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Urban Growth Patterns and Effectiveness of the Metropolitan Urban Service Areas in
Woodbury, Minnesota

By

Danielle R. Thomas

A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

In

Geography

Minnesota State University, Mankato

Mankato, Minnesota

May 2012

Urban Growth Patterns and Effectiveness of the Metropolitan Urban Service Areas in
Woodbury, Minnesota

Danielle R. Thomas

This thesis has been examined and approved by the following members of the thesis
committee.

Fei Yuan, Ph.D, Advisor

Martin Mitchell, Ph.D

Raymond Asomani-Boateng, Ph.D

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Abstract

This study evaluates the effectiveness of a specific urban sprawl containment strategy called the Metropolitan Urban Service Areas (MUSA). MUSA was developed for Minneapolis/St. Paul in order to ensure organized and practical development in areas that already had pre-built roads and sewer system infrastructures. Currently, MUSA is not an urban boundary; its specific goal is to, “synchronize urban growth with the provision of infrastructure needed to accommodate growth” (Council, August 2006). To evaluate the rigidity of the MUSA boundaries, the sample years of 1990, 2000, 2010 and the projected 2020 boundaries were subjected to spatial analysis utilizing three different software programs.

The following research questions were addressed: (1) Has MUSA been effective in limiting low-density development growth in Woodbury, MN? (2) Are the boundaries established by MUSA adaptable or more rigid? (3) How can the current strategy be improved to increase the effectiveness of urban growth control?

The research found a redefinition of the MUSA boundaries is necessary to curb urban expansion in Woodbury. The city of Woodbury and the Metropolitan Council can use this research as a model for regulating urban sprawl in fast-growing suburbs within designated MUSA boundaries. By adjusting the rigidity and the resulting effectiveness of the MUSA boundaries, a projected 3.1 billion dollars needed in order to provide infrastructure to low-density developments would be reduced.

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Chapter 1: Introduction

1.1 Research Objectives

Cities worldwide have developed a variety of strategies such as greenbelts (as seen, for example, in England and Spain), greenhearts (as seen in the Netherlands and Austria), and urban growth boundaries (as seen in Portland, Oregon) in order to combat urban sprawl. Each strategy has its own strengths and weaknesses; it is difficult to rate any of these strategies over the other. Nonetheless, it is important to study and evaluate the effectiveness of urban sprawl containment strategies.

A region's capacity for wastewater treatment and transportation infrastructure puts restraints on the quantity of land available to rapidly expanding cities (Yuan, 2010). The purpose of this study is to evaluate the effectiveness of a specific urban sprawl containment strategy called the Metropolitan Urban Service Areas (MUSA). MUSA was developed for Minneapolis/St. Paul to ensure organized and practical development in areas with pre-existing roads and sewer system infrastructure. There is intense debate pertaining to the flexibility of the MUSA boundary. Currently, MUSA is not an urban boundary; its specific goal is to, "synchronize urban growth with the provision of

infrastructure needed to accommodate growth” (Metropolitan Council 2006). Some advocates argue that MUSA should be defined as a strict urban growth boundary that would halt inefficient use of space and fill in low density developments.

The Metropolitan Council is presently supporting a balanced MUSA by planning for expansion while also advocating for efficiency (Metropolitan Council 2006; Mondale and Fulton 2003). MUSA boundaries from the years 1990, 2000, 2010, as well as projected MUSA boundary for the year 2030, were spatially analyzed to evaluate the rigidity of MUSA pre-and-post-implementation.

On a regional level, the Minneapolis/St. Paul area faces a looming problem resulting from lack of urban growth restrictions. The area is forecasted to require \$3.1 billion worth of new water and sewage services, to provide for an increase in population between now and 2020 (Brown et al. 2010).

This research addresses the following questions: (1) has MUSA been effective in limiting low-density development growth in Woodbury, MN? (2) Are the boundaries established by MUSA adaptable or more rigid? (3) How can the current strategy be improved to increase the effectiveness of urban growth control? The City of Woodbury was chosen because Yuan (2010) identified Woodbury as one of the two fastest growing communities in the Twin Cities area over the next twenty years, contingent upon MUSA expanding to support such rapid urban growth.

To establish a well-rounded evaluation of Woodbury’s growth and relationship with MUSA, three different software programs are utilized: ArcGIS, ERDAS Imagine

and IDRISI Taiga. The expectation is to allow spatial visualization of the growth of the Woodbury area due to the less rigid MUSA boundaries (Metropolitan Council 2006). A proposed Land Cover Model will show specifically how urban and rural land cover fluctuates depending on the rigidity of the MUSA boundaries in Woodbury, MN. Another expectation is to portray how Woodbury's proposed growth will continue to increase and subsequently its effects on the MUSA boundaries.

The research will prove that redefining the MUSA boundaries are necessary in order to curb urban expansion in Woodbury. The City of Woodbury and the Metropolitan Council will be able to utilize this research as a model for Woodbury and for other fast-growing suburbs within the designated MUSA boundaries, such as Lakeville, Minnesota. By examining the rigidity of the MUSA boundaries and their resulting effectiveness, the projected 3.1 billion dollars needed to provide infrastructure to low-density developments outside of present MUSA boundaries can be reduced as well as other possible issues resulting from low-density development.

Chapter 2: Literature Review

2.1 Background

2.1.1 Land Use and Land Cover Change and Its Impacts

Land use and land cover change (LULCC) are the alterations of the Earth's surface by mankind. For thousands of years, humans have shared the land to for purposes of sustenance and shelter. According to Campbell (2007), "Land use describes use of the land surface by humans. Normally, use of land is defined in an economic context, so we think of land as it is used for agricultural, residential, commercial, and other purposes. Land cover describes the visible features of Earth's surface- including in the vegetative cover, natural and as modified by humans, its structures, transportation and communications. As a practical matter, we must consider land use and land cover together, although also recognizing the distinction between the two."

The definitions of land use are subjective and vary between experts. Various definitions involve the amalgamation of social and scientific methods, which are used to distinguish between various human activities in relation to different portions of

the natural environment. According to *The Encyclopedia of Earth*, “Social scientists and land managers define land use more broadly to include the social and economic purposes and contexts for and within which lands are managed (or left unmanaged), such as subsistence vs. commercial agriculture, rented vs. owned, or private vs. public land” (Ellis and Pontius 2010).

Human activities such as economic factors, growth, governmental policies, and technology greatly affect LULCC. Complex interactions contribute to changes in the land use and cover. Such interactions include complex relationships between physical, biological, economic, political, and social aspects (Göl et al. 2010). Some argue that the leading cause of LULCC is consumption by humans; as demand for resource increases, more land is converted in order to suit that demand.

Another cause of LULCC results from the advancements in technology, which has allowed intense and efficient methods of alteration to occur. Heavy mechanized equipment used for the logging and mining industries is an example. These advancements cause a much more rapid conversion of land. Also, it appears that the set value of in situ natural resources is not high enough to compete with the drive to replace these resources with more profitable products, such as cash crops. The inefficient use and mismanagement of valuable natural land and resources by government bodies is another contributor to LULCC. For example, government-implemented incentives are used to advance urbanization and the growth of the local economy without taking into

consideration the effects of growth on its regional surroundings (Carr et al. 2005). In other words, cumulative effects are ignored.

There are several other causes associated with LULCC. These causes affect climate, ecology, and society, making LULCC a major contributor to the global environmental change (Campbell et al. 2005). For example, one of the impacts of LULCC is the loss of biodiversity. As LULCC increases and human habitats encroach on natural habitats such as forests, wetlands, and other ecosystems, these habitats are broken into smaller and smaller pieces, resulting in fragmentation of habitat. These fragmented habitats support a smaller number of individuals, and a more limited number of species, which can lead to divergence in the species and eventually to extirpation or in extreme cases, extinction. This can occur not only in animal populations, but also in plant populations, and as these situations become more and more frequent, the effect seen on the global ecosystem has the potential to be devastating.

The increase in human manipulation of the natural environment has led to extreme changes in ecosystems and environmental processes on a global scale. These changes have contributed to environmental concerns of unprecedented magnitude, including global climate change, loss of biodiversity, and extreme pollution of water bodies, soil, and atmospheric quality. Keeping tabs on the changes seen in the natural world caused by LULCC has become a matter of great concern to ecological researchers and politicians worldwide.

2.1.2 Sustainability and Sustainable Land Management

Sustainability, as defined by the United States Environmental Protection Agency (EPA), “creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of future generations” (What is sustainability? 2011). First brought into the planning spotlight, in the 1970s, the idea of sustainability was considered a radical concept. This radical idea became more mainstream when the Brundtland Report, proposed at the 1987 World Commission on Environment and Developments; brought sustainability to the forefront by integrating sustainability into the urban planning theory (Arbury 2005).

One of the greatest challenges in the struggle to maintain earth’s resources and natural systems is achieving sustainable land management. As human population increases, so does the need for food and natural resources. The struggle lies in maintaining a balance between being able to supply for a growing population while at the same time preserving the ecological richness of the natural environment. The changing landscapes have global, regional and local impacts, and it is the responsibility of mankind to ensure that as human population grows, the ecological impacts of this growth do not exceed the earth’s carrying capacity and expending the earth of its available resources.

Management of land refers to a wide range of policies and practices. The foremost of these is to establish biological reserves, which exclude human presence in order to preserve biological habitats. The next is to set up preserves in which human

presence and participation are allowed but the impact of human presence is restricted by strict regulation. These uses can also be used to the economic advantage of national, state, and local governments. An emphasis has been placed recently on the restoration of land, which has been altered or stripped of its original purpose for human uses (Ellis and Pontius 2010).

For example, there has been a push for greater management of existing agricultural and natural land as well as a nourishment of natural habitats existing within urban areas. Ever-increasing emphasis is being placed on the restoration of land, which has been reduced in quality due to overgrazing and mismanagement of soil nutrients. Enacted by Congress in 1985, the Conservation Reserve program, which takes 36 million acres out of production and restores them to native grasses, is a prime example (Mitchell and Kimmell 2009).

In addition to misuse of existing agricultural land, demand for land for industrial uses and residential uses has caused the changeover of some of the most productive agricultural land in the world. There have been efforts made in terms of initiation of policies to reduce this loss of productive land, but the success of these is greatly impacted by the nature of the current global market and the demand created thereof.

Yet another threat that goes hand in hand with LULCC is the widespread adoption of automobiles as the primary form of transportation in an increasing number of countries worldwide. This has caused the conversion of useful agricultural land into highways as well as low-density developments, which sprout up alongside major highways. This

results in urban sprawl, a low-density spreading of large urban centers into the surrounding land. The ecological repercussions of this phenomenon are vast, and sustainable land management, defined as “a system of technologies and/or planning that aims to integrate ecological with socio-economic and political principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity (Hurni 2000),” is vital in these situations in order to avoid total consumption of useful agricultural land (Ellis and Pontius 2010).

2.1.3 Urban Sprawl and Urban Planning

Since the early 1950s, the dream of the American people has shifted from the inner city out to the suburbs. Many policies provided incentives to draw homebuyers to the suburbs, such as special low-interest loans. In addition, an increase in road construction and change in community design occurred, which caused a rise in automobile dependence (Brueckner 2007; Anas and Rhee 2006). The inner cities were left behind for the prospect of a happier life in the suburbs, which resulted in low-density developments and higher rates of employment decentralization (Bento et al. 2006). Now, sixty years later, America is finally feeling the effects of this fast and cheap development, especially as fuel prices rise and property values fall or remain level (Brown et al. 1998; Choguill 1994).

“Sprawl is the spreading out of a city and its suburbs over more and more rural land at the periphery of an urban area. This involves the conversion of open space (rural land) into built-up, developed land over time” (What is Sprawl? 2010). There is no unanimously accepted definition for urban sprawl, which makes analysis and evaluation challenging (Bhatta et al. 2010). For instance, Florida’s administrative code defines urban sprawl as, “an urban development, which is located in an area of rural and low-intensity urban uses.” In Lancaster County, Pennsylvania, urban sprawl was exhibited by the arrival of a new Wal-Mart. Lancaster County is the location of several Amish farms, and they feared that Wal-Mart’s presence would cause acceleration in the growth of big-box stores, subdivisions, and roads (Peiser 2001). Despite its many definitions, urban sprawl is an issue that concerns citizens of nations worldwide (Ji et al. 2006; Bhatta et al. 2010). This concern is caused by a wide spectrum of issues.

From a practical standpoint, prevalent issues include time wasted in commute and loss of land that had been used for other valuable purposes such as wildlife habitats and agriculture (Brueckner and Largey 2008; Brown et al. 2010; McDonald et al. 2009). A significant contributing factor in the conversion of valuable land is the undervaluation of open space, which results in excessive land consumption (Arbury 2005).

Other issues resulting from sprawl include social and aesthetic issues. Exclusion is one social issue, which becomes a problem as well as introversion of families and a decrease in community activity and awareness. Also, socioeconomic segregation occurs as a result of an exclusionary housing market (Arbury 2005).

There are several push-pull factors, which have caused inner-city residents to move to the suburbs. For example, good schools and safer neighborhoods draw families to the suburbs. In contrast, poor schools, high crime rates and deteriorating home values have contributed to poverty in city neighborhoods, and trapping some families in the inner city (Peiser 2001). Major aesthetic issues include loss of countryside which is valued for its beauty and an increase in monotony in low-density developments (Millward 2005). This monotonous development can be contributed to by planning professionals abiding to out-of-date zoning regulations, and homeowners opposing new zoning changes that would allow for higher-density housing, which they fear would affect their property values (Peiser 2001).

In 2000, the United States Census Bureau projected that the U.S. population would climb from its 280 million people that year to 420 million people by the year 2050, albeit much of this increase is due to immigration. In contrast, the country experienced a population increase in the previous century from 76 million people in 1900 to 150 million people in 1950 (Peretz 2010). The negative effects of rapid population increase and urban expansion can be seen clearly in many cities. In McAllen, Texas, for instance, the population grew forty percent between 1990 and 1996, which in return put high demand on already scarce water supplies. In Las Vegas, the fastest-growing city in the United States, the population grew 238 percent between 1990 and 1996. This equates to one new resident every nine minutes. As a result, air and water quality have become a critical

problem. Another example is the Minneapolis/St. Paul area, where new water and sewage services, which are projected to be needed to provide for an increase in population between now and 2020, will cost \$3.1 billion (Brown et al. 2010; Turnbull 2004).

The draw of having a large home on a spacious parcel of land with convenient automobile access to services and amenities, even at the expense of a greater commute, remains attractive to developers and prospective property owners, even if this way of life is unsustainable at the city or regional level. This creates a contradiction because, in many cases, this way of life is encouraged through public funding of new infrastructure or through mortgage subsidies promoting home ownership (Arbury 2005). However, the resulting sprawl causes several issues, as noted previously.

Presently, land use regulations support public health by making sure that there is enough air and light in structures, and also that adequate ingress and egress are available. Promoters of managed growth aim for a shift in thinking which would support public health, safety and welfare by reducing the amount of land being consumed, which in return would reduce the amount of money required for roads and infrastructure. More specifically, this way of thinking focuses on achieving resource conservation by reducing land consumption, infrastructure provision, housing occupancy costs, and public service costs (Burchell and Mukherji 2003).

Urban planners have implemented a variety of strategies in an attempt to contain urban sprawl. The growth of cities cannot be prevented, but it can be regulated. There are many urban planning strategies that address urban sprawl, some seemingly more effective than others. These strategies include land use plans, greenbelts and urban growth boundaries (Table 2.1). In order for an urban planning strategy to be considered successful, it needs to resolve the contradiction between the property owners' aspirations on the personal level versus their ideals for the city on a united level (Arbury 2005).

