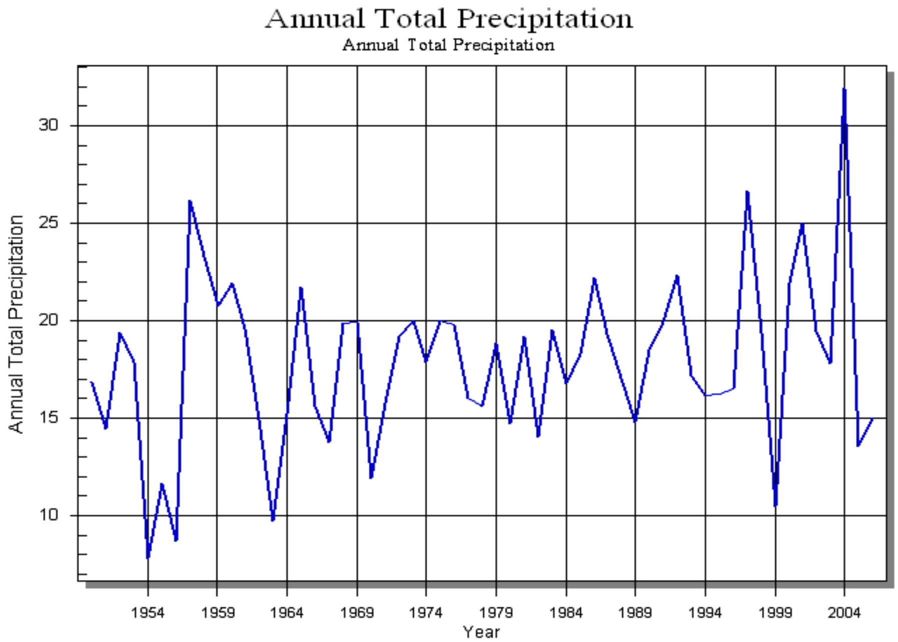

Figure 70 Annual Total Precipitation Trend, Blanco station 410832 (1954-2004) (Centimeters per year)

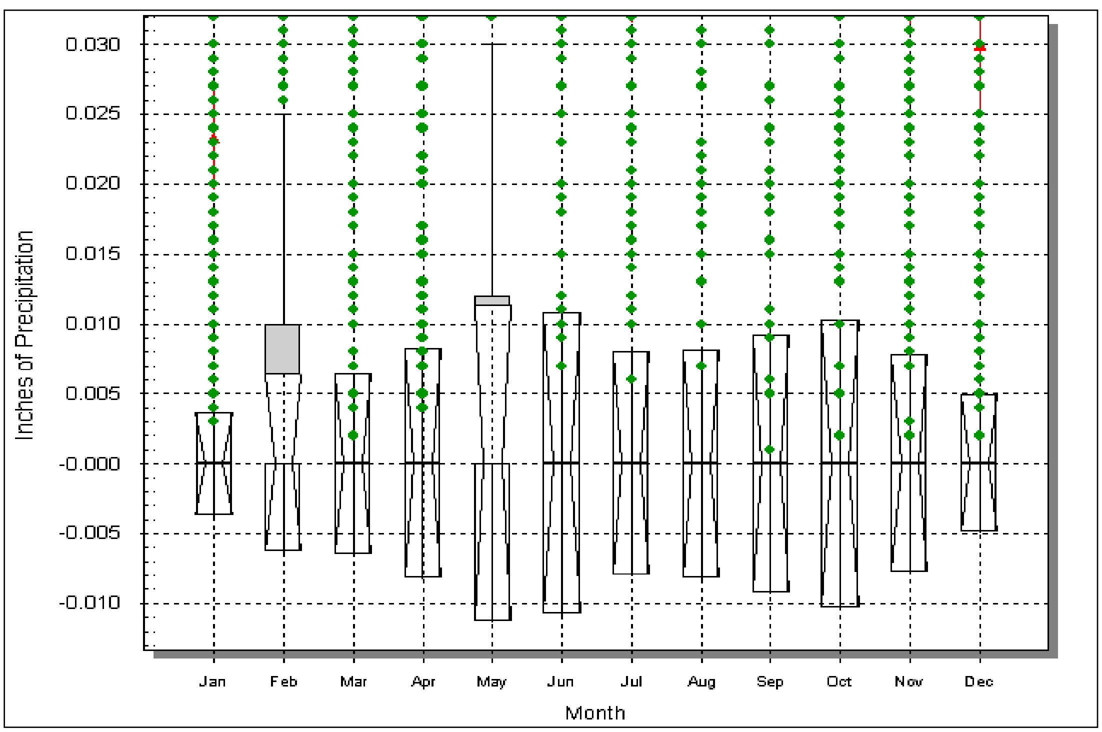

Figure 81 Monthly Average Precipitation, Blanco station 410832 (1954-2004).

2.3. Surface Water Hydrology Output Examples

The surface water hydrology section of the Tool reports stream, stream gages and stream flow information as well as flood plains. Several maps and graphs are generated for this section and examples are shown below.

2.3.1 Streams, Stream Gages and Stream Flows

Figure 12 shows the rivers and streams (level 1 though 4) within the watershed. The stream flow data used in this study was downloaded from the USGS daily stream flow data at five stream gages, shown in Figure 13. The stream gage data from 1950 to 2009 were utilized for this research. Figure 14 shows the monthly average stream flow data recorded at USGS station 8171000. Figure 15 presents the annual average stream flow data for the USGS station 417983.

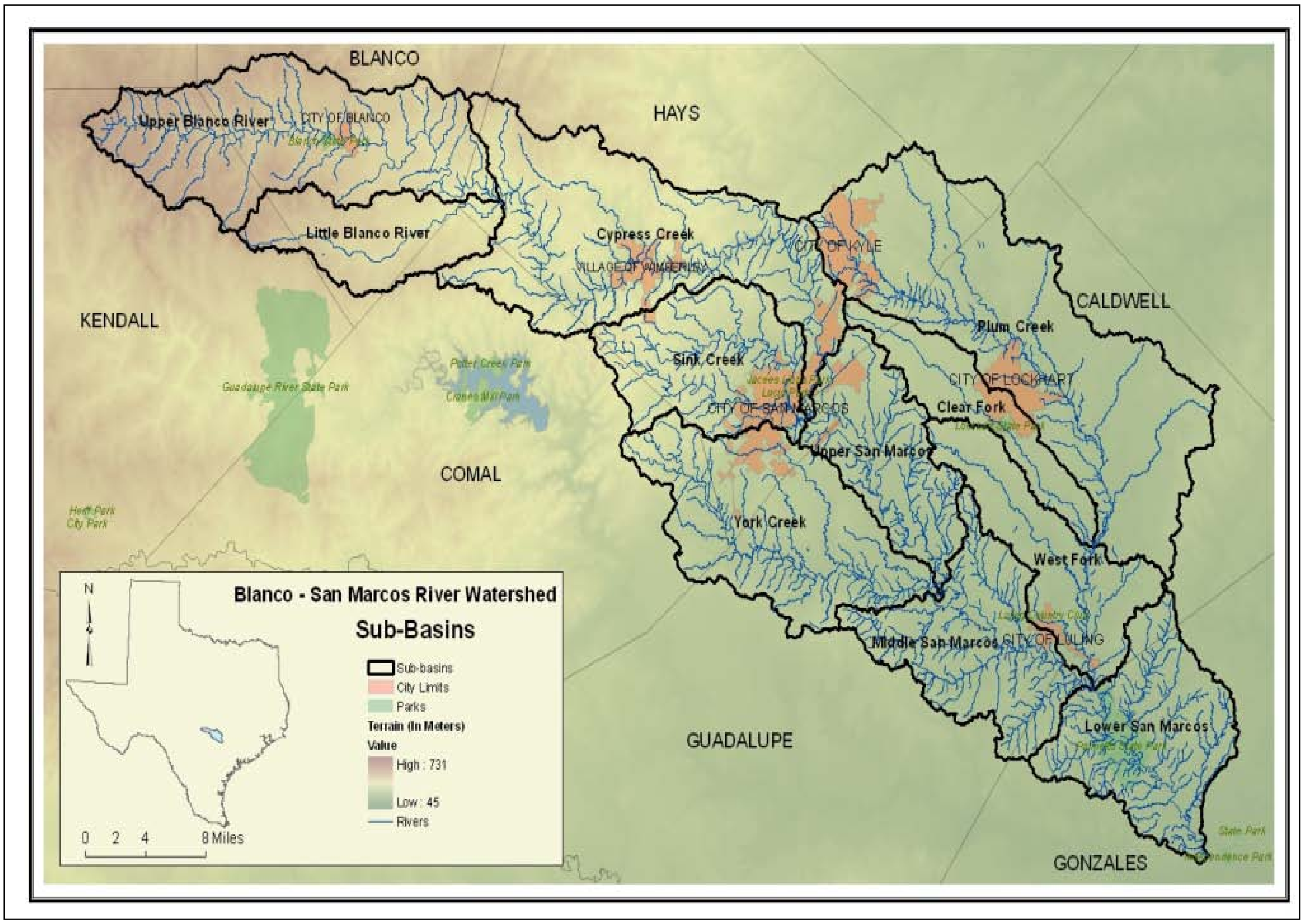

Figure 92 Rivers and Streams within the Watershed Study Area.

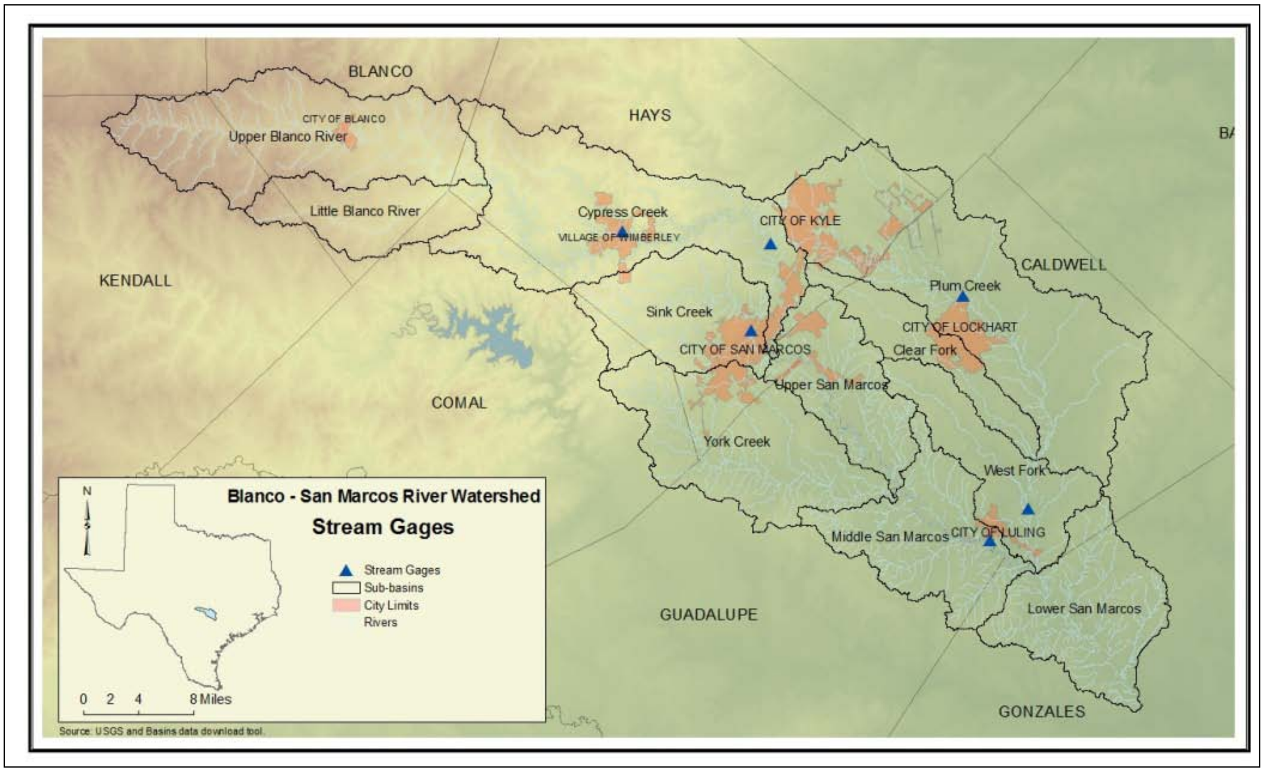

Figure 103 USGS Stream Gages Utilized in Study.

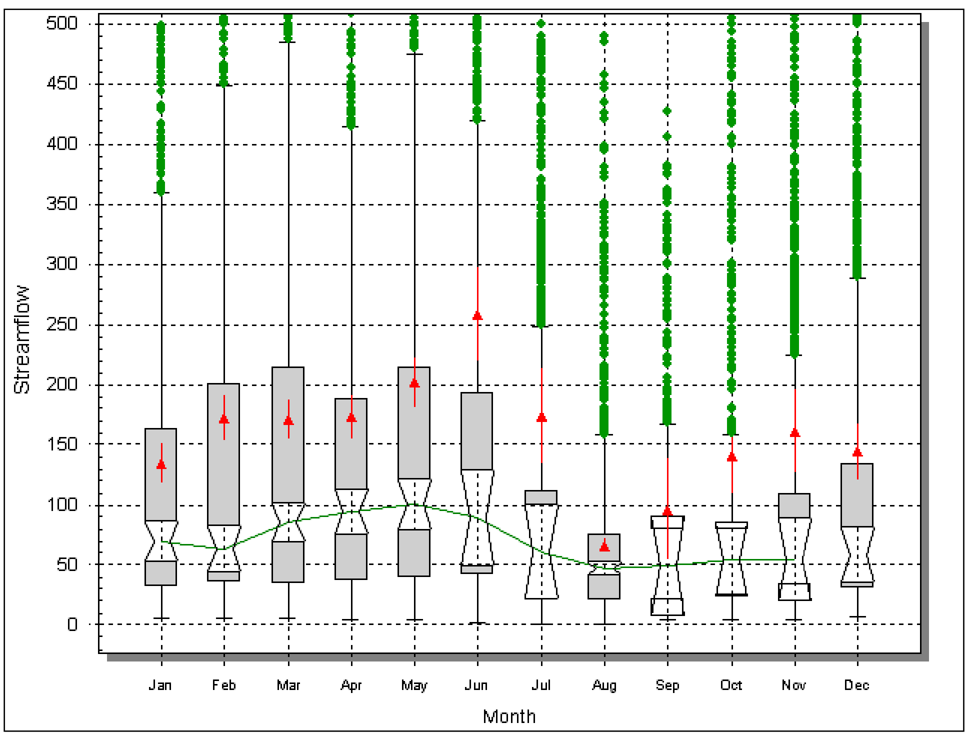

Figure 114 Monthly Average Stream Flow in the Cypress Creek sub-watershed, USGS Station 8171000, CFS (1950-2000)

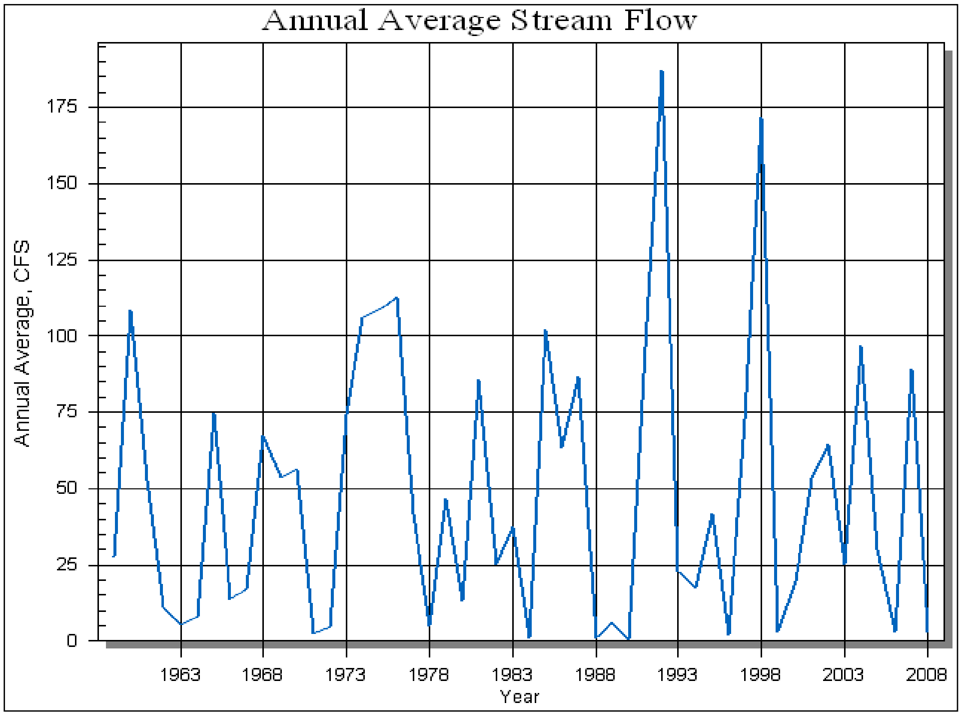

Figure 15 Annual Streamflow in the Cypress Creek Sub-watershed at USGS Station 417983

2.3.2 Flood Plains Output Examples

Flood plain maps, showing the 100-year flood plain, were available from Texas Natural Resources Information System (TNRIS) in all studies counties except Caldwell and Gonzales counties (TNRIS, 2008). First American Flood Data Services provided the digital data for those two counties (Figure 16).

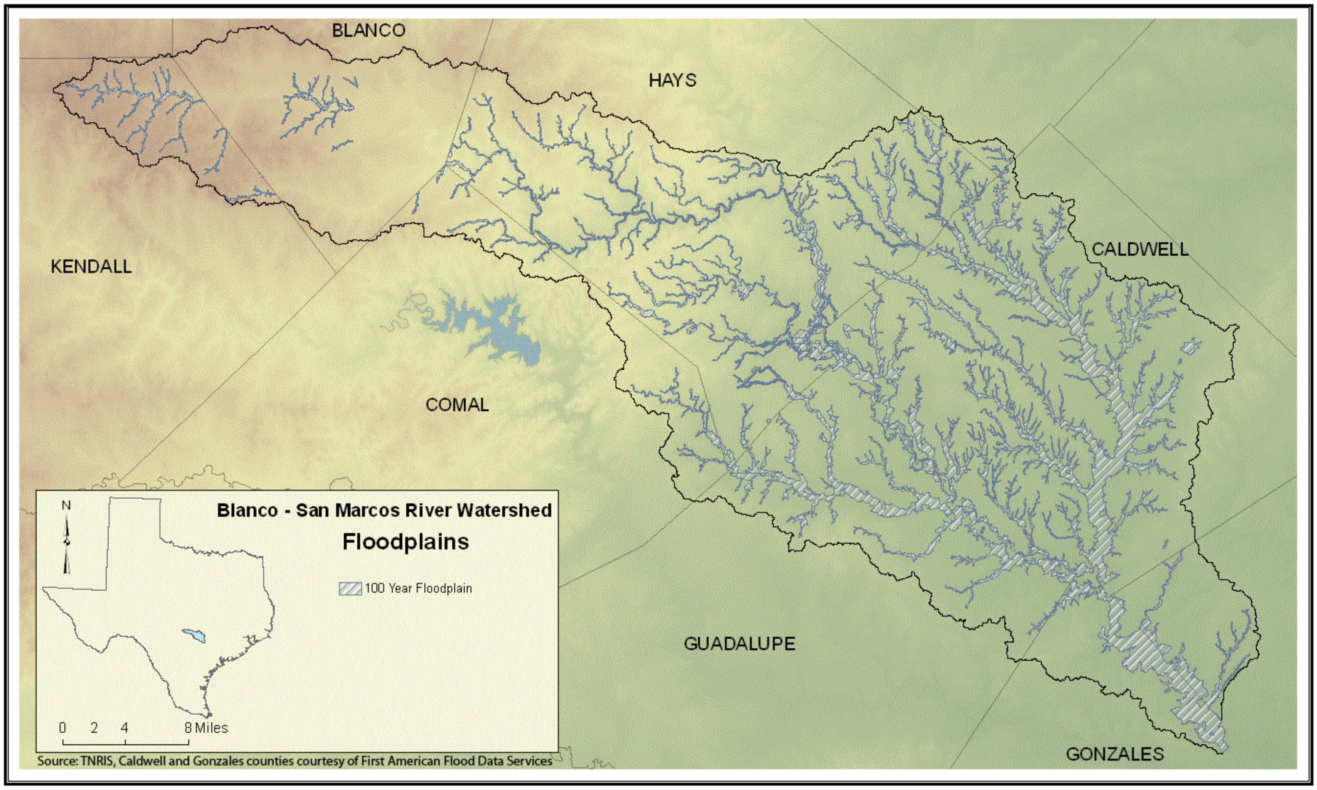

Figure 16 100-Year Flood Plains in Study Area/Watershed.

2.4. Groundwater Output Examples

Aquifers are the most important water sources for drinking and irrigation for communities in the watershed. There are four major aquifers in the study area. They are the Carrizo, Edwards, Trinity and Edward-Trinity aquifers (Figure 17). All zones of the Edwards Aquifer are present within the Blanco-San Marcos River Watershed (Figure 18).

