GIS modeling of urbanization impacts on natural resources, Dakota County, Minnesota

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

My academic interests include environmental planning, natural resource management and growth management policies. Although my undergraduate major was Automatic Control, I realized I was more interested in urban planning and environmental impacts after my graduation from college. Since I came to the United States in 2004 as a graduate student in Community and Regional Planning (CRP), I have been eagerly absorbing knowledge concerning planning and environmental issues, which led me to selecting Landscape Architecture (LA) as my second major in 2005.

This thesis is submitted in partial fulfillment of the requirements for the dual-degree (Master of Community and Regional Planning and Master of Landscape Architecture). As a combination product of these two subjects, the purpose of this thesis is to examine the land cover and natural resource changes resulting from urbanization, and furthermore, to analyze the effects of land use management policies and plans on such changes.

The impacts of urbanization on natural resources and land cover changes could be desirable or devastating, depending on local policies and plans. Growing up in the city of Beijing, China, I witnessed the tremendous changes of one of the largest metropolitan areas in the world, with impacts both positive and negative. I personally believe that, guided by a reasonable and practical land use plan, negative urbanization impacts on land cover changes and natural resources could be minimized.

Studying at Iowa State University, the Twin Cities (Minneapolis and Saint Paul), Minnesota, is one of the closest metropolitan areas to our university. One of the seven counties – Dakota County – was selected as the study area for my thesis research. Ideally, this study could be an example of modeling the impacts of urbanization on land cover changes and natural resources that is transferrable to the entire Twin Cities Metropolitan Area.

ABSTRACT

Urban areas play an important role in driving land-cover conversion and bringing about environmental change. Thus, long-term studies are essential to understanding the effects of urbanization on natural resources and the effectiveness of resource management. For those natural resource managers and planners who are interested in the impacts of urbanization, this thesis research can provide a model to manage the potential changes in land cover and natural resources. Results of this study also can aid development and implementation of urban growth-management plans.

This research focused on the impacts of urbanization in natural resources and land-cover changes due to urban development in Dakota County, Minnesota. An existing planning guide, the 2030 Regional Development Framework (2030 RDF) for the Twin Cities Metro Area, was analyzed and employed as a reference in this research. Geographic information systems (GIS) technology was used to help determine characteristics of urban land-cover changes, such as population change, land cover changes, and the environmental impacts on natural resources caused by urban development. Furthermore, land suitability modeling was utilized to analyze possible future development, from the perspectives of urban expansion and agricultural land protection. FRAGSTATS, a tool for ecological landscape analysis based on GIS, was also used to investigate patterns of urbanization. Integration of social and spatial data provided an effective mechanism to explore relationships between population increase and landscape change.

The results of the research show that the 2030 RDF is a feasible guide for Dakota County to direct their future development. Particularly, most of the urban development has occurred and is expected to take place in the northwest part of Dakota County, as well as in the community of Hastings. Similarly, urban expansion suitability modeling shows that almost 50% of the land with high suitability rating of urban expansion will become urban land use based on the 2030 RDF. Such land was located in the northwest part of Dakota County, as well as in Hastings. In contrast, most of the agriculture land in the southeast part of Dakota County has been or will be well protected under the guidance of 2030 RDF. Based on agricultural land protection suitability modeling, about 75% of the land with high suitability rating for agriculture protection will become agriculture land use based on the 2030 RDF. Such land was located in the southeast part of Dakota County. From an environmental view point, the 2030 RDF limits unnecessary urban sprawl, while maximizing agricultural land protection.

CHAPTER 1. INTRODUCTION

I. Introduction

Urban areas play an important role in driving land cover conversion and bringing about environmental change. We must study the process of urbanization itself in terms of understanding land cover changes. Urbanization is defined in terms of natural increase (excess births over deaths), net migration gain, and reclassification of rural areas to urban. Increasing levels of urbanization usually accompany the shift in a developing economy away from an agricultural basis (primary sector) to an industrial (secondary) and services (tertiary) basis (Goodall 2004).

Urbanization is a complex process of change of rural lifestyles into urban ones. Nowadays, urbanization is no longer typical for the growth of cities or towns only but it influences the processes in the rural countryside as well. There is always a mismatch between administrative boundaries and actual built-up land, which is a result of administrative boundaries routinely lagging behind urban growth and areal expansion (Boucek and Moran 2004). Landscape changes are induced by urbanization processes such as residential or industrial land development and new communication infrastructures (Antrop 2004). Antrop (2000b) defined urbanization as a complex process that transforms the rural or natural landscapes into urban and industrial ones forming star-shaped spatial patterns controlled by the physical conditions of the site and its accessibility by transportation routes. Moreover, the relation between urban and rural becomes extremely complex and has received a growing attention in spatial and environmental planning.

Several phases in the urbanization have been recognized and concluded by Antrop (2004). The urbanization phases are defined according to the combined growth and decline of the urban center and the urban fringe area. The first phase (called “urbanization”) consists of a concentration of the population in the city center due to migration of the people from the fringe. The second phase (“suburbanization”) still shows a growing population of the whole urban agglomeration, but the inner city loses population while the urban fringe zone is growing rapidly. The third phase (referred to as “counterurbanization” or “disurbanization”) consists of the beginning decline of the urban population by loss of people in both center and fringe. The fourth phase (called “reurbanization”) shows recovering of the population starting in the city center and later in the fringe zone (Antrop 2004).

The level of urbanization of a country is expressed as the percentage of the population living in urban places and is the complement of the ‘rural’ population living in smaller settlements. The high level of urbanization in the world is a recent phenomenon that was initiated by the industrial revolution and many accompanying social, cultural, economical, political and military changes, which caused profound changes in our society.

II. Statement of the Problem

Urbanization can be viewed as a massive, unplanned experiment that includes humans as critical elements of ecosystems (Kentula, Gwin and Pierson 2004). Thus, long-term studies are essential to understand the effects of urbanization on natural resources and the effectiveness of resource management. The continued urbanization of the world and its associated ecological effects make information on ecosystems in urbanized and urbanizing settings increasingly important (McDonnell and Pickett 1990). The challenge we are facing now is to protect natural resources given the pressures of development. This study focused on the consequences of urbanization in natural resources and land cover changes relative to the development management of Dakota County, Minnesota.

Although there is no standardized description of urban land cover, it is possible to model urban characteristics of land cover using Geographic Information Systems (GIS) technology. GIS modeling was used to investigate patterns of urbanization, land use/cover change, and the environmental and impacts caused by urban development in Dakota County, Minnesota. Integration of social and spatial data provided an effective mechanism to explore the inter-relationship between human behavior and landscape change.

III. Objectives

Urban land use/cover is an important component for understanding the interactions of urban development with natural resources, and thus it is necessary to detect such changes. With the new trend of economic globalization from 1990s, cities are facing a new boom of development, which is sure to be a mixture of urban land exploitation and redevelopment (Wang et al. 2004).

A strong economy, cultural amenities and a beautiful natural setting have transformed the Twin Cities Metro Area into one of the fastest growing metro areas in the northern half of the nation. And more growth is on the way (Metropolitan Council 2005). Despite the fact that many northern cities were losing population in the 1970's, the Twin Cities gained. The metro area population has grown by roughly 40 percent since 1970, and the population is projected to increase 22 percent from 2000 to 2020 for a total of 3.2 million. Since 1990, local business in the Twin Cities metro area created over 350,000 new jobs, a growth rate that was 5 percent faster than that of the nation as a whole (Northstar Partners 2005). As this growth occurs, a key question is how the region can preserve its incomparable natural resources: conserving natural lands – natural areas, parks, wildlife areas, working forests, wetlands, and grasslands – is increasingly challenged by land use changes. The study area's natural lands must be carefully managed and conserved.

Therefore, the overall goal of this study is to guide policy makers towards the conservation and enhancement of Dakota County's landscape and urban development, while providing sustainable natural resources for urban growth. The objective of this study is to understand impacts of urbanization to help minimize future impacts on natural resources and ecological systems.

IV. Research Questions

- What are the land use policies and plans of the study area? How do such policies and plans influence urban growth and development?
- What was the population change of Dakota County from 1990 to 2000?
- What land cover changes occurred in Dakota County between 1992 and 2001?
  - How did such changes affect natural resources?
  - What is the spatial pattern of the land cover changes?
- What are the impacts of urbanization on land cover from year 1990 to 2000?
- Which areas are suitable for development in the future?
- How can future decisions on land use policies and plans be influenced by knowledge of urbanization impacts?

V. Research Framework

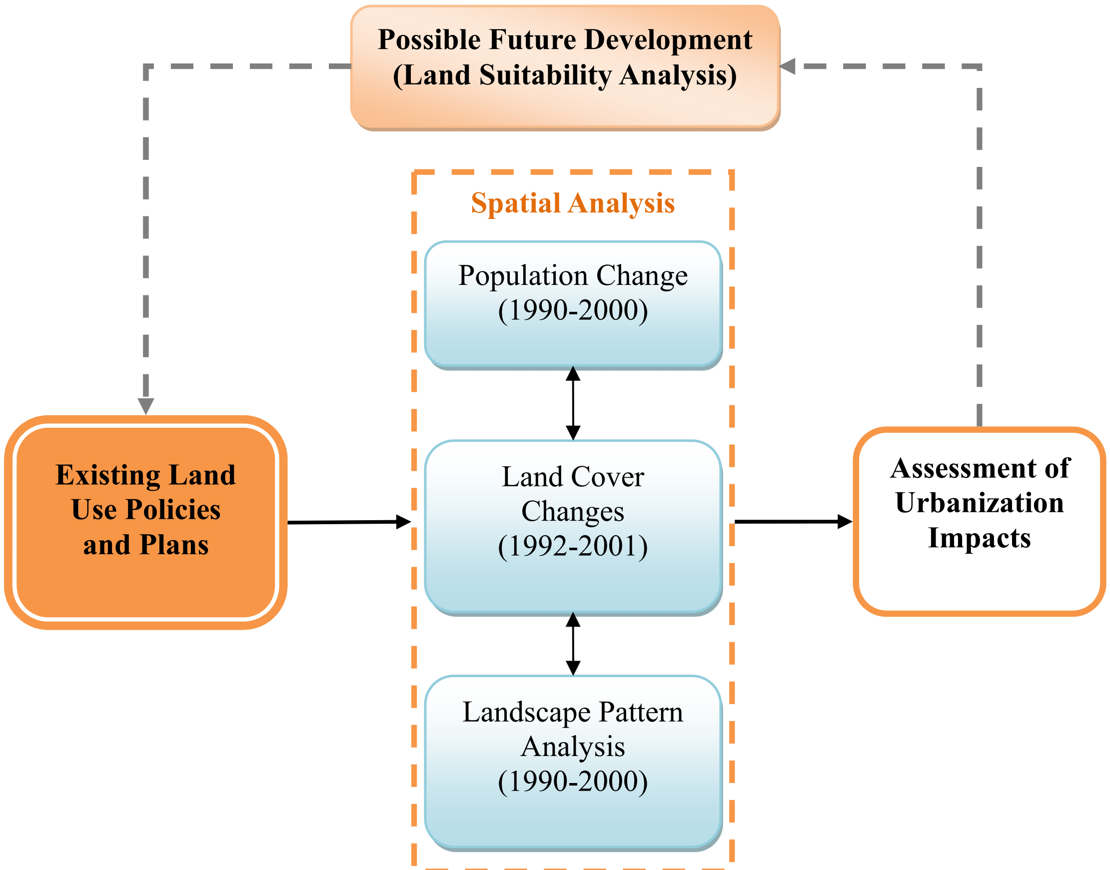

Figure 1. 1 Research framework

In this research, four stages of analyses were included: analyses of existing land use policies and plans, population change, land cover changes, landscape pattern analysis, and possible future development (land suitability analysis) that are especially pertaining to natural resource management. First of all, existing or current land use policies and plans influence the population change as well as land cover changes. Then, by detecting population and land cover changes, as well as conducting landscape pattern analysis, we can assess the urbanization impacts on such changes. Last but not least, in order to appropriately adopt further development, land suitability analysis was conducted. Based on the results from land suitability analysis, we are able to revise the existing land use policies and plans. Therefore, land use policies and plans, population and land cover changes, assessment of urbanization impacts and possible future development become a feedback loop that keeps land use policies and plans revised and updated.

VI. Significance of the Study

For those natural resource managers and planners who are interested in the impacts of urbanization, this study can provide a model to access the potential changes in natural resources and ecological systems. Results of the study can aid development and implementation of urban growth management plans as well. This study can, by using various GIS modeling techniques, influence the guidelines or proposals to policy makers, including managers and developers in outlining the development of Dakota County. This study can also guide the Twin Cities Metro Area, and the expansion of its urbanization, including urban growth and pattern of land uses in the future, so as to reach sustainable development for society by having a balanced ecosystem.

VII. Delimitations and Limitations

1. Population Change

   The block group boundary shapefiles obtained from the U.S. Census Bureau for 1990 and 2000 are different in terms of their ID, polygon count, area and shape. While population density was used to compare between two years, it represents only the average density in each polygon, regardless how population was distributed. Therefore, population density analysis is good for observing the trend of change, not for a geographically-specific evaluation.

2. Land Cover Data:

   The national land cover inventories of 2001 developed by the U.S. Geological Survey (USGS) were not completed until the end of 2006, thus the availability of data was once an obstacle when this thesis was written. Furthermore, land cover classifications of these two land cover datasets of 1992 and 2001 from USGS have some differences in classification, and need to be reclassified to make the classes equivalent. In addition, historical land cover data that before 1980s were not included due to lack of the data.

3. Data Quality

   Data collected by different agencies, using different methods, and for different purposes may affect the quality of data. Due to the large amount of data that used in this research, it is impossible to obtain the necessary data from the same data resource or from the same year.

4. This study was limited to only one county, which is Dakota County, out of the seven counties in the Twin Cities Metro Area. Thus, it does not reflect actual land cover changes that resulted from the urbanization of the entire Twin Cities Metro Area.
5. Because of the delimitations and limitations listed above, I made the following assumptions:
   a) Population in each polygon (Census block group) was evenly distributed; the population density of each Census block group represented the entire polygon.
   b) Land cover reclassifications were based on definitions and similarities of the original classification systems;
   c) Land cover changes and influences on natural resources were only because of the urbanization of the Twin Cities Metro Area. Impacts from other processes were not included.
   d) A reality check of data quality is needed. I used Google satellite images to compare the raster datasets of Dakota County land cover with the current aerial photos. Based on the pattern I observed from the Google satellite images, I assumed that the data quality, especially the raster datasets, is good enough to continue my research. A field trip, which is more reliable for reality check, was not made during the research.
   e) Land suitability analysis for both the urban expansion and agriculture protection analysis assumed that the input layers of land features were current and complete; reclassifications for each variable (GIS theme) were reasonable; and weight (% influence) of each land feature corresponded to Dakota County planning goals and scenarios.

VIII. Definitions

Ecosystem Management. The process of land use decision-making and land management practice that makes into account the best available understanding of the ecosystem's full suite of organisms and natural processes (ESA 2000, p. 2).

FRAGSTATS. A software package with a set of spatial statistics that were implemented by ecologists to describe the characteristics of landscapes and components of those landscapes (Raines 2002).

Geographic Information System (GIS). A computer system for capturing, storing, querying, analyzing, and displaying geographically referenced data (Chang 2004, p. 1).

Land Cover. The ecological state and physical appearance of the land surface (e.g., closed forests, open forests, grasslands) (ESA 2000, p. 2). Land cover materials include plants, water, soil, rock, ice, and construction materials.

Land Cover Classification. For the purpose of my study, land cover classification refers to the Minnesota Land Cover Classification System (MLCCS). MLCCS integrates classification of cultural features, non-native vegetation, natural and semi-natural vegetation into a comprehensive land cover classification system. It categorizes urban and built-up areas in terms of land cover rather than land use; it reveals important information of natural resources (Minnesota Department of Natural Resources 2004). (See Appendix 1).

Land Use. The purpose to which land is put by humans (e.g., protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, or human settlements) (ESA 2000, p. 2). The emphasis of land use classifications is human activity, rather than cover materials.

Landscape. A heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in similar form throughout. Landscapes vary in size, down to a few kilometers in diameter (Forman 1986, p. 594).

Landscape Change. The alteration in the structure and function of the ecological mosaic over time (Forman 1986, p. 594).

Metropolitan Area. Metropolitan areas are measured in part on the basis of commuting patterns between counties; so the more spread out the population, the greater the metro area tends to be (Daniels 1999, p. 5).

Population. A group of individuals of the same species located in a particular time and place (Forman 1986, p. 597).

Region. An area, usually containing a number of landscapes, that is determined by a complex of climatic, physiographic, biological, economic, social, and cultural characteristics (Forman 1986, p. 598).

Remote Sensing. The technology of acquiring data and information about an object or phenomena by a device that is not in physical contact with it (NASA). Typical forms, such as aerial photos and satellite images, can be used in GIS analysis as the source of land cover data.

Scale. The level of spatial resolution perceived or considered. Also, spatial proportion, or the ratio of length on a map to true length on the ground (Forman 1986, p. 599).

Urbanization. The replacement of undeveloped land, open space and natural vegetation land by residential and commercial development; the conversion of land from a rural or undeveloped state (U. S. Geological Survey 1999, p. 4).

IX. Overview of Chapters

The second chapter provides a review of literature about previous studies concerning land cover changes and natural resource management, their methods and results. The third chapter describes the methods and procedures I used in this study. The fourth chapter discusses and analyzes the results from my study, and possible reasons for leading to such results. It also describes the land use plan of Dakota County and its influences and effectiveness. The final chapter presents conclusions from the study and recommendations for the future.

CHAPTER 2. LITERATURE REVIEW

I. Land Cover and Land Use Changes

For much of the last century, environmental degradation (loss of forest cover and soil erosion) were held to increase linearly with population density (Bassett and Bi Zueli 2000). Human impacts affect different regions in different ways, but the cumulative effect – multiplied across landscapes and regions – is to change the earth in profound ways that are virtually irreversible on human time scales (Perlman and Milder 2004).

The linkage between people and the environment is bidirectional, involving both the effects of people on ecosystems and the effects of ecosystem structure and environmental quality on people's well-being (Wear 1998). Specifically, the size, shape, and spatial relationships of land cover types influence the dynamics of populations, communities, and ecosystems (ESA 2000).

Land cover is the most important source of anthropogenic change on the planet (Turner et al. 2001). Land cover data describe the surface cover of the earth, and usually distinguish among various types of forests, grasslands, or wetlands and are especially helpful for ecological inventories (Perlman and Milder 2004). Land cover change is an indicator of land use (the way the land is used by people), environmental conditions and human impacts, and the information and technology to calculate land cover is currently available (Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments etc. 2000). On the other hand, because changes in land use often affect land cover, land use is itself an indicator of land cover. Land use in some ways is more informative because it provides additional information on the status of areas, their ability to provide goods and services, and information on how land is used is predictive of future land cover. Nonetheless, a land use indicator requires much synthesis of existing information and some new information, and thus will take longer to develop than a land cover indicator (Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments etc. 2000). Furthermore, there is little agreement upon methods for systematically characterizing urban land cover and examining land use in an urban context. Part of the challenge is defining the difference between urban and rural so that change can be adequately assessed (for example, the expansion of urban areas into peri-urban and rural landscapes over time accompanying population growth and development) (Boucek and Moran 2004).

Wear (1998) considered urbanization to be a factor or gradient that organizes disturbance regimes and ecosystems in general, and the urbanization gradient describes a whole complex of processes that have a bearing on ecosystem structure and function. Two measures of position along an urban-rural gradient were introduced: human population density and distance to the closest metropolitan area (Wear 1998). In particular, population density can be used as an explanatory variable in empirical analysis of land cover changes, while its covariance with distance to the closest metropolitan area is also measured. Population data collected at the region level (point data) can be interpolated to provide a continuous surface of population density, and overlaid with a land cover change map to measure a correlation between high population density and areas where deforestation is occurring (Boucek and Moran 2004). Wear's (1998) findings indicate that position on the urban-rural gradient not only influences land-cover change regimes, but could have a substantial influence on resulting landscape patterns.

Urban land use is an important component in understanding the interactions of urban economic activities with environment as well as urban expansion, and thus it is necessary to simulate such changes. The theory of Metropolis Globalization holds that the demands of economic development show an impetus to urban sprawl; on the other hand, the possibility of urban sprawl lies in economic capacity (Wang et al. 2004). Therefore, economic development plays a critical role in the changes of urban land use: fast industrialization and urbanization has resulted in cities' rapid sprawl with the loss of a significant amount of agricultural land and allured a series of transformation in urban land use structure as well as spatial distribution (Wang et al.2004).

In areas where population growth and development are in initial phases, it may be possible to anticipate and thereby redirect some development that would prove detrimental to environmental qualities. Various tools and techniques, such as GIS, remote sensing, and FRAGSTATS, have been tested regarding the way that development, measured as extent and patterns of land-cover change, is organized along the urban-rural gradient (Wear 1998).

A number of geographic studies and models have been developed to measure the growth of cities or regions. Following are several studies that model urban growth, in which the SLEUTH Urban Growth Model has been well-known and practiced by land use professionals.

SLEUTH Urban Growth Model

SLEUTH is a product of the Clarke Urban Growth Model that uses environmental simulation modeling to address urban growth by applying concepts of urban dynamics. Developed by Dr. Keith C. Clarke of the University of California, Santa Barbara, SLEUTH consists of the Urban Growth Model (UGM) and the Land Cover Deltatron Model (LCD). The name SLEUTH was derived from the input requirements of the models: *S*lope, *L*and cover, *E*xclusion, *U*rbanization, *T*ransportation, and *H*illshade (U.S. Geological Survey 2006).

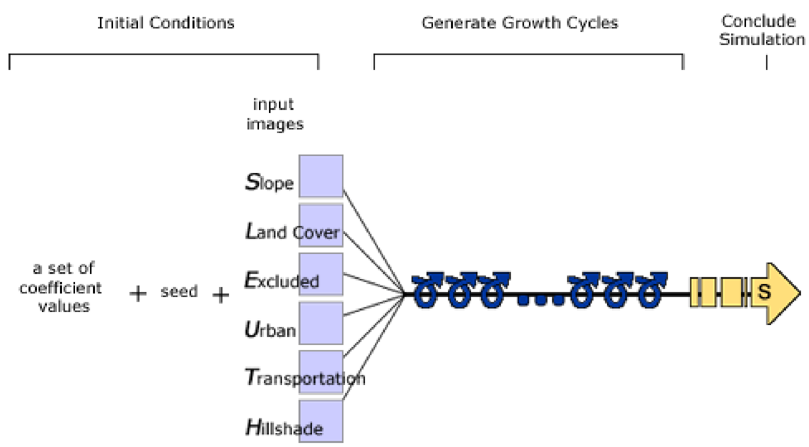

Figure 2. 1 Basic simulation (U.S. Geological Survey 2006)

The benefit of these tools is predicting urban growth on a regional, continental and eventually global scale. Furthermore, modeling results and created databases can guide local community planners in achieving desired smart and responsible urban growth throughout the region (U.S. Geological Survey 2006).

Implementation of the model occurs in two general phases: calibration, where historic growth patterns are simulated, and prediction, where the historic patterns of growth are projected into the future. SLEUTH simulates four types of growth, which are applied sequentially during each growth cycle:

1. Spontaneous new growth, which simulates the random urbanization of land,
2. New spreading centers, which simulates the development of new urban areas,
3. Edge growth, which stems from existing urban centers,
4. Road influenced growth, which simulates the influence of the transportation network on development patterns (Mid-Atlantic RESAC 2006).

In Brown's (2000) thesis research, he used the Clarke Urban Growth Model to develop future land use scenarios for a study of the environmental impacts of growth pressures on the landscape in a six-county area in central Iowa. Future habitat was modeled using historic cultural maps, soils maps, aerial photographs, and the Clarke Urban Growth Model. Transformation of non-urban land cover to urban land cover was modeled through four growth scenarios for each of six urban locations in the study area. The procedures for modeling the impacts of future urban growth on existing natural areas involved four components: a historic perspective of landscape change; the use of an urban growth-modeling component for estimating future spatial patterns of urban growth; the generation of future landscape patterns; and evaluating each landscape using landscape ecology statistics software. In terms of the third component, future landscape patterns were described using existing land use planning and zoning documents, a high conservation designation and current trends without limits. Each pattern was introduced in the urban growth model to generate a future landscape (Brown 2000).

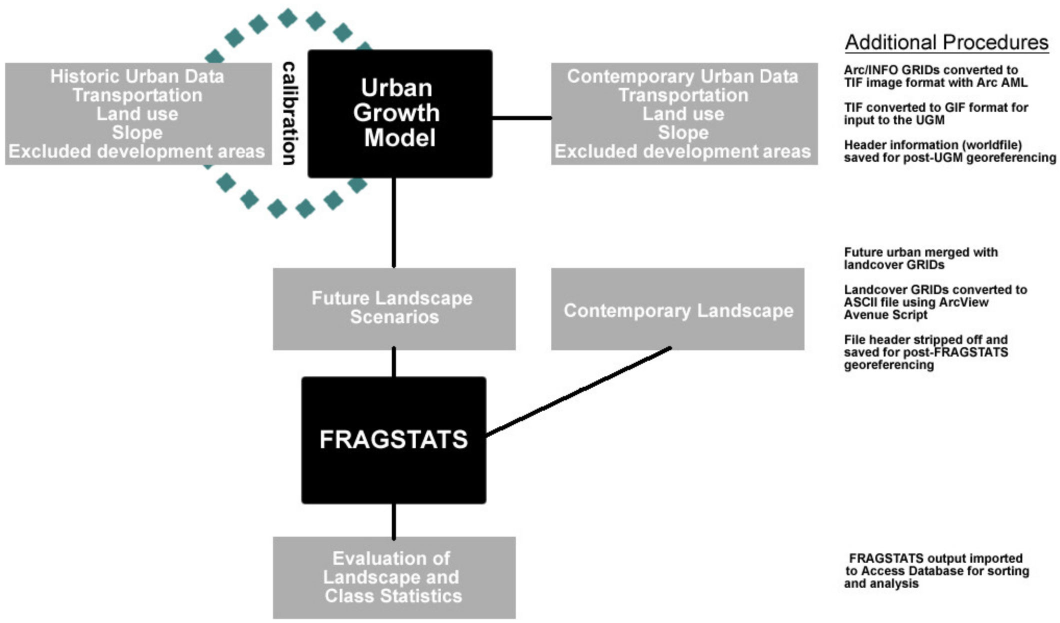

Figure 2. 2 Steps involved in the prediction and analysis of future urban growth on the landscape (Brown 2000)

IDRISI from the Clark Labs

IDRISI is an integrated GIS and image processing software system for the analysis and display of spatial data. It was developed by the Clark Labs at Clark University in 1987, and has been used by professionals in a wide range of fields, especially environmental scientists and mangers. IDRISI offers more than 250 modules, including GIS analysis, image processing, surface analysis, change and time series analysis, modeling, and decision support and uncertainty management (Clark Labs 2006).

Take the change and time series analysis for example, which is closely related to the research topic, it identifies and quantifies change and its impacts. IDRISI's image comparison tools include image differencing, image ratioing, regression differencing, change vector analysis, and qualitative data analysis. It also includes a set of tools for measuring change at both the local and global scales, including tools for image comparison, multiple image comparison, and predictive modeling and assessment. Multiple image comparison techniques look at trends and anomalies across multiple images (time series) and include tools for time series analysis using Principal Components analysis, time series Fourier analysis, spatial/temporal correlation and image profiling over time (Clark Labs 2006).

A suite of tools is also provided for predictive land cover change modeling as well as the assessment of those predictions, utilizing knowledge of past changes. These tools include Markov Chain Analysis, Cellular Automata, logistical regression and multinomial logistical regression, GEOMOD, and Artificial Neural Networks. The latter has been incorporated into the Land Change Modeler, a vertical application integrated within IDRISI, which provides tools for the assessment of land cover change, the identification of driving forces of change, and the use of that information to predict future scenarios (Clark Labs 2006).

An IDRISI single seat student license cost $295; an IDRISI student starter cost $95; and the information for prices can be found on their website at http://www.clarklabs.org/buy/buy-online.cfm.

Study of Land Cover Changes on Willamette River Basin, Oregon

Alternative futures analysis can inform community decisions regarding land and water use: Joan P. Baker, David W. Hulse and other professionals conducted an alternative futures analysis in the Willamette River Basin in western Oregon. Based on detailed input from local stakeholders, three alternative future landscapes for the year 2050 were created and compared to present-day (circa 1990) and historical (pre-EuroAmerican settlement) landscapes. The historical, present-day, and future landscapes are represented as maps of land use/land cover, using a consistent classification scheme and spatial resolution, and associated written assumptions about management practices and water use. The alternative futures are then compared based on their effects on a diverse array of endpoints, selected to represent the range of stakeholder interests as well as important ecological attributes. The benefits of the study allow stakeholders see results for the initial set of alternative futures, and it can further lead to new ideas or compromise positions that warrant design of additional future scenarios or analysis of additional endpoints (Baker et al. 2002).

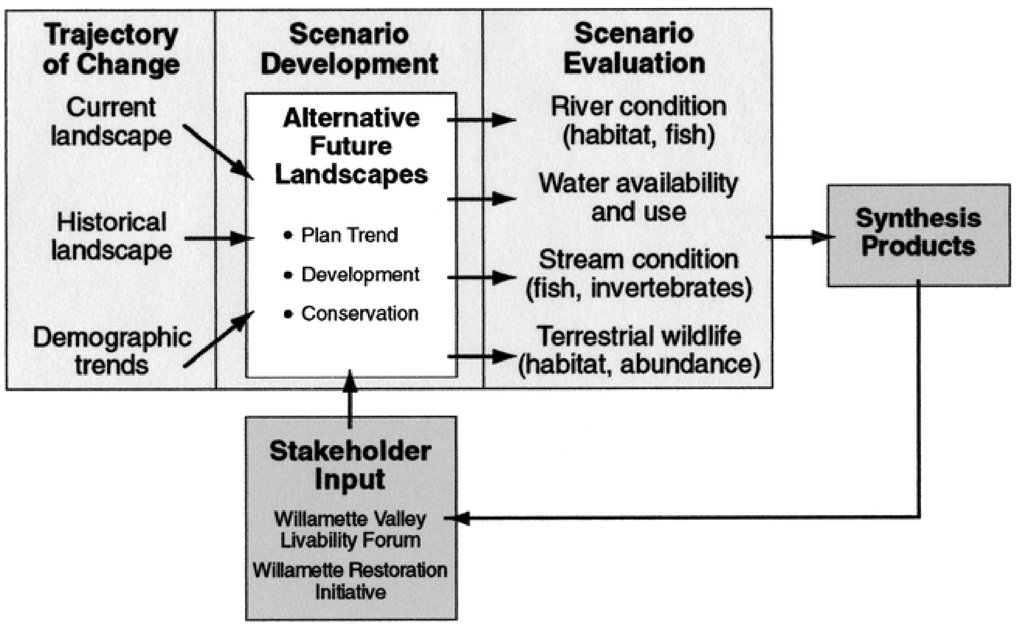

Figure 2. 3 Diagram of alternative futures analysis process, as applied in the Willamette River Basin (Baker et al. 2002)

Agent-based Models of Land Use and Land Cover Change

An increasing number of scholars are exploring the potential of agent-based or multi-agent system tools for modeling human land-use decisions and subsequent land cover change (Parker et al. 2001). As defined in Parker's (2001) report, an agent-based model of land-use/land-cover change (ABM/LUCC) consists of two key components: the first is a cellular model that represents the landscape under study; and the second component is an agent-based model (ABM) that represents human decision making and interactions. An agent-based model consists of autonomous decision-making entities (agents), an environment through which agents interact, rules that define the relationship between agents and their environment, and rules that determine sequencing of actions in the model (Parker et al. 2001).

Land use represents a critical intersection of human activities and the environment. However, land use and land cover research has been mainly GIS-based, unable to describe the human dynamics. In order to “socialize the pixel,” in other words, to establish the connection between social science and the GIS-based land-use models of geography, the ensemble of these actors is represented in a multi-agent model in the MameLuke project (Parker et al. 2001). Thus, decision-making processes of the inhabitants/actors (for example, an economic analysis) are linked to a spatially heterogeneous landscape that deals with biophysical or biological processes, in which changes in land use are viewed as dependent on how resources are transformed and managed by human activity.

The MameLuke project (Parker et al. 2001) is embedded in a program that also incorporates another project, the CLUE modeling framework. The project exchanges important information with the meso-scale project CLUE in terms of the various driving factors that are important for the options and/or motivations (hence the choices) of actors in the multi-agent model. In Figure 2.4, the abstract connection is given. For example, land use policies change the motivation of actors to invest in the land they work. The causal structure of the model (both the way the agents are modeled and the way they are interconnected) will support the quality of the causal structures as they are modeled at the meso-scale (for instance, in the regression analyses) (Parker et al. 2001).

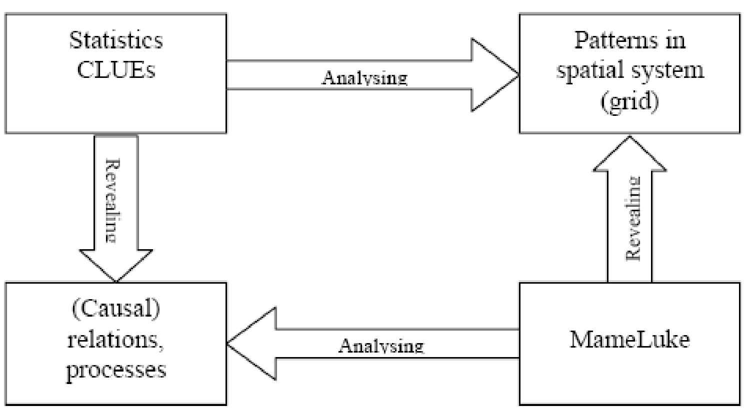

Figure 2. 4 The Rrlationship between MameLuke and CLUE (Parker et al. 2001)

II. Growth Management

1. Policies and Plans

Land policy in the context of growth is public policy aimed at modifying market-driven land use choices in ways that would reduce the negative environmental consequences of growth. Policies can refer to local, state, and federal jurisdictions. The federal government makes decisions on the use of federal parks, forests, military lands, research facilities, and other federal lands. In addition, in recent decades the federal government has dealt directly with such growth-related environmental problems as air and water quality and the disposition of wastes. At the local level, some towns, cities, counties, and regions have engaged in a flurry of growth management activity. When local governments go about the task of managing growth within their jurisdictions, their actions often affect which lands are developed and which are not, and the pattern of development that emerges (Chinitz 1990).

Growth is not only the increase of population, but also is the expansion of developed space (Chinitz 1990). It converts land from rural or open space uses and modifies on-site natural resources (Brower 1989). The sources of growth are typically increases in population and economic prosperity, which generate higher demands for housing, workplaces, service establishments, roads, and schools, and lead to the exploitation of land and natural resources (Chinitz 1990). The primary environmental influences on growth will continue to be water quality (including wetlands), natural hazards like flooding, and air quality. Managing growth so as to mitigate its impacts on natural resource systems is a major challenge due to the complex behavior of these systems, the diverse intergovernmental programs for environmental protection, and the fragmented state of knowledge about linkages between growth and natural resources (Brower 1989).

Growth management describes how people and their governments deal with change (Daniels 1999). States, regions, and communities use growth management to anticipate and mitigate the negative effects of development. Ultimately, effective growth management fits available land to uses that meet economic demands and human needs and that maintain environmental quality. Effective growth management requires the strategic use of diverse planning techniques to balance the immediate benefits of market-driven projects against the long-term risks of environmental degradation, fiscal inefficiency, and social injustice (Hoch 2000).

The goals of growth management are:

(1) protect lands hat provide public and quasi-public goods;
(2) accommodate development needs;
(3) provide adequate public facilities and services at minimum cost and distribute costs equitably;
(4) distribute the burdens and benefits of growth fairly;
(5) prevent or mitigate negative and foster positive externalities; and
(6) provide administrative efficiency (Hoch 2000).

To achieve its goals, growth management combines a range of regulatory, financial, and land use management tools and techniques:

- government land-use regulations, such as zoning;
- public infrastructure spending programs;
- tax policies, such as use-value taxation for farmland; and
- incentives (Daniels 1999, p. 3).

No one set of growth management techniques fits every community, county, or state. But many spending programs, regulations, and incentives that state and local governments employ or could implement are useful tools and techniques on helping manage growth (Daniels 1999).

A key technique to effect major change in managing growth is the Urban Growth Boundary (UGB), which set a limit on the extension of urban-type services such as public sewer and water, while identifying enough buildable land for 10-20 years (Daniels 1999). For example, because public sewer and water will not be extended beyond growth boundaries, developers have a strong incentive to look inside the boundaries for development land rather than search for greenfield sites in the countryside. A well-known example of a UGB is in Portland, Oregon. Within Portland's UGB, public funds are invested in infrastructure to support moderate to high development densities, while land uses outside the boundary are generally limited to agriculture, conservation, and very low-density development. Furthermore, the Portland UGB is reviewed and expanded from time to time to ensure that it always includes enough land for twenty years of projected growth (Perlman and Milder 2004). In short, UGB is intended as a growth management means for directing growth to specific areas.

Transfer of Development Rights (TDR) is another growth management technique used to transfer the rights to develop a land in the sending area to landowners or developers in the receiving area. Long-standing TDR programs, such as those in Montgomery County, Maryland, and the Pinelands of southern New Jersey, have protected thousands of acres of farmland and native habitats at little cost to the public while still providing economic return to the owners of the protected land (Perlman and Milder 2004).

Besides the UGB and TDR, other techniques, such as zoning ordinances (agricultural zoning, conservation zoning, etc.), property acquisitions (purchases of development rights, impact fees, etc.), incentives (agricultural districts, etc.) and other development controls (subdivision regulations, environmental impact assessments) are very common and useful growth management techniques (Daniels 1999).

Perhaps the greatest challenge facing land use decision makers and resource managers is to understand the factors influencing land cover structure well enough to predict respond to changing land cover conditions in land use management plans. Nevertheless, long-term planning should also recognize that one cannot simply extrapolate historical land-use impacts forward to predict future consequences of land use. Transitions of land from one use or cover type to another often are not predictable because of changes in demographics, public policy, market economies, and technological and ecological factors (ESA 2000).

To improve our ability to structure rational policies and management strategies for protecting environmental quality in developing areas, better information on the interactions between human populations and nature, both in terms of how people impact their environment and how environmental quality contributes to human well-being should be gathered and analyzed (Wear 1998).

Geographic Information Systems as a Tool for Growth Management

GIS technology, as one of the various tools for information management, provides capabilities to analyze the spatial and temporal patterns and cumulative impacts of growth on natural resources. GIS combines computer hardware, software, and data describing land in a way that allows information to be mapped, tabulated, or analyzed with comparisons to other information about the same or similar places (Brower 1989).

According to Banta (1989), the primary immediate needs for use of GIS technology to define sustainable development are to:

- create a situation where real property, resource, and development permit information can be systematically integrated with appropriate cartographic and professional standards;
- communicate to local governments at the urbanizing fringe with credible resource information in a comprehensive format; and
- communicate among professional disciplines to articulate development standards that are unambiguous and can be linked to build the sustainable development theme (Brower 1989, p. 146).

In general, graphic representations from GIS analysis bear a direct relationship to the physical or political properties seen on maps. This computer information technology dramatically changes the ways in which resource issues and options for growth are communicated to decision makers in both the public and private sectors, and the ways in which land resource analyses are exchanged among scientific disciplines (Brower 1989).

GIS techniques can furthermore be used to model future alternatives, such as growth patterns, effects of proposed polices, and resource management strategies and practices. Based on the results from assumptions and analyses, policy and decision makers can weigh these alternatives and select the best one to adopt.

2. Natural Resource Management

Humans are the major force of change around the globe, transforming land to provide food, shelter, and products for use. For example, patterns of human-settlement and land use decisions can have significant impacts on the landscape or otherwise alter land cover patterns. Land transformation affects many of the planet's physical, chemical, and biological systems and directly impacts the capacity of the Earth to continue providing the goods and services upon which humans depend (ESA 2000). Therefore, having a land use plan or natural resource management framework is a management tool that can describe the extent and content of various natural resources, and furthermore, improve resource managers' abilities to predict how land cover will change over time.

The cumulative impact of growth not only changes the aesthetics of the landscape, but also results in reduced air and water quality and the loss of wildlife habitat (Daniels, 1999).

Low-impact development (LID) approach combines a hydrologically functional site design with pollution prevention measures to compensate for land development impacts on hydrology and water quality. The primary goal of Low Impact Development methods is to mimic the predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, and detain runoff. LID enhances our ability to protect surface and ground water quality, maintain the integrity of aquatic living resources and ecosystems, and preserve the physical integrity of receiving streams. Prince George's County, Maryland's Department of Environmental Resources has pioneered several new tools and practices in this field, which strive to achieve good environmental designs that also make good economic sense (Prince George's County, Maryland 1999). In addition to benefits to water quality, LID has benefits for managing soil and wildlife resources.

Air Quality

Air pollution in metropolitan regions presents a serious challenge to environmental quality. The increase of number of vehicles and travel mileage results in greater gasoline consumption despite the improvement in the energy efficiency of vehicles. Many metropolitan areas have found that they are struggling in the combination of air pollution and traffic congestion (Daniels 1999).

Under the Clean Air Act Amendment of 1970, the Environmental Protection Agency (EPA) sets national primary standards to protect human health and secondary standards for visibility, building erosion, and plant and animal life. These standards are starting to impinge upon heavily auto-dependent metro areas that have tried to ignore their deterioration air quality (Daniels 1999).

Mitigation of air pollution has focused on introduction of nonleaded gasoline and automobile exhaust technology improvements. These air quality techniques may have to be supplemented with growth management efforts to control pollution generation by reducing private automobile travel, through placing housing and job sites closer together, limiting parking opportunities, and increasing mass transit usage (Brower 1989).

