A COMPARISON OF URBAN LAND COVER CHANGE:

A STUDY OF PASADENA AND INGLEWOOD, CALIFORNIA, 1992 - 2011

by

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DEDICATION

I dedicate my thesis in honor of my grandparents, who I would not be here without their love and support. I also dedicate my thesis to my loving parents who have supported me throughout everything, my sister for all of her encouragement to graduate, and my godmother for all the stress-relief phone calls. Last, but not least, this is for my cousins and friends for their support and encouragement.

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NLCD	National Land Cover Database
GIS	Geographical Information Systems
SPOT	Satellite Pour l'Observation de la Terre
MODIS	Moderate Resolution Imaging Spectroradiometer
PHX-UGM	Phoenix Urban Growth Model
MRLC	Multi-Resolution Land Characteristics Consortium
MSS	Multispectral Scanner
TM	Thermal Mapper
ETM+	Enhanced Thermal Mapper Plus
OLI	Operational Land Imager
TIRS	Thermal Infrared Sensor
DEM	Digital Elevation Model
CIR	Color Infrared Composite
USGS	United States Geological Survey
EPA	Environmental Protection Agency
NOAA	National Oceanic and Atmospheric Administration
USFS	United States Forestry Service
BLM	Bureau of Land Management
NASA	National Space and Aeronautics Administration
NPS	National Parks Service
USNFWS	United States National Fish and Wildlife Service
NASS	National Agriculture Statistics Service

ABSTRACT

Imagery and spatial data collected from different tools and satellite technologies have been used to complete land cover change studies at the scale of cities, countries and continents. Different methodologies have been used to complete these studies, dependent upon the technology and information available to complete land cover change. In this thesis, urban land cover has been analyzed by applying Landsat satellite imagery to spatial analysis as a way to examine land cover changes in Pasadena, California and Inglewood, California from 1992 to 2011. The objective for this study has been to review spatial data collected from Landsat data in order to understand urban land cover change in each city. Spatial data collected from the National Land Cover Database (NLCD) have been pre-processed with color infrared composite creation and image classification tools to show land cover. Imagery from Landsat 4 has been used to help compare land cover change from 1992 to 2001 since classifications of the NLCD were different in both years. The resulting maps display the land cover changes over time from the effective application of imagery analysis to complete a pattern of land cover change over the time of twenty years. The study's findings demonstrate that cities in the same metropolitan center can have similar urban growth patterns even when they have geographically diverse landscapes. These findings underscore the importance of understanding urban grown patterns when planning for urban.

CHAPTER 1: INTRODUCTION

Satellite imagery has enhanced the way the world can be viewed. This type of imagery can be manipulated and run through spatial analysis classification tools to further understand our world. Taking imagery from multiple decades and applying spatial analysis classification tools can illuminate the changes that have occurred during that period of time. Understanding the urban and population changes of the past can help the future of urban planning.

1.1 Landsat Imagery and Land Cover Change

To understand the structure, function, and dynamics of urban areas, it is necessary to integrate both ecological and human progress, such as physical geographic changes to road maps or population change, that result in land cover change. As a result of human activities, pervasive ecological changes have occurred at local, regional, and global scales, such as the change in land cover of natural landscapes to provide for human needs (Vitousek 1994, 1867-68). Urban landscapes exhibit the most conspicuous spatial heterogeneity of all landscapes, and the spatial form a city takes affects physical, ecological, and sociological processes (Picket *et al.*, 1997; Zipperer *et al.* 2000; Wu and David 2002). While the ecological and sociological effects of land conversion for agricultural uses have been studied (Riebsame *et al*. 1994, 351), the effects of land conversion for human habitation, or urbanization, are less understood (Pickett *et al*. 1997, 186). Urbanization is the general process of city growth; native land cover is appropriated for industrial, commercial, residential, and other land uses associated with human demands. As human population increases and as increasing proportions of people move to urban environments, the number and size of urbanized areas will also increase globally (Simpson 1993; Cohen 1995). The importance of these particularly human-dominated landscapes in controlling global biospheric processes is particularly important (Jenerette and Wu 2001, 611). The patterns and processes of urbanization should be integrated if the ecology of cities is to be fully understood (Foresman *et al*. 1997; Wu and David 2002).

A distinction between what is land cover and what is land use will help understand the focus of this study. Land use describes use of the land surface by humans, usually in an economic context, as in residential, commercial, agricultural (Campbell and Wayne 2011, 585). However land use can be hard to see, except under close examination. The visible features of the Earth's surface, such as vegetation cover, natural and modified by humans, structures, all fall comprise land cover. This study looks at the land cover in the imagery of the study areas.

Understanding the patterns and processes of land cover change over time has become easier to understand with the ability to interpolate satellite imagery to classify land cover types and the manner in the land cover has changed by comparing different periods of imagery with geographical information systems (GIS) software. The urban footprint can be seen through different remote sensing tools to provide imagery with real time conditions. In the case of this study, imagery of Pasadena and Inglewood, California has been obtained from Landsat 4 Thematic Mapper satellite sensors at the USGS GLOVIS website. These data have been analyzed with ArcMap 10.1, utilizing spatial analysis and image classification tools to achieve land cover types that are compared with NLCD data.

1.2 Existing Research Gaps

This study includes two non-coterminous, large populous and geographically different cities in Southern California; however, previous studies have covered much broader study areas. Some previous studies include provinces/states or even entire countries (Deng *et al*., 2009; Tian *et al*. 2005; Jenerette and Wu 2001), while others cover large metropolitan regions (Luck and Wu 2002; Berling-Wolff and Wu 2004; Shenghe, Prieler and Xiubin 2002). The ability to use large amounts of data enables for more work to correct inaccuracy due to the multitude of data involved. The ability of this study of Pasadena and Inglewood is to focus on two determinate locales within the same metropolitan area and begin the analysis with accuracy as the image classification work begins. However, this is not always a feature as there is usually some leniency with data accuracy that covers large areas.

Secondly, working with NLCD land cover data from 1992 and data from more recent years is not a simple task. The land cover classification utilized for the NLCD 1992 is based off the Anderson method for classification from the late 1970s. This method worked well with the satellite imagery from the Landsat 4 satellite in the early 1990s, however, did not work well with the more technologically advanced imagery that occurred thereafter, and a new See5 decision-tree classification method. This method is user friendly, and more importantly, allowed for better classification of urban elements based on imperviousness (Fry *et al*. 2008, 2). Using a broader classification system that is also based on the Anderson classifications method, the NLCD 1992 land cover data can be compared with land cover data gathered in the more recent years.

Another factor to keep in mind is time, as in the period of time in which the study is completed. There have been studies that span over centuries (Meiyappan and Jain 2012, 122; Aspinall 2004, 91), and yet others that only consider a decade of land cover change (Tian et al. 2005; Shenghe, Prieler and Xiubin 2002). There does not seem to be a corresponding time limit when it comes to these studies other than the limit to the data available to complete spatial analysis with satellite imagery. This thesis is based on the timeline of NLCD data from earliest available to the most recent.

The last point gathered from researching land cover change with GIS is that there has not been one single way to complete the analysis. Some studies use modeling to complete land cover change over time using a variety of data sources (Berling-Wolff and Wu 2004; Jenerette and Wu 2001; Aspinall 2004, 91). On the other hand, there are other studies that used satellite imagery to complete the urban land cover change analysis, but have different systems for the data. Imagery from the Landsat family, *Satellite Pour l'Observation de la Terre*, translated into English as Satellite for observation of Earth (SPOT), or Moderate-resolution Imaging Spectroradiometer (MODIS) on either the Terra or Aqua satellites (it was not stated by Meiyappan and Jain, 2012, on which was used) have been used with spatial analysis tools to complete land cover change studies.

The case for this study is to utilize a sound method of urban land cover change analysis based on image quality, data availability, and data manipulation. Previous studies have been completed to gain knowledge of certain areas and data was collected for those places. This study will focus on determinate places and a time period with the best data available to use and improve accuracy.

1.3 An Outlook on Pasadena and Inglewood

Understanding the past of these two cities ensures that the analysis is probably situated and ensures that we know to look for, i.e. places of constant change, parts of the city that will never change due to laws protecting open land or historic areas, etc. Without knowing what happened before the use of satellite imagery to examine land cover, it is hard to understand what and why the changes that are found through the use of this imagery might have occurred. The previous map shows the location of the study areas in Los Angeles County, with the inset showing a closer geographical relationship. The following briefly discusses the past of the two cities under study.

1.3.1 Pasadena

Historically, the land of Pasadena transitioned from agricultural farmland in the city's beginnings to a copy of an Industrial Revolution age city in the start of the twentieth century to the now technological and cultural focused urban lifestyle Pasadena is recognized as. The era of agricultural prosperity in Pasadena predates the technology to be used in analysis, but one can assume that urbanization drastically changed the look of the southern California city.
People were migrating west for new opportunities and industry was creating new jobs to be filled. Pasadena's population at the time of the Industrial Revolution in the 1920s was nearly ten times of what it was at the time of its incorporation in 1886 (Los Angeles Almanac 2014).
The population of the city during the twenty years of this study has grown from 131,591 in 1990 to 133,936 in 2000 and up to 137,122 in 2010 according to the United States Census. The majority of Pasadena is of white ethnicity, followed by Hispanic/Latino, Asian, and Black/African-American. The high school graduation rate is 85.6%, and about half of the adult population hold a Bachelor's degree or higher. As of 2010, there are 55,110 households in Pasadena, with an average of 2.43 persons per household. In 1990, the number of households was lower at 50,199 with an average of 2.53 persons per household. The city consumes 22.97 square miles of Los Angeles County. This leads to 5,969.6 persons per square mile, as of 2010.

Due to significant changes in land cover over the last few decades and great data availability, Pasadena makes for an interesting case study. The city is geographically diverse with both urban and natural landscape features. In addition, Pasadena is a good choice for this study since analysis can be cross-checked for study accuracy with its real physical locations in Southern California.

Another reason for the choice of Pasadena as a study area is the understanding of how the city has been planned out. Since Pasadena's beginning, the layout of streets, neighborhoods, and open space has been carefully architected. The current land use policies are now focused on density issues and creating a sense of place, great neighborhoods, gardens, plazas, parks, and trees (*Land Use and Mobility Element Policies* 2014). The latter is especially important since the city is known as Tree City USA, as stated by a sign in Pasadena.

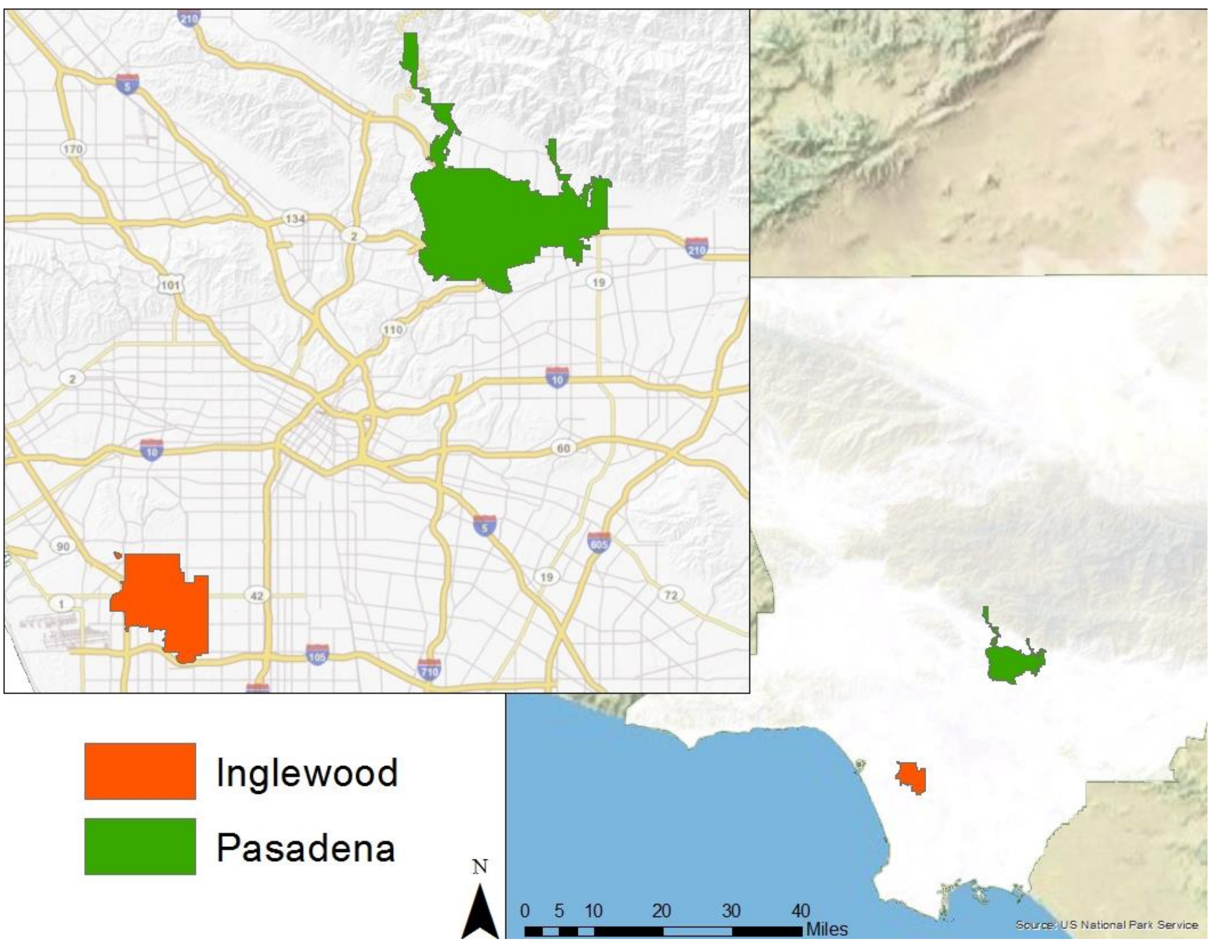

Figure 1. Location Comparison Map of Pasadena to Inglewood

1.3.2 Inglewood

With its past in agriculture as well, Inglewood made its mark in barley and poultry production. The city was incorporated in 1908 with a population of 1200. A small number by today's perspective, but in the early 1920s, Inglewood was known as the fastest growing city in the United States, mainly from visitors seeking earthquake damage and stayed for the coastal environment. Also in the 1920s, Inglewood became to be known as the chinchilla capital of the World as the locale was easy to import to from Peru.

