# A STORM WATER RUNOFF INVESTIGATION USING GIS AND REMOTE SENSING

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Environmental controls are becoming more and more expensive to implement, so environmental management is becoming more technologically advanced and efficient through the adoption of new techniques and models. This paper reviews the potential for storm water runoff for the city of Denton, Texas and with the main objective to perform storm water runoff analyses for three different land use datasets; each landuse dataset created with a different methodology. Also analyzed was the difference between two North Central Texas Council of Governments land use datasets and my own land use dataset as a part of evaluating new and emerging remote sensing techniques. The results showed that new remote sensing techniques can help to continually monitor changes within watersheds by providing more accurate data.

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# CHAPTER 1

# INTRODUCTION

Environmental controls are becoming increasingly more expensive to implement; as a result, environmental management is becoming more technologically advanced and efficient through the implementation of management tools and models. Mathematical models are important for analyzing quality and quantity problems resulting from urban storm water runoff. An intense concentration of human activity in a small area results in competition for resources with water being the most important. The purpose of this research is to help inform the city of Denton officials with accurate data so they can better manage their city. This study analyzed the potential for storm water runoff for the city of Denton, Texas using three different land use datasets; each landuse dataset created with a different methodology. The difference between the three land use datasets, two from the North Central Texas Council of Governments (NCTCOG) and one my own dataset, was also studied as a part of evaluating and comparing new remote sensing techniques. The hypothesis asks: Do new remote sensing techniques provide for more precise and effective land use data in stormwater runoff analyses?

In urban catchments, such as the one in Denton, natural water courses are altered and the amount of impervious surfaces increases significantly due to urban expansion. Impervious surfaces consist of man-made structures such as paved roads, sidewalks, driveways and parking lots. These structures are covered by impenetrable materials such as asphalt, concrete, brick and even soils compacted by urban development. They restrict the ability of storm water to soak into the soil and instead water runs off directly. This is a particular problem for the North Texas region of the United States due to the dominance of clayey soils and unpredictable weather patterns that tend to produce extreme events such as flash floods and tornadoes. The combination of mostly non-porous and expansive soils and intense urban infrastructure, resulting in impervious surfaces, creates a serious need for better monitoring technology and methodologies to combat storm water runoff that results in flooding. Procedures for predicting runoff volumes are constantly being designed and tested with more recent models implementing remote sensing and geographic information system technologies.

To evaluate new and emerging remote sensing techniques Definiens eCognition Developer was utilized with a pair of high resolution, four-band satellite images from the months of March and August in 2010. This software program is for object-based image analyses as opposed to the better known pixel-based analyses software Erdas Imagine. In this case, the purpose of evaluating new remote sensing techniques is to discover new methods to further the accuracy of land use data and analyses performed, such as a storm water runoff analysis, with the land use data.

After the 2010 land use data was created, it was then be compared to land use data for the years 2000 and 2005 that was made available for download by the North Central Texas Council of Governments. There are hundreds of storm water runoff models that have been developed and the most conventional hydrologic models have proven to be expensive and labor-intensive. This paper uses the Soil Conservation Service model with the runoff curve number method, developed by the United States Department of Agriculture (USDA), to compute direct runoff (Q) through an empirical equation that requires rainfall and a watershed coefficient as inputs (Coskun, 2004). A precipitation event of 5 inches was chosen because every five years Denton County will have over 5.46 inches in rainfall depth for a given return interval. The storm water runoff analysis was conducted using the 2010 land use data produced during the remote sensing part of this research as well as on 2000 and 2005 land use data provided by the North Central Texas Council of

Governments. These three analyses were done as an analysis of the land use change in 5 year increments over a 10 year period for Denton Texas as well as a comparison of the different methodologies used to derive the land use data. Finally, a comparison between ground control points collected in the field and the 2010 land use data was made to determine the percent accuracy of the classifications performed with a new remote sensing methodology.

CHAPTER 2

STUDY AREA

## 2.1 Denton, Texas

Denton, Texas encompasses an area of roughly 93 square miles and has a population of over 120,000 with a growth rate at 2 percent per year; it is among the top 25 fastest growing cities in the nation. The study area is encompassed by the major roads running through the city: I35 E and Loop 288 and has two primary eco-regions which are the Grand Prairie and Eastern Cross Timbers. This area provides a good cross section of various soil types and land use classes as well as many of the local businesses and residences. As of 2010 the study area comprised: 1669 acres of buildings, 685 acres of herbaceous, 4907 acres of mowed/grazed/agricultural, 2783 acres of transportation, 2683 acres of trees and 65 acres of water.

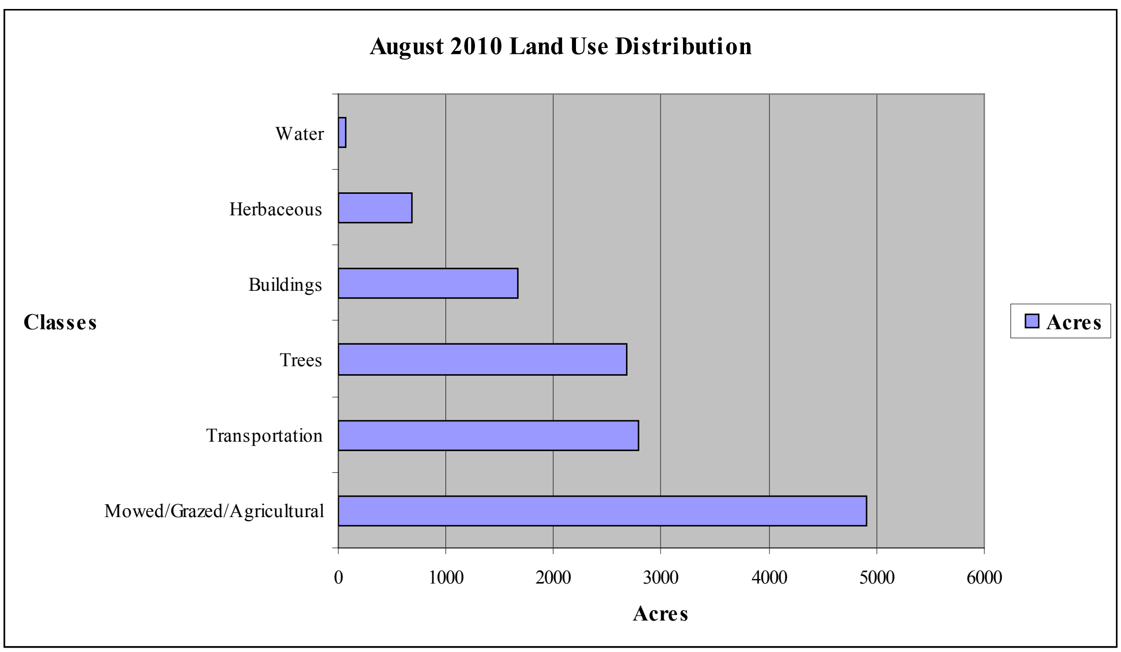


**Figure 1** *Land use distribution for the study area.*

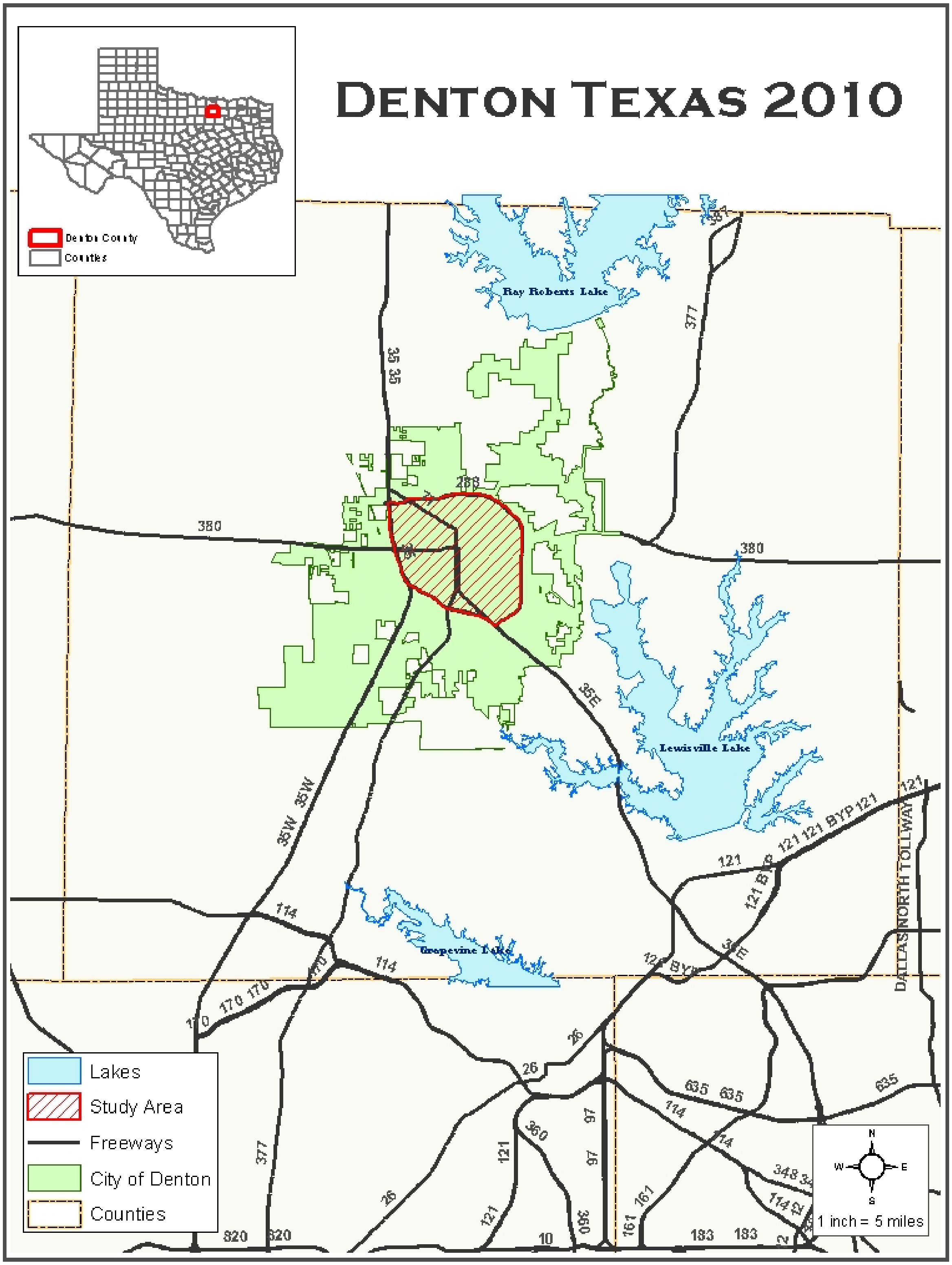


**Figure 2** *Map showing location of Denton, TX.*

2.2 Watersheds

Denton Texas is located within three main watersheds which are Cooper Creek, Hickory Creek and Pecan Creek. Refer to Figure 3. These watersheds are located within the Elm Fork Trinity Sub-Basin residing in the Upper Trinity Basin. Also, Lake Lewisville is the main drinking water reservoir for several cities, including Denton, receiving water for numerous utility wastewater treatment plant effluent streams, recreational and ecological amenity with a total of 25 cities located in the Lewisville Lake watershed (Viera, 2010).

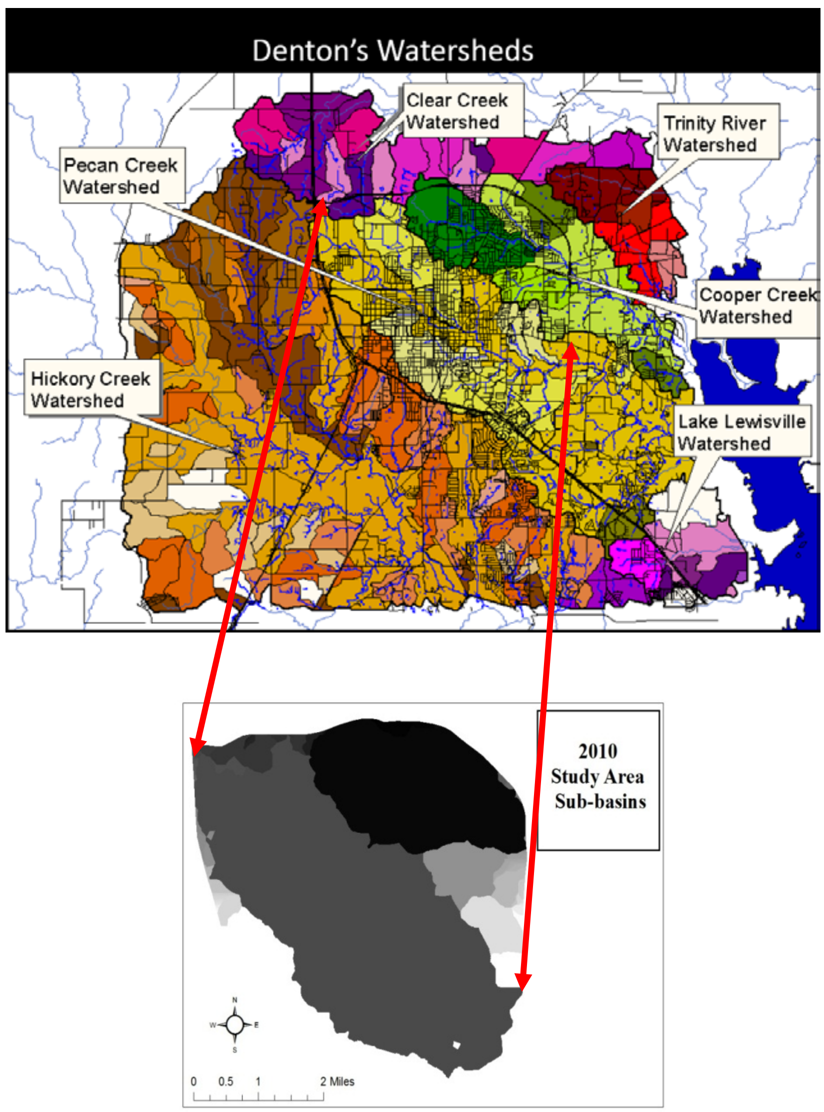


**Figure 3** *Delineated watersheds (by Deborah Viera, 2010) & sub-basins.*

2.3 Soils

Most of the soils found in Denton, Texas are clay-rich and fine-grained soils and this combination is not conducive for urban development. The most expansive soils may gain or lose up to 75percent of its original volume causing radical gain and loss of a structure foundation's solidity (*North Texas Soil Technical Data*, 2009). Annual losses have been estimated to have reached the range of $2 billion to $7 billion and expansive soils are one of the nation's largest causes of damage to structures such as buildings, sidewalks and driveways ("North Texas Soil Technical Data," 2009). The website www.foundationsolution.com cites a Federal Emergency Management Agency (FEMA) report from 1982 which concluded that the expansive soils cause billions of dollars of damage which is more costly than damage caused by earthquakes, floods, tornadoes and hurricanes combined (*North Texas Soil Technical Data*, 2009). Little research has been focused on expansive soils hazards even though, improper building or structure design, faulty construction and inappropriate landscaping unsuited to a specific soil can become a long and costly problem. Over 250,000 new homes, though only 60 percent built on expansive soils each year, will experience only minor damage.