Water Quality

Several issues of water quality become concerns as urban growth occurs:

- Some home lots are too small to absorb sewage effluent and keep it from entering the groundwater, thus wells become polluted and health crises loom;
- Development that results in poor percolating soils or areas with poor-quality groundwater should be avoided;
- Some septic systems are not properly maintained, causing serious water quality problems;
- As population increases, public water supplies come under increased demand and the construction of new buildings and pavement may impinge on public groundwater supplies;
- Storm water runoff can cause soil erosions, damage to neighboring properties, siltation in rivers, lakes, and streams; and pollution from impervious surfaces;
- State and local governments need to be aware of the link between land uses and water quality, adopting and implementing water quality standards that anticipate the impact of development (Daniels 1999, p. 153-154).

State and local governments should ensure that adequate, quality, long-term water supplies are available before new developments are approved. Water quality techniques include carrying-capacity analyses of water supply watersheds that document safe thresholds of pollutants based on state and federal standards, determine both point and non-point source contributions, and recommend land use and storm water management alternatives to keep quality at acceptable levels (Brower 1989).

Wildlife Habitat

An important effect of an urban's growth is the loss of native habitat. Natural habitats, agricultural lands, and urban land uses are three players in this zero-sum game: as one land use expands (typically, human-inhabited areas), one or both of the others contract. As human settlement spread and human activities expand, we affect native habitats in many ways: habitat destruction and fragmentation; habitat degradation and pollution; overharvesting of natural populations; and non-native or exotic species (Perlman and Milder 2004).

Several planning tools and design techniques on the habitat scale (sites and lots), such as reducing development's footprint, ecologically-based site development practices, and environmental review, can help land use professional create ecologically-compatible developments (Brower 1989).

Soil Quality

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (SQI, NRCS 2006).

According to the Natural Resources Conservation Service (NRCS), soil quality management consists of six components:

1. enhance organic matter to improve and maintain soil quality by adding new organic matter every year;
2. avoid excess tillage to minimize the loss of organic matter and protect the soil surface with plant residue;
3. manage pest and nutrients efficiently to avoid harming non-target organisms and pollute water and air;
4. prevent soil compaction, which reduces the amount of air, water, and space available to roots and soil organisms;
5. keep the ground covered to protect soil and provides habitats for larger soil organisms; and
6. diversify cropping systems to help control pest population, weed and disease (SQI, NRCS 2006).

The National Agricultural Land Study of 1980-81 found that millions of acres of farmland were being converted in the United States each year (NRCS 2006). The

Farmland Protection Policy Act is intended to minimize the negative impacts Federal programs have on the unnecessary and irreversible conversion of farmland to nonagricultural uses. For the purposes of Farmland Protection Policy Act, farmland includes prime farmland, unique farmland, and land of statewide or local importance (NRCS 2006).

Prime farmland is land that has the best combination of physical and chemical characteristics for producing food, feed, fiber, forage, oilseed, and other agricultural crops with minimum inputs of fuel, fertilizer, pesticides, and labor, and without intolerable soil erosion, as determined by the Secretary (NRCS 2006).

Visual Quality

The landscape image as aesthetic is the primary theoretical basis for visual resource management (VRM) systems. VRM systems were developed by federal agencies to deal with three classes of problems: (1) visual inventory and analysis systems for large landscape areas needing landscape planning; (2) systems for scoping of potential visual impact or determining thresholds; and (3) systems for detailed evaluation of visual impact (Smardon 1986, p. 144-145).

The visual resource management (VRM) process is divided into two stages: inventory and analysis. Inventory is associated with resource management planning, and analysis is used primarily to determine whether proposed actions are appropriate to a VRM class assigned through the Resource Management Plan (Sloan Canyon 2005).

Depending on the different characteristic and function of different federal agencies, such as Bureau of Land Management (BLM), U.S. Forest Service (USFS), Soil Conservation Service (SCS) (now NRCS), each one of them have customized VRM systems, each with its own emphasis. For instance, BLM is heavily involved with permit processing activity to determine whether private parties should be allowed to do different kinds of activities on federal lands, such as grazing. For each permit action, BLM procedures check the existing visual quality or management objective of the site in question and do a visual impact analysis via an environmental assessment or full environmental impact assessment (Smardon 1986).

3. Dakota Policies and Plans

Natural Resource Management Checklist

A series of natural resource guidance checklists (2001) was produced by the Minnesota Department of Natural Resources, Metro Region to help local units of government (LUG) integrate natural resources into local policies and plans.

Natural Resource Inventory and Analysis for City or County – helps LUG develop policies, inform land use decisions and identify areas for natural resource conservation and management. This checklist includes series of questions concerning the purposes of the inventory and analysis, context of the natural resource (larger landscape and community values), inventory content (species, habitats etc.), inventory methodology, analysis and results. Furthermore, such natural resource inventory should be done at least every 10 years or more frequently if the resources have changed significantly (MDNR, NRI 2001).

Addressing Natural Resources in a Comprehensive Plan – provides a list of natural resources issues for communities to consider during the development of their comprehensive plans. A community's comprehensive plan presents an opportunity to identify the natural resources that make the community unique and on which each community depends. Growth can then be accommodated away from important natural resource areas and towards better suited areas in a planned way. (MDNR, NRCP 2001).

Natural Area Management Plan – provides land managers with a list of key elements to include in a natural area management plan. A good natural area management plan contains many different kinds of site and landscape-level information. A clear management plan identifies management goals and implementation strategies appropriate to the site, and enhances the likelihood that management activities will succeed. (MDNR, NAMP 2001).

The Environment and Natural Resource Management Policy Plan (Plan) is a chapter of Dakota County's 2020 Comprehensive Plan. The Plan establishes the guidelines for Dakota County efforts in environment and natural resource protection, preservation and management. One of the main messages that comes out of the framework is that the County should take a stronger leadership role in some areas (e.g., sustainability, waste sites and water resources), and a facilitation and coordination role in other areas (e.g., energy, healthy environment, and aggregate) (Dakota County 2005).

III. Suitability Analysis

After an ecological inventory of a study area has been conducted, and understanding of the relationships between people and environment has been achieved, it is then necessary to make more detailed studies of these interactions to present options for future use. One such type of detailed study is a suitability analysis, which is considered to be the process of determining the fitness or the appropriateness, of a given tract of land for a specified use (Steiner 2000). In summary, the spatial questions that suitability modeling tries to answer that based on the purpose of the specified land use are the following: (1) what are the requirements of the land features; and (2) whether the piece of land is suitable or not suitable for the land use.

1. Types of GIS Modeling

Before a further examination of land suitability modeling, it is necessary to introduce two types of GIS modeling and their definitions based on purpose.

GIS modeling could be categorized into two basic types based on the purpose of the tasks: *descriptive* and *prescriptive*. Descriptive modeling is defined as characterization of the direct interactions of system components to gain insight into system processes (understand), which has the sole purpose of description. Prescriptive modeling is defined as characterization of direct and indirect factors related to system response used in determining appropriate management action (decide), whose primary purpose is to prescribe best uses of existing land resources on the basis of evaluation of known or predicted circumstances (Berry 1995; DeMers 2002).

Descriptive Models: In their simplest forms, descriptive models display quantitative or qualitative characteristics of the landscape. Among the more powerful capabilities of the descriptive GIS model is its ability to integrate or synthesize often seemingly disparate spatial data. In this context, the descriptive model could also be called a *synthetic* GIS model, not because it attempts to describe a situation by examining a single map element or even a single map, but because it often merges multiple themes to evaluate possible spatial relationships. An alternative to the synthetic type of descriptive model is the *deconstructive* type. For determining the sensitivity of certain factors in a descriptive model, it might prove useful to remove individual independent variables to ascertain the impact each has on the final model (Demers 2002).

Prescriptive Models: In its purest form, the prescriptive model is designed to impose a best solution for problems in which a description of existing conditions is insufficient as a decision aid. As with any prescription, there is not always a perfect solution for a given question. In this case, there are generally two approaches. One is to select a best solution on the basis of the best available data and the constraints that currently exist or are expected to exist (if the model is to be predictive). The second approach is to provide a range of possible solutions, some better fitting certain criteria than others. It is best applied when more information is known about the conditions of each included factor, because there is a range of possible factor ratings and weightings, a wider range of factor sensitivity and thus a greater opportunity for effective solutions. Moreover, among the most important characteristics of prescriptive models is their ability to derive a solution, not just to describe what is already there. As such, the prescriptive model tends to be more adept at prediction (Demers 2002).

In summary, land suitability analysis performs as a prescriptive (predictive) model and can provide a range of possible solutions for the specified land uses.

2. Approaches to Suitability Analysis

In his book, The Living Landscape, Steiner (2000) reviewed three methods of suitability analysis: (1) several NRCS systems; (2) the McHarg suitability analysis methods; and (3) suitability analysis methods developed in the Netherlands.

A. Natural Resources Conservation Service (NRCS) Systems

The oldest, most established system for defining the ability of soil to support agronomic uses is the U.S. Soil Conservation Service land capability classification (LCC), which is one of several interpretive groupings made by the NRCS in standard soil surveys. Groupings are made according to the limitations of the soils when they are used for field crops, the risk of damage when they are used, and the manner in which they respond to management (Steiner 2000).

In the capability system, all kinds of soils are grouped at three levels: the capability class, the subclass and the unit. Capability classes are the broadest groups and are designated by Roman numerals I to VII, which indicate progressively greater limitations and narrower choices for practical agricultural use. Capability subclasses are soil groups within one class, and they are identified by adding the lowercase letters e, w, s, or c to the

Roman numeral. Capability units are further distinctions of soil groups within the subclasses (Steiner 2000).

The NRCS has developed several systems to assist planners and resource managers, such as the NRCS farmland mapping program, and the Agricultural Land Evaluation and Site Assessment (LESA) System. The NRCS farmland mapping program is a classification system that identifies two major categories of farmland of national importance, prime and unique lands, and two other categories, farmlands of statewide and of local importance. LESA is a system that is defined as "all the factors, weights, and scales used in the evaluation f soils and other site conditions" (Steiner 2000, p. 190).

B. The Ian McHarg (University of Pennsylvania) Suitability Analysis Method

Ian McHarg (1969) developed his method of using suitability overlay maps following previous work by other landscape architects, such as Charles Eliot, George Augus Hill, Philip Lewis and others (Steiner 2000). McHarg's contributions were unique and important. McHarg provided a theoretical basis for suitability analysis. His approach focused on overlaying mapping information for both natural and human-made attributes of the study area and displaying them initially as individual transparent maps (Steiner 2000). The transparent layers of light and dark values were superimposed over each other to construct the necessary suitability maps for each use. These composite maps illustrated intrinsic suitabilities for land-use classifications for the specific planning area. These maps were then combined with each other as overlays to produce an overall composite suitability map (McHarg 1969). McHarg also observed that the phenomena represented by the maps were valued differently by various groups of people and thus could be weighted differently, depending on the circumstance (Steiner 2000).

In *Design with Nature*, McHarg explained suitability analysis in the following manner:

> In essence, the method consists of identifying the area of concern as consisting of certain processes, in land, water, and air – which represent values. These can be ranked – the most valuable land and the least, the most valuable water resources and the least, the most and least productive agricultural land, the richest wildlife habitats and those of no value…, and so on (McHarg 1969, p.34).

McHarg (1969) also selected eight dominant aspects of natural process and ranked them in an order of both value and intolerance to human use and then reversed the order, which can be seen as a gross hierarchy of urban suitability (McHarg 1969, p.57-62).

Natural-process Value; Degree of Intolerance	**Intrinsic Suitability for Urban Use**
Surface water	Flat land (other than prime agricultural land)
Marshes	Forest, woodlands
Floodplains	Steep slopes
Aquifer recharge areas	Aquifers
Aquifers	Aquifer recharge areas
Steep slopes	Floodplains
Forest, woodlands	Marshes
Flat land (other than prime agricultural land)	Surface water

The suitability analysis involves seven steps in its procedures:

1) Identify land uses and define the needs for each use;
2) Relate land-use needs to natural factors;
3) Identify the relationship between specific mapped phenomena concerning the biophysical environment and land-use needs;
4) Map the congruence of desired phenomena and formulate rules of combination to express a gradient of suitability. This step should result in maps of land-use opportunities;
5) Identify the constraints between potential land uses and biophysical processes;
6) Overlay maps of constraints and opportunities, and through rules of combination develop a map of suitabilities for various land uses; and
7) Develop a composite map of the highest suitabilities of the various land uses (Steiner 2000, p. 204).

Figure 2.5 illustrated the suitability analysis procedure used in an ecological inventory and land-use suitability analysis of Asotin County, Washington (Steiner 2000, p. 205).

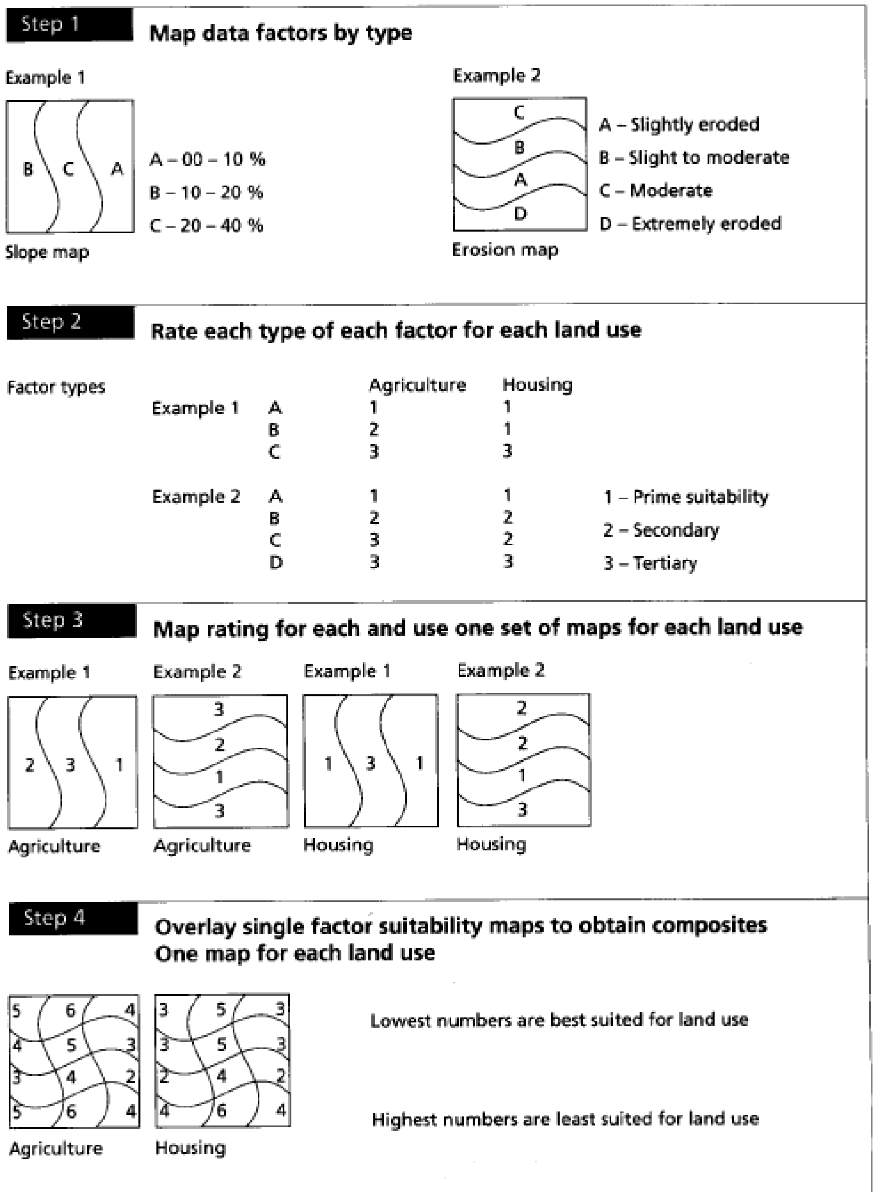

Figure 2. 5 Suitability analysis procedure

C. Dutch Suitability Analysis

The suitability analysis developed by A.P.A. Vink, a Dutch professor at the University of Amsterdam, is analogous to McHarg's suitability analysis. It is the category of Potential Land Suitability that distinguishes the Dutch approach. Vink defined that potential land suitability "relates the suitability of land units for the use in question at some future date after 'major improvements' have been effected where necessary suitability being assessed in terms of expected future benefits in relation to future recurrent and minor capital expenditure" (Steiner 2000, p. 207).

In the refined Dutch suitability analyses approaches, two elements, one more theoretical and the other more technical, are evident in suitability mapping. First, multiple criteria analyses are applied in order to weigh values among the various different, potential land uses. Second, digital GIS technology is employed in the analyses, making them more flexible and quick and easily applicable. These two elements enable Dutch planners to present a wider range of land-use possibilities, with varying suitabilities, to decision makers (Steiner 2000).

3. Computer Applications

McHarg's suitability analysis uses the overlay technique to place transparent maps with information about landscape elements on top of each other to reveal areas of opportunity and constraint; however, many practical difficulties exist in manually superimposing a large number of maps. GIS computer technology has helped to overcome the difficulties and limitations (Steiner 2000). GIS technology has become a valuable planning tool that can quickly provide decision makers with information in a concise map format.

Spatial information for planning use can be represented digitally in three ways: grid cells (raster), polygons (vector), and image processing (Steiner 2000). Figure 2.6 illustrates how mapped areas are represented with grid cells. Mapped areas in a polygon system area represented by enclosed spaces (Figure 2.7). Image processing is grid approach where the cell size is very small, and maps are created directly from photoimagery, such as from satellite or airplanes (Steiner 2000). An example of suitability analyses that were conducted for the Desert View Tri-Villages Area in Arizona is shown in Figure 2.8. Moreover, a point feature is any object at a given resolution that can be identified as being without area; in raster dataset, point features are represented by the smallest unit of a raster, a cell (ESRI 2006).

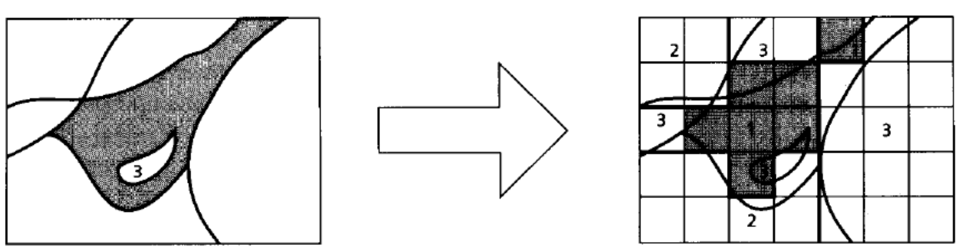

Figure 2. 6 Mapped areas represented by grid cells (Steiner 2000, p. 214)

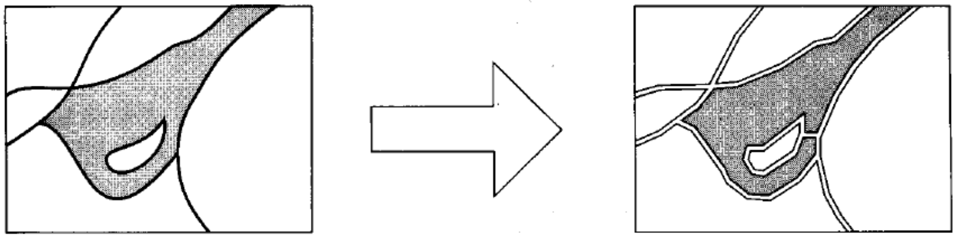

Figure 2. 7 Mapped areas represented by polygon system (Steiner 2000, p. 215)

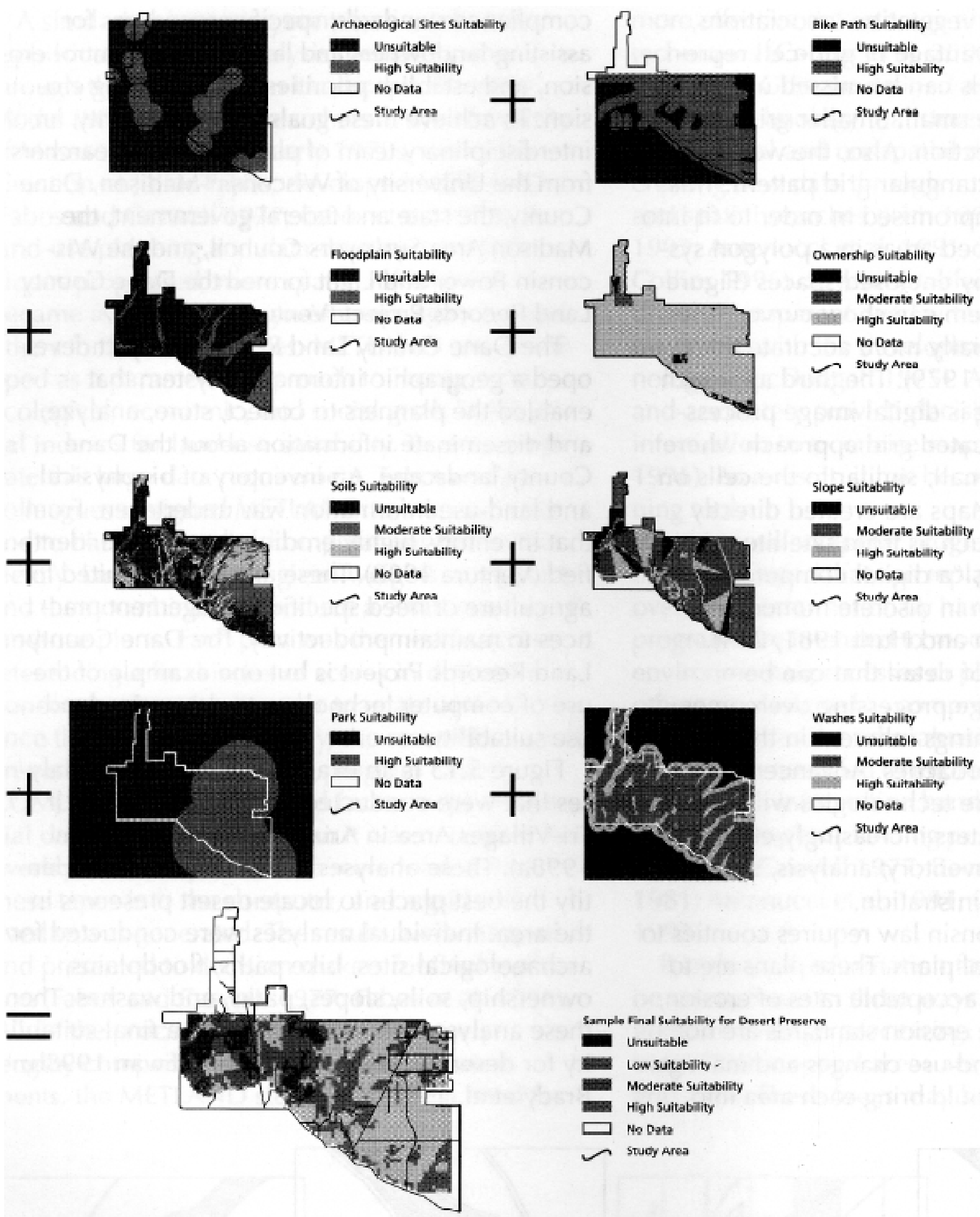

Figure 2. 8 Suitability analysis, desert view tri-villages area (Steiner 2000, p.216)

In conclusion, suitability evaluation supports a preferential decision to provide for certain types of activities (such as recreation, urban development, or agriculture) within a particular land condition (such as floodplains, wetlands, steep slopes, or soil type). The basic premise of suitability analysis is that each aspect of the landscape has intrinsic characteristics that are in some degree either suitable or unsuitable for the activities being planned, and that these relationships can be revealed through detailed evaluation and assessment. Ideally, the result is a site arrangement that takes advantage of the landscape's intrinsic characteristics while avoiding unsuitable locations for activities where obvious site conflicts or incompatibilities may be expected (Murphy 2005).

IV. Summary

Land cover and land use changes, as well as their main cause – population changes, are crucial factors that have significant influence on growth management policies and plans. Furthermore, they can be used as indicators in suitability analysis to determine the areas that potential growth will happen. After reviewing this chapter of literature about land cover and land use changes, growth management, and suitability analysis, I created a chain of methods that could measure population and land cover changes, and predict the possible development guided by the local growth management policies.

CHAPTER 3. METHODS

This following chapter briefly describes the study area, computer techniques, database, and methods that were covered in this research. Chapter 4 describes analysis procedures in more detail when describing results.

I. Study Area

Today's Twin Cities Metro Area settlement pattern and economy has been almost completely transformed during the past three decades. The seven-county Twin Cities metropolitan area is the economic powerhouse of Minnesota, as well as home to nearly half of the state's 4.6 million people (Daniels 1999). Both the strong economy and the absence of mountains or large bodies of water result in the Twin Cities metro area's steady growth. Decades ago, when people used the term Twin Cities, they usually meant Minneapolis and St. Paul. As the cities filled and growth expanded into the suburbs, the greater Twin Cities area spread over more than thirteen counties in Minnesota and Wisconsin, which is called the "Minneapolis-St. Paul-Bloomington, MN-WI 13-county Metropolitan Statistical Area (MSA)", according to the U.S. Census Bureau (Metropolitan Council 2000). By the late 1990s, the Greater Twin cities metro area was the fastest-growing region of the upper Midwest and the East Coast (Daniels 1999). Towns, villages and hamlets within highway commuting ranges of regional job centers in Minnesota are becoming bedroom suburbs, and incomes brought home from those jobs brings new economic vitality. Meanwhile, in unincorporated townships surrounding the regional centers and around the state's lakes, new houses are going up for retirees, weekenders, and commuters – especially along major and minor highways and country roads that provide access to nearby malls (Adams et. al 2003).

The study area for this research was Dakota County, one of the seven counties which comprise the Twin Cities Metropolitan Area (Anoka County, Carver County, Dakota County, Hennepin County, Ramsey County, Scott County, and Washington County) in Minnesota (Metropolitan Council 2000). The Twin Cities of Minneapolis and St. Paul and the surrounding area is the most highly-populated area in Minnesota and the 16th-largest metropolitan area in the United States as of the 2000 census (Metropolitan Council 2000). With a population of 2.6 million in 2000, the Twin Cities Metro Area is home to over half of the state's 4.8 million residents. There are over 189 cities within the metro area raging in size from fewer than 100 to Minneapolis with 382,295 (Northstar Partners 2005). I studied the urban expansion of Dakota County from 1990 to 2000, and the area was selected for study because urbanization and development have placed significant natural resources at risk for negative change.

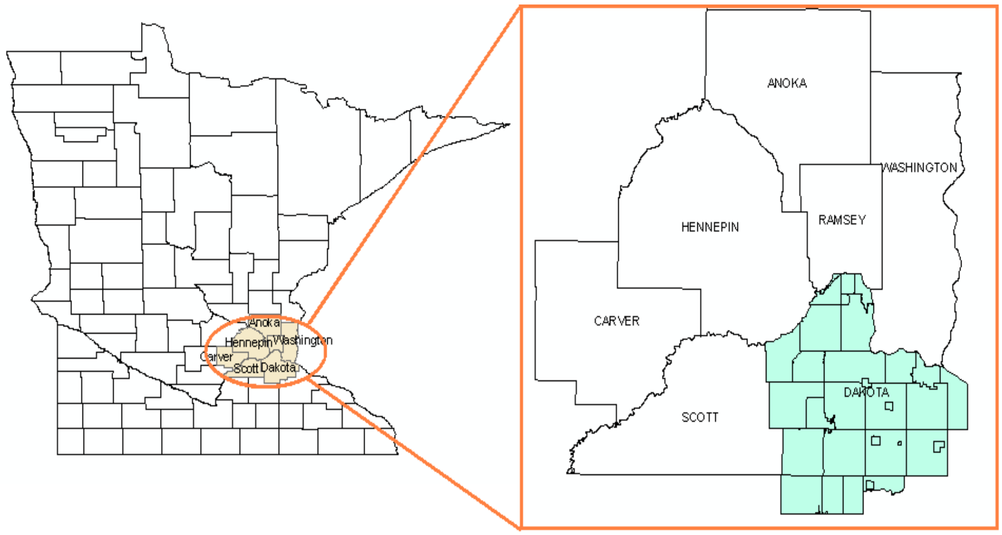

Figure 3. 1 Dakota County, Minnesota

II. Spatial Analysis

Spatial analysis is concerned with the relationship among geographical data, and its emphasis is on creative data displays and the use of simple indicators to elicit patterns and suggest hypotheses in an inductive manner (Anselin 1999). The central idea is to incorporate space into the analysis to be made. Geographic Information Systems (GIS) technology provides various techniques as well as extension functions to help analyze both feature and raster data. Remote sensing techniques, paired with GIS techniques, provide surface data of the earth. Many other spatial analysis tools, such as FRAGSTATS, expend GIS technology to further analyze the spatial patterns and provide statistical measures.

1. Geographic Information Systems

Landscape ecologists are rarely provided with digital data sources of all desired ecological parameters (Belaid 2003). Thus, new methods are needed to derive detailed spatial environmental data for large areas, with the increasing interest in and applications of landscape ecology and ecosystem management at regional scales. Over large areas, ground surveys are often not feasible and other methods of assessment need to be developed (He 1998). Recent technological advances, such as the development of Geographic Information Systems (GIS) and the general availability of databases for soils, roads, and land cover, make it possible to detect and analyze land cover/use changes. These GIS-based methods of data integration can enhance available information and help to fill current gaps in regional-scale data.

Remote sensing, along with GIS tools used to gather, display, store, analyze and output data related to the urban and sub-urban environment, can provide planners with certain datasets, in order to better manage the urban and sub-urban areas (Belaid 2003). Remote sensing and GIS techniques can be used in particular in:

1. location and extent of urban areas;
2. spatial distribution of different land use categories;
3. primary transportation network and related infrastructure;
4. various census-related statistics and socio-economical indicators;
5. 3-D structure of urban area for telecommunications and Environmental Impact Assessment (EIA) studies; and
6. the ability to monitor the changes in these features over time. (Belaid 2003, p. 2)

The data for items 1, 2 and 6 can be obtained using appropriate remote sensing techniques for image classification and land cover/use change detection and analysis (Belaid 2003). The accurate projection of satellite imagery is one prerequisite for successful change detection, so that the overlaid pixels in the time series represent the same location. This assumption is not always true causing studies of landscape change to include both false positives and false negatives.

There is a wide range of techniques used for land use change detection of urban areas. These techniques can be subdivided into the following categories: multi-date composite image; image comparison method; comparison of the classified images; combination of the classified images; classification of radar classification (Belaid 2003, p. 3). The methodology that Belaid adopted in his study consisted of four steps: 1) intensive geographical study; 2) extensive review of land use change detection methods; 3) visual interpretation of the satellite imagery to produce land use maps; and 4) spatial analysis and modeling of the remote sensing results (Belaid 2003, p. 2). In summary, the main steps such as geographical study, satellite and ancillary data acquisition, land use mapping using visual interpretation, data analysis and interpretation using GIS were involved.

2. Remote Sensing Techniques

Much of the research conducted using remote sensing in the urban context has been concerned with either management and planning or the general problem of urban expansion (Goodchild and Janelle 2004). This focus on urban and suburban expansion has not been explicitly linked to regional land use and land cover conversion processes occurring on the periphery of urban centers or their surrounding regions, although implicitly connected to larger concerns about the environment and consumption and exploitation of material resources and energy (Goodchild and Janelle 2004).

Remote sensing data (i.e., aerial photos and satellite images) paired with GIS technology offer large amounts of information at a modest cost and thus are a good place to start, especially when working at scales larger than individual sizes (Perlman and Milder 2004). Boucek and Moran (2004) used remote sensing data from satellite imagery and large-area aerial photography and GIS to document a time series of household-level land cover and land use changes. The authors employ traditional social survey methods to establish ground truth for their observations on housing modifications, crop patterns, road extensions, and other changes in local phenomena. Their work has clear policy relevance for linking the impact of social processes to environmental consequences (Goodchild and Janelle 2004).

According to Wear (1998), existing methods for detecting land cover/use changes over relatively short periods could be extended: models can be applied directly to existing landscapes to define where and how land cover is most likely to change; "hazard maps" could be especially useful for defining short-run implications of development within an area. Models can extend the analysis to address different epochs of human use, which could improve our understanding of the full range of effects and of the evolving interactions between people and their environment (Wear 1998).

3. FRAGSTATS

Landscape ecology is largely founded on the idea that the patterning of landscape elements (patches) strongly influences ecological characteristics, thus the ability to quantify landscape structure is prerequisite to the study of landscape function and change (McGarigal and Marks 1995).

A freely distributed software called FRAGSTATS was developed to apply landscape ecology concepts using landscape pattern indices and landscape structure measures

(McGarigal and Marks 1995). FRAGSTATS, spatial pattern analysis software for categorical maps developed by Dr. Kevin McGarigal and Barbara Marks of Oregon State University in 1994, offers a comprehensive choice of landscape metrics at the patch, class and landscape levels. It is a GIS extension to ArcMAP designed to compute a wide variety of landscape metrics for categorical map patterns, which quantifies the extent and spatial configuration of patches within a landscape. A large number of metrics and indices have been developed to characterize landscape composition and configuration based on categorical map patterns. These metrics are used to analyze landscape structure for a wide variety of applications, including quantifying landscape change over time and relating structure to ecosystem, population and metapopulation processes (Neel, McGarigal and Cushman 2004).

The major application of landscape structure metrics has been assessing effects of habitat loss and fragmentation on landscape connectivity (Neel, McGarigal and Cushman 2004). Fragmentation is a complex phenomenon that can be seen both as a consequence of habitat loss and as a process in and of itself (McGarigal and McComb 1995). Throughout the fragmentation process, many aspects of landscape composition and configuration are affected, including patch area, number of patches, amount of patch edge, patch shape complexity, interpatch distances, and adjacency of like cells. All of these characteristics affect landscape connectivity. An important aspect of land-use change is the change in connectivity, that is, the spatial continuity of a habitat or cover type across a landscape (Turner et al. 2001). Functionally, habitat connectivity influences the ease with which organisms or materials traverse the landscape between adjacent ecological units or landcover patches, and intact vegetation patches are especially important for many birds and mammals (Freeman 2003).

III. Database

Reliable and quality data are a key component of my research. Based on the research questions and literature review, several types of data were found necessary for the research. These are population, land cover, natural resource, and regional/local policies and plans. In order to better organize such comprehensive data, a Personal GeoDatabase was created using ArcCatalog.

1. Data Sources

- U.S. Census Bureau: demographic data
- U.S. Geological Survey: national land cover (1992 and 2001)
- Minnesota Department of Natural Resources: basic information, natural resource, and landscape data of Minnesota.
- Minnesota Geographic Data Clearinghouse of Minnesota Department of Administration: land-use, natural resources and other GIS data of Minnesota.
- MetroGIS Data Finder: GIS data of Minneapolis/St. Paul Metropolitan Area, Minnesota.
- Metropolitan Council: regional services including GIS data, environmental services, development policy and other data of Minneapolis/St. Paul Metropolitan Area, Minnesota.

2. Personal GeoDatabase

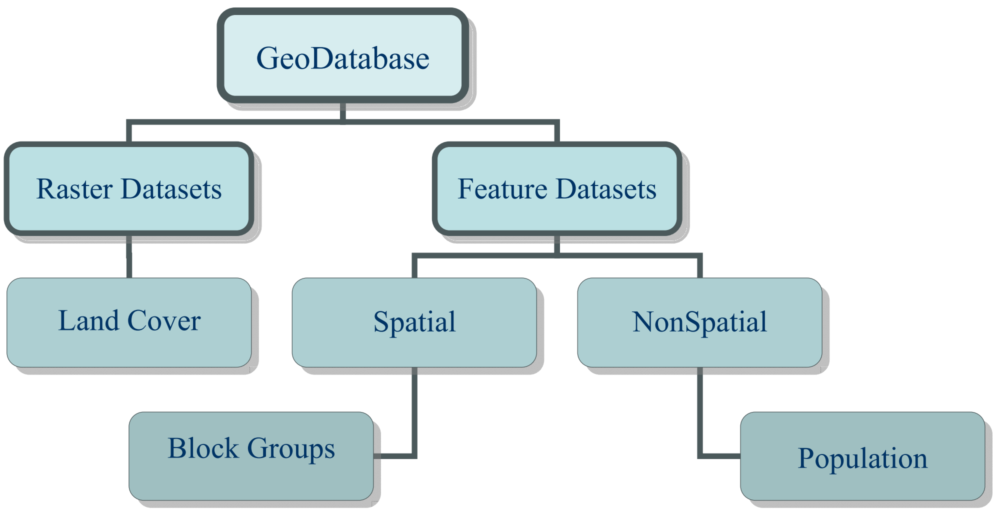

Figure 3. 2 Personal GeoDatabase

A Personal GeoDatabase was developed to collect and store necessary feature classes and raster datasets for this project. The Personal GeoDatabase format provides a framework for geographic information and supports topologically integrated feature classes. These datasets are stored, analyzed, and queried as layers similar to the coverage and shapefile models. The Personal GeoDatabase also extends these models with support for complex networks, topologies, relationships among feature classes, and other object-oriented elements (ESRI 2006).

Raster Datasets: land cover.

Feature Classes: spatial boundaries of State of Minnesota, counties, Census Blocks, and other complementary data.

Object Classes: demographic, environmental and other complementary data.

Table 3. 1 Database

Vector

Name	Area	File Name	Format	Source	Agency	Year	Coordinate system	File Size
Block Groups	Minnesota	MN_1990 _Block	Shapefile	http://www.census.gov/geo/www/cob/bg1990.html#shp	U.S. Census Bureau (Census)	1990	NAD27	733KB
Block Groups	Minnesota	MN_2000 _Block	Shapefile	http://www.census.gov/geo/www/cob/bg2000.html#shp	Census	2000	NAD83	1,178KB
City, Township and Unorganized Territory (CTU)	Twin Cities Metro Area	County_ctu	Shapefile	http://www.datafinder.org/metadata/county_ctu.htm	Metropolitan Council	2007	GCS_North_American_1983	3,092KB
Natural Resource Areas	Minnesota	dnr_rsnra	Shapefile	http://www.datafinder.org/metadata/dnr_rsnra.htm	Metropolitan Council	2000	GCS_North_American_1983	470KB
Soil	Dakota County	Soil_mn037	Shapefile	http://soildatamart.nrcs.usda.gov/	Natural Resources Conservation Service	2006	NAD83	84,608KB
FEMA Floodways	Dakota County	FEMA_flwy _Dakota	Shapefile	http://deli.dnr.state.mn.us/	Minnesota Department of Natural Resources	2003	NAD83	985KB
Wetlands	Dakota County	wetl_nwipy3	Shapefile	http://www.lmic.state.mn.us/chouse/metadata/nwi.html	Minnesota Department of Natural Resources	1997	NAD83	9,576KB

Raster

Name	File Name	Format	Source	Agency	Year	Cell Size	Coordinate system	File Size
Land Cover	NLCD1992	Raster Dataset	http://seamless.usgs.gov/	U.S. Geological Survey	1992	30m	GCS_North_American_1983	761KB
Land Cover	NLCD2001	Raster Dataset	http://seamless.usgs.gov/	U.S. Geological Survey	2001	30m	USA_Contiguous_Albers_Equal_Area_Conic_USGS_version	661KB
Digital Elevation Model	dem30m	Raster Dataset	http://www.datafinder.org/metadata/dem30m.htm	Metropolitan Council	1980	30m	GCS_North_American_1983	38,147KB

Tables

Name	Area	File Name	Format	Source	Agency	Year	File Size
SF 1 Block Groups	Dakota	Dakota_1990_SF1	DBF info	http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=DEC&_submenuId=datasets_0&_lang=en	U.S. Census Bureau (Census)	1990	22KB
SF 1 Block Groups	Dakota	Dakota_2000_SF1	DBF info	http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=DEC&_tabId=DEC2&_submenuId=datasets_1&_lang=en&_ts=180291241990	Census	2000	25KB

IV. Diagram of Methods

Most professional planners use a rational decision-making model that adapts a version of scientific inquiry as a guide for decision making. The model includes four major steps: (1) define the program or project goals; (2) identify the obstacles to fulfillment of these goals; (3) identify alternative solutions or strategies to the problems that will achieve the goals; and (4) compare the relative merits of each alternative as a solution to the problem (Hoch 2000, p. 23). For the purposes of this specific topic, after the research questions and objectives were identified, methods to answer such questions were developed in a step-by-step procedure.

As shown briefly the research framework in Chapter 1, four stages of analyses were included: existing local policies/plans pertaining to natural resources, analyses of population change, land cover change and possible future development. The following diagram of methods shows the tools and techniques that had been used in this research.