State	Type of Boundary	Authority	State-level Involvement	Support	Opposition	Presumption of Buildability	Dispute Resolution
Oregon	Urban Growth Boundary	State-wide legislation adopted in 1973.	Moderate.	Conservation/Environmental Organizations.	Developers; private property rights advocates.	Yes.	Land Use Board of Appeals.
Washington	Urban Growth Area	Washington Growth Management Act adopted in 1991.	Limited.	Conservation/Environmental Organizations; local governments.	Home builders associations; property rights advocates.	No.	Growth Management Hearings Board.
Minnesota	Urban Service Area	Regional Planning enabling legislation adopted in 1967.	Extensive.	Local governments; home builders associations.	Property rights advocates.	Reasonable Assurance.	Mediation.
Maryland	Growth Corridors	Maryland Smart Growth Act adopted in 1996.	Low to moderate.	Conservation/Environmental Organizations.	Local governments; private property rights advocates.	No.	Litigation at local level.
Florida	Urban Growth Boundary	Local Government Comprehensive Planning and Land Development Regulation Act adopted in 1993.	Moderate.	Conservation/Environmental Organizations.	Property rights advocates.	Reasonable degree of certainty; no vested rights.	Mediation; judicial review.
California	Urban Growth Boundary	Local Ordinances.	Limited.	Conservation/Environmental Organizations; local governments.	Home builders associations; property rights advocates.	Yes, but only in some cases.	Local government control.

Table 2.1: Examples of strategies that address urban sprawl and their parameters (Anderson 1999).

2.1.4 Urban Sprawl and Infrastructure

Infrastructure includes the financing mechanisms needed by a city in order to provide roads and water/sewer facilities. Typically, development is directed toward the areas with extra service capacity capabilities, versus areas where the expansion of infrastructure would be needed. The fiscal impacts are much more substantial when providing services to undeveloped land as opposed to providing to land which has already been serviced with public facilities.

Mathematical impact models were used by Burchell and Mukherji (2003) to produce U.S. estimates of differences in resources consumed according to a conventional development (sprawl uninhibited) growth model versus a managed growth model for the years 2000-2025. According to the study, “sprawl produces a 21% increase in amount of undeveloped land converted to developed land (2.4 million acres) . . . [and] furthermore sprawl causes about 10% more annual public service (fiscal) deficits (\$4.2 billion) and 8% higher housing occupancy costs (\$13,000 per dwelling unit)” (Burchell and Mukherji 2003).

The failure to properly plan for roads and infrastructure leads to greater issues while an area is being developed. However, if the infrastructure is built according to a regional plan, the issues may be short-term rather than permanent. Developers typically focus on individual subdivisions, but more focus needs to be directed toward the needs of the broader community in order to avoid the issues resulting from individual developers acting independently from the community ideals (Peiser 2001). This situation calls for effective comprehensive plans.

The multi-faceted nature of America's system of urban governance, with each interested group pursuing its own best interest, is a large reason for many of the consequences resulting from sprawl. Higher-income communities have the ability to attract high-end employers and retailers, as well as having the ability to exclude undesirable uses and fiscal strains. This capability to exclude often accentuates the differences between rich and poor suburbs and/or wealthier versus slum areas within the central cities. As the tax base of wealthier suburbs intensifies, the disparity between lower-income suburbs and the central city typically becomes more acute. The need for regional solutions is gaining acknowledgment. For example, Florida has attempted to control urban sprawl using a state-mandated review of comprehensive plans through the requirement that all infrastructure is to be in place before an area can be developed. This was instituted to ensure that water, sewer, roads and drainage were available (Peiser 2001).

2.2 Study Site

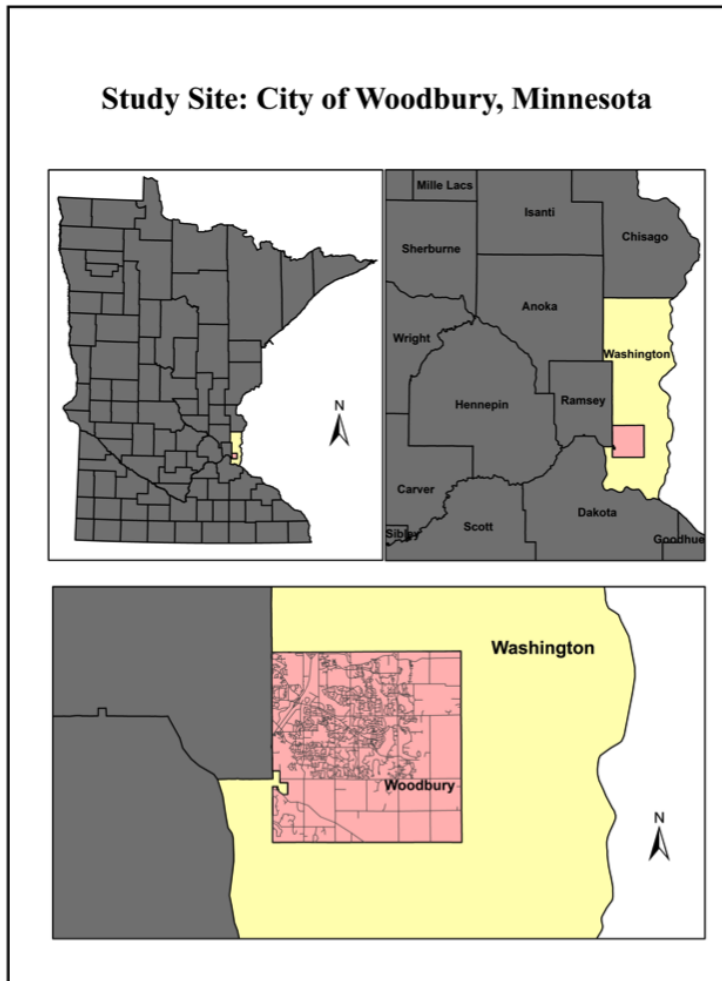


Figure 2.1: Location of the City of Woodbury in relation to Washington County.

Bordered by Interstate Highway 94, Interstate Highway 494, and Interstate Highway 694, the city of Woodbury is located 20 minutes from the Minneapolis/St. Paul International Airport, 15 minutes from downtown St. Paul, 25 minutes from downtown Minneapolis, and ten minutes from rail and port facilities. Direct access is available to the entire interstate system through seven interchanges.

2.2.1 Community Profile

Woodbury has been one of Minnesota's fastest-growing cities for the past 30 years, and it is currently the state's tenth-largest city. The population of Woodbury doubled from 1990-2000, growing from 20,075 residents in 1990 to 46,463. In 2010 it had approximately 60,000 residents, a 30% increase from 2000. It is estimated that the population will have reached 73,500 by 2020 and 84,000 in 2030 at full development. The mission statement of the Woodbury Community Development Department provides for, "planned development that produces and maintains high quality of life, a healthy environment and vibrant community, now and in the future" (Woodbury City 2011).

One of the problems associated with this growth is the stress on infrastructure, even though the city continues to push for new growth. At a meeting of Woodbury's Economic Development Commission on March 24, 2011, the question was raised as to whether Woodbury could continue its trend of rapid growth while still allotting the appropriate funds and energies into the maintenance of the pre-existing infrastructure. A delicate balance exists between the necessity for new growth and the upkeep of existing systems (Woodbury City 2011).

The city promotes itself as a secure location for business investment. Woodbury offers different competitive financing programs through their economic development authority to assist business expansion. Woodbury is home to three industrial parks: a 28-

acre Wooddale Center Industrial Park, a 70-acre Carver Lake Office Industrial Park, and the Woodbury Commerce Center, which takes up 100 acres. Another industrial park is also in the works with local residents in the northeast section of Woodbury. The suburb is also home to many big employers such as 3M, The Hartford, Assurant (formerly Fortis), Target.com, Woodwinds Health Campus, eFunds, EcoWater Systems, Woodbury Health Care Center, Dean Foods, Globe University, Allina, and Long Term Care Group.

Woodbury contains three large retail centers: Woodbury Village, Tamarack Village, and Woodbury Lakes center, which help to designate Woodbury as the central shopping district of the east metro region. Several colleges, universities, and technical institutions located near Woodbury, provide a more highly-skilled workforce for local businesses. Because of Woodbury's strong economic condition, they have not received local government aid for several years (Woodbury City 2011).

In 1967, the citizens of Woodbury approved, incorporated, and selected the mayoral form of government. The city council is made up of the mayor and four council members who are elected to serve four year terms. The city council legislates and sets the administrative policies (Woodbury City 2011).

The Woodbury Comprehensive Plan projects to the year 2030 and is a 2010 update of the 2000 comprehensive plan. The city council selected a 15-member citizen task force to update the comprehensive plan. The task force initiated a major public participation process by holding workshops to gather local suggestions in order to get residents' perspectives on the comprehensive plan. Once the task force completed its updates, the document was sent to the planning commission and the city council for

approval. Subsequently, the plan was submitted to surrounding communities for their comments. The final step involved Metropolitan Council's review of the plan. The Metropolitan Council found the plan met all the local and regional requirements. The adopted plan went into effect on July 14, 2010.

The comprehensive plan addresses land use and the phasing of development, housing, parks and trails, transportation, sanitary/sewer, water supply, and storm water management (Woodbury City 2011). The plan has a special focus on sustainability, growth management and infrastructure phasing; transportation system impacts on land use and livability, and redevelopment opportunities, among others items.

The land use and phasing section of Woodbury's 2030 comprehensive plan possesses two distinct phases directing growth for a 20-year time span. The first phase has been completed. Phase Two, calls for developing 2,150 acres, mainly residential uses except for a couple small-scale commercial projects. According to the land use and phasing section of Woodbury's 2030 comprehensive plan, Phase Two includes enough land to accommodate an average annual growth rate of 600 units per year over the next ten year period, from 2010-2020 (Figure 2.2). The city has begun planning for infrastructure to provide for Phase Two. The Woodbury staff has initiated a broad review of existing development-related policies covering residential infrastructure to growth management and school siting (Community Development Annual Report 2011).

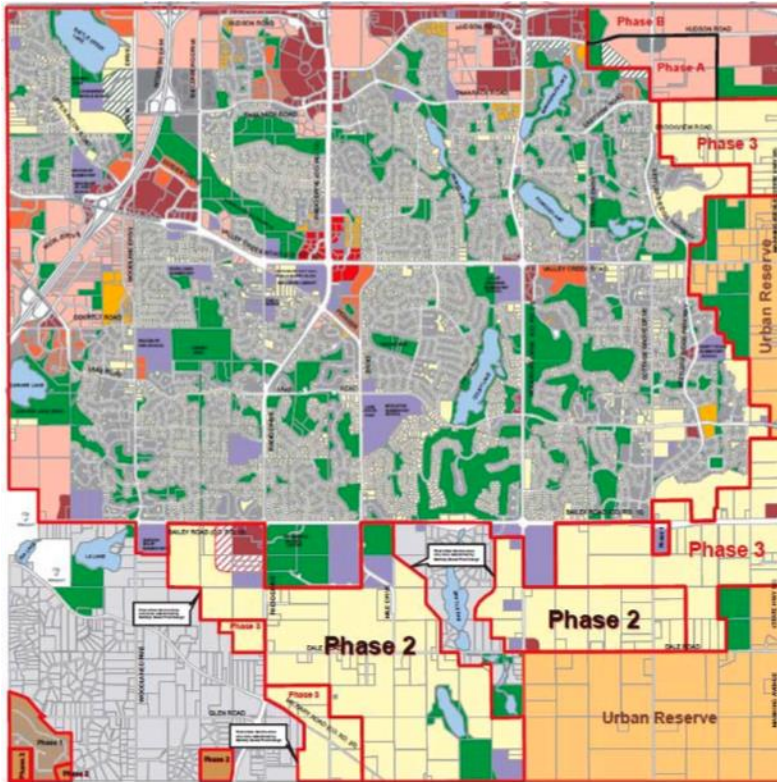


Figure 2.2: Land use and phasing section of Woodbury’s 2030 comprehensive plan (Woodbury City 2011).

The Woodbury park system, “consists of approximately 3000 acres of city-owned property, 130 miles of trails, 63 athletic fields, 38 play structures, 48 court facilities, 40 neighborhood parks, five major open-space sites, five community parks.” Neighborhood parks contain ball fields, tennis courts and picnic tables. In addition to a large skate park, Woodbury has a dog park, which spans 70 acres and includes mowed walking trails with benches, shelter areas, pet watering stations, trash containers and kiosks. Woodbury also owns a full 18-hole golf course on 225 acres of land.

Home to the Bielenberg Sports Center, its amenities include two indoor ice rinks, indoor dome field house, 18 softball/baseball fields, a sand volleyball court, play

equipment, and five miles of trails that wind through the complex, also, it is the future home of a specialty field designed to accommodate people with disabilities.

Woodbury was rated as one of the best places to raise kids in December 2010 by the website walletpop.com. *Money Magazine* rated Woodbury as thirteenth on its list of top 100 U.S. cities with populations between 50,000 and 300,000. Forbes.com also ranked Woodbury, MN as one of the best places to move to in July 2009.

2.2.2 Demographic Profile

Because of its many malls and shopping centers, Woodbury is a major shopping district within the east metro region, and its location near the St. Croix River Valley, provides a scenic locale and ample recreational opportunities for its citizens and visitors. The suburb is also known for a higher standard of living due, in part, to its “attractive residential neighborhoods, which are connected by more than 120 miles of multi-use trails,” as well as, “a wide choice of housing, ranging from apartments and townhomes to large-lot estates” (Woodbury City 2011).

Three independent public school districts have jurisdiction in Woodbury. The majority of the city is in the South Washington Country School District; the rest is covered by the Stillwater Area School District and the St. Paul-Maplewood-Oakdale district. The Washington Country School District operates six elementary schools, two middle schools, and two senior high schools.

The Woodbury workforce is highly skilled and rapidly growing. Over 50 percent of the residents (over age 25) hold a bachelor's degree. According to the 2005-2009 American Community Survey, the median family income was \$106,415/year, compared to the national average of \$62,363. Approximately 84% of the population are White/Caucasian, another 8% Asian, and the remaining 8% are Black/African American or other. Woodbury's average household size is 2.69 persons, with an average family size of 3.19 persons. The average residential property value in 2010 was approximately \$258,100 (Community Development Annual Report 2011).

The overall crime index in Woodbury as of 2006 was 2180.6 per 100,000 people, much lower than the national overall crime index of 4479.3 per 100,000 people. The overall crimes reported in Woodbury that year only came to 1152. Woodbury is considered a very safe community, with most of its crimes consisting of burglaries and thefts. The murder rate is extremely low (AreaConnect 2012).

2.2.3 Study Site- Historical

The City of Woodbury, in 1844, was mainly covered with timber. Wheat was the most highly produced crop, along with barley, corn, potatoes, and later, soybeans. In 1955, Woodbury Heights was the first housing development to be built. In the 1960s, urban development spread out into the farming community and began to replace

agriculture. Urban development continued as the metropolitan area grew in an easterly direction to allow more living space (Woodbury City 2011).

The City of Woodbury was originally named Red Rock, after a stone which had allegedly been painted by Dakota chief Little Crow. Renamed in 1859, because of a duplication of name with Red Rock township, Woodbury takes its name from Judge Levi Woodbury of New Hampshire, a friend of the first town board chairman. Most of the area's settlers migrated from Germany, Ireland, Sweden, Switzerland, and Scotland.