Dr. Harry Williams, associate professor of geography at the University of North Texas, has conducted and published extensive research on relating soils and urbanization with variables mapped in GIS. One such article is "Urbanization Pressure Increases Potential for Soils-Related Hazards, Denton County, Texas" which was published in the international journal *Environmental Geology* in the fall 2003 issue. "The results of Williams' analysis show a dramatic shift in the nature of soils in pre-1990 and post-1990 urban areas. Before 1990, approximately 77 percent of the 158 square miles of urban areas in Denton County was constructed on soils deemed either medium or high suitability for urban development. In 1990-

2000, approximately 53 percent of the 39 square miles of additional urban areas was constructed on soils deemed either very low or low suitability for urban development" (*North Texas Soil Technical Data*, 2009).

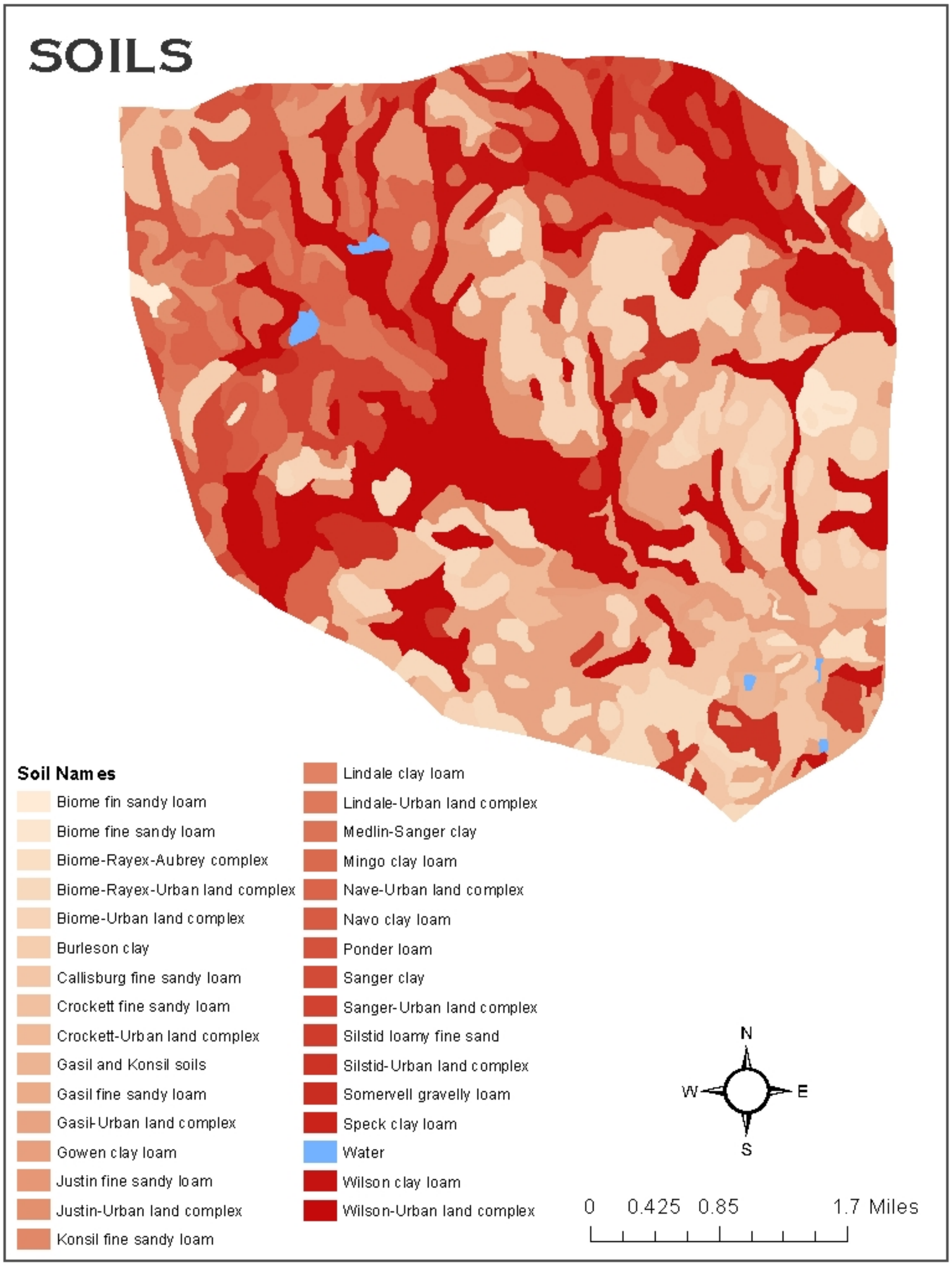


**Figure 4** *Map of study-area soils.*

## 2.4 Climate

The weather in Denton is typically very hot for the long summer months with temperatures easily reaching above 100 degrees Fahrenheit. In the winter months the weather is typically mild and cool with average temperatures ranging from 30-50 degrees Fahrenheit. Rain is not a common occurrence in this part of North Texas but when it does happen it is mostly in the spring months of March through June (May being the wettest month) and also in the fall months of September through October. The average climate and precipitation in Denton was calculated based on data reported by over 4,000 weather stations and this information was found at city-data.com. There is a stark difference between the United States average precipitation, around 3 inches a year, to Denton which can range anywhere from less than 2 inches to over 5 inches. The study area is in a geographic location that consists of random, short bursts of thunderstorms and heavy precipitation that can produce serious flooding issues due to the prominently clayey soils and constant urban development. This data highlights the radical and inconsistent weather patterns that are present in this part of the state. Also, this area of North Texas is on the southern cusp of the tornado alley corridor which can see tornados through the spring season on a significantly above state average and 268percent greater than the United States average level (*Stats about All US Cities*, 2011).

# CHAPTER 3

# BACKGROUND

## 3.1 City of Denton Tree Canopy Survey Project

The idea for this paper was spurred from a research contract, which I solely conducted and was responsible for, through the University of North Texas for the city of Denton Texas to quantify existing tree canopy for the city and its extra territorial jurisdiction (ETJ). The purpose of this research was to help arm the city officials with significantly accurate data so they can better manage their existing tree canopy and make smarter decisions regarding future land annexations that may or may not contain any tree canopy; as a bonus land use data was also produced. With problems such as the current economy and decreasing budgets this study will help municipal managers make tough choices regarding the management of the city's urban infrastructure. Urban trees perform a vital service by cleaning the air through sequestering (through its leaves) and storing pollutants such as carbon monoxide, ozone, nitrogen dioxide, particulate matter and sulfur dioxide in its biomass. This service affects the well-being of all urban dwelling citizens and that of the local water quality. Urban trees can prevent erosion, divert storm water runoff and encourage it to soak into the ground which helps recharge underground water supplies. All of these natural benefits from trees are quantified and explained through the analysis of satellite imagery using advanced remote sensing techniques. The city provided the funding for the satellite imagery and software in this analysis through means that did not use tax payer money. The money came from a fund that entails all fines imposed on individuals who illegally cut downs trees, etc; however local citizens and news sources were ill-informed and did not understand this. As a result there was some initial hesitation and resistance from a few individuals, but this proves as a prime example of how more than ever it is imperative to step up the education and information sharing to the public; better informed citizens equals a better managed city.

The remote sensing part of the analysis was accomplished using Definiens eCognition Developer and the initial segmentation of the image data was a multi-resolution analysis and top-down system that breaks down the image into super classification groups then subsystems are created to refine further the details in the image. In this object-based classification, object size, shape and other parameters can be adjusted to fit the needs of the research. Further, this study because of the spectral and structural heterogeneity of trees, the nearest neighbor classifier was be mostly used. Typically the method for classification has been pixel-based in programs such as Erdas Imagine. Pixel-based classification does not consider the relationship of each pixel data with its adjacent units. However eCognition takes a more human approach by its ability to filter out minor inconsistencies and in general streamline the work phase of tree canopy mapping. When a person looks at an object they subconsciously analyze image properties such as: what shape is that object, how big is it, what is its color scheme, what is the texture of the object and also what is surrounding the object. In this case the images were classified into one of the following classes: trees, buildings, herbaceous, agriculture/mowed/grazed, transportation, bare land and water. The classification process can become increasingly more complicated so the amount of subclasses created is entirely dependent on the time period given for the research to be completed; in this case 8 months. Also, the accuracy rate for this research was established by field work using a GPS system to map selected areas of tree clustering and other super classes for comparison. After a proper accuracy rate was achieved the newly created vector shapefile was further processed using another program called ArcMap.

Imagery analysis steps:

1. Project to .img

The projected coordinate system for the data images was WGS_1984_UTM_Zone_14N and the geographic coordinate system is GCS_WGS_1984 (the most commonly used by all GPS equipment). The projected coordinate system is a flat, two-dimensional surface which is based on the geographic coordinate system and locations are identified by X, Y coordinates on a grid. The geographic coordinate system is a reference system that uses X, Y, Z coordinates to define the locations of points on the surface of the earth which is shaped closely to a ellipsoid; with the X being the longitude, Y being the latitude and Z being the vertical datum. In this case the area of Denton, Texas falls into Zone 14N although Texas does have a total of 3 zones due to its large size.

The first step in the data analysis process is the importation/conversion of the format from GRID to IMAGE and this was completed in Erdas Imagine,

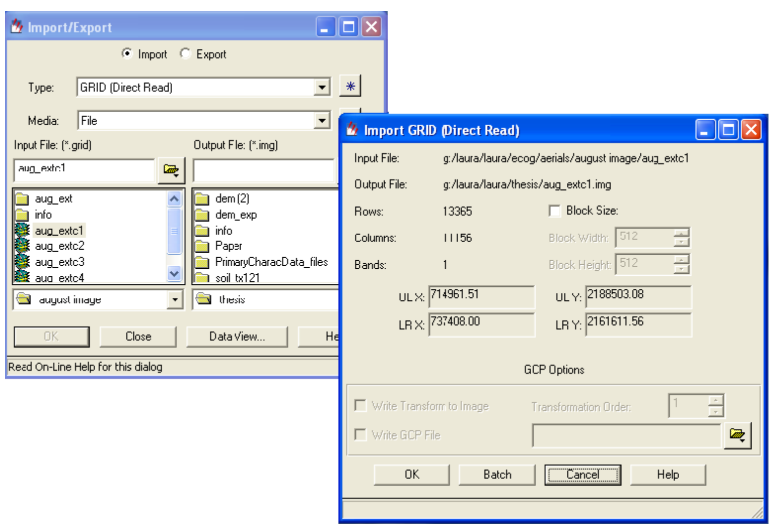


**Figure 5** *Screenshot of GRID to IMAGE conversion process.*

2. Mosaic Raster

The next step after converting the data to the proper format, .img, is to further prepare it for analysis. The imagery was delivered as four separate raster's so a mosaic was performed, in Erdas Imagine, to create a single raster dataset.

3. Rectify Image: First order polynomial transformation

The satellite imagery was projected as .img (image) files and the next step is to rectify the imagery; this can be done in the remote sensing software Erdas Imagine. The polynomial model will be used for this because it is the simplest model and can handle the georeferencing requirements. A first order polynomial transformation will shift, scale and rotate the raster and it can be used to rectify scanned maps or satellite images on flat areas. For each of the four satellite images ground control points (GCP's) were collected and used to transform the raster to map coordinates. Viewer 1 contained the satellite image and Viewer 2 contained the roads and streams shapefile for the City of Denton. The shapefiles were obtained by the NCTCOG DFW Clearinghouse website that provides free data to the public. The shapefiles being used as a reference to rectify the images has a projected coordinate system called NAD_1983_StatePlane_Texas_North_Central_FIPS_4202_feet but they were converted to match the images geographic coordinate system GCS_WGS_1984.

As the last part of the rectification process the four images were resampled to the coordinate system of the shapefiles. In Erdas Imagine there is a tool in the Data Preparation category that can re-project the images; note that the units for this projection will be in meters. Also the resample method of Nearest Neighbor was chosen because it assigns to each pixel the value of its nearest neighbor in the new coordinate system. It is the fastest re-sampling technique and is appropriate for thematic data; it's also the easiest and fastest method of interpolation. The shapefiles will have to be re-projected from the NCTCOG so they would match the coordinate system of the imagery. The Geographic Transformation of NAD_1983 to WGS_1984 with the zone of 4 will be applied because the State Plane coordinate system is based in Feet and not Meters like WGS_UTM. This is an example of one of the over 400 types of projection systems available. Roughly 30-100 data points were referenced, with 3 ground control points, from Viewer 1 to Viewer 2 in Erdas, based on road-road and stream-road intersections. These reference and index points were saved as files separate from each other. The goal was to get as many reference points as possible with the Root Mean Square (RMS) error of each point to be 5.0 or less.

The degree of which the transformation can accurately map all control points can be measured mathematically by comparing the actual location of the map coordinate to the transformed position in the raster. The distance between these two points is known as residual error. This value describes how consistent the transformation is between the different control points and after deleting the points exceeding this value, of 5.0, I was left with only 10-20 reference points on average. No matter how many reference points you start out with there is always a chance that more than half of them will be deleted. In the rectification the output cell size was set to 2.0 by 2.0 because the image was originally 2 meter in resolution.

4. Pan Sharpen
5. Dice Image into tiles
6. Create NDVI layer
7. Classify images using factors such as shape, size, color, texture, height etc.