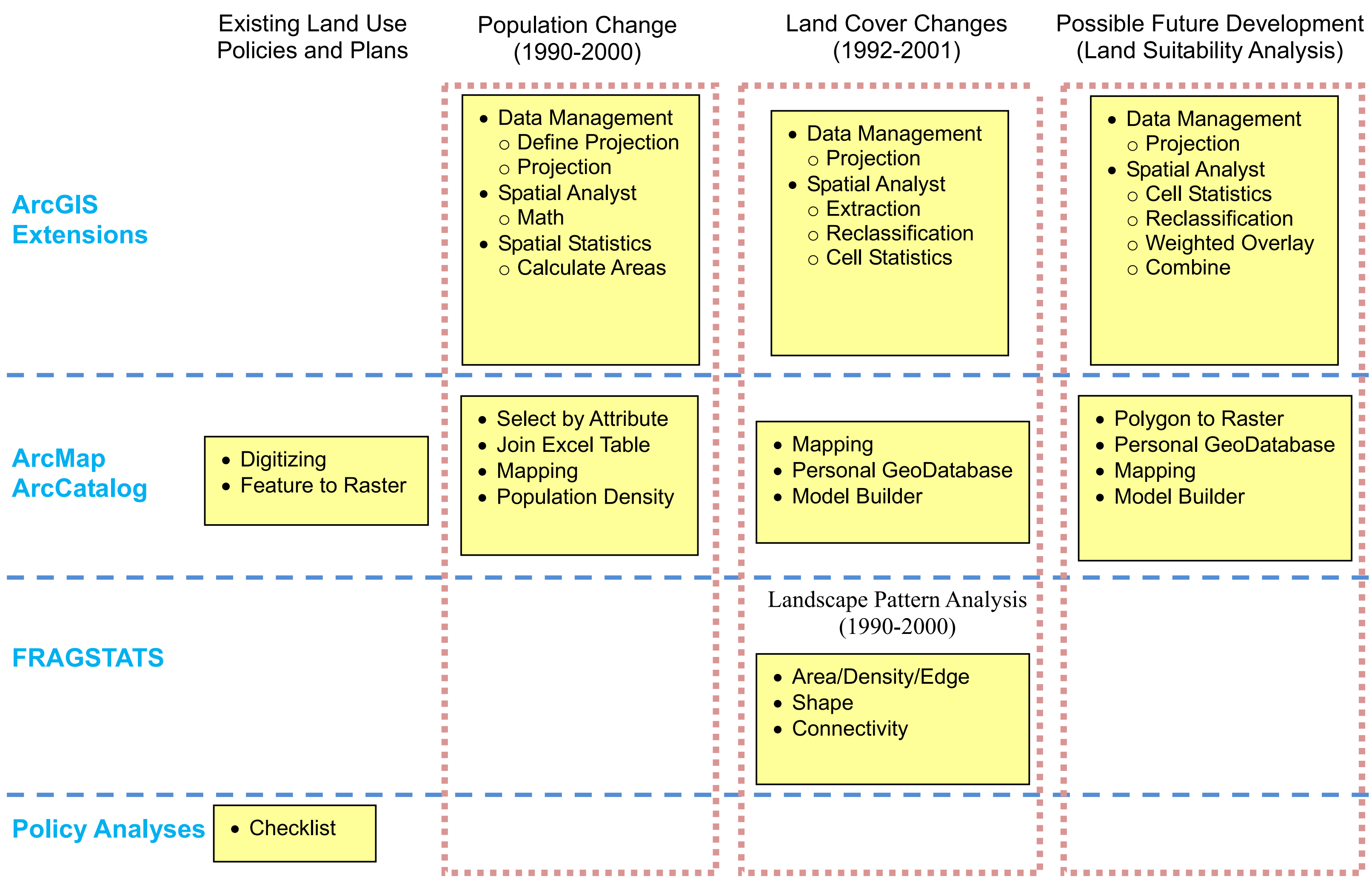

Figure 3. 3 Diagram of methods

CHAPTER 4. RESULTS AND DISCUSSION

I. Existing Land Use Policies and Plans

The 2030 Regional Development Framework (2030 RDF) is the initial "chapter" and unifying theme of the Metropolitan Council's metropolitan development guide. It was adopted in January 2004, and amended in December 2006. Together with the Metropolitan Council's regional policy plans, the Framework is intended to help ensure the orderly, economical development of the seven-county area and the efficient use of four regional systems: transportation, aviation, water resources and regional parks and open space (Metropolitan Council 2006).

The goals of the Metropolitan Council are:

- Working collaboratively with regional partners to accommodate growth within the metropolitan area;
- Maximizing the effectiveness and value of regional services, infrastructure investments and incentives;
- Enhancing transportation choices and improving the ability of Minnesotans to travel safely and efficiently throughout the region; and
- Preserving vital natural areas and resources for future generations (Metropolitan Council 2006, p.6-7).

The Council has tailored growth strategies for different community types – Developed Communities, Developing Communities and four types of communities within Rural Areas:

- The *Developed Communities* are the cities where more than 85% of the land is developed, infrastructure is well established and efforts must go toward keeping it in good repair;
- The *Developing Communities* are the cities where the most substantial amount of new growth—about 60 percent of new households and 40 percent of new jobs—will occur; and
- Roughly half of the 3,000 square miles in the seven-county Twin Cities area are rural. About 5% to 8% of new growth is forecast for the rural area—most of it in Rural Growth Centers. To acknowledge its diversity, the rural area is categorized into four geographic planning areas:
    - *Rural Centers* are the small towns located throughout the rural area. *Rural Growth Centers* are those Rural Centers both interested in and showing a potential for growth;
    - *Rural Residential Areas* are those places that are currently developed at one unit per 2 to 2 ½ acres or less, with no plans to provide urban infrastructure such as centralized wastewater treatment;
    - *Diversified Rural Communities* are the sparsely developed parts of the region, which host the widest variety of farm and non-farm land uses; and
    - *Agricultural Areas* are large contiguous land areas planned and zoned to maintain agriculture as the primary land use (Metropolitan Council 2006, p. 10-14).

The variations of different community types are illustrated on the Regional Growth Strategy Map. It outlines the roles of individual communities and strategies for accommodating expected growth (Metropolitan Council 2006).

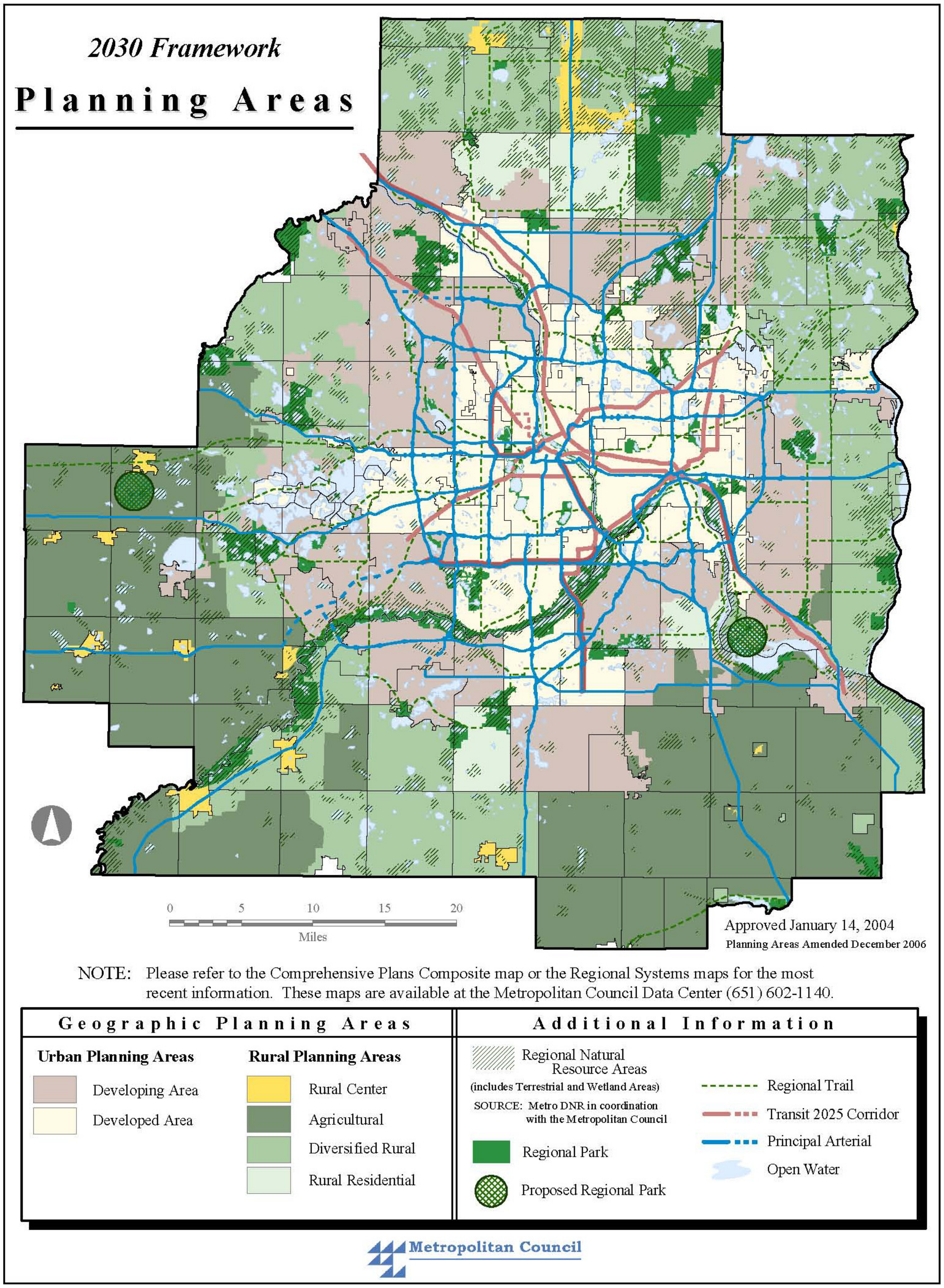

Figure 4. 1 2030 Framework planning areas

In Dakota County, there are a total of 34 communities of seven different types of growth accommodation. I combined the community type written in the 2030 RDF with the CTU shapefile, and generated a land use map for Dakota County in 2030 based on the framework.

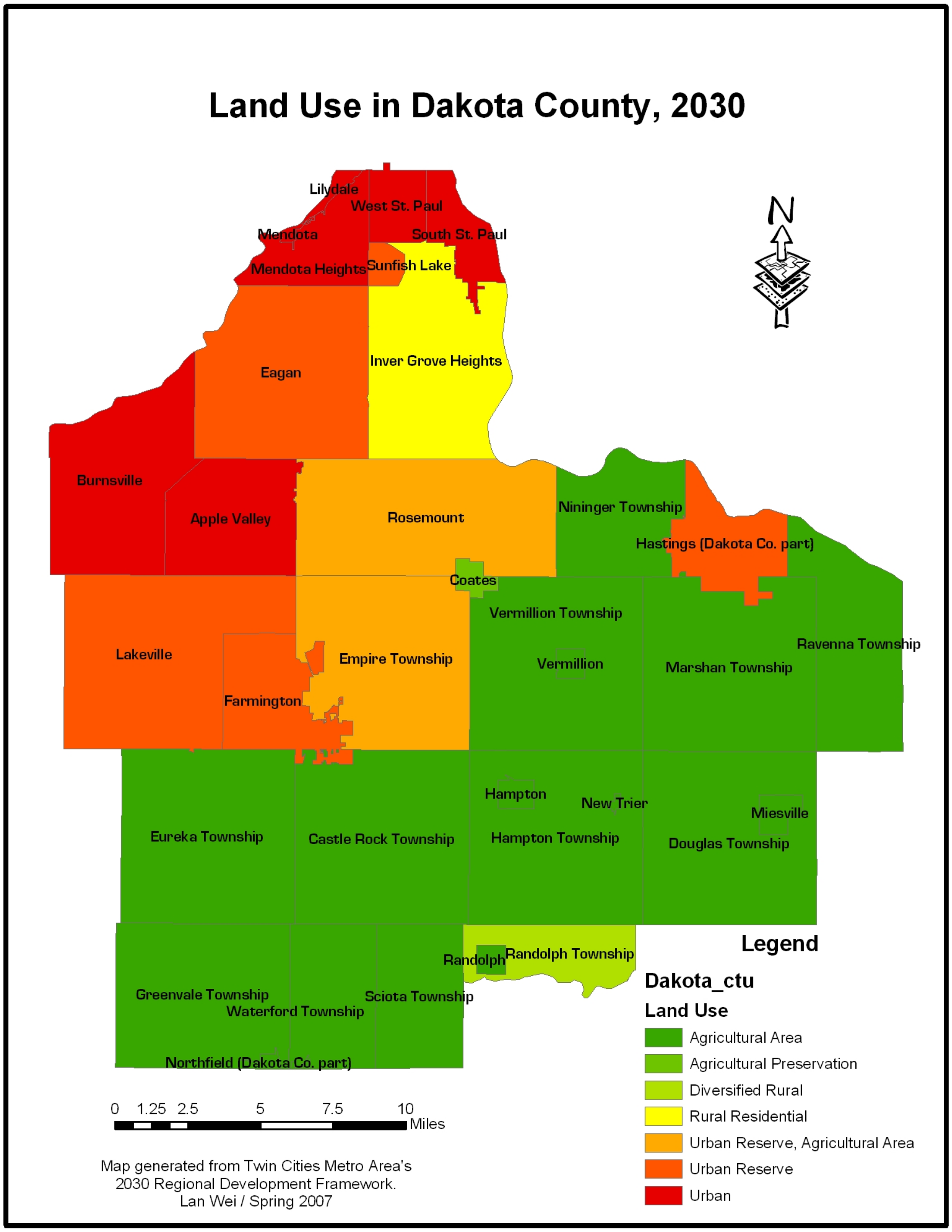

Figure 4. 2 Growth accommodation in communities, Dakota County

Table 4. 1 Growth accommodation in Dakota County data summary

Polygon Class	Frequency/Count	Acres	Percent
Agricultural Area	17	199,189.14	53.09%
Agricultural Preservation	1	889.20	0.24%
Diversified Rural	1	6,785.84	1.81%
Rural Residential	1	19,205.15	5.12%
Urban Reserve, Agricultural Area	2	43,181.99	11.51%
Urban Reserve	5	63,101.80	16.82%
Urban	7	42,832.03	11.42%
Totals	34	375,185.15	100.00%

From Figure 4.2 and Table 4.1, we can observe that, except the Hastings Community (Dakota County Part), all of the urban development (Urban, Urban Reserve, Urban Reserve/Agricultural Area, and Rural Residential) is expected to take place in the northwest part of Dakota County in 2030. The rest of Dakota will remain dominated by agriculture land.

Having the 2030 RDF as a guidance to growth management in Dakota County, I conducted analyses on population and land cover changes, landscape pattern, and possible future development in the following sections. The results of such analyses can help us understand whether the 2030 RDF is feasible and reasonable for planning purposes, and also whether the current trend of growth of Dakota County is consistent with the Framework.

II. Population Change (1990-2000)

1. Population Data by U.S. Census Bureau (1990-2000)

The U.S. Census Bureau (Census) provides information and data about the nation's people and economy. Due to the objectives of this study, which requires the combination of spatial and quantitative data analyses, I used two types of data from the Census website (www.census.gov): one was the geographic boundary data, and the other one was the detailed population data.

Geographic boundary files from the Census, which provide generalized, digital data for medium to small-scale thematic mapping, was downloaded from the Census website. In this study, I selected Census Block Groups (year 1990 and 2000) as the unit of analysis. *Census block group* is a cluster of census blocks having the same first digit of their four-digit identification numbers within a census tract. *Census tracts* are small, relatively permanent statistical subdivisions of a county delineated by local participants as part of the U.S. Census Bureau's Participant Statistical Areas Program (U.S. Census Bureau, Descriptions and Metadata 2006).

Detailed population data were also downloaded from the Census website, and I used the Census 1990/2000 Summary File 1 (SF 1) – 100-Percent Data as my data source. SF 1 presents counts and information (age, sex, race, Hispanic/Latino origin, household relationship, whether residence is owned or rented) collected from all people and housing units (U.S. Census Bureau, Decennial Census 2006). "Geo within geo" was chosen as the selection method to contain all the Census block groups in Dakota County, as well as to pair with the geographic boundary file. Because the "Urban/Rural Population" in the study area for Census 1990 was not defined in the SF1 table, only "Total Population" was selected as the indicator for this study: *Population* is defined as all people, male and female, child and adult, living in a given geographic area (U.S. Census Bureau, Decennial Census 2006).

To integrate the geographic boundary file with detailed population data, I used the unique ID for each Census Block Group (GEOID) in the geographic boundary file to match the geography identifier (GEOID2) in the population data file. Prior to the action of matching IDs, the extra geographic boundary data for other counties, other than Dakota County, were eliminated.

Table 4. 2 Dakota County population summary in census block group level

Total Population	**Census 1990**	**Census 2000**	**% Change**
Polygon	176	194	10.23%
Minimum	27	300	1011.11%
Maximum	7,252	5,890	-18.78%
Mean	1,564	1,835	17.33%
Standard Deviation	1,402	1,089	-22.33%
Sum	275,227	355,904	29.31%

As shown in Table 4.2, the total population of Dakota County increased by approximately 30% from 275,227 in 1990 to 355,904 in 2000. Spatially, in conjunction with the maps of total population of Dakota County in 1990 and 2000 (Figure 4.3), we can conclude that except for some areas in the northwest of Dakota County, the entire County experienced population increase from 1990 to 2000. Most of the population increase took place surrounding the high population areas in 1990 in the northwest part of

Dakota County, which means that the urbanization of the Twin Cities Metro Area has gradually affected Dakota County. Furthermore, we can see from the maps that highly and lowly populated areas were replaced by fairly high and low population areas. In other words, population inclined to become spread from higher population areas to lower population areas. To further support this conclusion, I conducted the population density analyses in the next section.

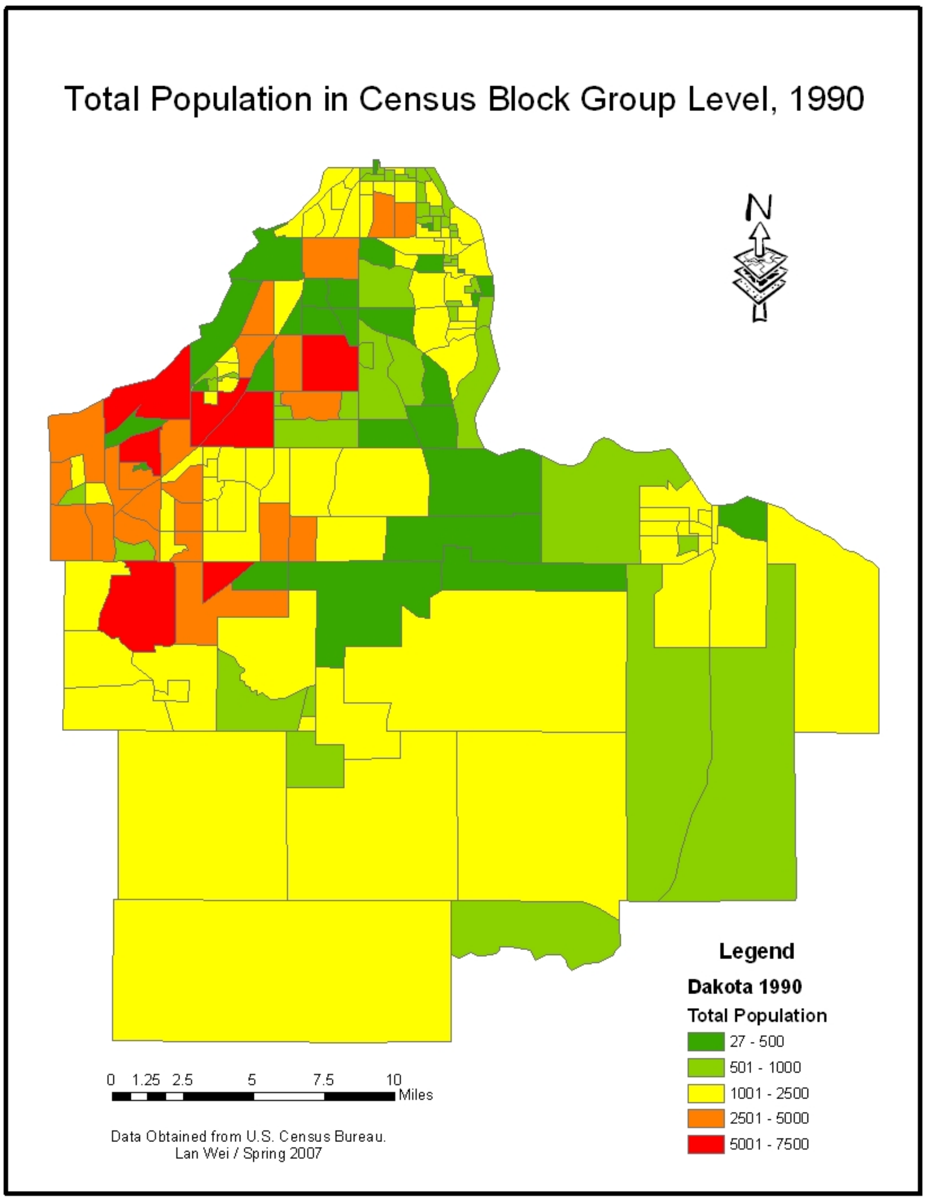

Figure 4. 3 Total population of Dakota County, MN in census block group level, 1990-2000

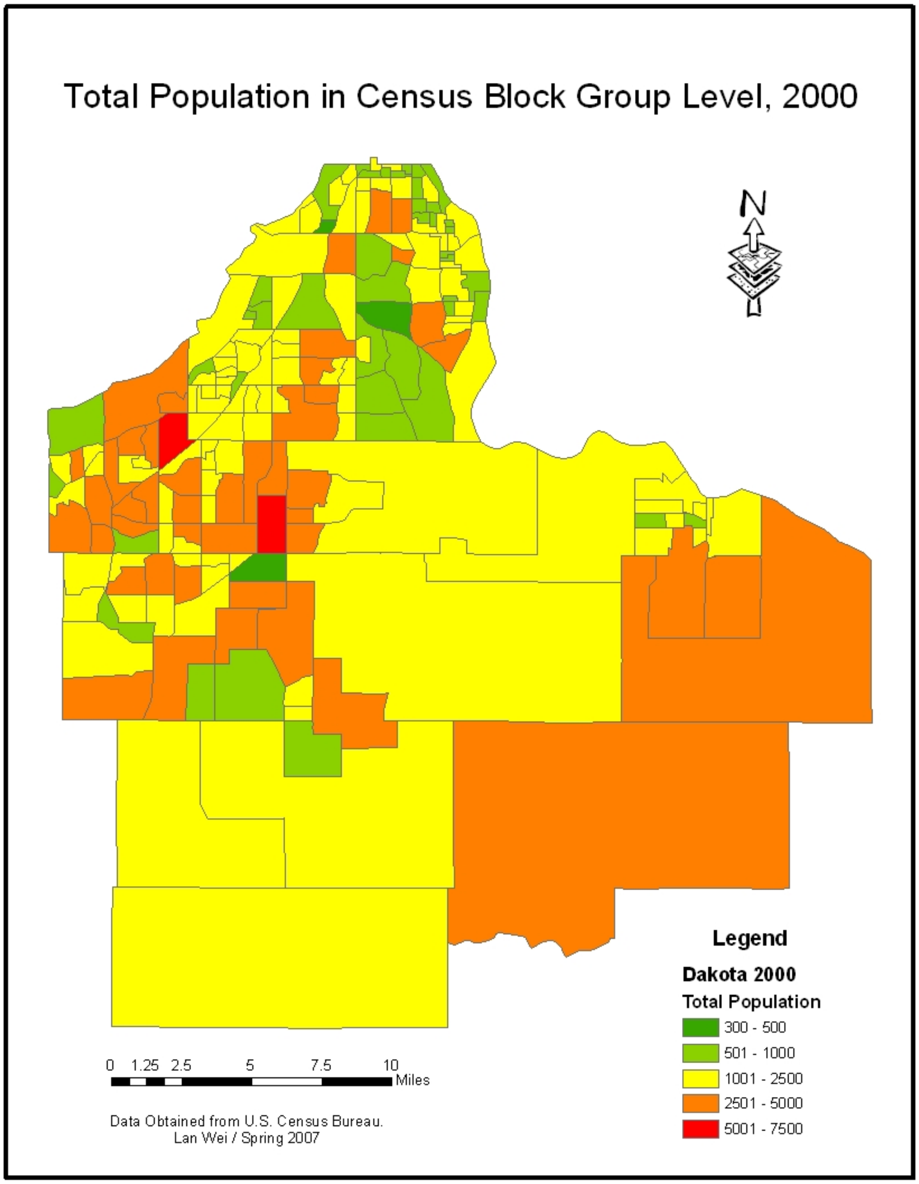

Figure 4.3 (continued)

2. Population Density

From Figure 4.3 "Total population of Dakota County, MN, in census block group level, 1990-2000", we can observe that the Census Block Group boundary files for these two years do not match in terms of their ID, polygon count and shape. In other words, the Census Bureau changed the ID, number and shape of the 2000 Census Block Group after their 1990 Census Block Group shapefile. As a result, it is not comparable in terms of calculating the population difference between 1990 and 2000. To be able to compare the population between two years, an identical unit should be employed to measure the changes and differences. Therefore, I used population density as an indicator to measure the population change from 1990 to 2000.

To calculate the population density (equal to population divided by area value) for both years, knowing the area value of each block group is necessary. The "Calculate Areas" tool (Spatial Statistics Tools → Utilities) in ArcGIS was utilized to calculate area values for each feature in a polygon feature class (ESRI 2006). In the output feature class, a field of area values was automatically added in the attribute table. To obtain the population density, use the field calculator to divide the total population field by the field of area values.

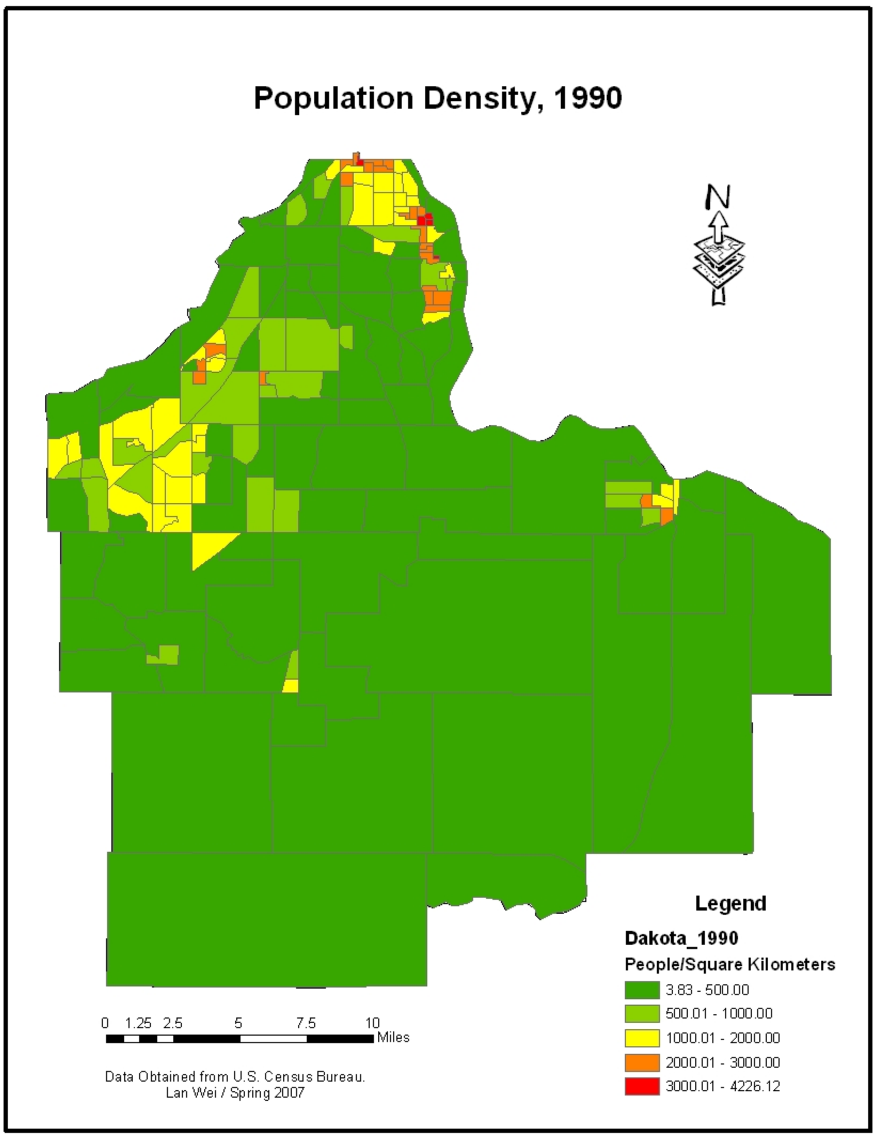

Figure 4. 4 Population density in census block group level, 1990-2000

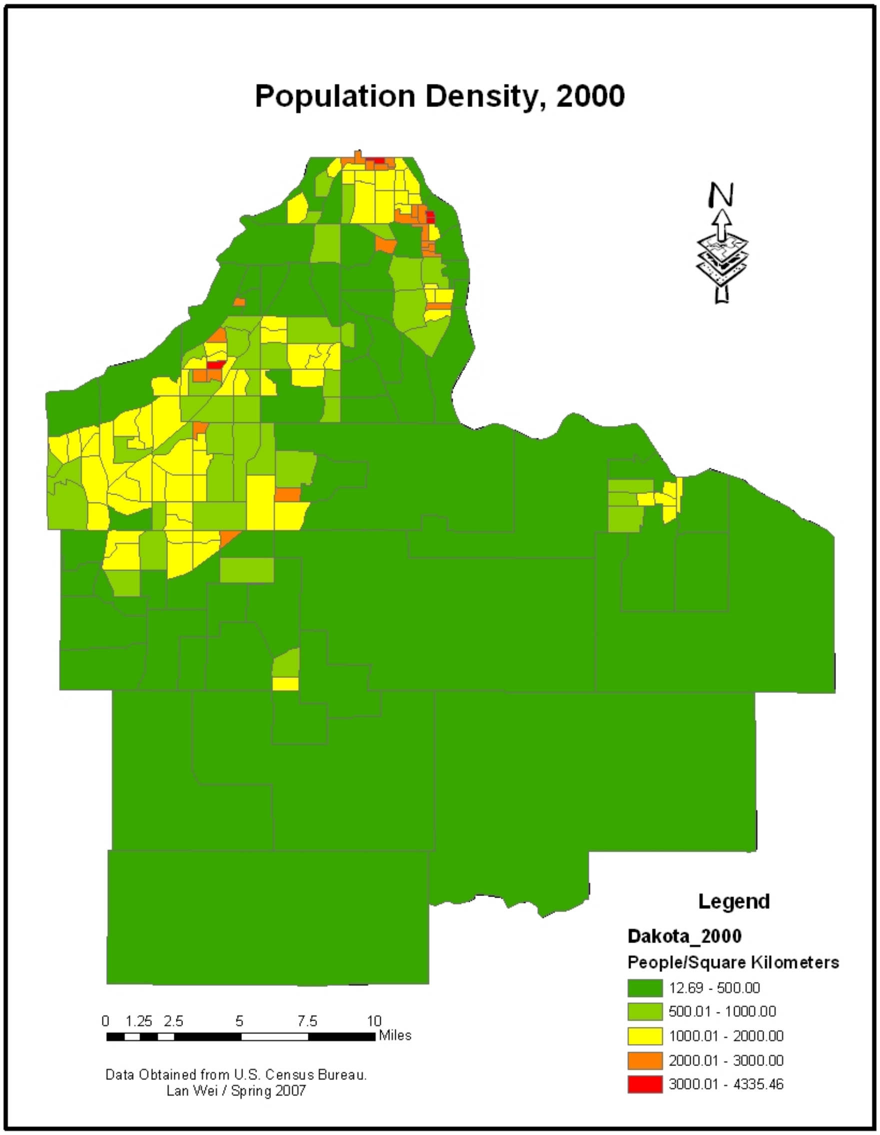

Figure 4. 4 (continued)

From Figure 4.4, we can observe the population density pattern in general. From 1990 to 2000, the population density of the northwest part of Dakota County appeared to increase, as discussed in the previous section.

The change of population density from 1990 to 2000 still cannot be calculated in different feature classes; nevertheless, it could be realized in different raster datasets with the same cell size. I used the “Feature to Raster” tool (Conversion Tools → To Raster) in ArcGIS to convert the feature classes with population density to raster datasets for both years. The newly created field of population density was selected as the only value in the output raster dataset. The cell size of the output raster dataset was set to be 30m by 30m, to be consistent with the land cover datasets that are described in the following sections.

To compare the population density from the 1990 census and 2000 census, I used the *Minus* function (Spatial Analyst Tools → Math) to subtract the value of 1990 population density from the value of 2000 population density on a cell-by-cell basis.

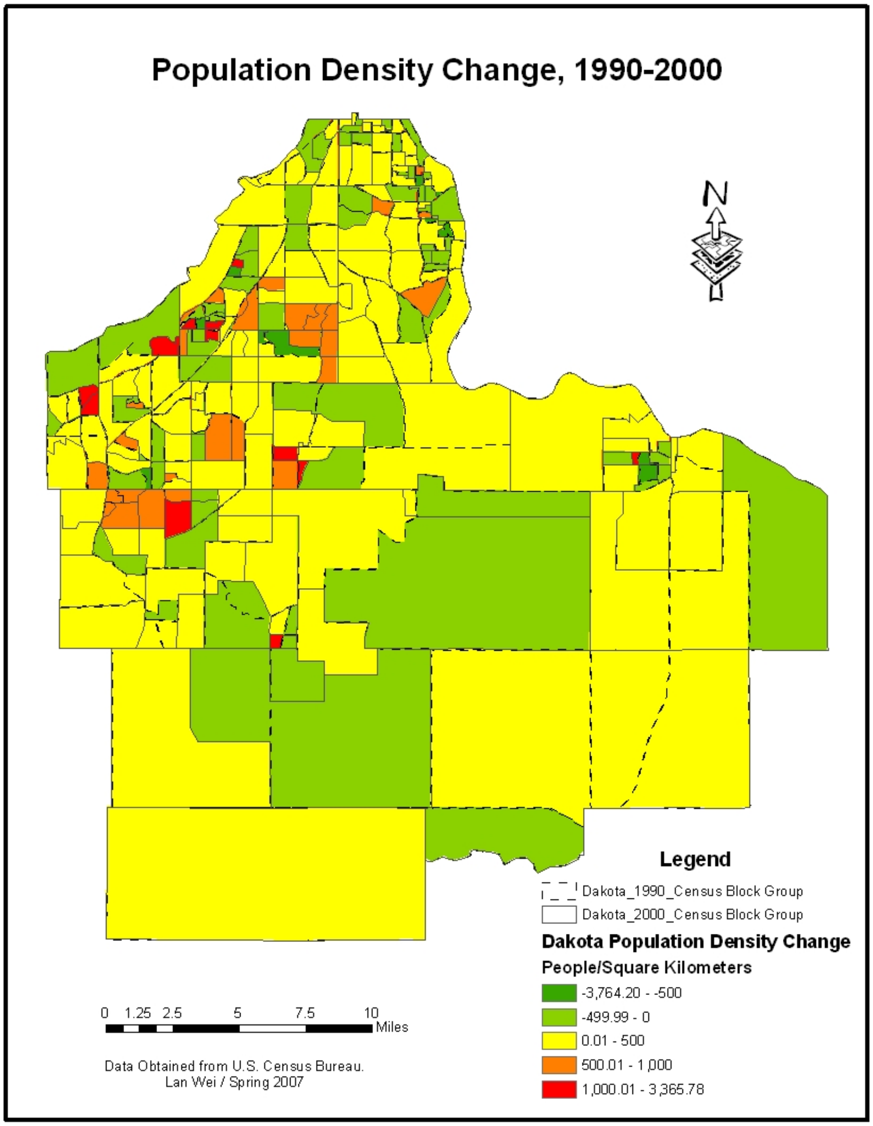

Figure 4. 5 Population density change 1990 – 2000

As shown in Figure 4.5, most of Dakota County faced an increase in Population Density from 1990 to 2000: some increase was subtle, whereas there was a noticeable large increase scattered in the northwest part of Dakota County. There was also a decrease in population density in the southeast as well as some scattered areas in the northwest part of Dakota County.

3. Dakota County Population Projection by Metropolitan Council (2000-2030)

The 2030 Regional Development Framework, prepared by the Metropolitan Council of the Twin Cities Metropolitan Area, provides a development guide for seven counties of the Twin Cities Metropolitan Area, including forecasts of population, households and employment from 2000 to 2030 (Metropolitan Council 2006). Forecasts of population, households and employment are a major quantitative element of long-range planning. The Council's forecasts are the basis for the development of the Council's, regional system plans. The Council's forecast process has continuously evolved in response to Council policy direction and available data (Metropolitan Council 2006b).

Generally, the Council's forecast process consists of two steps. The first step is to prepare forecasts for population, households and employment for the region as a whole. These overall forecasts are then allocated to subareas within the region: quadrants, planning areas, cities and townships and ultimately traffic analysis zones (TAZs) (Metropolitan Council 2006b). The *City, Township and Unorganized Territory* (CTU) boundary shapefile was downloaded from the Metropolitan Council (http://www.datafinder.org/metadata/county_ctu.htm).

The forecasts are organized by community (township), and there are a total of 34 communities in Dakota County. For purposes of comparison, a series of line charts and maps were generated to visualize the trends of population.

Table 4. 3 Population forecast of Dakota County in community and township level

Population	**2000**	**2010**	**2020**	**2030**	**% Change**
Polygon	34	34	34	34	0.00%
Minimum	116	120	120	120	3.45%
Maximum	63,557	67,000	78,400	88,800	39.72%
Mean	10,468	12,411	14,122	15,206	45.26%
Standard Deviation	17,482	20,260	22,889	24,463	39.93%
Sum	355,904	421,960	480,150	517,010	45.27%

As shown in Table 4.3, the total population of Dakota County increased by 45.27% from 355,904 in 2000 to 517,010 in 2030. From the series of maps of population forecast from 2000 to 2030 in Figure 4.6, we can conclude that most of the population increase is expected to take place in the northwest part of Dakota County, surrounding the highly populated areas at the northwest border.

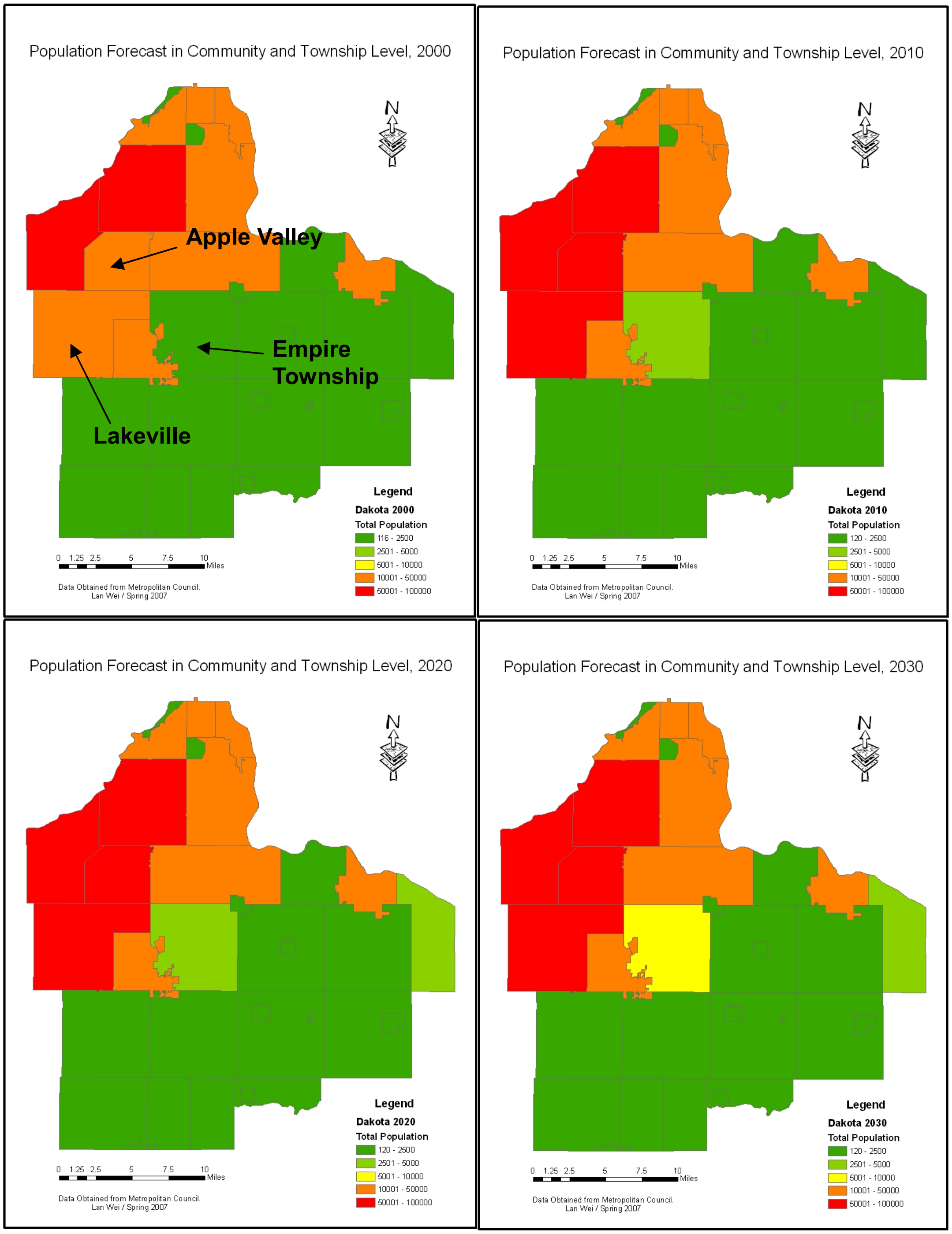

Figure 4. 6 Population forecast for Dakota County, 2000-2030

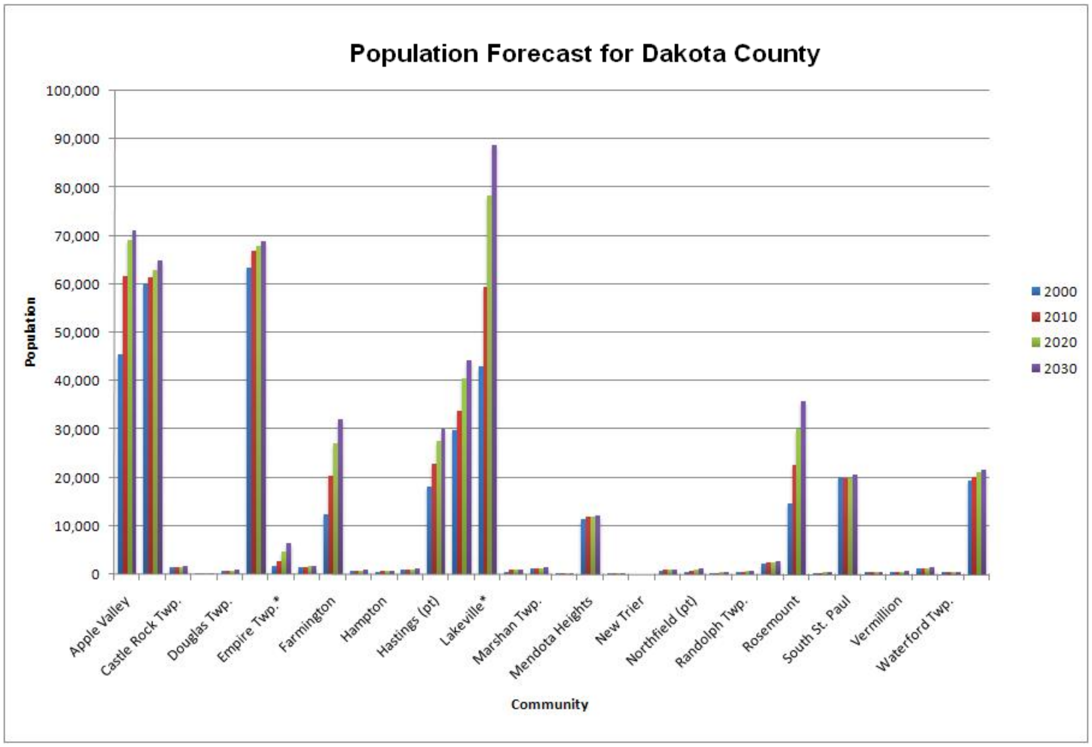

Figure 4. 7 Population forecast for Dakota County in community and township level

From Figure 4.6 and 4.7, we know that Apple Valley, Lakeville and Empire Township will face a significant increase in terms of their total population, surrounding those communities with higher population, in the northwest part of Dakota County.