World War II turned Inglewood from an agricultural hub into an urban community built by defense industries. During the 1960s and 1970s, the city continued to grow into a metropolitan city, embracing both its residential and commercial communities, and supporting sports with the Hollywood Park racetrack and having a few Olympians who grew up in the city. With its ease of accessibility to major freeways and Los Angeles International Airport, it made for an attractive business environment and ideal location for air freight business. The skyline began to change as more tall municipal and commercial buildings hovered over the historical places the citizens continue to protect and praise (City of Inglewood, 2015). Inglewood, unlike Pasadena, is not geographically diverse and is highly urbanized. This opposition makes Inglewood a good choice to compare against Pasadena in this case study.

Inglewood was chosen for its homogeneous physical landscape and for having an uneven population growth rate, to offset that of Pasadena. Inglewood is also located in Los Angeles County, but as its own entity like Pasadena. As seen in Figure 1, Inglewood and Pasadena are only separated by the city of Los Angeles. The population of Inglewood only grew by seventy from 1990 to 2010, as it went from 109,602 to 109,673. However, in 2000, the population spiked at 119,580 according to the U.S. Census. This means that there was growth, but an equal decline within those twenty years. The number of households reflected the same fluctuation, beginning with 36,102 households in 1990, rising to 36,805 in 2000, and declining to 36,461 in 2010. Inglewood comprises 9.07 square miles of land south of Los Angeles. Using the population totals for 2010, this leads to 12,094.5 people per square mile.

The majority ethnicity has also changed in those two decades. In 1990, the highest percentage of the population was fifty-two percent Black/African-American. While Black/African-American remained the majority in 2000, it declined with a rising Hispanic/Latino population. In 2010, the majority became Hispanic/Latino at 50.56%. All the meanwhile, the White percentage climbed higher from 17.47% in 1990 to 23.31% in 2010. Also, according to the U.S. Census, the high school graduation rate increased from 19.8% in the early nineties to 71.8% by 2010.

Inglewood also has a General Plan for the city's land use, mostly focusing on commercial, industrial, and transportation sections, with housing, open space, and other uses also under control, however, not as detailed as that of Pasadena. Having two different study areas that are geographically and socio-economically different enables this study to demonstrate the ability of land cover classification with different conditions involves, and to understand any demographic characteristic relationships.

1.4 Thesis Orientation

The objective for this study is to analyze land cover data for Pasadena and Inglewood, California from 1992, 2001, and 2011 to cover a twenty year timeline of urban land cover change in the greater Los Angeles metropolitan area to gain a better understanding of past land cover changes to prepare for the future in urban planning. This includes data acquisition, image classification, and urban land index comparison of NLCD data for 1992 and 2001, to be compared with NLCD data for the changes from 2001 to 2011. This allows the information to reflect future transitions within the city and help develop urban planning ideas for the community.

This thesis is divided into five chapters. Chapter Two reviews the development of the use of Landsat imagery, and satellite imagery in general, in GIS for land cover change analysis, along with a history of the study of land cover change in the past century. This chapter describes the different methods for spatial analysis including satellite imagery for understanding patterns of land cover change. Chapter Three describes the study area, data sources, and the methods for the image classification of the Landsat imagery. The conceptual framework is explained along with the expected outcomes. Chapter Four reviews and explains the outcomes of the study. Chapter Five discusses the impact of the findings and their contribution to existing research on urban land cover change over time.

CHAPTER 2: RELATED WORK

Geospatial analysis for urban land cover change over time has benefited from the use of GIS tools to analyze data and display results. Completing a review of previous studies gives an idea of what can occur in this study and what the results could be. This review also presents an idea of the obstacles to further spatial analysis of the data. Also, since this study will use previously completed image classification for land cover types from satellite imagery of Southern California to compare the land cover change of two cities to understand the urban growth in the Los Angeles metropolitan region, a review of how studying land cover has evolved over time will be conducted.

2.1 Previously Completed Studies

The following studies discuss the use of satellite imagery in land cover change in different parts of the United States and the world. The ideologies behind these studies helped guide in choosing the methodology for this study on land cover change.

This first study was the primary influence for the methodology of the study of Pasadena and Inglewood. Guangjin Tian and co-authors studied the spatio-temporal characteristics of urban expansion in China using Landsat TM imagery from 1990/1991, 1995/1996, and 1999/2000. These images interpreted to a 1:10000 vector land cover dataset helped to clarify where the fast urban growth occurred regionally throughout the entire country of China. Tian and co-authors calculated the urban land percentage and urban land expansion index of every 1 km^2 cell that covered China. The previous two terms are furthered explained as they are used in the method of completing the study. Their result was land cover dynamic changes reflect the strong impacts of economic growth regions and urban development policies.

Staying with the study area of China, Jin S. Deng and his co-authors focused in the Zhejiang province from 1996 to 2006. Their theory was the "analysis of spatio-temporal characteristics of land cover change was essential for understanding and assessing ecological consequences of urbanization (Deng *et al.* 2009, 187). They utilized SPOT imagery, along with spatial metrics derived from FRAGSTATS software to find that the rapid urbanization process included large amounts of land cover change and urban growth at high rates, changing the look of the landscape. Deng and his cohorts' methodology was based on pre-processing the data, enhancing and extracting land cover change information, and assessing the accuracy of the results. Their results confirmed the effectiveness of the combined method of using remote sensing and metrics to define spatio-temporal features to further define land cover patterns across time periods.

The third study is by Liu Shenghe, Sylvia Prieler, and Li Xiubin based on the urban growth centers of Beijing, China. They digitized land cover maps from 1982, 1992, and 1997 to create data to be used with spatial analysis tools. This study could have been completed with the use of satellite imagery to increase the accuracy of the data since digitizing decreases accuracy.

G. Darrel Jenerette and Jianguo Wu's land use methodology created a boundary line in the Central Arizona/Phoenix region and gained an understanding of what was urban, desert, agriculture, or other land cover classifications within that boundary. Their methodology consisted of creating landscape raster maps with 250 m^2 pixels, classifying the majority rule criterion of their design, and using a multiple of digressions, such as edge density, fractal dimension, and contagion/landscape configuration. This was completed to examine the relationships between potential socioeconomic drivers and environmental constraints, land cover pattern correlation of population size through population growth model and correlation of topography though estimated mean slope of each land cover class by overlaying a digital elevation model (DEM) onto each land cover map. A probabilistic cellular automata simulation model was used to complete a temporal sequence of land cover change pattern. This study was the inspiration to gain an understanding of the affect population has on the change in land cover in Pasadena and Inglewood.

Other studies conducted about the Phoenix area have been done by Matthew Luck and Jianguo Wu, and Sheryl Berling-Wolff and Jianguo Wu. Luck and Wu converted a vector dataset to a raster data set with a 50 in^2 pixel after resetting classifications from a 1995 Maricopa land cover dataset. Landscape metrics and a gradient transect were applied to the raster dataset to attempt to identify land cover type spatial signatures. Their approach was not land cover change over time, but land cover change over area and if there are any apparent spatial patterns of urbanization. Berling-Wolff and Wu also quantified spatial patterns of urbanization, along with temporal patterns of urbanization with dynamic modelling and spatial analysis. They developed the Phoenix Urban Growth Model (PHX-UGM), a spatially explicit urban landscape model, from the Human-Induced Land Transformations (HILT) model used in the San Francisco Bay area. Selected growth rules and new rules were added to appropriately identify ecological and social features of the Phoenix study area in the modelling. The methodology for this study would not work with Landsat imagery due to the best results at a 120 – 450m spatial resolution, and Landsat is 30m resolution.

Continuing with the use of model analysis for land cover change, Richard Aspinall links model selection and multi-model inference with empirical models and GIS for the Gallatin Valley in Montana between 1860 and 2000. He developed empirical models based on data for case studies of land cover change. The choice between multiple alternate empirical models that potentially can be developed for a given dataset was made for the best relationship of empirical modelling to drivers of land cover change.

The choice to use the methodology based on satellite imagery spatial analysis tools in ArcMap was used due to the complexity of the use of modelling to complete the study in Pasadena and Inglewood. A. Veldkamp and E.F. Lambin agree that land cover change models add to the complexity that is land cover systems. They add that land cover modelling can offer the possibility of testing the sensitivity of land cover patterns when variables are changed and these models can allow for the testing of the stability of linked social and ecological systems throughout the land cover systems. This also furthers the Pasadena/Inglewood study context of urban land cover change with population statistics. People make the changes; urban structure just does not change by itself. The modelling methodology is reviewed to demonstrate what can be done in understanding urban land cover change.

2.2 Land Cover Change over the Past Century

Land cover has been monitored since medieval times through cadastral maps of villages and kingdoms to monitor crops and people. As time and technology progressed, the way the world is looked at has changed. Aerial photography and satellites have given large area monitoring and images a huge leap forward in how land can be managed.

Cadastral maps in Sweden from the seventeenth and eighteenth centuries kept record of land use, ownership, physical features, yield, and quality of hay (Cousins 2001, 41). These maps demonstrate the importance of understanding the land for the suit of use. These maps were later used in a modern study as a source of information on present day ecological patterns. Sarah A.O. Cousins used local warping to rectify the cadastral maps to determine general trends in land use over three hundred years in Sweden to underestimate the full dynamics in land use change.

The next step after hand-drawn maps for understanding land cover is aerial imagery. Aerial photos represent a very useful tool for the identification of past and present ground features on large areas since photography has been available for over 150 years (Gennaretti 2011, 542). Aerial images can be used as basemaps or the imagery can be interpreted to categorize or assign attributes to surface features. Specialized cameras can minimize distortion and maximize image quality have been attached to aircraft, more recently to specialty aircraft designed for photographic mapping projects (Bolstad 2012, 228).

Image interpreters use the fundamentals of land cover classification to delineate separate land cover classes in an organized and systematic manner. This process has become computerized and is now completed much faster when first devised. A study completed by Fabio Gennaretti and his co-authors used some of the first aerial photos in France by photographer Nadar from 1858 while aloft in an aerostat, an unpowered balloon or airship filled with gas. They explained different procedures in which land cover mapping could be completed from those images. The most common procedure was based on photo interpretation and manual digitization of the land cover classes represented. However, this procedure proved time consuming for large study areas and was subject to individual interpretation. Another procedure for land cover maps to be obtained was by digital processing through the allocation of pixels into finite number of classes or categories on the base of their spectral values. This approach used images with few spectral bands and small pixel size that lead to classification errors.

A third procedure was object oriented which represented an updated method for the extraction of information from aerial photos for land cover. This process involved the segmentation of the initial images allowing for the extraction of vectorial polygons called objects, marking off homogenous areas for spectral signature, shape, position, and texture

(Gennaretti 2011, 544). This process can be used to develop an automated procedure permitting a computerized classification of land cover, which occurred for the process of Landsat imagery to be used in the NLCD databases.