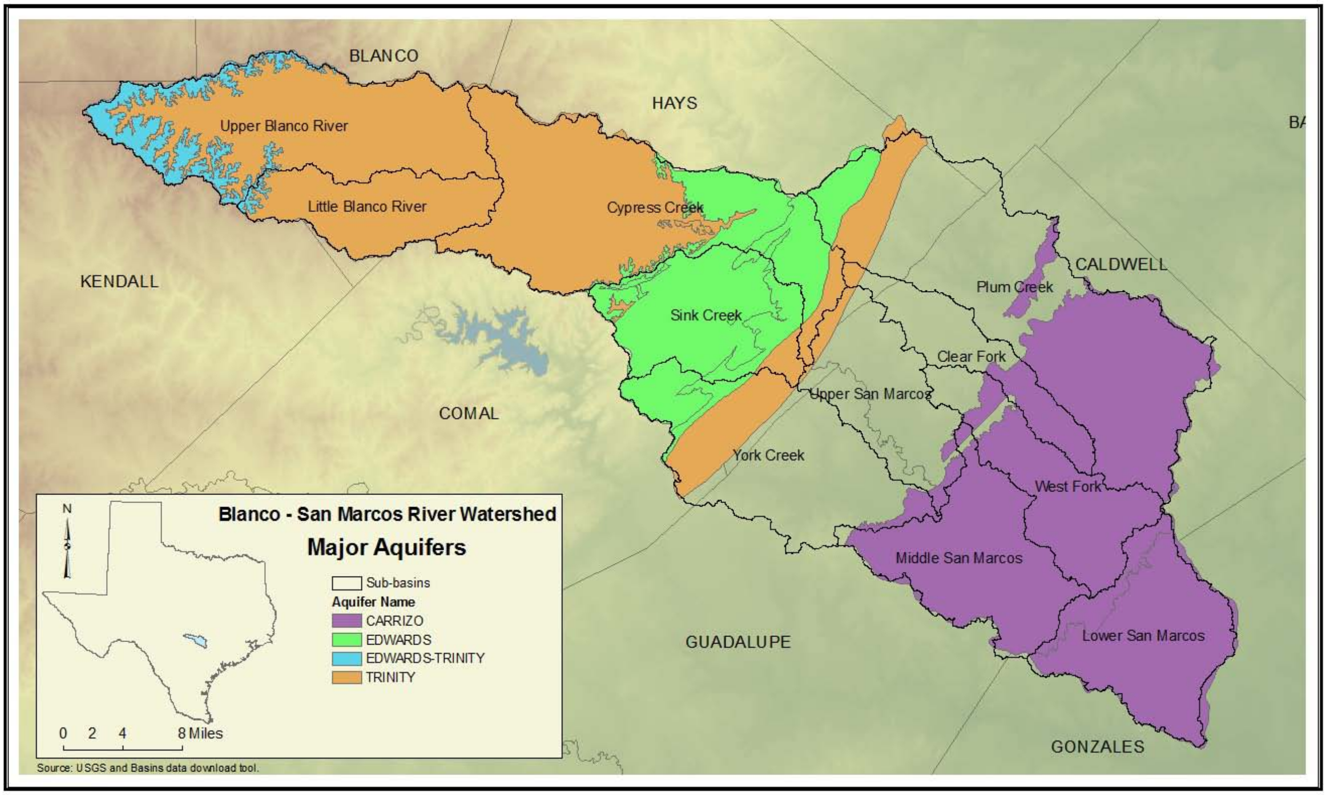

Figure 17 Aquifers in the Study Area/Watershed.

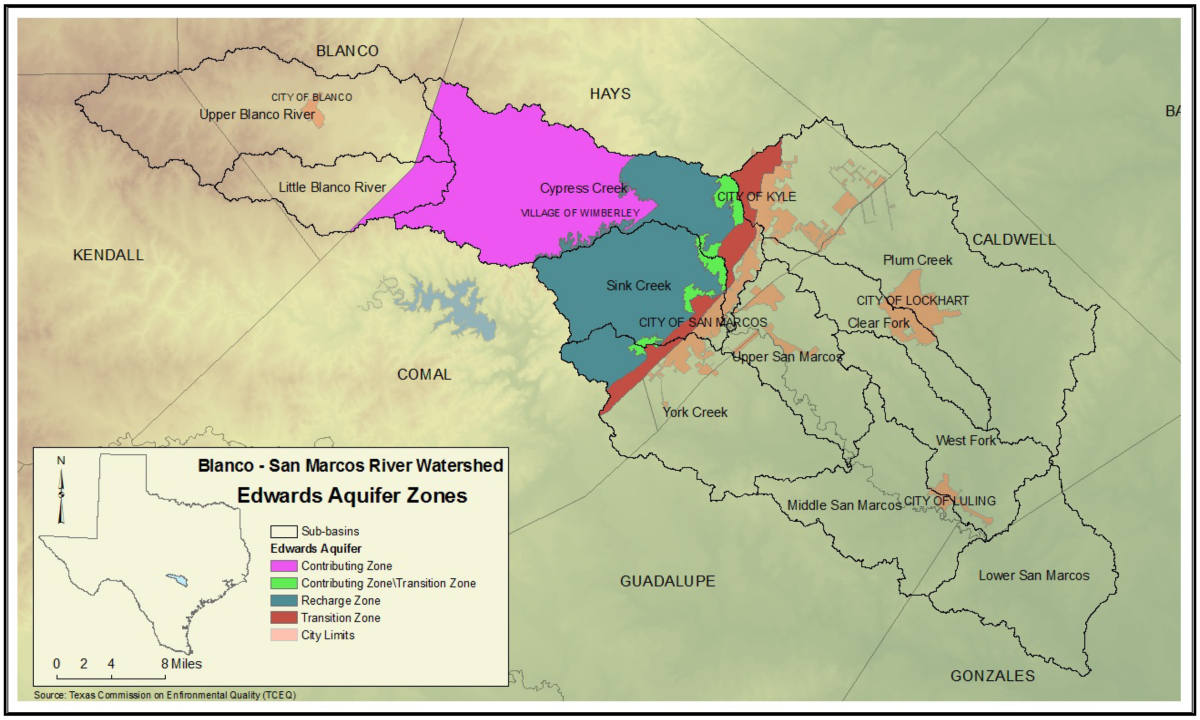

Figure 18 Edwards Aquifer Zones in the Study Area.

There are 1,142 registered wells in the area. The Watershed Characterization Report Tool reports these well locations with the owners of the wells and the total number of wells in the drainage selected, where the data are publicly available. Figure 19 illustrates that the majority of documented wells are within Plum Creek Watershed, Cypress Creek Watershed and the West Fork of Plum Creek.

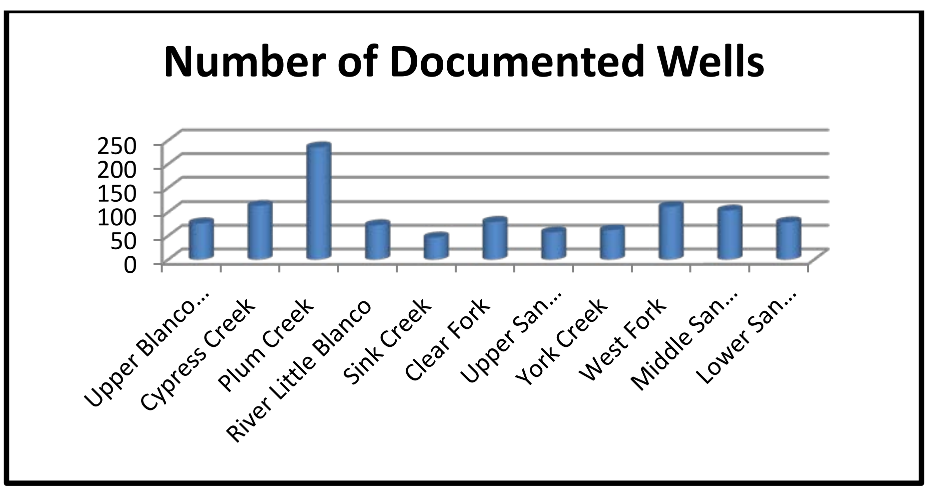

Figure 19 Number of Wells Located in Each Sub-watershed.

2.5. Water Quality Monitoring Stations Output Examples

The water quality section of the Tool contains information from water quality monitoring stations. There are 106 Texas Commission of Environmental Quality water quality monitoring stations in the watershed. However, there are no listed 303(d) sections in the study area. Figure 20 shows an example of water quality station maps generated by the watershed characterization tool.

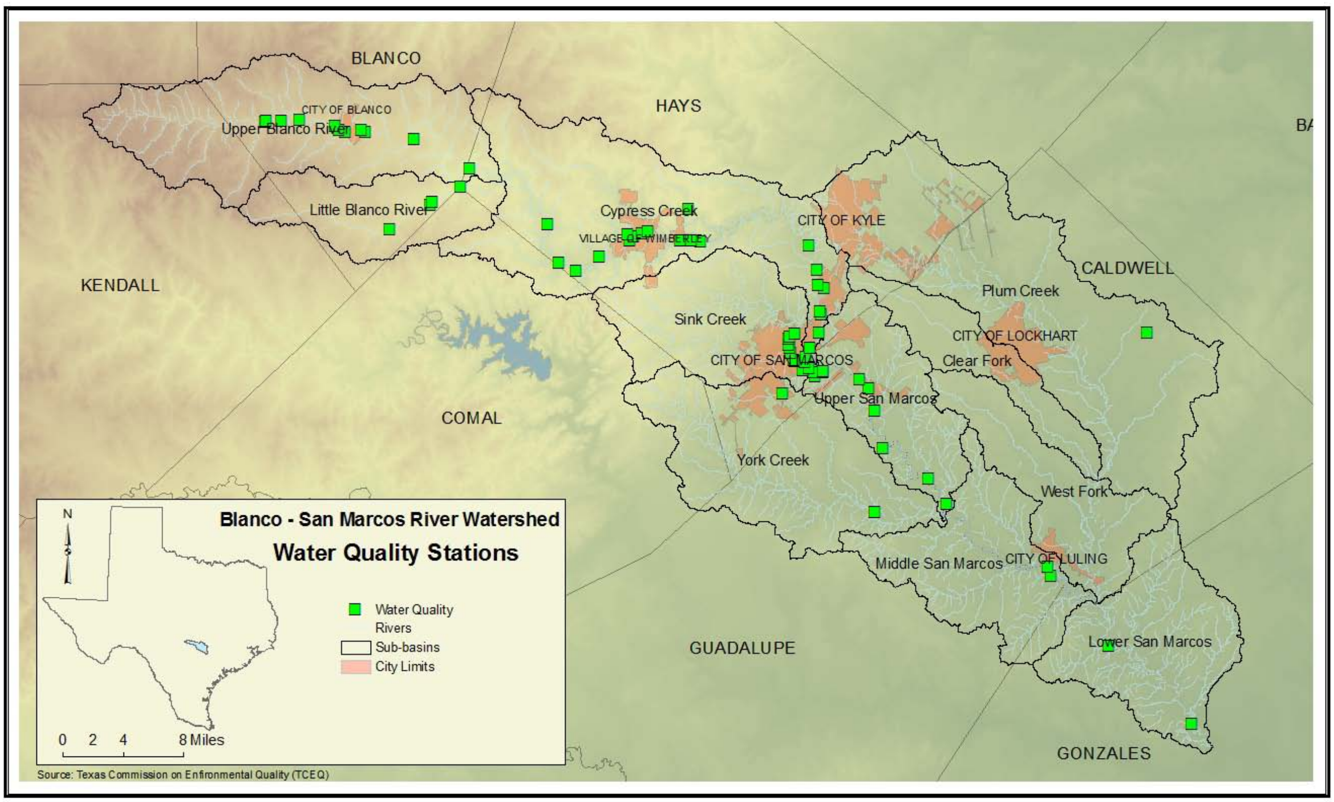

Figure 120 Water Quality Stations in the Study Area.

2.6. Water Budget Output Examples

The Water Budget section of the Tool reports water supply systems and water providers in the basin (Table 4).

Table 4 Water Supply Systems in Study Area/Basin.

System Name	Population Served
Aqua Texas INC	48,000
Blanco River Ranch HOA	66
Canyon Lake Water Service CO	22,000
Cedar Oaks Mesa WSC	550
Cielo Azul Ranch	80
City of Kyle	20,772
City of Lockhart	13,642
City of Luling	6,200
City of San Marcos	50,282
County Line WSC	4,839
County Line WSC	4,839
Crystal Clear WSC	12,669
Goforth WSC	11,202
Lago Vista Water System	36
LSR WSC	72
Maxwell WSC	5,245
Ottine WSC	67
Polonia WSC	1,524
Rancho Del Lago INC	159
Skyline Ranch Prop Owners INC	154

Staples Farmers Corp	645
Tri Community WSC	1,608
Wimberley WSC	78

Figure 21 provides an example of monthly evapotranspiration and precipitation in Plum Creek sub-watershed, which is representative of evaporation and precipitation rates in each of the study sub-watersheds. As expected, highest evapotranspiration rates occur in summer months, while rainfall lows occur in summer months. Peak increases in precipitation are observed in spring and fall datasets.

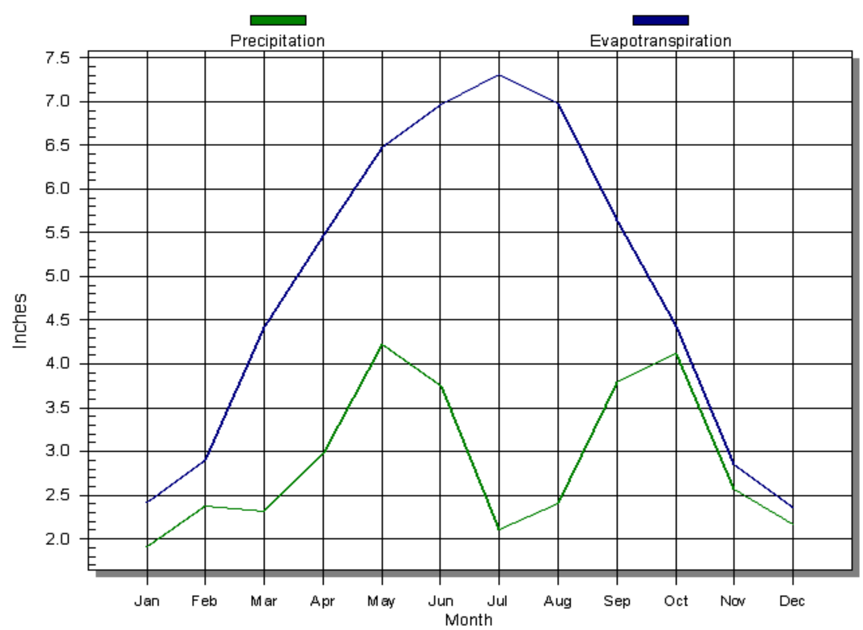

Figure 131 comparison of monthly precipitation and evapotranspiration rates for Plum Creek Sub-Watershed Example Output.

2.7 Land Use and Land Cover Output Examples

The data used for the land use and land cover section is derived from the 2001 National Land Cover Dataset (EPA, 2008). Figure 22 through 24 are examples of the land cover type, impervious level and canopy level maps generated in the watershed characterization tool. Figure 25 presents an example of distributions of the land cover type for a selected sub-watershed.

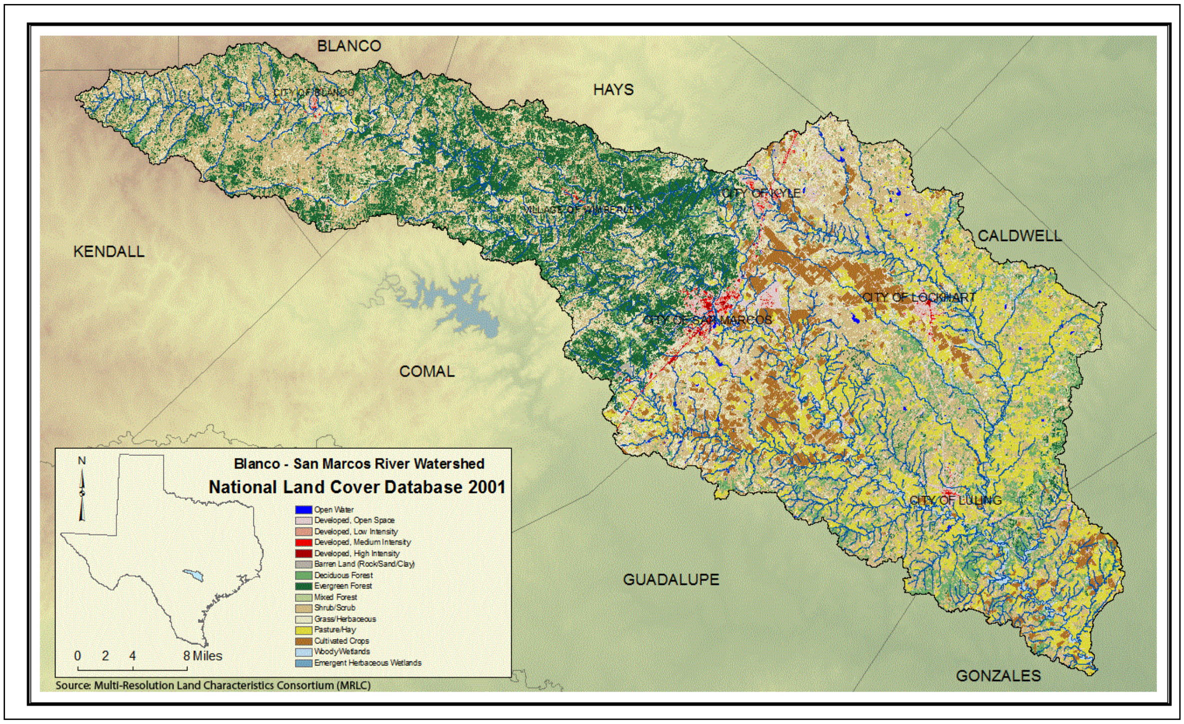

Figure 22 Land Use and Land Cover (NCLD 2001).

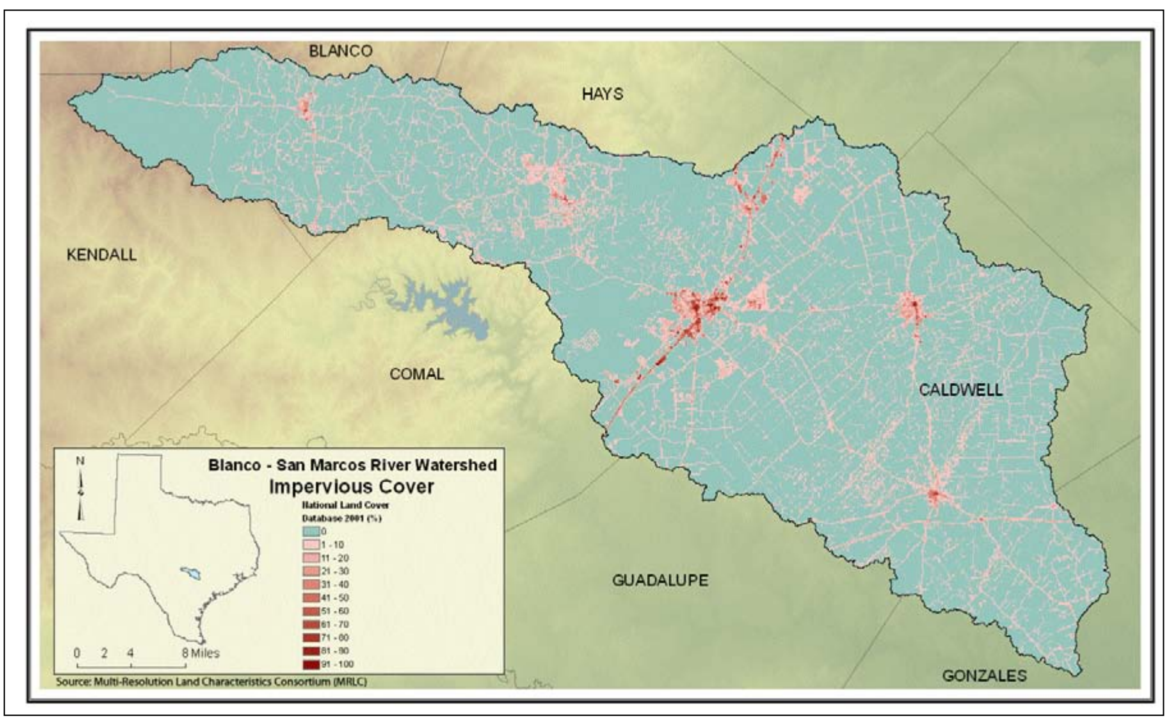

Figure 23 Impervious Cover Level (NLCD 2001).

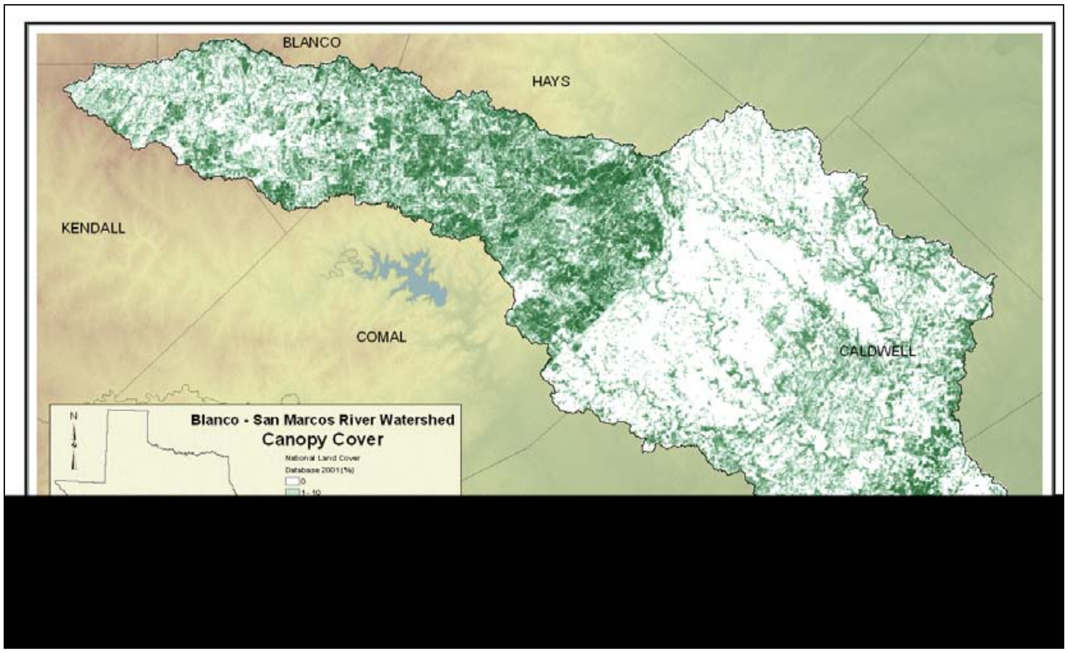

Figure 24 Canopy Cover (NLCD 2001).