Originally, town meetings were held in the homes of citizens until 1876, when the first town hall was built. The city's first comprehensive land use plan was developed in 1967. In 1975, a new city hall was constructed, approximately 100 years after the construction of the original (Woodbury City 2011).

Since the 1970s, urban planners have implemented a variety of strategies in an attempt to contain urban sprawl. MUSA is an example of one such strategy. Other communities and cities have chosen other strategies such as land use plans with urban limit lines and/or greenbelts. Some examples include land use plans, greenbelts and urban growth boundaries. Geographic Information Systems (GIS) and Remote Sensing are new technologies, which are used to plan, implement and monitor the effectiveness of urban sprawl containment strategies.

2.3 Examples of Urban Containment Strategies

2.3.1 Comprehensive Plans

Comprehensive plans create a blueprint for the future development and preservation of a community. A good comprehensive plan guides not only the physical and economic development of the municipality, but also accommodates social, environmental and regional concerns. For example, the primary goal of the Swiss Land Use Plan, as dictated by Swiss federal law on spatial planning, is the economical use of Switzerland's scarce land area.

Gennaio et al. (2009) evaluated the effectiveness of a Swiss Land Use Plan and its effectiveness at regulating expansion within and outside of the building zones. Building locations were geo-coded onto a map along with construction dates and types of use for each building. In each city, compactness was calculated by dividing the number of buildings in the city by the area of land in different decades. A developed area was defined as an area containing at least three buildings with a maximum of distance between the buildings of seventy meters. A limitation of the equation is that if there were one or two buildings, they were counted as buildings but not as being on developed land. Thus the results for building density outside the building zone is skewed slightly too high. Population density was calculated by dividing the number of residents in each building zone by the amount of developed land in and outside the zone (Gennaio et al. 2009).

Gennaio et al. (2009) found the Swiss Land Use Plan effective at limiting the spatial extent of growth until sufficient infilling occurred. For example, they found 72 percent of buildings constructed within the building zones of rural areas and 98 percent within urban areas. The findings indicate the Swiss effectively enforced dense infill development within the building zones.

2.3.2 Greenbelts

A greenbelt, as defined by Amati and Yokohari (2004) refers to, “a zone of land around the city where building development is severely restricted.” Osborn (1969) defined a greenbelt as “a narrow strip of park land more or less encircling part of a built-up metropolitan or large urban area.”

Since the mid-1950s, greenbelts have played an important role in planning policies pertaining to the containment of urban sprawl. Consistency of land preservation is a sign of success in the implementation of greenbelts, particularly in the context of a growing urban population. Another way of measuring the success of greenbelt implementation is to analyze the degree of new construction on land that contains existing development. For example, an increase in residences (either in number or in total units per acre) on land already developed alludes to a more successful greenbelt. This helps maintain a sequential pattern in opening up land for further development. Yet another measure of success of greenbelt implementation is the density of residences within the developable land. A high density measurement of residences indicates that the greenbelt was effective and vice versa (Karecha 2006).

First implemented in London in the early 1900s, greenbelts did not become prevalent until the 1930s (Amati and Yokohari 2004; Tang et al. 2006; Osborn 1969). As a result of Britain's occupation of Hong Kong, China until 1997, we see many examples of British urban planning strategies, including greenbelts, being incorporated in Hong Kong (Li and Yeh 2004). The greenbelt system implemented in Hong Kong is a prime example. Because of Hong Kong's dense population and mountainous terrain where only 20% of its land is suitable for development. Presently, roughly 13 percent of the total territory is taken up by its greenbelt. Tang et al. (2006) conducted a cross-sectional analysis of Hong Kong to determine whether each region implemented a greenbelt policy and its purpose within each community. The analysis included: defining limits of development, containing sprawl, passive recreation, drainage, buffering, country park extension, limited development, and small house development (when justified). This analysis found that Hong Kong's implementation of its greenbelt policy does not meet their needs because the policy is too diffused and weak to support Hong Kong's expanding population and urban growth (Tang et al. 2006).

2.3.3 Urban Growth Boundaries

Urban Growth Boundaries (UGBs) are tools implemented to control urban sprawl by forcing developers to fill in gaps found in the area within the UGB. They are not designed to stop urban growth entirely, but rather to re-designate the areas in which expansion occurs (Carlson and Dierwechter 2007).

Urban Growth Boundaries are very difficult to implement appropriately; if allotted land for urban development is too great, sprawl becomes an issue, whereas too much limitation on allotted land can lead to inflation in property value (Knaap and Hopkins 2001; Abbott and Margheim 2008). It is possible to implement a UGB without serious detrimental effects on land prices, as shown by the city of Portland, where there was no visible increase in value of urban land directly attributable to the UGB after it was initiated (Jun 2004; Myung-Jin 2006; Knaap 1985).

Policy-oriented methodologies of UGB implementation have not been subject to extensive evaluation. Realizing this, Carlson and Dierwechter (2007) designed a new means by which to measure urban sprawl in order to analyze the impact of UGBs on the geographical area of Pierce County, Washington. Building permit data from 1991 to 2002 was geo-coded into a city street shape file. A Kernel density calculation was performed for each year, which provided analyses of the effectiveness of the UGBs in hindering urban sprawl. “Kernel density calculates the density of point features around each output raster” (Carlson and Dierwechter 2007). A kernel density calculation, which was used, creates a smoothly curved surface, which is fitted over each point location. The surface value reaches its peak at a point; as distance from the point increases, so does the surface value.

Carlson and Dierwechter (2007) demonstrated that once the new regulatory policy was implemented, a steady decrease of building outside the UGBs occurred and conversely a steady increase of building inside the UGBs. While certain private land

owners outside the UGBs were able to push their building permits through the new system, the trends in the regions both inside and outside the UGBs illustrate that the new policy was an overall success.

2.3.4 Use and Implementation of Urban Growth Boundaries (Minnesota)

Minnesota State law encourages but does not require that counties to establish urban growth areas. The Minnesota State Statutes defines an urban growth area as, “an area around an urban area within which there is a sufficient supply of developable land for at least a prospective 20 year period, based on demographic forecasts and the time reasonably required to effectively provide municipal services...” (462.352 *Minn Stat.* (2005)).

A city that chooses to adopt a comprehensive plan must recognize growth areas that are established by the county, although the city can also establish its own urban growth areas. Both the city and county must then enter into an annexation agreement with townships where unincorporated land is located within the designated urban growth area. Two new programs were created in 1997, one of which established the Advisory Council (Metropolitan Council) on Community-based Planning. This council provides opportunities for discussions on community-based planning, incentives, and the tools needed to implement the plans. The other program is called the Land Use Planning Pilot Program, wherein counties that participate must adopt urban growth areas. Later, the Council created permanent rural and agricultural areas outside of the MUSA boundary, in

which the Council does not plan to extend urban services until after 2040, if at all. By designating these areas, the Council estimates that 1.6 billion dollars will be saved on new public infrastructure.

Actual locations of the MUSA boundaries are stated in the comprehensive plans of counties and cities. The Council has the authority to review the plans and to promote new development adjacent to existing development. The variables used to determine where MUSA should be drawn are, "...the history of development in the area, the size of the population the area will need to accommodate, the condition of the transportation system, and the cost to provide housing and services to the areas where transportation corridors will be extended (2030 Regional development framework 2004)."

Several groups have supported the boundary, including environmental groups, local governments, and the Home Builders Association. The Home Builders Association supports MUSA because it helps to reduce the cost of infrastructure, and also increases certainty of when and where new growth will be located. A large amount of the success of the boundary can be attributed to focus groups, community meetings, and tours of different areas. MUSA has had opposition from individual landowners who live outside the boundary and feel that their development rights have been infringed (Anderson 1999).

Implementation of the boundary is achieved because the comprehensive plans are committed to providing regional and local service, Comprehensive Plan Review Agreements (CPRAs) are established between the Metropolitan Council, counties, and

cities, specifying roles, responsibilities, and commitments of service or timing of urban development and the appurtenant infrastructure.

If there is any disagreement over MUSA, mediation is used to negotiate some sort of settlement. If there is no settlement, the dispute will go to binding arbitration. A hearing is held, and unless it is appealed, the State Planning Department or the local government issues an order consistent with the decision of the hearing (572A.02 *Minn Stat.* (2005)). If the arbitrators find that the city's estimates in the comprehensive plan are reasonable, relative to an identified urban growth area, the arbitrators may order approval of the city's plan (572A.03 *Minn Stat.* (2005)).

If strong urban planning policies are implemented and continuous evaluations and improvements are made, then misuse of land and threat of urban sprawl will slowly diminish. Technological advances in the form of new, more powerful geospatial software as well as advancements in construction efficiency, which provide for faster development, have increased the pressure on geographers and planners, as well as development firms. Both remote sensing and GIS have been utilized by geographers and planners alike in order to curb the threat of excessive urban growth and development (Mesev 1997).

2.4 Delineating, Monitoring and Evaluating Urban Growth

2.4.1 Delineating Urban Growth using Remote Sensing

Remote sensing technology has been used in mapping and analyzing urban growth in the past four decades. There are several benefits and limitations when using remote sensing as a methodology. In Schneider and Woodcock (2008) conducted a study evaluating the similarities and differences of urban growth across twenty-five mid-sized cities throughout the world. Some cities included Warsaw, Poland; Alexandria, Egypt; Nairobi, Kenya; and Sacramento, California, to name a few. To measure the land cover of the twenty-five cities, the urban land cover class had to be defined based on the 30-m resolution Landsat images from 1990 and 2000. A simple unsupervised clustering (the k-means algorithm) of the stacked, multi-date images was employed to discern both stable and changed land cover classes. The classes were designated as follows: stable urban areas, urban expansion (any other type of land cover converted to urban land cover), and stable non-urban land cover types. The general idea is that change classes have distinct combinations of spectral signatures from non-change classes (Schneider and Woodcock 2008).

An accuracy assessment based on field data from ten of the twenty-five cities, revealed an accuracy rate of 84-97 percent for ten of the cities. Schneider and Woodcock (2008) found that patterns of expansion occurred in three distinct patterns: “(1) Small plots developed at the edge of the urban core, (2) large tract development adjacent to existing urban land (but not necessarily in/near the core); (3) and small, patchy areas of

newly converted land located farther from the established urban core path density” (Schneider and Woodcock 2008). Most of the cities studied fell into the latter pattern (Schneider and Woodcock 2008).

A successive series of 1-km rings originating at each city’s center measured the patch density and found it was incidence of most prevalence near the core edge of the city. This finding is no surprise in an area where residential and cropland are mixed with green space and natural/anthropogenic vegetation. Beyond the core edge, patch density decreased, which signifies the decreasing urban cover and a more rural or undeveloped landscape. In some cities, secondary peaks occurred, but they were in clusters of urban land beyond the city core. Schneider and Woodcock (2008) found that to attain a full picture of urban expansion, multiple measures had to be used to present a complete illustration of urban sprawl. Another finding of the study was that, with few exceptions, the U.S. was unique from the rest of the world in the large, dispersed nature of the spatial forms of its cities (Schneider and Woodcock 2008).

This case study was influenced in part by the inconsistency in data from each of the 25 cities in terms of zoning ordinances, enforcement of zoning laws, and whether the land was suitable for development. Had this data been accounted for, the development rates might have been higher for certain cities studied. Conversely, the fragmentation of urban land cover may have been effected more by land availability than by social or economic reasons (Schneider and Woodcock 2008).

Another study, conducted by Forkuor and Cofie (2011), produced a land use land cover change map in Freetown, Sierra Leone. Multi-temporal Landsat data of 1974, 1986, and 2000 was classified into nine separate land use land cover classes. The conversion of one land use to another was identified, and agricultural conversions were emphasized. A supervised classification was used on each of the Landsat images. The analysis showed that the built-up areas increased 140% between the years 1974 and 2000. 27% of the agricultural land was found to have been converted to residential purposes between 1986 and 2000. Forkuor and Cofie (2011) found that as the city expands, the competition for land increases. Urban farmers are unable to compete, and therefore lose their land, resulting in the increase in conversion of agricultural land to residential use. A setback that challenged the classification of pixels was that some types of land uses are spectrally similar to other classes. An example of this is urban built-up land having a similar reflectance to some barren land (Forkuor and Cofie 2011).

Mundia and Ainya (2005) performed a classification analysis to analyze the land use/cover changes and identify the urban land cover in Nairobi, Kenya. Three Landsat images from 1976, 1988, and 2000 showed that the built-up area increased by approximately 29 miles. The integration of demographic and economic data showed that economic growth and its spatial relation to transportation routes have been a major factor in promoting urban expansion. An unsupervised classification allowed spectral clusters to be highlighted. The IsoData Algorithm in ERDAS Imagine was then used to identify spectral clusters. This method uses a minimum spectral distance to assign a pixel to a

cluster. The study noted that population, economic development, and site location characteristics were significant in determining the land use/cover changes.

Similarly to Forkuor and Cofie's study, Mundia and Ainya (2005) experienced spectral confusion as the major cause of inaccuracy in classifications. In this study especially, this confusion was more apparent in urban/built up and transitional areas than in any other land use class. Spectral confusion can be reduced using filters, models etc. that can help improve the accuracy, but even with these tools it is difficult to eliminate all of the spectral confusion, a characteristic of satellite and aerial images that must be always taken into account.

2.4.2 Delineating Urban Growth using Geographic Information Systems

GIS analysis and modeling techniques have been widely used in urban growth studies. Yuan (2010) used GIS to illustrate how metropolitan growth can be driven by governmental policies in the Minneapolis-St. Paul or the Twin Cities Metro Area (TCMA) from various planning organizations. For the 2,975 sq. miles of land in the TCMA (including 189 Cities, Townships and Unorganized Territories (CTU)), The Metropolitan Council defined six geographic planning areas based on municipal boundaries, land use and comprehensive plan data. Categorized as either being urban or rural by Yuan (2010), the urban areas were further described as being either developing or developed. Rural areas were classified as (1) rural center, (2) agricultural, (3) diversified rural and (4) rural residential. In addition, a Metropolitan Urban Service Areas (MUSA) boundary was used to delineate the outer reaches of regional services for

a specific period of time. The land cover classifications and change analysis was used Landsat TM images from 1975 and 2006. Using the land cover change images as the value layer and the CTU boundary file as the zonal layer, a GIS zonal analysis of landscape change identified varying degrees and directional trends of urbanization (Yuan 2010). A zonal analysis occurs when an output raster shows where the tool analyzed the cell values from the input value raster that falls in each zone of a specified input zone.

Through this zonal analysis, the twenty cities, which had expanded the fastest, were identified. It was found that three counties had experienced more expansion than the others. The total urban area of the Twin Cities Metro Area was found to have grown 8,094 square miles between 1975 and 2006, taking the place of agricultural land, wetland and forestland. Most of the development over the 31-year span took place within the 2010 MUSA boundary as well as along major highways and roads (Yuan 2010).

A region's capacity for wastewater treatment and transportation infrastructure puts restraints on the quantity of land available to rapidly expanding cities (Yuan 2010; Sudhira, Ramachandra, and Jagadish 2004). The zonal analysis performed by Yuan (2010) identified two communities, Woodbury and Lakeville, Minnesota, which are predicted to be the two fastest growing in the TCMA for the next twenty years. However for Woodbury and Lakeville to grow as predicted, the boundary needs to be expanded.