During the 1990s, digital aerial cameras were developed and proved more advantageous to film cameras previously used since the 1920s. Digital cameras allowed for more flexibility, stability, easier planning and execution, and direct digital output (Bolstad 2012, 230). Giles M. Foody considered the accuracy assessment of imagery in the digital age. The following are four historical stages of how accuracy of interpretation and analysis of imagery Foody listed. The first stage was basic visual appraisal of the derived map – basically if the resulting map looked good or not. The second stage was characterized by an attempt to quantify accuracy more objectively. The accuracy assessment was based on comparisons of the areal extent of the classes in the derived thematic map relative to their extent in some ground or other reference data set. The limitation of this process was representation of the class proportions was correct, however, in the wrong location. The third stage involved the derivation of accuracy metrics that were based on a comparison of the class labels in the thematic map and ground data for a set of locations. The fourth stage was a refinement of the third stage with a greater use of the information on the correspondence of the predicted map labels to those observed on the ground (Foody 2002, 190). These steps show the progress that has been made with aerial photos in the past decades.

In the 1960s and 1970s, the development of satellites allowed for a new point of view for imagery, about 400 miles away in space. Many satellites and tools collect imagery and data about the Earth's surface and more every day. The imagery covers more area and also better quality over that of aerial imagery due to the distance and positioning. Satellite imagery is also digital, allowing for computerized manipulation and classification. Satellite imagery and digital aerial imagery are made of pixels that can be classified by spectral bands and comparing them against one another. Satellite sensors began with four spectral bands and an infrared band and now have sensors that use 8 bands, to be further discussed in the next chapter.

CHAPTER 3: METHODOLOGY

This study's main examination of the physical urban characteristics, such as streets and highways, commercial and residential buildings, and parks and forests, helps to delineate the spatial-temporal land cover change patterns over the past twenty years. Then to identify and to describe the spatial patterns that occur over time to help understand how a city's urban footprint grows.

3.1 Framework

The analysis of this study was encouraged by the procedure used in a study by Tian, Liu, Xie, Yang, Zhuang, and Niu, in which each period of Landsat imagery is classified with the same method and then compared to the next chronological period. The extent of the methodology of their study is increased in this study from a five-year period that constituted their study to a comparison of imagery from three decades. Yet, that study included creating a mosaic of many images to include the whole country of China. This study excludes NLCD imagery data from 1992, 2001, and 2011 from the dataset that includes data from outside the study areas. The imagery is applied in ArcMap so the work is stored in a file geodatabase and utilized in the image classification tools. The resulting maps with the percentage of urban land cover by class are compared to the following decade with the Urban Land Expansion Index. The work flow chart in Figure 2 provides a visual understanding of this study's procedure of examining land cover change over time.

The land cover change will be compared with two different classification systems that the NLCD was classified with. The NLCD 1992 data and the NLCD 2001 data will be compared based on Anderson I classifications to merge the two different classifications used and the NLCD

2001 and NCLD 2011 data will be compared based on the decision-tree classifications used since 2001.

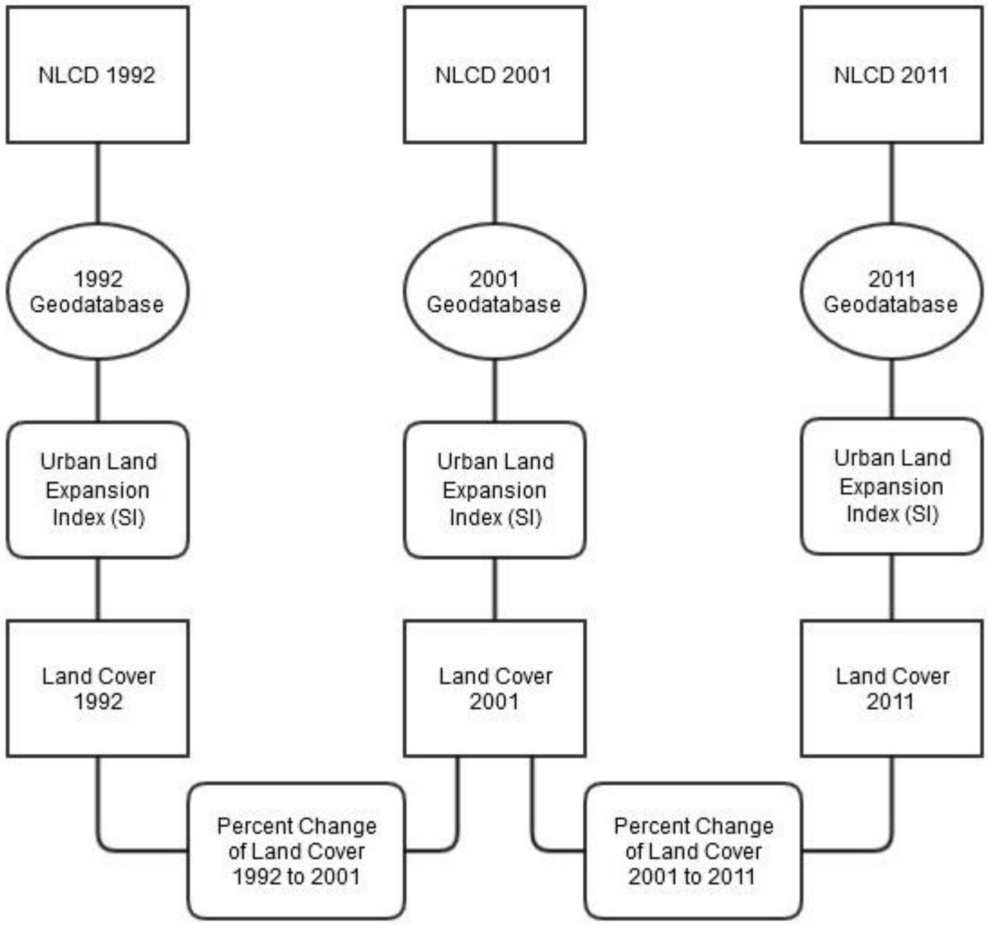

Figure 2. Analysis of spatio-temporal land cover change patterns in Pasadena and Inglewood, California from 1992 to 2011.

3.2 Data Acquisition

Two sets of information are needed for the land cover change examination, NLCD data and Landsat imagery. The NLCD data for all three years was obtained from Multi-Resolution Land Characteristics Consortium (MRLC) website, www.mrlc.gov. The data available on this website provides pre-classified land cover imagery for the United States.

For an accurate comparison, the land cover information for 1992 and 2001 had to fine an equal ground. This allowed for the difference in land cover classification to be put into a broad perspective over the study areas for this time period. The same land cover classification method was used for 2001 and 2011 so there is no need for reclassification.

Comparing the land cover change from each year of imagery constitutes of Urban Land Percentage (PU) which is generated from the image classification analysis distinguishing what percentage of the total area (TL) is urban land cover (UL), shown in below.

$$PU = UL/TL \times 100\%$$

The PU is graded into a system that will show the significance of the land cover classifications. The idea differentiates the urban developed areas and natural places such as parks and forests. Parks are considered part of urban growth as Pasadena has prided itself on its inclusion of parks and open space in the urban environment.

Next, the Urban Land Expansion Index (SI) is compared to the percentage of urban land cover from each year to the next chronologically. Achieving the SI gives the percentage of the land cover change between the two years being analyzed. The two years of UL are represented in the following equation by UL_j and UL_i respectably.

$$SI = UL_j – UL_i/TL \times 100\%$$

The SI is graded into different classes showing the different degrees of land cover that has occurred. The graded is also known after the completion of the image classification for 1992 and 2001. Dynamic urban change patterns can be determined by the SI, and thusly mapped.

3.3 Origins of the Imagery

As previously mentioned, satellite imagery did not exist previously to the 1950s, and with Landsat satellites, not until the 1970s. The original intent of this study was to analyze urban land cover change of the cities from earlier years, but it not feasible due to the lack of the proper data for comparison.

The next limitation is the pixel count of the Landsat imagery from the various tools aboard the satellites. Landsat satellites have carried two main tools aboard, a multispectral scanner (MSS) and a thematic mapper (TM), in various forms. As technology advanced, so did the Landsat satellites and the tools aboard them. The Landsat 4 satellite carried a multi-spectral scanner and thematic mapper, in their earliest forms. The combination of these tools obtained imagery of a 120 meter scale. The next generation, Landsat 5, included the same equipment, but with better advancement to obtain 30 meter resolution. Landsat 7 incorporated a MSS, along with and Enhanced Thematic Mapper Plus (ETM+). The latest in the Landsat lineage is the Landsat 8, which comprises of an Operational Land Imager (OLI) and a Thermal InfraRed Sensor (TIRS). The Landsat satellites and sensors that were utilized in the creation the land cover datasets are Landsat 5 for the 1992 dataset and Landsat 7 for the 2001 and 2011 datasets. Table 1 describes the facts about each of the satellites and Table 2 breaks down the two sensors aboard each satellite.

Table 1. Listing of Landsat satellites with specifications

Specifications	Satellites	
	Landsat 5	**Landsat 7**
Launch Date	March 1 ,1984	April 15, 1999
Sensors	TM, MSS	operational
Status	MSS disabled	ETM+
Altitude	704 km	705 km
Inclination	98.2	98.2
Orbit	polar, sun-synchronous	polar, sun-synchronous
Equatorial Crossing Time	nominally 9:45 am (15 min)	nominally 10 am (15 min)
Period of Revolution	99 minutes (`14.5 orbits per day)	99 min (`14.5 orbits per day)
Repeat Coverage	16 days	16 days
Terminated	June 5, 2013	Still Active
Duration	29 years, 3 months, 4 days	16 years, 1 month*

* reflects duration at time of table preparation

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

Table 2. Listing of each sensor used on each of the Landsat satellites

Specifications	Satellite Sensors	
	Thermal Mapper (TM)	Enhanced Thermal Mapper Plus (ETM+)
Satellite	Landsat 4 & 5	Landsat 7
Sensor Type	opto-mechanical	opto-mechanical
Spatial Resolution	30 m	30 m, thermal - 60 km, pan - 15 m
Spectral Range	0.45 - 12.5 um	0.45 - 12.5 um
Number of Bands	7	8
Temporal Resolution	16 days	16 days
Image Size	185 km by 172 km	183 km by 170 km
Swath	185 km	183
Programmable	Yes	Yes

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

The imagery from Landsat 5 Thematic Mapper was used to derive the data for the 1992 dataset by the MRLC (Vogelmann *et al* 2001, 651). Beginning in 1993, the 1992 prototype took five years to map, with the 30 m resolution creating about nine billion pixels over the conterminous United States. At this time, the MRLC consisted of four government groups: the U.S Geological Survey (USGS), the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Forestry Service (USFS). This consortium produced the product under the Anderson Level II classification. This classification system proved to be inappropriate with the development of the 2001 database.

The MRLC grew after the success of the land cover classification of the 1992 dataset with the addition of six more members: the Bureau of Land Management (BLM), the National Aeronautics and Space Administration (NASA), the National Parks Service (NPS), the U.S. Fish and Wildlife Service (USNFWS), the National Agricultural Statistics Service (NASS), and the U.S. Army Corps of Engineers (Homer *et al* 2004, 832). All of these government groups had sections to monitor within the databases. The NASS focused on land for agricultural use, the NOAA monitored the coast lines, and the NFS managed tree canopy cover. The newly-enlarged consortium had now the tools aboard the Landsat 7 satellite and needed a new way to classify land cover. The Landsat 7 image acquisition included multi-temporal data processed to standard procedures for three dates per path or row to represent three seasons for the United States and Puerto Rico. Ancillary data, including 30 m DEM, slope, aspect, and positional index, accompanied the imagery of the 88 mapping zones and a decision tree classification to create the NLCD 2001. The process was repeated for the NLCD 2006 and NLCD 2011.

3.4 Data Analysis

This section describes the methods used to complete the image pre-processing and analysis to achieve the Urban Land PUs and SIs to determine the land cover change. The science behind the following process is based on the methodology of Tian *et al*.

The use of three different geodatabases (one for each year) allows for the data to be organized throughout the processing and comparison analysis. The NLCD data from 2011 was the first data to be analyzed. When working with satellite imagery, multiple images are gathered from the different wavelength bands emitted from the Landsat 8 OLI remote sensing tool. However, only three select bands are needed to properly analyze the data for land cover change, Bands 5, 4, and 3 (in this order) to complete a color infrared (CIR) composite image to complete imagery classification. The process of creating a CIR composite image involves the conversion of multi-band raster imagery into a single-band raster with a number of categorical classes that can be related to different types of land cover. To achieve the proper land cover classifications to show the different types of urban elements of the land cover, training samples must be taken to create a signature file to be used with a classification tool so this tool can understand what the classifications are for analysis. This was then compared to the NLCD dataset for accuracy. All of the land cover classification was completed by the MRLC and used in this study for accuracy.