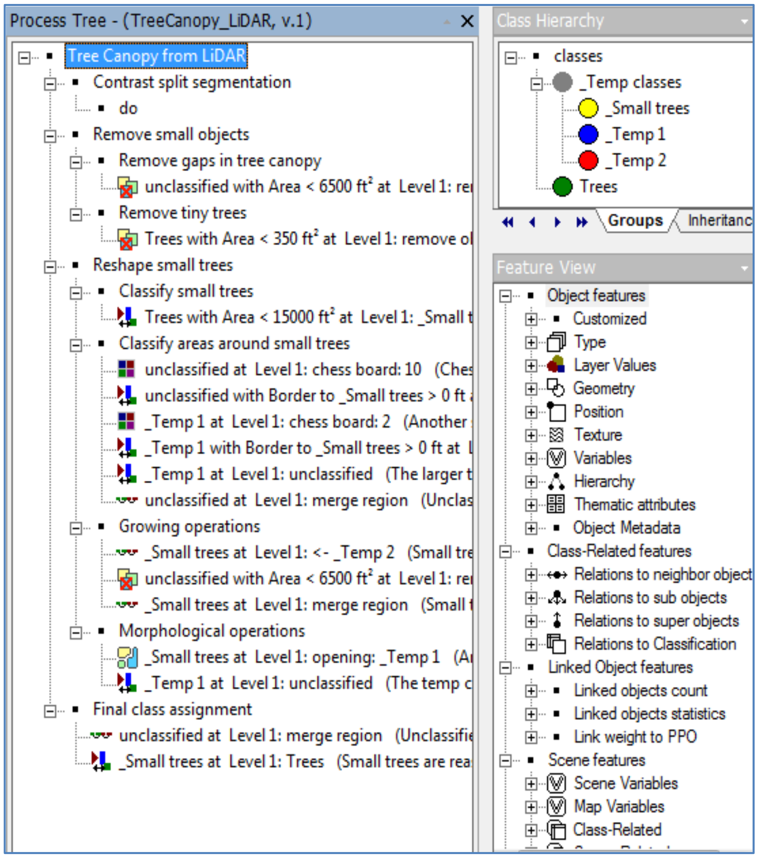


**Figure 6** *Example of algorithm process tree in eCognition Developer.*

8. Export results

***Table 1*** *Data from tree canopy survey*

| Data Format | Date | Type |
|---|---|---|
| Shapefile | August 2010 | Tree Canopy Cover/Leaf On |
| Shapefile | August 2010 | Land Use Cover/Leaf On |
| Shapefile | March 2010 | Tree Canopy Cover/Leaf Off |
| Shapefile | March 2010 | Land Use Cover/Leaf Off |

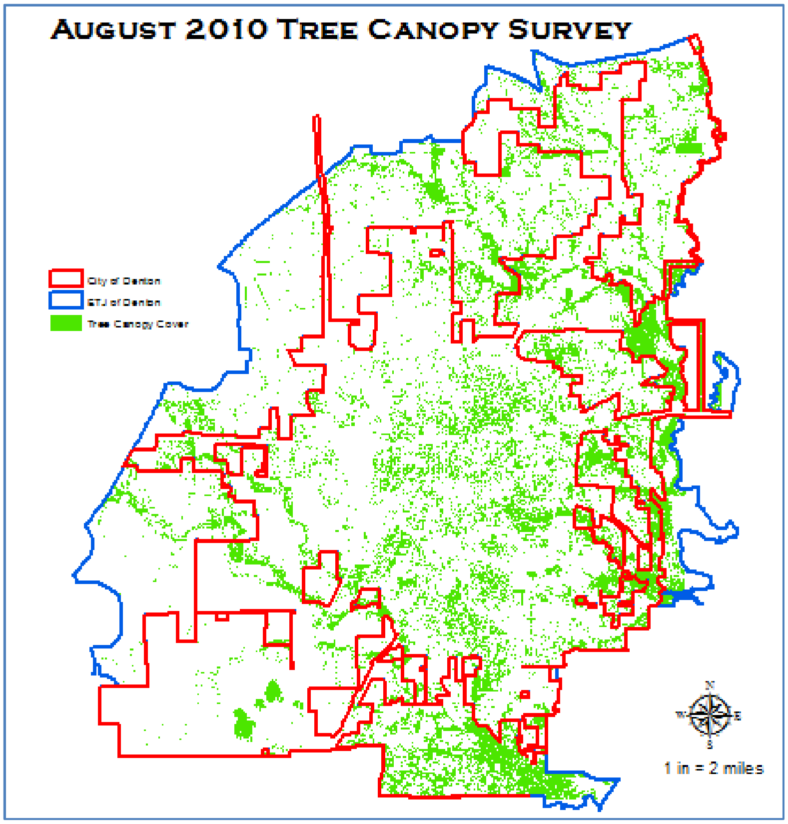


**Figure 7** *Denton city & ETJ tree canopy cCover.*

Ultimately trees and other green infrastructure in a community can solve many problems, such as flood prevention and increased water quality, through their natural services. This makes it imperative to have a baseline dataset from which to plan future projects, such as urban expansion, and fix current problematic areas. An example of this would be planting more trees around oil and gas well sites that are close to streams so water quality can be improved. This study will not only benefit the citizens of Denton but it will also not cost them a dime in tax payer's money. By putting a realistic monetary value (typically hundreds of thousands of dollars) on the natural functions of tree's city officials can make better informed decisions; also local citizens will potentially better understand the importance of the tree canopy to the community as a whole. The resulting data sets of the Tree Canopy Survey, of which I solely conducted, were used as variables in this research paper. The land use data was implemented in the storm water runoff model to represent Denton in the year of 2010.

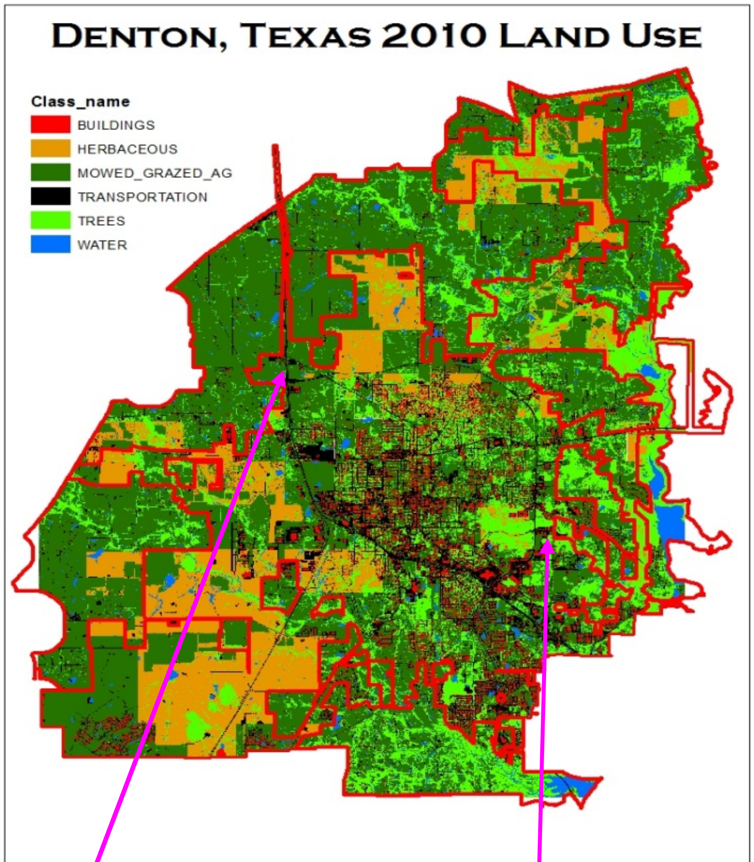


**Figure 8** *Denton city & ETJ 2010 land use.*

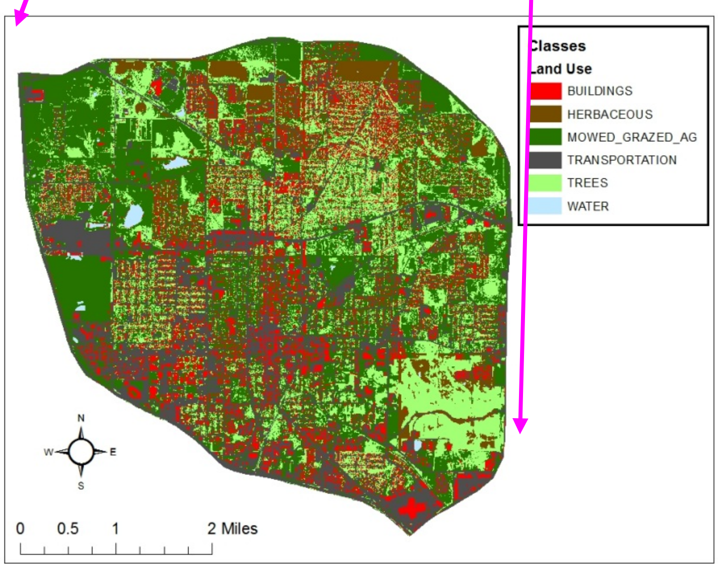


**Figure 9** *Study area 2010 land use.*

3.2 Storm Water Models

***Table 2*** *Characteristics of urban rainfall-runoff models*

**Types of Urban Rainfall-Runoff Model**

| Model Type | Model Characteristics |
|---|---|
| *Simple* | • Simple representation of the urban watershed.<br>• Produces long term averages (e.g. annual runoff / peak flow).<br>• Uses empirical and statistical methods such as coefficient and rational methods<br>• Includes SWMM level I; SCS soil-complex-cover method. |
| *Simple routing models* | • Routes flows through a rudimentary model of the drainage network, or accounts for delaying effect of routing.<br>• Typically used to produce hydrographs over several years at a limited number of locations.<br>• Uses statistical and deterministic approaches, principally bases on unit hydrograph methods.<br>• Includes STORM; HSPF, WASSP, WALLRUS. |
| *Complex routing models* | • Routes flows through an extensive model of the drainage<br>• network. Can perform continuous simulation of hydrologic catchment system. Typically used to produce hydrographs over the short term (e.g. hours/days) at a few or many locations for flood analysis<br>• Uses deterministic methods to describe processes.<br>• Includes SWMM, QQS. |

3.2.1 Screening Models

Screening models are preliminary, "first-cut", desktop procedures that do not require the use of a computer. Their goal is to provide a first estimate of the magnitude of urban runoff quantity and quality problems before an investment of time and resources into more complex computer based models. Only after the screening model indicates its necessity should one of the latter models be used (United States of America, 1992).

A very popular example of a screening model is the HSSM (hydrocarbon spill screening model) developed by the EPA which stimulates subsurface releases of light non-aqueous phase liquids. When it comes to hydrocarbon spills, there is no other model as powerful and versatile as

HSSM (Scientific Software Group, 2005). The Hydrocarbon Spill Screening Model serves as a simplified model for subsurface releases of fuel hydrocarbons and the most common problem that the model may be used to address is that of a leaking underground storage tank. “As of the end of 1997, there have been over 400,000 confirmed releases from underground storage tanks in the U.S. (“The Hydrocarbon Spill Screening Model,” 2011).

The EPA states that for subsurface contamination, the most important characteristics of fuel hydrocarbons are that they are: immiscible with water (oil and water don't mix), less dense than water, composed of chemicals that have varying water solubility’s and volatilities and composed of a number of chemicals that can have adverse health effects. This model was applied to a study done by James W. Weaver of the American Society of Civil Engineers in which field data from two case histories were used to develop input parameter sets for HSSM. In one case there was aqueous concentration data from an extensive monitoring network and in the second case the monitoring network was small, but the date and volume of the release could be estimated. The cases were chosen because they both have features that were well suited for testing of the model. In both cases the model was able to reproduce the trends in the data set and the concentrations to within an order of magnitude (Weaver, 1996).

### 3.2.2 Planning (Continuous) Models

Another type of model is planning which is used for an overall assessment of the urban runoff problem. It is also utilized for estimates of the effectiveness and costs of abatement procedures. These models are recognized by the relatively large time steps (hours) and long simulation times (months and years), i.e., continuous simulation; data requirements are kept to a minimum and their mathematical complexity is low. They may also be run to identify hydrologic events that may be of special interest for design or other purposes (United States of America, 1992).

The paper “A Case in Support of Continuous Modeling for Stormwater Management System Design” describes a case study in the Town of Milton (Sixteen Mile Creek Watershed) in which two methods, Design and Continuous, were applied in the analysis and preliminary design of end-of-pipe storm water management facilities. It was found that the Design approach tended to over-estimate antecedent moisture conditions for existing land use conditions, and the subsequent peak runoff which defines the target flows. Also this approach does not provide sufficient control for the more frequent storm events and does not provide an effective means for designing erosion control. The continuous modeling approach resulted in less overall storage than the Design approach and requires substantial amounts of reliable data for proper calibration and simulation. The results of this case study demonstrates that the continuous modeling approach was most appropriate for the Sixteen Mile Creek, Areas 2 and 7 Sub watershed Planning Study, the design approach could be considered for smaller catchments and local storm water management system design verification (Ferrell et al, 2001).

Another continuous model is Version 5 of the SWMM got Microsoft Windows and it is a freeware program. This model creates a continuous simulation using historical rainfall series and was used in the long-term modeling of the urban area of Lisbon. The continuous modeling allowed for the comparison of benefits of different scenarios of storage and sewage treatment plant capacities for the reduction of the overflow discharges. Also, in addition to increases in difficulties and uncertainties associated to the water quality model, there were no relevant benefits obtained by its use. It was concluded that some limitations were found such as only a maximum of about thirty days data could be loaded to SWMM5 from a 2-minute interval inflow time series; this limitation is considerably minimized with the introduction of rainfall time series (Cambez et al, 2008).