The GIS-based change detection and zonal analysis offered crucial information for the analysis of patterns in urban landscape change.

Another way of using GIS to measure urban sprawl is by incorporating Network Density Estimation (NDE), which involves the observation of clusters of human-related events on a network (e.g. a city street grid) using spatial statistical tools in GIS software. Borruso (2008) contrasted Kernel Density Estimation (KDE) with NDE. NDE focuses on density estimation of point patterns in a network rather than in the Euclidean continuous space of KDE.

Many studies use point pattern analysis, but human-related events in space are not continuous or homogenous. They are constrained to network structures such as resident locations and shopping centers, which are based strictly on city street addresses and used to analyze human events such as crime and car accidents relative to key points within the network. The visualization of point data over a space on a map can provide distributional information but more analysis is needed in order to identify clusters or regularity (Borruso 2008).

The KDE allows for the estimation of the intensity of a point pattern and uses a three-dimensional continuous surface to illustrate changes in density of point events over a region of study. This surface shows peaks, which allude to the presence of hotspots in the point pattern. Hence, KDE allows for density estimation at any location in the study region while maintaining the number of events (Borruso 2008).

A drawback of network density estimation is that this tool only computes point density along network segments, whereas kernel density estimation utilizes circular search windows to produce density measurements. Given the nature of urban areas, which are defined by street and road networks, the NDE is useful when trying to produce a spatial picture of human activities. A network-based density estimator is a good tool to use when measuring point densities such as shopping centers and other human events on a network such as a city street grid (Borruso 2008).

Guan et. al (2011) used a combined Markov Cellular Automata model with natural and socioeconomic factors to analyze change and the spatial distribution of land use in Saga, Japan. GIS was used to calculate area change from 1976-2006 and the spatial distribution of land cover. Land use maps of different years were spatially overlaid and analyzed using GIS. Natural and socioeconomic factors that were taken into consideration was slope of the landscape, elevation, distance to the nearest road/river, population density, GDP per capita, and land price. Then using the Analytic Hierarchy Process in GIS, weights were determined and used for the land use transition potential. Transition potential maps and matrices were used to simulate and forecast the future changes for the time period of 2015-2042. In Saga, Japan agricultural and forested land use is predicted to decrease, conversely the built up areas are predicted to continue and increase toward the suburban regions with a decline in the urban center. Guan et. al (2011) suggests that in order to improve and expand the model results by simulating different land cover/ land use scenarios which would help policy makers formulate solutions to different urban growth issues (Guan et. al 2011).

Another study that utilized GIS was conducted by Paudel and Yuan (2011) to examine changes in landscape structure and the ecological consequences of urban sprawl in the Twin Cities Metropolitan Area, specifically due to deforestation and conversion of agricultural land. Methodologies used were spatial indices, change analysis, and geospatial modeling. Multi-temporal classification maps from 1975 to 2006 were used for this study. Patch Analyst was used to calculate landscape indices and analyze the landscape for 1975, 1986, 1998, and 2006. The purpose of using Patch Analyst was to quantify the landscape change over a given period of time. The landscape indices were used to predict any future change using GIS modeling.

GEOMOD in IDRISI was used to predict forest change into the future. The purpose of the model was to highlight the forest to non-forest (mainly urban) change. Paudel and Yuan found that urban areas expanded 82% by displacing forests and agricultural lands within urban areas or near the periphery. One drawback of using GEOMOD is that the model can only simulate change between two land cover classes. It assumes there is no regrowth of disturbed areas, which is not always the case. It also does not predict the quantity of change.

Each of these studies shows at least one example of how GIS can be used as a tool to monitor and evaluate the urban form. They also each show problems that can present themselves when using GIS in different applications. This is why it is important to know the limitations of the software and how it will affect the accuracy of the final outputs. While some tools are better for network-based studies that lend themselves to street grids,

others are better for prediction of future growth projections. Knowing what tools to use for each specific application ensures accuracy and reduces the chances of error and inconsistencies.

Chapter 3: Data and Methodology

3.1 Data

This study used one-meter multi-temporal National Agriculture Imagery Program (NAIP) digital-ortho imagery, taken during the agricultural growing seasons. Available to government agencies and U.S. citizens within one year of acquirement, NAIP data uses the default Red, Green and Blue (RGB) spectral resolution (NAIP 2010). Since 2007, some states have included the Near Infrared band in the image bundle. According to NAIP's contract, the imagery may only contain 10% cloud cover per quarter quad tile pending weather conditions. This ensures a clear and concise data set with which to evaluate the MUSA boundary in relation to Woodbury (NAIP 2010).

A point dataset of building permits obtained from the City of Woodbury for the years 1990-2006, supplemented the raster dataset. A building permit is an official document authorizing the holder to construct a building on proposed particular piece of land. Predicted on the development's review and approval pursuant to the comprehensive plan and zoning ordinances, building permit records characteristics such as property lines setbacks, total square footage of the development, and the total cost of construction. The permits were then geocoded and used to measure the density of growth over 16 years.

Another dataset used was a city road shapefile obtained from the City of Woodbury, which was extremely detailed with address information as well as building permit dates and the cost of construction. All of this information was utilized for the density analysis of Woodbury's growth. This detailed dataset allowed the geo-coding of

building permits to be very accurate with only two building permits failing to be matched to a correct address.

3.2 Methods

Remote Sensing is a technological tool used by urban planners and geographers alike to plan implement and evaluate urban growth boundaries as well as monitoring sensitive land uses such as, aquifer recharge areas, wetlands, endangered species, and coastlines. In order to establish a well rounded evaluation of Woodbury's growth and relationship with MUSA, three different software programs were utilized: ERDAS Imagine, IDRISI Taiga, and ArcGIS 9.3.1.

3.2.1 Landcover Supervised Classification and Recode

NAIP from 2003-2009 was utilized in ERDAS Imagine to perform a growth analysis for Woodbury. ERDAS Imagine is a geo-spatial software program specializing in remote sensing analyses as well as spatial modeling (ERDAS IMAGINE, 2008). A supervised classification based on Maximum-likelihood classifier in ERDAS Imagine was conducted. It classifies the multi-spectral imagery into six classes defined by the signature file. A signature file is collected using an interactive signature editor, and it contains a collection of various spectral signatures. The six initial classes used were: (1)urban, (2)agriculture, (3)forest, (4)bare soil, (5)grass and (6)water. The signature Editor in ERDAS Imagine allows the user to manipulate and classify signatures. Then, a

series of tools was utilized in order to collect areas of interest in each of the six classes. Once all six classes were defined, then a supervised classification was completed and a recode of the six classes was performed. An image recode involves the assignment of new values to differing classes. Typically, recoding is used to reduce the number of classes. For this specific study, the six classes were re-classed into three classes: urban, water and rural (Figure 4). Reducing the number of classes to three allowed for further study of land cover changes throughout the time span of aerial imagery.

3.2.2 Post Classification

Once all the NAIP images were classified into three classes, the images were filtered in order to reduce the Salt and Pepper Effect. The Salt and Pepper noise results from misinterpretation of pixels in certain classes. For example, many of the images classified shadows as water; this error was especially prominent in the larger subdivisions of Woodbury (Figure 3.1). Consequently, a majority 3x3 statistical filter was performed twice on each image thereby reducing the Salt and Pepper Effect. A model isolated certain subdivisions needing further refinement. The post classification model uses a conditional statement in order to assign an accurate classification value to an otherwise wrongly classified pixel. For example, many Woodbury subdivisions were classified wrongly as water due to the shadows present on the NAIP aerial photograph.

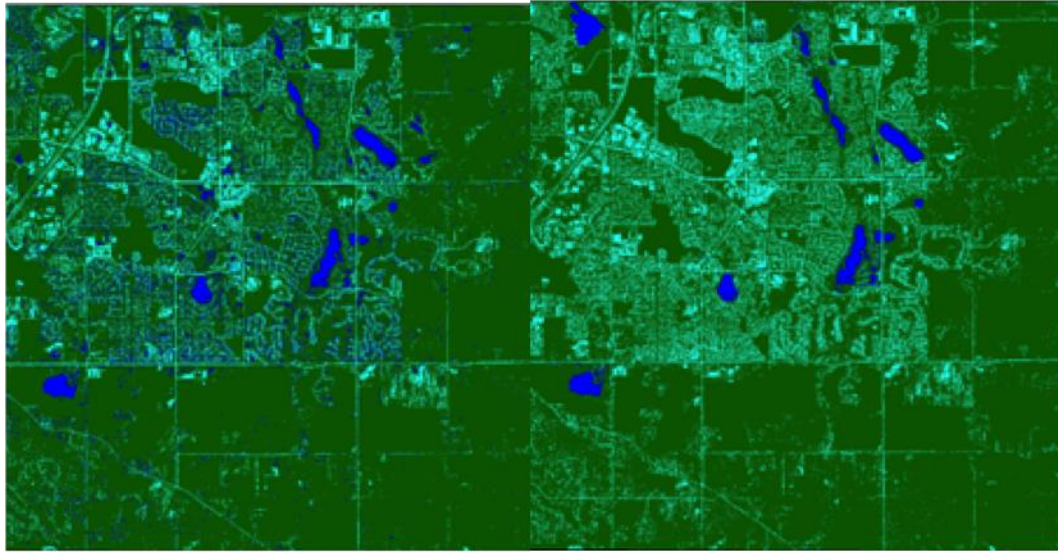


Figure 3.1: Example of the misclassification of water in Woodbury subdivisions

3.2.3 Environmental Change Analysis using the Spatial Modeler in ERDAS

To highlight the land conversion change, the spatial modeler and criteria function in ERDAS was utilized to produce a change image from the entire time span studied. Specifically, the criteria function uses a conditional statement in order to create a table of conditions that need to be met in order to output a cell value for the selected raster (Figure 3.2) (ERDAS IMAGINE, 2008). The criteria table contains the two classification maps from two different years. Since the images are classified into three classes (urban-1, rural-2, and water-3), the table contains nine possibilities of different land conversions Table 3.1. Once executed, the overall land use conversions from 2003-2009 were discerned with the rural-to-urban conversion being specifically highlighted.

Table 3.1

Urban Conversions	Rural Conversions	Water Conversions
Urban to Urban	Rural to Urban	Water to Urban
Urban to Rural	Rural to Rural	Water to Rural
Urban to Water	Rural to Water	Water to Water

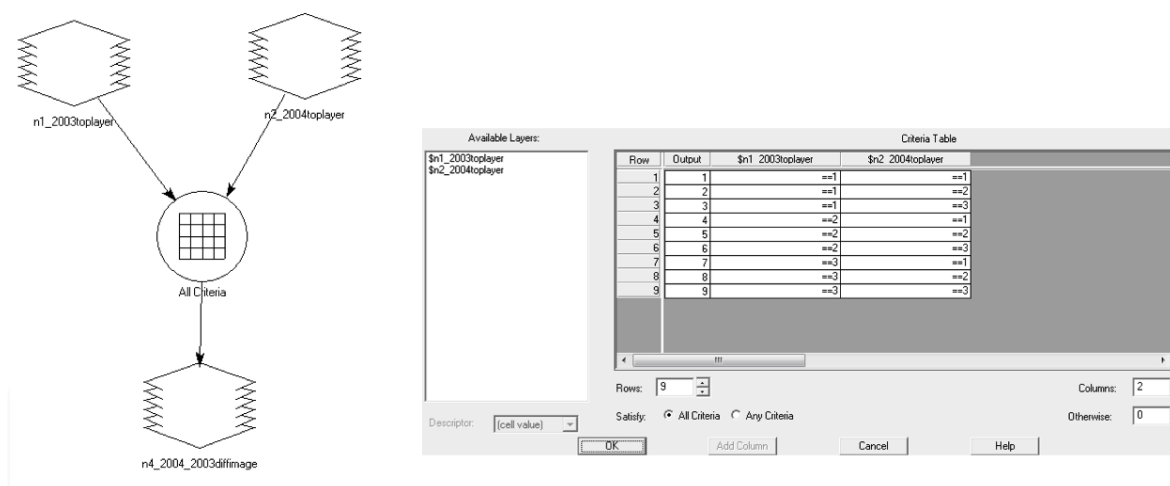


Figure 3.2: Screenshot of model and criteria function used in order to perform an environmental change analysis.

3.2.4 Accuracy Assessment

Two classification accuracy assessments were performed to compare certain pixels in the thematic raster layer to reference pixels. The reference pixels' classes are derived from the NAIP aerial photos. The original NAIP air photos from 2003 and 2009 as well as the two classified images were used for the accuracy assessments. A total of 50 Random points were generated by ERDAS Imagine's accuracy assessment function on the NAIP aerial photos (Figure 3.3). Each individual point was examined carefully and classified as a true class value. Once all the true class values were inputted, the accuracy report was generated.

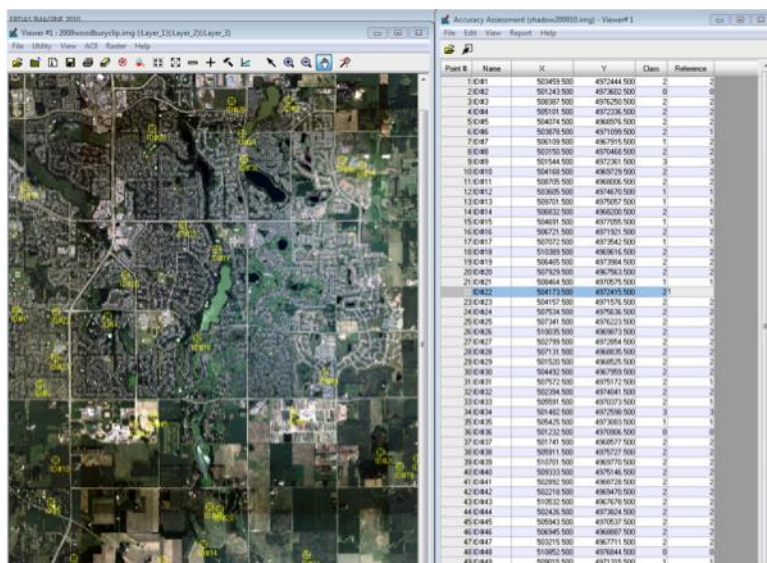


Figure 3.3: View of 2009 NAIP aerial photo including the 50 random points and a true class values.

3.2.5 GIS Modeling Using ArcGIS

A linear weighted model in ArcGIS was built to derive the areas with the highest probability of expansion. To produce this linear weighted model, three distance raster variables were produced as well as an exclusion raster to input into the model. The distance raster variables included: distance from Woodbury roads, distance from urban land cover, and finally distance from 2010 MUSA boundaries (Figure 3.4). The Woodbury road distance variable was chosen to pre-empt the bias of allocating urban growth to areas contiguous to existing roads. Reducing the allocation near roads lowers the probability of a high-density cluster. A high-density cluster of development is anti-theoretical to urban sprawl, contemporary society's default option for urbanization.