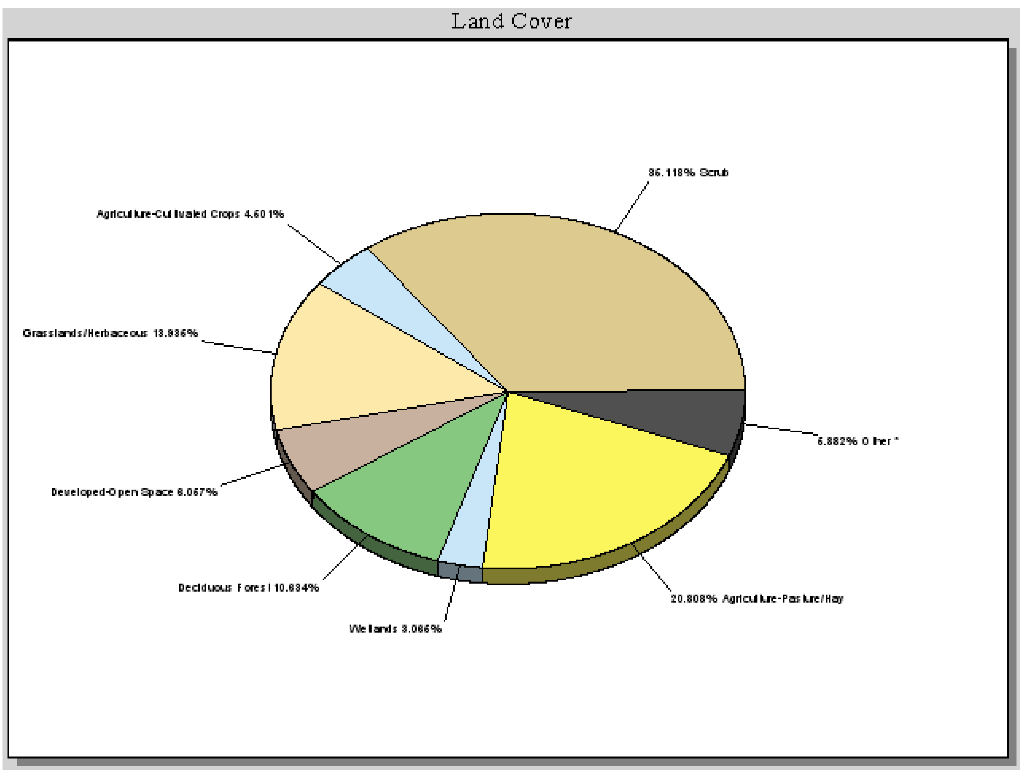

Figure 25 Land Cover Distribution for Plum Creek (NLCD 2001).

3. Land Use and Land Cover Change Detection

3.1 Land Sat Images Used in the Land Use and Land Cover Classification

This project utilized two Landsat 5 Images from October 1987 and October 2004 which were classified to show land use and land cover for the study area. Care was taken to obtain images from the same month to minimize phenological differences. The process was conducted in seven stages:

1. Field trip to the study area
2. Initial supervised classification using maximum likelihood method and the training sites collected from the field trip
3. Division of image into subsets to account for the differences between the Edwards Plateau to the west and the Blackland Prairies to the east.
4. Supervised classification of the image subsets using maximum likelihood method and the training sites collected from the field trip
5. Post-classification verification at the pixel level
6. Verification and correction using digital orthophoto quarter quad (DOQQ) images
7. Combination of the final classification into one image and clipped with the watershed boundary.

Since the land use land cover detection encompassed majority of the work in this project, the methodology and results are described in greater detail in the following sections.

3.2 Initial Supervised Classification

During the initial image processing tasks, the first task was to determine an appropriate set of classifications for land use and land cover (LULC), followed by data and image collection. Based on known and historic land uses in the study area, the desired classifications for the study were:

- Agricultural
- Urban
- Grass/shrubs

- Tree cover
- Water
- Barren

Figure 26 is a false color composite of the study area for the year 2004. The image was downloaded from the Landsat database (NASA, 2008). The image pixels were adjusted for color bands and then examined for features approximating the classification system. For example, recognizable bodies of water were identified, and through the image program, their pixel data were utilized as reference as to other bodies of water in the image. The initial supervised classification process continued to use 1) identification of areas throughout the image that fit different classes, followed by 2) use of image processing software to repeat the process and test for applicability of the classes.

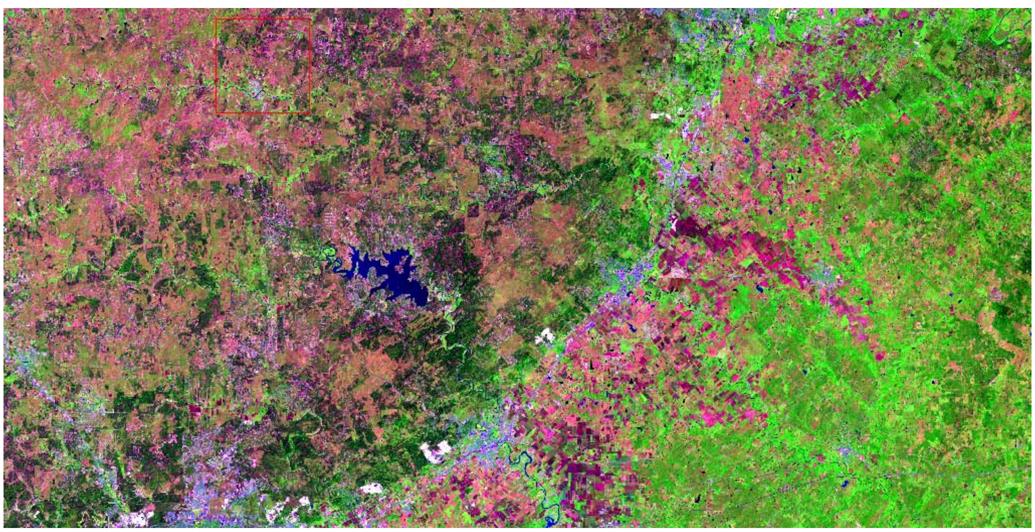

Figure 26 Landsat Image for the Study Area (May 2004).

While the selected classification schema fit the known profile of land uses in the study area, some of the major land uses in the image processing appeared to be mixed in the data processing of the Landsat image. The data processing problems included mis-application of the barren classification to known agricultural land, and on the northwest side of the watershed, barren classification mis-applied to urban land. The Landsat image was then separated into distinctly different geographic areas, one to the northwest and the second to the southeast. Regardless, the processing uncertainties resulted in the over-classification of barren as urban areas and nonagriculture land as agriculture land on the upper left part of the watershed as shown in Figure 32. The top half of the processed Landsat image shows the northwest portion of the study area and the bottom half shows the southeast portion. Figure 27 is also separated left and right; the left sides display raw satellite data, and the right sides demonstrate the results of the initial supervised classification, including the mis-applied classifications of the initial data processing.

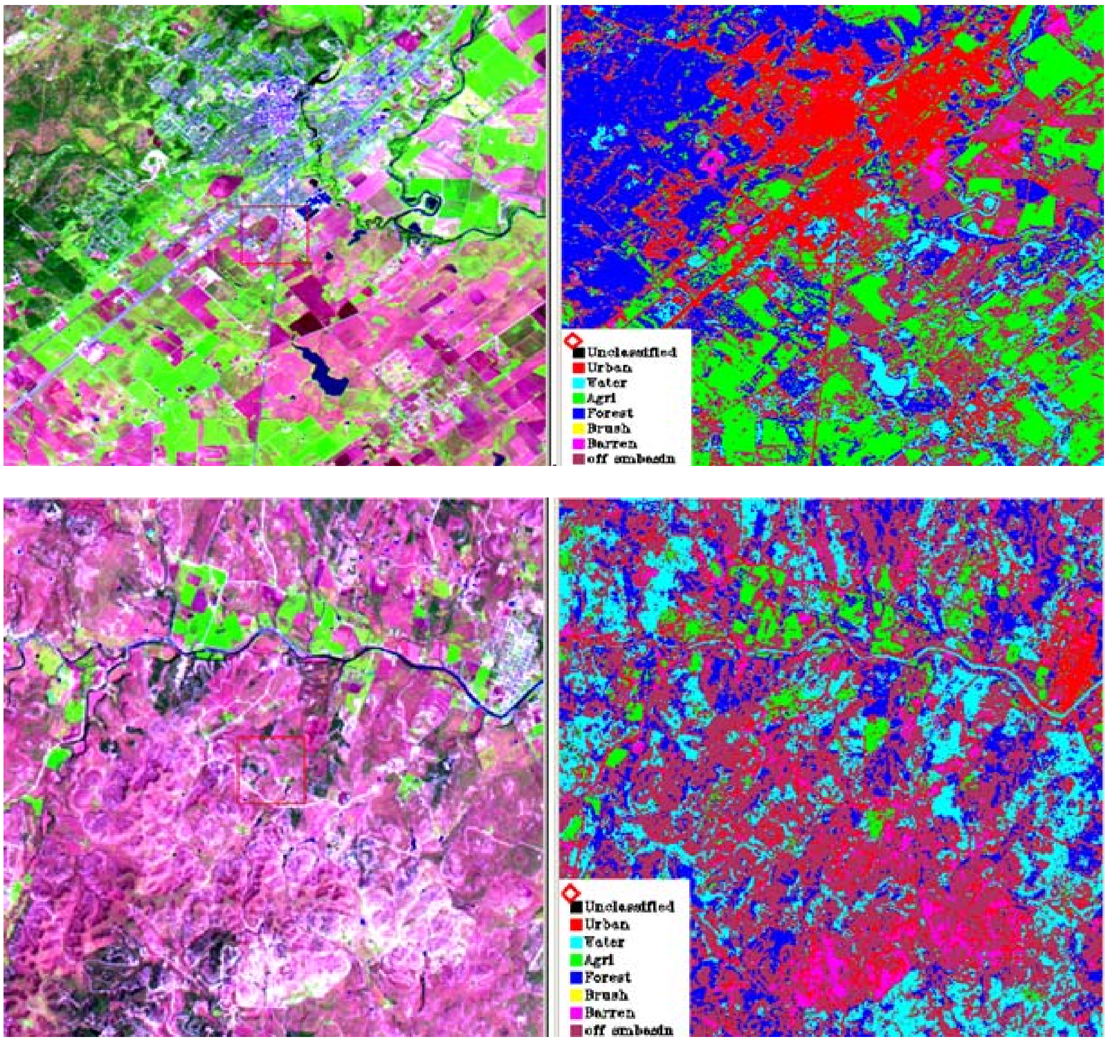

Figure 27 Results of the Initial Supervised Classification. ***(Top half is the NW study area; bottom half is the SW area. Left images display raw satellite data; right images show the initial supervised classification results.)***

To better understand these observed issues, the two images of the initial supervised classification were zoomed in without processing. Figures 28 and 29 compare the Landsat images for the northwest (upper) and southeast (lower) parts of the watershed. The images indicated that the data processing steps should include additional steps to better account for natural changes in topography.

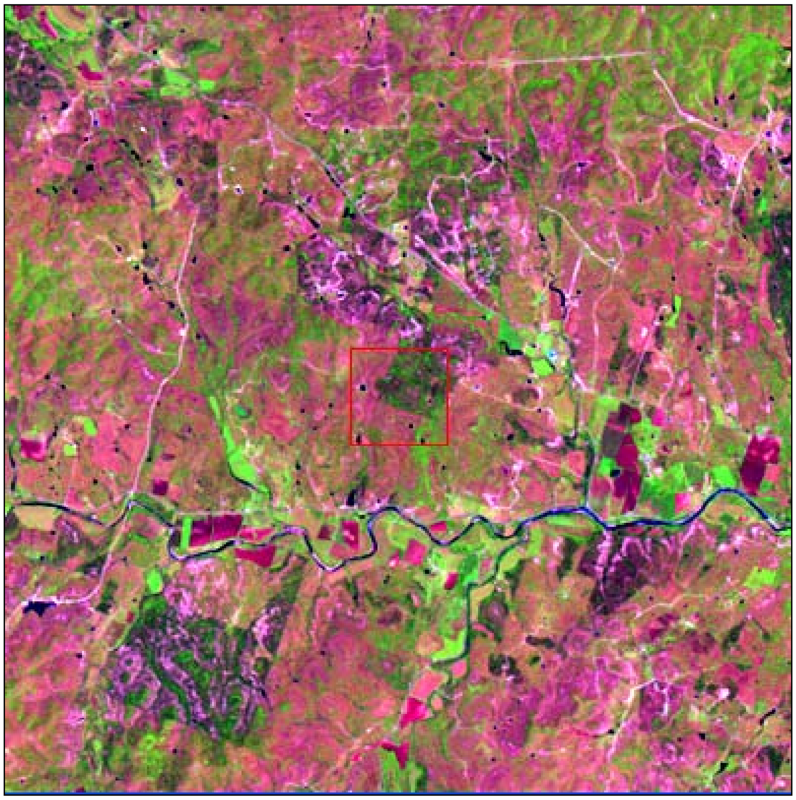

Figure 28 2004 Landsat Image (Northwest).

Figure 29 2004 Landsat Image (Southeast, or Lower Right of Image).

3.3 Division of Landsat Images

To overcome the data processing issues caused by the elevation, landscape, and similarities in land uses within the study area, the 2004 Landsat images were divided into two subsets – east and west – where a natural boundary delineates the change from hills to plains. Figures 30 and 31 show the sections used for classification of the respective eastern and western portions of the watershed.

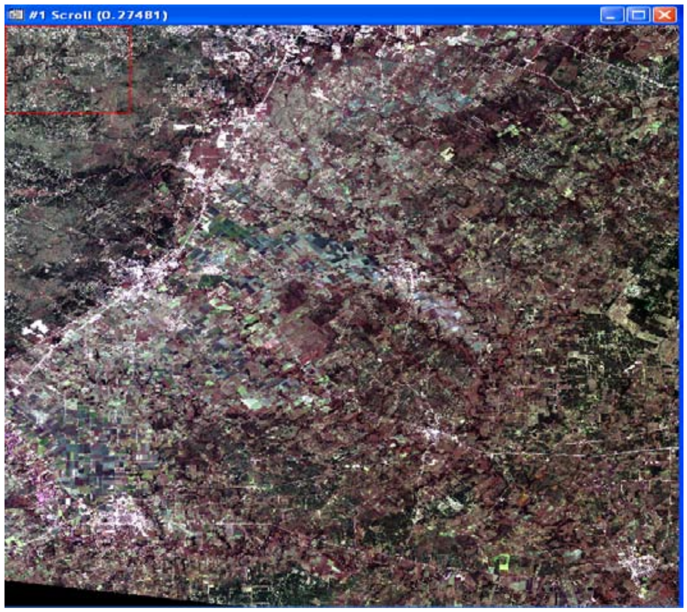

Figure 30 2004 Landsat Image Used for the East Portion of the Watershed.

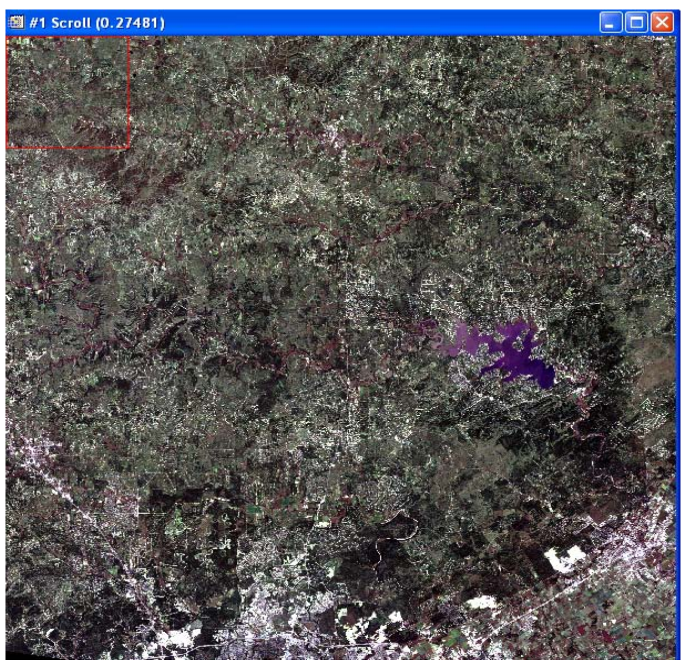

Figure 31 2004 Landsat Image Used for West Portion of the Watershed

3.4 Supervised Classification Using Maximum Likelihood Method

Based on the geographic distinction between east and west, the 2004 Landsat images were processed using supervised classification with the maximum likelihood method. The latter utilizes data processing programs to define the likelihood of each pixel in an image being associated with the appropriate classification. Images resulting from the more intensive data processing demonstrated the expected results with regard to desired classifications, locations of identified land uses such as urban or water, and depiction of the classification in the entire study area (Figures 32 and 33). The right images of the two figures display better resolution and definition of classes through use of the maximum likelihood method.

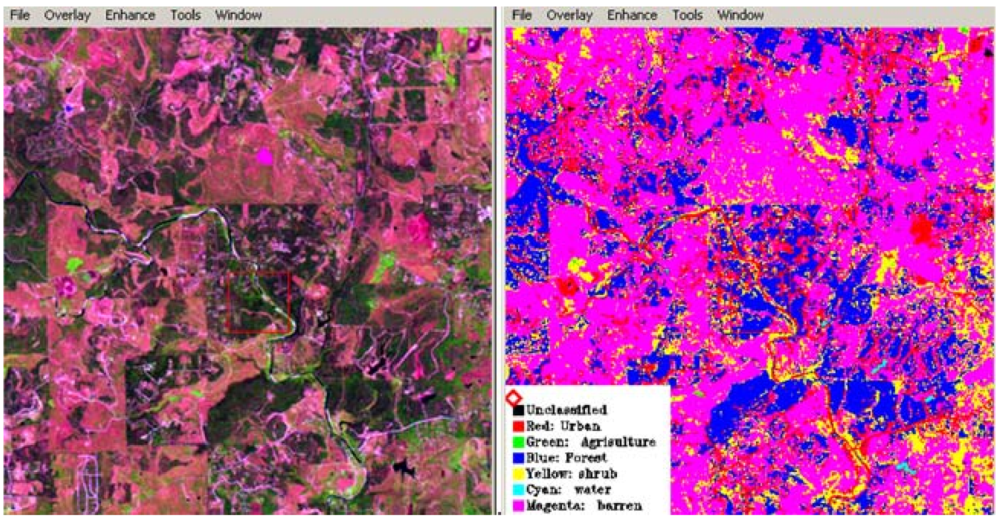

Figure 32 West Study Area, 2004 Landsat Raw Data (Left) and Supervised Classification/Maximum Likelihood Method Result (Right).

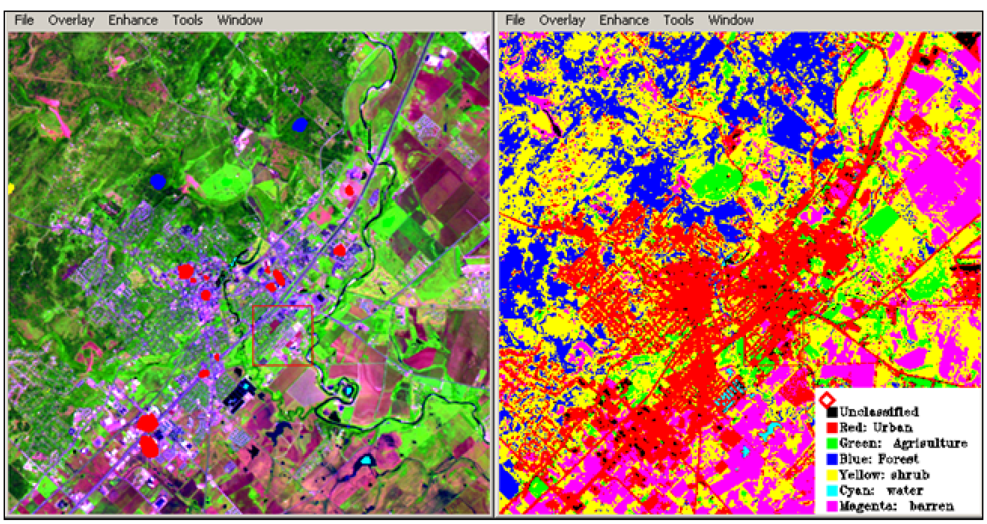

Figure 33 East Study Area, 2004 Landsat Raw Data (Left) and Supervised Classification/Maximum Likelihood Method Result (Right).

3.5 Post Classification

The classified images shown on the right in Figures 32 and 33 contained some noise and thus did not represent the study area as accurately as required. To address this gap, majority/minority analysis and clump and sieve classes were applied to the classified images in order to produce images that more closely represent the actual ground and land uses in the study area. These two techniques use algorithms to adjust pixels based on surrounding pixels. The result is more aggregation of pixels that give a “smoothing” effect with a minor loss of some resolution. The two techniques were run five times and compared to previous results. Applying these techniques significantly improved the classified images.

3.6 Land Classification Verification

To verify the classification system and data processing results with regard to land use, a total of 225 digital orthophoto quarter quad (DOQQ) images were utilized. Land classifications for 1987 were checked against 1990 DOQQ images. In addition, DOQQ images from 2004 were used to verify the land cover in a different year. Figure 34 shows the relative coverage of a DOQQ image, and Figure 35 shows the zoomed-in image represented by the small square in Figure 34. The images were zoomed in (Figures 35 and 36) to verify or to correct individual pixels or a cluster of pixels to prepare the final classified image. This stage was the most labor intensive. The final result, an applicable land use and land cover digital map, is shown in Figure 37.