The hourly precipitation time-series is a previous common practice that used the nearest precipitation gauge while the new and future practice of this model utilizes an extended precipitation time-series. To calculate the precipitation time-series you use the nearest hourly gauge and multiply all hourly values by a single scaling factor. The scaling factor is the ration of 25-year 24-hour precipitation at the site of interest relative to the gage. An MGS Flood Continuous Flow Model for Storm water Facility Design training workshop was put on by MGS Engineering Consultants Inc. in Olympia, Washington. A major issue that arose with the use of the Simple Scaling model was that the nearest gage may not have representative records for various reasons. It is not possible to rescale the time-series with a single scaling factor and manage to obtain the correct storm characteristics at all durations at the site of interest; storm characteristics could vary by the season and duration. Finally many gages have short record lengths making it impossible to use for the intended design purposes. To compensate for the shortcomings of this model they created an extended precipitation time-series. Essentially a long precipitation record was created by combining obtained records from distant gage stations. Records from each station were rescaled to have storm statistics representative of the site of interest. In the workshop they combined the precipitation data records for: Vancouver, BC (38 years), Seattle, WA (60 years) and Salem, OR (60 years). In the end this allows for the use of high-quality stations with long records and avoids the pot-luck of using nearby stations. It seems that many hourly stations have short records of poor-quality so this will provide greater diversity and variability of storm temporal patterns and provides for greater sampling of storm magnitudes and temporal patterns (Schaefer et al, 2002).

### 3.2.3 Design Models

Event-based models are often preferred to continuous models for real time operational applications and forecasting in combination with radar spatial rainfall. The response of a catchment to a rainfall event is greatly influenced by the antecedent soil moisture conditions, which are crucial parameters for flood models like design models. They are typically used to simulate of a single storm event and which will provide a description of flow and pollutant routing. This begins from the point of rainfall through the entire urban runoff system are a highly useful tool for both water quantity and quality problems in urban areas. The data requirements may be moderate to very extensive depending upon the specific model employed and it is characterized by short time steps (minutes) and short simulation. The EPA storm water management model (SWMM) is dynamic in rainfall-runoff simulation and is used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component operates from a collection of subcatchment area; rain falls and runoff is generated there. The routing part of the model will move the runoff through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators; flow rate, flow depth, and quality of water in a simulation period are comprised of multiple time steps. This computer model has changed significantly since it was first developed in 1971 and the current is Version 5 (Rossman, 2011).

Hydrologic processes accounted for in SWMM: time-varying rainfall**,** evaporation of standing surface water**,** snow accumulation and melting, rainfall interception from depression storage, infiltration of rainfall into unsaturated soil layers, percolation of infiltrated water into groundwater layers, interflow between groundwater and the drainage system, nonlinear reservoir routing of overland flow and even runoff reduction via low impact development (LID) controls

(Rossman, 2011). By dividing the study area into a collection of smaller, replicate subcatchment areas, each containing its own fraction of pervious and impervious sub-areas, the spatial variability can be achieved.

### 3.2.4 Other Models

There are many different types and applications of urban stormwater runoff models. Some other models include the operational model which is used to produce actual control decisions during a storm event. It works through the introduction of rainfall from telemetered stations and is used to predict system responses a short time into the future. Models are frequently being developed from more sophisticated design models and modified to be applied in a specific system. There are also many more models are available for purely hydrologic and hydraulic analysis.

### 3.2.5 Simple Model: SCS Runoff Curve Number Method

This model was chosen for use in this research paper because it is simple and based on a study area's hydrologic soil group, land use, treatment and hydrologic conditions. However a drawback to this method is that it will not calculate when the runoff will occur during the precipitation event. If the exact time of the runoff is also desired then you will have to introduce a time-of-concentration method, such as the lag method, to calculate it.

The runoff curve number method (RCN) was a method originally established by the Soils Conservation Society in 1954 and was initially designed to be an inter-agency tool for runoff estimation on agricultural fields. It has been adapted over the years within the urban hydrology community and become the most recognized method for computing peak runoff rates and volumes. Technical Release 55 (TR-55) was created to be a simplified NRCS tool for the computation of runoff rates that joins the NRCS runoff equation with unit hydrograph theory (Schiariti, n.d.). The higher the CN value the higher the potential will be for runoff and flooding.

The runoff equation is

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

Where

***Q*** is runoff ([L]; in)

***P*** is rainfall ([L]; in)

***S*** is the potential maximum soil moisture retention after runoff begins ([L]; in)

***$I_a$*** is the initial abstraction ([L]; in), or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and it is generally assumed that $I_a = 0.2S$

The runoff curve number, *CN*, is then related

$$S = \frac{1{,}000}{CN} - 10 \quad \text{(when water depths are expressed in inches)}$$

$$S = \frac{25{,}400}{CN} - 254 \quad \text{(when water depths are expressed in mm)}$$

Lower CN numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the more permeable the soil is.

Solution of runoff equation.

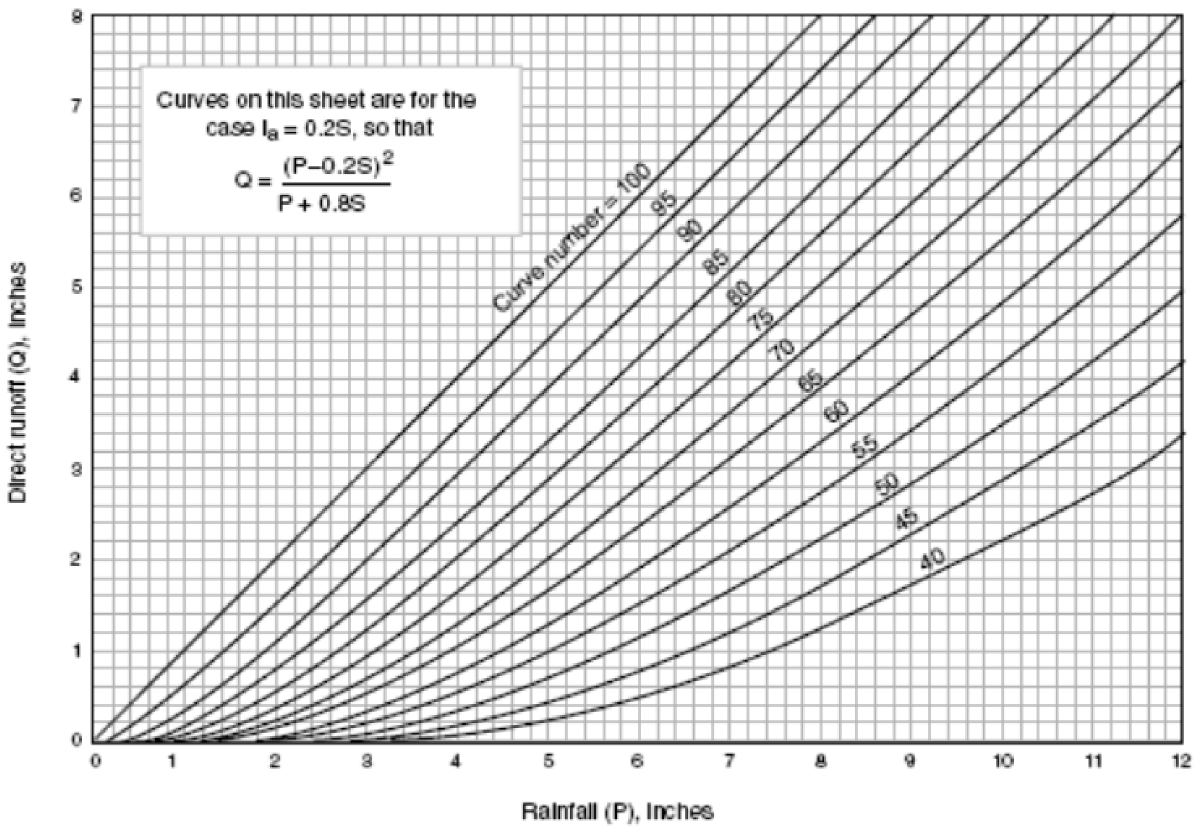


**Figure 10** *P vs. Q = curve number (Schiariti, n.d.).*

Modes of application for curve numbers:

1) Determination of runoff volume of a given return period, given total event rainfall for that return period.

2) Determine the direct runoff for individual events. This acknowledges the variation between events and is the basis for the development.

3) Process models, an inferred application as an infiltration model, or a soil moisture-CN relationship, or as a source area distribution.

The first is the most widely used in engineering and uses the curve number to transform the rainfall frequency distribution into a runoff frequency distribution. It was the reason for the development of the model. The runoff volume that is computed is often overlooked and the peak discharge, which is more frequently the desired value, calculated with a unit hydrograph model and used directly. The second mode of application is the basis for the original development and there is a wide variation of runoff from rainfalls of the same magnitude. This forces the realization that CN can vary between storms for many different reasons. The curve number model could potentially be seen as an infiltration model. This is because in its application it is used to determine runoff incrementally over the duration of the storm for input into a unit hydrograph model.

The antecedent moisture condition (AMC) is the preceding relative moisture of surfaces before a rainfall event and it comes in three different levels: AMC I, AMC II and AMC III. For this model we will consider the watershed to be in an AMC II state which is an average moisture condition. This is important to understand because if the conditions of pervious surfaces are very dry (AMC I condition) before a rainfall event it could affect the modeled results significantly; as well as a pre-existing AMC III condition (considerable preceding rainfall prior).

***Table 3*** *CN look-up table created from combined soils & land use grids*

| NRCS Cover Type A | My Cover Types | Hydrologic Condition | A | B | C | D |
|---|---|---|---|---|---|---|
| Herbaceous—mixture of grass, | Herbaceous | Poor | 67 | 80 | 87 | 93 |
| Paved; curbs and storm drains (excluding right-of-way) | Transportation | | 98 | 98 | 98 | 98 |
| Pasture, grassland, or range-continuous forage for grazing | Agriculture, Mowed & Grazed | Poor | 68 | 79 | 86 | 89 |
| | | Fair | 49 | 69 | 79 | 84 |
| | | Good | 39 | 61 | 74 | 80 |
| Woods – grass combination (orchard or tree farm) | Tree Canopy | Poor | 57 | 73 | 82 | 86 |
| | | Fair | 43 | 65 | 76 | 82 |
| | | Good | 32 | 58 | 72 | 79 |
| Paved parking lots, roofs, driveways, etc. (excluding right-of-way) | Buildings | | 98 | 98 | 98 | 98 |

### 3.3 Remote Sensing and GIS Techniques

"Remote sensing is the observation and measurement of objects from a distance, i.e. instruments or recorders are not in direct contact with objects under investigation" (Aber et al., 2002). There are four types of resolutions that contribute to the quality of the data: spatial, spectral, radiometric and temporal:

- Spatial resolution: pixel size recorded in a raster image (usually in meters)
- Spectral resolution: wavelength width of different band frequencies; Landsat has seven bands plus many from the infra-red spectrum, spectral resolution range of 0.07 to 2.1 μm
- Radiometric resolution: number of different intensities of radiation the sensor can detect and distinguish, range from 8 to 14 bits, 256 levels of gray scale and up to 16,384 intensities of color in each band
- Temporal resolution: frequency of flyovers by a satellite or plane, cloud cover makes it necessary to do multiple flyovers, only relevant in time-series studies or if averaged or mosaic image is required.

There are several remote sensing techniques and they are based on sensing electromagnetic energy that is emitted (or reflected) from the surface of the Earth which is then detected from an altitude high above the ground. There are two types of remote sensing: Passive: Detect available electromagnetic energy from naturally occurring sources such as sunlight. It is based on two energy sources.

1. Ultraviolet, visible, and near-infrared radiations (< 3 μm wavelength) are mainly reflected solar energy.
2. Mid-infrared, thermal-infrared, and microwave radiations (> 3 μm wavelength) are mostly emitted from the Earth's surface

Active*:* Utilizes an artificial "light" source, such as radar, to illuminate the scene.

There are three main types of remote sensing (Aber et al., 2002):

1. Aerial photography
   a. Spectral sensitivity: 0.3 µm (near-ultraviolet) to 0.9 µm (near infrared)
   b. Photographs taken in b/w panchromatic, b/w infrared, color-visible, color-infrared, and multiband types
   c. Equipment: airplanes or helicopters
   d. Useful in fields such: archeology, biology (habitat, wildlife census), forestry, geology, geomorphology, engineering, hydrology, mineral and oil prospecting, pollution (air, land, water), transportation or even urban planning
2. Manned-space photography
   a. Spectral response range: 0.4 to 1.1 µm
3. Landsat satellite imagery:
   a. Advantages: “(1) Synoptic view: Satellite images are "big-picture" views of large areas of the surface. The positions, distribution, and spatial relationships of features are clearly evident; mega patterns within landscapes, seascapes, and icescapes are emphasized. Major biologic, tectonic, hydrologic, and geomorphic factors stand out distinctly. (2) Repetitive coverage: Repeated images of the same regions, taken at regular intervals over periods of days, years, and decades, provide data bases for recognizing and measuring environmental changes. This is crucial for understanding where, when, and how the modern environment is changing. (3) Multispectral data: Satellite sensors are designed to operate in many different portions of the electromagnetic spectrum. Ultraviolet, visible, infrared,

and microwave energy coming from the Earth's surface or atmosphere contain a wealth of information about material composition and physical conditions. (4) Low-cost data: Near-global, repetitive collection of data is far cheaper using satellite sensors than collecting the same type and quantity of data would be through conventional ground surveys" (Aber et al., 2002).

b. Landsat Series of 1970s, 80s and 90s: Multispectral Scanner (MSS) – (1) Moderate-resolution scanner, collected data in four spectral bands: green, red, and two near-infrared channels. Pixel size in processed datasets is 57 m by 57 m. (2) Thematic Mapper (TM) -- An advanced high-resolution scanner that collects spectral data in seven bands: blue, green, red, near-infrared, two mid-infrared, and thermal-infrared. Pixel size in processed datasets is 28½ m by 28½ m. For more information--see Landsat TM (Aber et al., 2002).

Raster images are collections of pixels, which can be thought of as small squares in a very fine grid. Each pixel is associated with information on color value and intensity for that portion of the grid. Images in vector format are in the form of points, lines, and closed figures called polygons. Points are described by coordinates and the positions, directions, and shapes of lines are described by geometric and mathematical relationships. This is important to consider because ideally photographs should be taken midday to have less shadowing and provides for easier interpretation. Photo interpretation is also subject to classification errors/misclassification of the image. For example, tree shadows can be erroneously included as tree canopy or shrubs may be mistakenly classified as trees. Classification errors can lead to consistent overestimates or underestimates of canopy cover but it is simply another factor that must be taken into consideration when spending such a large amount of money on data and analysis. Digital image analysis can also be used to create permanent maps that may be incorporated into a geographic information system and be used to show how and where land use changes occur over time. If data will be used for these other purposes and future monitoring then the additional cost of digitizing a city's land use can be justified. Digital image analysis techniques have the potential to provide precise estimates of objects such as tree canopy cover (Swiecki et al., 2001). Also, it is made possible to collect data for dangerous areas that cannot be accessed or large areas that make it impossible to cover on foot.