The distance from urban land cover variable prevents the allocation of urban growth to the pre-existing built environment, and negates high densities as the general pattern of urban sprawl tends toward an outward expansion. The distance from the 2010 MUSA boundaries creates a variable that prevents the allocation of growth in rural areas beyond the MUSA boundary but within the city limits. As distance increases beyond the MUSA boundary toward Woodbury city limits the probability of sprawl decreases. The exclusion layer excluded all current urban and water land uses from the model (Figure 3.5). A weight of 30 percent was assigned to both the distance from roads and distance from the 2010 MUSA boundaries, and a weight of 40 percent was assigned to the distance from urban raster. Once the initial final raster calculation was outputted, the exclusion layer was subtracted in order to obtain the final linear weighted model. The

equation used for this model is, 'Distance to Roads'/1592*0.3 + 'Distance to MUSA 2010'/2407*0.3 + 'Distance to Urban'/269*0.4 = Calculation #1. To account for the exclusion layer, 'Calculation #1 was multiplied by the 'Exclusion layer.' The model used assumes linear growth, which, in reality, is not always the case, because non-linear growth (leap-frog development) can also occur as a result of several other variables such as zoning, transportation nodes, or exurban residential desires for country living within a reasonable commute to a city nearby. This linear weighted model used herein produces a general pattern of probable land cover conversion.

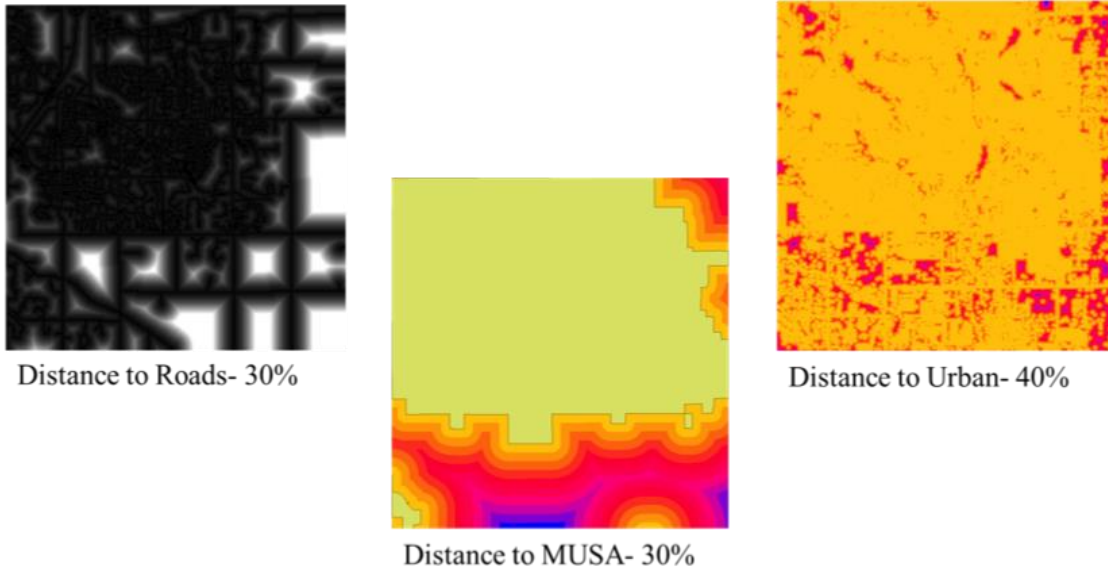


Figure 3.4: The three different variables used in the linear weighted model. From left to right: Distance to roads with a weight of 30%, distance to MUSA with a weight of 30%, and distance to urban with a weight of 40%.



Figure 3.5: The exclusion layer that was created in order to produce the linear weighted model.

3.2.6 Land Change Modeling Using IDRISI Taiga

3.2.6.1 Land Change Modeler

IDRISI Taiga is an integrated GIS and Image Processing software solution providing nearly 300 modules for the analysis and display of digital spatial information. Taiga has an application called the Land Change Modeler (LCM). This application explores, predicts and models impacts on land cover change. The LCM is oriented to the pressing problem of accelerated land conversion and the very specific analytical needs of biodiversity conservation (IDRISI Manual 2006). The inputs into the LCM were a distance to roads layer, distance to the original urban land cover, and an exclusion layer masking urban and natural areas, a 30 meter digital elevation model, and a base roads layer for Woodbury. The Transition Potentials Tab was utilized in order to get a statistical idea of the land change from 2003-2009. The main contributor to the increase in urban land cover was from the rural land cover. Approximately nine percent of the rural land cover was converted to urban land cover over six years.

3.2.6.2 Preparation of Model Inputs

The next step in the analysis was to prepare the inputs for the Markov tool in IDRISI Taiga. This tool is the precursor to the Markov Cellular Automata model. The Markov Chain Analysis tool conducts an analysis of the time 1 (2003) and time 2 (2009) images in order to produce a transition probability matrix and a transition area matrix. The transition area matrix expresses the total area (in cells) expected to change in the

next time period (IDRISI Manual). The transition area matrix will be used in the Markov Cellular Automata model later in the analysis.

After this, suitability maps were prepared. Suitability maps are a vital input in the Markov Cellular Automata model. The model requires a collection of suitability images depicting the suitability of a pixel for each of the land cover types under consideration. In this analysis, there are three suitability cover maps needed because there were three original land classes in the land cover maps. The three original classes were urban, rural, and water. The water suitability map was simple to create because the map depicts a binary or nominal dataset and classes pixels as either 0 or 1. An exclusion layer was created to mask the original urban and natural areas from the urban suitability map. To produce the urban and rural suitability images, the Euclidean Distance tool in ArcToolbox was used to calculate distances for both the rural and urban landcover. To calculate the urban and rural suitability images with 2020 MUSA, the Extract by Mask tool was used to convert the MUSA boundary shapefile into a raster image. Again, the Euclidean Distance tool in ArcToolbox was used to calculate the distance from the 2020 MUSA boundary. Current urban environment was reclassified as 0, similar to the exclusion layer.

The 2020 MUSA boundary hinders the model from projecting urban development outside of the boundary (Figure 3.6). Land cover areas will have a higher tendency to change to a new class when they are near existing areas of the new class (IDRISI Manual 2006).

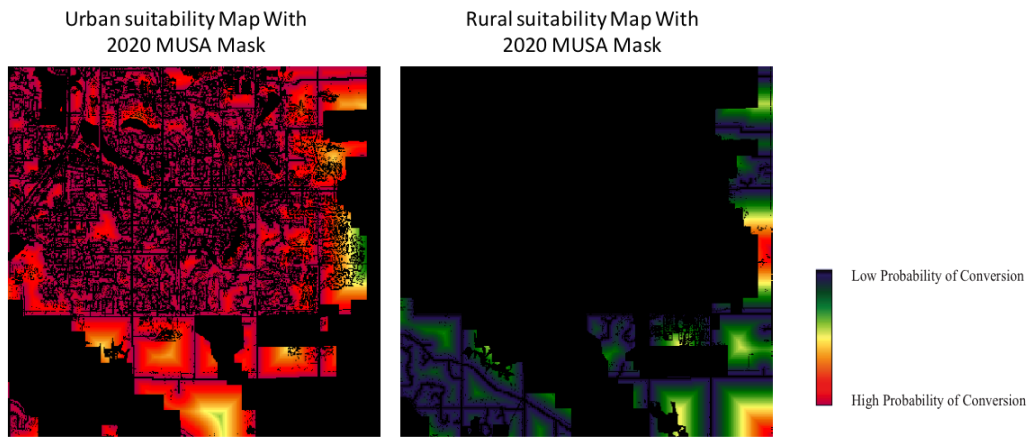


Figure 3.6: Example of the urban and rural suitability maps used and the 2020 MUSA boundary mask created.

Once the urban and rural suitability maps were finished and imported back into IDRISI Taiga, then the exclusion layer was created. The original urban and natural areas were reclassified to delineate urban from non-urban and natural areas from non-natural areas. The resulting images, produced a nominal or binary dataset with original urban and natural areas being classed as 0 and everything else being classed as 1.

After the suitability images were created, certain tools had to be executed for the images to be used correctly in the model. The first tool used was the Stretch tool in IDRISI Taiga. The Stretch tool performed a linear stretch, which rescaled the range of values on the three suitability maps from 0-255. The next tool used was the Fuzzy tool. The Fuzzy tool, which evaluates the fuzzy set possibilities of data cells. Fuzzy represents a form of uncertainty, arising from pixels that contain multiple land covers (IDRISI Manual 2006). This tool was used specifically for the urban suitability image to make the values gradually decrease as distance from the MUSA boundary increased (Figure 3.7).

Once all of the suitability maps were created, stretched and subjected to the fuzzy tool, the suitability maps were ready to be combined into an .rgf file. The .rgf file is the collection of suitability images that express the suitability of a pixel for each of the land cover types under consideration (Figure 3.7).

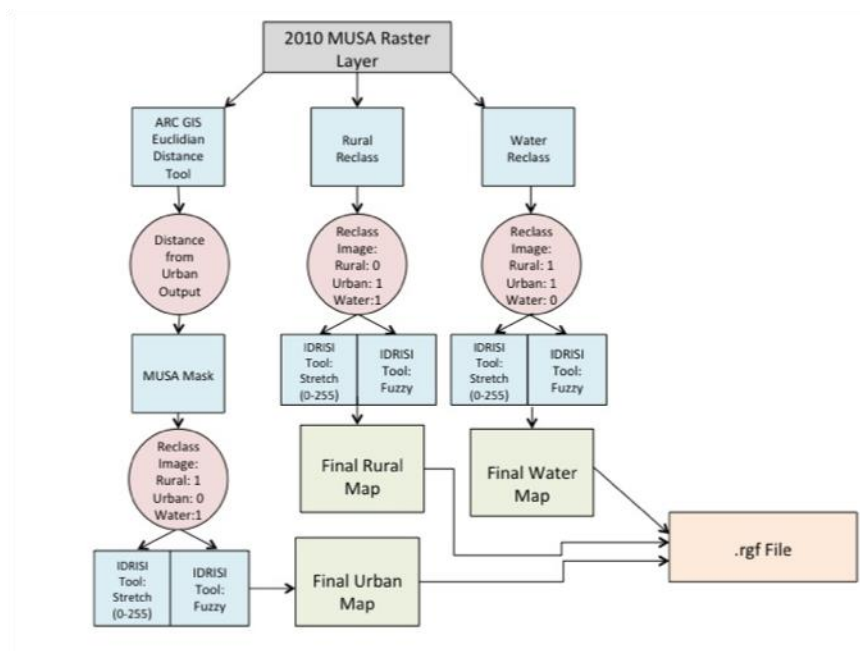


Figure 3.7: Flow chart illustrating the various steps in the process to produce a collection of suitability maps (.rgf file) for the Markov Cellular Automata Model.

3.2.6.3 Markov Cellular Automata Modeling

A cellular automaton is a cellular entity that independently varies its state based on its previous state, and on the state of its immediate neighbors. For example, an empty cell becomes highlighted or activated if there are three living automata in the 3x3 neighborhood surrounding the cell. The cell will stay alive as long as there are two or three living neighbors. If fewer than two neighbors are present, the cell dies from

loneliness/seclusion; if more than three are present, it dies from competition of resources. With each iteration, the software reduces the suitability of land away from existing areas of that type. The model uses a 5x5 mean filter to achieve continuity (IDRISI Manual 2006).

The Markov Cellular Automata model requires the land cover image from 2009, the transition areas file produced by the Markov tool, and the collection of suitability images that expresses the suitability of each land cover. The total number of iterations is based on the number of time steps, which in this case numbered 11 since the model will be projecting the growth for 2020 (IDRISI Manual 2006).

The Markov Cellular Automata model is computationally intensive. The model took several hours to process. In order for the model to run and produce results, the land cover image and suitability maps had to have their resolution reduced. The images were reduced to a 10 meter resolution from the original 1 meter resolution. By running the Contract tool, the model run time decreased from upwards of several hours to a few minutes. Reducing the resolution can introduce errors into the model, but for the sake of computer space and running time, the reduction was deemed necessary for the output to be produced.

3.2.7 Kernel Density Estimations

To compliment the previous methodologies, a density calculation was utilized to aid in visualization of the growth patterns of Woodbury. Acquired from the City of Woodbury, the data for the density calculation were comprised of building permit

information, including the date of issuance, the cost of construction, as well as its location.

After obtaining the building permits, their locations were geo-coded onto a Woodbury roads shapefile, obtained from NCompass Technologies, located in Eden Prairie, Minnesota. NCompass Technologies provided an exceptional base layer for analysis and spatial referencing, especially when the objective is to illustrate the overall spatial pattern of outward expansion.

Chapter 4: Results

The classification and recodes, environmental change analysis, Kernel Density analysis, linear weighted model, and the Markov Cellular Automata model all provided methodologies which were used to test the flexibility of the MUSA boundary. Several of these methods point to a lack of rigidity in the implementation of MUSA boundaries.

4.1 Image Classification and Recodes- Accuracy Assessment

The final results of the image classification and recode created the inputs for the environmental change analysis (Figure 4.1). Before performing the Environmental Change Analysis, an accuracy assessment was executed to derive the accuracy of the image classification and recode. The results of the accuracy assessment are: (1) 2003 supervised classification image had an 80% classification accuracy and (2) 2009 supervised classification image had a 90% classification accuracy (Figure 4.2). These accuracies are indicative of those used by Schneider and Woodcock (2008).

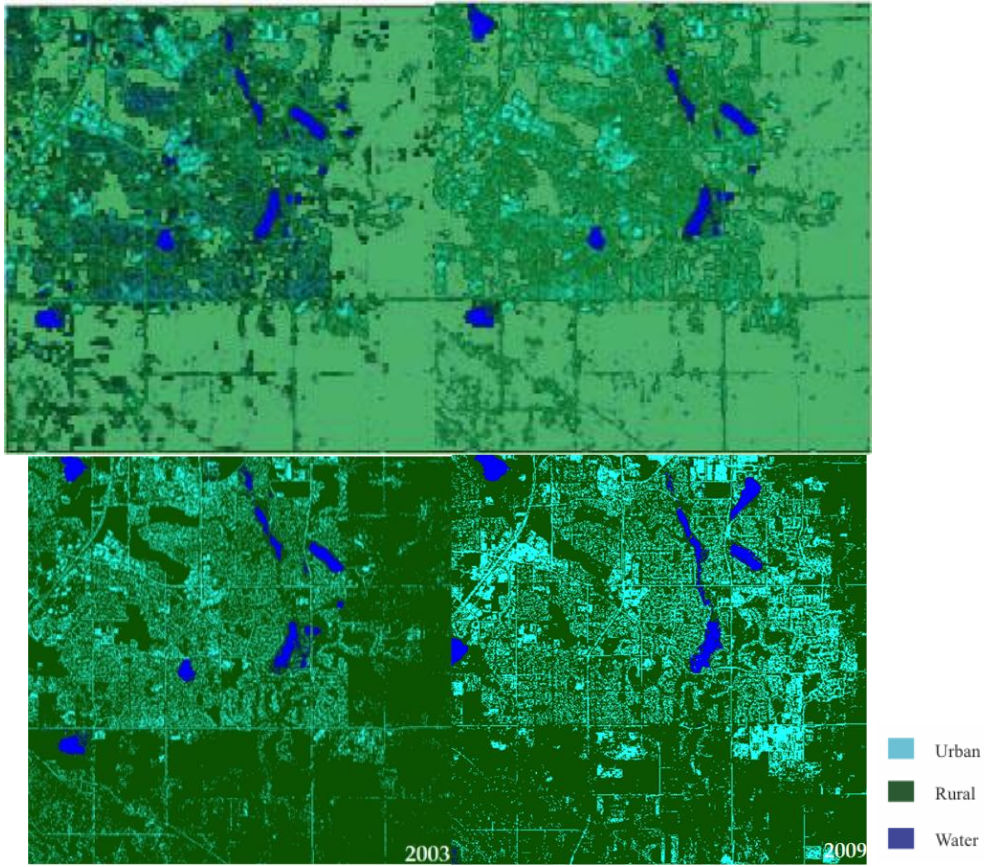


Figure 4.1: Examples of imagery recoded into three different classes: Urban-cyan, Rural-dark green, Water-blue

Classification Accuracy Assessment
Report:

Error Matrix

Classified Data	Background	Class 1	Class 2	Class 3
Background	0	0	0	0
Class 1	0	8	0	0
Class 2	0	9	32	1
Class 3	0	0	0	0
Column Total	0	17	32	1

Accuracy
Totals

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	0	0		
Class 1	17	0	8	47.06%	100.00%
Class 2	32	42	32	100.00%	76.19%
Class 3	1	0	0		
Totals	50	50	40		

Overall Classification Accuracy: 80.00%

Table 4.1: The 2003 accuracy assessment report that was generated (Erdas Imagine).