III. Land Cover Changes (1992-2001)

Geographic Information Systems technology can be used to apply spatial operators to GIS data to derive information. Of the three main types of GIS data – raster, vector, and TIN – the raster data structure provides the richest modeling environment and operators for spatial analysis of landscape change (McCoy 2004). Raster data is generally divided into two categories: thematic data and image data (McCoy 2004). The values in thematic raster data represent some measured quantity or classification of a particular phenomenon such as land cover; and the values of cells in an image represent reflected or emitted light or energy such as that of a satellite image. The analysis tools of Spatial Analyst are primarily intended for use on thematic raster data (McCoy 2004).

The functions associated with raster-cell cartographic modeling can be divided into five types:

- Local Functions: work on single cells;

- Focal Functions: work on cells within a neighborhood;
- Zonal Functions: work on cells within zones;
- Global Functions: work on all cells within the raster; and
- Application Functions: perform a specific application when combined in a series of functions (McCoy 2004, p. 93).

Among these functions, local functions such as reclassification and cell statistics were used to reclassify the land cover classification system and detect land cover changes. Focal functions were used to generalize the land cover data so that some unimportant "noise" cells were removed; population density was also calculated to observe relationships between population changes and land cover changes.

1. Land Cover Data (1992-2001)

For 1992 land cover, I used the National Land Cover Dataset 1992 (NLCD 1992) downloaded from the U.S. Geological Survey (http://seamless.usgs.gov/). The cell size (resolution) of this dataset is 30m by 30m. The classification system used for NLCD 1992 had nine major categories: water, developed, barren, forested upland, shrubland, non-natural woody, herbaceous upland, planted/cultivated, and wetlands (LCI of USGS 2006). See **Appendix 2 and 3** for definitions of land cover categories.

In the NLCD 1992 land cover dataset, all nine major categories of land cover existed in Dakota County except for the category, "Non-Natural Woody [6x]". All the other land cover categories and their cell counts are shown in Table 4.4.

For 2001 land cover, I used the National Land Cover Dataset 2001 (NLCD 2001) downloaded from the U.S. Geological Survey (http://seamless.usgs.gov/). The cell size of this dataset is 30m by 30m. The classification system used for NLCD 2001 had eight major categories: water, developed, barren, forested upland, shrubland, herbaceous upland, planted/cultivated, and wetlands (LCI of USGS 2006). Category 6 is not presented in NLCD 2001; thus, the land cover dataset for Dakota County does not have Category 6, either. All the other land cover categories and their cell counts are shown in Table 4.5.

Table 4. 4 NLCD 1992 summary of Dakota County

Category	Value	Land Cover	Count	Acres	Percent
Water [1]	11	Open Water	50,755	11,282.84	3.01%
Developed [2]	21	Low Intensity Residential	204,121	45,376.10	12.10%
	22	High Intensity Residential			
	23	Commercial/Industrial/ Transportation			
Barren [3]	32	Quarries/Strip Mines/Gravel Pits	7,003	1,556.77	0.42%
	33	Transitional			
Forested Upland [4]	41	Deciduous Forest	146,694	32,610.08	8.69%
	42	Evergreen Forest			
	43	Mixed Forest			
Shrubland [5]	51	Shrubland	187	41.57	0.01%
Non-Natural Woody[6]	61	Orchards/Vineyards/Other	0	0	0
Herbaceous Upland [7]	71	Grasslands/Herbaceous	8,442	1,876.66	0.50%
Planted/ Cultivated [8]	81	Pasture/Hay	1,182,697	262,913.54	70.10%
	82	Row Crops			
	83	Small Grains			
	85	Urban/Recreational Grasses			
Wetland [9]	91	Woody Wetlands	87,212	19,387.23	5.17%
	92	Emergent Herbaceous Wetlands			
		Totals =	1,687,111	375,044.78	100%

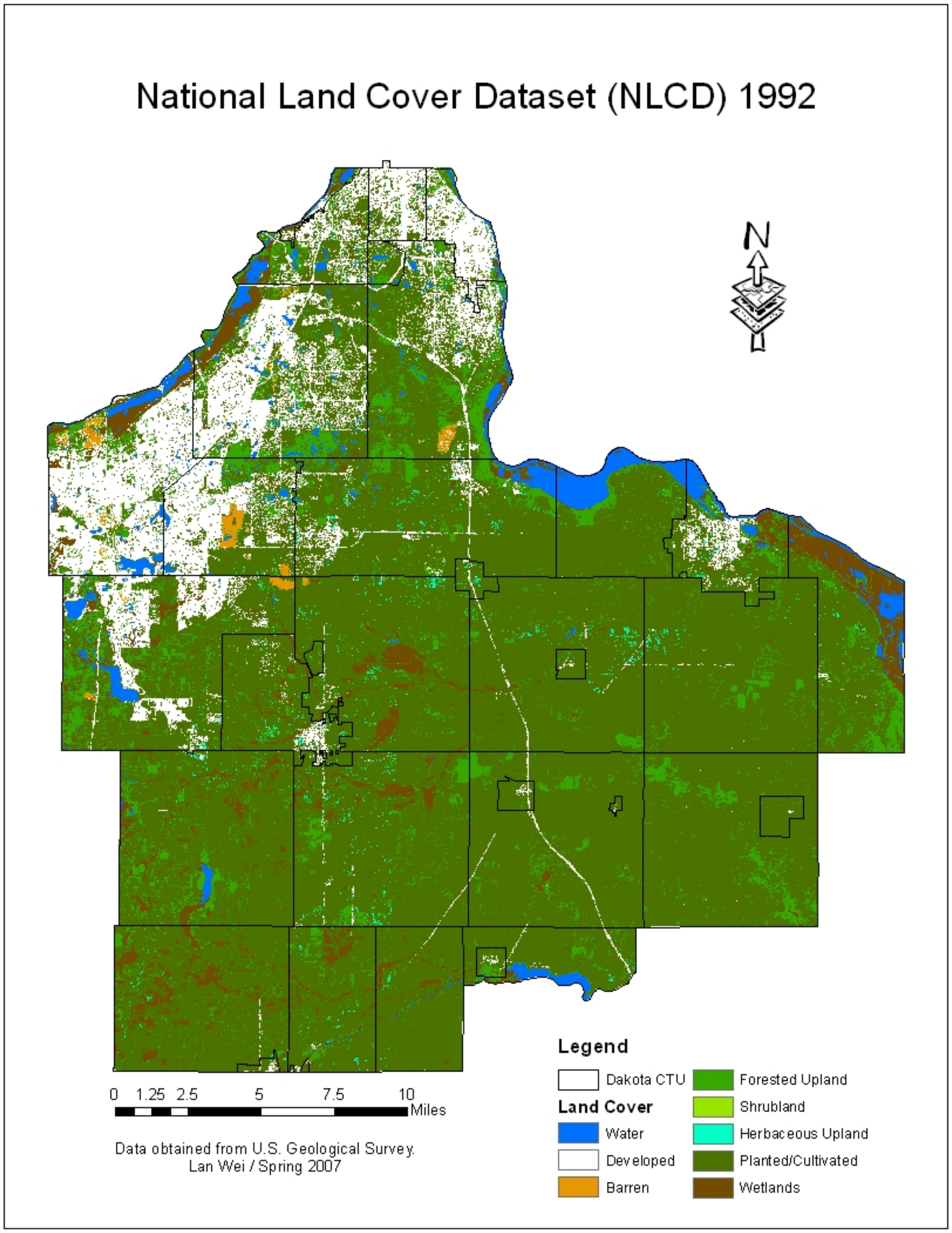

Figure 4. 8 NLCD 1992 in first-level categories

Table 4. 5 NLCD 2001 summary of Dakota County

Category	Value	Land Cover	Count	Acres	Percent
Water [1]	11	Open Water	52,696	11,714.32	3.12%
Developed [2]	21	Open Space	399,891	88,895.77	23.70%
	22	Low Intensity			
	23	Medium Intensity			
	24	High Intensity			
Barren [3]	31	Bare Land (Rock/Sand/Clay)	1,429	317.67	0.08%
Forested Upland [4]	41	Deciduous Forest	167,793	37,300.38	9.85%
	42	Evergreen Forest			
	43	Mixed Forest			
Shrubland [5]	52	Shrub/Scrub	11,608	2,580.46	0.69%
[6]	N/A	N/A	N/A	N/A	N/A
Herbaceous Upland [7]	71	Grasslands/Herbaceous	64,611	14,363.03	3.83%
Planted/ Cultivated [8]	81	Pasture/Hay	937,053	208,306.88	55.54%
	82	Cultivated Crops			
Wetland [9]	90	Woody Wetlands	52,030	11,566.27	3.08%
	95	Emergent Herbaceous Wetlands			
		Totals =	1,687,111	375,044.78	100%

Comparing Figure 4.9 with Figure 4.8, we can observe a general pattern of land cover change from 1992 to 2001, especially for the developed land (white area in the maps). In the northwest part of Dakota County, a large area of planted/cultivated land and forested upland were converted to developed land. Meanwhile, most of the wetlands in the mid and south part of Dakota were significantly reduced. Furthermore, we can also see from the maps that the land cover in 2001 became less diversified compared to 1992.

To better understand the land cover changes, especially for urban area, I conducted the following spatial analyses to detect not only urbanized areas but also all the other land cover changes that occurred from 1990 to 2000.

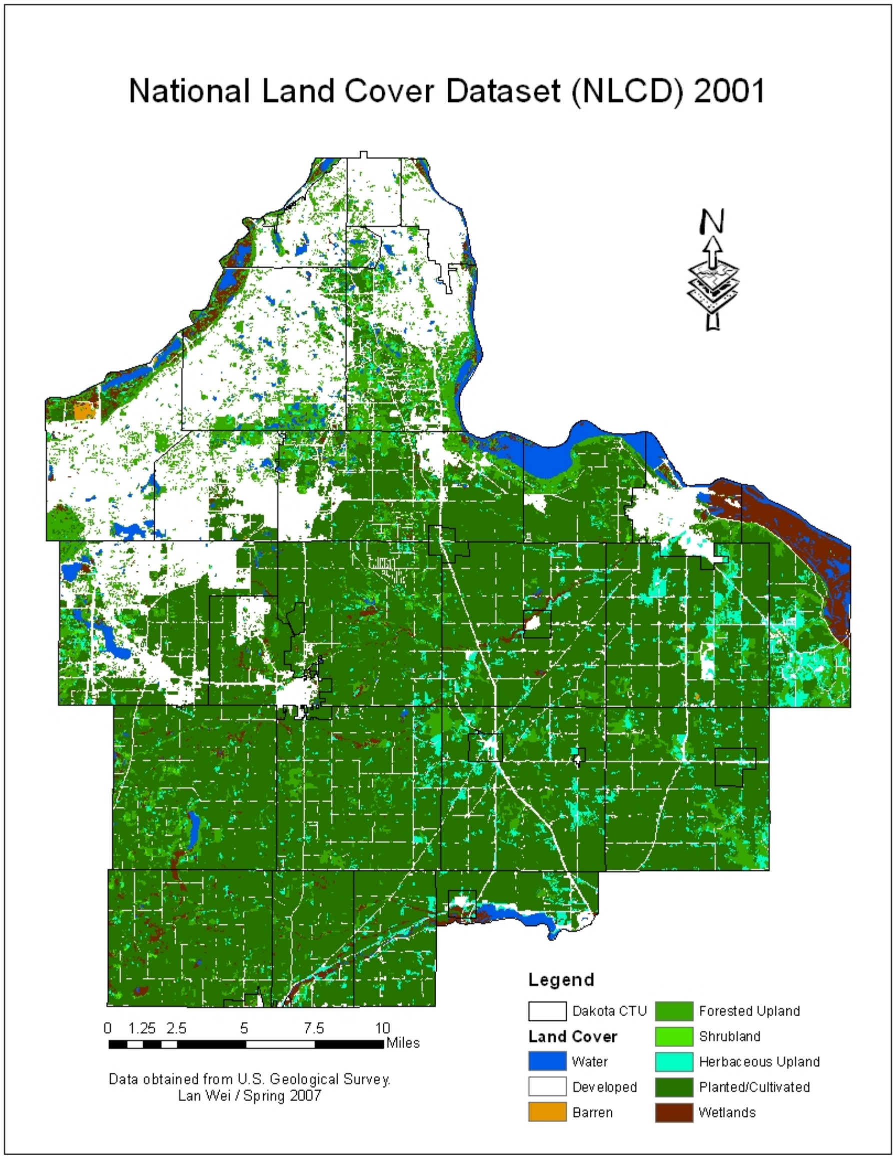

Figure 4. 9 NLCD 2001 in first-level categories

2. Land Cover Classification

Although the land cover classification systems of NLCD 1992 and NLCD 2001 use different classifications, based on the definitions of various land cover types, I used NLCD 2001 classification as the primary reference in my research, and aggregated the NLCD 1992 classification systems into the same eight classes as NLCD 2001. A comparison chart is shown in Table 4.6.

Table 4. 6 Comparison of different land cover classification systems

NLCD 2001	NLCD 1992
Water [1]	Water [1]
Developed [2]	Developed [2]
Barren [3]	Barren [3]
Forested Upland [4]	Forested Upland [4]
	Non-Natural Woody [6]
Shrubland [5]	Shrubland [5]
Herbaceous Upland [7]	Herbaceous Upland [7]
Planted/Cultivated [8]	Planted/Cultivated [8]
Wetlands [9]	Wetlands [9]

According to the NLCD 1992 dataset summary for Dakota County, the category "Non-Natural Woody [6x]" does not exist in the study area. Thus, for the purposes of studying the land cover changes of Dakota County, there was no need to reclassify the land cover dataset NLCD 1992 to match the classification of NLCD 2001.

3. Urbanized Areas (1992-2001)

Monitoring change in the landscape is a way of discovering trends in urban development, habitat loss, and crop management. *Cell statistics* allow us to compare two or more raster datasets on a cell-by-cell basis. The *Cell Statistics* function of Spatial Analyst in ArcGIS is a local function, where the value at each cell in the output raster is a function of the input value at each input cell (McCoy et al. 2004). It is especially useful when comparing time-series data, such as annual changes in land cover.

Cell Statistics was first used to delineate areas of land cover change from 1992 to 2001. *Variety* was selected as the overlay statistic to calculate the variety (number of unique values) of the input land cover datasets. Thus, for the output values, 2 represents that land cover changes occurred from 1992 to 2001, whereas 1 represents that no change occurred.

Table 4. 7 Land cover changes in Dakota County 1992-2001 data summary

Land Cover Changes 1992-2001	Cell Count	Acres	Percent
No Change	1,166,401	259,401.59	69.14%
Changes Occurred	520,710	115,803.23	30.86%
Totals	1,687,111	375,204.82	100.00%

As shown in Table 4.7 and Figure 4.10, more than 115,000 acres, about 30% of the total area of Dakota County, experienced land cover changes from 1992 to 2001.

Moreover, we can observe that most of the changes were occurred in the northwest part of Dakota. Knowing the total changes that occurred, I wanted to further analyze the ingredients that comprised the changes, especially the urbanized areas.

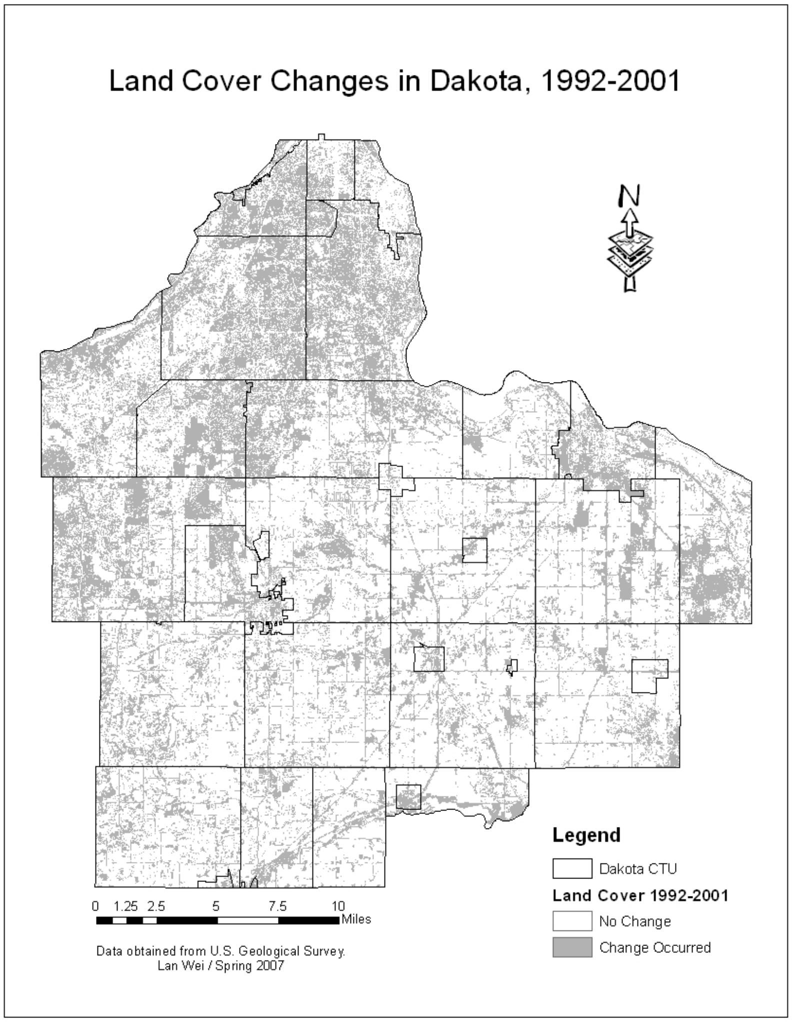

Figure 4. 10 Land cover changes in Dakota County 1992-2001

The *Extract by Attribute* function of Spatial Analyst was used to create a mask of the developed [Value = 2] land cover in 2001. The *Extract by Attributes* tool allows us to extract or select a set of cells that meet a specified attribute query. All cells that meet the query will return, for the cell location, the original value that was queried. Cell locations not meeting the specified query will be assigned NoData (McCoy et al. 2004).

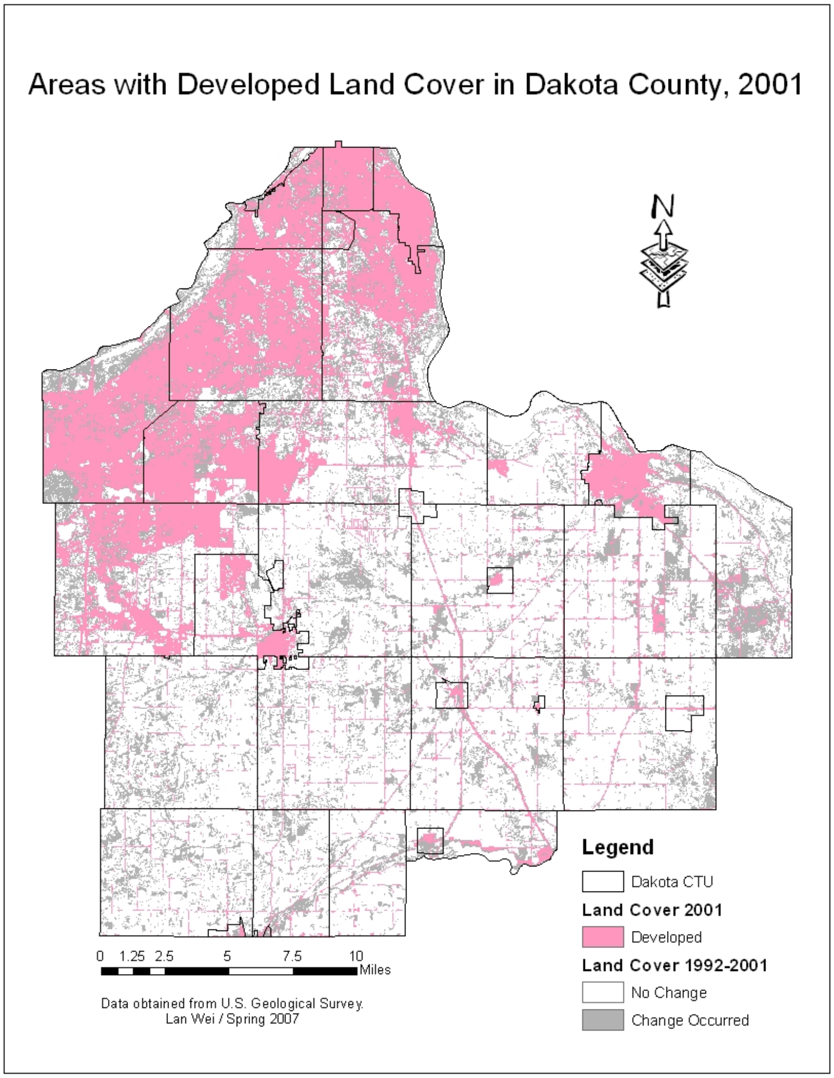

Figure 4. 11 Developed area in Dakota County 2001

Table 4. 8 Developed area in Dakota County 2001 data summary

Land Cover Type	Cell Count	Acres	Percent
Developed Area	399,891	88,933.70	23.70%

As shown in Figure 4.11 and Table 4.8, almost 90,000 acres, about 24% of the total area of Dakota County, were covered by developed land in 2001, whether it was developed land or not in 1992. Spatially, almost all the developed land was clustered in the northwest part of Dakota County, along with some developed land in the northeast corner. The next step was then to detect how much land was urbanized from 1992 to 2001. In other words, it was necessary to calculate how much undeveloped land was converted to developed land from 1992 to 2001.

Finally, the *Extract by Mask* function of Spatial Analyst was used to define the areas that were newly urbanized from 1992 to 2001 land cover datasets. Using the input of "Developed Areas in Dakota County 2001" as a mask to extract the "Land Cover Changes in Dakota County 1992-2001", as a result, output models were created of developed areas in both 1992 and 2001, as well as the newly developed areas from 1992 to 2001.

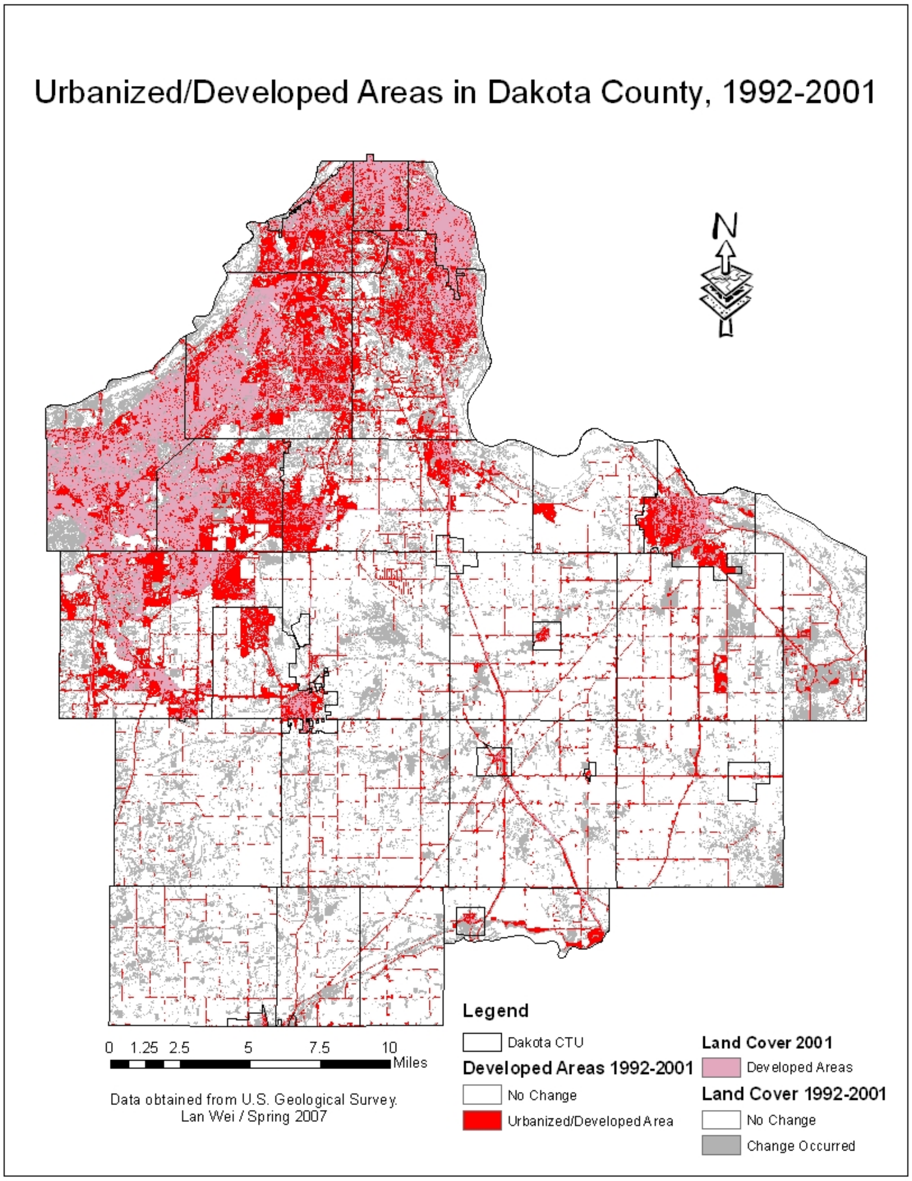

Figure 4. 12 Urbanized/developed areas in Dakota County 1992-2001

Table 4. 9 Urbanized/developed areas in Dakota County 1992-2001 data summary

Land Cover Type	Cell Count	Acres	Percent
Urbanized/Developed Areas 1992-2001	228,105	50,729.38	13.52%

As shown in Figure 4.12, the red areas were urbanized/developed areas in 2001, which were converted from undeveloped land in 1992; the pink areas were urbanized/developed land in 2001 as well as in 1992; and the gray areas were land that experienced land cover changes from 1992 to 2001, not considering what types of land cover were before and after. From Table 3.8, we know that in 2001, about 50,000 acres (13.52% of the total area of Dakota County) were urbanized/developed converted from land cover types other than developed land since 1992. Furthermore, as described in earlier sections, most of the growth/development occurred in the northwest part of Dakota, surrounding the existing urbanized/developed areas with higher population. The community of Hastings (Dakota County part) also experienced noticeable urbanization land cover changes. This result is consistent with the findings in the "population change" sections – most of the population increase took place in the northwest part of Dakota County, surrounding previous highly populated areas closer to the Twin Cities urbanized areas.

4. Land Cover Changes

To find out which land cover types changed and how much they changed from 1992 to 2001, I used the *Extract by Mask* function of the Spatial Analyst. By setting the raster dataset of *Land Cover Changes* as the mask of extraction, land cover changes that occurred from 1992 to 2001 were represented.

Figure 4.13 illustrates areas with land cover changes between 1992 and 2001. Other than the gray areas that represent land with no changes between 1992 and 2001, we can observe that not only did most of the changes occure in the northwest part of the Dakota County as well as in the Community of Hastings, but also most of the land cover conversion was from planted/cultivated land to developed land.

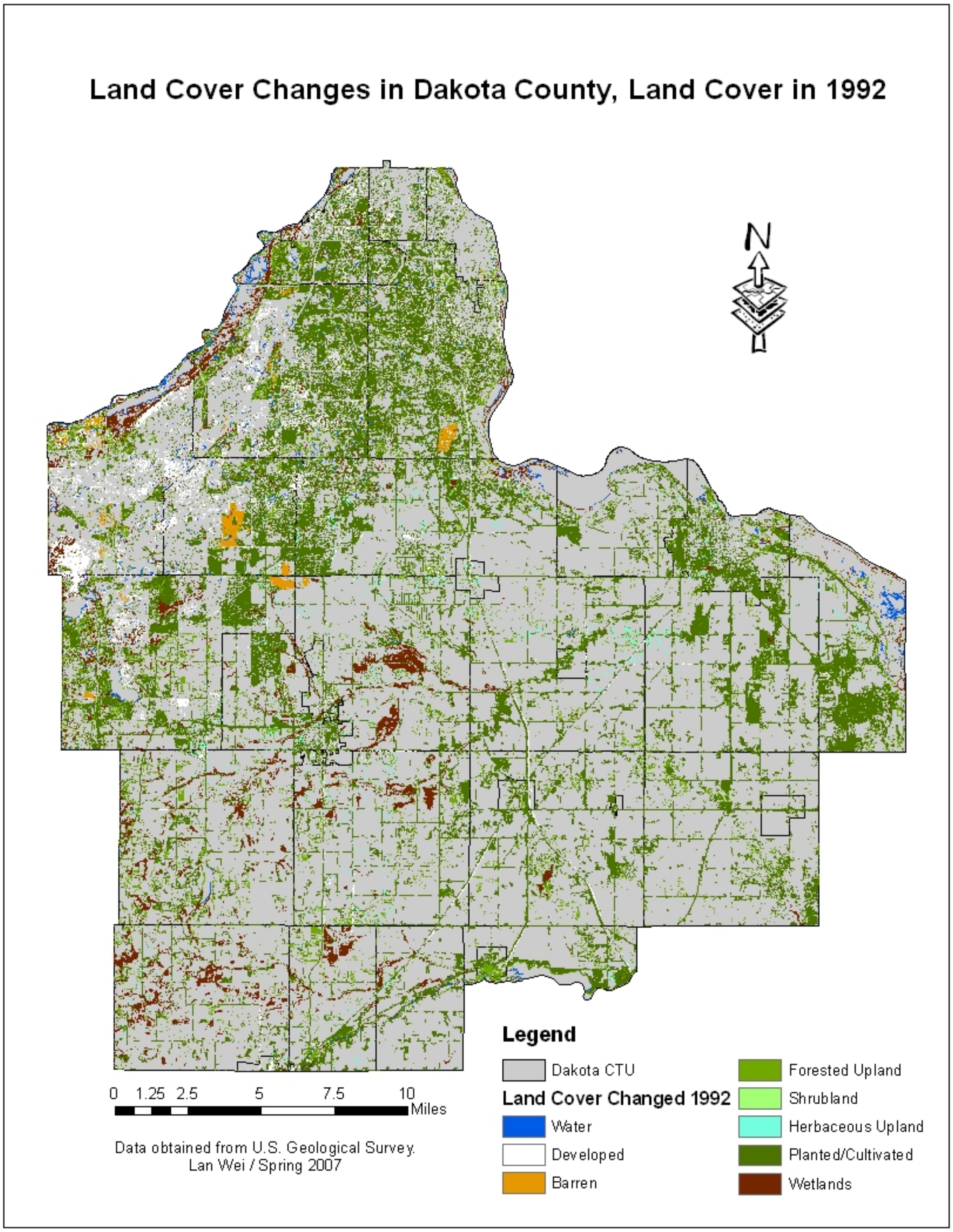

Figure 4. 13 Land cover changes in Dakota County between 1992 and 2001

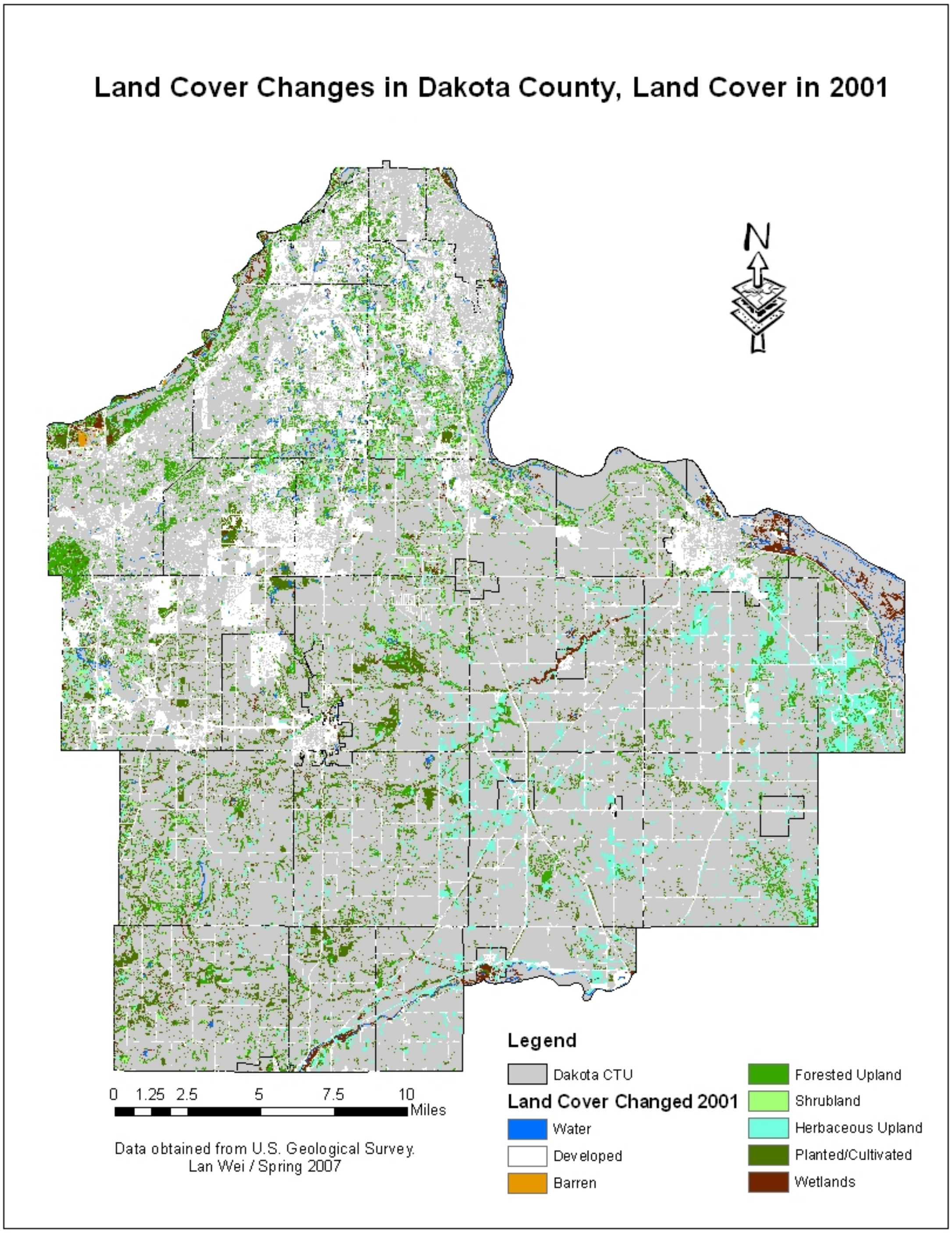

Figure 4.13 (continued)

To further understand the changes that occurred in Dakota County between 1992 and 2001, I also created charts to compare the land cover changes in both 1992 and 2001.

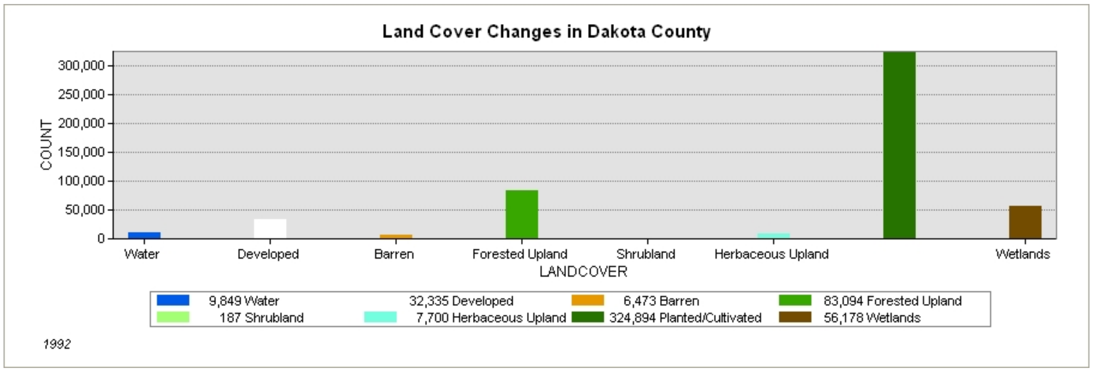

Figure 4. 14 Land cover changes between 1992 and 2001 in Dakota County 1992 column chart

Table 4. 10 Land cover changes between 1992 and 2001 in Dakota County 1992 data summary

Raster Class	**Cell Count**	**Acres**	**Percent**
Water [1]	9,849	2,190.37	1.89%
Developed [2]	32,335	7,191.14	6.21%
Barren [3]	6,473	1,439.56	1.24%
Forested Upland [4]	83,094	18,479.68	15.96%
Shrubland [5]	187	41.59	0.04%
Herbaceous Upland [7]	7,700	1,712.44	1.48%
Planted/Cultivated [8]	324,894	72,254.76	62.39%
Wetlands [9]	56,178	12,493.70	10.79%
Totals	520,710	115,803.23	100.00%

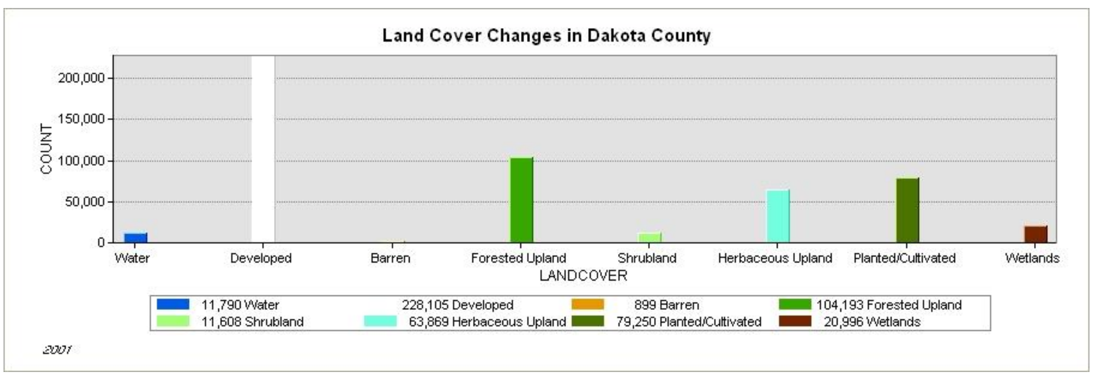

Figure 4. 15 Land cover changes between 1992 and 2001 in Dakota County 2001 column chart

Table 4. 11 Land cover changes between 1992 and 2001 in Dakota County 2001 data summary

Raster Class	**Cell Count**	**Acres**	**Percent**
Water [1]	11,790	2,622.04	2.26%
Developed [2]	228,105	50,729.38	43.81%
Barren [3]	899	199.93	0.17%
Forested Upland [4]	104,193	23,171.99	20.01%
Shrubland [5]	11,608	2,581.56	2.23%
Herbaceous Upland [7]	63,869	14,204.14	12.27%
Planted/Cultivated [8]	79,250	17,624.79	15.22%
Wetlands [9]	20,996	4,669.40	4.03%
Totals	520,710	115,803.23	100.00%

As shown in the above column charts and tables, the most converted land in 1992 was planted/cultivated land, which consisted of more than 72,000 acres of land, about 62% of the total area with changes between 1992 and 2001. On the other hand, the most converted land in 2001 was developed land, which consisted of 50,729 acres of land, about 43% of the total area with changes between 1992 and 2001. Some other noticeable land cover changes included the increase of forested upland and herbaceous upland, the reduction of wetlands, and the almost complete conversion of barren land. However, this does not show the specific land cover changes that occurred on a piece of land, in other words, what was the land cover classification before and after the land cover conversion.

A clearer way to detect the changes that occurred in Dakota County between 1992 and 2001 is to aggregate the land cover datasets for both years in a Change Matrix table. To be able to measure the amount each land cover class that changed or not changed between 1992 and 2001, I used the *Cell Statistics* function to calculate the range (difference between largest and smallest value) of the input two land cover datasets. Because the class values from both years' land cover datasets are one-digit numbers (1-5, 7-9), I reclassified the 2001 land cover class values to three-digit numbers (100-500, 700-900). Therefore, the range/difference of the land cover datasets is distinguishable to detect the land cover type for both years.

Figure 4.16 and Table 4.12 together show the specific land changes that occurred between 1992 and 2001. Take, for example, the land cover change from planted/cultivated land in 1992 to developed land in 2001. Its value is represented in the table as Developed (2001) [200] – Planted/Cultivated (1992) [8] = 192, as a light gray color in the map. As shown in the yellow highlighted cell in the table, 190,326 cells in the map were converted from planted/cultivated land in 1992 to developed land in 2001. In other words, 16.09% of the total planted/cultivated land in 1992 was converted to developed land in 2001, which consisted 47.59% of the total developed land. This land is located in the northwest part of Dakota County, surrounding cells with dark gray color – Developed (2001) [200] – Developed (1992) [2] = 198. The above results were also spatially consistent with the population change analysis, urbanized area analysis, as well as the land cover change analysis.