In most types of imagery, items of interest are typically represented as a collection of pixels that vary in color and/or intensity. Image analysis software uses a variety of techniques to convert an image into a series of monochromatic layers, each of which represents a single type of feature. One widely used and accepted software program currently being used throughout many universities, organizations and businesses worldwide is Erdas Imagine. Erdas Imagine is a geospatial raster data processing application that lets the user prepare data for mapping in areas such as GIS. This software is pixel based classification with the pixel reflectance from surfaces in the image mainly being used as the major classification parameter. This software is used for many different types of analysis including vegetation analysis, linear feature extraction, generation of processing work flows, import/export of data for a wide variety of formats and mosaicing of imagery. The two main benefits of this software package are: 1. it is relatively easy to learn on the fly and 2. The results from the software is universally accepted and respected. Erdas uses unsupervised, supervised or knowledge-based classification while eCognition uses segmentation and object-oriented classification. Definiens eCognition implements the process of how a person identifies objects with their brain and transfers it into an algorithm building application. A hierarchical network of segments in different scale levels is built while also choosing the proper thresholds for homogeneity and heterogeneity through trial and error (Ohlhof, 2006).

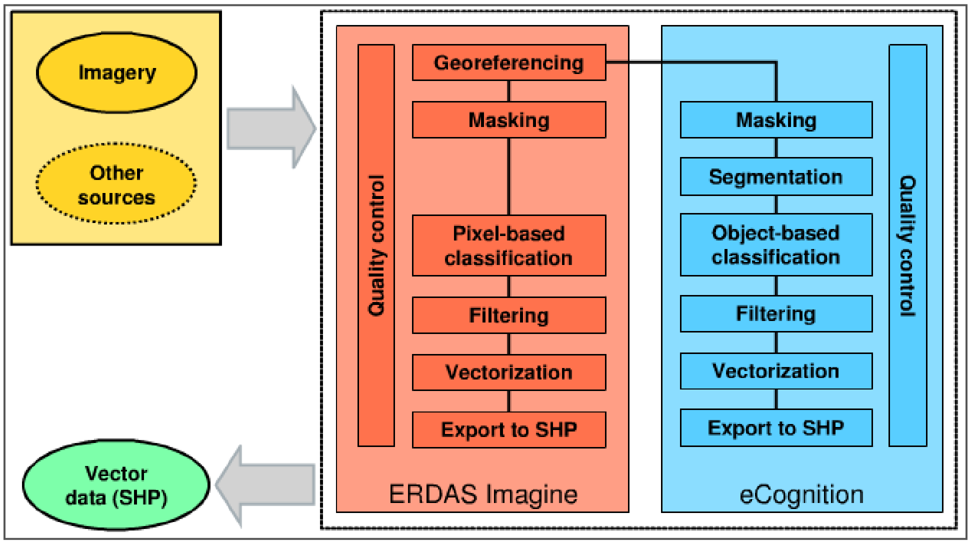


**Figure 11** *Erdas & eCognition characteristics (Ohlhof, 2006).*

Many case studies using Erdas Imagine software have been published, such as the one that was presented at the American Water Resources Association Symposium on GIS and Water Resources in 1996. This research incorporated remote sensing data into a water quality model as a more accurate initial condition and adapted GIS to enhance the contribution of water quality modeling to practical water quality forecasting. The QUAL2E model was used for water quality and Erdas Imagine were used in a case study of the Te-Chi reservoir in Taiwan. A regression model was developed in the water quality monitoring system with operations such as feature extraction, band ratio calculation, and image creation. These were developed into an automatic water quality monitoring system in Erdas. When no samples are available satellite imagery was shown to be an efficient tool in the study. The visualizing technique, which is made possible through the integration of GIS to a combined system, is helpful for rapid understanding of water quality conditions. It is a low-cost to quickly answer questions that occur randomly when meteorological condition or pollution sources change (Yang et al., 1996).

ERDAS is used frequently in digital photogrammetry so it is important for the accuracy to be assessed when aerial triangulation is carried out. The goal of aerial triangulation (AT) is to connect and increase ground control points through strip and/or block for other photogrammetric applications. In a study by the Faculty of Geoinformation Science & Engineering at the University Teknologi Malaysia, AT was performed based on one strip of photograph and a block of photograph. The study area is the community area encompassing University Teknologi Malaysia main campus in Johor Bahru. ERDAS assessed the accuracy of aerial triangulation based on a strip or block of aerial photographs and the results obtained from both the quantitative and qualitative analysis lead to the deduction that the aerial triangulation process in ERDAS software is fairly accurate for both strip and block aerial photographs. However it was also suggested in the RMSE (root mean square estimate) that the accuracy obtained from a strip of aerial photography is slightly higher than that obtained from the block of photographs. Some debate was brought up on how much control would be adequate for a given area to reach saturation; some suggest 25 to 30 or even up to 35 ground control points (Bisher et al., 2010).

The City of Fayetteville, Arkansas realized in 2003 that there was a need to rapidly and inexpensively generate an accurate, up-to-date map of impermeable surfaces within the city's utility service area. This area covers approximately 170 square miles in and around Fayetteville, Arkansas. Definiens eCognition was chosen for this project and was completed using the nearest-neighbor algorithm. Spectral values in the raw data, land-use information derived from Landsat 7 imagery, proximity to known buildings and roads, object size and border information were a number of spatial characteristics taken into account during the analysis. To obtain the high spatial/positional accuracies, the impervious surface maps were extracted from high resolution, ortho-corrected satellite imagery. These ortho-images were derived from Digital Globe's

Quickbird Standard Ortho-Ready image product. The “standard” Quickbird product was augmented using existing control point data supplemented with additional sub-meter GPS observations, and a 10 foot DEM provided by city of Fayetteville. The final map product was in the form of a five category map suitable for storm water management modeling. The categories are: impervious surface, forest/wooded, grasses/herbaceous, exposed soils, and water. Accuracies were determined based upon ground-truth points collected at times roughly corresponding to the image acquisition with overall accuracy for the map at 84.21percent (University of Arkansas, 2003).

Geographic information systems have been applied as a modeling tool for years because engineers use it to run hydrologic models such as the HEC-1 and HEC-2. This inherently supports the dynamic task of basin master planning because engineers are now finding ways to use GIS more and more. When data is made available in GIS, it can be extracted and/or combined with other data which can essentially be reformatted for various modeling processes and used to generate other inputs needed by the models. Another benefit of using GIS is that it can also be used to ensure data has been collected correctly (Robbins et al., 1999). Customized GIS technology will allow the city to organize its stormwater infrastructure and drainage system maintenance. Advanced technology as well as clear objectives and goals can allow for the evolution of better plans for urban stormwater management, watershed protection, and watershed restoration.

Typical applications of GIS for stormwater systems include (Shamsi, 2002):

- Watershed stormwater management
- Planning: assessment of the feasibility and impact of system expansion
- Floodplain mapping and flood hazard management

- Mapping work for Stormwater National Pollution and Discharge Elimination System (NPDES) permit requirements
- Hydrologic and hydraulic (H&H) modeling of combined and storm sewer systems, including: automatic delineation of watersheds, model simplification, estimating surface elevation and slope from digital elevation model (DEM) data & also estimating stormwater runoff from the physical characteristics of the watershed such as land use, soil, surface imperviousness, and slope
- Documenting field work, including: work order management and inspection and maintenance of stormwater system infrastructure

Essentially GIS is the combination of cartography, statistical analysis and database technology resulting in software packages such as the most widely known ArcGIS by ESRI. These software packages are capable of managing most data types as long as they contain a geographical component. GIS will be used for a variety of reasons throughout many different steps of this research, such as preparing the shapefiles containing the land use and soil data by clipping them to the study area. It will be used for running various calculations between raster datasets to obtain curve numbers, which will be accomplished by joining a curve number look up table to the combined land use and soils dataset. Also, GIS will be used to import GPS data collected to evaluate land use data accuracy through ground control points as well as to make specialized maps for visual representation of the different analyses outputs.

### 3.4 Technological Methods and Progress

When it comes to the progress of geography research philosophies, which ultimately determines the scientific methodology of the research, there is no single recommendation as to how science should be practiced. John Losee said it best with “Theories of science may be advanced as descriptive generalizations or as prescriptive recommendations about how science ought to be conducted." (Losee, 2004) There is some debate, however, about what a research philosophy actually is.

An important beginning step the scientific research process is identifying between an extensive and an intensive approach to data collection. Extensive research means that there will be a large sample of data collected which can then possibly be applied to conclude generalizations about a trend. This approach has some issues with it such as it is not necessarily good for actually explaining why something is the way it is. An intensive approach is a more small data sample/case study-based in that its goal is to actually explain a process either social or physical. It is important to note that sometimes studies do include both the extensive and intensive approach. This first step will help to define the actual research philosophy that leads to the methodological approaches and methods.

The overall applied method for this scientific research is based heavily on the realism philosophy. There is a triangulation of data sampling, collection and analysis methods in my research. It combines both subjectivity and objectivity because my form of data interpretation is heavily subjective due to the high involvement by the researcher. It is somewhat objective in the sense that the model will be built using data collected, such as elevation data, and mathematical equations which cannot be interpreted. The research is also deductive in nature because I am starting out with a hypothesis which will then be tested by the creation and analysis of data. It will also be quantitatively method-based and it will seek to treat the case as one of an exploratory nature. This was all based on the type of system my research target fell into which is that of an open system.

"A system is an object of study which is a collection of components, many of which are related to each other; that is, the components will often be coupled or interact with each other in various ways" (Wilson, 1981). The area outside of the system is known as its environment. There are two basic types of research which is categorized based on which system they are in; a closed system or an open system. A closed is isolated so that it cannot exchange matter or energy with its surroundings and can therefore attain a state of thermodynamic equilibrium. An open system transfers both matter and energy across its boundary to the surrounding environment; most ecosystems open. This research project is just a snapshot of what could actually be developed in understanding storm water runoff patterns and ways to prevent it.

# CHAPTER 4

# MATERIALS AND METHODOLOGY

## 4.1 Data

The data used in this study came from two distinct sources: 2-m spatial resolution rectified satellite images from February and July of 2010 and road, cities, lakes& streams shapefiles downloaded from the NCTCOG website in March of 2010. IKONOS is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. This satellite offers multispectral (MS) and panchromatic (PAN) imagery however the new GeoEye-1 satellite bests IKONOS in quality, which is what was used in this research. The city of Denton purchased the imagery from the company GeoEye. GeoEye made history with the Sept. 6, 2008 launch of GeoEye-1—the world's highest resolution commercial earth-imaging satellite. It is equipped with the most sophisticated technology ever used in a commercial satellite system. It offers unprecedented spatial resolution by simultaneously acquiring 0.41-meter panchromatic and 1.65-meter multispectral imagery. The detail and geospatial accuracy of GeoEye-1 imagery further expands applications for satellite imagery in every commercial and government market sector (GeoEye, 2011).

***Table 4*** *Satellite imagery information*

| | |
|---|---|
| **Band Count** | 4 & 1 |
| **Type** | R, G, B, NIR & Panchromatic |
| **Pixel Size** | 2 & 0.5 |
| **Map Units** | Meters |
| **Sensor Name** | GeoEye-1 |
| **Processing Level** | Standard Geometrically Corrected |
| **Image Type** | PAN/MSI |
| **Interpolation Method** | Cubic Convolution |

The data for the 2000 and 2005 land use surveys came directly from the north central Texas council of governments website. The NCTCOG data had to be prepared before the storm water analysis because the land classifications differed from the 2010 classifications I personally derived during the remote sensing part of this research. As this paper does not necessarily care about whom or how specifics such as buildings are used (ex: single family homes vs. multi-family homes) the land use classes are simplified to match the classes produced from the 2010 survey. This paper only cares about how each pixel affects storm water runoff and by consolidating classes the results and interpretations will be stream lined and easier to understand. Table 5 to the right was obtained from the NCTCOG website and it shows how the classifications are broken down in the attribute table and also provides an

***Table 5*** *NCTCOG land use code descriptions*

| Land Use Code (LUCODE) | Brief Description | Examples of Uses |
|---|---|---|
| 111 | single family | Single family detached units and duplexes |
| 112 | multi-family | Apartments, condominiums, residential hotels, converted apartments and townhouses (single family attached) |
| 113 | mobile home | Mobile homes inside mobile home parks and free-standing units outside parks |
| 114 | group quarters | Nursing homes, group homes, college dormitories, jails, military base personnel quarters |
| 121 | office | Generally includes any administration functions include corporate and government offices, banks* |
| 122 | retail | Retail trade and services, such as department stores, repair shops, supermarkets, restaurants* |
| 123 | institutional | Churches, governmental facilities, museums, education, hospitals, medical clinics, libraries and military bases |
| 124 | hotel/motel | Hotels and motels |
| 131 | industrial | Manufacturing plants, warehouses, office showrooms* |
| 141 | transportation | Railroads, radio and television communications stations, truck terminals* |
| 142 | roadway | Roadways and right-of-ways* |
| 143 | utilities | Sewage treatment and power plants, power line easements, pump stations, water treatment plants and water systems |
| 144 | airport | Airport terminals* |
| 145 | parking garage | Parking garages |
| 146 | runway | Airport runways |
| 147 | large stadium | Large stadiums |
| 160 | mixed use | Areas that contain both commercial (office and retail) and residential uses either in the same facility or in very close proximity |
| 171 | parks/recreation | Public and private parks, golf courses, cemeteries, public and private tennis courts and swimming pools, amusement parks |
| 172 | landfill | Sanitary landfills, land applications, and similar waste management facilities |
| 173 | under construction | Land that has undergone site preparation and construction has begun |
| 181 | flood control | Major flood control structures including levies and flood channels |
| 300 | vacant | Vacant land |
| 306 | parking CBD | Parking in Central Business Districts |
| 308 | expanded parking | Parking areas adjacent to or near large event venues and other large parking lots |
| 500 | water | Water |

example of possible uses. For this research the following shows how each LUCODE was integrated into the 2010 land use classes

- Buildings: 111,112,113, 114, 121, 122, 123, 124, 131, 143, 147, 160
- Transportation: 141, 142, 144, 145, 146, 173, 306 & 308
- Mowed/Grazed/Agricultural: 171, 172
- Herbaceous: 300
- Water: 500

In the NCTCOG list there is not a category for tree canopy cover and that is why the 2010 land use data created is so important; it adds another dimension to the data and knowledge base for the city.