A greater degree of urban in-fill development likely explains the lower class accuracy for 2003, whereas 2009 exhibited a large band of growth, particularly on the east side of city. With conversion happening amongst and within neighborhoods it can be more difficult to classify pixels that could be mistaken for water or rural. In 2009, the wide band of growth on the eastern side was more discernable than the infill development in 2003. Another source of inaccuracy could be related to the quality of the 2003 aerial image compared to the 2009 aerial image. Even though both images were of very high quality, minor flaws could have caused discrepancies between the two images and their classified pixels.

According to the Transition Potentials Tab in IDRISI Taiga, which was used to obtain a statistical quantification of land change from 2003-2009 (Figure 4.3), the main contributor to the increase in urban land cover originated from the rural land cover. According to the Transition Potentials Tab, approximately nine percent of the total rural land cover was converted to urban land cover over six years.

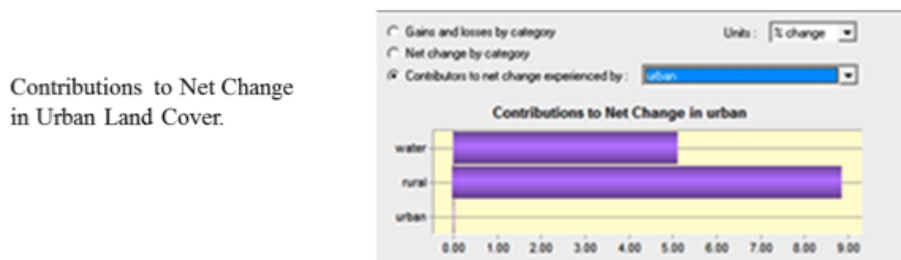


Figure 4.2: Transition Potentials Tab utilized in order to get a statistical idea of the land change from 2003-2009.

4.2 Environmental Change Analysis

The environmental change analysis provided a clear picture of regional growth; in particular, the environmental change analysis for the years 2003-2009 clearly demonstrated the lax nature of the MUSA boundaries. Although some noise can still be seen in the environmental change analysis, the general overall land use growth patterns can still be derived from the image. The environmental change analysis highlighted the rural-to-urban land cover conversion, which illustrates the overall spatial growth pattern of Woodbury (Figures 4.3-4.8). Figure 4.8 depicts urban expansion occurring between 2003-2009, and shows additional urban growth occurring outside of the 2010 MUSA boundary.

In the 2003 to 2004 and 2004 to 2005 images, there seems to be a general push outward in the easterly direction. The 2005 to 2006 environmental change image did have some similar growth changes occurring along the eastern border of Woodbury; however, the 2006 image had much more noise than any other NAIP aerial photograph acquired. This situation made correction very difficult and time-consuming. In the 2006 to 2009 image, the highlighted change is clearly seen on the eastern side with the growth being pushed towards the east. The final change analysis image from 2003 to 2009 highlighted the clearest change by a significant margin. The model performed best when there was a larger time span between the images. This allows more time for a greater amount of

growth to occur, which makes the change easier to see due to the larger span of time (e.g. parcel to parcel change v. subdivision's full development).

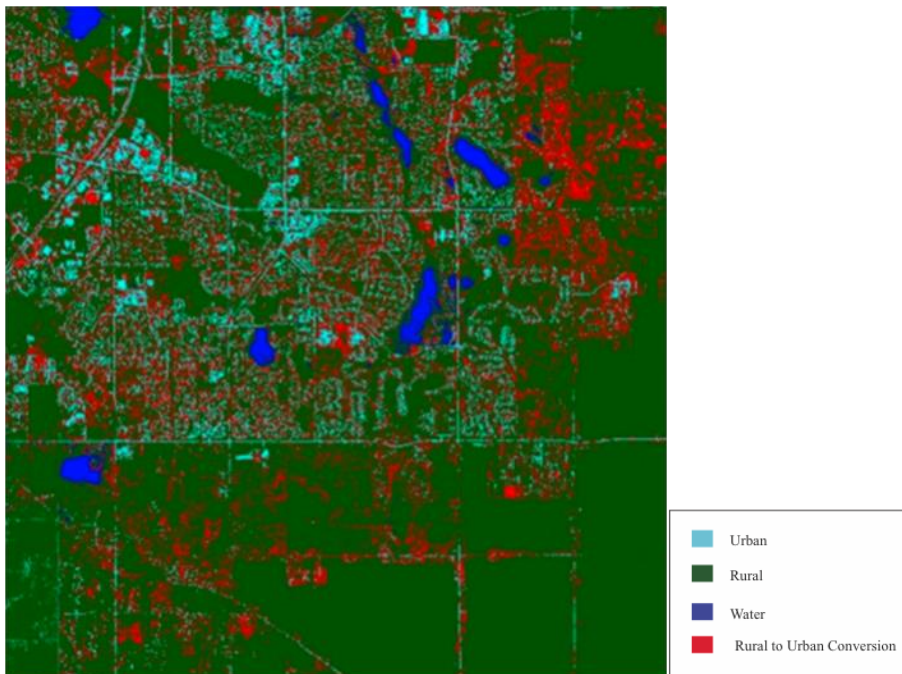


Figure 4.3: Screenshot of 2003-2004 environmental change analysis highlighting rural-to-urban conversion.

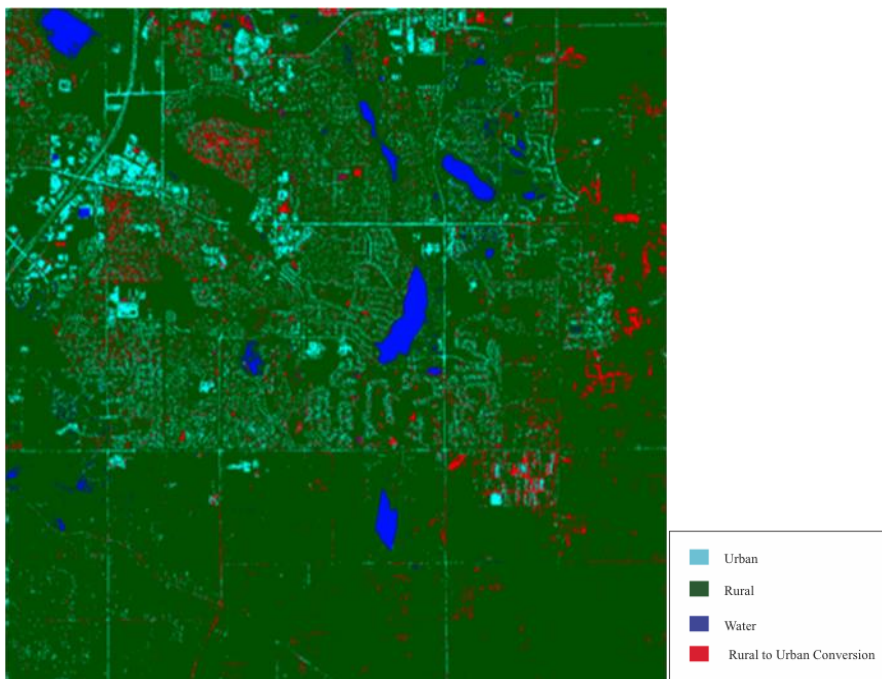


Figure 4.4: Screenshot of 2004-2005 classified images as well as the environmental change analysis highlighting rural-to-urban conversion.

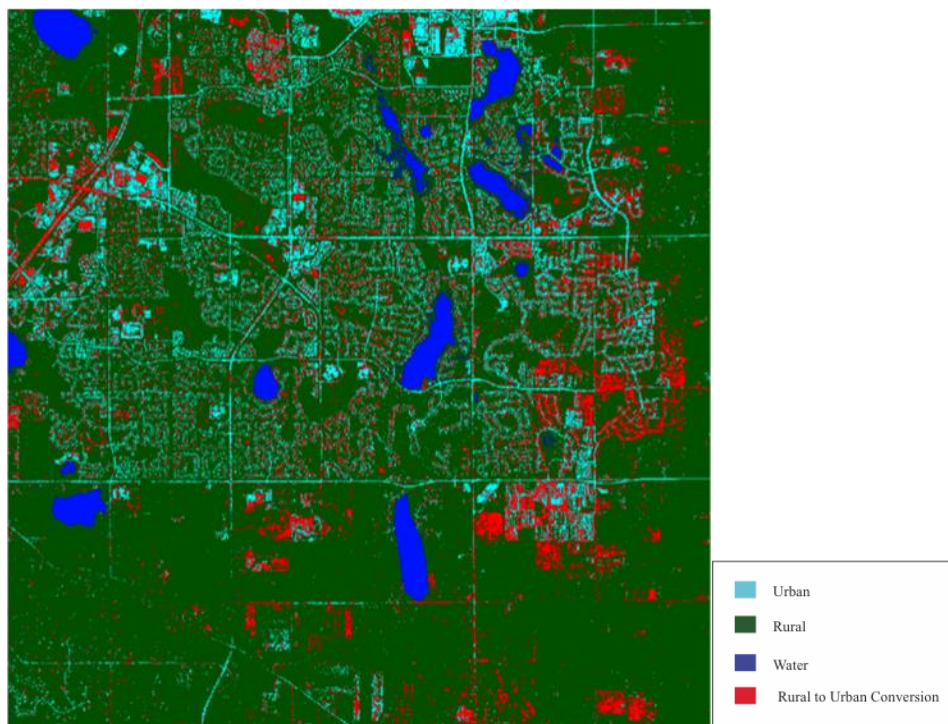


Figure 4.5: Screenshot of 2005-2006 classified images as well as the environmental change analysis highlighting rural-to-urban conversion.

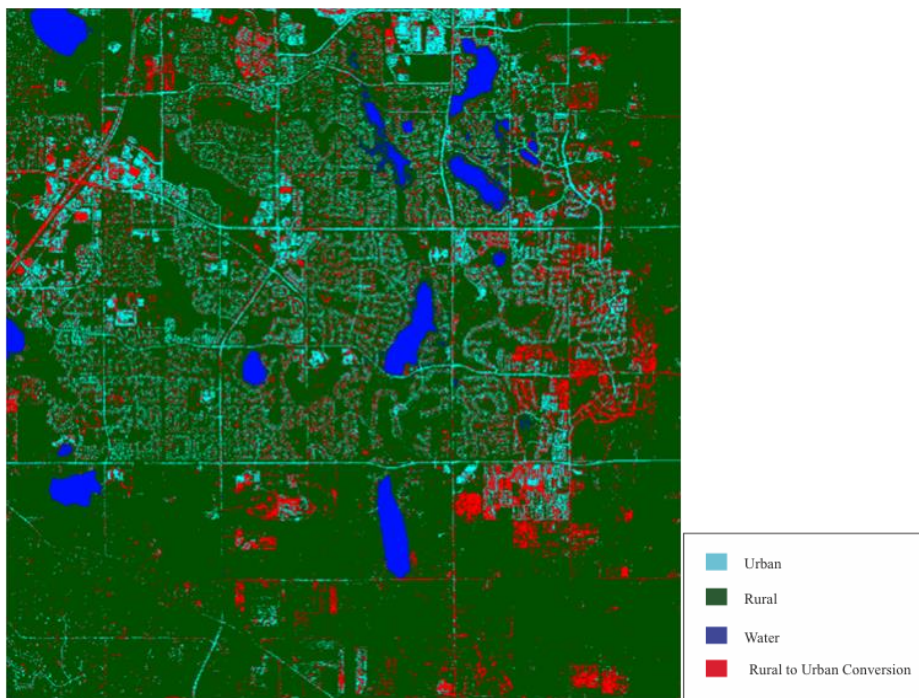


Figure 4.6: Screenshot of 2006-2009 classified images as well as the environmental change analysis highlighting rural-to-urban conversion.

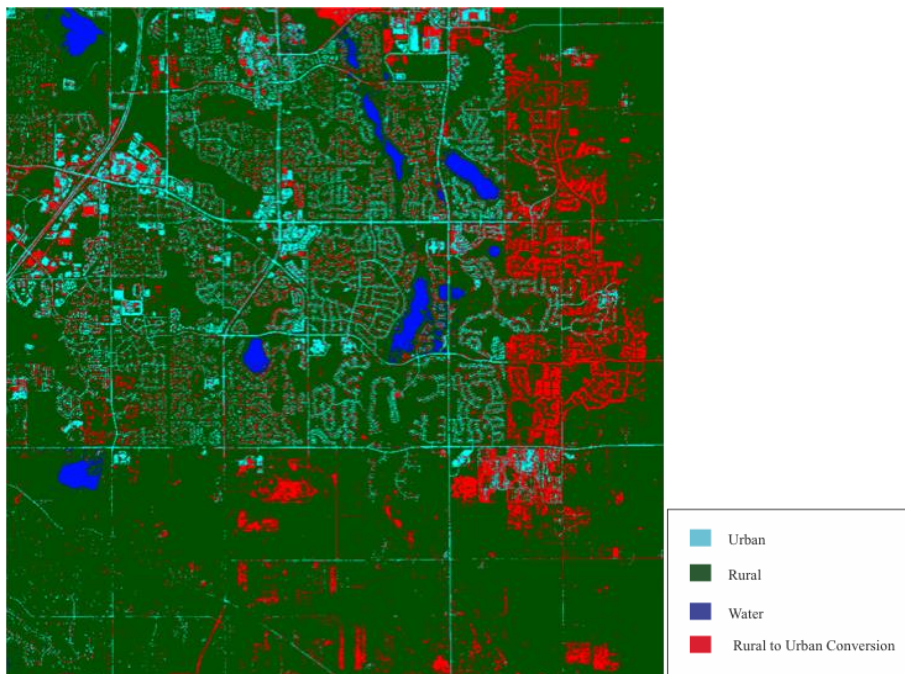


Figure 4.7: Screenshot of 2003-2009 classified images as well as the environmental change analysis highlighting rural-to-urban conversion over the entire time period studied.