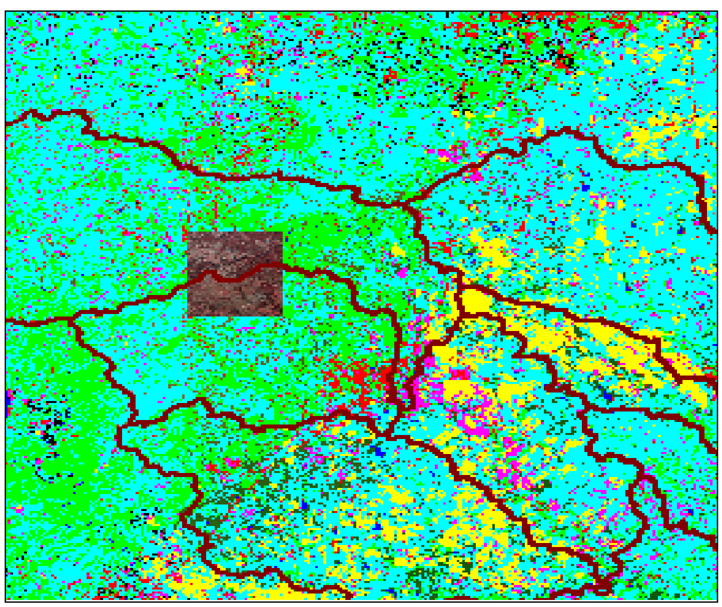

Figure 34 Coverage of Individual DOQQs.

Figure 35   Zoomed DOQQ Image

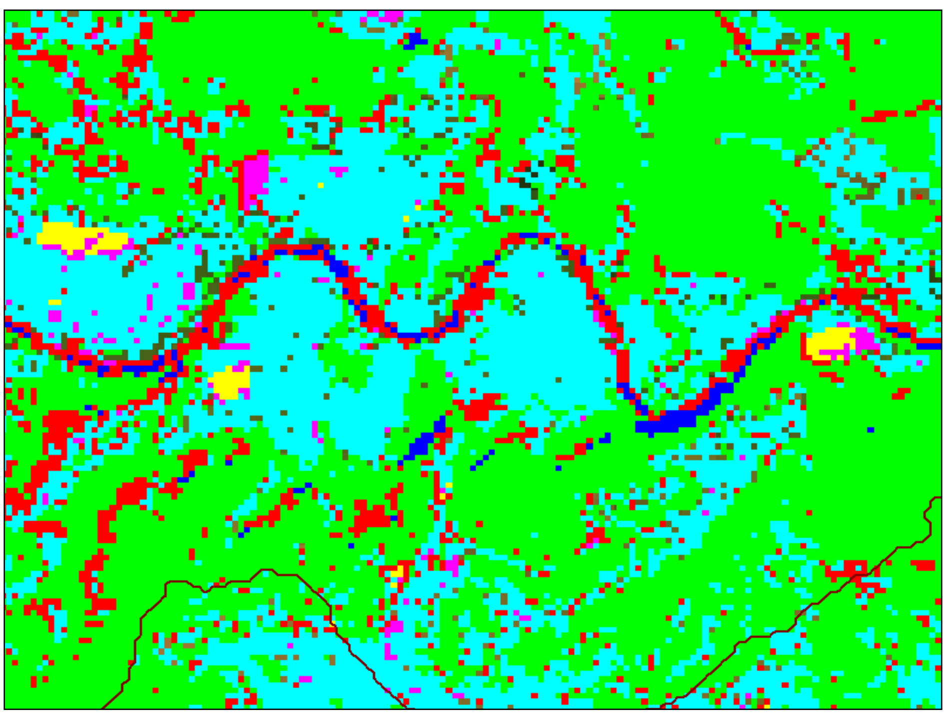

Figure 36 Land Classification Pixels for Verification and Correction.

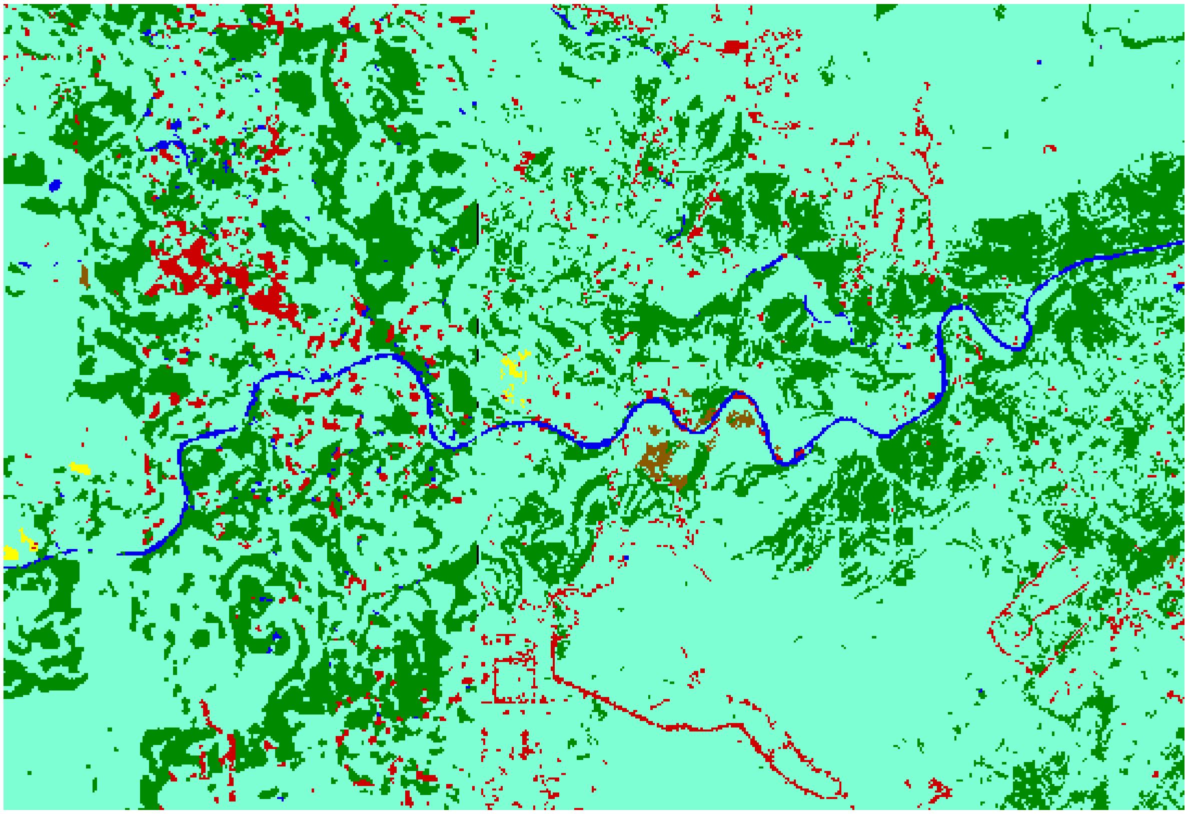

Figure 37 Final Land Use and Land Cover Image (2004).

3.7 Land Use and Land Cover Maps, 1987 and 2004

Based on the data processing and the resulting land use and land cover image after the verification and correction, the two sections of the land use image (east and west) were combined for the years 1987 and 2004. Because the satellite images cover a much greater area outside of the watershed, the watershed boundary map was used to clip the combined image to produce the final land use and land cover maps for 1987 and 2004. As noted in Section 3.1, it was considered critical to use maps from the same month but different years. Figures 38 and 39 present the final land use and land cover maps for October 1987 and October 2004.

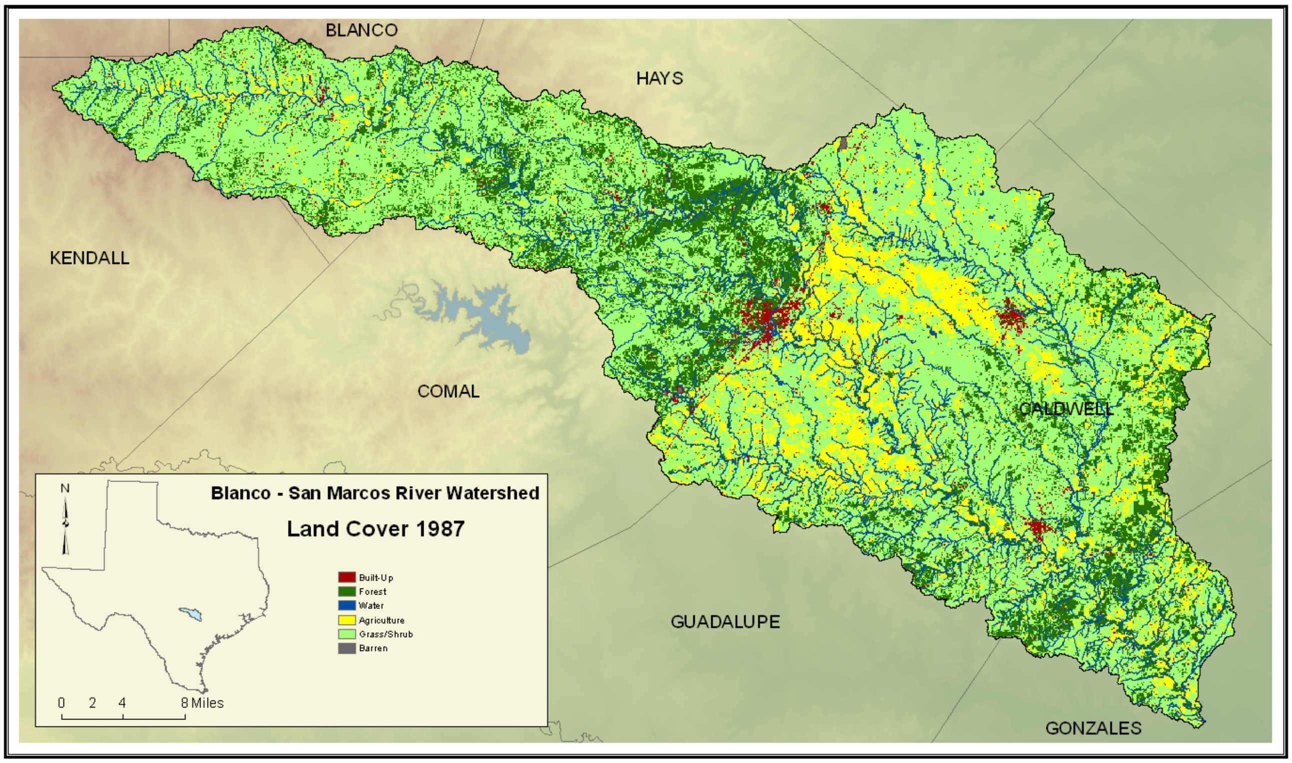

Figure 38 1987 Watershed Land Use and Land Cover.

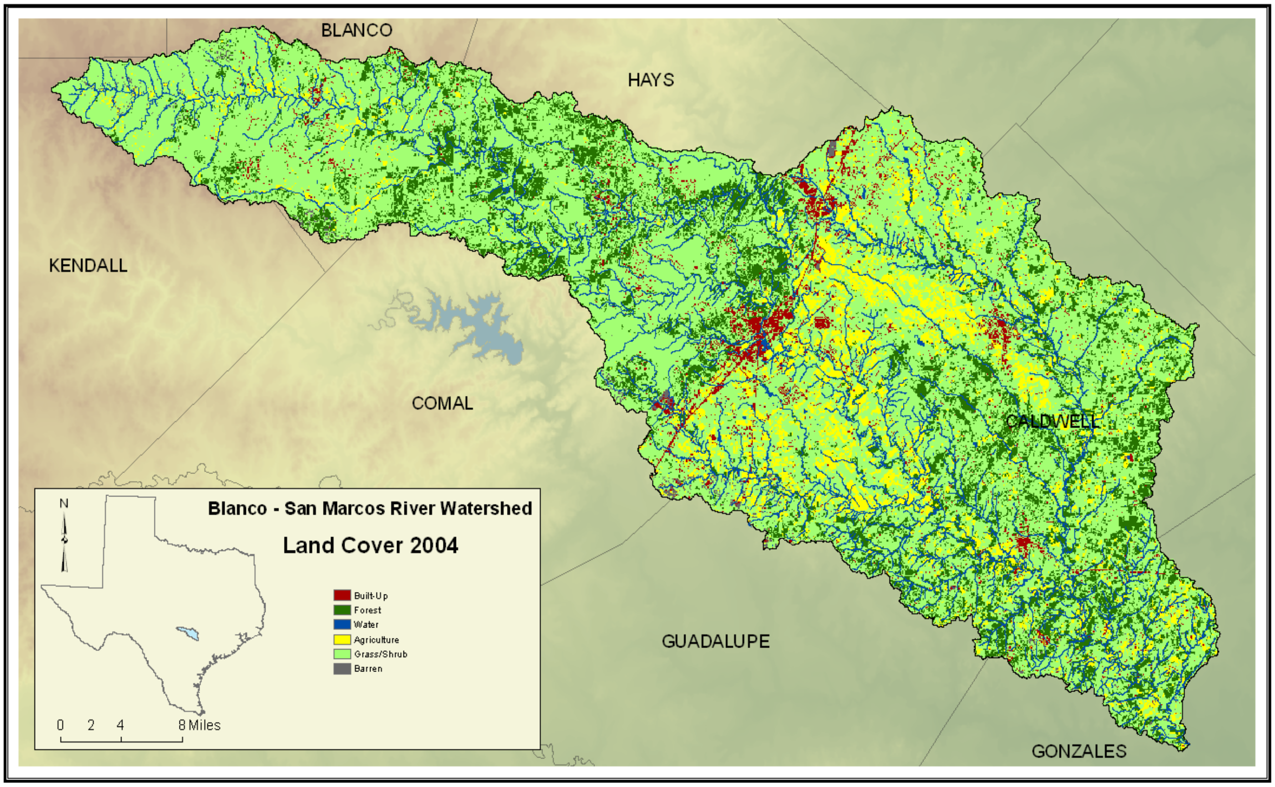

Figure 39 2004 Watershed Land Use and Land Cover.

3.8 Land Cover Changes

3.8.1 Land Use Change from 1987 to 2004

Using analysis from remote sensing software and interpreted through application to the final LULC image for the watershed, Figure 40 delineates land areas that have not changed from 1987 to 2004. The usefulness of this spatial analysis is its applicability as a baseline reference.

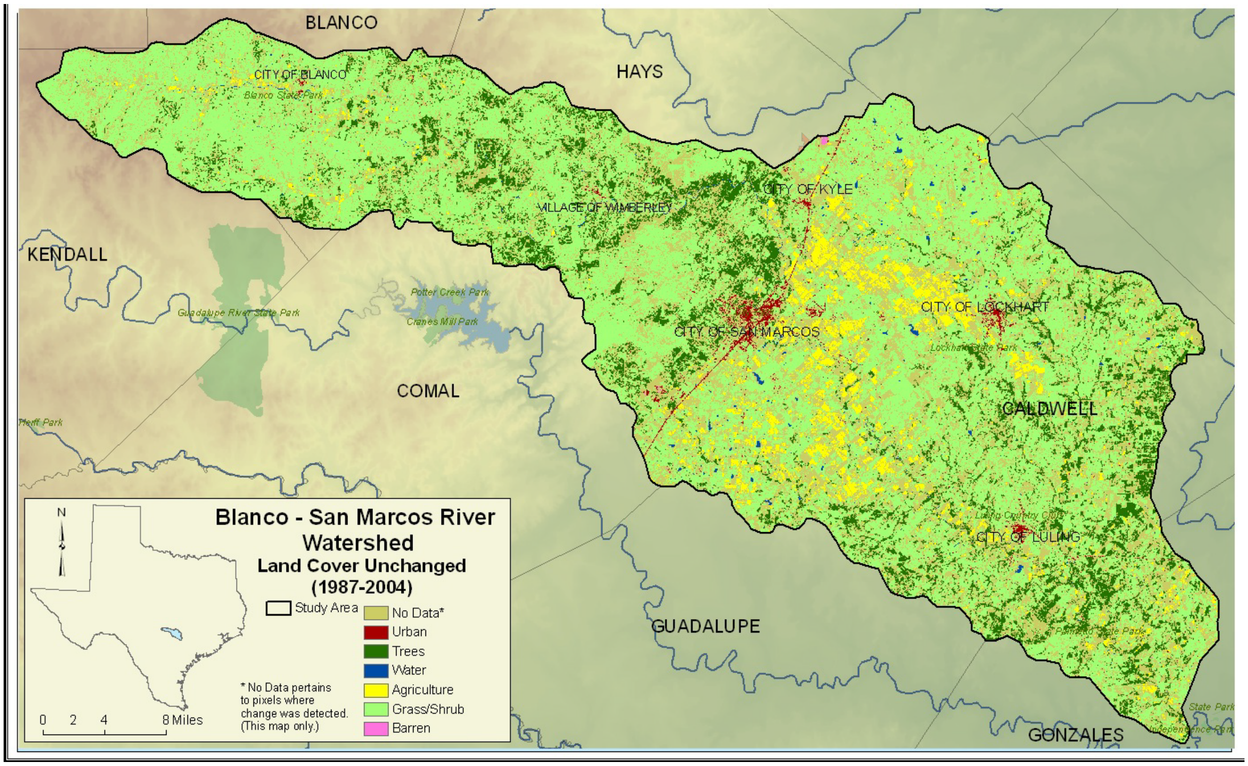

Figure 40 Land Cover Areas with No Changes between 1987-2004.

The mapped data in Figure 40 were used as the disturbance variables to calculate land cover change potentials for future land cover prediction. Figure 41 charts the total land area for each basic land cover type. As expected, the two classes that showed significant increase were urban areas and grass/shrub. The two classes that decreased during this period were tree cover and agricultural land use. Net changes between 1987 and 2004 are graphed in Figure 42.

The next few sections discuss the changes in different land use types – tree cover, cultivated crops, grass/shrubland, and urban - over time.

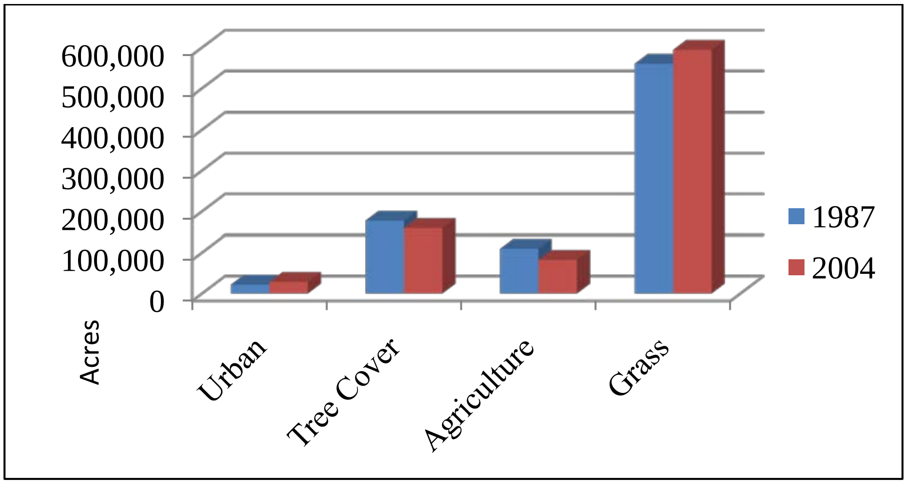

Figure 41 Changes in 1987 and 2004 Land Cover (Acres).

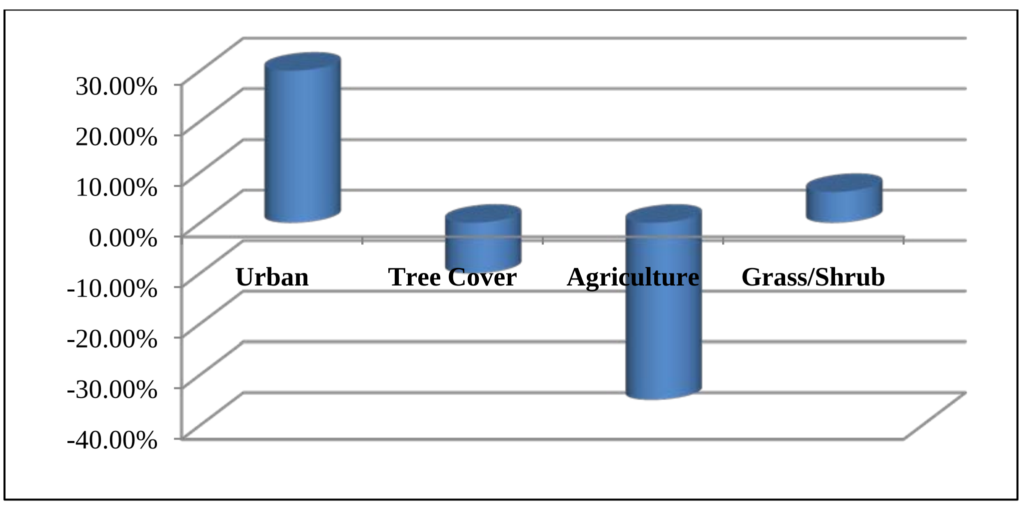

Figure 42 Net Changes for Urban, Tree cover, Cultivated Crops and Grass/Shrub (1987 to 2004)

3.8.2 Net Gains and Losses for Tree Cover

Using analytical tools in the software, the following figure (Figure 43) summarizes the loss and gains of forest tree cover in the study area between 1987 and 2004. The majority of the losses were converted into grass and shrubs. Some acreage was lost to agriculture and urban areas.