Also, there was an issue with the 2005 land use data in that a major part of the transportation infrastructure was absent, as seen in Figure 12 on the right. To compensate for this lack of data in ArcMap an "Erase" was performed using the Input as the NCTCOG 2000 land use and the Erase Feature was the NCTCOG 2005 land use. The resulting shapefile was then merged with the 2005 land use

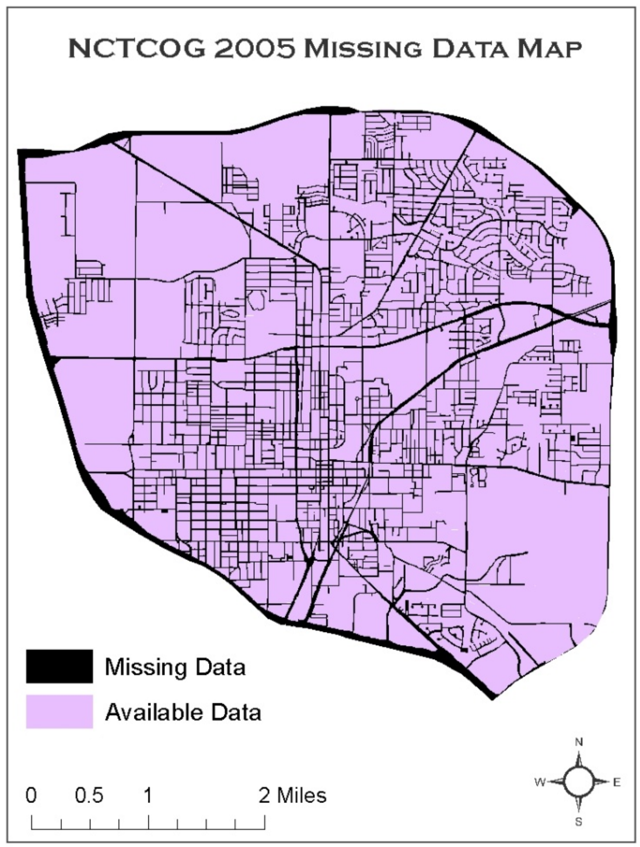


**Figure 12** *NCTCOG 2005 missing data.*

shapefile in an editing session in ArcMap to fill in the blanks and ensure the cohesiveness of the data. However after the merging of the 2000 and 2005 data there was still small spots of missing data which can clearly be seen, so despite efforts to smooth the data there is still some errors.

4.2 Geographic Information Systems Method

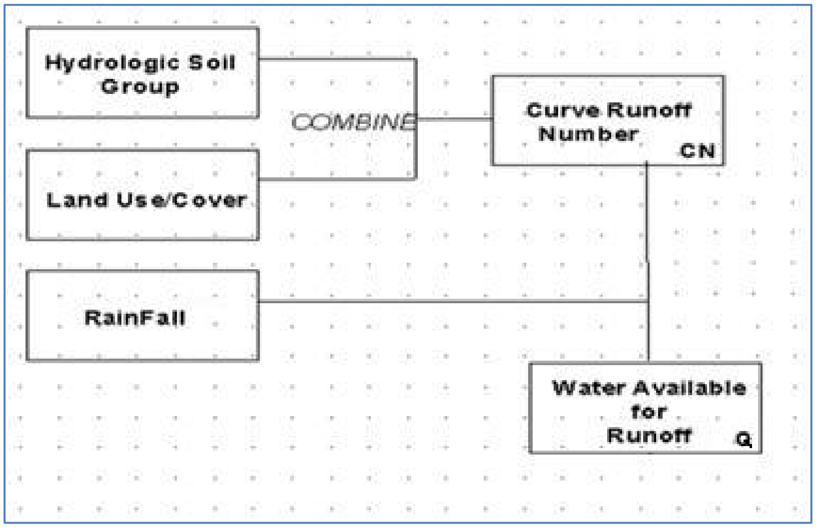


**Figure 13** *Flowchart for storm water runoff analysis.*

The implementation of a storm water runoff model is a process which initially starts with the collection and thorough understanding of the type of data available and how it could be applied. Surface runoff as well as infiltration was calculated using the land-use data produced from the remote sensing analysis along with the digital elevation model (DEM), hydrologic soil condition of AMCII and soil data. "There has been a vast increase in basic soils property data since Musgrave first proposed the concept of hydrologic soil groups in Handbook of Agriculture (USDA 1955)" (Van Mullem et al., 2004).

The first step in the Figure 13 flowchart is to take the prepared soil data, which was clipped to match the study area in ArcGIS, and designate the hydrologic soils groups based on each polygon's soil type.

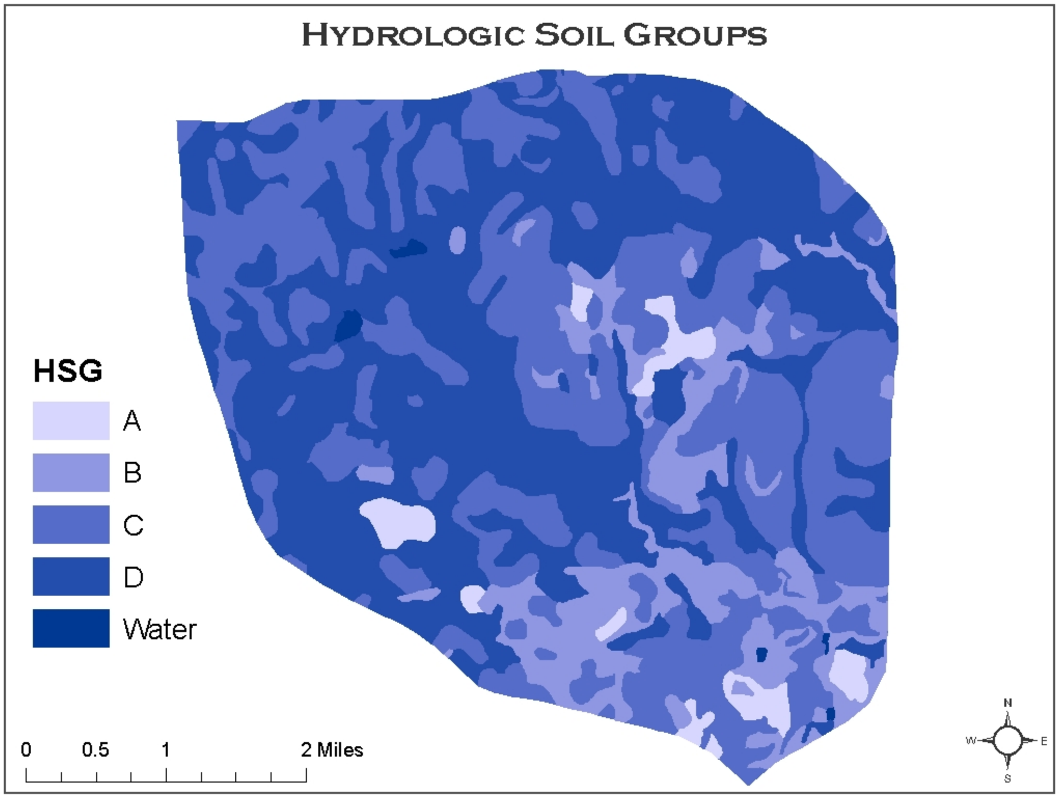


**Figure 14** *Hydrologic soil groups.*

Soil hydrologic groups are assigned to soil series based upon their interpretation of the published criteria; they are A, B, C, D, and dual groups A/D, B/D and C/D.

***Table 6*** *Hydrologic soil groups information*

| *HSG* | *Textures* | *Characteristics* |
|---|---|---|
| A | Sand, Loamy Sand or Sandy Loam | Low runoff potential & high infiltration rates |
| B | Silt Loam or Loam | Moderate rate of infiltration (when thoroughly wet) & moderate rate of water transmission |
| C | Sandy Clay Loam | Slow rate of infiltration rate (when thoroughly wet) & slow rate of water transmission |
| D | Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay | High runoff potential & very low infiltration rates (when thoroughly wet) & very slow rate of water transmission |

Dual hydrologic soil groups (A/D, B/D, and C/D): some wet soils that could be adequately drained. The first letter applies to the drained and the second to the un-drained condition. The table below shows what the curve numbers will look like for different combinations of land use and soil groups. These values below, in AMC II conditions, will serve as the basis for the curve numbers being derived in this model. This will be accomplished by combining both the SSURGO soil data and the land use data into one layer which is the next step in the Figure 13 flowchart.

The curve number is used in hydrologic models to divide rainfall events into storm runoff and other losses however it is important to note that curve numbers can vary due to changing seasons and different land use. The curve numbers where extracted after the combination of the land use and soil data using GIS. An Intersect was performed on these two layers in ArcGIS' ArcMap and data was produced reflecting the different combinations of land use and soil which then was used to produce the curve number.

The runoff curve number equation is often used to transform a rainfall frequency distribution into a runoff frequency distribution. The runoff availability equation is based on the CN number, calculated from the soil and land cover characteristics, which are usually easy to obtain in raster or vector format for GIS. The CN values range from 0-100 like a percentage with concrete having a CN value of nearly 100. It can also be used to predict the amount of water that will become runoff given a specific rainfall event. The following steps show how to combine the land cover and hydrologic soil group layers using the raster calculator in ArcMap GIS:

1. Enter in Raster Calculator
2. [Hydrologic Soil Group].Combine( { [Land Use and Cover] } )
3. Raster calculator will create a new grid

4. Values in the new grid represent zones of unique combinations of values in the input grids
5. Each of these soil/land cover combinations is then assigned a value of curve runoff based on a table obtained from the NRCS

Then plug in the CN grid and precipitation value into the available runoff equation.

[Equation 1] $S = (100 / CN) - 1$

Where $S$ = Potential Maximum Retention [inches]

$CN$ = SCS Curve Number

[Equation 2] $Q = (P - 0.2 * S)^{2} / (P + 0.8 * S)$

Where $Q$ = Precipitation excess (runoff) [inches]

$P$ = Cumulative Precipitation [inches]

# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 Land Use Changes

The study area in Denton, Texas consists of 12,774 acres of land which is divided into five groups based on the NCTCOG data provided and noticeably absent is the tree canopy cover category; the 2010 data will have a sixth category representing the tree canopy cover. The 2000 and 2005 land use data will be evaluated and compared with the 2010 land use data that I created. The acres and percentages for each classification will shift considerably once the sixth category of tree canopy cover is added into the equation for the 2010 data.

In 2000 transportation made up 2971 acres, herbaceous 4239 acres, buildings 5106 acres, mowed/grazed/agricultural 419 acres and water 39 acres; buildings have the highest percentage of acres in 2000. The methodology for the 2000 land use inventory by the North Central Texas Council of Governments (North Central Texas Council of Governments, 2000) was a combination of using the 1995 land use inventory, as a base, and updating the data using aerial photography, 2000 census data and county appraisal district data (North Central Texas Council of Governments, 2000).

In 2005 transportation made up 2320 acres, herbaceous 3923 acres, buildings 5974 acres, mowed/grazed/agricultural 502 acres and water 55 acres. In the five years from 2000 transportation lost 651 acres, herbaceous lost 316 acres, buildings showed a gain of 868 acres, mowed/grazed/agricultural gained 83 acres and water gained 16 acres. Based on the numbers it can be inferred that the resulting housing and business expansion, resulting in the development of maintained front and backyards (mowed land), developed on previously classified herbaceous land could have potentially been a reason for the number changes. It was noted that there was significant road development from 2000 to 2005 but the acreage for roads decreased. The loss of acres for the transportation classification could be attributed to the increased accuracy of the NCTCOG land use data as it was observed that the thickness of the road lines decreased from 2000 thus taking up less space.

The methodology used to create the 2005 land use was significantly different from the methodology that had been used in the 2000 land use survey. Denton County had appraisal data available for the 2005 survey of good quality along with very good quality of parcel shapes. The improvement of appraisal district data gave the NCTCOG the ability to assign land use codes to individual parcels. From 2005 and on the NCTCOG has used a methodology that analyzes: parcel data (being the most significant addition), aerial photographs, field work, and city input and development data from NCTCOG's development monitoring program. Prior to 2005 the NCTCOG used aerial photographs and extensive local review in the production of its land use data such as the 2000 data implemented in this paper (North Central Texas Council of Governments, 2005). The development monitoring program essentially monitors and new and upcoming buildings that has the criteria of being either 80,000 square feet, 80 employees on site, or 80 units (multi-family development only) as well as being either a public school, mobile home park or a public universities or colleges. The data for this program comes from various news media, construction reports, and direct contact with local professionals and developers to identify and verify items included in the database (North Central Texas Council of Governments, n.d.).This methodology is the reason entire parcels were coded as buildings when in reality the building/residence may have actually only taken up a small portion of the parcel and the rest could have been mowed/grazed/agricultural or tree canopy.

In 2010 transportation made up 2783 acres, herbaceous 685 acres, buildings 1669 acres, mowed/grazed/agricultural 4907, water 65 acres and tree canopy cover made up 2665 acres. This means that from 2005 to 2010 transportation had a gain of 463 acres, herbaceous lost an astounding 3238 acres, buildings lost an enormous 4305 acres, mowed/grazed/agricultural gained 4405 acres, water gained 10 acres and the tree canopy classification absorbed 2665 acres of previously otherwise classified land. The massive number changes show how new remote sensing techniques really make a difference in land use estimations. In Figure 18 below you can see the land use percentages and visually see how much they differ from 2000 and 2005's percentages.