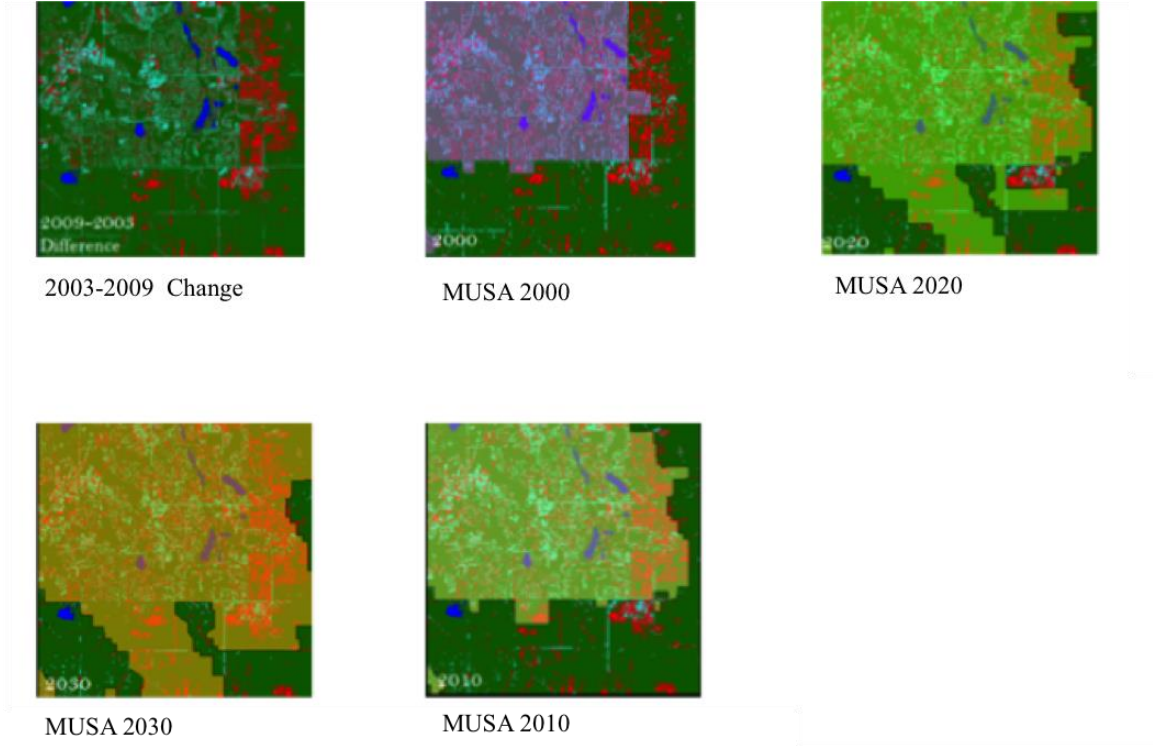


Figure 4.8: Screenshot of the relationship between MUSA and Woodbury illustrating the lax nature of the MUSA boundary.

4.3 Kernel Density

The building permit information acquired for this model supplements the environmental change analysis and growth models and illustrates the socioeconomic characteristics of the expansion. The general trend is that the most expensive homes are being built at the periphery of the new development (Figure 4.9).

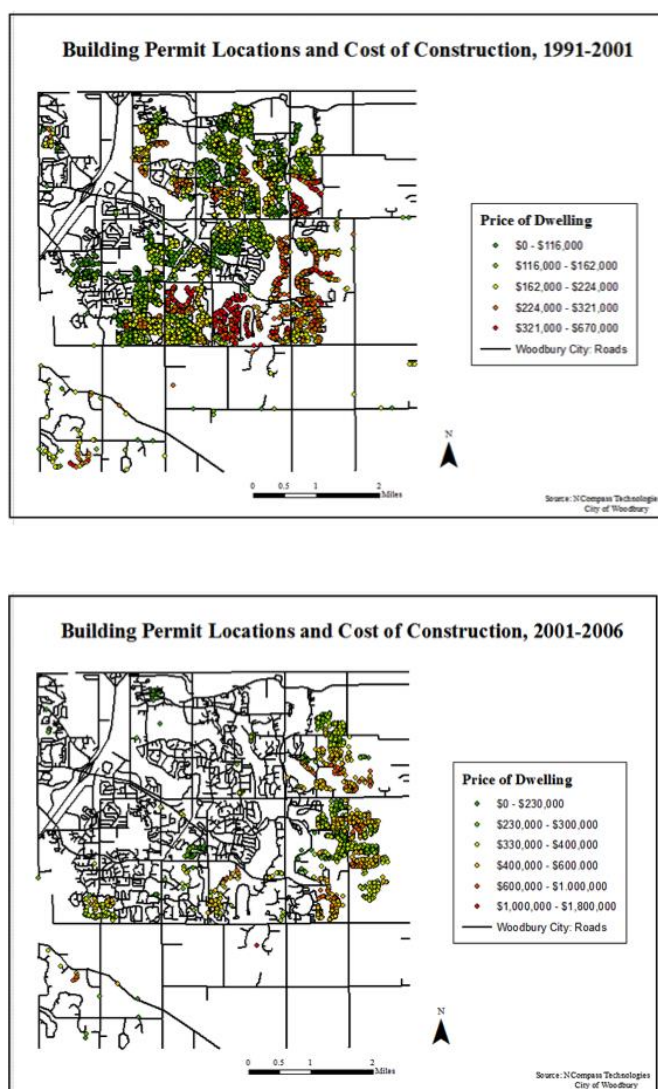


Figure 4.9: Geocoded building permit point locations on the NCompass Technologies road shapefile.

Kernel Density calculates the density of building permits in a neighborhood in relation to other building permit points. The 1990-2000 map shows pockets of dispersed expansion with the more densely built-up areas located around the edge of Woodbury (e.g. infill development). The map of 2000-2006 is a better example of clustered outward expansion.

Two final images were produced from the Kernel Density analysis (Figure 4.10), which show the change in growth patterns of Woodbury, spanning from 1990 to 2000 and 2000 to 2006. Theoretically, a smoothly curved surface is fitted over each building permit point location. The surface value reaches its peak at the building permit point; as distance from the point increases, so does the surface value.

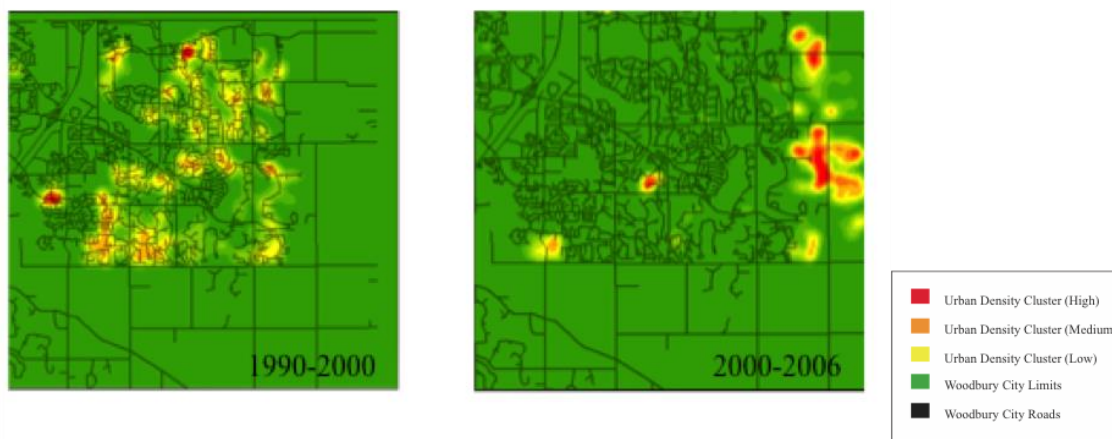


Figure 4.10: Kernel Density Analysis performed on the geocoded building permit point shapefile (left is the 1990-2000 output and right is the 2000-2006 output).

Figure 4.10 demonstrates an overall spatial pattern reflecting an outward expansion toward the periphery of Woodbury from the years between 2000 and 2006 and more infill development occurring between the years of 1990 to 2000. This analysis helped illustrate some of the socio-economic factors in the area.

4.4 Linear Weighted Model

The linear weighted model derived overall land conversions in order to illustrate possible future conversion trends. A weight of 30 percent was assigned to the distance from roads and distance from the 2010 MUSA boundaries, and a weight of 40 percent was assigned to the distance from the urban raster. Once the final raster calculation was outputted, the exclusion layer was subtracted in order to obtain the final linear weighted model.

A higher weight was placed on the distance from urban raster due to the assumption of urban sprawl occurring near currently developed urban areas. A lower weight was placed on the distance from any road raster, acting on the general assumption that roads are built to supplement a developer's own idea of location theory in cases when a project results in a comprehensive plan amendment and rezone. For example, a suburb development is not always dependent on the presence of existing roads or infrastructure, especially when the developer agrees to construct such infrastructure within the context of a special project. These costs become capitalized into the newly developed parcels through impact assessment fees.

Figures 4.11 and 4.12 illustrate growth occurring outside of the MUSA boundary based on the chosen variables and their assigned weights. This model is a linear example and the general pattern of growth is in an outward direction. Figure 4.12 does an excellent job in highlighting the growth just outside of the 2010 MUSA boundary. According to the Linear Weighted Model, this band of growth illustrates the areas most likely to experience future growth.

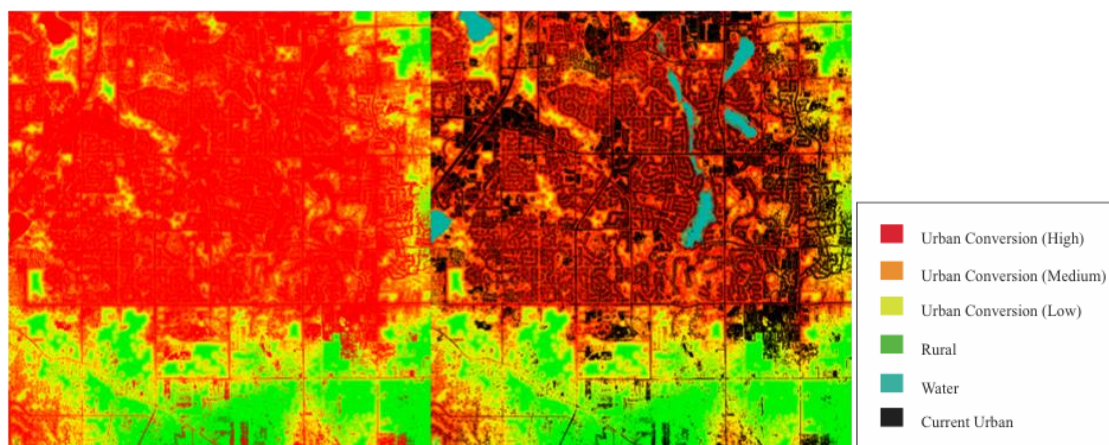


Figure 4.11: Screenshot of final output from the linear weighted model. Image on right includes an overlay of the urban outline.

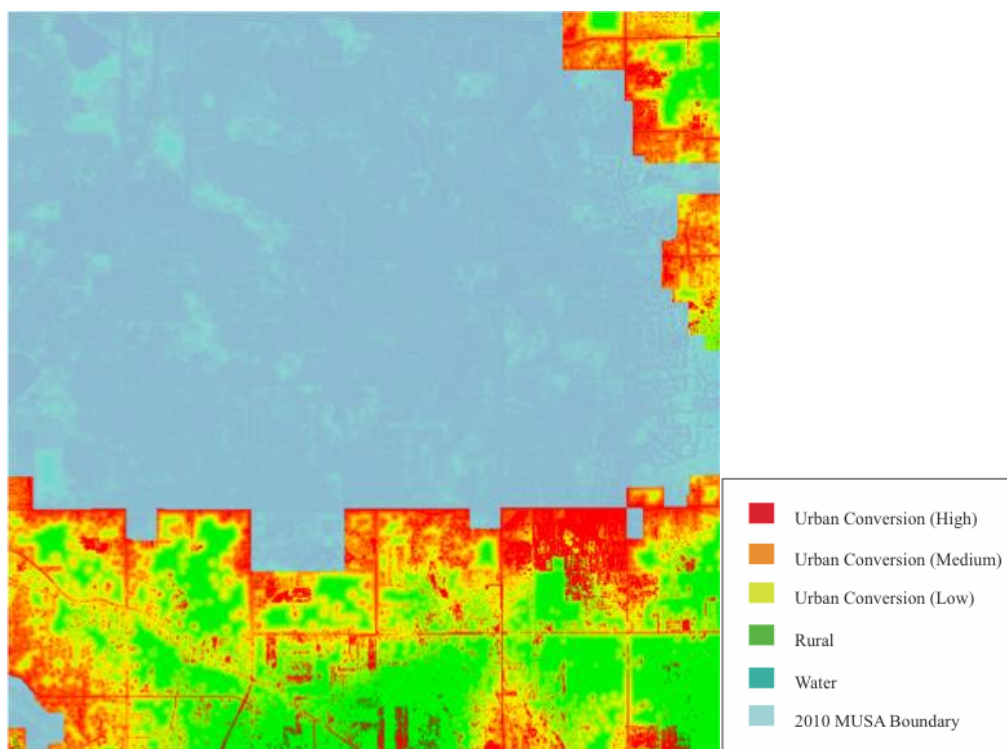


Figure 4.12: Screenshot demonstrating the overall land conversions in order to illustrate possible future conversion trends in relation to the 2010 MUSA boundary.

4.5 Markov Cellular Automata

Figure 4.13 shows an example of a model run with the 2020 MUSA boundary applied.

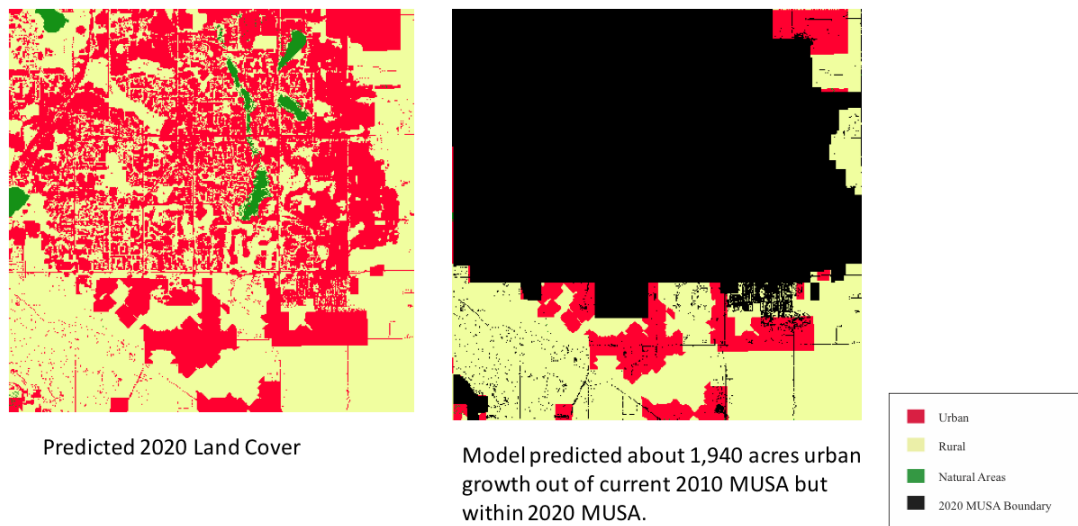


Figure 4.13: Results of Markov Cellular Automata model run.

Urban expansion development is predicted to be the major growth trend when taking the 2020 MUSA boundaries into account. Approximately 1,940 acres urban growth is predicted out of current 2010 MUSA. As seen in Figure 4.14, the model did show growth occurring outside of the 2010 MUSA boundary. The growth appears to be expanding in a southwardly direction, and there is a pocket of growth occurring in the northeastern portion of Woodbury. The MCA model that did account for the MUSA boundary showed greater expansion in a southerly direction than was seen in the linear weighted model, which showed a more consistent growth pattern along the MUSA boundary. The MCA model results are more consistent with the 2020 MUSA boundary delineated by the Metropolitan Council (Figure 4.14).