The NLCD data was focused into the greater Los Angeles area to narrow on the two study areas. The city boundary shapefile obtained from the Los Angeles County Geoportal allowed for the use of city outlines to highlight the study areas. This boundary shapefile was queried from the main shapefile that contained the political boundaries of all the municipalities in Los Angeles County. Pasadena and Inglewood are the focus of this study, therefore there is no advantage to completing a comparison of the whole image that covered the entire United States, and the NLCD data was clipped to only include the two cities that are represented in Figure 3.

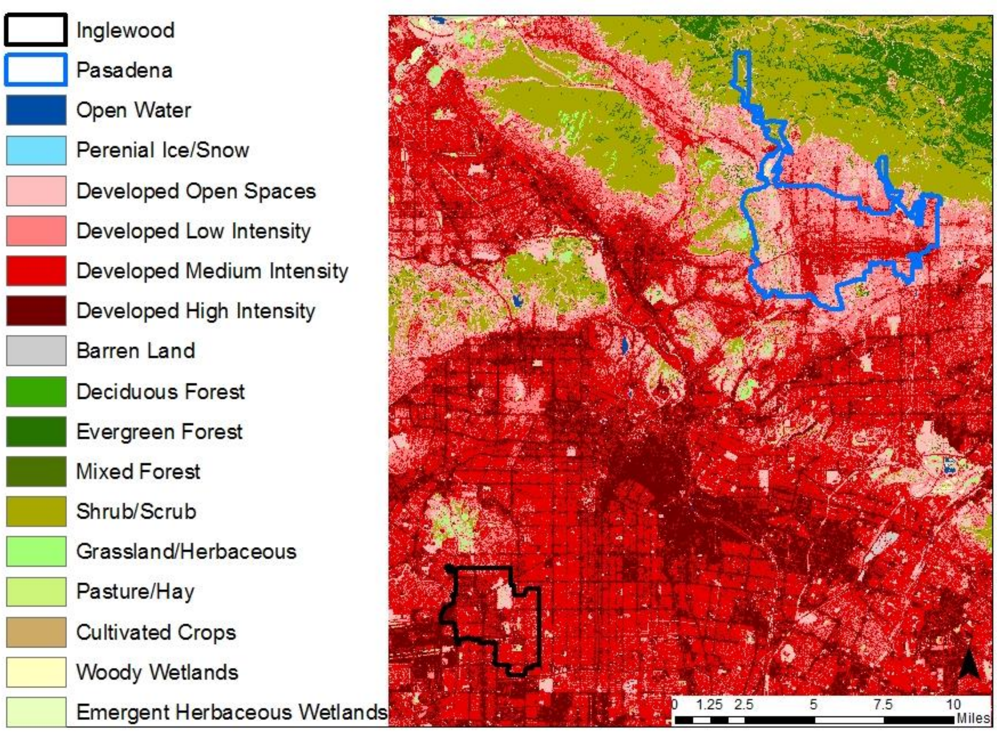

Figure 3. NLCD 2011 data of the study areas

For this study, there are two main categories from the MRLC land cover classification, developed areas and natural land cover. In the first comparison of NLCD 1992 to NCLD 2001, the reclassification will create a class that covers all urban features, as well as one for all forested areas, grassland and shrubland, agriculture, barren land, open water, and wetland. Originally in the NLCD 1992 data, the first category encompasses all man-made land cover at four levels of intensities of urban development that has occurred. In the case of the NLCD 1992 data, the classes are **Low Intensity Residential** areas that are 30% to 80% impervious surfaces with some vegetation, **High Intensity Residential** areas that are 80% to 100% impervious with some vegetation, **Commercial/Industrial/Transportation** areas that are 100% impervious with no vegetation, and **Urban/Recreational Grasses** that are semi-impervious areas with vegetation like sport fields, golf courses, and parks (Vogelmann *et al.* 2001, 651-63). However, for an accurate comparison, the classes will be grouped into the broader **Urban** class under the Anderson I classification. The NLCD 2001 land cover data is also reclassified with the Anderson I style for the comparison, but using different original classes.

For the NLCD 2001 and 2011, the first class is **Developed Open Space** areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. Next, **Developed Low Intensity** areas contain a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. **Developed Medium Intensity** areas have a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units. Finally, the

Developed High Intensity class contains highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, commercial and industrial properties. Impervious surfaces account for 80% to 100% of the total cover. These four classes are the main focal point for the urban land cover change in the study areas for the two cities are mostly urban and contain little or none natural features.

The second category of classes focuses on the natural environment. Classes contain land cover numbers for open water, vegetation, agriculture, and wetlands. Thinking of the land cover of Southern California, one does not think of natural land cover being a large focal point, but these classes are still important for comparison for urbanization usually lowers the percentage of these classes occurring from decade to decade. As mentioned before, Pasadena comprises of many large parks, plus forested areas in the mountainous sections of the city, so the main use of this category is represented in the land cover changes of Pasadena.

A listing of all of the classes from the NLCD that are relevant in this study can be seen in Table 3 for the 1992 classification and Table 6 for the 2001 and 2011 classifications. Tables 5a and 5b displays the reclassifications for the Anderson I method for the 1992 to 2001 comparison. Each of the classes has a number of occurrences in the image; therefore the percentage of each class can be concluded from this. The SI formula is utilized to understand each individual developed class land cover percentage and a larger look at the natural land cover.

However, to be used in this study, the classes have to be changed to the Anderson I classification system to accurately compare 1992 to 2001 because the current classification systems used for the NLCD 1992 and 2001 are not the same. The following table shows the Anderson I classes for which the classes from the NLCD 1992 and 2001 merge into in Table 5a and 5b.

Table 3. Class descriptions for NLCD 1992 classifications

Class	Description
11	Open Water
21	Low Intensity Residential (Impervious Surface 30-80%)
22	High Intensity Residential (Impervious Surfaces 80-100%)
23	Commerical/Industrial.Transportation (100% Impervious)
31	Bare Rock/Sand/Clay
32	Quarries/Strip Mines/Gravel Pits
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
51	Shrubland (area dominated by shrubs)
61	Orchards/Vineyards/Other
71	Grassland/Herbaceous (unmaintained, dominayed by herbaceous vegetation
81	Pasture/Hay (land intended for livestock grazing)
82	Row Crops (annual crop production)
83	Small Grains (areas used for the production of crops such as wheat, barley, oats, and rice)
84	Fallow (areas used for the production of crops that do not exhibit visible vegetation)
85	Urban/Recreational Grasses (parks, lawns, golf courses)
91	Woody Wetlands (areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water)
92	Emergent Herbaceous Wetlands (areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water)

Source: Data adapted from MRLC (2015)

Table 4. Listing of Anderson I classifications

Class Number	Class Name
1	Open Water
2	Urban
3	Barren
4	Forest
5	Grassland/Shrub
6	Agriculture
7	Wetlands

Source: Data adapted from MRLC (2015)

Table 5a. The reclassification of the NLCD 1992 classes.

NLCD 1992 Classification Number	Anderson I Classification Number
Open Water	Open Water
Low Intensity Residential	Urban
High Intensity Residential	Urban
Commercial/Industrial/Transportation	Urban
Bare Rock/Sand/Clay	Barren Land
Quarries/Strip Mines/Gravel Pits	Barren Land
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Shrubland	Grassland/Shrub
Orchards/Vineyards/other	Agriculture
Grassland/Herbaceous	Grassland/Shrub
Pasture/Hay	Agriculture
Row Crops	Agriculture
Small Grains	Agriculture
Fallow	Agriculture
Urban/Recreational Grasses	Urban
Woody Wetlands	Wetlands
Emergent Herbaceous Wetlands	Wetlands

Table 5b. The reclassification of the NLCD 2001 classes.

NLCD 1992 Classification Number	Anderson I Classification Number
Open Water	Open Water
Developed Open Space	Urban
Developed Low Intensity	Urban
Developed Medium Intensity	Urban
Developed High Intensity	Urban
Barren Land	Barren Land
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Shrub/Scrub	Grassland/Shrub
Grassland/Herbaceous	Grassland/Shrub
Pasture/Hay	Agriculture
Cultivated Crops	Agriculture
Woody Wetlands	Wetlands
Emergent Herbaceous Wetlands	Wetlands

As stated earlier, the NLCD data for 2001 is sufficient to be accurately examined against 2011 since the classification methods were the same, but not accurate for a comparison with the 1992 data. Therefore, the data from 2001 has to be worked with twice, once like the methods in 2011 and then a more complex, time consuming cross-examination with Landsat imagery to compare with the 1992 data. The MRLC has already completed a product that highlights areas of potential change between 1992 and 2001, titled Retrofit LCC Data, which is used as a guide in the land cover comparison of 1992 to 2001.

Table 6. Class descriptions for NLCD 2001 and 2011 classifications

Class	Description
11	Open Water
21	Developed Open Space (Impervious Surface -20%)
22	Developed Low Intensity (Impervious Surfaces 20-49%)
23	Developed Medium Intensity (Impervious Surfaces 50-79%)
24	Developed High Intensity (Impervious Surface +80%)
31	Barren Land (Rock/Sand/Clay)
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
52	Shrub/Scrub (area dominated by shrubs)
71	Grassland/Herbaceous (unmaintained, dominayed by herbaceous vegetation
81	Pasture/Hay (land intended for livestock grazing)
82	Cultivated Crops (annual crops/orchards/vineyards)
90	Woody Wetlands (areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water)
91	Emergent Herbaceous Wetlands (areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water)

Source: Data adapted from MRLC (2015)

The NCLD 2001 data was processed as the NLCD 2011 data with the city boundaries and denoting the pertaining classes. The Landsat 7 ETM+ imagery needed to be composited for a natural color image. This was completed in ArcMap with the Composite tool using Bands 5, 4, and 3. Now having obtained a natural color image of this section of Southern California, the same comparison was made for image quality. A boundary shapefile was utilized to narrow in on the two study areas. The clip tool was used to focus only on the two cities using the boundary shapefile as an input feature on the NLCD imagery. With this achievement, a comparison can now be done with both 2011 and ultimately, 1992.

The same process was completed for the data for 1992. The only difference here is that Landsat 5 MSS imagery was used to complete the natural color composite image instead of the Landsat 7 ETM+ since the Landsat 7 satellite was not in operation in 1992. Bands 4, 3, and 2 were used in this case to create the composite image.

The percent of change have been obtained and the results is discussed in the following chapter with a comparison to the population change to understand the increase in residential and light commercial land cover and decrease in heavy commercial and industrial land cover.

CHAPTER 4: RESULTS

The most land cover change in both cities was in the classes referring to developed urban land cover, with little change occurring in the classes referring to natural features such as forests and bodies of water. The classes Developed Open Space and Low Intensity generally showed a decrease in percentage, which was reflected in the growth of the Developed Medium and High Intensity classes. Also, areas classified as in the Shrub/Scrub class declined in size in both Pasadena and Inglewood. Inglewood had few classes for comparison due to its urban landscape; meanwhile, Pasadena had a few more classes for a more exciting examination.

The main error in the process was that when clipping the NLCD data to the city boundary lines, the data was not contained to just the city boundaries. ArcMap also took into result the pixels that made a square clip that included the entire city boundary. This means, in large part to Pasadena with its irregular size, more data from outside the actually boundaries were taken into effect.

Each of the following figures displays the mapped results for each city for the appropriate year with a legend showing the classes, along with a pie chart that displays the percentage of each class with a listing of the number of times a class is represented on the map in order of most to least (not all classes are listed but all are displayed in the chart).

4.1 Comparison of Land Cover, 1992 to 2001

Since the classes did not match up perfectly, the following results show the best class comparison between 1992 and 2001 with the classes of the Anderson classification method for 1992 to 2001. The classes are broader, therefore, showing less detail than the decision-tree classification used to determine the land cover change from 2001 to 2011. These results still prove to be valid as classifications grouped as a whole, such as urban development, natural vegetation, and crop cover still gave a land cover change percentage.

4.1.1 1992 Classifications

The percent of land cover by class for 1992 can be seen in Table 7 and Table 8 for Pasadena and Inglewood, respectably. The first column in each table are the Anderson I classes, the second column is the number of pixels of each class resides in each clip for each city, and the third column is the percentage of the total land cover from the amount of total pixels. The percentage is what will be put into the SI calculation to reach the land cover percent change.