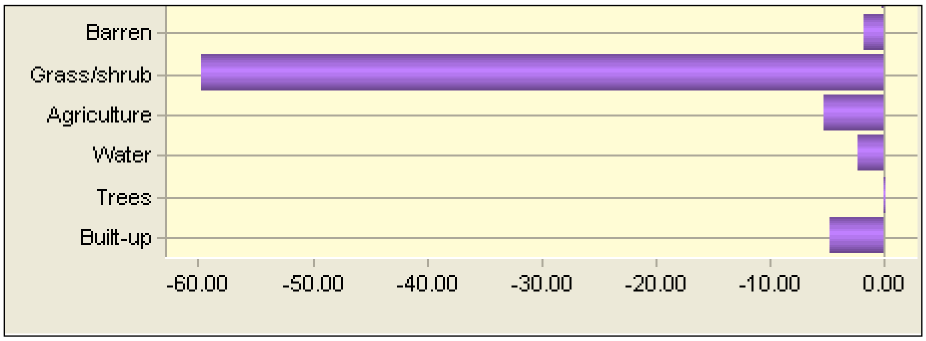

Figure 43 Gains and Losses of Tree Cover (Sq Kilometers), 1987-2004.

3.8.3 Net Gains and Losses for Cultivated Crops

As indicated in Figure 44, the loss of agricultural (cultivated crop) land appears due to conversion from cropland to grass or shrub land. The nature of using satellite images to compare land use types can lead to “false” changes in the Agriculture land class. Lightly planted, harvested, or temporarily unused fields can appear to have changed to grass/shrub lands. Because of inherent obscurities in the lowest scale of the processed data, it is best to focus on the changes to Urban or Trees categories. It appears that a small portion of land within the basin changed into urban areas, and slight increases were seen in tree coverage. In addition, a portion of land previously classified as trees was converted to agricultural land (trees were removed).

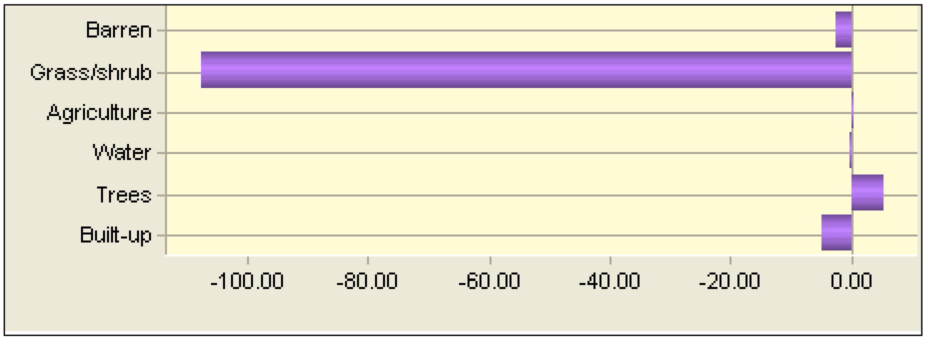

Figure 144 Gains and Losses of Cultivated Crop Land (Sq Kilometers) 1987-2004.

3.8.4 Net Gains and Losses for Grass and Shrubland

Figure 45 shows that conversion of grass and shrub land has mostly been to urban areas. Agricultural land and trees are the contributors to the gains of the grass/shrub land. Again it should be noted that grass/shrub and agriculture can be miscalculated in the data processing. Focusing on changes to urban land use/cover is most useful to the study.

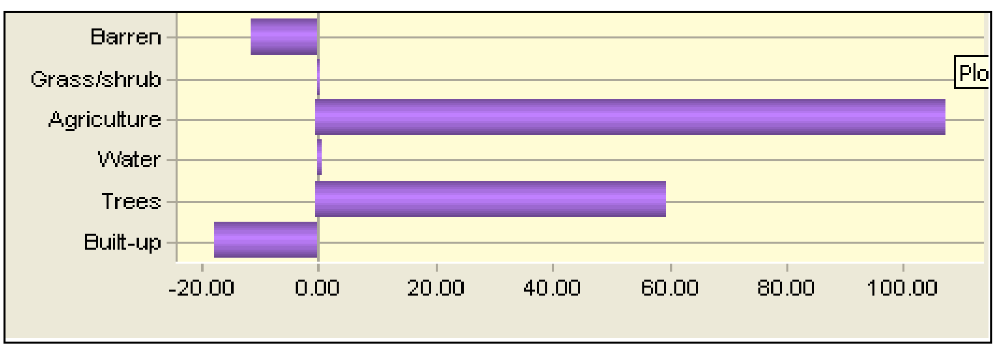

Figure 45 Gain and Losses of Grass/Shrub Land (Sq Kilometers) 1987-2004.

3.8.5 Net Gains and Losses for Urban Areas

Not surprisingly, the land that has changed into urban and urban areas includes agricultural crop land, tree covered land and grass/shrub land (Figure 46). It is important to note that urban land is not being allowed to return to nature. As neighborhoods mature, trees become the dominate feature detected by the classification techniques. The relevant change is in land cover/land use to urban, in this case primarily a change from grass/shrublands to urban uses.

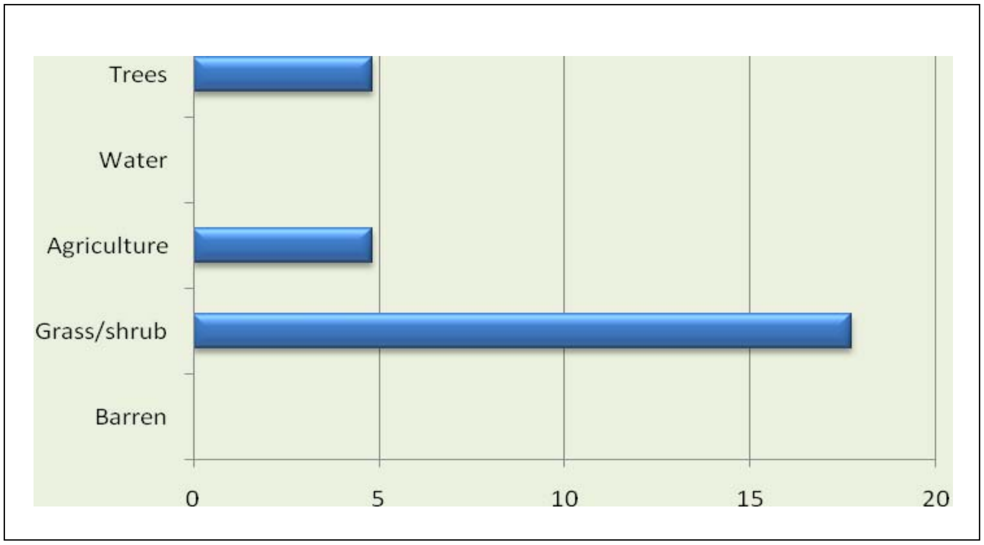

Figure 46 Land Cover Change to Urban Areas (Sq Kilometers) 1987-2004.

Figure 47 shows the areas where grass or shrub land uses changed into urban or other developed land. This alteration occurred along the I-35 corridor, predominantly in and near San Marcos and Kyle. Wimberley, Luling, Lockhart, and Blanco also witnessed significant changes in grass land, shrub land, urban and other developed land. The third type of change happened along the existing or new added roads. Areas that have changed from grass or shrub land to forest land as well as forest land changed to grass or shrub land are shown in Figure 48.

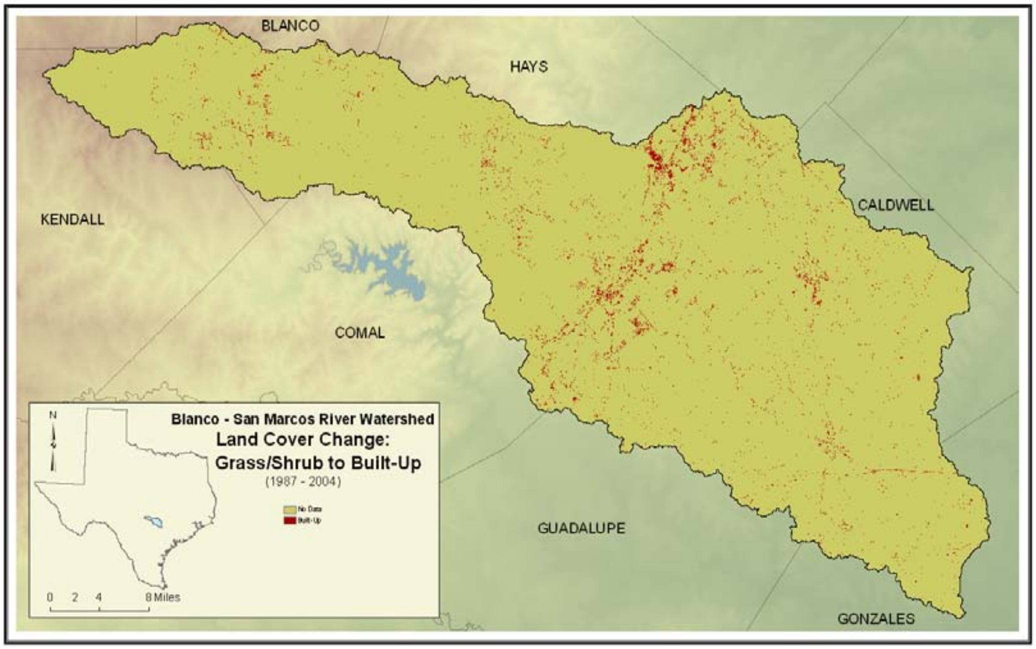

Figure 47 Land Area Changed from Grass/Shrub to Urban, 1987-2994.

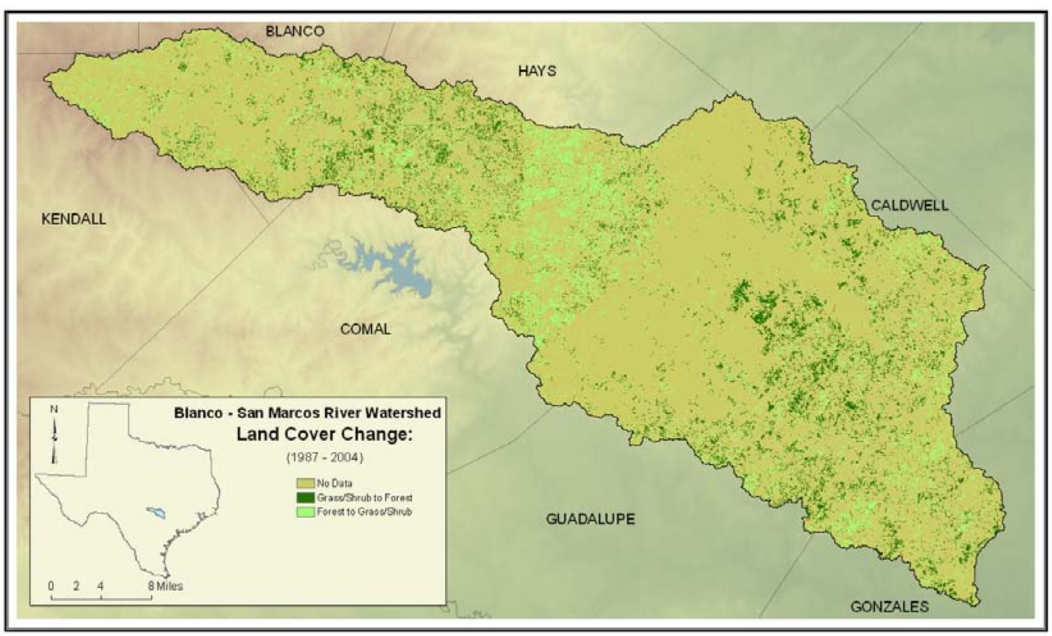

Figure 48 Grass/Shrub Land Changed to Forest Land and Forest Land Changed to Grass/Shrub Land.

The area west of I-35 lost forest land to grass or shrubs. Figure 49 shows those areas that have changed from agricultural to grass or shrub land as well as shrub or grass land converted to agricultural land.

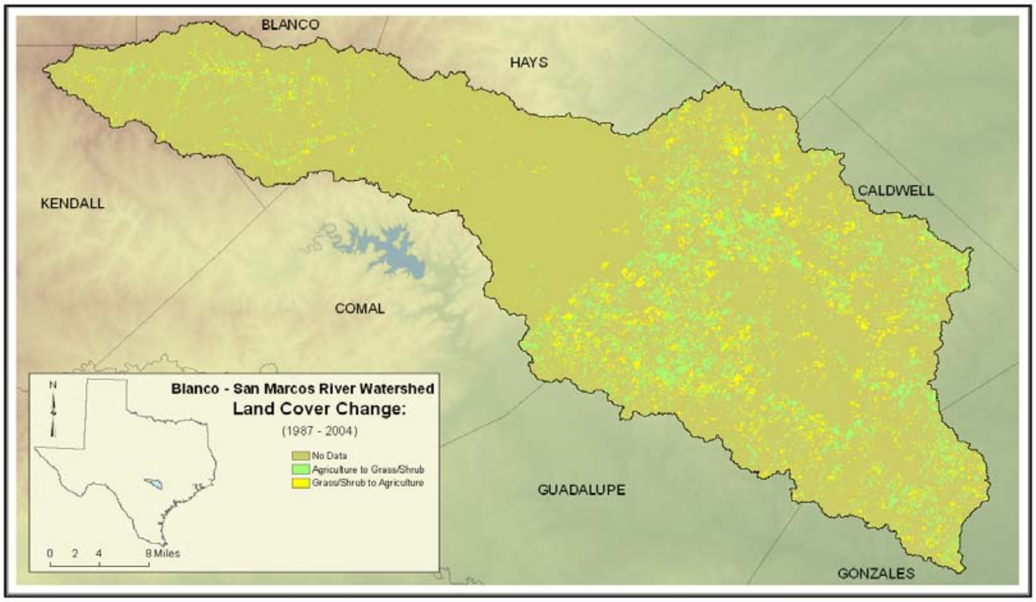

Figure 49 Grass/Shrub Land Changed to Agricultural Land and Agricultural Land Changed to Grass/Shrub Land.

4. Land Cover Change Prediction Modeling

The land use and land cover maps shown in Section 3, and the associated data and information, were used to predict future land use and land cover. This research used a multilayer perceptron neural l network for the modeling process. The process included three stages:

(1) Select land cover change variables that are the driving forces of the previous change,
(2) Generate transition potential data, and
(3) Create change prediction maps.

4.1 Land Cover Change Variables

We were interested in the potential land that might be used for urban growth and other development because runoff from urban areas and urban landscapes can have significant impacts on aquifers and streams. Three variables were chosen for the modeling – distance to the river, distance to urban areas and distance to previously disturbed areas. All model outputs are shown as potentials for land cover change in percentages.

4.2 Land Cover Transition Potentials

Maps were generated from the variables reported above to determine the potential for particular land cover types to be converted to other types or land uses. These transition potential maps were exported directly from the IDRISI software. Values higher on the scale are more likely to change to urban pixels.

Figure 50 shows the potential of land cover change from tree cover to urban land with a scale of 0 to 1. As the map shows, areas in proximity to Blanco, Wimberley, Luling, Lockhart and areas along I-35 corridor have the highest potential for change from tree cover to urban land. The highest potential calculated was 0.8.

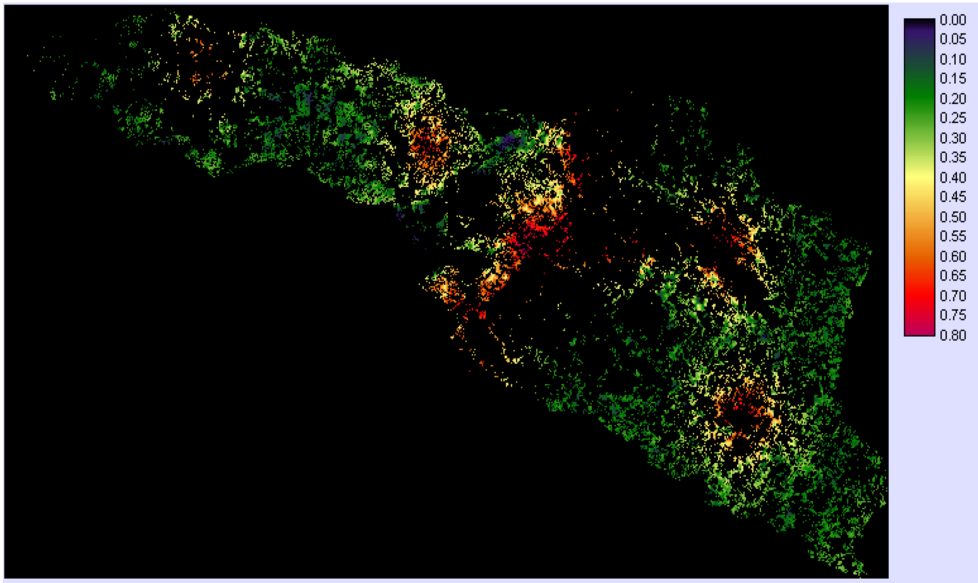

Figure 150 Transition Potential from Tree Cover to Urban Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

The possibility of agricultural land changing to urban and development land is not as high as grass land, shrub land or tree cover. The highest potential only reaches to 0.41 (Figure 51).

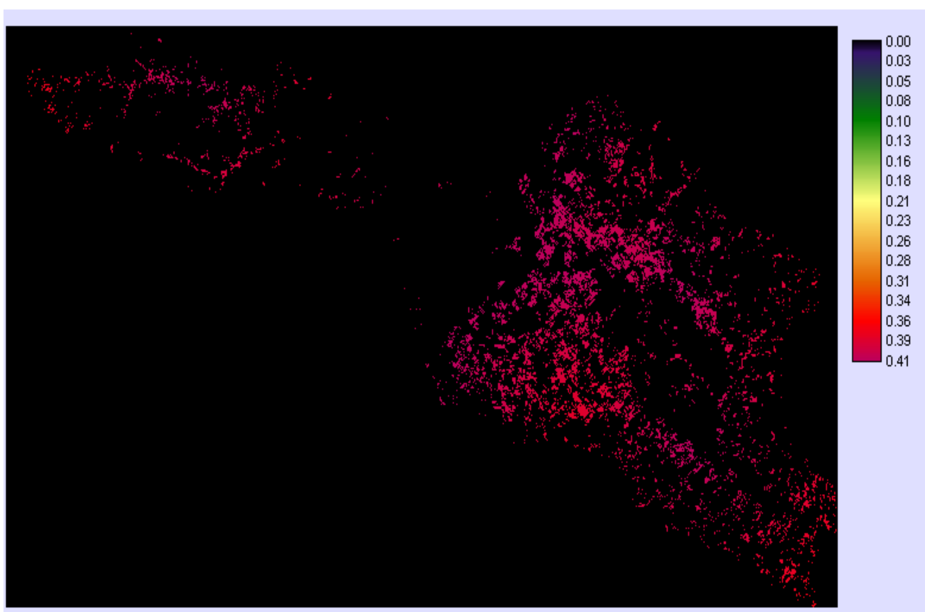

Figure 161 Transition Potential from Agricultural Land to Urban Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

Figure 52 maps the transition potential of land cover change from grass and shrub land to urban and other urban areas. It appears there is a high potential grass land or shrub land that will be used for urban growth and other development. The potential scale reaches 0.86.

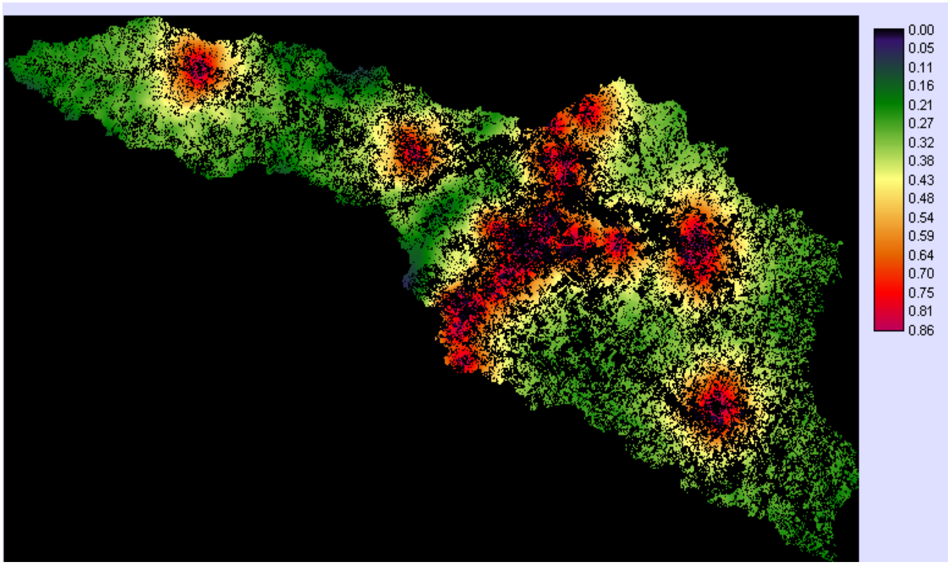

Figure 52 Transition Potential from Grass/Shrub to Urban Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

Figure 53 shows the potential of land cover change from trees to agricultural land. It is interesting to note that both the highest and the lowest potential are located around communities and I-35 corridor. The highest potential is about 0.65.

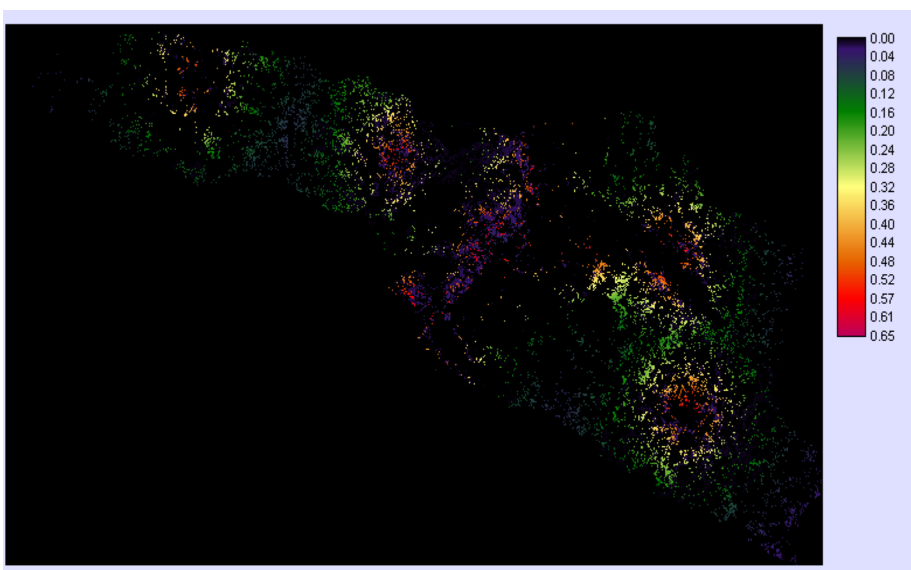

Figure 53 Transition Potential from Tree Cover to Agricultural Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

Despite new and continued development in the area, this modeling effort indicates a good potential for trees to increase in land area/land cover. Figure 54 shows the potential of converting agricultural land into forest land.