There is always the potential for errors in the process of creating geographical data and it is important to have an idea of data accuracy to determine its usability. The best way to reliably check the accuracy of a map is to design and implement an accuracy assessment to examine the validity of the data. The assessment does not determine how or why the errors exist, simply that they do and that the sources of said errors could be human, computer and/or equipment related. A simple accuracy assessment was designed for this research study and consisted of thirty ground control points (GCPs) collected to assess the accuracy of the 2010 land use data I created. To identify sites likely to provide easily recognizable features that could be located in the field, and are distributed throughout the study area, a preliminary examination of the original 2010 imagery was conducted before collecting the GCP data. The GCPs were collected using a Garmon Colorado 400t GPS unit with the thirty points divided by each of the six land use classifications equally, so five ground control points for each land use classification. Table 7 shows the results from comparing the ground control points to the 2010 land use data created during the city of Denton tree canopy survey. Out of thirty points, twenty-five of them were accurate and five were incorrect resulting in an accuracy rate of just a little over 83 percent which is significant. This was calculated by dividing one hundred (percent) with the total number of GCPs (30), then I multiplied the resulting value with 25 (total GCPs with 100 percent accuracy).

***Table 7*** *Ground control points vs. classified land use data*

| Accuracy | GCP | Classification |
|---|---|---|
| Y | Buildings | Buildings |
| Y | Buildings | Buildings |
| Y | Buildings | Buildings |
| Y | Buildings | Buildings |
| Y | Buildings | Buildings |
| Y | Herbaceous | Herbaceous |
| Y | Herbaceous | Herbaceous |
| Y | Herbaceous | Herbaceous |
| Y | Herbaceous | Herbaceous |
| Y | Herbaceous | Herbaceous |
| N | Mowed/Grazed/Agricultural | Trees |
| Y | Mowed/Grazed/Agricultural | Mowed/Grazed/Agricultural |
| N | Mowed/Grazed/Agricultural | Buildings |
| Y | Mowed/Grazed/Agricultural | Mowed/Grazed/Agricultural |
| Y | Mowed/Grazed/Agricultural | Mowed/Grazed/Agricultural |
| Y | Transportation | Transportation |
| N | Transportation | Buildings |
| N | Transportation | Water |
| Y | Transportation | Transportation |
| N | Transportation | Buildings |
| Y | Trees | Trees |
| Y | Trees | Trees |
| Y | Trees | Trees |
| Y | Trees | Trees |
| Y | Trees | Trees |
| Y | Water | Water |
| Y | Water | Water |
| Y | Water | Water |
| Y | Water | Water |
| Y | Water | Water |
| **Total: 25Y/5N** | | |

The National Parks Services (NPS) branch of the United States Geological Survey (USGS) has decided on an accuracy standard of >80 percent for all remotely sensed vegetation mapping in their USGS-NPS vegetation mapping program. In this program they also used the remote sensing program eCognition developer to perform their segmentation and classification (Brown, 2008). Now, many professionals conducting land use classification studies have started to adopt the NPS data accuracy standard of 80 percent or greater. An example of this is the accuracy assessment study prepared for the National Park Service by NatureServe for the Guilford Courthouse National Military Park in Durham, North Carolina in May 2007 used the 80 percent accuracy standard of the NPS. The accuracy of this study, on its finest scale, was also 83 percent which was considered to be good and acceptable for use (NatureServe, 2007).

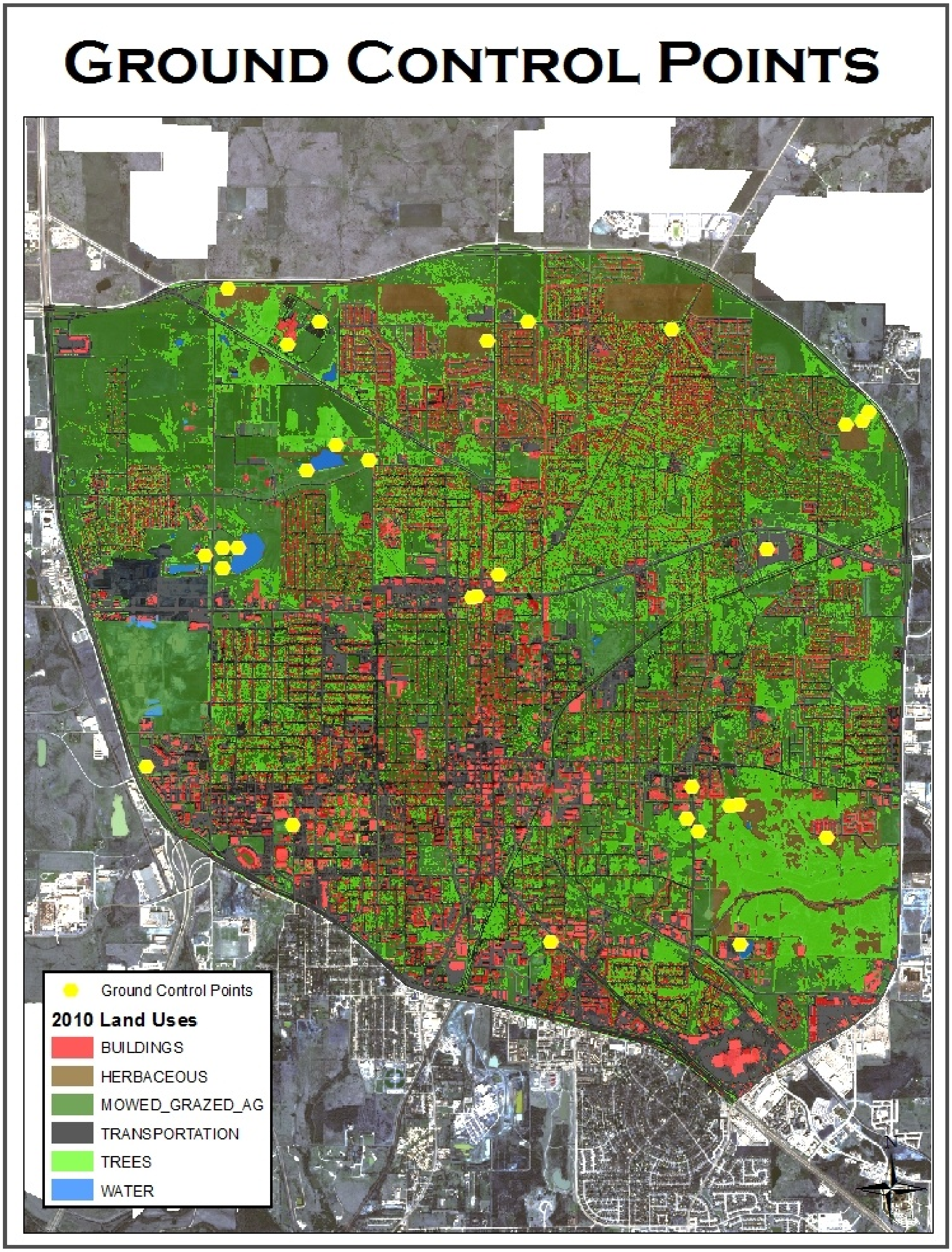


**Figure 15** *Ground control points map.*

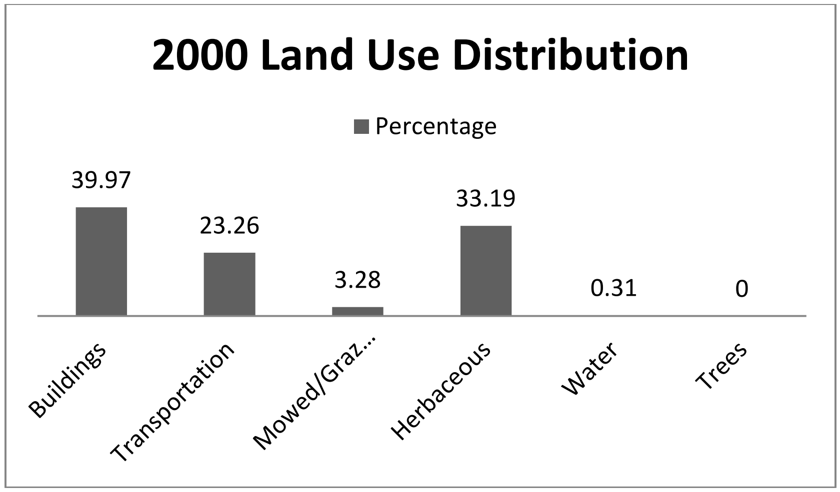


**Figure 16** *2000 land classification percentages.*

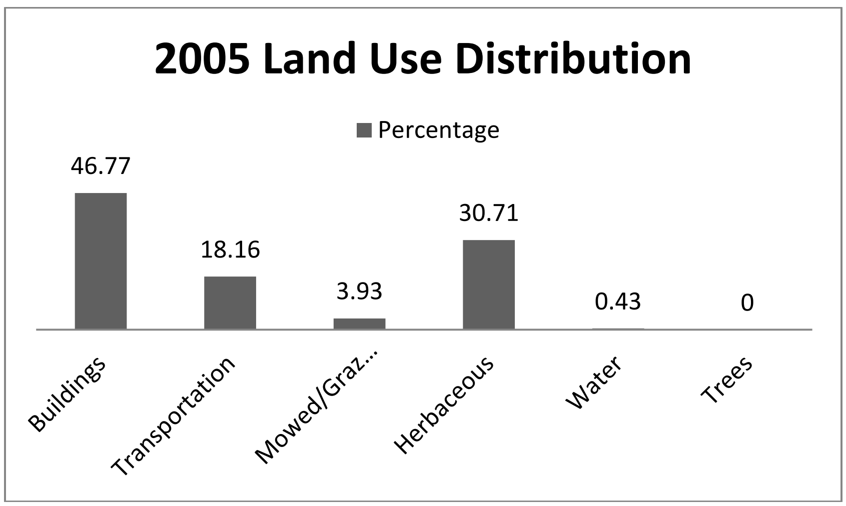


**Figure 17** *2005 land classification percentages.*

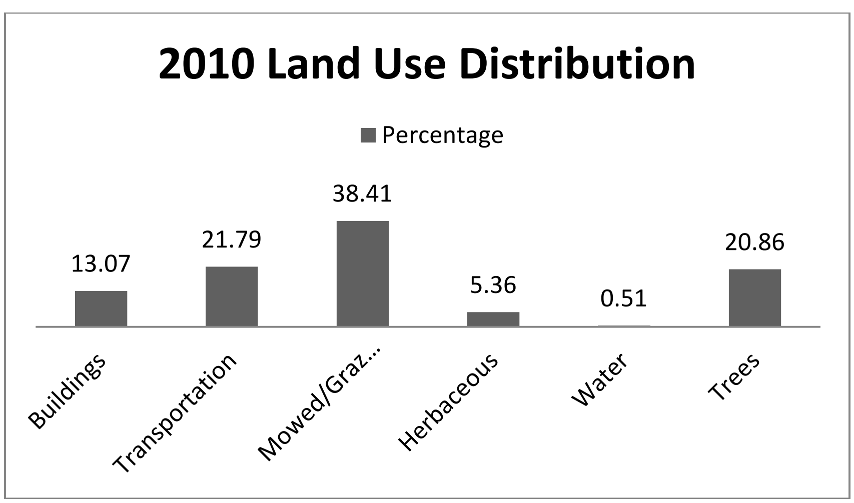


**Figure 18** *2010 land classification percentages.*

5.2 Storm Water Model Results

Data of soils, showing hydrologic soil groups, and land use classifications were first joined together to derive the curve numbers for storm water runoff. To estimate the curve numbers and runoff depth for the study area a curve number look-up table was created and populated in Microsoft Access. The values were obtained from The Hydraulic Design Manual- Section 7: NRCS Curve Number Methods – Runoff Curve Number (RCN) which provides guidance and recommended procedures for the design of Texas department of transportation drainage facilities (TxDOT, 2011). After the curve number grid was generated the storage capacity (S) was calculated using the curve numbers. Then the water available for runoff (Q) was calculated using the storage capacity coefficient in combination with the precipitation input which was set as five inches for this study. Each process was completed a total of three times, one for each land survey, indicated previously in this paper.

In Figure 19 the curve number color most dominant is blue, meaning there is a high propensity for runoff. With 9,761 acres, of the total 12,774 acres, in the category of 91-100 this represents 76 percent of the total study area. This result is unrealistic considering there is far less construction and urban development in 2000 than in 2010. This map shows the inaccuracies of the NCTCOG's methodology as of 2000 for the land use survey, because the results could not be used for any type of realistic storm water runoff modeling. The calculations for the runoff depth (Q), seen in Figure 20, show that nearly the entire study area has a propensity for direct runoff with no saturation into the ground.

The map representing curve number runoff for 2005, Figure 21, shows the gaps in data (white spots) that are present. The gaps are a result of the missing transportation infrastructure that occurred from the beginning despite fixing the majority of the issue when combined with the

2000 data through the ‘Erase’ & merging in ArcMap. Visually there is not much difference from the 2000 and 2005 curve number runoff maps, and the category of 91-100 still holds a disproportionate percentage of the study area with 9,915 acres or almost 78percent. The calculations for the runoff depth (Q), seen in Figure 22, shows how nearly the entire study area has a propensity for direct runoff with no saturation into the ground just like the 2000 runoff map showed. This map again shows the inaccuracies of the NCTCOG’s methodology as of 2005 for the land use survey, because the results could not be used for any type of realistic storm water runoff modeling.

Below in Figure 23 you can see what the curve number values look like spatially with over 43 percent of the area being in the 71-80 curve number range and over 37 percent of the total study area having CN values greater than 90. The spatial distribution of runoff depth (Q) calculated from five inches of rainfall, seen in Figure 24, indicated that the study area had more varied runoff depths for 2010 than the previous 2000 and 2005 calculations.