Table 7. Percentage of land cover by Anderson I class for Pasadena in 1992

Pasadena Classifications 1992	Pixel Count	Percent of Land Cover
Open Water	52	0.02%
Urban	105092	35.54%
Barren Land	1697	0.57%
Forest	59379	20.08%
Grassland/Shrub	129296	43.72%
Agriculture	186	0.06%
Wetlands	27	0.01%

Source: Derived from the NCLD data

Table 8. Percentage of land cover by Anderson I class for Inglewood in 1992

Inglewood Classifications 1992	Pixel Count	Percent of Land Cover
Open Water	2	0.00%
Urban	51955	88.52%
Barren Land	935	1.59%
Forest	1034	1.76%
Grassland/Shrub	4673	7.97%
Agriculture	96	0.16%
Wetlands	1	0.00%

Source: Derived from the NLCD data

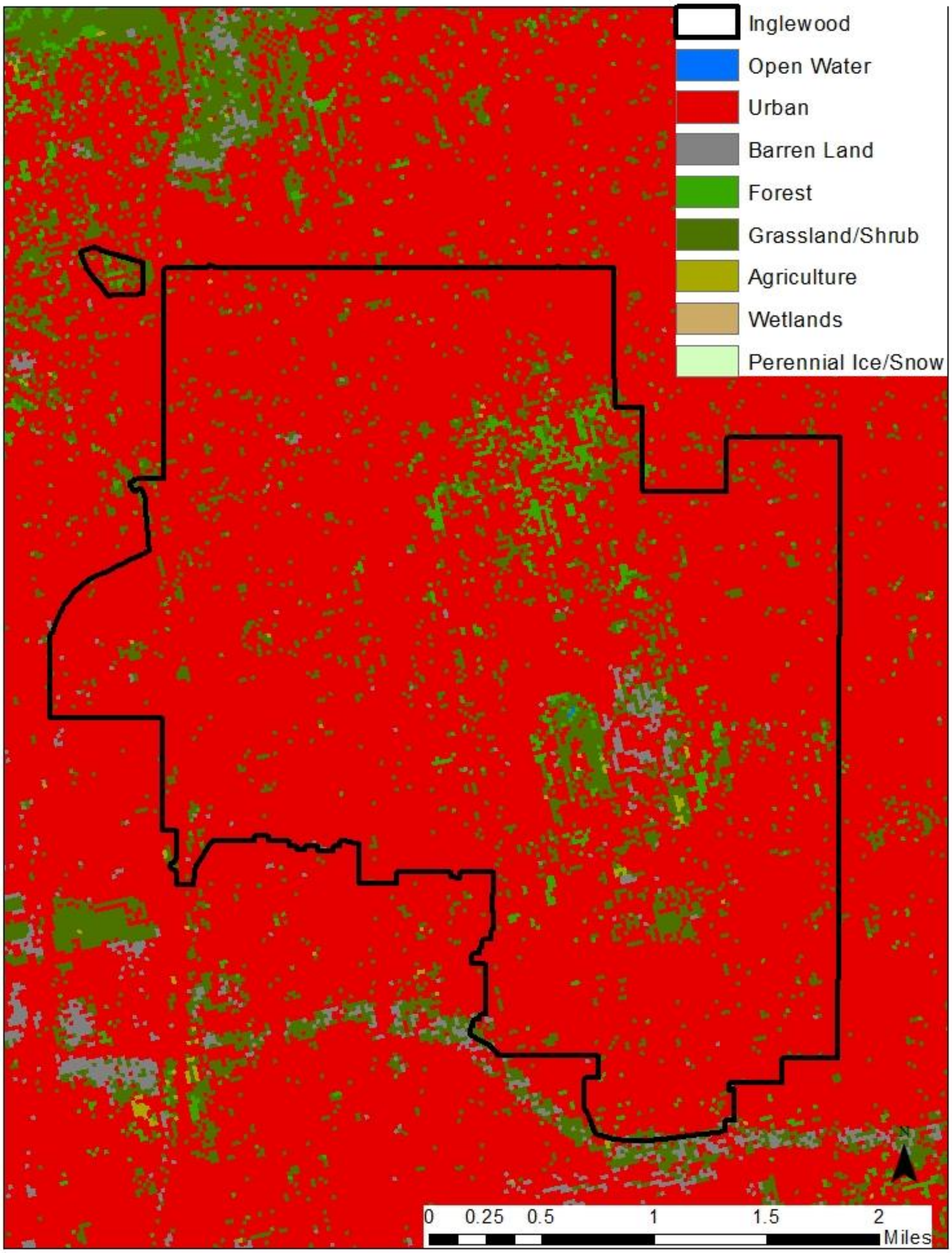

Figure 4. Anderson I classification of land cover for Inglewood in 1992

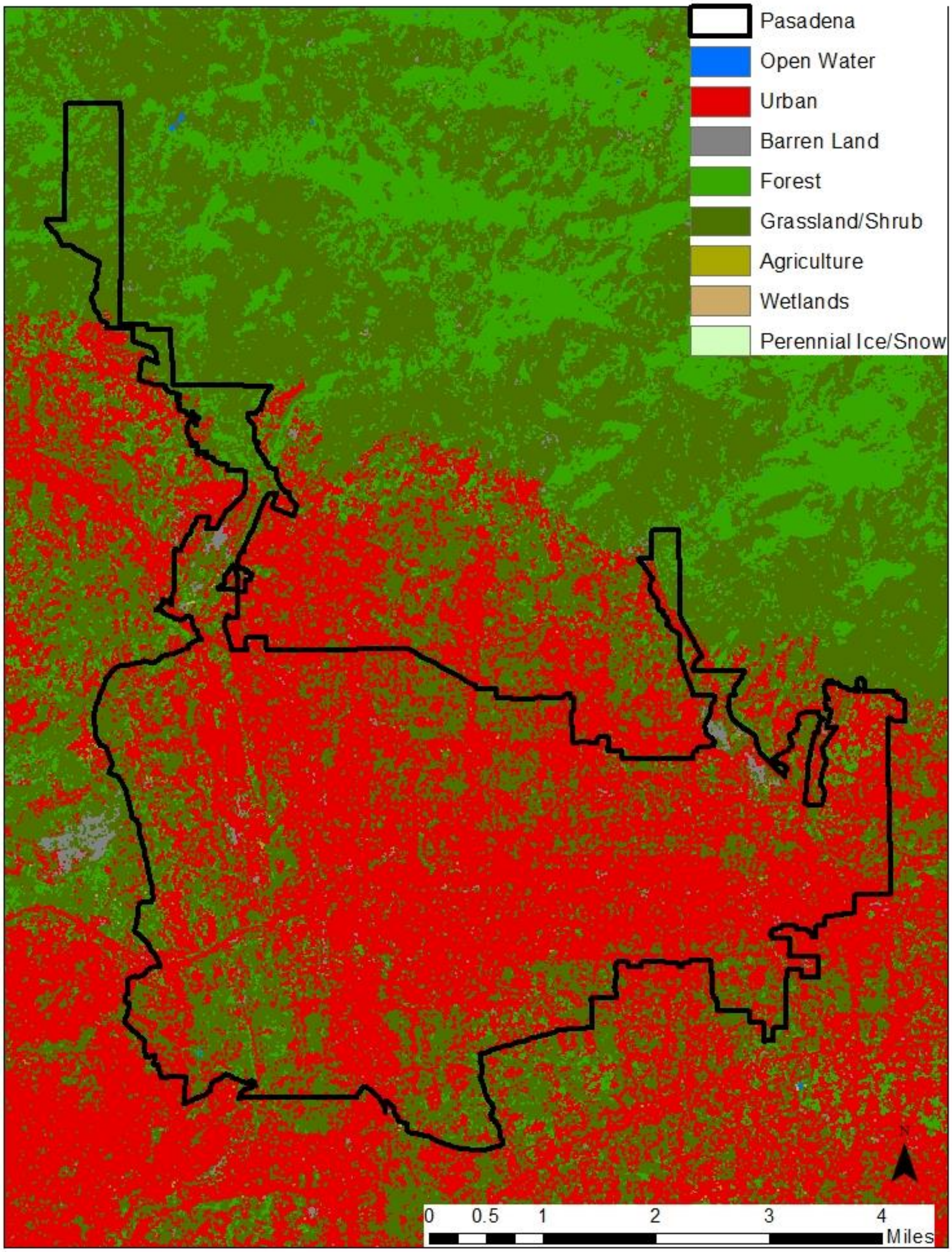

Figure 5. Anderson I classification of land cover for Pasadena in 1992

In Inglewood, 88.52% of the land cover was urban based. The remaining land cover is comprised mostly of grassland/shrub, forest, barren land, and with agriculture representing a mere 0.16%. As a whole in Pasadena, the urban land cover was 35.54% of the total land cover. This also results in a 64.46% of non-urban cover in the city. That means most of the city was still covered in forest, shrub, and cropland. However, as stated above, much of that vegetation data comes from outside the city boundary. Figure 4 displays the resulting clip for Inglewood and for Pasadena in Figure 5.

Both maps are weighted in red which represents the impervious land cover, and orange to represent the urban and recreational turf to make up the urban land cover classes.
Pasadena contains more classes over Inglewood because of Pasadena's geographical location next to the San Gabriel Mountains. Visually inside the boundary lines, thirteen natural land cover classes are represented in Pasadena and only nine in Inglewood. The interesting thing is that Inglewood does have more natural land cover classes than hypothesized. The classes representing forest and agriculture were surprising results for the heavy urbanized city.

4.1.2 2001 Classification

Against the data from 1992, the classes for 2001 had to be presented in the same way, even with the new land cover classification system that took place in 2001. Tables 9 and 10 display the results of the 2001 Anderson I classification for each study area. Visually, the Agriculture class is outside the city boundary, therefore, those results are dismissed from comparison, with its 0.17% not influencing the results greatly. Overall, Inglewood is covered in red or impervious land cover. Pasadena, on the other hand, is geographically diverse and contains more natural land cover classes.