These lands spread around the edges of the watershed and away from cities and I-35. This could be a temporary trend as increasingly agricultural fields are not used or maintained. The natural landscape may return until the land is converted to urban uses, for example developed as suburbs. The potential of change from forest to agricultural land, however, is very low. The highest potential area only reaches 0.4, e.g. less than 50% (Figure 55).

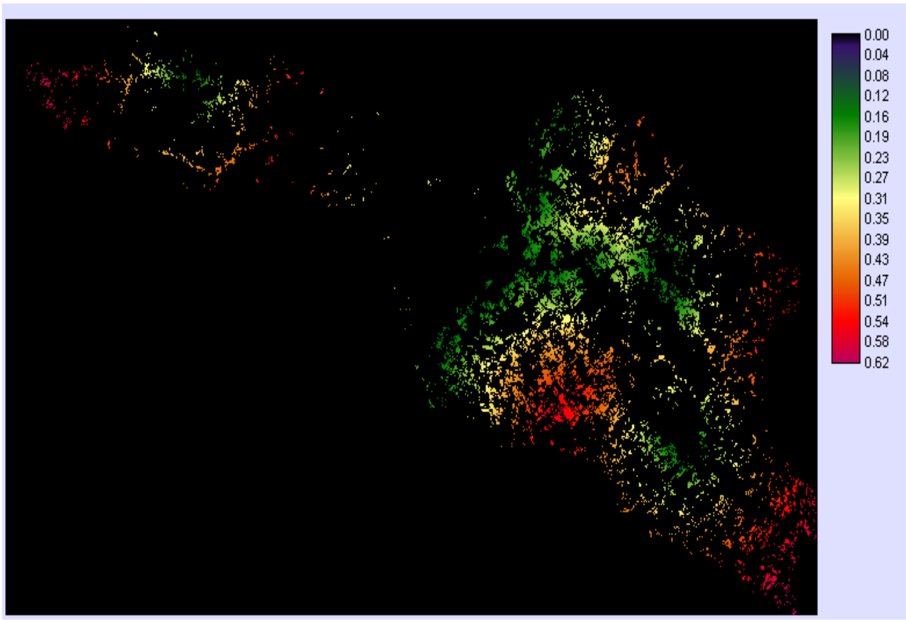

Figure 54 Transition Potential from Agricultural Crop Land to Trees. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

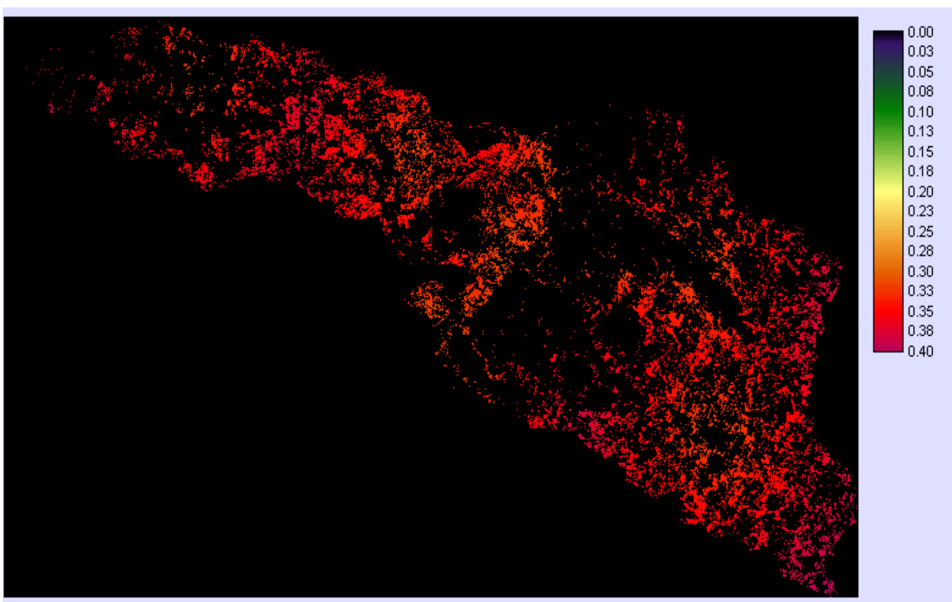

Figure 55 Transition Potential from Forest to Agricultural Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

Figure 56 maps the areas that may change from Grass/Shrub Land to Barren Land in the future. Those areas are located at the upper Blanco River and Upper Cypress Creek. Elevation and erosion are likely to be contributing factors to this type of land cover change. It is very unlikely that agricultural land would be converted to barren land. Figure 57 shows the highest potential rate of this type of change is less than 50%.

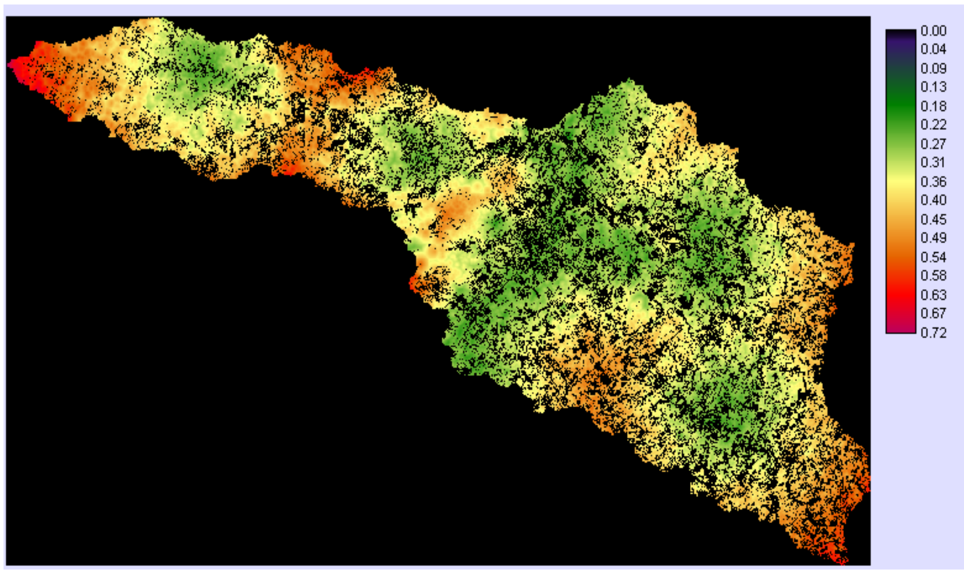

Figure 56 Transition Potential from Grass/Shrub Land to Barren Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

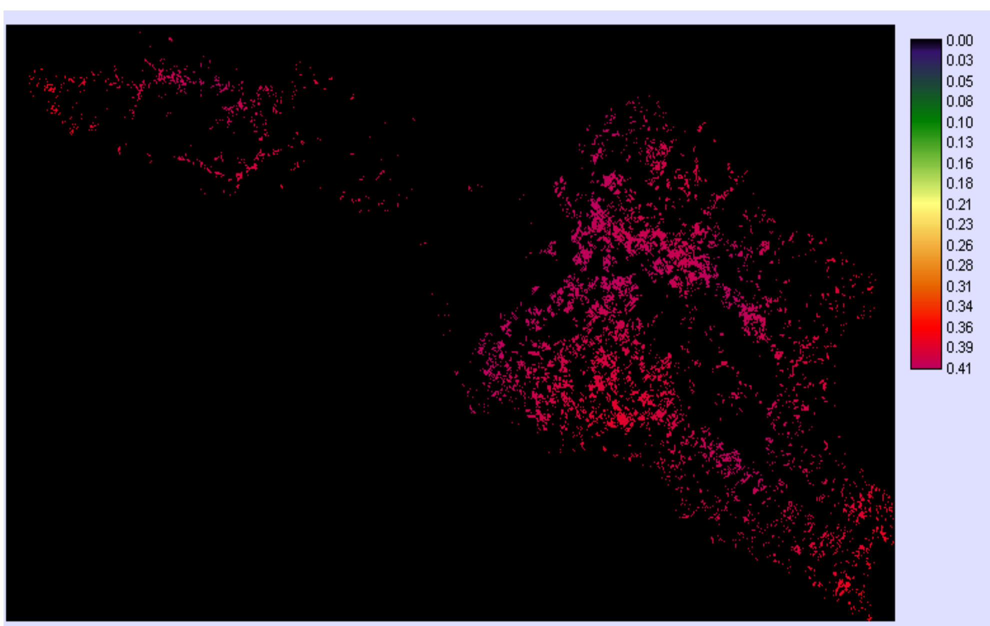

Figure 57 Transition Potential from Agricultural Land to Barren Land. The scale denotes the probability of the predicted land change. Areas in red have the highest probability of change.

4.3 Land Cover Prediction Results

The results discussed below are from the multilayer perceptron neutral network modeling. The accuracy rate for the prediction is 68.43%. Figure 58 and 59 are maps of land cover for the years 2020 and 2050 resulting from predictions through application of IDRISI software predictive programs. It is interesting to note that Gonzales, which is outside of the study area, is predicted to grow and expand into the lower portion of the San Marcos River watershed.

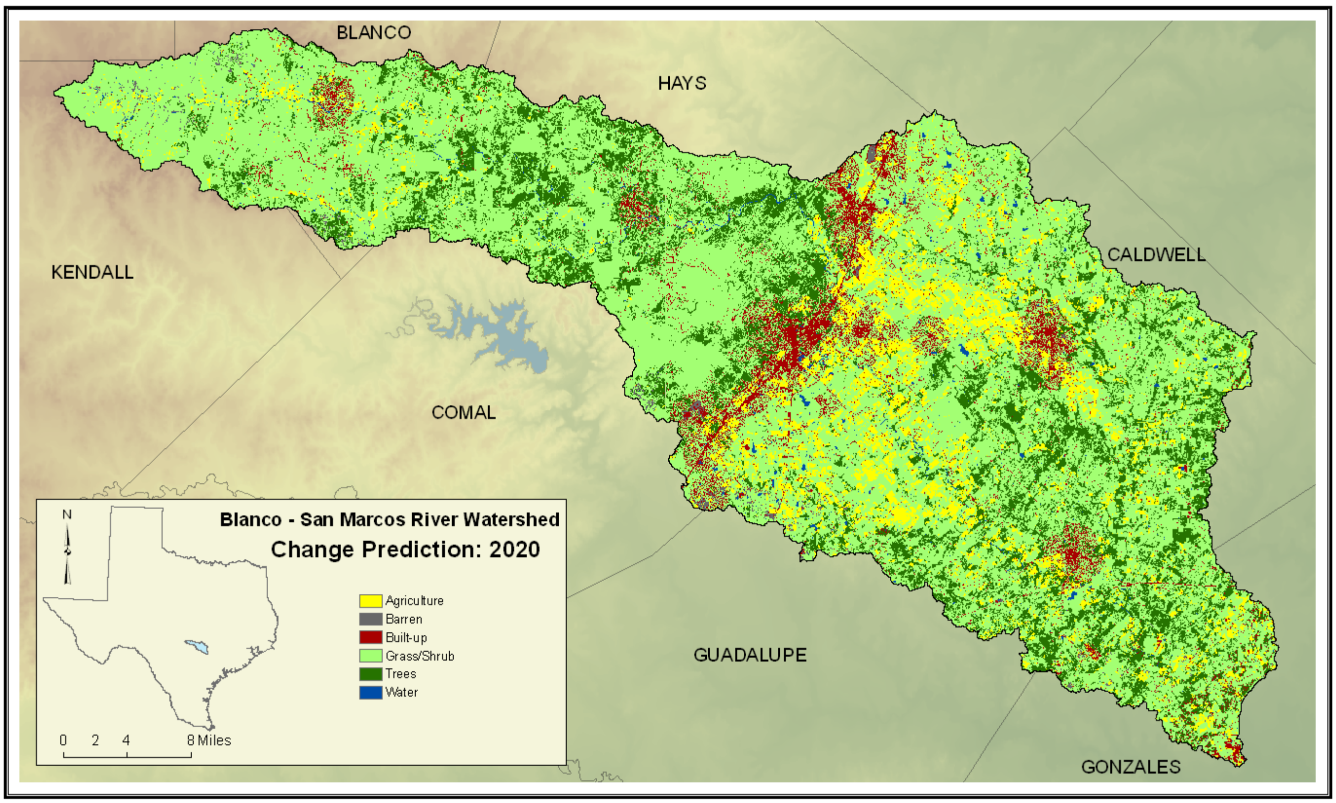

Figure 17 Predicted Blanco-San Marcos Watershed Land Cover in 2020.

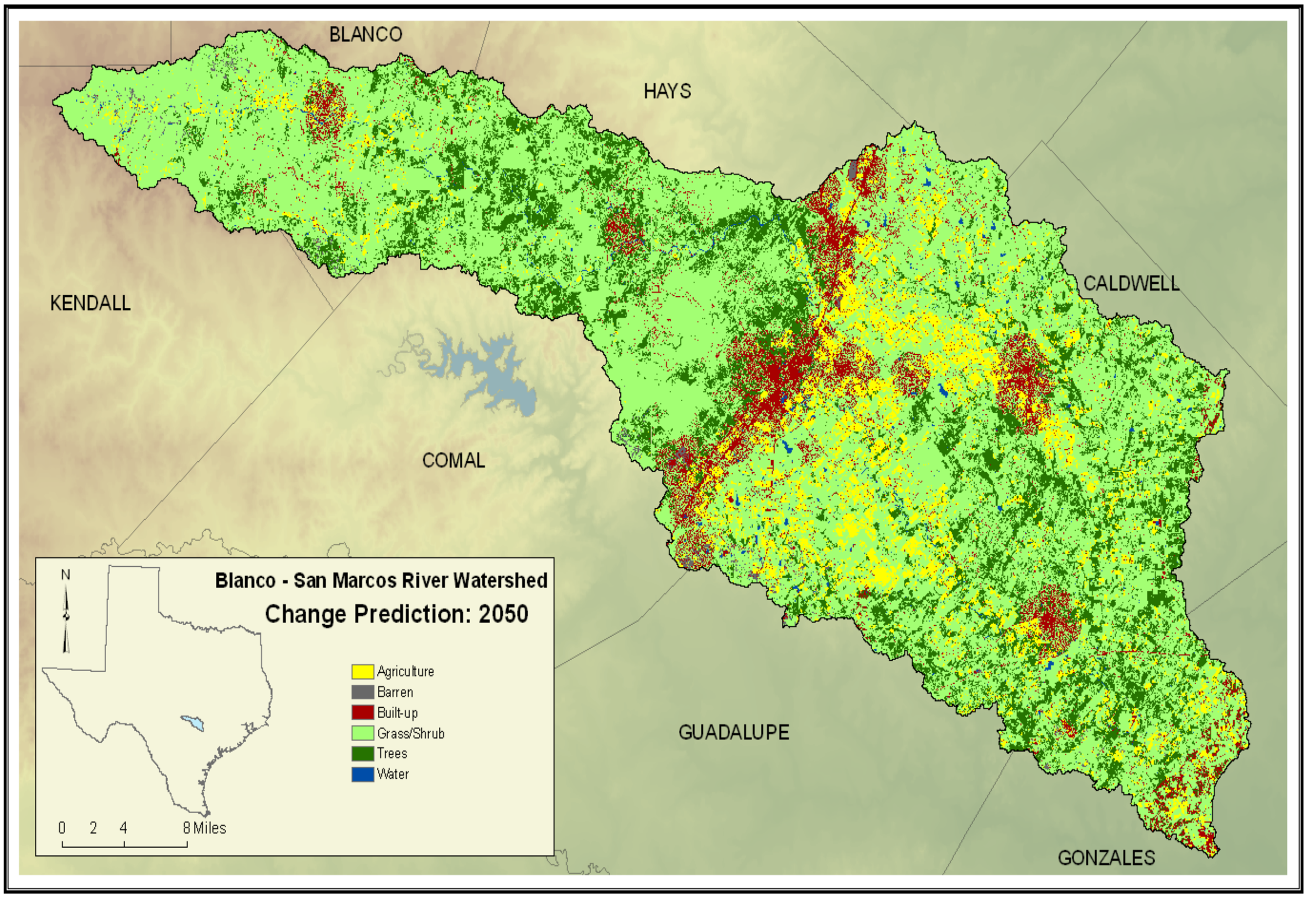

Figure 18 Predicted Blanco-San Marcos Watershed Land Cover in 2050.

4.4.1 Kappa Statistics

The average Kappa index of agreement of the two resulting images for year 2020 and 2050 was calculated. Table 5 lists the resulting Kappa index for each land cover class. The results indicate that urban and urban area are the most likely to change in those 30 years.

Table 5 Kappa Index of Agreement (KIA).

Land Cover Classes	Kappa Index of Agreement (KIA) Using 2020 as the reference image	Kappa Index of Agreement (KIA) Using 2050 as the reference image
Urban	0.7560	0.6279
Tree Covers	0.9776	0.9959
Water	1.0000	1.0000
Agricultural Crop Land	0.9610	0.9769
Grass/Shrub Land	0.9652	0.9783

V. Preliminary Watershed Streamflow and Non-Point Source Pollution Model Testing

This project used Hydrological Simulation Program in Fortran (HSPF) to simulate watershed streamflow and non-point source pollutant loading. Model inputs included climate data from 1970 to 2006, and the sub-watersheds were delineated from digital elevation model (DEM) files to simulate streamflow, runoff, and sediment loading within these sub-watersheds. For this preliminary test, one of the 11 sub-watersheds was selected to evaluate the efficacy of the modeling approach. Flow data from USGS monitoring station 12100203 located in the middle section of the San Marcos River, defined as Reach 11 in the HSPF model, were used to calibrate the period of 1970 to 2004. The Middle San Marcos River sub-watershed was selected due to its geographic location downstream of the City of San Marcos and the availability of data for the sub-watershed.

Land use in the study area rapidly changed from the mid-1980s through 2005. Therefore, two scenarios in the Middle San Marcos River sub-watershed were assessed to identify potential impacts of land cover change on the watershed in those twenty years. One simulation used land cover data that represented land use and land cover in the 1970s and 1980s (EPA, 2010, USGS LCI 2010). The second scenario used land cover data that represented land use and land cover in 1990s and 2000s (MRLC, 2001, USGS LCI 2010). The two simulated scenarios produced constituent time series of streamflow, surface run off, and sediment. The results were then compared and correlated. The following sections discuss simulation results on the selected sub-watershed, the Middle San Marcos or Reach 11 of the model. Future model testing and calibration can be used to answer the question of whether the land cover change during that period has made significant impact in the entire watershed on the three selected hydrologic parameters - streamflow, runoff, and sediment loading – and thus potentially impacting water quality associated with these parameters.

5.1 Watershed model

Figure 60 presents the sub-watershed delineation for modeling and resulting reaches. This delineation is the same 11 sub-watersheds and reaches presented in Section 1 (see Table 1 and Figure 2); however, Figure 60 displays the DEM drainage features. The Middle San Marcos River sub-watershed, Reach 11, is the focus of the model evaluation. Reach 11 is located upstream and to the northwest of the lowest sub-watershed, the Lower San Marcos sub-watershed, in the overall Blanco-San Marcos watershed. Based on the sub-watershed delineation, Figure 61 shows the correspondent HSPF model diagram that simplifies the hydrologic relationships in the model.

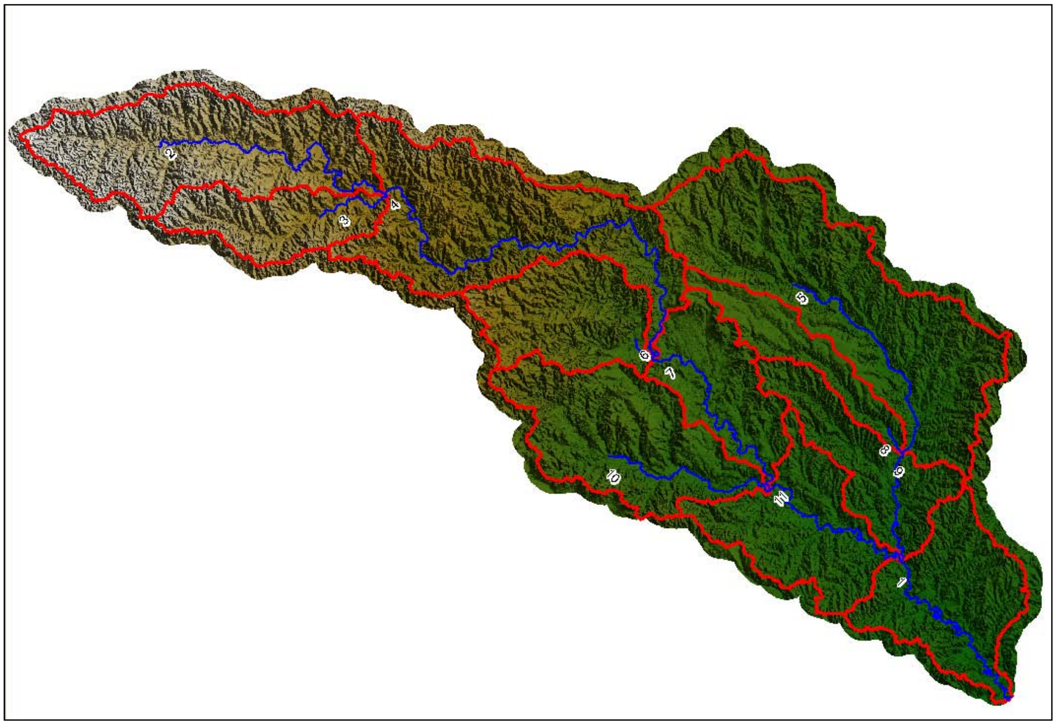

Figure 19 HSPF Model Delineated Sub-watersheds and Reaches.