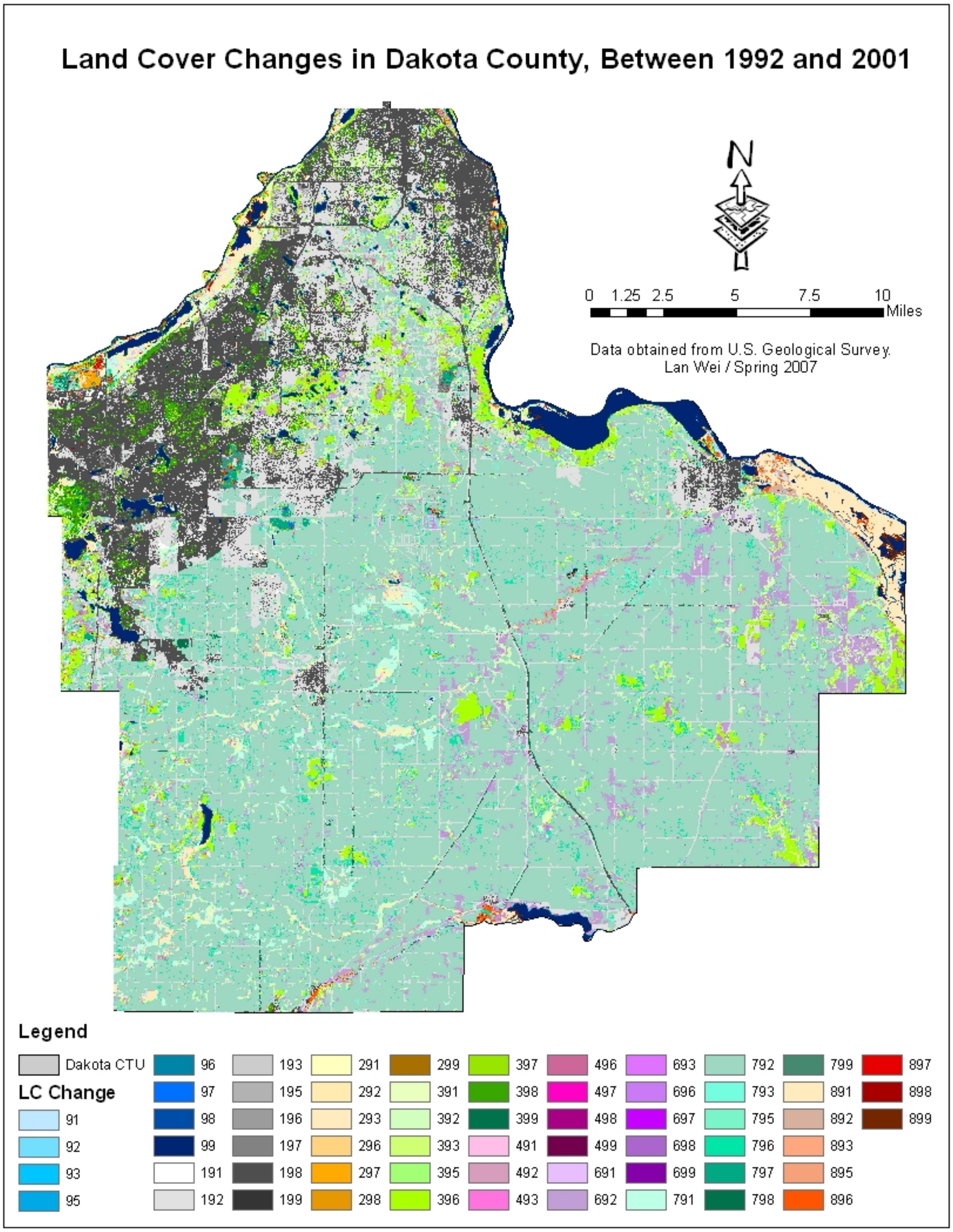

Figure 4. 16 Land cover changes matrix map

Table 4. 12 Matrix table of land cover changes between 1992 and 2001

1992 \ 2001	W [100]	D [200]	B [300]	F [400]	S [500]	H [700]	P [800]	WL [900]	Totals
Water (W) [1]	**40,906** 80.60% (R) 77.63% (C)	2,555 5.03% 0.64%	61 0.12% 4.27%	3,557 7.01% 2.12%	44 0.09% 0.38%	103 0.20% 0.16%	261 0.51% 0.03%	3,268 6.44% 6.28%	50,755 100%
Developed (D) [2]	1,200 0.59% 2.28%	**171,786** 84.16% 42.96%	247 0.12% 17.28%	22,604 11.07% 13.47%	364 0.18% 3.14%	584 0.29% 0.90%	6,283 3.08% 0.67%	1,053 0.52% 2.02%	204,121 100%
Barren (B) [3]	161 2.30% 0.31%	2,578 36.81% 0.64%	**530** 7.57% 37.09%	607 8.67% 0.36%	3 0.04% 0.03%	28 0.40% 0.04%	2,735 39.05% 0.29%	361 5.15% 0.69%	7,003 100%
Forested Upland (F) [4]	4,283 2.92% 8.13%	23,435 15.98% 5.86%	62 0.04% 4.34%	**63,600** 43.36% 37.90%	4,321 2.95% 37.22%	5,573 3.80% 8.63%	39,446 26.89% 4.21%	5,974 4.07% 11.48%	146,694 100%
Shrubland (S) [5]	3 1.60% 0.01%	86 45.99% 0.02%	0 0.00% 0.00%	15 8.02% 0.01%	**0** 0.00% 0.00%	0 0.00% 0.00%	67 35.83% 0.01%	16 8.56% 0.03%	187 100%
Herbaceous Upland (H) [7]	12 0.14% 0.02%	1,660 19.66% 0.42%	2 0.02% 0.14%	214 2.53% 0.13%	25 0.30% 0.22%	**742** 8.79% 1.15%	5,690 67.40% 0.61%	97 1.15% 0.19%	8,442 100%
Planted/Cultivated (P) [8]	2,274 0.19% 4.32%	190,326 16.09% 47.59%	442 0.04% 30.93%	60,072 5.08% 35.80%	6,345 0.54% 54.66%	55,208 4.67% 85.45%	**857,803** 72.53% 91.54%	10,227 0.86% 19.66%	1,182,697 100%

1992 \ 2001	**W [100]**	**D [200]**	**B [300]**	**F [400]**	**S [500]**	**H [700]**	**P [800]**	**WL [900]**	**Totals**
Wetlands (WL) [9]	3,857 4.42% 7.32%	7,465 8.56% 1.87%	85 0.10% 5.95%	17,124 19.63% 10.21%	506 0.58% 4.36%	2,373 2.72% 3.67%	24,768 28.40% 2.64%	**31,034** 35.58% 59.65%	87,212 100%
Totals	52,696 100%	399,891 100%	1,429 100%	167,793 100%	11,608 100%	64,611 100%	937,053 100%	52,030 100%	**1,687,111** 100%

Note: The first number in each cell represents frequency; the second number represents row percent; and the third number represents column percent.

IV. Landscape Pattern Analysis (1990-2000)

1. Landscape Metrics

In spatial analysis, the term “landscape metrics” commonly refers exclusively to indices developed for categorical map patterns. Landscape metrics are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics. These metrics are divided into two general categories: those that quantify the composition of the map without reference to spatial attributes, and those that quantify the spatial configuration of the map, requiring spatial information for their calculation. Composition is more easily quantified and refers to features associated with the variety and abundance of patch types within the landscape, but without considering the spatial character, placement, or location of patches within the mosaic. Spatial configuration is much more difficult to quantify and refers to the spatial character and arrangement, position, or orientation of patches within the class or landscape.

There are three levels of metrics in FRAGSTATS – patch, class and landscape (See Figure 4.17).

- Patch-level: Metrics defined for individual patches;
- Class-Level: Metrics integrated over all the patches of a given type (class); and
- Landscape-level: Metrics integrated over all patch types or classes over the extent of the data.

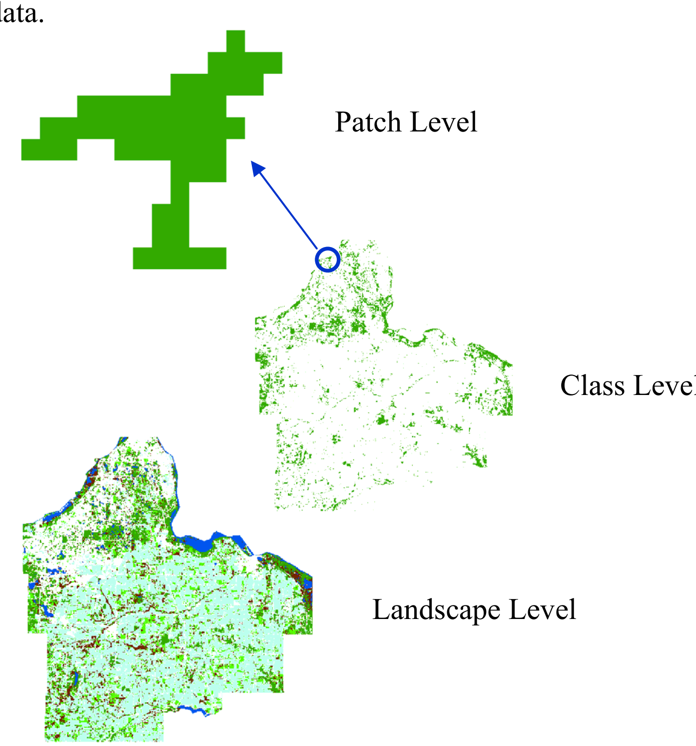

Figure 4. 17 Level of metrics

Selecting an appropriate metric or suite of metrics for a particular situation should be based on the spatial questions being asked, on aspects of landscape structure that are relevant to the organism or process of interest, and on characteristics of the landscape itself. Thus, informed metric selection requires thorough understanding of the conceptual and computational basis of each metric.

FRAGSTATS offers eight categories of metrics at the patch, class and landscape levels, including more than 60 landscape metrics. However, many of them can be highly correlated (Li at. al 2004); thus, an important principle is to select uncorrelated metrics. For the purpose of my study, only class and landscape level of metrics were selected because my study is based on land cover classes.

2. Procedures

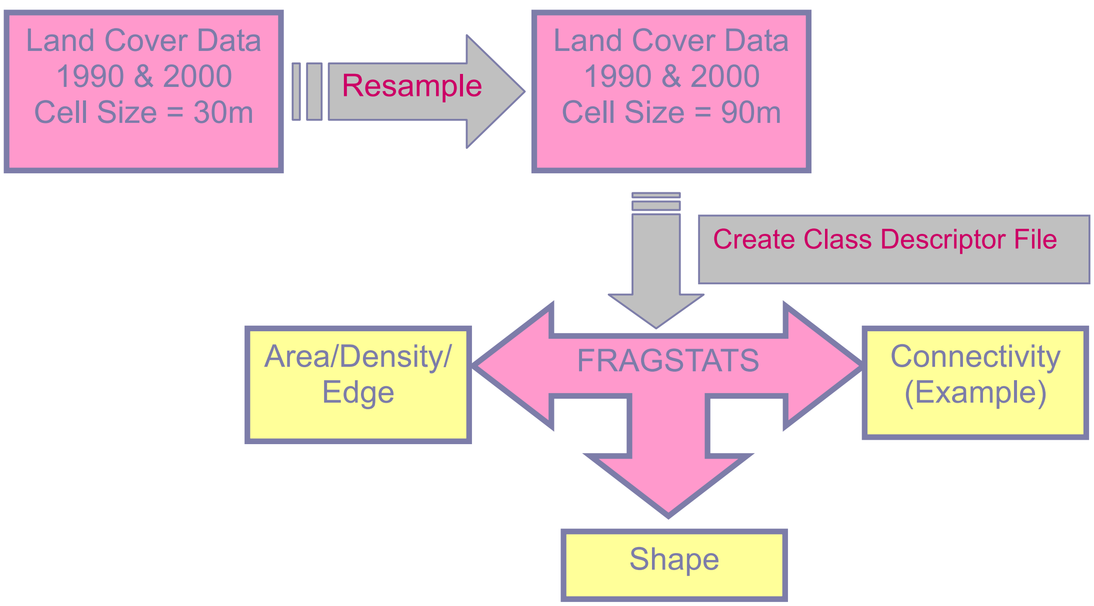

Figure 4. 18 Diagram of landscape pattern analysis

It is very important to be aware that this landscape pattern analysis was conducted before the 2001 National Land Cover Dataset was officially published on their website. Therefore, the 2000 Minnesota Land Cover Classification System (MLCCS) (see appendix 1) was used as a substitute for the 2000 Land Cover Dataset. Due to the limited time for this research project, a new landscape pattern analysis using the NLCD 2001 was not conducted.

Figure 4.18 shows the procedures used in this landscape pattern analysis. First, land cover datasets for 1992 obtained from the National Land Cover Dataset (NLCD 1992) were reclassified to the same classification system as the 2000 Minnesota Land Cover Classification System (MLCCS).

Second, these data were resampled using the nearest neighbor assignment, so that the original values of the input cells were kept unchanged. The principle of nearest neighbor assignment is that once the location of the cell's centroid on the output raster dataset is located on the input raster, nearest neighbor assignment will determine the value of that cell on the output raster (FRAGSTATS Program Help). After resampling, the cell size of the output datasets enlarged from 30m, the cell size of the input datasets, to 90m. This procedure brought two advantages to this project: (1) it allowed me to analyze the large area in a reasonable computing time, and (2) it was easier to observe landscape patterns using a larger resolution because some cells that can be considered as “noise” were removed in this procedure.

Third, a class properties file was created as shown in Figure 4.19. It had four parts: (1) ClassID (an integer value corresponding to a class value in the landscape); (2) ClassName (a descriptive name of the class); (3) Status (determines whether the corresponding class should be processed and added to the results or simply ignored in the output files); and (4) isBackground (determines whether the corresponding class should be reclassified and treated as background). Because I am interested in detecting land cover changes on natural resources, I selected the land cover type “urban” as background, so that I could observe land cover changes while also considering the effects of “urban” patch type on landscape metrics as a background.

Fourth, three groups of metrics were tested in this project: Area/Density/Edge, Shape and Connectivity. Each group of metrics had a collection of metrics that measured the same perspective of a landscape pattern. Area/Density/Edge computes several simple statistics representing area and perimeter (or edge) at the patch, class, and landscape levels. Shape quantifies landscape configuration in terms of the complexity of patch shape at the patch, class, and landscape levels. Connectivity computes a few metrics whose sole purpose is to measure connectivity, even though connectivity can be evaluated using a wide variety of metrics that indirectly say something about either the structural or functional connectedness of the landscape. An important aspect of land-use change is the change in connectivity; that is, the spatial continuity of a habitat or cover type across a landscape (Turner et al. 2001).

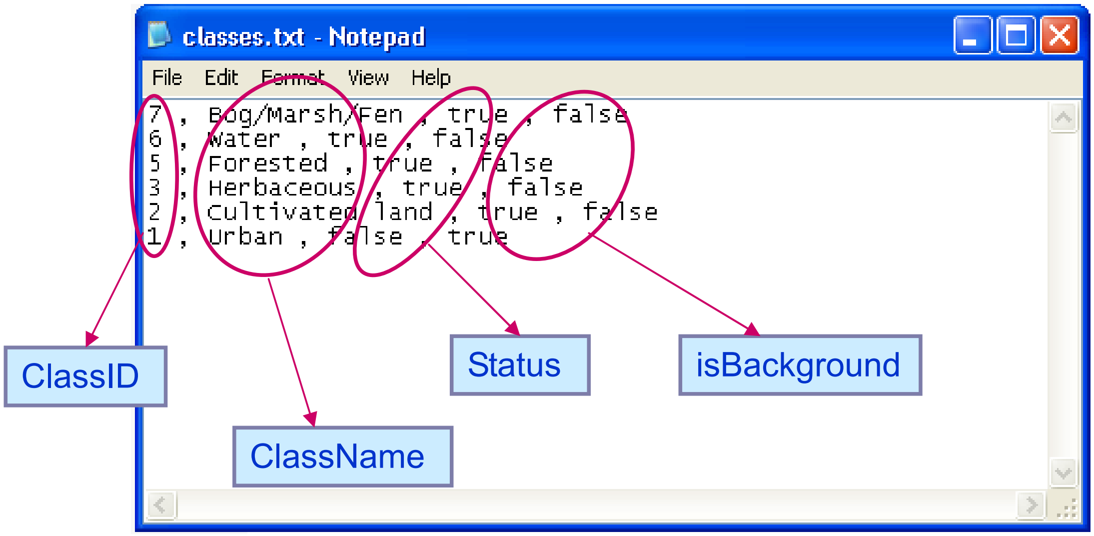

Figure 4. 19 Class properties file

3. Metrics Testing

In my analysis of the landscape structure at both the class-level and landscape-level, three groups of metrics were selected: Area/Density/Edge, Shape and Connectivity. The FRAGSTATS 3.3 user's guide gives the definition and full description of these metrics. **Appendix 4** lists the acronyms and provides a brief description of the metrics used in this study. FRAGSTATS with Arc Grids was used in this analysis.

A. Area/Density/Edge

Table 4. 13 Area/Density/Edge in landscape-level

LID	TA	NP	PD	LPI	TE	ED	LSI
lc1990_90m	151614.18	11713	7.73	39.88	4828680	31.85	32.32
lc2000_90m	151686.27	6510	4.29	48.46	3176820	20.94	21.74

Table 4.13 and 4.14 show the results of Area/Density/Edge metrics. The area of water and cultivated land increased, while area of forested, bog/marsh/fen and herbaceous decreased from 1990 to 2000. Comparison charts are shown in Figure 4.20, 4.21 and 4.22.

Table 4. 14 Area/Density/Edge in class-level

LID	lc1990_90m				
TYPE	Water	Forested	Bog/Marsh/Fen	Cultivated land	Herbaceous
CA	4553.82	15741.54	11174.76	68294.34	15617.61
PLAND	3.00	10.38	7.37	45.04	10.30
NP	395	2013	3698	1709	3898
PD	0.26	1.33	2.44	1.13	2.57
LPI	0.98	0.51	0.19	39.88	0.17
ED	2.40	11.14	14.62	19.15	16.38
LSI	20.57	53.13	69.31	53.49	71.72
LID	lc2000_90m				
CA	5560.65	13039.38	1282.23	80095.23	12540.42
PLAND	3.67	8.60	0.85	52.80	8.27
NP	913	1986	488	814	2309
PD	0.60	1.31	0.32	0.54	1.52
LPI	1.30	1.05	0.02	48.46	0.20
ED	3.30	10.83	2.02	13.28	12.47
LSI	30.25	57.28	25.48	36.80	59.18

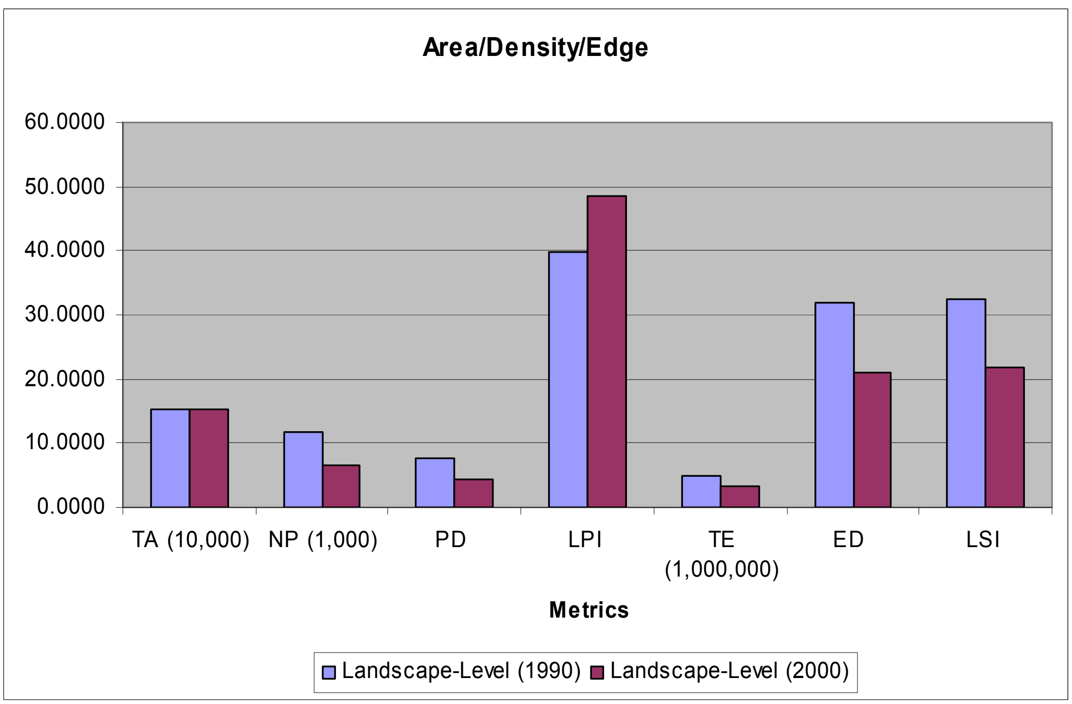

Figure 4. 20 Comparison of Area/Density/Edge in landscape-level

Figure 4.20 shows that LPI in the landscape-level increased, rather than decreased as other metrics; in other words, the overall patch size increased from 1990 to 2000.

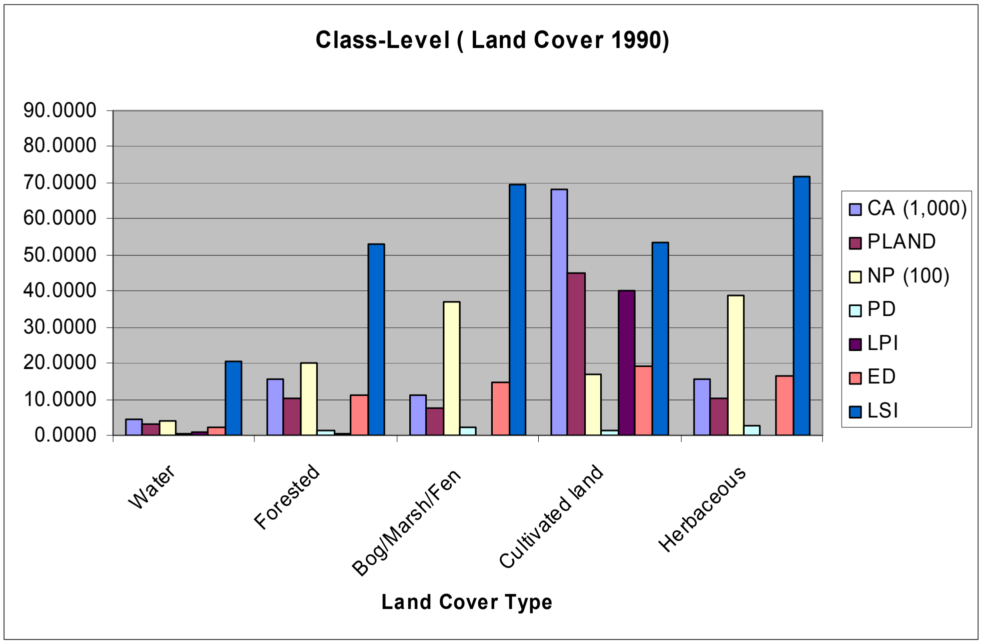

Figure 4. 21 Area/Density/Edge metrics based on land cover dataset of 1990

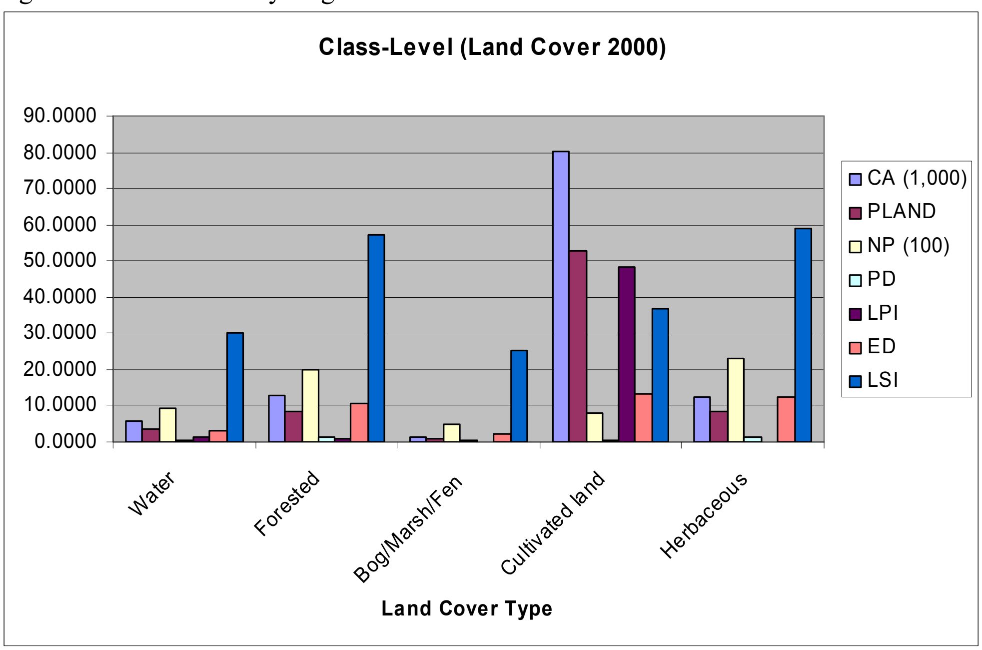

Figure 4. 22 Area/Density/Edge metrics based on land cover dataset of 2000

After comparing Figure 4.21 and 4.22, we can conclude that area and patch numbers of bog/marsh/fen decreased dramatically; in the meantime, cultivated land had the largest area, and increased from 1990 to 2000.

B. Shape

Table 4. 15 Shape in landscape-level

LID	lc1990_90m	lc2000_90m
SHAPE_MN	1.17	1.22
SHAPE_RA	39.68	27.84
FRAC_MN	1.03	1.03
FRAC_RA	0.37	0.33
PARA_MN	369.32	347.76
PARA_RA	398.16	401.86
CONTIG_MN	0.15	0.19
CONTIG_RA	0.88	0.89
PAFRAC	1.45	1.47

Table 4. 16 Shape in class-level

LID	lc1990_90m				
TYPE	Water	Forested	Bog/Marsh/Fen	Cultivated land	Herbaceous
SHAPE_MN	1.20	1.21	1.14	1.18	1.17
SHAPE_RA	3.79	6.59	5.74	39.68	2.94
FRAC_MN	1.03	1.03	1.03	1.03	1.03
FRAC_RA	0.22	0.26	0.26	0.37	0.21
PARA_MN	348.57	354.47	380.18	374.56	366.49
PARA_RA	398.16	392.44	349.88	382.42	369.33
CONTIG_MN	0.19	0.18	0.13	0.14	0.15
CONTIG_RA	0.88	0.87	0.76	0.84	0.81
PAFRAC	1.40	1.44	1.48	1.45	1.45
LID	lc2000_90m				
SHAPE_MN	1.14	1.25	1.14	1.25	1.22
SHAPE_RA	7.57	11.34	2	27.84	4
FRAC_MN	1.02	1.037	1.03	1.04	1.04
FRAC_RA	0.26	0.30	0.19	0.33	0.23
PARA_MN	378.22	347.61	371.54	321.78	339.98
PARA_RA	376.27	391.81	314.81	401.86	386.40
CONTIG_MN	0.13	0.19	0.14	0.24	0.20
CONTIG_RA	0.83	0.87	0.65	0.89	0.86
PAFRAC	1.45	1.51	1.46	1.46	1.46

Table 4.15 and 4.16 show the results of Shape metrics. Using Excel, I created charts as shown in Figure 4.23, 4.24 and 4.25.

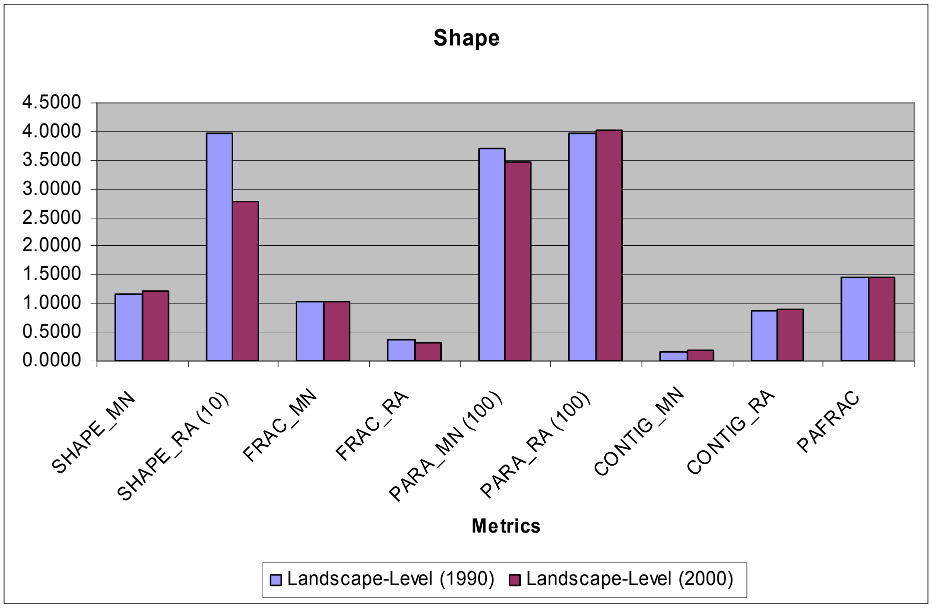

Figure 4. 23 Comparison of Shape in landscape-level

Based on shape metrics used to measure the shape complexity, the overall patch shape became more regular from 1990 to 2000 (Figure 4.23).

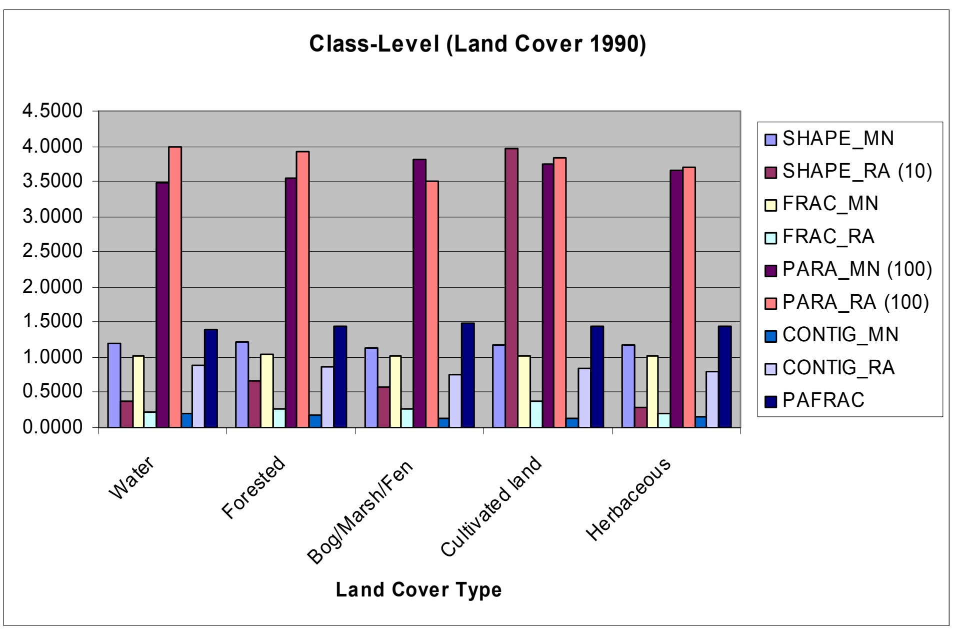

Figure 4. 24 Shape metrics based on land cover dataset of 1990

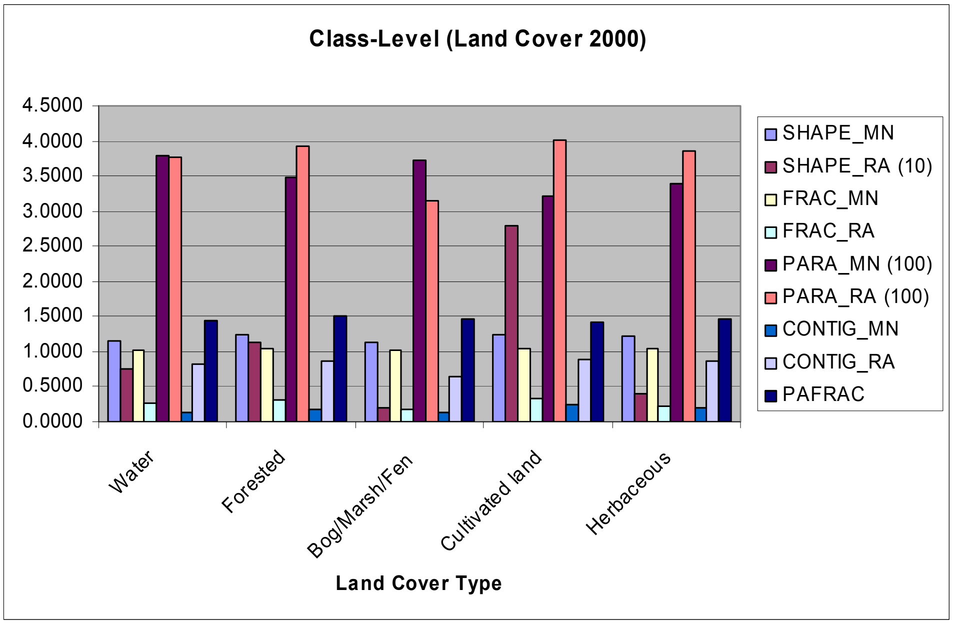

Figure 4. 25 Shape metrics based on land cover dataset of 2000

After comparing Figure 4.24 and 4.25, we can conclude that shape of patches, especially the patch shape of cultivated land, became more regular in the class-level from 1990 to 2000.

C. Connectivity

COHESION is useful in quantifying the connectivity of habitat as perceived by organisms dispersing in binary landscapes. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected.

Table 4. 17 COHESION in landscape-level

LID	COHESION
lc1990_90m	98.93
lc2000_90m	99.19

Table 4. 18 COHESION in class-level

LID	**lc1990_90m**				
TYPE	**Water**	**Forested**	**Bog/Marsh/Fen**	**Cultivated land**	**Herbaceous**
COHESION	91.10	88.47	70.42	99.76	72.71
LID	**lc2000_90m**				
COHESION	91.73	88.24	56.96	99.83	77.50

As shown in Table 4.17, overall, patches became more connected. Moreover, for the class-level as shown in Table 4.18, COHESION of forested and bog/marsh/fen decreased, which means that these two patch types became less aggregated and physically connected from 1990 to 2000.

Connectance is defined as the number of functional joinings between patches of the corresponding patch type, where each pair of patches is either connected or not based on a user-specified distance criterion. The threshold distance can be based on either Euclidean distance or functional distance. Connectance is reported as a percentage of the maximum possible connectance given the number of patches.

In the Isolation/Proximity Metrics, Euclidean Nearest-Neighbor Distance (ENN) is defined as the shortest straight-line distance between the focal patch and its nearest neighbor of the same class. In addition, the minimum ENN is constrained by the cell size, and is equal to twice the cell size when the 8-neighbor patch rule is used or the distance between diagonal neighbors when the 4-neighbor rule is used. Because I used the 8-neighbor patch rule for my analysis, the Euclidean distance would be twice the cell size, in other words, the threshold distance for CONNECT is 90m×2=180m.

To analyze the tread of connectance based on distance, I set the threshold distance to 90m, 270m, 460m, 450m, 540m and 630m in addition to 180m, the minimum ENN.

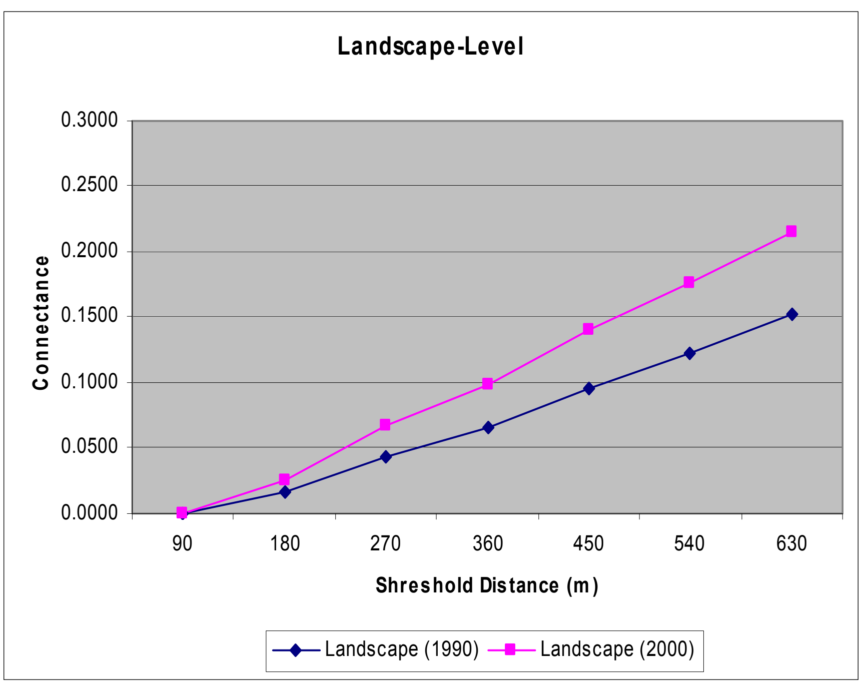

Figure 4. 26 Comparison of Connectance in landscape-level

Figure 4.26 shows that the overall patches connectance increased.

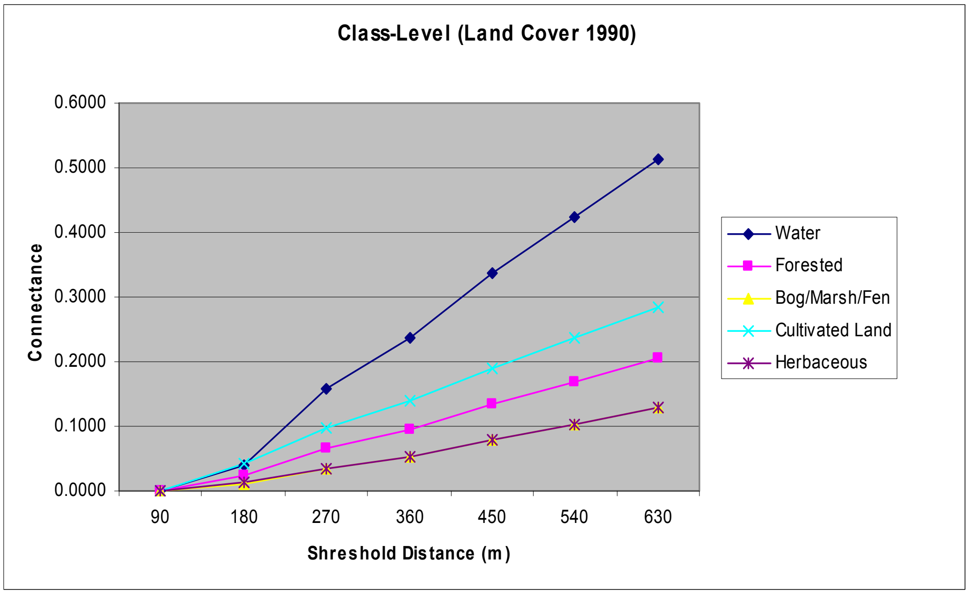

Figure 4. 27 Connectance based on land cover dataset of 1990

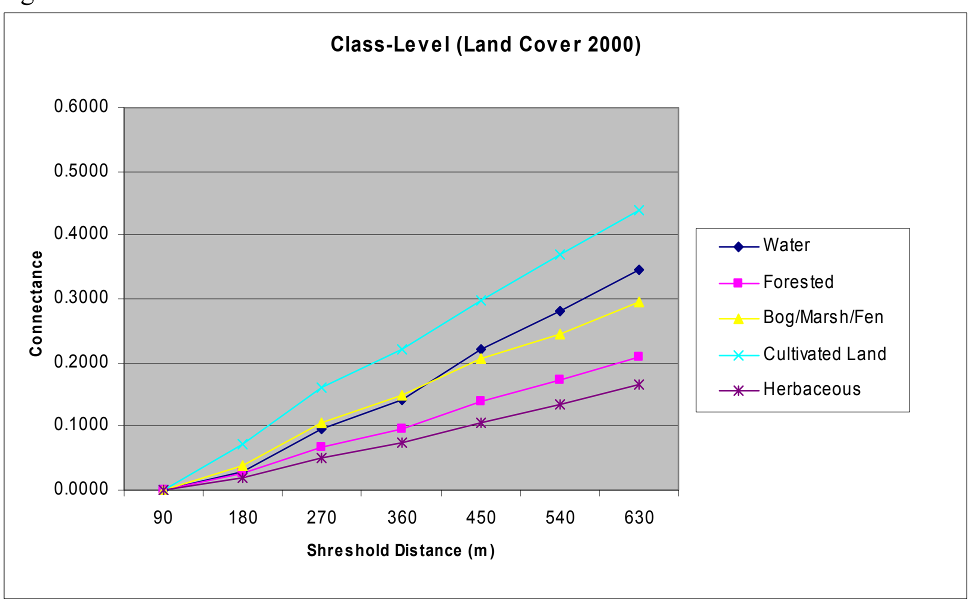

Figure 4. 28 Connectance based on land cover dataset of 2000

After comparing Figure 4.27 and 4.28, I concluded that cultivated land and bog/marsh/fen became more connected from 1990 to 2000, and cultivated land became the most connected patch type.

V. Conclusions

This chapter followed the methods diagram illustrated in Chapter 3, and found results of each major element, such as population change, land cover changes, landscape pattern analysis, in the research methods respectively. Given the results, it is possible for me to better understand the research subject and to answer the research questions. As all the analyses were completed and results were obtained, I connected the results together to not only find the relationships among the research elements but also got conclusions of this research. Chapter 5 and 6 answered the research questions in conclusions, revealed the relationships among the results found in this chapter, and furthermore, provided recommendations to future potential researches and studies.