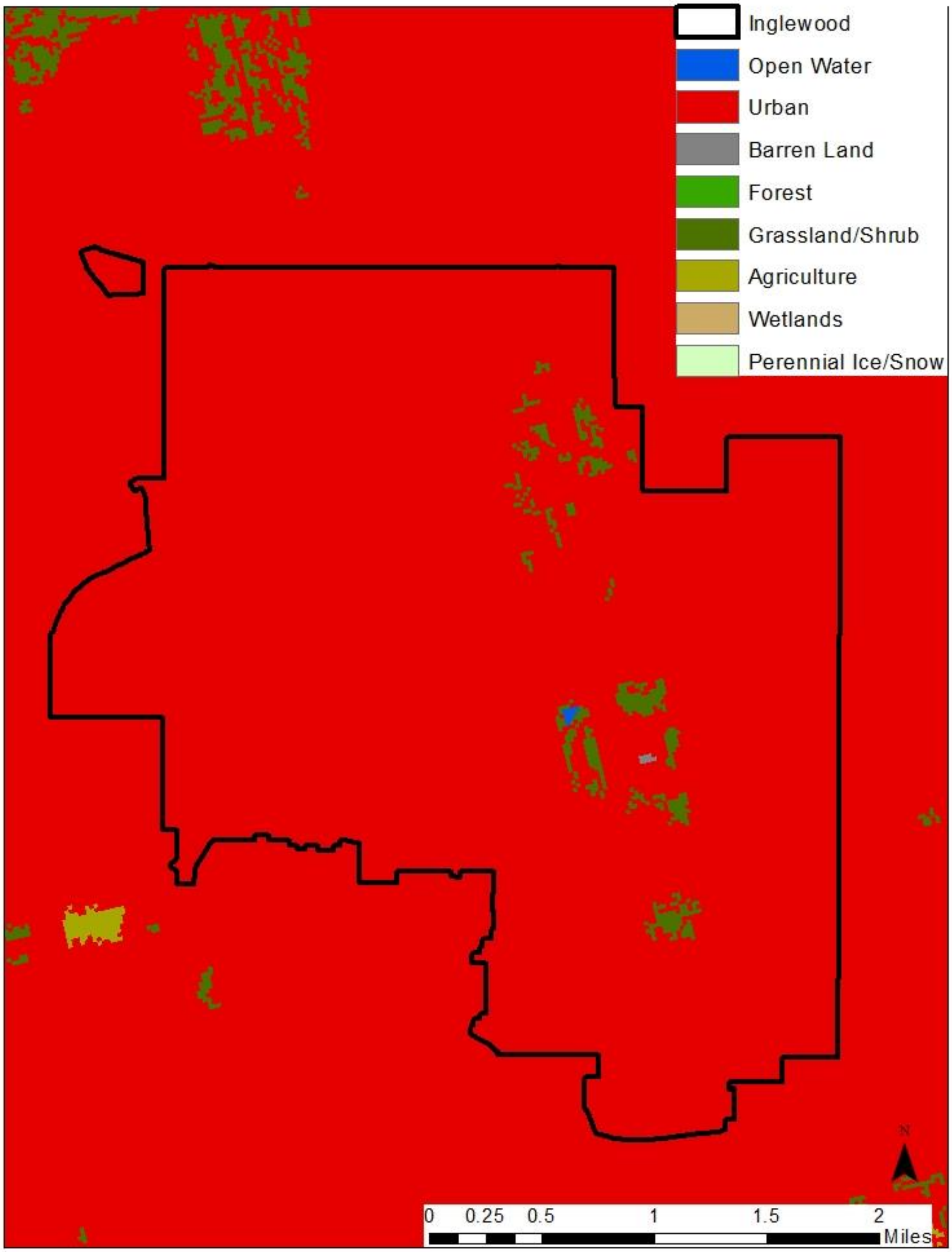

Figure 6. Anderson I classification of land cover for Inglewood in 2001

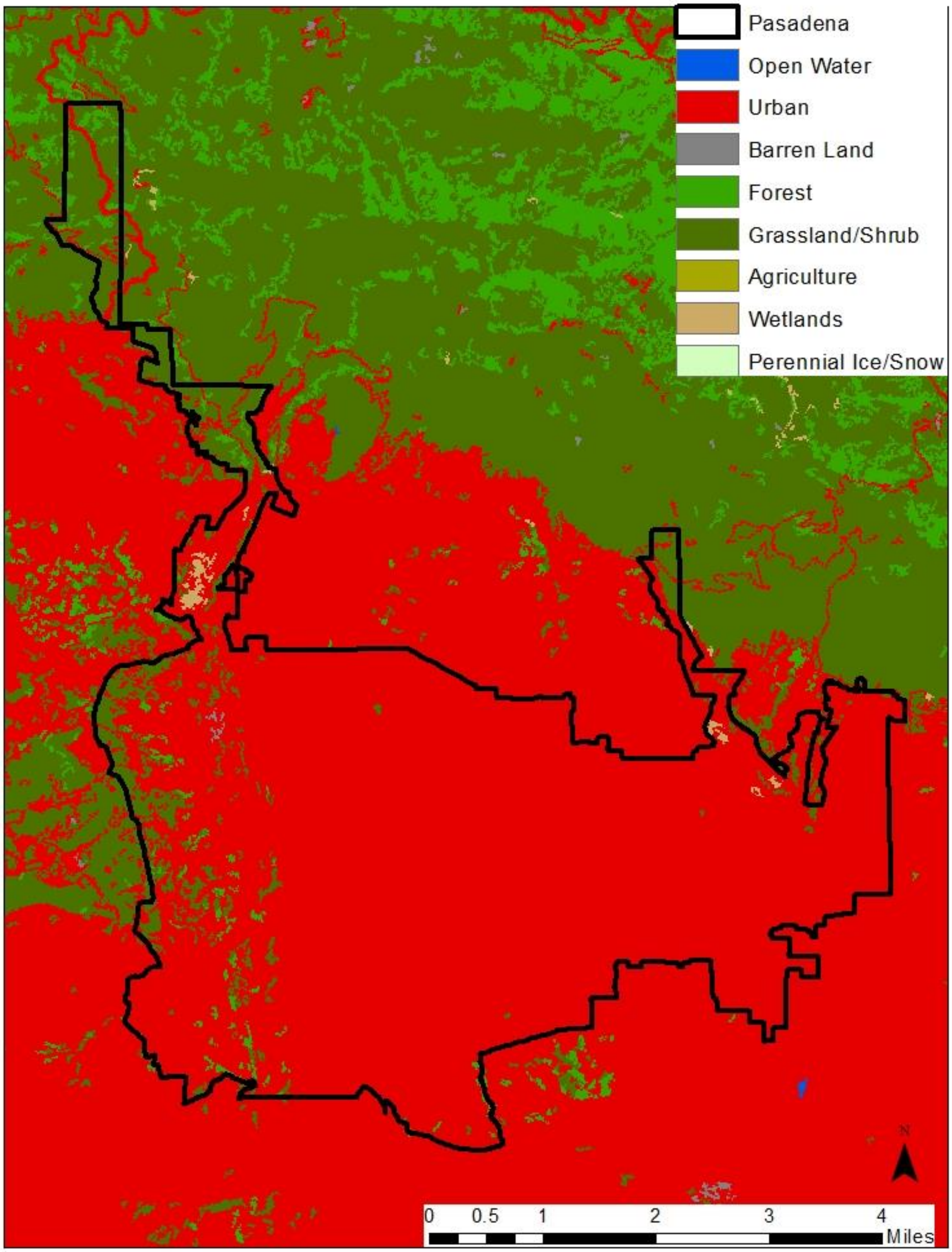

Figure 7. Anderson I classification of land cover for Pasadena in 2001

Table 9. Percentage of land cover by Anderson I class for Pasadena in 2001

Pasadena Classifications 2001	Pixel Count	Percent of Land Cover
Open Water	48	0.02%
Urban	170210	57.59%
Barren	290	0.10%
Forest	28668	9.70%
Grassland/Shrub	95924	32.45%
Agriculture	0	0.00%
Wetlands	422	0.14%

Source: Derived from the NLCD data

Table 10. Percentage of land cover by Anderson I class for Inglewood in 2001

Inglewood Classifications 2001	Pixel Count	Percent of Land Cover
Open Water	10	0.02%
Urban	58049	98.90%
Barren	7	0.01%
Forest	0	0.00%
Grassland/Shrub	529	0.90%
Agriculture	101	0.17%
Wetlands	0	0.00%

Source: Derived from the NLCD data

The city is majority urban land cover at 57.59%, with the remaining totals being natural land cover which are mostly tallied from the land cover outside the city boundary. The natural land cover classes do exist inside the boundaries so those classes were not removed from the comparison.

4.1.3 1992-2001 Land Cover Percent Changes

The difference in color representations on the maps from 1992 and 2001 displays the variations of the two classification systems used. In Inglewood, there is a visual loss of natural classes represented from the 1992 map to the 2001 map. There are also appears to be open water represented on the Inglewood 2001 map that was not on the Inglewood 1992 map.

Table 11 shows the percent land cover change by classes for Pasadena and Table 12 for Inglewood. The percent changes noted in red reflect a negative change from 1992 to 2001. The total urban percent change for Inglewood was 10.38% and the percent change in Pasadena was 22.05%.

Table 11. Land cover percent change of Pasadena from 1992 to 2001. Red numbers highlight land cover change that decreased from 1992 to 2001.

Pasadena Classifications 1992-2001	Percent 1992	Percent 2001	Percent Change
Open Water	0.02%	0.02%	0.00%
Urban	35.54%	57.59%	22.05%
Barren	0.57%	0.10%	0.47%
Forest	20.08%	9.70%	10.38%
Grassland/Shrub	43.72%	32.45%	11.27%
Agriculture	0.06%	0.00%	0.06%
Wetlands	0.01%	0.14%	0.13%

Table 12. Land cover percent change of Inglewood from 1992 to 2001. Red numbers highlight land cover change that decreased from 1992 to 2001.

Inglewood Classifications 1992-2001	Percent 1992	Percent 2001	Percent Change
Open Water	0.00%	0.02%	0.02%
Urban	88.52%	98.90%	10.38%
Barren	1.59%	0.01%	1.58%
Forest	1.76%	0.00%	1.76%
Grassland/Shrub	7.97%	0.90%	7.07%
Agriculture	0.16%	0.17%	0.01%
Wetlands	0.00%	0.00%	0.00%

4.2 Comparison of Land Cover, 2001 to 2011

The results for this comparison are more accurate and detailed due to the use of the same decision-tree classification system in both years that accompanied the NLCD data. Direct class comparisons were completed because of this fact, rather than the broad urban land cover classes. The land cover percentage results of the 2001 classes were previously explained in the former subchapter, but will now go into more detail in this chapter for more accurate comparison with the 2011 data.

4.2.1 *2001 Classifications*

The urban land cover classes for 2001 and 2011 are Developed Open Space (21), Developed Low Intensity (22), Developed Medium Intensity (23), and Developed High Intensity (24). The total for total urban land cover for Inglewood is 98.89%. Figure 8 displays the land cover map for Inglewood with the decision-tree classification showing densely covered in the pink-to-red symbology for the urban land cover.

Table 13. Percentage of land cover by decision-tree classification for Pasadena in 2001

Pasadena Classifications 2001	Pixel Count	Percent of Land Cover
Open Water	48	0.02%
Developed Open Space	56905	19.25%
Developed Low Intensity	68920	23.32%
Developed Medium Intensity	40419	13.68%
Developed High Intensity	3966	1.34%
Barren Land	290	0.10%
Deciduous Forest	7	0.00%
Evergreen Forest	25479	8.62%
Mixed Forest	3182	1.08%
Shrub/Scrub	92711	31.36%
Grassland/Herbaceous	3213	1.09%
Woody Wetlands	422	0.14%