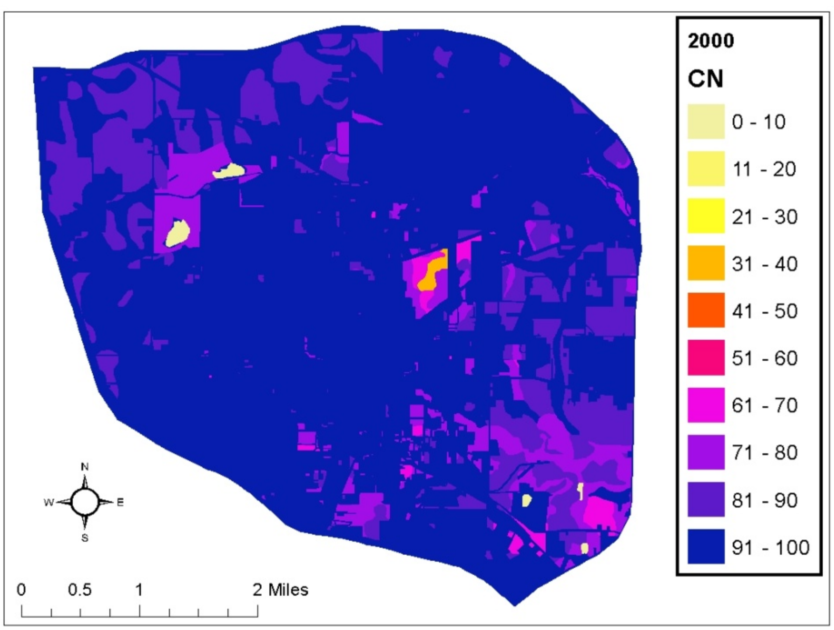


**Figure 19** *2000 curve numbers (CN).*

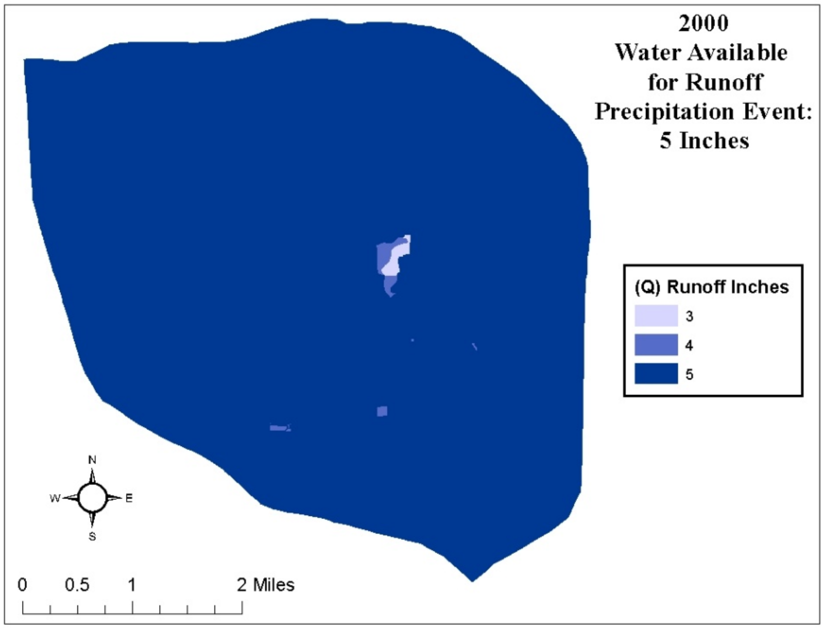


**Figure 20** *2000 runoff (Q) for 5 inch precipitation event.*

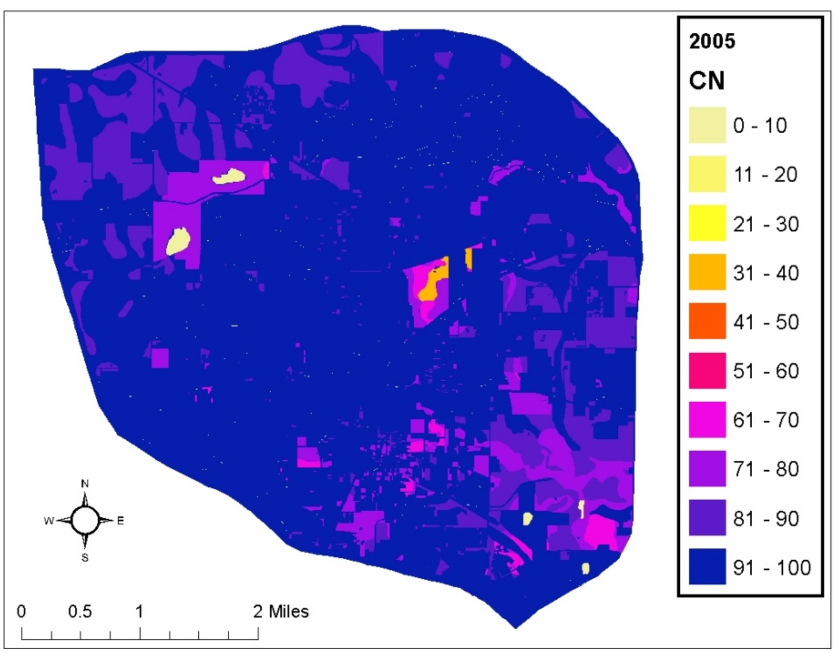


**Figure 21** *2005 curve numbers (CN).*

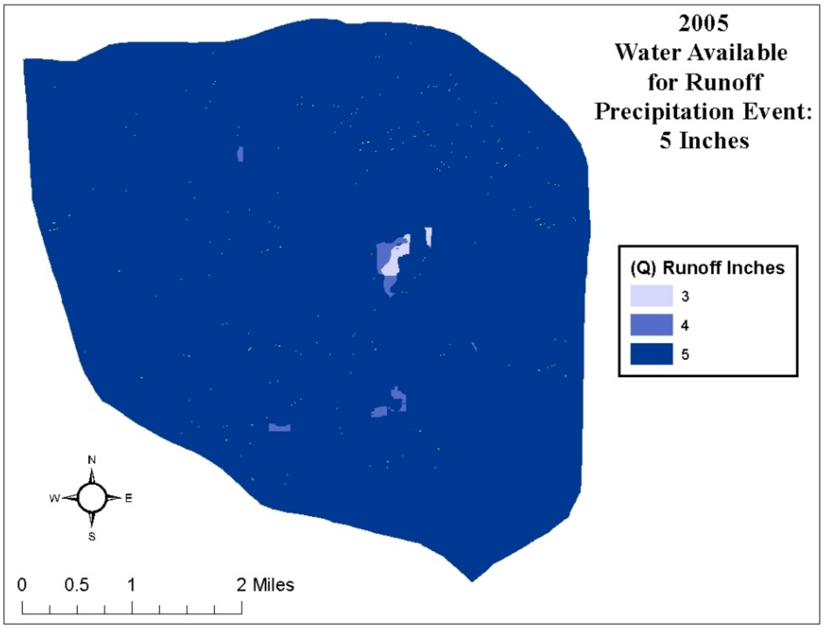


**Figure 22** *2005 runoff (Q) for 5 inch precipitation event.*

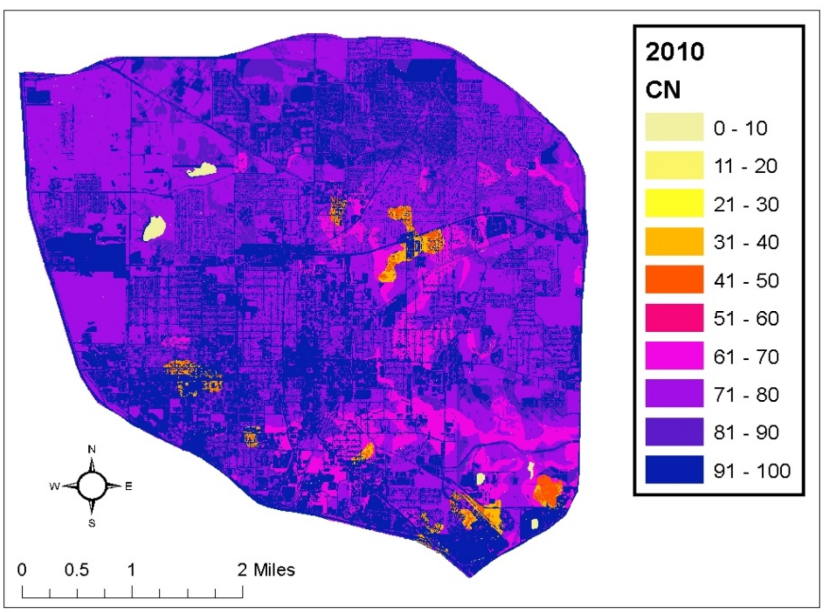


**Figure 23** *2010 curve numbers (CN).*

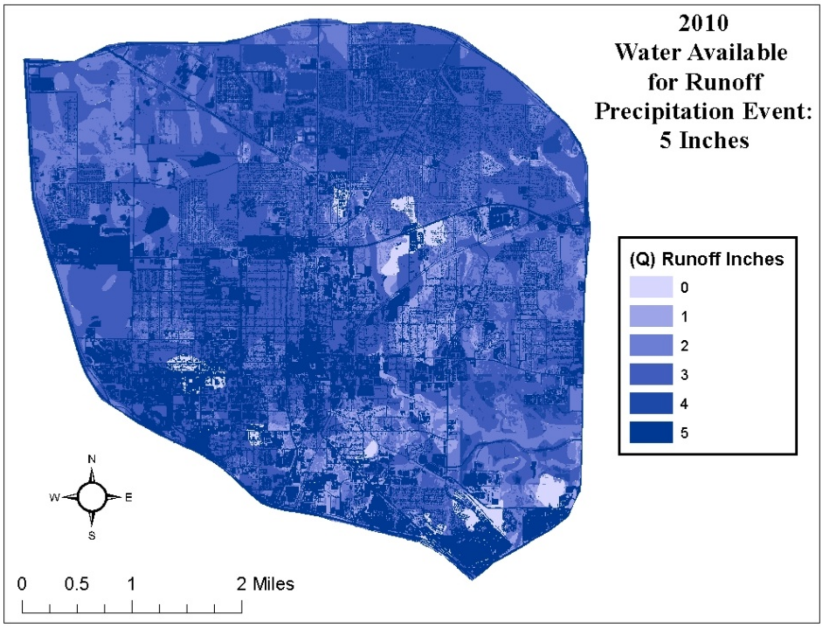


**Figure 24** *2010 runoff (Q) for 5 inch precipitation event.*

# CHAPTER 6

# CONCLUSIONS

The purpose of this research was to help inform the city of Denton officials with accurate data so they can better manage their city. Increased impervious surfaces from urban expansion, man-made structures like paved roads, sidewalks, driveways and parking lots, severely reduces the amount of water that is naturally absorbed into the ground. This prevents water from being naturally filtered and cleaned, keeps groundwater aquifers from recharging and causes toxins (such as oil) on the surfaces of streets to wash into our water supply only to spend hours later trying to clean it out. The combination of mostly non-porous and expansive soils and intense urban infrastructure, resulting in impervious surfaces, creates a serious need for better monitoring technology and methodologies to combat storm water runoff that results in flooding.

This study analyzed the potential for storm water runoff for the city of Denton, Texas using three different land use datasets; each land use dataset created with a different methodology. The difference between the three land use datasets, two from the North Central Texas Council of Governments (NCTCOG) and one is my own dataset, were also be studied as a part of evaluating and comparing new remote sensing techniques. The hypothesis asked: Do new remote sensing techniques provide for more precise and effective land use data in stormwater runoff analyses? The results showed that new remote sensing techniques can be very useful and help in the continuation of monitor changes within watersheds by providing more accurate data. It was also noted that areas heavily laden with tree canopy cover affected the curve number values by lowering them thus resulting in less storm water runoff.

This paper used spatially distributed rainfall as the input for the analysis of a stormwater runoff event during AMCII moisture conditions. It was found, based on the 2010 model results that the peak runoff increases significantly in the more urbanized areas due to the higher runoff coefficient. Compared to the available NCTCOG land use survey data, my own 2010 land use data succeeded at providing for more accurate storm water runoff modeling results. In general, the NCTCOG is the accepted default-go-to for local free data which many people take advantage of. The NCTCOG specifically states that the free data they make available should be used for graphical representation only and the accuracy is not to be taken/used as data produced for engineering purposes or by a registered professional land surveyor for the state of Texas (North Central Texas Council of Governments, n.d.). However, individuals with little or no experience in remote sensing or GIS are more likely to use the free land use data readily available if they cannot afford to purchase custom high-quality data or make it themselves.

There ended up being some problems encountered throughout the research that should be highlighted. The land use survey for 2005 from the NCTCOG provided discrepancies in the data due to a major part of the transportation infrastructure being missing. This could be fixed by perhaps contacting the NCTCOG directly and discussing with them the purpose behind the missing information and trying to get better data from them in the future. Also, the land use data for 2010 could be developed into even more detailed land use categorizations thus generating even more accurate curve numbers for use in the analysis. As an example, roads could be broken down into even finer categories based upon their material such as gravel, concrete or asphalt.

## 6.1 Applications of Data for City

Future approaches to better land management within Denton, Texas should be to instill in society and researchers the will to create and sustain soil and land conditions that encourage the infiltration of rainfall where it falls, and to counteract the causes of runoff (Shaxson et al., 2003). Tree canopy, low bushes, herbs and surface litter provide an excellent protective cover for surface soils from loss of porosity by direct impact of raindrops. Also serving as a food and energy source for soil organisms, the litter encourages formation of soil organic matter and faunal passages which ultimately leads to higher infiltration rates (Shaxson et al., 2003). Another approach the city could take to increase storm water infiltration and slow down runoff is by detaining the precipitation with physical structures that have been constructed across slopes and parallel to the surface contour; examples of these include stone lines, walls and earth banks. Also using large quantities of organic manure, which can be used to fertilize mowed/grazed/agricultural land, in the place of chemical fertilizers will increase the available water capacity (AWC) of soils. However the quantities of organic materials required to markedly increase the AWC are very high so the applications must be continued over many years Shaxson et al., 2003).

6.2 Future Research

This research could be taken a step farther in the future by adjusting the runoff curve number (RCN) from the AMCII condition to AMCI and AMCIII conditions. This will give the city of Denton an even better and more precise idea of how storm water will runoff based on the pre-existing moisture conditions. AMCI and AMCIII conditions can be calculated from the existing AMCII value by using the following equations:

$$CNI = \frac{4.2 \times (CNII)}{10 - 0.058 \times (CNII)}$$

$$CNIII = \frac{23 \times (CNII)}{10 + 0.13 \times (CNII)}$$

Other suggested future efforts include: (1) The investigation of additional flow events for the many sub-basins in Denton, TX, (2) study alternative measures of watershed wetness because the main issues appear to be in assessing an area’s wetness before an event, (3) development of relationships between outlet flow components and water quality parameters, (4) re-evaluating land-use data to make it even more specific and accurate to the true terrain, (5) compare old techniques and their accuracy to new ones and also (6) calculate the accumulated flow for each of the three land use datasets to get an idea of where the water will eventually flow. Something to also consider for future development is the major benefits of creating a set of standards for those conducting the research and those relying on the results. As a result there would always be an agreed upon baseline for all future research and it would help make the flow of information uniform and concise.

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