CHAPTER 5. POSSIBLE FUTURE DEVELOPMENT

According to the 2030 Regional Development Framework, different land use will be accommodated in communities, depending on their spatial locations, natural resources and urban growth. Although several predictive models described in Chapter 2, such as SLEUTH Urban Growth Model and IDRISI from the Clark Labs, have the capacity to project the future growth and land use based on the existing datasets, it is fundamental to start from the basic land suitability analysis. The land suitability analysis determines the appropriateness of a given landscape for a particular use. The intention of the analysis is to determine the optimum site location for activities while minimizing negative impacts on the environment.

Furthermore, the suitability analysis process provides a systematic method of assessing a wide range of site conditions and land uses. In their composite form, suitability maps provide a cumulative, overall assessment of site locations that possess the most supportive, as well as the most problematic, array of site conditions in regard to each particular type of land use. From this comprehensive assessment, overall site organization decisions may be made on the basis of spatially specific evidence (Murphy 2005).

I. Data of Land Features

Several basic land features were included in the land suitability analysis. Each one of the land features were first organized and mapped using a descriptive model. Moreover, raster datasets were created if the original inputs were feature classes.

1. Wetlands

The shapefile of *National Wetlands Inventory Polygons* was downloaded from Minnesota Department of Natural Resources (http://deli.dnr.state.mn.us/). The National Wetlands Inventory (NWI) digital data files are records of wetlands location and classification as defined by the U.S. Fish & Wildlife Service (USFWS). This data set is available in 7.5 minute by 7.5 minute quadrangles containing ground planimetric coordinates of wetlands area features and wetlands attributes. The study area – Dakota County - covers 21 quadrangles of the NWI polygons. Thus, I first used the *Merge* function (Data Management Tools → General) to merge these 21 separate shape files together. Then, I used the *Clip* function (Analysis Tools → Extract) to clip the shapefile to Dakota County. Furthermore, I used the *Dissolve* function (Data Management Tools → Generalization) to make the visible boundaries of the blocks disappear, by selecting the dissolve field as "SYSTEM" from the NWI attributes. The attribute of "SYSTEM" has four values, which are Lacustrine (L), Palustrine (P), Riverine (R) and Uplands (U).

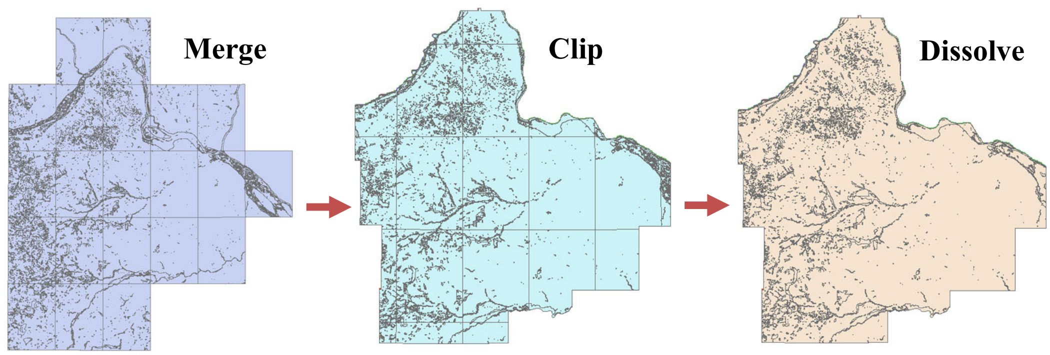

Figure 5. 1 NWI data preparation procedure

Table 5. 1 NWI in Dakota County data summary

Polygon Class	Frequency/Count	Acres	Percent
Lacustrine (L)	1	9,388.41	2.50%
Palustrine (P)	1	24,823.23	6.62%
Riverine (R)	1	416.50	0.11%
Uplands (U)	1	340,557.00	90.77%
Totals	4	375,185.14	100.00%

2. Slope Steepness

The Digital Elevation Model (DEM) was downloaded from the MetroGIS DataFinder (http://www.datafinder.org/catalog/index.asp). This dataset is a 30 meter raster DEM of the seven county Twin Cities Metropolitan Area, representing an elevation surface with a single elevation value for each cell given in feet above mean sea level. To derive slope steepness in percent, I used the Slope function under Spatial Analyst Tools → Surface in the ArcToolbox of ArcGIS to calculate the steepness in "Percent Rise". Slope steepness of Dakota County is shown in Figure 5.3. The range of slope steepness in Dakota County is from zero to 239.75 (percent rise).

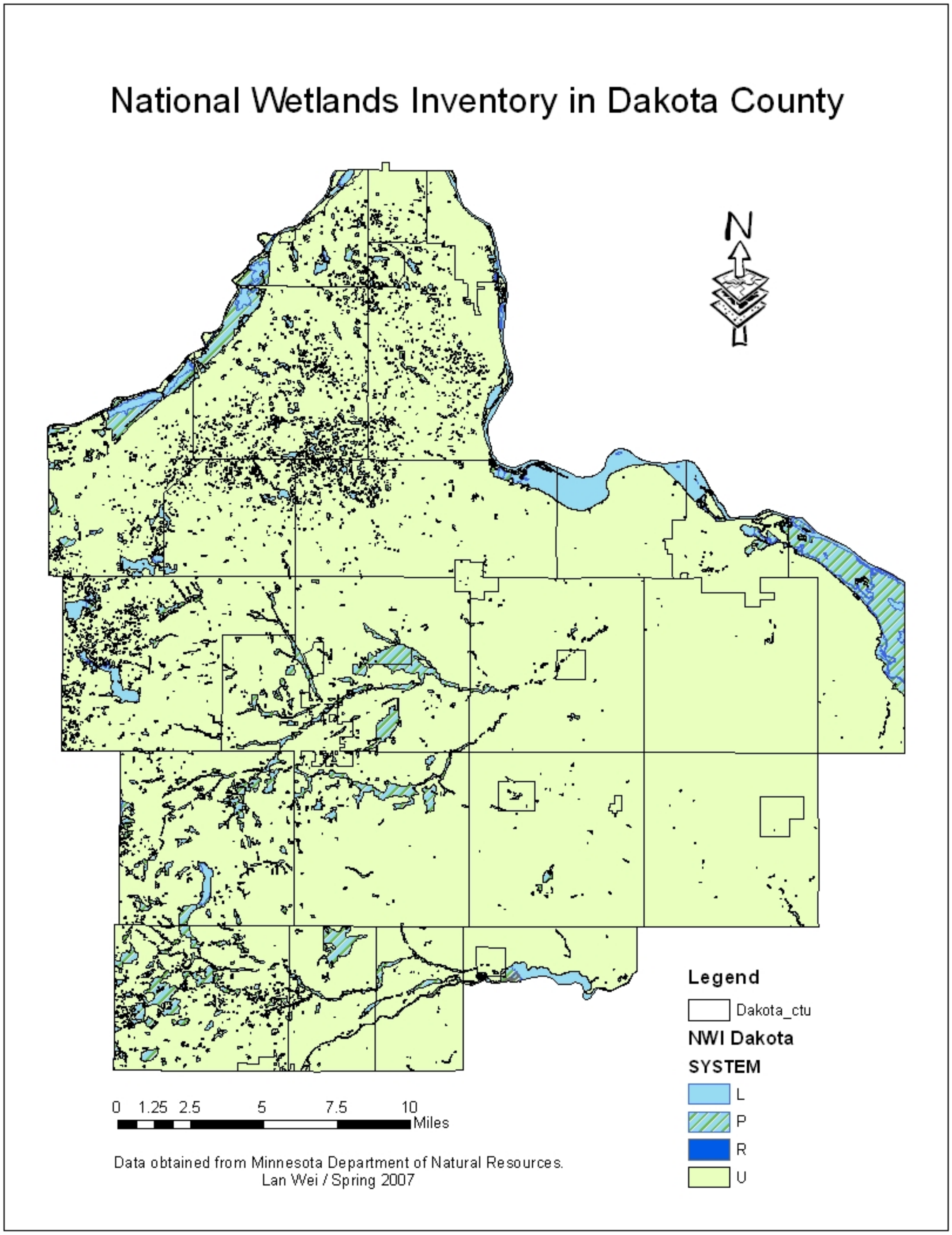

Figure 5. 2 Water features in Dakota County

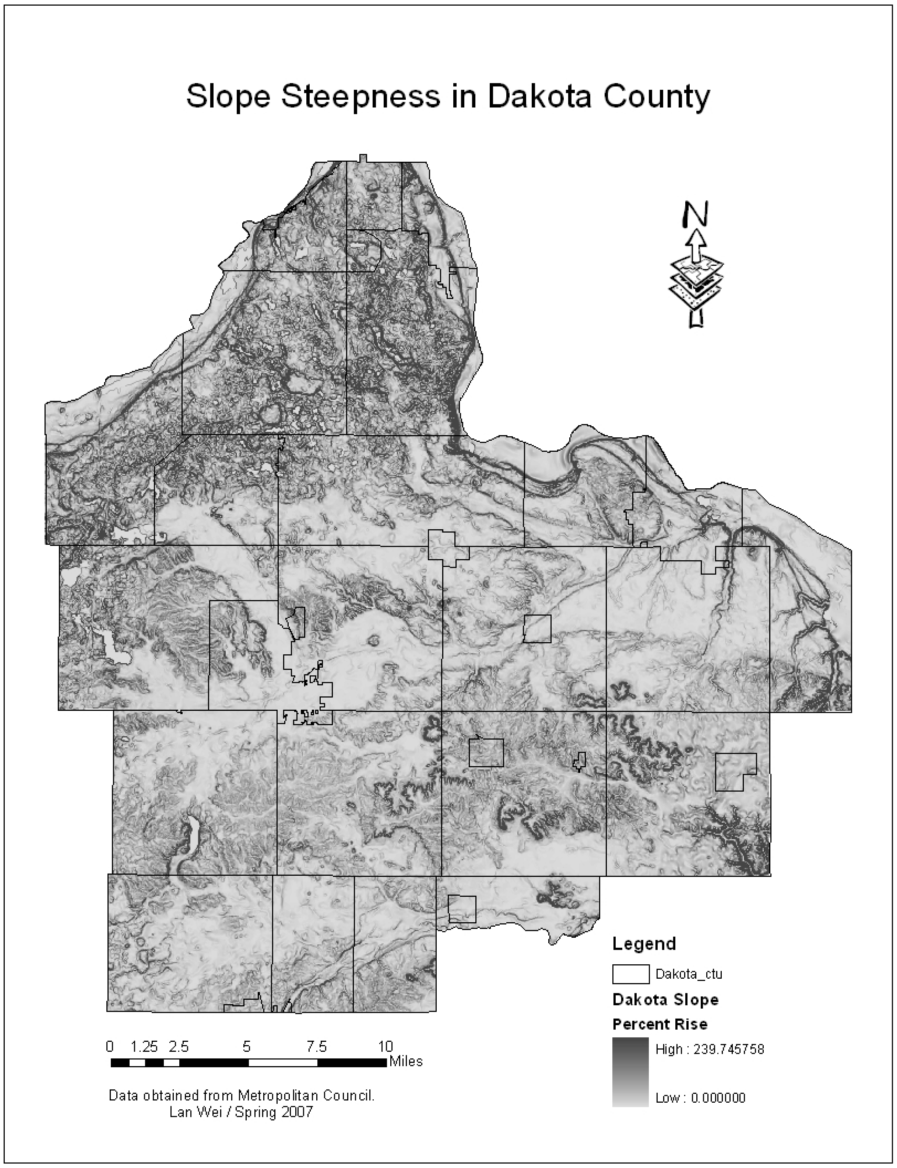

Figure 5. 3 Slope in Dakota County

3. Natural Resource Areas

The 2030 Framework Regional Natural Resource Areas shapefile was downloaded from the MetroGIS DataFinder (http://www.datafinder.org/catalog/index.asp). The shapefile is a preliminary analysis of the regionally significant natural resource areas in the Twin Cities Metro Area. It was created by the Minnesota Department of Natural Resources. This dataset was used in the Metropolitan Council's Blueprint 2030 and subsequent 2030 Regional Development Framework. After the Blueprint was approved by the Council, the DNR provided a different dataset named Regional Significant

Ecological Areas at http://www.datafinder.org/metadata/mndnr_eco_patches.htm. Some significant differences exist between the two datasets. DNR is distributing only the latter dataset. The Metropolitan Council is distributing this dataset because it was used for the 2030 Regional Development Framework (MetroGIS DataFinder 2007).

Table 5. 2 2030 Framework regional natural resource areas data summary

Polygon Class	Frequency/Count	Acres	Percent
Moderate (Value = 1)	26	417.71	1.75%
High (Value = 2)	56	5,946.95	24.89%
Outstanding (Value = 3)	37	17,528.10	73.36%
Totals	119	23,892.76	100.00%

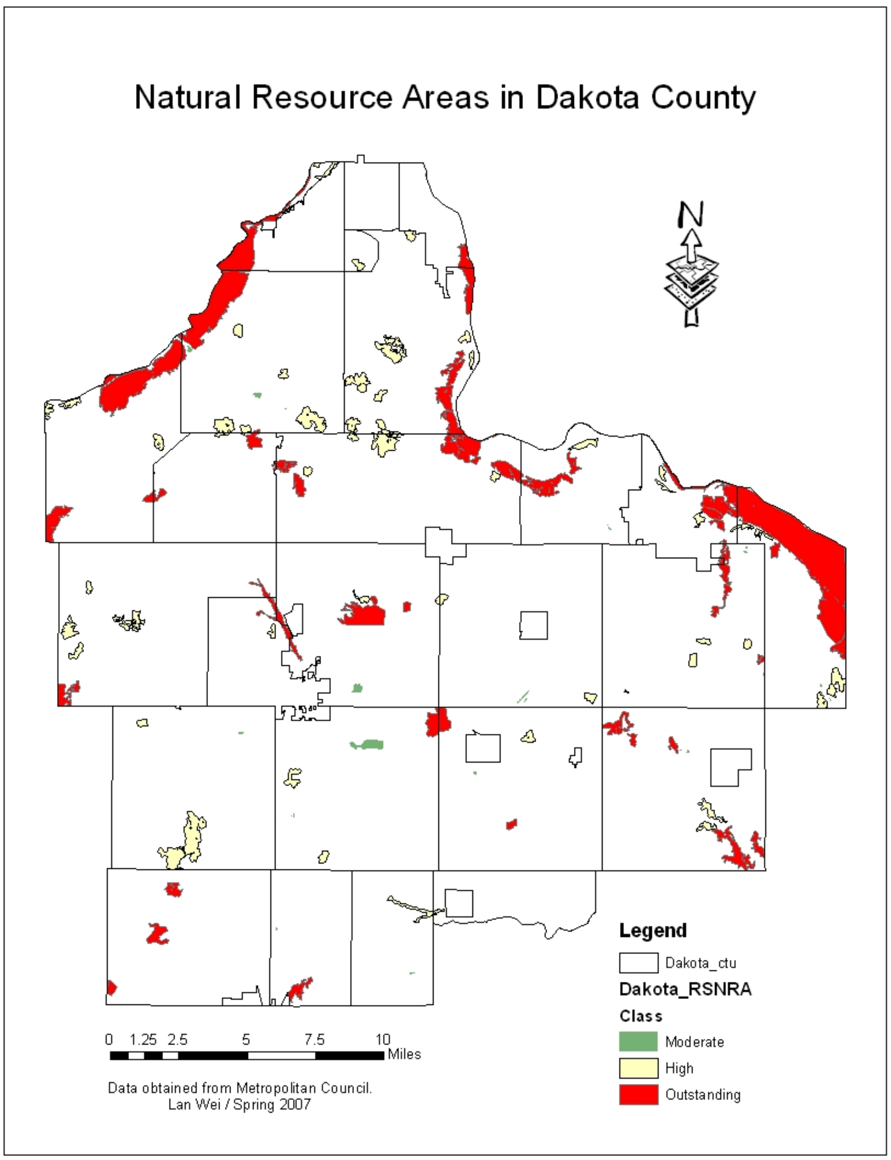

Figure 5. 4 Natural resource areas in Dakota County

4. Soil Survey

The Soil Survey Geographic Data Base (SSURGO) of Dakota County was downloaded from the Soil Data Mart (http://soildatamart.nrcs.usda.gov/) of the Natural Resources Conservation Service. This dataset consists of a tabular component and a spatial component. The tabular component can be imported from Microsoft Access into a database for querying, reporting and analysis, and further be observed from ArcCatalog as a Personal GeoDatabase. The spatial component can be viewed and analyzed using ArcGIS.

The attributes from the SSURGO database that I used in this study include the following: *Farm Class* (farmlndcl) from table Mapunit (mapunit); *Drainage Class* (drclassdcd) and *Flooding Frequency* (flodfreqdcd) from table Mapunit Aggregated Attribute (muaggatt). I first joined these two tables to the spatial soil shapefile of Dakota County, and to get a permanent shapefile with attributes from these two tables, I exported the temporary shapefile with data to a permanent one. Then I used the Feature to Raster function (Conversion Tools → To Raster) to convert the polygon shapefile to raster datasets based on those three attributes. Cell size of the raster datasets are 30m by 30m.

Prime Farmland Class (farmlndcl): Six prime farmland classes exist in Dakota County, and they are summarized in Table 5.3.

Table 5. 3 Prime farmland class data summary

Raster Class	**Value**	**Cell Count**	**Acres**	**Percent**
Not prime farmland	1	456,981	101,630.23	27.10%
All areas are prime farmland	2	773,032	171,918.34	45.85%
Farmland of statewide importance	3	228,398	50,794.54	13.55%
Farmland of local importance	4	73,091	16,255.06	4.33%
Prime farmland if protected from flooding or not frequently flooded during the growing season	5	17,354	3,859.44	1.03%
Prime farmland if drained	6	137,277	30,529.70	8.14%
Totals		1,686,133	374,987.31	100.00%

As shown in Figure 5.5, most of the prime farmland or important farmland is located in the south and east part of Dakota County

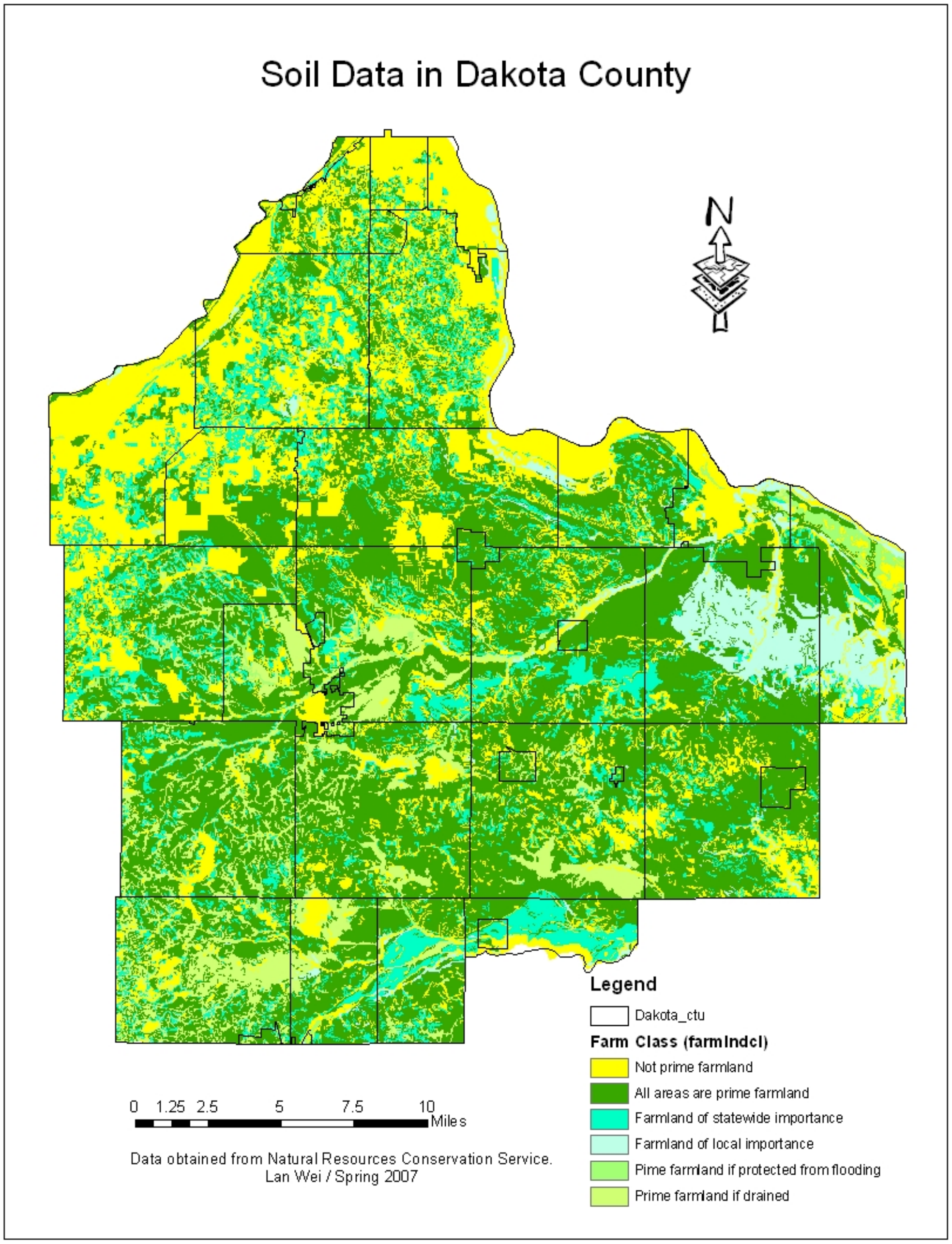

Figure 5. 5 Prime farmland class in Dakota County

Drainage Class (drclassdcd): In the drainage raster dataset, eight classes exist in Dakota County, including NoData. After careful observation, I found that all the NoData cells are located in either urban (disturbed soil) areas or water. Thus, I created a new raster dataset with nine drainage classes as summarized in Table 5.4.

Table 5. 4 Soil drainage class data summary

Raster Class	Value	Cell Count	Acres	Percent
Disturbed soil	1	122,605	27,266.72	7.27%
Well drained	2	925,610	205,850.91	54.90%
Somewhat excessively drained	3	72,205	16,058.02	4.28%
Water	4	55,324	12,303.77	3.28%
Moderately well drained	5	42,034	9,348.15	2.49%
Excessively drained	6	145,078	32,264.60	8.60%
Somewhat poorly drained	7	99,708	22,174.55	5.91%
Very poorly drained	8	71,270	15,850.08	4.23%
Poorly drained	9	152,299	33,870.51	9.03%
Totals		1,686,133	374,987.31	100.00%

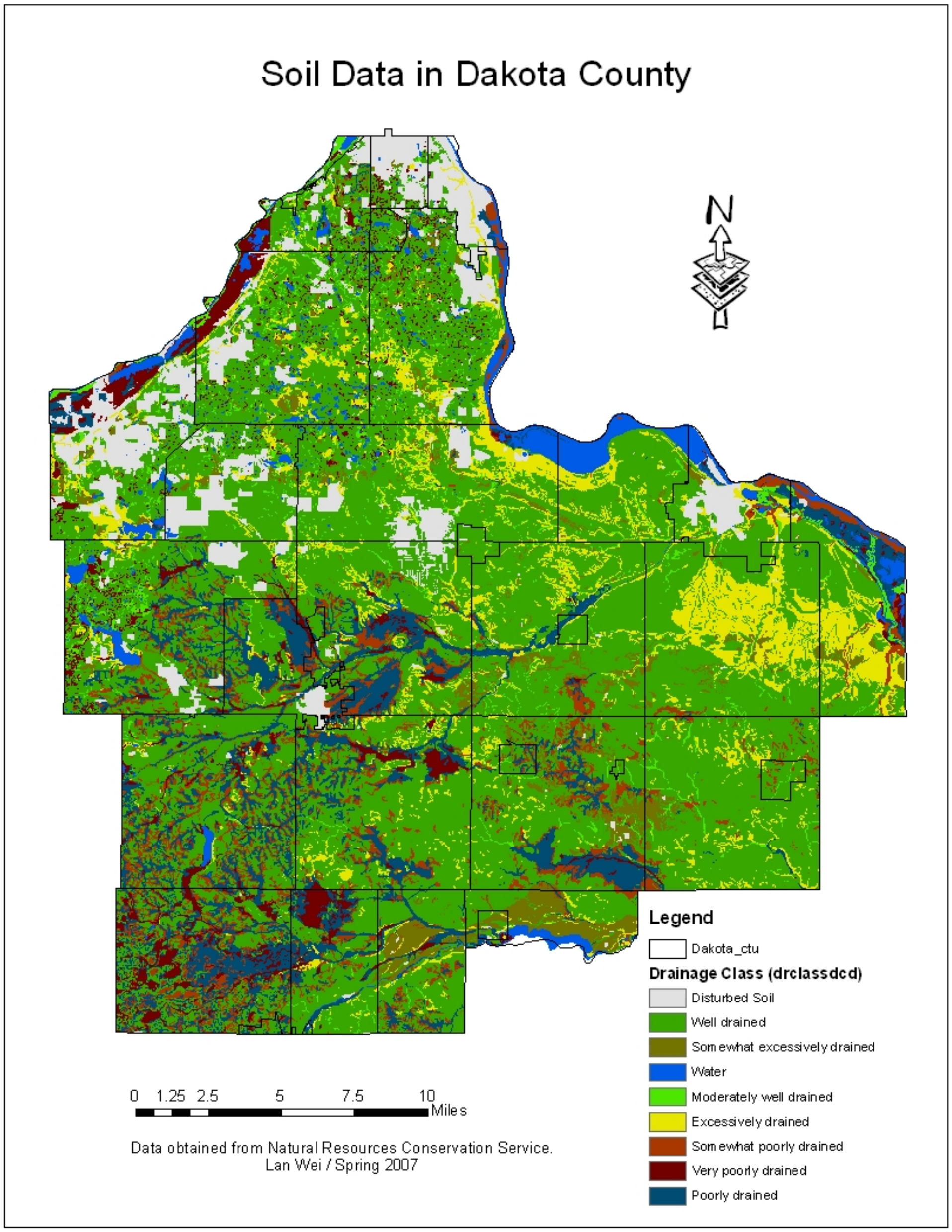

Figure 5. 6 Soil drainage class in Dakota County

Flooding Frequency (flodfreqdcd): In the flooding frequency raster dataset, five classes exist in Dakota County, including NoData. Just like the Drainage Class (drclassdcd), I found that all the NoData cells are located in either urban (disturbed soil) areas or water. Thus, I created a new raster dataset with six drainage classes as summarized in Table 5.5.

Table 5. 5 Soil flooding frequency data summary

Raster Class	Value	Cell Count	Acres	Percent
Disturbed Soil	1	111,501	24,797.25	6.61%
None	2	1,432,346	318,546.39	84.95%
Water	3	55,354	12,310.45	3.28%
Occasional	4	39,944	8,883.34	2.37%
Frequent	5	42,733	9,503.60	2.53%
Rare	6	4,202	934.50	0.25%
Totals		1,686,080	374,975.53	100.00%

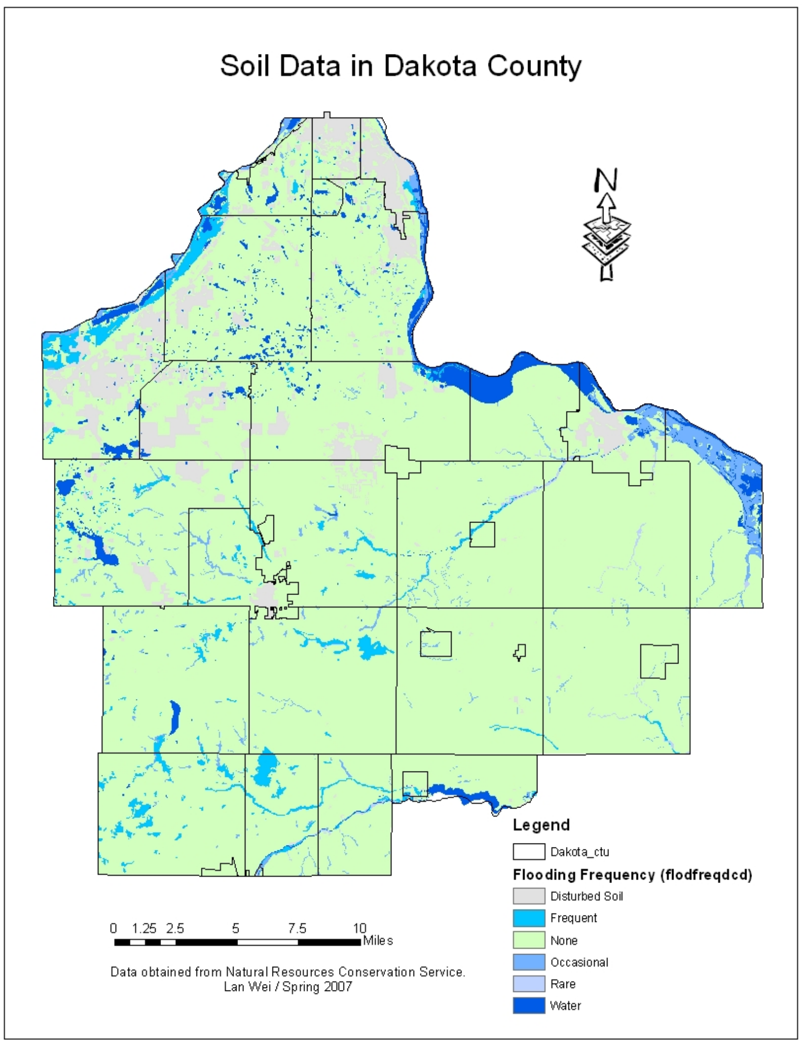

Figure 5. 7 Soil flooding frequency in Dakota County

5. FEMA Floodways

The Federal Emergency Management Agency (FEMA) Floodways shapefile of the Twin Cities Metro Area was downloaded from Minnesota Department of Natural Resources (http://deli.dnr.state.mn.us/). The Floodways Data are derived from the Flood Insurance Rate Maps (FIRMs) published by FEMA. The FIRMs are the basis for floodplain management, mitigation, and insurance activities for the National Flood Insurance Program (NFIP). Floodways Data files are intended to convey certain key features from the existing hard copy FIRM to provide users with automated flood risk data.

Table 5. 6 FEMA Floodways Data Summary

Polygon Class	Frequency/Count	Acres	Percent
100 Year Floodplain	155	44,772.29	95.88%
500 Year Floodplain	138	1,922.19	4.12%
Totals	293	46,694.48	100.00%

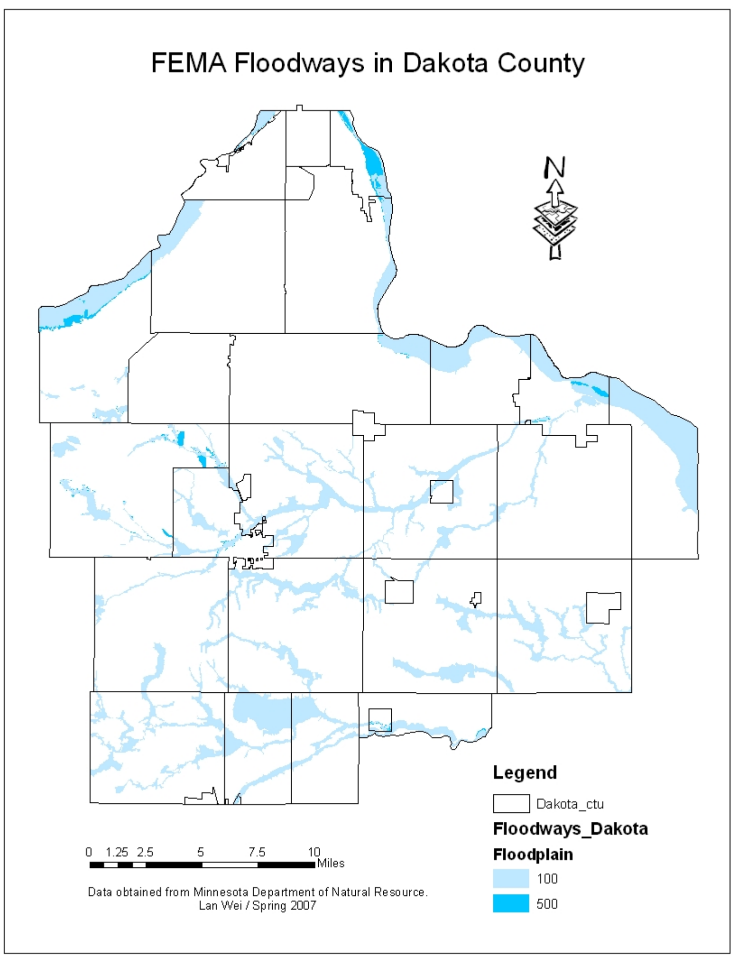

Figure 5. 8 FEMA floodways in Dakota County

II. Suitability Modeling

Each of the features was organized and mapped as a descriptive model, and further reclassified to three suitability classes: high, moderate and low suitability. A *numerical rating (scale value) (1, 2, or 3)* was assigned to each class within each land feature dataset to represent the land suitability as *low, moderate or high*.

With necessary land feature data compiled and aggregated, land suitability models were developed for both urban expansion and agricultural production. Reclassifying land features according to the goals and objectives of the analyses and the Weighted Overlay function were the two major tools of Spatial Analyst in ArcGIS used in this modeling.

1. Urban Expansion Analysis

For urban expansion analysis, five goals of growth management were included. Each goal has one or more objectives, and the GIS theme that can be used to analyze and realize the objective. *Scale Value* is a representation of the suitability rating or ranking to indicate whether each class is high (3), moderate (2) or low (1) suitability for urban development (Metropolitan Council 2006).

To explore different value systems, I developed four scenarios, each with a different emphasis: equal weight (% influence); economic cost, ecological cost and land use policy from the 2030 RDF.

To model these four scenarios in ArcGIS, I used the *Weighted Overlay* function (Spatial Analyst Tools → Overlay) to set different *% Influence* for each land feature theme. The *Weighted Overlay* function overlays several rasters using a common measurement scale and weights each according to its importance. It calculates a multiple criteria analysis between rasters. The "*% Influence*" is defined as the influence of the raster compared to the other criteria as a percentage of 100. "*Scale Value*" is the scaled weights for the criterion (ESRI 2006).

Table 5. 7 Suitability table and decision tree for urban expansion analysis

Goals	Objectives	Variable (GIS Theme)	Category	Scaled Value
Minimize Construction Cost	Avoid building on wetlands	National Wetlands Inventory	Lacustrine [1]	1
			Palustrine [2]	1
			Riverine [3]	1
			Uplands [4]	3
	Avoid building on steep slopes	Slope	0 to 5%	3
			5% to 15%	2
			>15% (p.158)	1
	Avoid building in poorly drained areas	Soil Drainage Class	Disturbed soil [1]	3
			Well drained [2]	3
			Somewhat excessively drained [3]	2
			Water [4]	1
			Moderately well drained [5]	3
			Excessively drained [6]	2
			Somewhat poorly drained [7]	1
			Very poorly drained [8]	1
			Poorly drained [9]	1
Minimize Environmental Impact	Avoid disturbance to protection areas	Distance from NWI (Wenger 1999)	0-30m	1
			30-100m	2
			>100m	3
	Avoid building on valuable resource areas	Natural Resource Areas	Natural Resource Areas	Restricted
			Not Natural Resource Areas	3
	Avoid building on natural resource areas	Land Cover	Water [1]	1
			Developed [2]	3
			Barren [3]	3
			Forested Upland [4]	1
			Shrubland [5]	2
			Herbaceous Upland [7]	1
			Planted/Cultivated [8]	2
			Wetlands [9]	1
Minimize Impact on Agriculture	Avoid expanding to highly productive agricultural areas	Soil Prime Farmland Class	Not Prime Farmland [1]	3
			Prime Farmland [2]	1
			Farmland of Statewide Importance [3]	1
			Farmland of Local Importance [4]	1
			Prime Farmland if protected from flooding or not frequently flooded during the growing season [5]	2
			Prime Farmland if drained [6]	2
Minimize Maintenance Cost	Avoid building in flood areas	FEMA Floodway	100 year floodplain	1
			500 year floodplain	2
			Not in floodplain	3
Comply with the 2030RDF	Be consistent with growth accommodation	Land Use (2030 RDF)	Urban [1]	3
			Agricultural Preservation [2]	1
			Agricultural Area [3]	1
			Urban Reserve [4]	3
			Rural Residential [5]	3
			Diversified Rural [6]	3
			Urban Reserve, Agricultural Area [7]	2

Note: "*Restricted*" in the Scale Value column means restriction on further development in the assigned area. In the *Weighted Overlay* function, "Restricted" assigns the restricted value (the minimum value of the evaluation scale set, minus one – in this analysis, the restricted value equals zero) to cells in the output, regardless of whether other input rasters have a different scale value set for the cell.

Table 5. 8 Urban Expansion Analysis Scenarios

Scenario	***One***	***Two***	***Three***	***Four***
Goals	**Equal Weight**	**Economic Cost**	**Ecological Cost**	**Land Use Policy**
Minimize Construction Cost	20%	50%	20%	20%
Minimize Environmental Impact	20%	20%	50%	20%
Minimize Impact on Agriculture	20%	10%	10%	15%
Minimize Maintenance Cost	20%	10%	10%	15%
Comply with the 2030RDF	20%	10%	10%	30%
Total Weight	**100%**	**100%**	**100%**	**100%**

Scenario One

In scenario one, I assigned equal weight to each of the five goals, thus each goal had 20% influence of the urban expansion analysis model. Inside each goal, percent influence was equally divided into each variable (GIS theme).

Table 5. 9 Scenario one – Equal Weight

Equal Weight	**Goals**	**Objectives**	**% Influence**	**Variable (GIS Theme)**
20%	Minimize Construction Cost	Avoid building on wetlands	7%	National Wetlands Inventory
		Avoid building on steep slopes	7%	Slope
		Avoid building in poorly drained areas	6%	Soil Drainage Class
20%	Minimize Environmental Impact	Avoid erosive soils	7%	Distance from NWI
		Avoid building on valuable resource areas	6%	Distance from Natural Resource Areas
		Avoid building on natural resource areas	7%	Land Cover
20%	Minimize Impact on Agriculture	Avoid expanding to highly productive agricultural areas	20%	Soil Prime Farmland Class
20%	Minimize Maintenance Cost	Avoid building in flood areas	20%	FEMA Floodway
20%	Comply with the 2030RDF	Be consistent with growth accommodation	20%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.9, the green areas represent land that is suitable for urban expansion. Therefore, we know that based on the assumptions we made in Urban Expansion Analysis Scenario One, the northwest part of Dakota County contains most of the high suitability rating land in terms of urban expansion. 77,135 acres land, about 20% of the total area of Dakota County, was rated high suitability in the entire County area. It is also noticeable that the Community of Hastings has high suitability rating for urban expansion as well.

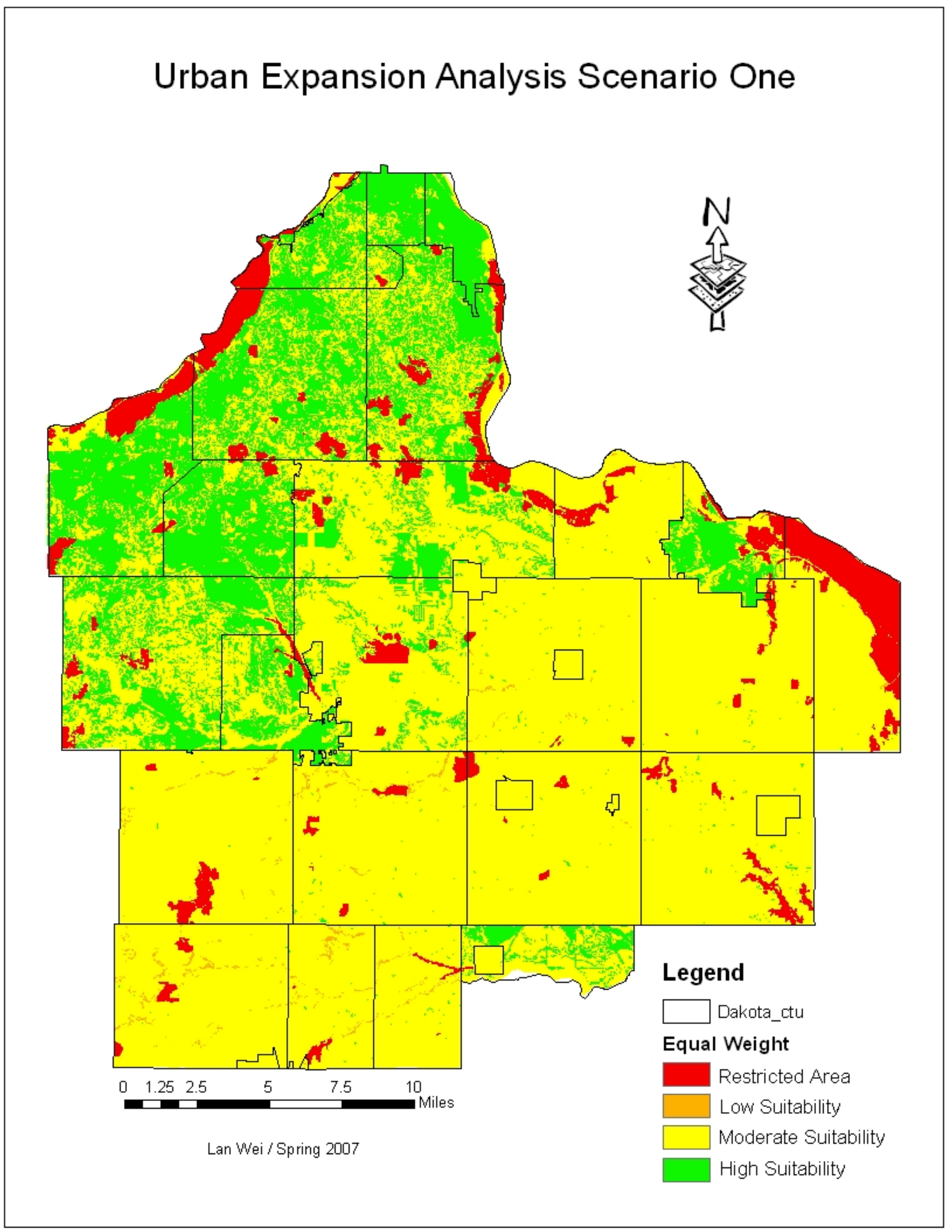

Figure 5. 9 Urban expansion analysis scenario one – Equal Weight

Table 5. 10 Urban expansion analysis scenario one summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	7,506	1,669.30	0.45%
Moderate Suitability	2	1,223,112	272,013.82	72.61%
High Suitability	3	346,837	77,134.77	20.59%
Totals		1,684,490	374,621.92	100.00%

Scenario Two

In scenario two, I assigned 50% weight to the goal of "Minimize Construction Cost" to emphasize the economic aspect of urban expansion.