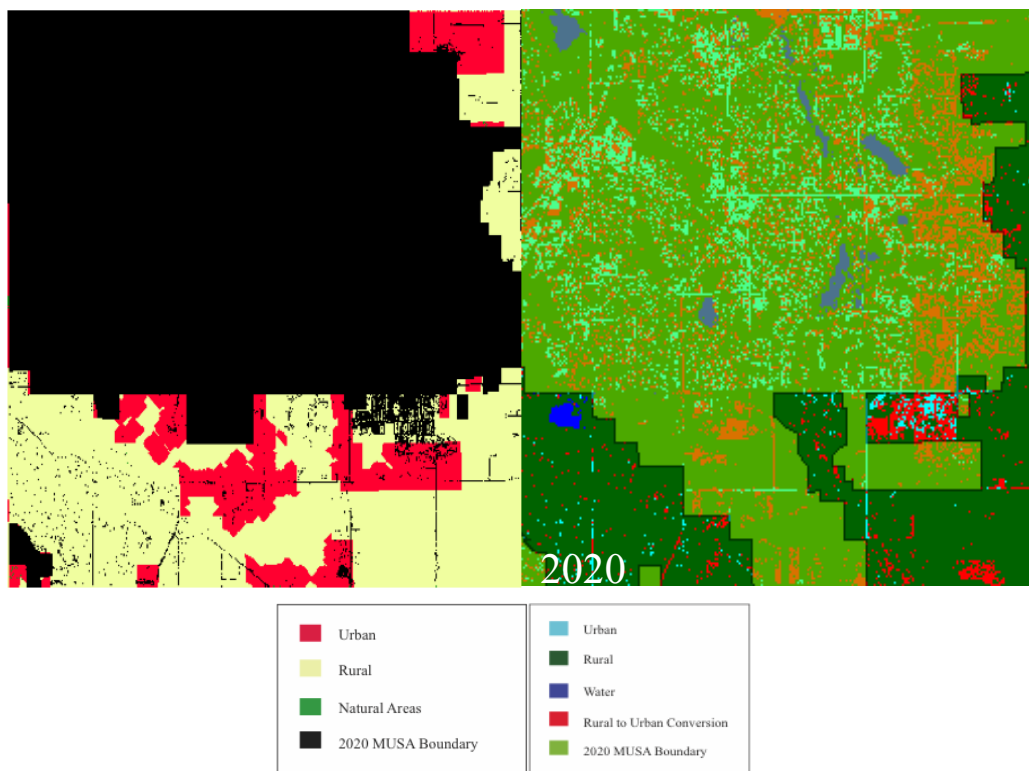


Figure 4.14 Consistent growth patterns between the projected growth in Woodbury (left) and the delineated 2020 MUSA boundaries (right).

Chapter 5: Discussion

5.1 Image Classification and Recodes

The supervised classification used six classes, which were later recoded to three to reduce the possible number of land cover conversions. The three classes provided nine possible land use conversions. An increase in land cover classes would have allowed for more land cover conversions, resulting in a lack of clarity (ERDAS IMAGINE, 2008). After completing the conversions, the images were reclassified into three categories. One drawback is that the three classes do not give the software much flexibility to allocate land cover classifications, which are not considered rural, urban, or water.

Once classified, a filter was applied to all the images to reduce the Salt and Pepper Effect. Several pixels were classified wrongly because the software mistook shadows for water. This situation illustrates how the software classified correctly, resulting in inaccurate acreages being assigned to water. These methodologies were necessary in order to provide a clear base land cover image to be utilized for further analysis. Without these methods, the satellite image would prove too cumbersome and complex to use in more advanced analyses.

5.2 Environmental Change Analysis

The 2003-2009 environmental change analysis output provides a clear idea of the increasing growth on the eastern and southeastern portions of Woodbury (Figures 15-20). This coincides with the idea of urban sprawl as, “the spreading out of a city and its suburbs over more and more rural land at the periphery of an urban area [which] involves the conversion of open space (rural land) into built-up, developed land over time” (*What is Sprawl?* 2010).

The analysis of Woodbury illustrates the physical conversion of agricultural land to newer suburbs. MUSA has effectively kept urban growth from expanding outside its boundaries; however each time the boundaries have been reviewed, they have expanded considerably to accommodate more growth within the new MUSA boundary. While MUSA proves effective in restricting growth temporarily, the long-term effect is that MUSA is not a strict boundary and this is apparent when reviewing the MUSA boundary limits over time.

5.3 Kernel Density

The Kernel Density results illustrate that living on the periphery is more desirable to homebuyers; ipso facto, the market force driving expansion is the availability and ability to construct larger homes on bigger lots. MUSA boundaries put some pressure on

this trend, but outward expansion still occurs, stretching and testing the rigidity of the boundary. The density and locations of the building permits do allude to the current American ideal of owning one's own parcel of land. Property rights have been the foundation of this nation, and the idea of the white picket fence still holds a great deal of appeal to the American homebuyer, and in many ways is indicative of a suburbanized Jeffersonian ideal.

The Kernel Density analysis complimented the growth models, because of its specific attribute data and the ability to aide in the clarity of visualization of growth patterns. Again, a trend is evident of homes of higher value being developed on the edge of the new expansion. It seems that as the distance increases from the MUSA boundaries, the price of the homes also exhibits a generally increasing trend. The general push outward does seem evident in both the environmental change analysis and the Kernel Density analysis, which seems to allude to a more adaptable and flexible MUSA boundary. Accommodating developers in the context of encouraging growth in the area is a positive and important aspect of community development in order to support economic growth; it is also important to take into consideration the regional growth and possible effects that new developments will have on surrounding communities and the available water and sewer services.

5.4 Linear Weighted Model

The City of Woodbury is growing fast, and providing for the fast growth is going to have to be carefully balanced. The Linear Weighted Model did reflect growth outside of the 2010 MUSA boundary. This model was used in order to demonstrate a basic idea of probability of growth, more specifically a linear example of growth. A setback of the model is that human factors and city planning, which do affect growth, were not taken into account. Woodbury practices phased development, which is not reflected in the final output. Without the phased development this model could exhibit a general idea of Woodbury's growth pattern, but since planning and zoning are involved, this model allows a basis of comparison for the Markov Cellular Automata model.

Woodbury must be very vigilant with possible new developments because the costs may be carried over to the taxpayers, resulting in unhappy citizens. While MUSA could help provide the city staff with a guideline of where growth needs to be halted in order to preserve the local region, the balance of inviting new growth but also being cautious of unbridled growth can be very tricky. MUSA has been growing in area for many decades but in order for MUSA to perform its potential purpose, it should be somewhat stringent in maintaining its size and shape. By encouraging in-fill, which more intensely utilizes existing infrastructure, rather than building new infrastructure that serves a more diffused population base will reduce the overall costs.

5.5 Markov Cellular Automata

An issue with the MCA model was the size of the land cover and suitability images. Using the 1-2 meter resolution made the model cumbersome and time consuming. For example, the 1 meter resolution model took several hours to run and was aborted due to time and space constraints. Consequently, to produce the final image, the resolution was reduced to 10 meters, yet still required six hours of computational time. This introduces some error in the final output.

While the current strategy of MUSA provides a balanced approach, these analyses illustrate that a more rigid boundary will reduce the cost of projected water and sewer services, because new development will be concentrated on open space within the boundary rather than spreading outward from existing urban areas. Limiting the community's ability to request a MUSA expansion will help contain urban sprawl and reduce its negative effects. The MCA result indicates the boundary's lack of rigidity accommodates projected future growth of Woodbury in an outward direction.

Chapter 6: Conclusions and Future Research

The existing trend toward better management of agricultural, natural land and natural habitats within urban areas has led to the development of several management strategies. Advocates for sustainable management struggle against an increasing demand for commercial and residential uses, which has caused land transitions from productive agricultural land to suburban neighborhoods.

The concept of sustainability addresses the importance of preserving the ideal conditions by which people can productively and efficiently make use of their environment. It involves a balance between expanding to allow for population growth and increased productivity while maintaining respect and consciousness for the preservation of the natural environment. While the action taken by the Metropolitan Council to recognize the needs for curbing growth has focused on the financial benefits of sustainability, these actions have also minimized the negative impacts caused by habitat fragmentation, which is prone to occurring when leap-frog development becomes the norm.

Urban expansion in a suburban context is not free from its own problems. From increased dependence on automobiles as a primary form of transportation to general disintegration of ecological landscapes, America is attempting to mitigate the negative impacts brought on by the sprawl that had been occurring since the 1950s.

While sprawl is difficult to define, its effects are clear and evident. Regardless of the definition used, urban sprawl, is based on the conversion of open rural space to built-up urban impervious surfaces. The increase in the time wasted in commute causes excess pollution and fuel consumption. In addition, much valuable, productive agricultural land or wildlife habitat is irrevocably lost to the expanding suburbs.

Exclusion and socioeconomic segregation are a small sampling of the social issues that can arise from suburbanization and urban sprawl. These issues reinforce a rift between classes and foster social segregation of neighborhoods. In addition to the social issues, the aesthetic issues caused by sprawl, namely the inherent loss of natural beauty and habitat fragmentation, can greatly decrease the livability and even home values of an area.

Another factor adding to the monotony of low-density developments is out-of-date zoning regulations, which typically are Euclidian zoning. Euclidian zoning has divided different land uses, which has increased the dependency on automobile transportation to facilitate daily activities. Other types of non-traditional zoning, such as

Planned Unit Developments (PUDs) allow for mixed uses, which are generally frowned upon in traditional zoning practices. Whether non-traditional zoning is the solution, or if it lies in increasing the strictness of urban growth boundaries depends upon the attitude of the management of municipalities and the attitudes of the citizens. The comprehensive plan reflects attitudes and goals for the community in the future. An updated and useable comprehensive plan guides the community into the future. It offers a framework for the establishment of regulations and restrictions for land uses and future. A comprehensive plan that seeks to maximize development relative to the infrastructure in place within its current MUSA boundary is strongly encouraged because it will: (1) encourage infill development (2) reduce costs of constructing new infrastructure (3) promote an efficient plan of land consumption to retain a consciousness of natural preservation.

A specific stress that urban sprawl creates is the need for additional infrastructure to supply the newly converted land with necessary amenities. Water and sewer lines are expensive, and the maintenance is equally costly. Municipalities are struggling with the balance between focusing money on the maintenance of current infrastructure versus the necessary cost of adding infrastructure and increasing roadway miles as urban areas expand.

This study analyzed Woodbury, whose growth strategy is overseen by the Metropolitan Council, which has implemented the Metropolitan Urban Service Areas. An advantage to looking at infrastructure growth regionally is that the ability to address infrastructure issues is greater due to the immediate availability of resources. When developing subdivisions, the idea is to focus on subdivision infrastructure and not the

infrastructure of the municipality. Drawing away from individual developers' needs and more toward the needs of the community and region will streamline different interests and requests, which will be addressed accordingly.

To many, Woodbury would be an attractive place to call home. Being one of the fastest-growing cities in Minnesota, and located at an ideal junction of highways, rail lines, and port facilities, makes Woodbury an attractive location for commerce and businesses as well. With new shopping centers and a state-of-the-art recreation center, in addition to accessibility to walking and biking trails as well as being located near the St. Croix River Valley, Woodbury has much to offer for citizens with different lifestyles and tastes. All these amenities and more contribute to the fast and furious growth that Woodbury has experienced and will continue to experience, raising the intensity of need for progressive land use management. An increase in rigidity of the MUSA boundaries as they stand in 2012 would ease the planning and implementation process needed to develop strict, rigid urban boundaries. Access to the Metropolitan Council's resources and regional knowledge benefits Woodbury's land use management plans and also gives them a legal backbone for implementation of progressive land use strategies.

The final output of the Markov Cellular Automata Model raises a question of land use planning fundamentals. The model shows that the future growth trend will follow the delineated 2020 MUSA boundary. This is a reflection of the reality of the ideal prospects of the American landowner especially in growing suburbs where development

emphasizes housing developments. The question is whether this approach is healthy for the future of the region. Analysis of the final Markov Cellular Automata Model also raised the fundamental question of whether this future growth model correctly projected Woodbury's prospective growth. If Woodbury's land use planners are diligent, this model could prove to be accurate. However, if the market forces and economic pressures relax on the land use and zoning regulations, then the Markov Cellular Automata Model will not be an accurate reflection of the resulting uninhibited growth of urban sprawl.

While urban sprawl has several detrimental effects, the merit of the counterargument still stands. The long-standing American dream of owning a sizeable plot of land to call one's own has driven the formation of America since its earliest years. This dream stands on the principle of maintaining the right to ownership of property and the opportunity to identify one's self through the freedom to own land. While this idea is based on sound principles, the fact remains that regulation of land use and expansion is necessary in order to minimize degradation of natural resources, wildlife habitats, and increase the efficiency of infrastructure use within the urban area.

Future research of Woodbury's land management plans could be done to analyze whether new development follows current infrastructure or whether new infrastructure is created to accommodate for growth independent of the existing infrastructure. A current infrastructure mask could be created in order to prevent the model from allocating weight

to locations near existing infrastructure. This could show that, as a result of the land use management, the growth is, in fact, driving the construction of infrastructure. Another avenue for future research could be continual monitoring of environmental change around Woodbury using aerial photography. Building off of this current environmental change analysis, a broader picture could be provided of the effects of the future growth of the suburb. Also, the continuation of collecting building permit data would add to the socioeconomic aspects of future growth trend analysis. Being able to illustrate the development's housing prices would allow for the visualization of market factors and the preferences of different socioeconomic classes on the location of their homes.

Another factor to consider for future research is whether Woodbury will continue to be one of the fastest-growing communities in Minnesota. If the rate of growth significantly decreases or stagnates, land conversion pressures will be alleviated, thus reducing the necessity for focus on progressive land use management.

Whether Woodbury takes the route of strengthening: (1) the rigidity of the current MUSA boundaries, (2) the rigidity of zoning and land use regulations, or (3) a combination of both, remains in the hands of the Woodbury City Council and community, with the guidance of professional staff and the Metropolitan Council. This decision will reflect the community's priorities, concerns, and goals for their future.

One of the primary challenges which the planners of Woodbury and most other urban areas face is that of the American dream. Most American citizens long for a

sizeable plot of land to call their own and fashion after their own needs. The “not in my back yard” mindset possessed by American citizens pushes development away from the hustle and bustle of urban areas and into the more scenic and sparsely-populated peripheries. However, these same people expect the same amenities as those who live within the urban core: water, sewer, electricity, accessibility, and mobility. They want to be detached, but not disconnected. This ideal leads to heavy additional infrastructure costs, which could be avoided with higher-density development, and more focus could be placed on the maintenance and upkeep of existing infrastructure. Unfortunately, people are willing to pay to live in the outskirts of suburbia, which is what draws the growth outward. It is difficult to convince prospective homeowners to go against their instincts and limit their private property ownership rights.

Woodbury has many factors working in its favor, which will aid in the effort to control the negative effects of uninhibited expansion. The support of the Metropolitan Council and the resources provided thereof give a good starting point for strengthening of land use management regulations. Also, the existence of the MUSA boundaries alone provides a foundation for the drawing of possible urban growth boundaries. In addition to these factors, Woodbury also has the factor of time. It is important that the swift implementation of more rigid restrictions, be implemented to rein in expansion and encourage infill development to accommodate future population growth. While economic growth and development are pushed by the City of Woodbury and are important for the growth of the community, these priorities often overshadow the need for land use

management and making a conscious effort to allocate growth and resources accordingly. Completely capping growth is not a reasonable solution to Woodbury's vigorous land use expansion. On the other hand, the importance of land use management and planning can help facilitate a stronger community and long-term economic stability for the City of Woodbury.

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