Reach 11, the Middle San Marcos River, is upstream and to the northwest of Reach 1, the Lower San Marcos River, located at the bottom right of the figure.

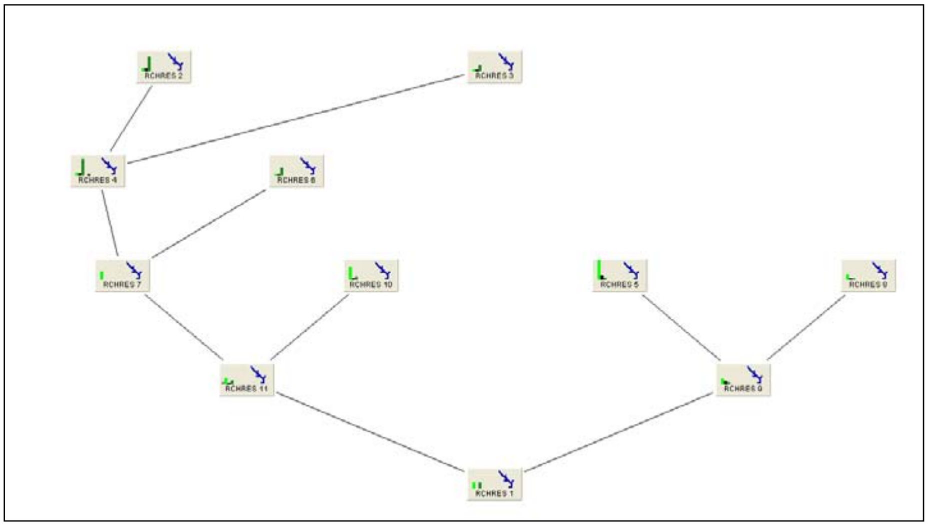

Figure 20 HSPF Watershed Model Diagram.

Within the flow domain of the model, Reach 11 is upstream (to the left) of Reach 1, shown at the lowest point in the diagram.

5.2 Comparison of Stream Simulation Results for the Middle San Marcos Sub-Watershed (Reach 11)

5.2.1 Streamflow

Streamflow was simulated specifically for mean historical precipitation data in order to view potential impacts of precipitation on stream flow modeling results. Comparisons of the results were through use of the 1987 and 2004 land cover data sets for the Middle San Marcos Sub-Watershed (Reach 11).

Figures 62 – 64 present example simulation results for stream flow from 1970 through 2006 for Reach 11. Figure 62 shows little change in streamflow patterns between the two years (1987 and 2004); both sets of data indicate similar high flow rates in peak years. Data from 1987 land cover indicate only slightly higher flows (see red graph lines in Figure 62) that those from the 2004 data (blue graph lines). This slight difference in results is attributed to model calibrations that focused on mean conditions rather than specific calibration targets of peak flow events. The simulation results suggest that land cover change occurring between the 1970s and 2000s has not made a significant impact on the stream flow in Reach 11, a relatively undeveloped area. Although significant land conversion to urban areas has occurred, such changes have been confined to small geographic pockets or expansion of existing development in urban areas pre-dating the 1970s data set used for the model.

Overall, the basin-wide percentage change in land cover is very low. The Middle San Marcos sub-watershed is relatively undeveloped as it is downstream of urban development in San Marcos and adjacent in its lower sub-basin to urbanization occurring in Luling within the sub-watershed to the east.

Figure 63 shows a strong correlation between the two simulations runs for average daily flow (0.99), although the occurrence of only slightly higher flow rates in 1987 values shown in Figure 62 above are attributed to calibrations of mean conditions rather than high flow events. As would be expected, the duration curves, or likelihood that simulated stream flows for the two data sets exceed expected flows, are almost identical (Figure 64). The similar duration curves also suggest that overall total changes in land cover in Reach 11 are small and have not greatly impacted stream flows along this segment.

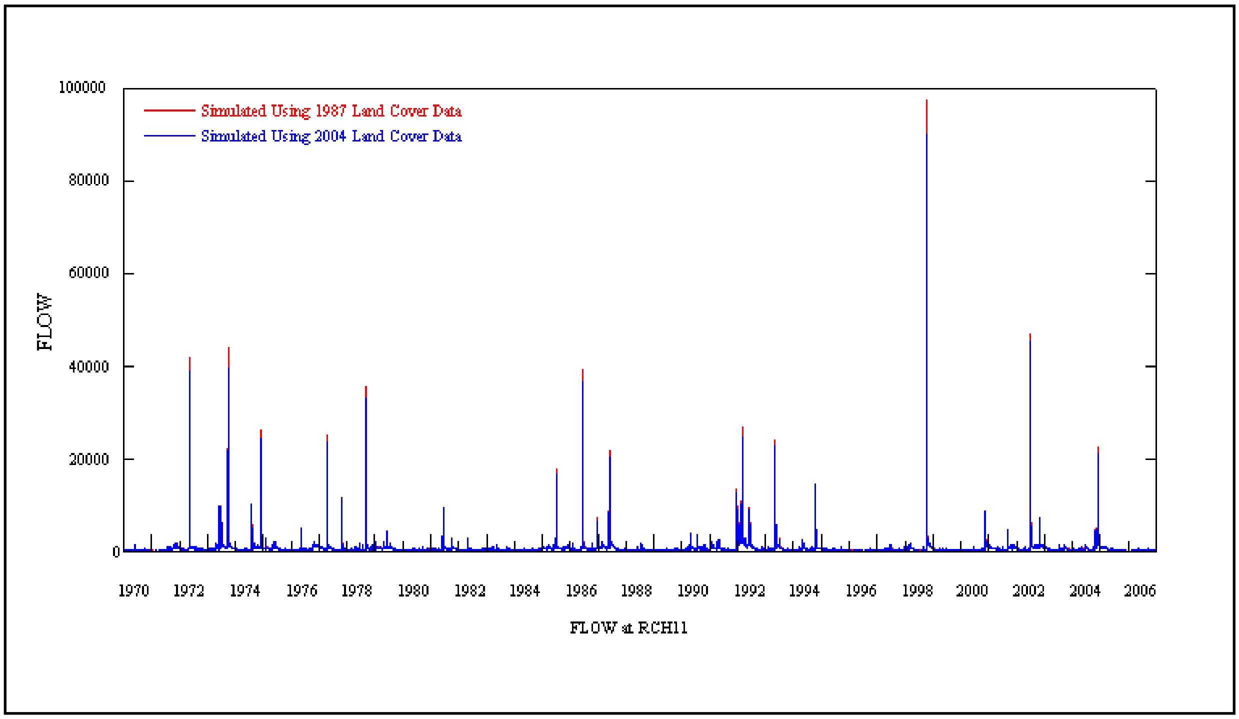

Figure 21 Simulated Streamflow Results for 1987 and 2004 Land Cover Data (Middle San Marcos Reach 11).

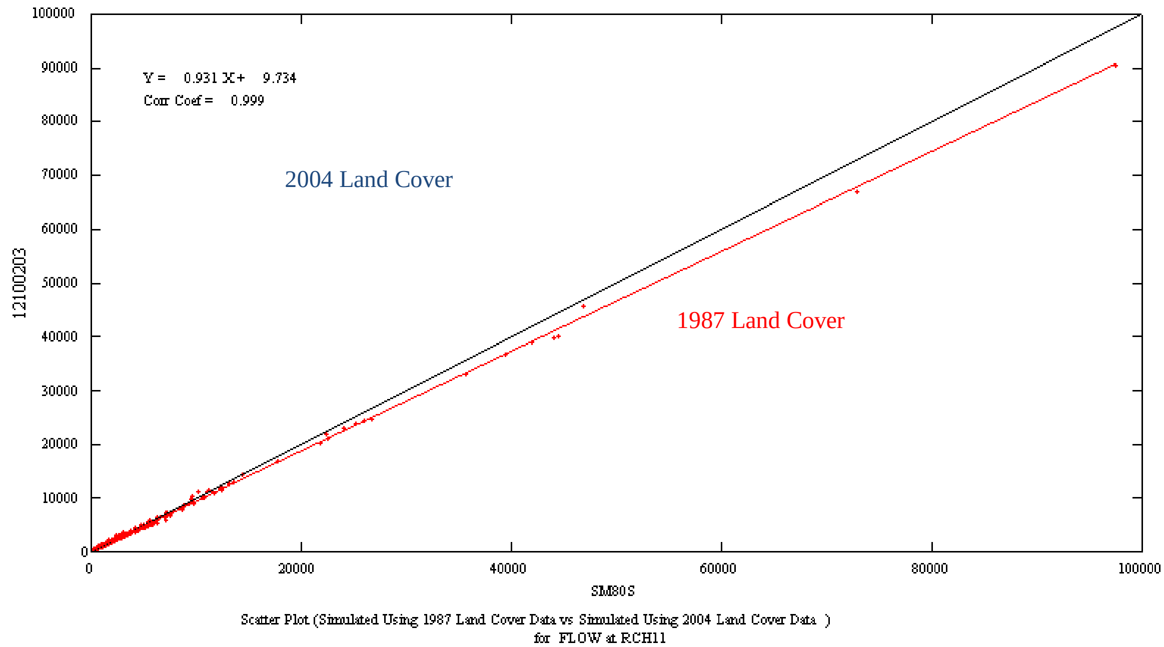

Figure 22 Scatter Plot of Daily Flow Averages (Correlation of Simulated Streamflow Results for 1987 and 2004 Land Cover Data (Middle San Marcos Reach 11).

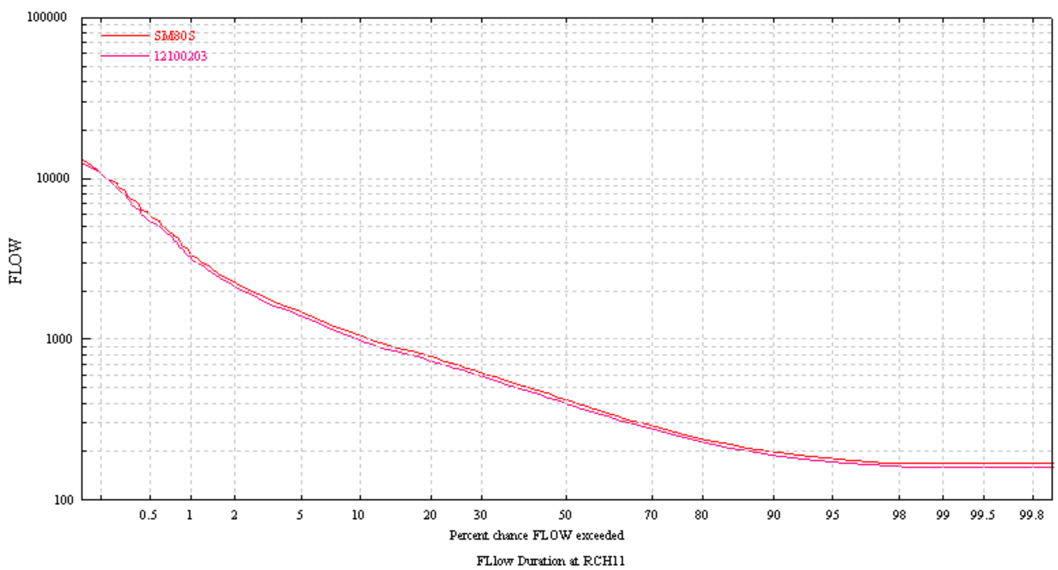

Figure 23 Percent Chance of Simulated Streamflow Exceedance for 1987 and 2004 Land Cover Data Simulations (Middle San Marcos Reach 11).

The impervious cover for the watershed in 2001 is mapped in Figure 65. The map demonstrates the small amount of impervious cover relative to the entire basin. Section 3.8, "Land Cover Changes", reports the various types of land cover converted to urban cover. Even with these additions to urban and impervious cover, the total percentage of impervious areas remains very small relative to total basin area. Such geographically limited areas of impervious cover throughout the watershed aid in understanding the model simulations.

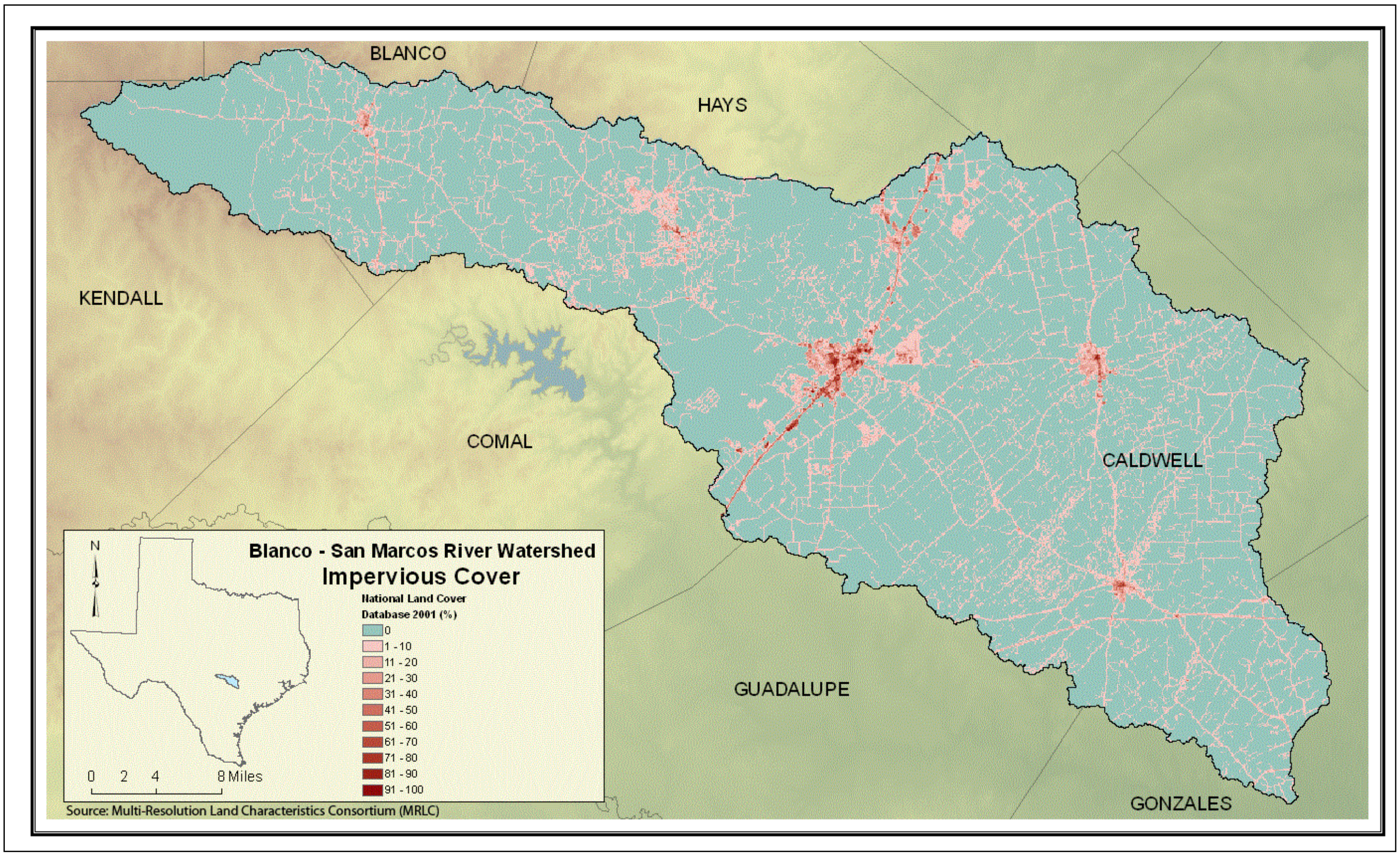

Figure 24 Total Impervious Cover in 2001.

5.2.2 Total Runoff

Figures 66 – 68 show example simulation results for total runoff in the Middle San Marcos (Reach 11) using the two land cover scenarios (1987 and 2004). Similar to the results from stream flow simulations, the two scenarios produced almost identical values for total runoff during the simulation period. Figure 66 shows slightly higher total annual runoff rates and peaks for the 2004 simulation. Figure 67 shows a high correlation between the two years of simulation outputs for average daily runoff. The duration curves in Figure 68 show little variation, suggesting small changes in overall land cover as discussed in Section 5.2.1. These results appear to indicate that land development in recent years has not had considerable impact on the total runoff occurring in Reach 11.

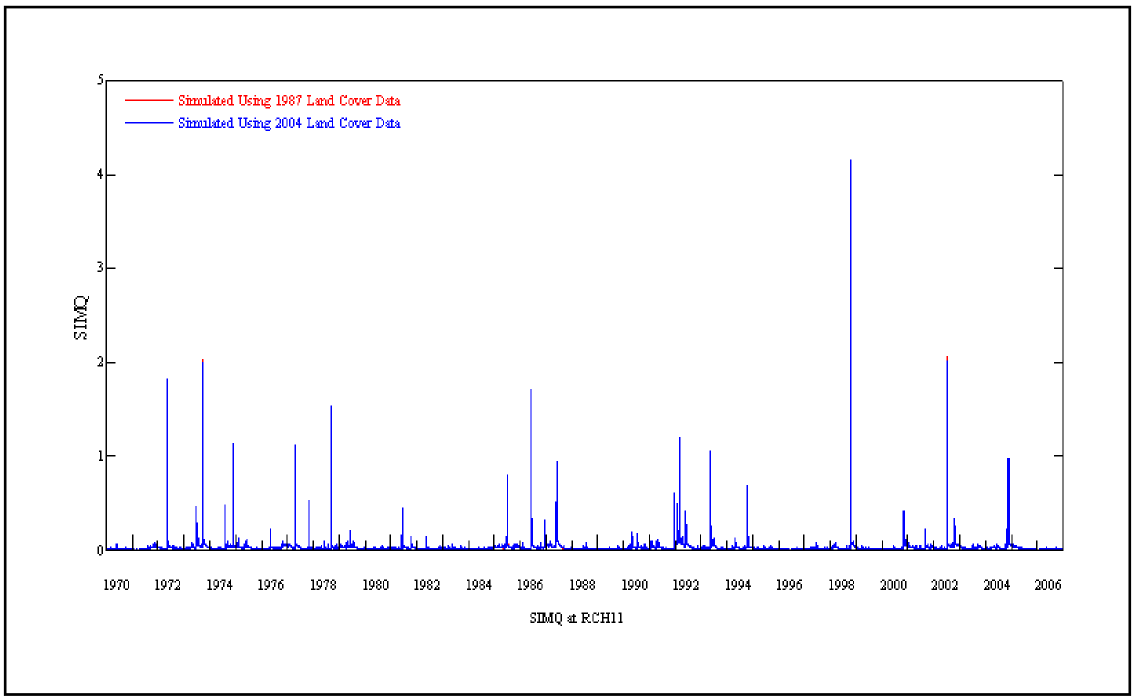

Figure 66 Simulated Annual Runoff Totals 1970-2006 Using 1987 and 2004 Land Cover Data (Middle San Marcos Reach 11) in Inches.

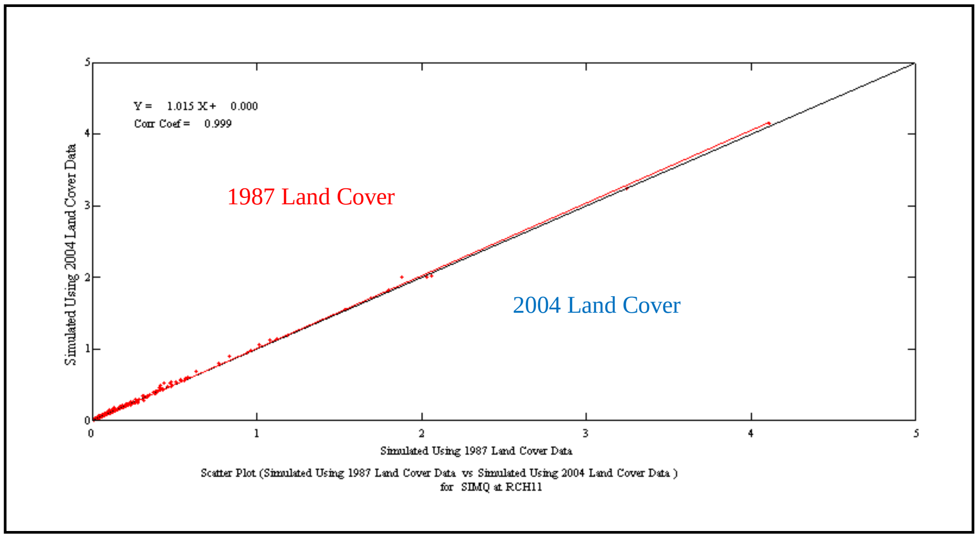

Figure 25 Scatter Plot of Daily Runoff Averages (Correlation of Simulated Daily Runoff Results for 1987 and 2004 Land Cover Data (Middle San Marcos Reach 11).