Table 5. 11 Scenario two – Economic Cost

Economic Cost	Goals	Objectives	% Influence	Variable (GIS Theme)
50%	Minimize Construction Cost	Avoid building on wetlands	17%	National Wetlands Inventory
		Avoid building on steep slopes	17%	Slope
		Avoid building in poorly drained areas	16%	Soil Drainage Class
20%	Minimize Environmental Impact	Avoid erosive soils	7%	Distance from NWI
		Avoid building on valuable resource areas	6%	Distance from Natural Resource Areas
		Avoid building on natural resource areas	7%	Land Cover
10%	Minimize Impact on Agriculture	Avoid expanding to highly productive agricultural areas	10%	Soil Prime Farmland Class
10%	Minimize Maintenance Cost	Avoid building in flood areas	10%	FEMA Floodway
10%	Comply with the 2030RDF	Be consistent with growth accommodation	10%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.10, we know that based on the assumptions we made in Urban Expansion Analysis Scenario Two, as to "Minimize Construction Cost", about 35% of the land in Dakota County was rated high suitability, especially in the north part of the County.

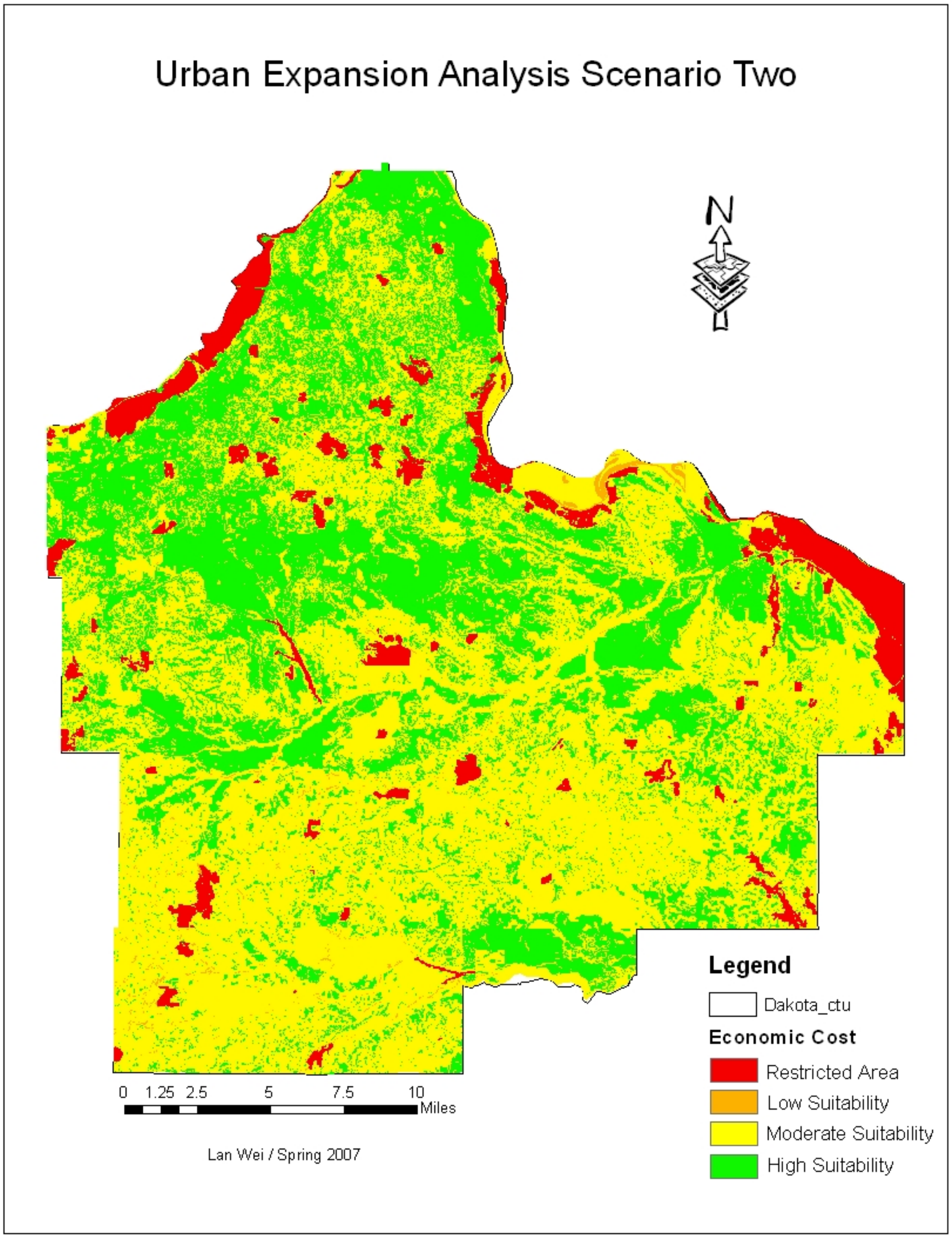

Figure 5. 10 Urban expansion analysis scenario two – Economic Cost

Table 5. 12 Urban expansion analysis scenario two summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	7,599	1,689.98	0.45%
Moderate Suitability	2	987,925	219,709.44	58.65%
High Suitability	3	581,931	129,418.46	34.55%
Totals		1,684,490	374,621.92	100.00%

Scenario Three

In scenario three, I assigned 50% weight to the goal of "Minimize Environmental Cost" to emphasize the environmental aspect of urban expansion.

Table 5. 13 Scenario three – Ecological Cost

Ecological Cost	Goals	Objectives	% Influence	Variable (GIS Theme)
20%	Minimize Construction Cost	Avoid building on wetlands	7%	National Wetlands Inventory
		Avoid building on steep slopes	7%	Slope
		Avoid building in poorly drained areas	6%	Soil Drainage Class
50%	Minimize Environmental Impact	Avoid erosive soils	17%	Distance from NWI
		Avoid building on valuable resource areas	16%	Distance from Natural Resource Areas
		Avoid building on natural resource areas	17%	Land Cover
10%	Minimize Impact on Agriculture	Avoid expanding to highly productive agricultural areas	10%	Soil Prime Farmland Class
10%	Minimize Maintenance Cost	Avoid building in flood areas	10%	FEMA Floodway
10%	Comply with the 2030RDF	Be consistent with growth accommodation	10%	Land Use (2030 RDF)
100%		**Total Weight**	**100%**	**Total Influence**

As shown in Figure 5.11, we know that based on the assumptions we made in Urban Expansion Analysis Scenario Three, as to "Minimize Environmental Cost", about 30% of the land in Dakota County was rated high suitability, especially in the northwest part of the County. The Community of Hastings area has high suitability rating for urban expansion as well.

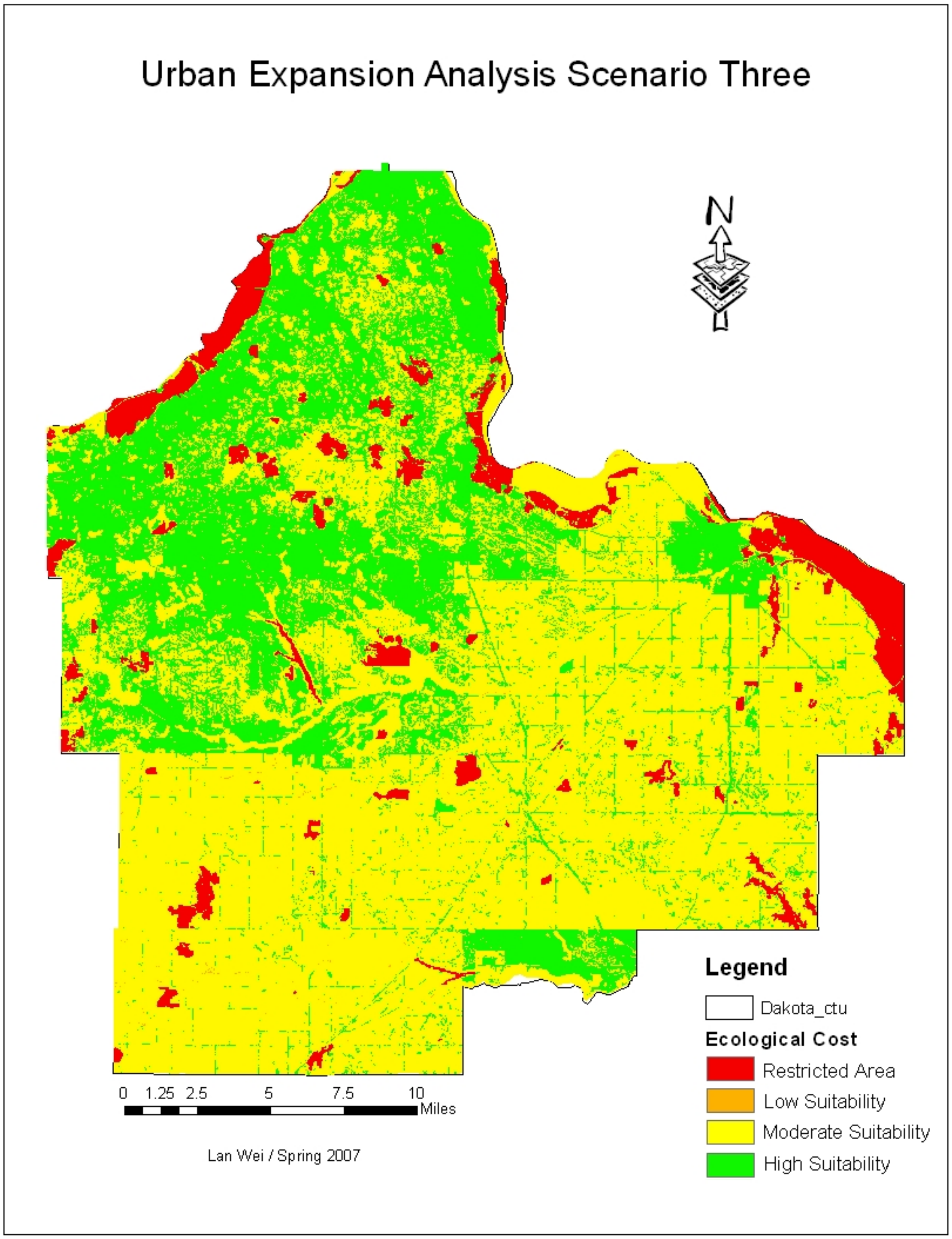

Figure 5. 11 Urban expansion analysis scenario three – Ecological Cost

Table 5. 14 Urban expansion analysis scenario three summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	727	161.68	0.04%
Moderate Suitability	2	1,061,140	235,992.08	62.99%
High Suitability	3	515,588	114,664.12	30.61%
Totals		1,684,490	374,621.92	100.00%

Scenario Four

In scenario four, I assigned 30% weight to the goal of "Comply with the 2030 Regional Development Framework" to emphasize the land use policy aspect of urban expansion.

Table 5. 15 Scenario Four – Land Use Policy

Land Use Policy	Goals	Objectives	% Influence	Variable (GIS Theme)
20%	Minimize Construction Cost	Avoid building on wetlands	7%	National Wetlands Inventory
		Avoid building on steep slopes	7%	Slope
		Avoid building in poorly drained areas	6%	Soil Drainage Class
20%	Minimize Environmental Impact	Avoid erosive soils	7%	Distance from NWI
		Avoid building on valuable resource areas	6%	Distance from Natural Resource Areas
		Avoid building on natural resource areas	7%	Land Cover
15%	Minimize Impact on Agriculture	Avoid expanding to highly productive agricultural areas	15%	Soil Prime Farmland Class
15%	Minimize Maintenance Cost	Avoid building in flood areas	15%	FEMA Floodway
30%	Comply with the 2030RDF	Be consistent with growth accommodation	30%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.12, we know that based on the assumptions we made in Urban Expansion Analysis Scenario Four, as to "Comply with the 2030 Regional Development Framework", about 25% of the land in Dakota County was rated high suitability, especially in the northwest part of the County. The Community of Hastings area has high suitability rating for urban expansion as well.

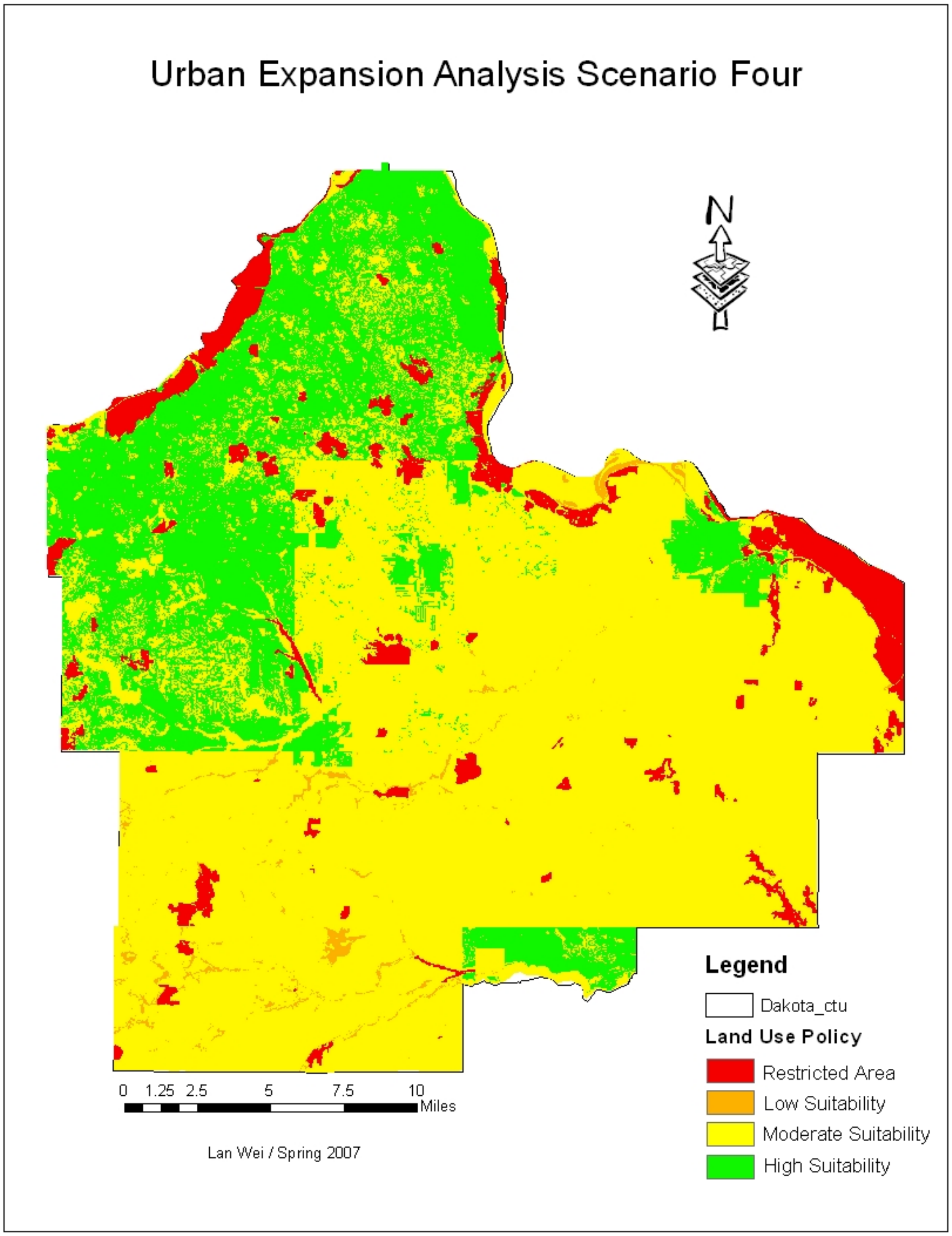

Figure 5. 12 Urban expansion analysis scenario four – Land Use Policy

Table 5. 16 Urban expansion analysis scenario four summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	16,843	3,745.80	1.00%
Moderate Suitability	2	1,136,814	252,821.59	67.49%
High Suitability	3	423,798	94,250.50	25.16%
Totals		1,684,490	374,621.92	100.00%

Comparison of Urban Expansion Scenarios

In order to compare the four scenarios using the urban expansion modeling, I created Table 5.17 and highlighted the highest numbers of low, moderate and high suitability land in the corresponding scenario.

Table 5. 17 Comparison of urban expansion scenarios

Raster Class	Scenario One (Cell Count; Percent)	Scenario Two	Scenario Three	Scenario Four
Restricted Area [0]	107,035 (6.35%)	107,035 (6.35%)	107,035 (6.35%)	107,035 (6.35%)
Low Suitability [1]	7,506 (0.45%)	7,599 (0.45%)	727 (0.04%)	16,843 (1.00%)
Moderate Suitability [2]	1,223,112 (72.61%)	987,925 (58.65%)	1,061,140 (62.99%)	1,136,814 (67.49%)
High Suitability [3]	346,837 (20.59%)	581,931 (34.55%)	515,588 (30.61%)	423,798 (25.16%)
Totals	1,684,490 (100%)	1,684,490 (100%)	1,684,490 (100%)	1,684,490 (100%)

As shown in the above table, Scenario One (equal weight) has the most moderate suitability land for urban expansion; Scenario Two (economic cost) has the most high suitability land; and Scenario Four (land use policy) has the most low suitability land.

Composite of Scenarios

After creating four scenarios of urban expansion analysis, I used the *Combine* function (Spatial Analyst Tools → Local) to combine these four scenarios as multiple raster inputs so that, for each cell, a unique output value is assigned to each unique combination of input values. Out of 25 combinations of the output raster, there were four combinations that each contained the same value: 3, 2, 1, or 0. Therefore, I can find the areas where agreement exists in all four scenarios. In other words, I mapped the cells in which the suitability rating/ranking are the same in all four scenarios: high [3], moderate [2] or low [1] suitability for urban expansion.

Furthermore, I reclassified urban expansion analysis composite of scenarios, which includes 25 values, into five classes: restricted area [0], low suitability [1], moderate suitability [2], high suitability [3] and no agreement [9].

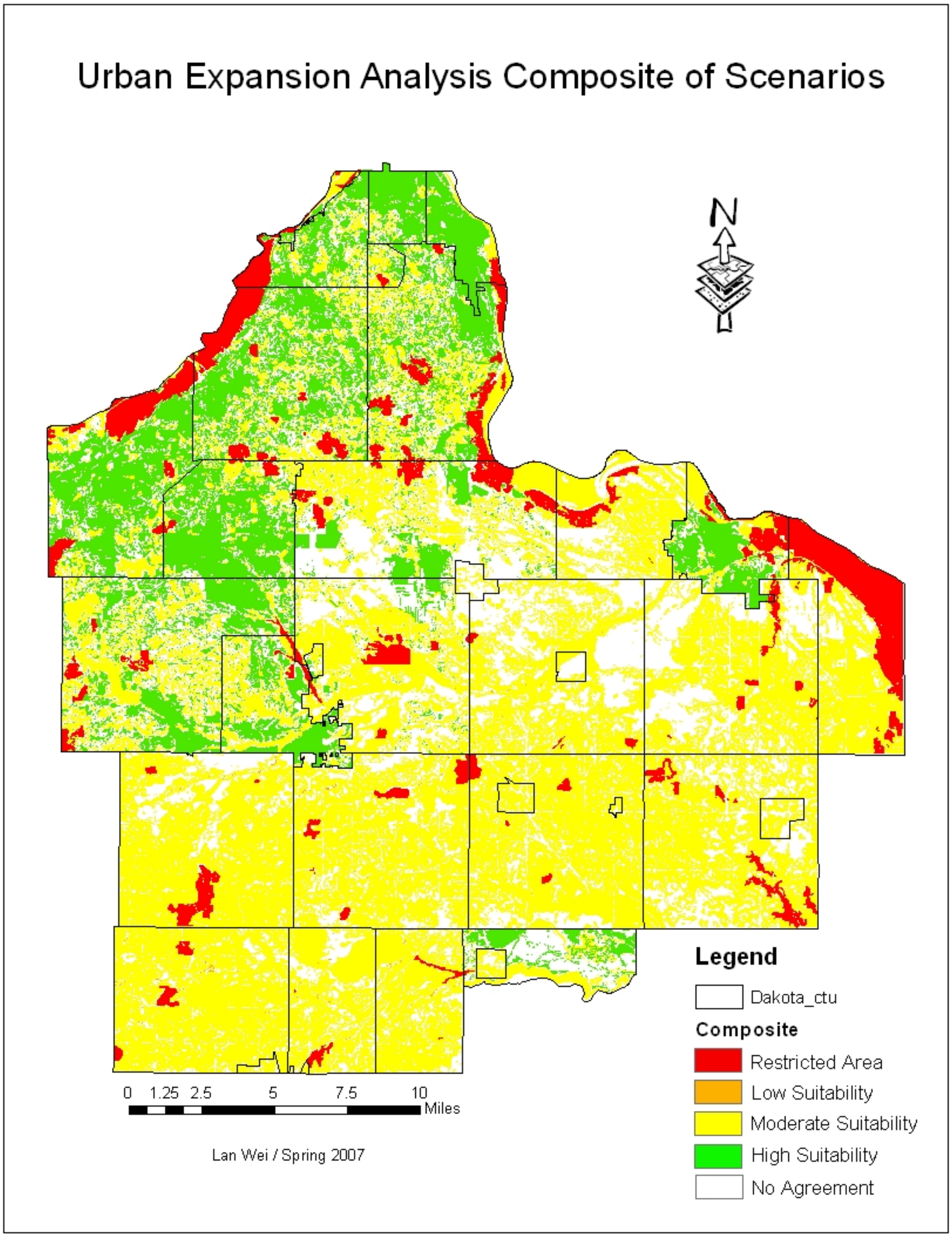

Figure 5. 13 Urban expansion analysis composite of scenarios

Table 5. 18 Urban expansion analysis composite of scenarios summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	727	161.68	0.04%
Moderate Suitability	2	824,873	183,447.52	48.97%
High Suitability	3	280,055	62,282.79	16.63%
No Agreement	9	471,800	104,925.90	28.01%
Totals		1,684,490	374,621.92	100.00%

As shown in Figure 5.13 and Table 5.18, we can conclude that 16.63% of the total area in Dakota County was rated high suitability in terms of urban expansion in all four scenarios, most of which is located in the northwest part of the County. The Community of Hastings (Dakota County part) is covered primarily by high suitability land as well.

2. Agriculture Protection Analysis

Because Dakota and two other counties (Scott and Carver) of the Twin Cities Metro Area contain a total of about a half-million acres of the region's best soils (2030 RDF), these lands are planned and zoned to maintain agriculture as the primary long-term land use. Therefore, agriculture productivity was modeled for Dakota County, an issue especially in the southern part of the County. For this agriculture suitability model, four goals of agriculture production were included.

To explore different value systems for agriculture protection analysis, I developed four scenarios, each with a different emphasis: equal weight (or % influence); environmental impact, agricultural productivity and land use policy from the 2030 RDF. Same as the urban expansion suitability modeling, I used the *Weighted Overlay* function for the agriculture suitability modeling to set different *% Influence* for each goal and land feature theme.

Table 5. 19 Suitability table and decision tree for agriculture protection analysis

Goals	Objectives	Variable (GIS Theme)	Category	Scaled Value
Minimize Environmental Cost	Avoid natural resource areas	Land Cover	Water [1]	1
			Developed [2]	1
			Barren [3]	3
			Forested Upland [4]	1
			Shrubland [5]	2
			Herbaceous Upland [7]	1
			Planted/Cultivated [8]	3
			Wetlands [9]	1
	Avoid steep slopes	Slope	0 to 5%	3
			5% to 9%	2
			>9%	1
	Avoid poor soil drainage	Soil Drainage Class	Disturbed soil [1]	1
			Well drained [2]	3
			Somewhat excessively drained [3]	2
			Water [4]	1
			Moderately well drained [5]	3
			Excessively drained [6]	2
			Somewhat poorly drained [7]	1
			Very poorly drained [8]	1
			Poorly drained [9]	1
Minimize Environmental Impact	Avoid disturbance to protection areas	Distance from NWI	0-50m	1
			50-150m	2
			>150m	3
	Avoid valuable resource areas	Natural Resource Areas	Natural Resource Areas	Restricted
			Not Natural Resource Areas	3
Maximize Agricultural Productivity	Avoid low productivity agricultural areas	Soil Prime Farmland Class	Not Prime Farmland [1]	1
			Prime Farmland [2]	3
			Farmland of Statewide Importance [3]	3
			Farmland of Local Importance [4]	3
			Prime Farmland if protected from flooding or not frequently flooded during the growing season [5]	2
			Prime Farmland if drained [6]	2
	Avoid flood areas	Soil Flooding Frequency	Disturbed Soil [1]	1
			None [2]	3
			Water [3]	1
			Occasional [4]	2
			Frequent [5]	1
			Rare [6]	2

Goals	Objectives	Variable (GIS Theme)	Category	Scaled Value
Comply with the 2030RDF	Be consistent with growth accommodat ion	Land Use (2030 RDF)	Urban [1]	1
			Agricultural Preservation [2]	3
			Agricultural Area [3]	3
			Urban Reserve [4]	1
			Rural Residential [5]	1
			Diversified Rural [6]	1
			Urban Reserve, Agricultural Area [7]	2

Table 5. 20 Agriculture protection analysis scenarios

Scenario	*One*	*Two*	*Three*	*Four*
Goals	**Equal Weight**	**Environmental Aspect**	**Agriculture Productivity**	**Land Use Policy**
Minimize Environmental Cost	25%	30%	20%	20%
Minimize Environmental Impact	25%	30%	20%	20%
Maximize Agricultural Productivity	25%	20%	40%	20%
Comply with the 2030RDF	25%	20%	20%	40%
Total Weight	**100%**	**100%**	**100%**	**100%**

Scenario One

In scenario one, I assigned equal weight to the total four goals, thus each goal has 25% influence of the agriculture protection analysis model. Inside each goal, percent influence was equally divided into each variable (GIS theme).

Table 5. 21 Scenario one – Equal Weight

Equal Weight	Goals	Objectives	% Influence	Variable (GIS Theme)
25%	Minimize Environmental Cost	Avoid natural resource areas	9%	Land Cover
		Avoid steep slopes	8%	Slope
		Avoid poor soil drainage	8%	Soil Drainage Class
25%	Minimize Environmental Impact	Avoid erosion to protection areas	13%	Distance from NWI
		Avoid valuable resource areas	12%	Distance from Natural Resource Areas
25%	Maximize Agricultural Productivity	Avoid low productivity agricultural areas	13%	Soil Prime Farmland Class
		Avoid flood areas	12%	Soil Flooding Frequency
25%	Comply with the 2030RDF	Be consistent with growth accommodation	25%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.14, the green areas represent land that is suitable for agriculture protection. Therefore, we know that based on the assumptions we made in Agriculture Protection Analysis Scenario One, the southeast part of Dakota County contains most of the high suitability rating land in terms of agriculture protection. 187,918 acres land, 50.17% of the total area of Dakota County, was rated high suitability in the entire County area. About 3% of the total area of Dakota County was rated low suitability for agriculture protection.

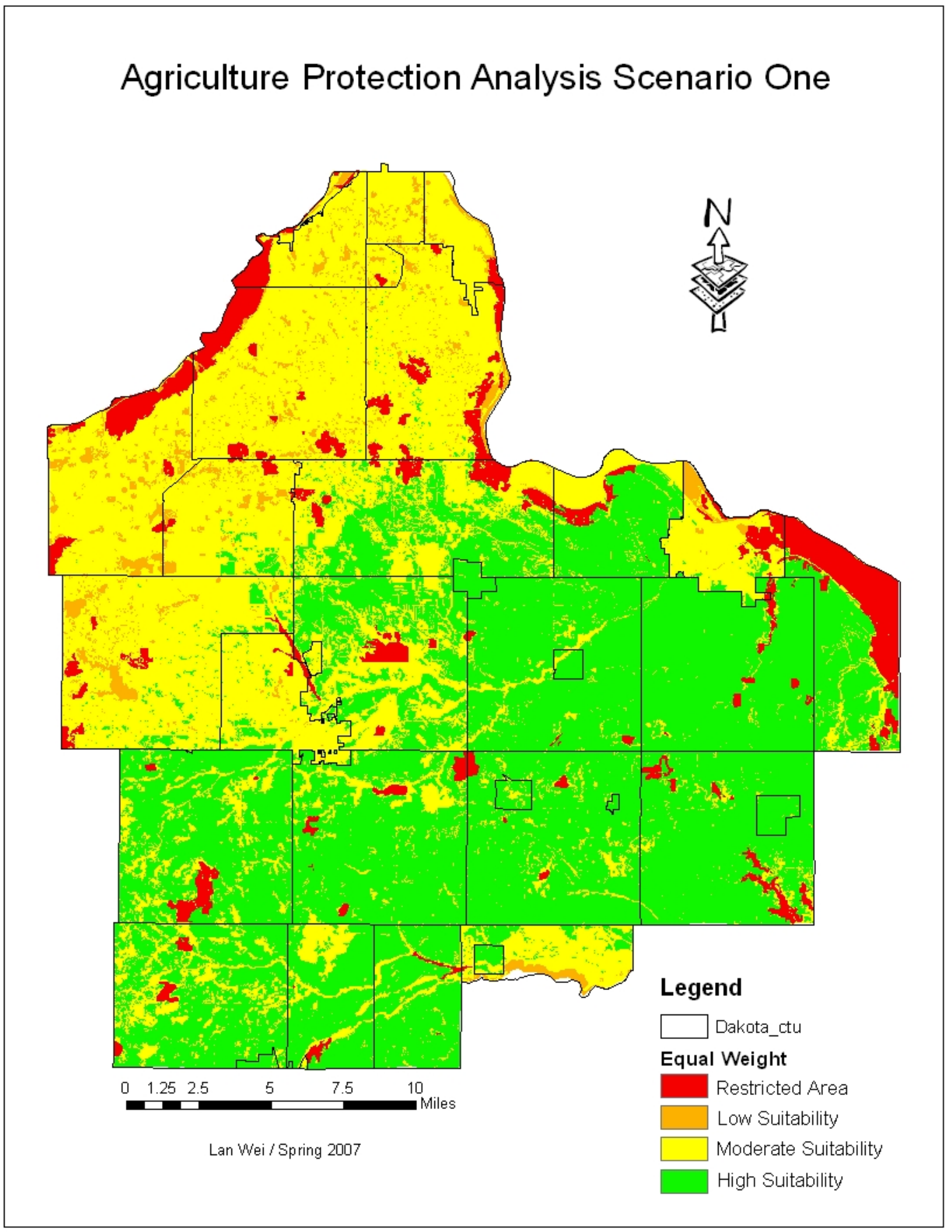

Figure 5. 14 Agriculture protection analysis scenario one – Equal Weight

Table 5. 22 Agriculture protection analysis scenario one summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	50,412	11,211.37	2.99%
Moderate Suitability	2	681,885	151,647.72	40.48%
High Suitability	3	844,974	187,917.88	50.17%
Totals		1,684,306	374,581.00	100.00%

Scenario Two

In scenario two, I assigned 60% weight to the goals of "Minimize Environmental Cost" and "Minimize Environmental Impact" to emphasize the environmental aspect of agriculture protection analysis.

Table 5. 23 Scenario two – Environmental Aspect

Environmental Aspect	Goals	Objectives	% Influence	Variable (GIS Theme)
30%	Minimize Environmental Cost	Avoid natural resource areas	10%	Land Cover
		Avoid steep slopes	10%	Slope
		Avoid poor soil drainage	10%	Soil Drainage Class
30%	Minimize Environmental Impact	Avoid erosion to protection areas	15%	Distance from NWI
		Avoid valuable resource areas	15%	Distance from Natural Resource Areas
20%	Maximize Agricultural Productivity	Avoid low productivity agricultural areas	10%	Soil Prime Farmland Class
		Avoid flood areas	10%	Soil Flooding Frequency
20%	Comply with the 2030RDF	Be consistent with growth accommodation	20%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.15, we know that based on the assumptions we made in Agriculture Protection Analysis Scenario Two, as to "Minimize Environmental Cost" and "Minimize Environmental Impact", 50.78% of the land in Dakota County was rated high suitability, especially in the southeast part of the County. It is also noticeable that the result of Scenario Two is very similar to Scenario One. 2.42% of the total area of Dakota County was rated low suitability for agriculture protection.

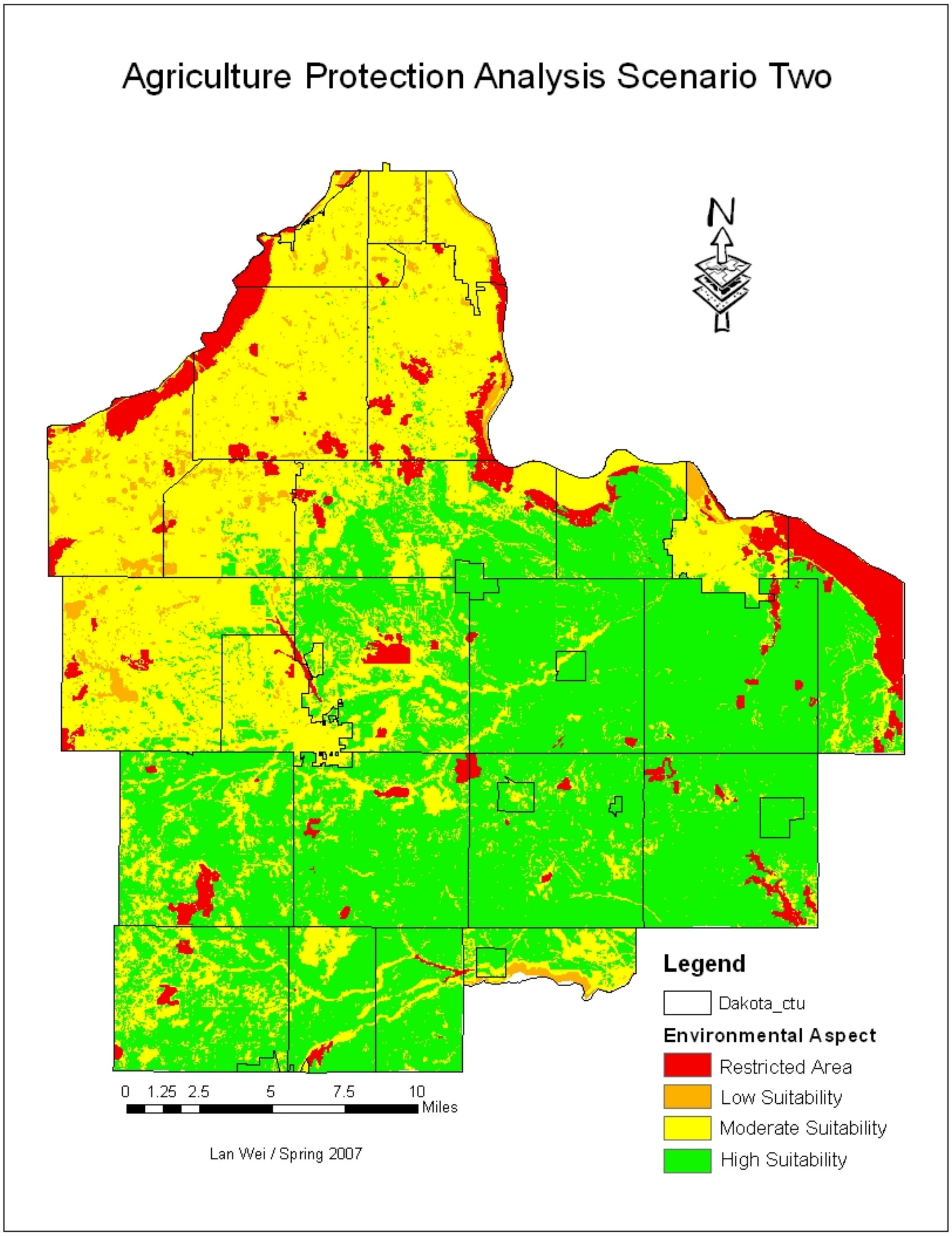

Figure 5. 15 Agriculture protection analysis scenario two – Environmental Aspect

Table 5. 24 Agriculture protection analysis scenario two summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	40,694	9,050.14	2.42%
Moderate Suitability	2	681,355	151,529.85	40.45%
High Suitability	3	855,222	190,196.98	50.78%
Totals		1,684,306	374,581.00	100.00%

Scenario Three

In scenario three, I assigned 40% weight to the goals of “Maximize Agricultural Productivity” to emphasize the agriculture productivity aspect of agriculture protection analysis.

Table 5. 25 Scenario three– Agricultural Productivity

Agricultural Productivity	Goals	Objectives	% Influence	Variable (GIS Theme)
20%	Minimize Environmental Cost	Avoid natural resource areas	7%	Land Cover
		Avoid steep slopes	7%	Slope
		Avoid poor soil drainage	6%	Soil Drainage Class
20%	Minimize Environmental Impact	Avoid erosion to protection areas	10%	Distance from NWI
		Avoid valuable resource areas	10%	Distance from Natural Resource Areas
40%	Maximize Agricultural Productivity	Avoid low productivity agricultural areas	20%	Soil Prime Farmland Class
		Avoid flood areas	20%	Soil Flooding Frequency
20%	Comply with the 2030RDF	Be consistent with growth accommodation	20%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.16, we know that based on the assumptions we made in Agriculture Protection Analysis Scenario Three, as to “Maximize Agricultural Productivity”, 50.23% of the land in Dakota County was rated high suitability, especially in the southeast part of the County. The result of Scenario Three is still very similar to Scenario One and Two. Nevertheless, about 6% of the total area of Dakota County was rated low suitability for agriculture protection, which was mainly located in the northwest part of the County.

Table 5. 26 Agriculture protection analysis scenario three summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	98,269	21,854.52	5.83%
Moderate Suitability	2	633,057	140,788.62	37.59%
High Suitability	3	845,945	188,133.82	50.23%
Totals		1,684,306	374,581.00	100.00%

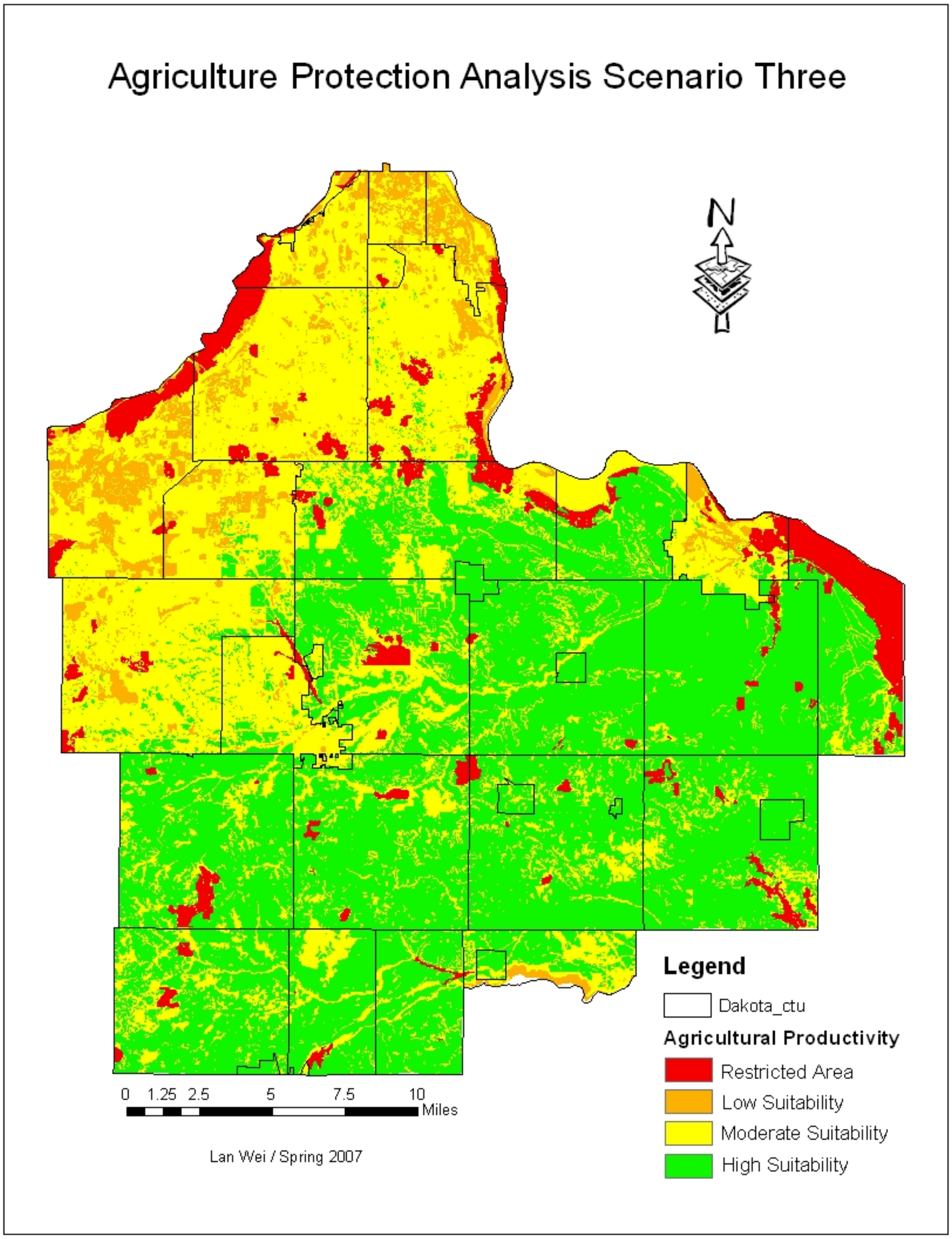

Figure 5. 16 Agriculture protection analysis scenario three – Agricultural Productivity

Scenario Four

In scenario four, I assigned 40% weight to the goal of "Comply with the 2030 Regional Development Framework" to emphasize the land use policy aspect of agriculture protection.