Source: Derived from the NLCD data

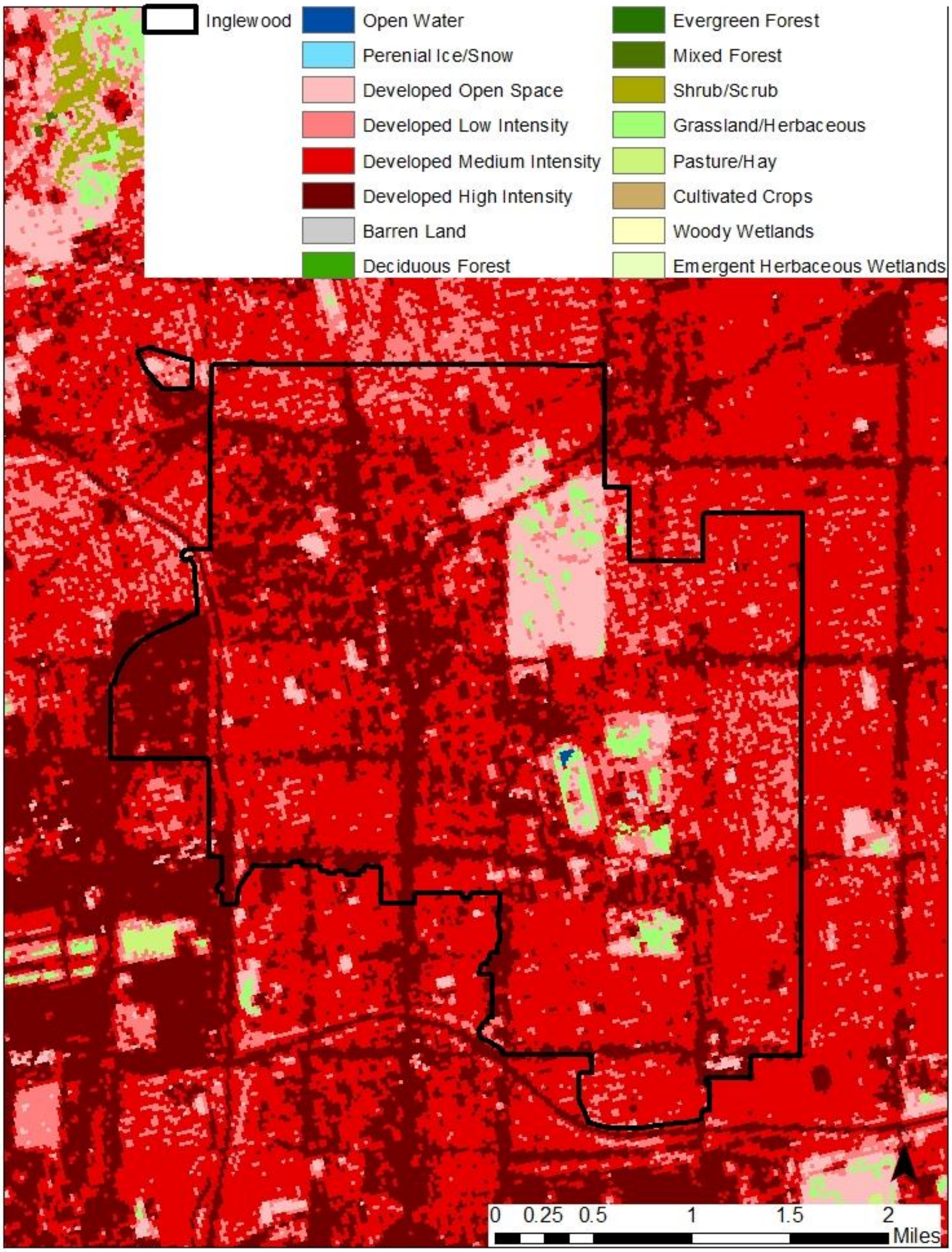

Figure 8. Decision-tree classification of land cover for Inglewood in 2001

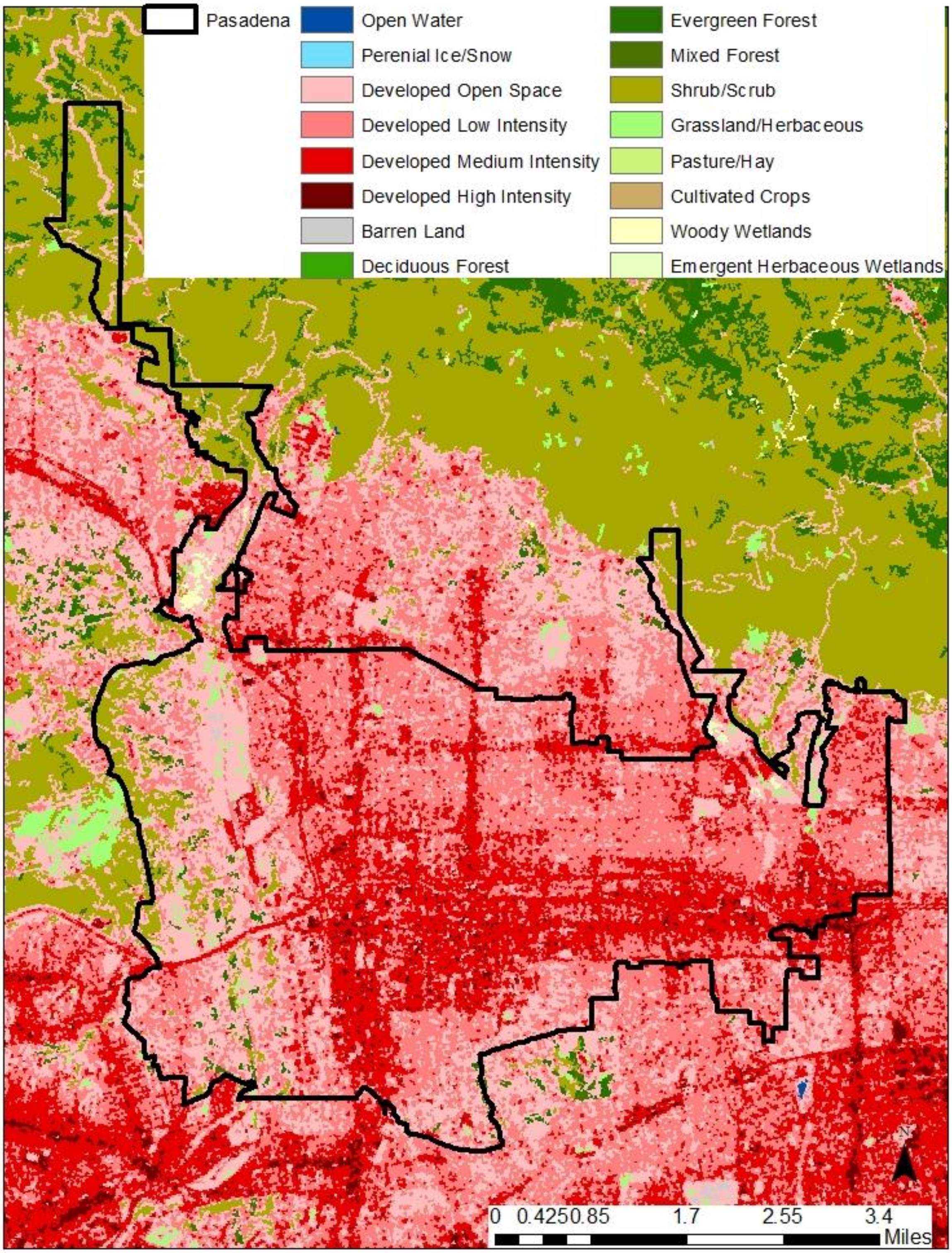

Figure 9. Decision-tree classification of land cover for Pasadena in 2001

Table 14. Percentage of land cover by decision-tree classification for Inglewood in 2001

Inglewood Classifications 2001	Pixel Count	Percent of Land Cover
Open Water	10	0.02%
Developed Open Space	2138	3.64%
Developed Low Intensity	6207	10.57%
Developed Medium Intensity	33767	57.54%
Developed High Intensity	15937	27.15%
Barren Land	7	0.01%
Grassland/Herbaceous	529	0.90%
Pasture/Hay	101	0.17%

Source: Derived from the NLCD data

The other classes represented in the Inglewood classification are Open Water (11), Barren Land (31), Grassland/Herbaceous (71), and Pasture/Hay (81). Pasadena, represented in Figure 9, shows more natural feature classes due to its geographically diverse location.

4.2.2 2011 Classifications

In 2011, Pasadena still had its geographically diverse land cover which gives it less of an urban land cover percentage. As seen in Table 15, the city's total urban percentage was 57.79%, with most of the urban land cover having less than a 50% impervious surface. The percentages show that Pasadena is still covered in large tracts of forest and shrubland. According to Table 16, Inglewood on the other hand had a 99.48% urban land cover, with the rest made up of Grassland/Herbaceous at .51% and Barren Land at .01%.

Table 15. Percentage of land cover by decision-tree classification for Pasadena in 2011

Pasadena Classifications 2011	Pixel Count	Percent of Land Cover
Open Water	54	0.02%
Developed Open Space	55676	18.83%
Developed Low Intensity	67795	22.94%
Developed Medium Intensity	42397	14.34%
Developed High Intensity	4940	1.67%
Barren Land	234	0.08%
Deciduous Forest	7	0.00%
Evergreen Forest	25499	8.63%
Mixed Forest	3174	1.07%
Shrub/Scrub	92632	31.34%
Grassland/Herbaceous	2738	0.93%
Woody Wetlands	435	0.15%

Source: Derived from the NLCD data

Table 16. Percentage of land cover by decision-tree classification for Inglewood in 2011

Inglewood Classifications 2001	Pixel Count	Percent of Land Cover
Open Water	0	0.00%
Developed Open Space	2072	3.53%
Developed Low Intensity	5841	9.95%
Developed Medium Intensity	34025	57.97%
Developed High Intensity	16451	28.03%
Barren Land	7	0.01%
Grassland/Herbaceous	300	0.51%
Pasture/Hay	0	0.00%

Source: Derived from the NLCD data

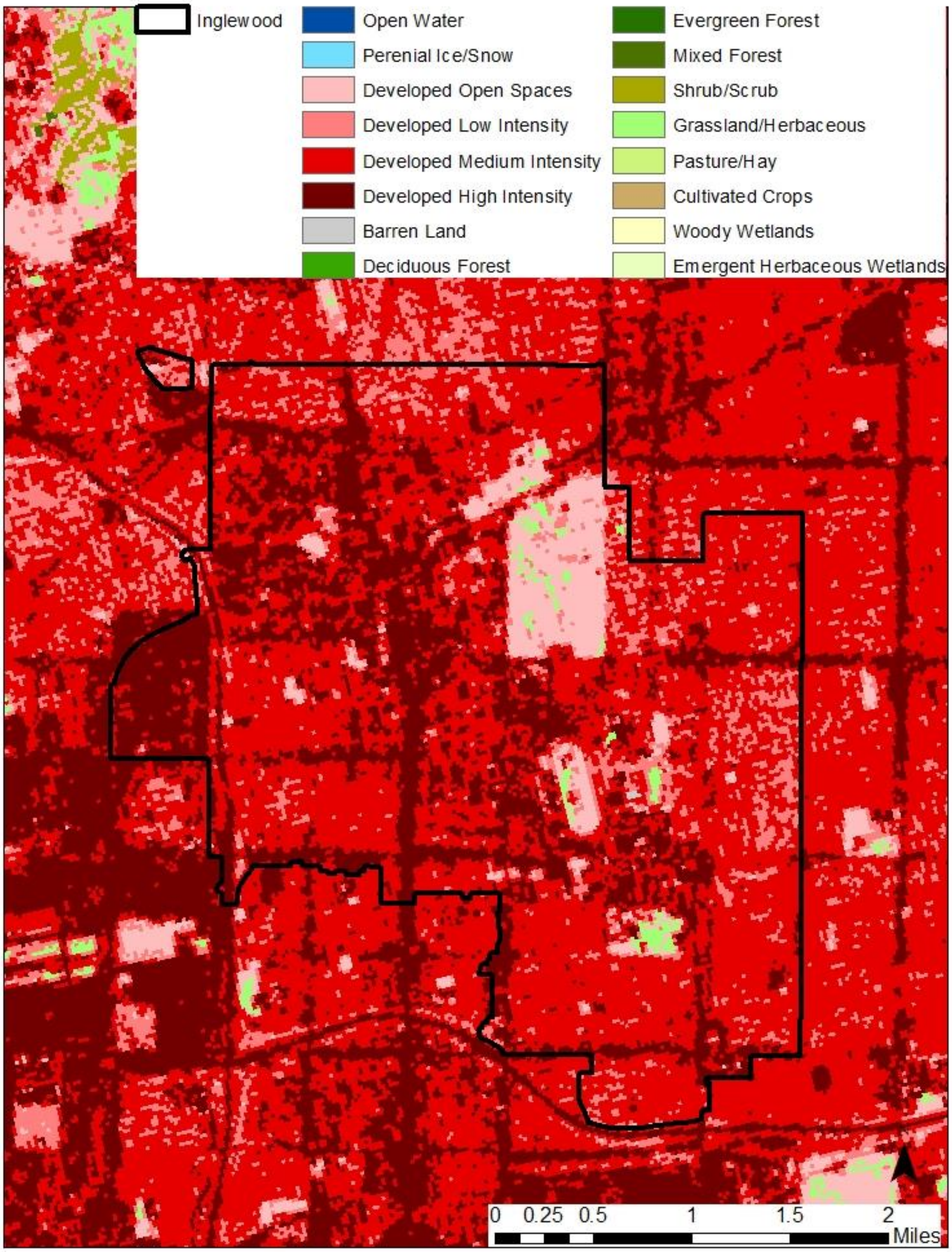

Figure 10. Decision-tree classification of land cover for Inglewood in 2011

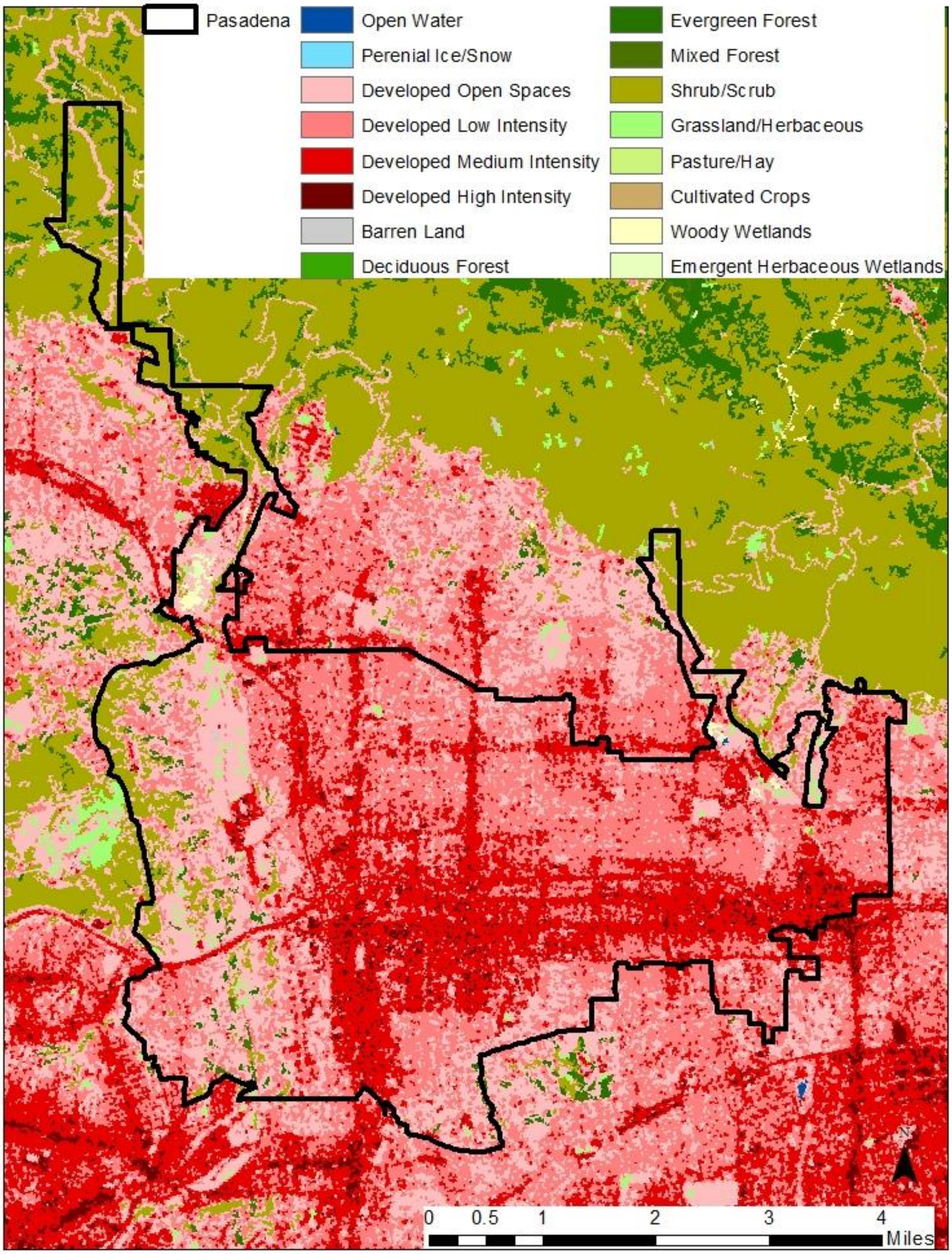

Figure 11. Decision-tree classification of land cover for Pasadena in 2011

4.2.3 2001-2011 Land Cover Percent Changes

The results for the comparison of 2001 to 2011 followed the same hypothesis that the urban land cover would change to higher developed intensities. Tables 17 and 18 shows the percent changes for the classes of each city, with the red percent changes representing the negative changes. Both cities have a negative percent change in the Developed Open Space and Developed Low Intensity classes, which is made up for in the Developed Medium and High Intensity classes. Inglewood's highest percent change was in the Developed High Intensity class and Pasadena's highest percent change was in the Developed Medium Intensity class.