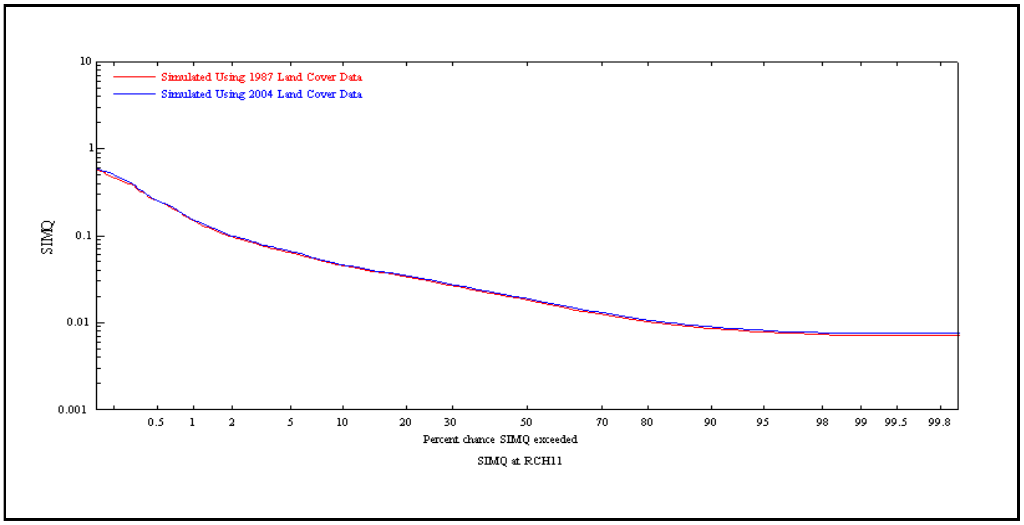

Figure 26 Percent Chance of Simulated Runoff Exceedance for 1987 and 2004 Land Cover Data Simulations (middle san marcos Reach 11).

5.2.3 Soil Moisture -Upper and Lower Zone Storage

This section provides a brief review of soil hydrology simulations during periods when the water table approaches or exceeds the ground surface level. The diagram below illustrates the upper and lower soil zones as defined by the HSPF model, where P_{cw} denotes the porosity of cohesion water and P_{gw} is the porosity of gravity water (Figure 69). Water is accumulated in soil as "cohesion" water, which is bonded by capillary forces and considered equal to the available water. Water that drains into the unsaturated zone is considered "gravity" water. The porosity of a soil is the volume of pore space as a fraction, or a percentage, of the total soil volume. Porosity values for sand range from 40% for sands to higher values for silts and clays (Engenious Systems, 2010). Cohesion and porosity do not require consideration when viewing the simulation outputs.

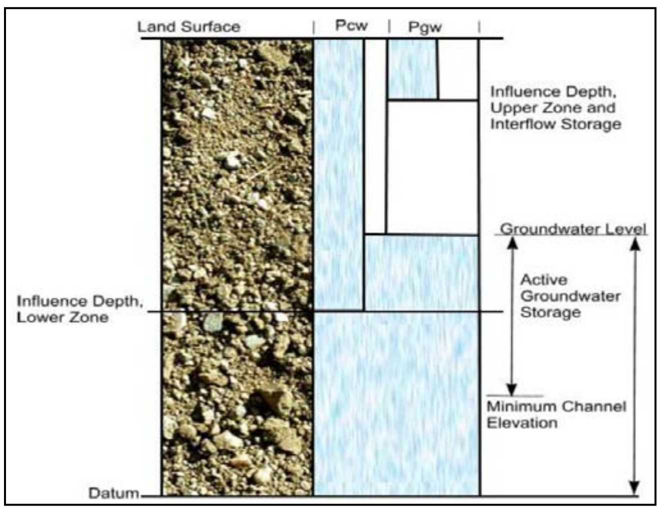

Figure 69 HSPF-Defined Soil Moisture Storage Zones for Average-High Water Table Conditions

Using 1987 and 2004 land cover scenarios, Figures 70 and 73 show simulation outputs for monthly upper and lower soil zone storage totals for the years (1980-2006). With increases in impervious cover in the overall watershed, soil saturation and storage rates are expected to be lower. Both upper and lower soil zone storage show little variation between the two land cover scenarios, with the 1987 scenarios exhibiting slightly higher volumes. As with outputs presented previously, some variation between the two land cover simulations was expected;, although the 1987 volumes were slightly higher, the difference does not appear to be significant. One likely cause may be the majority of change in land cover affecting moisture storage was confined to geological regions that have very low initial storage potential. Figures 71 and 73 show high rates of correlation (1.00) for daily upper zone storage averages and lower zone storage averages between the two land cover scenarios.

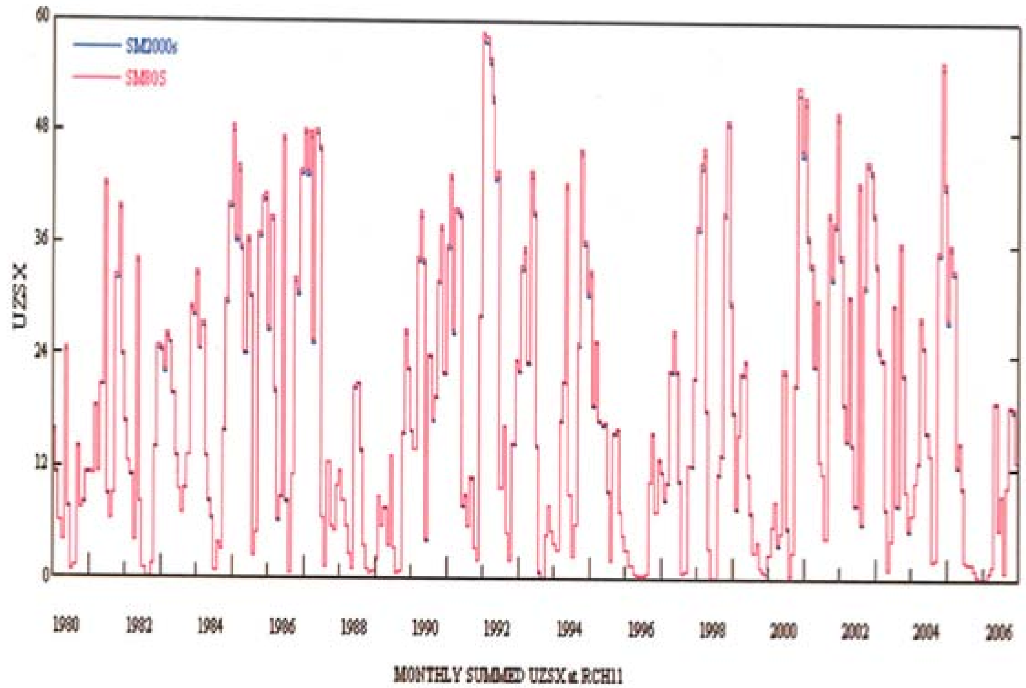

Figure 70 Simulated Monthly Upper Zone Storage Totals 1980-2006

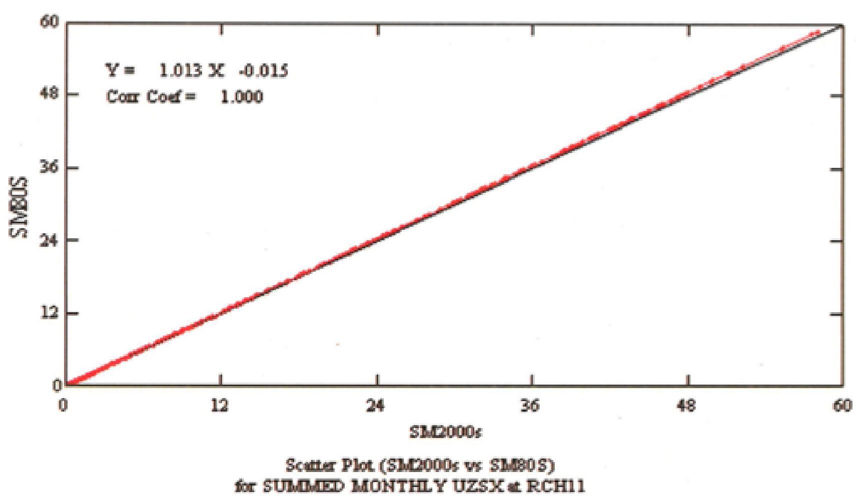

Figure 71 Scatter Plot of Daily Upper Zone Storage Averages (Correlation of Simulated Upper Zone Storage Results for 1987 and 2004 Land Cover Data (Middle San Marcos Reach 11).

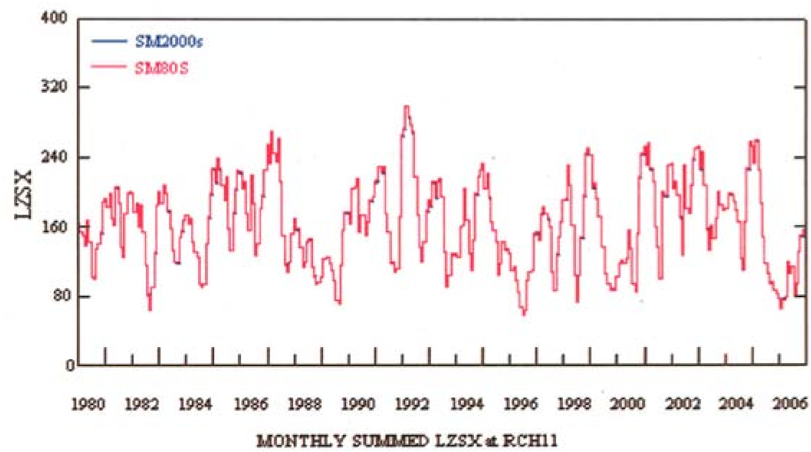

Figure 72 Simulated Monthly Lower Zone Storage Totals 1980-2006 Using 1987 and 2004 Land Cover Data (middle san marcos Reach 11) in Inches.

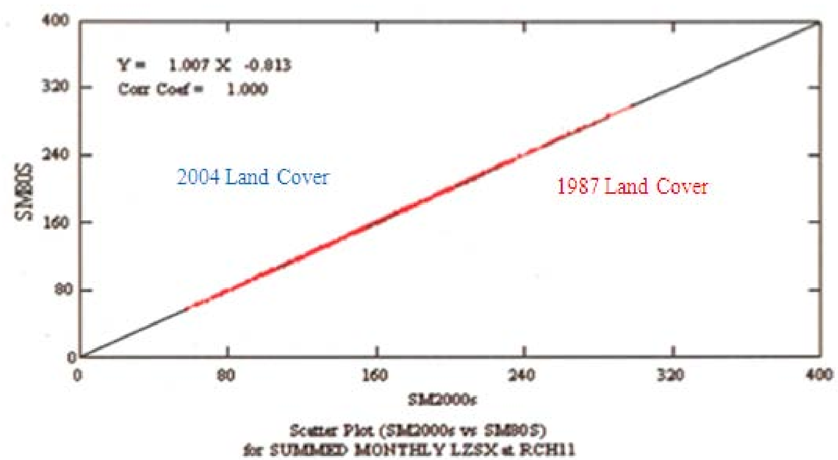

Figure 73 Scatter Plot of Daily Lower Zone Storage Averages (Correlation of Simulated Lower Zone Storage Results for 1987 and 2004 Land Cover Data (middle san marcos Reach 11).

5.2.4 Sediments

Three sediment classes - sand, silt, and clay- were simulated in scenarios as initial concentrations (SDD1, SDD2, and SDD3). Figures 74 – 76 illustrate the simulated values. All three sediment classes show lower levels of deposition in the 2004 land coverage scenario.

Typically, urbanization leads to higher rates of runoff and potential sediment deposition. The results for sedimentation simulations in this sub-watershed (Middle San Marcos River) appear to indicate that land cover change between the 1970s and 2000s may be associated with decreased sediment deposition in the lower reach of the study area. However, there are multiple factors that may account for these results. Land use changes associated with urbanization that primarily occurred in areas of limestone bedrock formations, such as found west and northwest of the I-35 corridor and the Balcones fault zone, most likely do not substantially contribute to sediment input as there is less available sediment in these areas. The model does not account for short-term sediment loading associated with construction.

In addition, changes in land cover associated with vegetation can result in reductions in export coefficients depending on the specific vegetation (or land cover) type. In recent years significant efforts to improve and restore riparian vegetation to help retain sediment carried in overland flow and prevent in channel deposition have also occurred throughout regions of the basin. Changes in in-stream vegetation yield similar soil retention outcomes. Throughout the basin, increased requirements for preventing erosion have mitigated some sediment loading, preventing sediments from being carried by overland flow and rainfall to stream channels. Other possible reductions in sediment deposition in this particular Reach 11 may include upstream impoundments and diversions, reductions in upstream flows due to surface and groundwater withdrawals (likely associated with population growth and development).

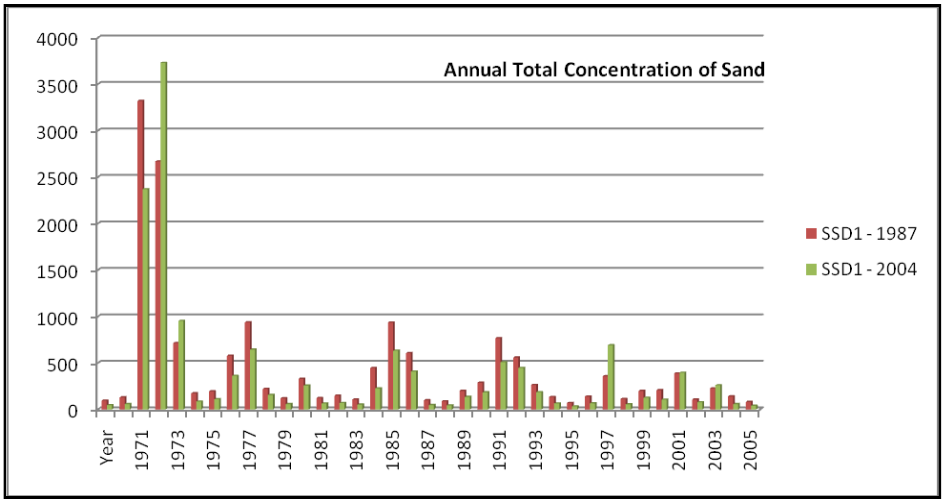

Figure 74 Simulated Concentrations of Sand Using 1987 and 2004 Land Cover Data (middle san marcos Reach 11) in Mg/L.

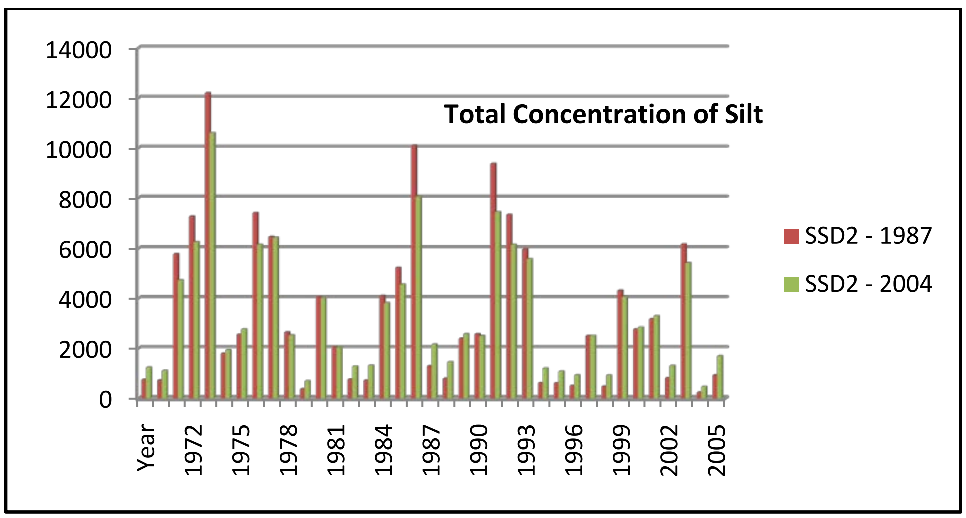

Figure 75 Simulated Concentrations of Silt Using 1987 and 2004 Land Cover Data (middle san marcos Reach 11) in Mg/L.

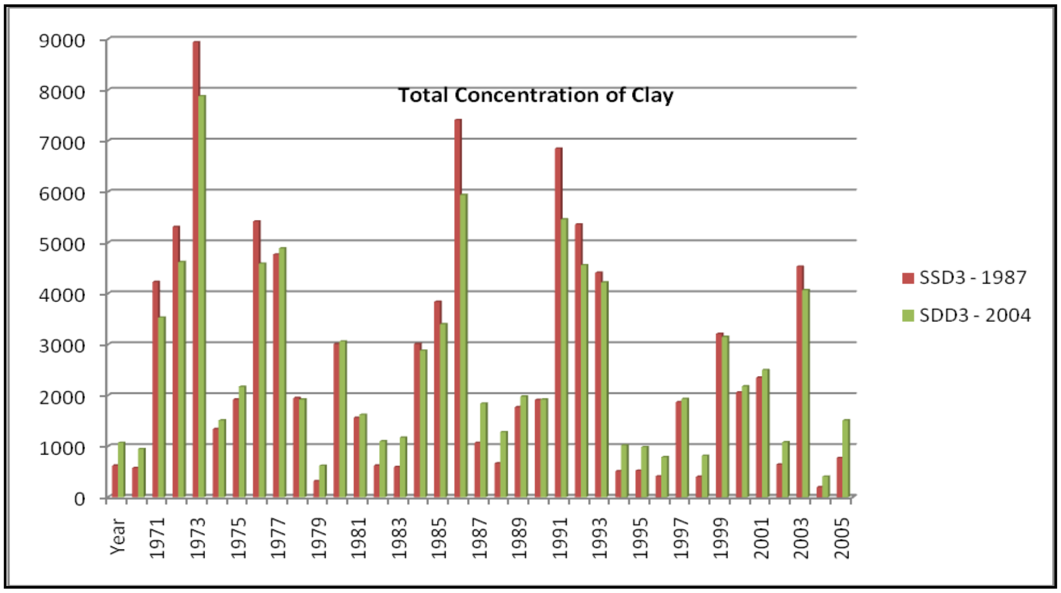

Figure 76 Simulated Concentrations of Clay Using 1987 and 2004 Land Cover Data (Middle San Marcos Reach 11) in Mg/L.

5.3 Conclusion

The scenario results presented above for the Middle San Marcos sub-watershed (reach 11) do not demonstrate significant impacts of land cover changes on streamflow, runoff, surface flow and storage and unequivocal results regarding sediment deposition., Potential causes of these simulation results include calibration to mean conditions rather than low and high flow regimes, lack of model sensitivity, resolution, and the nature of the selected sub-watershed, which is a relatively undeveloped reach of the San Marcos river. Although land cover and land use changes are rapidly occurring throughout portions of the basin, the overall percentage of conversion and total urbanized (impervious) land cover is still small relative to total basin area, and is the probable underlying cause for model insensitivity at the larger basin scale nodes used in this research. Model test sites such as Reach 11 near the terminal end of the basin may not effectively capture changes in water quality and flow and may require reconsideration of intermediate simulation node locations immediately downstream of key areas to better define smaller spatial scale impacts. Future calibrations, modifications and validity testing will be necessary to fully implement this model.

It is known that runoff of pollutants and sediments from urban landscapes can be stressful on the natural environment, present in elevated pollution and sediment levels, declining aquatic habitat, unhealthy conditions for contact recreation, and increased costs for high quality and plentiful drinking water supplies. With refinement, this model will be useful in long-term watershed protection planning processes and will be incorporated into the River Systems Institute’s San Marcos River Observation System, a critical management tool designed to monitor and provide real time and estimated future information regarding ecosystem and water quality management. This technology will improve existing planning processes and best management practices for remediating 319 waters, complying with total maximum daily load (TMDL) and national pollutant discharge elimination system (NPDES) requirements, as well as protect existing standards in the face of land use and cover change impacts.

References

Engenious Systems. *Soil Moisture Concepts.* Retrieved December 15, 2010, from

http://www.engenious.com/downloads/HighWaterTable.pdf

Environmental Protection Agency (EPA). *GIRAS.* Retrieved December 15, 2010, from

http://water.epa.gov/scitech/datait/models/basins/metadata_giras.cfm

Environmental Protection Agency (EPA). *2001 National Land Cover Data (NLCD 2001).* Retrieved in 2008 from

http://www.epa.gov/mrlc/nlcd-2001.html

Multi-Resolution Land Characteristics Consotrium (MRLC). *National Land Cover Database 2001 (NLCD 2001).*

http://www.mrlc.gov/nlcd.php

National Aeronautics and Space Administration (NASA). *Landsat data.* Retrieved in 2008 from

http://landsat.gsfc.nasa.gov/

National Land Cover Database (NLCD). *Multi-Resolution Land Characteristics Consotrium (MRLC).*

http://www.mrlc.gov/nlcd.php

Texas Natural Resources Information System (TNRIS). *Floodplain Mapping.* Retrieved in 2008 from

http://www.tnris.state.tx.us/Programs/NFIP/Index.aspx

Texas State Library and Archives Commission (TSLAC). *1990 Census: Population of Texas Cities.* Retrieved December 15, 2010, from

http://www.tsl.state.tx.us/ref/abouttx/popcity1.html

Texas State Library and Archives Commission (TSLAC 2010 B). *2000 Census: Population of Texas Cities.* Retrieved December 15, 2010, from

http://www.tsl.state.tx.us/ref/abouttx/popcity12000.html

United States Census Bureau. (2010). *American FactFinder Fact Sheet: Kyle city, Texas.* Retrieved December 15, 2010, from

http://factfinder.census.gov/servlet/SAFFPopulation?_event=Search&geo_id=16000US4845096&_geoContext=01000US|04000US48|16000US4845096&_street=&_county=kyle&_cityTown=kyle&_state=0400

0US48&_zip=&_lang=en&_sse=on&ActiveGeoDiv=geoSelect&_useEV=&pctxt=fph&pgsl=160&_submenuId=population_0&ds_name=null&_ci_nbr=null&qr_name=null&reg=null:null&_keyword=&_industry=

U.S. Geological Survey Land Cover Institute (USGS LCI) . Retrieved December 15, 2010, from http://landcover.usgs.gov/

Utah State University. (November 2008). *WRIA 1 Decision Support System*. Retrieved December 15, 2010, from http://wria1project.whatcomcounty.org/uploads/PDF/Decision%20Support%20System/Decision%20Support%20System%20Executive%20Summary_Final_11.14.08_11x17.pdf