Table 5. 27 Scenario four – Land Use Policy

Land Use Policy	Goals	Objectives	% Influence	Variable (GIS Theme)
20%	Minimize Environmental Cost	Avoid natural resource areas	7%	Land Cover
		Avoid steep slopes	7%	Slope
		Avoid poor soil drainage	6%	Soil Drainage Class
20%	Minimize Environmental Impact	Avoid erosion to protection areas	10%	Distance from NWI
		Avoid valuable resource areas	10%	Distance from Natural Resource Areas
20%	Maximize Agricultural Productivity	Avoid low productivity agricultural areas	10%	Soil Prime Farmland Class
		Avoid flood areas	10%	Soil Flooding Frequency
40%	Comply with the 2030RDF	Be consistent with growth accommodation	40%	Land Use (2030 RDF)
100%	**Total Weight**		**100%**	**Total Influence**

As shown in Figure 5.17, we know that based on the assumptions we made in Agriculture Protection Analysis Scenario Four, as to "Comply with the 2030 Regional Development Framework", 50.09% of the land in Dakota County was rated high suitability, especially in the southeast part of the County. Again, the result of Scenario Four is very similar to the first three scenarios. Nevertheless, 6.46% of the total area of Dakota County was rated low suitability for agriculture protection, which was mainly located in the northwest and mid part of the County.

Table 5. 28 Agriculture protection analysis scenario four summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	108,888	24,216.13	6.46%
Moderate Suitability	2	624,723	138,935.18	37.09%
High Suitability	3	843,660	187,625.65	50.09%
Totals		1,684,306	374,581.00	100.00%

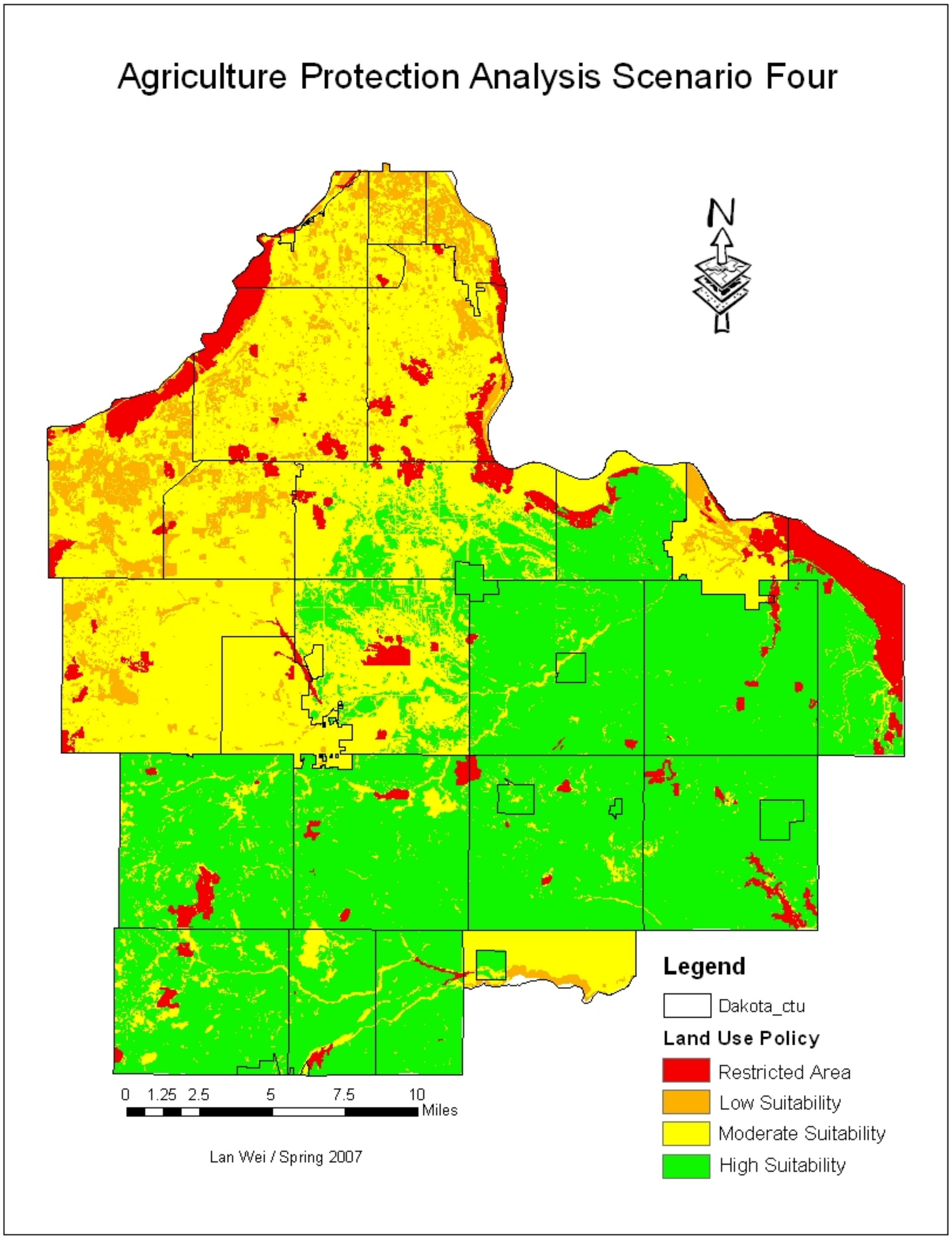

Figure 5. 17 Agriculture protection analysis scenario four – Land Use Policy

Comparison of Agriculture Protection Scenarios

As with the comparison of Urban Expansion Scenarios, I created Table 5.29 and highlighted the highest numbers of low, moderate and high suitability land in the corresponding scenario.

Table 5. 29 Comparison of agriculture protection scenarios

Raster Class	Scenario One (Cell Count; Percent)	Scenario Two	Scenario Three	Scenario Four
Restricted Area [0]	107,035 (6.35%)	107,035 (6.35%)	107,035 (6.35%)	107,035 (6.35%)
Low Suitability [1]	50,412 (2.99%)	40,694 (2.42%)	98,269 (5.83%)	108,888 (6.46%)
Moderate Suitability [2]	681,885 (40.48%)	681,355 (40.45%)	633,057 (37.59%)	624,723 (37.09%)
High Suitability [3]	844,974 (50.17%)	855,222 (50.78%)	845,945 (50.23%)	843,660 (50.09%)
Totals	1,684,306 (100%)	1,684,306 (100%)	1,684,306 (100%)	1,684,306 (100%)

As shown in the above table, Scenario One (equal weight) has the most moderate suitability land for agriculture protection; Scenario Two (Environmental Aspect) has the most high suitability land; and Scenario Four (land use policy) has the most low suitability land.

Composite of Scenarios

As with the urban expansion suitability modeling, I used the *Combine* function to find the areas where agreement exists in all four scenarios. In other words, the suitability rating/ranking are the same in all four scenarios: high [3], moderate [2] or low [1] suitability for agriculture protection.

Furthermore, I reclassified agriculture protection analysis composite of scenarios, which includes 25 values, into five classes: restricted area [0], low suitability [1], moderate suitability [2], high suitability [3] and no agreement [9].

Table 5. 30 Agriculture protection analysis composite of scenarios summary

Raster Class	Value	Cell Count	Acres	Percent
Restricted Area	0	107,035	23,804.03	6.35%
Low Suitability	1	40,293	8,960.96	2.39%
Moderate Suitability	2	528,465	117,527.90	31.38%
High Suitability	3	734,733	163,400.84	43.62%
No Agreement	9	273,780	60,887.27	16.25%
Totals		1,684,306	374,581.00	100.00%

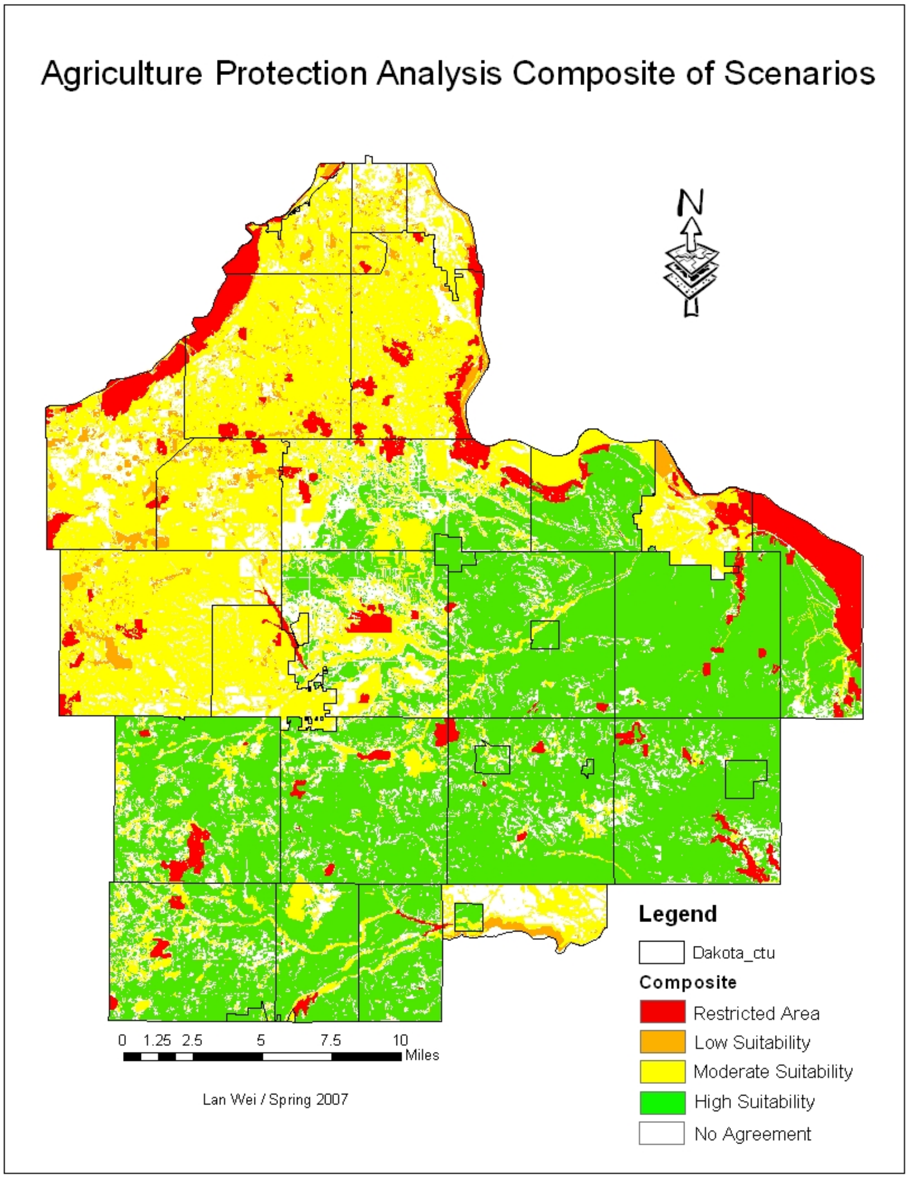

Figure 5. 18 Agriculture protection analysis composite of scenarios

As shown in Figure 5.18 and Table 5.30, we can conclude that 43.62% of the total area in Dakota County was rated high suitability in terms of agriculture protection in all four scenarios, most of which is located in the southeast part of the County.

III. 2030 RDF Review Based on Suitability Modeling

Based on the results of suitability modeling, the feasibility of the Twin Cities Metro Area's 2030 RDF was reviewed in terms of urban expansion and agriculture protection.

As shown in Figure 4.2. Growth accommodation in communities, Dakota County, seven different types of growth accommodation exist in Dakota County. To be able to compare the 2030 RDF with the results of suitability modeling, the 2030 RDF CTU feature class was converted to a raster dataset, having the land use information as the only value of the output raster. By using the "Polygon to Raster" tool, a raster dataset of the 2030 RDF growth accommodation was created, with seven values ranging from 0 to 6.

Table 5. 31 Growth accommodation in Dakota County data summary

Raster Class	Value	Cell Count	Acres	Percent
Agricultural Area	2	895,617	199,095.66	53.09%
Agricultural Preservation	1	3,992	887.42	0.24%
Diversified Rural	5	30,511	6,782.60	1.81%
Rural Residential	4	86,247	19,172.71	5.11%
Urban Reserve, Agricultural Area	6	194,203	43,171.33	11.51%
Urban Reserve	3	283,887	63,108.08	16.83%
Urban	0	192,654	42,826.98	11.42%
Totals		1,687,111	375,044.78	100.00%

To be consistent with the suitability modeling, I reclassified these seven types of growth accommodation into three categories: agricultural, urban and other, as shown in Table 5.32. Similar to the detection of land cover change, I used a Comparison Matrix table to not only compare the difference between the 2030 RDF and suitability modeling results, but also track high suitability areas that are suitable for urban expansion or agriculture protection. Because the class values from the suitability modeling are one-digit numbers (0, 1, 2, 3 and 9), I reclassified the 2030 RDF class values to two-digit numbers (10, 20 and 30). Therefore, the range/difference of the land cover datasets is distinguishable to detect the differences.

Table 5. 32 Reclassified growth accommodation and data summary

<table>
<tr><th>Growth Accommodation</th><th>Category</th><th>Value</th><th>Cell Count</th><th>Acres</th><th>Percent</th></tr>
<tr><td>Agricultural Area [2]</td><td rowspan="2">Agricultural</td><td rowspan="2">10</td><td rowspan="2">899,609</td><td rowspan="2">199,983.08</td><td rowspan="2">53.32%</td></tr>
<tr><td>Agricultural Preservation [1]</td></tr>
<tr><td>Diversified Rural [5]</td><td rowspan="3">Other</td><td rowspan="3">20</td><td rowspan="3">310,961</td><td rowspan="3">69,126.63</td><td rowspan="3">18.43%</td></tr>
<tr><td>Rural Residential [4]</td></tr>
<tr><td>Urban Reserve, Agricultural Area [6]</td></tr>
<tr><td>Urban Reserve [3]</td><td rowspan="2">Urban</td><td rowspan="2">30</td><td rowspan="2">476,541</td><td rowspan="2">105,935.06</td><td rowspan="2">28.25%</td></tr>
<tr><td>Urban [0]</td></tr>
<tr><td>Totals</td><td colspan="2"></td><td>1,687,111</td><td>375,044.78</td><td>100.00%</td></tr>
</table>

1. Compare with Urban Expansion Analysis Results

Instead of comparing the 2030 RDF growth accommodation with four scenarios of the urban expansion analysis separately, I used the composite of four scenarios as the generalized results of the urban suitability modeling. The comparison was done by using the *Cell Statistics* function to calculate the range (difference between largest and smallest value) of the two input datasets.

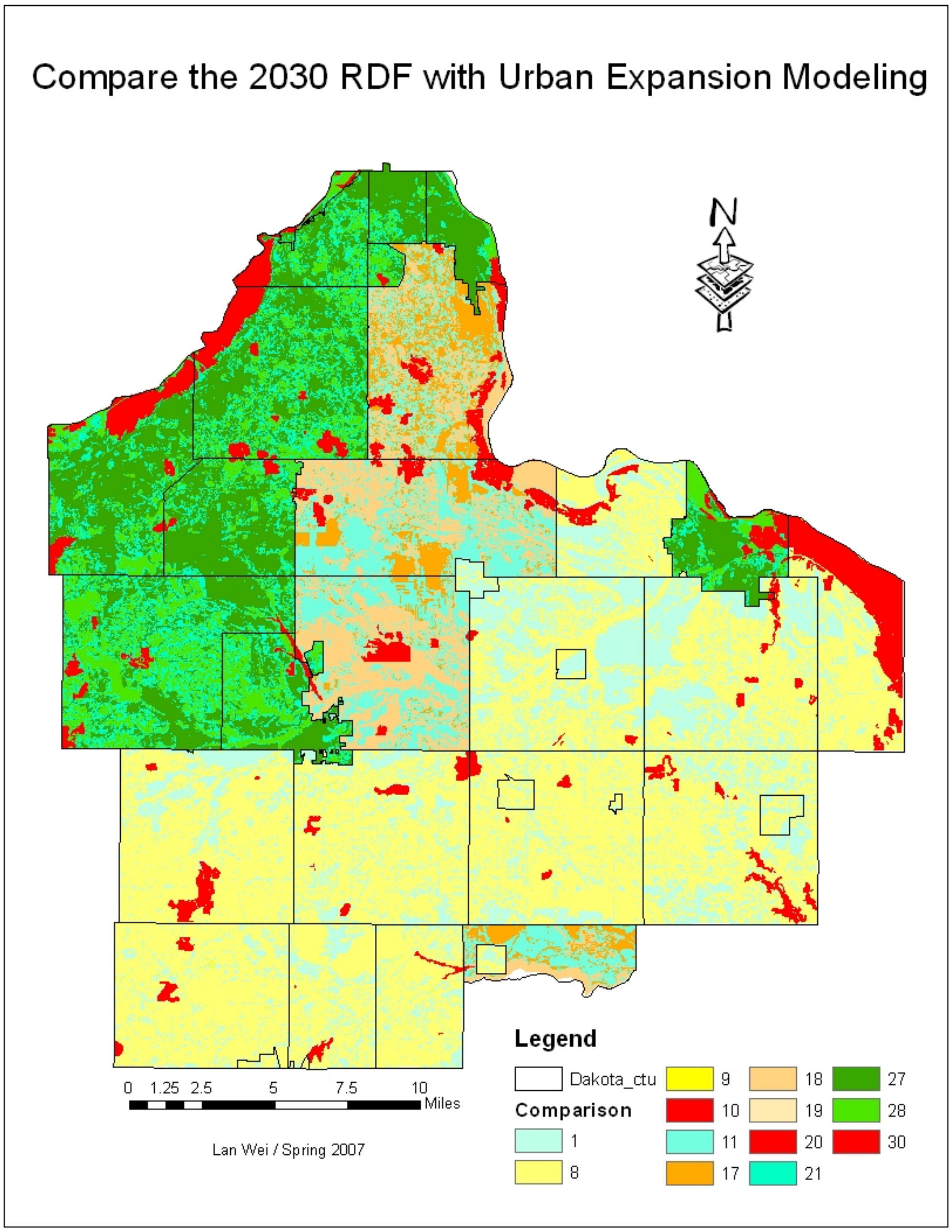

Figure 5. 19 Comparison matrix of 2030 RDF with urban expansion modeling

Table 5. 33 Comparison of 2030 RDF and urban expansion analysis results

2030 RDF / Urban Expansion	Urban [30]	Other [20]	Agricultural [10]	Total
High Suitability [3]	**223,093** 79.66% (R) 46.87% (C)	56,962 20.34% 18.38%		280,055 100%
Moderate Suitability [2]	102,427 12.42% 21.52%	**114,708** 13.91% 37.01%	607,738 73.68% 67.63%	824,873 100%
Low Suitability [1]		10 1.38% 0.00%	**717** 98.62% 0.08%	727 100%
Restricted Area [0]	38,321 35.80% 8.05%	21,609 20.19% 6.97%	47,105 44.01% 5.24%	107,035 100%
Other [9]	112,114 23.76% 23.56%	116,611 24.72% 37.63%	243,075 51.52% 27.05%	471,800 100%
Totals	475,955 100%	309,900 100%	898,635 100%	**1,684,490** 100% 100%

To fully understand this part of analysis, Figure 5.19 and Table 5.33 needed to be read together. Take, for example, the developed (urbanized) land in the 2030 RDF. In order to find out how much of the developed land in the 2030 RDF is actually suitable for urban growth based on the Urban Expansion Analysis, we can go to Table 3.51 to read the corresponding cell. In this case, the value was represented in the table as Urban (2030 RDF) [30] – High Suitability (Urban Expansion Analysis) [3] = 27, as in a dark green color in the map. As shown in the dark green highlighted cell in the table, 223,093 cells in the map were developed land in the 2030 RDF, which were also with high suitability for urban growth based on the Urban Expansion Analysis. To put in another way, almost 50% of the land with high suitability rating of urban expansion will become urban land use based on the 2030 RDF. Such land was displayed in the northwest part of Dakota County, as well as in the Hastings Community (Dakota County part). The above results were consistent with the population change analysis, urbanized area analysis, the land cover change analysis, as well as the 2030 RDF.

2. Compare with Agriculture Protection Analysis Results

As with the comparison of the 2030 RDF with the urban expansion analysis results, I compared the 2030 RDF with the composite of four scenarios as the generalized results of the agriculture protection modeling. The comparison was done by using the *Cell Statistics* function to calculate the range of the two input datasets.

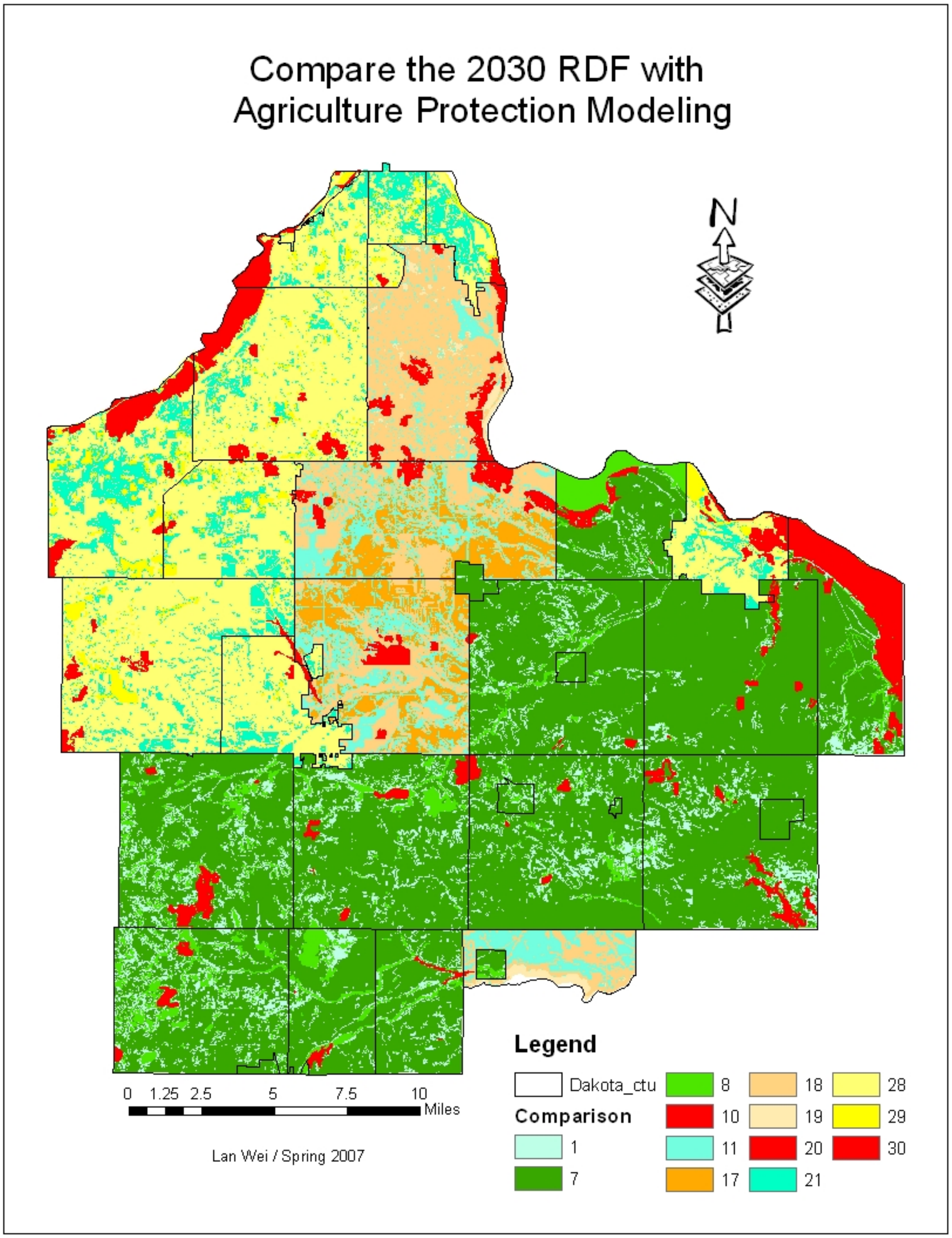

Figure 5. 20 Comparison matrix of 2030 RDF with agriculture protection modeling

Table 5. 34 Comparison of 2030 RDF with agriculture protection analysis results

Agriculture Protection \ 2030 RDF	Agricultural [10]	Other [20]	Urban [30]	Total
High Suitability [3]	**677,661** 92.23% (R) 75.42% (C)	57,072 7.77% 18.42%		734,733 100%
Moderate Suitability [2]	64,843 12.27% 7.22%	142,707 27.00% 46.05%	320,915 60.73% 67.44%	528,465 100%
Low Suitability [1]		7,785 19.32% 2.51%	32,508 80.68% 6.83%	40,293 100%
Restricted Area [0]	47,105 44.01% 5.24%	21,609 20.19% 6.97%	38,321 35.80% 8.05%	107,035 100%
Other [9]	108,927 39.79% 12.12%	80,726 29.49% 26.05%	84,127 30.73% 17.68%	273,780 100%
Totals	898,536 100%	309,899 100%	475,871 100%	**1,684,306** 100% 100%

As with the Urban Expansion and the 2030 RDF comparison, results were shown in a map (Figure 5.20) and a table (Table 5.34). In order to find out how much of the agricultural land in the 2030 RDF has high suitability based on the Agriculture Protection Analysis, we can go to Table 3.52 to read the corresponding cell. In this case, the value was represented in the table as Agricultural (2030 RDF) [10] – High Suitability (Urban Expansion Analysis) [3] = 7, as in a dark green color in the map. As shown in the dark green highlighted cell in the table, 677,661 cells in the map were agriculture land in the 2030 RDF, which were also with high suitability for agriculture protection based on the Agriculture Protection Analysis. To put in another way, about 75% of the land with high suitability rating of agriculture protection will become agriculture land use based on the 2030 RDF. Such land was displayed in the southeast part of Dakota County. The above results were consistent with the population change analysis, urbanized area analysis, the land cover change analysis, as well as the 2030 RDF.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This chapter answers the research questions posted in Chapter One. Furthermore, it provides conclusions and recommendations for future research and studies based on the results of this thesis research.

I. Conclusions

Using the research questions posed in the introduction chapter, I made the following conclusions based on the results found in Chapter Four.

What are the land use policies and plans of the study area? How do such policies and plans influence urban growth and development?

- The 2030 Regional Development Framework (2030 RDF) is the initial "chapter" and unifying theme of the Metropolitan Council's metropolitan development guide. Together with the Metropolitan Council's regional policy plans, the Framework is intended to help ensure the orderly, economical development of the seven-county area and the efficient use of four regional systems: transportation, aviation, water resources and regional parks and open space (Metropolitan Council 2006).
- In Dakota County, there are a total of 34 communities of seven different types of growth accommodation: agricultural area; agricultural preservation; diversified rural; rural residential; urban reserve, agricultural area; urban reserve; and urban. Specific growth accommodations are assigned to different communities based on their spatial location and existing natural resources.
- According to the 2030 RDF, 18 out of 34 communities in Dakota County are dominated with agricultural land use (southeast part of Dakota County); urban growth will continue to take place surrounding the Twin Cities urbanized area (northwest).

What was the population change of Dakota County from 1990 to 2000?

- From 1990 to 2000, the total population of Dakota County increased from 275,227 to 355,904, an increase of 29.31%. Spatially, except for some areas in the northwest of Dakota County, the entire County experienced population increase from 1990 to 2000. Most of the population increase took place surrounding the high population areas in 1990 in the northwest part of Dakota County. Furthermore, population inclined to spread from higher population areas to lower population areas.
- In terms of population density, most of Dakota County faced an increase in

population density from 1990 to 2000: some increase was subtle, whereas there was some noticeable large increase scattered in the northwest part of Dakota County. There was also some decrease in population density in the southeast as well as some scattered areas in the northwest part of Dakota County.

- From 2000 to 2030, the population in Dakota County will continue to increase from 355,904 to 517,010, an increase of 45.27%, based on the population forecast provided in the 2030 RDF. Spatially, most of the population increase is expected to take place in the northwest part of Dakota County, surrounding the highly populated Twin Cities urbanized areas at the northwest border.

<u>What land cover changes occurred in Dakota County between 1992 and 2001?</u>

- Generally speaking, more than 115,000 acres, about 30% of the total area of Dakota County, experienced land cover changes between 1992 and 2001. Moreover, most of the changes were occurred in the northwest part of Dakota.

- In 2001, about 50,000 acres, 13.52% of the total area of Dakota County, were urbanized/developed land converted from land cover types other than developed land since 1992. Furthermore, most of the growth/development was occurred in the northwest part of Dakota, surrounding the existing urbanized/developed areas with higher population. The community of Hastings (Dakota County part) also experienced noticeable urbanization land cover changes.

- The results of urbanization are consistent with the findings in the "population change" element. In other words, the results proved that population increase is a crucial factor that causes urban growth and land cover conversion.

<u>How did such changes affect natural resources?</u>

- The most converted land in 1992 was planted/cultivated land, which consisted of more than 72,000 acres of land, about 62% of the total area with changes occurred between 1992 and 2001. On the other hand, the most converted land in 2001 was developed land, which consisted of 50,729 acres of land, about 43% of the total area with changes occurred between 1992 and 2001. Some other noticeable land cover changes included the increase of forested upland and herbaceous upland, the reduction of wetlands, and the almost extinguishment of barren land.

<u>What is the spatial pattern of the land cover changes?</u>

- The results of the landscape pattern analysis show that the landscape of Dakota

County has become more continuous, clumped and more homogeneous – area and patch numbers of bog/marsh/fen decreased dramatically; cultivated land had the largest area, and increased; shape of patches became more regular in the landscape-level; and cultivated land and bog/marsh/fen became more connected.

What are the impacts of urbanization on land cover from year 1990 to 2000?

- It was concluded that planted/cultivated land contributed the most in terms of land cover conversion to developed land – 16.09% of the total planted/cultivated land in 1992 was converted to developed land in 2001, which consisted 47.59% of the total developed land. Such land was concentrated in the northwest part of Dakota County. In other words, agricultural land had been sacrificed most for urban growth to take place.
- Along with the conversion form planted/cultivated land to developed/urban land, other types of land cover, such as wetlands and barren, decrease as the urban area keeps expanding. The consequences of such impacts are more continuous, clumped and homogeneous land cover types. Such changes on land cover can bring significant negative impacts on wildlife species and natural resources.

Which areas are suitable for development in the future?

- For the purposes of finding suitable land for possible future urban development, Urban Expansion Analysis was conducted, with four scenarios based on different assumptions emphasizing four aspects: equal weight; economic cost, ecological cost; and land use policy from the 2030 RDF.
- As the results of the Urban Expansion Analysis, Scenario One (equal weight) has the most moderate suitability land for urban expansion and is the most consistent with the 2030 RDF; Scenario Two (economic cost) has the most high suitability land and is the least consistent with the 2030 RDF; and Scenario Four (land use policy) has the most low suitability land. In the composite map of these four scenarios, 16.63% of the total area in Dakota County was rated high suitability in all four scenarios, most of which is located in the northwest part of the County. The Community of Hastings (Dakota County part) is covered primarily by high suitability land as well.
- For the purposes of protecting agricultural land from future urban development, Agriculture Protection Analysis was conducted, with four scenarios provided based on different assumptions emphasizing four aspects: equal weight; environmental impact,

agricultural productivity; and land use policy from the 2030 RDF.

➢ Based on the results of the Agriculture Protection Analysis, Scenario One (equal weight) has the most moderate suitability land for agriculture protection; Scenario Two (Environmental Aspect) has the most high suitability land; and Scenario Four (land use policy) has the most low suitability land. In the composite map of these four scenarios, 43.62% of the total area in Dakota County was rated high suitability in all four scenarios, most of which is located in the southeast part of the County.

How can future decisions on land cover changes be influenced by knowledge of urbanization impacts?

➢ Based on the results of suitability modeling, the feasibility of the Twin Cities Metro Area's 2030 RDF was reviewed in terms of urban expansion and agriculture protection.

➢ 49,593.57 acres (223,093 cells, almost 80%) of the developed land in the 2030 RDF, is rated high suitability for urban growth based on the Urban Expansion Analysis. To put it another way, almost 50% of the land with high suitability rating of urban expansion will become urban land use based on the 2030 RDF. Such land was located in the northwest part of Dakota County, as well as in the Hastings Community (Dakota County part).

➢ 150,644.04 acres (677,661 cells, 92.23%) of the agricultural land in the 2030 RDF, has high suitability for agriculture protection based on the Agriculture Protection Analysis. To put it another way, about 75% of the land with high suitability rating for agriculture protection will become agriculture land use based on the 2030 RDF. Such land was located in the southeast part of Dakota County.

In conclusion, the results of the population change analysis, the land cover change analysis, landscape pattern analysis, and possible future development modeling were consistent with the 2030 RDF. Particularly, most of the urban development has occurred and is expected to take place in the northwest part of Dakota County, as well as in the community of Hastings. In contrast, most of the agriculture land in the southeast part of Dakota County has been or will be well protected under the guidance of 2030 RDF. From an environmental view point, the 2030 RDF limits unnecessary urban sprawl, in the meanwhile, maximize the possibility of agriculture protection.

Therefore, I am able to conclude that the 2030 RDF not only was generated under careful scrutiny so that it is feasible for Dakota County to employ, but also can be a guide for Dakota County to direct their future development.

II. Recommendations

1. ArcGIS and Extensions

Spatial Analyst extension provides a wide range of tools for cell-based analysis and modeling. More specifically, in this research, the spatial analyst extension and its various tools are especially helpful in terms of:

- Identifying spatial relationships, for example, detecting land cover changes;
- Creating and analyzing cells with values for doing cell-based spatial analysis, for example, helping conduct the landscape pattern analysis; and
- Finding suitable locations, for example, the land suitability modeling.

The combination of Model Builder and Personal GeoDatabase makes ArcGIS-based analysis easier. Model Builder helps organize the procedures in function, and can also be considered as a “notebook” in terms of recording all the steps that had taken, especially when the analysis was very comprehensive and a large number of tools were used. On the other hand, Personal GeoDatabase stored and organized both vector and raster data as a spatial database. It not only keeps the storage drive organized, but also normally uses smaller storage space. Furthermore, by storing the output features/datasets of Model Builder in a Personal GeoDatabase, the previous output features/datasets can be automatically replaced by the new output (using same name as the previous output) after updating and running Model Builder.

2. FRAGSTATS

In conclusion, this landscape pattern analysis provided several insights into the behavior and utility of landscape metrics. Landscape structure metrics were organized conceptually according to the aspect of landscape composition or configuration they supposedly measure. It is common for practitioners to choose metrics from each of the conceptual classes in order to describe different aspects of a landscape (Neel, McGarigal and Cushman 2004).

While landscape metrics have proven useful for describing landscape structure and hold promise for broader application, they are often difficult to interpret. Understanding expected metric behavior can aid in selecting and interpreting metrics that are sensitive to changes resulting from a phenomenon of interest (Neel, McGarigal and Cushman 2004).

This analysis demonstrates that the application of FRAGSTATS is an effective approach for analyzing the direction, rate and spatial pattern of land cover changes. However, there were some difficulties when using this software: (1) no tutorial material is available online or hard copy; (2) data have to be located on the local disk (rather than a network drive); and Arc Grid (raster) datasets cannot be loaded without ArcGIS.

3. 2030 RDF

Inevitably, the 2030 RDF has its limitations and can be improved better as guidance for Dakota County, as well as the Twin Cities Metro Area.

First, although there are 34 communities with corresponding growth accommodations, it is still not detailed enough to help decision makers, inside one community, to decide which parcel of land is suitable for urban growth or agriculture protection. To achieve this aim, the 2030 RDF should add more detailed information by sub-dividing the communities by Census blocks or block groups, or by land parcels, or by local land use or zoning maps. Ideally, information and maps will be enriched, and more types of growth can be developed to correspond with the more detailed development plan.

Second, different growth scenarios should be provided in the 2030 RDF from various perspectives, for example, urban expansion and agriculture protection. Scenarios in the suitability modeling process can emphasize on equal weight, economic cost, environmental cost and so on. In this way, it provides the governments or agencies some flexibility to make their decisions, under the premise of not harming the environment that people live in. Furthermore, it helps the decision makers understand how the growth accommodations were assigned, and how the 2030 RDF was formulated.

Last, the approach of Urban Growth Boundary (UGB) can be practiced in the 2030 RDF by specifying the areas that are anticipating urban growth by 2030. As a consequence, utilities, such as power lines, water and sewer lines, can be regulated to put inside the UGB; developers will take advantages of the exiting utilities and avoid high expenditures on infrastructure; and incentives for developing inside the UGB can be employed to diminish the negative effects of urban sprawl.

4. Future Research

For future studies, more FRAGSTATS metrics may be useful to measure characteristics of landscape change. For example, there are several groups of metrics that I did not test in this study, such as Core Area and Isolation/Proximity. To detect land cover changes from a comprehensive perspective, we can implement such metrics and analyze the results based on different aspects. Furthermore, I used only the land cover class “Urban” as the background in the project. In future studies, we can test metrics after selecting another class as background. For example, we can set all the other land cover types except “Urban” as background, and use FRAGSTATS to measure changes of urban areas.

In addition, other counties in the Twin Cities Metro Area can be examined so as to further test not only the research methods in this study but also the 2030 RDF. Furthermore, other data, such as socio-economic, land parcel, ownership and so on, can be added to the land suitability analysis, to increase the accuracy of the prediction of future possible development.

APPENDIX

1. Minnesota Land Cover Classification System (MLCCS)

Super System	Terrestrial								
System	Cultural		Natural / Semi-natural						
Level 1	Artificial surfaces with <96% Vegetation	Cultural Vegetation	Forests	Woodland	Shrubland	Herbaceous	Nonvascular	Sparse Vegetation	Open Water
numerical code	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000

2. National Land Cover Dataset (NLCD) 1992 Classification System

Land Cover	ID	Definition
Water	1x	All areas of open water or permanent ice/snow cover.
Open Water	11	Al areas of open water, generally with less than 25% cover of vegetation/land cover.
Perennial Ice/Snow	12	Al areas characterized by year-long surface cover of ice and/or snow.
Developed	2x	Developed Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).
Low Intensity Residential	21	Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
High Intensity Residential	22	Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.
Commercial/Industrial /Transportation	23	Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.
Barren	3x	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.
Bare Rock/Sand/Clay	31	Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.
Quarries/Strip Mines/Gravel Pits	32	Areas of extractive mining activities with significant surface expression.
Transitional	33	Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).
Forested Upland	4x	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.
Deciduous Forest	41	Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	42	Areas dominated by trees where 75 percent or more of the tree species `maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest	43	Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover

Land Cover	ID	Definition
		present.
Shrubland	5x	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.
Shrubland	51	Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.
Non-Natural Woody	6x	Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.
Orchards/Vineyards/Other	61	Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.
Herbaceous Upland	7x	Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.
Grasslands/ Herbaceous	71	Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.
Planted/Cultivated	8x	Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.
Pasture/Hay	81	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
Row Crops	82	Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.
Small Grains	83	Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
Fallow	84	Areas used for the production of crops that do not exhibit visable vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
Urban/Recreational Grasses	85	Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.
Wetlands	9x	Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.
Woody Wetlands	91	Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	92	Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

3. National Land Cover Dataset (NLCD) 2001 Classification System

Land Cover	ID	Definition
Water	1x	All areas of open water or permanent ice/snow cover.
Open Water	11	All areas of open water, generally with less than 25% cover of vegetation or soil.
Perennial Ice/Snow	12	All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	2x	Developed Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).
Open Space	21	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent 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.
Low Intensity	22	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
Medium Intensity	23	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
High Intensity	24	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.
Barren	3x	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.
Bare Land (Rock/Sand/Clay)	31	Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Unconsolidated Shore	32	Unconsolidated material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms representing this class.
Forested Upland	4x	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.
Deciduous Forest	41	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	42	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than

Land Cover	ID	Definition
		75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest	43	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
Shrubland	5x	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.
Dwarf Scrub	51	Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
Shrub/Scrub	52	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous Upland	7x	Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.
Grasslands/Herbaceou s	71	Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Sedge/Herbaceous	72	Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
Lichens	73	Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
Moss	74	Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	8x	Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.
Pasture/Hay	81	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
Cultivated Crops	82	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
Wetlands	9x	Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.
Woody Wetlands	90	Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	95	Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

4. FRAGSTATS Metrics

Area/Density/Edge		
Acronym	**Metric Name (units)**	**Description**
CA	Class area (ha)	Total area of all patches per class
PLAND	Percentage of landscape (%)	Equals the percentage the landscape comprised of the corresponding patch type
NP	Number of patches	The number of patches in the landscape
PD	Patch density (Number/100 ha)	Number of patches on a per unit area
LPI	Largest patch index (%)	Percentage of the landscape composed of the largest patch
ED	Edge density (m/ha)	Edge length on a per unit area
LSI	Landscape shape index	Measure of class aggregation or clumpiness

Shape		
Acronym	**Metric Name (units)**	**Description**
SHAPE	Shape index	Equals patch perimeter divided by the minimum perimeter possible for a maximally compact patch
FRAC	Fractal Dimension index	Reflects shape complexity across a range of patch sizes
PARA	Perimeter-area ratio	Equals the ratio of the patch perimeter to area. Measure of shape complexity
CONTIG	Contiguity index	Assesses the spatial connectedness or contiguity of cells within a grid-cell patch to provide an index of patch boundary configuration and patch shape
PAFRAC	Perimeter-area fractal dimension	Reflects shape complexity across a range of patch sizes

Connectivity		
Acronym	**Metric Name (units)**	**Description**
COHESION	Patch cohesion index	Measures the physical connectedness of the corresponding patch type
Connect	Connectance index	Percentage of the maximum possible Connectance given the number of patches. Based on either Euclidean distance or functional distance

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