Table 17. Land cover percent change in Pasadena from 2001 to 2011. Red numbers highlight land cover change that decreased from 2001 to 2011.

Pasadena Classifications 2001-2011	Percent 2001	Percent 2011	Percent Change
Open Water	0.02%	0.02%	0.00%
Developed Open Space	19.25%	18.83%	0.42%
Developed Low Intensity	23.32%	22.94%	0.38%
Developed Medium Intensity	13.68%	14.34%	0.66%
Developed High Intensity	1.34%	1.67%	0.33%
Barren Land	0.10%	0.08%	0.02%
Deciduous Forest	0.00%	0.00%	0.00%
Evergreen Forest	8.62%	8.63%	0.01%
Mixed Forest	1.08%	1.07%	0.01%
Shrub/Scrub	31.36%	31.34%	0.02%
Grassland/Herbaceous	1.09%	0.93%	0.16%
Woody Wetlands	0.14%	0.15%	0.01%

Inglewood also had a negative percent change in the two classes that represent the natural land cover. The Grassland/Herbaceous class dropped thirty-nine percent. Even though previously stated that the Pasture/Hay class was visually outside the city boundary on the map, a note was taken in the fact that the class has dropped to a zero percentage.

Table 18. Land cover percent change in Inglewood from 2001 to 2011. Red numbers highlight land cover change that decreased from 2001 to 2011.

Inglewood Classifications 2001-2011	Percent 2001	Percent 2011	Percent Change
Open Water	0.02%	0.00%	0.02%
Developed Open Space	3.64%	3.53%	0.11%
Developed Low Intensity	10.57%	9.95%	0.62%
Developed Medium Intensity	57.54%	57.97%	0.43%
Developed High Intensity	27.15%	28.03%	0.88%
Barren Land	0.01%	0.01%	0.00%
Grassland/Herbaceous	0.90%	0.51%	0.39%
Pasture/Hay	0.17%	0.00%	0.17%

Pasadena also saw a loss in natural land cover. There was a negative percent change for the Barren Land class, Mixed Forest class, Shrub/Scrub class, and Grassland/Herbaceous class. This negative percent change added to the growth of the urban land cover.

4.3 Pasadena vs. Inglewood

As stated before, these two cities are nothing alike other than the fact that they reside within the Los Angeles metropolitan area. The graph seen in Figure 12 displays the land cover change of the two cities, changing at different rates over the twenty year period. Pasadena is larger with a landscape that contains both mountains with large tracts of natural forest and shrubland and urban features, while Inglewood is a highly urbanized city with little vegetation, according to the land cover data. Yet, both cities grew in urban land cover over the twenty year study period, losing parts of their landscape that is classified as natural land cover.

The presumption of this study was to understand Inglewood as an always urban dominate city. This is true since the early nineties; however, there was more land cover classified as non-urban land cover from the 1992 data, which has been replaced with almost 100% urban landscape according to the 2011 land cover data. The fact that there were non-urban classifications in Inglewood was an eye-opener. The city has changed to highly urbanized rather than always being highly urbanized in this time period. In Pasadena, the results occurred as expected. The city's already urbanized center just became heavier urbanized while keeping most of it natural land cover intact. The cities did not gain much land area in urban land cover, however, where there was existing urban land cover, it got more dense.

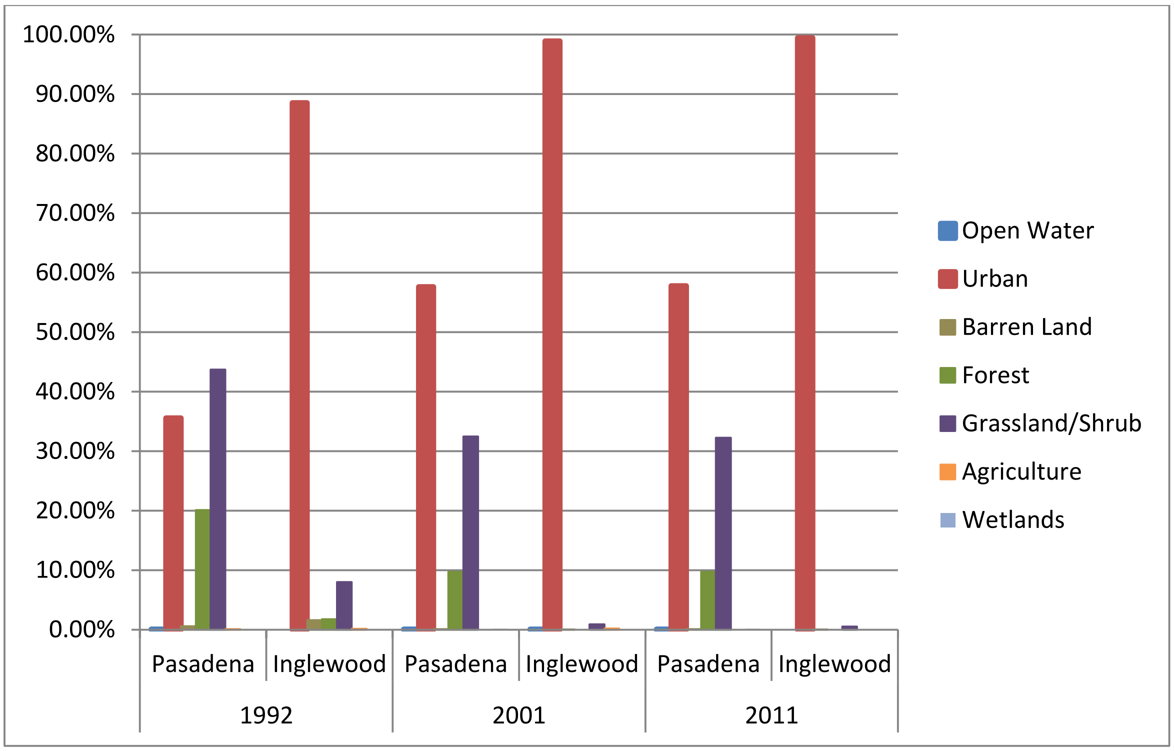

Figure 12. Bar graph displaying the land cover change by classification over the twenty year period.

CHAPTER 5: DISCUSSION AND REVIEW

The urban land cover change for the study areas by analyzing NLCD data reflected the real world change that satellite imagery can provide. Working with the challenge of comparing different classification systems proved to be a challenge, but the NLCD data was able to be roughly compared to understand the resulting land cover changes. The Urban Land Expansion Index accurately compared the percentage or urban land change to demonstrate the increases and decreases of certain classes.

5.1 Observations and Limitations

The overall comparison of the NLCD data showed the expected urban land cover increase in both Pasadena and Inglewood, at different rates respectably. Pasadena increased urban land cover in the lower developed intensities while Inglewood increased in the higher developed intensities. This means that Pasadena grew more residentially, in both single and multi-family structures, and in light commercial, along with urban and recreational turf. This is seen on the maps in the growth of the lighter red colors. Pasadena maintains counts in the natural classes in the more mountainous areas of the city where urban sprawl cannot spread into. However, knowing that Pasadena is titles a “Tree City USA” as mentioned in Chapter One, there does not seem to be green to represent trees or grass mixed in with the red urban areas. This is accounted in the classification process. Each pixel is classified as the most determining characteristic and prominent features. This means, for an example, a pixel with an office building with a couple of trees around the outside would get classified as urban due to the office building being the prominent feature of that pixel.

As for Inglewood, the already highly dense urban center grew in commercial and industrial properties, which reflects in the maps as getting more and more dark red. There is less than a one percent representation of non-urban land cover in this metropolitan city. The decrease in the Developed Low Intensity class reflects the decrease of the population that occurred from 2000 to 2010. The city is being built up for more commercialism rather than housing.

The findings of this study are that both cities seem to have peaked with land cover change, reflected in the minimal change from 2001 to 2011. The only noticeable changes are from lower intensity developed urban classes into higher intensity developed classes. The city's urban planning policies have restrictions, keeping what is residential, or Developed Low Intensity, from conversion into commercial, so there is no real land cover change. Only already built-up areas becoming more dense, and that is what the policies are more concerned about. There does not look like there will be much land cover change in the next decade for either city if the past decade is any indication.

5.2 Significance

The results of the Urban Land Expansion Index analysis demonstrated that not all data are created equal. The comparison of the 1992 NLCD data to that of 2001 was a challenge. The information on the NLCD data website warned against the direct comparison since the classification systems were different. However, they did not say it was impossible. The method of using the SI and grouping classes together worked to show land cover changes.

The urban land cover change for both Inglewood and Pasadena increased as a whole over the twenty years. Inglewood developed into a highly dense urban city; meanwhile is Pasadena majorly urbanized, but still has concentrations of natural land cover. Pasadena has mountains on its northern and western borders where the natural landscape is hard to urbanize so it is left in the natural state and will most likely remain that way. In the case for Inglewood, the very little barren land that remains will most likely be reclassified into one of the developed intensity classes for the next NLCD dataset.

The results of comparison between 1992 and 2001 are not perfectly accurate because of the nature of rough class grouping; therefore, the work completed by the MRLC which have already completed the comparison should be utilized for more accurate answers. This study did not take a look into the report done by the MRLC because the methodology was being tested to see if the results would still work.

The second case for error in this study was the clipping of the imagery with the city boundary shapefiles. The manner in which ArcMap clipped the NLCD data did not accurately follow the boundaries of the study areas and included more data that made the classification counts higher than they should be. A technique that replicates using the shapefiles as cookie cutters will benefit the study so that the results are confined to only to the study areas.

5.3 Future Research

This study's method can be replicated for other cities to compare themselves to either Pasadena or Inglewood or a new city or cities to understand whether there is a need to update or develop their urban planning. The case here is that the land cover data along with population statistics can show the preliminary future, with the understanding that there are fluxes and those fluxes should be accounted for also. An application of the socio-economic information to understand the urban land cover changes could prove useful with understanding the reasons for urban land cover growth. The land use policies created and used by both cities can benefit from understanding the land cover changes that occurred to either changed or strengthen those policies that are in place.

In a study completed by Robert W. Hoyer and Heejun Chang, they focused on the ever-changing surface of the Earth in the hands of humankind to understand what has happened to understand potential solutions for the future. The answer to their research question became based on future population totals; more people living in the Oregon metropolitan area require more living space. This leads to the involvement of research of population data to understand what the population will amount to in study areas to help understand the growth of urban land cover. Using U.S. Census data could help predict how Pasadena and Inglewood grow, or decline, in population to better understand their future land cover change.

This process can be replicated, with errors in mind, in many cities and regions across the United States because the NLCD data covers the entire country so the process can be easily transferred to another study area. The process does not only work for urban land cover change, rural areas can also benefit from this process to maintain cropland, forested areas, or wetlands since the NLCD data has classifications for natural features. Tree cover data can be included to help with finer detail of vegetation cover. Needless to say, this process can be easily replicated for many situations with the concurrent use of NLCD data.

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